Department of Civil Engineering

Course File

Concrete Technology

(Course Code: CE402PC)

IIB.Tech II Semester

2023-24

S.NARESH
Asst Professor

Ananthagiri, Kodad, Telangana 508 206, India.

Concrete Technology

Check List

Int. Marks:30 Ext. Marks:70 Total Marks:100

(CE402PC) Concrete Technology

B.Tech. II Year II Sem.

L	T	P	C
3	0	0	3

UNIT - I:

Aggregate: Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine, manufactured sand and coarse Aggregates – Gap graded aggregate – Maximum aggregate size, Properties Recycled aggregate

Admixtures: Types of admixtures – mineral and chemical admixtures.

UNIT – II:

Fresh Concrete: Workability – Factors affecting workability – Measurement of workability by different tests –Setting times of concrete – Effect of time and temperature on workability – Segregation & bleeding – Mixing,vibration and re vibration of concrete – Quality of mixing water.

UNIT – III:

Hardened Concrete: Water / Cement ratio – Abram's Law – Gel/space ratio – Gain of strength of concrete – Maturity concept – Strength in tension and compression – Factors affecting strength – Relation between compression and tensile strength - Curing. Testing of Hardened Concrete: Compression tests– Tension tests

– Factors affecting strength –Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods –codal provisions for NDT.

UNIT –IV:

Elasticity, Creep & Shrinkage: Modulus of elasticity – Dynamic modulus of elasticity – Poisson's ratio –Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects ofcreep — Shrinkage — types of shrinkage.

UNIT – V:

Mix Design: Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete –Statistical methods – Acceptance criteria – Proportioning of concrete mixes by various methods – BIS method of mix design- Steps in manufacture of concrete.

Special Concretes: Introduction to Light weight concrete – Cellular concrete – No-fines concrete – Permeable concrete – Fibre reinforced concrete – Polymer concrete – Bacterial concrete –Self-compacting concrete -Nano silica and Nano Alumina concrete.

Text Books:

1. Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
2. Concrete Technology by A.R. Santha kumar, 2nd Edition, Oxford University Press, NewDelhi
3. Concrete Technology by M. L. Gambhir. – Tata Mc. Graw Hill Publishers, 5THEdition,NewDelhi

Reference Books:

1. Properties of Concrete by A. M. Neville – Low priced Edition – 4th edition.
2. Concrete: Micro structure, Properties and Materials – P.K. Mehta and J.M. Monteiro, Mc.Graw Hill Publishers.

IS Codes:

IS 383: 2016
IS 516: 2018 (Part -1 - 4)
IS 10262 – 2019

Timetable

II B.Tech. II Semester – CT

Day/Hour	9.30-10.20	10.20-11.10	11.20-12.10	12.10-1.00	1.40-2.25	2.25-3.10	3.15-4.00
Monday				CT			CT
Tuesday			CT				
Wednesday	CT				CT		
Thursday							
Friday							
Saturday							

Department of Civil Engineering

Vision of the Institute

To be a premier Institute in the country and region for the study of Engineering, Technology and Management by maintaining high academic standards which promotes the analytical thinking and independent judgment among the prime stakeholders, enabling them to function responsibly in the globalized society.

Mission of the Institute

To be a world-class Institute, achieving excellence in teaching, research and consultancy in cutting-edge Technologies and be in the service of society in promoting continued education in Engineering, Technology and Management.

Quality Policy

To ensure high standards in imparting professional education by providing world-class infrastructure, top-quality-faculty and decent work culture to sculpt the students into Socially Responsible Professionals through creative team-work, innovation and research

Vision of the Department

To impart knowledge, skill and excellence in civil engineering with a global perspective to enable the students as competent, qualitative & ethically strong engineers with an intuition to improve quality of life for the benefit of the society.

Mission of the Department

To train the students in the civil engineering domain. To develop knowledge and skill to solve regional and global problems. To transform into qualitative and ethically strong professional engineers through research and Development.

Department of Civil Engineering

Program Educational Objectives (B.Tech. – CE)
Graduates will be able to

PEO 1: To provide knowledge in mathematics, science and engineering principles for a successful Career in sectors of civil engineering and allied industry and/or higher education.

PEO 2: To develop an ability to identify, formulate, solve problems along with adequate analysis, Design, synthesizing and interpretation skills in civil engineering systems.

PEO 3: To exhibit professionalism, ethics, communication skills and team work in their profession and engaged in lifelong learning of contemporary civil engineering trends.

Program Outcomes (B.Tech. –CE)
At the end of the Program, a graduate will have the ability to

PO 1: An ability to apply knowledge of mathematics, science, and engineering
PO 2: An ability to design and conduct experiments, as well as to analyze and interpret data
PO 3: An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability
PO 4: An ability to function on multidisciplinary teams
PO 5: An ability to identify, formulates, and solves engineering problems
PO 6: An understanding of professional and ethical responsibility
PO 7: An ability to communicate effectively
PO 8: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
PO 9: A recognition of the need for, and an ability to engage in lifelong learning.
PO 10: A knowledge of contemporary issues.
PO 11: An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
PO 12: An ability to carry out research in different areas of Civil Engineering including latest technology like GIS/Remote Sensing resulting in design, development, analyse and journal publications and technology development.

Department of Civil Engineering

COURSE OBJECTIVES

On completion of this Subject/Course the student shall be able to:

S.No	Objectives
1	Know different types of cement as per their properties for different field applications.
2	Understand Design economic concrete mix proportion for different exposure conditions andIntended purposes.
3	Know field and laboratory tests on concrete in plastic and hardened stage.
4	Understand the shrinkage and creep properties in concrete.
5	Know the different types of special concrete.

COURSE OUTCOMES

The expected outcomes of the Course/Subject are:

S.No	Outcomes
1	Determine the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.
2	Recognize the effects of the rheology and early age properties of concrete on its long-termbehaviour.
3	Apply the use of various chemical admixtures and mineral additives to designCement-based materials with tailor-made properties.
4	Use advanced laboratory techniques to characterize cement-based materials.
5	Perform mix design and engineering properties of special concretes such as high-performanceconcrete, self-compacting concrete, and fiber reinforced concrete.

Signature of faculty

Note: Please refer to Bloom's Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

Department of Civil Engineering

GUIDELINES TO STUDY THE COURSE / SUBJECT

Course Design and Delivery System (CDD):

- The Course syllabus is written into number of learning objectives and outcomes.
- Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.
- The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, swayam chapters etc.

The faculty be able to –

- Understand the principles of Learning
- Understand the psychology of students
- Develop instructional objectives for a given topic
- Prepare course, unit and lesson plans
- Understand different methods of teaching and learning
- Use appropriate teaching and learning aids
- Plan and deliver lectures effectively
- Provide feedback to students using various methods of Assessments and tools of Evaluation
- Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

COURSE SCHEDULE

The Schedule for the whole Course / Subject is:

S. No.	Description	Duration (Date)		Total No. of Periods
		From	To	
1.	**Aggregate:** Deleterious substance in aggregate – Soundness of aggregate – Alkali aggregate reaction – Thermal properties – Sieve analysis – Fineness modulus – Grading curves – Grading of fine, manufactured sand and coarse Aggregates – Gap graded aggregate – Maximum aggregate size, Properties Recycled aggregate **Admixtures:** Types of admixtures – mineral and chemical admixtures.	22.01.2024	03.02.2024	10
2.	**Fresh Concrete:** Workability – Factors affecting workability – Measurement of workability by different tests –Setting times of concrete – Effect of time and temperature on workability – Segregation & bleeding – Mixing, vibration and re vibration of concrete – Quality of mixing water.	06.02.2024	16.02.2024	9
3.	**Hardened Concrete:** Water / Cement ratio – Abram's Law – Gel/space ratio – Gain of strength of concrete – Maturity concept – Strength in tension and compression – Factors affecting strength –Relation between compression and tensile strength - Curing. Testing of Hardened Concrete: Compression tests– Tension tests – Factors affecting strength –Flexure tests – Splitting tests – Pull-out test, Non-destructive testing methods –codal provisions for NDT.	17.02.2024	23.03.2024	15
4.	**Elasticity, Creep & Shrinkage:** Modulus of elasticity – Dynamic modulus of elasticity – Poisson's ratio – Creep of concrete – Factors influencing creep – Relation between creep & time – Nature of creep – Effects ofcreep — Shrinkage — types of shrinkage.	26.03.2024	20.04.2024	12
5.	**Mix Design:** Factors in the choice of mix proportions – Durability of concrete – Quality Control of concrete – Statistical methods –	23.04.2024	12.06.2024	15

	Acceptance criteria – Proportioning of concrete mixes by various methods – BIS method of mix design- Steps in manufacture of concrete. **Special Concretes:** Introduction to Light weight concrete – Cellular concrete – No-fines concrete – Permeable concrete – Fibre reinforced concrete – Polymer concrete – Bacterial concrete –Self-compacting concrete - Nano silica and Nano Alumina concrete.			

Total No. of Instructional periods available for the course: 61 Hours

Department of Civil Engineering

SCHEDULE OF INSTRUCTIONS - COURSE PLAN / UNIT PLANT

Unit No.	Lesson No.	Date	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References (Textbook, Journal)
1.	1	22-Jan-24	1	Aggregates-Classification of aggregates	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	2	23-Jan-24	1	Mechanical properties of aggregates, Sp.gravity,Bulk density, Porosity, Adsorption	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	3	24-Jan-24	1	Bulking of sand, Deleterious substance, Soundness, Alkali aggregate reaction, Thermal properties	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	4	25-Jan-24	1	Sieve analysis, Fineness Modulus (FM),	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	5	27-Jan-24	1	Grading of Fine and Coarse aggregate	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	6	30-Jan-24	1	Grading curves, Gap graded aggregate, Maximum aggregate size.	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	7	31-Jan-24	1	Properties Recycled aggregate	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	8	1-Feb-24	1	Admixtures in concrete. Mineral admixtures	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	9	2-Feb-24	1	Types of Mineral admixtures,	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004

	10	3-Feb-24	1	Chemical admixtures	1 1	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
2	1	6-Feb-24	1	Fresh concrete, Manufacture of concrete, mixing, compaction curing	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	2	7-Feb-24	1	Workability-Factors affecting workability	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	3	8-Feb-24	1	Tests on workability (slump test, compaction factor test, V Bee test)	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	4	9-Feb-24	1	Setting times of concrete, effect of time on workability	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	5	12-Feb-24	1	Segregation, bleeding, Mixing (hand and machine - mixing)	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	6	13-Feb-24	1	Compaction of concrete	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	7	14-Feb-24	1	Segregation & bleeding – Mixing	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	8	15-Feb-24	1	vibration and re vibration of concrete	2 2	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	9	16-Feb-24	1	Quality of mixing water.	2 2	Concrete Technology by M.S. Shetty. – S.

						Chand & Co.; 2004
3	1	17-Feb-24	1	Hardened concrete, w/c ratio, Abraham's law, Gel - space ratio	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	2	19-Feb-24	1	Factors effecting segregation and bleeding	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	3	20-Feb-24	1	Maturity concept and problems	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	4	21-Feb-24	1	Strength in tension &compression, factors affecting strength	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	5	5-Mar-24	1	Relation between compression & tensile strength, curing	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	6	6-Mar-24	1	Testing of hardened concrete	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	7	7-Mar-24	1	Compression and Tension tests	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	8	12-Mar-24	1	Flexure tests, Splitting tests	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	9	13-Mar-24	1	Non -Destructive Testing methods (NDT)	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	10	14-Mar-24	1	Codal provisions of NDT	3 3	Concrete Technology by M.S. Shetty. – S.

						Chand & Co.; 2004
	11	15-Mar-24	1	Non -Destructive Tests – types	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	12	16-Mar-24	1	Behavior of concrete in extreme environment; temperature problem in concreting	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	13	21-Mar-24	1	Resistance to freezing, sulphate and acid attack, efflorescence, fire resistance	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	14	22-Mar-24	1	Inspection and testing of concrete -Concrete cracking, types of cracks, causes and remedies	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	15	23-Mar-24	1	Types of cracks, causes and remedies	3 3	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
4	1	26-Mar-24	1	Causes	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	2	27-Mar-24	1	Elasticity, Creep& Shrinkage of Concrete	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	3	28-Mar-24	1	Types of elasticity	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	4	2-Apr-24	1	Creep of concrete & Poisson's ratio	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	5	3-Apr-24	1	Factors influencing creep	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004

	6	4-Apr-24	1	Nature of creep, effects of creep	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	7	6-Apr-24	1	Shrinkage -Types of shrinkage	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	8	10-Apr-24	1	Factors influencing shrinkage	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	9	16-Apr-24	1	Difference between creep and shrinkage	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	10	18-Apr-24	1	Relation between creep & time – Nature of creep –	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	11	19-Apr-24	1	Problems on creep	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	12	20-Apr-24	1	Effects of creep – Shrinkage – types of shrinkage.	4 4	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
5	1	23-Apr-24	1	Mix Design, Factors in the choice of mix proportions	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	2	24-Apr-24	1	Durability & Quality control of concrete	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	3	25-Apr-24	1	Stastical methods and acceptance criteria	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004

	4	26-Apr-24	1	Proportioning of concrete mixes by different methods	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	5	27-Apr-24	1	Methods of Mix design	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	6	30-Apr-24	1	BIS method of mix design	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	7	1-May-24	1	BIS method of mix design (contd.)	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	8	2-May-24	1	Problems - BIS method of mix design	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	9	3-May-24	1	Miscellaneous Problems in mix design	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	10	4-May-24	1	Introduction to Special concretes, Light weight aggregate and concrete, Cellular concrete	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	11	7-May-24	1	Fibre Reinforced Concrete (FRC), Different types of fibre, Factors affecting FRC, Applications of FRC	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	12	8-May-24	1	About polymer concrete, Types of polymer concrete Properties of polymer concrete and applications	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	13	6-Jun-24	1	High density concrete, No fines concrete, Applications of HDC and No fines concrete	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004

Department of Civil Engineering

	14	11-Jun-24	1	High performance concrete, Applications of High performance concrete	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004
	15	12-Jun-24	1	Self consolidating concrete and its applications, Nano silica and Nano Alumina concrete.	5 5	Concrete Technology by M.S. Shetty. – S. Chand & Co.; 2004

Signature of HOD

Date:

Signature of faculty

Date:

Note:

1. Ensure that all topics specified in the course are mentioned.
2. Additional topics covered, if any, may also be specified in bold.
3. Mention the corresponding course objective and outcome numbers against each topic.

Department of Civil Engineering
LESSON PLAN (U-I)

Lesson No: 01 Duration of Lesson: 50 min

Lesson Title: Introduction to Concrete Technology

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 02 Duration of Lesson: 50 min

Lesson Title: Aggregates-Classification of aggregates

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 03 Duration of Lesson: 50 min

Lesson Title: Mechanical properties of aggregates, Sp. gravity, Bulk density, Porosity, Adsorption

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 04 Duration of Lesson: 50 min

Lesson Title: Bulking of sand, deleterious substance, Soundness, Alkali aggregate reaction, Thermal properties

Instructional / Lesson Objectives:

- Definition of Bulking of sand.
- Know basic concept of deleterious substance, Soundness, Alkali aggregate reaction.
- Know the Thermal properties.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 05 Duration of Lesson: 50 min

Lesson Title: Sieve analysis, Fineness Modulus (FM), Grading of Fine and Coarse aggregate

Instructional / Lesson Objectives:

- Detailed concept on Sieve analysis.
- Know different types of Fineness Modulus (FM).
- Know the types of Grading of Fine and Coarse aggregate.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering
LESSON PLAN (U-I)

Lesson No: 06 Duration of Lesson: 50 min

Lesson Title: Grading curves, Gap graded aggregate, Maximum aggregate size.

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 07 Duration of Lesson: 50 min

Lesson Title: Grading curves, Gap graded aggregate, Maximum aggregate size.

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 08 Duration of Lesson: 50 min

Lesson Title: Grading curves, Gap graded aggregate, Maximum aggregate size.

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering
LESSON PLAN (U-I)

Lesson No: 09 Duration of Lesson: 50 min

Lesson Title: Grading curves, Gap graded aggregate, Maximum aggregate size.

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-I)

Lesson No: 10 Duration of Lesson: 50 min

Lesson Title: Grading curves, Gap graded aggregate, Maximum aggregate size.

Instructional / Lesson Objectives:

- Definition of concrete and its materials.
- Know different types of cement as per their properties for different field applications.
- Know the properties of concrete ingredients i.e., cement, sand, coarse aggregate byconducting different tests.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 min for taking attendance 40 min for the lecture delivery 5 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – I & tutorial-I sheets

Signature of faculty

Department of Civil Engineering
LESSON PLAN (U-II)

Lesson No:1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Fresh concrete, Manufacture of concrete, mixing, compaction curing, Workability-Factors affecting workability, Tests on workability (slump test, compaction factor test, V Bee test)

Instructional / Lesson Objectives:

- Fresh concrete, Manufacture of concrete
- Workability-Factors affecting workability

Teaching AIDS : White board, Different colour markers

Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Setting times of concrete, effect of time on workability, Segregation, bleeding, Mixing (hand and machine - mixing), Compaction of concrete

.

Instructional / Lesson Objectives:

- Setting times of concrete, effect of time on workability
- Segregation, bleeding, Mixing (hand and machine - mixing)
- Compaction of concrete

Teaching AIDS : White board, Different colour markers

Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-II)

Lesson No: 7,8,9 Duration of Lesson: 2hr 30 min

Lesson Title: Segregation & bleeding – Mixing, vibration and re vibration of concrete, Quality of mixing water.

Instructional / Lesson Objectives:

- Segregation & bleeding – Mixing
- Vibration and re vibration of concrete
- Quality of mixing water.

Teaching AIDS : White board, Different colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – II & tutorial-II sheets

Signature of faculty

Department of Civil Engineering
LESSON PLAN (U-III)

Lesson No:1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Hardened concrete, w/c ratio, Abraham's law, Gel - space ratio, Factors effecting segregation and bleeding, Maturity concept and problems

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Hardened concrete, w/c ratio, Abraham's law
- Gel - space ratio, Factors effecting segregation and bleeding
- Maturity concept and problems

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

-

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No:4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Strength in tension &compression, factors affecting strength, Relation between compression & tensile strength, curing, Testing of hardened concrete

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Strength in tension &compression
- Relation between compression & tensile strength, curing

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No:7,8,9 Duration of Lesson: 2hr 30 min

Lesson Title: Compression and Tension tests, Flexure tests, Splitting tests, Non -Destructive Testing methods (NDT)

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Compression and Tension tests
- Flexure tests, Splitting tests
- Non -Destructive Testing methods (NDT)

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No:10,11,12 Duration of Lesson: 2hr 30 min

Lesson Title: Codal provisions of NDT, Non -Destructive Tests – types

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Codal provisions of NDT
- Non -Destructive Tests – types

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-III)

Lesson No: 13,14,15 Duration of Lesson: 2hr 30 min

Lesson Title: Behavior of concrete in extreme environment; temperature problem in concreting Resistance to freezing, sulphate and acid attack, efflorescence, fire resistance

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Analyze the propped cantilever beam under different loadings.
- Analyze the fixed beam under different loadings.
- To draw Bending Moment Diagram (BMD) & Shear force diagram (SFD)

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – III & tutorial-III sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No:1,2,3 Duration of Lesson: 2hr 30 min

Lesson Title: Elasticity, Creep& Shrinkage of Concrete. Creep of concrete & Poisson's ratio

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Analyze the Continuous beam under different loadings.
- To draw Bending Moment Diagram (BMD) & Shear force diagram (SFD)

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 4,5,6 Duration of Lesson: 2hr 30 min

Lesson Title: Factors influencing creep, Nature of creep, effects of creep.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Factors influencing creep
- Nature of creep, effects of creep.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 7,8,9 Duration of Lesson: 2hr 30 min

Lesson Title: Shrinkage -Types of shrinkage, Factors influencing shrinkage

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Factors influencing creep
- Nature of creep, effects of creep.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-IV)

Lesson No: 10,11,12 Duration of Lesson: 2hr 30 min

Lesson Title: Difference between creep and shrinkage

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Understand the Difference between creep and shrinkage

.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 mins for taking attendance 15 for revision of previous class 115 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – IV & tutorial-IV sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 1,2 Duration of Lesson: 1hr 40 min

Lesson Title: Mix Design, Factors in the choice of mix proportions

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- Understand the mix design and its factors

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance 80 min for lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 3,4 Duration of Lesson: 1hr 40 min

Lesson Title: Stastical methods and acceptance criteria

Instructional / Lesson Objectives:

On completion of this lesson the student shall be able to:

- To understand about Stastical methods and acceptance criteria

Teaching AIDS : White board, Different Colour markers

Time Management of Class :

5 mins for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:

(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 5,6 Duration of Lesson: 1hr 40 min

Lesson Title: Methods of Mix design, BIS method of mix design.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Methods of Mix design
- BIS method of mix design.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 7,8 Duration of Lesson: 1hr 40 min

Lesson Title: BIS method of mix design (contd.), Problems - BIS method of mix design

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- BIS method of mix design
- Problems - BIS method of mix design.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 9,10 Duration of Lesson: 1hr 40 min

Lesson Title: Miscellaneous Problems in mix design, Introduction to Special concretes, Light weight aggregate and concrete, Cellular concrete

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- Introduction to Special concretes, Light weight aggregate and concrete
- Cellular concrete

.

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 11,12 Duration of Lesson: 1hr 40 min

Lesson Title: Fibre Reinforced Concrete (FRC), Different types of fibre, Factors affecting FRC, Applications of FRC

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:
Fibre Reinforced Concrete (FRC), Different types of fibre, Factors affecting FRC, Applications of FRC

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 13,14 Duration of Lesson: 1hr 40 min

Lesson Title: About polymer concrete, Types of polymer concrete Properties of polymer concrete and applications, High density concrete, No fines concrete, Applications of HDC and No fines concrete

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- High density concrete, No fines concrete, Applications of HDC and No fines concrete

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

LESSON PLAN (U-V)

Lesson No: 15,16 Duration of Lesson: 1hr 40 min

Lesson Title: High performance concrete, Applications of High performance concrete, Nano silica and Nano Alumina concrete.

Instructional / Lesson Objectives:
On completion of this lesson the student shall be able to:

- High density concrete, No fines concrete, Applications of HDC and No fines concrete

Teaching AIDS : White board, Different Colour markers
Time Management of Class :

5 min for taking attendance 15 min for revision session 65 min for lecture delivery 15 min for doubts session

Assignment / Questions:
(Note: Mention for each question the relevant Objectives and Outcomes Nos.1,2,3,4 & 1,3..)

Refer assignment – V & tutorial-V sheets

Signature of faculty

Department of Civil Engineering

ASSIGNMENT – 1

This Assignment corresponds to Unit No. 1

Question No.	Question	Objective No.	Outcome No.
1	Write down about the grading curves and gap grading.	1	1
2	Discuss the classification of aggregates.	1	1
3	List out the Mineral admixtures? And explain any three.	1	1

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 2

This Assignment corresponds to Unit No. 2

Question No.	Question	Objective No.	Outcome No.
1	Write down the procedure of measuring workability of concrete by flow test	2	2
2	Explain the causes and remedies of bleeding of concrete	2	2

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

ASSIGNMENT – 3

This Assignment corresponds to Unit No. 3

Question No.	Question	Objective No.	Outcome No.
1	Explain about Abraham's law.	3	3
2	Write down the flexure test procedure.	3	3
3	Write down the test procedure of Surface hardness and rebound hammer.	3	3
4	Explore the various non-destructive testing (NDT) methods used for assessing the quality of hardened concrete.	3	3

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering
ASSIGNMENT – 4

This Assignment corresponds to Unit No. 4

Question No.	Question	Objective No.	Outcome No.
1	Explain the stress-strain relationship of concrete.	4	4
2	Describe the relationship between creep and time in concrete structures?	4	4
3	Discuss the nature of creep in concrete, distinguishing between immediate and delayed effects?	4	4

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering
ASSIGNMENT – 5

This Assignment corresponds to Unit No. 5

Question No.	Question	Objective No.	Outcome No.
1	Explain the concept of lightweight concrete and discuss its advantages and applications compared to conventional concrete mixes.	5	5
2	What are the unique characteristics of self-compacting concrete (SCC), and how does it differ from traditional concrete in terms of placement and compaction?	5	5
3	Describe the properties and uses of fiber-reinforced concrete (FRC). How do fibers enhance the performance and durability of concrete structures?	5	5

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering
TUTORIAL – 1

This tutorial corresponds to Unit No. 1 (Objective Nos.: 1, Outcome Nos.: 1)

Q1. What is the primary chemical composition of Portland cement?

a) Silica

b) Alumina

c) Calcium oxide

d) All of the above

Q2. Bulking of sand occurs due to:

a) Absorption of water

b) Evaporation of water

c) Mixing with cement

d) Vibration during compaction

Q3. Which of the following is not a mechanical property of aggregates?

a) Specific gravity

b) Bond strength

c) Thermal conductivity

d) Porosity

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 2

This tutorial corresponds to Unit No. 2 (Objective Nos.: 2, Outcome Nos.: 2)

Q1Workability of concrete is measured by
a) Vicat apparatus b) Le-chatlier Apparatus c) Slump test d) Pycnometer

Q2. Separation of coarse aggregates from mortar during transportation, is known
a) Segregation b) Bleeding c) Creep d) Shrinkage

Q3. Strength of concrete with passage of time
a) Increases b) Decreases c) Constant d) None of above

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 3

This tutorial corresponds to Unit No. 3 (Objective Nos.: 3, Outcome Nos.: 3)

Q1. Which of the following factors does NOT typically affect the strength of hardened concrete?

a) Water-cement ratio

b) Curing conditions

c) Ambient temperature

d) Concrete color

Q2 Which test is primarily used to assess the compressive strength of hardened concrete?

a) Tension test

b) Flexure test

c) Compression test

d) Splitting test

Q3. Which codal provisions are commonly followed for non-destructive testing (NDT) of concrete structures?

a) IS 456:2000

b) ACI 318

c) BS EN 12390

d) ASTM C805

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 4

This tutorial corresponds to Unit No. 4 (Objective Nos.: 4, Outcome Nos.: 4)

Q1. What does the modulus of elasticity represent in concrete?

a) Resistance to compression

b) Resistance to bending

c) Resistance to deformation under stress

d) Resistance to shear forces

Q2. Which term refers to the ratio of lateral strain to longitudinal strain in a material under stress?

a) Modulus of elasticity

b) Dynamic modulus of elasticity

c) Poisson's ratio

d) Creep

Q3. How does the creep of concrete change with time?

a) It decreases linearly

b) It increases exponentially

c) It remains constant

d) It varies inversely with temperature

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

TUTORIAL – 5

This tutorial corresponds to Unit No. 5 (Objective Nos.: 5, Outcome Nos.: 5)

Q1. Which statistical method is commonly used for quality control of concrete?

a) ANOVA (Analysis of Variance)

b) Regression analysis

c) Standard deviation analysis

d) Chi-square test

Q2. Which type of concrete is specifically designed to have air voids distributed throughout its structure, resulting in low density and improved thermal insulation properties?

a) Cellular concrete

b) No-fines concrete

c) Permeable concrete

d) Fibre reinforced concrete

Q3. What is the main characteristic of lightweight concrete?

a) High compressive strength

b) Low density

c) High water-cement ratio

d) High slump value

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

EVALUATION STRATEGY

Target (s)

a. Percentage of Pass : 95%

Assessment Method (s) (Maximum Marks for evaluation are defined in the Academic Regulations)

a. Daily Attendance
b. Assignments
c. Online Quiz (or) Seminars
d. Continuous Internal Assessment
e. Semester / End Examination

List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this semester

Case Study of any one existing application

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

COURSE COMPLETION STATUS

Actual Date of Completion & Remarks if any

Units	Remarks	Objective No. Achieved	Outcome No. Achieved
Unit 1	Completed on 3.02.2024	1	1
Unit 2	Completed on 16.02.2024	2	2
Unit 3	Completed on 23.03.2024	3	3
Unit 4	Completed on 20.04.2024	4	4
Unit 5	Completed on 12.06.2024	5	5

Signature of HOD

Date:

Signature of faculty

Date:

Department of Civil Engineering

Mappings

1. Course Objectives-Course Outcomes Relationship Matrix

(Indicate the relationships by mark "X")

Course-Objectives \ Course-Outcomes	1	2	3	4	5
1	H		M		
2		H			
3			H		
4				H	
5					H

2. Course Outcomes-Program Outcomes (POs) & PSOs Relationship Matrix

(Indicate the relationships by mark "X")

C-Outcomes \ P-Outcomes	a	b	c	d	e	f	g	h	i	j	k	l	PSO 1	PSO 2
1	H			M									H	
2		M	H			M							H	H
3					H				M		M			M
4						M	H						M	
5										H				

Department of Civil Engineering

Rubric for Evaluation

Performance Criteria	Unsatisfactory	Developing	Satisfactory	Exemplary
	1	2	3	4
Research & Gather Information	Does not collect any information that relates to the topic	Collects very little information some relates to the topic	Collects some basic Information most relates to the topic	Collects a great deal of Information all relates to the topic
Fulfill team role's duty	Does not perform any duties of assigned team role.	Performs very little duties.	Performs nearly all duties.	Performs all duties of assigned team role.
Share Equally	Always relies on others to do the work.	Rarely does the assigned work - often needs reminding.	Usually does the assigned work - rarely needs reminding.	Always does the assigned work without having to be reminded
Listen to other team mates	Is always talking—never allows anyone else to speak.	Usually doing most of the talking-- rarely allows others to speak	Listens, but sometimes talks too much.	Listens and speaks a fair amount.

II B.TECH IV SEMESTER I MID EXAMINATIONS - APRIL 2024

Branch : B.Tech. (CE) **Subject : Concrete Technology,CE402PC** **Max. Marks: 30**
Date : 01.04.2024 **Time: 120 Minutes**

PART - A

ANSWER ALL QUESTIONS **10 X 1M – 10M**

Q.No	Question	CO	BTL
1.	What is the maximum size of aggregate recommended for use in concrete? ( ) (A). 5 mm (B). 10 mm (C). 20 mm (D). 40 mm	C1	L2
2.	Which test is commonly used to determine the setting time of cement? ( ) (A). Soundness test (B). Fineness test (C). Vicat apparatus test (D). Compression test	C1	L2
3.	What property of water is crucial for its suitability in concrete mixing? ( ) (A). Taste (B). Color (C). pH level (D). Quality	C1	L1
4.	What is the primary chemical composition of Portland cement? ( ) (A). Silica (B). Alumina (C). Calcium oxide (D). All of the above	C1	L1
5.	What does the water/cement ratio primarily affect in concrete? ( ) (A). Strength (B). Setting time (C). Workability (D). Color	C2	L1
6.	What is the purpose of mixing and vibration in concrete? ( ) (A). To increase setting time (B). To reduce bleeding (C). To increase workability (D). To ensure uniform distribution of ingredients	C2	L1
7.	What is the purpose of the Gel-space ratio concept in concrete? ( ) (A). To measure setting time (B). To assess workability (C). To calculate compressive strength (D). To determine aggregate size	C2	L2
8.	What is the primary cause of concrete segregation? ( ) (A). Improper mixing (B). High water content (C). Low water content (D). Excessive vibration	C2	L2
9.	Which statistical methods are commonly used in quality control of concrete? ( ) (A). Mean and median (B). Standard deviation and range (C). Mode and variance (D). Correlation and regression	C3	L2
10.	What does quality control of concrete involve? ( ) (A). Monitoring the strength of concrete only (B). Ensuring the concrete meets specified requirements throughout the construction process (C). Determining the cost of concrete (D). None of the above	C3	L2

PART - B

ANSWER ANY FOUR **4 X 5 M – 20 M**

Q.No	Question	CO	BTL
11.	Discuss the significance of water quality in concrete mixing and how it affects the properties of concrete.	C1	L4
12.	Discuss the tests conducted to determine the physical properties of cement and their importance in quality control.	C1	L3
13.	Describe the factors that influence the workability of concrete and how they can be managed during construction.	C2	L4

14.	Discuss the effects of time and temperature on the workability of concrete and strategies to mitigate these effects.	C2	L4
15.	Explain briefly about BIS, mix design procedure as per 10262-2019 code provision?	C3	L4
16.	Explain briefly about M25 grade of mix design as per 10262-2016. code provision /	C3	L3

II B.TECH IV SEMESTER II MID EXAMINATIONS - JUNE 2024

Branch : B.Tech. (CE) **Max. Marks : 30M**
Date : 18-Jun-2024 **Session : Afternoon** **Time : 120 Min**
Subject : Concrete Technology,CE402PC

PART - A

ANSWER ALL THE QUESTIONS **10 X 1M = 10M**

Q.No	Question		CO	BTL
1.	Which of the following factors does NOT typically affect the strength of hardened concrete? (A). Water-cement ratio (B). Curing conditions (C). Ambient temperature (D). Concrete color	( )	CO3	L1
2.	What is the main objective of non-destructive testing (NDT) methods for concrete structures? (A). To assess the aesthetic appearance of concrete surfaces (B). To evaluate the long-term durability of concrete structures (C). To detect defects and flaws without causing damage to the structure (D). To determine the exact water-cement ratio used in concrete mixtures	( )	CO3	L1
3.	What does the modulus of elasticity represent in concrete? (A). Resistance to compression (B). Resistance to bending (C). Resistance to deformation under stress (D). Resistance to shear forces	( )	CO4	L1
4.	Which type of shrinkage in concrete occurs due to the evaporation of excess mixing water? (A). Autogenous shrinkage (B). B) Plastic shrinkage (C). Drying shrinkage (D). Carbonation shrinkage	( )	CO4	L2
5.	Which term refers to the ratio of lateral strain to longitudinal strain in a material under stress? (A). Modulus of elasticity (B). Dynamic modulus of elasticity (C). Poisson's ratio (D). Creep	( )	CO4	L2
6.	What are the effects of creep on concrete structures? (A). Decrease in long-term deflection (B). Increase in long-term deflection (C). Increase in compressive strength (D). Decrease in tensile strength	( )	CO4	L1
7.	Which type of concrete is specifically designed to have air voids distributed throughout its structure, resulting in low density and improved thermal insulation properties? (A). Cellular concrete (B). No-fines concrete (C). Permeable concrete (D). Fibre reinforced concrete	( )	CO5	L1
8.	What is the main purpose of quality control in concrete production? (A). To increase the cost of production (B). To ensure uniformity and consistency in concrete properties (C). To reduce the workability of concrete (D). To decrease the curing time of concrete	( )	C5	L2
9.	Which type of concrete incorporates polymer resins as a binder, offering enhanced chemical resistance and durability? (A). Polymer concrete (B). Bacterial concrete (C). Nano silica concrete (D). Nano alumina concrete	( )	CO5	L2
10.	What is the main advantage of self-compacting concrete (SCC)? (A). High tensile strength (B). Improved workability and flowability (C). Resistance to chemical attack (D). Lower cost of production	( )	CO5	L1

PART - B

ANSWER ANY FOUR **4 X 5M = 20M**

Q.No	Question	CO	BTL

11.	**Explain the procedures involved in conducting Compressive test on concrete?**	CO3	L3
12.	Explore the various non-destructive testing (NDT) methods used for assessing the quality of hardened concrete.	CO3	L4
13.	Define creep of concrete and identify the main factors that influence its magnitude in structural elements?	CO4	L4
14.	Describe the relationship between creep and time in concrete structures?	CO4	L4
15.	explain briefly about durability of concrete and its importance?	CO5	L4
16.	design concrete mix praportion as per IS-10262-2019?	CO5	L4

Continuous InternalAssessment (R-22)

Programme**: BTech** Year: **II** Course: **Theory** **A.Y: 2023-24**

Course: CONCRETE TECHNOLOGY Section: A Faculty Name: S.NARESH

S.No.	H.T.No.	Mid - I Marks (30)	Mid - II Marks (30)	Avg of Mid-I & Mid-II (A)	Assignment - I (5)	Assignment - II (5)	Avg of Assg.-I & Assg.-II (B)	Viva Voce (5) (C)	Total (A+B+C)
1	21C11A0113	AB	15	8	5	5	5	5	18
2	22C11A0101	6	14	10	AB	5	3	5	18
3	22C11A0102	15	25	20	5	5	5	5	30
4	22C11A0103	6	17	12	AB	5	3	AB	15
5	22C11A0104	7	14	11	5	5	5	5	21
6	22C11A0105	24	29	27	5	5	5	5	37
7	22C11A0106	11	20	16	5	5	5	5	26
8	22C11A0107	14	19	17	AB	5	3	5	25
9	23C15A0101	15	19	17	5	5	5	5	27
10	23C15A0102	23	25	24	5	5	5	5	34
11	23C15A0103	20	28	24	5	5	5	5	34
12	23C15A0104	10	18	14	5	5	5	5	24
13	23C15A0105	26	27	27	5	5	5	5	37

No. of Absentees: NIL

Total Strength: 13

Signature of Faculty

: **Signature of HoD**

① Explain step by step design process of concrete as per IS-10262-2019.

Step 1: Data collection

collect all necessary data for mix design, including:

- Characteristic strength: The target mean strength of concrete.
- Type of cement: The specific type and grade of cement used.
- Type of aggregates: properties of coarse and fine aggregates, including their specific gravities, water absorption, and moisture content.
- Exposure conditions: Environmental conditions in which the concrete will be placed.
- Workability: required slump or compaction factor for the concrete.

Step 2: Target mean strength

Calculate the target mean compressive strength (f_{ck}) to account for variability: $f'_{ck} = f_{ck} + 1.65 \times$ standard deviation

If the standard deviation is not known, use values provided in IS 456.

Step 3: selection of water-cement ratio

Based on the target mean strength and exposure conditions, select an appropriate water-cement ratio. ensure the selected w/c ratio satisfies both strength and durability requirements.

Step 4: Estimation of air content

Estimate the entrapped air content based on the maximum size of aggregate, referring to the values provided in IS 10262.

Step 5: Calculation of water and cement content

Determine the water content based on the required workability. Adjust for the type of aggregate and admixtures if any. The cement content is then calculated using:

$$\text{cement content} = \frac{\text{water content}}{\text{w/c ratio}}$$

Step 6: Calculation of aggregate proportions.

Calculate the proportions of fine and coarse aggregates content.

Step 7: mix calculation.

perform the mix calculation considering the specific gravities and water absorption of the materials

$$\text{Absolute volume} = \frac{\text{mass}}{\text{specific gravity} \times 1000}$$

Step 8: trial mixes

prepare trial mixes and test for workability and strength. adjust the mix proportions if the results deviate from the desired properties

Step 9: final mix design

finalize the mix proportions based on the trial mixes, ensuring that the mix meets the required strength, workability and durability parameters.

Step 10: Documentation

Document the mix design process, including:

- Data collected
- calculations and assumptions made
- Trial mix results.

• final mix proportions.

Example calculation:

consider designing a mix for M25 grade concrete with the following assumptions

• Target strength $f'_{ck} = 25 + 1.65 * 5 = 33.25$ MPa

• maximum size of aggregate = 20mm

• slump = 75 mm

• cement: OPC 43 grade

• specific gravities: cement = 3.15, FA = 2.65, CA = 2.74

1, water-cement ratio: Assume w/c ratio of 0.5

2. water content: for 75 mm slump, use 186 kg/m^3.

3, cement content: 186/0.5 = 372 kg/m^3.

4, volume of cement: 372/(3.15 x 1000) = 0.118 m^3.

5, volume of water: 186/1000 = 0.186 m^3.

6, volume of aggregates: 1 - 0.118 - 0.186 - 0.02 (air content) = 0.676 m^3.

7, fine aggregate: → 0.35 x 0.676 x 2.65 x 1000 = 627 kg/m^3.

8, coarse aggregate: → 0.65 x 0.676 x 2.74 x 1000 = 1204 kg/m^3.

② Discuss briefly about types of special concrete and its advantages and disadvantages?

1, High-strength concrete: for high-rise buildings and bridges; strength > 6000 psi.

2, High-Performance concrete: Enhanced strength, durability, and environmental resistance

3, Lightweight concrete: uses lightweight aggregates, ideal for reducing structural weight.

4. Self-consolidating concrete: flows into place without vibration, perfect for complex forms and dense reinforcement.

5. fiber-reinforced concrete: contains fibers for improved tensile strength and crack resistance; used in floors and pavements.

6. Air-entrained concrete: contains air bubbles for freeze thaw resistance, used in cold climates

7. Pervious concrete: Allows water passage, used in pavements and parking lots to manage runoff

8. Polymer concrete: polymers instead of cement for chemical resistance and quick curing, used in industrial repairs.

Advantages :-

1. Enhanced performance
2. Customization
3. Innovative solutions
4. Improved durability
5. Environmental benefits.

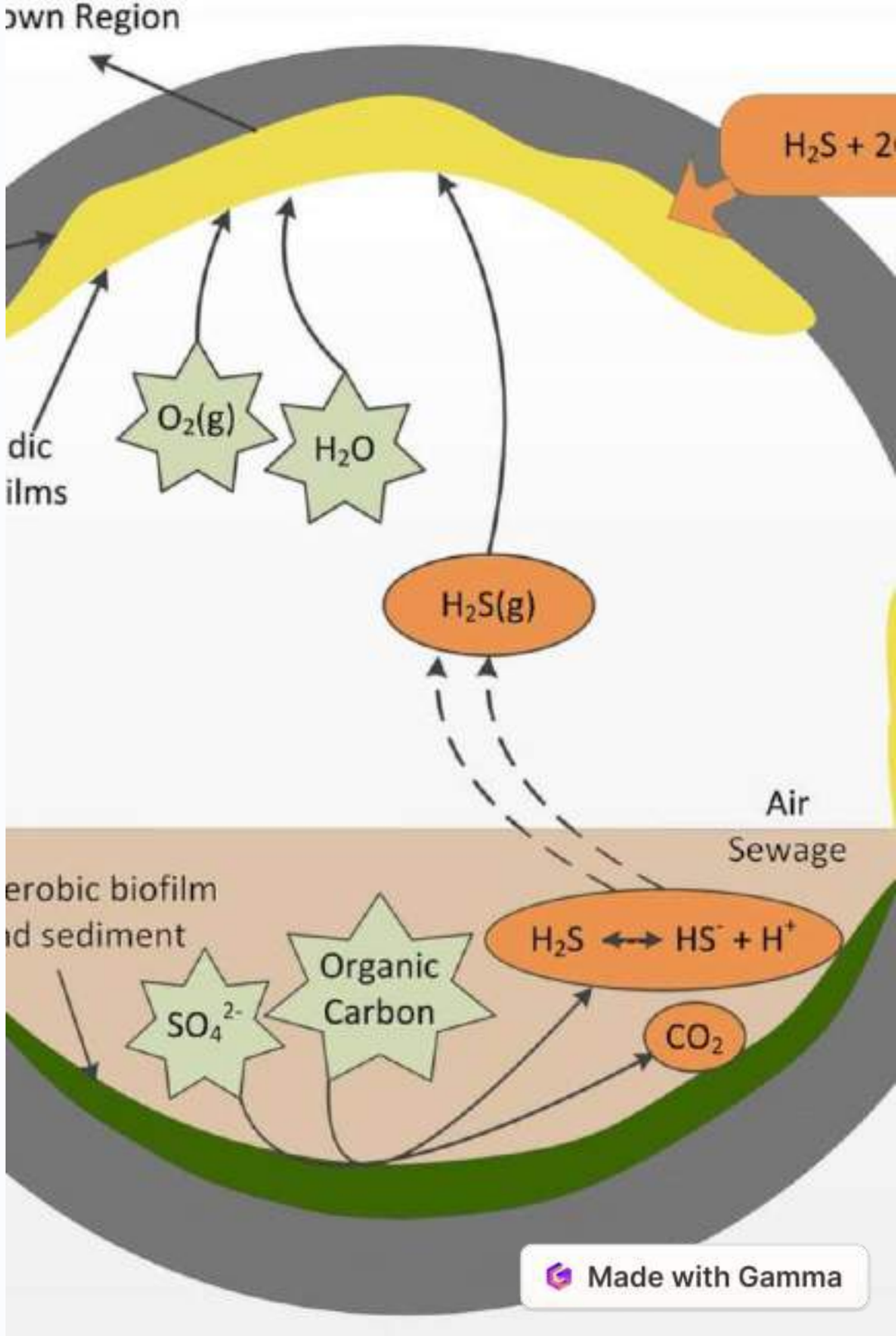
Disadvantages :-

1. Higher cost
2. Increased complexity
3. Limited availability
4. Quality control challenges
5. Potential for cracking

Deleterious Substance in Aggregate

Deleterious substances in aggregates can have a negative impact on the quality of concrete. These substances include materials such as clay lumps, wood, and other organic materials that can affect the strength and durability of the concrete.

S **by S Naresh --**



Soundness of Aggregates

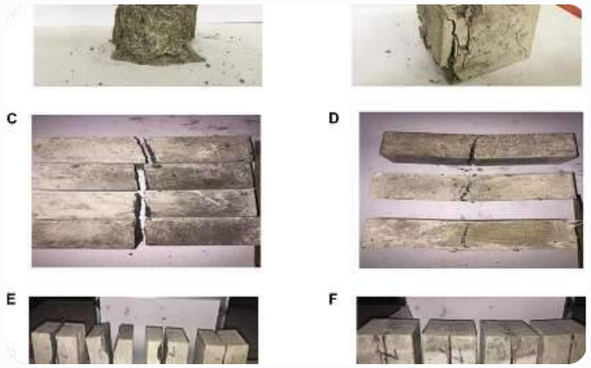
The soundness of aggregates refers to their ability to withstand weathering. It's crucial for ensuring the long-term durability of concrete. Aggregates that undergo excessive expansion and disintegration due to weathering can lead to concrete failure.

Durable Aggregates

Properly sound aggregates are essential for durable concrete structures.

Weathering Effects

Soundness testing helps assess the resistance of aggregates to weathering.



Concrete Durability

Soundness tests aid in ensuring the longevity of concrete structures.

Alkali Aggregate Reaction

Alkali-aggregate reaction is a chemical reaction in concrete between alkalis, present in the cement, and certain types of reactive minerals in the aggregate. This reaction can lead to the cracking and deterioration of concrete over time.

1

Understanding the Reaction

Study the potential for alkali-aggregate reaction to prevent concrete damage.

2

Preventive Measures

Identify strategies to mitigate the alkali-aggregate reaction in concrete.

3

Long-term Impact

Understand the long-term effects of alkali-aggregate reaction on concrete structures.

Thermal Properties of Aggregates

Understanding the thermal properties of aggregates is critical for applications in which temperature differentials are expected. Aggregates with low thermal expansion coefficients are often preferred for use in concrete subjected to high temperature variations.

Thermal Conductivity

Assess the thermal conductivity of different types of aggregates used in construction.

Expansion Coefficients

Evaluate the expansion coefficients of aggregates in response to temperature changes.

Heat-resistant Aggregates

Identify aggregates suitable for applications in high-temperature environments.

Sieve Analysis

Sieve analysis is used to assess the particle size distribution of aggregates. It helps ensure that the aggregates used in concrete production meet size specifications. Proper grading of aggregates is crucial for the workability and strength of concrete.

Particle Size Distribution

Understand how sieve analysis is used to determine the gradation of aggregates.

Quality Control

Implementing sieve analysis for quality control in concrete production.

Fineness Modulus

The fineness modulus of aggregate is an index number that represents the mean size of the aggregate particles. It is an important factor in concrete mix design, influencing the workability and finish of the concrete.

1 Concrete Mix Design

Understand how fineness modulus impacts the overall mix design of concrete.

2 Strength & Workability

Assess the effects of fineness modulus on the strength and workability of concrete.

3 Particle Size Distribution

Learn about the relationship between fineness modulus and aggregate gradation.

Grading Curves

Grading curves are graphical representations of the particle size distribution of aggregates. They help visualize how well the aggregates blend together in concrete mixtures, impacting the properties of fresh and hardened concrete.

Particle Size	Distribution (%)	Curve Analysis
Coarse	40	Curve should be well graded
Fine	60	Curve should be dense and continuous

Grading of Fine, Manufactured Sand and Coarse Aggregates

The grading of fine and coarse aggregates is crucial for achieving concrete with desirable properties. Properly graded aggregates contribute to improved workability, reduced void content, and higher strength of concrete.

Optimal Gradation

Understand the importance of achieving an optimal gradation for different aggregate types.

Strength Enhancement

Explore how grading contributes to enhancing the strength of concrete.

Gap Graded Aggregate – Maximum Aggregate Size, Properties Recycled Aggregate

Gap-graded aggregates are designed to minimize the void content in concrete and improve its workability. Understanding the maximum aggregate size and properties of recycled aggregate is essential for sustainable and efficient construction practices.

1

Maximum Size

Assess the influence of maximum aggregate size on concrete properties.

2

Recycled Aggregate

Explore the benefits of utilizing recycled aggregates in construction.

Admixtures: Types of Admixtures – Mineral and Chemical Admixtures

Admixtures play a vital role in modifying and enhancing the properties of concrete. Both mineral and chemical admixtures are used to achieve specific performance requirements such as improved workability, strength, and durability of concrete mixes.

1

Roles in Concrete

Understand the distinct roles and functions of mineral and chemical admixtures in concrete.

2

Application Techniques

Learn about the different application techniques for mineral and chemical admixtures.

3

Performance Criteria

Evaluate the performance criteria influenced by the use of admixtures in concrete.

Concrete Pump and Placing Boom at Work in a Major Construction Site.

CHAPTER 6

Fresh Concrete

- Workability
- Segregation
- Bleeding
- Setting Time of Concrete
- Process of Manufacture of Concrete
- Choosing the Correct Pump
- General Points on Using Vibrators
- Further Instructions on use of Vibrators
- Curing of Concrete
- Finishing

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state. It is worthwhile looking back at what we have discussed in Chapters I and III regarding quantity of water before we discuss its role in fresh concrete in this chapter.

In Chapter I, we have discussed the role of water and the quantity of water required for chemical combination with cement and to occupy the gel pores. We have seen that the theoretical water/cement ratio required for these two purposes is about 0.38. Use of water/cement ratio more than this, will result in capillary cavities; and less than this, will result in incomplete hydration and also lack of space in the system for the development of gel.

In Chapter III, we have discussed that while making mortar for concrete, the quantity of water used will get altered at site either due to the presence of free surface moisture in the aggregates or due to the absorption characteristics of dry and

porous aggregates. The water/cement ratio to be actually adopted at site is required to be adjusted keeping the above in mind.

In this chapter one more aspect for deciding the water/cement ratio will be introduced i.e., the water/cement ratio required from the point of view of workability of concrete.

Workability

A theoretical water/cement ratio calculated from the considerations discussed above is not going to give an ideal situation for maximum strength. Hundred per cent compaction of concrete is an important parameter for contributing to the maximum strength. Lack of compaction will result in air voids whose demaging effect on strength and durability is equally or more predominant than the presence of capillary cavities.

Degree of workability

To enable the concrete to be fully compacted with given efforts, normally a higher water/cement ratio than that calculated by theoretical considerations may be required. That is to say the function of water is also to lubricate the concrete so that the concrete can be compacted with specified effort forthcoming at the site of work. The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of a certain quantity of water is of vital importance.

The quality of concrete satisfying the above requirements is termed as workable concrete. The word "workability" or workable concrete signifies much wider and deeper meaning than the other terminology "consistency" often used loosely for workability. Consistency is a general term to indicate the degree of fluidity or the degree of mobility. A concrete which has high consistency and which is more mobile, need not be of right workability for a particular job. Every job requires a particular workability. A concrete which is considered workable for mass concrete foundation is not workable for concrete to be used in roof construction, or even in roof construction, concrete considered workable when vibrator is used, is not workable when concrete is to be compacted by hand. Similarly a concrete considered workable when used in thick section is not workable when required to be used in thin sections. Therefore, the word

workability assumes full significance of the type of work, thickness of section, extent of reinforcement and mode of compaction.

For a concrete technologist, a comprehensive knowledge of workability is required to design a mix. Workability is a parameter, a mix designer is required to specify in the mix design process, with full understanding of the type of work, distance of transport, loss of slump, method of placing, and many other parameters involved. Assumption of right workability with proper understanding backed by experience will make the concreting operation economical and durable.

Many research workers tried to define the word workability. But as it signifies much wider properties and qualities of concrete, and does not project any one particular meaning, it eludes all precise definitions. Road Research laboratory, U.K, who have extensively studied the field of compaction and workability, defined workability as "the property of concrete which determines the amount of useful internal work necessary to produce full compaction." Another definition which envelopes a wider meaning is that, it is defined as the "ease with which concrete can be compacted hundred per cent having regard to mode of compaction and place of deposition." Without dwelling much on the merits and demerits of various definitions of workability, having explained the importance and full meaning of the term workability, we shall see the factors affecting workability.

Factors Affecting Workability

Workable concrete is the one which exhibits very little internal friction between particle and particle or which overcomes the frictional resistance offered by the formwork surface or reinforcement contained in the concrete with just the amount of compacting efforts forthcoming. The factors helping concrete to have more lubricating effect to reduce internal friction for helping easy compaction are given below:

(a) Water Content *(b) Mix Proportions*

(c) Size of Aggregates *(d) Shape of Aggregates*

(e) Surface Texture of Aggregate *(f) Grading of Aggregate*

(g) Use of Admixtures.

(a) Water Content: *Water content in a given volume of concrete, will have significant influences on the workability. The higher the water content per cubic meter of concrete, the higher will be the fluidity of concrete, which is one of the important factors affecting workability. At the work site, supervisors who are not well versed with the practice of making good concrete, resort to adding more water for increasing workability. This practice is often resorted to because this is one of the easiest corrective measures that can be taken at site. It should be noted that from the desirability point of view, increase of water content is the last recourse to be taken for improving the workability even in the case of uncontrolled concrete. For controlled concrete one cannot arbitrarily increase the water content. In case, all other steps to improve workability fail, only as last recourse the addition of more water can be considered. More water can be added, provided a correspondingly higher quantity of cement is also added to keep the water/cement ratio constant, so that the strength remains the same.*

(b) Mix Proportions: *Aggregate /cement ratio is an important factor influencing workability. The higher the aggregate /cement ratio, the leaner is the concrete. In lean concrete, less quantity of paste is available for providing lubrication, per unit surface area of aggregate and hence the mobility of aggregate is restrained. On the other hand, in case of rich concrete with lower aggregate /cement ratio, more paste is available to make the mix cohesive and fatty to give better workability.*

(c) Size of Aggregate: *The bigger the size of the aggregate, the less is the surface area and hence less amount of water is required for wetting the surface and less matrix or paste is required for lubricating the surface to reduce internal friction. For a given quantity of water and paste, bigger size of aggregates will give higher workability. The above, of course will be true within certain limits.*

(d) Shape of Aggregates: *The shape of aggregates influences workability in good measure. Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates. Contribution to better workability of rounded aggregate will come from the fact that for the given volume or weight it will have less surface area and less voids than angular or flaky aggregate. Not only that, being round in shape, the frictional resistance is also greatly reduced. This explains the reason why river sand and gravel provide greater workability to concrete than crushed sand and aggregate.*

The importance of shape of the aggregate will be of great significance in the case of present day high strength and high performance concrete when we use very low w/c in the order of about 0.25. We have already talked about that in the years to come natural sand will be exhausted or costly. One has to go for manufactured sand. Shape of crushed sand as available today is unsuitable but the modern crushers are designed to yield well shaped and well graded aggregates.

(e) Surface Texture: *The influence of surface texture on workability is again due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. From the earlier discussions it can be inferred that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability. A reduction of inter particle frictional resistance offered by smooth aggregates also contributes to higher workability.*

(f) Grading of Aggregates: *This is one of the factors which will have maximum influence on workability. A well graded aggregate is the one which has least amount of voids in a given volume. Other factors being constant, when the total voids are less, excess paste is available to give better lubricating effect. With excess amount of paste, the mixture becomes cohesive and fatty which prevents segregation of particles. Aggregate particles will slide past each other with the least amount of compacting efforts. The better the grading, the less is the void content and higher the workability. The above is true for the given amount of paste volume.*

(g) Use of Admixtures: *Of all the factors mentioned above, the most import factor which affects the workability is the use of admixtures. In Chapter 5, it is amply described that the plasticizers and superplasticizers greatly improve the workability many folds. It is to be noted that initial slump of concrete mix or what is called the slump of reference mix should be about 2 to 3 cm to enhance the slump many fold at a minimum doze. One should manupulate other factors to obtain initial slump of 2 to 3 cm in the reference mix. Without initial slump of 2 – 3 cm, the workability can be increased to higher level but it requires higher dosage – hence uneconomical.*

Use of air-entraining agent being surface-active, reduces the internal friction between the particles. They also act as artificial fine aggregates of very smooth surface. It can be viewed that air bubbles act as a sort of ball bearing between the particles to slide past each other and give easy mobility to the particles. Similarly, the fine glassy pozzolanic materials, inspite of increasing the surface area, offer better lubricating effects for giving better workability.

Measurement of Workability

It is discussed earlier that workability of concrete is a complex property. Just as it eludes all precise definition, it also eludes precise measurements. Numerous attempts have been made by many research workers to quantitatively measure this important and vital property of concrete. But none of these methods are satisfactory for precisely measuring or expressing this property to bring out its full meaning. Some of the tests, measure the parameters very close to workability and provide useful information. The following tests are commonly employed to measure workability.

(a) Slump Test
(b) Compacting Factor Test
(c) Flow Test
(d) Kelly Ball Test
(e) Vee Bee Consistometer Test.

Slump Test

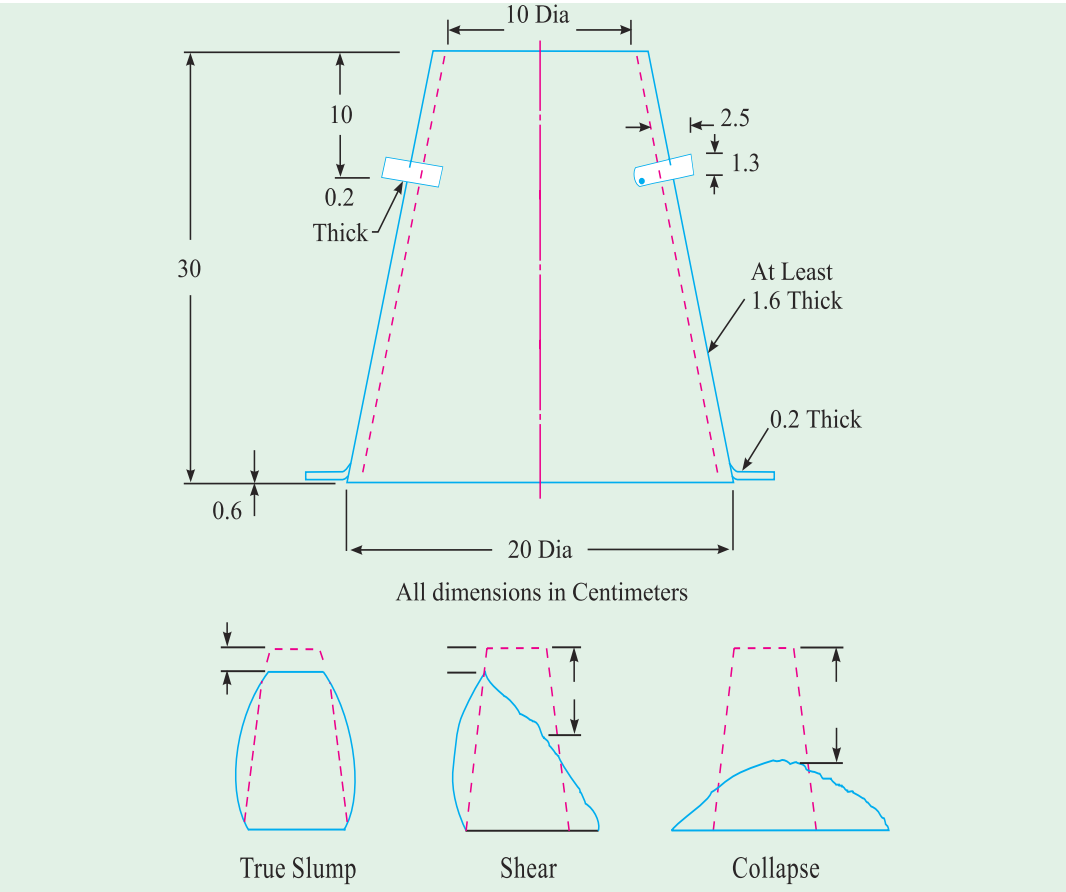
Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work. It is not a suitable method for very wet or very dry concrete. It does not measure all factors contributing to workability, nor is it always representative of the placability of the concrete. However, it is used conveniently as a control test and gives an indication of the uniformity of concrete from batch to batch. Repeated batches of the same mix, brought to the same slump, will have the same water content and water cement ratio, provided the weights of aggregate, cement and admixtures are uniform and aggregate grading is within acceptable limits. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slumps. Quality of concrete can also be further assessed by giving a few tappings or blows by tamping rod to the base plate. The deformation shows the characteristics of concrete with respect to tendency for segregation.

The appartus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as under:

Bottom diameter	:	*20 cm*
Top diameter	:	*10 cm*
Height	:	*30 cm*

The thickness of the metallic sheet for the mould should not be thinner than 1.6 mm. Sometimes the mould is provided with suitable guides for lifting vertically up. For tamping the concrete, a steel tamping rod 16 mm dia, 0.6 meter along with bullet end is used. Fig. 6.1, shows the details of the slump cone appartus. The internal surface of the mould is thoroughly cleaned and freed from superfluous moisture and adherence of any old set concrete before commencing the test. The mould is placed on a smooth, horizontal, rigid and non-absorbant surface The mould is then filled in four layers, each approximately 1/4 of the height of the mould. Each layer is tamped 25 times by the tamping rod taking

Slump Test Apparatus



care to distribute the strokes evenly over the cross section. After the top layer has been rodded, the concrete is struck off level with a trowel and tamping rod. The mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred as SLUMP of concrete. The difference in level between the height of the mould and that of the highest point of the subsided concrete is measured. This difference in height in mm. is taken as Slump of Concrete. ASTM measure the centre of the slumped concrete as the difference in height. ASTM also specifies 3 layers.

The pattern of slump is shown in Fig. 6.2. It indicates the characteristic of concrete in addition to the slump value. If the concrete slumps evenly it is called true slamp. If one half of the cone slides down, it is called shear slump. In case of a shear slump, the slump value is measured as the difference in height between the height of the mould and the average value of the subsidence. Shear slump also indicates that the concrete is non-cohesive and shows the characteristic of segregation.

It is seen that the slump test gives fairly good consistent results for a plastic-mix. This test is not sensitive for a stiff-mix. In case of dry-mix, no variation can be detected between mixes of different workability. In the case of rich mixes, the value is often satisfactory, their slump being sensitive to variations in workability. IS 456 of 2000 suggests that in the "very low" category of workability where strict control is necessary, for example, pavement quality concrete, (PQC) measurement of workability by determination of compacting factor will be more appropriate than slump and a value of 0.75 to 0.80 compacting factor is suggested.

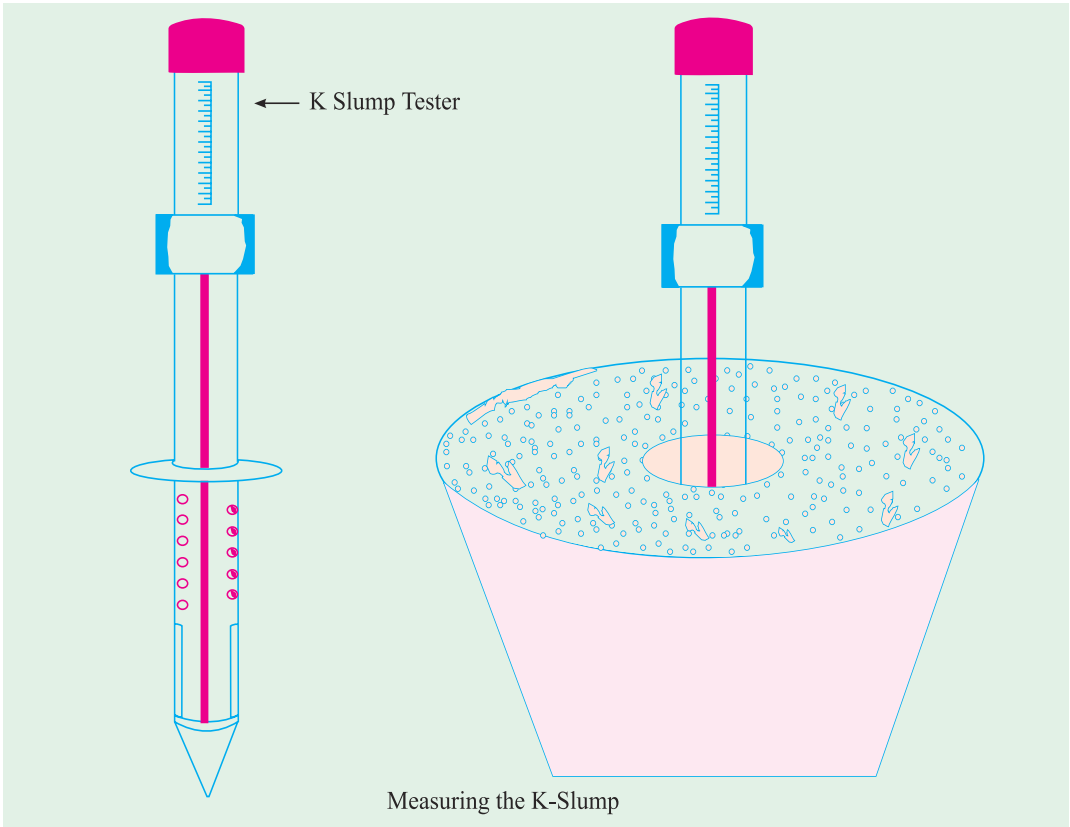
The above IS also suggests that in the "very high" category of workability, measurement of workability by determination of "flow" by flow test will be more appropriate. However, in a lean-mix with a tendency of harshness a true slump can easily change to shear slump. In such case, the tests should be repeated.

Despite many limitations, the slump test is very useful on site to check day-to-day or hour-to-hour variation in the quality of mix. An increase in slump, may mean for instance that the moisture content of the aggregate has suddenly increased or there has been sudden change in the grading of aggregate. The slump test gives warning to correct the causes for change of slump value. The simplicity of this test is yet another reason, why this test is still popular in spite of the fact that many other workability tests are in vogue. Table 6.1 shows the nominal slump value for different degrees of workability.

The Bureau of Indian standards, in the past, generally adopted compacting factor test values for denoting workability. Even in the IS 10262 of 1982 dealing with Recommended Guide Line for Concrete Mix Design, adopted compacting factor for denoting workability. But now in the revision of IS 456 of 2000 the code has reverted back to slump value to denote the workability rather than compacting factor. It shows that slump test has more practical utility than the other tests for workability.

K-Slump Tester

Very recently a new appartus called "K-Slump Tester" has been devised.[6.1] *It can be used to measure the slump directly in one minute after the tester is inserted in the fresh concrete to the level of the floater disc. This tester can also be used to measure the relative workability.*



Measuring the K-Slump

The appartus comprises of the following four principal parts:-

1. *A chrome plated steel tube with external and internal diameters of 1.9 and 1.6 cm respectively. The tube is 25 cm long and its lower part is used to make the test. The length of this part is 15.5 cm which includes the solid cone that facilitates inserting the tube into the concrete. Two types of openings are provided in this part: 4 rectangular slots 5.1 cm long and 0.8 cm wide and 22 round holes 0.64 cm in diameter; all these openings are distributed uniformly in the lower part as shown in Figure 6.3.*

K-Slump Tester

Table 6.1. Workability, Slump and Compacting Factor of Concretes with 20 mm or 40 mm Maximum Size of Aggregate

Degree of workability	*Slump mm*	*Compacting factor*		*Use for which concrete is suitable*
		Small appartus	*Large appartus*	
Very Low *compacting factor is suitable*	–	*0.78*	*0.80*	*Roads vibrated by power-operated machines. At the more workable end of this group, concrete may be compacted in certain cases with hand-operated machines.*
Low	*25–75*	*0.85*	*0.87*	*Roads vibrated by hand-operated machines. At the more workable end of this group, concrete may be manually compacted in roads using aggregate of rounded or irregular shape. Mass concrete foundations without vibration or lightly reinforced sections with vibration.*
Medium	*50–100*	*0.92*	*0.935*	*At the less workable end of this group, manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections with vibration*
High	*100–150*	*0.95*	*0.96*	*For sections with congested reinforcement. Not normally suitable for vibration. For pumping and tremie placing*
Very High	–	–	–	*Flow table test is more suitable.*

2. *A disc floater 6 cm in diameter and 0.24 cm in thickness which divides the tube into two parts: the upper part serves as a handle and the lower one is for testing as already mentioned. The disc serves also to prevent the tester from sinking into the concrete beyond the preselected level.*
3. *A hollow plastic rod 1.3 cm in diameter and 25 cm long which contains a graduated scale in centimeters. This rod can move freely inside the tube and can be used to measure the height of mortar that flows into the tube and stays there. The rod is plugged at each end with a plastic cap to prevent concrete or any other material from seeping inside.*
4. *An aluminium cap 3 cm diameter and 2.25 cm long which has a little hole and a screw that can be used to set and adjust the reference zero of the apparatus. There is also in the upper part of the tube, a small pin which is used to support the measuring rod at the beginning of the test. The total weight of the appartus is 226 g.*

The following procedure is used:

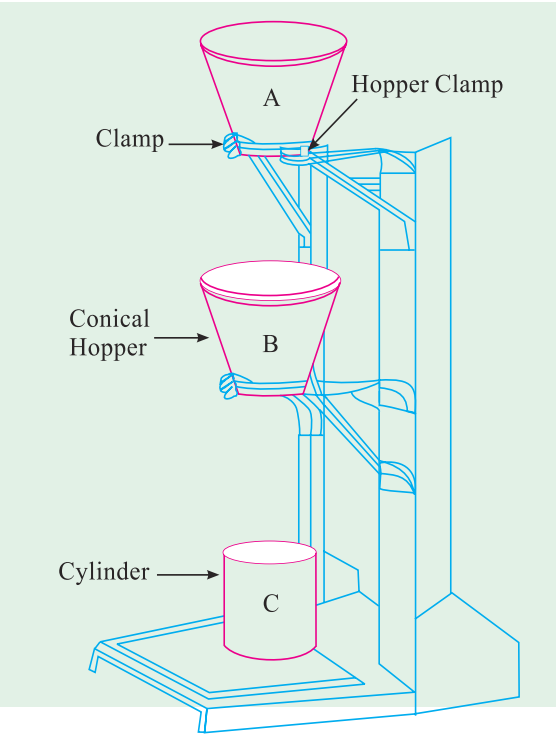
(a) Wet the tester with water and shake off the excess.

(b) Raise the measuring rod, tilt slightly and let it rest on the pin located inside the tester.

(c) Insert the tester on the levelled surface of concrete vertically down until the disc floater rests at the surface of the concrete. Do not rotate while inserting or removing the tester.

(d) After 60 seconds, lower the measuring rod slowly until it rests on the surface of the concrete that has entered the tube and read the K-Slump directly on the scale of the measuring rod.

(e) Raise the measuring rod again and let it rest on its pin.



Compacting Factor Apparatus

(f) Remove the tester from the concrete vertically up and again lower the measuring rod slowly till it touches the surface of the concrete retained in the tube and read workability (W) directly on the scale of the measuring rod.

Remarks

In the concrete industry, the slump test is still the most widely used test to control the consistency of concrete mixtures, even though there are some questions about its significance and its effectiveness. Many agree that the test is awkward and is not in keeping with the strides that the industry has made since 1913 when the slump cone was first introduced. Several apparatus have been proposed to replace or supplement the slump cone, but in general they have proved to be rich in theory and poor in practice. Their use is still limited mainly to research work in laboratories.

The K-slump apparatus is very simple, practical, and economical to use, both in the field and the laboratory. It has proven, with over 450 tests, that it has a good correlation with the slump cone.

The K-slump tester can be used to measure slump in one minute in cylinders, pails, buckets, wheel-barrows, slabs or any other desired location where the fresh concrete is placed. A workability index can be determined by the tester.

Compacting Factor Test

The compacting factor test is designed primarily for use in the laboratory but it can also be used in the field. It is more precise and sensitive than the slump test and is particularly useful for concrete mixes of very low workability as are normally used when concrete is to be compacted by vibration. Such dry concrete are insensitive to slump test. The diagram of the apparatus is shown in Figure 6.4. The essential dimensions of the hoppers and mould and the distance between them are shown in Table 6.2.

The compacting factor test has been developed at the Road Research Laboratory U.K. and it is claimed that it is one of the most efficient tests for measuring the workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height. The degree of compaction, called the compacting factor is measured by the density ratio i.e., the ratio of the density actually achieved in the test to density of same concrete fully compacted.

Table 6.2. Essential Dimension of the Compacting Factor Appartus for use with Aggregate not exceeding 40 mm Nominal Max. Size

Upper Hopper, A	Dimension cm
Top internal diameter	25.4
Bottom internal diameter	12.7
Internal height	27.9
Lower hopper, B	
Top internal diameter	22.9
Bottom internal diameter	12.7
Internal height	22.9

Cylinder, C	
Internal diameter	*15.2*
Internal height	*30.5*
Distance between bottom of upper hopper and top of lower hopper	*20.3*
Distance between bottom of lower hopper and top of cylinder	*20.3*

The sample of concrete to be tested is placed in the upper hopper up to the brim. The trap-door is opened so that the concrete falls into the lower hopper. Then the trap-door of the lower hopper is opened and the concrete is allowed to fall into the cylinder. In the case of a dry-mix, it is likely that the concrete may not fall on opening the trap-door. In such a case, a slight poking by a rod may be required to set the concrete in motion. The excess concrete remaining above the top level of the cylinder is then cut off with the help of plane blades supplied with the apparatus. The outside of the cylinder is wiped clean. The concrete is filled up exactly upto the top level of the cylinder. It is weighed to the nearest 10 grams. This weight is known as "Weight of partially compacted concrete". The cylinder is emptied and then refilled with the concrete from the same sample in layers approximately 5 cm deep. The layers are heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete is then carefully struck off level with the top of the cylinder and weighed to the nearest 10 gm. This weight is known as "Weight of fully compacted concrete".

$$\text{The Compacting Factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

The weight of fully compacted concrete can also be calculated by knowing the proportion of materials, their respective specific gravities, and the volume of the cylinder. It is seen from experience, that it makes very little difference in compacting factor value, whether the weight of fully compacted concrete is calculated theoretically or found out actually after 100 per cent compaction.

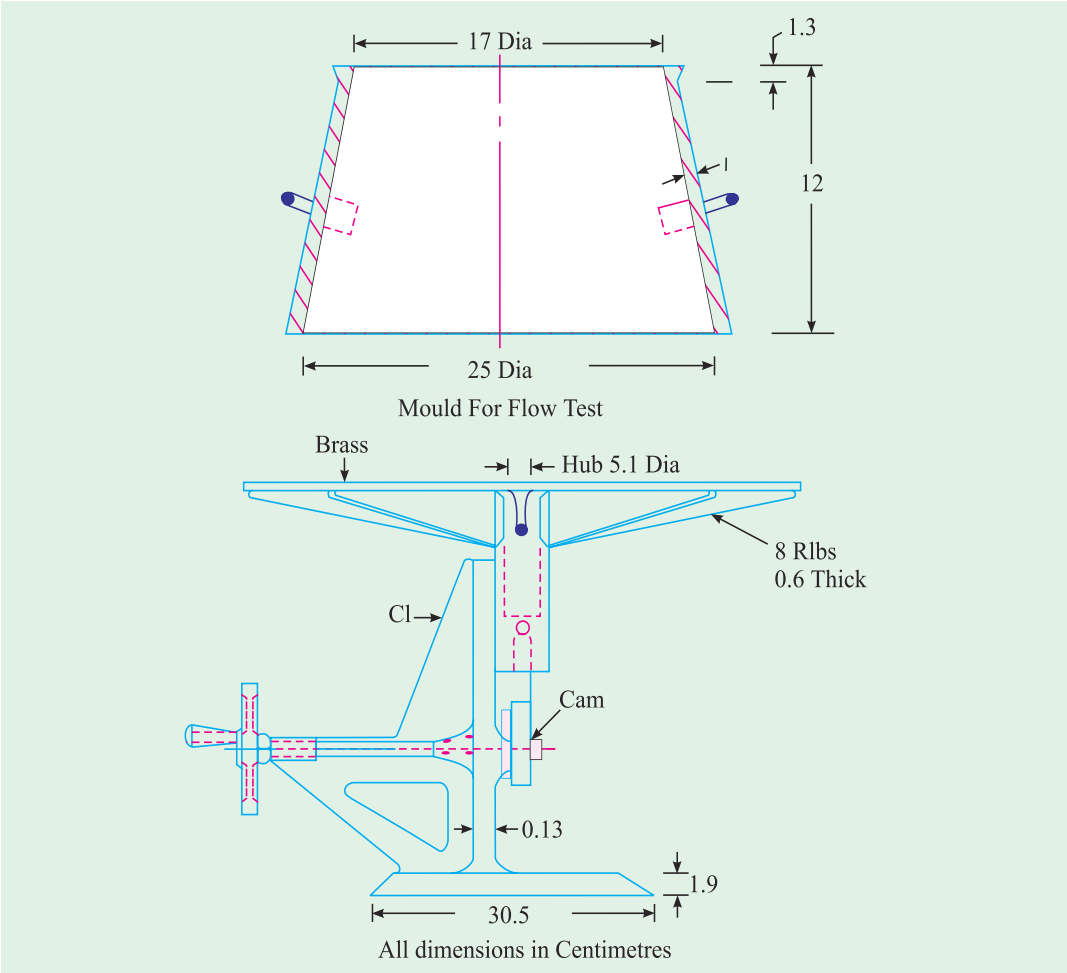
It can be realised that the compacting factor test measures the inherent characteristics of the concrete which relates very close to the workability requirements of concrete and as such it is one of the good tests to depict the workability of concrete.

Flow Test

This is a laboratory test, which gives an indication of the quality of concrete with respect to consistency, cohesiveness and the proneness to segregation. In this test, a standard mass of concrete is subjected to jolting. The spread or the flow of the concrete is measured and this flow is related to workability.

Fig. 6.5 shows the details of apparatus used. It can be seen that the apparatus consists of flow table, about 76 cm. in diameter over which concentric circles are marked. A mould made from smooth metal casting in the form of a frustum of a cone is used with the following internal dimensions. The base is 25 cm. in diameter, upper surface 17 cm. in diameter, and height of the cone is 12 cm.

The table top is cleaned of all gritty material and is wetted. The mould is kept on the centre of the table, firmly held and is filled in two layers. Each layer is rodded 25 times with a tamping rod 1.6 cm in diameter and 61 cm long rounded at the lower tamping end. After



the top layer is rodded evenly, the excess of concrete which has overflowed the mould is removed. The mould is lifted vertically upward and the concrete stands on its own without support. The table is then raised and dropped 12.5 mm 15 times in about 15 seconds. The diameter of the spread concrete is measured in about 6 directions to the nearest 5 mm and the average spread is noted. The flow of concrete is the percentage increase in the average diameter of the spread concrete over the base diameter of the mould

$$\text{Flow, per cent} = \frac{\text{Spread diameter in cm} - 25}{25} \times 100$$

The value could range anything from 0 to 150 per cent.

A close look at the pattern of spread of concrete can also give a good indication of the characteristics of concrete such as tendency for segregation.

Flow Table Apparatus

The BIS has recently introduced another new equipment for measuring flow value of concrete. This new flow table test is in the line with BS 1881 part 105 of 1984 and DIN 1048 part I. The apparatus and method of testing is described below.

The flow table apparatus is to be constructed in accordance with Fig. 6.6. (a) and (b) Flow table top is constructed from a flat metal of minimum thickness 1.5 mm. The top is in plan 700 mm x 700 mm. The centre of the table is marked with a cross, the lines which run paralled to and out to the edges of the plate, and with a central circle 200 mm in diameter. The front of the flow table top is provided with a lifting handle as shown in Fig. 6.6 (b) The total mass of the flow table top is about 16 ± 1 kg.

The flow table top is hinged to a base frame using externally mounted hinges in such a way that no aggregate can become trapped easily between the hinges or hinged surfaces. The front of the base frame shall extend a minimum 120 mm beyond the flow table top in order to provide a top board. An upper stop similar to that shown in Fig. 6.6. (a) is provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± 1 mm.

The lower front edge of the flow table top is provided with two hard rigid stops which transfer the load to the base frame. The base frame is so constructed that this load is then transferred directly to the surface on which the flow table is placed so that there is minimal tendency for the flow table top to bounce when allowed to fall.

Accessory Apparatus

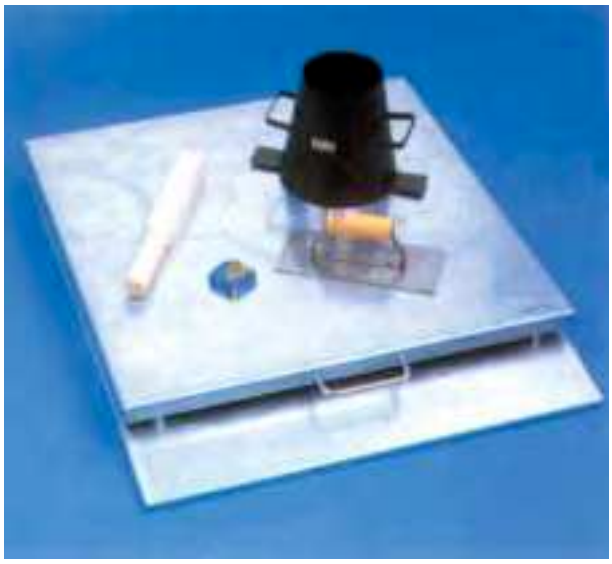
Mould: The mould is made of metal readily not attacked by cement paste or liable to rust and of minimum thickness 1.5 mm. The interior of the mould is smooth and free from projections, such as protruding rivets, and is free from dents. The mould shall be in the form of a hollow frustum of a cone having the internal dimensions as shown in Fig. 6.7. The base and the top is open and parallel to each other and at right angles to the axis of the cone. The mould is provided with two metal foot pieces at the bottom and two handles above them.

Tamping Bar: *The tamping bar is made of a suitable hardwood and having dimensions as shown in Fig. 6.8.*

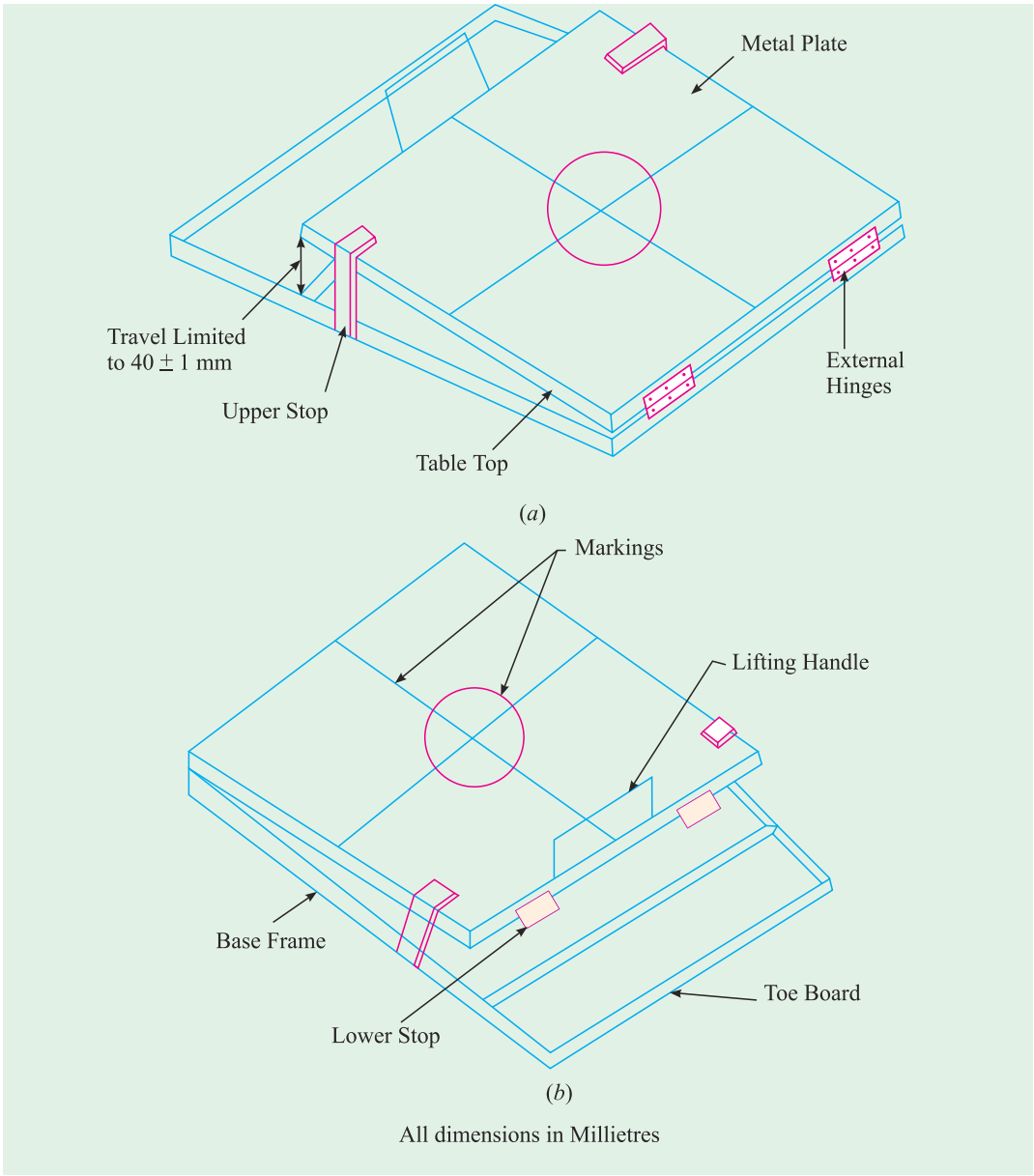
Sampling : *The sample of freshly mixed concrete is obtained.*

Procedure : *The table is made level and properly supported. Before commencing the test, the table-top and inner surface of the mould is wiped with a damp cloth. The slump cone is placed centrally on the table. The slump cone is filled with concrete in two equal layers, each layer tamped lightly 10 times with the wooden tamping bar. After filling the mould, the concrete is struck off flush with the upper edge of the slump cone and the free area of the table-top cleaned off.*

Half a minute after striking off the concrete, the cone is slowly raised vertically by the handles. After this, the table-top raised by the handle and allowed to fall 15 times in 15 seconds. The concrete spreads itself out. The diameter of the concrete spread shall



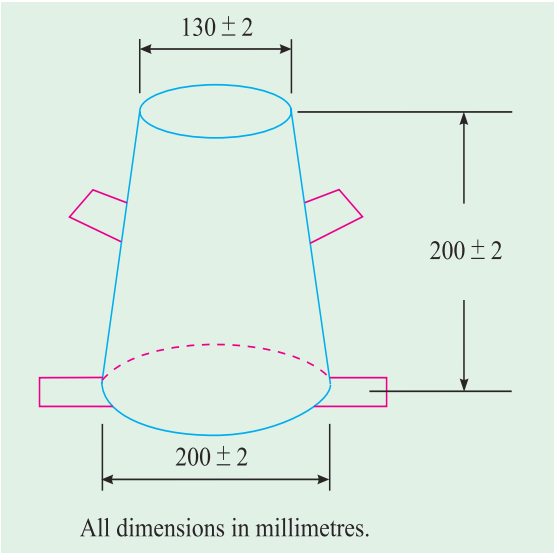
Flow Table Apparatus



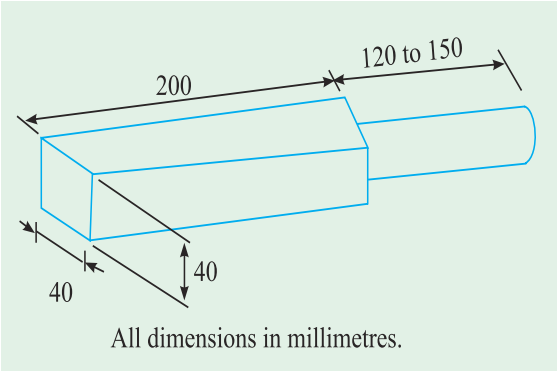
then be measured in two directions, parallel to the table edges. The arithmetic mean of the two diameters shall be the measurement of flow in millimeters.

