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Th 4(a). CONCRETE TECHNOLOGY(ELECTIVE)

6th semester, Diploma Engineering.

Lecture Notes

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1 Concrete as a construction material:

1.1 Grades of concrete.

New Modified Grade of Concrete As per IS 456-2000 Amendment -4

First I would like to share some information about Old provision for the Grade of Concrete that is Mentioned in Table-2 of IS 456-2000. In this article, you will find some differences between the old provision of IS 456-2000 and Amendment 4 of IS 456-2000.

Grade of Concrete As per IS 456-2000 (Older Version)

According to the Table-2 of IS 456-2000, the Grade of concrete is classified into three categories i.e. Ordinary Concrete, Standard Concrete, and High Strength Concrete.
There are three Grades such as M 10, M 15, M 20 comes under Ordinary Concrete and its respective Specified characteristics compressive strength of 150 mm cube at 28 days are 10 N/mm2, 15 N/mm2, and 20 N/mm2. The Grade Designation of M 10 Stands such that M stands for Mix and 10 stands for Specified characteristics compressive strength of 150 mm cube at 28 days is 10 N/mm2.
The Second Category is Standard Concrete. In Standard Concrete includes the Grade Designation such as M 25, M 30, M 35, M 40, M 45, M 50, and M 55 and it corresponding compressive strength are 25 N/mm2, 30 N/mm2, 35 N/mm2, 40 N/mm2, 45 N/mm2, 50 N/mm2, and 55 N/ mm2.
So, all the design Parameter Mentioned in IS 456-2000 is applicable for the Grade of concrete less than M 55 and above M 55 grade of concrete, this standard is not applicable.

Modification As per IS 456-2000 Amendment -04

In the 4th Revision of IS 456-2000 i.e. Amendment-4 modified the Grade of concrete. This modification happened in May 2013. As per this Amendment, the Grade of concrete is classified into three groups i.e. Ordinary Concrete, Standard Concrete, and High Strength Concrete. In Ordinary Concrete, there are Grades such as M 10, M 15, M 20.
There are some modification in Standard Concrete Grade i.e. Number of Grades comes under Standard concrete are M 25, M 30, M 35, M 40, M 45, M 50, M 55, and M 60. High Strength concrete includes the Grade Designation such as M 65, M 70, M 75, M 80, M 85, M 90, M 95, and M 100.

Table 2 Grades of Concrete
(*Clauses* 6.1, 9.2.2, 15.1.1 *and* 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 days N/mm^2
(1)	(2)	(3)
Ordinary Concrete	M 10	10
	M 15	15
	M 20	20
Standard Concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
	M 60	60
High Strength Concrete	M 65	65
	M 70	70
	M 75	75
	M 80	80
	M 85	85
	M 90	90
	M 95	95
	M 100	100

Note: For the Concrete Grade above M 60, design parameters given in the standard may not be applicable and the values may obtain from the specified literature and experimental results.

Table 2 Grades of Concrete
(Clause 6.1, 9.2.2, 15.1.1 and 36.1)

Group	Grade Designation	Specified Characteristic Compressive Strength of 150 mm Cube at 28 Days in N/mm²
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	M 15	15
	M 20	20
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	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High Strength Concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

The Third Category is High Strength Concrete. Grade Designation such as M 60, M 65, M 70, M 75, M 80 Comes under the High Strength Grade of Concrete. There are 5 Concrete Grade falls in High strength concrete.

Note: For Concrete of compressive strength greater than M 55, the design parameter given in this standard may not be applicable and the values may be obtained from specialized literature and experimental results.

Major Difference Observed for a grade of concrete as per IS 456-2000 (Older version) and IS 456-2000 Amendment-04.

S. No	IS 456-2000 (Old version)	IS 456-2000, Amendment- 04.
1.	There are total 15 Grade of Concrete Available.	There are total 19 Grade of Concrete Available.

2.	M 60 Grade of concrete Comes Under the Category of High Standard Concrete.	M 60 Grade of concrete Comes Under the Category of Standard Concrete.
3.	There are 7 Grades that come under Standard Concrete. i.e. M 25, M 30, M 35, M 40, M 45, M 50, and M 55.	There are 8 Grades that come under Standard Concrete i.e. M 25, M 30, M 35, M 40, M 45, M 50, M 55 and M 60.
4.	There is 5 Concrete Grade come under the category of High strength concrete. i.e. M 60, M 65, M 70, M 75, M 80	4 New ConcreteGrade is added in High Strength Concrete i.e. M 85, M 90, M 95, and M 100.
5.	For the ConcreteGrade above M 55, design parameters given in the standard may not be applicable and the values may obtain from the specified literature and experimental results.	For the Concrete Grade above M 60, design parameters given in the standard may not be applicable and the values may obtain from the specified literature and experimental results.

1.2 Advantages and disadvantages of concrete.

Advantages of Concrete


Advantages of concrete

The following are the advantages of concrete :

1. **Availability of concrete ingredients easily.**

2. Easy handling and moulding of concrete into any shape.
3. Easy transportation from the place of mixing to place of casting before initial set takes place.
4. Ability to pump/spray to fill into cracks and lining of tunnels.
5. When reinforced, all types of the structures are made possible from an ordinary lintel to massive fly overs
6. Monolithic character gives better appearance and much i rigidity to the structure.
7. The property of concrete to possess high compressive strength, makes a concrete structure more economical than that of steel structure.