Kelly Ball Test

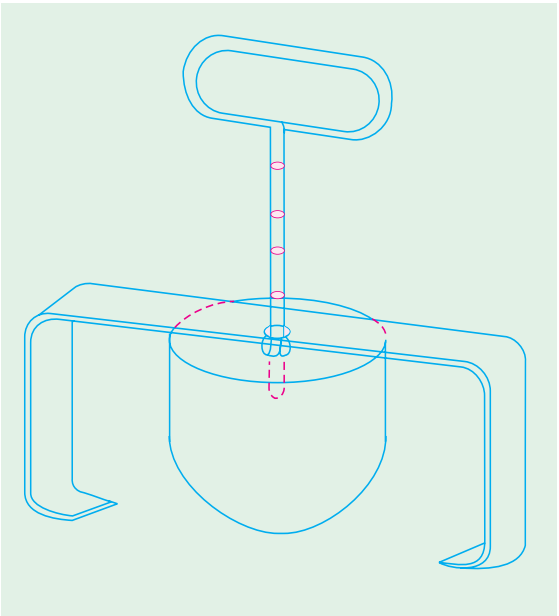
This is a simple field test consisting of the measurement of the indentation made by 15 cm diameter metal hemisphere weighing 13.6 kg. when freely placed on fresh concrete. The test has been devised by Kelly and hence known as Kelly Ball Test. This has not been covered by Indian Standards Specification. The advantages of this test is that it can be performed on the concrete placed in site and it is claimed that this test can be performed faster with a greater precision than slump test. The disadvantages are that it requires a large sample of concrete and it cannot be used when the concrete is placed in thin section. The minimum



All dimensions in millimetres.



All dimensions in millimetres.



depth of concrete must be at least 20 cm and the minimum distance from the centre of the ball to nearest edge of the concrete 23 cm.

The surface of the concrete is struck off level, avoiding excess working, the ball is lowered gradually on the surface of the concrete. The depth of penetration is read immediately on the stem to the nearest 6 mm. The test can be performed in about 15 seconds and it gives much more consistent results than Slump Test. Fig. 6.9. shows the Kelly Ball apparatus.

Vee Bee Consistometer Test

This is a good laboratory test to measure indirectly the workability of concrete. This test consists of a vibrating table, a metal pot, a sheet metal cone, a standard iron rod. The apparatus is shown in Figure. 6.10.

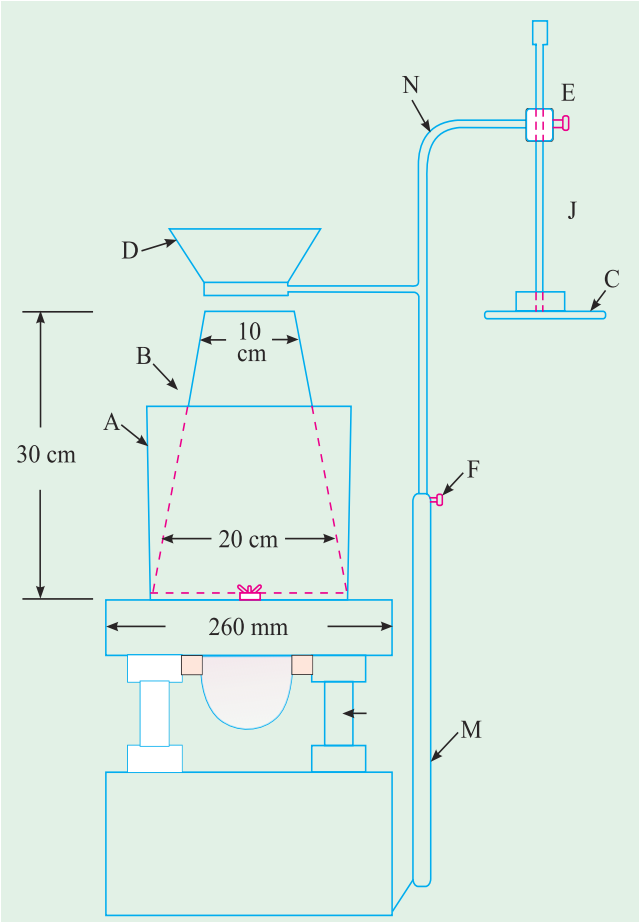
Slump test as described earlier is performed, placing the slump cone inside the sheet metal cylindrical pot of the consistometer. The glass disc attached to the swivel arm is turned and placed on the top of the concrete in the pot. The electrical vibrator is then switched on and simultaneously a stop watch started. The vibration is continued till such a time as the conical shape of the concrete disappears and the concrete assumes a cylindrical shape. This can be judged by observing the glass disc from the top for disappearance of transparency. Immediately when the concrete fully assumes a cylindrical shape, the stop watch is switched off. The time required for the shape of concrete to change from slump cone shape to cylindrical shape in seconds is known as Vee Bee Degree. This method is very suitable for very dry concrete whose slump value cannot be measured by Slump Test, but the vibration is too vigorous for concrete with a slump greater than about 50 mm.

Segregation

Segregation can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. If a sample of concrete exhibits a tendency for separation of say, coarse aggregate from the rest of the ingredients, then, that sample is said to be showing the tendency for segregation. Such concrete is not only going to be weak; lack of homogeneity is also going to induce all undesirable properties in the hardened concrete.

There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart. Segregation may be of three types — firstly, the coarse aggregate separating out or settling down from the rest of the matrix, secondly, the paste or matrix separating away from coarse aggregate and thirdly, water separating out from the rest of the material being a material of lowest specific gravity.

Vee-Bee Consistometer



A well made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time, the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients.

The conditions favourable for segregation are, as can be seen from the above para, the badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates. Insufficiently mixed concrete with excess water content shows a higher tendency for segregation. Dropping of

concrete from heights as in the case of placing concrete in column concreting will result in segregation. When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades, concrete shows a tendency for segregation. Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete.

Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. It too wet a mix is excessively vibrated, it is likely that the concrete gets segregated. It should also be remembered that vibration is continued just for required time for optimim results. If the vibration is continued for a long time, particularly, in too wet a mix, it is likely to result in segregation of concrete due to settlement of coarse aggregate in matrix.

In the recent time we use concrete with very high slump particularly in RMC. The slump value required at the batching point may be in the order of 150 mm and at the pumping point the slump may be around 100 mm. At both these points cubes are cast. One has to take care to compact the cube mould with these high slump concrete. If sufficient care and understanding of concrete is not exercised, the concrete in the cube mould may get segregated and show low strength. Similarly care must be taken in the compaction of such concrete in actual structures to avoid segregation.

While finishing concrete floors or pavement, with a view to achieve a smooth surface, masons are likely to work too much with the trowel, float or tamping rule immediately on placing concrete. This immediate working on the concrete on placing, without any time interval, is likely to press the coarse aggregate down, which results in the movement of excess of matrix or paste to the surface. Segragation caused on this account, impairs the homogeneity and serviceability of concrete. The excess mortar at the top causes plastic shrinkage cracks.

From the foregoing discussion, it can be gathered that the tendency for segregation can be remedied by correctly proportioning the mix, by proper handling, transporting, placing, compacting and finishing. At any stage, if segregation is observed, remixing for a short time would make the concrete again homogeneous. As mentioned earlier, a cohesive mix would reduce the tendency for segregation. For this reason, use of certain workability agents and pozzolanic materials greatly help in reducing segregation. The use of air-entraining agent appreciably reduces segregation.

Segregation is difficult to measure quantitatively, but it can be easily observed at the time of concreting operation. The pattern of subsidence of concrete in slump test or the pattern of spread in the flow test gives a fair idea of the quality of concrete with respect to segregation.

Bleeding

Bleeding is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding.

Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel and floats, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as "Laitance".

In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season. Owing to the fact that the top surface has a higher content of water and is also devoid of aggregate matter; it also develops higher shrinkage cracks. If laitance is formed on a particular lift, a plane of weakness would form and the bond with the next lift would be poor. This could be avoided by removing the laitance fully before the next lift is poured.

Example of external bleeding

Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and unsegmented by the development of gel. This continuous bleeding channels are often responsible for causing permeability of the concrete structures.

While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste. The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars, particularly below the cranked bars, reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by revibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement.

Bleeding is an inherent phenomenon in concrete. All the same, it can be reduced by proper proportioning and uniform and complete mixing. Use of finely dwided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse. It has been already discussed that the use of air-entraining agent is very effective in reducing the bleeding. It is also reported that the bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less susceptible to bleeding than lean mixes.

The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its role in providing workability, from the body of concrete by way of bleeding will do good to the

concrete. Early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, that causes undue harm to the concrete. Controlled revibration may be adopted to overcome the bad effect of bleeding.

Bleeding presents a very serious problem when Slip Form Paver is used for construction of concrete pavements. If two much of bleeding water accumulates on the surface of pavement slab, the bleeding water flows out over the unsupported sides which causes collapsing of sides. Bleeding becomes a major consideration in such situations.

In the pavement construction finishing is done by texturing or brooming. Bleeding water delays the texturing and application of curing compounds.

Method of Test for Bleeding of Concrete

This method covers determination of relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

A cylindrical container of approximately 0.01 m^3 capacity, having an inside diameter of 250 mm and inside height of 280 mm is used. A tamping bar similar to the one used for slump test is used. A pepette for drawing off free water from the surface, a graduated jar of 100 cm^3 capacity is required for test.

A sample of freshly mixed concrete is obtained. The concrete is filled in 50 mm layer for a depth of 250 ± 3 mm (5 layers) and each layer is tamped by giwing strokes, and the top surface is made smooth by trowelling.

The test specimen is weighed and the weight of the concrete is noted. Knowing the total water content in 1 m^3 of concrete quantity of water in the cylindrical container is also calculated.

The cylindrical container is kept in a level surface free from vibration at a temperature of 27°C ± 2°C. it is covered with a lid. Water accumulated at the top is drawn by means of pipette at 10 minutes interval for the first 40 minutes and at 30 minutes interval subsequently till bleeding ceases. To facilitate collection of bleeding water the container may be slightly tilted. All the bleeding water collected in a jar.

$$\text{Bleeding water percentage} = \frac{\text{Total quantity of bleeding water}}{\text{Total quantity of water in the sample of concrete}} \times 100$$

Setting Time of Concrete

We have discussed about the setting time of cement in Chapter 2. Setting time of cement is found out by a standard vicat apparatus in laboratory conditions. Setting time, both initial and final indicate the quality of cement.

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which the concrete is made. The setting time of concrete depends upon the w/c ratio, temperature conditions, type of cement, use of mineral admixture, use of plasticizers–in particular retarding plasticizer. The setting parameter of concrete is more of practical significance for site engineers than setting time of cement. When retarding plasticizers are used, the increase in setting time, the duration upto which concrete remains in plastic condition is of special interest.

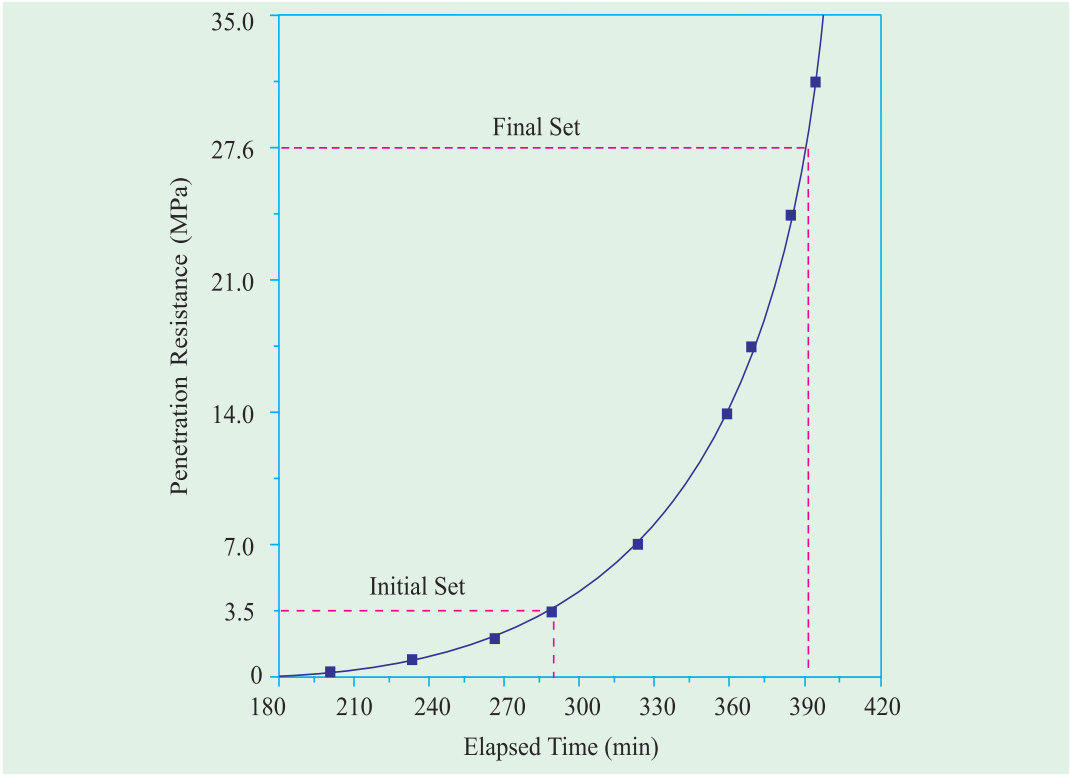
The setting time of concrete is found by pentrometer test. This method of test is covered by IS 8142 of 1976 and ASTM C – 403. The procedure given below may also be applied to prepared mortar and grouts.

The apparatus consist of a container which should have minimum lateral dimension of 150 mm and minimum depth of 150 mm.

There are six penetration needles with bearing areas of 645, 323, 161, 65, 32 and 16 mm^2. Each needle stem is scribed circumferentially at a distance of 25 mm from the bearing area.

A device is provided to measure the force required to cause penetration of the needle.

The test procedure involves the collection of representative sample of concrete in sufficient quantity and sieve it through 4.75 mm sieve and the resulting mortar is filled in the container. Compact the mortar by rodding, tapping, rocking or by vibrating. Level the surface and keep it covered to prevent the loss of moisture. Remove bleeding water, if any, by means of pipette. Insert a needle of appropriate size, depending upon the degree of setting of the mortar in the following manner.



Bring the bearing surface of needle in contact with the mortar surface. Gradually and uniformly apply a vertical force downwards on the apparatus until the needle penetrates to a depth of 25 ± 1.5 mm, as indicated by the scribe mark. The time taken to penetrate 25 mm depth could be about 10 seconds. Record the force required to produce 25 mm penetration and the time of inserting from the time water is added to cement. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle. This is the penetration resistance. For the subsequent penetration avoid the area where the mortar has

been disturbed. The clear distance should be two times the diameter of the bearing area. Needle is inserted at least 25 mm away from the wall of container.

Plot a graph of penetration resistance as ordinate and elapsed time as abscissa. Not less than six penetration resistance determination is made. Continue the tests until one penetration resistance of at least 27.6 MPa is reached. Connect the various point by a smooth curve.

Needle with different bearing area

From penetration resistance equal to 3.5 MPa, draw a horizontal line. The point of intersection of this with the smooth curve, is read on the x-axis which gives the initial setting time. Similarly a horizontal line is drawn from the penetration resistance of 27.6 MPa and point it cuts the smooth curve is read on the x-axis which gives the final set.

A typical graph is shown in Fig. 6.11

Process of Manufacture of Concrete

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredients of good concrete and bad concrete are the same. If meticulous care is not exercised, and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care is taken to exercise control at every stage, it will result in good concrete. Therefore, it is necessary for us to know what are the good rules to be followed in each stage of manufacture of concrete for producing good quality concrete. The various stages of manufacture of concrete are:

(a) Batching (b) Mixing (c) Transporting
(d) Placing (e) Compacting (f) Curing
(g) Finishing.

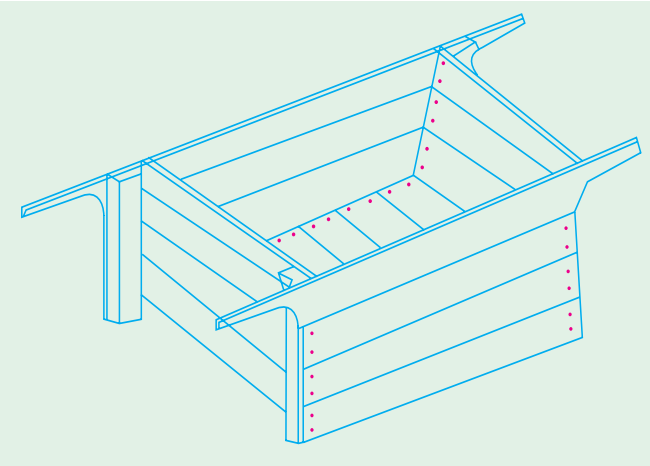
(a) Batching

The measurement of materials for making concrete is known as batching. There are two methods of batching:

(i) Volume batching (ii) Weigh batching

(i) Volume batching: Volume batching is not a good method for proportioning the material because of the difficulty it offers to measure granular material in terms of volume. Volume of moist sand in a loose condition weighs much less than the same volume of dry compacted sand. The amount of solid granular material in a cubic metre is an indefinite quantity. Because of this, for quality concrete material have to be measured by weight only. However, for unimportant concrete or for any small job, concrete may be batched by volume.

Cement is always measured by weight. It is never measured in volume. Generally, for each batch mix, one bag of cement is used. The volume of one bag of cement is taken as thirty five (35) litres. Gauge boxes are used for measuring the fine and coarse aggregates. The typical sketch of a guage box is shown in Figure 6.12. The volume of the box is made equal to the volume of one bag of cement i.e., 35 litres or multiple thereof. The gauge boxes are



made comparatively deeper with narrow surface rather than shallow with wider surface to facilitate easy estimation of top level. Sometimes bottomless gauge-boxes are used. This should be avoided. Correction to the effect of bulking should be made to cater for bulking of fine aggregate, when the fine aggregate is moist and volume batching is adopted.

Gauge boxes are generally called farmas. They can be made of timber or steel plates. Often in India volume batching is adopted even for large concreting operations. In a major site it is recommended to have the following gauge boxes at site to cater for change in Mix Design or bulking of sand. The volume of each gauge box is clearly marked with paint on the external surface.

Table 6.3. Volume of Various gauge boxes

Item	Width cm	Height cm	Depth cm	Volume litres	Quantity number
A	33.3	30	20	20	1
B	33.3	30	25	25	2
C	33.3	30	30	30	2
D	33.3	30	35	35	2
E	33.3	30	40	40	2
F	33.3	30	45	45	2
G	33.3	30	50	50	1

The batch volume for some of the commonly used mixes is shown in Table 6.4.

Table 6.4 Batch volume of materials for various mixes

	Cement kg.	Sand, litres	Coarse aggregate, litres
1 : 1 : 2 (M 200)	50	35	70
1 : 1 1/2 : 3 (M 200)	50	52.5	105
1 : 2 : 3	50	70	105
1 : 2 : 4 (M 150)	50	70	140
1 : 2 1/2 : 5	50	87.5	175
1 : 3 : 6 (M 100)	50	105	210

Water is measured either in kg. or litres as may be convenient. In this case, the two units are same, as the density of water is one kg. per litre. The quantity of water required is a product of water/cement ratio and the weight of cement; for a example, if the water/cement

ratio of 0.5 is specified, the quantity of mixing water required per bag of cement is 0.5 x 50.00 = 25 kg. or 25 litres. The quantity is, of coarse, inclusive of any surface moisture present in the aggregate.

The following table gives the approximate surface moisture carried by aggregates

Table 6.5. Approximate Surface moisture in aggregate–I.S. 456-2000

Aggregates	*Approximate Quantity of surface water*	
	Percent by Mass	*Litre per m^3*
(1)	*(2)*	*(3)*
Very wet sand	*7.5*	*120*
Moderately wet sand	*5.0*	*80*
Moist sand	*2.5*	*40*
Moist gravel or crushed rock	*1.25 – 2.5*	*20 – 40*

(ii) Weigh Batching: *Strictly speaking, weigh batching is the correct method of measuring the materials. For important concrete, invariably, weigh batching system should be adopted. Use of weight system in batching, facilitates accuracy, flexibility and simplicity. Different types of weigh batchers are available, The particular type to be used, depends upon the nature of the job. Large weigh batching plants have automatic weighing equipment. The use of this automatic equipment for batching is one of sophistication and requires qualified and experienced engineers. In this, further complication will come to adjust water content to cater for the moisture content in the aggregate. In smaller works, the weighing arrangement consists of two weighing buckets, each connected through a system of levers to spring-loaded dials which indicate the load. The weighing buckets are mounted on a central spindle about which they rotate. Thus one can be loaded while the other is being discharged into the mixer skip. A simple spring balance or the common platform weighing machines also can be used for small jobs.*

Weigh Batcher

On large work sites, the weigh bucket type of weighing equipments are used. This fed from a large overhead storage hopper and it discharges by gravity, straight into the mixer. The weighing is done through a lever-arm system and two interlinked beams and jockey weights. The required quantity of say, coarse aggregate is weighed, having only the lower beam in operation. After balancing, by turning the smaller lever, to the left of the beam, the two beams are interlinked and the fine aggregate is added until they both balance. The final balance is indicated by the pointer on the scale to the right of the beams. Discharge is through the swivel gate at the bottom.

Automatic batching plants are available in small or large capacity. In this, the operator has only to press one or two buttons to put into motion the weighing of all the different

materials, the flow of each being cut off when the correct weight is reached. In their most advanced forms, automatic plants are electrically operated on a punched card system. This type of plant is particularly only suitable for the production of ready-mixed concrete in which very frequent changes in mix proportion have to be made to meet the varying requirements of different customers.

In some of the recent automatic weigh batching equipments, recorders are fitted which record graphically the weight of each material, delivered to each batch. They are meant to record, and check the actual and designed proportions.

Aggregate weighing machines require regular attention if they are to maintain their accuracy. Check calibrations should always be made by adding weights in the hopper equal to the full weight of the aggregate in the batch. The error found is adjusted from time to time.

In small jobs, cement is often not weighed; it is added in bags assuming the weight of the bag as 50 kg. In reality, though the cement bag is made of 50 kg. at the factory, due to transporation, handling at a number of places, it loses some cement, particularly, when jute bags are used. In fact, the weight of a cement bag at the site is considerably less. Sometimes, the loss of weight becomes more than 5 kg. This is one of the sources of error in volume batching and also in weigh batching, when the cement is not actually weighed. But in important major concreting jobs, cement is also actually weighed and the exact proportion as designed is maintained.

Measurement of Water: *When weigh batching is adopted, the measurement of water must be done accurately. Addition of water by graduated bucket in terms of litres will not be accurate enough for the reason of spillage of water etc. It is usual to have the water measured in a horizontal tank or vertical tank fitted to the mixer. These tanks are filled up after every batch. The filling is so designed to have a control to admit any desired quantity of water. Sometimes, water-meters are fitted in the main water supply to the mixer from which the exact quantity of water can be let into the mixer.*

Cans for measuring water

In modern batching plants sophisticated automatic microprocessor controlled weigh batching arrangements, not only accurately measures the constituent materials, but also the moisture content of aggregates. Moisture content is automatically measured by sensor probes and corrective action is taken to deduct that much quantity of water contained in sand from the total quantity of water. A number of such sophisticated batching plants are working in our country. for the last 4 – 5 years.

Mixing

Thorough mixing of the materials is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. There are two methods adopted for mixing concrete:

(i) Hand mixing (ii)Machine mixing

Hand Mixing: Hand mixing is practised for small scale unimportant concrete works. As the mixing cannot be thorough and efficient, it is desirable to add 10 per cent more cement to cater for the inferior concrete produced by this method.

Hand mixing should be done over an impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured quantity of coarse aggregate and fine aggregate in alternate layers. Pour the cement on the top of it, and mix them dry by shovel, turning the mixture over and over again until uniformity of colour is achieved. This uniform mixture is spread out in thickness of about 20 cm. Water is taken in a water-can fitted with a rose-head and sprinkled over the mixture and simultaneously turned over. This operation is continued till such time a good uniform, homogeneous concrete is obtained. It is of particular importance to see that the water is not poured but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the just required consistency. At that stage, even a small quantity of water makes difference.

Laboratory tilting drum mixer

Machine Mixing: Mixing of concrete is almost invariably carried out by machine, for reinforced concrete work and for medium or large scale mass concrete work. Machine mixing is not only efficient, but also economical, when the quantity of concrete to be produced is large.

Many types of mixers are available for mixing concrete. They can be classified as batch-mixers and continuous mixers. Batch mixers produce concrete, batch by batch with time interval, whereas continuous mixers produce concrete continuously without stoppage till such time the plant is working. In this, materials are fed continuously by screw feeders and the materials are continuously mixed and continuously discharged. This type of mixers are used in large works such as dams. In normal concrete work, it is the batch mixers that are used. Batch mixer may be of pan type or drum type. The drum type may be further classified as tilting, non-tilting, reversing or forced action type.

Very little is known about the relatiwe mixing efficiencies of the various types of mixers, but some evidences are there to suggest that pan mixers with a revolving star of blades are more efficient. They are specially suitable for stiff and lean mixes, which present difficulties with most other types of mixers, mainly due to sticking of mortar in the drum. The shape of the drum, the angle and size of blades, the angle at which the drum is held, affect the efficiency of mixer. It is seen that tilting drum to some extent is more efficient than non-tilting drum. In non-tilting drum for discharging concrete, a chute is introduced into the drum by operating a lever. The concrete which is being mixed in the drum, falls into the inclined chute and gets discharged out. It is seen that a little more of segregation takes place, when a non-tilting mixer is used. It is observed in practice that, generally, in any type of mixer, even after thorough mixing in the drum, while it is discharged, more of coarse aggregate comes out first and at the end matrix gets discharged. It is necessary that a little bit of re-mixing is essential, after discharged from mixer, on the platform to off-set the effect of segregation caused while concrete is discharged from the mixer.

As per I.S. 1791–1985, concrete mixers are designated by a number representing its nominal mixed batch capacity in litres. The following are the standardized sizes of three types:

a. Tilting: 85 T, 100 T, 140 T, 200 T

b. Non-Tilting: 200 NT, 280 NT, 375 NT, 500 NT, 1000 NT

c. Reversing: 200 R, 280 R, 375 R, 500 R and 1000 R

The letters T, NT, R denote tilting, non-tilting and reversing respectively. Fig 6.13 illustrates diagrammatically the type of mixers.

Pan / paddle mixer

Concrete mixer with hydraulic hopper 10/7

Normally, a batch of concrete is made with ingredients corresponding to 50 kg cement. If one has a choice for indenting a mixer, one should ask for such a capacity mixer that should hold all the materials for one bag of cement. This of course, depends on the proportion of the mix. For example, for 1 : 2 : 4 mix, the ideal mixer is of 200 litres capacity, whereas if the ratio is 1 : 3 : 6, the requirement will be of 280 litres capacity to facilitate one bag mix. Mixer of 200 litres capacity is insufficient for 1 : 3 : 6 mix and also mixer of 280 litres is too big, hence uneconomical for 1 : 2 : 4 concrete.

To get better efficiency, the sequence of charging the loading skip is as under:

Firstly, about half the quantity of coarse aggregate is placed in the skip over which about half the quantity of fine aggregate is poured. On that, the full quantity of cement i.e., one bag is poured over which the remaining portion of coarse aggregate and fine aggregate is deposited in sequence. This prevents spilling of cement, while discharging into the drum and also this prevents the blowing away of cement in windy weather.

Before the loaded skip is discharged to the drum, about 25 per cent of the total quantity of water required for mixing, is introduced into the mixer drum to wet the drum and to prevent any cement sticking to the blades or at the bottom of the drum. Immediately, on discharging the dry material into the drum, the remaining 75 per cent of water is added to the drum. If the mixer has got an arrangement for independent feeding of water, it is desirable that the remaining 75 per cent of water is admitted simultaneously along with the other materials. The time is counted from the moment all the materials, particularly, the complete quantity of water is fed into the drum.

Reversible drum concrete mixer / mini batching plant

When plasticizer or superplasticizer

Concrete high-speed mixer in a batching plant.

is used, the usual procedure could be adopted except that about one litre of water is held back. Calculated quantity of plasticizer or superplasticizer is mixed with that one litre of water and the same is added to the mixer drum after about one minute of mixing. It is desirable that concrete is mixed little longer (say 1/2 minute more) so that the plasticizing effect is fully achieved by proper dispersion.

When plasticizers are used, generally one has to do number of trials in the laboratory for arriving at proper dosage and required slump. Small scale laboratory mixers are inefficient and do not mix the ingredients properly. Plasticizer in small quantity do not get properly dispersed with cement particles. To improve the situations, the following sequence may be adopted.

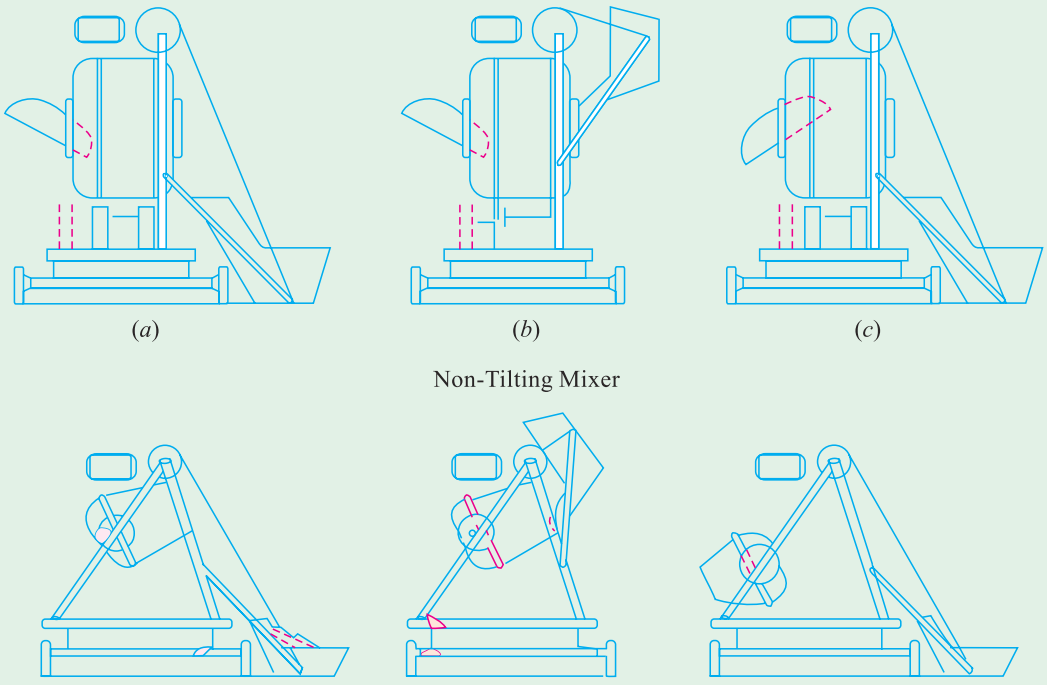
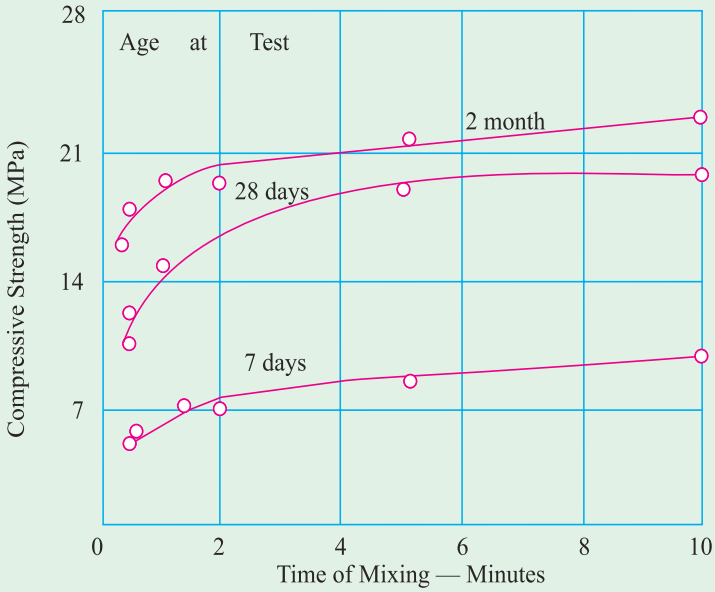


Fig. 6.13. Illustrating Diagrammatically the Method of Operation of the Rotary and Tilting Type Concrete Mixer

Firstly, add all the water except about half a litre. Add cement and then add sand. Make an intimate mortar mix. Dilute calculated quantity of plasticizer with the remaining half a litre of water and pour it into the drum. Rotate the drum for another half a minute, so that plasticizer gets well mixed with cement mortar and then add both the fractions (20 mm and 10 mm) of coarse aggregate. This procedure is found to give better and consistent results.

Mixing Time: *Concrete mixers are generally designed to run at a speed of 15 to 20 revolutions per minute. For proper mixing, it is seen that about 25 to 30 revolutions are required in a well designed mixer. In the site, the normal tendency is to speed up the outturn of concrete by reducing the mixing time. This results in poor quality of concrete. On the other*



hand, if the concrete is mixed for a comparatively longer time, it is uneconomical from the point of view of rate of production of concrete and fuel consumption. Therefore, it is of importance to mix the concrete for such a duration which will accrue optimum benefit.

It is seen from the experiments that the quality of concrete in terms of compressive strength will increase with the increase in the time of mixing, but for mixing time beyond two minutes, the improvement in compressive strength is not very significant. Fig. 6.14. shows the effect of mixing time on strength of concrete.

Concrete mixer is not a simple apparatus. Lot of considerations have gone as input in the design of the mixer drum. The shape of drum, the number of blades, inclination of blades with respect to drum surface, the length of blades, the depth of blades, the space between the drum and the blades, the space between metal strips of blades and speed of rotation etc., are important to give uniform mixing quality and optimum time of mixing.

Generally mixing time is related to the capacity of mixer. The mixing time varies between 1½ to 2½ minutes. Bigger the capacity of the drum more is the mixing time. However, modern high speed pan mixer used in RMC, mixes the concrete in about 15 to 30 secs. One cubic meter capacity high speed Pan Mixer takes only about 2 minutes for batching and mixing. The batching plant takes about 12 minutes to load a transit mixer of 6 m^3 capacity.

Sometimes, at a site of work concrete may not be discharged from the drum and concrete may be kept rotating in the drum for long time, as for instance when some quarrel

or dispute takes place with the workers, or when unanticipated repair or modification is required to be done on the formwork and reinforcement. Long-time mixing of concrete will generally result in increase of compressive strength of concrete within limits. Due to mixing over long periods, the effective water/cement ratio gets reduced, owing to the absorption of water by aggregate and evaporation. It is also possible that the increase in strength may be due to the improvement in workability on account of excess of fines, resulting from the abrasion and attrition of coarse aggregate in the mix, and from the coarse aggregates themselves becoming rounded. The above may not be true in all conditions and in all cases. Sometimes, the evaporation of water and formation of excess fines may reduce the workability and hence bring about reduction in strength. The excess of fine may also cause greater shrinkage.

Modern ready mixed concrete plant.

In case of long haul involved in delivering ready-mixed concrete to the site of work, concrete is mixed intermittently to reduce the bad effect of continuous mixing. A pertinent point to note in this connection is that when the concrete is mixed or agitated from time to time with a short interval, the normal rule of initial setting time is not becoming applicable. The concrete that is kept in agitation, does not exactly follow the setting time rule as applicable to concrete kept in an unagitated and quiescent condition.

Retempering of Concrete

Often long hauls are involved in the following situation-delivery of concrete from central mixing plant, in road construction, in constructing lengthy tunnels, in transportation of concrete by manual labour in hilly terrain. Loss of workability and undue stiffening of concrete may take place at the time of placing on actual work site. Engineers at site, many a time, reject the concrete partially set and unduly stiffened due to the time elapsed between mixing and placing. Mixed concrete is a costly material and it can not be wasted without any regard to cost. It is required to see whether such a stiffened concrete could be used on work without

undue harm. The process of remixing of concrete, if necessary, with addition of just the required quantity of water is known as "Retempering of Concrete". Sometimes, a small quantity of extra cement is also added while retempering. Many specifications do not permit retempering. I.S. 457 – 1957 did not permit retempering of partially hardened concrete or mortar requiring renewed mixing, with or without addition of cement, aggregate or water. However, many research workers are of the view that retempering with the addition of a small quantity of water may be permitted to obtain the desired slump provided the designed water/cement ratio is not exceeded. They caution that the production of concrete of excessive slump or adding water in excess of designed water cement ratio to compensate for slump loss resulting from delays in delivery or placing should be prohibited. It is seen from the investigations, retempering of concrete which is too wet a mix, at a delay of about one hour or so showed an increase in compressive strength of 2 to 15 per cent. Retempering at further delay resulted in loss of strength. However, this loss of strength is smaller than would be expected from the consideration of the total water/cement ratio i.e., the initial water cement ratio plus water added for retempering to bring the mix back into the initial degree of workability.

Maintenance of Mixer

Concrete mixers are often used continuously without stopping for several hours for continuous mixing and placing. It is of utmost importance that a mixer should not stop in between concreting operation. For this reason, concrete mixer must be kept well maintained. Mixer is placed at the site on a firm and levelled platform. The drum and blades must be kept absolutely clean at the end of concreting operation. The drum must be kept in the tilting position or kept covered when not in use to prevent the collection of rain water. The skip is operated carefully and it must rest on proper cushion such as sand bags.

Transporting Concrete

Concrete can be transported by a variety of methods and equipments. The precaution to be taken while transporting concrete is that the homogeneity obtained at the time of mixing should be maintained while being transported to the final place of deposition. The methods adopted for transportation of concrete are:

(a) Mortar Pan
(b) Wheel Barrow, Hand Cart
(c) Crane, Bucket and Rope way
(d) Truck Mixer and Dumpers
(e) Belt Conveyors
(f) Chute
(g) Skip and Hoist
(h) Tansit Mixer
(i) Pump and Pipe Line
(j) Helicoptor.

Mortar Pan: Use of mortar pan for transporation of concrete is one of the common methods adopted in this country. It is labour intensive. In this case, concrete is carried in small quantities. While this method nullifies the segregation to some extent, particularly in thick members, it suffers from the disadvantage that this method exposes greater surface area of concrete for drying conditions. This results in

Tough Rider for transporting concrete.

Truck mixer and dumper for transporting stiff concrete

greater loss of water, particularly, in hot weather concreting and under conditions of low humidity. It is to be noted that the mortar pans must be wetted to start with and it must be kept clean during the entire operation of concreting. Mortar pan method of conveyance of concrete can be adopted for concreting at the ground level, below or above the ground level without much difficulties.

Wheel Barrow: Wheel barrows are normally used for transporting concrete to be placed at ground level. This method is employed for hauling concrete for comparatively longer distance as in the case of concrete road construction. If concrete is conveyed by wheel barrow over a long distance, on rough ground, it is likely that the concrete gets segregated due to vibration. The coarse aggregates settle down to the bottom and matrix moves to the top surface. To avoid this situation, sometimes, wheel barrows are provided with pneumatic wheel to reduce vibration. A wooden plank road is also provided to reduce vibration and hence segregation.

Crane, Bucket and Rope Way: A crane and bucket is one of the right equipment for transporting concrete above ground level. Crane can handle concrete in high rise construction projects and are becoming a familiar sites in big cities. Cranes are fast and versatile to move concrete horizontally as well as vertically along the boom and allows the placement of concrete at the exact point. Cranes carry skips or buckets containing concrete. Skips have discharge door at the bottom, whereas buckets are tilted for emptying. For a medium scale job the bucket capacity may be 0.5 m^3.

Rope way and bucket of various sizes are used for transporting concrete to a place, where simple method of transporting concrete is found not feasible. For the concrete works in a valley or the construction work of a pier in the river or for dam construction, this method of transporting by rope way and bucket is adopted. The mixing of concrete is done on the bank or abutment at a convenient place and the bucket is brought by a pulley or some other arrangement. It is filled up and then taken away to any point that is required. The vertical movement of the bucket is also controlled by another set of pullies. Sometimes, cable and car arrangement is also made for controlling the movement of the bucket. This is one of the methods generally adopted for concreting dam work or bridge work. Since the size of the bucket is considerably large and concrete is not exposed to sun and wind there would not be much change in the state of concrete or workability.

For discharging the concrete, the bucket may be tilted or sometimes, the concrete is made to discharge with the help of a hinged bottom. Discharge of concrete may also be through a gate system operated by compressed air. The operation of controlling the gate may be done manually or mechanically. It should be practised that concrete is discharged from the smallest height possible and should not be made to freely fall from great height.

Truck Mixer and Dumpers: For large concrete works particularly for concrete to be placed at ground level, trucks and dumpers or ordinary open steel-body tipping lorries can be used. As they can travel to any part of the work, they have much advantage over the jubilee wagons, which require rail tracks. Dumpers are of usually 2 to 3 cubic metre capacity, whereas

the capacity of truck may be 4 cubic metre or more. Before loading with the concrete, the inside of the body should be just wetted with water. Tarpaulins or other covers may be provided to cover the wet concrete during transit to prevent evaporation. When the haul is long, it is advisable to use agitators which prevent segregation and stiffening. The agitators help the mixing process at a slow speed.

For road construction using Slip Form Paver large quantity of concrete is required to be supplied continuously. A number of dumpers of 6 m^3 capacity are employed to supply concrete. Small dumper called Tough Riders are used for factory floor construction.

Belt Conveyors: *Belt conveyors have very limited applications in concrete construction. The principal objection is the tendency of the concrete to segregate on steep inclines, at transfer points or change of direction, and at the points where the belt passes over the rollers. Another disadvantage is that the concrete is exposed over long stretches which causes drying and stiffening particularly, in hot, dry and windy weather. Segregation also takes place due to the vibration of rubber belt. It is necessary that the concrete should be remixed at the end of delivery before placing on the final position.*

Modern Belt Conveyors can have adjustable reach, travelling diverter and variable speed both forward and reverse. Conveyors can place large volumes of concrete quickly where access is limited. There are portable belt conveyors used for short distances or lifts. The end discharge arrangements must be such as to prevent segregation and remove all the mortar on the return of belt. In adverse weather conditions (hot and windy) long reaches of belt must be covered.

Chute: *Chutes are generally provided for transporting concrete from ground level to a lower level. The sections of chute should be made of or lined with metal and all runs shall have approximately the same slope, not flatter than 1 vertical to 2 1/2 horizontal. The lay-out is made in such a way that the concrete will slide evenly in a compact mass without any separation or segregation. The required consistency of the concrete should not be changed in order to facilitate chuting. If it becomes necessary to change the consistency the concrete mix will be completely redesigned.*

Transporting and placing concrete by chute.

This is not a good method of transporting concrete. However, it is adopted, when movement of labour cannot be allowed due to lack of space or for fear of disturbance to reinforcement or other arrangements already incorporated. (Electrical conduits or switch boards etc.,).

Skip and Hoist: *This is one of the widely adopted methods for transporting concrete vertically up for multistorey building construction. Employing mortar pan with the staging and human ladder for transporting*

Tower Hoist and Winch, for lifting concrete to higher level.

concrete is not normally possible for more than 3 or 4 storeyed building constructions. For laying concrete in taller structures, chain hoist or platform hoist or skip hoist is adopted.

At the ground level, mixer directly feeds the skip and the skip travels up over rails upto the level where concrete is required. At that point, the skip discharges the concrete automatically or on manual operation. The quality of concrete i.e. the freedom from segregation will depend upon the extent of travel and rolling over the rails. If the concrete has travelled a considerable height, it is necessary that concrete on discharge is required to be turned over before being placed finally.

Transit Mixer, a popular mathod of transporting concrete over a long distance.

Transit Mixer

Transit mixer is one of the most popular equipments for transporting concrete over a long distance particularly in Ready Mixed Concrete plant (RMC). In India, today (2000 AD) there are about 35 RMC plants and a number of central batching plants are working. It is a fair estimate that there are over 600 transit mixers in operation in India. They are truck mounted having a capacity of 4 to 7 m^3. There are two variations. In one, mixed concrete is transported to the site by keeping it agitated all along at a speed varying between 2 to 6 revolutions per minute. In the other category, the concrete is batched at the central batching plant and mixing is done in the truck mixer either in transit or immediately prior to discharging the concrete at site. Transit-mixing permits longer haul and is less vulnerable in case of delay. The truck mixer the speed of rotating of drum is between 4–16 revolution per minute. A limit of 300 revolutions for both agitating and mixing is laid down by ASTM C 94 or alternatively, the concretes must be placed within $1\frac{1}{2}$ of mixing. In case of transit mixing, water need not be added till such time the mixing is commenced. BS 5328 – 1991, restrict the time of 2 hours during which, cement and moist sand are allowed to remain in contact. But the above restrictions are to be on the safe side. Exceeding these limit is not going to be harmful if the mix remains sufficiently workable for full compaction.

With the development of twin fin process mixer, the transit mixers have become more efficient in mixing. In these mixers, in addition to the outer spirals, have two opposed inner spirals. The outer spirals convey the mix materials towards the bottom of the drum, while the opposed mixing spirals push the mix towards the feed opening. The repeated counter current mixing process is taking place within the mixer drum.

Sometimes a small concrete pump is also mounted on the truck carrying transit mixer. This pump, pumps the concrete discharged from transit mixer. Currently we have placer boom also as part of the truck carrying transit mixer and concrete pump and with their help concrete is transported, pumped and placed into the formwork of a structure easily.

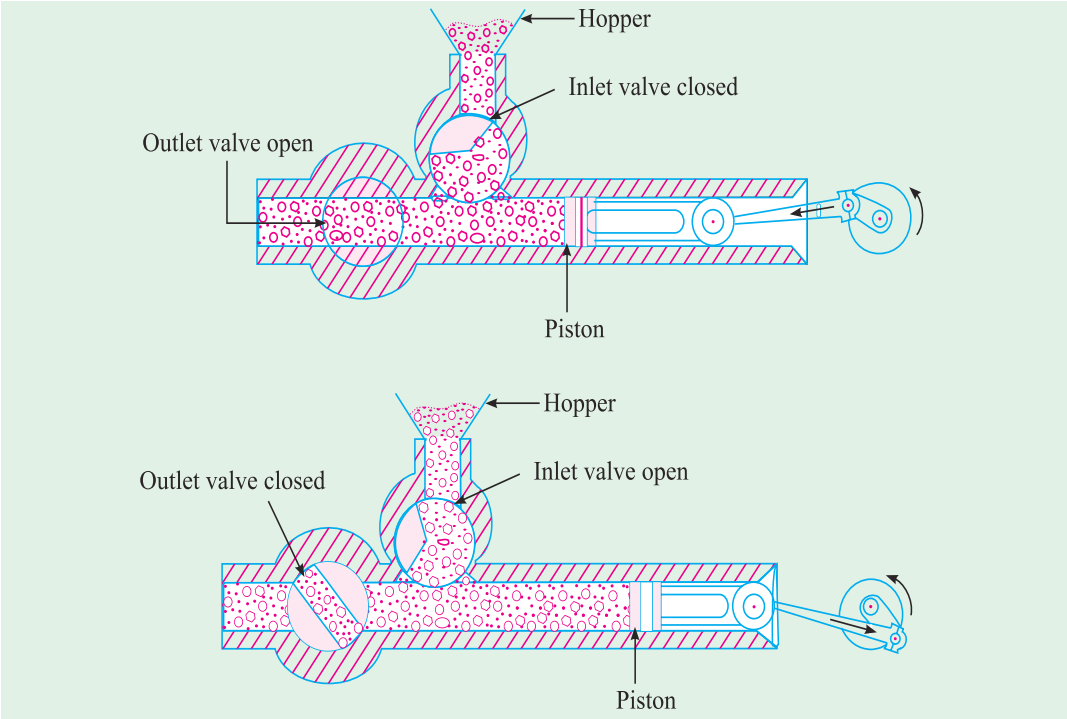
Pumping arrangements

As per estimate made by CM Doordi, the cost of transportation of concrete by transit mixer varies between Rs 160 to 180 per cubic metre.[6.2]

Pumps and Pipeline

Pumping of concrete is universally accepted as one of the main methods of concrete transportation and placing. Adoption of pumping is increasing throughout the world as pumps become more reliable and also the concrete mixes that enable the concrete to be pumped are also better understood.

Development of Concrete Pump: *The first patent for a concrete pump was taken in USA in the year 1913* [6.3]*. By about 1930 several countries developed and manufactured concrete pump with sliding plate valves. By about 1950s and 1960s concrete pumping became widely used method in Germany. Forty per cent of their concrete was placed by pumping. The keen rivalry between the leading German manufacturers, namely, Schwing, Putzmeister and Elba, has boosted the development of concrete pump and in particular the valve design which is the most important part of the whole system.*



Concrete Pumps: *The modern concrete pump is a sophisticated, reliable and robust machine. In the past a simple two-stroke mechanical pump consisted of a receiving hopper, an inlet and an outlet valve, a piston and a cylinder. The pump was powered by a diesel engine. The*

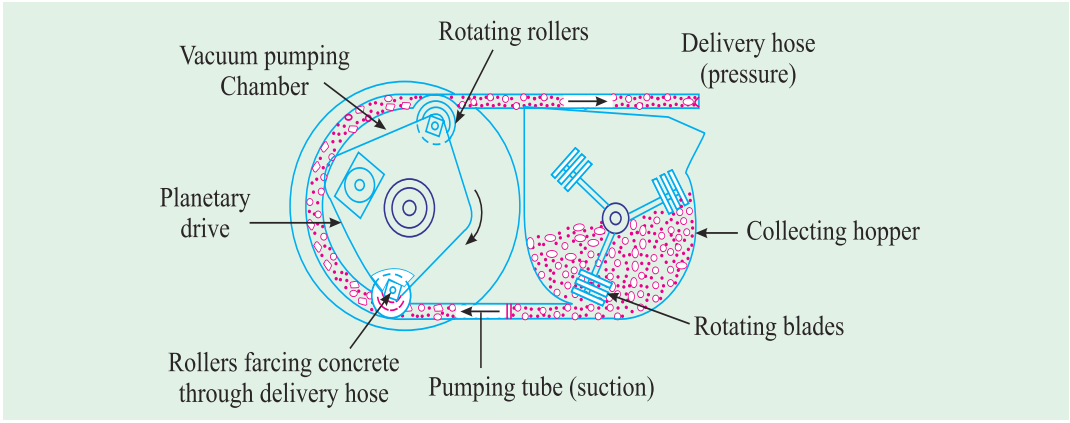
Pump and pipeline

pumping action starts with the suction stroke drawing concrete into the cylinder as the piston moves backwards. During this operation the outlet value is closed. On the forward stroke, the inlet valve closes and the outlet valve opens to allow concrete to be pushed into the delivery pipe. Fig. 6.15 illustrates the principle.

The modern concrete pump still operates on the same principles but with lot of improvements and refinements in the whole operations. During 1963, squeeze type pump was developed in U.S.A. In this concrete placed in a collecting hopper is fed by rotating blades into a flexible pipe connected to the pumping chamber, which is under a vacuum of about 600 mm of mercury. The vacuum ensures that, except when being squeezed by roller, the pipe shape remains cylindrical and thus permits a continuous flow of concrete. Two rotating rollers progressively squeeze the flexible pipes and thus move the concrete into the delivery pipe. Fig. 6.16. shows the action of squeeze pump.

The hydraulic piston pump is the most widely used modern pump. Specification differ but concept of working of modern pump is the same as it was for original mechanically driven pumps. A pump consists of three parts, a concrete receiving happer, a valve system and a power transmission system.

There are three main types of concrete pump. They are mobile, trailor or static and screed or mortar pump.



Types of valve: *The most important part of any concrete pump is the valve system. The main types of valve are peristaltic or squeeze type valves, sliding gate or rotating value, flapper valves, and hollow transfer tube valves.*

Hollow transfer tube valves are most commonly used type of valve. Another type which is used extensively is the Rock Valve. The S valve used by Putzmeister is another example of a transfer tube value.

Pipelines and couplings: *It is not enough to have an efficient pump. It is equally important to have correct diameter of pipeline with adequate wall thickness for a given operating pressure and well designed coupling system for trouble free operation. A poor pipeline can easily cause blockages arising from leakage of grout. Pushing of abrasive material at high pressure, through pipeline inevitably creates a great deal of wear. Continuous handling, frequent securing and releasing of couplings creates wear at joints. All these must be maintained well for trouble free function and safety.*

It is important to choose the correct diameter and wall thickness of the pipeline to match the pump and required placing rate. Generally almost all pumped concrete is conveyed through 125 mm pipeline. There are exceptions. For long, horizontal distance involving high pumping pressures, a large diameter pipe would be more suitable on account of less resistance to flow. For pumping concrete to heights, on account of the fact that gravity and the weight of concrete in the line, a smallest possible diameter of pipelines should be used.

As a guide, a pump with an output of 30 m^3/h and with not more than 200 m of pipeline one may suggest 100 mm diameter, but for length in excess of 500 meter, a 150 mm diameter could be considered.

Diameter of pipeline has also bearing on the size of aggregate. General rule is that the pipe diameter should be between 3 to 4 times the largest size of aggregate. For example if maximum size of aggregate in concrete is 40 mm, the diameter of pipe could be between 120 mm to 160 mm. But use of 125 mm pipe can be considered suitable.

The individual pipe sections with lengths of 1m, 2m or 3 m are connected by means of various types of quick-locking couplings. For change in pipe line directions bends of different degrees (90 deg., 60 deg., 45 deg., 30 deg. and 15 deg.) are available. The bends have a radius of 1 m. But bends with radius of r = 250 mm are used in placing booms.

Laying the Pipeline: *A carefully laid pipeline is the prerequisite for trouble free pumping operation. Time, money and trouble are saved at sites if the installation of concrete pump and the laying of pipelines are thoroughly planned and carried out with care. Leaky pipes and coupling points often results in plugs and impede the pushing of concrete on account of escape of air or water. Pipelines must be well anchored when bends are introduced.*

Particular care must be taken when laying vertical line. It is difficult to dismantle individual pipe. Therefore, install only such pipes which are in good condition. Pumps should not be kept very close to the vertical pipe. There must be some starting distance. This could be about 10 to 15% of the vertical distance.

Capabilities of Concrete Pump: *Concrete has been pumped to a height over 400 m and a horizontal distance of over 2000 m. This requires selected high pressure pump and special attention to concrete mix design. It is reported that in February, 1985, a record for vertical concrete pumping of 432 m was achieved at the Estangento sallente power station in the Spanish Pyrenees. A Putzmeister stationary high pressure pump with an S-transfer tube valve was used. This pump had a theoretical output of 120 m^3/h, 180 mm delivery cylinder and an effective concrete pressure of over 200 bar, 630 meter of 125 mm diameter high pressure pipeline was used.*

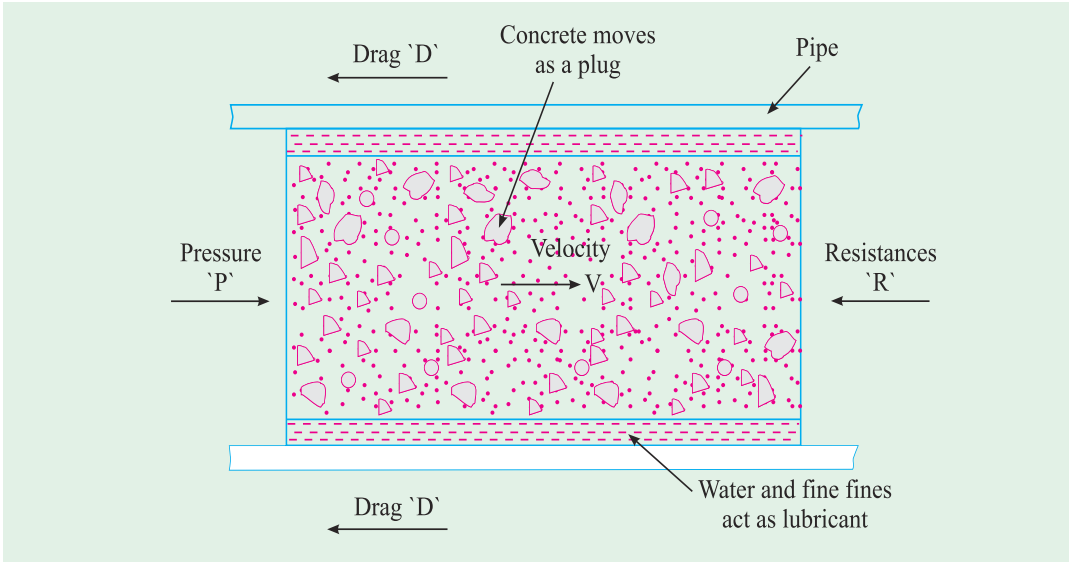
Well pumpable concrete

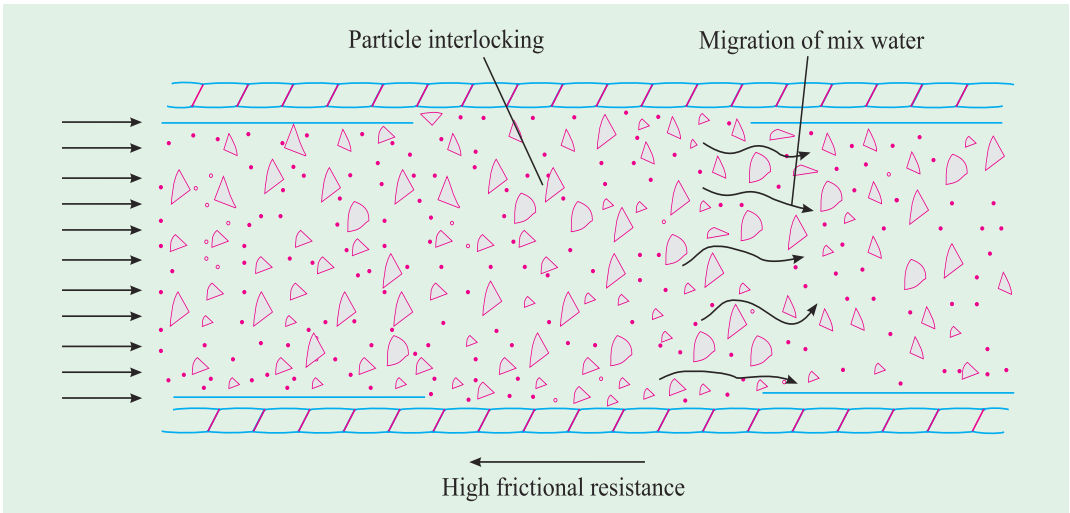
Badly pumpable concrete

For the above work, concrete mix consisted of 506 kg 12 – 25 mm granite aggregate, 362 kg 5 – 12 mm granite aggregate, 655 kg 0 – 5 mm granite sand, 0 – 3 mm river sand, 211 kg cement, 90 kg fly ash and 183 litre water.

Pumpable Concrete : *A concrete which can be pushed through a pipeline is called a pumpable concrete. It is made in such a manner that its friction at the inner wall of the pipeline does not become very high and that it does not wedge while flowing through the pipeline. A clear understanding of what happens to concrete when it is pumped through pipeline is fundamental to any study of concrete pumping. Pumpable concrete emerging from a pipeline flows in the form of a plug which is separated from the pipe wall by a thin lubricating layer consisting of cement paste. The water in the paste is hydraulically linked with the interparticle water layer in the plug. Fig. 6.17 shows the concrete flow under pressure.*

For continuous plug movement, the pressure generated by the flow resistance must not be greater than the pump pressure rating. However, if the concrete is too saturated at higher w /c ratio, the concrete at certain pump pressures may be such that water is forced out of the





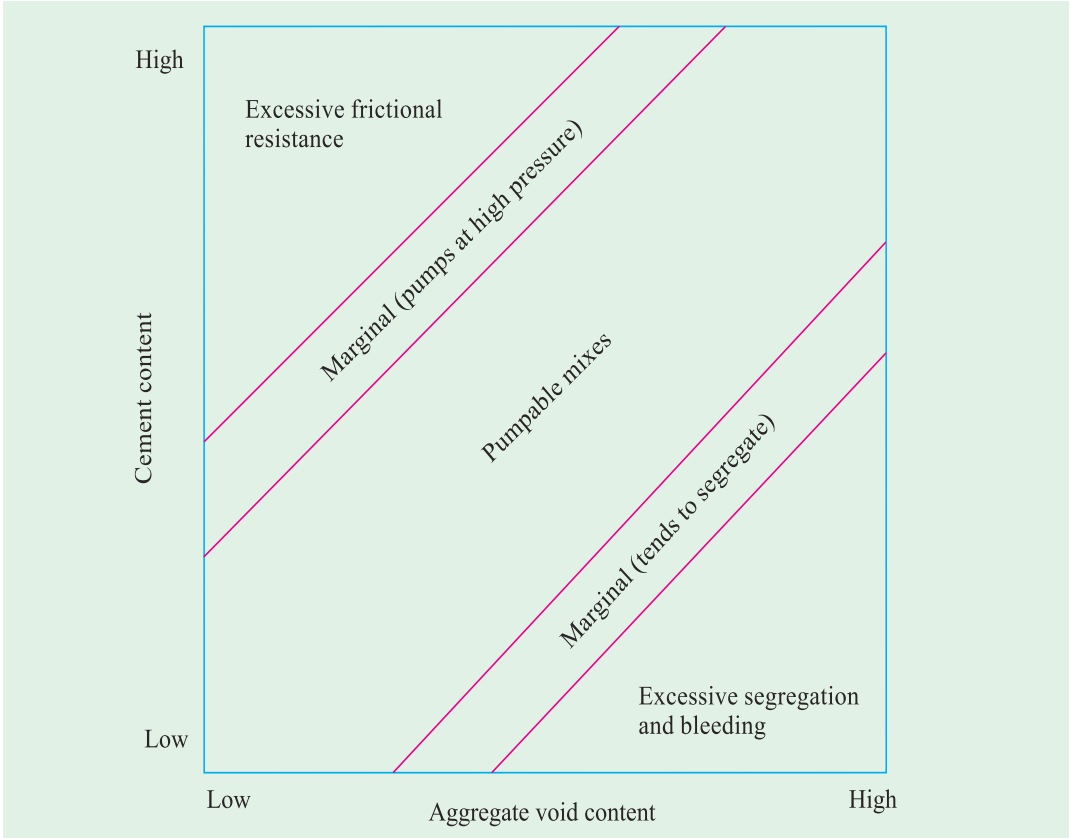
mix, creating an increase in flow resistance and a possible blockage. Fig. 6.18 illustrates such a condition. In other words, a very stiff concrete is not pumpable and also a concrete with high w/c ratio is also not pumpable. It is interesting to note that if a concrete is pumpable, it is implied that it is a good concrete.

Design Considerations for Pumpable Concrete : *The mix is proportioned in such a way that it is able to bind all the constituent materials together under pressure from the pump and thereby avoiding segregation and bleeding. The mix must also facilitate the radial movement of sufficient grout to maintain the lubricating film initially placed on the pipeline wall. The mix should also be able to deform while flowing through bends. To achieve this, the proportion of fines i.e., cement and fine particles below 0.25 mm size (particles below 300 microns Appx.) is of prime importance. The quantities of fine particles between 350 to 400 kg/m^3 are considered necessary for pumpable concrete. The above quantities are not only found necessary for maintaining the lubricating film, but it is important for quality and workability and to cover individual grains.*

There are two main reasons why blockages occur and that the plug of concrete will not move:

- *Water is being forced out of the mix creating bleeding and blockage by jamming, or*
- *There is too much frictional resistance due to the nature of the ingredients of the mix.*

Fig. 6.19. shows the relationship between cement content and aggregate void content and excessive frictional resistance on segregation and bleeding.



While it is important to maintain good grading and low void content, it is not always possible to design pumpable mix around ideal aggregate. Naturally occurring aggregate as well as crushed aggregates are suitable for pumpable mix, but it is essential to be aware of grading, void content and uniformity. The slump of pumpable concrete is kept at 75 mm to collapse range and the diameter of the pipeline is at least 3 – 4 times the maximum size of aggregate.

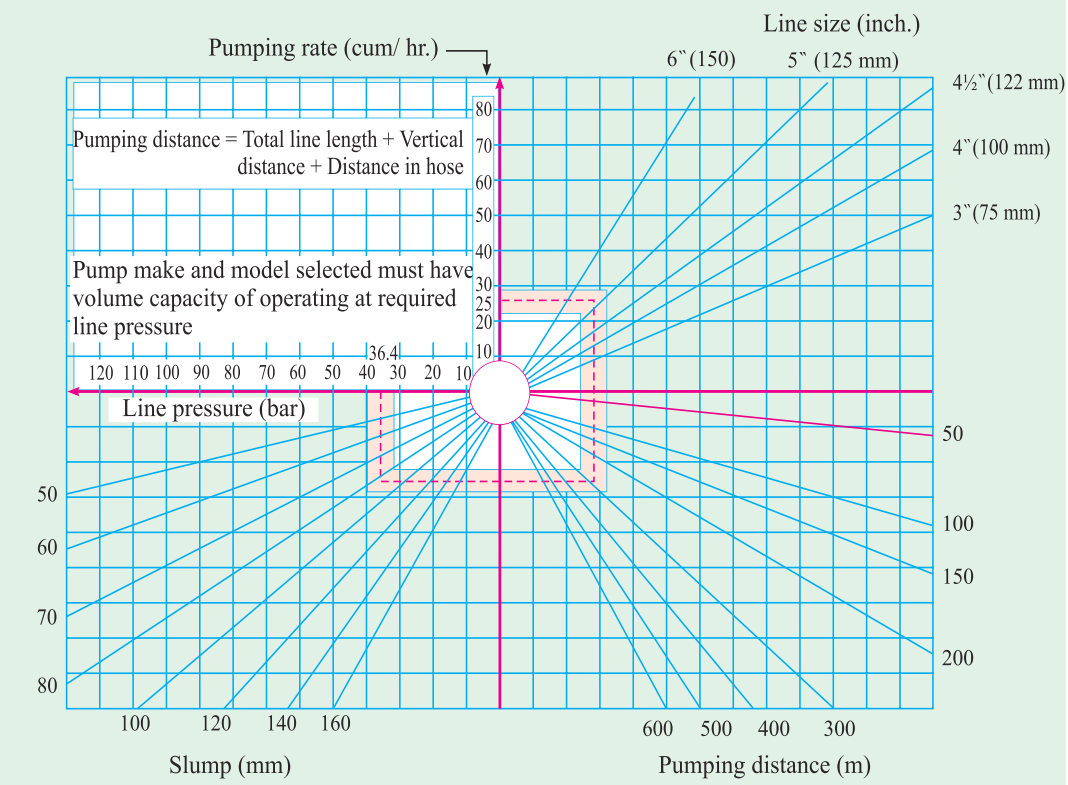
Mix Design process of pumpable concrete will be further dealt in Chapter 11under "Concrete Mix Design."

Choosing the Correct Pump

For choosing the correct pump one must know the following factors

- *Length of horizontal pipe*
- *Length of vertical pipe*
- *Number of bends*
- *Diameter of pipeline*
- *Length of flexible hose*
- *Changes in line diameter*
- *Slump of Concrete.*

Fig. 6.20 hows the line pressure and pumping rate as functions of line diameter, pumping distance and slump. Making use of this nomograph one can find the rated capacity of the pump. This rated capacity should be modified to actual capacity required.



Pressure in the pipe can be estimated using the following guidelines.

- *Start up pressure required by pump* = *20 bars*
- *Every 20 m horizontal pipeline* = *1.0 bar*
- *Every 4 m Vertical pipeline* = *1.0 bar*
- *Every 90° bend* = *1.0 bar*
- *Every 45° bend* = *0.5 bar*
- *Every pipe coupling* = *0.1 bar*
- *Every 5 m end hose* = *2.0 bar*
- *Safety factor* = *10% extra*

Example No. 1. *If a trailer mounted pump kept 40 m away from the building and if it is required to pump concrete 100 m vertically, calculate pressure in the pipeline.*

● *Start up pressure*		*20 bars*
● *Vertical length of pipeline*	= *100 m*	
∴ *Pressure*	$= \frac{100}{4}$	*25 bars*
● *Horizontal length*	= *40 m*	
∴ *Pressure*	$= \frac{40}{20}$	*2 bars*
● *Couplings 60 Nos*		
Pressure	= *60 x 0.1*	*6 bars*
● *90° bends 2 nos*		
Pressure	= *2 x 1*	*2 bars*
● *End Hose 5 m*		
Pressure	= *1 x 2*	*2 bars*
Total Pressure		*57 bars*
Add 10% as safety factor		*6*
∴ *Total Pressure*		*63 bars*

Example No. 2. *A concrete pump is placed 45 m from a building of height 50 m. The placing boom projects 4 m extra height over the building and it can reach a vertical height of another 25 m with four 90° bends and three 30° bends. The average out put required is 30 m^3/h. The diameter of pipeline is 125 mm. The slump of concrete is 70 mm.*

First find out the theoretical length of pipeline

The length of pipeline = 45 m + 50 m = 95 m

There are four 90° bends and three 30° bends making a total of 4 x 90 + 3 x 30 = 360° + 90° = 450°.

Assuming that the bends have a radius of 1 m, 30° is equivalent to 1 m, and, therefore, 450° is equivalent to $\frac{450}{30}$ *= 15 m*

The vertical reach of placing is 25 m, and the bends in the placing boom are assumed to be equivalent to 10 m.

Therefore, the theoretical length of pipeline is 95 + 15 + 25 + 10 = 145 m.

The height to which the concrete has to be pumped is 50 + 4 = 54 m

The static pressure due to vertical pumping is, therefore, 54 x 0.25 = 14 bar

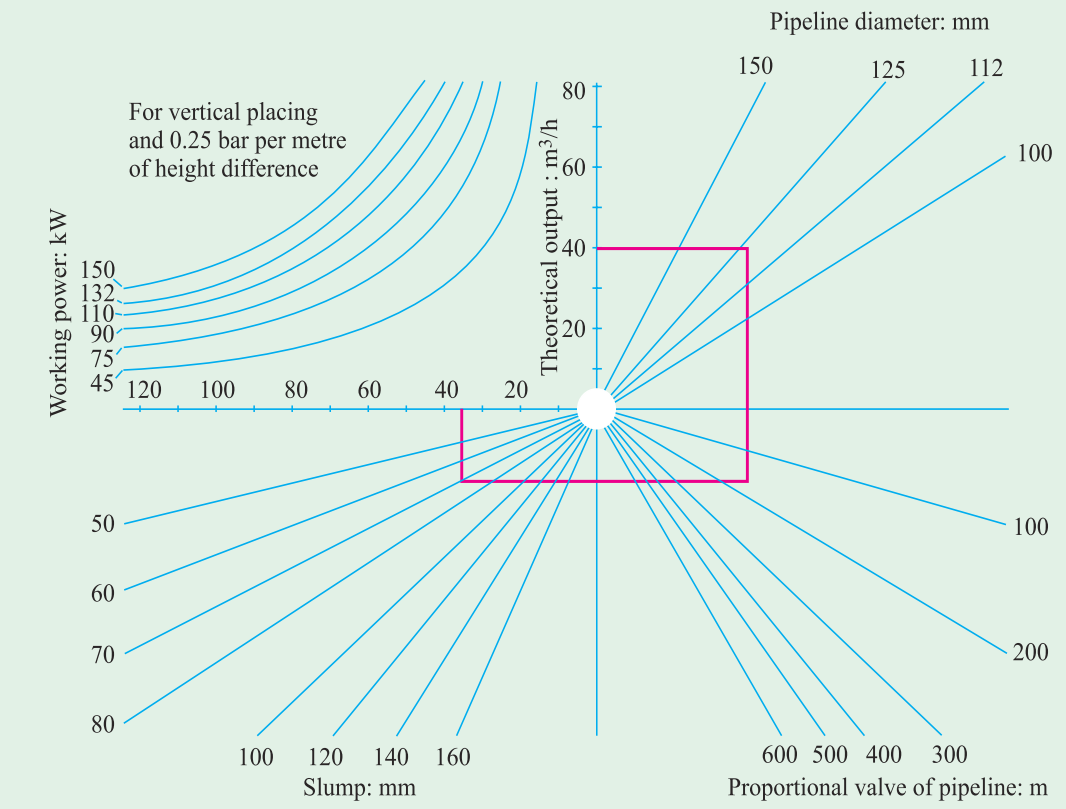
Using the above data i.e., corrected output, pipeline diameter, theoretical length of pipeline and slump, it is possible to arrive at the line pressure using nomograph Fig. 6.21.

On the nomograph Fig 6.21 locate 40 m^3/h output. (30 m^3 x 4/3 = theoretical output = 40 m^3/h). Move across to the right to cut pipeline diameter (125 mm). Then move downwards to meet the theoretical length of pipeline (145 m). Now move to left to intersect the slump line (70 mm). Then move vertically up to meet the pumping pressure line. The reading at this point is shown as 35 bar (Appnox). To this should be added the static pressure of 14 bar, giving a total of 49 bar. The pump chosen, therefore, should have a rated maximum pressure of a figure in excess of 49 bar. The manufacturers will provide their recommended percentage to be added which is normally between 20 and 30%. in this case, the pump required would, therefore, have a line pressure capacity of between 60 and 70 bars.

Common Problems in Pumping Concrete: *The most common problem in pumping concrete is blockage. If concrete fails to emerge at the end of pipeline, if pump is mechanically sound, it would mean that there is blockage somewhere in the system. This will be indicated by an increase in the pressure shown on the pressure gauge. Most blockages occur at tapered sections at the pump end.*

Blockages take place generally due to the unsuitability of concrete mix, pipeline and joint deficiencies and operator's error or careless use of hose end.

It has been already discussed regarding the quality of pumpable concrete. A concrete of right consistency which forms a concrete plug surrounded by lubricating slurry formed inside



the wall of pipeline with right amount of water, well proportioned, homogeneously mixed concrete can only be pumped. It can be rightly said that a pumpable concrete is a good concrete.

Sometimes, high temperature, use of admixtures, particularly, accelerating admixtures and use of high grade cement may cause blockages. Chances of blockage are more if continuous pumping is not done.

A pipeline which is not well cleaned after the previous operation, uncleaned, worn-out hoses, too many and too sharp bends, use of worn out joints are also other reasons for blockages.

Operators must realise and use sufficient quantity of lubricating grout to cover the complete length of pipeline before pumping of concrete. The hose must be well lubricated. Extreme care should be taken in handling the flexible rubber end hose. Careless bending can cause blockages.

Clearing Blockages: *A minor blockage may be cleared by forward and reverse pumping. Excess pressure should not be blindly exerted. If may make the problem worse.*

Sometime shortening the pipeline will reduce pressure and on restarting pumping the blockage gets cleared off.

Tapping the pipeline with hammer and observing the sound one can often locate a blockage.

Blockage could be cleared by rodding or by using sponge ball pushed by compressed air or water at high pressure.

Placing Concrete

It is not enough that a concrete mix correctly designed, batched, mixed and transported, it is of utmost importance that the concrete must be placed in systematic manner to yield optimum results. The precautions to be taken and methods adopted while placing concrete in the under-mentioned situations, will be discussed.

Paving concrete by slip-forming to get sinusoidal profile for linking with the adjacent slab.

Courtesy : Wirtgen

(a) *Placing concrete within earth mould.*
(example: Foundation concrete for a wall or column).

(b) *Placing concrete within large earth mould or timber plank formwork.*
(example: Road slab and Airfield slab).

(c) *Placing concrete in layers within timber or steel shutters.*
(example: Mass concrete in dam construction or construction of concrete abutment or pier).

(d) *Placing concrete within usual from work.*
(example: Columns, beams and floors).

(e) *Placing concrete under water.*

Concrete is invariably laid as foundation bed below the walls or columns. Before placing the concrete in the foundation, all the loose earth must be removed from the bed. Any root of trees passing through the foundation must be cut, charred or tarred effectively to prevent its further growth and piercing the concrete at a later date. The surface of the earth, if dry, must be just made damp so that the earth does not absorb water from concrete. On the other hand if the foundation bed is too wet and rain-soaked, the water and slush must be removed completely to expose firm bed before placing concrete. If there is any seepage of water taking place into the foundation trench, effective method for diverting the flow of water must be adopted before concrete is placed in the trench or pit.

Mould with floating suspension for simultaneous castig of parapetwall.

For the construction of road slabs, airfield slabs and ground floor slabs in buildings, concrete is placed in bays. The ground surface on which the concrete is placed must be free from loose earth, pool of water and other organic matters like grass, roots, leaves etc. The earth must be properly compacted and made sufficiently damp to prevent the absorption of water from concrete. If this is not done, the bottom portion of concrete is likely to become weak. Sometimes, to prevent absorption of moisture from concrete, by the large surface of earth, in case of thin road slabs, use of polyethylene film is used in between concrete and ground. Concrete is laid in alternative bays giving enough scope for the concrete to undergo sufficient shrinkage. Provisions for contraction joints and dummy joints are given. It must be remembered that the concrete must be dumped and not poured. It is also to be ensured that concrete must be placed in just required thickness. The practice of placing concrete in a heap at one place and then dragging it should be avoided.

When concrete is laid in great thickness, as in the case of concrete raft for a high rise building or in the construction of concrete pier or abutment or in the construction of mass concrete dam, concrete is placed in layers. The thickness of layers depends upon the mode of compaction. In reinforced concrete, it is a good practice to place concrete in layers of about 15 to 30 cm thick and in mass concrete, the thickness of layer may vary anything between 35 to 45 cm. Several such layers may be placed in succession to form one lift, provided they follow one another quickly enough to avoid cold joints. The thickness of layer is limited by the method of compaction and size and frequency of vibrator used.

Before placing the concrete, the surface of the previous lift is cleaned thoroughly with water jet and scrubbing by wire brush. In case of dam, even sand blasting is also adopted. The old surface is sometimes hacked and made rough by removing all the laitance and loose material. The surface is wetted. Sometimes, a neat cement slurry or a very thin layer of rich mortar with fine sand is dashed against the old surface, and then the fresh concrete is placed.

The whole operation must be progressed and arranged in such a way that, cold joints are avoided as far as possible. When concrete is laid in layers, it is better to leave the top of the layer rough, so that the succeeding layer can have a good bond with the previous layer. Where the concrete is subjected to horizontal thrust, bond bars, bond rails or bond stones are provided to obtain a good bond between the successive layers. Of course, such arrangements are required for placing mass concrete in layers, but not for reinforced concrete.

Certain good rules should be observed while placing concrete within the formwork, as in the case of beams and columns. Firstly, it must be checked that the reinforcement is correctly tied, placed and is having appropriate cover. The joints between planks, plywoods or sheets must be properly and effectively plugged so that matrix will not escape when the concrete is vibrated. The inside of the formwork should be applied with mould releasing agents for easy stripping. Such purpose made mould releasing agents are separately available for steel or timber shuttering. The reinforcement should be clean and free from oil. Where reinforcement is placed in a congested manner, the concrete must be placed very carefully, in small quantity at a time so that it does not block the entry of subsequent concrete. The above situation often takes place in heavily reinforced concrete columns with close lateral ties, at the junction of column and beam and in deep beams. Generally, difficulties are experienced for placing concrete in the column. Often concrete is required to be poured from a greater height. When the concrete is poured from a height, against reinforcement and lateral ties, it is likely to segregate or block the space to prevent further entry of concrete. To avoid this, concrete is directed by tremie, drop chute or by any other means to direct the concrete within the reinforcement and ties. Sometimes, when the formwork is too narrow, or reinforcement is too congested to allow the use of tremie or drop chute, a small opening in one of the sides is made and the concrete is introduced from this opening instead of pouring from the top. It is advisable that care must be taken at the stage of detailing of reinforcement for the difficulty in pouring concrete. In long span bridges the depth of prestressed concrete girders may be of the order of even 4 – 5 meters involving congested reinforcement. In such situations planning for placing concrete in one operation requires serious considerations on the part of designer.

Placing concrete by pump and placing boom.

Form work: *Form work shall be designed and constructed so as to remain sufficiently rigid during placing and compaction of concrete. The joints are plugged to prevent the loss of slurry from concrete.*

Stripping Time: *Formwork should not be removed until the concrete has developed a strength of at least twice the stress to which concrete may be subjected at the time of removal of formwork. In special circumstances the strength development of concrete can be assessed*

by placing companion cubes near the structure and curing the same in the manner simulating curing conditions of structures. In normal circumstances, where ambient temperature does not fall below 15°C and where ordinary Portland cement is used and adequate curing is done, following striking period can be considered sufficient as per IS 456 of 2000.

Table 6.6. Stripping Time of Formwork

Sr. No.	*Type of Formwork*	*Minimum period before striking formwork*
1.	*Vertical formwork to columns walls and beams*	*16 – 24 hours*
2.	*Soffit formwork to slabs (props to be refixed immediately after removal of formwork)*	*3 days*
3.	*Soffit formwork to beams (Props to be refixed immediately after removal of formwork)*	*7 days*
4.	*Props to slab*	
	spanning up to 4.5 m	*7 days*
	spanning over 4.5 m	*14 days*
5.	*Props to beam and arches*	
	Spanning up to 6 m	*14 days*
	Spanning over 6 m	*21 days*

Note: *For other cements and lower temperature, the stripping time recommended above may be suitably modified.*

Underwater Concreting

Concrete is often required to be placed underwater or in a trench filled with the bentonite slurry. In such cases, use of bottom dump bucket or tremie pipe is made use of. In the bottom dump bucket concrete is taken through the water in a water-tight box or bucket and on reaching the final place of deposition the bottom is made to open by some mechanism and the whole concrete is dumped slowly. This method will not give a satisfactory result as certain amount of washing away of cement is bound to occur.

In some situations, dry or semi-dry mixture of cement, fine and coarse aggregate are filled in cement bags and such bagged concrete is deposited on the bed below the water. This method also does not give satisfactory concrete, as the concrete mass will be full of voids interspersed with the putricible gunny bags. The satisfactory method of placing concrete under water is by the use of tremie pipe.

The word "tremie" is derived from the french word hopper.

A tremie pipe is a pipe having a diameter of about 20 cm capable of easy coupling for increase or decrease of length. A funnel is fitted to the top end to facilitate pouring of concrete. The bottom end is closed with a plug or thick polyethylene sheet or such other material and taken below the water and made to rest at the point where the concrete is going to be placed. Since the end is blocked, no water will have entered the pipe. The concrete having a very high slump of about 15 to 20 cm is poured into the funnel. When the whole length of pipe is filled up with the concrete, the tremie pipe is lifted up and a slight jerk is given by

a winch and pully arrangement. When the pipe is raised and given a jerk, due to the weight of concrete, the bottom plug falls and the concrete gets discharged. Particular care must be taken at this stage to see that the end of the tremie pipe remains inside the concrete, so that no water enters into the pipe from the bottom. In other words, the tremie pipe remains plugged at the lower end by concrete. Again concrete is poured over the funnel and when the whole length of the tremie pipe is filled with concrete, the pipe is again slightly lifted and given slight jerk. Care is taken all the time to keep the lower end of the tremie pipe well embedded in the wet concrete. The concrete in the tremie pipe gets discharged. In this way, concrete work is progressed without stopping till the concrete level comes above the water level.

Fig. 6.22 shows the underwater concreting by tremie.

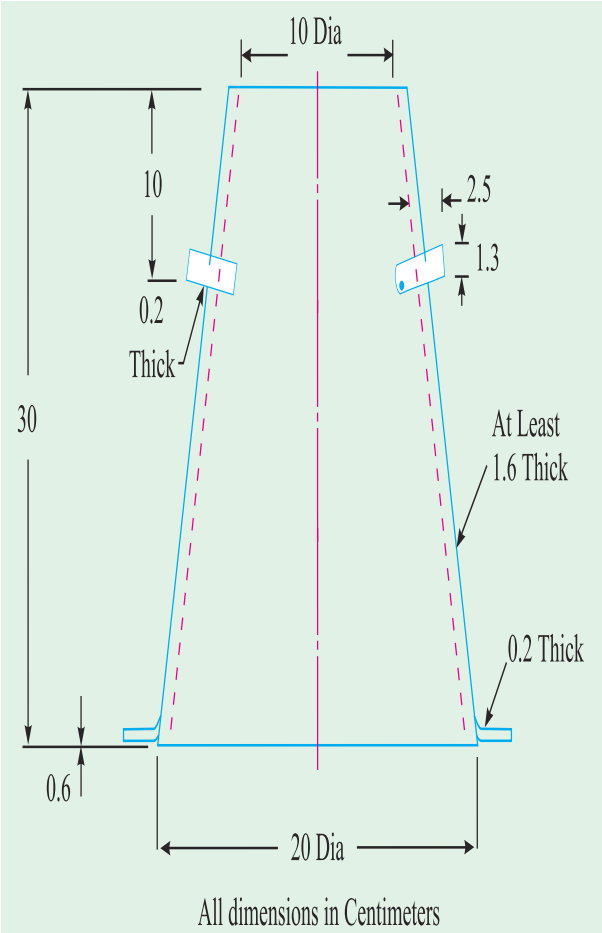


Fig. 6.22. Under Water Concreting by Tremie Method.

This method if executed properly, has the advantage that the concrete does not get affected by water except the top layer. The top layer is scrubbed or cut off to remove the affected concrete at the end of the whole operation.

During the course of concreting, no pumping of water should be permitted. If simultaneous pumping is done, it may suck the cement particles. Under water concreting need not be compacted, as concrete gets automatically compacted by the hydrostatic pressure of water. Secondly, the concrete is of such consistency that it does not normally require compaction. One of the disadvantages of under water concreting in this method is that a high water/cement ratio is required for high consistency which reduces the strength of concrete. But at present, with the use of superplasticizer, it is not a constraint. A concrete with as low a w/c ratio as 0.3 or even less can be placed by tremie method.

Another method, not so commonly employed to place concrete below water is the grouting process of prepacked aggregate. Coarse aggregate is dumped to assume full dimension of the concrete mass. Cement mortar grout is injected through pipes, which extend up to the bottom of the aggregate bed. The pipes are slowly withdrawn, as the grouting progresses. The grout forces the water out from the interstices and occupies the space. For plugging the well foundation this method is often adopted.

Concrete also can be placed under water by the use of pipes and concrete pumps. The pipeline is plugged at one end and lowered until it rests at the bottom. Pumping is then

started. When the pipe is completely filled, the plug is forced out, the concrete surrounding the lower end of the pipe seals the pipe. The pumping is done against the pressure of the plug at the lower end. When the pumping effort required is too great to overcome the pressure, the pipe is withdrawn and the operation is repeated. This process is repeated until concrete reaches the level above water.

Slip-Form Technique

There are special methods of placement of concrete using slip-form technique. Slip-forming can be done both for vertical construction or horizontal construction.

Slip-forming of vertical construction is a proven method of concrete construction generally adopted for tall structures. In this method, concrete is continuously placed, compacted and formwork is pulled up by number of hydraulic Jacks, giving reaction, against jack rods or main reinforcements. The rate of slipping the formwork will vary depending upon the temperature and strength development of concrete to withstand without the support of formwork. In India number of tall structures like chimneys and silos have been built by this technique. Although this method of construction is suitable for uniform shapped structures it was adopted for the core construction of stock exchange building at Bombay having irregular shape and number of openings. The core of 380 feet tall structure was completed in about 38 days. The formwork was slipped at the rate of about 12.5 cm per hour.

The horizontal slip-form construction is rather a new technique in India. It is adopted for road pavement construction. For the first time the slip-form paving method was adopted in Delhi-Mathura concrete Road construction during mid 1990's.

The slip-form pavers were used by many contracting firms in the construction of Mumbai-Pune six lane express highway. The state-of the art method of slip form pavement construction has come to India in a big way.