Disadvantages of Concrete


Disadvantages of concrete

The following are the disadvantages of concrete :

1. Due to low tensile strength, concrete is required to be reinforced to avoid cracks.
2. In long structures expansion joints are required to be provided if there is large temperature variance in the area.
3. Construction joints are provided to avoid cracks due to drying shrinkage and moisture-expansion.
4. Soluble salts in concrete cause efflorescence if moisture reacts with them.
5. Concrete made with ordinary Portland cement, gets integrated in the presence of alkalies, sulfates etc.
6. Sustained loads develop creep in structures.

Advantages of concrete	Disadvantages of concrete
It possesses high compressive strength to withstand a huge amount of load.	It has low tensile strength and hence cracks are developed.
It has less corrosive and weathering effects due to the environment.	Fresh concrete shrinks on drying and harden concrete expand on drying.
The green concrete can be easily handled, remolded or formed into any shape or size.	It may cause an efflorescence effect. It has a lack of ductility and may crack suddenly after jerk.
It is durable and fire-resistant and comparatively required little maintenance.	It require proper curing till hydration to get required amount of strength.

2 Cement:

Composition of cement

Composition of cement

Introduction

Portland cement gets its strength from chemical reactions between the cement and water. The process is known as hydration. This is a complex process that is best understood by first understanding the chemical composition of cement.

Manufacture of cement

Portland cement is manufactured by crushing, milling and proportioning the following materials:

- **Lime or calcium oxide, CaO: from limestone, chalk, shells, shale or calcareous rock**
- **Silica, SiO_2: from sand, old bottles, clay or argillaceous rock**
- **Alumina, Al_2O_3: from bauxite, recycled aluminum, clay**
- **Iron, Fe_2O_3: from from clay, iron ore, scrap iron and fly ash**
- **Gypsum, $CaSO_4.2H_20$: found together with limestone**

The materials, without the gypsum, are proportioned to produce a mixture with the desired chemical composition and then ground and blended by one of two processes - dry process or wet process. The materials are then fed through a kiln at 2,600º F to produce grayish-black pellets known as clinker. The alumina and iron act as fluxing agents which lower the melting point of silica from 3,000 to 2600º F. After this stage, the clinker is cooled, pulverized and gypsum added to regulate setting time. It is then ground extremely fine to produce cement.

Chemical shorthand

Because of the complex chemical nature of cement, a shorthand form is used to denote the chemical compounds. The shorthand for the basic compounds is:

Compound	Formula	Shorthand form
Calcium oxide (lime)	Ca0	C
Silicon dioxide (silica)	SiO_2	S
Aluminum oxide (alumina)	Al_2O_3	A

Iron oxide	**Fe_2O_3**	**F**
Water	**H_2O**	**H**
Sulfate	**SO_3**	**S**

Chemical composition of clinker

The cement clinker formed has the following typical composition:

Compound	Formula	Shorthand form	% by weight[1]
Tricalcium aluminate	**$Ca_3Al_2O_6$**	**C_3A**	**10**
Tetracalcium aluminoferrite	**$Ca_4Al_2Fe_2O_{10}$**	**C_4AF**	**8**
Belite or dicalcium silicate	**Ca_2SiO_5**	**C_2S**	**20**
Alite or tricalcium silicate	**Ca_3SiO_4**	**C_3S**	**55**
Sodium oxide	**Na_2O**	**N**	**))Up to 2**
Potassium oxide	**K_2O**	**K**	
Gypsum	**$CaSO_4.2H_2O$**	**CSH_2**	**5**

Representative weights only. Actual weight varies with type of cement.

Source: Mindess & Young

Properties of cement compounds

These compounds contribute to the properties of cement in different ways

Tricalcium aluminate, C_3A:-

It liberates a lot of heat during the early stages of hydration, but has little strength contribution. Gypsum slows down the hydration rate of C_3A. Cement low in C_3A is sulfate resistant.

Tricalcium silicate, C_3S:-

This compound hydrates and hardens rapidly. It is largely responsible for portland cement's initial set and early strength gain.

Dicalcium silicate, C_2S:

C_2S hydrates and hardens slowly. It is largely responsible for strength gain after one week.

Ferrite, C_4AF:

This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln (from 3,000^o F to 2,600^o F). It hydrates rapidly, but does not contribute much to strength of the cement paste.

By mixing these compounds appropriately, manufacturers can produce different types of cement to suit several construction environments.

hydration of cement:

The Chemical reaction that takes place between cement and water is called as hydration of cement. This reacion is exothermic in nature, due to which considerable amount of heat is released during hydration of cement. This is called as 'heat of hydration'. The hydration of cement is not a sudden process. This reaction is faster in early period and continues indefinitely at a decreasing rate.

What Happens During Hydration of Cement

During hydration of cement, C3S and C2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide Ca(OH)2.

2 C3S + 6H → C3S2H3 + 3 Ca(OH)2

2 C2S + 4H → C3S2H3 + Ca(OH)2

Calcium silicate hydrate is one of the most important product of hydration process and it determines the good properties of cement. It can be seen from the above reactions that C3S produces more quantity of calcium hydroxide than C2S.
Calcium hydroxide is not a desirable product in concrete mass as it is soluble in water and gets leached out thereby making the concrete porous, particularly in hydraulic structures, thus decreasing the durability of concrete.
Calcium hydroxide also reacts with sulphates present in water and soils to form calcium sulphate which further reacts with C3A and causes deterioration of concrete. This process is known as Sulphate Attack. The only advantage of calcium hydroxide is that, being alkaline in nature it maintains a high pH value in concrete which resists the corrosion of reinforcement.
It has been estimated that on an average 23% of water by weight of cement is required for chemical reaction with portland cement compounds. As this 23% of water chemically combines with cement, it is called as bound water.
A certain quantity of water is absorbed by the gel pores. This water is known as gel water. The bound water and gel water are complementary to each other. It has been estimated that 15% water by weight of cement is required to fill up the gel pores.
Therefore a total of 38% of water by weight of cement is required for the complete chemical reaction of cement and occupy the space within gel pores. If water equal to 38% by weight of cement is only used then it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities.