Slip-form paver is a major equipment, capable of spreading the concrete dumped in front of the machine by tippers or dumpers, compacting the concrete through number of powerful internal needle vibrators and double beam surface vibrators. The paver carries out the smooth finishing operation to the highest accuracy and then texture the surface with nylon brush operating across the lane. The equipment also drops the tie bar at the predetermined interval and push them through and places them at the predetermined depth and recompact the concrete to cover up the gap that are created by the dowel bars. Generally no bleeding takes place because of the stiff consistency of the concrete (2 cm slump) that is designed for placing by slip-form paver. If at all any little bleeding water is there, upon its disappearance, membrane forming curing compound is sprayed on to the textured surface of concrete.

All the above operations are continuously carried out and the slip-form paver crawls continuously on tracked wheel, guided by laser control. Proper alignment to cater for straight line, or curve of any degree with calculated super elevation, or upward or downward gradients are controlled by laser application. Computerised laser control is the backbone of this state-of- the art slip-form paver equipment. The speed of construction i.e., the speed of continuous movement of paver is around 1 meter per minute and in a day of 16 hours working, this equipment can complete about one km of one lane road of width 3.75 m and depth 35 cm.

In the Mumbai-Pune express highway construction, they have used two types of paving equipments namely wirtgen SP 500 and CMI.

They are used for lane by lane construction. Whereas in Europe and the other advanced countries, slip-form pavers capable of completing two or three lanes in one operation are used.

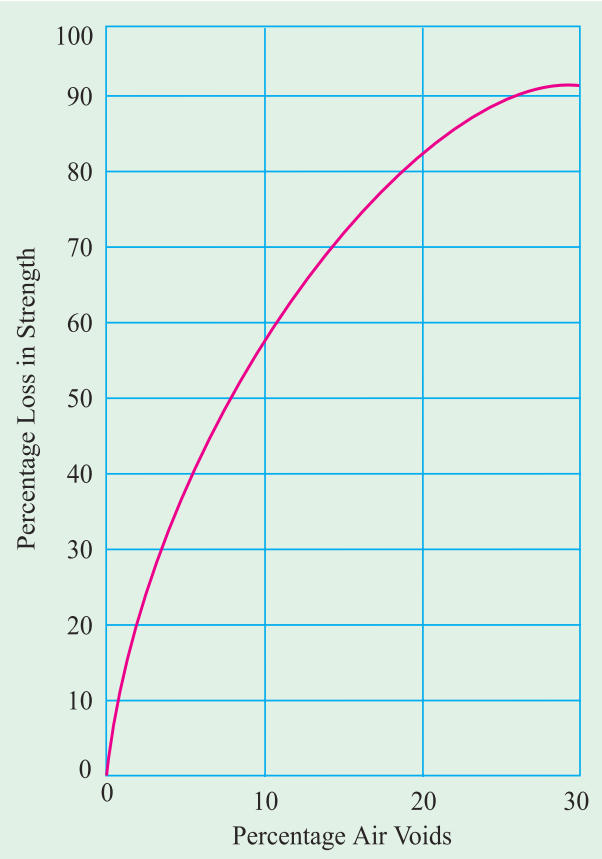
Placing high quality concrete by slip-form technique for a width of 8.5 m.

To feed such a paver, large quantity of concrete of uniform quality is required. In India today, the capacity of batching is a limitation. In Europe continuous batching plants which can supply consistent quality of concrete at a rate of 150 to 250 m^3/hr are available. This rate will make it possible to supply extra wide slip-form paver. Sophistication in road construction has just started in India. With the experience gained, we will be able to produce large quantities of manufactured fine and coarse aggregate of right quality needed for high rate of production of concrete to meet the requirement of multi lane slip-form paver.

Compaction of Concrete

Compaction of concrete is the process adopted for expelling the entrapped air from the concrete. In the process of mixing, transporting and placing of concrete air is likely to get entrapped in the concrete. The lower the workability, higher is the amount of air entrapped. In other words, stiff concrete mix has high percentage of entrapped air and, therefore , would need higher compacting efforts than high workable mixes.

If this air is not removed fully, the concrete loses strength considerably. Fig. 6.23 shows the relationship between loss of strength and air voids left due to lack of compaction. It can be seen from the figure that 5 per cent voids reduce the strength of cocrete by about 30 per cent and 10 per cent voids redduce the strength by over 50 per cent. Therefore, it is imperative that 100 per cent compaction of concrete is one of the most important aim to be kept in mind in good concrete-making practices.



It must be borne in mind that 100 per cent compaction is important not only from the point of view of strength, but also from the point of durability. In recent time, durability becomes more important than strength.

Insufficient compaction increases the permeability of concrete resulting in easy entry for aggressive chemicals in solutin, which attack concrete and reinforcement to reduce the durability of concrete. Therefore, 100 per cent compaction of concrete is of paramount importance.

In order to achieve full compaction and maximum density, with reasonable compacting efforts available at site, it is necessary to use a mix with adequate workability. It is also of common knowledge that the mix should not be too wet for easy compaction which also reduces the strength of concrete. For maximum strength, driest possible concrete should be compacted 100 per cent. The overall economy demands 100 per cent compaction with a reasonable compacting efforts available in the field.

The following methods are adopted for compacting the concrete:

(a) Hand Compaction
  (i) Rodding *(ii) Ramming* *(iii) Tamping*

(b) Compaction by Vibration
  (i) Internal vibrator (Needle vibrator)
  (ii) Formwork vibrator (External vibrator)
  (iii) Table vibrator
  (iv) Platform vibrator
  (v) Surface vibrator (Screed vibrator)
  (vi) Vibratory Roller.

(c) Compaction by Pressure and Jolting

(d) Compaction by Spinning.

Hand Compaction: *Hand compaction of concrete is adopted in case of unimportant concrete work of small magnitude. Sometimes, this method is also applied in such situation, where a large quantity of reinforcement is used, which cannot be normally compacted by mechanical means. Hand compaction consists of rodding, ramming or tamping. When hand compaction is adopted, the consistency of concrete is maintained at a higher level. The thickness of the layer of concrete is limited to about 15 to 20 cm. Rodding is nothing but poking the concrete with about 2 metre long, 16 mm diameter rod to pack the concrete*

between the reinforcement and sharp corners and edges. Rodding is done continuously over the complete area to effectively pack the concrete and drive away entrapped air. Sometimes, instead of iron rod, bamboos or cane is also used for rodding purpose.

Ramming should be done with care. Light ramming can be permitted in unreinforced foundation concrete or in ground floor construction. Ramming should not be permitted in case of reinforced concrete or in the upper floor construction, where concrete is placed in the formwork supported on struts. If ramming is adopted in the above case the position of the reinforcement may be disturbed or the formwork may fail, particularly, if steel rammer is used.

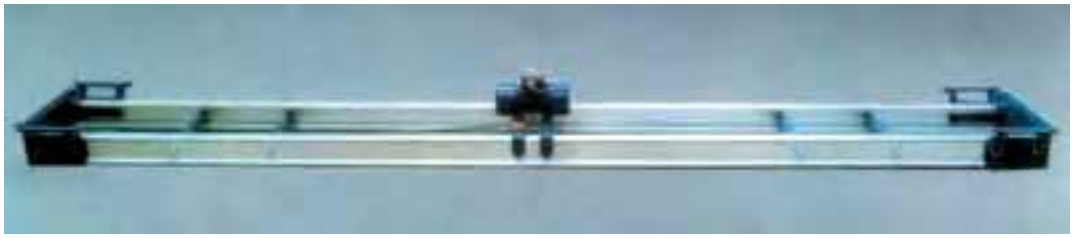
Tamping is one of the usual methods adopted in compacting roof or floor slab or road pavements where the thickness of concrete is comparatively less and the surface to be finished smooth and level. Tamping consists of beating the top surface by wooden cross beam of section about 10 x 10 cm. Since the tamping bar is sufficiently long it not only compacts, but also levels the top surface across the entire width.

Compaction by Vibration: *It is pointed out that the compaction by hand, if properly carried out on concrete with sufficient workability, gives satisfactory results, but the strength of the hand compacted concrete will be necessarily low because of higher water cement ratio required for full compaction. Where high strength is required, it is necessary that stiff concrete,*

with low water/cement ratio be used. To compact such concrete, mechanically operated vibratory equipment, must be used. The vibrated concrete with low water/cement ratio will have many advantages over the hand compacted concrete with higher water/cement ratio.

The modern high frequency vibrators make it possible to place economically concrete which is impracticable to place by hand. A concrete with about 4 cm slump can be placed and compacted fully in a closely spaced reinforced concrete work, whereas, for hand compaction, much higher consistency say about 12 cm slump may be required. The action of vibration is to set the particles of fresh concrete in motion, reducing the friction between them and affecting a temporary liquefaction of concrete which enables easy settlement.

While vibration itself does not affect the strength of concrete which is controlled by the water/cement ratio, it permits the use of less water. Concrete of higher strength and better quality can, therefore, be made with a given cement factor with less mixing water. Where only



Double Beam Screed Board Vibrator

a given strength is required, it can be obtained with leaner mixes than possible with hand compaction, making the process economical. Vibration, therefore, permits improvement in the quality of concrete and in economy.

Compaction of concrete by vibration has almost completely revolutionised the concept of concrete technology, making possible the use of low slump stiff mixes for production of high quality concrete with required strength and impermeability. The use of vibration may be essential for the production of good concrete where the congestion of the reinforcement or the inaccessibility of the concrete in the formwork is such that hand compaction methods are not practicable. Vibration may also be necessary if the available aggregates are of such poor shape and texture which would produce a concrete of poor workability unless large amount of water and cement is used. In normal circumstances, vibration is often adopted to improve the compaction and consequently improve the durability of structures. In this way, vibration can, under suitable conditions, produce better quality concrete than by hand compaction. Lower cement content and lower water-cement ratio can produce equally strong concrete more economically than by hand compaction.

Although vibration properly applied is a great step forward in the production of quality concrete, it is more often employed as a method of placing ordinary concrete easily than as a method for obtaining high grade concrete at an economical cost. All the potential advantages of vibration can be fully realised only if proper control is exercised in the design and manufacture of concrete and certain rules are observed regarding the proper use of different types of vibrators.

Internal Vibrator: *Of all the vibrators, the internal vibrator is most commonly used. This is also called, "Needle Vibrator", "Immersion Vibrator", or "Poker Vibrator". This essentially consists of a power unit, a flexible shaft and a needle. The power unit may be electrically driven or operated by petrol engine or air compressor. The vibrations are caused by eccentric weights attached to the shaft or the motor or to the rotor of a vibrating element. Electromagnet, pulsating equipment is also available. The frequency of vibration varies upto 12,000 cycles of vibration per minute. The needle diameter varies from 20 mm to 75 mm and its length varies from 25 cm to 90 cm. The bigger needle is used in the construction of mass concrete dam. Sometimes, arrangements are available such that the needle can be replaced by a blade of approximately the same length. This blade facilitates vibration of members, where, due to the congested reinforcement, the needle would not go in, but this blade can effectively vibrate. They are portable and can be shifted from place to place very easily during concreting operation. They can also be used in difficult positions and situations.*

Formwork Vibrator (External Vibrator): *Formwork vibrators are used for concreting columns, thin walls or in the casting of precast units. The machine is clamped on to the external wall surface of the formwork. The vibration is given to the formwork so that the concrete in the vicinity of the shutter gets vibrated. This method of vibrating concrete is particularly useful and adopted where reinforcement, lateral ties and spacers interfere too*

much with the internal vibrator. Use of formwork vibrator will produce a good finish to the concrete surface. Since the vibration is given to the concrete indirectly through the formwork, they consume more power and the efficiency of external vibrator is lower than the efficiency of internal vibrator.

Vibrating Table

Table Vibrator: *This is the special case of formwork vibrator, where the vibrator is clamped to the table. or table is mounted on springs which are vibrated transferring the vibration to the table. They are commonly used for vibrating concrete cubes. Any article kept on the table gets vibrated. This is adopted mostly in the laboratories and in making small but precise prefabricated R.C.C. members.*

Vibrating Table

Platform Vibrator: *Platform vibrator is nothing but a table vibrator, but it is larger in size. This is used in the manufacture of large prefabricated concrete elements such as electric poles, railway sleepers, prefabricated roofing elements etc. Sometimes, the platform vibrator is also coupled with jerking or shock giving arrangements such that a thorugh compaction is given to the concrete.*

Surface Vibrator: *Surface vibrators are sometimes knows as, "Screed Board Vibrators". A small vibrator placed on the screed board gives an effective method of compacting and levelling of thin concrete members, such as floor slabs, roof slabs and road surface. Mostly, floor slabs and roof slabs are so thin that internal vibrator or any other type of vibrator cannot be easily employed. In such cases, the surface vibrator can be effectively used. In general, surface vibrators are not effective beyond about 15 cm. In the modern construction practices like vaccum dewatering technique, or slip-form paving technique, the use of screed board vibrator are common feature. In the above situations double beam screed board vibrators are often used.*

Compaction by Pressure and Jolting: *This is one of the effective methods of compacting very dry concrete. This method is often used for compacting hollow blocks, cavity blocks and solid concrete blocks. The stiff concrete is vibrated, pressed and also given jolts. With the combined action of the jolts vibrations and pressure, the stiff concrete gets compacted to a dense form to give good strength and volume stability. By employing great pressure, a concrete of very low water cement ratio can be compacted to yield very high strength.*

Compaction by Spinning: *Spinning is one of the recent methods of compaction of concrete. This method of compaction is adopted for the fabrication of concrete pipes. The plastic concrete when spun at a very high speed, gets well compacted by centrifugal force. Patented products such a "Hume Pipes", "spun pipes" are compacted by spinning process.*

Vibratory Roller: *One of the recent developments of compacting very dry and lean concrete is the use of Vibratory Roller. Such concrete is known as Roller Compacted Concrete. This method of concrete construction originated from Japan and spread to USA and other countries mainly for the construction of dams and pavements. Heavy roller which vibrates while rolling is used for the compaction of dry lean concrete. Such roller compacted concrete of grade M 10 has been successfully used as base course, 15 cm thick, for the Delhi-Mathura highway and Mumbai-Pune express highways.*

General Points on Using Vibrators

Vibrators may be powered by any of the following units:

(a) Electric motors either driving the vibrator through flexible shaft or situated in the head of the vibrator.

(b) Internal combustion engine driving the vibrator needle through flexible shaft, and

(c) Compressed-air motor situated near the head of the vibrator.

Where reliable supplies of electricity is available the electric motor is generally the most satisfactory and economical power unit. The speed is relatively constant, and the cables supplying current are light and easily handled.

Small portable petrol engines are sometimes used for vibrating concrete. They are more easily put out of action by site conditions. They are not so reliable as the electric or compressed-air motors. They should be located conveniently near the work to be vibrated and should be properly secured to their base.

Compressed-air motors are generally quite suitable but pneumatic vibrators are sometimes difficult to manipulate where the compressor cannot be placed adjacent to the work such as on high scaffoldings or at depths below ground level due to the heavy weight of air hoses.

Compressed-air vibrators give trouble especially in cold weather, by freezing at exhaust unless alcohol is trickled into the air line or dry air is used. Glycol type antifreeze agents tend to cause gumming of the vibrator valves. There is also a tendency for moisture to collect in the motor, hence care should be taken to remove the possible damage.

The speed of both the petrol and compressed-air motors tend to vary giving rise to variation in the compacting effect of the vibrator.

Further Instructions on use of Vibrators

Care shall be taken that the vibrating head does not come into contact with hard objects like hardened concrete, steel and wood, as otherwise the impact may damage the bearings. The prime mover should as far as possible, be started only when head is raised or resting on soft support. Similar precautions shall be observed while introducing or withdrawing the vibrator in the concrete to be consolidated. When the space for introduction is narrow, the vibrator should be switched on only after the vibrator head has been introduced into the concrete. Unnecessary sharp bends in the flexible shaft drive shall be avoided.

Vibrators conforming to the requirements of IS 2505-1963 (i.e., Specification for concrete vibrators, immersion type) shall be used. The size and characteristics of the vibrator suitable for a particular job vary with the concrete mix design, quality and workability of concrete, placing conditions, size and shape of the member and shall be selected depending upon various requirements. Guidance regarding selection of a suitable vibrator may be obtained from Table 6.7.

Correct design of concrete mix and an effective control in the manufacture of concrete, right from the selection of constituent materials through its correct proportioning to its placing, are essential to obtain maximum benefits of vibration. For best results, the concrete to be vibrated shall be of the stiffest possible consistency, generally within a range of 0.75 to 0.85 compacting factor, provided the fine mortar in concrete shows at least a greasy wet appearance when the vibrator is slowly withdrawn from the concrete and the material closes over the space occupied by the vibrator needle leaving no pronounced hole. The vibration of concrete of very high workability will not increase its strength; it may on the contrary, cause segregation. Formation of a watery grout on the surface of the concrete due to vibration is an indication that the concrete is too softly made and unsuitable for vibration; a close textured layer of viscous grout may, however, be allowed.

For vibrated concrete, the formwork shall be stronger than is necessary for hand compacted concrete and greater care is exercised in its assembly. It must be designed to take up increased pressure of concrete and pressure variations caused in the neighbourhood of the vibrating head which may result in the excessiwe local stress on the formwork. More exact details on the possible pressures are not available and much depends upon experience, judgement and the character of work. The joints of the formwork shall be made and maintained tight and close enough to prevent the squeezing out of grout or sucking in of air during vibration. Absence of this precaution may cause honey-combing in the surface of concrete, impairing the appearance and sometimes weakening the structure.

The amount of mortar leakage or the permissible gap between sheathing boards will depend on the desired final appearance of the work but normally gaps larger than 1.5 mm between the boards should not be permitted. Sometimes even narrower joints may be objectionable from the point of view of their effect on the surface appearance of certain structures. The number of joints should be made as few as possible by making the shutter sections large. Applications of mould releasing agents on the formwork, to prevent the adhesion on concrete should be very thin as otherwise they may mix with the concrete under the effect of vibration, and cause air entrainment and blow holes on the concrete surface.

The vibrator may be used vertically, horizontally or at an angle depending upon the nature of the job. But needle vibrators should be immersed in beams and other thick sections, vertically at regular intervals. The concrete to be vibrated shall be placed in position in level layers of suitable thickness not greater than the effective length of the vibrator needle.

The concrete at the surface must be distributed as horizontally as possible, since the concrete flows in slopes while being vibrated and may segregate. The vibration shall, therefore, not be done in the neighbourhood of slopes. The internal vibrator should not be used to spread the concrete from the filling as this can cause considerable segregation of concrete. It is advisable to deposit concrete well in advance of the point of vibration. This prevents the concrete from subsiding non-uniformly and thus prevents the formation of incipient plastic cracks. When the concrete is being continuously deposited to an uniform depth along a member, vibrator shall not be operated too near the free end of the advancing concrete, usually not within 120 cm of it. Every effort must be made to keep the surface of the previously placed layer of concrete alive so that the succeeding layer can be bonded with it by the vibration process. However, if due to unforeseen circumstances the concrete has hardened in the underlying layer to such an extent that it cannot be penetrated by the vibrator but is still fresh (just after initial set) unimposed bond can be achieved between the top and underlying layers by systematically and thoroughly vibrating the new concrete into contact with old.

Height of Concrete Layer

Concrete is placed in thin layers consistent with the method being used to place and vibrate the concrete. Usually concrete shall be placed in a thickness not more than 60 cm and on initial placing in thickness not more than 15 cm. The suprimposed load increasing with the height of the layer will favour the action of the vibrator, but as it is also the path of air forced upwards, it may trap air rising up by vibration. Very deep layers (say more than 60 cm) should, therefore, be avoided although the height of layer can also be one metre provided the vibrator used is sufficiently powerful, as in dams.

Depth of Immersion of Vibrator

To be fully effective, the active part of the vibrator shall be completely immersed in the concrete. Its compacting action can be usually assisted by maintaining a head of concrete

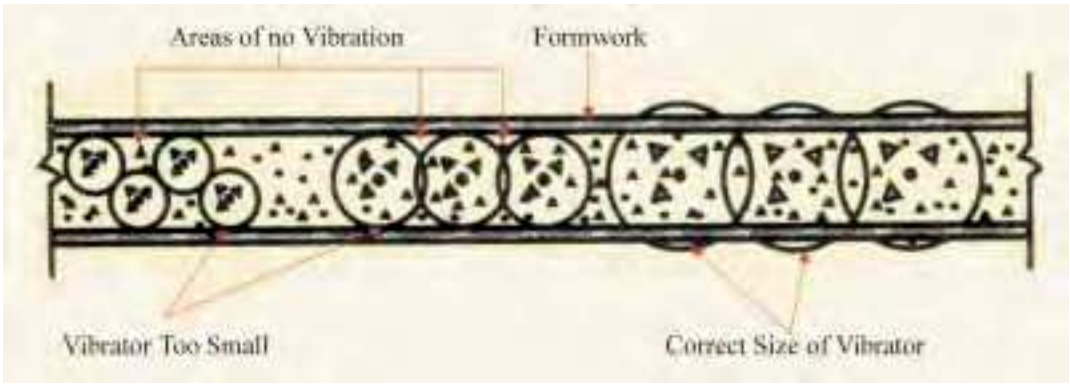
above the active part of the vibrator, the primary object of which is to press down upon and confine the concrete in the zone of influence of the vibrator. The vibrator head shall be dipped through the filling which is to be consolidated to a further depth of 10 to 20 cm in the lower layer which has already been consolidated so that there is a good combination of various layers and the grout in the lower layer is distributed in the new filling.

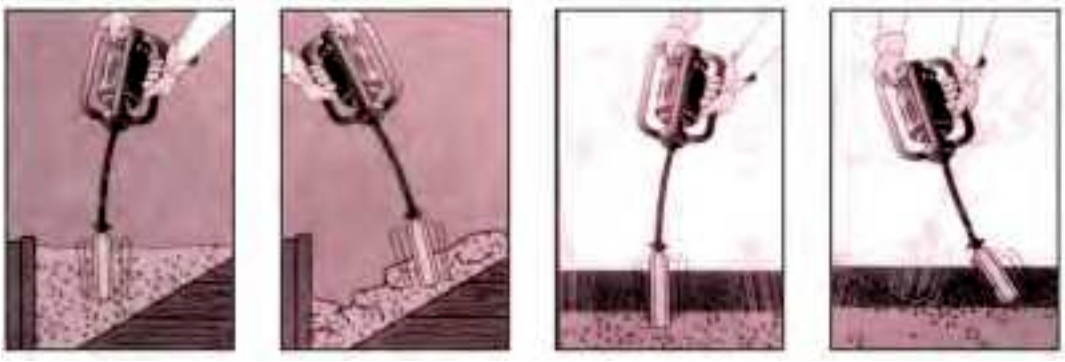
Spacing and Number of Insertion Positions

The points of insertion of the vibrator in the concrete shall be so spaced that the range of action overlap to some extent and the freshly filled concrete is sufficiently compacted everywhere. The range of action varies with the characteristics of the vibrator and the composition and workability of concrete. The range of action and the degree of compaction can be recognized from the rising air bubbles and the formation of a thin shining film around the vibrating head. With concrete of workability of 0.78 to 0.85 compacting factor, the vibrator shall generally be operated at points 35 to 90 cm apart. The specified spacing between the dipping positions shall be maintained uniformly throughout the surface of concrete so that the concrete is uniformly vibrated.

Speed of Insertion and Withdrawal of the Vibrating Head

The vibrating head shall be regularly and uniformly inserted in the concrete so that it penetrates of its own accord and shall be withdrawn quite slowly whilst still running so as to allow redistribution of concrete in its wake and allow the concrete to flow back into the hole behind the vibrator. The rate of withdrawal is determined by the rate at which the compaction in the active zone is completed. Usually a speed of 3 cm/s gives sufficient consolidation without undue strain on the operator. Further concrete is added as the vibrators are





Correct Incorrect Correct Incorrect

withdrawn so as to maintain the head of the concrete until the lift of the concrete is completed.

Duration of Vibration

New filling shall be vibrated while the concrete is plastic, preferably within one hour. The duration of vibration in each position of insertion is dependent upon the height of the layer, the size and characteristics of the vibrator and the workability of the concrete mix. It is better to insert the vibrating head at a number of places than to leave it for a long time in one place, as in the latter case, there is a tendency for formation of mortar pocket at the point of insertion of the vibrator.

The vibrator head shall be kept in one position till the concrete within its influence is completely consolidated which will be indicated by formation of circular shaped cement grout on the surface of concrete, appearance of flattened glistening surface and cessation of the rise of entrapped air. Vibration shall be continued until the coarse aggregate particles have blended into the surface but have not disappeared.

The time required to effect complete consolidation is readily judged by the experienced vibrator operator through the feel of the vibrator, resumption of frequency of vibration after the short period of dropping off of frequency when the vibrator is first inserted. Doubt about the adequacy of vibration should always be resolved by further vibration; well proportioned concrete of the correct consistency is not readily susceptible to over-vibration.

Vibrating Concrete at Junctions with Hardened Concrete

In cases where concrete has to be joined with rock or hardened concrete, defects can occur owing to the layers nearest to the hardened concrete not being sufficiently vibrated. In such cases the procedure given below should be adopted:

The hardened concrete surface should be prepared by hacking or roughening and removing laitance, greasy matter and loose particles. The cleaned surface shall be wetted. A cement sand grout of proportion 1:1 and of creamy consistency is then applied to the wet surface of the old concrete, and the fresh concrete vibrated against it.

Vibrating the Reinforced Concrete

The reinforcement should be designed to leave sufficient space for the vibrating head. Where possible, the reinforcement may be grouped so that the width of groups of bars does not exceed 25 cm and a space of 7.5 cm exists between the groups of bars to allow the vibrator to pass freely; the space between the bars in any group may be reduced to two-thirds of the nominal size of coarse aggregate.

When the reinforcements lie very close to each other, greater care is taken in vibrating so that no pockets or collections of grout are formed. Except where some of the concrete has already set and provided that the reinforcement is adequately supported and secured, the vibrator may be pressed against the reinforcement.

Vibrating near the Formwork

For obtaining a smooth close textured external surface, the concrete should have a sufficient content of matrix. The vibrator head shall not be brought very near the formwork as this may cause formation of water whirls (stagnations), especially if the concrete containing too little of fine aggregate. On the other hand, a close textured surface may not be obtained, if the positions of insertion are too far away from the formwork. The most suitable distance of the vibrator from the formwork is 10 to 20 cm. With the vibration done at the correct depth

Table 6. 7. Characteristics and Applications of Immersion Vibrators

Sr. No.	Characteristics of Vibrator				Application
	Length of the Vibrating Needle mm	Diameter of the Vibrating Needle mm	Recommended frequency of vibration under no Load State, Min Vibration VPM	* Recommended vibration Acceleration (operation in Air), Min g^+	
(1)	(2)	(3)	(4)	(5)	(6)
(i)	up to 350	up to 35	9000	30 to 50	Plastic, workable concrete in very thin members and confined places and for fabrication of laboratory test specimens. Suitable as an auxiliary to larger vibrators in prestressed work, where many cables and ducts cause congestion in the forms.
(ii)	250 to 500	Over 35 up to 60	9000	Over 30 up to 60	Plastic, workable concrete in thin walls, columns, beams, precast piles, light bridge decks, and along construction joints.
(iii)	250 to 700	Over 60 up to 75	7000	Over 60 up to 75	Plastic, workable concrete in general construction, such as walls, columns. beams, precast piles, heavy floors, bridge deck and roof slabs. Auxiliary vibration adjacent to forms mass concrete and pavements.

Table 6.7 (Contd.)

(1)	(2)	(3)	(4)	(5)	(6)
(iv)	300 to 450	Over 75 up to 90	7000	Over 75 up to 90	Mass and structural concrete deposited in increments up to 2 m^3 in heavy construction in relatively open forms, in power houses, heavy bridge piers and foundations and for auxiliary vibration in foundations and for auxiliary vibration in dam construction near forms and around embedded items and reinforcing steel.
(v)	200 to 475	Over 90	6000	Over 90	Mass concrete containing 15 cm. aggregate deposited in increments up to 8 m^3, in gravity dams, large piers, massive walls, etc. Two or more vibrators will be required to operate simultaneously to melt down and consolidate increments of concrete of 4 m^3 or greater volume deposited at one time in the forms.

* Value of acceleration measured in concrete should not be less then 75 per cent of the values given above.

† Acceleration due to gravity.

and with sufficient grout rising up at the formwork, the outside surface will generally have a close textured appearance. In the positions of formwork difficult to reach and in concrete walls less than 30 cm thick it is preferable to use vibrators of small size which can be brought to the required place and which will not excessively strain the formwork.

Vibrating High Walls and Columns

While designing the formwork, reinforcement, as well as the division of layers for high walls and columns, it should be kept in mind that with the usual driving shaft lengths it is not possible to penetrate the vibrating head more than three metres in the formwork. In the case of higher walls and columns it is recommended to introduce the shaft driven vibrating needle through a side opening into the formwork. For use with high walls and columns, the flexible driving shaft can be brought to a length of six to eight metres or even more by using adopter pieces. The motor-in-head type vibrators are more useful for the purpose in cases where a very long current cable can be used for sinking the vibrator to a greater depth.

Over-Vibration

There is a possibility of over-vibration while trying to achieve thorough vibration, but it is exceedingly unlikely in well proportioned mixes containing normal weight aggregates. Generally, with properly designed mixes, extended vibration will be only a waste of effort without any particular harm to the concrete.

However, where the concrete is too workable for the conditions of placing, or where the quantity of mortar is excess of the volume of voids in the coarse aggregate, or where the grading of the aggregate is unsatisfactory, over-vibration will encourage segregation, causing migration of the lighter and smaller constituents of the mix to the surface, thereby producing layer of mortar or laitance on the surface, and leakage of mortar through the defective joints in the formwork. This may produce concrete with poor resistance to abrasion and attack by various agencies, such as frost, or may result in planes of weakness where successive lifts are being placed. If over vibration occurs, it will be immediately evident to an experienced vibrator operator or supervisor by a frothy appearance due to the accumulation of many small air bubbles and the settlement of coarse aggregates beneath the surface. These results are more liable to occur when the concrete is too wet and the proper correction will be to reduce the workability (not the vibration), until the evidence of over-vibration disappears during the amount of vibration judged necessary to consolidate the concrete and to eliminate air-bubble blemishes.

Output of Immersion Vibrator

Output of compacted concrete may be taken as 3 to 5 cubic metre per hour depending upon the consistency of the mix for a light type of vibrator, having a centrifugal force of about 200 kg. The out-turn will be as much as 12 to 25 cubic metre per hour for a heavy type of vibrator having a centrifugal force of 450 kg.

Re-vibration

Re-vibration is delayed vibration of concrete that has already been placed and compacted. It may occur while placing successive layers of concrete, when vibrations in the upper layer of fresh concrete are transmitted to the underlaying layer which has partially hardened or may be done intentionally to achieve certain advantages.

Except in the case of exposed concrete and provided the concrete becomes plastic under vibration, re-vibration is not harmful and may be beneficial. By repeated vibration over a long

period (repetition of vibration earliest after one hour from the time of initial vibration), the quality of concrete can be improved because it rearranges the aggregate particles and eliminates entrapped water from under the aggragae and reinforcing steel, with the consequence of full contact between mortar and coarse aggregate or between steel and mortar and thus produces stronger and watertight concrete. Plastic shrinkage cracks as well as other disturbances like hollow space below the reinforcement bars and below the coarse aggregate, can thereby be closed again provided the concrete becomes soft again when the vibrator head in introduced. Re-vibration of concrete results in improved compressive and bond strength, reduction of honey-comb, release of water trapped under horizontal reinforcing bars and removal of air and water pockets.

Re-vibration is most effective at the lapse of maximum time after the initial vibration, provided the concrete is sufficiently plastic to allow the vibrator to sink of its own weight into the concrete and make it momentarily plastic.

Vibration of Lightweight Concrete

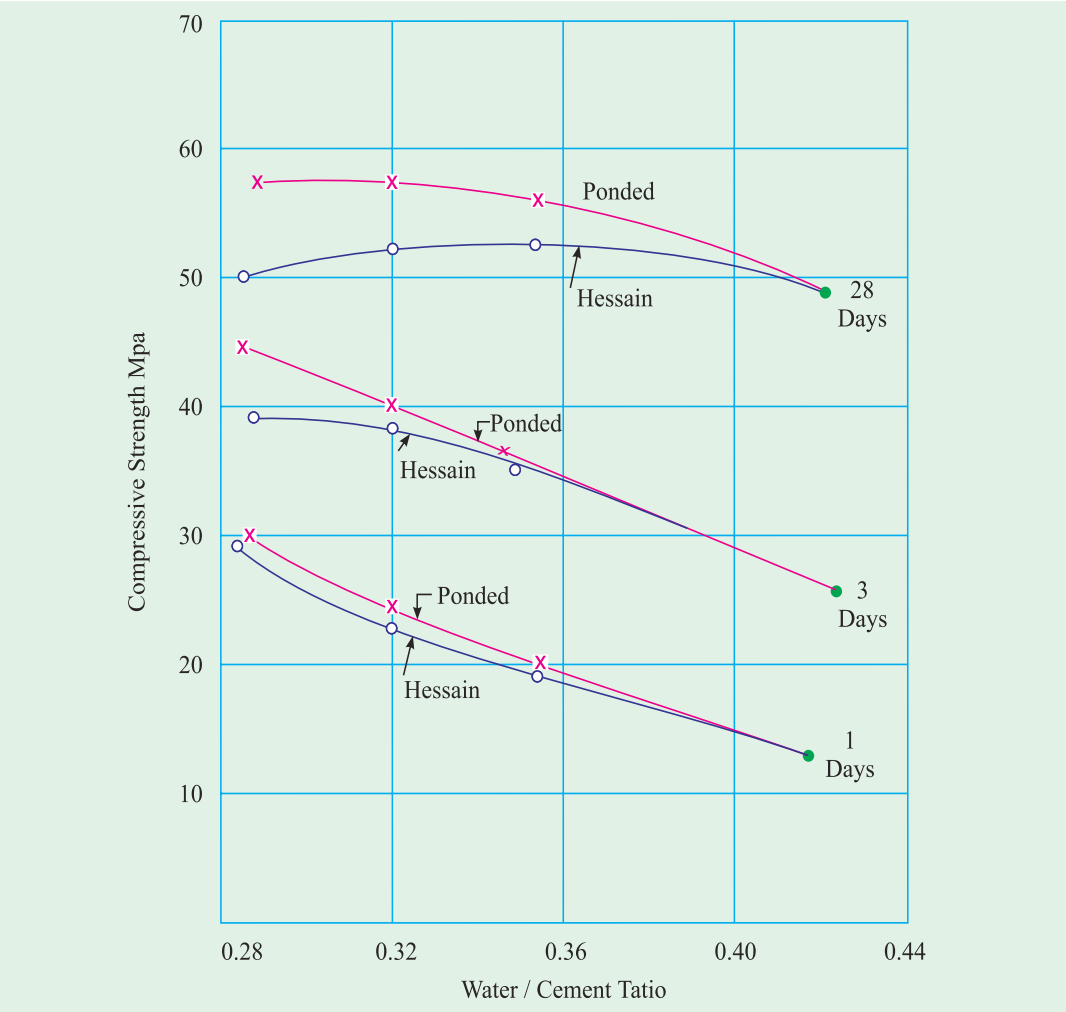
In general, principles and recommended practices for consolidation of concrete of normal weight hold good for concrete made with light weight aggregate, provided certain precautions are observed.

There is always a tendency for light weight pieces of aggregate to rise to the surface of fresh concrete, particularly under the action of over-vibration; and a fairly stiff mix, with the minimum amount of vibration necessary to consolidate the concrete in the forms without honey-comb is the best insurance against undesirable segregation. The rise of lightweight coarse aggregate particles to the surface, caused by over-vibration resulting from too wet a mix makes finishing difficult if not impossible.

Curing of Concrete

We have discussed in Chapter I the hydration aspect of cement. Concrete derives its strength by the hydration of cement particles. The hydration of cement is not a momentary action but a process continuing for long time. Of cource, the rate of hydration is fast to start with, but countinues over a very long time at a decreasing rate. The quantity of the product of hydration and consequently the amount of gel formed depends upon the extent of hydration. It has been mentioned earlier that cement requires a water/cement ratio about 0.23 for hydration and a water/cement ratio of 0.15 for filling the voids in the gel pores. In other words, a water/cement ratio of about 0.38 would be required to hydrate all the particles of cement and also to occupy the space in the gel pores. Theoretically, for a concrete made and contained in a sealed container a water cement ratio of 0.38 would satisfy the requirement of

Fig.6.24. Cracks on concrete surface due to inadequate curing.



water for hydration and at the same time no capillary vavities would be left. However, it is seen that practically a water/cement ratio of 0.5 will be required for complete hydration in a sealed container for keeping up the desirable relative humidity level.

In the field and in actual work, it is a different story. Even though a higher water/cement ratio is used, since the concrete is open to atmosphere, the water used in the concrete evaporates and the water available in the concrete will not be sufficient for effective hydration to take place particularly in the top layer. Fig. 5.33 on page 173, Chapter 5, shows the drying behaviour of concrete. If the hydration is to continue unbated, extra water must be added to replenish the loss of water on account of absorption and evaporation. Alternatively, some measures must be taken by way of provision of impervious covering or application of curing compounds to prevent the loss of water from the surface of the concrete. Therefore, the curing can be considered as creation of a favourable environment during the early period for uninterrupted hydration. The desirable conditions are, a suitable temperature and ample moisture.

Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process

of maintaining a satisfactory moisture content and a favourable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree to meet the requirement of service.

Curing is being given a place of increasing importance as the demand for high quality concrete is increasing. It has been recognized that the quality of concrete shows all round improvement with efficient uninterrupted curing. If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss. An efficient curing in the early period of hydration can be compared to a good and wholesome feeding given to a new born baby.

A concrete laid in the afternoon of a hot summer day in a dry climatic region, is apt to dry out quickly. The surface layer of concrete exposed to acute drying condition, with the combined effect of hot sun and drying wind is likely to be made up of poorly hydrated cement with inferior gel structure which does not give the desirable bond and strength characteristics. In addition, the top surface, particularly that of road or floor pavement is also subjected to a large magnitude of plastic shrinkage stresses. The dried concrete naturally being weak, cannot withstand these stresses with the result that innumerable cracks develop at the surface Fig. 6.24, shows plastic shrinkage cracks on concrete surface due to quick drying and inadequate early curing. The top surface of such hardened concrete on account of poor gel structure, suffers from lack of wearing quality and abrasion resistance. Therefore, such surfaces create mud in the rainy season and dust in summer.

The quick surface drying of concrete results in the movement of moisture from the interior to the surface. This steep moisture gradient cause high internal stresses which are also responsible for internal micro cracks in the semi-plastic concrete.

Concrete, while hydrating, releases high heat of hydration. This heat is harmful from the point of view of volume stability. If the heat generated is removed by some means, the adverse effect due to the generation of heat can be reduced. This can be done by a thorough water curing. Fig. 6.25, shows the influence of curing by ponding and wet covering.[6.4]

Curing Methods

Curing methods may be divided broadly into four categories:

(a) Water curing (b) Membrane curing (c) Application of heat (d) Miscellaneous

Water Curing

This is by far the best method of curing as it satisfies all the requirements of curing, namely, promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. It is pointed out that even if the membrane method is adopted, it is desirable that a certain extent of water curing is done before the concrete is covered with membranes. Water curing can be done in the following ways:

(a) Immersion (b) Ponding

(c) Spraying or Fogging (d) Wet covering

The precast concrete items are normally immersed in curing tanks for a certain duration. Pavement slabs, roof slab etc. are covered under water by making small ponds. Vertical retaining wall or plastered surfaces or concrete columns etc. are cured by spraying water. In some cases, wet coverings such as wet gunny bags, hessian cloth, jute matting, straw etc., are wrapped to vertical surface for keeping the concrete wet. For horizontal surfaces saw dust,

earth or sand are used as wet covering to keep the concrete in wet condition for a longer time so that the concrete is not unduly dried to prevent hydration.

Membrane Curing

Sometimes, concrete works are carried out in places where there is acute shortage of water. The lavish application of water for water curing is not possible for reasons of economy. It has been pointed out earlier that curing does not mean only application of water, it means also creation of conditions for promotion of uninterrupted and progressive hydration. It is also pointed out that the quantity of water, normally mixed for making concrete is more than sufficient to hydrate the cement, provided this water is not allowed to go out from the body of concrete. For this reason, concrete could be covered with membrane which will effectively seal off the evaporation of water from concrete. It is found that the application of membrane or a sealing compound, after a short spell of water curing for one or two days is sometimes beneficial.

Membrane curing by spraying.

Sometimes, concrete is placed in some inaccessible, difficult or far off places. The curing of such concrete cannot be properly supervised. The curing is entirely left to the workmen, who do not quite understand the importance of regular uninterrupted curing. In such cases, it is much safer to adopt membrane curing rather than to leave the responsibility of curing to workers.

Large number of sealing compounds have been developed in recent years. The idea is to obtain a continuous seal over the concrete surface by means of a firm impervious film to prevent moisture in concrete from escaping by evaporation. Sometimes, such films have been used at the interface of the ground and concrete to prevent the absorption of water by the ground from the concrete. Some of the materials, that can be used for this purpose are bituminous compounds, polyethylene or polyester film, waterproof paper, rubber compounds etc.

Bituminous compound being black in colour, absorbs heat when it is applied on the top surface of the concrete. This results in the increase of temperature in the body of concrete which is undesirable. For this purpose, other modified materials which are not black in colour are in use. Such compounds are known as "Clear Compounds". It is also suggested that a lime wash may be given over the black coating to prevent heat absorption.

Membrane curing is a good method of maintaining a satisfactory state of wetness in the body of concrete to promote continuous hydration when original water/cement ratio used is not less than 0.5. To achieve best results, membrane is applied after one or two days' of actual wet curing. Since no replenishing of water is done after the membrane has been

applied it should be ensured that the membrane is of good quality and it is applied effectively. Two or three coats may be required for effective sealing of the surface to prevent the evaporation of water.


Curing vertical surface by wet covering.

Enough has been written in Chapter 5 on the modern curing compounds that are available today. Increase in volume of construction, shortage of water and need for conservation of water, increase in cost of labour and availability of effective curing compounds have encouraged the use of curing compounds in concrete construction. Curing compound is an obvious choice for curing canal lining, sloping roofs and textured surface of concrete pavements.

It is seen that there are some fear and apprehension in the mind of builders and contractors regarding the use of membrane forming curing compounds. No doubt that curing compounds are not as efficient and as ideal as water curing. The efficiency of curing compounds can be at best be 80% of water curing. But this 80% curing is done in a foolproof manner. Although water curing is ideal in theory, it is often done intermittently and hence, in reality the envisaged advantage is not there, in which case membrane curing may give better results.

For further details refer Chapter 5 where more information about curing compounds. Method for determining the efficiency of curing compounds etc., are given.

When waterproofing paper or polyethylene film are used as membrane, care must be taken to see that these are not punctured anywhere and also see whether adequate laping is given at the junction and this lap is effectively sealed.

Application of heat

The development of strength of concrete is a function of not only time but also that of temperature. When concrete is subjected to higher temperature it accelerates the hydration process resulting in faster development of strength. Concrete cannot be subjected to dry heat to accelerate the hydration process as the presence of moisture is also an essential requisite. Therefore, subjecting the concrete to higher temperature and maintaining the required wetness can be achieved by subjecting the concrete to steam curing.

A faster attainment of strength will contribute to many other advantages mentioned below.

(a) Concrete is vulnerable to damage only for short time.

(b) Concrete member can be handled very quickly.

(c) Less space will be sufficient in the casting yerd.

(d) A smaller curing tank will be sufficient.

(e) A higher outturn is possible for a given capital outlay.

(f) The work can be put on to service at a much early time,

(g) A fewer number of formwork will be sufficient or alternatively with the given number of formwork more outturn will be achieved.

(h) Prestressing bed can be released early for further casting.

From the above mentioned advantages it can be seen that steam curing will give not only economical advantages, but also technical advantages in the matter of prefabrication of concrete elements.

The exposure of concrete to higher temperature is done in the following manner:

(a) Steam curing at ordinary pressure.

(b) Steam curing at high pressure.

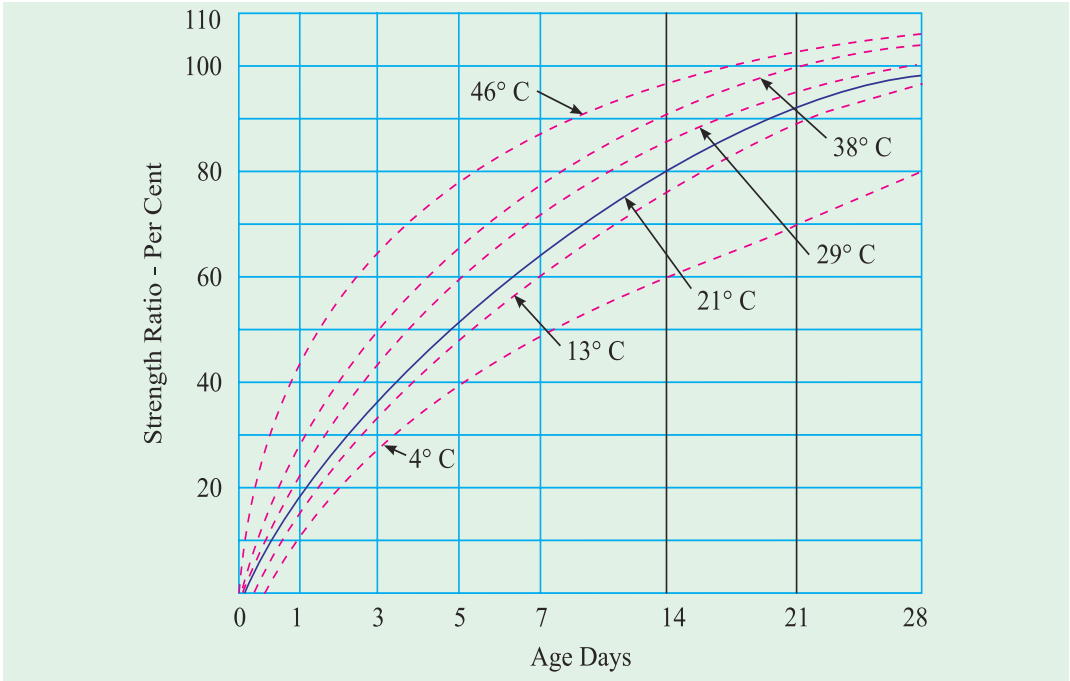
(c) Curing by Infra-red radiation.

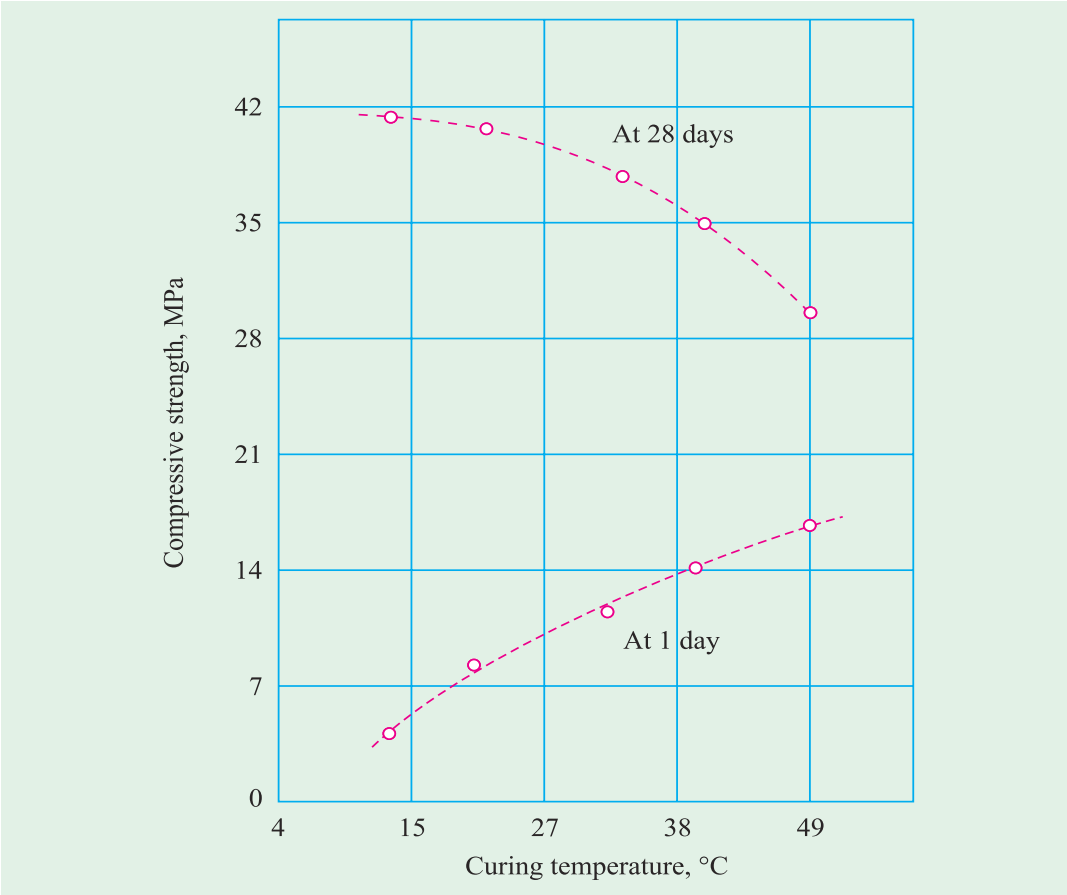
(d) Electrical curing.

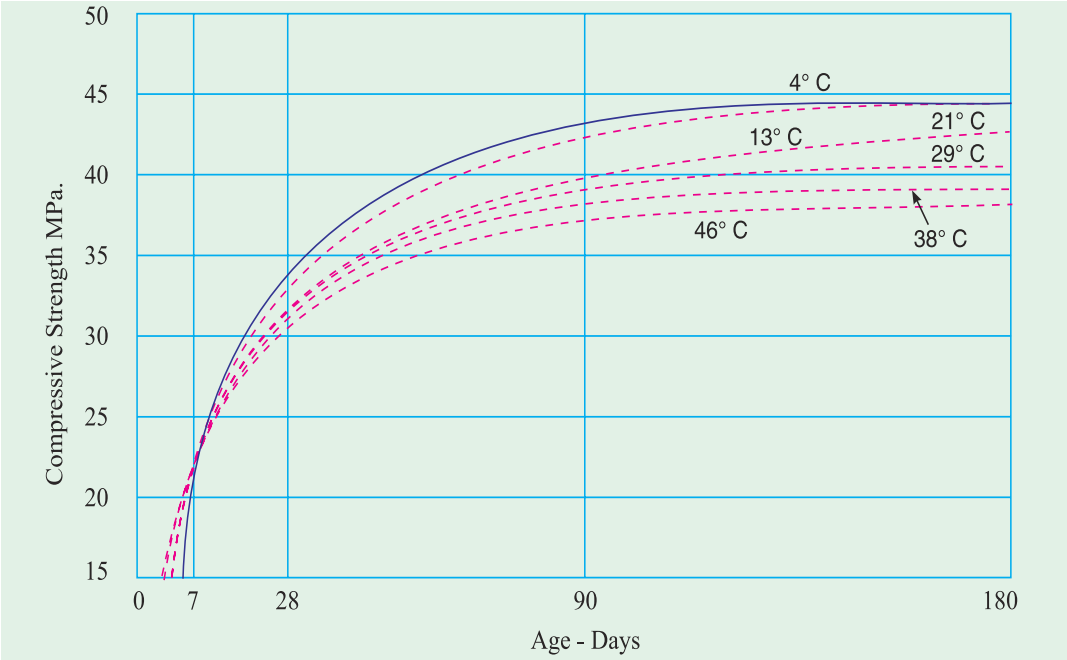
Steam curing at ordinary pressure

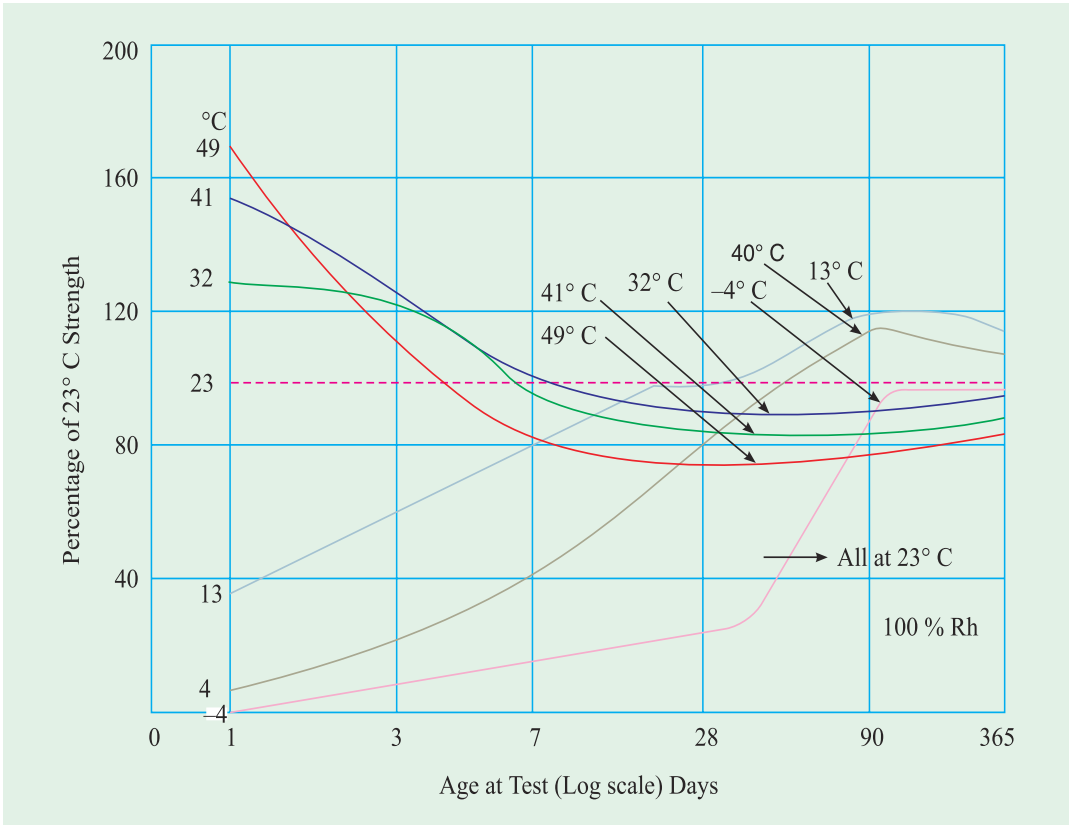
This method of curing is often adopted for pefabricated concrete elements. Application of steam curing to in situ construction will be a little difficult task. However, at some places it has been tried for in situ construction by forming a steam jacket with the help of tarpaulin or thick polyethylene sheets. But this method of application of steam for in situ work is found to be wasteful and the intended rate of development of strength and benefit is not really achieved.

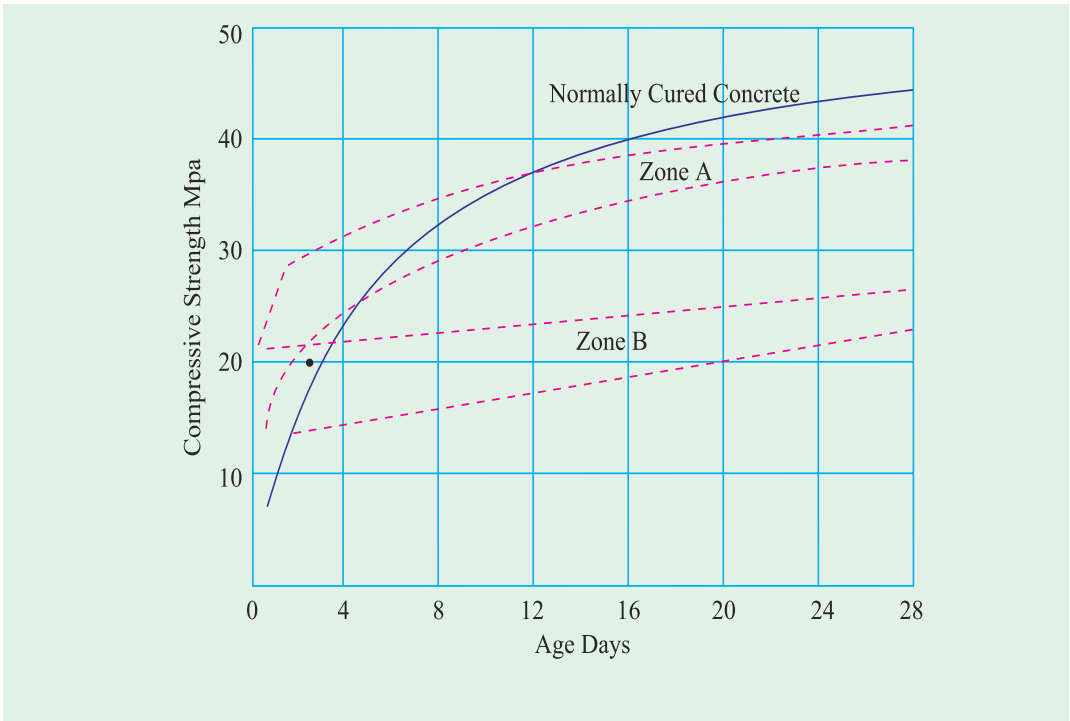
Beam under steam curing.

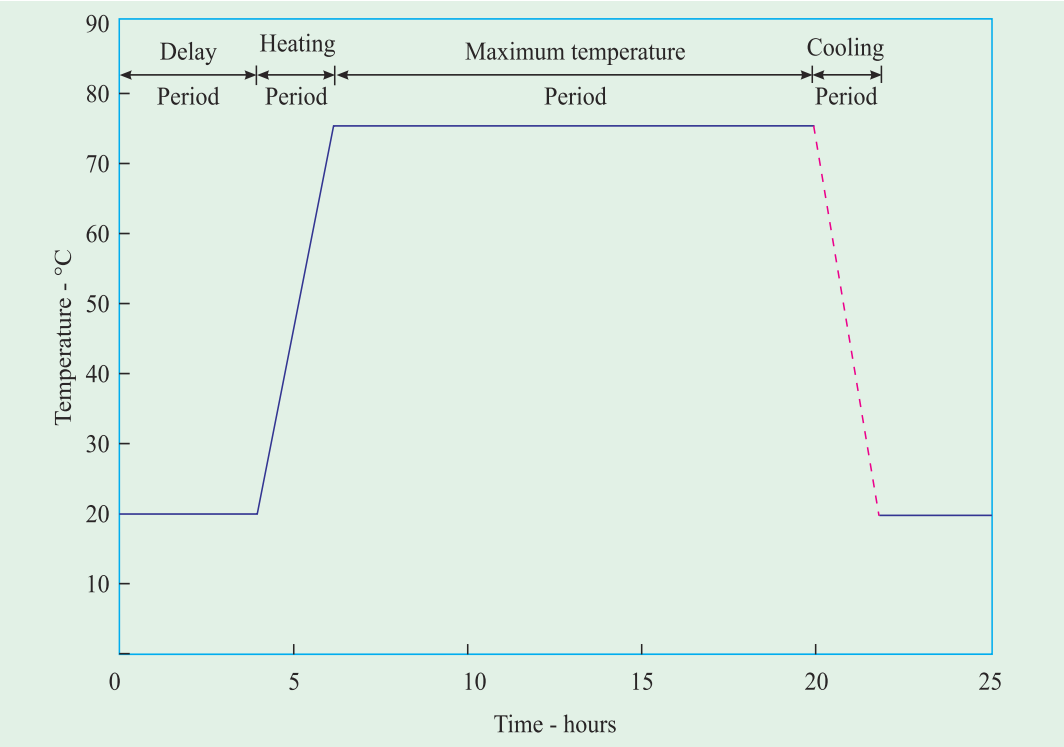



42
35
28
21
14
7
0
Compressive strength, MPa
At 28 days
At 1 day
4
15
27
38
49
Curing temperature, °C


50
45
40
35
30
25
20
15
Compressive Strength MPa.
4° C
21° C
13° C
29° C
46° C
38° C
0
7
28
90
180
Age - Days


200
160
120
80
40
°C
49
41
32
23
13
4
–4
Percentage of 23° C Strength
41° C
49° C
32° C
40° C
–4° C
13° C
All at 23° C
100 % Rh
0
1
3
7
28
90
365
Age at Test (Log scale) Days


50
40
30
20
10
Compressive Strength Mpa
Normally Cured Concrete
Zone A
Zone B
0
4
8
12
16
20
24
28
Age Days



Steam curing at ordinary pressure is applied mostly on prefabricated elements stored in a chamber. The chamber should be big enough to hold a day's production. The door is closed and steam is applied. The steam may be applied either continuously or intermittently. An accelerated hydration takes place at this higher temperature and the concrete products attain the 28 days strength of normal concrete in about 3 days.

In large prefabricated factories they have tunnel curing arrangements. The tunnel of sufficient length and size is maintained at different temperature starting from a low temperature in the beginning of the tunnel to a maximum temperature of about 90°C at the end of the tunnel. The concrete products mounted on trollies move in a very slow speed subjecting the concrete products progressively to higher and higher temperature. Alternatively, the trollies are kept stationarily at different zones for some period and finally come out of tunnel.

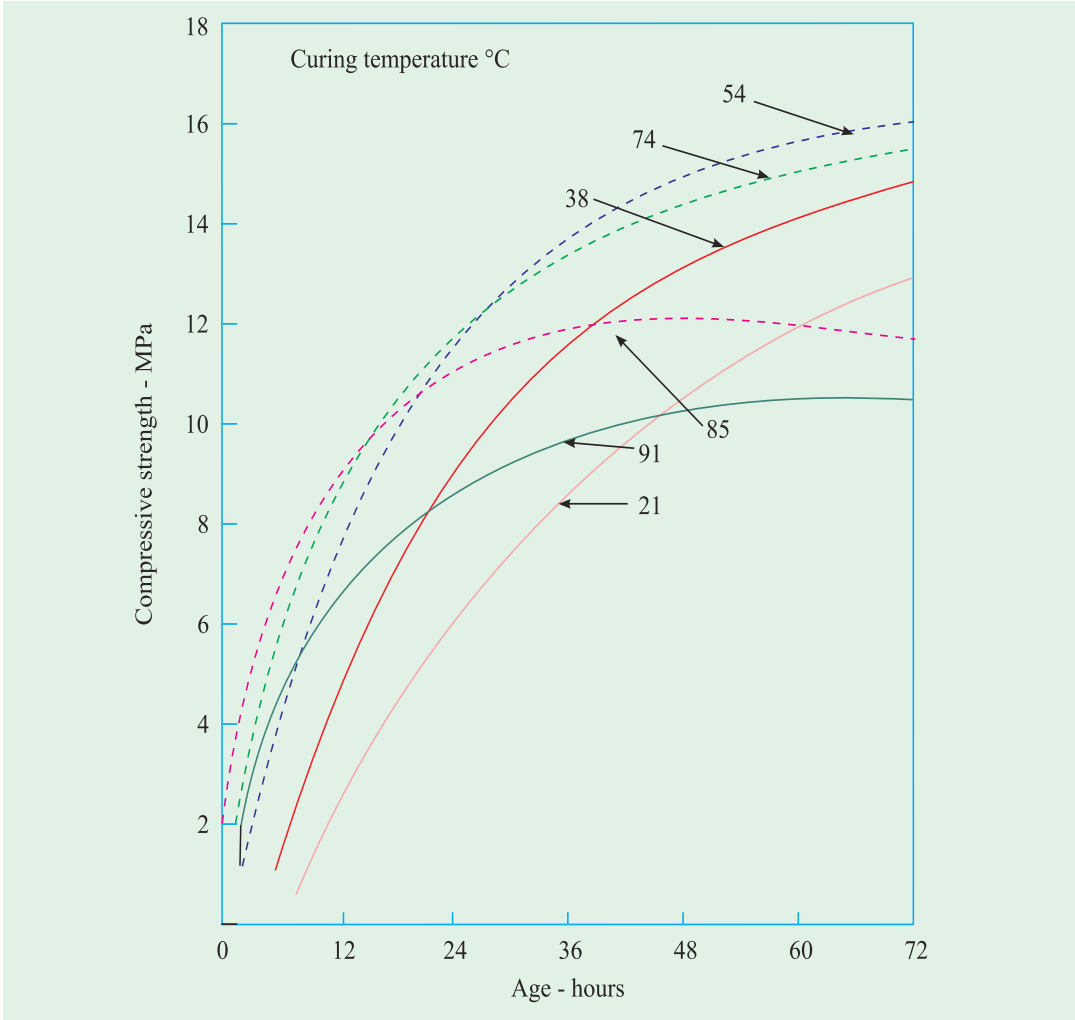
The influence of curing temperature on strength of concrete is shown in Fig. 6.26 and 6.28.[6.5]

It is interesting to note that concrete subjected to higher temperature at the early period of hydration is found to lose some of the strength gained at a later age. Such concrete is said to undergo "Retrogression of Strength". Figure 6.29 shows the effect of temperature on strength of concrete. It can be seen from Figure 6.29 that the concrete subjected to higher temperature at early age, no doubt attains higher strength at a shorter duration, but suffers considerable retrogression of strength. Fig. 6.29 . On the contrary, concrete cured at a comparatively lower temperature takes longer time to develop strength but the strength attained will not be lost at later ages. The phenomenon of retrogression of strength explains that faster hydration will result in the formation of poor quality gels with porous open structure, whereas the gel formed slowly but steadily at lower temperature are of good quality which are compact and dense in nature. This aspect can be compared to the growth of wood

cells. It is common knowledge that a tree which grows faster, will yield timber of poor and non-durable quality, whereas a tree, which grows slowly will yield good durable timber. Similarly, concrete subjected to higher temperature in the early period of hydration will yield poor quality gels and concrete which is subjected to rather low temperature (say about 13 degree Centigrade) will yield the best quality gel, and hence good concrete.

It has been emphasized that a very young concrete should not be subjected suddenly to high temperature. Certain amount of delay period on casting the concrete is desirable. It has been found that if 49°C is reached in a period shorter than 2 to 3 hours or 99°C is reached in less than 6 to 7 hours from the time of mixing, the gain of strength beyond the first few hours is effected adversely. The strength of such rapidly heated concrete falls in the zone B and the strength of gradually heated concrete falls within the zone A in Figure. 6.30.

Concrete subjected to steam curing exhibits a slightly higher drying shrinkage and moisture movement. Subjecting the concrete to higher temperature may also slightly effect the aggregate quality in case of some artificial aggregate. Steam curing of concrete made with rapid hardening cement will generate a much higher heat of hydration. Similarly, richer mixes may have more adverse effect than that of lean mixes.



In India, steam curing is often adopted for precast elements, specially prestressed concrete sleepers. Concrete sleepers are being introduced on the entire Indian Railway. For rapid development of strength, they use special type of cement namely IRST 40 and also subject the sleepers to steam curing.

Large number of bridges are being built for infrastructural development in India. There are requirements for casting of innumerable precast prestressed girders. These girders are steam cured for faster development of strength which has many other associated advantages.

A steam-curving cycle consists of:

- *an initial delay prior to steaming,*
- *a period for increasing the temperature,*
- *a period for retaining the temperature,*
- *a period for decreasing the temperature.*

A typical steam curing cycle at ordinary pressure is shown Fig. 6.31and typical strength of steam cured concrete at different temperature in shown in Fig. 6.32.

High Pressure Steam Curing

In the steam curing at atmospheric pressure, the temperature of the steam is naturally below 100°C. The steam will get converted into water, thus it can be called in a way, as hot water curing. This is done in an open atmosphere.

The high pressure steam curing is something different from ordinary steam curing, in that the curing is carried out in a closed chamber. The superheated steam at high pressure and high temperature is applied on the concrete. This process is also called "Autoclaving". The autoclaving process is practised in curing precast concrete products in the factory, particularly, for the lightweight concrete products. In India, this high pressure steam curing is practised in the manufacture of cellular concrete products, such as Siporex, Celcrete etc. The following advantages are derived from high pressure steam curing process:

(a) High pressure steam cured concrete develops in one day, or less the strength as much as the 28 days' strength of normally cured concrete. The strength developed does not show retrogression.

(b) High pressure steam cured concrete exhibits higher resistance to sulphate attack, freezing and thawing action and chemical action. It also shows less efflorescence.

(c) High pressure steam cured concrete exhibits lower drying shrinkage, and moisture movement.

In high pressure steam curing, concrete is subjected to a maximum temperature of about 175°C which corresponds to a steam pressure of about 8.5 kg /sq.cm.

When the concrete is to be subjected to high pressure steam curing, it is invariably made by admixing with 20 to 30 per cent of pozzolanic material such as crushed stone dust. In case of normal curing, the liberation of $Ca(OH)_2$ is a slow process. Therefore, when pozzolanic materials are added, the pozzolanic reactivity also will be a slow process. But in case of high pressure steam curing a good amount of $Ca(OH)_2$ will be liberated in a very short time and reaction between $Ca(OH)_2$ and pozzolanic material takes place in an accelerated manner. A good amount of technical advantage is achieved by admixing the concrete with pozzolanic material.

High pressure steam curing exhibits higher strength and durability particularly in the case of cement containing a proportionately higher amount of C_3S. A sample of cement containing

higher proportion of C_2S is not benefited to the same extent, as it produces lower amount of $Ca(OH)_2$

It is also observed that improvement in durability is more for the concrete made with higher water/cement ratio, than for the concrete made with low water/cement ratio.

Owing to the combination of $Ca(OH)_2$ with siliceous material within a matter of 24 hours in the case of high steam curing, concrete becomes impervious and hence durable. The fact is that the concrete in the absence of free Calcium Hydroxide becomes dense and less permeable, and also accounts for higher chemical resistance and higher strength.

The higher rate of development of strength is attributed to the higher temperature to which a concrete is subjected. Earlier it is brought out that if the concrete is subjected to very high temperature, particularly in the early period of hydration, most of the strength gained will be lost because of the formation of poor quality gel. The above is true for steam cured concrete at atmospheric pressure. The high pressure steam cured concrete does not exhibit retrogression of strength. The possible explanation is that in the case of high pressure steam curing, the quality and uniformity of pore structure formed is different. At high temperature the amorphous calcium silicates are probably converted to crystalline forms. Probably due to high pressure the frame work of the gel will become more compact and dense. This perhaps explains why the retrogression of strength does not take place in the case of high pressure steam curing.

In ordinarily cured concrete, the specific surface of the gel is estimated to be about two million sq cm per gram of cement, whereas in the case of high pressure steam cured concrete, the specific surface of gel is in the order of seventy thousand sq cm per gram. In other words, the gels are about 20 times coarser than ordinarily cured concrete. It is common knowledge, that finer material shrinks more than coarser material. Therefore, ordinary concrete made up of finer gels shrinks more than high pressure steam cured concrete made up of coarser gel. In quantitative terms, the high pressure steam cured concrete undergoes shrinkage of 1/3 to 1/6 of that of concrete cured at normal temperature. When pozzolanic material is added to the mix, the shrinkage is found to be higher, but still it shrinks only about 1/2 of the shrinkage of normally cured concrete.

Due to the absence of free calcium hydroxide no efflorescence is seen in case of high pressure steam cured concrete.

Due to the formation of coarser gel, the bond strength of concrete to the reinforcement is reduced by about 30 per cent to 50 per cent when compared with ordinary moist-cured concrete. High pressure steam cured concrete is rather brittle and whitish in colour. On the whole, high pressure steam curing produces good quality dense and durable concrete:

The concrete products as moulded with only a couple of hours delay period is subjected to maximum temperature over a period of 3 to 5 hours. This is followed by about 5 to 8 hours at this temperature. Pressure and temperature is realeased in about one hour. The detail steaming cycle depends on the plant, quality of material thickness of member etc. The length of delay period before subjecting to high pressure steam curing does not materially affect the quality of high pressure steam cured concrete.

Curing by Infra-red Radiation

Curing of concrete by Infra-red Radiation has been practised in very cold climatic regions in Russia. It is claimed that much more rapid gain of strength can be obtained than with steam curing and that rapid initial temperature does not cause a decrease in the ultimate strength

as in the case of steam curing at ordinary pressure. The system is very often adopted for the curing of hollow concrete products. The normal operative temperature is kept at about 90°C.

Electrical Curing

Another method of curing concrete, which is applicable mostly to very cold climatic regions is the use of electricity. This method is not likely to find much application in ordinary climate owing to economic reasons.

Concrete can be cured electrically by passing an alternating current (Electrolysis trouble will be encountered if direct current is used) through the concrete itself between two electrodes either buried in or applied to the surface of the concrete. Care must be taken to prevent the moisture from going out leaving the concrete completely dry. As this method is not likely to be adopted in this country, for a long time to come, this aspect is not discussed in detail.

Miscellaneous Methods of Curing

Calcium chloride is used either as a surface coating or as an admixture. It has been used satisfactorily as a curing medium. Both these methods are based on the fact that calcium chloride being a salt, shows affinity for moisture. The salt, not only absorbs moisture from atmosphere but also retains it at the surface. This moisture held at the surface prevents the mixing water from evaporation and thereby keeps the concrete wet for a long time to promote hydration.

Formwork prevents escaping of moisture from the concrete, particularly, in the case of beams and columns. Keeping the formwork intact and sealing the joint with wax or any other sealing compound prevents the evaporation of moisture from the concrete. This procedure of promoting hydration, can be considered as one of the miscellaneous methods of curing.

When to Start Curing and how Long to Cure

Many a time an engineer at site wonders, how early he should start curing by way of application of water. This problem arises, particularly, in case of hot weather concreting. In an arid region, concrete placed as a road slab or roof slab gets dried up in a very short time, say within 2 hours. Often questions are asked whether water can be poured over the above concrete within two hours to prevent the drying. The associated problem is, if water is applied within say two hours, whether it will interfere with the water/cement ratio and cause harmful effects. In other words, question is how early water can be applied over concrete surface so that uninterrupted and continued hydration takes place, without causing interference with the water/cement ratio. The answer is that first of all, concrete should not be allowed to dry fast in any situation. Concrete that are liable to quick drying is required to be covered with wet gunny bag or wet hessian cloth properly squeezed, so that the water does not drip and at the same time, does not allow the concrete to dry. This condition should be maintained for 24 hours or at least till the final setting time of cement at which duration the concrete will have assumed the final volume. Even if water is poured, after this time, it is not going to interfere with the water/cement ratio. However, the best practice is to keep the concrete under the wet gunny bag for 24 hours and then commence water curing by way of ponding or spraying. Of course, when curing compound is used immediately after bleeding water, if any, dries up, the question of when to start water curing does not arise at all.

There is a wrong notion with common builders that commencement of curing should be done only on the following day after concreting. Even on the next day they make arrangements and build bunds with mud or lean mortar to retain water. This further delays

the curing. Such practice is followed for concrete road construction by municipal corporations also. It is a bad practice. It is difficult to set time frame how early water curing can be started. It depends on, prevailing temperature, humidity, wind velocity, type of cement, fineness of cement, w/c used and size of member etc. The point to observe is that, the top surface of concrete should not be allowed to dry. Enough moisture must be present to promote hydration. To satisfy the above conditions any practical steps can be undertaken, including the application of fine spray or fogging without disturbing surface finish. Such measures may be taken as early as two hours after casting. It is pointed out that early curing is important for 53 grade cement.

Incidentally, it is seen that test cubes cast at site are allowed to dry without covering the top with wet covering. They are allowed to dry in the hot sun. Such cubes develop cracks and show low strength when crushed. It is usual that they complain about poor quality of cement or concrete.

Regarding how long to cure, it is again difficult to set a limit. Since all the desirable properties of concrete are improved by curing, the curing period should be as long as practical. For general guidance, concrete must be cured till it attains about 70% of specified strength. At lower temperature curing period must be increased.

Since the rate of hydration is influenced by cement composition and fineness, the curing period should be prolonged for concretes made with cements of slow strength gain characteristics. Pozzolanic cement or concrete admixed with pozzolanic material is required to be cured for longer duration. Mass concrete, heavy footings, large piers, abutments, should be cured for at least 2 weeks.

Finishing of road pavement

To assertain the period of curing or stripping of formwork, cubes or beams are cast and kept adjacent to the structure they represent and cured by the same method. The strength of these cubes or beams at different intervals of time would give better idea about the strength development of structures. The above method does not truly indicate the strength development of massive girder subjected to steam curing because of size difference of cubes and girders.

Finishing

Finishing operation is the last operation in making concrete. Finishing in real sence does not apply to all concrete operations. For a beam concreting, finishing may not be applicable, whereas for the concrete road pavement, airfield pavement or for the flooring of a domestic building, careful finishing is of great importance. Concrete is often dubbed as a drab material, incapable of offering pleasant architectural appearance and finish. This shortcoming of concrete is being rectified and concretes these days are made to exhibit pleasant surface finishes. Particularly, many types of prefabricated concrete panels used as floor slab or wall unit are made in such a way as to give very attractive architectural affect. Even concrete claddings are made to give attractive look.

In recent years there has been a growing tendency to develop and use various surface treatments which permit concrete structures to proudly proclaim its nature instead of covering itself with an expensive veneer. The property of concrete to reproduce form markings such as board mark finishes, use of linings or special types of formworks, special techniques for the application of applied finishes have been encouraged. Surface finishes may be grouped as under:

(a) Formwork Finishes (b) Surface Treatment (c) Applied Finishes.

Formwork Finishes

Concrete obeys the shape of formwork i.e., centering work. By judiciously assembling the formwork either in plane surface or in undulated fashion or having the joints in a particular "V" shaped manner to get regular fins or groves, a pleasing surface finish can be given to concrete. The architect's imaginations can be fully exploited to give many varieties of look to the concrete surface. The use of small battens can give a good look to the concrete surface.

A pre-fabricated wall unit cast between steel formwork having very smooth surface using right proportioning of materials can give such a nice surface which can never be obtained by the best masons. Similarly, the prefabricated floor units can have such a fine finish at the ceiling which cannot be obtained by the best masons with the best efforts. These days with the cost of labour going up, attention is naturally directed to the self-finishing of the concrete surface,

Mechanical trowel for finishing factory floor.
Sometimes surface hardener is sprinkled and finished.

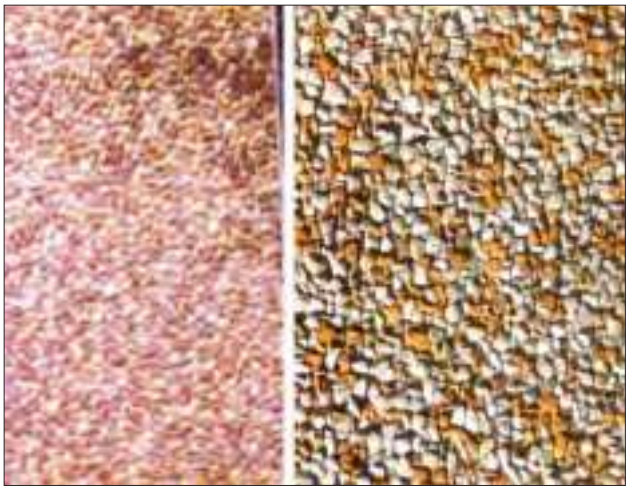
particularly, for floor slabs, by the use of good formwork material such as steel sheets or shuttering type plywood.

Surface Treatment

This is one of the widely used methods for surface finishing. The concrete pavement slab is required to be plane but rough to exhibit skid resistance, so is the air-field pavements and road slabs. Concrete having been brought to the plane level surface, is raked lightly or broomed or textured or scratched to make the surface rough.

A domestic floor slab is required to be smooth, wear resisting and crack-free. The technique of finishing the concrete floor requires very careful considerations. The proportioning of the mix must be appropriate without excess or deficient of matrix. Water/cement ratio should be such that it provides the just required consistency to facilitate spreading and good levelling, yet to give no bleeding. Surface must be finished at the same rate as the placing of concrete. Particular care must be taken to the extent and time of trowelling. Use of wooden float is better to start with but at the end steel trowel may be used. In all the operation, care must be taken to see that no laitance is formed and no excessive mortar or water accumulates on the surface of the floor, which reduces the wear resistance of the floor. The excess of mortar at the surface causes craziness due to increased shrinkage. Achieving a good surface finish to a concrete floor requires considerable experience and devotion on the part of the mason. A hurried completion of surface operation will make a poor surface.

Often concrete is placed at a much faster rate than the speed of finish by the masons with the result that concrete dries up and mason is not able to bring the concrete to a good level. He resorts to applying extra rich mortar to bring the floor surface to good level. This practice of applying rich mortar spcecially made to the surface is not desirable. This practice, firstly reduces the bond. Secondly, reduces the strength and wear resistance than the homogeneous concrete. Thirdly, mortar shrinks more than that of concrete. Therefore, application of a thick layer of mortar over set concrete is objectionable. It is a good practice to the finish the floor with the matrix that comes to the top of the concrete due to the compaction of concrete and by working with mason's tamping rule. In case the above is not possible, use of extra mortar may be permitted to avoid very poor surface finish. But it is necessary to observe the following precautions:



Exposed aggregate finish

(a) *The mortar composition be the same as that of concrete.*

(b) *It should be applied as thin a layer as possible before the base concrete is hardened, and rubbed smooth.*

(c) *Sprinkling of dry cement in good quantity is not a good practice, however a small quantity may be permitted to reduce the bad effect of bleeding, taking care to see that it does not make the top layer too rich.*

Exposed Aggregate-Finish: *This is one of the methods of giving good look to the concrete surface. The beauty can be further enhanced by the use of coloured pebbles or quartz. One or two days after casting, the matrix is removed by washing the surface with water or by slight brushing and washing. One face of the aggregate particles will adhere to the matrix and the other face gets exposed. This exposed surface will give a pleasing look. Sometimes, retarding agent is applied to the formwork surface. The matrix at the surface being in contact with the retarding agent, does not get hardened, whereas rest of the portion gets hardened. On washing or light brushing, the unhardened matrix gets washed out, exposing the aggregate.*

Applied finish work done at CME

Sometimes use of hydrochloric acid solution made up of one part of acid to six parts of water is used for washing the concrete surface to expose the aggregate. The acid attacks the cement and enables it to be brushed off. Care must be taken that the workman should use rubber-gloves and on completion of washing by the acid, the surface should be treated with alkaline solution to neutralise any remaining acid. This method of using acid should not be applied for concrete made with limestone aggregate.

Bush Hammering: *A Bush Hammer is a tool with a series of pyramidal teeth on its face. They may be hand operated or pneumatically or electrically operated. Hand tools are suitable for small jobs but power operated equipment is used for large surface.*

Bush Hammer gives rapid blows to the concrete surface and not only removes the outer cement film but also breaks some of the exposed aggregate giving a bright, colourful and attractive surface. Very pleasant effects may be obtained by carefully arranging large aggregates at the surface and later removing the matrix by bush hammer.

Concrete should be at least three weaks old, before it is bush hammered. Otherwise, there is a danger of whole pieces of aggregates being dislodged. The quality of concrete which is to be treated this way by bush hammering must be of high quality and good workmanship.

Applied Finish: *The term applied finish is used to denote the application of rendering to the exteriors of concrete structures. The concrete surface is cleaned and roughned and kept wet for sufficiently long time. Over this a mortar of proportion of about 1:3 is applied. This mortar rendering can be given any required pleasant finish, such as cement stippling either fine or coarse,* ***combed finish****, keying, renderings etc.*

*Sometimes this rendering applied on wall is pressed with sponge. The sponge absorbs cement and water exposes sand particles. The sponge is washed and again rubbed against the surface. With the repetition of this process, the surface gets a finish, known as "****Sand Facing****".*

*A wet plastic mix of three parts of cement, , one part of lime, six parts of sand and 4 parts of about 5 mm size peagravel aggregate is thrown against wall surface by means of a scoop or plasterer's trowel. This finish is known as "****Rough Cast Finish****".*

Upon a 10 mm thick coat of one part of cement, one part of lime and five parts of sand, while it is still plastic, is thrown about 6 mm size selected well-washed pebbles. This kind of finish is known as "**Pebble Dash**".

The latest method of finish given to the concrete surface is known as "**Fair Crete**" finish. This rendering can be given to the concrete in situ or better still to the concrete panels. Such panels are used as cladding to the concrete structures.

Fair crete is nothing but a highly air-entrained mortar (air-entrainment is to be extent of 25 per cent) mixed with chopped jute fibre. This mortar is spread and pressed by a mould having different designs. The impression of the mould is translated into the mortar. Air entrained mortar being foamy in nature takes the impression of the mould. A wide variety of designs and murals can be translated to the air entrained mortar surface. The jute fibre increases the tensile strength of the fair crete.

Miscellaneous Finishes: Non-slip Finish: Surface of ramps, railway platforms, surroundings of swimming pools etc., are required to posses a highly nonslip texture. To obtain this quality, an abrasive grit is sprinkled over the surface during the floating operations. The surface is lightly floated just to embed the abrasive grit at the surface. Sometimes, epoxy screed is also given to the surface over which silica sand is sprinkled while the epoxy is still wet.

Coloured Finish: Principal materials used for colouring concrete are:

(a) Pigment admixtures (b) Chemical stains
(c) Paints (d) White cement (e) Coloured concrete.

Pigment admixtures may be added integrally to the topping mix, blended with the dry cement, or pigments may be dusted on to the topping immediately on application of screed. Of all the methods, mixing integrally with the mortar is the best method, next to using coloured cements. Sometimes, certain chemicals are used to give desirable colour to the concrete surface. Similarly, cement based paints or other colour paints are also used.

White cement is used in different ways to give different look to the concrete. White and coloured cements have been used as toppings in factory floor finish.

Recently RMC (India), a Ready Mix Concrete supplying company, have started supplying Ready Mixed coloured concrete in various colours. They incorporate certain percentage of fibres in this concrete to take care of shrinkage cracks and to impart other desirable properties to the concrete.. Such coloured concrete can be used indoors or outdoor application as a substitute to ordinary concrete.

Wear Resistant Floor Finish: A wear resisting quality of a concrete floor surface can be improved by using solutions of certain chemicals known as "Liquid Harderners". They include, fluosilicates of magnesium and zinc, sodium silicate, gums and waxes. When the compounds penetrate the pores in the topping, they form crystalline or gummy deposits and thus tend to make the floor less pervious and reduce dusting either by acting as plastic binders or making the surface harder.

Sometimes, iron filing and iron chips are mixed with the toppings and the floor is made in a normal manner. The rusting of the iron filings and chips increases in volume and thereby makes the concrete dense giving the floor better wear resistance. They are known as "Ironite floor toppings". Fibre reinforced concrete also has demonstrated a better wear-resistance quality in case of road and airfield slabs. We have already discussed about Wear Resistant floor finish in Chapter 5 under construction chemicals. Attention is drawn to the present day availability and application Epoxy Paint, Epoxy mortar, self levelling Epoxy screed etc., for the

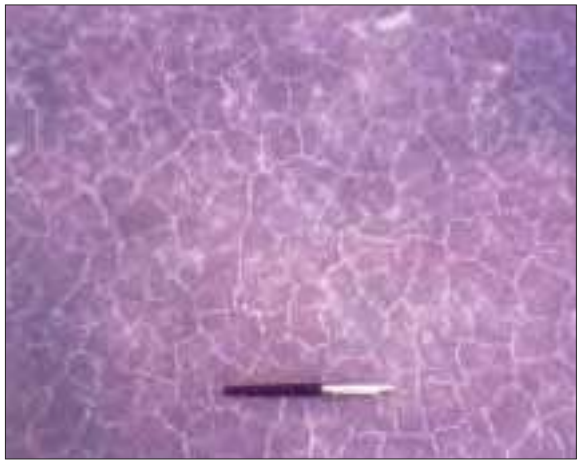
use of Wear Resistant floor and decorative floor finish. They are widely used in modern construction.