1. WHAT IS HYDRATION OF CEMENT?

   The chemical reaction of the major compounds of cement with water is termed the hydration of cement.

2. WHAT IS HEAT OF HYDRATION OF CEMENT?

   The amount of heat liberated in joule per gram of cement during the process of complete hydration at a specified temperature is termed as the heat of hydration of cement.

3. WHAT IS HYDRATION RATE?

The rate at which the hydration reaction proceeds is called hydration rate.

In cement, the rate of hydration of major compounds is in the order:
$C_3A > C_4AF > C_3S > C_2S$

4. WHAT IS Heat of hydration AND Significance of Heat of hydration in concrete?

Heat of hydration is the amount of heat liberated in joule per gram of cement during the process of complete hydration at a specified temperature.
Significance of Heat of hydration in concrete:

- **Heat evolved can help in activating the hydration reactions in cold weather concreting**
- **In mass concreting, too much heat is evolved, which is needed to be controlled to prevent the shrinkage cracks**

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fineness of cement:

What is Fineness of Cement?

The strength and durability of the structure depend on the properties of cement.
The fineness of the cement test is conducted to find whether the cement has been grind well or not.

What is the fineness of cement?

The fineness represents the particle size of cement. It should not be greater than 90-microns when sieved as per **IS standard.**

Importance of fineness of cement

- More cement coarse particles affect and reduce the rate of hydration. If the hydration rate decreases, then it impacts the strength development of concrete or mortar.
- More fineness induces dry cracks on concrete surfaces.
- Fineness cement can easily blend with other ingredients.

- The fine particles are easily mixed with the water to make the cement paste as compared to the coarser cement particle.
- Bleeding can be reduced.
- More fineness means high concrete workability and thus increases the setting time.

How it is measured?

The fineness of cement is determined by the sieving method.
It is measured by the ratio between coarse particles (which retained in 90-micron sieve analysis) to the fineness particles (which passed through the sieve analysis).
IS code – The test should be conducted as per IS code 4031 Part 1, and the test sample should be collected as per IS code 3535.

Apparatus Required

- Lid
- Pan
- Nylon brush
- 90-micron sieve
- Weighing balance – nearly weight 10 mg

Test Procedure

- A quantity of 100g cement should be taken and weighed as **W1**.
- The sample cement should be free from lumps. Nicely stir the cement with a clean rod to spread the fineness to the whole area.
- Now place the cement sample into the 90-micron sieve and close it by the lid.
- Then shake the sieve gently for at least 15 minutes.
- Now note down the weight of retained cement particles in the sieve as **W2**.

Calculation

Fineness of cement = (W2/W1) x 100

The test has to be done with at least three samples from the same batch. The average value is the fineness of the cement.

The ratio between the test samples should not be greater than 0.2% if else then repeat the test. The retaining cement particles in sieve should not be more than 10%.

Lab Report

SI	Description	Sample 1	Sample 2	Sample 3

1	Weight of cement sample **W1**	
2	Weight of retained cement in sieve **W2**	
3	Percentage of Fineness	

The fineness ratio will differ based on the types of cement.

- Ordinary Portland cement – 10%
- Low heat cement – 5%
- Rapid hardening cement – 3 to 5%

Precaution

- The cement sample should be dry.
- Accurate weighing is avoiding repeatability tests.
- Wear a hand glove when rub the sample cement by hand.
- Shake the sieve gently to prevent loss of cement or use sieve shaker

Importance of Cement Fineness

- The fineness of cement affects hydration rate, and in turn, the strength. Increasing fineness causes an increased rate of hydration, high strength, and high heat generation.
- Bleeding can be reduced by increasing fineness. However, increased fineness can also lead to the requirement of more water for workability, resulting in a higher possibility of dry shrinkage.

- The increased surface area-to-volume ratio will ensure a more available area for water-cement interaction per unit volume.

FAQ:

The size of the sieve used to test the fineness of cement is?

The size of the sieve used to test the fineness test of cement is 90 microns IS Sieve.

What is the value of the fineness of cement?

Generally, Cement used for construction should have a value of fineness of less than 10%.

Why fineness of cement is important?

Cement smaller particles react much quicker than larger particles. A cement particle with a diameter of 1μm will react entirely in 1 day, whereas a particle with a diameter of 10μm takes about 1 month. If a fine cement particle is more in cement then it will be set too quickly and that not feasible on-site to place concrete properly.

fineness of cement

The fineness of cement is a measure of cement particle size and is denoted in terms of the specific surface area of cement. The weight of cement particle whose size is greater than 90 microns is determined and the percentage of retained cement particle are calculated. This is known as the Fineness of cement.

Significance Of Cement Fineness

The fineness of cement is an important factor that affects the performance of the concrete mix. Fineness refers to the particle size of the cement and is typically measured by the surface area of the cement particles per unit weight. The finer the cement particles, the greater the surface area, and the higher the reactivity of the cement. Here are some of the reasons why fineness is important for cement

1. Early strength development: Finer cement particles hydrate more quickly and contribute to the early strength development of the

concrete. This is important in projects where early strength is required, such as in precast concrete applications.