Requirement of a good finish: *A good concrete floor should have a surface which is durable, non-absorptive, suitable texture, free from cracks, crazing and other defects. In other words, the floor should satisfactorily withstand wear from traffic. It should be sufficiently impervious to passage of water, oils or other liquids. It should possess a texture in keeping with the required appearance, should be easy to clean and be safe against slipping. It should structurally be sound and must act in unison with sub-floor.*

Grinding and Polishing: *Floors when properly constructed using materials of good quality, are dustless, dense, easily cleaned and attractive in appearance. When grinding is specified, it should be started after the surface has hardened sufficiently to prevent dislodgement of aggregate particles and should be continued until the coarse aggregates are exposed. The machine used should be of approved type with stones that cut freely and rapidly. The floor is kept wet during the grinding process and the cuttings are removed by spraying and flushing with water. After the surface is ground, air holes, pits and the other blemishes are filled with a thin grout composed of one part of fine carborundum grit and one part of portland cement. This grout is spread over the floor and worked into the pits with the straight edge after which it is rubbed into the floor with a grinding machine. When the fillings are hardened for seven days, the floor is given final grinding.*

Craziness: *While we are discussing about the surface finish it will be pertinent to discuss the craziness i.e., the development of fine shallow hair cracks on concrete surface.*

The surface appearance of concrete is often spoilt by a fairly close pattern of hair cracks which may appear within the first year, occasionally after longer periods. The cracks do not penetrate deep into the concrete and do not indicate any structural weakness. They are most obvious immediately after the surface of the concrete has dried when wetted they become prominent. It is not possible to state any precautions which will definitely prevent craziness but its occurrence can be minimised. Craziness is due to drying shrinkage or carbonation or due to differential shrinkage between the surface of the concrete and the main body of the concrete. This differential shrinkage is accentuated if the skin is richer than the parent concrete. It is known that drying shrinkage is greatest when the concrete dries up fast after casting. The first precaution to take, therefore, is very careful curing so that the initial drying period is extended over as long a time as possible so that the shrinkage of the outer skin is kept in conformity with the shrinkage of the main body of the concrete. Steep moisture gradients between the surface and the interior of the concrete must be avoided if possible. Cracking will not occur if the concrete is sufficiently strong to resist the tensile forces caused by differential shrinkage but it does not appear possible to prevent crazing by making a very strong concrete.



Craziness in the surface of concrete.

The object must therefore be to minimise shrinkage of the surface skin and this is best achieved by adequate curing and by taking measures to prevent shrinkage by avoiding too rich surface. The following precautions will help greatly:

(a) Trowelling the surface as little as possible and in particular avoiding the use of a steel float.

(b) Avoiding the use of rich facing mixes, say, not richer than 1:3.

(c) Use of as low a water-cement ratio as possible consistent with adequate compaction.

(d) Avoiding grouting processes or rubbing the surface with neat cement paste.

(e) Over vibration which results in bringing too much slurry to the top or side. (adjacent to formwork).

Crazing may also be due to carbonation and thermal effects. A cement-rich skin is liable to expand and contract more with difference in temperature than the interior of the concrete. The wetting and drying process is, however, a far more potent factor for causing craziness. The most important causes of crazing are thermal stresses and long term drying shrinkage.

Whisper Concrete Finish : *One of the disadvantages of Concrete Roads is that they produce lot of noise when vehicles travel at high speed, due to friction between tyres and hard road surface. In Europe the noise level has become intolerable to the people living by the side of roads where about a lakh of vehicles move at a speed of about 120 km per hour. Belgium was the first country to take measure to reduce noise pollution.*

It may be recalled that, texturing or brooming is done as a surface finish for the new road pavement construction to provide skid resistance. Over the time, the texturing gets worn out and the surnace becomes smooth. When it rains, the pool of water on the smooth concrete surface causes a phenomenon called "Hydroplaning" when vehicle move at high speed, which results in loss of control and skidding.

Concrete roads needs roughening and resurfacing after some years of use. This is done by regrooving. Regrooving is nothing but cutting and creating grooves about 2 mm deep across the vehicular movement. This is a costly and laborious practice. Instead, Belgium authorities tried exposed aggregate finish. On the smoothened road surface, they overlaid 40–50 mm of concrete, having a maximum size of 6–8 mm coarse aggregate. The surface of new concrete, while still green, was sprayed with a retarder consisting of glucose, water and alcohol. It was immediately covered by polyethylene sheet. After about 8–36, hours, the polyethylene sheet is removed and the road surface was swept and washed with stiff rotating bristle brushes. The top unset cement mortar to a depth of about 1.5 to 2 mm is removed exposing the aggregate, making the surface rough enough for safe high speed vehicular movement.

When vehicles moved at high speed on such exposed aggregate surface it was found to every ones surprise that noise level was much reduced than normal concrete surface. In fact, it was found that noise level was lower than the case of black-topped road pavement. Further trials were conducted and it was confirmed that exposed aggregate finish provides not only skid resistance but also reduces the noise. The Belgian authorities called it as ***"whisper"*** *concrete.*

Mostly in many continental countries where concrete pavements are popular, they provide 40–50 mm layer of whisper concrete. They found that there is very little difference in cost between regrooving and providing whisper concrete. It was also seen that providing a

white topping, that is, providing concrete pavement over bituninous pavement, adoption of whisper concrete gave good economy.

In U.K, they took up the use of whisper concrete pavement during 1995, and has given good guide lines for adoption of whisper concrete.

Some of the important guidelines are:

- *Under standard highway conditions, a concrete road should consist of cement bound sub-base, between 150–200 mm thick. On top of this, there should be 200 mm of continuously reinforced concrete pavement (CRCP) followed by 50 mm of whisper concrete surfacing.*
- *Normally 8 mm size coarse aggregate should be used for whisper concrete layer. Not more than 3% of these should be oversize and 10% undersize.*
- *The flakiness index should be less than 25%.*
- *Coarse aggregate should form around 60% of whisper concrete. Sand should be very fine.*
- *Spray retarder consisting of glucose, water and alcohol. They cover the surface with polyethylene sheet.*
- *After 8 to 36 hours, remove the polyethylene sheet and brush the surface with mechanically rotating stiff bristle to remove cement mortar from the top 1.5 mm.*

As far as India is concerned, whisper concrete is not going to be a necessity for some years to come.

REFERENCES

6.1 Nasser KW, *New and simple tester for slump of concrete ACI Journal*, October 1976.

6.2 Dordi C.M., Equipment for Transporting and Placing Eoncrete, Seminar on Concrete Plant and Equipment, Ahmedabad, Nov. 1995.

6.3 cooke T.H., Concrete Pumping and Spraying, A Practical Guide, Thomas Telford, London.

6.4 Klieger P, *Early High Strength Concrete for Prestressing, world conference on prestressed concrete* July 1957.

6.5 Price W.H., *Factors Influencing Concrete strength, ACI Journal* Feb. 1951.

6.6 Verbick et.al., Structure and Physical Properties of Cement Pastes, Proceedings, Fifth International Symposium on the Chemistry of Cement, The Cement Association of Japan, Tokyo, 1968.

6.7 Klier P, *Effect of Mixing and Curing Temperature on concrete strength ACI Journal* June 1958.

6.8 U.S. Bureau of Reclamation, Concrete Manual, 8th Edition, Denver, Colarado, 1975.

Top

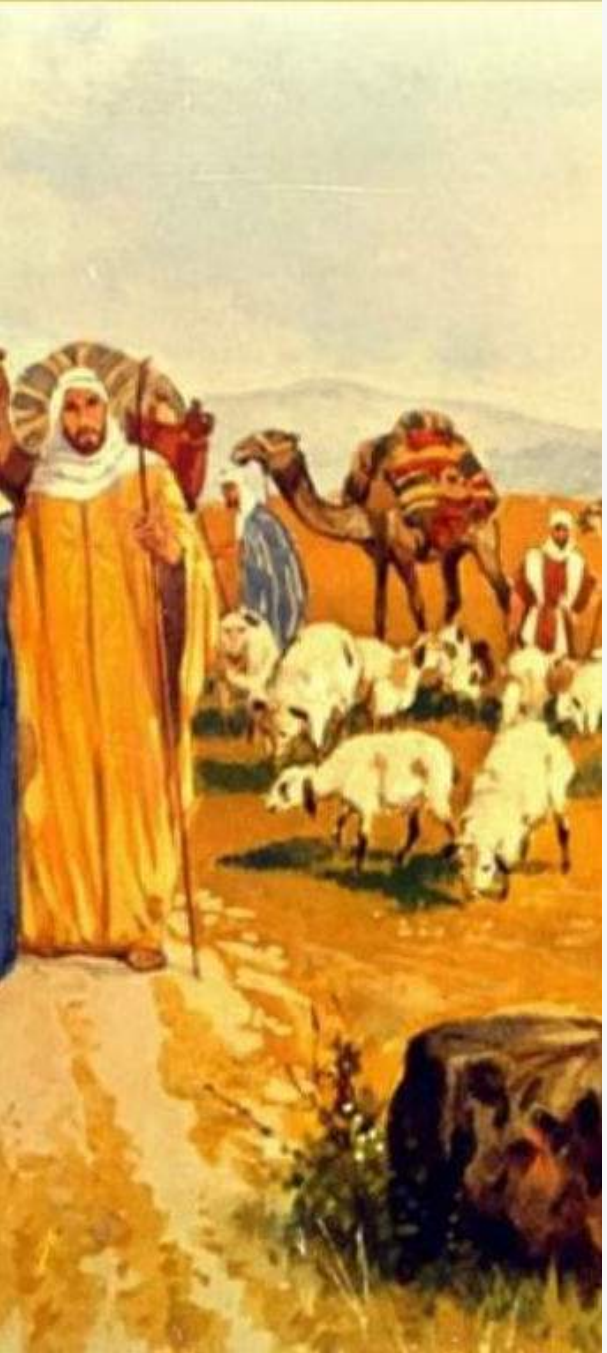
Introduction to Hardened Concrete

Hardened concrete is a durable building material that plays a crucial role in construction projects. Its strength and durability make it suitable for various applications, from residential to commercial structures.

by S Naresh --

Significance of Water / Cement Ratio

- **Strength:** Proper ratio is crucial for concrete strength and durability
- **Workability:** Affects ease of placement and finishing
- **Permeability:** Influences resistance to water and chemical penetration



Abram's Law and its Application

1

Development of Abram's Law

Abram's Law is a concept in concrete technology formulated to predict the strength of concrete based on the water-to-cement ratio.

2

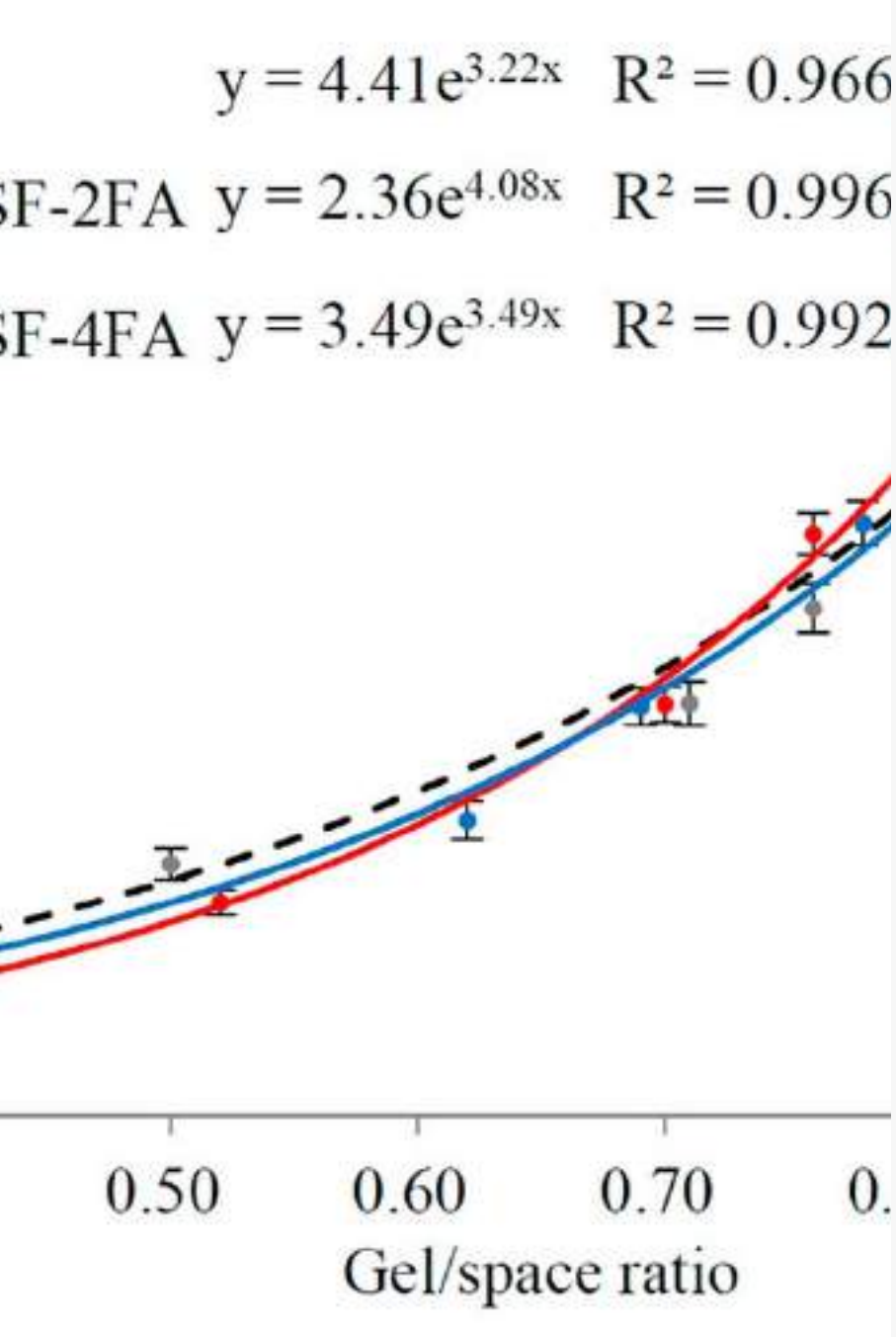
Application in Concrete Design

This law is widely used in the construction industry to determine the optimal mix proportions for achieving desired concrete strength.

3

Impact on Concrete Quality Control

The application of Abram's Law plays a crucial role in ensuring the quality and durability of concrete structures.



Understanding Gel/Space Ratio

The gel/space ratio in hardened concrete refers to the balance between the solid gel structure and the open spaces within the concrete mix. It directly impacts the concrete's strength and durability by influencing its microstructure and permeability.

A well-optimized gel/space ratio ensures a denser and more cohesive concrete matrix, enhancing its resistance to deterioration and environmental effects.

Factors Affecting Gain of Strength of Concrete

Concrete strength is influenced by factors such as curing conditions, water-cement ratio, aggregate quality, and admixtures. Proper curing and avoiding early age drying are crucial for strength development. Additionally, temperature and humidity during curing can significantly impact concrete strength.

Exploring the Maturity Concept in Concrete

1

Maturity Concept

Tracking concrete strength over time

2

Calorimetry Method

Measuring heat release for maturity

3

In-situ Maturity Testing

Real-time strength assessment

The maturity concept in concrete involves tracking the development of its strength over time, often using the calorimetry method or in-situ testing. Understanding the maturity concept is essential for optimizing construction schedules and ensuring the structural integrity of concrete elements.

Strength in Tension and Compression

Tension Strength

Tension strength is the ability of concrete to resist pulling forces, such as those exerted by stretching or bending. Factors affecting tension strength include the quality of aggregates and the curing conditions.

Compression Strength

Compression strength refers to the ability of concrete to withstand pushing forces. It is influenced by factors like water-to-cement ratio, air content, and the presence of reinforcing materials.

Fiber-Reinforced Concrete

In the case of tension strength, using fiber-reinforced concrete can improve the ability to withstand pulling forces while maintaining structural integrity.

Creep and Shrinkage

Long-term deformation due to sustained load or drying shrinkage can compromise the strength of concrete, especially in tension, emphasizing the need for proper curing and reinforcement.

Compression tests- Tension tests - Factors affecting strength

1 Importance of Compression Tests

Compression tests assess the ability of concrete to withstand loads that compress and shorten it.

2 Significance of Tension Tests

Tension tests evaluate the capacity of concrete to resist forces that pull and elongate it.

3 Factors Affecting Strength

Various factors such as water-cement ratio, curing conditions, and aggregate quality impact concrete strength.

Pull-out Test and Non-Destructive Testing Methods

Pull-out Test

The pull-out test is used to determine the bond strength between concrete and reinforcement.

Non-Destructive Testing

NDT methods like ultrasonic testing and radiography ensure the integrity of concrete structures without causing damage.

Codal Provisions for NDT

Codal provisions set the standards and guidelines for non-destructive testing techniques in concrete construction.

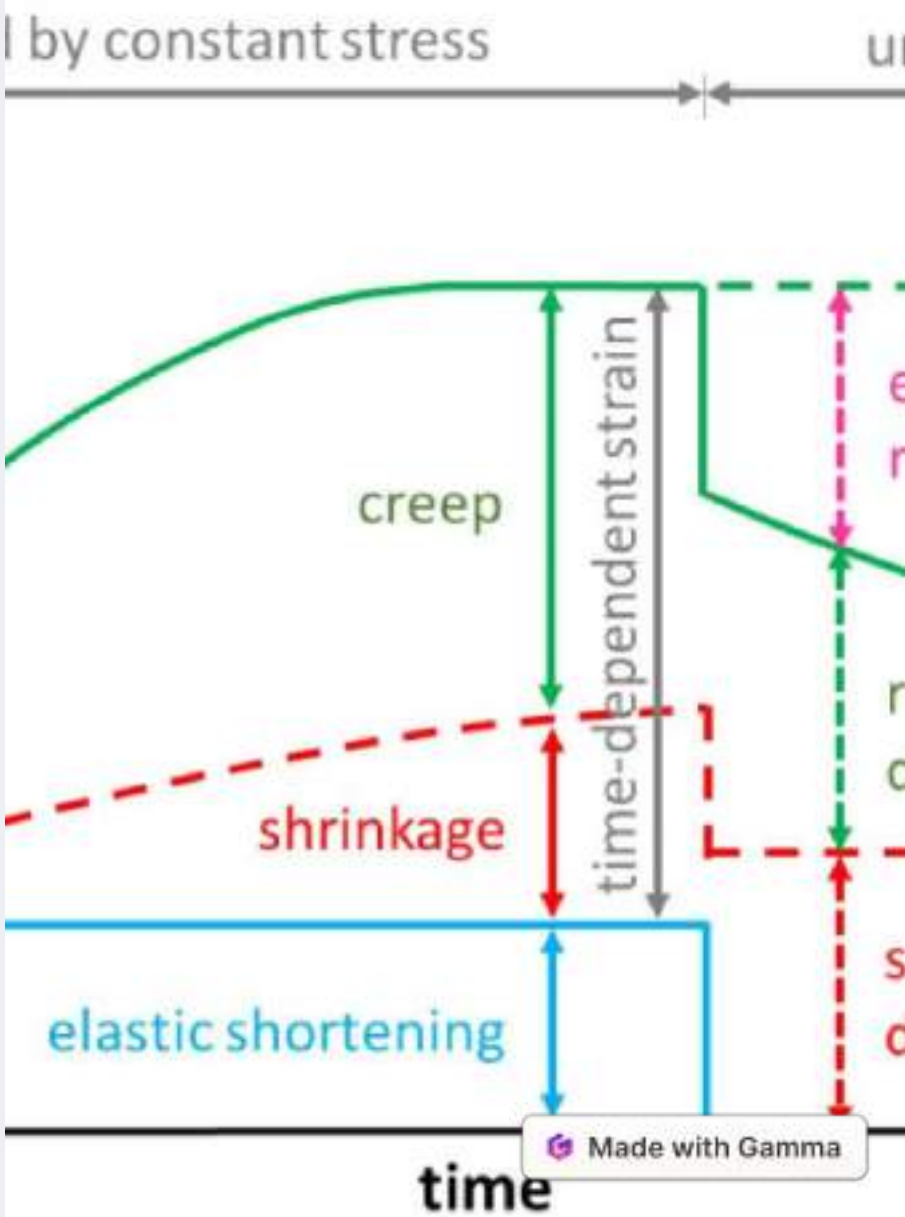
Flexure Tests and Splitting Tests

Flexure Tests	Assess the strength of concrete under bending.
Splitting Tests	Evaluate the tensile strength of concrete across a plane.

Introduction to Elasticity, Creep, and Shrinkage

In the field of structural engineering, understanding the concepts of elasticity, creep, and shrinkage is crucial for the design and analysis of buildings, bridges, and other infrastructure. Elasticity describes the ability of a material to deform under stress and then return to its original shape and size when the stress is removed. Creep, on the other hand, is the tendency of a material to slowly move or deform over time under the influence of mechanical stresses. Shrinkage, a related phenomenon, refers to the reduction in volume of a material, such as concrete, due to the loss of moisture. Together, these three properties play a vital role in determining the long-term performance and integrity of structures.

by naresh sankuru



Modulus of Elasticity

Definition

The modulus of elasticity, also known as Young's modulus, is a measure of the stiffness of a material. It represents the relationship between the stress applied to a material and the resulting strain, within the elastic limit. The modulus of elasticity is an important property in engineering, as it determines how a material will behave under various loading conditions, such as compression, tension, or bending.

Importance in Construction

In the construction industry, the modulus of elasticity is crucial for the design and analysis of structures. It is used to determine the deformation of structural elements, such as beams, columns, and slabs, under applied loads. A higher modulus of elasticity indicates a stiffer material, which is desirable for load-bearing members, as it minimizes deflection and ensures the stability of the structure.

Factors Affecting Modulus of Elasticity

The modulus of elasticity can be influenced by various factors, including the material composition, temperature, and loading conditions. For example, the modulus of elasticity for concrete can vary depending on the mix design, the age of the concrete, and the presence of reinforcement. Understanding these factors is essential for accurate structural analysis and the selection of appropriate materials for construction projects.

Dynamic Modulus of Elasticity

1 Definition

The dynamic modulus of elasticity, also known as the complex modulus, represents the material's stiffness when subjected to dynamic or cyclic loading. Unlike the static modulus of elasticity, which measures a material's response under constant, slowly applied loads, the dynamic modulus captures the material's behavior when it experiences rapid, oscillating stresses and strains.

2 Measurement Techniques

To determine the dynamic modulus of elasticity, specialized testing methods are used, such as resonance tests or impulse excitation techniques. These techniques involve applying a small, controlled vibration or impact to the material and measuring its response. The relationship between the applied force and the resulting deformation allows the calculation of the dynamic modulus.

3 Importance in Structural Design

The dynamic modulus of elasticity is crucial in the design of structures and components that will be subjected to dynamic loads, such as earthquakes, wind, or machine vibrations. It helps engineers accurately predict the material's behavior and ensure the structure's integrity under these challenging loading conditions. Additionally, the dynamic modulus is used in the analysis of the natural frequencies and vibration modes of structures, which is essential for avoiding resonance and ensuring structural stability.

4 Applications in Concrete and Composites

The dynamic modulus of elasticity is particularly important in the analysis and design of concrete and other composite materials, which exhibit complex behavior under dynamic loading. Understanding the dynamic modulus helps engineers model the material's response to impact, fatigue, and cyclic stresses, enabling more accurate predictions of the structure's long-term performance and durability.

Poisson's Ratio

Definition

Poisson's ratio is a fundamental material property that describes the lateral contraction of a material when it is stretched longitudinally. In other words, when a material is subjected to a tensile or compressive stress, it not only experiences a change in length along the direction of the applied stress, but it also undergoes a change in its transverse or perpendicular dimensions. Poisson's ratio quantifies this lateral deformation in relation to the longitudinal deformation.

Importance in Engineering

Poisson's ratio is an essential parameter in engineering design and analysis, particularly in structural and mechanical applications. It is used to calculate the deformation of materials under various loading conditions, which is crucial for predicting the behavior and performance of structures, components, and systems. Knowing the Poisson's ratio of a material helps engineers determine the appropriate material selection, design dimensions, and load-bearing capacity for a given application.

Typical Values

The value of Poisson's ratio typically ranges from 0 to 0.5 for most common engineering materials. For example, metals like steel and aluminum have Poisson's ratios around 0.3, while rubber-like materials can have values close to 0.5. Certain specialized materials, such as auxetic materials, can have negative Poisson's ratios, which means they exhibit an expansion in the transverse direction when stretched longitudinally.

Measurement and Determination

Poisson's ratio is determined through experimental testing, where a specimen is subjected to a known tensile or compressive stress, and the resulting longitudinal and transverse strains are measured. These measurements are then used to calculate the Poisson's ratio using the formula: Poisson's ratio = - Transverse Strain / Longitudinal Strain. Accurate determination of Poisson's ratio is crucial for reliable engineering calculations and predictions.

Creep of Concrete

Concrete, a widely used construction material, exhibits a unique phenomenon known as creep. Creep refers to the gradual deformation of concrete over time under sustained loads. This behavior is particularly important in structural engineering, as it can impact the long-term performance and stability of concrete structures.

Creep in concrete occurs due to the rearrangement and gradual deformation of the cement paste and aggregate particles within the concrete mixture. As concrete is subjected to a constant load, the material slowly adjusts and deforms, leading to an increase in overall strain over time. This process is influenced by various factors, including the composition of the concrete, the applied stress level, environmental conditions, and the age of the concrete.

Understanding and predicting the creep behavior of concrete is crucial for the design and construction of safe, reliable, and long-lasting structures. Engineers must carefully consider the effects of creep when calculating the design loads, deflections, and stresses in concrete members to ensure the structure's integrity and functionality throughout its intended lifespan.

Factors Influencing Creep

1

Concrete Composition

The mix design and ingredients of the concrete play a significant role in its creep behavior. Factors such as the water-cement ratio, cement type, and the presence of admixtures can all influence the creep characteristics of the concrete. For example, concretes with a higher water-cement ratio tend to exhibit greater creep due to the increased porosity and lower strength of the cement paste.

2

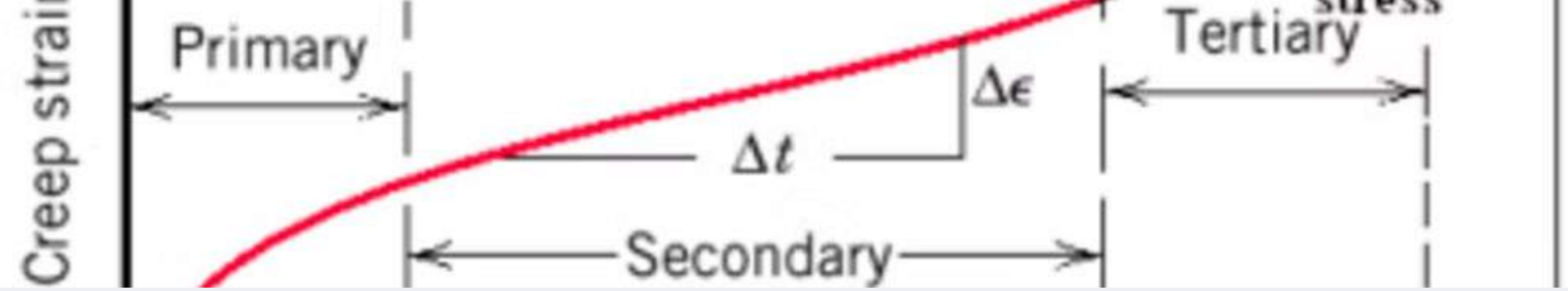
Stress Level

The level of stress applied to the concrete is a crucial factor in determining its creep response. Higher stress levels can lead to increased creep deformation, as the concrete undergoes a more significant rearrangement of its internal structure. The relationship between stress and creep is often nonlinear, with higher stresses resulting in a disproportionate increase in creep.

3

Environmental Conditions

The environmental conditions surrounding the concrete, such as temperature and humidity, can significantly impact its creep behavior. Increased temperatures tend to accelerate the creep process, as the higher energy levels facilitate the rearrangement of the concrete's internal structure. Similarly, higher humidity levels can lead to increased creep due to the plasticizing effect of moisture on the cement paste.



Relationship between Creep and Time

1 Short-Term Creep

Concrete exhibits significant creep deformation in the initial stages, often within the first few days or weeks after loading. This rapid increase in strain is attributed to the rearrangement of the concrete's internal microstructure, as the cement paste and aggregate particles adjust to the applied stresses. The rate of creep is highest during this short-term phase, gradually decreasing over time as the concrete's internal structure stabilizes.

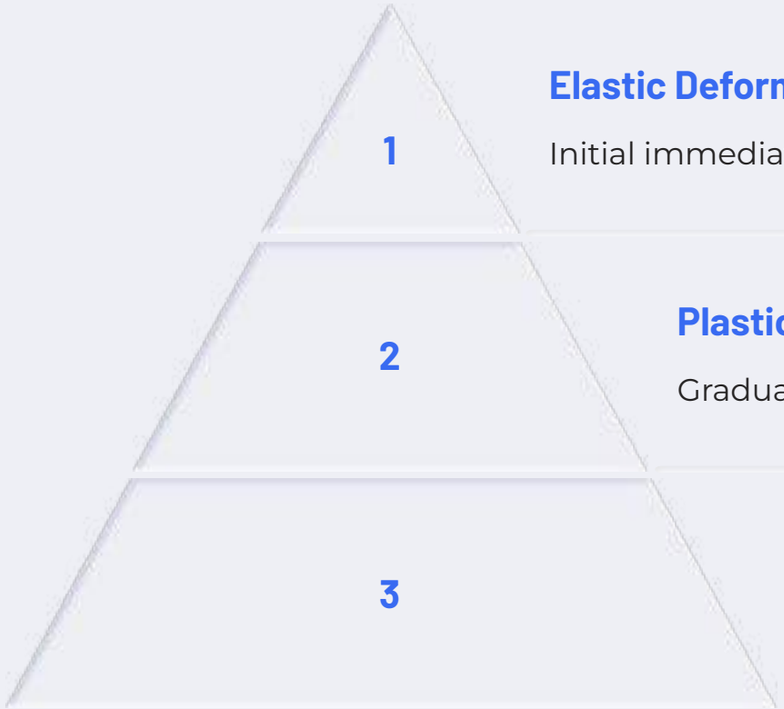
2 Long-Term Creep

Over time, the rate of creep in concrete slows down, but it continues to occur at a diminishing rate. This long-term creep is influenced by factors such as the continued hydration of cement, the gradual breakdown of the cement paste, and the movement of water within the concrete. While the initial rapid creep may be more pronounced, the long-term creep can have a significant impact on the structural performance of concrete elements, especially in structures subjected to sustained loads over many years.

3 Time-Dependent Creep Behavior

The relationship between creep and time is not linear, but rather follows a logarithmic or power function. This means that the rate of creep decreases as time passes, with the majority of the creep occurring in the early stages of loading. Researchers have developed various mathematical models to describe the time-dependent creep behavior of concrete, allowing engineers to predict the long-term deformation and behavior of concrete structures more accurately.

Nature of Creep



Elastic Deformation

Initial immediate deformation under load

Plastic Deformation

Gradual deformation over time under constant load

Time-Dependent

Creep continues to increase as long as the load is sustained

The nature of concrete creep is complex, exhibiting both elastic and plastic deformation behaviors. When a constant load is applied to concrete, an initial immediate elastic deformation occurs. This is followed by a gradual, time-dependent plastic deformation known as creep. The plastic deformation continues to increase as long as the load is sustained, resulting in a progressive increase in strain over time. This time-dependent nature of creep is a key characteristic that distinguishes it from the initial elastic response of the material. Understanding the complex nature of creep is essential for accurately predicting the long-term behavior and service life of concrete structures under sustained loads.

Creep is fundamentally a microstructural phenomenon, driven by the rearrangement and flow of cement paste molecules and the gradual breakdown of the material's internal structure over time. Factors such as the composition of the concrete mix, curing conditions, and environmental exposure all contribute to the specific nature and rate of creep observed in a given application.

Effects of Creep

Creep in concrete can have significant effects on the performance and lifespan of concrete structures. One of the primary effects is the gradual deformation of the concrete over time, which can lead to issues with the structural integrity and serviceability of the building or infrastructure.

5-15%

Typical Range

—

Increase in Deflection

Concrete structures may experience an increase in deflection of 5-15% due to creep over their lifespan, which can compromise the structure's load-bearing capacity and lead to cracking or failure if not properly accounted for in the design.

Another significant effect of creep is the redistribution of internal stresses within the concrete. As the concrete deforms, the stresses are redistributed, which can lead to the development of cracks or the weakening of critical structural elements. This stress redistribution can also affect the performance of reinforcing steel, potentially leading to corrosion or bond failure.

15-35%

Typical Range

—

Increase in Compressive Stresses

Compressive stresses in concrete members can increase by 15-35% due to creep, which can result in premature failure or the need for additional reinforcement to maintain structural integrity.

Creep can also have long-term effects on the serviceability of concrete structures, such as increased deflection, loss of prestress in post-tensioned members, and changes in the distribution of internal forces. These effects must be carefully considered in the design and construction of concrete structures to ensure their safety and performance over their lifespan.

Types of Shrinkage

Concrete, a ubiquitous building material, is susceptible to various types of shrinkage, each with its own unique characteristics and implications. Understanding the different forms of shrinkage is crucial for engineers and architects to design structures that can withstand the stresses and deformations caused by these phenomena.

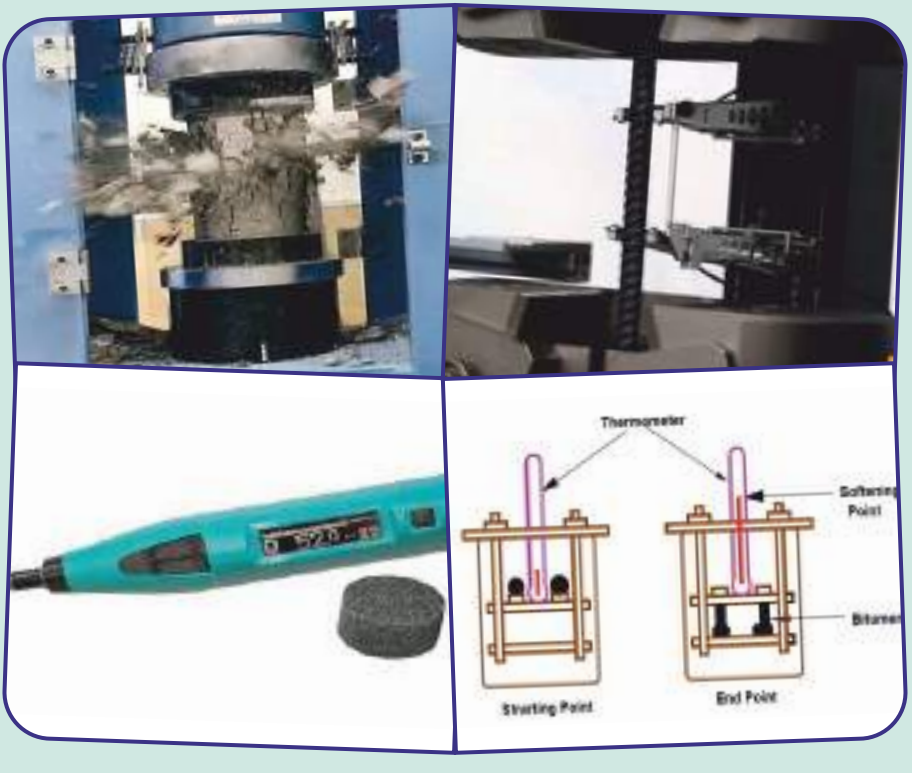
1. **Plastic Shrinkage** - This type of shrinkage occurs in the early stages of concrete curing, before the material has fully hardened. As the concrete mixture loses moisture through evaporation, it can lead to the formation of cracks and surface defects, potentially compromising the structural integrity of the concrete element.
2. **Drying Shrinkage** - As the concrete dries and loses moisture over time, it undergoes a gradual volumetric reduction, known as drying shrinkage. This can result in the development of internal stresses and the formation of cracks, particularly in large concrete structures or those with complex geometries.
3. **Autogenous Shrinkage** - Autogenous shrinkage is a phenomenon that occurs during the hydration process, where the chemical reactions between cement and water cause a reduction in the volume of the concrete mixture. This type of shrinkage is particularly significant in high-strength concrete mixes and can lead to the formation of microcracks, potentially impacting the long-term durability of the structure.
4. **Carbonation Shrinkage** - When concrete is exposed to carbon dioxide in the atmosphere, a chemical reaction can occur, known as carbonation. This process can result in a reduction in the volume of the concrete, leading to additional shrinkage and potential cracking, especially in structures with a high surface area-to-volume ratio.

Effectively managing and mitigating the effects of these various types of shrinkage is a critical aspect of concrete design and construction. Engineers must carefully consider the appropriate mix design, curing techniques, and structural detailing to ensure the long-term durability and performance of concrete structures.

ज्ञान ज्योति से मार्गदर्शन

To Beam As A Beacon of Knowledge

HANDBOOK OF MATERIAL TESTING



November 2022

Indian Railways Institute of Civil Engineering

Pune - 411001

Published By
Indian Railways Institute of Civil Engg.
11-A, South Main Road, Koregaon Park, Pune 411 001.

FIRST EDITION : 2006

SECOND EDITION : NOVEMBER 2022

Price ₹ 200/-

HANDBOOK OF MATERIAL TESTING

November 2022

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING,
Pune 411001

FOREWORD TO SECOND EDITION

Testing of materials is an essential part of the Quality Control system for any Civil Engineering work. Awareness about relevant test procedures is necessary for the officials carrying out these tests in the lab as well as for the field engineers executing the works at site.

Seeing the importance of testing of materials, IRICEN had published "Handbook of Material Testing" in year 2006. This publication needed revision due to change in codes/standards. The tests related to Soil & Blanket materials have been deliberated in a separate book titled "Geotechnical Testing for Earthwork in Railway Projects". A need was also felt to include the tests for water quality and reinforcement also as separate chapters.

Therefore, the thoroughly revised/rewritten second edition of the "Handbook of Material Testing" has been authored by Shri R. K. Shekhawat (Senior Professor/IRICEN). For testing of Concrete & its' ingredients and Bitumen, this will serve as a ready reckoner for the officials performing tests in lab and the engineers executing the works at site.

Suggestions for further improvements, including those related to addition/deletion of any topics, may be sent to IRICEN for consideration in next revision of the book.

Pune
November, 2022

Ashok Kumar
Director General
IRICEN, Pune

PREFACE TO SECOND EDITION

The materials being used in any Civil Engineering work need to be tested, to ensure their conformance to relevant technical specifications. Proper understanding and appreciation of these tests is essential for field engineers to get these tests performed as per correct procedure and to interpret the test results. For the officials performing tests in lab also, proper appreciation of relevant test procedures is necessary to obtain reliable test results.

These tests are carried out as per relevant Indian Standard (IS Code) or Indian Railway Standard (IRS). But it is very difficult, for every field engineer to possess all these Standards/Codes and use them. To facilitate this, IRICEN had published "Handbook of Material Testing" in year 2006. But this book needed thorough revision as:

(i) Many of the relevant codes have been revised after year 2006.

(ii) For tests related to Soil and Blanket materials, separate detailed book on "Geotechnical testing for Earthwork in Railway Projects" has been published by IRICEN in year 2018.

(iii) Tests related to Reinforcement Steel and Water are to be added, as they were not included in the earlier book.

(iv) Some test procedures are to be added/elaborated as compared to the earlier book.

Therefore, to serve as a "ready reckoner" for field engineers and to serve as "laboratory manual", this revised "Handbook of Material Testing" is being published;

which covers all the tests required to be performed for Concrete & its' gradients and Bitumen. Objective of Test, Reference Standard, Equipment used for performing the Test, Observations to be recorded, Results to be presented and General Remarks (if any) have been brought out for each of the test.

The support and help rendered by Shri B. Ravi Kumar (Senior Instructor/IRICEN) and Shri Sabyasachi Roy (Senior Instructor/IRICEN), in collecting the contents, proof reading of the book and offering valuable suggestions, is appreciated.

It is felt that this book will be useful to engineers of Indian Railways. However, there is always a scope for improvement in any publication. Therefore, the suggestions for improvement are welcome from all the readers and the same may please be forwarded for incorporation in the future editions.

Pune
November, 2022

R. K. Shekhawat
Senior Professor (Projects)
IRICEN, Pune
shekhawat.rajesh@iricen.gov.in

PREFACE

While designing a structure, engineer assumes certain value of strength for each of material being used therein. When the structure is being constructed, it is the bounden duty of the field engineers to get the same validated by regular testing of material. The quality of materials used in any infrastructure does play a vital role with regard to its ultimate strength and durability in the long run. Hence, the materials need to be tested according to certain standard procedures developed by ASTM, BIS, RDSO to give a clear picture of material strength.

The "Handbook of Material Testing" is an attempt by IRICEN to bring together the standard test procedures for materials frequently used in the civil engineering infrastructure of Indian Railways. It is hoped that this will be a helpful guide to the field engineers. A list of suppliers of various testing equipments has also been provided alongwith their addresses to enable the engineers in setting up of a field laboratory, in case the need be.

Any suggestions to ameliorate the content of this handbook would be welcome.

Shiv Kumar
Director
IRICEN, Pune

ACKNOWLEDGEMENT

Strength and durability of any infrastructure is a reflection of the quality of materials used. Quality control of materials can only be ensured through certain standard test procedures designed by ASTM, BIS, RDSO and others.

The "Handbook of Material Testing" is an attempt towards this aim, of creating a collection of standard test procedures for materials, commonly used in civil engineering infrastructure on the Indian Railways. This will serve as a guide to the field engineers. The readers are advised in their interest to refer to the latest standards to avoid any omission, due to changes/amendments in the standards. The handbook also includes a list of suppliers of material testing equipments, alongwith their addresses to facilitate the setting up of a field laboratory.

The support rendered by the faculty and staff of IRICEN in this endeavour, needs mention. Shri Praveen Kumar, Professor/Computers and Shri J.M. Patekari, Chief Technical Assistant, have been of technical assistance and Shri Vijayakumaran. V, my Personal Assistant, has been extremely useful in the task of word processing.

I am thankful to Shri Shiv Kumar, Director/IRICEN for his guidance and encouragement.

R.K. Verma
Sr. Professor/Track
IRICEN, Pune

Table of Contents

Chapter - 1

TESTS ON CEMENT

The quality of cement being used is to be determined on the basis of its conformity to the performance characteristics given in the respective Indian Standard Specification for that cement. Any trade mark or any trade name indicating any special features not covered in the standard or any qualification or other special performance, characteristics sometimes claimed/ indicated on the bags or containers or in advertisements alongside the "Statutory Quality Marking" or otherwise have no relation whatsoever with the characteristics guaranteed by the Quality Marking. It is, therefore, advisable to go by the characteristics as given in the corresponding Indian Standard Specification or seek specialist advise to avoid any problem in concrete making and construction.

Following are the test typically conducted to check the performance characteristics of the cement:

(1.1) Fineness of Cement:

- (A) By 90 Micron Sieve
- (B) By Blain's Air Permeability

(1.2) Consistency of Cement

(1.3) Initial and Final Setting Time of Cement

(1.4) Soundness of Cement:

- (A) By Le-Chatelier Method
- (B) By Autoclave Method

(1.5) Strength Test of Cement

This Page
is
Intentionally
Left Blank

1.1 Fineness of Cement

Fineness of the cement represents the particle size of the cement. The fineness of cement effects the rate of hydration and, therefore, the rate of gain of strength and the rate of heat evolution. The Finer cement provides a greater surface area for the hydration process and faster strength development. But increase in fineness of the cement also increases the drying shrinkage of the concrete.

(A) By 90 Micron Sieve

1. Introduction: In this method, the fineness of cement is measured by sieving it on standard sieve (i.e. 90 micron). A sample having a known proportion of material coarser than 90 micron size is taken as per the provisions of IS 3535:1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly mixed and sieved on the 90 micron sieve. The proportion of cement with grain sizes larger than the specified mesh size is determined.

2. Reference: IS-4031(Part-I):1996 (Reaffirmed-2021) "Method of Physical Tests for Hydraulic Cement-Determination of Fineness by Dry Sieving".

3. Apparatus required

(i) **Test Sieve:** With a firm, durable, non-corrodible, cylindrical frame of 150 mm to 200 mm nominal diameter and 40 mm to 100 mm depth, fitted with 90 micron mesh sieve cloth of woven stainless steel, or other abrasion-resisting and non-corrodible metal wire. A tray fitting beneath the sieve frame and a lid fitting above it shall be provided to avoid loss of material during sieving.

(ii) **Balance:** capable of weighing up to 10 g to the nearest 10 mg.

(iii) **Brush:** A nylon or pure bristle brush, preferably with 25 to 40 mm bristle, for cleaning the sieve.

4. Material for Checking the Sieve: A Standard reference material of known sieve residue shall be used for checking the sieve. The material shall be stored in sealed, airtight containers to avoid changes in its characteristics due to absorption or deposition from the atmosphere. The containers shall be marked with the sieve residue of the reference material.

5. Procedure

5.1 Determination of the Cement Residue

(i) Agitate the sample of cement to be tested by shaking for 2 min in a stoppered jar to disperse agglomerates. Wait 2 min. Stir the resulting powder gently using a clean dry rod in order to distribute the fines throughout the cement.

(ii) Fit the tray under the sieve, weigh approximately 10 g of cement to the nearest 0.01 g and place it on the sieve, being careful to avoid loss. Disperse any agglomerates. Fit the lid over the sieve. Agitate the sieve by swirling, planetary and linear movement until no more fine material passes through it. Remove and weigh the residue. Express its mass as a percentage, R1, of the quantity first placed in the sieve to the nearest 0.1 percent. Gently brush all the fine material off the base of the sieve into the tray.

(iii) Repeat the whole procedure using a fresh 10 g sample to obtain R2. Calculate R as the mean of R1 and R2 as a percentage, expressed to the nearest 0.1 percent. If the results differ by more than 1 percent absolute, carry out a third sieving and calculate the mean of the three values.

(iv) The sieving process is carried out manually. Alternatively, a sieving machine may be used provided that it can be shown to give the same results as the manual operation.

5.2 Checking the Sieve

(i) Agitate the sample by shaking for 2 min. in a stoppered jar to disperse agglomerates. Wait 2 min. Stir the resulting powder gently using a clean dry rod in order to distribute the fines throughout the cement.

(ii) Fit the tray under the sieve. Weigh approximately 10 g of the reference material to the nearest 0.01 g and place it in the sieve, being careful to avoid loss.

(iii) Carry out the sieving procedure as in Para 5.1 including the repeat determination of residue to yield two values P1 and P2, expressed to the nearest 0.1 percent. The two values of P1 and P2 for a satisfactory sieve should differ by not more than 0.3 percent. Their mean P characterizes the state of the sieve.

(iv) Given the known residue on the 90 micron mesh of the reference material, R0, calculate R0/P as the sieve factor, F, expressed to the nearest 0.01. The residue, R, determined as in Para 5.1 shall be corrected by multiplying by F, which may have a value of 1.00 ± 0.20.

(v) Check the sieve after every 100 sievings.

NOTE: Any other checking procedure, such as the optical methods described in IS 460 (Part 3):1985 may be used. All sieves will wear slowly and consequently their sieve factor, F, will slowly change.

6. Reporting of Result: Report the value of R, to the nearest 0.1 percent, as the residue on the 90 micron sieve for the cement tested.

The standard deviation of the repeatability is about 0.2 percent and of the reproducibility is about 0.3 percent.

(B) By Blain's Air Permeability

1. Introduction: In this test the fineness of cement is represented by specific surface expressed as total surface area in cm^2/g. The samples of the cement shall be taken according to the requirements of IS 3535:1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly mixed before testing.

2. Reference: IS-4031(Part-II):1999 (Reaffirmed-2013) "Method of Physical Tests for Hydraulic Cement-Determination of Fineness by Blain's Air Permeability Method".

3. Apparatus required:

(i) Variable Flow Type Air Permeability Apparatus (Blain's Type) and the accessories: conforming to IS 5516 (Fig. 1.1.1).

(ii) Timer: with a positive starting and stopping mechanism and capable of being read to the nearest 0.2 s or better. The timer shall be accurate to 1 percent or better over time intervals up to 300 s.

Fig. 1.1.1: Blain Apparatus

Fig. 1.1.2: Pycnometer

(iii) Balances: capable of weighing about 3 g to the nearest 1 mg for the cement and about 50 g to 110 g to the nearest 10 mg for the mercury.

(iv) Standard Weights.

(v) Pycnometer or other convenient means of determining the density of cement (Fig. 1.1.2).

(vi) Manometer Liquid: The manometer shall be filled to the level of the lowest etched line with a non-volatile, non-hygroscopic liquid of low viscosity and density, such as dibutyl phthalate or light mineral oil.

(vii) Mercury of reagent grade or better.

(viii) Reference cement of known specific surface.

(ix) Light oil, to prevent formation of mercury amalgam on the inner surface of the cell.

(x) Circular discs of filter paper, having a smooth circumference adapted to the dimensions of the cell. The filter paper is of medium porosity (mean pore diameter 7 micron).

(xi) Light grease, for ensuring an airtight joint between cell and manometer and its stopcock.

4. Test Procedure

4.1 Test Condition: The laboratory in which the air permeability test is carried out shall be maintained at a temperature of 27±2°C and a relative humidity not exceeding 65 percent. All materials for test and calibration shall be at the laboratory temperature when used and shall be protected from absorption of atmospheric moisture during storage. A laboratory temperature of 20±2°C may be maintained, if desired by the purchaser.

4.2 Compacted Cement Bed

4.2.1 Basis: The compacted cement bed comprises a reproducible arrangement of cement particles with a specified volume of air included between the particles. This air volume is defined as a fraction of the total volume of the bed and is termed the porosity, e.

It follows that the volume fraction occupied by the cement particles is (1-e). If V is the total

volume of the bed, the absolute volume of cement is V(1-e) (cm^3), and the mass of cement m is ρV(1-e) (g) where ρ is the solid density of the cement particles ρ (g/cm^3).

Thus, knowing ρ, a mass of cement can be weighed to produce a desired porosity, e, in the compacted bed of total volume V. The determination of ρ is described in Para 4.2.3 and that of V in Para 4.4.1.

4.2.2 Preparation of the Samples: Agitate the sample of cement to be tested by shaking for 2 min in a stoppered jar to disperse agglomerates. Wait for 2 min. Stir the resulting powder gently using a clean dry rod in order to distribute the fines throughout the cement.

4.2.3 Determination of Density: Determine the density of the cement using a device such as a pycnometer or Le-Chatelier flask. Use a non-reactive liquid in the determination. The quantity of cement used will depend on the nature of the apparatus but shall be such that the value of ρ determined is accurate to 0.01 g/cm^3. Verify this accuracy by a repeat determination and record the mean of the two determinations to the nearest 0.01 g/cm^3 as the density.

4.2.4 Formation of the Bed: To give a cement bed of porosity e = 0.500 weigh a quantity of cement, m_1, calculated from:

$m_1 = 0.500\ \rho V$ (g)

where:

ρ is the density of the cement (g/cm^3), and

V is the volume of the cement bed (cm^3).

This mass, correctly compacted, will produce a bed of porosity 0.500. Place the perforated disc on the ledge at the bottom of the cell and place on it a new filter paper disc. Ensure that the filter

paper disc fully covers the perforated disc and is flat by pressing with a clean dry rod. Place the weighed quantity of cement, m_1, in the cell taking care to avoid loss.

Tap the cell to level the cement. Place a second new filter paper disc on the levelled cement. Insert the plunger to make contact with the filter paper disc. Press the plunger gently but firmly until the lower face of the cap is in contact with the cell. Slowly withdraw the plunger about 5 mm, rotate it through 900 and gently but firmly press the bed once again until the plunger cap is in contact with the cell. The bed is now compacted and ready for the permeability test. Slowly withdraw the plunger.

NOTE: Too rapid and vigorous pressing may change the particle size distribution and therefore change the specific surface of the bed. The maximum pressure should be that comfortably exerted by a thumb on the plunger.

4.3 Air Permeability Test

4.3.1Basis: The specific surface, S (in cm^2/g), is conveniently expressed as:

$$S = \frac{K}{\rho} X \frac{\sqrt{e^3}}{(1 - e)} X \frac{\sqrt{t}}{\sqrt{0.1\eta}}$$

Where:

K is the apparatus constant,

e is the porosity of bed,

t is the measured time (s),

ρ is the density of cement (g/cm^3), and

n is the viscosity of air at the test temperature taken from Table 1.1 (Pa.s).

With the specified porosity of e=0.5000 and temperatures:

(a) at 27±2^{0}C (in cm^2/g)

$$S = \frac{521.08\ K \text{ x}\sqrt{t}}{\rho}$$

(b) at 20±2^{0}C (in cm^2/g)

$$S = \frac{524.2\ K \text{ x}\sqrt{t}}{\rho}$$

Table 1.1: Density of Mercury D, Viscosity of Air (n) and $\sqrt{(0.1v)}$ as Function of Temperature

Temperature (^{0}C)	Mass Density of Mercury (g/cm^3)	Viscosity of Air (Pa.s)	$\sqrt{(0.1n)}$
16	13.56	0.00001788	0.001337
18	13.55	0.00001798	0.001341
20	13.55	0.00001808	0.001345
22	13.54	0.00001818	0.001348
24	13.54	0.00001828	0.001352
26	13.53	0.00001837	0.001355
28	13.53	0.00001847	0.001359
30	13.52	0.00001857	0.001363
32	13.52	0.00001867	0.001366
34	13.51	0.00001876	0.001370

NOTE: Intermediate value shall be obtained by Linear interpolation

4.3.2 Procedure

(i) Insert the conical surface of the cell into the socket at the top of the manometer, using if necessary a little light grease to ensure an airtight joint. Take care not to disturb the cement bed.

(ii) Close the top of the cylinder with a

suitable plug. Open the stopcock and with gentle aspiration raise the level of the manometer liquid to that of the highest etched line, close the stopcock and observe that the level of the manometer liquid remains constant. If it falls, remake the cell -manometer joint and check the stopcock, repeat the leakage test until the improved sealing produces a steady level of the liquid. Open the stopcock and by gentle aspiration adjust the level of the liquid, to that of the highest etched line. Close the stopcock. Remove the plug from the top of the cylinder. The manometer liquid will begin to flow. Start the timer as the liquid reaches the second etched line and stop it when the liquid reaches the third etched line. Record the time t, to the nearest 0.2s and the temperature to the nearest 10^0C.

(iii) Repeat the procedure on the same bed and record the additional values of time and temperature. Prepare a fresh bed of the same cement with a second sample following the procedure of Para 4.2.4 or, where there is little cement available, by breaking up the first bed and reforming it as in Para 4.2.4. Carry out the permeability test twice on the second bed, recording the values of time and temperature as before.

4.4 Calibration of Apparatus

4.4.1 Determination of the Bed Volume

(i) Owing to the need for clearance between the cell and the plunger, the volume of the compacted cement bed varies for each cell-plunger combination. The volume of the compacted cement bed shall be established for a given cell-plunger clearance, this volume is to be determined as follows.

a. Apply a very thin film of light mineral oil to the cell interior. Place the perforated disc on the ledge in the cell. Place two new filter paper discs on the perforated disc and ensure that each covered the base of the cell whilst lying flat by pressing with a rod.

b. Fill the cell with mercury. Remove any air bubbles with a clear dry rod. Ensure that the cell is full by pressing a glass plate on the mercury surface until it is flush with the cell top. Empty the cell, weigh the mercury to the nearest 0.01 g, m^2, and record the temperature. Remove one filter paper disc. Form a compacted cement bed by the method described in and place on it a new filter paper disc. Refill the cell with mercury, removing air bubbles and levelling the top as before. Remove the mercury, weigh it to the nearest 0.01 g, m^3, and check the temperature.

The bed volume V is given by:

$V = (m_2 - m_3)/D \quad (cm^3)$

Where, D is the density of mercury at the test temperature taken from Table 1.1

(ii) Repeat the procedure with fresh cement beds until two values of V are obtained differing by less than 0.005 cm^3. Record the mean of these two values as V.

NOTE: Care should be taken to avoid spilling or splashing the mercury and any contact between it and the operator's skin and eyes.

4.4.2 Determination of the Apparatus Constant:

From a supply of reference cement of known

specific surface prepare a compacted cement bed and measure its permeability by the procedures given in Para 4.2.2 to Para 4.2.4 and Para 4.3.2. Record the time t, and the temperature of test using the same bed; repeat twice the procedure of Para 4.3.2 and record the two further values of time and of temperature. Repeat the whole procedure on two further samples of the same reference cement. For each of the three samples calculated the means of the three times and temperatures. For each sample calculate:

$$K = \frac{S_0 \rho_0 (1-e)\sqrt{0.1\eta_0}}{\sqrt{e^3}\sqrt{t_0}}$$

Where:

S_0 is the specific surface of the reference cement (cm^2/g),

ρ_0 is the density of the reference cement (g/cm^3),

t_0 is the mean of the three measured times (s), and

n_0 is the air viscosity at the mean of the three temperatures (Pa.s) (Table 1.1)

with the specified porosity of e=0.5000

$$K = 1.414\, S_0 \rho_0 \frac{\sqrt{0.1\eta_0}}{\sqrt{t_0}}$$

Take the mean of the three values of K as the constant K for the apparatus.

4.4.3 Recalibration: Repeated use of apparatus may cause changes in the cement bed volume and in the apparatus constant (because of the wear of cell, plunger and perforated disc). These changes can be determined with the help of a so-called secondary reference cement whose specific surface has been measured.

The cement bed volume and the apparatus constant shall be recalibrated with the reference cement:

a) after 1000 tests,

b) in the case of using:

- another type of manometer fluid,
- another type of filter paper, and
- a new manometer tube; and

c) at systematic deviations of the secondary reference cement.

4.5 Special Cements: Certain cements having unusual particle size distributions and in particular, fine cements of higher strength grades may prove difficult to form into a compacted bed of porosity e=0.500 by the method of Para 4.2.4. Should thumb pressure on the plunger cap fail to bring it in contact with the top of the cell or if, after making contact and removing the pressure the plunger moves upwards, the porosity of e=0.500 shall be considered unattainable.

For such cases the porosity required for a well-compacted bed shall be determined experimentally. The mass of cement, m_4 weighed to make the bed as in Para 4.2.4 then becomes:

$m_4 = (1-e_1)\ \rho_1\ V\ (g)$

where, e_1 is the porosity determined experimentally.

4.6 Simplification of the Calculation

4.6.1 Basic Formula

The specific surface, S, of the cement under test is calculated from the formula:

$$S = \frac{\rho_0}{\rho} \times \frac{(1 - e_0)}{(1 - e)} \times \frac{\sqrt{e^3}}{\sqrt{e_0^3}} \times \frac{\sqrt{0.1\eta o}}{\sqrt{0.1\eta o}} \times \frac{\sqrt{t}}{\sqrt{t_0}} So$$

Where:

S_o is the specific surface of the reference cement (cm^2/g)

e is the porosity of the cement under test

e_0 is the porosity of the bed of reference cement

t is the measured time of cement under test(s)

t_0 is the mean of three times measured on the reference cement(s)

ρ is the density of cement under test (g/cm^3)

ρ_0 is the density of the reference cement (g/cm^3)

η is the air viscosity at the test temperature taken from Table 1.1 (Pa.s) and

η_0 is the air viscosity at the mean of three temperatures (Table 1.1) for the reference cement (Pa.s)

4.6.2 Effect of specified Porosity

Use of the specified porosity, e=0.5000 for both the reference and test cement simplifies the formula to:

$$S = \frac{\rho_0}{\rho} \frac{\sqrt{0.1\eta o}}{\sqrt{0.1\eta o}} x \frac{\sqrt{t}}{\sqrt{t_0}} So \ (cm^2/g)$$

In the case of cements requiring a porosity other than e=0.500, this formula cannot be used unless a reference cement has been tested at that porosity.

4.6.3 Effect of Density of Cement: The only remaining possibility of simplification is the elimination of density (ρ) terms. This has previously been done where the only cements for which is a value of ρ of 3.15 was assumed to supply. That assumption is known to produce errors up to 1 percent.

5. Expression of Results

(i) Where the porosity is e=0.500, the four times and temperatures resulting from the procedure of Para 4.3.2 shall be examined to check that the temperatures fall within the specified range of 27 ± 2^0C or 20 ± 2^0C. The resulting value of S, to the nearest 10 cm^2/g, shall be reported as the specific surface of the cement.

(ii) A difference of 1 percent between the means of the fineness measurements carried out on two different powder beds from one and the same sample is acceptable.

(iii) The standard deviation of the repeatability is about 50 cm^2/g and of the reproducibility is about 100 cm^2/g.

(iv) If, owing to a breakdown in control or for other reasons, the four temperatures do not lie within the specified range of 27 ± 2^0C or 20 ± 2^0C a value of S shall be reported, to the nearest 10 cm^2/g, as specific surface of the cement.

1.2 Consistency of Cement

1. Introduction: Consistency of cement is defined as minimum quantity of water added in cement to form uniform paste that provide sufficient viscosity and desirable strength for different type of structural work. Adding less or excess amount of water in cement causes reduction in its strength.

The samples of cement shall be taken as per IS:3535-1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly tested before testing. The temperature of moulding room, dry materials and water shall be maintained at 27±2^{0}C. The relative humidity of the laboratory shall be 65±5 percent.

2. Reference: IS-4031(Part-IV):1988 (Reaffirmed-2019) "Method of Physical Tests for Hydraulic Cement-Determination of Consistency of Standard Cement Paste".

3. Apparatus required:

(i) **Vicat Apparatus:** Conforming to IS 5513-1976 (Fig. 1.2.1).

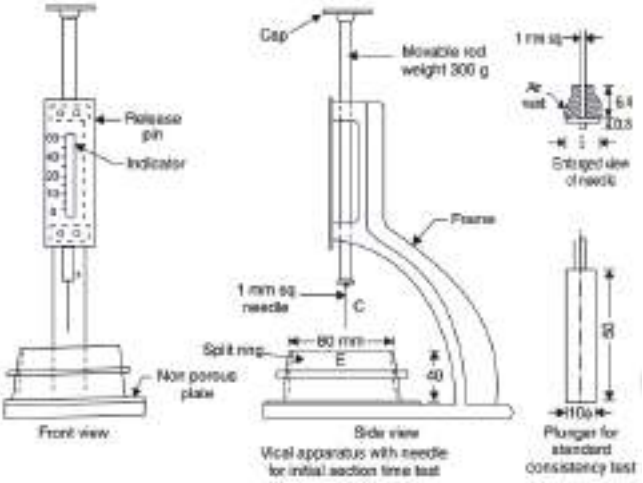


Fig. 1.2.1: Vicat Apparatus

(ii) Balance: On balance in use, the permissible variation at a load of 1000 g shall be plus or minus 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall not be greater than twice the permissible variation.

NOTE-1: The sensibility reciprocal is generally defined as the change in load required to change the position of rest of the indicating element or elements of a non-automatic indicating scale a definite amount at any load.

NOTE-2: Self-indicating balance with equivalent accuracy may also be used.

(iii) Standard Weights: The permissible variation in weights in weighing the cement shall be as prescribed in Table 1.2

Table 1.2: Permissible variation of Weights

Weight (g)	Permissible variation on weight in use, plus or minus (g)
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15

50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

(iv) Gauging Trowel: confirming to IS:10086-1982 (Fig. 1.2.2)

Fig. 1.2.2: Gauging Trowel

4. Procedure

4.1 The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger to penetrate to a point 5 to 7mm from the bottom of the Vicat mould when the cement paste is tested as described in Para 4.2 to 4.4.

4.2 Prepare a paste of weighed quantity of cement with a weighed quantity of potable or distilled water, taking care that the time of gauging is not less than 3 min., nor more than 5 min, and the gauging shall be completed before any sign of setting occurs. The gauging time shall be counted from the time of adding water to the dry cement until commencing to fill the mould. Fill the Vicat mould with this paste, the mould resting upon a non-porous plate. After completely filling the mould, smoothen the surface of the paste, making it level with the top of the mould. The mould

may be slightly shaken to expel the air.

Clean appliance shall be used for gauging. In filling the mould, the operator's hands and blade of the gauging trowel shall alone be used.

4.3 Place the test block in the mould, together with the non-porous resting plate, under the rod bearing the plunger; lower the plunger gently to touch the surface of the test block, and quickly release, allowing it to sink into the paste. This operation shall be carried out immediately after filling the mould.

4.4 Prepare trial pastes with varying percentages of water and test as described above until the amount of water necessary for making up the standard consistency as defined in 4.1 is found.

5. Interpretation and Reporting of Result: Express the amount of water as a percentage by mass of the dry cement to the first place of decimal.

1.3 Initial and Final Setting Time of Cement

1. Introduction: The initial setting time is regarded as the time elapsed between the time when the water is added to the cement, to the time that the paste starts losing its plasticity. If delayed further, cement loses its' strength. Initial setting time is an important time to know for concrete transportation, placing and curing. Initial setting time is also utilized to delay the process of hydration or hardening.

The final setting time is the time elapsed between the time when the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure. The final setting time is utilized for the safe removal of scaffolding or formwork.

The samples of cement shall be taken as per IS:3535-1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly tested before testing. The temperature of moulding room, dry materials and water shall be maintained at 27 ± 2^0C. The relative humidity of the laboratory shall be 65±5 percent. The moist closer or moist room shall be maintained at 27 ± 2^0C and at a relative humidity of not less than 90 percent.

2. Reference: IS-4031(Part-V):1988 (Reaffirmed-2019) "Method of Physical Tests for Hydraulic Cement-Determination of Initial and Final Setting Times".

3. Apparatus required

(i) Vicat Apparatus: conforming to IS 5513-1976 (Fig. 1.3.1).

(ii) Balance: On balance in use, the permissible variation at a load of 1000 g shall be plus or minus 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall not be greater than twice the permissible variation.

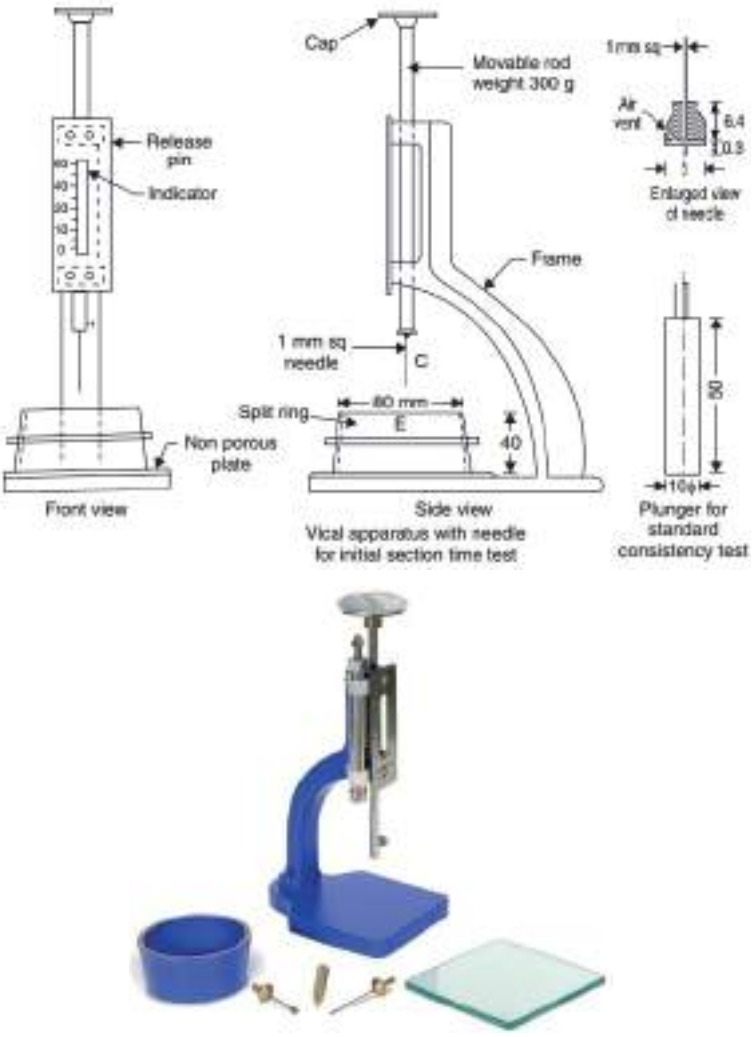


Fig. 1.3.1: Vicat Apparatus

NOTE-1: The sensibility reciprocal is generally defined as the change in load required to change the position of rest of the indicating element or elements of a non-automatic indicating scale a definite amount at

any load.

NOTE-2: Self-indicating balance with equivalent accuracy may also be used.

(iii) Standard Weights: The permissible variation in weights in weighing the cement shall be as prescribed in Table 1.3

Table 1.3: Permissible variation of Weights

Weight (g)	Permissible variation on weight in use, plus or minus (g)
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15
50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

(iv) Gauging Trowel: confirming to IS:10086-1982 (Fig. 1.3.2)

Fig. 1.3.2: Gauging Trowel

4. Procedure

4.1 Preparation of Test Block: Prepare a neat cement paste by gauging the cement with 0.85 times the water required to give a paste of standard consistency. Potable or distilled water shall be used in preparing the paste. The paste shall be gauged in the manner and under the conditions prescribed in IS:4031 (Part 4)- 1988. Start a stop-watch at the instant when water is added to the cement. Fill the Vicat mould with a cement paste gauged as above, the mould resting on a nonporous plate. Fill the mould completely and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared in the mould is the test block.

4.1.1 Immediately after moulding, place the test block in the moist closet or moist room and allow it to remain there except when determinations of time of setting are being made.

NOTE-1: Clean appliances shall be used for gauging.

NOTE-2: All the apparatus shall be free from vibration during the test.

NOTE-3: Care shall be taken to keep the needle straight.

4.2 Determination of Initial Setting Time: Place the test block confined in the mould and resting on the non-porous plate, under the rod bearing the needle; lower the needle gently until it comes in contact with the surface of the test block and quickly release, allowing it to penetrate into the test block. In the beginning, the needle will completely pierce the test block. Repeat this procedure until the needle, when brought in contact with the test block and released as described above, fails to pierce the block beyond 5.0 ± 0.5 mm measured from the bottom of the mould.

The period elapsing between the time when water is added to the cement and the time at which the

needle fails to pierce the test block to a point 5.0 ± 0.5 mm measured from the bottom of the mould shall be the initial setting time.

4.3 Determination of Final Setting Time: Replace the needle of the Vicat apparatus by the needle with an annular attachment "F". The cement shall be considered as finally set when, upon applying the needle gently to the surface of the test block, the needle makes an impression thereon, while the attachment fails to do so.

The period elapsing between the time when water is added to the cement and the time at which the needle makes an impression on the surface of test block while the attachment fails to do so shall be the final setting time.

In the event of a scum forming on the surface of the test block, use the underside of the block for the determination.

5. Interpretation and Reporting of Result: The results of initial and final setting time shall be reported to the nearest five minutes.

1.4 Soundness of Cement

1. Introduction: One of the physical characteristics of cement is its ability to resist a change in its volume or shape as it hardens or sets. The degree of restraint it provides to any volumetric alteration characterizes its soundness. It is important that the cement after setting shall not undergo any appreciable change of volume. Lack of soundness may lead to volume expansion that may induce tensile stresses, ultimately leading to cracking, which will cause serious difficulties for the durability of structures when such cement is used. The unsoundness in cement is due to the presence of excess of free lime than that could be combined with acidic oxide at the kiln. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement.

2. Sampling and Selection of Test Specimen: The samples of the cement shall be taken in accordance with the requirements of IS:3535-1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly mixed before testing.

3. Temperature and Humidity: The temperature of moulding room, dry materials and water shall be maintained at 27 ± 2°C. The relative humidity of the laboratory shall be 65 ± 5 percent. The moist closet or moist room shall be maintained at 27 ± 2°C and at a relative humidity of not less than 90 percent.

4. Reference: IS-4031(Part-III):1988 (Reaffirmed-2019) "Method of physical tests for Hydraulic cement-Determination of Soundness".

(A) By Le-Chatelier Method

1. Apparatus required

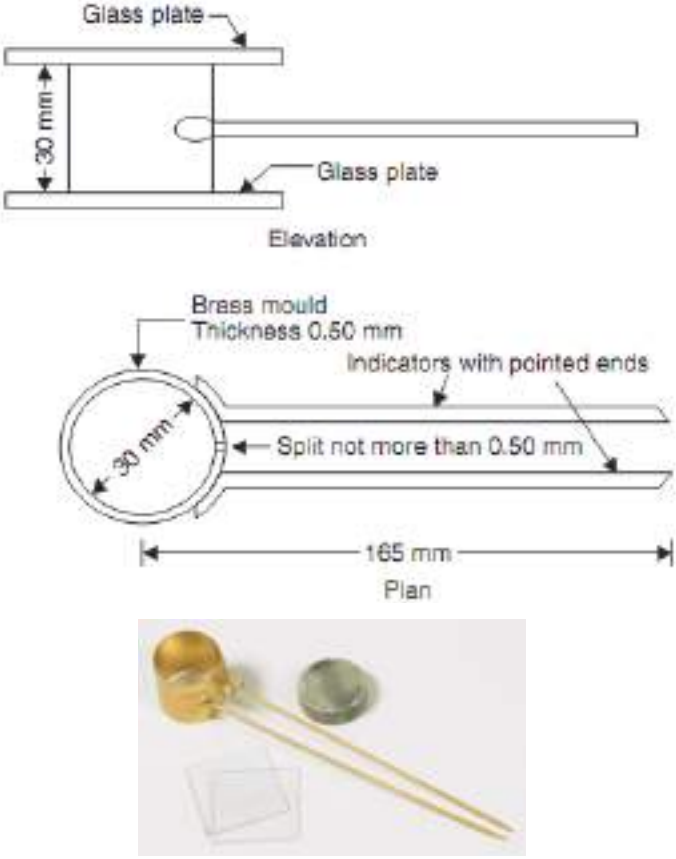


Fig. 1.4.1: Le-Chatelier Apparatus

(i) Le Chatelier Apparatus: conforming to IS 5514-1969 (Fig. 1.4.1)

(ii) Balance: On balance in use, the permissible variation at a load of 1000 g shall be plus or minus 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall not be greater than twice the permissible variation.

(iii) Weights: The permissible variation in weights in weighing the cement shall be as prescribed in Table 1.4

Table 1.4: Permissible variation of Weights

Weight (g)	Permissible variation on weight in use, plus or minus (g)
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15
50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

(iv) Water Bath: capable of containing immersed Le-Chatelier moulds with specimens and of raising their temperature from 27 ± 2°C to boiling in 27 ± 3 minutes (Fig. 1.4.2).

Fig. 1.4.2: Water Bath

NOTE-1: The sensibility reciprocal is generally defined as the change in load required to change the position of rest of the indicating element or elements of a non-automatic indicating scale a definite amount at any load.

NOTE-2: Self-indicating balance with equivalent accuracy may also be used.

2. Procedure

2.1 Place the lightly oiled mould on a lightly oiled glass sheet and fill it with cement paste formed by gauging cement with 0.78 times the water required to give a paste of standard consistency. The paste shall be gauged in the manner and under the conditions prescribed in IS:4031 (Part 4)-1988, taking care to keep the edges of the mould gently together while this operation is being performed. Cover the mould with another piece of lightly oiled glass sheet, place a small weight on this covering glass sheet and immediately submerge the whole assembly in water at a temperature of 27 ± 2^0C and keep there for 24 hours.

2.2 Measure the distance separating the indicator points to the nearest 0.5 mm. Submerge the mould again in water at the temperature prescribed above. Bring the water to boiling, with the mould kept submerged, in 25 to 30 minutes, and keep it boiling for three hours. Remove the mould from the water, allow it to cool and measure the distance between the indicator points. The difference between these two measurements indicates the expansion of the cement.

3. Interpretation and Reporting of Result: Calculate the mean of two values to the nearest 0.5 mm to represent the expansion of cement.

4. Retest: In the event of cement failing to meet the test for soundness, a retest may be made after aeration. For this purpose, spread out the cement in a layer of 75 mm thickness and store it for 7 days in an atmosphere

maintained at 27 ± 2'C and relative humidity of 50 to 80 percent. Retest this cement as described in Para 3.

(B) By Autoclave Method

1. Apparatus required

(i) Autoclave: The autoclave shall consist of a high-pressure steam boiler equipped with suitable safety device. The capacity of heating unit shall be such that with maximum load (water plus specimens) the pressure of the saturated steam in the autoclave may be raised to a gauge pressure of 2.1 MPa or to an absolute pressure of about 2.2 MPa, in 1 to 1¼ hour from the time the heat is turned on. The automatic pressure control shall be capable of maintaining the pressure at 2.1 ± 0.1 Mpa corresponding to a temperature of 215.7 ± 1.7^0C. The autoclave shall be designed to permit the pressure to drop from 2.1 MPa to less than 0.07 MPa in one hour after the heat supply has been shut off. It shall be equipped with a vent valve for allowing the escape of air during the early part of the heating period and for releasing any steam pressure remaining at the end of the one-hour cooling period. The pressure gauge shall have a nominal dial diameter of 115 mm and shall be graduated from 0 to 4.1 MPa with scale division of not more than 0.04 MPa. The error in the gauge shall not exceed plus or minus 0.02 MPa at the operating pressure of 2.1 MPa (Fig. 1.4.3).

(ii) Length Comparator: Changes in length of the test specimen shall be measured by an apparatus conforming to IS:9459-1980 (Fig. 1.4.4).

2. Preparation of Test Specimens

2.1 Preparation of Moulds: The moulds shall be thinly covered with mineral oil. After this operation, the stainless steel or non-corroding metal reference inserts with knurl heads shall be set to obtain an effective gauge length of 250 mm, care being taken to keep them clean and free from oil.

Fig. 1.4.3: Autoclave

Fig. 1.4.4: Length Comparator

2.2 Mixing Cement Paste: The standard batch of cement paste shall consist of 500 g of cement, mixed with sufficient water to give a paste of standard

consistency.

2.3 Moulding Specimens: Immediately following the completion of mixing, the test specimens shall be moulded in one or two layers, each layer being compacted with the thumb or forefinger by pressing the paste into the corners, around the reference inserts, and along the surfaces of the moulds until a homogeneous specimen is obtained. After the top layer has been compacted, the paste shall be cut off flush with the top of the mould and the surface smoothed with a few strokes of the trowel. During the operations of mixing and moulding, the hand shall be protected by rubber gloves.

2.4 Storage of Test Specimens: After the mould has been filled, it shall be immediately placed in a moist closet or a moist room. Specimens shall remain .in the moulds in the moist room for at least 24 hours. If removed from the moulds before 24 h, they shall be kept in the moist closet or moist room until tested.

3. Procedure

3.1 At 24±½ hours after moulding, the specimens shall be removed from the moist atmosphere, measured for length, and placed in the autoclave at room temperature in a rack so that the four sides of each specimen shall be exposed to saturated steam. The autoclave shall contain enough water to maintain an atmosphere of saturated steam vapour during the entire period of test. Ordinarily, 7 to 10 percent of the volume of the autoclave shall be occupied by water.

3.2 To permit air to escape from the autoclave during the early portion of the heating period, the vent valve shall be left open until steam begins to escape. The valve shall then be closed and the temperature of the autoclave shall be raised at such a rate as will bring the gauge pressure of the steam to 2.1 MPa in 1 to 1¼ hour from the time the heat is turned on. The 2.1 ± 0.1 MPa pressure shall be maintained for 3 hours. At the end of 3 hours period, the heat supply shall be

shut off and the autoclave cooled, at a rate such that the pressure will be less than 0.1 MPa at the end of the hour, and any pressure remaining shall be slow released by partially opening the vent valve until atmospheric pressure is attained. The autoclave shall then be opened and the test specimens immediately placed in water, the temperature of which is above 90^0C. The water surrounding the bars shall then be cooled at a uniform rate by adding cold water so that the temperature of the water shall be lowered to 27 ± 2^0C in 15 min. The water surrounding the specimens shall then be maintained at 27 ± 2^0C in 15 min when the specimens shall be surface dried and their lengths measured again.

4. Safety Precautions

4.1 The pressure gauge should have a maximum capacity of 4.2 MPa. This is important because with too small a capacity there is but a little length of arc in which the gauge hand may indicate pressure above the specified maximum working pressure. The operator must be sure that the gauge hand has not passed the maximum graduation on the scale.

4.2 It is well to leave the pressure gauge tested, but in any event thermometer shall always be used together with the pressure gauge, so as to provide a means of detecting any failure of the pressure gauge to operate properly and also to indicate any unusual conditions such as that resulting from loss of water from the autoclave during the test.

4.3 The automatic control shall be maintained in proper working order at all times.

4.4 The safety valve shall be set so as to relieve the pressure at about 6 to 10 percent above the maximum of 2.1 MPa specified, that is at about 2.3 MPa. The safety valve shall be tested at least twice a year, either with a gauge testing device or by adjusting the automatic controls so as to allow the autoclave to reach a pressure of about 2.3 MPa at which pressure

the safety valve shall either open or be adjusted to open. The safety valve discharge shall be directed away from the operator.

4.5 Heavy leather work gloves shall be worn to prevent burning of the hands when removing the top of the autoclave at the end of the test. The vent valve shall be directed away from the operator. When removing the autoclave lid, the lid shall be so tilted that any steam escaping from beneath the lid may be discharged away from the operator. Care shall be taken to avoid scalding by any liquid that may have been used in the autoclave well.

4.6 It shall be remembered that for many of the autoclave pressure gauges now in use the return of the gauge hand to the initial rest or starting point does not necessarily indicate zero pressure within the autoclave; there may then still remain an appreciable pressure.

4.7 A few drops of kerosene placed in the vent valve about once a week will aid in keeping the needle clean and in good-working condition.

5. Interpretation and Reporting of Result: The difference in lengths of the test specimen before and after autoclaving shall be calculated to the nearest 0.01 percent of the effective gauge length which is the length between the innermost points of the metal inserts used as reference points and shall be reported as the autoclave expansion of the cement. A contraction (negative expansion) shall be indicated by prefixing a minus sign to the percentage expansion reported.

6. Retest: In the event of cement failing to meet the test for soundness, a retest may be made after aeration. For this purpose, spread out the cement in a layer of 75 mm thickness and store it for 7 days in an atmosphere maintained at 27 ± 2'C and relative humidity of 50 to 80 percent. Retest this cement as described in Para 2 to 3.

1.5 Strength Test of Cement

1. Introduction: The compressive strength of hardened cement is one of its most important properties. Therefore, the cement is always tested for its strength at the laboratory before being used in works. Strength tests are not made on neat cement paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement.

The samples of the cement shall be taken in accordance with the requirements of IS:3535-1986 and the relevant standard specification for the type of cement being tested. The sample shall be thoroughly mixed before testing.

The temperature of moulding room, dry materials and water shall be maintained at 27 ± 2°C. The relative humidity of the laboratory shall be 65 ± 5 percent. The moist closet or moist room shall be maintained at 27 ± 2°C and at a relative humidity of not less than 90 percent.

Standard Sand to be used in the preparation of mortar cubes shall conform to IS:650-1966.

2. Reference: IS:4031 (Part-VII) : 1988 (Reaffirmed-2019) "Method of physical tests for Hydraulic Cement-Determination of Compressive Strength of Masonry Cement".

3. Apparatus required

(i) Balance: On balance in use, the permissible variation at a load of 1000 g shall be plus or minus 1.0 g. The permissible variation on new balance shall be one-half of this value. The sensibility reciprocal shall not be greater than twice the permissible variation.

NOTE-1: The sensibility reciprocal is generally defined as the change in load required to change the position of rest of the indicating element or elements of a non-automatic indicating scale a definite amount at any load.

NOTE-2: Self-indicating balance with equivalent accuracy may also be used.

(ii) Weights: The permissible variation in weights in weighing the cement shall be as prescribed in Table 1.5

Table 1.5: Permissible variation of Weights

Weight (g)	Permissible variation on weight in use, plus or minus (g)
500	0.35
300	0.30
250	0.25
200	0.20
100	0.15
50	0.10
20	0.05
10	0.04
5	0.03
2	0.02
1	0.01

(iii) Cube Moulds: of 50 mm size and accessories conforming to IS:10086-1982 (Fig. 1.5.1).

Fig. 1.5.1: Cube Mould

Fig. 1.5.2: Planetary Mixer

Fig. 1.5.3: Flow Table

(iv) Planetary Mixer: conforming to IS:10890-1984 (Fig. 1.5.2).

(v) Flow Table and Accessories: conforming to

IS:5512-1983 (Fig. 1.5.3).

(vi) Tamping Rod: conforming to 6.1 (c) of IS:10086-1982.

4. Procedure

4.1 Preparation of Moulds: The interior faces of the specimen moulds shall be thinly covered with mineral oil or light cup grease. After assembling the moulds, excessive oil or grease shall be removed from the interior faces and the top and bottom surfaces of each mould. Moulds shall then be set on plane, non-absorbent base plates that have been thinly coated with the mineral' oil, petrolatum or light cup grease.

4.2 Preparation of Mortar

(i) Clean appliances shall be used for mixing. Temperature of water and that of the test room at the time when these operations are being performed shall be 27±2°C. Potable/distilled water shall be used in preparing the cubes.

(ii) The material for each set of three specimens shall be mixed separately and shall be as follows:

1.	Masonry Cement	420 g
2.	Other Cement	440 g

(iii) The amount of water used for gauging shall be such as to produce a flow of 10±5 percent with 25 drops in 15 seconds as determined in Para 4.3

4.3 Determination of Flow

4.3.1 Trial Mixing: With dry material as specified in Para 4.2, make trial mortars with different percentages of water until specified flow is obtained. Make each trial flow test with fresh mortar. The mixing shall be done mechanically by means of mixing apparatus as specified in Para 3 (iv). Place the dry paddle and the dry bowl in the mixing position in the mixer, then

introduce the materials for batch into the bowl and mix in the following manner:

a) Place all the mixing water in the bowl;

b) Add the masonry cement to the water, then start the mixer and mix at the slow speed (140±5 rev/min) for 30 second;

c) Add the entire quantity. of sand slowly over a period of 30 s, while mixing at slow speed (140±5 rev/min);

d) Stop the mixer, change to medium speed (285±10 rev/min), and mix for 30 seconds;

e) Stop the mixer, and let the mortar stand for one and a half minutes. During the first 15 s of this interval, quickly scrap down into the batch any mortar that may have collected on the side of the bowl, then for the remainder of this interval, cover the bowl with the lid;

f) Finish by mixing for one minute at medium speed (285±10 rev/min); and

g) In cases requiring further remixing, any mortar adhering to the side of the bowl shall be quickly scraped down into the batch with the scraper prior to remixing which is to be continued till a uniform mortar is obtained.

Upon completion of the mixing, the mixing paddle shall be shaken to remove excess mortar into the mixing bowl.

4.3.2 Carefully wipe the flow-table top clean and dry and place the mould at the centre. Place about 25 mm thick layer of mortar mixed in accordance with Para 4.3.1 in the mould and tamp 20 times with the tamping rod. The tamping pressure shall be just sufficient to ensure uniform filling of the mould. Then fill the mould with mortar and tamp as specified for the first layer. Cut off the excess mortar to a plain

surface flush with the top of the mould by drawing the straight edge of a trowel (held nearly perpendicular to the mould) with a sawing motion across the top of the mould. Wipe the table top clean and dry, particularly taking care to remove any water from around the edge of the flow mould. Lift the 'mould 'away from the mortar one minute after completion of the mixing operation. Immediately drop the table through a height of 12.5 mm, 25 times in 15 seconds. The flow is the resulting increase in average base diameter of the mortar mass, measured on at least four diameters at approximately equispaced intervals expressed as a percentage of the original base diameter.

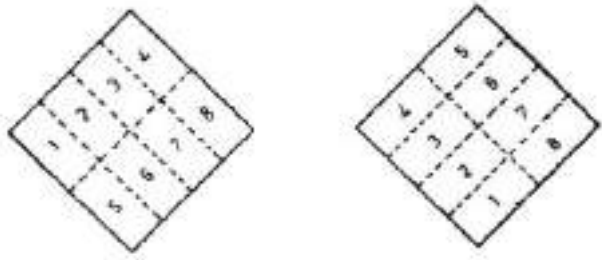
4.4 The material for moulding each batch of test specimens shall be mixed separately using the quantities of dry materials, conforming to the proportions specified in Para 4.2 and the quantity of water as determined in 4.3. Mixing of mortar shall be done mechanically as described in Para 4.3.1

4.5 Moulding of Specimens

4.5.1 Immediately following completion of the flow test, return the mortar from the flow mould to the mixing bowl. Quickly scrape down into the batch the mortar that may have collected on the side of the bowl and give the entire batch a 15 seconds mixing at medium speed (285±10 rev /min). Start moulding the specimens within a total elapsed time of not more than 2 min and 15 seconds after completion of the original mixing of the mortar batch. Place a layer of mortar about 25 mm in thickness in all the cube compartments. Tamp the mortar in each cube compartment 32 times in about 10 seconds in four rounds, each round to beat right angles to the other and consisting of eight adjoining strokes over the surface of the specimen as illustrated in Fig. 1.5.4. The tamping pressure

shall be just sufficient to ensure uniform filling of the moulds. The four rounds of tamping (32 strokes) of the mortar shall be completed in one cube before going to the next. When the tamping of the first layer in all of the cube compartments is completed, fill the compartments with the remaining mortar and then tamp as specified for the first layer. During tamping of the second layer, bring in the mortar forced out on to the tops of the moulds after each round of tamping by means of the gloved fingers and the tamper upon completion of each round and before starting the next round of tamping. On completion of the tamping, the tops of all cubes should extend slightly above the tops of the moulds. Bring in the mortar that has been forced out on to the tops of the moulds with a trowel and smooth off the cubes by drawing the flat side of the trowel, (with the leading edge slightly raised) once across the top of each cube at right angles to the length of the mould. Then for the purpose of levelling the mortar and making the mortar that protrudes above the top of the mould of more uniform thickness, draw the flat side of the trowel with the leading edge slightly raised lightly once along the length of the mould. Cut off the mortar to a plane surface flush with the top of the mould by drawing the straight edge of the trowel (held nearly perpendicular to the mould) with a sawing motion over the length of the mould.

NOTE: When a duplicate batch is to be made immediately for additional specimens the repetition of flow test may be omitted and the mortar allowed to stand in the mixing bowl for 90 seconds and then remixed for 15 seconds. at medium speed before starting the moulding of the specimens.



ROUNDS 1 AND 3 ROUNDS 2 AND 4

Fig. 1.5.4

4.6 Storage and Curing of Specimens: All test specimens, immediately after moulding and compaction, shall be kept in moulds on plane plates in a moist cabinet, maintained at a temperature of 27±2°C and the relative humidity of 90 percent or more, from 48 to 52 hours in such a manner that the upper surfaces shall be exposed to the moist air. The cubes shall then be removed from the moulds and placed in the moist cabinet for five days in such a manner as to allow free circulation of air around at least five faces of the specimens. After five days curing in moist cabinet, the cubes for 7-day compressive strength shall be removed for testing whereas the cubes for 28-day compressive strength test shall be immersed in clean water for another twenty-one days in storage tanks of non-corrosive materials.

4.7 Testing

(i) Test not less than three cubes for compressive strength for each of the curing periods of 7 and 28 days as indicated in Para 4.6, the periods being reckoned from the completion of moulding and compaction.

(ii) Testing of the cube specimens shall be carried out immediately after their removal from the moist cabinet for 7-day specimens, and from storage water for all other specimens. If more

than one specimen at a time is removed from the moist cabinet for 7-day tests, these cubes shall be covered with a damp cloth until the time of testing. If more than one specimen at a time is removed from storage water for testing, these cubes shall be placed in a pan of water at a temperature of 27±2^{O}C and of sufficient depth to completely immerse each cube until the time of testing.

(iii) The cubes shall be tested on their sides without any packing between the cube and the steel plattens of the electrically operated testing machine. One of the plattens shall be carried on a base and shall be self-adjusting. An initial loading up to one-half of the expected maximum load for specimens having expected maximum loads of more than 13,500 N may be applied at any convenient rate. Apply no initial loading to specimens having expected maximum loads of less than 13,500 N. Adjust the rate of load without interruption so that the breaking strength of the cube is reached in not less than 20 seconds and not more than 80 seconds. Make no adjustment in the control of the testing machine while a specimen is yielding rapidly immediately before failure.

5. **Interpretation and Reporting of Result:** The measured compressive strength of the cubes shall be calculated by dividing the maximum load applied to the cubes during the test by the cross-sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest 0.5 N/mm2. In determining the compressive strength, do not consider specimens that are manifestly faulty, or that give strengths differing by more than 10 percent from the average value of all test specimens. After discarding specimens or strength values, if less than two strength values are left for determining the compressive strength at any given period, a retest shall be made.

Chapter - 2

TESTS ON AGGREGATES

Aggregates shall be naturally occurring (crushed or uncrushed) stones, gravel, sand or combination thereof or produced from other than natural sources. They shall be hard, dense, strong, durable, clear and free from veins; and free form injurious amounts of disintegrated pieces, alkali, fee lime, vegetable matter and other deleterious substances as well as adherent coating.

Following are the tests typically conducted on the aggregates :

(2.1) Sieve Analysis

(2.2) Water Absorption

(2.3) Aggregate Abrasion Value

(2.4) Aggregate Impact Value

(2.5) Aggregate Crushing Value

(2.6) Silt Content

(2.7) Bulking of Sand

(2.8) Flakiness Index and Elongation Index

This Page
is
Intentionally
Left Blank

2.1 Sieve Analysis

Aggregates are important components for making concrete and properties of concrete are substantially affected by various characteristics of the aggregates used, with Size and Gradation of aggregates needing one of these characteristics. Sieve analysis is the most common method to determine the Size and Gradation of Coarse and Fine aggregates.

1. **Introduction:** This method covers the procedure for determination of particle size distribution of fine, coarse and all-in-aggregates by sieving or screening.

2. Reference: IS-2386(Part-I):1963 (Reaffirmed- 2021) "Method of Tests for Aggregates for Concrete. Part-I: Particle Size and Shape".

3. Apparatus required

3.1 Sieves: Sieves of the sizes given in Table-2.1, conforming to IS: 460-1962 Specification for Test Sieves (Revised).

Table 2.1: IS Sieves for Sieve Analysis

Type	Sieve Designation
Square hole, perforated plate	80mm, 63mm, 50mm, 40mm, 31.5mm, 25mm, 20mm, 16mm, 12.5mm, 10mm, 6.3mm, 4.75mm
Fine mesh, wire cloth	3.35mm, 2.36mm, 1.18mm, 600 micron, 300 micron, 150 micron, 75 micron

3.2 Balance: Readable and accurate to 0.1 percent of the weight of the test sample.

4. Sample: The weight of sample for Coarse and Fine aggregates shall not be less than the weight given in Table-2.2. The weight of sample for all-in-aggregates shall not be less than the weight given in Table-2.3. The sample shall be prepared from the larger sample either by quartering or by means or a sample divider.

5. Procedure:

5.1 The sample shall be air dried, at room temperature or by heating at a temperature of 100°-110°C, before weighing and sieving. The sample shall then be weighed and sieved successively on the appropriate sieves starting with the largest.

Table 2.2: Minimum Weight for Sampling (Coarse and fine Aggregates)

Maximum Size present in substantial proportion (mm)	Minimum weight of Sample for testing (kg)
63	100
50	100
40	50
25	50
20	25
16	25
12.5	12
10	6
6.3	3

Table 2.3: Minimum Weight for Sampling (All-in-aggregates)

Maximum Size present in substantial proportion (mm)	Minimum weight of Sample for testing (kg)
63	50
50	35
40 or 31.5	15
25	5
20 or 16	2

12.5	1
10	0.5
6.3	0.2
4.75	0.2
2.36	0.1

5.2 Each sieve shall be shaken separately until not more than a trace passes, but for a period of not less than two minutes. Material shall not be forced through the sieve by hand pressure, but on sieves coarser than 20mm, placing of particles is permitted. Lumps of fine material, if present, may be broken by gentle pressure with fingers against the side of the sieve. Light brushing may be done on the underside of the sieve, with a soft brush, to clear the sieve openings. Light brushing with a fine camel hair brush may be used on the 150 micron and 75 micron IS Sieves to prevent aggregation of powder and blinding of apertures.

5.3 On completion of sieving, the material retained on each sieve, together with any material cleaned from the mesh, shall be weighed.

5.4 In order to prevent binding of the sieve apertures by over-loading, the weight of the aggregate retained on the sieve at completion of the operation shall not be greater than the value given Table-2.4. This normally requires several operations on each sieve.

Table 2.4: Maximum Weight retained after Sieving

Coarse Aggregate			Fine Aggregate	
IS Sieve	Maximum Weight (kg) for		IS Sieve	Maximum weight (g) for 20 cm dia sieve
	45 cm dia. sieve	45 cm dia. sieve		
50 mm	10	4.5	2.36 mm	200
40 mm	8	3.5	1.18 mm	100
31.5 or 25 mm	6	2.5	600 micron	75
20 mm	4	2.0	300 micron	50
16 or 12.5 mm	3	1.5	150 micron	40
10 mm	2	1.0	75 micron	25
6.3 mm	1.5	0.75		
4.75 mm	1.0	0.50		
3.35 mm	-	0.30		

6. Reporting of Result: The results shall be calculated and reported as:

(a) the cumulative percentage by weight of the total sample passing each of the sieves, to the nearest whole number; or

(b) the percentage by weight of the total sample passing one sieve and retained on the next smaller sieve, to the nearest 0.1 percent.

6.1 Graphical Method of Recording Results: The results of sieve analysis may be recorded graphically on the chart for recording sieve analysis shown in Fig. 2.1.

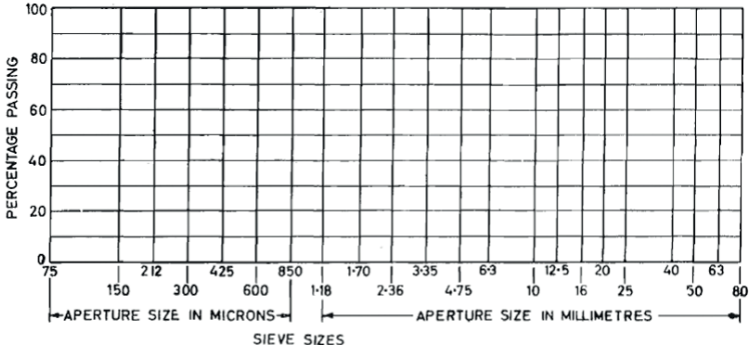


Fig. 2.1: Chart of Sieve Analysis Results

2.2 Water Absorption

1. Introduction: All aggregates have pores, which can get filled with water. The water absorption of the aggregates, along with the moisture content of the aggregates, are important factors to consider when proportioning the concrete mix, particularly the amount of water required.

2. Reference: IS-2386(Part-III):1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-III: Specific Gravity, Density, Voids, Absorption and Bulking".

(A) Method-I: Aggregate larger than 10mm

3. Apparatus required

(a) Balance: Of capacity not less than 3 kg, accurate to 0.5 g and of such a type and shape as to permit the basket containing the sample to be suspended from the beam and weighed in water.

(b) Oven: A well ventilated oven, thermostatically controlled, to maintain a temperature of 100 to 110^0C.

(c) Wire basket of not more than 6.3 mm mesh or a perforated container of convenient size, preferably chromium plated and polished, with wire hangers not thicker than one millimeter for suspending it from the balance.

(d) A stout watertight container in which the basket may be freely suspended.

(e) Two dry soft absorbent cloths each not less than 75 X 45 cm.

(f) A shallow tray of area not less than 650 cm^2.

(g) An airtight container of capacity similar to that of the basket.

4. Sample: A sample of not less than 2000 g shall be tested. Aggregates which have been artificially heated shall not normally be used. If such material is used, the fact shall be stated in the report. Two tests shall be made, and it is recommended that the two samples are not tested concurrently.

5. Procedure:

(a) The sample shall be thoroughly washed to remove finer particles and dust, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22°C and 32°C with a cover of at least 5 cm of water above the top of the basket.

(b) The entrapped air shall be removed from the sample by lifting the basket 25mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second. The basket and aggregate shall remain completely immersed during the operation and for a period of 24 ± 1/2 hours afterwards.

(c) The basket and the aggregate shall then be removed from the water and allowed to drain for a few minutes, after which the, aggregate shall be gently emptied from the basket on to one of the dry clothes.

(d) The aggregate placed on the dry cloth shall be gently surface dried with the cloth, transferring it to the second dry cloth when the first will remove no further moisture. It shall then be spread out not more than one stone deep on the second cloth, and lest exposed to the atmosphere away from direct sunlight or any other source of heat for not less than 10 minutes, or until it appears to be completely surface dry (which with some aggregates may take an hour or more). The aggregate shall be turned over at least once during this period and a gentle current of unheated air may be used after the first ten minutes to accelerate the drying of difficult aggregates. The

aggregate shall then be weighed (weight B).

(e) The aggregate shall then be placed in the oven in the shallow tray, at a temperature of 100 to 110^0C and maintained at this temperature for 24 ± 1/2 hours. It shall then be removed from the oven, cooled in the airtight container and weighed (weight C).

6. Calculations: Water absorption shall be calculated as follows:

Water absorption (percent of dry weight) = 100 (B-C)/C

7. Reporting of Result: The individual and mean results shall be reported. The size of the aggregate tested shall be stated.

(B) <u>Method-II: Aggregate between 40mm and 10mm</u>

3. Apparatus required

(a) <u>Balance:</u> Of capacity not less than 3 kg and accurate to 0.5 g, and of such a type as to permit the weighing of the vessel containing the aggregate and water.

(b) <u>Oven:</u> A well ventilated oven, thermostatically controlled to maintain a temperature of 100 to 110^0C.

(c) <u>Glass Vessel or Jar:</u> A wide mouthed glass vessel such as a jar of about 1.5 liters capacity, with a flat ground lip and a plane ground disc of plate glass to cover it, giving a virtually watertight fit.

(d) Two dry soft absorbent cloths, each not less than 75 X 45 cm.

(e) A shallow tray of area not less than 325 cm^2.

(f) An airtight container large enough to take the sample.

4. Sample: A sample of about one kilogram shall be tested. Aggregates which have been artificially heated shall not normally be used. If such material is used, the fact shall be stated in the report. Two tests shall be made,

and it is recommended that the two samples are not tested concurrently.

5. Procedure

(a) The sample shall be screened on a 10mm IS sieve, thoroughly washed to remove fine particles of dust, and immersed in distilled water in the glass vessel; it shall remain immersed at a temperature of 22 to 32°C for 24 ± 1/2 hours. Soon after immersion and again at the end of the soaking period, air entrapped in or bubbles on the surface of the aggregate shall be removed by gentle agitation. This may be achieved by rapid clockwise and anti-clockwise rotation of the vessel between the operator's hands.

(b) The vessel shall be overfilled by adding distilled water and the plane ground-glass disc slid over the mouth so as to ensure that no air is trapped in the vessel.

(c) The aggregate shall be placed on the dry cloth shall be gently surface dried with the cloth, transferring it to a second dry cloth when the first will remove no further moisture. It shall then be spread out not more than one stone deep on the second cloth, and left exposed to the atmosphere away from direct sunlight or any other source of heat for not less than 10 minutes or until it appears to be completely surface dry (which with some aggregates may take an hour or more) The aggregate shall be turned over at least once during this period and a gentle current of unheated air may be used after the first ten minutes to accelerate the drying of difficult aggregates. The aggregate shall then be weighed (weight B).

(d) The aggregate shall be placed in the oven in the shallow tray, at a temperature of 100 to 110^0C for 24 ± 1/2 hours. It shall then be cooled in airtight container and weighed (weight C).

6. Calculations: Water absorption shall be calculated as follows:

Water absorption (percent of dry weight) = 100 (C-D)/D

7. Reporting of Result: The individual and mean results shall be reported. The size of the aggregate tested shall be stated.

(C) Method-III: Aggregate smaller than 10mm

3. Apparatus required

(a) Balance: Of capacity not less than 3 kg and accurate to 0.5 g, and of such a type as to permit the weighing of the vessel containing the aggregate and water.

(b) Oven: A well ventilated oven, thermostatically controlled, to maintain a temperature of 100 to 110^0C.

(c) Vessel: Any form of vessel capable of holding 0.5 to 1 kg of material up to 10 mm in size and capable of being filled with water to a constant volume with an accuracy of ± 0.5 ml. Either of the two following vessels is suitable:

(i) A glass vessel, referred to later as a pycnometer, of about one liter capacity having a metal conical screw top with a 6-mm diameter hole at its apex. The screw top shall be watertight when it is screwed on to the jar, and, if necessary, a rubber or fibre washer shall be inserted in the joint. If such a washer is used, a mark shall be made on the jar to correspond with a mark on the screw top so that the screw is tightened to the same position every time and the volume contained by the jar is constant throughout the test. A suitable vessel can be made from a 1kg fruit preserving jar in which the glass lid normally used is replaced by a sheet metal cone as shown in Fig. 2.2.1; or

(ii) A wide-mouthed glass vessel, such as a gas jar, of about 1.25 litres capacity, with a flat ground lip and a plane ground disc of plate glass to cover it giving a virtually watertight fit.

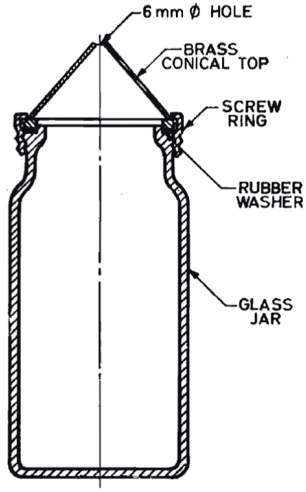


Fig. 2.2.1: Pycnometer

(d) A means of supplying a current of warm air, such as a hair drier.

(e) A tray of area not less than 325 cm^2.

(f) An airtight container large enough to take the sample.

(g) Filter papers and funnel.

4. Procedure

(a) A sample of about 1 kg for 10mm to 4.75 mm or 500 g if finer than 4.75 mm, shall be placed in the tray and covered with distilled water at a temperature of 22 to 32°C. The air entrapped in or bubbles on the surface of the aggregate shall be removed by gentle agitation with a rod. The sample shall remain immersed for 24 ± 1/2 hours.

(b) The water shall then be carefully drained from the sample, by decantation through a filter paper, any material retained being returned to the sample. The aggregate including any solid matter retained on the filter paper shall be exposed to a gentle current of warm air to evaporate surface moisture and shall

be stirred at frequent intervals to ensure uniform drying until no free surface moisture can be seen and the material just attains a 'free-running' condition. Care shall be taken to ensure that this stage is not passed. The saturated and surface-dry sample shall be weighed (weight A).

(c) The water shall then be carefully drained from the sample by decantation through a filter paper and any material retained returned to the sample. The sample shall be placed in the oven in the tray at a temperature of 100 to 110°C for 24 ± 1/2 hours, during which period it shall be stirred occasionally to facilitate drying. It shall be cooled in the air-tight container and weighed (weight D).

(d) Two tests shall be made.

5. Calculations: Water absorption shall be calculated as follows:

Water absorption (percent of dry weight) = 100 (A-D)/D

6. Reporting of Result: The individual and mean results shall be reported and the grading of the aggregate shall be stated.

2.3 Aggregate Abrasion Value

1. Introduction: The Los Angeles Abrasion Machine is used to determine the Aggregate Abrasion Value (AAV) by testing the measure of the resistance of aggregates to surface wear by abrasion.

As per IS:383, the Abrasion Value for the Aggregate to be used for concrete for wearing surfaces (such as runways, roads, pavements, tunnel lining carrying water, spillways and silting basins) shall be 30 percent maximum. For aggregates to be used in concrete other than wearing surfaces, the Abrasion Value shall be 50 percent maximum.

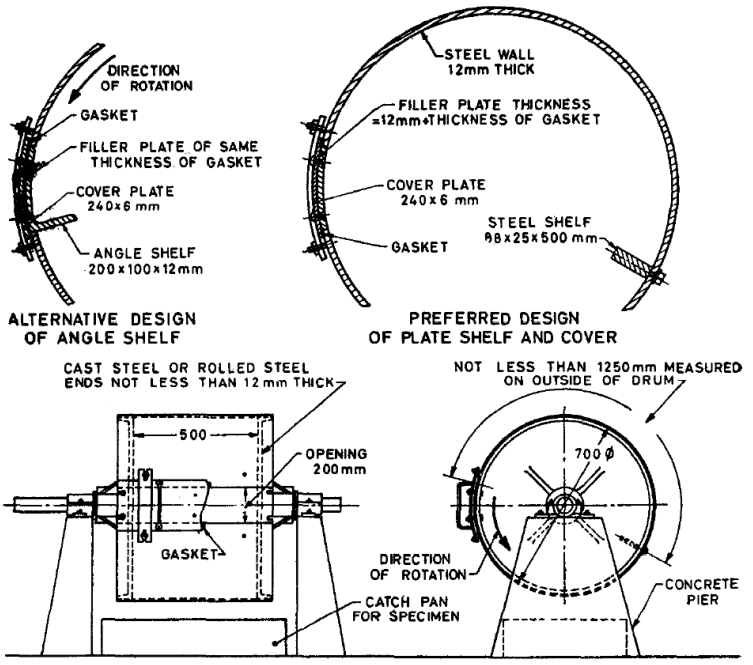
2. Reference: IS-2386(Part-IV):1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-IV: Mechanical Properties".

3. Apparatus required

3.1 Los Angeles Machine: The machine shall consist of a hollow steel cylinder, closed at both ends, having an inside diameter of 700 mm and an inside length of 500 mm. The cylinder shall be mounted on stub shafts attached to the ends of the cylinders but not entering it, and shall be mounted in such a manner that it may be rotated about its axis in a horizontal position. An opening in the cylinder shall be provided for the introduction of the test sample. The opening shall be closed dust-tight with a removable cover bolted in place. The cover shall be so designed as to maintain the cylindrical contour of the interior surface unless the shelf is so located that the charge will not fall on the cover, or come in contact with it during the test. A removable steel shelf, projecting radially 88 mm into the cylinder and extending its full length, shall be mounted along one element of the interior surface of the cylinder. The shelf shall be of such thickness and so mounted, by bolts or other approved means, as to be firm and rigid. The position of the shelf shall be such that the distance from the shelf to the opening,

measured along the circumference of the cylinder in the direction of rotation, shall be not less than 1250 mm (Fig. 2.3.1 and 2.3.2)

3.2 Abrasive Charge: The abrasive charge shall consist of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 and 445 g (Fig. 2.3.3). The abrasive charge, depending upon the grading of the sample as described in Table 2.6 shall be as given in Table 2.5.



NOTE 1 — Shaft bearing will be mounted on concrete piers or other rigid supports.

NOTE 2 — Suggested horse power for motor is not less than one.

Fig. 2.3.1: Los Angeles Abrasion Testing Machine

Fig. 2.3.2 **Fig. 2.3.3**

Table 2.5: Weight of Charge

Grading	Number of Spheres	Weight of Charge (g)
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3300 ± 25
D	6	2500 ± 25
E	12	5000 ± 25
F	12	5000 ± 25
G	13	5000 ± 25

4. Sample: The test sample shall consist of clean aggregate which has been dried in an oven at 105 to 110°C to substantially constant weight and shall conform to one of the gradings shown in Table 2.6. The grading used shall be those most nearly representing the aggregate furnished for the work.

Table 2.6: Grading of Test Samples

Sieve Size (Square Hole)		Weight in g of Test Sample for Grade						
Passing (mm)	Retained on (mm)	A	B	C	D	E	F	G
80	63					2500*		
63	50					2500*		
50	40					3000*	5000*	
40	25	1250					5000*	5000*
25	20	1250						5000*
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			
* Tolerance of ± 2% permitted								

5. Procedure

(a) The test sample and the abrasive charge shall be placed in the testing machine and the machine rotated at a speed of 20 to 33 rev/min. For gradings A, B, C and D, the machine shall be rotated for 500 revolutions; for gradings E, F and G, it shall be rotated for 1000 revolutions. At the completion of the test, the material shall be discharged from the machine and a preliminary separation of the sample made on a sieve coarser than the l.70 mm IS Sieve. The finer portion shall then be sieved on a 1.70-mm IS Sieve

(b) The material coarser than the 1.70mm IS Sieve shall be washed dried in an oven at 105 to 110°C to a substantially constant weight, and accurately weighed to the nearest gram.

6. Reporting of Result: The difference between the original weight and the final weight of the test sample shall be expressed as a percentage of the original weight of the test sample. This value shall be reported as the percentage of wear.

2.4 Aggregate Impact Value

1. Introduction: The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load. Thus, it indicates the toughness property of the ballast. This test can be used as alternate to Aggregate Crushing Value test.

As per IS:383, the Impact Value for the Aggregate to be used for concrete for wearing surfaces (such as runways, roads, pavements, tunnel lining carrying water, spillways and silting basins) shall be 30 percent maximum. For aggregates to be used in concrete other than wearing surfaces, the Crushing Value shall be 45 percent maximum.

2. Reference: IS-2386(Part-IV):1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-IV: Mechanical Properties".

3. Apparatus required

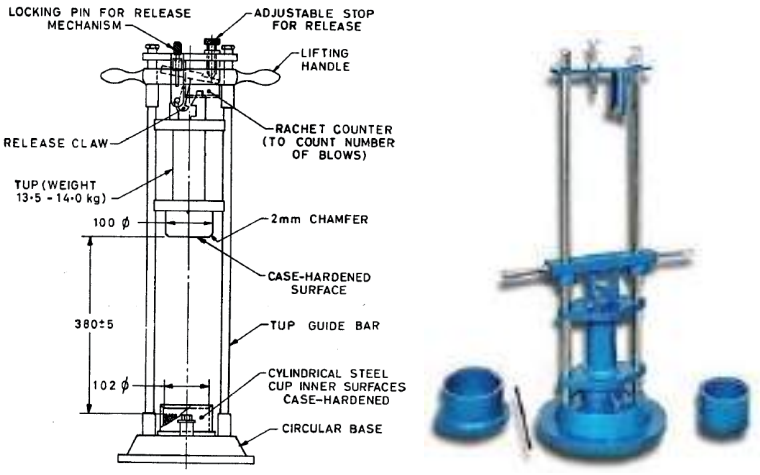


Fig. 2.4.1: Aggregate Impact Testing Machine

3.1 Aggregate Impact Testing Machine (Fig. 2.4.1) complying with the following:

(1) Total weight between 45 kg and 60 kg.

(2) Having a metal base weighing between 22 and 30kg with a plane lower surface of not less than 30m diameter, and supported on a level, plane and firm floor at least 45 cm thick. The machine shall be prevented from rocking either by fixing it to the floor or by supporting it on a level and plane metal plate cast into the surface of the floor.

(3) A cylindrical steel cup of internal diameter 102mm, internal depth 50mm and thickness not less than 6.3mm, with its inner surface case hardened, fastened at the centre of the base and easily removed for emptying.

(4) A metal hammer weighing 13.5 to 14.0kg, the lower end of which shall be cylindrical in shape, 100mm in diameter and 5cm long, with a 2mm chamfer at the lower edge, and case-hardened. It shall slide freely between vertical guides and be concentric with the cup.

(5) Means for raising the hammer and allowing it to fall freely between the vertical guides from a height of 380 ± 5.0mm on to the test sample in the cup, and means for adjusting the height of fall within 5mm.

NOTE: Some means for automatically recording the number of blows is desirable.

3.2 Sieves: The IS Sieves of sizes 12.5, 10 and 2.36mm.

3.3 Measure: A cylindrical metal measure, tared to the nearest gram, of sufficient rigidity to retain its form under rough usage, and of internal diameter 75mm and internal Depth 50mm.

3.4 Tamping Rod: A straight metal tamping rod of circular cross-section, 10mm in diameter and 230mm long, rounded at one end.

3.5 Balance: A balance of capacity not less than 500g, readable and accurate to 0.1 g.

3.6 Oven: A well-ventilated oven, thermostatically controlled to maintain a temperature of 100 to 110°C.

4. Preparation of Test Sample

4.1 The test sample shall consist of aggregate passing 12.5mm IS Sieve and retained on 10mm IS Sieve. It shall be dried in oven for four hours at a temperature of 100 to 110°C and cooled.

4.2 The measure shall be filled about one-third full with the aggregate and tamped with 25 strokes of the rounded end of the tamping rod. Further similar quantity of aggregate shall be added and a further tamping of 25 strokes given. The measure shall finally be filled to overflowing, tamped 25 times and the surplus aggregate struck off, using the tamping rod as a straight-edge. The net weight of aggregate in the measure shall be determined to the nearest gram (Weight A).

5. Test Procedure

5.1 The impact machine shall rest without wedging or packing upon the level plate, block or floor; so that it is rigid and the hammer guide columns are vertical.

5.2 The cup shall be fixed firmly in position on the base of the machine with the whole of the test sample placed in it.

5.3 The hammer shall be raised until its lower face is 380mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate. The test sample shall be subjected to a total of 15 such blows each being delivered at an interval of not less than one second.

5.4 The crushed aggregate shall then be removed from the cup and the whole of it sieved on the 2.36mm IS Sieve until no further significant amount passes in one minute. The fraction passing the sieve shall

be weighed to an accuracy of 0.1g (Weight B). The fraction retained on the sieve shall also be weighed (Weight C) and, if the total weight (B+C) is less than the initial weight (Weight A) by more than one gram, the result shall be discarded and a fresh test made. Two tests shall be made.

6. Calculations: The ratio of the weight of fines formed to the total sample weight in each test shall be expressed, as a percentage, the result being recorded to the first decimal place:

Aggregate impact value = (B / A) X 100

Where:

B = Weight of fraction passing 2.36 mm IS Sieve, and

A = Weight of oven-dried sample

7. Reporting of Result: The mean of the two results shall be reported to the nearest whole number as the aggregate impact value of the tested material.

2.5 Aggregate Crushing Value

1. Introduction: Aggregate Crushing value of aggregates indicates its strength and it is a numerical index of the strength of the coarse aggregate used in concreting, construction of roads, railway ballast and pavements etc.

As per IS:383, the Crushing Value of the Aggregate to be used for concrete for wearing surfaces (such as runways, roads, pavements, tunnel lining carrying water, spillways and silting basins) shall be 30 percent maximum. For aggregates to be used in concrete other than wearing surfaces, in case the Crushing Value of the Aggregate to be used exceeds 30 percent, then the test for "ten percent fines" should be conducted and the minimum test load for the ten percent fines should be 50 kN.

2. Reference: IS-2386(Part-IV):1963 (Reaffirmed-2021) "Methods of Test for Aggregates for Concrete. Part-IV: Mechanical Properties".

3. Apparatus required

3.1 A 15cm diameter open-ended steel cylinder, with plunger and base-plate, of the general form and dimensions shown in Fig. 2.5.1 and Table 2.7. The surfaces in contact with the aggregate shall be machined and case hardened or otherwise treated so as to have a diamond pyramid hardness number (VH) of not less than 650 VH.

3.2 A straight metal tamping rod of circular cross-section 16mm in diameter and 45 to 60cm long, rounded at one end.

3.3 A balance of capacity 3kg, readable and accurate to one gram.

3.4 IS Sieves of sizes 12.5, 10 and 2.36mm.

3.5 A compression testing machine capable of applying a load of 46 tonnes and to give a uniform rate of loading so that the maximum load is reached in 10 minutes. The machine may be used with or without a spherical seating.

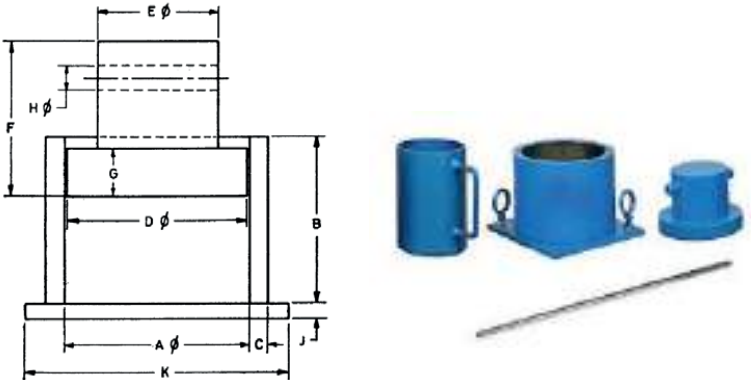


Fig. 2.5.1: Aggregate Crushing Value Test Cylinder

Table 2.7: Principal Dimensions of Test Cylinder

Letter	Dimension for	150mm Cylinder	75mm Cylinder
	Cylinder	mm	mm
A	Internal Diameter	152.0 ± 0.5	77 ± 0.5
B	Height	130 to 140	70 to 80≥
C	Wall Thickness	≥ 16	≥ 8
	Plunger		
D	Diameter of Piston	150 ± 0.5	75 ± 0.5
E	Diameter of Stem	100 to 150	50 to 75
F	Height	100 to 115	65 to 75
G	Depth of Piston	≥ 25	≥ 20
H	Diameter of Hole (nominal)	20	10
	Base Plate		
J	Thickness (nominal)	6.3	6.3
K	Side length of Square	200 to 230	110 to 115

3.6 Cylindrical metal measure of sufficient rigidity to retain its form under rough usage and of internal

diameter 11.5cm and internal height 18.0cm.

4. Preparation of Test Sample: The material for the standard test shall consist of aggregate passing 12.5mm IS Sieve and retained on 10mm IS Sieve. For other sizes, the material shall be separated on the appropriate sieves given in Table 2.8.

4.1 The aggregate shall be tested in a surface-dry condition. If dried by heating, the period of drying shall not exceed four hours, the temperature shall be 100 to 110°C and the aggregate shall be cooled to room temperature before testing.

4.2 The quantity of aggregate shall be such that the depth of material in the cylinder, after tamping, shall be 10 cm.

Table 2.8: For non-standard Size of Aggregates

Nominal Sizes (IS Sieves)		Diameter of Cylinder to be used (cm)	Size of IS Sieve for separating fines
Passing through	Retained on		
mm	mm		
25	20	15.0	4.75 mm
20	12.5	15.0	3.35 mm
10	6.3	15.0 or 7.5	1.70 mm
6.3	4.75	15.0 or 7.5	1.18 mm
4.75	3.35	15.0 or 7.5	850 microns
3.35	2.36	15.0 or 7.5	600 microns
Note: About 6.5 kg of natural aggregate is required to provide the two test samples for the 15 cm cylinder, or about 1 kg for 7.5 cm cylinder.			

4.3 The cylindrical measure may be filled in three layers of approximately equal depth, each layer being tamped 25 times with the rounded end of the tamping rod and finally levelled off, using the tamping rod as a straight-edge.

4.4 The weight of material comprising the test sample shall be determined (Weight A) and the same weight of sample shall be taken for the repeat test.

5. Test Procedure: The cylinder of the test apparatus shall be put in position on the base-plate and the test sample added in thirds, each third being subjected to 25 strokes from the tamping rod. The surface of the aggregate shall be carefully levelled and the plunger inserted so that it rests horizontally on this surface, care being taken to ensure that the plunger does not jam in the cylinder.

5.1 The apparatus, with the test sample and plunger in position, shall then be placed between the platens of the testing machine and loaded at as uniform a rate as possible so that the total load is reached in 10 minutes. The total load shall be 40 tonnes.

5.2 The load shall be released and the whole of the material removed from the cylinder and sieved on a 2.36mm IS Sieve for the standard test, or the appropriate sieve given in Table 2.8. The fraction passing the sieve shall be weighed (Weight B). In all of these operations, care shall be taken to avoid loss of the fines. Two tests shall be made.

6. Calculations: The ratio of the weight of fines formed to the total sample weight in each test shall be expressed, as a percentage, the result being recorded to the first decimal place:

Aggregate crushing value = (B / A) x 100

Where:

B = Weight of fraction passing the appropriate sieve, and

A = Weight of surface-dry sample.

7. Reporting of Results: The mean of the two results shall be reported to the nearest whole number as the "aggregate crushing value" of the size of material tested, which shall be stated.

Note-1: Aggregate larger than 12.5mm - In general, the

larger sizes of aggregate will give a higher aggregate crushing value, but the relationship between the values obtained with different sizes will vary from one aggregate to another. Particular care shall be taken with larger sizes of aggregate to ensure that the plunger does not jam in the cylinder. However, for such aggregate, a 7.5cm diameter cylinder may be used, and this has been found to give slightly higher results than the standard cylinder, so that the errors are compensating.

Note-2: Aggregate smaller than 10mm - In general, the smaller sizes of aggregate will give a lower aggregate crushing value, but the relationship between the values obtained with different sizes will vary from one aggregate to another.

Note-3: For testing aggregate smaller than 10 mm

(a) The form and dimensions of the 7.5cm cylinder shall be as shown in Fig. 2.5.1 and Table 2.7, and the surfaces shall be as for the standard cylinder.

(b) The tamping rod shall be 8mm in diameter and 30cm long, rounded at one end.

(c) The balance shall be of capacity 500g, readable and accurate to 0.2g.

(d) The IS Sieves shall be as given in Table 2.8.

(e) The compression testing machine shall be capable of applying a load of 10 tonnes uniformly in 10 minutes.

(f) The metal measure shall be 6cm in diameter and 9cm in height.

(g) The depth of material in the 7.5cm cylinder shall be 5cm after tamping.

(h) The total load applied in 10 minutes shall be 10 tonnes.

2.6 Silt Content

Silt is granular material of a size between sand and clay, with mineral origin of mainly quartz and feldspar. Excessive quantity of silt, with fine aggregates in concrete, not only reduces the bonding of cement and fine aggregates but also affects the strength and durability of concrete adversely.

1. Introduction: This method covers the procedure for determination of Clay, Fine Silt and Fine Dust in fine aggregates, by using Sedimentation Method, which is a Gravimetric Method. Gravimetric Method is a method of quantitative chemical analysis in which the constituent sought is converted into a substance (of known composition) that can be separated from the sample and weighed. The steps commonly followed in gravimetric analysis are (1) Preparation of a solution containing a known weight of the sample, (2) Separation of the desired constituent, (3) Weighing the isolated constituent, and (4) Computation of the amount of the particular constituent in the sample from the observed weight of the isolated substance.

2. Reference: IS-2386 (Part-II) : 1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-II: Estimation of Deleterious Materials and Organic Impurities".

3. Apparatus required

3.1 A watertight screw-topped glass jar of dimensions similar to a 1kg fruit preserving jar.

3.2 A device for rotating the jar about its long axis, with this axis horizontal, at a speed of 80±20 rev/min.

3.3 A sedimentation pipette of the Andreason type of approximately 25ml capacity and of the general form indicated in Fig. 2.6.1. This consists mainly of a pipette fitted at the top with a two-way tap and held

rigidly in a clamp which can be raised or lowered as required, and which is fitted with a scale from which the changes in height of the pipette can be read.

The volume of the pipette A, including the connecting bore of the tap B, is determined by filling with distilled water; by reversing the tap, the water is run out into a bottle, weighed and the volume calculated.

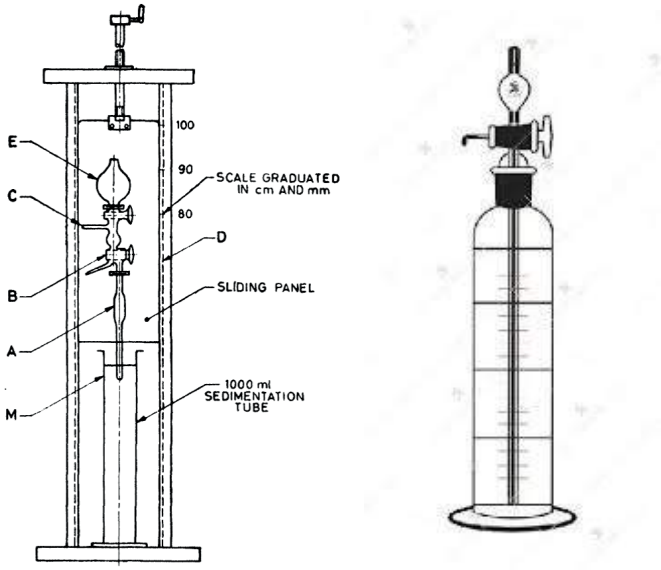


Fig. 2.7.1: Andreason type Pipette

3.4 A 1000 ml measuring cylinder.

3.5 A scale or balance of capacity not less than 10kg, readable and accurate to one gram.

3.6 A scale or balance of capacity not less than 250g, readable and accurate to 0.001g.

3.7 A well-ventilated oven, thermostatically controlled, to maintain a temperature of 100 to 110°C.

3.8 Chemicals: A solution containing 8g of sodium oxalate per litre of distilled water shall be taken. For use, this stock solution is diluted with distilled water

to one tenth (that is 100ml diluted with distilled water to one litre).

4. Test Sample: The sample for test shall be prepared from the main sample taking particular care that the test sample contains a correct proportion of the finer material. The amount of sample taken for test shall be in accordance with Table 2.9.

Table 2.9: Weight of Sample

Maximum Size present in substantial proportion	Approximate Weight of Sample for Test
(mm)	(kg)
63 to 25	6
20 to 12.5	1
10 to 6.3	0.5
4.75 or smaller	0.3

All-in aggregates shall be separated into fine and coarse fractions by sieving on a 4.75mm IS Sieve and the two samples so obtained shall be tested separately.

5. Test Procedure

5.1 Method for Fine Aggregate: Approximately 300g of the sample in the air-dry condition, passing the 4.75mm IS Sieve, shall be weighed and placed in the screw-topped glass jar, together with 300ml of the diluted sodium oxalate solution. The Tubber washer and cap shall be fixed, care being taken to ensure watertightness. The jar shall then be rotated about its long axis, with this axis horizontal, at a speed of 80±20 rev/min for a period of 15 minutes.

5.1.1 At the end of 15 minutes, the suspension shall be poured into the 1000 ml measuring cylinder and the residue washed by gentle swirling and decantation of successive 150 ml

portions of sodium oxalate solution, the washings being added to the cylinder until the volume is made up to 1000 ml. The determination shall be completed as described in Para 5.3.

5.2 Method for Coarse Aggregate: The weighed sample shall be placed in a suitable container, covered with a measured volume of sodium oxalate solution (0.8 g per litre), agitated vigorously to remove all adherent fine material and the liquid suspension transferred to the 1000 ml measuring cylinder. This process shall be repeated as necessary until all clayey material has been transferred to the cylinder. The volume shall be made up to 1000 ml with sodium oxalate solution and the determination completed as described in Para 5.3.

5.3 The suspension in the measuring cylinder shall be thoroughly mixed by inversion and the tube and contents immediately placed in position under the pipette. The pipette A shall then be gently lowered until the tip touches the surface of the liquid, and then lowered a further 10cm into the liquid. Three minutes after placing the tube in position, the pipette A and the bore of tap B shall be filled by applying gentle suction at C. A small surplus may be drawn up into the bulb between tap B and tube C, but this shall be allowed to run away and any solid matter shall be washed out with distilled water from E. The pipette shall then be removed from the measuring cylinder and its contents run into a weighed container, any adherent solids being washed into the container by distilled water from E through the tap B.

The contents of the container shall be dried at 100 to 110°C to constant weight, cooled and weighed.

6. Calculations: The proportion of fine silt and clay or fine dust shall then be calculated from the following formula:

Percentage of clay and fine silt or fine dust =

$$\frac{100}{W_1}\left(\frac{1000W_2}{V}\right) - 0.8$$

Where:

W1 = Weight in g of the original sample,

W2 = Weight in g of the dried residue,

V = Volume in ml of the pipette, and

0.8 = Weight in g of sodium oxalate in one litre of the diluted solution.

7. Reporting of Result: The clay, fine silt and fine dust content shall be reported to the nearest 0.1 percent.

2.7 Bulking of Sand

The free moisture content in the fine aggregate or sand results in bulking of its volume. The phenomenon of increase in sand volume due to the addition of water or increase of moisture content is termed as Bulking of Sand. Bulking of Sand depends on the size of the particles in the sand and also on the quantity of moisture content in sand. The volume of sand can increase from 20% to 40% due to an increase of 5 to 8% of moisture content. When concrete mix is designed, bulking of sand needs to be considered. If this is not done, the concrete designed will have an insufficient amount of sand resulting in a harsh mix.

1. Introduction: This method covers the the field method for determining the necessary adjustment for the bulking of fine aggregates.

2. Reference: IS-2386(Part-III):1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-III: Specific Gravity, Density, Voids, Absorption and Bulking".

3. Test Procedure

3.1 The procedure to be adopted may be varied, but two methods are suggested in Para 3.2 and Para 3.3. Both depend on the fact that the volume of inundated sand is the same as if the sand were dry.

3.2 Put sufficient quantity of the sand loosely into a container. Until it is about two-thirds full. Level off the top of the sand and pushing a steel rule vertically down through the sand at the middle to the bottom, measure the height. Suppose this is h cm.

3.2.1 Empty the sand out of the container into another container where none of it will be lost. Half fill the first container with water. Put back about half the sand and rod it with a steel rod, about 6mm in diameter, so that its volume is

reduced to a minimum. Then add the remainder of the sand and rod it in the same way. Smooth and level the top surface of the inundated sand and measure its depth at the middle with the steel rule. Suppose this is h' cm.

3.2.2 The percentage of bulking of the sand due to moisture shall be calculated from the formula:

$$\text{Percentage bulking} = \left(\frac{h}{h'}-1\right) \text{x } 100$$

3.3 In a 250ml measuring cylinder, pour the damp sand (consolidated by shaking) until it reaches the 200ml mark. Then fill the cylinder with water and stir the sand well. The water shall be sufficient to submerge the sand completely. It will be seen that the sand surface is now below its original level. Suppose the surface is at the mark y ml.

The percentage of bulking of the sand due to moisture shall be calculated from the formula:

$$\text{Percentage bulking} = \left(\frac{200}{y}-1\right) \text{x } 100$$

4. Reporting of Result: Report the percentage bulking of the sand to the nearest whole number.

2.8 Flakiness Index and Elongation Index

"Flakiness Index" of the coarse aggregates is the percentage by weight of particles in it, whose least dimension (i.e. thickness) is less than three-fifths of its mean dimension. "Elongation Index" of the coarse aggregates is the percentage by weight of particles in it, whose largest dimension (i.e. length) is greater than one and four-fifths times its mean dimension. Flaky and elongated aggregates may have adverse effects on concrete and bituminous mix. For instance, flaky and elongated particles tend to lower the workability of concrete mix which may impair the long-term durability. For bituminous mix, flaky particles are liable to break up and disintegrate during the pavement rolling process.

Flakiness and Elongation Index should be determined using same sample. After carrying out the Flakiness Index test, the flaky material shall be removed from the sample and the remaining material shall be used for Elongation Index test. As per IS:3838, the combined Flakiness and Elongation Index shall not exceed 40 percent; but the Engineer in-charge may relax this limit keeping in view the requirement & availability of aggregates and performance based on test on concrete.

1. Introduction: This method covers the procedure for determination of Flakiness Index and Elongation Index of coarse aggregates.

2. Reference: IS-2386(Part-I):1963 (Reaffirmed- 2021) "Method of Tests for Aggregates for Concrete. Part-I: Particle Size and Shape".

(A) <u>Determination of Flakiness Index</u>

3. Apparatus required

3.1 <u>Balance:</u> The balance shall be of sufficient capacity and sensitivity and shall have an accuracy of 0.1 percent of the weight of the test sample.

3.2 Metal Gauge: The metal gauge (called as Flakiness Index gauge or Thickness gauge also) shall be of the pattern shown in Fig. 2.8.1 and Fig. 2.8.2.

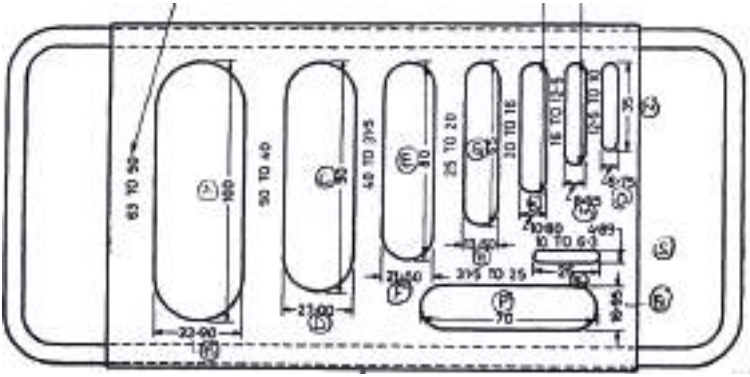


Fig. 2.8.1: Flakiness Index Gauge

Fig. 2.8.2: Flakiness Index Gauge

3.3 Sieves: IS Sieves of sizes shown in Table 2.10.

Table 2.10: Dimension of Thickness and Length Gauges

Size of Aggregates		Thickness Gauge (*) (mm)	Length Gauge ($) (mm)
Passing through IS Sieve	Retained on IS Sieve		
63 mm	50 mm	33.90	-
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	-
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10 mm	6.75	20.2
10 mm	6.3 mm	4.89	14.7
(*) This dimension is equal to 0.60 times the mean sieve size. ($) This dimension is equal to 1.80 times the mean sieve size.			

4. Sample: A quantity of aggregate shall be taken sufficient to provide the minimum number of 200 pieces of any fraction to be tested.

5. Procedure:

5.1 Sieving: The sample shall be with the sieves specified in Table 2.10.

5.2 Separation of Flaky Material: Each fraction shall be gauged in turn for thickness on a metal gauge of the pattern shown in Fig. 2.8.1 and Fig. 2.8.2 or in bulk on sieves having elongated slots. The width of the slot used in the gauge or sieve shall be of the dimensions specified in Col.3 of Table 2.10 for the appropriate size of material.

5.3 Weighing of Flaky Material: The total amount passing the gauge shall be weighed to an accuracy of at least 0.1 percent of the weight of the test sample.

6. Reporting of Result: The flakiness index is the total weight of the material passing the various thickness gauges or sieves, expressed as a percentage of the total weight of the sample gauged.

(B) Determination of Elongation Index

3. Apparatus required

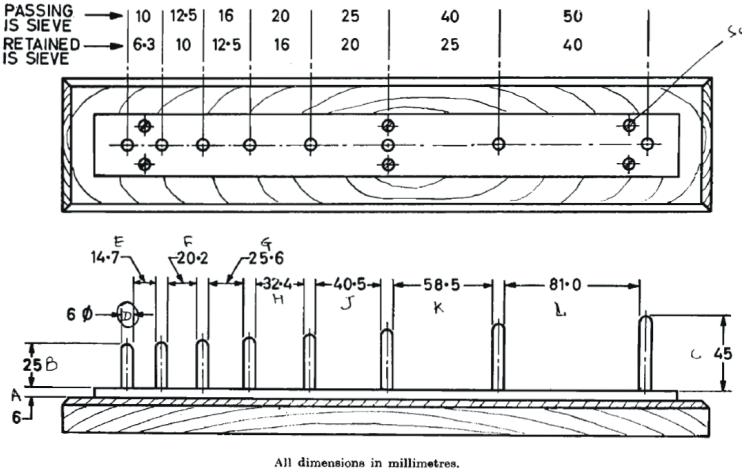


Fig. 2.8.3: Elongation Index Gauge

Fig. 2.8.4: Elongation Index Gauge

3.1 Balance: The balance shall be of sufficient capacity and sensitivity and shall have an accuracy of 0.1 percent of the weight of the test sample.

3.2 Metal Gauge: The metal gauge (called as Elongation Index gauge or Length gauge also) shall be of the pattern shown in Fig. 2.8.3 and Fig. 2.8.4.

3.3 Sieves: IS Sieves of sizes shown in Table 2.10.

4. Sample: A quantity of aggregate shall be taken sufficient to provide the minimum number of 200 pieces of any fraction to be tested.

5. Procedure:

5.1 Sieving: The sample shall be with the sieves specified in Table 2.10.

5.2 Separation of Elongated Material: Each fraction shall be gauged individually for length on a metal length gauge of the pattern shown in Fig. 2.8.3 and Fig. 2.8.4. The gauge length used shall be that specified in Col. 4 of Table 2.10 for the appropriate size of material.

5.3 Weighing of Elongated Material: The total amount retained by the length gauge shall be weighed to an accuracy of at least 0.1 percent of the weight of the test sample.

6. Reporting of Result: The elongation index is the total weight of the material passing the various length gauges, expressed as a percentage of the total weight of the sample gauged.

This Page
is
Intentionally
Left Blank

Chapter - 3

TESTS ON REINFORCEMENT STEEL

The reinforcement shall be free from loose mill scales, loose rust and coats of paint, oil, mud or any other substances which may destroy or reduce bond. Sand blasting or other treatment is recommended to clean reinforcement.

The modulus of elasticity of steel shall be taken as 200 kN/mm^2. The characteristic yield strength of different steel shall be assumed as the minimum yield stress/0.2 percent proof stress specified in the relevant Indian Standard.

Following test are typically conducted on the reinforcement steel:

(3.1) Tensile Test

(3.2) Bend Test

(3.3) Re-bend Test

This Page
is
Intentionally
Left Blank

3.1 Tensile Test

1. Introduction: The tension test subjects a specimen of the material under examination to a measured load sufficient to cause rupture. This chapter describes the method for tensile testing of metallic materials and defines the mechanical properties which can be determined at room temperature.

2. Reference: IS-1608 (Part 1): 2022 "Metallic Materials- Tensile Testing, Part-1: Method of Test at Room Temperature".

3. Definitions

3.1 Gauge length (L): length of the parallel portion of the test piece on which elongation is measured at any moment during the test.

3.1.1 Original gauge length (Lo): Length between gauge length marks on the test piece measured at room temperature before the test.

3.1.2 Final gauge length after fracture (Lu): Length between gauge length marks on the test piece measured after rupture, at room temperature, the two pieces having been carefully fitted back together so that their axes lie in a straight line.

3.2 Parallel length (Lc): Length of parallel reduced section of the test piece. The concept of parallel length is replaced by the concept of distance between grips for non-machined test pieces.

3.3 Elongation: Increase in the original gauge length (Lo) at any moment during the test.

3.4 Percentage elongation: Elongation expressed as a percentage of the original gauge length (Lo).

3.4.1 Percentage permanent elongation: Increase in the original gauge length of a test piece after removal of a specified stress, expressed as a percentage of the original gauge length.

3.4.2 Percentage elongation after fracture (A): Permanent elongation of the gauge length after fracture (Lu - Lo), expressed as a percentage of the original gauge length.

3.5 Extensometer gauge length (Le): Initial gauge length of the extensometer used for measurement of extension.

3.6 Extension: Increase in the extensometer gauge length (Le) at any moment during the test.

3.6.1 Percentage extension strain (e): Extension expressed as a percentage of the extensometer gauge length.

3.6.2 Percentage permanent extension: Increase in the extensometer gauge length, after removal of a specified stress from the test piece, expressed as a percentage of the extensometer gauge length

3.6.3 Percentage total extension at maximum force (Agt): Total extension (elastic extension plus plastic extension) at maximum force, expressed as a percentage of the extensometer gauge length.

3.6.4 Percentage plastic extension at maximum force (Ag): Plastic extension at maximum force, expressed as a percentage of the extensometer gauge length.

3.6.5 Percentage total extension at fracture (At): Total extension (elastic extension plus plastic extension) at the moment of fracture, expressed as a percentage of the extensometer gauge length.

3.7 Testing rate: Rate used during the test.

3.7.1 Strain rate (eLe): Increase of strain, measured with an extensometer, in extensometer gauge length, per time.

3.7.2 Estimated strain rate over the parallel

length (eLc): Value of the increase of strain over the parallel length of the test piece per time based on the crosshead separation rate and the parallel length of the test piece.

3.7.3 Stress rate (R): Increase of stress per time

3.8 Percentage reduction of area (Z): Maximum change in cross-sectional area which has occurred during the test (S_o - S_u), expressed as a percentage of the original cross sectional area So :

$$Z = [(S_o - S_u) / S_o] \times 100$$

3.9 Maximum force (F_m): Highest force that the test piece withstands during the test.

3.10 Stress (R): At any moment during the test, force divided by the original cross-sectional; area (S_o) of the test piece.

3.10.1 Tensile strength (R_m): Stress corresponding to the maximum force.

3.10.2 Yield strength: When the metallic material exhibits a yield phenomenon, stress corresponding to the point reached during the test at which plastic deformation occurs without any increase in the force.

3.10.2.1 Upper yield strength (R_{eH}): Maximum value of stress prior to the first decrease in force.

3.10.2.2 Lower yield strength (R_{eL}): Lowest value of stress during plastic yielding, ignoring any initial transient effects.

3.10.3 Proof strength, plastic extension (R_p): Stress at which the plastic extension is equal to a specified percentage of the extensometer gauge length.

3.10.4 Proof strength, total extension (R_t): Stress at which total extension (elastic plus plastic extension) is equal to a specified percentage of the extensometer gauge length.

3.10.5 Permanent set strength (R_r): Stress at which, after removal of force, a specified permanent elongation or extension expressed respectively as a percentage of original gauge length or extensometer gauge length, has been exceeded.

3.11 Fracture: Phenomenon which is deemed to occur when total separation of the test piece occurs.

3.12 Modulus of elasticity (E): Quotient of change of stress (ΔR) and change of percentage extension (Δe) in the range of evaluation, multiplied by 100%.

$$E = (\Delta R / \Delta e) \times 100\ \%$$

3.13 Coefficient of determination (R^2): Additional result of the linear regression which describes the quality of stress-strain curve in the evaluation range.

3.14 Standard deviation of the slope (S_m): Additional result of the linear regression which describes the difference of the stress values from the best fit line for the given extension values in the evaluation range.

4. Symbols

Table 3.1: Symbols and Designation

Symbol	Unit	Designation
Test piece		
a_0, T^a	mm	Original thickness of flat test piece or wall thickness of a tube
b_0	mm	Original width of the parallel length of a flat test piece or average width of the longitudinal strip taken from a tube or width of flat wire
d_0	mm	Original diameter of the parallel length of a circular test piece, or diameter of round wire or internal diameter of a tube
D_0	mm	Original external diameter of a tuber

L_0	mm	Original gauge length
L_0'	mm	Initial gauge length for determination of A_{wn}
L_c	mm	Parallel length
L_e	mm	Extensometer gauge length
L_t	mm	Total length of test piece
L_u	mm	Final gauge length after fracture
L_u'	mm	Final gauge length after fracture for determination of A_{wn}
S_0	mm^2	Original cross-sectional area of the parallel length
S_u	mm^2	Minimum cross-sectional area after fracture
k	-	Coefficient of proportionality
Z	%	Percentage reduction of area
Elongation		
A	%	Percentage elongation after fracture
A_{wn}	%	Percentage elongation without necking
Extension		
e	%	Extension
A_e	%	Percentage yield point extension
A_g	%	Percentage plastic extension at maximum force F_m
A_{gt}	%	Percentage total extension at maximum force F_m
A_t	%	Percentage total extension at fracture
ΔL_m	mm	Extension at maximum force
ΔL_f	mm	Extension at fracture
Rates		
e_{Le}	s^{-1}	Strain rate

e_{Lc}	s^{-1}	Estimated strain rate over the parallel length
R	MPa $^{s-1}$	Stress rate
v_c	MPa s^{-1}	Crosshead separation rate
Force		
F_m	N	Maximum force
Yield strength – Proof strength – Tensile strength		
R	MPa	Stress
R_{eH}	MPa	Upper yield strength
R_{eL}	MPa	Lower yield strength
R_m	MPa	Tensile strength
R_p	MPa	Proof strength, plastic extension
R_r	MPa	Specified permanent set strength
R_t	MPa	Proof strength, total extension
Modulus of elasticity – slope of stress-percentage extension curve		
E	GPa	Modulus of elasticity
m	MPa	Slope of the stress-percentage extension curve at a given moment of the test
m_E	MPa	Slope of the elastic part of the stress-percentage extension curve
R_1	MPa	Lower stress value
R_2	MPa	Upper stress value
e_1	%	Lower strain value
e_2	%	Upper strain value
R^2	-	Coefficient of determination
S_m	MPa	Standard deviation of the slope
$S_{m(rel)}$	%	Relative standard deviation of the slope

5. Test pieces

5.1 Shape and dimension

5.1.1 General: The shape and dimensions of the test pieces may be constrained by the shape and dimensions of the metallic product from which the test pieces are taken. The cross-section of the test pieces may be circular, square, rectangular, annular or, in special cases, some other uniform cross-section.

Preferred test pieces have a direct relationship between the original gauge length (L0) and cross-sectional area (S0), expressed by the formula $L0 = k\sqrt{S0}$, where k is a coefficient of proportionality, and are called proportional test pieces. The internationally adopted value for k is 5.65. The original gauge length shall be not less than 15mm. When the cross-sectional area of the test piece is too small for this requirement to be me with, a higher value of k (preferably 11.3) or a non-proportional test piece may be used, wherein the original gauge length is independent of the original cross-sectional area.

The test piece is usually obtained by machining a sample from the product or a pressed blank or casting. However, products of uniform cross-section (sections, bars, wires, etc.) and also as-cast test pieces (i.e. for cast iron and non-ferrous alloys) may be tested without being machined.

5.1.2 Machined test pieces: Machined test pieces shall incorporate a transition radius between the gripped ends and the parallel length if these have different dimensions.

The gripped ends may be of any shape to suit the grips of the testing machine. The axis of the test piece shall coincide with the axis of application of the force.

The parallel length, Le, or, in the case where the

test piece has no transition radii, the free length between the grips, shall always be greater than the original gauge length, L_0.

5.1.3 Unmachined test pieces: If the test piece consists of an unmachined length of the product or of an unmachined test bar, the free length between the grips shall be sufficient for gauge marks to be at a reasonable distance from the grips.

As-cast test piece shall incorporate a transition radius between the gripped ends and the parallel length. The gripped ends may be of any shape to suit the grips of the testing machine provided that they enable the center of the test piece to coincide with the axis of application of force. The parallel length, Lc, shall always be greater than the original gauge length, L_0.

5.2 Types: The main types of test pieces are defined in the Annexes-B to E of the IS 1608 (Part- 1):2022, according to the shape and type of the product, as shown in Table 3.2.

Table 3.2: Main types of Test Pieces

Dimensions in mm

Type of product				**Corresponding Annex**
Sheets – Plates - Flats	**Wire – Bars - Sections**			
				
Thickness α	**Diameter or Side**			
0.1 ≤ α < 3	-			B
-	< 4			C
α ≥ 3	≥ 4			D
Tubes				E

6. Determination of original cross-sectional area: The relevant dimensions of the test piece should be measured at sufficient cross-sections perpendicular to the longitudinal axis in the central region of the parallel length of the test piece. A minimum of three cross-sections is recommended. The original cross-sectional area (S_0) is the average cross-sectional area.

7. Original gauge length and extensometer gauge length

7.1 Choice of the original gauge length: For proportional test pieces, if the original gauge length is not equivalent to $5.65\sqrt{S_0}$, where S_0 is the original cross-sectional area of the parallel length, the symbol A should be supplemented by a subscription indicating the coefficient of proportionality used (e.g. $A_{11.3}$ indicates a percentage elongation of the gauge length $L_0 = 11.3\sqrt{S_0}$).

For non-proportional test pieces, the symbol A should be supplemented by a subscript indicating the original gauge length used, expressed in mm (e.g. A_{80} indicates percentage elongation of a gauge length L_0 of 80mm).

7.2 Marking the original gauge length: For the manual determination of the elongation after fracture A, each end of the original gauge length, L_0, shall be marked to an accuracy of ±1 %.

For proportional test pieces, the calculated value of the original gauge length may be rounded to the nearest multiple of 5mm, provided that the difference between the calculated and marked gauge length is less than 10% of L_0.

If the parallel length, Lc, is much greater than the original gauge length, as for instance, with unmachined test pieces, a series of overlapping gauge lengths may be marked.

7.3 Choice of the extensometer gauge length: For measurement of yield and proof strength

parameters, Le should span as much of the parallel length of the test piece as possible. Ideally, as a minimum, Le should be greater than 0.50L0 but less than approximately 0.90Lc. This should ensure that the extensometer detects all yielding events that occur in the test piece. Further, for measurement of parameters "at" or "after reaching" maximum force, Le should be approximately" equal to L0.

8. Conditions of testing

8.1 Setting the force zero point: The force-measuring system shall be set to zero after the testing loading train has been assembled, but before the test piece is actually gripped at both ends. Once the force zero point has been set, the force measuring system shall not be changed in any way during the test.

8.2 Method of gripping: The test pieces shall be gripped by suitable means, such as wedges, screwed grips, parallel jaw faces, or shouldered holders. Every endeavour should be mad e to ensure that test pieces are held in such a way that the force is applied as axially as possible, in order to minimize bending. In order to ensure the alignment of the test piece and grip arrangement, a preliminary force may be applied provided it does not exceed a value corresponding to 5 % of the specified or expected yield strength. A correction of the extension should be carried out to take into account the effect of the preliminary force.

8.3 Testing rates

8.3.1 General information: Unless otherwise agreed, the choice of method (A1, A2 or B) and test rates are at the discretion of the producer or the test laboratory assigned by the producer, provided that these meet the requirements of this document.

The difference between Method A and Method B is that the necessary testing speed of Method A is defined at the point of interest (e.g. $R_{p0.2}$), where

the property has to be determined, whereas, in Method B, the necessary testing speed is set in the elastic range before the property (e.g. $R_{p0.2}$) has to be determined.

8.3.2 Testing rate based on strain rate (Method A)

8.3.2.1 General: Method A is intended to minimize the variation of the test rates during the moment when strain rate sensitive parameters are determined and to minimize the measurement uncertainty of the test results. Two different types of strain rate control are described in this subclause.

- Method A1 closed loop involves the control of the strain rate itself, e_{Le} that is based on the feedback obtained from an extensometer.
- Method A2 open loop involves the control of the estimated strain rate over the parallel length, e_{Lc}, which is achieved by using the crosshead separation rate calculated by multiplying the required strain rate by the parallel length.

The testing rate shall conform to the following requirements:

(a) Unless otherwise specified, any convenient speed of testing may be used up to a stress equivalent to half of the expected yield strength. Above this range and for the determination of R_{eH}, R_p or R_t, the specified strain rate, eLe (or for Method A2 the crosshead separation rate vc), shall be applied.

In this range, to eliminate the influence of the compliance of the tensile testing machine,

the use of an extensometer measuring the extension of the test piece is necessary to have accurate control over the strain rate. For testing machines unable to control by strain rate, method A2 may be used.

(b) During discontinuous yielding, the estimated strain rate over the parallel length, e_{Lc} should be applied. In this range, it is impossible to control the strain rate using the extensometer clamped on to the test piece because local yielding can occur outside the extensometer gauge length. The required estimated strain rate over the parallel length may be maintained in this range sufficiently accurately using a constant crosshead separation rate, v_c (open loop).

$v_c = L_c \, e_{Lc}$

where:

e_{Lc} is the estimated strain rate over the parallel length

Lc is the parallel length

(c) In the range following R_p or R_t or end of yielding, e_{Le} or e_{Lc} can be used. The use of e_{Lc} is recommended to avoid any control problems which may arise if necking occurs outside the extensometer gauge length.

The strain rates specified in Para 8.3.2.2 to 8.3.2.4 shall be maintained during the determination of the relevant material property.

During switching to another strain rate or to another control mode, no discontinuities in the stress strain curve should be introduced which distort the values of R_m, A_g or A_{gt}). This effect can be reduced by a suitable gradual switch between the rates.

The testing rate used should be documented.

8.3.2.2 Strain rate for the determination of the upper yield strength, R_{eH}, or proof strength properties, R_p and R_t: The strain rate, e_{LE}, shall be kept as constant as possible up to and including the determination of R_{eH} or R_p or R_t. During the determination of these material properties, the strain rate, e_{Le}, shall be in one of the two following specified ranges.

Range 1: e_{Le} = 0.00007 s^{-1}, with a relative tolerance of ±20%.

Range 2: e_{Le} = 0.00025 s^{-1}, with a relative tolerance of ±20% (recommended, unless otherwise specified).

If the testing machine is not able to control the strain rate directly, Method A2 shall be used.

8.3.2.3 Strain rate for determination of the lower yield strength, R_{eL}, and percentage yield point extension, A_e: Following the detection of the upper yield strength, the estimated strain rate over the parallel length, eLc, shall be maintained in one of the following specified ranges until discontinuous yielding has ended:

Range 2: e_{Lc} = 0.00025 s^{-1}, with a relative tolerance of ±20% (recommended, when ReL is determined).

Range 3: 0.002 s^{-1}, with a relative tolerance of ±20%.

8.3.2.4 Strain rate for the determination of the tensile strength, Rm, percentage elongation after fracture, A, percentage

total extension at the maximum force, A_{gt}, percentage plastic extension at maximum force, A_g, and percentage reduction area, Z: After determination of the required yield/proof strength properties, the estimated strain rate over the parallel length, e_{Lc}, shall be changed to one of the following specified ranges.

Range 2: e_{Lc} = 0.00025 s^{-1}, with a relative tolerance of ±20% .

Range 3: 0.002 s^{-1}, with a relative tolerance of ±20%.

Range 4: 0.0067 s^{-1}, with a relative tolerance of ±20% (0.4 min^{-1}, with a relative tolerance of ±20%) (recommended, unless otherwise specified).

If the purpose of the tensile test is only to determine the tensile strength, then an estimated strain rate over the parallel length of the test piece according to range 3 or 4 may be applied throughout the entire test.

8.3.3 Testing rate based on stress rate (Method B)

8.3.3.1 General: The testing rates shall conform to the following requirements depending on the nature of the material. Unless otherwise specified, any convenient speed of testing may be used up to a stress equivalent to half of the specified yield strength. The testing rates above this point are specified below.

It is not the intent of Method B to maintain constant stress rate or to

control stress rate with closed loop force control while determining yield properties, but only to set the crosshead speed to achieve the target stress rate in the elastic region (see Table 3.3). When a specimen being tested begins to yield, the stressing rate decreases and can even become negative the case of a specimen with discontinuous yielding. The attempt to maintain a constant stressing rate through the yielding process requires the testing machine to operate at extremely high speeds and, in most cases, this is neither practical nor desirable.

Table 3.3: Stress Rate

Modulus of elasticity of the material, E (MPa)	Stress rate, (MPa s-1)	
	Min.	Max.
< 150000	2	20
≥ 150000	6	60

8.3.3.2 Yield and proof strengths

8.3.3.2.1 Upper yield strength, R_{eH}: The rate of separation of the crossheads of the machine shall be kept as constant as possible and within the limits corresponding to the stress rates in Table 3.3.

8.3.3.2.2 Upper and lower yield strengths, R_{eH} and R_{eL}: If only the lower yield strength is being determined, the strain rate during yield of the parallel length of the test piece shall be between 0.00025 s^{-1} and 0.0025 s^{-1}. The strain rate

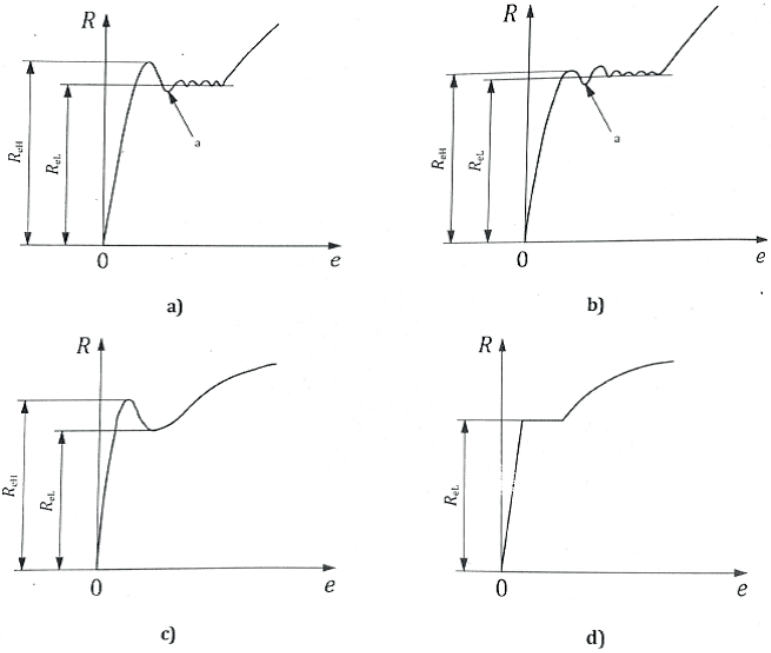
within the parallel length shall be kept as constant as possible. If this rate cannot be regulated directly, it shall be fixed by regulating the stress rate just before yield begins, the controls of the machine not being further adjusted until completion of yield.

In no case shall the stress rate in the elastic range exceed the maximum rates given in Table 3.3

8.3.3.2.3 Upper and lower yield strengths, R_{eH} and R_{eL}: If both the upper and lower yield strengths are determined during the same test, the conditions for determining the lower yield strength shall be complied with.

8.3.3.2.4 Proof strength (plastic extension) and proof strength (total extension), R_p and R_t: The crosshead separation rate of the machine shall be kept as constant as possible and within the limits corresponding to the stress rates in Table 3.3 for the elastic range. This crosshead separation rate shall be maintained up to the proof strength (plastic extension or total extension). In any case, the strain rate shall not exceed 0.0025 s-1.

8.3.3.2.5 Rate of separation: If the testing machine is not capable of measuring or controlling the strain rate, a crosshead separation rate equivalent to the stress rate given in Table 3.3 shall be used until completion of yield.



Key:

e	Percentage extension	R	Stress
R_{eH}	Upper yield strength	R_{eL}	Lower yield strength
a	Initial transient effect		

Fig. 3.1.1: Example of upper and lower yield strengths for different types of curves

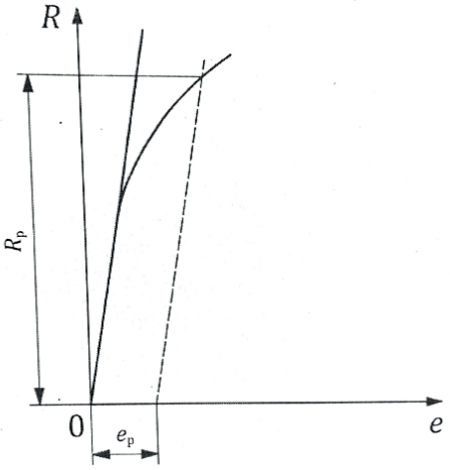
9. Determination of the upper yield strength: R_{eH} may be determined from the force-extension curve or peak load indicator and is defined as the maximum value of stress prior to the first decrease in force. The value is calculated by dividing this force by the original cross-sectional area of the test piece, S_o (see Fig. 3.1.1).

10. Determination of the lower yield strength: R_{eL} is determined from the force-extension curve and is defined as the lowest value of stress during plastic yielding, ignoring any initial transient effects. The value is calculated

by dividing this force by the original cross-sectional area of the test piece, S_o (See Figure 3.1.1).

In case of materials having yield phenomena and when Ae is not to be determined: for productivity of testing, R_{eL} may be reported as the lowest stress within the first 0.25% strain after R_{eH}, not taking into account any initial transient effect. After determining R_{eL} by this procedure, the test rate may be increased as per Para 8.3.2.4 or Para 8.3.3.3. Use of this shorter procedure should be recorded on the test report.

11. Determination of proof strength, plastic extension



Key

e Percentage extension

e_p Specified percentage plastic extension

R Stress

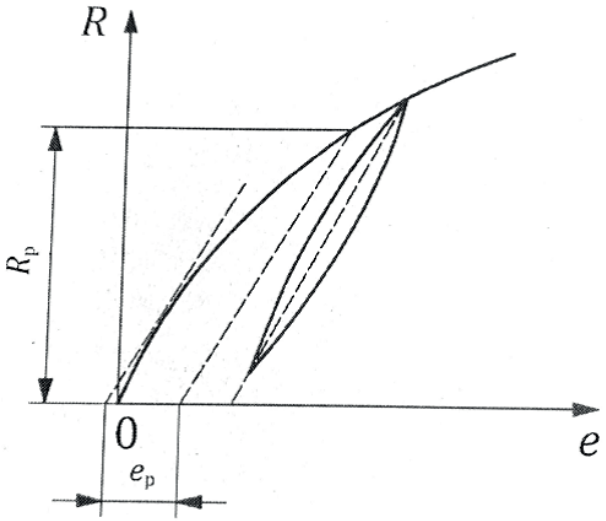
R_p Proof strength plastic extension

Fig. 3.1.2: Proof strength, plastic extension, Rp

11.1 R_p is determined from the force-extension curve by drawing a line parallel to the linear portion of the curve and at a distance from it equivalent

to the prescribed plastic percentage extension, e.g. 0.2%. The point at which this line intersects the curve gives the force corresponding to the desired proof strength plastic extension. The latter is obtained by dividing this force by the original cross-sectional area of the test piece, S_o (see Fig. 3.1.2).

If the straight portion of the force-extension curve is not clearly defined, thereby preventing drawing the parallel line with sufficient precision, the following procedure is recommended (see Fig. 3.1.3):



Key

e Percentage extension

e_p Specified percentage plastic extension

R Stress

R_p Proof strength, plastic extension

Fig. 3.1.3: Proof strength, plastic extension, Rp, alternative procedure

When the presumed proof strength has been exceeded, the force is reduced to a value equal to about 10% of the force obtained. The force is then increased again until it exceeds the value obtained originally. To determine the desired proof strength, a line is drawn through the hysteresis loop. A line is then drawn parallel to this line, at a distance from the corrected origin of the curve, measured along the abscissa, equal to the prescribed plastic percentage extension. The intersection of this parallel line and the force-extension curve gives the force corresponding to the proof strength. The value is calculated by dividing this force by the original cross-sectional area of the test piece, So (see Fig. 3.1.3).

NOTE: Several methods can be used to define the corrected origin of the force-extension curve. One of these is to construct a line parallel to that determined by the hysteresis loop so that it is tangential to the force-extension curve. The point where this line crosses the abscissa is the corrected origin of the force-extension curve (see Fig. 3.1.3).

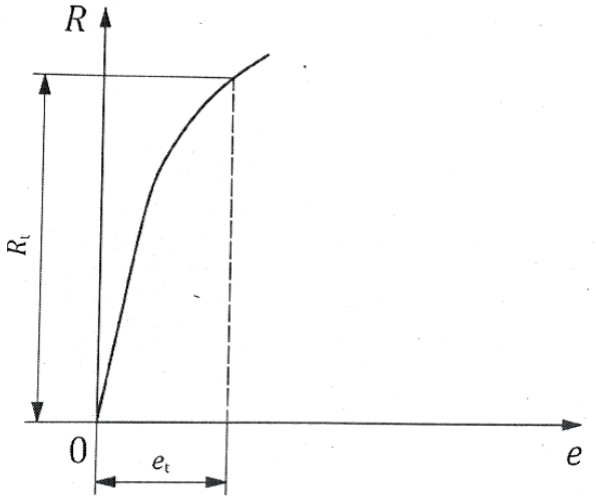
Care should be taken to ensure that the hysteresis is performed after the final proof strength has passed, but at as low an extension as possible, as performing it at excessive extensions will have an adverse effect on the slope obtained.

11.2 The property may be obtained without plotting the force-extension curve by using automatic devices (microprocessor, etc.).

12. Determination of proof strength, total extension

12.1 R_t is determined on the force-extension curve, taking Para 8.2 into consideration, by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage extension. The point at which this line intersects the curve gives the force corresponding to

the desired proof strength. The value is calculated by dividing this force by the original cross-sectional area of the test piece, S_o (see Fig. 3.1.4).



Key

e Percentage extension

e_t Percentage total extension

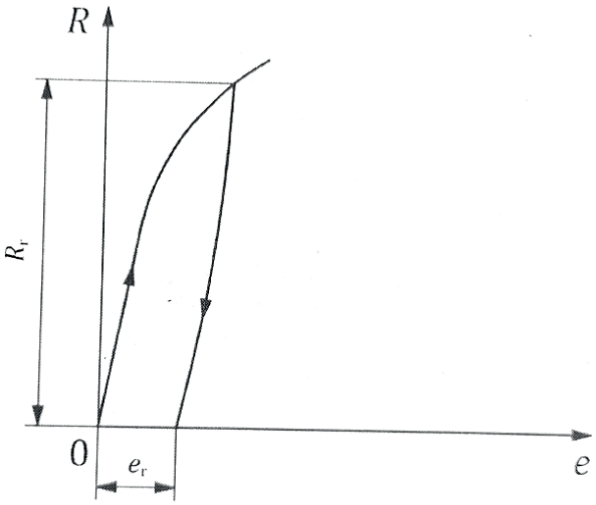
R Stress

R_t Proof strength, total extension

Fig. 3.1.4: Proof strength, total extension, Rt

12.2 The property may be obtained without plotting the force-extension curve by using automatic devices.

13. Method of verification of permanent set strength: The test piece is subjected to a force corresponding to the specified stress for 10 s to 12 s. This force is obtained by multiplying the specified stress by the original cross-sectional area of the test piece, So. After removing the force, it is then confirmed that the permanent set extension or elongation is not more than the percentage specified for the original gauge length; see Fig. 3.1.5.



Key

e Percentage elongation or percentage extension

e_r Percentage permanent set extension or elongation

R Stress

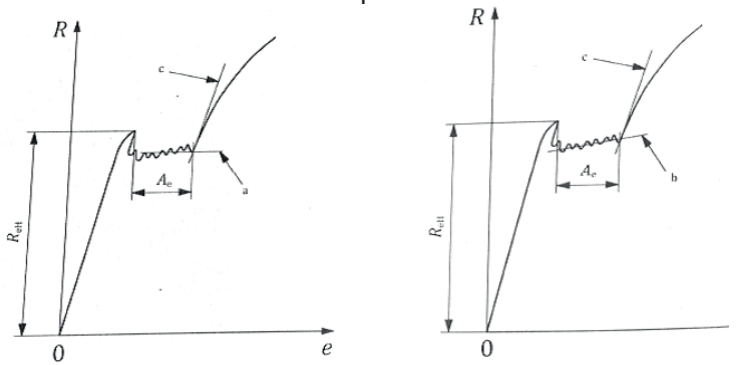
R_r Specified permanent set strength

Fig. 3.1.5: Permanent set strength, Rr

Note: This is a pass/fail test, which is not normally performed as a part of the standard tensile test. The stress applied to the test piece and the permissible set extension or elongation are specified either by the product specification or the requester of the test. Example: Reporting "$R_{r0.5}$ = 750 MPa Pass" indicates that a stress of 750 MPa was applied to the test piece and the resulting permanent set was less than or equal to 0.5%.

14. Determination of the percentage yield point extension: For materials that exhibit discontinuous yielding, A_e is determined from the force-extension curve by subtracting the extension ReH from the extension at

the start of uniform work-hardening. The extension at the start of uniform work-hardening is defined by the intersection of a horizontal line through the last local minimum point, or a regression line through the range of yielding, prior to uniform work-hardening and a line corresponding to the highest slope of the curve occurring at the start of uniform work-hardening (see Fig. 3.1.6). It is expressed as a percentage of the extensometer gauge length, L_e. The method used (see Fig. 3.1.6a or b) should be documented in the test report.



(a) Horizontal line method (b) Regression method

Key

A_e Percentage yield point extension

e Percentage extension

R Stress

R_{eH} Upper yield strength

a Horizontal line through the last local minimum, prior to uniform work-hardening

b Regression line through the range of yielding, prior to uniform work-hardening

c Line corresponding to the highest slope of the curve occurring at the start of uniform work-hardening

Fig. 3.1.6: Different evaluation methods for percentage yield point extension, Ae

15. Determination of the percentage plastic extension at maximum force: The method consists of determining the extension at maximum force on the force-extension curve obtained with an extensometer and subtracting the elastic strain. Calculate the percentage plastic extension at maximum force, A_g, from the following formula:

$$A_g = [(\Delta L_m / L_e) - (R_m / m_E)] \times 100$$

Where:

ΔL_m is the extension at maximum force

L_e is the extensometer gauge length

R_m is the tensile strength

m_E is slope of elastic part of stress-percentage extension curve

Key

A Percentage elongation after fracture (determined from the extensometer signal or directly from the test piece)

A_g Percentage plastic extension at maximum force

A_{gt} Percentage total extension at maximum force

A_t Percentage total extension at fracture

e Percentage extension

m_E Slope of the elastic part of the stress-percentage elongation curve

R Stress

R_m Tensile strength

Δe Plateau extent (for determination of A_g, see Para 15, for determination of A_{gt}, see Para 16)

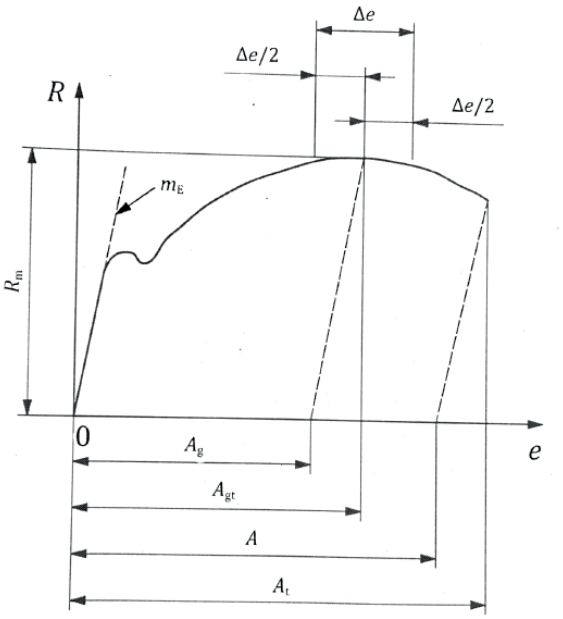


Fig. 3.1.7: Definition of extension

NOTE: For materials which exhibit a plateau at maximum force, the percentage plastic extension at maximum force is the extension at the mid-point of the plateau (see Fig. 3.1.7).

16. Determination of the percentage total extension at maximum force: The method consists of determining the extension at maximum force on the force-extension curve obtained with an extensometer. Calculate the percentage total extension at maximum force, Agt, from the following formula:

$A_{gt} = (\Delta L_m / L_e) \times 100$

Where:

ΔL_m is the extension at maximum force

L_e is the extensometer gauge length

NOTE: For materials which exhibit a plateau at maximum force, the percentage plastic extension at maximum force is the extension at the mid-point of the plateau (see Fig. 3.1.7).

17. Determination of the percentage total extension at fracture: The method consists of determining the extension at fracture on the force-extension curve obtained with an extensometer. Calculate the percentage total elongation at fracture, At, from the following formula:

$A_t = (\Delta L_f / L_e) \times 100$

Where:

ΔL_f is the extension at fracture

L_e is the extensometer gauge length

18. Determination of the percentage elongation after fracture

18.1 Percentage elongation after fracture shall be determined in accordance with the definition given in Para 3.4.2. For this purpose, the broken pieces of the test piece shall be carefully fitted back together so that their axes lie in a straight line. Special precautions shall be taken to ensure proper contact between the broken parts of the test piece when measuring the final gauge length. This is particularly important for test pieces of small cross-section and test pieces having low elongation values.

Calculate the percentage elongation after fracture, A, from the following formula:

$A = [(L_u - L_o) / L_o] \times 100$

Where:

L_u is the final gauge length after fracture

L_o is the original gauge length

Elongation after fracture, $L_u - L_o$, shall be determined to the nearest 0.25 mm or better using a measuring device with sufficient resolution.

If the specified minimum percentage elongation is less than 5%, it is recommended that special precautions be taken (as given in App. H of the IS:1608, Part 1). The result of this determination is valid only if the distance between the fracture and the nearest gauge mark is not less than $L_0/3$. However, the percentage elongation after fracture can be regarded as valid, irrespective of the position of the fracture, if the percentage elongation after fracture is equal to or greater than the specified value. To avoid having to reject test pieces where the distance between the fracture and the next gauge mark is less than $L_0/3$, the method described in Annex. I of IS:1608 (Part 1) may be used by agreement.

18.2 When extension at fracture is measured using an extensometer, it is not necessary to mark the gauge lengths. The elongation is measured as the total extension at fracture, and it is therefore necessary to deduct the elastic extension in order to obtain percentage elongation after fracture. To obtain comparable values with the manual method, additional adjustments can be applied (e.g. high enough dynamic and frequency bandwidth of the extensometer) (see A 2.2 of IS:1608, Part 1).