2. Workability: Finer cement particles require less water to produce a workable mix, which can result in more cohesive and easier-to-place concrete. This can be important in projects where concrete is being placed in difficult-to-reach areas.
3. Durability: Finer cement particles can lead to a more dense and impermeable concrete, which can improve the durability and resistance to water and chemical attacks.
4. Heat of hydration: Finer cement particles produce a higher rate of heat of hydration, which can be a concern in large concrete pours, especially in hot weather conditions.
5. Cost: Finer cement is generally more expensive due to the higher energy requirements needed to produce it. However, the benefits of using finer cement, such as improved strength, workability, and durability, may offset the higher cost.

How to Conduct the Fineness Test of Cement

Aim

To determine the fineness of cement by using a 90 μm IS sieve as per IS: 4031 (Part 1) – 1996.

Apparatus
Apparatus

Fineness Test of Cement Apparatus

- 90µm IS Sieve,
- Weight Balance has a capacity of 10 mg to 100 g,
- Nylon or pure bristle brush

Procedure For Testing The Fineness Of Cement

1. Collect a sample of cement and rub it with your hands. The Fineness test sample should be free of lumps.
2. Take 100 gm of cement sample and note its weight as W1.
3. Drop 100 gm of cement in a 90 µm sieve and close it with the lid.
4. Now, shake the sieve with your hands by agitating the sieve in planetary and linear movements for 15 minutes.

5. After that take the weight of the retained cement on the 90 µm sieve as W2. To calculate the fineness of cement formula is given below,

Fineness = (W2/W1) * 100
Then, calculate the percentage of Weight of cement retained on the Sieve.
Repeat this procedure with three different samples of cement and average the values for accurate results.

The Calculation Of Cement's Degree Of Fineness

The following table provides a comprehensive overview of the value and significance of cement fineness.

Sr.No.	**Weight of Cement Sample**	**Weight Cement Sample Retained on 90µm Sieve**	**Fineness of Cement**
1	100 gm	4.65	4.65 %
2	100 gm	8.25	8.25 %
3	100 gm	7.95	7.95 %
		Average	**6.95 %**

Fineness Modulus of Cement

Result: The standard value of the fineness of cement should have a fineness of less than 10 % or fineness of cement should not be more than 10% as per IS Recommendations.

setting time of cement

Initial and Final Setting Time of Cement Test

The setting time of cement is an important characteristic that determines its performance and application. The setting time refers to the time it takes for cement to harden and become stable after it has been mixed with water. This process involves a series of chemical reactions that lead to the formation of a hardened mass.

To measure the setting time of cement, two tests are commonly used – the initial and final setting time tests. These tests are critical in ensuring that the cement is used appropriately and that it performs as expected in various applications. In this context, understanding the significance and methods of conducting initial and final setting time tests is crucial for anyone involved in the production, distribution, or use of cement.

Initial Setting Time

The initial setting time of cement is the time taken by the cement paste to set and harden to a point where it can no longer be disturbed by any external force. This is typically measured using the Vicat apparatus, and the standard requirement is that the initial setting time should not be less than 30 minutes for ordinary Portland cement.

Final Setting Time

The final setting time of cement is the time taken by the cement paste to reach a state of complete hardening and development of strength. This is also measured using the Vicat apparatus, and the standard requirement is that the final setting time should not be more than 10 hours for ordinary Portland cement.

Importance of initial and final setting time of cement

- It is required that cement does not lose its plasticity too early or too late. If cement is set too early, there is insufficient time for transportation and place of concrete.

- If cement is set too late then there is a delay in construction work. Also, concrete will not get sufficient strength early and the formwork removal process delayed.
- The proper setting time is required for the stiffening of cement paste to a defined consistency.
- It is indirectly related to the chemical reaction of cement with water to form an aluminum-silicate compound.
- 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 utilized for the safe removal of scaffolding or form.
-

Factors Affecting Setting Time of Cement

The initial and final setting times of cement are important properties that determine its suitability for various construction applications.

The initial setting time refers to the time taken by the cement paste to lose its plasticity and become rigid enough to resist certain loads without any appreciable indentation. This time is important for processes such as handling, transportation, and placement of concrete. If the initial setting time is too short, the concrete may not be workable, and if it is too long, the concrete may start setting before it is placed, causing difficulty in finishing.

The final setting time is the time taken by the cement paste to harden and attain its ultimate strength. This is important for ensuring that the concrete attains its full strength and durability, and can resist external loads and environmental factors over a long period of time. If the final setting time is too short, the concrete may not attain its full strength, while if it is too long, the setting may be delayed, leading to prolonged construction times and increased costs.

In summary, the initial and final setting times of cement are crucial parameters that impact the workability, strength, and durability of concrete. Therefore, it is important to ensure that these parameters are within the desired range to achieve the best results in construction projects.

Procedure For Initial and Final Setting Time of Cement

As Per IS: 4031 (Part 5) – 1988. The initial and final setting time of cement is calculated using the VICAT apparatus conforming to IS: 5513 – 1976.