The result of this determination is valid only if fracture and localized extension (necking) occur within the extensometer gauge length, L_e. The percentage elongation after fracture can be regarded as valid regardless of the position of the fracture cross-section if the percentage elongation after fracture is equal to or greater than the specified value. If the product standard specifies the determination of percentage elongation after fracture for a given gauge length, the extensometer gauge length should be equal to this length.

19. determination of percentage reduction of area: Percentage reduction of area shall be determined in accordance with the definition given in Para 3.8. If

necessary, the broken pieces of the test piece shall be carefully fitted back together so that their axes lie in a straight line.

For round test pieces, the measurements at the minimum reduced section should be made in 2 planes at 90° to each other and the average used for the calculation of Z. Care should be taken to ensure that the fracture surfaces are not displaced when making the readings. Calculate the percentage reduction of area, Z, from the following formula:

$$Z = [(S_o - S_u) / S_o] \times 100$$

Where:

S_0 is the original cross-sectional area of the parallel length

S_u is the minimum cross-sectional area after fracture

It is recommended to measure Su to an accuracy of ±2%. Measuring Su with an accuracy of ±2% on small diameter round test pieces, or test pieces with other cross-sectional geometries, may not be possible.

20. Test report: The test report shall contain at least the following information, unless otherwise agreed by the parties concerned:

(a) Reference to this document, extended with the test condition information specified in Para 8.3.4;

(b) Identification of the test piece;

(c) Specified material, if known;

(d) Type of test piece;

(e) Location and direction of sampling of test pieces, if known;

(f) Testing control mode(s) and testing range(s) (see Para 8.3.1) if different from the recommended methods and values given in Para 8.3.2 and Para 8.3.3;

(g) Test results: Results should be rounded to the following precisions or better, if not otherwise specified in product standards: strength values, in MPa, to the nearest whole number;

- Percentage yield point extension values, Ae, to the nearest 0.1%;
- All other percentage extension and elongation values to the nearest 0.5%;
- Percentage reduction of area, Z, to the nearest 1%.

3.2 Bend Test

1. Introduction: The steel bars are bent to form a specific shape such as shear stirrups, L-bars, and other shapes, prior to installation into concrete structure. Therefore, steel should have sufficient ductility to enable the bending of reinforcement bars without affecting the steel strength. Hence, the bending test of reinforcement steel is performed to verify the steel ductility and to ensure that no fracture or cracks occur during the bending.

This chapter specifies a method for determining the ability of metallic materials to undergo plastic deformation in bending. It applies, to test pieces taken from metallic products as specified in the relevant product standard. It is not applicable to certain materials and/or products, for example tubes in full section or welded joints, for which other standards exist.

2. Reference: IS-1599: 2019 "Metallic Materials – Bend Test".

3. Principle: The bend test consists of submitting a test piece of round, square, rectangular, or polygonal cross section to plastic deformation by bending, without changing the direction of loading, until a specified angle of bend is reached.

The axes of the two legs of the test piece remain in a plane perpendicular to the axis of bending. In the case of 180O bend, the two lateral surfaces may, depending on the requirements of the product standard, lie flat against each other or may be parallel at a specified distance, an insert being used to control this distance.

4. Symbols and Designations

Symbol	Designation	Unit
a	Thickness or Diameter of Test piece (or diameter of the inscribed circle for pieces of polygon cross-section)	mm
b	Width of the Test piece	mm
L	Length of Test Piece	mm
l	Distance between supports	mm
D	Diameter of Mandrel	Mm
α	Angle of Bend	Degree
r	Internal radius of bend portion of test piece after bending	mm
f	Displacement of the former	Mm
c	Distance between the plane including the horizontal axis of supports and the central axis of the rounded portion of the former before test	mm
p	Distance between the vertical planes including the central axis of supports and the vertical plane including the central axis of the former	mm
R	Radius of the supports	mm

5. Test equipment

5.1 General: The bend test shall be carried out in testing machines or presses equipped with the following devices:

(a) Bending device with two supports and a former, as shown in Fig. 3.2.1

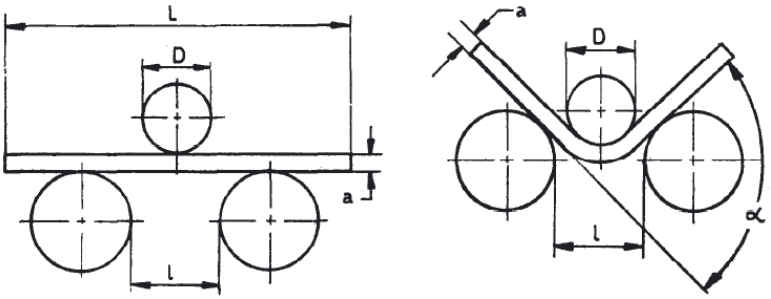


Fig. 3.2.1: Bending device with two supports and s former

(b) Bending device with a V-block and a former, as shown in Fig. 3.2.2.

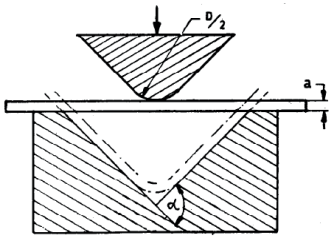


Fig. 3.2.2: Bending device with a V-block and a former

(c) Bending device with a clamp and a former, as shown in Fig. 3.2.3

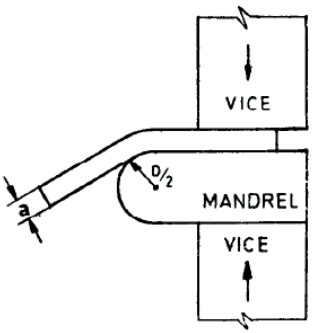


Fig. 3.2.3: Bending device with a clamp

5.2 Bending device with supports and a former

5.2.1 The length of the supports and the width of the former shall be greater than the width or diameter of the test piece. The diameter of the former is determined by the product standard. The test piece supports and former shall be of sufficient hardness (Fig. 3.2.1)

5.2.2 Unless otherwise specified, the distance between the supports, "l", shall be:

$$l = (D + 3a) \pm a/2$$

and shall not change during the bend test

NOTE: When the distance between the supports (l) is specified smaller than or equal to D + 2a, it can result in clamping during the test and stretch forming of the test piece.

5.3 Bending device with a V-block: The tapered surfaces of the V-block shall form an angle of $180^0 - \alpha$ (see Fig. 3.2.2). The angle α is specified in the relevant standard. The edges of the V-block shall be rounded to a radius between 1 and 10 times the thickness of the test piece and shall be of sufficient hardness.

5.4 Bending device with a clamp: The device consists of a clamp and a former of sufficient hardness; it may be equipped with a lever for applying force to the test piece (Fig. 3.2.3). Because the position of the left face of the clamp could influence the test results, the left face of the clamp (as shown in Fig. 3.2.3) should not reach up to or beyond the vertical line through the center of the circular former shape.

6. Test Piece

6.1 General: Round, square, rectangular or polygonal cross section test pieces shall be used in the test. Any areas of the material affected by shearing or flame cutting and similar operations during the cutting of test pieces shall be removed. However, testing a

test piece, the affected parts of which have not been removed, is acceptable provided the resultant bend is satisfactory.

6.2 Edges of rectangular test pieces: The edges of rectangular test pieces shall be rounded to a radius not exceeding the following values:

- 3mm, when the thickness of test pieces is 50mm or greater;
- 1.5mm, when the thickness of test pieces is less than 50mm and more than or equal to 10mm (inclusive);
- 1mm, when the thickness is less than 10mm.

The rounding shall be made so that no transverse burrs, scratches or marks are formed which might adversely affect the test result. However, testing a test piece, the edges of which have not been rounded, is acceptable provided the result is satisfactory.

6.3 Width of the test piece: Unless otherwise specified in the relevant standard, the width of the test piece shall be as follows:

(a) The same as the product width, if the later is equal to or less than 20mm;

(b) When the width of a product is more than 20mm:

(i) 20 ± 5 mm for products of thickness less than 3mm,

(ii) Between 20 and 50mm for products of thickness equal to or greater than 3mm.

6.4 Thickness of the test piece:

6.4.1 The thickness of the test pieces from sheets, strips and sections shall be equal to the thickness of the product to be tested. If the thickness of the product is greater than 25mm, it may be reduced by machining one surface to not less than 25mm. During

bending, the unmachined side shall be the tension-side surface of the test piece.

6.4.2 Test pieces of round or polygonal cross-section shall have a cross-section equal to that of the product, if the diameter (for a round cross section) or the inscribed circle diameter (for polygonal cross-section) does not exceed 30mm. When the diameter or the inscribed circle diameter, of the test piece exceeds 30mm and including 50mm, it may be reduced to not less than 25mm. When the diameter or the inscribed circle diameter, of the test piece exceeds 50mm, it shall be reduced to not less than 25mm (refer Fig. 3.2.4). During bending, the unmachined side shall be the tension-side surface of the test piece.

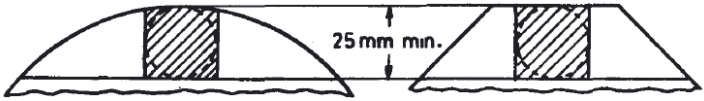


Fig. 3.2.4: Diameter and the inscribed circle diameter

6.5 Test pieces from forgings, castings and semi-finished products: In the case of forgings, castings and semifinished products, the dimensions of the test piece and sampling shall be as specified in the relevant standard or by agreement.

6.6 Agreement for test pieces of greater thickness and width: By agreement, test pieces of a greater thickness and width than those specified in Para 6.3 and 6.4 may be subjected to the bend test.

6.7 Length of test piece: The length of the test piece depends on the thickness of the test piece and the test equipment used.

7. Procedure

7.1 In general, tests are carried out at ambient temperature between 10^0C and 35^oC. Tests carried out under controlled conditions shall be made at a temperature of 23 ± 5°C.

7.2 The bend test is carried out using one of the following methods specified in the relevant standard:

(a) A specified angle of bend is achieved under the force and for the given conditions (see Fig. 3.2.1, 3.2.2 and 3.2.3).

(b) The legs of the test piece are parallel to each other at a specified distance apart while under the force (see Fig. 3.2.6).

(c) The legs of the piece are in direct contact while under an appropriate force (see Fig. 3.2.7)

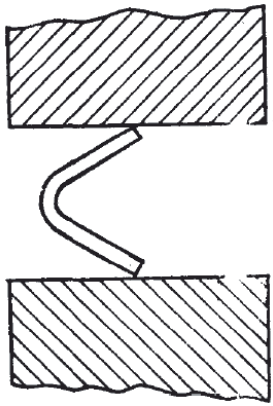


Fig. 3.2.5: Bending the legs of the test piece

7.3 In the bend test to a specified angle of bend, the test piece shall be placed on the supports (see Fig. 3.2.1) or on the V-block (see Fig. 3.2.2) and bend it in the middle between supports by the action of a force. The angle of bend, α, can be calculated from the measurement of the displacement of the former as given in Annex. A.

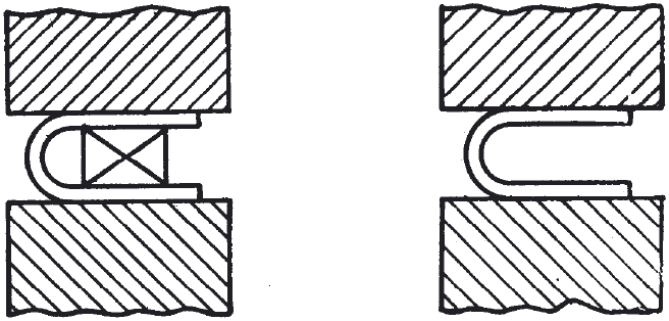


Fig. 3.2.6: Legs of the test piece parallel to each other

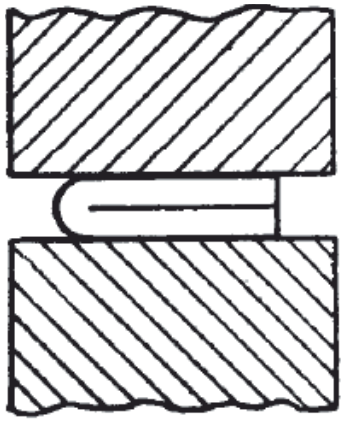


Fig. 3.2.7: Legs of test piece in direct contact

For the three methods (Fig. 3.2.1, 3.2.2 and 3.2.3), the bending force shall be applied slowly so as to permit free plastic flow of the material.

In case of dispute, a testing rate of (1 ± 0.2) mm/s shall be used.

If it is not possible to bend the test piece directly to the specified angle in the manner described above, the bend shall be completed by pressing directly on the ends of the legs of the test piece (see Fig. 3.2.5).

In a bend test requiring parallel legs, the test piece

may be bent first, as indicated in Fig. 3.2.5, and then placed between the parallel plates of the press (see Fig. 3.2.6), where it is further formed by application of a force to obtain parallelism of the legs. The test may be carried out with or without an insert. The thickness of the insert shall be as defined in the relevant standard or by agreement.

An alternate method of test is that of bending over a former (see Para 5.4).

7.4 If specified, the test piece, after its preliminary bending, shall be further bent between the parallel plates of the press, by application of a force, to obtain direct contact between the legs of the test piece (see Fig. 3.2.7).

8. Interpretation of Result

8.1 The interpretation of the bend test is carried out according to the requirements of the product standards. When these requirements are not specified, absence of cracks visible without the use of magnifying aids is considered as the evidence that the test piece withstood the bend test.

8.2 The angle of bend, specified in product standards, is always considered as a minimum. If the internal radius of a bend is specified, it is considered as a maximum.

9. Test report: The test report shall include the following information:

(a) Reference to this standard;

(b) Identification of the test piece (type of material, cast number, direction of the test piece axis relative to a product, etc.);

(c) Shape and dimensions of the test piece;

(d) Test method;

(e) Any deviation from this standard; and

(f) Test result.

Annex. A

[Determination of the bend angle from the measurement of the displacement of the former]

$\sin \alpha/2 = [(p \times c) \times + \{W \times (f - c)\}] / [p^2 + (f - c)^2]$

$\cos \alpha/2 = [(W \times p) - \{c \times (f - c)\}] / [p^2 + (f - c)^2]$

where:

$W = [p^2 + (f - c)^2 - c^2]^{0.5}$

$c = R + a + D/2$

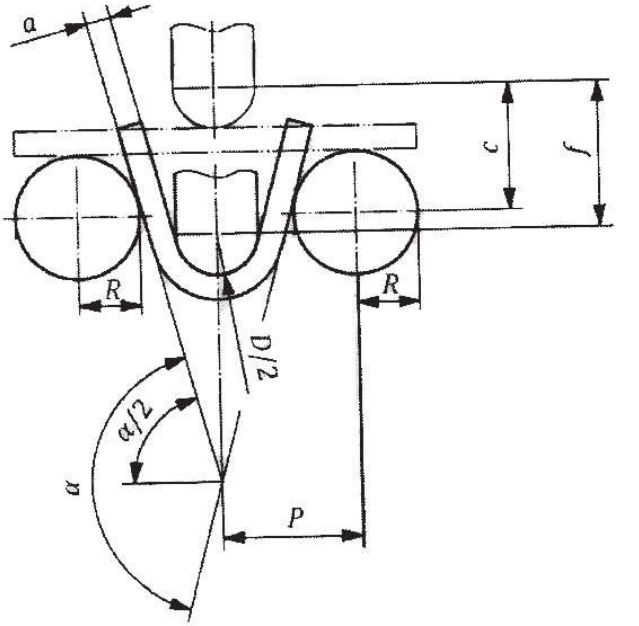


Fig. 3.2.8: Values for the calculation of the bend angle, α

3.3 Re-bend Test

The purpose of re-bend test is to measure the effect of strain ageing on steel. Strain ageing has embrittlement effect which takes place after cold deformation by diffusion of nitrogen in steel.

1. Introduction: This chapter describes the procedure for conducting the re-bend test on reinforcement steel bars.

2. Reference: IS-1786:2008 (Reaffirmed-2018) "High Strength Deformed Steel Bars and Wires for Concrete Reinforcement - Specification".

3. Preparation of Test Sample: The test pieces shall be full sections of the bars and shall be subjected to test without any further modifications. No reduction in size by machining or otherwise shall be permissible, except in case of bars of size 28mm and above. Before the test pieces are selected, the manufacturer or supplier shall furnish the purchaser or his authorized representative with copies of the mill records giving the mass of bars in each bundle/cast with sizes as well as the identification marks.

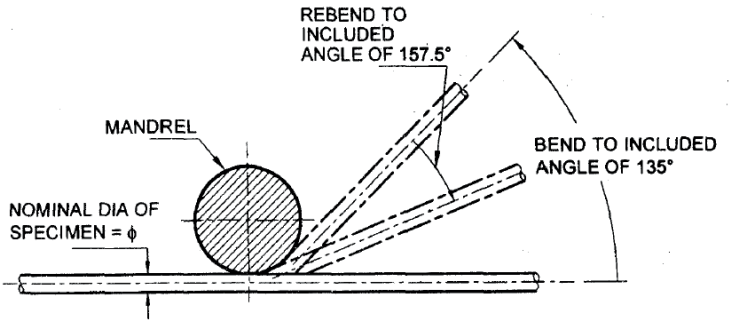


Fig. 3.3.1: Re-bend Test

Table 3.4: Diameter of Mandrel

SN	Nominal Size of Specimen	For Fe415 & Fe500	For Fe415D & Fe500D	For Fe550 & Fe600	For Fe550D & Fe600D
1	Upto and including 10mm	5 Ø	4 Ø	7 Ø	6 Ø
2	Over 10mm	7 Ø	6 Ø	8 Ø	7 Ø

Where Ø is the nominal size of test piece, in mm.

4. Procedure: Tine test piece snail be bent to an included angle of 135^0 (see Fig. 3.3.1) using a mandrel of appropriate diameter (see Table 3.4). The bent piece shall be aged by keeping in boiling water (100^0C) for 30 min and then allowed to cool. The piece shall then be bent back to have an included angle of $157½^0$. The specimen shall be considered to have passed the test if there is no rupture or cracks visible to a person of normal or corrected vision on the re-bent portion.

5. Retest: Should any one of the test pieces first selected fail to pass the test, two further samples shall be selected for testing in respect of each failure. Should the test pieces from both these additional samples pass, the material represented by the test samples shall be deemed to comply with the requirements of the test. Should the test piece from either of these additional samples fail, the material presented by the samples shall be considered as not having complied with this standard.

This Page
is
Intentionally
Left Blank

Chapter - 4

TESTS ON WATER

Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel.

Potable water is generally considered satisfactory for mixing concrete. However, in case of doubt regarding development of strength, the suitability of water for making concrete shall be ascertained by the compressive strength and initial setting time tests as given below:

(i) Average 28 days compressive strength of at least three 150mm concrete cubes prepared with water proposed to be used shall not be less than 90 percent of the average of strength of three similar concrete cubes prepared with distilled water. The cubes shall be prepared, cured and tested as per provisions of lS:516.

(ii) The initial setting time of test blocks made with the appropriate cement and the water proposed to be used shall not be less than 30 min and shall not differ by ± 30 min from the initial setting time of control test block prepared with the same cement and distilled water. The test blocks shall be prepared and tested as per provisions of IS:4031(Part-15).

Following laboratory tests are typically conducted on the water to confirm its suitability for use in mixing concrete:

(4.1) Total Suspended Solids (Matter) in Water

(4.2) Total Solids (Matter) in Water

(4.3) Acidity of Water

(4.4) Alkalinity of Water

(4.5) pH Value of Water

(4.6) Chlorides in Water

(4.7) Sulphates in Water

This Page
is
Intentionally
Left Blank

4.1 Total Suspended Solids (Matter) in Water

1. Introduction: Total Suspended Solids (TSS) is suspended particles (by dry weight) in water that is not dissolved and can be trapped by a filter by using a filtration system. Presence of impurities in water for concrete mix leads to decrease in structural properties of concrete such as strength and durability to a large extent. It is found that high content of suspended particles does not affect the strength of the concrete, but affect other properties of the same. The IS:456-2000 prescribes an allowable limit of 2000 mg/liter for suspended particles in water. Before use of water in concrete, the muddy water should undergo settlement in the basin. This chapter describes a gravimetric method for the determination of non-filterable residue.

2. Reference: IS-3025(Part-17):2022 "Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-17: Non-Filterable Residue (Total Suspended Solids at 103^0C-105^0C)".

3. Principle: The non-filterable residue is determined by passing the sample through a weighed filter and drying the filter at 103°C-105°C in an oven. The increase in the filter weight represents Total Suspended Solids (TSS).

4. Apparatus required

4.1 Hot Plate/Block, to maintain < 100^oC temperature (Fig. 4.1.1).

Fig. 4.1.1

Fig. 4.1.2

4.2 Wide-Bore Pipettes, Class B glass, mechanical or electronic (Fig. 4.1.2).

4.3 Graduated Cylinders, Class A.

4.4 Evaporating Dish, 90 mm, 100 ml capacity made of platinum, porcelain, silica or borosilicate glass. Platinum is suitable for all tests; porcelain, silica and glass may be used for samples with a pH value less than 9.0.

4.5 Drying Oven, with thermostatic control for maintaining temperature with 103°C - 105°C.

4.6 Muffle Furnace, capable of operation at 550°C (Fig. 4.1.3).

Fig. 4.1.3 **Fig. 4.1.4**

4.7 Filter, anyone of the following may be used.

4.7.1 Glass Fibre Filter Disc, (Whatman GF/C or equivalent) 22mm to 125mm diameter, ≤ 2 µm nominal pore size without organic binder.

4.7.2 Paper, acid washed, ash-less hard filter finish; filter paper sufficiently retentive for fine particles (Pore size 2 µm to 2.5 µm equivalent to Whatman filter No. 542).

4.7.3 Sintered Disc, G-5 or its equivalent with pore size 1 µm to 2 µm.

4.7.4 Membrane Filter, 0.45 µm membrane.

4.7.5 Gooch Crucible, 30 ml capacity with 2.1cm,

2.4cm or 5.5cm diameter (pore size 1.2 µm) glass fibre filter disc. (Whatman GF/C or equivalent).

4.7.6 Crucible, Porous-bottom silica, sintered glass, porcelain, stainless steel or Alundum crucible with a maximum pore size of 5 µm.

4.7.7 Glass Fibre Filter Disc, (Whatman GF/C or equivalent) 2.1cm to 5.5cm in diameter, pore size 1.2 µm.

4.8 Filtering Apparatus, depending on type of filter used.

4.9 Desiccator, provided with a colour indicating desiccant (Fig. 4.1.4).

4.10 Analytical Balance, of 200 g capacity and capable of weighing to nearest 0.1 mg.

4.11 Magnetic Stirrer, with Teflon coated stirring bars.

5. Procedure

5.1 Preparation of Glass Fibre Filter Disc: Place the glass fibre filter on the membrane filter apparatus or insert into bottom of a suitable Gooch crucible with wrinkled surface up. While vacuum is applied, wash the dish with three successive 20 ml volumes of reagent grade water. Remove all traces of water by continuing suction. Remove filter from membrane filter apparatus (or both crucible and filter, if Gooch crucible is used) and dry in an oven at 103°C - 105°C for 1 hour. Transfer to a desiccator and weigh after half an hour. Repeat the drying cycle until a constant mass is obtained (mass loss is less than 0.5 mg in successive weighing). Weigh immediately before use. After weighing, handle the filter or crucible filter with forceps or tongs only.

5.2 Sample Volume: In potable waters non-filterable residue is usually small. Relatively large volume of water is passed through filter so as to obtain between 2.5 mg to 200 mg dried residue. For deciding volume to be taken, turbidity values may be taken into

consideration. If turbidity values of a sample is less than 50 units, filter 1 sample and if turbidity value exceeds 50 units, filter sufficient sample so that non-filterable residue is 50 mg to 100 mg.

5.3 Stir volume of sample with a magnetic stirrer or shake it vigorously. Assemble the filtering apparatus and begin suction. Wet the filter with a small volume of distilled water to seat it against the fitted support.

5.4 Shake the sample vigorously and quantitatively transfer the predetermined sample volume selected according to Para 5.2 to the filter using a graduated cylinder. Remove all traces of water by continuing to apply vacuum after sample has passed through.

5.5 With suction on, wash the graduated cylinder filter non-filterable residue with portions of > 10 ml reagent grade water allowing complete drainage between washings. Remove all traces of water by continuing to apply vacuum after the wash water has passed through.

5.6 After filtration, transfer the filter along with contents to an oven maintained at either 103°C - 105°C for at least 1 hour. Cool in a desiccator and weigh. Repeat the drying cycle till constant mass is obtained. Alternatively, remove crucible and filter from crucible adapter, wipe dry from outside with filter paper and dry at 103°C-105°C in an oven. Cool in a desiccator and weigh. Repeat the drying cycle to constant mass till the difference in the successive mass is less than 0.5 mg.

6. Calculation: Calculate the total suspended solids from the following equation:

Total suspended solids, mg/l = [(A – B) / V] x 1000

Where:

A = final weight of (filter + dish), in mg;

B = weight of dish, in mg; and

V = volume of the sample, in ml.

7. Report: Report in whole numbers for less than 100 mg/l and to three significant figures for higher values. Report the temperature of determination.

8. Precision and Accuracy: Precision of the method is about 5 percent. Accuracy cannot be estimated because the non-filterable residue as determined by this method is a quantity define by the procedure followed.

4.2 Total Solids (Matter) in Water

1. Introduction: The water used for concrete mixing should be reasonably free from impurities such as suspended solids, organic solids and dissolved salts (inorganic solids), which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value, etc. This chapter describes a gravimetric method for the determination of volatile and fixed portions of total, filterable and non-filterable solids (residues) in water. The IS:456-2000 prescribes an allowable limit of 200 mg/liter for organic solids and 3000 mg/liter for inorganic solids in water.

2. Reference: IS-3025(Part-18):2022 "Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-18: Volatile and Fixed Solids (Total, Filterable and Non-filterable) at 550^0C".

3. Terminology

3.1 "Total solids" is the material left in a vessel after evaporation of a sample of water and its subsequent drying in an oven at a definite temperature. Total solids include "total suspended solids" the portion of total solids retained by a filter and "total dissolved solids" the portion that passes through the filter.

3.2 Total Fixed Solids: The dish with residue after completion of test for total residue is heated in a muffle furnace at (550 ± 50)°C for 1 hour. The solid portion that is volatilised during ignition is called volatile solids. It will be mostly organic matter. The balance matter will be inorganic matter.

4. Apparatus required

4.1 Wide-Bore Pipettes, Class B glass, mechanical or electronic.

4.2 Graduated Cylinders, Class A.

4.3 Drying Oven, with thermostatic control for maintaining temperature with 103°C - 105°C.

4.4 Filter, anyone of the following may be used:

4.4.1 Glass Fibre Filter Disc, (Whatman GF/C or equivalent) from 22 mm to 125 mm diameter, </– 2um nominal pore size without organic binder.

4.4.2 Paper, acid washed, ashless hard filter finish; filter paper sufficiently retentive for fine particles (Pore size 2 - 2.5 µm equivalent to Whatman filter No. 542).

4.4.3 Gooch Crucible, 25 ml to 40 ml capacity with Gooch crucible adapter (Fig. 4.2.1).

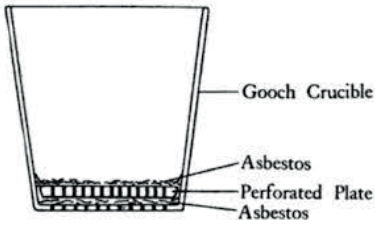


Fig. 4.2.1

Fig. 4.2.2

4.4.4 Sintered Disc, G-5 or its equivalent with pore size from 1 µm to 2 µm (Fig. 4.2.2).

4.4.5 Membrane Filter, 0.45 µm membrane.

4.5 Evaporating Dish, 90 mm, 100 ml capacity made of platinum, porcelain, silica or borosilicate glass. Platinum is suitable for all tests; porcelain, silica and glass may be used for samples with a pH value less than 9.0.

4.6 Desiccator, provided with a colour indicating desiccant.

4.7 Muffle Furnace, capable of operation at 550°C.

4.8 Analytical Balance, of 200 g capacity and capable of weighing to nearest 0.1 mg.

5. Sample: Preservation of sample is not practical. Refrigeration or chilling to 4°C is recommended.

6. Procedure

6.1 Heat the clean evaporating dish to 550°C for 1 hour. Cool, desiccate, weigh and store in desiccator until ready for use.

6.2 Select volume of the sample which has residue between 25 mg and 250 mg, preferably between 100 mg and 200 mg. This volume may be estimated from values of specific conductance. To obtain a measurable residue, successive portions of sample may be added to the sample dish.

6.3 Pipette this volume in a weighed evaporating dish on steam-bath. Evaporation may also be performed in a drying oven. The temperature shall be lowered to approximately 98°C to prevent boiling and splattering of the sample. After complete evaporation of water from the residue, transfer the dish to an oven at 103°C - 105°C or 179°C - 181°C and dry to constant mass, that is, till the difference in the successive weighing is less than 0.5 mg. Drying for a long duration (usually 1 hour to 2 hour) is done to eliminate necessity of checking for constant mass. The time for drying to constant mass with a given type of sample when a number of samples of nearly same type are to be analyzed, has to be determined by trial.

6.4 Weigh the dish as soon as it has cooled avoiding residue to stay for long time as some residues are hygroscopic and may absorb water from desiccant that is absolutely dry.

6.5 After weighing, ignite the dish in a muffle furnace at (550 ± 50)°C for 1 hour. After ignition, allow the vessel to partially cool in air and transfer to desiccator, cool and weigh.

7. Calculations: Calculate the fixed residue and volatile residue as follows (total filterable or non-filterable):

Volatile solids, mg/1 = [(A – B) / V] x 1000

Fixed solids, mg/1 = [(B – C) / V] x 1000

Where:

A = final weight of residue + dish/filter before ignition, in mg;

B = final weight of residue + dish/filter after ignition, in mg;

C = weight of dish/filter, in mg; and

V = volume in ml, of the sample.

8. Report: Report to the nearest whole number for values up to 100 mg/l and to three significant figures for higher values. Report the temperature of determination.

4.3 Acidity of Water

1. Introduction: The water that consists of industrial waste is not suitable for concrete construction. The industrial water consists of detrimental acids or alkalis that depend on the waste product of the respective industry. In terms of pH value, the water that has a pH value greater than 6 can be employed for the concrete construction. But the pH value will not give a proper and adequate measure about the acid content in the water. The acid content in water can be gauged accurately based on total acidity. As per IS:456-2000, to neutralize 100 ml sample of water, using phenolphthalein as indicator, it should not require more than 5 ml of 0.02 normal NaOH (Caustic soda).

2. Reference: IS-3025(Part-22):1986 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-22: Acidity".

3. Principle and Theory: Acidity of water is its quantitative capacity to react with a strong base to a designated pH. It may be defined as equivalent concentration of hydrogen ions in mg/l. The equation in its simplest form is as follows:

$$H + NaOH = H2O + Na$$

4. Sample: The test sample used should be free from turbidity or filtered through 0.45 μm membrane filter.

5. Apparatus

5.1 pH Meter (Fig. 4.3.1)

5.2 Burette – 50 ml capacity.

5.3 Magnetic Stirring Device

Fig. 4.3.1: pH Meter

6. Reagents

6.1 Distilled Water : pH should not be less than 6.0. If the pH is less than 6.0, it shall be freshly boiled for 15 minutes and cooled to room temperature. Deionized water may be used provided that it has a conductance of less than 2 µS/m and a pH more than 6.0.

6.2 Potassium Acid Phthalate : 0.02 N. Dissolve 4.0846 g of potassium acid phthalate salt ($KHC_8H_4O_4$) (dried at 120°C for 2 hours) in carbon dioxide free distilled water and dilute to 1 litre.

6.3 Sodium Hydroxide Solution : 15 N.

6.3.1 Sodium hydroxide solution : 1 N. Dilute 67 ml of 15 N sodium hydroxide solution (Para 6.3) to one litre with distilled water.

6.3.2 Sodium hydroxide solution : 0.02 N. Dilute 20 ml of 1 N sodium hydroxide solution (Para 6.3.1) to one litre and standardize using standard potassium acid phthalate (Para 6.2).

6.4 Phenolphthalein Indicator : Dissolve 0.5 g of phenolphthalein in 100 ml, 1: 1 (v/v) alcohol water mixture and add 0.02 N sodium hydroxide solution

drop by drop till very faint pink colour is observed.

6.5 Methyl Orange Indicator : Dissolve 0.5 g of methyl orange in distilled water and make up to 100 ml in a volumetric flask.

7. Procedure

7.1 Indicator Method: Pipette 20 ml or a suitable portion of sample into a 100 ml beaker. The sample size shall be so selected so that not more than 20 ml of titrant is needed for the titration. Determine the pH of water. If pH is less than 3.7, add two drops of methyl orange indicator into the first sample beaker and titrate with standard 0.02 N sodium hydroxide solution until the colour changes to the faint orange characteristic of pH 3.7. Record the volume of sodium hydroxide used. To the second sample beaker, add 2 to 3 drops of phenolphthalein indicator and titrate with 0.02 N sodium hydroxide solution to the appearance of faint pink colour characteristics of pH 8.3. Record the volume used.

7.2 Potentiometric Method: Pipette 20 ml or a suitable portion of sample into a 100 ml beaker. Titrate with standard sodium hydroxide solution to pH 3.7 and pH 8.3. Record the volume of standard sodium hydroxide used. No indicator is required.

8. Calculation: Calculate acidity in the sample as follows:

Acidity at pH 3.7, as mg/l $CaCO_3$ = (A x N X 50000) / V

Acidity at pH 8.3, as mg/l $CaCO_3$ = (B x N X 50000) / V

Where:

A = Volume in ml of standard sodium hydroxide used to titrate to pH 3.7,

N = Normality of standard sodium hydroxide,

V = Volume in ml of sample taken for test, and

B = Volume in ml of standard sodium hydroxide used to titrate to pH 8.3.

4.4 Alkalinity of Water

1. Introduction: The water that consists of industrial waste is not suitable for concrete construction. The industrial water consists of detrimental acids or alkalis that depend on the waste product of the respective industry. In terms of pH value, the water that has a pH value greater than 6 can be employed for the concrete construction. But the pH value will not give a proper and adequate measure about the alkalinity of the water. As per IS:456-2000, to neutralize 100 ml sample of water, using neutral indicator, it should not require more than 25 ml of 0.02 normal H_2SO_4.

2. Reference: IS-3025(Part-23):1986 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-22: Alkalinity".

3. Principle and Theory: Alkalinity of water is the capacity of that water to accept protons. It may be defined as the quantitative capacity of an aqueous medium to react with hydrogen Icons to pH 8.3 (phenolphthalein alkalinity) and then to pH 3.7 (total alkalinity or methyl orange alkalinity). The equation in its simplest form is as follows:

$CO_3^{--} + H^+ = HCO_3^{--}$ (pH 8.3)

From pH 8.3 to 3.7, the following reaction may occur:

$HCO_3^- + H^+ = H_2CO_3$

4. Sample: The sample used for analysis should be either free from turbidity or should be allowed to settle prior to analysis.

5. Apparatus

5.1 pH Meter (Fig. 4.3.1)

5.2 Burette – 50 ml capacity.

5.3 Magnetic Stirring Device

6. Reagents

6.1 Distilled Water: Distilled water used should have pH not less than 6.0. If the water has pH less than 6.0, it shall be freshly boiled for 15 minutes and cooled to room temperature. Deionized water may be used provided that it has a conductance of less than 2 μs/cm and a pH more than 6.0.

6.2 Sulphuric Acid: Dilute 5.6 ml of concentrated sulphuric acid (relative density 1.84) to one litre with distilled water.

6.3 Standard Solution of Sulphuric Acid: 0.02 N.

6.4 Phenolphthalein Indicator: Dissolve 0.5 g of phenolphthalein in 100 ml, 1: 1 (v/v), alcohol water mixture.

6.5 Mixed Indicator Solution: Dissolve 0.02 g methyl red and 0.01 g bromocresol green in 100 ml, 95 percent, ethyl or isopropyl alcohol.

7. Procedure

7.1 Indicator Method: Pipette 20 ml or a suitable portion of sample into 100 ml beaker. If the pH of the sample is over 8.3, then add 2 to 3 drops of phenolphthalein indicator and titrate with standard sulphuric acid solution till the pink colour observed by indicator just disappears (equivalence of pH 8.3). Record the volume of standard sulphuric acid solution used. Add 2 to 3 drops of mixed indicator to the solution in which the phenolphthalein alkalinity has been determined. Titrate with the standard acid to light pink colour (equivalence of pH 3.7). Record the volume of standard acid used after phenolphthalein alkalinity.

7.2 Potentiometer Method: Pipette 20 ml or a suitable portion of sample into a 100 ml beaker and titrate with standard sulphuric acid to pH 8.3 and then to pH 3.7, using a potentiometer. No indicator is required.

8. Calculation: Calculate alkalinity in the sample as follows:

Phenolphthalein alkalinity (as mg/l of $CaCO_3$) =

(A x N x 50000) / V

Total alkalinity (as mg/l of $CaCO_3$) =

[(A + B) x N x 50000] / V

Where:

A = ml of standard sulphuric acid used to titrate to pH 8.3,

B = ml of standard sulphuric acid used to titrate from pH 8.3 to pH 3.7,

N = Normality of acid used, and

V = Volume in ml of sample taken for test.

4.5 pH Value of Water

1. Introduction: The pH value of the mixing water has a significant impact on the durability of concrete. Concrete uses cement as a binding agent, which has a pH of 11, and if this pH varies too much then it loses its binding properties as it is broken down. This will create more cracks and pores in the concrete speeding up the process exponentially leading to more problems and a swifter deterioration. If the pH of the concrete drops below 7 there will be noticeable degradation and surface damage as the cement loses its ability to bind the concrete together. From the research it has been observed that the pH value of water had little effect on 28 days compressive strength of concrete, the 90 days strength varies greatly with pH values of mixing water. Chloride ion penetration and Thermal conductivity also vary with change in Ph values of mixing water. As per IS:456-2000, the pH value of water shall not be less than 6. This chapter describes electrometric and colorimetric methods for the determination of pH value. Both methods are applicable to all types of water and waste water.

2. Reference: IS-3025(Part-11): 2002 "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-11: pH Value".

3. Principle: The determination of pH value is based on measuring the potential difference of an electrochemical cell using a suitable pH meter. The pH of sample also depends on the temperature because of dissociation equilibrium. Therefore, the temperature of sample is always stated together with the pH measurements.

4. Reagents: Standard pH buffer solutions from available tablets or powder, or known amount of chemicals may be used for the preparation. Procedures for the preparation of some standard pH buffer solutions are given below and Table-4.1 shows the pH value of these buffers at different temperatures.

4.1 Distilled or Deionised water: with conductivity < 0.2 mS/m.

4.2 Buffer solutions: Preferably certified buffers with stated measurement inaccuracy for calibrating pH meters. Follow the manufacturer's instructions regarding storage and stability.

4.3 Electrolytes for liquid-filled reference electrodes: Use the electrolyte solutions recommended by the manufacturer.

4.4 Potassium chloride solution (KCl): = 3 mol/l. To prepare the potassium chloride solution as electrolyte for reference electrodes, use as suitable amount of solid potassium chloride and dissolve it in water.

5. Apparatus

5.1 Sampling bottle: Sealable, flat-bottomed, and made of polyethylene or glass. The type of stopper used shall allow the exclusion of all air from the sample bottle.

5.2 Temperature measurement device: Capable of measurement with a total uncertainty not greater than 0.5°C. The temperature sensor (Para 5.2.2) is preferred.

5.2.1 Thermometer with a 0.5°C scale.

5.2.2 Temperature sensor, separate or integrated into the pH electrode.

Temperature measurement deviations due to the device shall be corrected against a calibrated thermometer.

5.3 pH meter, providing the following means for adjustment:

(a) Zero point of the pH electrode (or offset voltage);

(b) Slope of the pH electrode;

(c) Temperature of the pH electrode;

(d) Input resistance > 1012 Ω.

Moreover, it shall be possible to change the display of the pH meter to give readings of either the pH value or the voltage. The resolution of the pH value reading on the pH meter shall be 0.01 or better.

5.4 Glass electrode and reference electrode: The chain zero-point of glass electrodes should not deviate by more than ΔpH = 0.5 (manufacturer's declared value) from the nominal pH electrode value. The value of the practical slope shall be at least 95% of the theoretical slope.

Use electrodes with electrolyte solutions and a flow rate of 0.1 ml/day to 2 ml/day as reference electrodes.

For reference electrodes with an electrolyte solution, ensure that an excess hydrostatic pressure is generated by setting the filling level of the electrolyte in the reference electrode to be higher than that of the buffer solution or the measuring solution, as appropriate. It is also possible to use pressurized reference electrodes. In limited applications, reference electrodes with a solidified electrolyte (electrolyte gel or a polymerizate of an electrolyte) may also be used.

For samples with low conductivity, electrodes with high electrolyte discharge should be used. If the conductivity is > 30 mS/m, it is also possible to use an electrolyte gel or polymerizate in the reference electrodes. In general, ensure that for electrolyte gels or polymerizates, the exchange within the diaphragm is not be caused by the discharge of the electrolyte, but by diffusion of the ions involved.

5.5 Stirrer or agitator, operating with a minimum exchange of gas between the test portion and air.

6. Sampling: The pH value may change rapidly as a result of chemical, physical or biological processes in the water sample. For this reason, whenever applicable, it is advisable to measure the pH value immediately at

the sampling point. If this is not possible, take a water sample in a sampling bottle (Para 5.1). When filling the sampling bottle, avoid gas exchange, e.g. release of carbon dioxide, between the sample and the ambient air. Fill the bottle completely and stopper it, bubble-free, e.g. with a solid stopper. The sampling bottle is preferably filled by flushing to overflowing from a water sampler via a flexible tube extending to the bottom of the bottle.

Samples should be kept cool (2°C to 8°C) and in the dark during transport and storage.

In the laboratory, measure the pH value as soon as possible. When the samples are measured in the laboratory, check possible influences of transport and storage on the pH value of the samples to be analyzed.

7. Procedure

7.1 Preparation: Ensure the functionality of the pH electrode by periodic maintenance and testing (Para 7.2). Prepare the calibration buffer solutions. For devices with automatic buffer identification, follow the manufacturer's calibration instructions. Choose the buffer solutions so that the expected measurement of the sample lies between the values of the two buffers. When using a pH electrode without an internal temperature sensor, immerse a temperature sensor in the test solution.

For measurement, prepare the glass and either the reference electrode or the mono-rod pH electrode, following the manufacturer's instructions. Turn on the measuring device; for devices with automatic buffer identification, activate the stored data of the buffer solutions prepared for calibration.

Measure the temperature of the buffer and of the sample solutions. If possible, buffer and sample should have the same temperature.

If there is no temperature sensor, adjust the device to the measuring temperature.

Take the pH values of the buffer solutions from the respective certificates, depending on the existing temperature or use automatic buffer recognition.

7.2 Calibration and adjustment of the measuring equipment: Calibrate the pH electrode at two points using buffer solutions of the expected range of pH values (two-point calibration), following the manufacturer's instructions. Afterwards, adjust the devices manually, based on the data determined. For automatic measuring devices, ensure that the prepared buffer solutions correspond to the data of the buffer solutions stored in the software of the measuring device.

Immerse the pH electrode and the temperature sensor in the first buffer, usually the one at pH 7, which is used for adjusting the zero point. Subsequently stir to avoid the enrichment of potassium chloride caused by leaking reference electrolytes near the glass electrode. Turn off the stirrer and start the calibration procedure on the measuring device. Automatic devices independently identify the stability of the measurement, store this value and adjust the zero point. When using devices with manual adjustment, initially adjust the zero point at pH 7, unless otherwise specified in the manufacturer's instructions.

Thoroughly rinse the pH electrode and the temperature sensor before, between, and after the measurements using water. Immerse the pH electrode in the second buffer solution and stir. Turn off the stirrer and start the calibration procedure for the second buffer on the measuring device. Automatic devices independently identify the stability of the measurement, store this value, and adjust the slope. For devices with manual adjustment, adjust the slope so that the pH value of the second buffer is reached.

Check the result of the adjustment of the pH electrode on two new samples of the buffer solutions used. The calibration should be checked by measuring

an independent calibration checking solution buffer instead of the buffer solutions used. The measurements shall not deviate by more than 0.03 from the relevant set point. Otherwise, repeat the procedure, and replace the pH electrode if necessary.

As a result of the calibration, record the zero point and the slope of the pH electrode together with the measuring temperature. If information is required either on the condition of the pH electrode for a broad pH range or on the quality of the buffer solutions, calibrate the pH electrode at more than two points, usually at five points (multi-point calibration).

7.3 Measurement of the samples: Whenever possible, measure the samples under the same conditions as during calibration. Preferably, determine the pH value in the sampling bottle.

When changing solutions, rinse the pH electrode and the measuring vessel with distilled or deionized water and then, if possible, with the next solution to be measured. Repeat the procedure with other subsamples, if appropriate.

The mass concentrations of solids in liquid sludge should be < 5 %.

8. Expression of results: In general, the value for the quantity pH is expressed to one decimal place. Only if the composition of the unknown solution is similar to the composition of the buffer solutions and the quality of calibration justifies it, is it reasonable to report a second decimal place. If the second decimal place is required although the conditions mentioned are not met, the reasons for taking this decision should be stated in the test report. Report also the measuring temperature.

9. Test report: The test report shall contain at least the following information:

(a) All the information required for the complete identification of the sample;

(b) The sampling method used (see Para 6);

(c) The test method used, together with reference to this International Standard;

(d) All operating details not specified in this Standard, or regarded as optional, together with details of any incident that may have influenced the result(s);

(e) The measuring conditions;

(f) The test result(s) obtained.

4.6 Chlorides in Water

1. Introduction: The presence of chlorides in the concrete is a serious cause of corrosion of the steel reinforcement. This can lead to cracking of concrete due to the expansive nature of the corrosion, as well as failures of structural steel due to loss of the steel integrity. The severity of the damage depends on the concentration of the chlorides present in the concrete, as well as the variation of the chloride from one point to another. The contamination effects of chloride salt on the compressive strength of concrete worsen with concrete age and thus should be prevented at all cost. As per IS:456-2000, the maximum permissible limit of chloride in water is 2000 mg/l for plain concrete and 500 mg/l for reinforced concrete.

This chapter describes four methods for the determination of chlorides. The argentometric method is suitable for use in relatively clear waters when 0.15 to 10 mg of chloride is present in the portion titrated. The end point of mercuric nitrate method is easier to detect. Potentiometric method is suitable for coloured or turbid samples. The ferricyanide method is an automated technique. In case of any difference of opinion, the argentometric method shall be the referee method.

2. Reference: IS-3025(Part-32):1988 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-2: Chloride".

(A) Argentometric Method

3. Principle: In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated before red silver chromate is formed.

4. Apparatus

4.1 Erlenmeyer flask: 250 ml (Fig. 4.6.1).

4.2 Burette: 50 ml (Fig. 4.6.2).

5. Reagents

5.1 Potassium chromate indicator solution: Dissolve 50 g of potassium chromate in a little distilled water. Add silver nitrate solution until a definite red precipitate is formed. Let it stand for 12 hour, filter and dilute to 1 litre with distilled water.

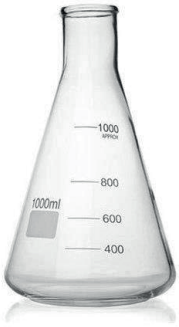


Fig. 4.6.1: Erlenmeyer flask

Fig. 4.6.2: Burette

5.2 Standard silver nitrate titrant: 0.014 1 N. Dissolve 2.395 g of silver nitrate in distilled water and dilute to 1 litre. Standardize against 0.014 1 N sodium chloride solution as prescribed in Para 6. 1.00 ml = 500 µg of chloride. Store in a brown bottle.

5.3 Standard sodium chloride solution: 0.014 1 N. Dissolve 824.00 mg of sodium chloride (dried at 140°C) in distilled water and dilute to 1 litre. 1.00 ml = 500 µg of chloride.

5.4 Special reagents for removal of interferences

5.4.1 Aluminium hydroxide suspension: Dissolve 1.25 g of aluminium potassium sulphate or aluminium ammonium sulphate [AlK $(SO_4)^2$ $.12H_2O$ or Al NH4 $(SO_4)^2$. $12H_2O$] in 1 litre of distilled water. Warm to 60°C and add 55 ml of

concentrated ammonium hydroxide slowly with stirring. Let it stand for 1 hour, transfer to a large bottle and wash precipitate by successive additions, with thorough mixing and decanting with distilled water, until free from chloride. When freshly prepared, the suspension occupies a volume of about 1 litre.

5.4.2 Phenolphthalein indicator solution

5.4.3 Sodium hydroxide - 1 N.

5.4.4 Sulphuric acid - 1 N.

5.4.5 Hydrogen peroxide - 30 percent.

6. Procedure: Use 100 ml sample or a suitable portion diluted to 100 ml. If the sample is highly coloured, add 3 ml of aluminium hydroxide suspension, mix, let settle and filter. If sulphide, sulphite or thiosulphate is present, add 1 ml of hydrogen peroxide and stir for 1 minute. Directly titrate the samples in the pH range 7 to 10. Adjust sample pH to 7-10 with sulphuric acid or sodium hydroxide if it is not in the range. Add 1.0 ml of potassium chromate indicator solution. Titrate with standard silver nitrate solution to a pinkish yellow end point. Standardize silver nitrate solution and establish reagent blank value by titration method.

7. Calculation

Chloride, mg/l = [(V1 - V2) x N x 35450] / V3

Where:

V1= Volume in ml of silver nitrate used by the sample,

V2= Volume in ml of silver nitrate used in the blank titration,

V3= Volume in ml of sample taken for titration, and

N = Normality of silver nitrate solution.

(B) <u>Mercuric Nitrate Method</u>

3. Principle: Chloride can be titrated with mercuric nitrate because of the formation of soluble, slightly dissociated

mercuric chloride. In the pH range 2.3 to 2.8, diphenyl carbazone indicates the end point by the formation of a purple complex with excess mercuric ions.

4. Apparatus

4.1 Erlenmeyer flask: 250 ml capacity.

4.2 Micro-burette: 5 ml with 0.01 ml graduation intervals.

5. Reagents

5.1 Standard sodium chloride solution: See Para (A)5.3 above.

5.2 Nitric acid: 0.1 N.

5.3 Sodium hydroxide: 0.1 N.

5.4 Reagents for chloride concentrations below 100 mg/l

5.4.1 Indicator-acidifier reagent: The nitric acid concentration of this reagent is an important factor in the success of the determination and can be varied as indicated in (a) or (b) to suit the alkalinity range of the sample. Reagent (a) contains -sufficient nitric acid to neutralize a total alkalinity of 150 mg as $CaCO_3$/l to the proper pH in a 100 ml sample. Adjust amount of nitric acid to accommodate samples of alkalinity different from 150 mg/l.

(a) Dissolve, in the order named, 250 mg s-diphenylcarbazone, 4.0 ml concentration nitric acid and 30 mg xylene cyanol FF in 100 ml 95 percent ethyl alcohol or isopropyl alcohol. Store in a dark bottle in a refrigerator. This reagent is not stable indefinitely. Deterioration causes a slow end point and high results.

(b) Because pH control is critical, adjust pH of highly alkaline or acid samples to 2.5 ± 0 1 with 0.1 N nitric acid or sodium hydroxide

not with sodium carbonate (Na_2CO_3). Use a pH meter with a non-chloride type of reference electrode for pH adjustment. If only the usual chloride-type reference electrode is available for pH adjustment, determine amount of acid or alkali required to obtain a pH of 2.5 ± 0.1 and discard this sample portion. Treat a separate sample portion with the determined amount of acid or alkali and continue analysis. Under these circumstances, omit nitric acid, from indicator reagent.

5.4.2 Standard mercuric nitrate titrant: 0.014 1 N. Dissolve 2.3 g mercuric nitrate [Hg $(NO_3)^2$ or 2.5 g Hg $(NO_3)^2$. H_20] in 100 ml distilled water containing 0.25 ml concentrated nitric acid. Dilute to just under 1 litre. Make a preliminary standardization by following the procedure described in Para 6.1. Use replicates containing 5.00 ml standard Sodium chloride solution and 10 mg sodium bicarbonate ($NaHCO_3$) diluted to 100 ml with distilled water. Adjust titrant to 0.014 1 N and make a final standardization; 1.00 ml = 500 µg Cl-. Store away from light in a dark bottle.

5.5 Reagent for chloride concentration greater than 100 mg/l

5.5.1 Mixed indicator reagent: Dissolve 0.50g diphenylcarbazone powder and 0.05g bromophenol blue powder in 75 ml 95 percent ethyl or isopropyl alcohol and dilute to 100 ml with the same alcohol.

5.5.2 Strong standard mercuric nitrate titrant: 0.141 N. Dissolve 25 g mercuric nitrate [Hg $(NO_3)^2$. H_2O] in 900 ml distilled water containing 5.0 ml concentrated nitric acid. Dilute to just under 1 litre and standardize by following the procedure described in Para 6.2. Use replicates

containing 25.00 ml standard sodium chloride solution and 25 ml distilled water. Adjust titrant to 0.141 N and make a final standardization; 1.00 ml = 5.00 mg Cl.

6. Procedure:

6.1 Titration of chloride concentration less than 100 mg/l: Use a 100 ml sample or small portions so that the chloride content is less than 10 mg. Add 1.0 ml indicator-acidifier reagent. For highly alkaline or acid waters, adjust pH to about 8 before adding indicator-acidifier reagent. Titrate with 0.014 1 N mercuric nitrate to a definite purple end point. The solution turns from green blue to blue a few drops before the end point. Determine the blank by titrating 100 ml distilled water containing 10 mg of sodium bicarbonate.

6.2 Titration of chloride concentrations greater than 100 mg/l: Use a sample portion requiring less than 5 ml titrant to reach the end point. Measure into a 160 ml beaker. Add approximately 0.5 ml mixed indicator reagent and mix well. The colour should be purple. Add 0.1 N nitric acid dropwise until the colour just turns yellow. Titrate with 0.141 N mercuric nitrate to first permanent dark purple. Titrate a distilled water blank using the same procedure.

7. Calculation

Chloride, mg/l = [(V1 - V2) x N x 35450] / V3

Where:

V1 = Volume in ml of titrant used for sample,

V2 = Volume in ml of titrant used for blank,

V3 = Volume in ml of the sample taken for test, and

N = Normality of the sample taken for test.

(C) Potentiometric Method

3. Principle: Chloride is determined by potentiometric titration with silver nitrate solution with a glass and silver-

silver chloride electrode system. The end point of the titration is that instrument reading at which the greatest change in voltage has occurred for a small and constant increment of silver nitrate.

4. Apparatus

4.1 Glass and silver-silver chloride electrodes

4.2 Electronic voltmeter

4.3 Mechanical stirrer

5. Reagents

5.1 Standard sodium chloride solution - 0.014 1 N.

5.2 Nitric acid - concentrated.

5.3 Standard silver nitrate titrant - 0.014 1 N.

5.4 Pretreatment reagents

5.4.1 Sulphuric acid - 1:1.

5.4.2 Hydrogen peroxide - 30 percent.

5.4.3 Sodium hydroxide - 1 N.

6. Procedure:

6.1 Standardization: Place 10.0 ml of standard sodium chloride solution in a 260 ml beaker; dilute to about 100 ml and add 2.0 ml concentrated nitric acid. Immerse stirrer and electrodes. Set instrument to desired range of millivolts or pH units. Start stirrer. Add standard silver nitrate titrant, recording scale reading after each addition. At the start large increments of silver nitrate may be added, then as the end point is approached, add small and equal increments at longer intervals so that the exact end point can be determined. Determine the volume of silver nitrate used at the point at which there is the greatest change in instrument reading per unit addition of silver nitrate. Plot a differential titration curve if the exact end point cannot be determined by inspecting the data. Plot change in instrument reading for equal increments of silver nitrate against

volume of silver nitrate added, using average of burette readings before and after each addition.

6.2 Sample analysis: Pipette 100 ml of sample or a portion containing not more than 10 mg of chloride, into a 250 ml beaker. In the absence of interfering substances, proceed as above.

In the presence of organic compounds, sulphite or other interferences, acidify sample with sulphuric acid using litmus paper. Boil for 5 minutes to remove volatile compounds. Add more sulphuric acid, if necessary, to keep solution acidic. Add 3 ml of hydrogen peroxide and boil for 15 minutes, adding chloride free distilled water to keep the volume above 60 ml. Dilute to 100 ml, add sodium hydroxide solution dropwise until alkaline to litmus, then 10 drops in excess. Boil for 5 minutes, filter into a 250 ml beaker, and wash precipitate and paper several times with hot water. Add concentrated nitric acid dropwise until acidic to litmus paper, then 2.0 ml in excess. Cool and dilute to 100 ml, if necessary. Immerse stirrer and electrodes and start stirrer. Make necessary adjustments according to manufacturer's instructions and set selection switch to appropriate setting for measuring the difference of potential between electrodes. Complete determination as detailed in Para 6.1. If an end point reading has been established from previous determinations for similar samples and conditions. use this predetermined end point. For the most accurate work, make a blank titration by carrying chloride free distilled water through the procedure.

7. Calculation

Chloride (as Cl) = [(V1 - V2) x N x 35450] / V

Where:

V1 = Volume in ml of silver nitrate titrant used in sample,

V2 = Volume in ml of silver nitrate used in blank,

V3 = Volume in ml of sample used in the test, and

N = Normality of titrant.

(D) Automated Ferricyanide Method

3. Principle: Thiocyanate ion is liberated from mercuric thiocyanate by the formation of soluble mercuric chloride. In the presence of ferric ion, free thiocyanate ion forms highly coloured ferric thiocyanate, of which the intensity is proportional to the chloride concentration.

4. Apparatus

4.1 Automated analytical equipment: The required continuous flow analytical instrument consists of the interchangeable components as shown in Fig. 4.6.3.

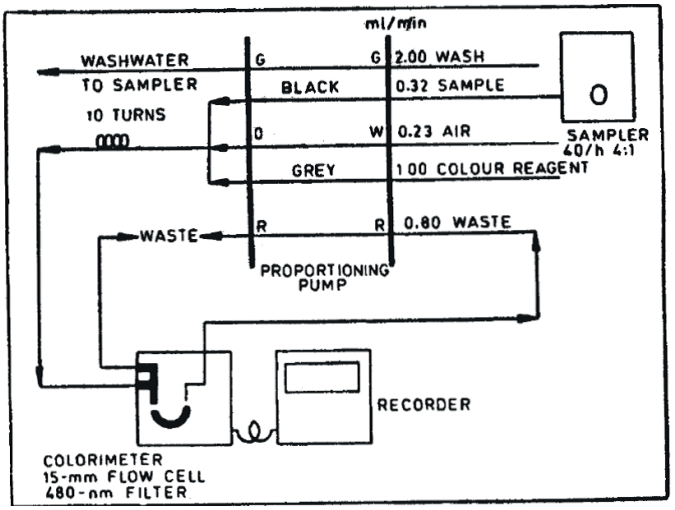


Fig. 4.6.3: Automated analytical equipment

4.2 Filters: 480 nm.

5. Reagents

5.1 Stock mercuric thiocyanate solution: Dissolve 4.17 g of mercuric thiocyanate in about 500 ml of methanol, dilute to 1000 ml with methanol, mix and filter through filter paper.

5.2 Stock ferric nitrate solution: Dissolve 202 g of ferric

nitrate [Fe $(NO_3)^3$. g H_2O] in about 500 ml of distilled water, then carefully add 21 ml of concentrated nitric acid. Dilute to 1000 ml with distilled water and mix. Filter through paper and store in coloured bottle.

5.3 Colour reagent: Add 150 ml stock mercuric thiocyanate solution to 150 ml of stock ferric nitrate solution. Mix and dilute. to 1000 ml with distilled water. Add 0.5 ml of polyoxymethylene 23 lauryl ether.

5.4 Stock chloride solution: Dissolve 1.648 2 g sodium chloride, dried at 140°C in distilled water and dilute to 1000 ml, 1.00 ml = 1.00 mg of chloride.

5.5 Standard chloride solutions: Prepare chloride standards in the desired concentration range, such as 1 to 200 mg/l, using stock chloride solution.

6. Procedure: Set up manifold as shown in Fig. 4.6.3 and follow general procedure prescribed by the manufacturer.

7. Calculation: Prepare standard curves by plotting peak heights of standards processed through the manifold against chloride concentrations in standards. Compute sample chloride concentration by comparing sample peak height with standard curve.

4.7 Sulphates in Water

1. Introduction: Sulphates are chemical salts, which dissolve in water forming solution. Solid sulphates do not react with concrete severely, but when in water solution they penetrate into the porous mass of concrete and react with the hydrated products of cement. Magnesium sulphate is more reactive and causes maximum damage to the concrete than others. Magnesium sulphate decomposes the hydrated calcium silicates as well as $Ca(OH)_2$ and hydrated tricalcium aluminate (C_3A). Eventually it forms hydrated magnesium silicate, which has no binding properties. The sulphate attack or reaction is indicated by the characteristic whitish appearance on the surface. In the hardened concrete calcium aluminate hydrate (C_3A) can react with sulphate salt from outside through pores. The product of reaction is calcium sulpho-aluminate, forming within frame work of hydrated cement paste. Due to this reaction the volume of solid phase increases upto 227%, causing gradual disintegration of concrete. The extent of sulphate attack depends on the concentration of sulphate solution and permeability of concrete. As per IS:456-2000, the Sulphate content in the water used for concrete mixing has to be limited to 400 mg/l.

2. Reference: IS-3025(Part-24/Sec-1):2022 "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-24: Sulphates. Section-1: Gravimetric and turbidity methods".

(A) <u>Gravimetric Method</u>

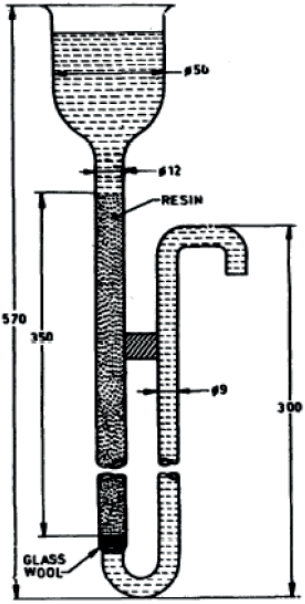
3. Applicability: This method is applicable for all the waters having sulphate concentrations above 10 mg/l; however, it is a time-consuming method.

4. Principle: Sulphate is precipitated in hydrochloric acid medium as barium sulphate by the addition of barium chloride solution. The precipitation is carried out near boiling temperature and after a period of digestion, the precipitate is filtered and washed with distilled water until

free of chlorides. It is then ignited or dried and weighed as barium sulphate ($BaSO_4$). The reaction in its simplest form is:

5. Sampling and Storage: Sampling and storage shall be done as prescribed in IS:3025 (Part 1). Highly polluted or contaminated samples should be stored at low temperature or treated with formaldehyde. Sulphite may be oxidized to sulphate by dissolved oxygen above pH 8.0; samples containing sulphite should have their pH adjusted below this value.

6. Apparatus



(All dimensions are in mm)

Fig. 4.7.1: Ion exchange Column

6.1 Steam Bath

6.2 Drying Oven, equipped with thermostatic control.

6.3 Muffle Furnace, with heat indicator.

6.4 Desiccator

6.5 Analytical Balance, with least count of 0.1 mg.

6.6 Filter Paper, acid washed, ash-less hard finish filter paper sufficiently retentive for fine precipitates (preferably Whatman No. 42/equivalent).

6.7 Crucible, porous bottom silica or porcelain crucible with a maximum pore size of 5 microns.

6.8 Ion-Exchange Column, see Fig. 4.7.1 for details. The exchange column should be regenerated by passing hydrochloric acid solution after five or six samples have passed through the column, followed by washing with distilled water.

7. Reagents

7.1 Methyl Red Indicator: Dissolve 100 mg methyl red sodium salt in distilled water and dilute to 100 ml.

7.2 Hydrochloric Acid Solution (1:4): Dilute one volume of concentrated hydrochloric acid with four volumes of distilled water.

7.3 Barium Chloride Solution: Dissolve 100 g of barium chloride ($BaCl_2$. $2H_2O$) in 1 litre distilled water. Filter through a membrane filter or hard finish filter paper (1 ml of this reagent is capable of precipitating approximately 40 mg SO_4^{2-}).

7.4 Silver Nitrate : Nitric Acid Reagent: Dissolve 8.5 g of silver nitrate and 0.5 ml of nitric acid in 500 ml distilled water.

7.5 Ion Exchange Resin: Strong cation exchange resin, amberlite IR-120 or equivalent.

8. Sample preparation

8.1 The sample used for analysis should either be free from turbidity or filtered through 0.45 µm filter.

8.2 If the total cation concentration in the sample is more than 250 mg/l or if the total heavy metal ion concentration is more than 10 mg/l, pass the sample through a cation removing ion exchange column.

8.3 If the silica concentration exceeds 25 mg/l, evaporate the sample nearly to dryness in a platinum dish on a steam bath. Add 2 ml hydrochloric acid solution (see Para 7.2), tilt the dish and rotate it until the acid comes in contact with the residue; continue the evaporation to dryness. Complete the drying in an oven at 180°C and if organic matter is present, char over the flame of a burner. Moisten the residue with 2 ml distilled water and 2 ml hydrochloric acid solution (see Para 7.2) and evaporate to dryness on steam bath. Add 5 ml hydrochloric acid solution (see Para 4.6.2), take up the soluble residue in hot water and filter. Wash the insoluble silica with several small portions of hot distilled water. Combine the filtrate and washings.

9. Procedure

9.1 Adjust the clarified sample, treated if necessary to remove interfering agents, to contain approximately 100 mg of sulphate ion in 500 ml volume.

9.2 Add 2 to 3 drops of methyl red indicator solution (see Para 7.1). Add hydrochloric acid solution (see Para 7.2) drop by drop till an orange red colour appears. Lower concentrations of sulphate ion may be tolerated if it is impracticable to concentrate the sample to the optimum level, but in such cases it is better to fix the total volume at 150 ml after concentration on hot plate.

9.3 Heat the solution to boiling, while stirring gently, add warm barium chloride solution (see Para 7.3) slowly until precipitation appears to be complete, then add about 2 ml in excess. Digest the precipitate at 80-90 °C for at least 2 hour.

9.4 Filtration: Filter the precipitate through filter paper and wash the precipitate with small portion of warm distilled water until the washings are free of chloride ions as indicated by testing with silver nitrate-nitric acid reagent (see Para 7.4).

9.5 Transfer the filter paper along with the precipitate in the crucible and dry the precipitate and ignite at 800 °C for 1 hour.

9.6 Cool in a desiccator and weigh.

10. Calculation: The concentration of sulphates in the sample from the equation:

Sulphate concentration as mg/l BaSO4 = (m × 411.5) / V

Where:

m = Mass of $BaSO_4$, in mg; and

V = volume of sample, in ml.

(B) <u>Turbidity Method</u>

3. Applicability and Range

3.1 This method can be applied for all concentration ranges of sulphate; however readings are accurate for sample aliquots containing not more than 40 mg/l of SO_4^{2-}.

3.2 The minimum detectable limit is approximately 1 mg/l SO_4^{2-}.

4. Principle: Sulphate ion is converted into barium sulphate suspension under controlled conditions. This suspension can be measured by using a nephelometer or spectrophotometer and light absorbance is measured at different concentrations; sample concentrations may be evaluated from standard curve.

5. Sampling and Storage: Sampling and storage shall be done as prescribed in IS:3025 (Part 1). The bottles shall be capped tightly as soon as the sample is collected.

6. Apparatus

6.1 Magnetic Stirrer, constant stirring speed so that it can be held constant just below splashing. Use identical sizes and shapes of magnetic stirrer bars.

Fig. 4.7.1: Nephelometer

Fig. 4.7.2: Spectrophotometer

6.2 Photometer (use one of the following, given in order of preference):

(a) Nephelometer (Fig. 4.7.1)

(b) Spectrophotometer (Fig. 4.7.2), for use at 420 nm with light path of up to 5 cm.

6.3 Stopwatch, to be used if magnetic stirrer is not equipped with an accurate timer.

6.4 Measuring Spoon, capacity from 0.2 ml to 0.3 ml.

7. Reagents

7.1 Buffer Solution: Dissolve 30 g magnesium chloride ($MgCl_2$. $6H_2O$), 5g Sodium acetate ($CH_3COONa.3H_2O$), 1 g Potassium nitrate (KNO_3) and 20 ml acetic acid (CH_3COOH) in distilled water in a 500 ml volumetric flask and make up volume up to 1000 ml.

7.2 Standard Sulphate Solution: Dissolve 0.1479 g anhydrous Na_2SO_4 in distilled water and dilute to 1000 ml (1 ml = 100 µg SO_4^{2-}).

7.3 Barium Chloride : crystals, 20 to 30 mesh.

8. Procedure

8.1 Preparation of Calibration Curve: Take 1.0 ml, 5.0 ml, 10.0 ml, 20.0 ml and 40.0 ml of the standard sulphate solution (see Para 7.2) into 250 ml conical flasks and make up to the 100 ml mark with distilled water. Take 100 ml distilled water in a 250 ml flask for

preparing distilled water blank. The concentration of the standards corresponding to 1.0 ml, 5.0 ml, 10.0 ml, 20.0 ml and 40.0 ml standard sulphate solution (1 ml = 100 µg SO_4^{2-}) are 100 µg (1 mg/l), 500 µg (5 mg/l), 1000 µg (10 mg/l), 2000 µg (20 mg/l) and 4000 µg (40 mg/l) respectively. Add 10 ml of buffer solution (see Para 7.1) and mix using magnetic stirrer. While stirring, add a spoonful of $BaCl_2$ crystals (see Para 7.3) and begin timing immediately. Stir for 30 seconds at constant speed. After stirring has ended, pour the solution into absorbance cell. Measure turbidity at 420 nm against distilled water in 30 seconds interval for 5 minutes. Record the maximum reading obtained in the 5 min period. The corrected absorbance readings of the standard solutions are obtained by subtracting the absorbance readings of the standard solutions from that of distilled water blank. Plot the corrected absorbance readings of the standard solutions against concentrations.

8.2 Sample Analysis

8.2.1 Measure 100 ml sample, or suitable portion made up to 100 ml into a 250 ml conical flask. Prepare a distilled water blank by taking 100 ml distilled water in another 250 ml conical flask. Add 10 ml buffer solution (see Para 7.1) and mix using magnetic stirrer. Follow the next procedures as done for standard solutions. Measure the absorbance reading of sample and distilled water blank against distilled water as reference. The corrected absorbance reading of sample is obtained by subtracting absorbance reading of distilled water blank from that of sample.

8.2.2 For samples having turbidity or colour, prepare a sample blank by taking 100 ml of the turbid or colured sample in a 250 ml conical flask. Add 10 ml of buffer solution (see Para 7.1) and take absorbance reading at 420 nm (without

adding BaCl2) against distilled water as reference. The corrected absorbance reading of sample is obtained by subtracting the absorbance reading of distilled water blank and sample blank from the observed absorbance reading of sample.

9. Calculation: The concentration of sulphates in the sample from the equation:

Sulphate concentration (as SO_4^{2-}) = (A × 1000) / (V x k)

Where:

A = Corrected absorbance reading of sample;

k = Slope from calibration curve; and

V = Volume of sample taken (in ml).

If the sulphate content of sample is found to be greater than 10 mg/L, then the sample analysis is repeated using buffer solution A. A distilled water blank is prepared by using buffer solution A. The corrected absorbance reading of sample is obtained by subtracting absorbance reading of distilled water blank from absorbance reading of sample.

Chapter - 5

TESTS ON FRESH CONCRETE

Workability is the most commenely tested parameter for the fresh Concrete. It can be checked by three different methods, as listed below:

(5.1) Workability of Concrete:

(A) Slump Test

(B) Compacting Factor Test

(C) Vee-Bee Consistometer Test

This Page
is
Intentionally
Left Blank

5.1 Workability of Concrete

1. General: Workability of Concrete is a broad term describing how easily freshly mixed concrete can be mixed, placed, consolidated, and finished with minimal loss of homogeneity. It is a property that directly impacts strength, quality, appearance, and even the cost of labour for placement and finishing operations. A concrete mix with good workability brings many attributes together and results in a quality product with long service life.

Another similar term used to describe freshly prepared concrete is "consistency" which is the ease with which it will flow. It is a measure of fluidity or mobility of concrete.

The consistency of the concrete can be determined by many methods, out of which three most commonly used methods (Slump Test, Compacting Factor Test and Vee-Bee Consistometer Test) are covered in this chapter. It is to be noted that all these three tests are not applicable for foam concrete, no fines concrete, or where the nominal maximum aggregate size exceeds 40mm. If the concrete contains coarse aggregate with size larger than 40mm, the concrete shall be wet-sieved through 40mm screen to exclude aggregate particles bigger than 40mm.

2. Reference: All these tests are conducted as per IS-1199 (Part-2):2018 "Fresh Concrete – Methods of Sampling, Testing and Analysis; Part-2 – Determination of Consistency of Fresh Concrete".

3. Sampling: Samples for all these three tests shall be obtained as per IS 1199(Part 1). Each sample shall be remixed before carrying out the tests. The sampling is to be done as below:

3.1 Terminology

3.1.1 Batch: Quantity of concrete, mixed in one cycle of operations of a batch mixer or the quantity of concrete conveyed ready mixed in a vehicle, or the quantity of concrete discharged

over 1 min from a continuous mixer.

3.1.2 Composite Sample: Quantity of concrete consisting of a number of increments, distributed through a batch or mass of concrete, which are thoroughly mixed together.

3.1.3 Spot Sample: Quantity of concrete taken from a part of a batch or mass of concrete, consisting of one or more increments that are thoroughly mixed together.

3.1.4 Increment: Quantity of concrete taken by the single operation of a scoop.

3.2 Taking a composite sample: Concrete is sampled from a stream of moving concrete or from a pile, in a series of increments. These increments are then thoroughly mixed together.

3.3 Taking a Spot Sample: Concrete is sampled from a stream of moving concrete or from a pile, at a single point. Spot samples are not representative of the batch and should not be used to cast strength specimens.

3.4 Apparatus

3.4.1 Scoop, made from non-absorbent material not readily attacked by cement paste, with a size suitable for taking increments of concrete.

3.4.2 Containers, one or more containers, made from non-absorbent material (preferably made of metal) not readily attacked by cement paste, for receiving, transporting and remixing the concrete samples.

3.4.3 Thermometer, (when required), to measure the temperature of fresh concrete to an accuracy of ±1°C.

3.5 Procedure: Whether a composite sample or spot sample is to be taken will depend on intended use of the sample. Spot samples are not representative of the batch and should not be used to make strength

specimens.

For samples to be used for strength test, a minimum quantity of 0.02 m3 will be essential. For other tests such as air content, temperature and determination of consistency, smaller size samples may suffice. The size of samples shall also depend upon the maximum size of aggregate.

3.5.1 Obtaining a Composite Sample: Ensure that the apparatus is clean and dampen it with a moist, but not wet, cloth prior to use. Using the scoop, take the required number of increments uniformly distributed throughout the batch. When sampling from a stationary batch mixer or ready-mixed concrete truck, disregard the very first and the very last of the discharge (about 10 to 15 percent). When sampling from a falling stream, the increments shall be taken in such a way as to represent the whole width and thickness of the stream. If the batch has been deposited in a heap of concrete, take the increments, wherever possible, distributed through the depth of the concrete as well as over the exposed surface. Increments shall not be taken from parts of the concrete that appear to be segregated. The increments shall be taken from at least four points. Deposit the increments into the container(s).

3.5.2 Obtaining a Spot Sample: Ensure that the apparatus is clean and dampen it with a moist, but not wet, cloth prior to use. Take the sample increment(s) by a scoop from the required part of a batch or mass of concrete. Deposit the increment(s) into the container(s).

3.5.3 Mixing, Transporting and Handling of Samples: The samples, obtained by either of the methods described above, shall be mixed thoroughly in non-absorbent container with shovel or by other suitable implement.

At all stages of sampling, transporting and handling, care shall be taken to protect the fresh concrete samples against contamination, increase or loss of moisture, excessive vibration, and against extreme variations of temperature.

The properties of fresh concrete change with time after mixing, depending upon climatic conditions, more so if the concrete contains admixture. This should be taken into account in deciding when test specimens are made and when tests are carried out.

It is recommended that the tests for slump, temperature, and air content should start within 5 min after obtaining the final portion of the composite sample. Complete these tests expeditiously.

3.5.4 Measuring the Temperature of the Sample: Whenever required, measure the temperature of the concrete in the container(s) at the time of sampling.

3.6 Sampling Record: The following information regarding the samples shall be included in the sample report:

(a) Clear identification of the sample (sample number),

(b) Type of sample (composite or spot),

(c) Date and time of sampling,

(d) Type and grade (if applicable) of cement and admixtures (if used),

(e) Identification of the works which the sample represents,

(f) Identification of the batch or truck mixer sampled,

(g) Ambient temperature,

(h) Temperature of the concrete sample (when

required),

(j) Any deviations from the standard method of sampling,

(k) A declaration by the person responsible for sampling that the sample was obtained in accordance with this Indian standard, except as noted in (j), and

(m) Name and signature of person responsible for sampling.

(A) By Slump Test

1. Introduction: It is the most common method for measuring the workability of freshly mixed concrete. The fresh concrete is compacted into a mould in the shape of a frustum of a cone. When the cone is withdrawn upwards, the distance that the concrete has slumped provides a measure of the consistency of the concrete.

It can be performed both in lab and at site. Uniformity of the concrete regarding workability and quality aspects can be assessed from batch to batch by observing the nature in which the concrete slumps.

The slump test is applicable to a range of consistency of concrete that corresponds to slumps between 10mm and 210mm. Outside this range, other method of determination of consistency should be considered.

2. Apparatus required

(i) Mould: It shall be made of metal, not readily attacked by cement paste and having at least 1.6mm thickness. The mould shall have a smooth internal surface and free from dents. It shall be in the form of a hollow frustum of a cone and shall have the following internal dimensions:

(a) Diameter of base: 200 ± 2 mm

(b) Diameter of top: 100 ± 2 mm

(c) Height: 300 ± 2 mm

The base and the top shall be open and parallel to

each other and at right angle to the axis of the cone. The mould shall be provided, on the upper portion, with two handles at two-thirds of the height, and at the bottom with fixing clamps or foot pieces to hold it steady. A typical mould without guide is shown in Fig. 5.1.1.

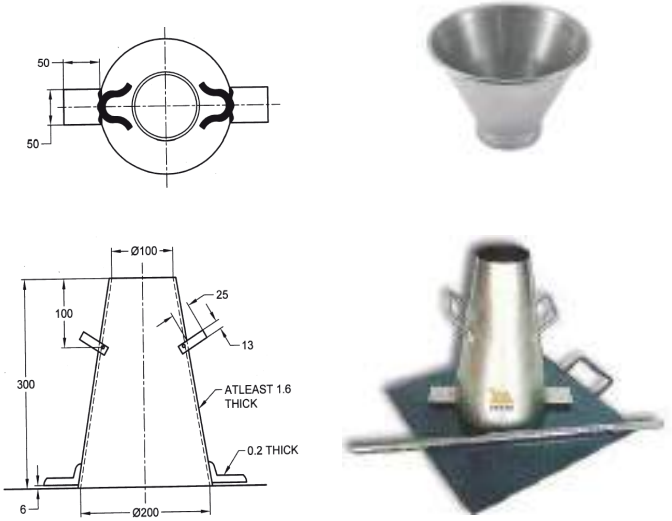


Fig. 5.1.1: Slump Test Mould and Funnel

The mould shall be visually inspected prior to each use to ensure that the interior is clean and free from concrete deposits.

The mould shall be checked annually to ensure that its dimensions and condition remain within specified tolerances.

(ii) Tamping rod: Made of steel, having a circular cross-section with a diameter of 16 ± 1mm, 600 ± 5mm in length and with rounded ends. The rod may be extended with a handle of plastic conduit, provided that the overall length does not exceed 1000mm. The tamping rod shall be checked annually to ensure that its dimensions and condition remain within the tolerances.

(iii) Funnel (optional): Made of non-absorbent material, not readily attacked by cement paste. The funnel shall consist of two coaxial conical frustums having a common diameter of 100 ± 2mm, the ends being of greater diameter, one frustum to act as a filling funnel and the other as a collar to enable the funnel to be located on the outer surface of the mould (Fig. 5.1.1). The funnel shall be checked annually to ensure that its dimensions and condition remain within tolerances.

(iv) Rule: Graduated from 0mm to 300mm, at intervals not exceeding 5mm, with zero point being at extreme end of the rule.

(v) Base plate/surface: It shall be rigid, flat, non-absorbent and smooth plate on which the mould is to be placed.

(vi) Shovel: It shall have a square blade.

(vii) Re-mixing tray: It shall be of good construction and fabricated from a non-absorbent material, not readily attacked by cement paste. It shall be of appropriate dimensions such that the concrete can be thoroughly remixed, using the square bladed shovel.

(viii) Scoop: It shall be of adequate size.

(ix) Timer: It shall allow time measurement accurate to 1s. The timer shall be calibrated at suitable frequency.

3. Procedure

(a) Dampen the mould and base plate with a moist cloth. Wipe any excessive water from the surfaces using an absorbent cloth. Place the mould on the surface of the rigid horizontal base plate free from extraneous vibration and shock.

(b) Immediately after obtaining the sample, fill the mould in three layers, each approximately one-third of the height of the mould when compacted. During filling, clamp or hold the mould firmly in place by

standing on the two foot pieces.

(c) When filling the mould, ensure that the concrete is distributed symmetrically around the mould.

(d) Tamp each layer with 25 strokes of the tamping rod. The strokes shall be distributed in an uniform manner over the cross-section area of the mould. For the bottom layer, this will necessitate inclining the rod slightly and positioning approximately half the strokes spirally towards centre.

(e) Tamp the second layer and top layer each throughout its depth, so that the strokes just penetrate into the underlying layer.

(f) In filling and tamping the top layer, heap the concrete above the mould before the tamping is started.

(g) If the tamping operation of the top layer results in subsidence of the concrete below the top edge of the mould, add more concrete to keep an excess above the top of the mould at all times. Also ensure that the addition of concrete to the top layer does not provide extra compaction of the concrete.

(h) After the top layer has been tamped, scrap off the surface of the concrete level with the top of the mould by means of a sawing and rolling motion of the tamping rod. Remove spilled concrete from the base plate/surface.

(j) Remove the mould in 5 ± 2s by a straight upward push with no lateral or torsional motion being imparted to the concrete.

(k) The entire operation from the start of the filling to the removal of the mould shall be carried out without interruption and shall be completed within 180 s.

(l) Immediately after removal of the mould, determine the slump, h, by measuring the difference between the height of the mould and the highest point of the slumped concrete (see Fig. 5.1.2).

(m) Measure slump to the nearest 5mm.

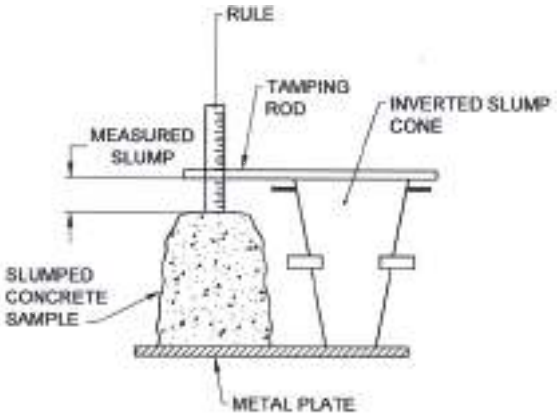


Fig. 5.1.2: Slump Measurement

4. Test Results: The test is valid only if it yields a true slump, this being a slump in which the concrete remains substantially intact and symmetrical as shown in 3A of Fig. 5.1.3. If a specimen shears as shown in 3B of Fig. 5.1.3 or collapses as shown in 3C of Fig. 4.1.3, take another sample and repeat the entire procedure as described above.

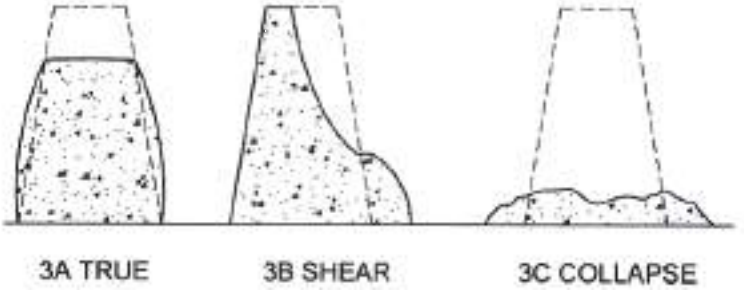


Fig. 5.1.3: Types of Slump

Record the true slump, to the nearest 5mm.

If two consecutive test show portion of concrete shearing of from the mass of the test specimen or collapsing, report the test as being invalid as the concrete lacks the

necessary plasticity and cohesiveness for the slump test to be suitable.

5. Test Report: The test report shall also include the following:

(a) Slump, if there is a true slump, measured to the nearest 5mm; or

(b) A notation that the test gave a sheared/collapsed slump.

(B) By Compacting Factor Test

1. Introduction: This test is generally carried out in laboratory but can be used in site also. It is particularly useful for concrete mixes of very low workability (or very dry concrete), with the nominal maximum size of the aggregate not exceeding 40mm, as they are insensitive to slump test. It is more precise and sensitive than the slump test.

This test works on the principle of determining the degree of compaction achieved by a standard amount of work done by allowing the concrete to fall through a standard height.

2. Apparatus: A diagram of the apparatus is shown in Fig. 5.1.4. It shall consist of the two conical hoppers (A and B) mounted above a cylindrical mould (C).

The essential dimensions of the hoppers and mould and distances between them shall be as shown in Table 5.1.

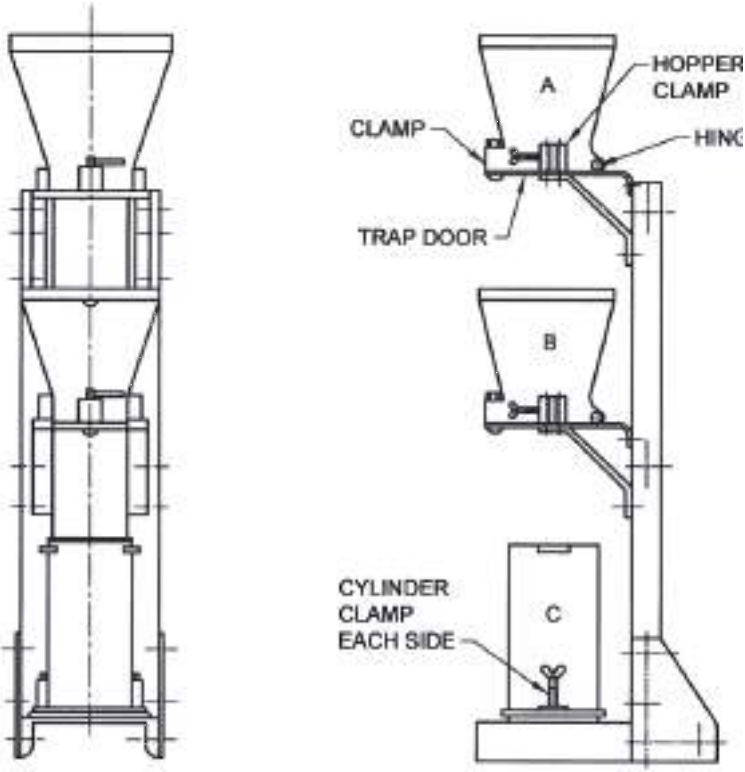


Fig. 5.1.4: compaction Factor Apparatus

Table 5.1: Dimensions of Compaction Factor Apparatus

Sl. No.	Details (see Fig. 4.1.5)	Dimension (mm)
(i)	Upper hopper, A:	
	(a) Top internal diameter	250
	(b) Bottom internal diameter	125
	(c) Internal height	280
(ii)	Lower hopper, B:	
	(a) Top internal diameter	230

	(b) Bottom internal diameter	125
	(c) Internal height	230
(iii)	Cylinder, C:	
	(a) Internal diameter	150
	(b) Internal height	300
(iv)	Distance between bottom of upper hopper and top of lower hopper	200
(v)	Distance between bottom of lower hopper and top of cylinder	200

The hopper and cylinder shall be of rigid construction, true to shape and smooth inside. They shall preferably be made of cast brass or bronze, but stout sheet brass or steel may also be considered satisfactory provided the inside surfaces of the joints are smooth and flush. The lower ends of the hoppers shall be closed with tightly fitting hinged trap-doors having quick release catches. Metal plate 3mm thick is suitable for the doors. The frame in which the hoppers and cylinder are mounted shall be of rigid construction and shall firmly locate them in the relative positions indicated in Table 4.1. The cylinder and hoppers shall be easily detachable from the frame.

The apparatus shall also include two ordinary trowels, one scoop of adequate size, a tamping rod made of steel, having a circular cross-section with a diameter of 16 ± 1mm, 600 ± 5mm in length and with rounded ends, and scales (or a balance) to weigh up to 50kg, with an accuracy to the nearest 10g.

3. Sampling: The sample shall be taken as per Para 3 above. In the case of concrete containing aggregate of maximum size more than 40mm, the concrete shall be wet sieved through 40mm screen to exclude aggregate particles bigger than 40mm.

4. Procedure: Dampen the inside of the hopper and cylinder with a moist cloth before its use. The sample of concrete to be tested shall be placed gently in the upper hopper, using the scoop. The hopper shall be filled level with its brim and the trap-door shall be opened so that the concrete falls into the lower hopper. Certain mixes have a tendency to stick in one or both of the hoppers. If this occurs, the concrete may be helped through by pushing the rod gently into the concrete from the top. During this process, the cylinder shall be covered by the trowels. Immediately after the concrete has come to rest, the cylinder shall be uncovered, the trap-door of the lower hopper opened, and the concrete allowed to fall into the cylinder. The excess of concrete remaining above the level of the top of the cylinder shall then be cut off by holding a trowel in each hand, with the plane of the blades horizontal, and moving them simultaneously one from each side across the top of the cylinder, at the same time keeping them pressed on the top edge of the cylinder. The outside of the cylinder shall then be wiped clean. The above operation shall be carried out at a place free from vibration or shock. The weight of the concrete in the cylinder shall then be determined to the nearest 50g. This weight shall be known as the weight of partially compacted concrete. The cylinder shall be refilled with concrete from the same sample in layers approximately 5cm deep, the layers being heavily rammed or preferably vibrated so as to obtain full compaction. The top surface of the fully compacted concrete shall be carefully struck off level with the top of the cylinder. The outside of the cylinder shall then be wiped clean. The weight of the concrete in the cylinder shall then be determined to the nearest 50g. This weight shall be known as the weight of fully compacted concrete.

Note: The test is sufficiently sensitive to enable differences in workability arising from the initial processes in the hydration of the cement to be measured. Each test, therefore, should be carried out at a constant time interval after the mixing is completed, if strictly comparable

results are to be obtained.

5. Calculation: The compacting factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete. It shall normally be stated to the nearest second decimal place.

6. Test Report: The test report shall include the compacting factor value, expressed to the nearest two decimal places.

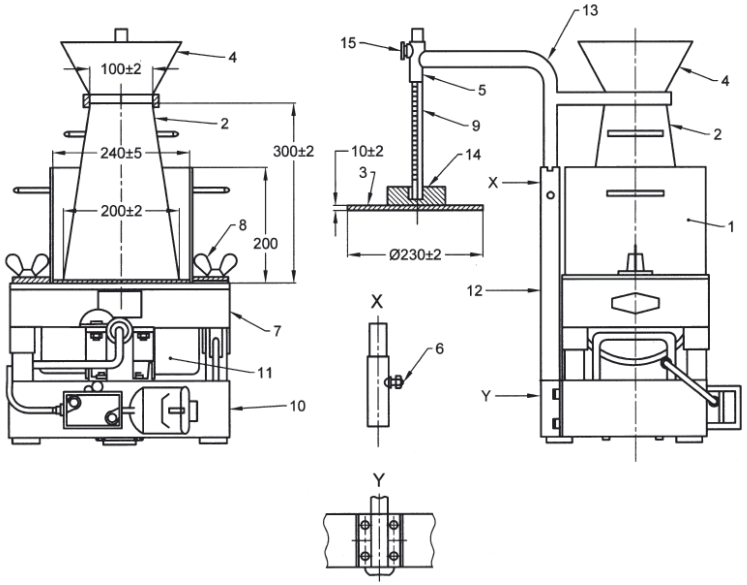
(C) By Vee-Bee Consistometer Test

1. Introduction: Vee-Bee test is a good laboratory test suitable for stiff concrete mixes having low and very low workability. The Vee-Bee consistometer test determines the time required for transforming, by vibration, a concrete specimen in the shape of a conical frustum into a cylinder. The fresh concrete is compacted into a slump mould. The mould (cone) is lifted of the concrete and a transparent disc is swung over the top of the concrete and carefully lowered until it comes in contact with the concrete. The slump of the concrete is recorded. The vibrating table is started and the time taken for the lower surface of the transparent disc to be fully in contact with cement paste of the concrete is measured.

If the Vee bee time is less than 5 s or more than 30 s, the use of the test method to determine consistency may be unsuitable and other methods should be considered for this purpose (modified Vee bee consistometer test can be used for testing of very stiff dry concretes such as roller compacted concrete).

2. Apparatus

2.1 Consistometer (Vee-Bee meter) consists of the following items as shown in Fig. 5.1.5:



(All dimensions are in mm)

Fig. 5.1.5: Vee Bee Consistometer

Key:

1 container	6 set-screw	11 vibrator unit
2 mould	7 vibrating table	12 holder
3 transparent disc	8 wing nuts	13 swivel arm
4 funnel	9 rod	14 weight
5 guide sleeve	10 base for vibrator	15 screw

(a) Container (see 1 in Fig. 5.1.5): It is cylindrical in shape, having an internal diameter of 240 ± 5mm and a height of 200 ± 2mm and made of a metal, not readily attacked by cement paste. The thickness of wall shall be 3mm and that of the base 7mm. The container shall be watertight and of sufficient rigidity to retain its shape under rough usage. It shall be fitted with handles and protected from corrosion. The container shall be

provided with suitable foot pieces to enable it to be securely clamped to the top of the vibrating table (see 7 in Fig. 5.1.5) by means of wing nuts (see 8 in Fig. 5.1.5).

(b) Mould (see 2 in Fig. 5.1.5), same as for the Slump Test, except that the fixing clamps or foot pieces are not required. The mould shall be visually checked prior to each use to ensure that it is clean and not damaged or dented.

(c) Disc (see 3 in Fig. 5.1.5): A transparent and horizontal disc attached to a rod (see 9 in Fig. 5.1.5) that slides vertically through a guide sleeve (see 5 in Fig. 5.1.5) mounted on swivel arm (see 13 in Fig. 5.1.5) and which can be fixed in a position by a screw (see 15 in Fig. 5.1.5). The swivel arm also supports a funnel (see 4 in Fig. 5.1.5), the bottom of which coincides with the top of the conical mould when the latter is positioned concentrically in the container. The swivel arm is located by a hold (see 12 in Fig. 5.1.5) and can be fixed in a position by set screw (see 15 in Fig. 5.1.5). When in the proper position, the axes of the rod and of the funnel shall be coincident with the axis of the container.

The transparent disc shall be 230 ± 2mm in diameter and 10 ± 2mm in thickness. A weight placed directly above the disc shall be provided such that the moving assembly consisting of the rod, the disc and the weight has a mass of 2 750 ± 50g. The rod shall be provided with a scale graduated to at least 5mm intervals to record the slump of the concrete.

(d) Vibrating table: It shall be 380 ± 3mm in length and 260 ± 3mm in width, supported on four rubber shock absorbers.

A vibrator unit (see 11 in Fig. 5.1.5), carried on a base resting on three rubber feet, shall be securely fixed beneath it. The vibrator shall

operate at a frequency of 55 ± 5.5 Hz and the vertical amplitude of vibration of the table with empty container on the top of it shall be approximately 0.5 ± 0.02mm.

The vibrating table shall be checked annually to ensure that the frequency and the vertical amplitude remain within tolerances. All the elements of the vibration table shall be checked annually to ensure that their dimensions remain within tolerances.

3.2 Tamping rod: It is a straight rod, made of steel or other suitable material, of circular cross-section, having a diameter of 16 ± 1mm, 600 ± 5mm in length, and with rounded ends.

3.3 Stopwatch or clock, capable of recording time to an accuracy of 1 s.

3.4 Remixing container: It is of rigid construction, made from non-absorbent material not readily attacked by cement paste.

3.5 Scoop, of adequate size.

3. Procedure

(a) Place the Vee-Bee meter (consistometer) on a rigid horizontal base free from extraneous vibration and shock. Make sure that the container is firmly fixed to the vibrating table by means of wing nuts. Dampen the inside of the mould with a moist cloth and place it in the container. Swing the funnel into position over the mould and lower the funnel on the mould. Tighten the screw so that the mould cannot rise from the bottom of the container. During the subsequent operations ensure that the mould does not rise or move until it is manually raised and ensure that concrete has not fallen into the container. From the sample of concrete, immediately fill the mould in three layers, each approximately one-third of the height of the mould when compacted. When adding the concrete, ensure that it is distributed

symmetrically around the mould.

(b) Tamp each layer with 25 strokes of the tamping rod. The strokes shall be distributed in a uniform manner over the cross-section area of the mould. For the bottom layer, this will necessitate inclining the rod slightly and positioning approximately half the strokes spirally towards centre. Tamp the second layer and top layer each throughout its depth, so that the strokes just penetrate into the underlying layer. In filling and tamping the top layer, heap the concrete above the mould before tamping is started. If necessary, add further concrete to maintain excess above the top of the mould throughout the tamping operation. After the top layer has been tamped, loosen the screw, raise and swing the funnel through 90° and tighten the screw. Scrape off the concrete level with the top of the mould with a sawing and rolling motion of the tamping rod. Lift the mould from the concrete

by raising it carefully in a vertical direction, using the handles. The operation of raising the mould shall be performed in 7 ± 2s by a steady upward lift with no lateral or torsional motion being imparted to the concrete. If the concrete shears, collapses or slumps to the extent that it touches the wall of the container, this information shall be recorded. Swing the transparent disc over the top of the concrete, loosen the screw and very carefully lower the disc until it just comes in contact with the concrete. When the disc just touches the highest point of the concrete without disturbing it, tighten the screw. When there is a true slump, the value of the slump shall be read from the scale and the value recorded. The screw shall be loosened to allow the disc to follow the concrete as it settles under the subsequent vibration. Simultaneously, start the vibration of the table and the timer. Observe through the transparent disc how the concrete is being re-moulded. As soon as the lower surface of the disc is fully in contact

with cement paste of the concrete, stop the timer and switch off the vibrating table. Record the time taken to the nearest second. Complete the procedure within a period of 5 min from the start of filling.

The consistency of the concrete mix changes with the time due to hydration of the cement and possibly, loss of moisture. Tests on different samples should, therefore, be carried out at a constant time interval after mixing, if strictly comparable results are to be obtained.

4. Test Result: Record the time read from the stopwatch to the nearest second. This is the Vee bee time which indicates the consistency of the concrete under test.

5. Test Report: The test report shall include the following:

(a) Time from completion of mixing of the concrete until the time of removal of the mould; and

(b) Vee bee time, in second.

This Page
is
Intentionally
Left Blank

Chapter - 6

TESTS ON HARDENED CONCRETE

Following are the most commenly performed tests on hardened concrete :

(6.1) Compressive Strength of Concrete

(6.2) Flexural Strength of Concrete

(6.3) Splitting Tensile Strength of Concrete

(6.4) Permeability of Concrete

- (A) As per IS:3085
- (B) As per IRS:CBC

(6.5) Rebound Hammer Test

(6.6) Ultrasonic Pulse Velocity Test

This Page
is
Intentionally
Left Blank

6.1 Compressive Strength of Concrete

1. Introduction: Concrete gains strength with time, after pouring and casting. It takes very long time to gain 100% strength and it often remains unknown. The rate of gain of compressive strength is higher during the first 28 days of casting, which gradually slows down. Therefore, compressive strength is checked after 28 days. The Characteristic Strength of Concrete (fck) is defined as the compressive strength of concrete cubes (cast as per relevant code of practice, cured for 28 days and then tested) below which not more than 5% of the test results are expected to fall.

2. Reference: IS-516 (Part-1/Sec-1) : 2021 "Hardened Concrete – Methods of Test. Part-1: Testing of Strength of Hardened Concrete. Section-1: Compressive, Flexural and Split Tensile Strength".

3. Test Specimen

3.1 The test specimen shall be a cube or a cylinder meeting the requirements of IS:1199 (Part 5) and IS:516 (Part 4) for concrete cores. The standard cube and cylinder specimen shall not be tested if they are badly honeycombed as this is an indication of poor specimen making. When such specimens are tested, the test report shall include the fact that the specimen was honeycombed.

3.2 Age at Test: Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days.

3.3 Number of Specimens: At least three specimens shall be tested at each selected age.

4. Apparatus required: The test shall be carried out using a compression testing machine conforming to IS:14858. The test machine shall be in calibration at the time of test. The calibration shall be carried out at least once per year.

5. Procedure:

5.1 Preparation and Positioning of Specimens: For specimens stored in water, excess moisture shall be wiped from the surface of the specimen. The dimensions of the specimens to the nearest 0.2 mm and their weight shall be noted before testing. The time between the extraction of the specimen from the curing tank, and the testing, shall be as short as possible or not more than 2 hour. During the time the specimen is outside the curing tank, it shall be protected from drying, may be by covering with wet cloth.

All testing machine bearing surfaces shall be wiped clean and any loose grit or other extraneous material removed from the surfaces of the specimen that will be in contact with the platens.

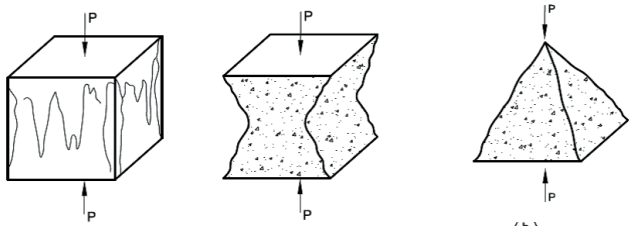
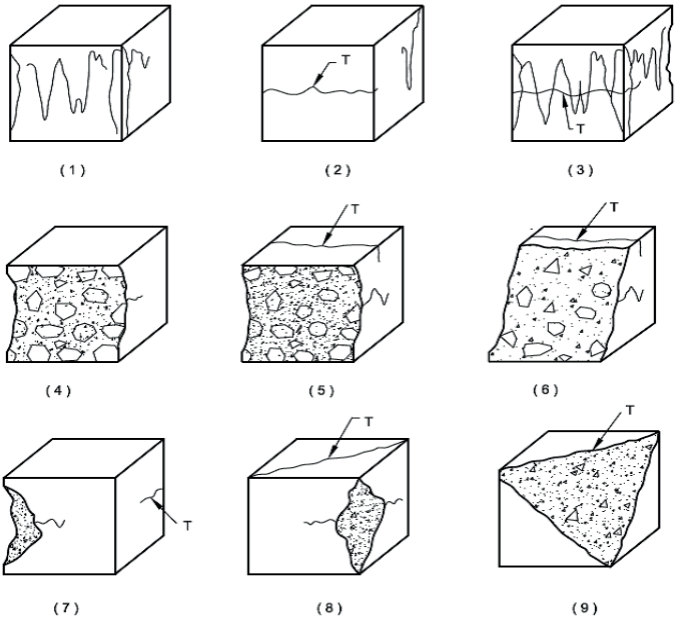


Fig. 6.1.1: Satisfactory Failure of Cube Specimen

Cube specimens shall be compressed perpendicularly to the direction of casting. The specimen shall be centered on the lower platen to an accuracy of 1 percent of the designated size of cubic, or diameter of cylindrical specimens.

5.2 Loading: The load shall be applied without shock and shall be increased continuously at a constant rate of 14 N/mm^2/min until no greater load can be sustained. The maximum load indicated shall be recorded.



Note T = Tensile Crack

Fig. 6.1.2: Unsatisfactory Failure of Cube Specimen

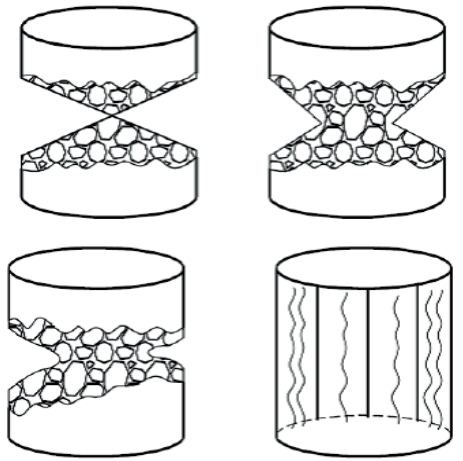


Fig. 6.1.3: Satisfactory Failure of Cylindrical

Specimen

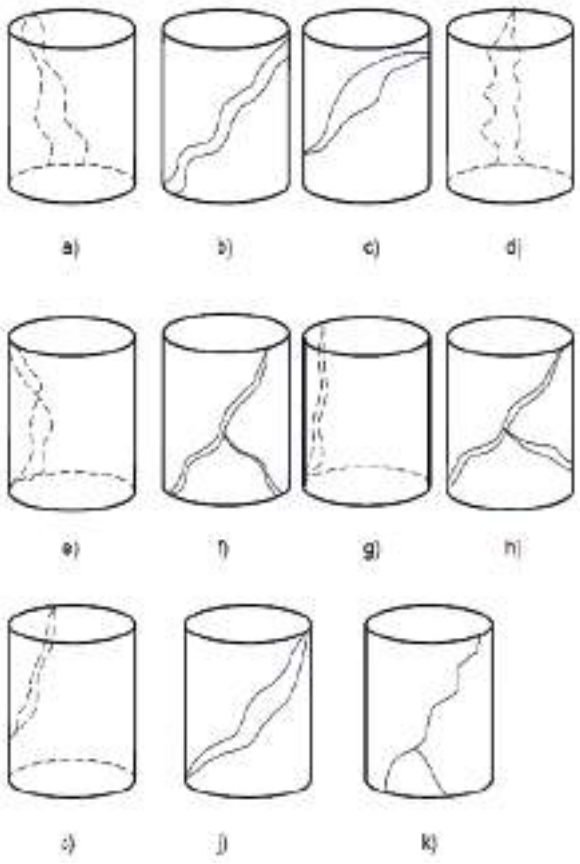


Fig. 6.1.4: Unsatisfactory Failure of Cylindrical Specimen

5.3 Assessment of Type of Failure: If the failure is satisfactory (see Fig. 6.1.1 or Fog. 6.1.3), this fact shall be recorded. If the failure pattern is unsatisfactory, this fact shall be recorded and the type of failure recorded using the pattern number in Fig. 6.1.2 or Fig. 6.1.4 closest to that observed.

6. Test Result: The compressive strength is given by the equation:

$$fc = F / Ac$$

where:

fc = compressive strength, in MPa;

F = maximum load, in N; and

Ac = cross-sectional area, in mm^2, of the specimen on which the compressive force acts.

Average of three values shall be taken as the representative of the batch provided the individual variation is not more than ± 15 percent of the average. Otherwise repeat test shall be made, however if there is no further sample, then the average of two closest values may be taken as the average result.

The actual dimensions of test specimens shall conform to IS:10086. If the actual dimensions are within the tolerance limits as mentioned in IS:10086, the strength may be calculated on the basis of designated size. If the actual dimensions are outside this tolerance, the strength calculation shall be based on the actual dimensions of the test specimen, however, perpendicularity of the surface of specimens should be maintained as per IS:10086.

The compressive strength shall be expressed to the nearest 0.5 MPa.

7. Test Report: The following information shall be included in the report:

(a) Details of the concrete like grade, mix details, etc, in case of cast specimens; and details of the structure, like structure type, origin member/ structure, in case of cored specimen;

(b) Type of specimen: cast (cube/cylinder) or drilled core;

(c) Size of the specimen, and capping details, if applicable;

(d) Identification mark;

(e) Age of specimen;

(f) Date of test;

(g) Curing conditions;

(h) Weight of specimen;

(j) Dimension of specimen;

(k) Maximum load;

(m) Details of the machine used for testing (manual/ automated, loading range, date of calibration, etc);

(n) Compressive strength of specimen (to the nearest 0.5 MPa); and

(p) Type of failure (satisfactory or unsatisfactory and, if unsatisfactory, the nearest type).

6.2 Flexural Strength of Concrete

1. Introduction: Flexural strength of Concrete, also known as Modulus of rupture, is an indirect measure of the tensile strength of unreinforced concrete. Apart from external loading, tensile stresses can also be caused by warping, corrosion of steel, drying shrinkage and temperature gradient. Designers of pavements use a theory based on flexural strength. Therefore, laboratory mix design based on flexural strength tests may be required, to obtain the needed design MR.

Unlike compression, tensile strength of a member cannot be found directly as no apparatus or specimen model has been developed to evenly distribute the tensile force to the member. However, the indirect measurement of the flexural strength like the One-point loading test and the Two-point loading test fetch satisfying results.

2. Reference: IS-516 (Part-1/Sec-1) : 2021 "Hardened Concrete – Methods of Test. Part-1: Testing of Strength of Hardened Concrete. Section-1: Compressive, Flexural and Split Tensile Strength".

3. Test Specimen: The test specimen shall be a prism conforming to IS 1199 (Part 5). Sawn specimens of nominal width of 100mm or 150mm with a square cross-section and overall length of 500mm and 700mm may also be used.

3.1 Age at Test: Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Ages of 90 days and 1 year are recommended if tests at greater ages are required.

3.2 Number of Specimens: At least three specimens shall be tested at each selected age.

4. Apparatus

4.1 Testing Machine: The permissible errors shall be not greater than ± 1 percent of the applied load. The bed of the testing machine shall be provided with

two steel rollers, 38mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from centre to centre is 600mm for 150mm specimens and 400mm for 100mm specimens. The load shall be applied through two similar rollers mounted at the third points of the supporting span, that is, spaced at 200 or 133mm respectively centre-to-centre. The load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints. Each roller, except one of the lower ones shall be capable of rotating around its axis and of being inclined in a plane normal to the longitudinal axis of the test specimen.

4.2 Force Application: The device for applying loads shall consist of two upper rollers and two lower rollers (see Fig. 6.2.1).

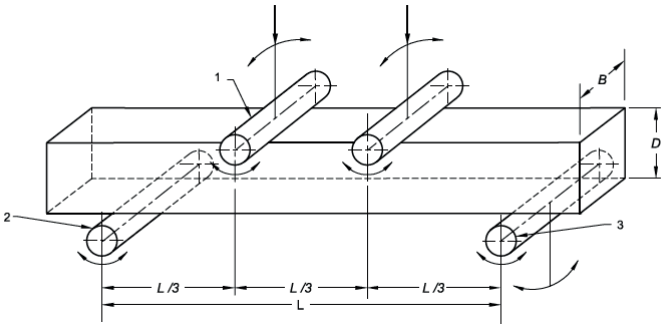


Fig. 6.2.1: Test Setup

Key:

1. Loading Roller (Capable of Rotation and being inclined)

2. Supporting Roller

3. Supporting Roller (Capable of Rotation and being inclined)

5. Procedure

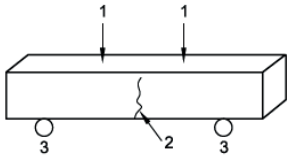
5.1 Preparation and Positioning of Specimens: The specimen shall be examined and any abnormalities shall be reported. For specimens stored in water, excess moisture shall be wiped from the surface of the specimen before placing in the testing machine. The time between the extraction of the specimen from the curing tank until the test shall be as short as possible or not more than 2 hour. During the time the specimen is outside the curing tank, it shall be protected from drying, like by covering with wet cloth. The test specimen shall be placed in the machine, correctly centred with the longitudinal axis of the specimen at right angles to the longitudinal axis of the upper and lower rollers. The reference direction of loading shall be perpendicular to the direction of casting of the specimen.

5.2 Loading: The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers. The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould.

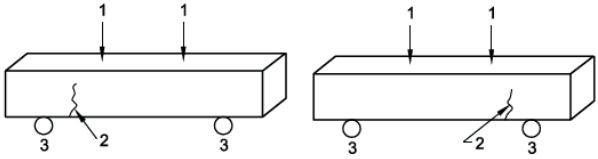
The load shall not be applied until all loading and supporting rollers are resting evenly against the test specimen. The load shall be applied without shock and shall be increased continuously at a constant rate until no greater load can be sustained. The load shall increase at a rate 0.7 N/mm^2/min (rate of loading being 4 kN/min for 150mm specimens and 1.8 kN/min for 100mm specimens).

The maximum load indicated shall be recorded.

5.3 Assessment of Type of Fracture: The fractured specimen shall be examined and the appearance of the concrete and type of fracture shall be recorded (see Fig. 6.2.1).



Failure Type A



Failure Type B

Fig. 6.2.1: Types of Failure Pattern

Key:

1. Loading Rollers
2. Line of Fracture
3. Supporting Rollers

6. Test Results: The flexural strength of the specimen shall be expressed as "Modulus of Rupture" Fb and shall be calculated to the nearest 0.05 MPa as follows in case of failure Type A (Fig. 6.2.1):

$$F_b = (P \times L) / B \times D^2$$

in which 'a' is greater than 200mm for 150mm specimen, or greater than 133mm for 100mm specimen, or in case of failure Type B (Fig. 6.2.1), "Modulus of Rupture" Fb shall be calculated to the nearest 0.05 MPa by the following formula:

$$F_b = (3P \times a) / B \times D^2$$

in which 'a' is less than 200mm but greater than 170mm for 150mm specimen or less than 133mm but greater than 110mm for 100 mm specimen.

Where:

F_b= Flexural Strength, in MPa;

P= Maximum load, in N;

a= the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen, in mm;

B, D are the lateral dimensions (breadth and height) of the specimen, mm; and

L= Length of span on which the specimen is supported, expressed in mm.

If 'a' is less than 170mm for 150mm or less than 110mm for a 100mm specimen, the results of the test shall be discarded.

The flexural strength shall be expressed to the nearest 0.05 MPa.

7. Test Report: The following information shall be included in the report:

(a) Size of specimen;

(b) Identification mark;

(c) Age of specimen;

(d) Date of test;

(e) Details of concrete mix such as grade, cement content, curing condition, etc;

(f) Weight of specimen;

(g) Maximum load;

(h) Type of fracture and flexural strength of specimen (to the nearest 0.05 MPa);

(j) In case of failure Type B, value of 'a'.

6.3 Splitting Tensile Strength of Concrete

1. Introduction: One of the important properties of concrete is "tensile strength" as structural loads make concrete vulnerable to tensile cracking. Tensile strength of concrete is much lower than its compressive strength (that's why steel is used to carry the tension forces). To determine the tensile strength, indirect methods are applied due to the difficulty of the direct method. Splitting Tensile Strength test is one of these indirect methods to check tensile strength of the concrete.

2. Reference: IS-516 (Part-1/Sec-1) : 2021 "Hardened Concrete – Methods of Test. Part-1: Testing of Strength of Hardened Concrete. Section-1: Compressive, Flexural and Split Tensile Strength".

3. Specimens: The specimen shall be a cube or cylinder meeting the requirements of IS:1199(Part-5). Damaged or badly honeycombed specimens shall not be tested.

3.1 Age at Test: Tests shall be made at the recognized ages of the test specimens, the most usual being 7 and 28 days. Tests at any other age at which the tensile strength is desired may be made, if so required. The age at test shall be reported along with the results.

3.2 Number of Specimens: At least three specimens shall be tested for each age of tests.

4. Apparatus

4.1 Testing Machine: The test shall be carried out using a compression testing machine conforming to IS:14858. The test machine shall be in calibration at the time of test. The calibration shall be carried out at least once per year.

4.2 Jigs: Jig shown in Fig. 6.3.1 may be used for splitting cylindrical and cubic specimens. Curved steel loading pieces may be used in place of conventional plane platens when tests are carried out on cubical specimen. Alternatively, a jig shown in Fig. 6.3.2 may

be used for cubic specimen.

4.3 Two packing strips of tempered hardboard of nominal thickness 4mm conforming to IS:1658 having following dimensions of the test specimen shall be used for each specimen and shall be discarded after each such test:

(a) Width 15 ± 2 mm,

(b) Nominal thickness 4 ± 1 mm, and

(c) Length greater than the length of the line of content of the test specimen.

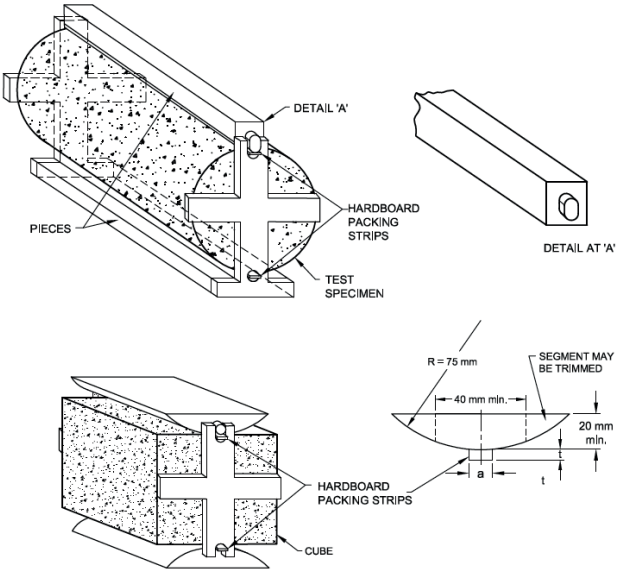


Fig. 6.3.1: Jig for Splitting Cylinder and Cube

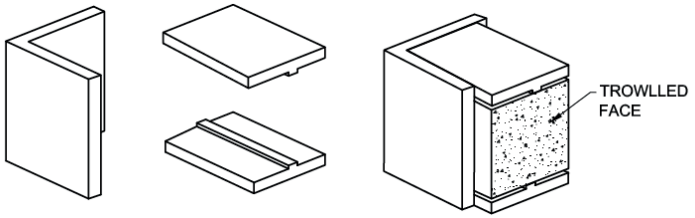


Fig. 6.3.2: Alternate Apparatus for Splitting Cubes

4.4 Steel Loading Strips: A steel loading plate having minimum hardness value, when tested in accordance with IS:1500 (Part 1) shall be used between the platen of the machine and the hardboard packing strip. The piece shall not be shorter than the specimen. For cylindrical specimens it shall be of rectangular cross-section and for cubic specimens, it shall be a section of a cylinder, with a radius of 75mm, so that the load is applied along a line on the surface of the specimen.

5. Procedure

5.1 Specimens when received dry shall be kept in water for 48 hour before testing. The specimens shall be tested immediately on removal from the water whilst they are still wet. Surface water and grit shall be wiped off the specimens and any projecting fins removed from the surfaces which are to be in contact with the packing strips.

5.2 Marking: Central lines shall be drawn on the two opposite faces of the cube using any suitable procedure and device that will ensure that they are in the same axial plane (Fig. 6.3.3).

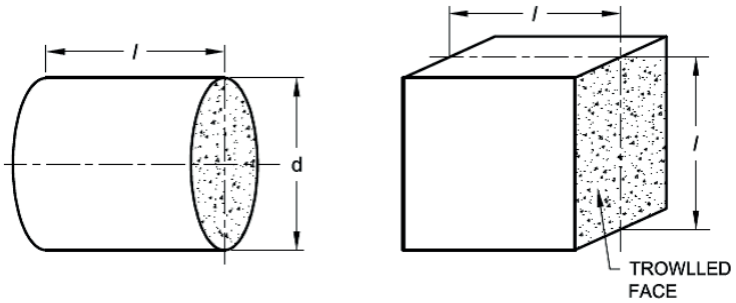


Fig. 6.3.3: Plane of Loading

5.3 Placing of the Specimen in the Testing Machine: The bearing surfaces of the testing machine and of the loading strips shall be wiped clean.

5.4 Positioning: The test specimen shall be placed in

the centering jig with packing strip and/or loading pieces carefully positioning along the top and bottom of the plane of loading of the specimen. The jig shall then be placed in the machine so that the specimen is located centrally. In the case of cubic specimens, the load shall be applied on the moulded faces in such a way that the fracture plane will cross the trowelled surface. For cylindrical specimen it shall be ensured that the upper platen is parallel with the lower platen.

5.5 Rate of Loading: The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/mm^2/min to 2.4 N/mm^2/min. Maintain the rate, once adjusted, until failure. The maximum load applied shall then be recorded. The appearance of concrete and any unusual features in the type of failure shall also be noted. The rate of increase of load may be calculated from the formula:

$$(1.2 \text{ to } 2.4) \times \pi/2 \times l \times d \quad \text{N/min}$$

6. Calculation: The measured splitting tensile strength Fc, of the specimen shall be calculated to the nearest 0.05 N/mm2 using the following formula:

(a) For cylinders: $Fc = 2P / \pi ld$

(b) For cubes: $Fc = P / 2l2$

Where:

P = Maximum load applied to specimen, in N;

l = Length of cylinder/side of the cube, in mm; and

d = cross sectional dimension of cylindrical specimen, in mm.

7. Examination of Specimen: The fractured specimen shall be examined and the appearance of the concrete and type of fracture, if unusual, shall be recorded. An example of unusual type of fracture is when the plane of fracture is not vertical.

8. Report: The following information shall be included in the report on each specimen:

(a) Date of test.

(b) Identification mark, shape and size of the specimen, in mm.

(c) Age of specimen.

(d) Splitting tensile strength to the nearest 0.05 N/ mm^2.

(e) Fracture pattern, in line with Fig. 6.3.3

(f) Weight of specimen.

6.4 Permeability of Concrete

1. Introduction: Concrete is a composite material comprising of Cement, Sand & coarse aggregate. Presence of voids in concrete makes it permeable, which in turn allows water flow into it. The permeability of concrete is the ability of concrete to resist the water flow into it when the external force is applied. Permeability is a measure of the amount of water, that can enter the concrete matrix. In reinforced concrete, ingress of water and air will cause steel erosion causing the concrete to expand, crack, and disintegrate. If the concrete becomes saturated with water because of permeability, it is more susceptible to frost action. It is critical in case of liquid retaining structures like water tanks and dams where water tightness is critical. This chapter describes two methods of testing permeability of concrete i.e. as per IS code which is to be used for concrete in other than Railway Bridges and as per IRS:CBC which is to be used for concrete in Railway Bridges.

(A) As per Bureau of Indian Standard (IS) Code

2. General: This chapter covers the method for determining the permeability of concrete specimens either cast in the laboratory or obtained by cutting out cores from existing structures.

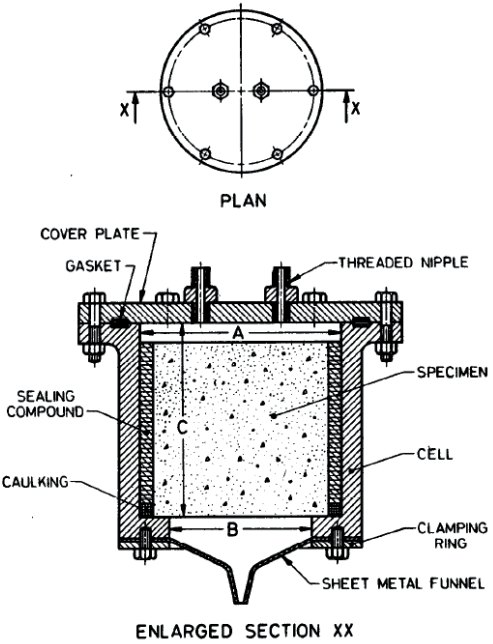
3. Reference: IS-3085:1965 (Reaffirmed-2021) "Method of Test for Permeability of Cement Mortar and Concrete".

4. Apparatus required

4.1 Permeability Cell: It consist of a metal cylinder with a ledge at the bottom for retaining the specimen, a flange at the top, a removable cover plate and a sheet metal funnel which can be securely bolted to the cell. Gunmetal, aluminium or other suitable corrosion-resistant metal shall be used for fabrication of the cell and cover plate. A rubber or neoprene O-ring or other suitable gasket, seated in matching grooves, shall be used between the cell and the cover plate to render the joint water-tight. A typical

permeability cell is shown in Fig. 6.4.1.

4.2 Water Reservoir: A suitable reservoir may consist of a length of metal pipe, 50 to 100 mm in diameter and about 500 mm long. The reservoir shall be fitted with a graduated side arm gauge-glass, and the necessary fittings and valves for admitting water and compressed air and for draining, bleeding and connection to the permeability cell, as shown in Fig. 6.4.2.



Specimen Dia. (mm)	Dimension of Cell (mm)		
	A	B	C
100	115	80	110
150	170	120	160
300	330	260	320

Fig. 6.4.1: Typical Permeability Cell

4.3 Pressure Lines: Heavy duty armoured rubber hose or suitable metal tubing or any other equally suitable hose or pipe shall be used for the various high pressure connections. All joints shall be properly made to render them leakproof.

5. Accessories

5.1 Compressed Air: Suitable arrangements shall be made for supplying compressed air at 5 kg/cm2 to 15 kg/cm^2 to the permeability cell assemblies. Compressed air (or nitrogen) cylinders or alternatively a compressor of adequate capacity may be used. Suitable regulating valves and pressure gauges shall be provided. Several cells at different operating pressures may be served by a common source as shown in Fig. 6.4.2.

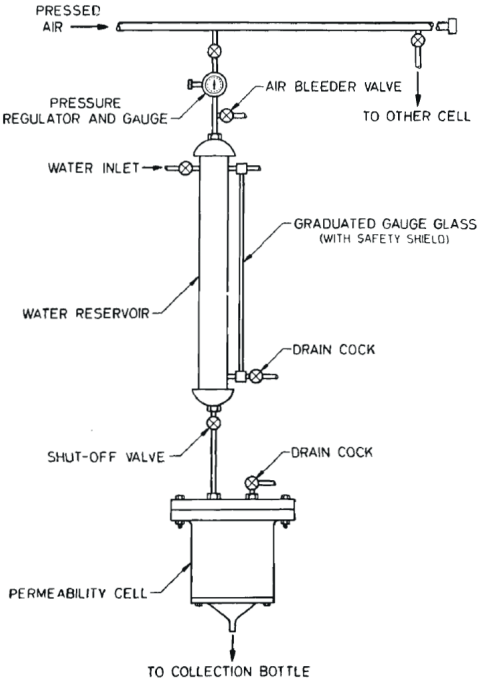


Fig. 6.4.2: Permeability Test Set-up

5.2 De-aired Water: An adequate supply of clean de-aired water shall be available. Water may be easily de-aired by boiling and cooling. It may be stored in closed containers, which should, as far as possible, be kept full. Unnecessary agitations and contact with air shall be avoided.

6. Test Specimens

6.1 Size of Specimens: The specimens shall be cylindrical in shape with height equal to the diameter. The standard size of specimen shall have diameter (and height) of 150mm. In the case of specimens containing aggregates whose nominal size does not exceed 20mm, the diameter (and the height) of the specimen may be reduced to 100mm. In the case of specimens containing aggregates whose nominal size exceeds 40mm, the diameter (and the height) of the specimen should not be less than about four times the nominal size of the aggregate.

6.2 Casting and Curing: The concrete mix shall be cast in split moulds of the required size, with a removable collar of about half the height set on the top. The material shall be compacted either by hand rodding or vibration, as proposed to be done during construction. The collar shall then be removed and the mould shall be struck off level with a straight-edge using a sawing motion without further trovelling or finishing, which might raise the fines to the surface. The specimen shall be cured for 28 days unless otherwise specified by the engineer-in-charge.

7. Procedure

7.1 Pressure Head: The standard test pressure head to be applied to the water in the reservoir should be 10 kg/cm2. This may, however, be reduced up to 5 kg/cm2 in the case of relatively more permeable specimens where steady state of flow is obtained in a reasonable time, and may be increased up to 15 kg/cm2 for relatively less permeable specimens and where sealing could be ensured to be fully effective.

7.2 Calibrating the Reservoir: Each reservoir shall be calibrated under the operating pressures of 5 kg/cm2 to 15 kg/cm2 as indicated below:

With the reservoir drain-cock and the shut-off valve between the reservoir and the cell closed, and with the air bleeder valve open, the reservoir shall be filled with water. The reservoir drain-cock shall then be opened to flush out any air and closed again. The reservoir shall be refilled to a point above the zero mark of the gauge-glass scale; the bleeder valve shall be closed and the desired air pressure applied. The drain-cock shall be carefully opened to bring the water to the zero mark and quickly closed. Water shall then be drawn off and caught in 250 ml increments in a graduated jar and the level in the gauge-glass read on the scale. The calibration constant for the reservoir shall be expressed in millilitres per division of the scale.

7.3 Preparing the Specimen: The specimen shall be thoroughly cleaned with a stiff wire brush to remove all laitance. The end faces shall then be sand-blasted or lightly chiselled.

7.4 Sealing the Specimen: The specimen shall be surface-dried and the dimensions measured to the nearest 0.5mm. It shall then be centred in the cell, with the lower end resting on the ledge. The annular space between the specimen and the cell shall be tightly caulked to a depth of about 10mm using a cotton or hemp cord soaked in a suitable molten sealing compound. The rest of the space shall be carefully filled with the molten sealing compound, level with the top of the specimen. Any drop in the level due to cooling shall be made up, using a heated rod to remelt the solidified compound before pouring fresh material over it. A mixture of bees-wax and rosin, applied smoking hot, forms an effective seal. Other suitable materials are stearin pitch, marine glue, and various asphaltic compounds.

7.5 Testing the Seal: It is essential that the seal is watertight. This may be checked very conveniently by bolting on the top cover plate, inverting the cell and applying an air pressure of 1 to 2 kg/cm2 from below. A little water poured on the exposed face of the specimen is used to detect any leaks through the seal, which would show up as bubbles along the ledge. In case of leaks the specimen shall be taken out and resealed.

7.6 Assembling the Apparatus: After a satisfactory seal has been obtained, the funnel shall be secured in position and the cell assembly connected to the water reservoir. With the air bleeder valve, the valve between the reservoir and the cell, and the drain-cock in the cell open, de-aired water shall be allowed to enter the reservoir. When water issues freely through the drain-cock, it shall be closed and the water reservoir filled. The reservoir water inlet and air bleeder valves shall then be closed.

7.7 Running the Test: With the system completely filled with water, the desired test pressure shall be applied to the water reservoir and the initial reading of the gauge-glass recorded. At the same time a clean collection bottle shall be weighed and placed in position to collect the water percolating through the specimen. The quantity of percolate and the gauge-glass readings shall be recorded at periodic intervals. In the beginning, the rate of water intake is larger than the rate of outflow. As the steady state of flow is approached, the two rates tend to become equal and the outflow reaches a maximum and stabilizes. With further passage of time, both the inflow and outflow generally register a gradual drop. Permeability test shall be continued for about 100 hours after the steady state of flow has been reached and the outflow shall be considered as average of all the outflows measured during this period of 100 hours.

NOTE - The steady state of flow is defined as the

stage at which the outflow and inflow of water become equal for the first time.

7.8 Test Temperature: The test shall preferably be carried out at a temperature of 27°±2°C. In case arrangements are not available for maintaining the above temperature, a record shall be maintained of the actual temperature. An approximate correction may be made on the basis that each 5°C increase of temperature above the standard temperature, results in 10 percent increase in the coefficient of permeability and vice versa.

7.9 Precautions: Following important precautions should be observed:

(a) The seal around the specimen shall be effective. Leakage through it can give rise to entirely misleading results.

(b) Air content of the water entering the specimen should not exceed about 0.2 percent. Excessive amounts of dissolved air can result in air locks in the specimen and apparent reduction in permeability. Periodical samples shall be drawn from the cell drain-cock and the dissolved air determined. The system shall be drained and replenished with fresh de-aired water as soon as the air content exceeds the above limit.

(c) The flow should be permitted to attain the steady state before the coefficient of permeability is calculated. Examination of the inflow and outflow rate data or suitable graphs of the same may be used to determine the establishment of the steady state.

(d) The observation of outflow from the specimen is liable to be influenced by evaporation of the percolate during collection. The collection bottle may be housed in a humid chamber, or alternatively, blank observations on a similar bottle containing water should be made and

the necessary correction for evaporation loss applied. The inflow measurement provides an additional check.

(e) It is very important that the specimen surface is carefully prepared by sand blasting or chiselling, as even a thin highly impervious skin can result in considerable underestimation of the permeability.

8. Calculation: The coefficient of permeability shall be calculated as follows:

$$K = Q / \{A * T * (H/L)\}$$

Where:

K = Coefficient of permeability in cm/sec;

Q = Quantity of water in millilitres percolating over the entire period of test after the steady state has been reached;

A = Area of the specimen face in cm2;

T = Time in seconds over which Q is measured; and

H/L= Ratio of the pressure head to thickness of specimen, both expressed in the same units.

9. Report: The following information shall be included in the report on each specimen:

(a) Identification mark of the specimen,

(b) Particulars of mix,

(c) Age at commencement of the test,

(d) Duration of test,

(e) Size of specimen,

(f) Test pressure,

(g) Test temperature,

(h) Coefficient of permeability at test temperature, and

(j) Corrected coefficient of permeability at standard temperature.

(B) <u>As per IRS: Concrete Bridge Code</u>

2. General: Permeability test is required in following cases:

(i) Mandatory for all RCC/PSC bridges under severe and extreme environment;

(ii) Under moderate environment, this test shall be mandatory for all major bridges and for other bridges this test is desirable to the extent possible; and

(iii) It is required for RCC/PSC structural element only.

3. Reference: Indian Railway Standard (IRS): Code of Practice for Plain, Reinforced & Prestressed Concrete for General, Bridge Construction (Concrete Bridge Code). Reprint-September 2014".

4. Test Specimen: Test specimen of 200mm dia and 120mm thick shall be used. After 24 hours of casting of specimen, central circular area of 100mm diameter shall be roughened with a wire brush on the side on which the water pressure is to be applied. The unroughened part of the side of the test specimen which is subjected to water pressure is to be sealed with two coats of cement water paste (W/C = 0.4).

5. Procedure:

5.1 After 28 days curing, test specimen is fitted in to a test apparatus where water pressure acts on the required face and remaining faces can be observed (Fig. 6.4.3).

5.2 At first, a pressure of 1 bar is applied for 48 hours, then 3 bar for 24 hours and 7 bar for 24 hours. After the test, the specimen is split in the middle by compression applied on two round steel bars lying on opposite sides, above and below. The side after test specimen exposed to the water pressure should face downwards.

5.3 The greatest water penetration depth, is taken as

the average value of the greatest penetration depths on three test specimens.

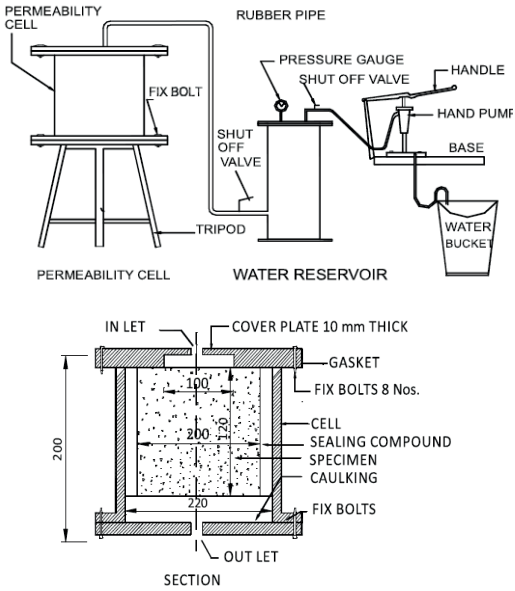


Fig. 6.4.3: Typical Permeability Test Set-up

6. Result: The average value of the greatest penetration depths of moisture shall not exceed 25mm.

6.5 Rebound Hammer Test

1. Introduction: Rebound Hammer test is a Non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The rebound hammer test for concrete is considerably factual when the concrete is at least 28 days old. It is a simple yet adequate tool that is useful to test concrete on site. It is easy to use and does not need special training.

2. Reference: IS-516 (Part-5/Sec-4) : 2020 "Hardened Concrete – Methods of Test. Part-5: Non-destructive Testing of Concrete. Section-4: Rebound Hammer Test".

3. Apparatus

3.1 Rebound Hammer: It consists of spring-loaded steel hammer (mass) that strikes the metal plunger in contact with the concrete surface when released (Fig. 6.5.1).

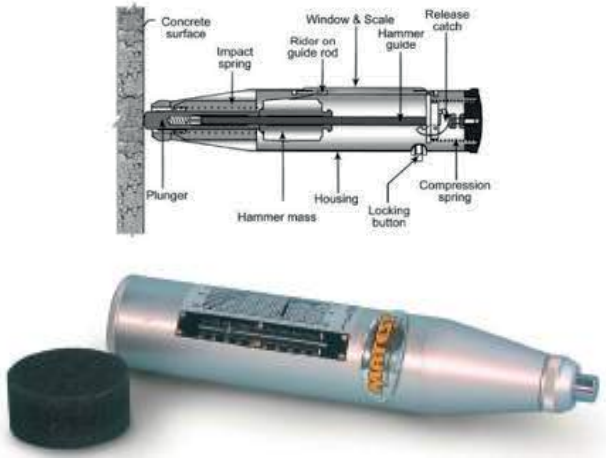


Fig. 6.5.1: Rebound Hammer

The impact energy required for rebound hammers for different applications is given in Table 6.1.

3.2 Abrasive Stone: It consists of medium-grain texture silicon carbide or equivalent material.

3.3 Testing Anvil: It consists of a steel cylinder with 150mm diameter and 150mm height (Fig. 6.5.2). The hardness Rockwell C (HRC) value of the impact area shall be 64 to 68. The supplier/manufacturer of the rebound hammer should indicate the range of readings on the anvil suitable for different types of rebound hammers. It is necessary that the rebound hammer is checked against the testing anvil before commencement of a test and after completion of test to ensure reliable results.

Table 6.1: Impact Energy for Different Applications

Sl. No.	Application	Approximate Impact Energy required (Nm)
1	For testing normal weight concrete	2.25
2	For light-weight concrete or small and impact sensitive part of concrete	0.75
3	For testing mass concrete, for example, in roads, air-field pavements and hydraulic structures	30.00

Fig. 6.5.2: Testing Anvil

4. Checking of Apparatus: To use this test method to estimate strength, it is necessary to establish a correlation

between rebound number and strength for a particular concrete and particular apparatus by any method given below:

4.1 Using Cube Compressive Strength: The satisfactory way of establishing a correlation between compressive strength of concrete and its rebound number is to measure both the properties simultaneously on concrete cubes. The correlation shall be derived on project specific concrete cubes for all bigger projects. The general correlation can be derived from concrete cubes used in smaller projects in a region with similar materials including cement type and the same shall be repeated every year. For bigger projects at least three cubes each for three different concrete grades shall be cast and tested for establishing the correlation. Cube specimens should be wet cured for 27 days and they should be removed from wet storage and kept in the laboratory atmosphere for about 24 hour before testing. The concrete cube specimens are held in a compression testing machine under a fixed load, measurements of rebound number taken using the particular hammer/ hammers for which conditions are to be established and then the compressive strength determined as per IS:516 (Part-1/Sec-1). The fixed load required is of the order of 7 N/mm^2 when the impact energy of the hammer is about 2.25 Nm. The load should be increased for calibrating rebound hammers of greater impact energy and decreased for calibrating rebound hammers of lesser impact energy. The test specimens should be as large a mass as possible in order to minimise the size effect on the test result of a full scale structure. 150mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.25 Nm), whereas for rebound hammers of higher impact energy, for example 30 Nm, the test cubes should not be smaller than 300mm. Only the vertical faces of the cube as cast should be tested. At least nine readings should be taken on each of

the two vertical faces accessible in the compression testing machine when using the rebound hammers. The points of impact on the specimen must not be nearer an edge than 25mm and should be not less than 25mm from each other. The same points must not be impacted more than once.

4.2 Using Core Compressive Strength: To establish correlation between rebound number and strength for a particular concrete and particular apparatus, rebound numbers measured on the structure can be correlated with the few core strengths measured on the structure on corresponding members. At least two replicate cores shall be taken from at least six locations with different rebound numbers. The test conditions and surface conditions of the locations where strengths are to be estimated using developed correlation shall be similar to the locations used for development of correlation. For smaller projects the number of cores may be limited to six. The locations where these tests are conducted and cores are taken should have ultrasonic pulse value greater or equal to 3.50 km/s for grades ≤ M25, and 3.75 km/s for grades above M25, by direct method of probing, when tested as per IS:516 (Part 5/Sec 1).

NOTES :

1. Predetermined curve prepared for similar concrete in the same region may be used for approximate estimation of strength of concrete used in the structural members tested for cases where correlation cannot be developed either by cube compressive strength or in-situ core strengths.

2. Different instruments of the same type may give rebound numbers differing from 1 to 3 units. Therefore, tests should be made with the same instrument in order to compare results. If more than one instrument is to be used, perform comparative tests on a range of typical concrete surfaces so as to determine the magnitude of the differences to be

expected in the readings of different instruments.

For readings to be compared, the direction of impact must be the same or established correlation factors shall be applied to the readings. In the absence of data, manufacturer correlation for direction effect can be adopted.

5. Procedure

5.1 For testing, smooth, clean and dry surface is to be selected. If loosely adhering scale is present, this should be rubbed off with a grinding wheel or stone. Rough surfaces resulting from incomplete compaction, loss of grout, spalled or tooled surfaces do not give reliable results and should be avoided.

5.2 The point of impact should be at least 25mm away from any edge or shape discontinuity.

5.3 For taking a measurement, the rebound hammer should be held at right angles to the surface of the concrete member. The test can thus be conducted horizontally on vertical surfaces (preferably) or vertically upwards or downwards on horizontal surfaces. If the situation demands, the rebound hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.

NOTE: Digital angle gauges are available that can be attached to the body of the instrument to allow quick measurement of the angle with respect to horizontal. However, correlation taking into account the direction effect can also be developed between equivalent cube compressive strength of concrete cores (minimum 6 nos.) with rebound number in vertically upward or downward direction for the specific project.

5.4 Rebound hammer test shall be conducted around all the points of observation on all accessible faces of the structural element. Concrete surfaces shall be thoroughly cleaned before taking any measurement. Around each point of observation, six readings of

rebound indices are taken and average of these readings after deleting outliers as per IS/ISO:16269 (Part-4) becomes the rebound index for the point of observation.

6. Factors Influencing Test Results: The rebound numbers are influenced by a number of factors like:

6.1 Type of Cement: Concretes made with high alumina cement can give strengths 100 percent higher than that with ordinary Portland cement. Concretes made with super-sulphated cement can give 50 percent lower strength than that with ordinary Portland cement.

6.2 Type of Aggregate: Normal aggregates such as gravels and crushed rock aggregates give similar correlations, but concrete made with lightweight aggregates require special calibration.

6.3 Surface Condition and Moisture Content: This test is suitable only for close texture concrete. Open texture concrete typical of masonry blocks, honeycombed concrete or no-fines concrete are unsuitable for this test. All correlations assume full compaction, as the strength of partially compacted concrete bears no unique relationship to the rebound numbers. Trowelled and floated surfaces are harder than moulded surfaces, and tend to overestimate the strength of concrete.

A wet surface will give rise to underestimation of the strength of concrete calibrated under dry conditions. In structural concrete, this can be about 20 percent lower than in an equivalent dry concrete.

6.4 Curing and Age of Concrete: The relationship between hardness and strength varies as a function of time. Variations in initial rate of hardening, subsequent curing and conditions of exposure also influence the relationship. The effect of age can be ignored for concrete above 14 days old.

6.5 Carbonation of Concrete Surface: The influence

of carbonation of concrete surface on the rebound number is very significant. Carbonated concrete gives an overestimate of strength which in extreme cases can be up to 50 percent. The carbonation depth shall be checked in cases where the age of concrete is more than 6 months and same shall be reproduced in the test report.

6.6 Vertical Distance from the Bottom of Concrete: The influence of vertical distance from the bottom of concrete placement on the rebound number is very significant. Generally, a higher rebound number is observed near the bottom of concrete placement as during compaction, concentration of aggregates will be higher at the bottom.

6.7 Surface Conditions: The direct correlation between rebound numbers and strength of wet cured and wet tested cubes is not recommended. It is necessary to establish a correlation between the strength of wet tested cubes and the strength of dry tested cubes on which rebound readings are taken.

7. Interpretation of Results

7.1 The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by establishing a suitable correlation between the rebound index and the compressive strength of concrete (Ref. Para 4). In general, the rebound number increases as the strength increases but it is also affected by several parameters as mentioned in Para 6. It is also pointed out that rebound indices are indicative of compressive strength of concrete to a limited depth from the surface. If the concrete in a particular member has internal micro-cracking, flaws or heterogeneity across the cross-section, rebound hammer indices will not indicate the same. As such, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in a structure can be

up to ± 25 percent depending upon correlation curve and methodology adopted for establishing correlation between rebound index and likely compressive strength. If the relationship between rebound index and compressive strength can be checked by tests on core samples obtained from the structure or standard specimens made with the same concrete materials and mix proportion, then the accuracy of results and confidence thereon are greatly increased.

7.2 Because of the various limitations in rebound hammer test, the combined use of ultrasonic pulse velocity (UPV) test [IS-516 (Part 5/Sec 1)] and rebound hammer test is a must for proper interpretation. If the quality of concrete assessed by ultrasonic pulse velocity method is 3.50 km/s for grades ≤ M25, and 3.75 km/s for above M25 or above, only then the in-situ compressive strength assessed from the rebound hammer test is valid. This shall be taken as indicative of strength of concrete in the entire cross-section of the concrete member represented by the both tests.

7.3 In cases the quality of concrete assessed by UPV is doubtful, no assessment of concrete strength shall be made from rebound hammer test.

8. Test Report: The report shall include the following:

(a) Date/period of testing;

(b) Identification of the concrete structure/element;

(c) Location of test area(s);

(d) Identification of the rebound hammer;

(e) Details of concrete and its condition;

(f) Date/time of performance of the test;

(g) Test result and hammer orientation for each test area.

6.6 Ultrasonic Pulse Velocity Test

1. Introduction: Ultrasonic Pulse Velocity test on concrete is a simple non-destructive test to assess the homogeneity and integrity of concrete. With this test the qualitative assessment of strength of concrete, its gradation in different locations of structural members, discontinuity in cross section like cracks, cover concrete delamination etc., depth of surface cracks and dynamic modulus of elasticity of concrete can be ascertained.

2. Reference: IS-516 (Part-5/Sec-1) : 2020 "Hardened Concrete – Methods of Test. Part-5: Non-destructive Testing of Concrete. Section-1: Ultrasonic Pulse Velocity Testing".

3. Apparatus required

Fig. 6.5.1: Test Set-up

3.1 Electronic Pulse Generator

3.2 Transducers: One Pair : Piezoelectric and magneto-strictive types of transducers may be used, the latter being more suitable for the lower part of the frequency range. Frequencies as low as 10 kHz

and as high as 200 kHz can sometimes be used. It is preferable to use high-frequency transducers (60 kHz to 200 kHz) for short path lengths (down to 50mm) and low frequency transducers (10 kHz to 40 kHz) for long path lengths (up to a maximum of 15m). Transducers with a frequency of 25 kHz to 100 kHz are found to be useful for most applications.

3.3 Standard Calibration Bar: Two standard calibration bars, as per details given in Para 4.1 shall be provided by the manufacturer of the apparatus for calibrating the apparatus.

3.4 Amplifier

3.5 Electronic Timing Device: It shall be capable of measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and the onset of its arrival at the receiving transducer.

4. Performance Requirement of Apparatus

4.1 The apparatus shall be capable of measuring transit times to an accuracy of ±1 percent over a range of 20 microsecond to 10 millisecond. For this, it is necessary to check the overall performance by making measurements on two standard reference specimens in which the pulse transit times are known accurately. The two reference specimens (usually steel bars) shall have pulse transit times of about 25 microsecond to 100 microsecond respectively; these times being specified by the supplier of the equipment to an accuracy of ±0.2 microsecond. The shorter of the reference specimens shall be used to set the zero for the apparatus and the longer one shall be used to check the accuracy of transit time measurement of the apparatus. The measurement obtained shall not differ from the known value for the reference specimen by more than ±0.5 percent.

4.2 Along with the calibration of the equipment, it is also advisable to perform a zero time check on the

unit by applying a coupling agent to the transducers and pressing the faces together. Check the zero adjustment on regular intervals.

4.3 The electronic excitation pulse applied to the transmitting transducer shall have a rise time of not greater than one quarter of its natural period. This is to ensure a sharp pulse onset.

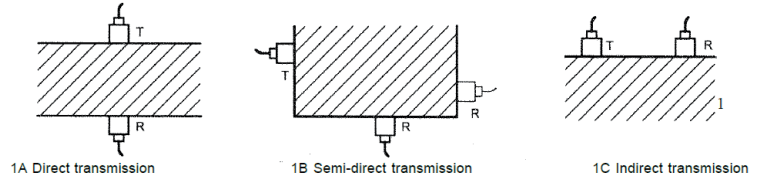
4.4 The interval between pulses shall be low enough to ensure that the onset of the received signal in small concrete test specimens is free from interference by the reverberations produced within the preceding working cycle.

4.5 The apparatus shall maintain its performance over the range of ambient temperature, humidity and power supply voltage as stated by the supplier.

4.6 When using long leads (above 20m) caution shall be taken during transit time measurement that the leads do not come into close contact with each other. In case the leads are close together, it may pickup unwanted signals from the transmitter lead resulting in incorrect and unstable readings.

5. Procedure

5.1 Surface Preparation: At the point of observation, the concrete surface shall be suitably prepared and any plaster or other coating shall be removed to expose the concrete surface. For this purpose, the use of carborundum stones or grinders may be adopted. However, care shall be taken to avoid any damage to concrete surface or concrete structure.



Key: T = Transmitter and R = Receiver

Fig. 6.6.1: Positioning of Transducers

5.2 Ultrasonic Measurements: Place the two transducers on opposite faces (direct transmission), or on adjacent faces (semi-direct transmission), or on the same face (indirect or surface transmission) (Fig. 6.6.1). Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses that have travelled through the concrete in some other direction. Direct transmission method of ultrasonic pulse velocity measurements is the most efficient method and shall be adopted, if possible. However, sometimes, it may be necessary to place the transducers on opposite faces but not directly opposite each other. Such arrangements shall be regarded as a semi-direct transmission. The third method for measurement of ultrasonic pulse velocity is the indirect transmission method. The indirect transmission arrangement is the least sensitive and shall be used when only one face of the concrete is accessible, or when the quality of the surface concrete relative to the overall quality is of interest.

5.3 Determination of Ultrasonic Pulse Velocity for Different Transducer Arrangements

5.3.1 Factors influencing pulse velocity measurements: There are various factors which influence pulse velocity measurements, such as:

(A) Surface Conditions and Moisture Content: For most concrete surfaces, the finish is usually sufficiently smooth to ensure good acoustical contact by the use of a coupling medium and by pressing the transducer against the concrete surface. When the concrete surface is rough and uneven, it is necessary to smoothen the surface to make the pulse velocity measurement possible.

In general, pulse velocity through concrete increases with increased moisture content of concrete. This influence is more for

low strength concrete than high strength concrete. The pulse velocity of saturated concrete may be up to 5 percent higher than that of similar dry concrete. In general, drying of concrete may result in somewhat lower pulse velocity.

(B) Path Length, Shape and Size of the Concrete Member: As concrete is inherently heterogeneous, it is essential that path lengths be sufficiently long so as to avoid any error introduced due to its heterogeneity. In field work, this does not pose any difficulty as the pulse velocity measurements are carried out on thick structural concrete members. However, in the laboratory where generally small specimens are used, the path length can affect the pulse velocity readings. The velocity of short pulses of vibrations is independent of the size and shape of the specimen in which they travel, unless its least lateral dimension is less than a certain minimum value. Below this value, the pulse velocity may be reduced appreciably. The extent of this reduction depends mainly on the ratio of the wave length of the pulse vibrations to the least lateral dimension of the specimen but is insignificant, if the ratio is less than unity. Table 6.2 gives the relationship between the pulse velocity in the concrete, the transducer frequency and the minimum permissible lateral dimension of the specimen.

If the minimum lateral dimension is less than the wavelength or if the indirect transmission arrangement is used, the mode of propagation changes and, therefore, the measured velocity will be different. This is particularly important in cases where concrete elements of significantly different sizes are being compared.

Table 6.2: Minimum Specimen Dimension

Sl. No.	Transducer Frequency (kHz)	Pulse Velocity in Concrete		
		3.50 km/s	4.00 km/s	4.50 km/s
		Minimum Permissible Lateral Specimen Dimension (mm)		
1	24	146	167	188
2	54	65	74	83
3	82	43	49	55
4	150	23	27	30

(C) Temperature of Concrete: Variations of the concrete temperature between 5°C and 30°C do not significantly affect the pulse velocity measurements in concrete. At temperatures between 30 to 60°C there can be reduction in pulse velocity up to 5 percent. Below freezing temperature, the free water freezes within concrete, resulting in an increase in pulse velocity up to 7.5 percent.

(D) Stress: When concrete is subjected to a stress which is abnormally high for the quality of the concrete, the pulse velocity may be reduced due to the development of micro-cracks. This influence is likely to be the greatest when the pulse path is normal to the predominant direction of the planes of such micro-cracks. This occurs when the pulse path is perpendicular to the direction of a uniaxial compressive stress in a member. This influence is generally insignificant unless the stress is greater than about 60 percent of the ultimate strength of the concrete.

(E) Reinforcing Bars: The pulse velocity measured in reinforced concrete in the vicinity of reinforcing bars is usually higher than in plain concrete of the same composition. This is because the pulse velocity in steel is 1.2 to 1.9 times the velocity in plain concrete and, under certain conditions, the first pulse to arrive at the receiving transducer travels partly in concrete and partly in steel. The apparent increase in pulse velocity depends upon the proximity of the measurements to the reinforcing bar, the diameter and number of the bars and their orientation with respect to the path of propagation.

(F) Contact Between Transducer and Concrete: Poor contact will affect the reading. It is essential to use grease or other couplants to improve the contact between the transducer and the concrete.

(G) Cracks and Voids: When an ultrasonic pulse travelling through concrete meets a concrete-air interface, there is negligible transmission of energy across this interface. Thus, any air-filled crack or void lying immediately between two transducers will obstruct the direct ultrasonic beam when the projected length of the void is greater than the width of the transducers and the wavelength of sound used. When this happens, the first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect. It is possible to make use of this effect for locating flaws, voids or other defects greater than about 100mm in diameter or depth. Relatively small defects have little or no effect on transmission times, but equally are probably

of minor engineering importance. Plotting contours of equal velocity often gives significant information regarding the quality of a concrete unit. In cracked members, where the broken faces of the members are held tightly together in close contact by compression forces, the pulse energy may pass unimpeded across the crack. If the crack is filled with liquid which transmits the ultrasonic energy (like in marine structures), the crack is undetectable using digital reading equipment. Measurements of attenuation may give valuable information in these cases.

A grid shall be drawn on the concrete member with its points of intersection spaced to correspond to the size of void that might significantly affect its performance. A large survey of measurements at the grid points enables a large cavity to be investigated by measuring the transit times of pulses passing between the transducers when they are placed so that the cavity lies in the direct path between them.

The size of such cavities may be estimated by assuming that the pulses pass along the shortest path between the transducers and around the cavity. Such estimates are valid only when the concrete around the cavity is uniformly dense and the pulse velocity can be measured in that concrete.

5.3.2 Procedure

(A) The ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traversing a known path length L in the concrete, the pulse of vibrations is converted into an electrical signal by

the second transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transit time (T) of the pulse to be measured. The pulse velocity (V) is given by:

$$V = L / T$$

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross probing).

However, in many situations two opposite faces of the structural member may not be accessible for measurements. In such cases, the receiving transducer is also placed on the same face of the concrete member (surface probing or indirect transmission). Surface probing is not as efficient as cross probing, because the signal produced at the receiving transducer has amplitude of only 2 to 3 percent of that produced by cross probing and the test results are greatly influenced by the surface layers of concrete which may have different properties from that of concrete inside the structural member. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5 to 20 percent depending largely on the quality of the concrete under test. For good quality concrete, a difference of about 0.5 km/s may generally be encountered. For the procedure and for calculating the exact value of ultrasonic pulse velocity by surface probing

(see Annex A).

(B) To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer, it is essential that there be adequate acoustical coupling between the concrete and the face of each transducer. Typical couplants are petroleum jelly, grease, liquid soap and kaolin glycerol paste. If there is very rough concrete surface, it is required to smoothen and level an area of the surface where the transducer is to be placed. If it is necessary to work on concrete surfaces formed by other means, for example trowelling, it is desirable to measure pulse velocity over a longer path length than would normally be used. A minimum path length of 150mm is recommended for the direct transmission method involving one unmoulded surface and a minimum of 400mm for the surface probing method along an unmoulded surface.

(C) Since size of aggregates influences the pulse velocity measurement, it is recommended that for direct transmission method, the minimum path length shall be 100mm for concrete in which the nominal maximum size of aggregate is 20mm or less and 150mm for concrete in which the nominal maximum size of aggregate is between 20 and 40mm.

(D) In view of the inherent variability in the test results, sufficient number of readings are taken by dividing the entire structure in suitable grid markings of 300 × 300 mm or even smaller. Each junction point of the grid becomes a point of observation. Larger grid spacing up to maximum 500 × 500mm may be adopted for general overall assessment

of larger structures having uniform cross-section showing no signs of distress. The number of individual test points or grid spacing depends upon the size of the structure, the accuracy required and the variability of the concrete. Transducers are held on corresponding points of observation on opposite faces of a structural element to measure the ultrasonic pulse velocity by direct transmission, that is, cross probing. If one of the faces is not accessible, ultrasonic pulse velocity is measured on one face of the structural member by surface probing.

(E) Surface probing in general gives lower pulse velocity than in case of cross probing and depending on number of parameters, the difference could be of the order of about 0.5 km/s. In view of this, it is recommended that, in surface probing method the pulse velocity may be increased by 0.5 km/s, for values > 3.0 km/s.

6. Interpretation of Results

6.1 The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete. For example, if the concrete is not compacted as thoroughly as possible, or if there is segregation of concrete during placing or there are internal cracks or flaws, the pulse velocity will be lower, although the same materials and mix proportions are used.

6.2 The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc (indicative of the level of workmanship employed) can be assessed using the guidelines given in Table 6.3. This table is only for concrete quality grading and shall not be used for

estimating the concrete grades from ultrasonic pulse velocity values.

Table 6.3: Velocity Criterion for Concrete Grading

Sl. No.	Average Value of Pulse Velocity by Cross Probing (km/s)	Concrete Quality Grading
1	Above 4.40	Excellent
2	3.75 to 4.40	Good
3	3.00 to 3.75	Doubtful (*)
4	Below 3.00	Poor
(*) In case of "Doubtful" quality, it may be necessary to carry out further tests.		

6.3 Since actual values of the pulse velocity obtained, depend on a number of parameters, any criterion for assessing the quality of concrete on the basis of pulse velocity as given in Table 6.3 can be held as satisfactory only to a general extent. However, when the comparison is made amongst different parts of a structure, which have been built at the same time with supposedly similar materials, construction practices and supervision, the assessment of quality becomes more meaningful and reliable. Whenever the UPV values are lesser by more than 10 percent of average value of the member/part of structure, the location shall be considered as having internal flaws or segregation caused by poor workmanship or there could be micro cracks.

6.4 The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate because the statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high. The reason is that a large number of parameters are involved, which influence the pulse velocity and compressive strength of concrete to different

extents. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the pulse velocity and the compressive strength of concrete specimens made with such materials and mix proportions, under environmental conditions similar to that in the structure. The estimated strength may vary from the actual strength by ± 20 percent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials. If correlation graph is not available but the velocities on concrete cubes are available, the average pulse velocities in members of structures are not expected to deviate by more than 10 to 15 percent of the pulse velocity values obtained on concrete cubes (dry surface).

7. Estimating depth of a surface crack

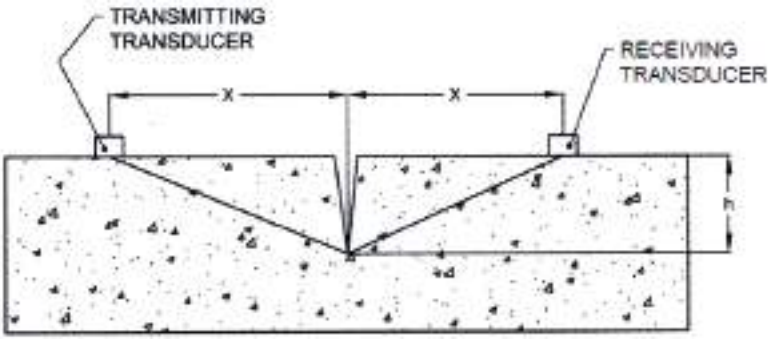


Fig. 6.6.2: Measurement of Depth of Crack

Longitudinal pulse velocity = α

Distance travelled in uncracked concrete = 2X (Fig. 6.6.2)

Distance travelled in cracked concrete = $2 * (X^2 + h^2)0.5$

Tc^2 (in cracked concrete) = $(4X^2 + 4h^2) / \alpha^2$

Ts^2 (in uncracked concrete) = $4X^2 / \alpha^2$

Therefore, $(Tc^2 / Ts^2) = (X^2 + h^2)/X^2$

Or

$$h = X * [(Tc^2 / Ts^2) - 1]^{0.5}$$

where:

Tc = Travel time around the crack,

Ts = Travel time along the surface of the same type of concrete without any crack, and

h = Depth of crack (see Fig. 6.6.2)

8. Determining dynamic Young's Modulus of Elasticity (E): The dynamic Young's modulus of elasticity (E) of the concrete may be determined from the pulse velocity and the dynamic Poisson's ratio (μ), using the following relationship:

$$E = [\rho (1 + \mu) (1 - 2\mu) V2] / (1 - \mu)$$

Where:

E = Dynamic Young's Modulus of elasticity, in MPa;

ρ = Density, in kg/m3; and

V = Pulse velocity, in m/s.

The above relationship may be expressed as:

$$E = \rho f(\mu) V2$$

Where:

$$f(\mu) = [(1 + \mu) (1 - 2\mu)] / (1 - \mu)$$

The value of the dynamic Poisson's ratio varies from 0.20 to 0.35, with 0.24 as average. However, it is desirable to have an independent measure of it for the particular type of concrete under test. The dynamic Poisson's ratio may be obtained from measurements on concrete test-beams of the pulse velocity (V) along with length (l) of the beam and the fundamental resonant frequency (n) of the beam in longitudinal mode of vibration. From these measurements, the factor f(μ) is calculated by the relation:

$$f(\mu) = (2nl)^2 / V^2$$

Where:

n = Fundamental resonant frequency in cycles per second; and

l = length of specimen, in m.

This Page
is
Intentionally
Left Blank

Chapter - 7

TESTS ON BITUMEN

As per the current instructions of Railway Board, the Items and Specifications of CPWD's DSOR and the corresponding Technical Specifications of CPWD are to be used for works related to roads (the works in which Bitumen is used as a constituent material). In CPWD's Specifications, Vol. 2, 2019, Sub Head: 16.0 for "Road Works" contains the "List of Mandatory Tests" for various constituent of Road Work (Page 751) and Sl. No. 3 of this list is about "Bitumen" wherein it is stipulated that tests should be done as Per IS:73.

Clause 6.2 of the IS:73-2013 (Reaffirmed in 2018) specifies that the Bitumen shall conform to the requirements prescribed in Table-1 therein. The requirements listed in Table-1 prescribes following tests:

(7.1) Determination of Penetration

(7.2) Determination of Absolute Viscosity

(7.3) Determination of Kinematic Viscosity

(7.4) Determination of Flash Point

(7.5) Determination of Solubility in Trichloroethylene

(7.6) Determination of Softening Point

(7.7) Determination of Viscosity Ratio

(7.8) Determination of Ductility

This Page
is
Intentionally
Left Blank

7.1 Determination of Penetration

1. Introduction: Penetration value test on bitumen is a measure of hardness or consistency of bituminous material. It is carried to determine (i) Consistency of bituminous material, and (ii) Suitability of bitumen for use under different climatic conditions & various types of construction.

This chapter covers the method for the determination of penetration of semi-solid and solid bituminous materials.

2. Reference: IS-1203:2022 "Methods for Testing Tar and Bituminous Materials — Determination of Penetration".

3. Apparatus

Fig. 7.1.1: Test setup

3.1 Container: A metal or glass cylindrical, flat bottom container of essentially the following dimensions shall be used:

For penetration below 225:

Diameter, mm	55
Internal depth, mm	35

For penetration between 225 and 350:

Diameter, mm	70
Internal depth, mm	45

3.2 Needle: A straight, highly polished, cylindrical, stainless steel (SS 316), rod, with conical and parallel portions co-axial, having the shape, dimensions and tolerances given in Fig. 7.1.2. The needle is provided with a shank approximately 3mm in diameter into which it is immovably fixed. The taper shall be symmetrical and the point shall be 'blunted' by grinding to a truncated cone.

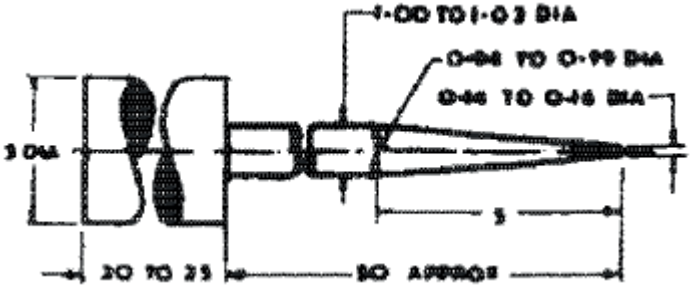


Fig. 7.1.2: Needle for Penetration test

3.3 Water Bath: A water bath preferably with a thermostat maintained at 25.0 ± 0.1 containing not less than 10 litres of water. The sample being immersed to a depth of not less than 100 mm from the top and supported on a perforated shelf not less than 50 mm from the bottom of the bath.

3.4 Transfer Dish: A small dish or tray provided with some means which ensure a firm bearing and prevent the rocking of the container and of such capacity as will ensure complete immersion of the container during the test.

3.5 Penetration Apparatus: Any apparatus that will allow the needle to penetrate without appreciable friction, and that is accurately calibrated to yield results in tenths of millimetre shall be adopted.

3.6 Thermometer: It shall conform to the following requirements:

Characteristic	Requirement
Range	0 to 440 C
Least Count	0.10 C

3.7 Time Device: For hand-operated penetrometers, any convenient timing device, such as electric timer, stop watch, or any other spring actuated device may be used provided it is graduated 0.1 s or less and is accurate to within ± 0.1 s for a 60 s interval. An audible seconds counter adjusted to provide 1 beat each 0.5 s may also be used. The time for a 1 1-count interval shall be 5 ± 0.1 s. Any automatic timing device attached to a penetrometer shall be accurately calibrated to provide the desired test interval within ± 0.1 s.

4. Procedure

4.1 Preparation of Test Sample

4.1.1 Soften the material to a pouring consistency at a temperature not more than 60°C for tars and pitches and not more than 90°C for bitumen above the respective approximate softening point and stir it thoroughly until it is homogeneous and is free from air bubbles and water. Pour the melt into the container to a depth at least 10mm in excess of the expected penetration. Protect the sample from dust and allow it to cool in atmosphere at a temperature between 15 to 30°C for 1 to 2 hour for 45mm deep container and 1 hour when the container of 35mm depth is used. Then place it along with the transfer dish in the water bath at 25.0 ± 0.1°C and allow it to remain for 1 to 2 hour and 1 hour for 45mm and 35mm deep container respectively.

4.2 Testing

4.2.1 Unless otherwise specified, testing shall be carried out at 25.0 ± 0.1°C.

4.2.2 Fill the transfer dish with water from the

water bath to a depth sufficient to cover the container completely; place the sample in it and put it upon the stand of the penetration apparatus. Adjust the needle to make contact with the surface of the sample.

4.2.2.1 This may be accomplished by placing the needle point in contact with its image reflected by the surface of the material from a suitably placed source of light.

4.2.2.2 Unless otherwise specified, load the needle holder with the weight required to make a total moving weight (that is, the sum of the weights of the needle, carrier and superimposed weights) of 100 ± 0.25 g.

4.2.3 Note the reading of the dial or bring the pointer to zero. Release the needle and adjust the points, if necessary to measure the distance penetrated. Make at least three determinations at points on the surface of the sample not less than 10mm apart and not less than 10mm from the side of the dish. After each test, return the sample and transfer dish to the water bath, and wash the needle clean with toluene and dry. In the case of material of penetration greater than 225, three determinations on each of two identical test specimens using a separate needle for each determination shall be made, leaving the needle in the sample on completion of each determination to avoid disturbance of the specimen.

4.2.4 For determining the penetration ratio, testing shall also be carried out a 4.0° ± 0.1° C.

NOTE: For test at 4° C, the total weight on the penetration needle shall be 200 ± 0.25 g and the time of penetration shall be 60 s.

5. Report

5.1 Express the depth of penetration of the needle in tenths of millimetre.

5.2 The value of penetration reported shall be the mean of not less than three determinations whose values do not differ by more than the amount given below:

Penetration	Maximum Difference
0 to 49	2
50 to 149	4
150 to 249	6
250 and above	8

5.3 Determine the penetration ratio as under:

$$\text{Penetration Ratio} = \frac{\text{Pen. At } 4^0\text{C, 200 g, 60 s}}{\text{Pen. At } 25^0\text{C, 200 g, 60 s}} \times 100$$

6. Precision

67.1 The duplicate results should not differ by more than the following:

Penetration	Repeatability	Reproducibility
Below 50	1 Unit	4 Units
Above 50	3% of their mean	8% of their mean

7. Precautions

7.1 If the sample contains extraneous matter, it should be sieved through IS Sieve 30 (see IS 460).

7.2 To avoid overheating at the bottom of the container, use of an air oven or sand bath is recommended.

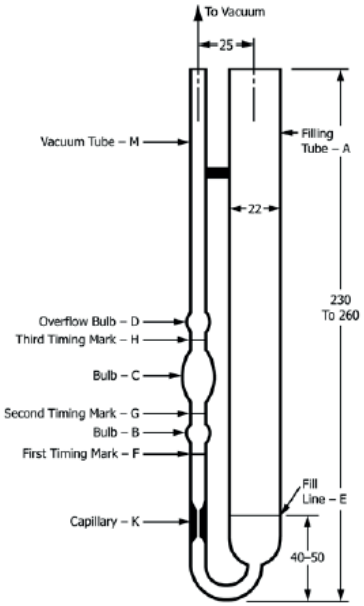
7.3 While the needle is penetrating into the sample, if there is any movement of the container, that determination shall be discarded.

7.2 Determination of Absolute Viscosity

1. Introduction: Viscosity shows how easily bitumen flows. The higher the viscosity of the bitumen, the harder it is to flow. Consequently, it behaves more like semi-solid matter. This chapter covers the method for the determination of absolute viscosity of bitumen by vacuum capillary viscometers at any specified temperature. It is applicable to materials having a viscosity range of 42 to 200000 Poises.

2. Reference: IS-1206 (Part-2):2022 "Methods for Testing Tar and Bituminous Material – Determination of Viscosity: Part-2: Absolute Viscosity".

3. Terminology: For the purpose of this standard, the following definitions and those given in IS 334 shall apply.



All dimensions are in mm

Fig. 7.2.1: Cannon-Manning Vacuum Capillary Viscometer

3.1 Absolute or Dynamic Viscosity of a Newtonian Liquid: The ratio between the applied shear stress and rate of shear is called the coefficient of viscosity. This coefficient is thus a measure of the resistance to flow of the liquid. It is commonly called the viscosity of the liquid. The SI unit of viscosity is 1 Pa. s (1 $N.s/m^2$) and is called a Pascal-second. The CGS unit of viscosity is 1 g/cm.s (1 $dyne.s/cm^2$) and is called a poise (P). 1 Pa.s is equivalent to 10 P.

3.2 Newtonian Liquid: A liquid in which the shear stress is directly proportional to the rate of shear. The constant ratio of shear stress to the rate of shear is called the coefficient of viscosity of the liquid. If this ratio is not constant then the liquid is non-Newtonian.

4. Apparatus

4.1 Viscometers: Capillary type made of borosilicate glass, annealed suitable for this test are given in Para 4.1.1 to 4.1.3.

4.1.1 Cannon-Manning Vacuums Viscometer: (Fig. 7.2.1) The size numbers/approximate bulb factors K and viscosity ranges for the series of Cannon-Manning Vacuum Capillary Viscometer are as follows:

Viscometer Size No.	Approximate Calibration Factor 30cm Hg Vacuum (Poises per s)		Viscosity Range (Poises)
	Bulb B	Bulb C	
10	2.0	0.6	36 to 800
11	6.0	2.0	120 to 2400
12	20.0	6.0	360 to 8000
13	60.0	20.0	1200 to 24000
14	200.0	60.0	3600 to 80000

For all viscometer sizes the volume of measuring bulb C is approximately three times that of bulb B. The viscosity ranges correspond to a filling time of 60 and 400 s for both measuring bulbs.

Sizes 10 through 14 are best suited to viscosity measurements of bituminous binders at 60 °C.

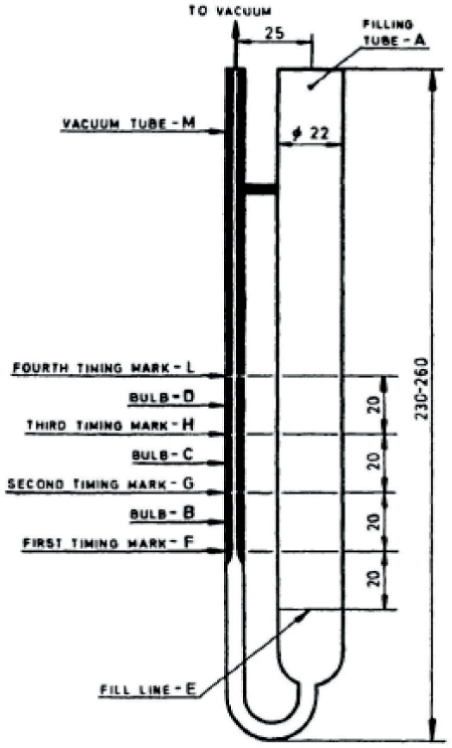
NOTE: The calibration factors have to be determined either by calibration through viscosity standards or through calibration by competent agency.

4.1.2Asphalt Institute Vacuum Viscometer: (Fig. 7.2.2) The size numbers. Approximate radii. approximate bulb factors K and viscosity ranges for the series of Asphalt Institute Vacuum Capillary Viscometer are as follows:

Viscometer Size No.	Capillary Radius K (cm)	Approximate Calibration Factor 30cm Hg Vacuum (Poises per s)			Viscosity Range (Poises)
		Bulb B	Bulb C	Bulb D	
25	0.0125	2	1	0.7	42 to 800
50	0.025	8	4	3	180 to 3200
100	0.050	32	16	10	600 to 12800
200	0.100	128	64	40	2400 to 52000
400	0.200	500	250	160	9600 to 200000

This viscometer has measuring bulbs B, C and D located on the viscometer arm M which is a precision bore glass capillary. The measuring bulbs are 2cm long capillary segments separated by timing marks F, G, H and L.

Sizes 50 through 200 are best suited to viscosity measurements of bituminous binders at 60°C.