Apparatus

Apparatus Initial and Final Setting Time of Cement

1. Balance – The permissible variation at a load of 1000 g shall be ± 1.0 g.
2. Vicat Apparatus – Vicat apparatus should confirm to IS: 5513-1976.
3. Stop Watch
4. Gauging or Mixing Trowel
5. Glass Plate
6. Enamel tray

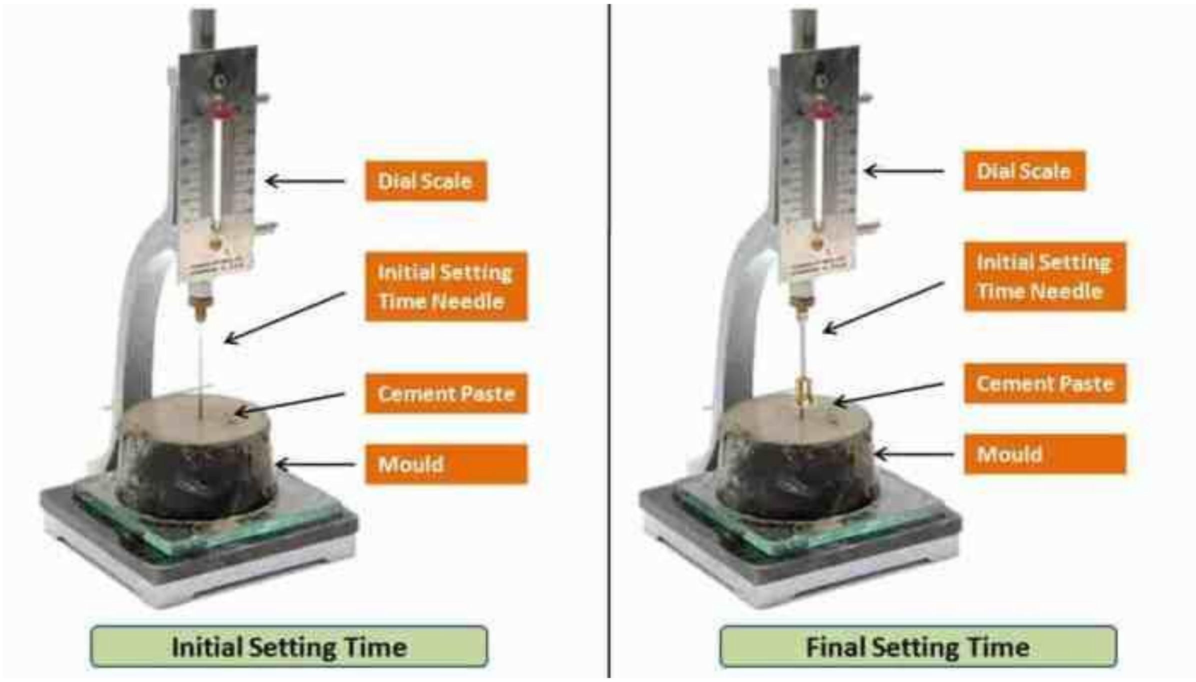
Test Procedure:

Preparation of Test

1. Consistency of cement shall be tested before conducting a test to find out % of the water required by the weight of cement as normal consistency of cement (P).
2. Take about 400 gm of cement and add water about 0.85x P (P is % water required for normal consistency of cement)
3. Mix water with cement quickly in a short time about 3 min to 5 min. Start the stopwatch at the instance when water is added to the cement. Record this time (T1).
4. Now, fill this prepared cement paste in a Vicat apparatus mould having a diameter of 80 mm and a height of 50 mm resting on a non–porous glass plate. Properly fill and smooth off the top surface of the mould and level it.

For Initial Setting Time:

1. For determining the initial setting time of cement, place this mould filled with cement paste below the Vicat apparatus and fit the needle used for testing the initial setting time.
2. Lower the bottom of the needle such that it touches the top of cement paste filled in mould.
3. Remove the locking pin from the top and quickly release the needle, allowing it to penetrate into the cement paste.
4. At the beginning, the needle penetrates and touches the bottom of mould. Repeat this process, like quickly releasing the needle after every 2 minutes till the needle fails to penetrate the cement paste for about 5 mm measured from the bottom of the mould.
5. Note Time (T2) when the needle fails to penetrate 5 mm from the bottom of the mould.



Fitial Setting Time

1. For determining the final setting time of cement replace the needle with another needle having an angular ring attachment.
2. Now, slightly release this needle on the surface of the cement paste and observe whether it is making an impression of the ring on the surface or not. Not the time when need fails to make an impression on the surface of cement paste. (T2)

Calculation of Initial and Final Time:

Initial setting time of cement = Time when needle fails to penetrate 5 m from the bottom of mould.(T2) – The time when added to cement (T1)

Final setting time of cement = Time when angular need ring impression stop on cement paste (T3) – Time when water added to cement (T1)

Practical Calculations

Suppose, Consistency of cement (P) = 30% and Weight of cement = 400 kg

Water to be added in cement = (0.85 x P) x 400 = (0.85 x 30%) x 400 = 102 ml

The time when water added to cement = 7:00 am

Time, when needle fails to penetrate less than 5 mm from the bottom of mould = 7:45, am
Initial Setting Time of Cement = 7:45 am – 7:00 am = 45 min.
Time When angular ring needle fails to make impression on the surface of cement paste = 12:00 pm
Final setting Time of Cement = 12:00 pm – 7:00 am = 5 hr = 300 min.

Standard Setting Times for Various Cement

There are various types of cement used in the construction industry. Depending on the types of cement and admixture used in the manufacturing of cement initial setting time and final setting time are differs for cement. The standard-setting time for different types of cement is given below.

Name of Cement	**Ref. IS Code**	**Initial Setting Time(min)**	**Final Setting Time(Max)**
OPC (33)	IS: 269	30	600
OPC (43)	IS: 8112	30	600
OPC (53)	IS: 12269	30	600
SRC	IS: 12330	30	600
PPC	IS 1489.P1	30	600
RHPC	IS: 8041	30	600

PSC	IS: 455	30	600
High Alumina	IS: 6452	30	600
Super Sulphate	IS: 6909	30	600
Low Heat	IS: 12600	60	600
Masonry Cement	IS: 3466	90	1440
IRS – T -40	Railway	60	600

Types of Cement and Their Initial and Final Setting Times

FAQs:

Initial and Final Setting Time of OPC Cement?

For OPC, the Minimum setting initial setting is 30 min and the maximum final setting time is 600 min.

Initial setting time of PPC cement?

The Minimum initial setting time of PPC cement is 30 min.

Setting Time of Cement

The initial setting time gives an idea about how fast cement can start losing its plasticity and the final setting time of cement gives an idea about how much cement takes to lose its full plasticity and gain some strength to resist pressure.

Setting Time Test of Cement

The setting Time of the cement test is conducted to find out the initial and final setting time of any cement. Initial Setting Time is the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity. It is the time elapsed between the moment the water is added to the cement and the time when cement paste loses its plasticity completely

soundness of cement:

What Is the Soundness of Cement?

The **soundness of cement** indicates the **stability of any cement** during the **volume change** in the process of **setting and hardening**. In case the **volume change** in cement is **unstable after setting** and hardening, the concrete element will **crack**, which can **affect the quality of the structure** or even cause **serious accidents**, known as **poor dimensional stability.**

The soundness test of cement determines the expansion of **cement** after it starts setting. **Certain** cement has been **found** to **undergo** a large **expansion after setting** causing **disruption** of the set and **hardened mass**.

This expansion of **cement** can cause serious **problems** for the durability of **structures** when such **cement** is used.

The **soundness of cement** is mainly **measured** by two methods: **EN-196 (1995),** which is based on the **Le Châtelier test method,** and the **autoclave test (ASTM-C151, 2015),** in which **pressure** is also **applied to the sample.**

Significance of Soundness of Cement

The testing of the soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion of prime importance. The unsoundness is **occurring** mainly due to an **excess lime** that could be **combined** with acidic oxide at the **kiln**.

This is also due to **inadequate** burning or **insufficient** fineness of grinding or **thorough** mixing of **raw materials**. It also may occur due to too high a proportion of **magnesium content or calcium sulfate content** may cause **unsoundness** in **cement**.

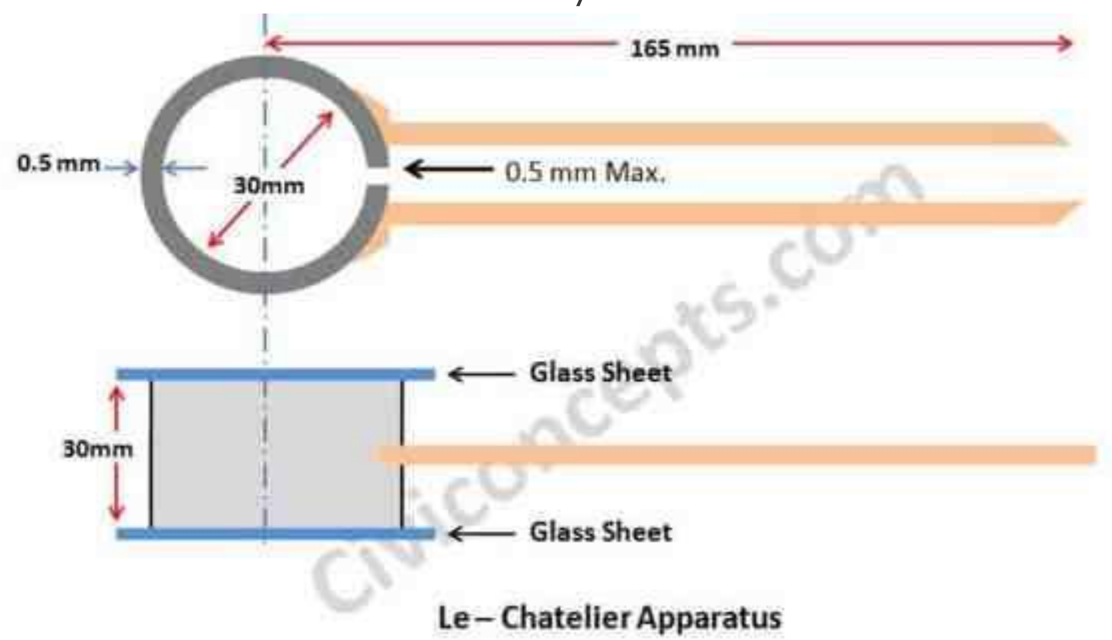
For this **reason**, the magnesia content **allowed** in cement is **limited** to 6 percent, It can be **recalled** that to prevent **flash setting**, calcium sulfate is **added** to the clinker while **grinding**. The quantity of **gypsum added** will vary from **3 to 5 percent** depending upon **C3A content**.

If the **addition** of gypsum is **more than** could be **combined** with C3A, excess **gypsum** will remain in the **cement** in Free State. This **high percentage of gypsum** leads to an **expansion** and **consequent disruption** of the set **cement paste**.