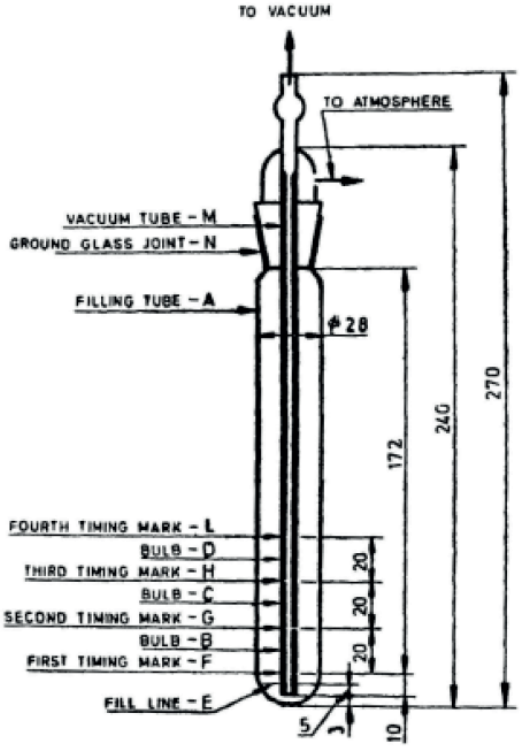


All dimensions are in mm

Fig. 7.2.2: Asphalt Institute Vacuum Capillary Viscometer

Note: The calibration factors have to be determined either by calibration through viscosity standards or through calibration by competent agency.

4.1.3 Modified Koppers Vacuum Viscometer: (Fig. 7.2.3) The size numbers approximate radii. approximate bulb factors K and viscosity ranges for the series of modified Koppers vacuum capillary viscometer are as follows:



All dimensions are in mm

Fig. 7.2.3: Modified Koppers Vacuum Capillary Viscometer

Viscometer Size No.	Capillary Radius K (cm)	Approximate Calibration Factor 30cm Hg Vacuum (Poises per s)			Viscosity Range (Poises)
		Bulb B	Bulb C	Bulb D	
25	0.0125	2	1	0.7	42 to 800
50	0.025	8	4	3	180 to 3200
100	0.050	32	16	10	600 to 12800

200	0.100	128	64	40	2400 to 52000
400	0.200	500	250	160	9600 to 200000

Sizes 50 through 200 are best suited to viscosity measurements of bituminous binders at 60 °C.

NOTE: The calibration factors have to be determined either by calibration through viscosity standards or through calibration by competent agency.

This viscometer consists of a separate filling tube A, and a precision bore glass capillary vacuum tube M. These two parts are joined by borosilicate ground glass joint N, having a 24/40 standard taper. The measuring bulbs B, C, and D on the glass capillary are 2 cm capillary segments separated by timing marks F, G, H and L.

A viscometer holder can be made by drilling a 28mm hole through the center of a No. 11 rubber stopper and setting the stopper between the hole and the edge. When placed in a 5cm diameter hole in the bath cover, it holds the viscometer in place.

4.2 Thermometer: The thermometer shall be calibrated from a competent agency with least count of 0.1°C.

4.3 Bath: A suitable bath for immersion of the viscometer so that the liquid reservoir or top of the capillary, whichever is uppermost is at least 20mm below the upper bath level, and with a provision for the visibility of the viscometer and the thermometer. Firm support for the viscometer shall be provided. The efficiency of the stirring and the balance between heat losses and heat input must be such that the temperature of the bath medium does not vary by more than ± 0.1°C.

NOTE: All tubing is of glass with 6.35mm OD

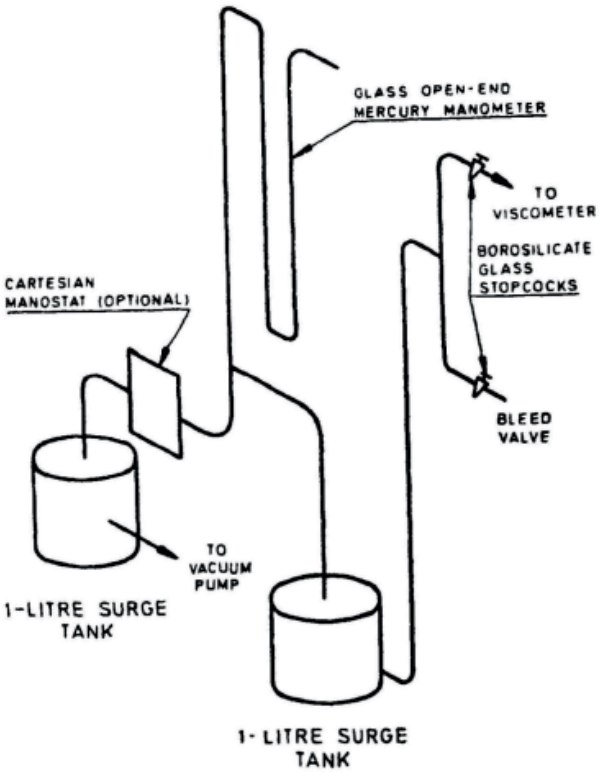


Fig. 7.2.4: Suggested Vacuum System

4.4 Vacuum System: A vacuum system capable of maintaining a vacuum to within ± 0.05cm of the desired level up to and including 30cm of mercury. One such system is shown in Fig. 7.2.4. The glass tubing of 6.35mm diameter and all glass joints should be completely airtight and no loss of vacuum should be permitted till the experiment is on. A vacuum or aspirator pump is suitable for the vacuum source.

NOTE: The vacuum measuring system for this test method must be standardized at least once a year.

4.5 Timing Device: A Stop watch or other timing device graduated in divisions of 0.2 s or less, and

accurate to within 0.1 percent when tested over a 60 min period.

5. Calibration of Viscometer

5.1 Reference Material: Viscosity standard (certified viscosity reference standard) may be used for calibration purposes.

5.2 Calibration: Charge a clean-dry viscometer by pouring the reference material to within ± 2 mm of fill line E (Fig. 7.2.1, 7.2.2 and 7.2.3). Place the charged viscometer in the viscometer bath maintained within ± 0.1°C at the calibration temperature. Establish a 30 ± 0.05cm vacuum in the vacuum system and connect it to the viscometer with valve closed in the line leading to the viscometer. After the viscometer has been in the bath for 30 ± 5 min, start the flow of liquid in the viscometer by opening the stop cock in the line leading to the vacuum system. Measure to within 0.5 s the time required for the leading edge of the meniscus to pass between timing marks F and G. Also measure to within 0.5 s the time required for the leading edge of the meniscus to pass between timing marks G and H. Calculate the calibration factor K for each bulb as follows:

$$K = V / t$$

Where:

K Viscometer bulb calibration factor poises/s at 30.0 cm Hg;

V Absolute viscosity of reference material at calibration temperature in poises; and

t Flow time, in seconds.

Repeat the calibration procedure using the same viscosity standard or another reference material. Record the average calibration constant K.

5.2.1 The duplicate determination of calibration constant K for each bulb shall be within 2 percent of the mean value. The value of viscometer

constants shall be expressed to the nearest 0.1 percent.

6. Procedure

6.1 Preparation of the Sample: Heat the sample to a temperature not more than 60°C for the tars and pitches and not more than 90°C for bitumen above their respective approximate softening point temperature respectively until it has become sufficiently fluid to pour. Transfer about 20 ml into a suitable container and maintain it to a temperature of 135 ± 5.5°C stirring occasionally to prevent local overheating and allow the entrapped air to escape.

6.1.1 Charge the viscometer by pouring the prepared sample to within ± 2mm of fill line E. Place the charged viscometer in an oven or bath maintained at 135 ± 5.5°C for a period of 10 ± 2 min to allow large air bubbles to escape.

6.2 Testing: Maintain the bath at the test temperature within ± 0.1°C. Place the charged viscometer vertically in the water bath with the help of a holder so that the uppermost timing mark is at least 2cm below the surface of the bath liquid. Establish a vacuum of 30 ± 0.05cm of mercury in the vacuum system and connect it to the viscometer with the valve closed. After the viscometer has remained in the bath for 30 ± 5 min open the valve and allow the asphalt to flow into the viscometer. Measure to within ± 0.5 s the time required for the leading edge of the meniscus to pass between successive pairs of timing marks. Upon completion of the test, remove the viscometer from the bath and place it in an inverted position in an oven maintained at 135 ± 5°C until asphalt is drained off thoroughly from the viscometer. Clean the viscometer thoroughly by rinsing several times with an appropriate solvent completely. Dry the tube by passing a slow stream of filtered dry air through the capillary for 2 min. Periodically clean the instrument with chromic acid to remove organic deposits. Rinse

thoroughly with distilled water and acetone and dry with clean air.

7. Calculation

7.1 Calculate and report the absolute viscosity to by the following equation:

Viscosity (in Poises) = K x t

Where:

K = selected calibration factor, in poise per second; and

t = flow time, in seconds.

NOTE: Measure the time required for the leading edge of the meniscus to pass between successive pairs of timing marks. Report the first flow time which exceeds 60s between a pair of timing marks, noting the identification of the pair of timing marks.

7.2 Always report the test temperature and vacuum with the viscosity test results. For example, viscosity at 60°C, 30 cm Hg vacuum in poises.

8. Precision

8.1 The duplicate test results should not differ by more than the following:

(a) Repeatability: The duplicate test results by the same operator using the same viscometer should not differ by more than 7 percent of their mean.

(b) Reproducibility: Results obtained by two laboratories should not differ by more than 10 percent of their mean.

Please also note that this precision is only for meant for measurement made at 60°C and hence should not be used for any other temperature measurements.

7.3 Determination of Kinematic Viscosity

1. Introduction: Viscosity shows how easily bitumen flows. The higher the viscosity of the bitumen, the harder it is to flow. Consequently, it behaves more like semi-solid matter. This chapter covers the method for the determination of kinematic viscosity of paving grade and cut-back bitumen and distillation residues of cut-backs. It is applicable to the materials having a viscosity range of 30-100 000 cSt.

2. Reference: IS-1206 (Part-3) : 2021 "Method or Testing Tar and Bituminous Materials – Determination of Viscosity. Part-3: Kinematic Viscosity".

3. Terminology: For the purpose of this standard the following definitions and those given in IS 334 shall apply.

3.1 Viscosity of a Newtonian Liquid: The ratio between the applied shear stress and rate of shear is called the coefficient of viscosity. This coefficient is thus a measure of the resistance to flow of the liquid. It is commonly called the viscosity of the liquid. The SI unit of viscosity is 1 Pa.s (1 $N.s/m^2$) and is called a Pascal-second. The CGS unit of viscosity is 1 g/cm.s (1 $dyne.s/cm^2$) and is called a poise (P). 1 Pa.s is equivalent to 10 P.

3.2 Density: It is mass per unit volume, the CGS unit of density is g/cm^3 and the SI unit of density is kg/m^3.

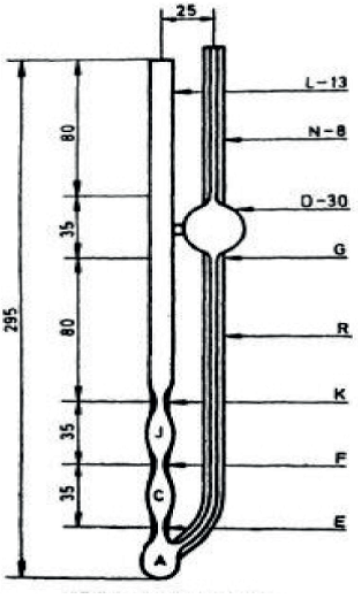
3.3 Kinematic Viscosity of a Newtonian Liquid: The ratio of the viscosity to the density of a liquid. It is a measure of the resistance to flow of a liquid under gravity.

3.4 Newtonian Liquid: A liquid in which the shear stress is directly proportional to the rate of shear. The constant ratio of shear stress to the rate of shear is called the coefficient of viscosity of the liquid. If this ratio is not constant then the liquid is non-Newtonian.

4. Apparatus

4.1 Viscometers : The capillary type of viscometer of borosilicate glass annealed suitable for the test are as given in Para 4.1.1 and 4.1.2.

4.1.1 Cannon-Fenske Viscometer for Opaque Liquids: Detailed drawings of the reverse-flow Cannon-Fenske viscometer is given in Fig. 7.3.1. The size, dimensions, approximate constant. kinematic viscosity range, capillary diameter and bulb volumes shall be as given in Table 7.1.

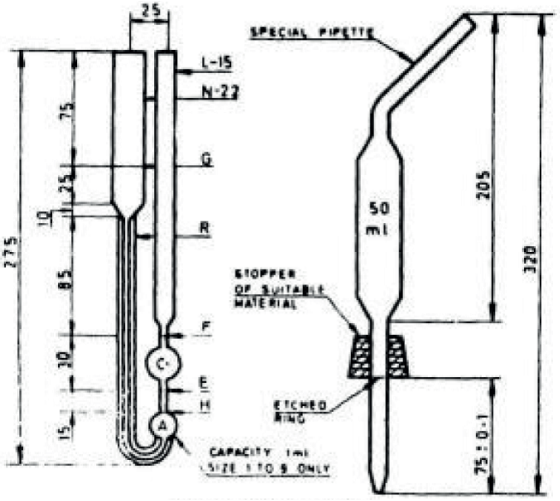


All dimensions are in mm

Fig. 7.3.1: Cannon-Fenske Viscometer

Table 7.1: Dimensions of Cannon-Fenske Viscometer

Size No.	Approx. Constant	Kinematic Viscometer Range	Inside Dia. of Tube	Inside Dia. of Tube	Volume Bulbs A	Volume Bulbs
	cSt/s	cSt	R mm (±2%)	N & G Tube E, F & K mm (±5%)	C & J ml (±5%)	D ml (±5%)
150	0.035	2.1 to 35	0.78	3.2	2.1	11
200	0.1	6 to 100	1.02	3.2	2.1	11
300	0.25	15 to 250	1.26	3.4	2.1	11
350	0.5	30 to 500	1.48	3.4	2.1	11
400	1.2	72 to 1200	1.88	3.4	2.1	11
450	2.5	150 to 2500	2.20	3.7	2.1	11
500	8	480 to 8000	3.1	4.0	2.1	11
600	20	1200 to 20000	4.00	4.7	2.1	13



All dimensions are in mm

Fig. 7.3.2: BS/IP/RF U-Tube Reverse Flow Viscometer

Table 7.2: Dimensions of BS/IP/RF-U Viscometer

Size No.	Approx. Constant	Kinematic Viscometer Range	Inside Dia. of Tube	Length of Tube	Inside Dia. at E, F, & G	Bulb C ml
	cSt/s	cSt	R mm (±2%)	R mm	mm	(±5%)
4	0.1	6-100	1.26	185	3.0-3.3	4.0
5	0.3	18-300	1.64	185	3.0-3.3	4.0
6	1.0	60-1000	2.24	185	3.0-3.3	4.0
7	3.0	180-3000	2.93	185	3.3-3.6	4.0
8	10	600-10000	4.00	185	4.4-4.8	4.0
9	30	1800-30000	5.5	185	6.0-6.7	4.0
10	100	6000-100000	7.00	210	7.7	4.0
11	300	18000-300000	10.00	210	10	4.0

4.1.2 BS U Tube Modified Reverse Flow Viscometer: The viscometer shall be made of clear borosilicate or other heat resistant glass free from visible defects. All glass tubing used in the construction of a single viscometer shall be of the same composition and the finished instrument shall be thoroughly annealed. The design and dimensions of the viscometer are given in Fig. 7.3.2 and Table 7.2.

4.2 Bath: A suitable bath for immersion of the viscometer so that the liquid reservoir or top of the capillary whichever it; uppermost is at least 20mm below the upper bath level. Provision shall be there for visibility of the viscometer and the thermometer. The efficiency of the stirring and the balance between heat losses and heat input shall be such that the temperature of the bath medium is maintained at ± 0.1°C over the entire length of the viscometer.

4.3 Thermometers: The thermometer shall be with least count reading of 0.1°C and shall be calibrated from competent agency.

4.4 Timing Device: Any timing device, such as stop-watch or stop clock capable of being read up to 0.5 s.

5. Calibration of Viscometer

5.1 Reference Material: Viscosity standard (Certified Viscosity reference standard) may be used for calibration purposes.

5.2 Calibration: Charge the clean dry viscometer by pouring the reference material. Place the charged viscometer in the viscometer bath maintained at calibration temperature within ± 0.1°C. Allow the charged viscometer to remain in the bath for 30 m to reach the test temperature. Measure to within 0.1 s the time required for the leading edge of the meniscus to pass from the first timing mark to the second. Calculate the viscometer constant C, as follows:

$$C = V / t$$

Where:

V = viscosity in centistokes for the standard liquid, and

t = efflux time, in seconds.

5.2.1 The duplicate determination of calibration constant K for each bulb shall be within 2 percent of the mean value. The value of Viscometer constants shall be expressed to the nearest 0.1 percent.

5.3 If the viscometer is used at a location other than the calibrating laboratory the constant C should be corrected for the difference in the acceleration of gravity "g" at the two locations as follows:

$$C2 = (g2 / g1) \times C1$$

Where:

C2 = Calibration constant in the testing laboratory,

C1= Calibration constant in the calibration

laboratory,

g2 = Acceleration of gravity at the testing laboratory, and

g1 = Acceleration of gravity at the calibration laboratory.

6. Preparation of Sample

6.1 Procedure for Cut-Back Bitumen and Oil Distillates: Open the sample container and mix the sample thoroughly by stirring for 30 s taking care to avoid entrapped air. For too viscous samples, heat the sealed container in a bath or oven maintained at about 60°C. Pour immediately 20 ml into a clean dry container having a capacity of about 30 ml and seal the container immediately.

6.2 Procedure for Bitumen-Heat: the sample to a temperature not more than 60°C for tars and pitches and not more than 90°C for bitumen above the corresponding approximate softening point temperature respectively until it attains pouring consistency. Stir it thoroughly and transfer approximately 20 ml in a 30 ml container. Local over-heating and entrapped air should be avoided.

7. Procedure

7.1 Procedure for Cannon-Fenske Viscometer

7.1.1 To charge the Carmon-Fenske viscometer invert the viscometer and apply suction to the tube L, immersing tube N in the liquid sample. Draw liquid through tube N filling bulbs D to fill mark G, wipe excess sample off tube N and invert the viscometer to its normal position. Align the viscometer vertically in the bath. Visual observation is sufficient. However, it can be done more accurately and quickly by suspending a plumb bulb in the tube L. Allow the viscometer to remain in the constant temperature bath for a sufficient time to ensure that the sample reaches

temperature equilibrium. Allow the viscometer to remain in the constant temperature bath a sufficient time to ensure that the sample reaches temperature equilibrium (10 min minimum and 30 min maximum). When the test temperature is reached, remove the stopper in the tubes N and L respectively and allow the sample to flow by gravity. Measure to the nearest 0.1 s the time required for the leading edge of the meniscus to pass from timing mark E to timing mark F. If this efflux time is less than 60 s, select a viscometer of smaller capillary diameter and repeat the operation.

7.1.2 Upon completion of the test, clean the viscometer thoroughly by several rinsing with an appropriate solvent completely miscible with the sample, followed by a completely volatile solvent. Dry the tube by passing a slow stream of filtered dried air through the capillary for 2 min or until last trace of solvent is removed.

7.2 Procedure for BS U - Tube Modified Reverse Flow Viscometer

7.2.1 Mount the BS U-tube viscometer in the constant temperature bath keeping tube L vertical. Pour sample through tube N to a point just above filling mark G, allow the sample to flow freely through capillary R, taking care that the liquid column remains unbroken until the lower mark H and then arrest its flow by closing the timing tube with a cork or rubber stopper in tube L. Add more liquid, if necessary to bring the upper meniscus slightly above mark G. After allowing the sample to attain bath temperature and any air bubble to rise to the surface (usually about 20-30 min is required), gently loosen the stopper allowing the sample to flow until it is approximately at the lower filling mark H and press back the stopper to arrest flow. Remove

the excess sample above filling mark G by inserting the special pipette until its cork rests on top of the tube N and apply gentle suction until air is drawn through. The upper meniscus shall coincide with mark G. Allow the viscometer to remain in the constant temperature bath for a sufficient time to ensure that the sample reaches temperature equilibrium. It takes about 20 min at 38°C, 25 min at 100°C and 30 min at 135°C. Remove the stopper in the tube N and L respectively and allow the sample to flow by gravity. Measure to the nearest 0.1 s the time required for the leading edge of the meniscus to pass from timing mark E to timing mark F. If this efflux time is less than 60 s select a viscometer of smaller capillary diameter and repeat the operation.

7.2.2 Upon completion of the test, remove the viscometer from the bath and place it in an inverted position in an oven maintained at 135 ± 5°C until asphalt is drained off thoroughly from the viscometer. Clean the viscometer thoroughly by rinsing several times with an appropriate solvent completely. Dry the tube by passing a slow stream of filtered dry air through the capillary for 2 minutes. Periodically clean the instrument with chromic acid to remove organic deposits. Rinse thoroughly with distilled water and acetone and dry with clean air.

8. Calculation: Calculate the kinematic viscosity up to three significant figures with the help of following equation:

Kinematic viscosity cSt = C x t

Where:

C = Calibration constant of the viscometer, in centistokes per second, and

t = Efflux time, in seconds.

9. Report: Report always the test temperature along with the results as follows:

Kinematic Viscosity at 135 °C = X

where X = C.t

C = Calibration factor

t = Time

1 mm^2s^{-1} = 1cSt

10. Precision: The duplicate test results should not differ by more than the values given in Table 7.3.

10.1 Repeatability: The closeness of agreement between independent results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory and after short intervals of time).

10.2 Reproducibility: The closeness of agreement between independent results obtained with the same method on identical test material but under different conditions (different operators, different apparatus, different laboratories and/or after different intervals of time).

Table 7.3: Precision of Test Results

Sl. No.	Material	Repeatability	Reproducibility
		% of Mean	% of Mean
i	Bitumen at 135°C	1.8	8.8
ii	Cut back Bitumen at 60°C		
	(a) Below 3000 cSt	1.5	3
	(b) 3000 to 6000 cSt	2.0	9.9
	(c) Above 6000 cSt	8.9	10.0

7.4 Determination of Flash Point

1. Introduction: The "flash point" of a material is the lowest temperature at which the application of test flame causes the vapours from the material momentarily catch fire in the form of a flash under specified conditions of test. In practical view the "fire point" is the lowest temperature at which the application of test flame causes the material to ignite and burn at least for 5 seconds under specified conditions of test. At high temperatures, bituminous materials emit hydrocarbon vapours which are susceptible to catch fire. Therefore, the heating temperature of bituminous material should be restricted to avoid hazardous conditions. Flash point and fire point tests are used to determine the temperature to which bituminous material can safely be heated.

This chapter describes a procedure for determination of flash and fire points of petroleum products using the Cleveland open cup apparatus. It is applicable to petroleum products having open cup flash points between 79°C and 400°C.

2. Reference: IS-1448 [P:69]:2019 "Methods of Test Petroleum and its Products. P:69- Determination of Flash and Fire Points – Cleveland Open Cup Method".

3. Terms and definitions: For the purpose of this standard, following terms and definitions apply:

3.1 Flash point: Lowest temperature of the test portion, corrected to a standard atmospheric pressure of 101.3 kPa, at which application of a test flame causes the vapour of the test portion to ignite under the specified conditions of test.

3.2 Fire point: Lowest temperature of the test portion, corrected to a barometric pressure of 101.3 kPa, at which application of a test flame causes the vapour of the test portion to ignite and sustain burning for a minimum of 5 sec under the specified conditions of test.

4. Principle: The test cup is filled to a specified level with the test portion. The temperature of the test portion may be increased rapidly (50 C/min to 170 C/min) at first and then at a slow constant rate (50 C/min to 6°C/min) as the flash point is approached. At specified temperature intervals, a small test flame is passed across the test cup.

The lowest temperature at which application of the test flame causes the vapour above the surface of the liquid to ignite is taken as the flash point at ambient barometric pressure. To determine the fire point, the test is continued until the application of the test flame causes the vapour above the test portion to ignite and burn for at least 5 sec. The flash point and fire point obtained at ambient barometric pressure are corrected to standard atmospheric pressure using a formula.

5. Chemicals and materials

5.1 Cleaning solvent, for removal of traces of sample from the test cup and cover. The choice of solvent depends upon the previous material tested and the tenacity of the residue. Low volatility aromatic (benzene-free) solvents may be used to remove traces of oil, and mixed solvents can be efficacious for the removal of gum type deposits.

5.2 Verification liquids, certified reference material (CRM) or secondary working standards (SWS).

5.3 Steel wool, any grade capable of removing carbon deposits without damage to the test cup.

6. Apparatus

6.1 Cleveland open cup apparatus: (Fig. 7.4.1) as per the specifications given in the Anne. A of the IS 1448 [P:69]:2019. If automated testers are used, the user shall ensure that all the manufacturer's instructions for adjusting and operating the instrument are followed.

Fig. 7.4.1: Cleveland Open Cup Apparatus

6.2 Shield, to cover at least three sides of the test cup. The apparatus may include built-in draught shield.

6.3 Temperature measuring device, which shall meet the requirements for accuracy and have the response as specified in Annex. B of the IS 1448 [P:69]:2019.

6.4 Barometer, reading absolute pressure accurate to 0.5 kPa with a resolution of 0.1 kPa. Barometers pre-corrected to give sea level readings, such as those used at weather stations and airports, shall not be used.

7. Preparation of apparatus

7.1 Location of apparatus: Place the apparatus on a level and steady surface in a draught-free room. Shield the top of the manual apparatus from strong light by any suitable means to permit detection of the flashpoint. When draughts cannot be avoided, it is recommended good practice to surround the apparatus with a shield.

7.2 Cleaning the test cup: Wash the test cup with an appropriate solvent to remove any traces of gum or residue remaining from a previous test. Dry the test cup using a stream of clean air to ensure complete removal of the solvent used. If any deposits of carbon are present, remove them by rubbing with steel wool.

7.3 Preparing the test cup: Before use, cool the test cup to at least 56°C below the expected flash point.

7.4 Assembly of apparatus: Support the liquid in glass thermometer in a vertical position with the bottom of the bulb (6.4 ± 0.5) mm from the bottom of the test cup, and located at a point halfway between the Centre and side of the test cup on a diameter perpendicular to the arc (or line) of the sweep of the test flame, and on the side opposite to the test flame applicator. It is not necessary to restrict electronic temperature measuring devices to be mounted vertically, provided their performance is in accordance with the requirements in the test method. The vertical position of the temperature measuring device may be set by lowering until it contacts the bottom of the test cup, and then raise it by (6.4 ± 0.5) mm.

7.5 Verification of apparatus

7.5.1 Verify the correct functioning of the apparatus at least once a year by testing a certified reference material (CRM). The result obtained shall be equal to or less than $R/\sqrt{2}$ from the certified value of the CRM, where R is the reproducibility of the method.

It 1s recommended practice during verification of an automated apparatus to visually observe the detected flash point for correct operation.

It is recommended that more frequent verification checks are made using secondary working standards (SWSs) or other verification materials with a proven value.

7.5.2 The numerical values obtained during the verification check shall not be used to provide a bias statement, nor shall they be used to make any correction to the flash points subsequently determined.

7.5.3 It is good practice to select a CRM or SWS that has a certified value similar to the flash point of products being tested.

8. Sampling

8.1 Place samples in tightly sealed containers, appropriate to the material being sampled, and for safety purposes, ensure that the sample container is only filled 85% to 95% of its capacity.

8.2 Store the samples in conditions to minimize vapour loss and pressure build up. Avoid storing the samples at temperatures in excess of 30° C.

8.3 Subsampling: Subsample at a temperature at least 56°C below the expected flash point. If a part of the original sample is to be stored prior to testing, ensure that the container is filled to more than 50 % of its capacity.

NOTE: The results of flash point determinations can be affected if the sample volume falls below 50% of the container capacity.

8.4 Samples containing undissolved water: Flash point results can be affected by the presence of water; if a sample contains undissolved water, decant a water-free aliquot prior to mixing.

NOTE: Flash and fire point results can be affected by the presence of water, and splashing can occur.

8.5 Samples that are liquid at ambient temperature: Mix samples by gently shaking by hand prior to the removal of the test portion, taking care to minimize the loss of volatile components, and proceed in accordance with Para 9.

8.6 Samples that are semisolid or solid at ambient temperature: Heat the sample in its container in a heating bath or oven at a temperature not exceeding 56°C below the expected flashpoint. Ensure that high pressures do not develop in the container. Avoid overheating the sample as this could lead to the loss of volatile components. After gentle agitation, proceed in accordance with Para 9.

9. Procedure for determining flash point

9.1 Samples that can form a skin during testing may be tested by removing the skin formed as described in Para 9.6 to 9.8.1, An alternative procedure is given in Annex. D of IS 1448 [P:69]: 2019.

9.2 Record the absolute barometric pressure μsing a barometer in the vicinity of the apparatus at the time of test.

NOTE: It is not considered necessary to correct the barometric pressure reading to 0°C, although some Barometers are designed to make this correction automatically.

9.3 Fill the test cup at ambient or elevated temperature (see Para 9.6) so that the top of the meniscus is level with the filling mark. Position the test cup on the centre of the heating plate. If too much sample has been added to the test cup, remove the excess using a pipette or other suitable device; however, if there is any sample on the outside of the apparatus, empty, clean and refill It. Destroy or remove any air bubbles or foam on the surface of the sample while maintaining the correct level of test portion in the test cup. If foam persists in the final stages of the test, discard the result.

9.4 Light the test flame and adjust it to a diameter between 3.2mm and 4.8mm. As a safety practice, it is strongly advised, before heating the test cup and test portion, to pass the test flame across the test portion in the test cup to check for the presence

of unexpected volatile material. Thereafter, it is recommended to test for a flash every 10°C until the test portion is within 56°C of the expected flashpoint.

9.5 Apply heat initially so that the rate of temperature rise of the test portion is 5°C/min to 17°C/min. When the test portion temperature is approximately 56 °C below the expected flash point, decrease the heat so that the rate of temperature rise for the last 28°C before the expected flash point is 5°C/min to 6°C/min.

9.6 Avoid disturbing the vapours in the test cup by careless movements or breathing near the test cup.

9.7 Apply the test flame when the temperature of the test portion is 28°C below the expected flash point. The test flame is applied in one direction with a smooth continuous motion, taking (1 ± 0.1) sec, to pass across the centre of the test cup, at right angles to the diameter which passes through the thermometer, either in a straight line or along the circumference of a circle having a radius of at least 150mm. The Centre of the test flame shall move in a horizontal plane not more than 2mm above the plane of the upper edge of the test cup. For the next test flame application, pass the flame in the opposite direction.

NOTE: Some automated apparatus pass the test flame in one single direction.

9.8 If a flash is detected on this application of the test flame or during a preliminary application (see Para 9.4), discontinue the test and repeat the test using a fresh test portion with an expected flash point of at least 280C below the previous test value.

9.8.1 If a skin forms over the test portion, carefully move it aside with a spatula or comb and continue the determination.

9.8.2 If a flash has not been detected, continue applying the test flame each time thereafter at a

temperature reading that is a multiple of 20C.

NOTE: Higher flash points have been detected when skins formed on the surfaces of test portions have not been removed.

9.9 When testing a sample whose expected flash point temperature is not known, bring the test portion in the lest cup to a temperature no greater than 50°C, or if the sample required heating to be transferred into the test cup, bring the test portion In the test cup to that temperature. Apply the test flame, in the manner described in Para 9.7, beginning at least 50C above the starting temperature. Continue heating the test specimen at 5°C/min to 6°C/min and testing the test specimen every 2°C as described in Para 9.7 until the flash point is obtained.

This value may be used as the expected flashpoint when a fresh test portion is tested in the standard mode of operation. Flash point results determined in an unknown expected flash point mode should be considered approximate.

9.10 Record as the detected flash point, the temperature of the test portion, read on the thermometer, when application of the test flame causes the vapours of the test portion to ignite at any point on the surface of the test portion and a large flame propagate over the surface of the test portion, under the specified conditions of test. Do not confuse the true flash point with the bluish halo that sometimes surrounds the test flame.

10. Procedure for determining fire point: To determine the fire point, after carrying out the procedure specified in Para 9, continue heating so that the test portion temperature increases at a rate of 5° C/min to 6° C/min. Continue the application of the test flame at 2° C intervals until the vapour of the test portion ignites and continues to burn for at least 5 sec. Record the temperature at this point as the detected fire point of the sample.

If the fire persists for more than 5 sec, extinguish it with a cover made of metal or other fire-resistant material fitted with a handle.

11. Calculation

11.1 If the barometric pressure reading is measured in a unit other than kPa, convert it to kPa using one of the following formulae:

Reading in hPa x 0.1 = kPa

Reading in mbar x 0.1 = kPa

Reading in mmHg x 0.1333 = kPa

11.2 Calculate the corrected flash point or fire point, tc, using the following formula:

$$tc = td + 0.25 (101.3 - p)$$

where

td is the detected flash point or fire point at ambient barometric pressure, in °C;

p is the absolute barometric pressure, in kPa;

0.25 is a constant with dimensions °C/kPa;

101.3 is used as the standard atmospheric pressure in kPa.

12. Expression of results: Record the following:

(a) The flash point, corrected to standard atmospheric pressure, rounded to the nearest 10 C, and, if required,

(b) The fire point, corrected to standard atmospheric pressure, rounded to the nearest 1° C.

13. Precision

13.1 Repeatability (r): The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material, would in the long run, in the normal and correct operation of the test method,

exceed the following values in only one case in 20.

Flash point, R = 8^0C

Fire point, R = 14^0C

13.2 Reproducibility (R): The difference between two single and independent test results, obtained by different operators working in different laboratories on identical test material, would in the long run, in the normal and correct operation of the test method, exceed the following values in only one case in 20.

Flash point, R = 18^0C

Fire point, R = 14^0C

14. Test report: The test report shall contain at least the following information:

(a) A reference to the testing standard;

(b) The type and complete identification of the product tested;

(c) The result of the test (see Para 12);

(d) Whether the procedure in Annex. D was used or not;

(e) Any deviation, by agreement or otherwise, from the procedure specified;

(f) The date of the test.

7.5 Determination of Solubility in Trichloroethylene

1. Introduction: The pure bitumen is completely soluble in some solvents like carbon di-sulphide or trichloroethylene. Hence, the solubility test is carried out to know the amount of pure bitumen in a sample of bitumen. This chapter covers the solubility in carbon disulphide or trichloroethylene for asphaltic bitumen and native asphalts.

2. Reference: IS-1216:1978 "Methods for Testing Tar and Bituminous Materials. Determination of Solubility in Carbon Di-sulphide or Trichloroethylene".

(A) Method A (For Asphaltic Bitumen)

3. Apparatus

3.1 Crucible: Gooch Crucible (Fig. 7.5.1)

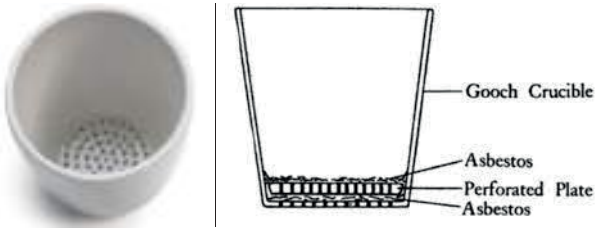


Fig. 7.5.1: Gooch Crucible

3.2 Conical Glass Flask - of 200 ml capacity.

4. Solvent

4.1 Carbon disulphide: Redistilled grade, conforming to IS:717.

4.2 Trichloroethylene: Conforming to IS:245.

5. Preparation of the Material: If the material contains water, heat it to a temperature not exceeding 130°C until the water has been removed, stirring constantly, when possible, during heating. Perform this operation as expeditiously as possible.

6. Preparation of Gooch Crucible: Insert the filter tube in the stopper of the filtering flask, set the Gooch crucible in the filter tube, and connect the flask to the suction pump. Fill the crucible with some of the suspension of asbestos in the water, allow it to settle partly in the crucible and apply a light suction to draw off the water, leaving a firm mat of asbestos in crucible. Add more suspended asbestos and repeat the process until a mat weighing 0.5 ± 0.1 g is built up after drying. Wash the asbestos mat thoroughly with water and dry in the oven at a temperature of 150°C. Coll the crucible in the desiccator, weigh and replace it in the dry filter tube supported in the clean, dry filtering flask.

6.1 In the determination, the asbestos apparently absorbs a small amount of soluble bitumen (usually 1 to 5 mg/g of asbestos) which is not removed by a subsequent washing with solvent. The weight of asbestos used, therefore, shall be kept within the specified limits to ensure reproducible results.

7. Procedure: Weigh about 2 g of the dry material correct to the nearest 0.001 g into 1 200 ml conical flask and add 100 ml of carbon disulphide or trichloroethylene. Stir the contents of the flask, and then allow it to stand for a period of one hour. Filter the contents of the flask through the Gooch crucible prepared as described under Para 6 which has been weighed to the nearest 0.001 g. Moisten the asbestos pad with carbon disulphide before commencing filtration, and filter at a rate of not more than two drops per second at first. The filtrate shall be quite clear. Transfer the insoluble matter remaining in the flask to the crucible by washing out the flask with a stream of carbon disulphide or trichloroethylene from a wash bottle. Wash the material retained in the crucible with successive small amounts of carbon disulphide or trichloroethylene until a filtrate is obtained which is not discoloured. Allow the crucible to dry in air for 30 minutes, after which place it in an oven at 100 to 110^{0}C for one hour. Allow the crucible to cool in a desiccator and then weigh.

8. Calculation and Report: Calculate the matter soluble in carbon disulphide or trichloroethylene as follows:

Matter soluble in carbon disulphide or trichloroethylene (in %) =

$$[(W_1 - W_2) / W_1] \times 100$$

where:

W_1 = Weight in g of dry sample taken for the test, and

W_2 = Weight in g of insoluble material retained in the Gooch crucible.

Report the result to the nearest 0.05 percent as the matter soluble in carbon disulphide or trichloroethylene of the dry material.

9. Precision: Test results shall not differ from the mean by more than the following:

Matter soluble in Carbon Disulphide or Trichloroethylene	Repeatability	Reproducibility
Below 98 percent	0.5	1.0
98 to 100 percent	1.0	0.2

(B) Method B (For Native Asphalts)

3. Apparatus

3.1 Glass Tap Funnel: Approximately 100 mm in diameter, the stem fitted with a tap and the top ground flat.

3.2 Glass Plate: To cover the funnel, about 120 mm in diameter, with a hole of about 16mm diameter in centre.

3.3 Glass Funnel: Smaller than that described under Para 3.1, with its stem passing through a cork placed in the hole in the glass plate, the lower end of the

stem reaching half-way down the tap funnel.

3.4 Filter Papers: Two, Whatman No. 5 or equivalent filter papers, 185mm in diameter, in a suitable oven, cooled in a desiccator, counterpoised and folded together as a cone.

4. Solvent and Material

4.1 Carbon Disulphide: Redistilled, conforming to IS:717.

4.2 Cement: Suitable for sealing the glass plate to the funnel. It may be prepared with 10 g of gelatin, 80 ml of water and 20 g of glycerine.

5. Preparation of Sample: If the sample contains water, heat a 100 g portion at a temperature not exceeding 130°C, the material being constantly stirred, when possible, until the rate of loss in weight of the sample does not exceed 0.1 g during a 15-minute period of heating.

5.1 If the loss in weight on drying exceeds 0.1 percent, determine the water content of another sample of the the material in accordance with IS:1211.

6. Procedure: Dry the two filter papers in an oven at 100 to 110^{0}C, cool in a desiccator, counterpoise, fold together and place in the funnel. Weigh about 2 g of the dry material, to the nearest 0.001 g in the filter papers and secure the cover to the funnel by means of the cement. Now add carbon disulphide or trichloroethylene through the small funnel until the filter paper is about half filled, and then allow it to stand for 30 minutes. Draw the solution off the tap. Place a watch glass on the small funnel to minimize evaporation. Close the tap and introduce a further quantity of carbon disulphide or trichloroethylene through the small funnel and draw the solution off after 30 minutes. Repeat this procedure until the solvent drawn off is no longer discoloured. When filtration is completed, remove the cover and allow the filter papers to dry in air for 30 minutes before placing them in a ventilated air oven at 100 to 110°C for one hour. Next place the filter papers in a desiccator and when cool, the inner filter paper and

contents, using the outer filter paper as a counterpoise.

7. Calculation: Calculate the solubility of the dry material as follows:

Matter soluble in carbon disulphide or trichloroethylene (in %) =

$$[(W_1 - W_2) / W_1] \times 100 \times [100 / (100 + W_3)]$$

where:

W_1 = Mass in g of dry sample taken for the test;

W_2 = Mass in g of recovered insoluble matter; and

W_3 = Water content of sample, if determined.

8. Report: Report the result to the nearest 0.05 percent as the matter soluble in carbon disulphide or trichloroethylene.

9. Precision: Test result shall not differ from the mean by more than the following:

Repeatability	0.5
Reproducibility	0.5

7.6 Determination of Softening Point

1. Introduction: Softening point is defined as the temperature at which bitumen softens beyond some specified softness. This test gives an idea of the temperature at which the bitumen attain certain viscosity. Softening point should be higher than the hottest day temperature, otherwise bitumen may sufficiently soften and result in bleeding and development of ruts. Bitumen with higher softening point may be preferred in warmer places. This chapter covers the determination of the softening point of bitumen using the ring-and-ball apparatus immersed in distilled water (up to 80° C) or glycerine (above 80° C)

2. Reference: IS-1205:2022 "Methods for Testing Tar and Bituminous Materials. Determination of Softening Point – Ring and Ball Apparatus".

3. Apparatus

3.1 Ring and Ball Apparatus: A convenient form of apparatus is illustrated in Fig. 7.6.1.

Fig. 7.6.1: Ring and Ball Apparatus

3.1.1 Steel Balls: Two; each 9.5mm in diameter and weighing 3.50 ± 0.05 g.

3.1.2 Brass Rings: Two; the rings shall be tapered and shall conform to the following dimensions:

Depth	6.4 ± 0.1 mm
Inside diameter at bottom	15.9 ± 0.1 mm
Inside diameter at top	17.5 ± 0.1 mm
Outside diameter	20.6 ± 0.1 mm

For convenience in mounting the rings in the support, the outside diameter of the ring at the bottom may be smaller, but shall be not less than 19.0 mm.

3.1.3 Ball Guide: A convenient form of ball centering guide.

3.1.4 Support: Any means of supporting the rings may be used provided the following conditions are observed:

(a) The rings shall be supported in a horizontal position with the upper surface of the rings 50mm below the surface of the bath liquid.

(b) There shall be a distance of exactly 25mm between the bottom of the rings and the top surface of the bottom plate of the support, if any, or the bottom of the bath.

(c) The thermometer shall be suspended so that the bottom of the bulb is level with the bottom of the rings, and within 10 mm of the rings, but not touching them.

3.1.5 Thermometer: The dimensions, tolerances and graduations of the thermometer shall be as follows and it shall be calibrated and with LC 0.1° C:

	Low Temperature	**High Temperature**
Range	-2^0 to 80^0C	30^0 to 200^0C
Graduation at each	0.2^0C	0.5^0C
Longer lines at each	1^0C	1^0C

Figured at each	2^0C	5^0C
Immersion, mm	Total	Total
Overall length	378 to 384 mm	378 to 384 mm
Length of graduated portion	243 to 279 mm	243 to 279 mm
Distance from bottom of bulb to 0 °C	75 to 90 mm	75 to 90 mm
Scale error, Max	± 0.2	± 0.3

3.1.6 Bath: A heat resistance glass vessel not less than 85mm in diameter and 120mm in depth. The bath liquid shall be freshly boiled with distilled water when testing materials having softening points up to 80^0C, and pure glycerin for materials having softening points above 80° C.

3.1.7 Stirrer: Manual or mechanical, which operates smoothly to ensure uniform heat distribution at all times throughout the bath. The stirrers shall be so placed that the moulds are not disturbed when the stirrer is in operation.

4. Procedure

4.1 Preparation of Test Sample: Heat the material to a temperature between 75° C and 100° C above its softening point, stir until it is completely fluid and free from air bubbles and water, and filter, if necessary, through IS Sieve 30 (see IS:460). Place the rings, previously heated to a temperature approximating to that of the molten material, on a metal plate which has been coated with a mixture of equal parts of glycerin and dextrin, and fill with sufficient melt to give an excess above the level of the ring when cooled. After cooling for 30 min in air, level the material in the ring by removing the excess with a warmed, sharp knife.

4.2 Materials of Softening Point up to 80° C: Assemble the apparatus with the rings, thermometer

and ball guides-in position, and fill the bath to a height of 50mm above the upper surface of the rings with freshly boiled distilled water at a temperature of 5° C. Maintain the bath at a temperature of 5° C for 15 min after which place a ball, previously cooled to a temperature of 5° C, by means of forceps in each ball guide. Apply heat to the bath and stir the liquid so that the temperature rises at a uniform rate of 5 ± 0.5° C per minute until the material softens and allows the ball to pass through the ring. The rate of temperature rise shall not be averaged over the period of the test, and any test in which the rate of temperature rise does not fall within the specified limits after the first three minutes shall be rejected. Make the determination in duplicate.

4.3 Materials of Softening Point Above 80° C: The procedure for materials of softening point above 80° C is similar to that described under Para 4.2 with the difference that glycerine is used in place of water in the bath and the starting temperature of the test is 30 + 1° C. Make the determination in duplicate.

5. Report

5.1 Record for each ring and ball, the temperature shown by the thermometer at the instant the sample surrounding the ball touches the bottom plate of the support, if any, or the bottom of the bath.

5.2 Report to the nearest 0.5° C the mean of the temperature recorded in duplicate determinations, without correction for the emergent stem of the thermometer, as the softening point.

NOTES:

1. For a given bitumen specimen, the softening point determined in a water bath will be lower than that determined in a glycerine bath.

2. To convert softening points slightly above 80°C determined in water to those determined in glycerine, the correction for bitumen is + 4.2° C. For referee

purposes, repeat the test in a glycerine bath.

3. Under any circumstances, if the mean of the two temperatures determined in water is 85.0° C or higher, repeat the test in a glycerin bath.

6. Precision

6.1 Test results shall not differ from the mean by more than the following:

Softening Point ^{0}C	Repeatability ^{0}C	Reproducibility ^{0}C
40 to 60	1.0	5.5
61 to 80	1.5	5.5
81 to 100	2.0	5.5
101 to 120	2.5	5.5
121 to 140	3.0	5.5

7. Precautions

7.1 Only freshly boiled distilled water shall, be used in the test, as otherwise air bubbles may form on the specimen and affect the accuracy of the results.

7.2 The prescribed rate of heating shall be rigidly adhered to for ensuring accuracy of results.

7.3 A sheet of filter paper or thin amalgamated sheet, placed on the bottom of the glass vessel and conveniently weighed would prevent the material from sticking to the glass vessel, and considerable time and trouble in cleaning would thereby be saved.

7.7 Determination of Ductility

1. Introduction: Ductility of bitumen is its property to elongate under traffic load without getting cracked in road construction works. Temperature changes cause bitumen to expand and contract. If the bitumen is not ductile enough, cracking will occur. Therefore, bitumen must have sufficient ductility to be resistant to temperature changes and it must not tear in heavy traffic and must adhere well to the aggregates. This chapter covers the method of determination of ductility of distillation residue of cutback bitumen, blown type bitumen and other bituminous products.

2. Reference: IS-1208:1978 (Reaafirmed-2010) "Methods for Testing Tar and Bituminous Material – Determination of Ductility".

3. Apparatus

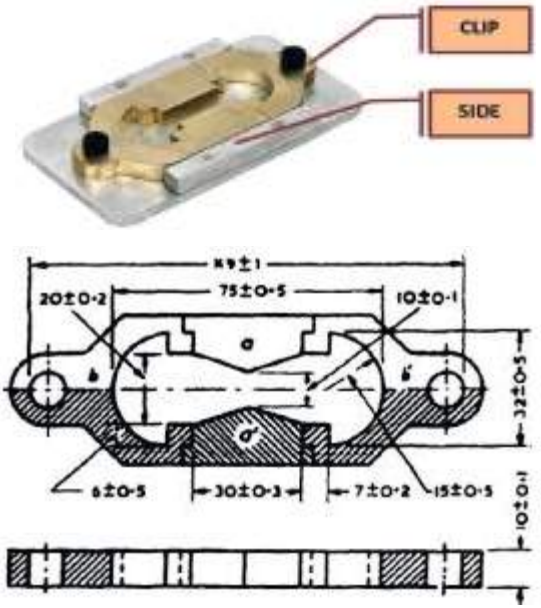


Fig. 7.7.1: Mould for Ductility Test

3.1 Mould: Made of brass with the shape, dimensions and tolerances as shown in Fig. 7.7.1. The ends b and b' are known as clips, and the parts a and a' as sides of the mould. The dimensions of the mould shall be such that when properly assembled, it will form a briquette specimen having the following dimensions:

Total length	75.0 ± 0.5 mm
Distance between clips	30.0 ± 0.3 mm
Width at mouth of clip	20.0 ± 0.2 mm
Width at minimum cross-section (half way between clips)	10.0 ± 0.1 mm
Thickness throughout	10.0 ± 0.1 mm

3.2 Water Bath: A bath preferably with a thermostat maintained within ± 0.1^0C of the specified test temperature, containing not less than 10 litres of water, the specimen being immersed to a depth of not less than 100mm and supported on a perforated shelf not less than 50mm from the bottom of the bath.

3.3 Testing Machine: For pulling the briquette of bituminous material apart, any apparatus may be used which is so constructed that the specimen will be continuously immersed in water as specified under Para 4.3 while the two clips are pulled apart horizontally with minimum vibrations at a uniform speed as specified and with suitable arrangement for stirring the water for attaining uniformity in temperature.

3.4 Thermometer: Conforming to the following requirements:

Characteristic	Requirement
Range	0 to 44^0C
Graduations	0.2^0C
Immersion	65mm

Overall length	340 ± 10 mm
Stem diameter	5.5 to 8.0 mm
Bulb length	10 to 16 mm
Bulb diameter	Not larger than stem diameter
Length of graduated portion	150 to 190 mm
Longer lines at each	1°C and 5°C
Figured at each	5°C
Scale	± 0.2^0C

4. Procedure

4.1 Unless otherwise specified, the test shall be conducted at a temperature of 27.0 ± 0.5° C and at a rate of pull of 50.0 ± 2.5 mm/min.

4.1.1 When a low temperature ductility test is desired, the test shall be made at a temperature of 4.0 ± 0.5° C and at a rate of pull 10.0 ± 0.5 mm/min.

4.2 Completely melt the bituminous material to be tested to a temperature of 75 to 100° C above the approximate softening point until it becomes thoroughly fluid. Assemble the mould on a brass plate and in order to prevent the material under test from sticking, thoroughly coat the surface of the plate and interior surfaces of the sides of the mould (a and a' in Fig. 7.7.1) with a mixture of equal parts of glycerine and dextrin. In filling, pour the material in a thin stream back and forth from end to end of the mould until it is more than level full. Leave it to cool at the room temperature for 30 to 40 min, and then place in a water bath maintained at the specified temperature for 30 min after which cut off the excess bitumen by means of a hot, straight edge putty knife or spatula so that the mould shall be just level full.

4.3 Testing: Place the brass plate and mould with briquette specimen, in the water bath and at the

specified temperature for about 85 to 95 minutes. Then remove the briquette from the plate, detach the side pieces, and test the briquette immediately.

4.3.1 Attach the rings at each end of the to the clips to the pins or hooks in the resting machine and pull the two clips apart horizontally at a uniform speed as specified until the briquette ruptures. Measure the distance in centimetres through which the clips have been pulled to produce rupture. While the test is being made, make sure that the water in the tank of the testing machine covers the specimen both above and below it by at least 25mm and is maintained continuously within ±0.5° C of the specified temperature.

5. Report

5.1 A normal test is one in which the material between the two clips pulls out to a point or to a thread and rupture occurs where the cross-sectional area is a minimum. Report the average of three normal tests as the ductility of the sample, provided the three determinations be within ± 5 percent of their mean value.

5.1.1 If the value of three determinations do not lie within ± 5 percent of their mean but the two higher values are within ± 5 percent of their mean then record the mean of the two higher values as test result.

5.2 If the bituminous material comes in contact with the surface of the water or the bottom of the bath, the test shall not be considered normal. Adjust the specific gravity of the water in the bath by the addition of either methyl alcohol or sodium chloride so that the bituminous material does not either come to the surface of the water, or touch the bottom of the bath at any time during the test.

5.3 If a normal test is not obtainable on three

successive tests. Report the ductility as being unobtainable under the conditions of test.

6. Precision

6.1 Test results shall not differ by more than the following:

Repeatability	10 percent of the mean
Reproducibility	10 percent of the mean

7. Precautions

7.1 The plate upon which the mould is placed shall be perfectly flat and level so that the bottom surface of the mould touches it throughout.

7.2 In filling the mould, care shall be taken not to disarrange the parts and thus distort the briquette and to see that no air pocket shall be within the moulded sample.

Bibliography and References

1. IS-4031(Part-I) : 1996 (Reaffirmed-2021) "Method of Physical Tests for Hydraulic Cement- Determination of Fineness by Dry Sieving".
2. IS-4031(Part-II) : 1999 (Reaffirmed-2013) "Method of Physical Tests for Hydraulic Cement- Determination of Fineness by Blaine Air Permeability Method".
3. IS-4031 (Part-IV) : 1988 (Reaffirmed-2019) "Method of Physical Tests for Hydraulic cement- Determination of Consistency of Standard Cement Paste".
4. IS-4031 (Part-V) : 1988 (Reaffirmed-2019) "Method of Physical Tests for Hydraulic Cement- Determination of Initial and Final Setting Times".
5. IS-4031 (Part-III) : 1988 (Reaffirmed-2019) "Method of Physical Tests for Hydraulic Cement- Determination of Soundness".
6. IS:4031 (Part-VII) : 1988 (Reaffirmed-2019) "Method of physical tests for Hydraulic Cement- Determination of Compressive Strength of Masonry Cement".
7. IS-2386 (Part-I) : 1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-I: Particle Size and Shape".
8. IS-2386 (Part-III) : 1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-III: Specific Gravity, Density, Voids, Absorption and Bulking".
9. IS-2386(Part-IV) : 1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-IV: Mechanical Properties".
10. IS-2386(Part-II) : 1963 (Reaffirmed-2021) "Method of Tests for Aggregates for Concrete. Part-II: Estimation of Deleterious Materials and Organic Impurities".
11. IS-1608 (Part 1): 2022 "Metallic Materials- Tensile Testing, Part-1: Method of Test at Room Temperature".

12. IS-1599:2019 "Metallic Materials – Bend test"
13. IS-1786:2008 (Reaffirmed-2018) "High Strength Deformed Steel Bars and Wires for Concrete Reinforcement- Specification".
14. IS-3025(Part-17):2022 "Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-17: Non-Filterable Residue (Total Suspended Solids at 1030C-1050C)".
15. IS-3025(Part-18):2022 "Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-18: Volatile and Fixed Solids (Total, Filterable and Non-filterable) at 5500C".
16. IS-3025(Part-22):1986 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-22: Acidity".
17. IS-3025(Part-23):1986 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-22: Alkalinity".
18. IS-3025(Part-11): 2002 "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-11: pH Value".
19. IS-3025(Part-32):1988 (Reaffirmed-2019) "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-2: Chloride".
20. IS-3025(Part-24/Sec-1):2022 "Method of Sampling and Test (Physical and Chemical) for Water and Wastewater. Part-24: Sulphates. Section-1: Gravimetric and turbidity methods".
21. IS-1199 (Part-2):2018 "Fresh Concrete – Methods of Sampling, Testing and Analysis; Part-2 – Determination of Consistency of Fresh Concrete".
22. IS-516(Part-1/Sec-1):2021 "Hardened Concrete – Methods of Test. Part-1: Testing of Strength of Hardened Concrete. Section-1: Compressive, Flexural and Split Tensile Strength".

23. IS-3085:1965 (Reaffirmed-2021) "Method of Test for Permeability of Cement Mortar and Concrete".
24. Indian Railway Standard (IRS): Code of Practice for Plain, Reinforced & Prestressed Concrete for General, Bridge Construction (Concrete Bridge Code). Reprint-September 2014".
25. IS-516(Part-5/Sec-4):2020 "Hardened Concrete – Methods of Test. Part-5: Non-destructive Testing of Concrete. Section-4: Rebound Hammer Test".
26. IS-516(Part-5/Sec-1):2020 "Hardened Concrete – Methods of Test. Part-5: Non-destructive Testing of Concrete. Section-1: Ultrasonic Pulse Velocity Testing".
27. IS-73:2013 (Reaffirmed 2013) "Paving Bitumen – Specification".
28. IS-1203:2022 "Methods for Testing Tar and Bituminous Materials — Determination of Penetration".
29. IS-1206 (Part-2):2022 "Methods for Testing Tar and Bituminous Material – Determination of Viscosity: Part-2: Absolute Viscosity".
30. IS-1206(Part-3):2021 "Method or Testing Tar and Bituminous Materials – Determination of Viscosity. Part-3: Kinematic Viscosity".
31. IS-1448 [P:69]:2019 "Methods of Test Petroleum and its Products. P:69- Determination of Flash and Fire Points – Cleveland Open Cup Method".
32. IS-1216:1978 "Methods for Testing Tar and Bituminous Materials. Determination of Solubility in Carbon Di-sulphide or Trichloroethylene".
33. IS-1205:2022 "Methods for Testing Tar and Bituminous Materials. Determination of Softening Point – Ring and Ball Apparatus".
34. IS-1208:1978 (Reaafirmed-2010) "Methods for Testing Tar and Bituminous Material – Determination of Ductility".

For any suggestions, errors etc, please contact
on Email : mail@iricen.gov.in

Published by
Indian Railways Institute of Civil Engineering
11-A, South Main Road, Koregaon Park, Pune - 411001.

Mix Design: Factors in the Choice of Mix Proportions

The selection of appropriate mix proportions is a critical step in the design of concrete mixes. A multitude of factors must be carefully considered to ensure the concrete will meet the desired performance requirements, while also optimizing cost-effectiveness and sustainability. From the strength and durability needs of the structure, to the availability and properties of local materials, mix design involves a delicate balance of variables to arrive at the optimal blend of cement, aggregates, water, and admixtures.

Factors such as the intended application, exposure conditions, and desired service life of the concrete play a major role in determining the mix proportions. For example, concrete used in a marine environment will require a different mix design than concrete for an indoor floor slab. The required compressive strength, workability, and resistance to weathering, chemical attack, and other forms of deterioration must all be taken into account. Additionally, the physical characteristics and gradation of the aggregates, as well as the specific cement type and admixture dosages, can significantly influence the final mix design.

by hod civil

Durability of Concrete

The durability of concrete is a crucial factor that must be carefully considered in the mix design process. Concrete structures are expected to withstand the rigors of their environment and maintain structural integrity over the course of their intended service life, which can span decades or even centuries. Factors such as exposure to weathering, chemical attacks, freeze-thaw cycles, and mechanical stresses can all contribute to the deterioration of concrete if not properly addressed through the mix design.

To ensure the long-term durability of concrete, the mix design must incorporate materials and proportions that enhance the concrete's resistance to these various forms of degradation. This includes selecting the appropriate cement type, minimizing the water-to-cement ratio, incorporating supplementary cementitious materials, and incorporating admixtures that can improve the concrete's resistance to specific threats. For example, the use of air-entraining admixtures can enhance the concrete's resistance to freeze-thaw cycles, while the incorporation of silica fume or fly ash can improve the concrete's resistance to chemical attack.

Additionally, proper curing and compaction of the concrete during the construction process are critical to achieving the desired level of durability. Inadequate curing can lead to premature drying and cracking, while improper compaction can result in the formation of voids and increased permeability, both of which can compromise the concrete's long-term performance. By carefully considering all of these factors in the mix design and construction process, concrete structures can be designed to withstand the rigors of their environments and provide reliable, long-lasting service.

Quality Control of Concrete

Maintaining consistent quality control is essential in the production of high-performing concrete. A robust quality control process ensures that the concrete meets or exceeds the specified requirements for strength, durability, and other critical properties. This process involves a comprehensive set of procedures and tests conducted at various stages of the concrete manufacturing and placement process.

Key aspects of quality control for concrete include:

- **Material Testing:** Rigorous testing of cement, aggregates, water, and admixtures to verify compliance with industry standards and project specifications.
- **Batching and Mixing:** Careful monitoring of the batching process to ensure the correct proportions of all ingredients are used, and thorough mixing to achieve a homogeneous blend.
- **Fresh Concrete Testing:** Regular testing of the freshly mixed concrete to assess properties such as slump, air content, and temperature, which directly impact the concrete's workability and placement.
- **Strength Testing:** Compressive strength testing of concrete cylinders or cubes at various curing ages to ensure the concrete meets or exceeds the specified strength requirements.
- **Durability Testing:** Specialized tests to assess the concrete's resistance to factors like freeze-thaw cycles, chemical attack, and abrasion, ensuring long-term performance.
- **Placement and Curing:** Strict monitoring of the concrete placement and curing processes to maintain quality and prevent defects like honeycombing, cracking, or improper consolidation.

By implementing a comprehensive quality control program, concrete producers can consistently deliver a high-quality product that meets or exceeds the project's requirements, ultimately ensuring the safety, reliability, and longevity of the concrete structure.

Statistical Methods

1 Sampling and Data Collection

Rigorous statistical analysis of concrete mixes starts with careful sampling and data collection. This involves taking representative samples of concrete at various stages of the production process, from the raw materials to the fresh and hardened concrete. The samples must be collected using standardized methods to ensure they accurately reflect the true properties of the concrete. Additionally, detailed records must be kept on the mix proportions, environmental conditions, and any other relevant factors that could impact the concrete's performance.

2 Hypothesis Testing

Once the data has been collected, statistical methods are employed to test hypotheses about the concrete's properties. This could involve comparing the measured compressive strength of the concrete to the specified design strength, or assessing the concrete's resistance to chemical attack or freeze-thaw cycles. Hypothesis testing allows concrete producers to determine whether the concrete meets the required standards and identify any areas where the mix design or production process may need to be adjusted.

3 Regression Analysis

Advanced statistical techniques, such as regression analysis, can be used to model the relationships between various concrete properties and the mix design parameters. This can provide valuable insights into how changes to the mix proportions or the use of admixtures might impact the concrete's performance. Regression analysis can also help identify the most critical factors in the mix design, allowing concrete producers to focus their efforts on the areas that will have the greatest impact on the final product.

Acceptance Criteria

Strength Requirements

Establishing clear and measurable strength requirements is a critical aspect of acceptance criteria for concrete. This typically involves specifying the minimum compressive strength the concrete must achieve at various curing ages, such as 7, 28, and 90 days. These strength targets are determined based on the structural design requirements and the intended use of the concrete in the project. Meeting these strength thresholds ensures the concrete will have the load-bearing capacity to safely support the structure as designed.

Durability Benchmarks

In addition to strength, the acceptance criteria for concrete must also address its long-term durability. This includes requirements for the concrete's resistance to factors like weathering, chemical attack, freeze-thaw cycles, and abrasion. Depending on the project's environmental conditions and service life, the acceptance criteria may specify performance tests to measure the concrete's permeability, resistance to sulfate attack, and other durability-related properties. Meeting these durability benchmarks helps ensure the concrete will withstand the rigors of its intended application over the course of its lifespan.

Workability Standards

The acceptance criteria for concrete should also address the material's workability, which is critical for ensuring proper placement and consolidation. This may involve setting requirements for the concrete's slump, air content, and temperature at the time of delivery and placement. Maintaining the appropriate workability characteristics helps prevent segregation, honeycombing, and other defects that can compromise the concrete's strength and durability.

ds of concret

Overall variation

tion for different c

ery good	Good
00 to 500 .8 to 3.4)	500 to 6 (3.4 to 4
00 to 250 .4 to 1.7)	250 to 3 (1.7 to 2

thin-batch variati

f variation for diffe

ery good	Good
.0 to 4.0	4.0 to 5
.0 to 3.0	3.0 to 4

Proportioning of Concrete Mixes by Various Methods

Absolute Volume Method

One of the most widely used methods for proportioning concrete mixes is the absolute volume method. This approach aims to determine the exact volumes of cement, water, and aggregates required to produce a cubic meter of concrete with the desired properties. By accounting for the specific gravity and absolute volumes of each ingredient, this method ensures the proper balance of materials to achieve the target strength, workability, and durability.

ACI Mix Design Method

The American Concrete Institute (ACI) has developed a comprehensive mix design method that considers both empirical relationships and theoretical calculations. This approach starts by estimating the required compressive strength and then adjusts the mix proportions based on factors such as the maximum size of the aggregate, the desired slump, and the air content. The ACI method provides a systematic process for arriving at the optimal blend of cement, water, and aggregates to meet the project's specifications.

Fuller's Curve Method

The Fuller's Curve method is another popular approach for proportioning concrete mixes. This method aims to achieve the most efficient packing of aggregates by following a specific gradation curve that minimizes the void space between particles. By optimizing the aggregate gradation, this method can help reduce the cement content required while maintaining the desired workability and strength. The Fuller's Curve method is particularly useful for designing high-performance concrete mixes with reduced cement consumption and enhanced sustainability.

Fineness Modulus Method

The fineness modulus method is a simple and widely used technique for proportioning concrete mixes. This approach relies on the concept of fineness modulus, which is a measure of the coarseness or fineness of the aggregates. By adjusting the fineness modulus of the combined aggregates, concrete producers can achieve the desired workability, strength, and durability. The fineness modulus method is often used for routine concrete production, as it provides a straightforward way to arrive at the appropriate mix proportions.

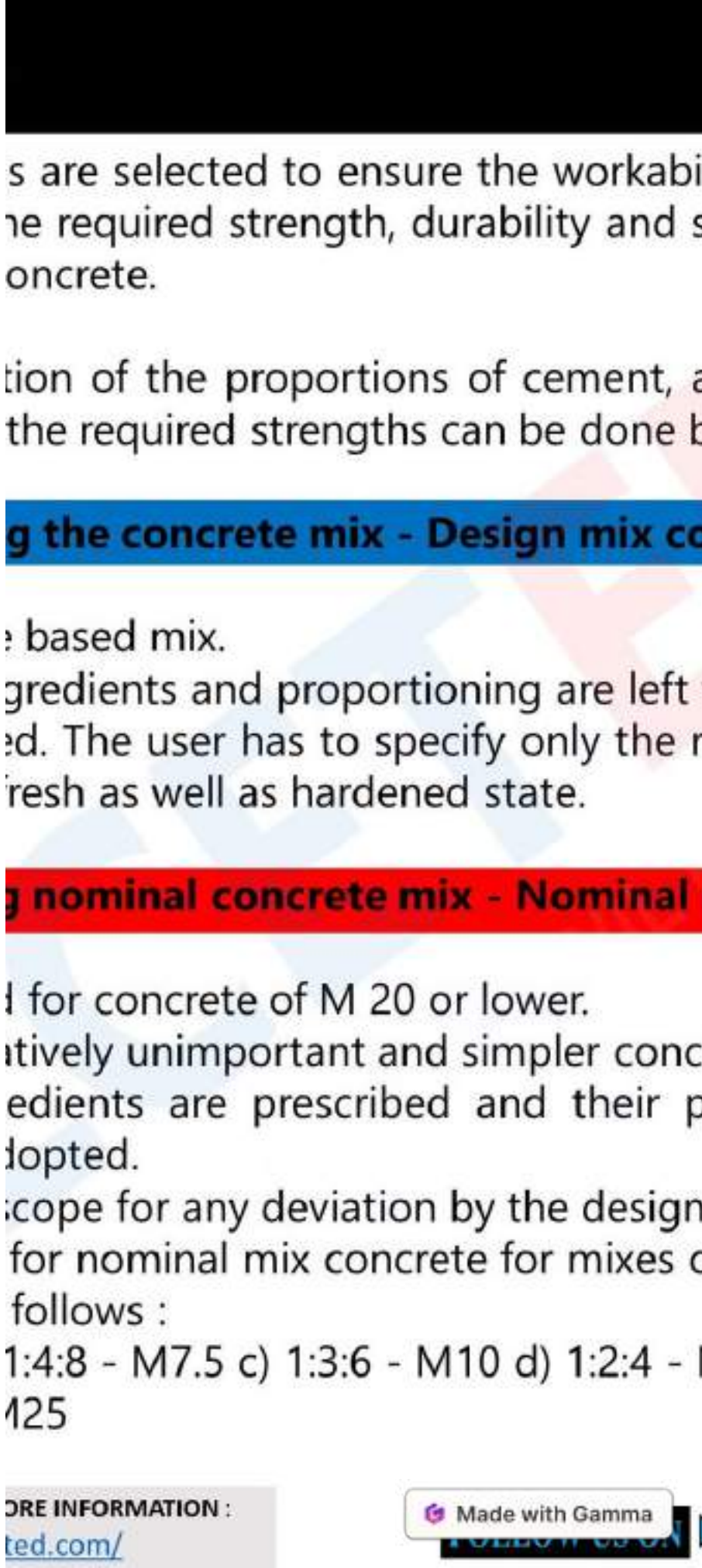
BIS Method of Mix Design

The Bureau of Indian Standards (BIS) has developed a comprehensive method for proportioning concrete mixes that is widely used in the Indian construction industry. This systematic approach considers a range of factors to arrive at the optimal blend of cement, aggregates, water, and admixtures to meet the desired performance requirements.

The BIS mix design method begins by establishing the target compressive strength and durability criteria for the concrete, based on the specific application and environmental conditions. It then considers the physical properties of the available cement and aggregates, including their specific gravity, fineness, and gradation. Using these inputs, the method determines the appropriate water-cement ratio to achieve the target strength while maintaining adequate workability.

A key aspect of the BIS method is the incorporation of various safety factors to account for construction variability and ensure a high probability of meeting the specified strength requirements. This includes adjusting the mix proportions to compensate for potential losses in strength during transportation, placement, and curing of the concrete.

The BIS method provides a structured approach to concrete mix design that considers both theoretical calculations and empirical relationships. By following this standardized process, concrete producers can consistently deliver a high-quality product that meets the project's performance specifications and ensures the long-term durability of the concrete structure.



Steps in Manufacture of Concrete

1

Material Procurement

The first step in the manufacture of concrete is the procurement of the necessary raw materials, including cement, aggregates (both fine and coarse), water, and any required admixtures. These materials must be sourced from reliable suppliers and carefully inspected to ensure they meet the specified quality standards and project requirements.

2

Batching and Mixing

Once the materials have been obtained, the next step is the batching and mixing process. This involves carefully measuring and proportioning the cement, aggregates, and water in accordance with the predetermined mix design. The materials are then thoroughly blended in a specialized concrete mixer, ensuring a homogeneous and consistent mixture.

3

Transportation and Placement

After the concrete has been mixed, it must be transported to the construction site and placed in the designated formwork or molds. This process requires careful handling and monitoring to maintain the concrete's workability and prevent segregation or loss of quality. Proper placement techniques, such as vibration or tamping, are crucial to ensure the concrete is consolidated and fills the desired space without voids or honeycombing.

4

Curing and Finishing

Once the concrete has been placed, the next critical step is the curing process. This involves maintaining the appropriate moisture and temperature conditions to allow the concrete to hydrate and develop the desired strength and durability. Depending on the project requirements, the concrete may also undergo various finishing processes, such as smoothing, texturing, or the application of specialized coatings or sealers.

5

Quality Control and Testing

Throughout the manufacturing process, a robust quality control program is essential to ensure the concrete meets or exceeds the specified performance requirements. This includes regular testing of the raw materials, the fresh concrete, and the hardened concrete at various stages of curing. The test results are carefully analyzed to identify any issues or opportunities for improvement in the manufacturing process.

Importance of Proper Mix Design

Optimized Performance

A well-designed concrete mix ensures the final product meets or exceeds the required performance specifications, such as compressive strength, durability, and workability. By carefully considering the properties of the constituent materials and how they interact, the mix design process allows concrete producers to create a blend that is tailored to the specific needs of the project.

Cost-Effectiveness

Proper mix design can lead to significant cost savings by minimizing the use of expensive materials like cement, while still achieving the desired performance. By optimizing the aggregate gradation, water-cement ratio, and admixture dosages, the mix design process can help reduce the overall material costs without compromising the concrete's quality or structural integrity.

Sustainability

Sustainable construction practices are becoming increasingly important, and proper mix design plays a crucial role in this regard. By reducing the cement content and incorporating supplementary cementitious materials, such as fly ash or slag, the environmental impact of concrete production can be significantly reduced. This helps conserve natural resources and lowers the carbon footprint associated with the construction industry.

Durability and Longevity

Concrete structures are expected to withstand the rigors of their environment and maintain structural integrity over their intended service life, which can span decades or even centuries. Proper mix design, which considers factors like exposure conditions, chemical resistance, and freeze-thaw cycles, is essential for ensuring the long-term durability and reliability of concrete structures.

Challenges and Considerations in Concrete Mix Design

Variability in Raw Materials

One of the primary challenges in concrete mix design is the inherent variability in the raw materials, such as cement, aggregates, and water. The physical and chemical properties of these ingredients can fluctuate based on factors like geographic location, production processes, and environmental conditions. This variability can impact the concrete's performance, making it essential for mix designers to closely monitor and adjust the proportions to maintain consistent quality.

Comprehensive Testing and Analysis

Ensuring the concrete mix meets the desired performance requirements necessitates a robust testing and analysis program. This includes testing the raw materials, the fresh concrete, and the hardened concrete at various stages of the manufacturing process. From compressive strength tests to durability assessments, the data gathered through this rigorous testing regime helps concrete producers make informed decisions about the mix design and identify any areas for improvement.

Incorporating Admixtures

The use of chemical admixtures can greatly enhance the properties of concrete, but their incorporation adds an additional layer of complexity to the mix design process. Concrete producers must carefully select and dose the appropriate admixtures to achieve the desired workability, setting time, or durability characteristics without adversely impacting other critical performance factors. Proper compatibility testing and adjustments to the mix proportions are essential when using admixtures.

Site Conditions and Placement Challenges

The concrete mix design must also consider the site-specific conditions and construction challenges that may be encountered during the placement and curing process. Factors such as ambient temperature, humidity, wind, and precipitation can all impact the concrete's behavior and performance. Mix designers must anticipate these variables and incorporate appropriate adjustments, such as modifying the water-cement ratio or using specialized admixtures, to ensure the concrete delivers the desired results in the field.

Special Concretes: An Introduction

In the world of construction, traditional concrete has long been the backbone of many projects. However, the growing demand for more specialized and innovative building materials has given rise to a new class of concretes, known as "special concretes." These advanced concrete formulations are designed to address specific needs, offering enhanced performance, improved sustainability, and unique properties that expand the possibilities of modern construction.

From lightweight concretes that reduce structural loads to permeable concretes that mitigate stormwater runoff, the field of special concretes is a testament to the ingenuity of engineers and material scientists. This introduction will explore the diverse range of special concretes, including cellular, no-fines, fiber-reinforced, polymer, bacterial, and self-compacting varieties, as well as the cutting-edge advancements in nano-engineered concretes. By understanding the capabilities and applications of these specialized materials, architects, engineers, and construction professionals can unlock new design solutions and create structures that push the boundaries of what's possible.

by hod civil

Lightweight Concrete

Lightweight concrete is a specialized form of concrete that has been engineered to be significantly less dense than traditional concrete mixes. By incorporating lightweight aggregates such as expanded clay, shale, or slag, as well as reducing the amount of heavy Portland cement, lightweight concrete can achieve a dry density of as little as 300 kg/m3, compared to the 2,400 kg/m3 or more of standard concrete. This reduced weight makes lightweight concrete an ideal choice for construction projects where load-bearing capacity is a critical concern, such as high-rise buildings, bridges, and even offshore platforms.

Beyond its weight advantages, lightweight concrete also offers improved thermal and acoustic insulation properties, enhancing energy efficiency and occupant comfort in buildings. The porous nature of the lightweight aggregates traps air, providing effective thermal barriers that can reduce heating and cooling costs. Additionally, the lower density of lightweight concrete results in superior sound absorption, creating more peaceful living and work environments. Architects and engineers have embraced this versatile material, leveraging its unique properties to push the boundaries of modern construction and create innovative, sustainable structures.

Cellular Concrete

Cellular concrete, also known as aerated concrete or foamed concrete, is a remarkable type of special concrete that is both lightweight and highly insulative. Formulated by introducing air bubbles or gas-producing agents into the concrete mix, cellular concrete achieves a porous, sponge-like structure that can significantly reduce its overall density while maintaining impressive compressive strength. This makes it an ideal choice for a variety of construction applications, from load-bearing walls and floor slabs to insulation panels and roofing materials.

One of the key advantages of cellular concrete is its thermal efficiency. The trapped air pockets within the material act as effective thermal barriers, providing superior insulation properties compared to traditional concrete. This not only enhances energy efficiency in buildings but also contributes to improved indoor comfort and reduced heating and cooling costs. Additionally, cellular concrete's lightweight nature can lead to substantial savings in material and transportation costs, making it a cost-effective solution for many construction projects.

Cellular concrete's versatility extends beyond its insulative and lightweight properties. The material can be molded into a wide range of shapes and sizes, allowing for creative architectural designs and complex structural elements. Its inherent fire-resistance and water-resistance also make it a popular choice for applications in harsh environments or areas prone to natural disasters. As the construction industry continues to focus on sustainability and energy efficiency, cellular concrete has emerged as a cutting-edge solution that combines innovative engineering with environmental consciousness.

No-Fines Concrete

No-fines concrete, also known as permeable concrete or porous concrete, is a specialized type of concrete that has been engineered to allow water to freely pass through its structure. Unlike traditional concrete, which is designed to be dense and impermeable, no-fines concrete is created by omitting the fine aggregate (sand) from the concrete mix, leaving only the coarse aggregate (gravel or crushed stone) and cement paste. This unique composition results in a highly porous and open-textured material that can effectively manage stormwater runoff and mitigate the impact of heavy rainfall.

The primary benefit of no-fines concrete is its ability to reduce the risk of flooding and improve urban drainage systems. By allowing water to percolate through the concrete surface, it helps to recharge groundwater supplies and reduce the load on municipal stormwater infrastructure. This makes it an increasingly popular choice for applications such as parking lots, driveways, sidewalks, and other outdoor surfaces where traditional impervious concrete would lead to the accumulation of water and potential flooding. Additionally, the porous nature of no-fines concrete can help to filter out pollutants and contaminants, making it an environmentally-friendly solution for sustainable urban development.

Beyond its stormwater management capabilities, no-fines concrete also offers several other advantages. Its open-cell structure provides enhanced thermal insulation, helping to regulate the temperature of buildings and reduce energy consumption. The reduced density of no-fines concrete can also lead to significant weight savings, making it suitable for applications where structural load is a concern, such as in roof construction. Furthermore, the unique aesthetic of the exposed aggregate in no-fines concrete can be leveraged for decorative purposes, creating visually appealing surfaces that integrate seamlessly with the surrounding environment.

Permeable Concrete

Permeable concrete, also known as porous concrete or pervious concrete, is a unique type of special concrete that revolutionizes the way we manage stormwater and urban runoff. Unlike traditional concrete, which is designed to be impermeable, permeable concrete features a carefully engineered composition that allows water to freely flow through its porous structure. This innovative material is transforming the landscape of modern construction, offering a sustainable solution to the growing challenges of urban flooding and water pollution.

At the core of permeable concrete is the strategic omission of fine aggregates, such as sand, from the concrete mix. This creates a network of interconnected voids and channels that enable water to percolate through the surface, replenishing groundwater supplies and reducing the strain on overburdened stormwater systems. The resulting material is not only highly permeable but also maintains impressive compressive strength, making it suitable for a variety of load-bearing applications, including parking lots, driveways, walkways, and low-traffic roads.

Beyond its stormwater management capabilities, permeable concrete also provides several other benefits that contribute to sustainable urban development. The porous structure of the material enhances heat dissipation, reducing the urban heat island effect and improving overall energy efficiency. Additionally, the filtration properties of permeable concrete can help to remove contaminants and sediments from runoff, promoting cleaner water discharge and healthier ecosystems. This makes permeable concrete an invaluable tool in the fight against water pollution and the promotion of responsible water management practices.

Fiber Reinforced Concrete

Enhanced Durability

Fiber reinforced concrete (FRC) is a revolutionary construction material that incorporates small, discrete fibers into the concrete mix. These fibers, which can be made from materials like steel, glass, synthetic polymers, or natural plant sources, significantly enhance the concrete's tensile strength, impact resistance, and durability. By bridging cracks and distributing stresses more evenly, FRC reduces the risk of catastrophic failures and extends the lifespan of structures, making it an increasingly popular choice for applications where high-performance concrete is required.

Improved Structural Integrity

The addition of fibers to concrete has a remarkable effect on its structural integrity. The fibers act as reinforcement, effectively transferring loads and stresses throughout the material, rather than relying solely on the inherently weak tensile properties of plain concrete. This results in enhanced load-bearing capacity, flexural strength, and resistance to cracking, making FRC an ideal choice for infrastructure projects, industrial floors, and other applications where heavy loads and dynamic stresses are a concern.

Diverse Applications

The versatility of fiber reinforced concrete extends far beyond its structural benefits. FRC can be tailored to meet specific performance requirements, such as increased fire resistance, improved abrasion resistance, or enhanced corrosion protection. This adaptability has led to its widespread use in a variety of construction projects, from high-rise buildings and bridges to tunnel linings and precast concrete elements. Furthermore, the ability to incorporate recycled or sustainable fibers has made FRC an increasingly eco-friendly solution, contributing to the growing emphasis on sustainable construction practices.

Polymer Concrete

Unique Composition

Polymer concrete is a revolutionary construction material that differs significantly from traditional cement-based concrete. Instead of using Portland cement as the binding agent, polymer concrete is formulated with organic polymers, typically epoxy resins or polyester resins, which act as the primary binder. These polymer binders are combined with aggregates, such as sand, gravel, or crushed stone, to create a durable and high-performance composite material.

Enhanced Properties

The incorporation of polymers into the concrete mix gives polymer concrete a distinct set of properties that set it apart from conventional concrete. Polymer concrete exhibits superior tensile strength, flexural strength, and impact resistance compared to its traditional counterpart. It also demonstrates exceptional resistance to chemical attack, corrosion, and wear, making it an ideal choice for applications in harsh environments or where structural integrity is of utmost importance.

Rapid Curing and Versatility

One of the key advantages of polymer concrete is its rapid curing time. Unlike traditional concrete, which can take several days or even weeks to fully harden, polymer concrete can achieve its full strength in a matter of hours, significantly accelerating construction timelines. This rapid curing also allows for the easy shaping and molding of polymer concrete, enabling the creation of intricate and customized architectural elements, as well as the rapid repair and restoration of damaged infrastructure.

Sustainable Applications

In addition to its exceptional performance characteristics, polymer concrete also offers sustainability benefits. The use of recycled or repurposed aggregates, as well as the potential for the incorporation of waste materials, can contribute to the overall environmental friendliness of polymer concrete. Furthermore, the material's resistance to weathering and chemical attack can extend the lifespan of structures, reducing the need for frequent maintenance and replacement, ultimately leading to a lower carbon footprint over the life cycle of a project.

Bacterial Concrete

Self-Healing Properties

Bacterial concrete is a revolutionary construction material that harnesses the power of microorganisms to achieve self-healing capabilities. By incorporating specialized bacteria into the concrete mix, this innovative material is able to autonomously repair cracks and fissures that may develop over time. When the concrete cracks, the embedded bacteria are activated and begin to produce calcite, a mineral that fills the voids and restores the structural integrity of the material.

Increased Durability

The self-healing properties of bacterial concrete not only enhance its longevity but also reduce the need for costly and labor-intensive repairs. By continuously repairing itself, this advanced concrete can extend the lifespan of structures, bridges, and infrastructure, making it a highly attractive option for projects that require increased durability and reduced maintenance. Additionally, the bacterial processes involved in the self-healing mechanism can help to improve the overall compressive strength and resistance to weathering, further contributing to the longevity of the material.

Sustainable Construction

Bacterial concrete represents a significant stride towards more sustainable construction practices. By reducing the need for traditional repair methods, which often involve the use of energy-intensive and carbon-intensive materials, this innovative concrete helps to lower the environmental impact of construction projects. Furthermore, the incorporation of bacteria into the concrete mix can create a more eco-friendly alternative to traditional concrete, as the bacteria can help to sequester carbon dioxide and improve the overall carbon footprint of the material.

Broad Applications

The versatility of bacterial concrete extends beyond its self-healing properties, making it a suitable choice for a wide range of construction applications. From infrastructure projects and bridge decks to building foundations and parking structures, this advanced material can be tailored to meet the specific performance requirements of various construction environments. Its ability to adapt to different climates and weather conditions further enhances its suitability for diverse construction needs, positioning bacterial concrete as a cutting-edge solution for the future of sustainable building.

Self-Compacting Concrete

Enhanced Workability

Self-compacting concrete (SCC) is a revolutionary concrete mixture that is designed to flow and spread under its own weight, without the need for external vibration or compaction. This unique property is achieved through a carefully engineered balance of high-range water reducers, viscosity modifiers, and specialized aggregates. The result is a highly workable concrete that can easily fill formwork and molds, ensuring uniform density and eliminating the risk of honeycombing or voids commonly associated with traditional concrete placement methods.

Improved Quality and Finish

The self-compacting nature of this concrete provides several benefits that contribute to enhanced construction quality and a superior final finish. By eliminating the need for vibration, SCC minimizes the risk of air entrapment and improves the overall homogeneity of the mixture. This translates to a smoother, more uniform surface with fewer defects, as well as improved dimensional accuracy and reduced permeability. The ease of placement also allows for intricate architectural designs and complex structural elements that would be challenging to achieve with traditional concrete.

Enhanced Durability and Sustainability

In addition to its exceptional workability and finish, self-compacting concrete also offers significant advantages in terms of durability and sustainability. The reduced air content and increased density of SCC result in enhanced resistance to weathering, chemical attack, and other forms of deterioration. This extended service life not only reduces the need for costly repairs and maintenance but also contributes to the overall environmental impact of construction projects. Furthermore, the efficient placement process of SCC can lead to reduced material consumption and construction waste, making it a more sustainable choice for modern construction.

Versatile Applications

The versatility of self-compacting concrete has made it an increasingly popular choice for a wide range of construction applications. From high-rise buildings and complex architectural structures to precast elements and infrastructure projects, SCC can be tailored to meet the specific performance requirements of each application. Its ability to flow effortlessly around reinforcement and into intricate formwork has made it a preferred solution for projects with complex geometries or limited access, such as bridges, tunnels, and underground structures. The adaptability of SCC continues to expand the possibilities of modern construction, pushing the boundaries of what can be achieved with concrete.

Nano Silica and Nano Alumina Concrete

Nano-Scale Innovations

Nano silica and nano alumina are groundbreaking nano-scale materials that are revolutionizing the world of concrete. These ultra-fine particles, measured in billionths of a meter, are carefully engineered to enhance the performance of traditional concrete at the molecular level, unlocking unprecedented strength, durability, and sustainability.

Enhanced Strength

The incorporation of nano silica and nano alumina into concrete mixes results in a remarkable increase in compressive and flexural strength. These nano-particles act as micro-fillers, densifying the concrete matrix and reducing the formation of tiny cracks and voids. This strengthening effect allows for the creation of thinner, lighter, and more efficient concrete structures, pushing the boundaries of what's possible in modern construction.

Improved Durability

Beyond their strength-enhancing properties, nano silica and nano alumina also significantly improve the durability of concrete. These nano-materials effectively mitigate the effects of chemical attack, freeze-thaw cycles, and other environmental stressors, dramatically extending the service life of concrete structures. This enhanced resistance to deterioration translates to reduced maintenance costs and a lower environmental impact over the lifetime of a project.

Sustainable Solutions

The incorporation of nano silica and nano alumina into concrete not only improves performance but also contributes to the growing demand for sustainable construction practices. These nano-materials can be derived from waste products, such as silica fume and alumina waste, effectively repurposing industrial byproducts and reducing the environmental footprint of concrete production. Additionally, the enhanced durability and reduced material consumption of nano-enhanced concrete support the principles of circular economy and low-carbon construction, making it an invaluable tool in the fight against climate change.