The **unsoundness** in cement majorly **occurs** due to **excess lime**, excess **magnesia**, or excessive **proportion** of sulfates. The **unsoundness effect** of cement does not **come** to the **surface** for a **considerable period** of time,

Le Chatelier Test

Therefore, **accelerated** tests are required to **detect them**. The soundness of **cement** is tested by is **Le – chatelier's soundness test.**



Soundness Test of Cement Apparatus

Soundness Test of Cement [Le chatelier Test]

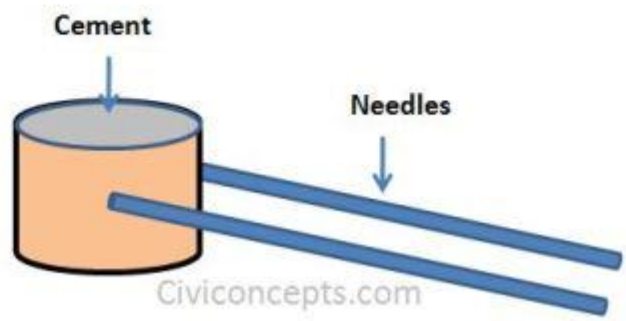
IS Code for soundness cement Test is IS:4031-Part 3-1988

Soundness Test Apparatus

1. **Le- chatelier mould**
2. **Cement**
3. **Glass sheets**
4. **Mixing pan**
5. **Trowel**
6. **Weight**

It consists of a small split cylinder of spring brass or other sulfa metal. Le- Chatelier mold is 30 mm in diameter and 30 mm high. On both sides of the mold are attached two indicator arms 165 mm long with pointed ends.
Water is added to cement as 0.78 P. where P is % of water for standard consistency of cement. Well, a mixed paste is filled in mold and covered with a glass plate on both faces of mold.
Procedure Of Soundness Test
The Soundness test of the cementing procedure is as follows,

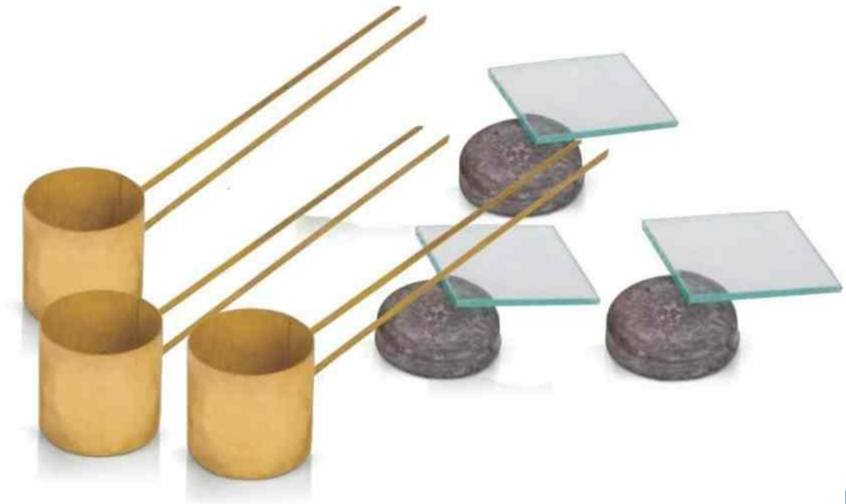
- **The mould and the glass plates are oiled before conducting the test.**
- **Take 400 grams of cement sample.**
- **For this test to be performed we need standard consistency of cement. Water is taken as 0.78 x P (Where P is water required for Standard consistency in percentage)**
- **For example, Standard consistency is 30% of water, then take water percentage for soundness is 0.78 x 30% = 23.4%. So water mixed in 400 gm of cement will be 400 x (23.4/100) = 93.6ml.)**
- **Make a well-mixed paste of cement and fill in Le- Chatelier mould taking care to keep the edges of the mould gently together during the operation.**
- **Clean the upper surface and make it smooth and place a small weight over the cover plate.**



Le- Chatelier Apparatus

- **Put this assembly quickly in water at a temperature of 27º C + 2ºC and keep it there for 24 hours.**
- **Take out mould from water and measure the distance between the indicators points as Reading-1.(Suppose it is 2 mm)**
- **Now, again put this assembly in boiling water for 25 to 30 minutes and keep at boiling for 3 hours. The mould should be in boiled water during this period**
- **Remove the mould from the water and allow it to cool at room temperature.**
- **Measure the distance between the indicator points as Reading-2. (Suppose it is 10mm)**
- **The soundness of cement = (Reading-2) – (Reading-1)**

= 10 mm – 2mm
= 8 mm



Le Chatelier Apparatus

Read More: What Is Curing Of Concrete And Different Methods Of Curing

The difference between needle readings indicates the soundness of cement. The soundness limit must exceed 10 mm for ordinary, rapid hardening, and low heat Portland cement. If in case the c expansion is more than 10 mm as tested above, the cement is said to be unsound.

The Le Chatelier test has the drawback in that it detects lime-caused unsoundness. This method does not measure unsoundness caused by the presence of an excess of magnesia.

Indian Standard Specification stipulates that cement having a magnesia content of more than 3 percent shall be tested for soundness by Autoclave test which is sensitive to both free magnesia and free lime.

In this test, a neat cement specimen 25 x 25 mm is placed in a standard autoclave and the steam pressure inside the autoclave is raised at such a rate as to bring the gauge pressure of the steam to 21 kg/sq cm in 1 — 1′/4 hour from the time the heat is turned on.

This pressure is maintained for 3 hours, the autoclave is cooled and the length is measured again. The Stream pressure applied eventually accelerates the hydration of both magnesia and lime. To determine the unsoundness due to excess calcium sulfate there is no satisfactory test is available. But, the amount present can be easily determined by chemical analysis.

FAQs:

What is the purpose of the soundness test?

The testing of the soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion of prime importance. The unsoundness is occurring mainly due to an excess lime that could be combined with acidic oxide at the kiln.

What is Le Chatelier apparatus?

The most popular and simple instrument used to measure the Soundness Test of Cement is Le – chatelier's soundness test.

IS code for soundness test of cement?

IS Code for soundness test of cement is IS:4031-Part 3-1988

Soundness Test

The soundness test of cement has measured the expansion of cement after it starts setting. Certain cement has been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This expansion of cement can cause serious problems for the durability of structures when such cement is used.

Soundness of cement

The soundness of cement has measured by the expansion of cement after it starts setting. If the volume change is unstable after setting and hardening, the concrete structures will crack, which can affect the quality of buildings or even cause serious accidents, known as poor dimensional stability.

What is the meaning of the soundness of cement?

The soundness of cement has measured by the expansion of cement after it starts setting. Certain cement has been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This expansion of cement can cause serious problems for the durability of structures when such cement is used.

types of cement.

Different Types Of Cement

1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement also known as OPC is a type of cement that is manufactured and used worldwide. It is widely used for all purposes including:

Concrete: When OPC is mixed with aggregates and water, it makes concrete, which is widely used in the construction of buildings

Mortar: For joining masonry

Plaster: To give a perfect finish to the walls

Cement companies in Malaysia offer OPC in three different grades, namely grades 33, 43, and 53.
Besides the aforementioned purposes, Ordinary Portland cement is also used to manufacture grout, wall putty, solid concrete blocks, AAC blocks, and different types of cement.

2. Portland Pozzolana Cement (PPC)

To prepared PPC or Portland Pozzolana cement, you need to grind pozzolanic clinker with Portland cement.

PPC has a high resistance to different chemical assaults on concrete. It is widely used in construction such as:

Marine structures

Sewage works

Bridges

Piers

Dams

Mass concrete works

3. Rapid Hardening Cement

Cement suppliers in Malaysia also offer rapid Hardening cement. Rapid Hardening Cement is made when finely grounded C3S is displayed in OPC with higher concrete.

It is commonly used in rapid constructions like the construction pavement.

4. Extra Rapid Hardening Cement

As the name suggests, Extra rapid hardening cement gains strength quicker and it is obtained by adding calcium chloride to rapid hardening cement.

Extra rapid hardening cement is widely used in cold weather concreting, to set the cement fast. It is about 25% faster than that of rapid hardening cement by one or two days.

5. Low Heat Cement

Cement manufacturers in Malaysia offers low heat cement that is prepared by keeping the percentage of tricalcium aluminate below 6% and by increasing the proportion of C2S.

This low heat cement is used in mass concrete construction like gravity dams. It is important to know that it is less reactive and the initial setting time is greater than OPC.

6. Sulfates Resisting Cement

This type of cement is manufactured to resist sulfate attack in concrete. It has a lower percentage of Tricalcium aluminate.

Sulfates resisting cement is used for constructions in contact with soil or groundwater having more than 0.2% or 0.3% g/l sulfate salts respectively.

It can also be used in concrete surfaces subjected to alternate wetting and drying like bridge piers.

7. Quick Setting Cement

Cement suppliers in Malaysia also offer quick setting cement which sets faster than OPC but the strength remains the same. In this formula, the proportion of gypsum is reduced.

Quick setting cement is used for constructions that need a quick setting, like underwater structures and in cold and rainy weather conditions.

8. Blast Furnace Slag Cement

This type of cement is manufactured by grinding the clinker with about 60% slag and it is similar to Portland cement. It is used for constructions where economic considerations are important.

9. High Alumina Cement

High alumina cement is obtained by mixing calcining bauxite and lime with clinker during the manufacturing process of OPC.

To be considered high alumina cement, the total amount of alumina content should be at least 32%, and the ratio of the weight of alumina to lime should be kept between 0.85 to 1.30.

The most common uses are in constructions that are subject to high temperatures like a workshop, refractory, and foundries.

10. White Cement

This type of cement is manufactured by using raw materials that are free from iron and oxide. White cement needs to have lime and clay in a higher proportion. It is similar to OPC but it is more expensive.

15 types of cement

There are a variety of types of cement you can use depending on your project's purpose and conditions. Here are 15 types of cement:

1. Ordinary Portland cement (OPC)

Ordinary Portland cement is the most widely used type of cement manufactured and used worldwide. “Portland” is a generic name derived from a type of building stone quarried on the Isle of Portland in Dorset, England. OPC is suitable for most general concrete jobs and mortar or stucco construction projects.

2. Portland pozzolana cement (PPC)

Manufacturers create Portland pozzolana cement by grinding pozzolanic clinker, sometimes with additives of gypsum or calcium sulfate, with ordinary Portland cement. Compared to OPC, it has a higher resistance to various chemical reactions within concrete. PPC is often used for projects like bridges, piers, dams, marine structures, sewage works or underwater concrete projects.

3. Rapid-hardening cement

Contractors or construction teams may choose rapid-hardening cement for its high strength in the early stages of the hardening process. Its strength in three days is comparable to OPC strength at seven days with the same water-to-cement ratio. Rapid-hardening cement may have an increased lime content, combined with a finer grinding process, or better strength development. It is often used for projects with early-stage formwork removal or when the focus is on increasing construction rates and decreasing costs.

4. Extra-rapid-hardening cement

Extra-rapid-hardening cement may set and become durable even faster than OPC and rapid-hardening cement. Construction professionals achieve this by adding calcium chloride to rapid-hardening cement. This cement type may be useful for cold-weather concrete projects due to its fast setting rate.

5. Quick-setting cement

Similar to extra-rapid-hardening cement, this concrete type may set and become stronger even quicker than OPC and rapid-hardening cement. Its grain and strength rate are similar to OPC, but it hardens faster. Quick-setting cement may be beneficial for time-sensitive projects or those located near stagnant or running water.

6. Low-heat cement

Manufacturers produce low-heat cement by monitoring the percentage of tricalcium aluminate in the mixture to ensure it stays below 6% of the whole. This helps maintain low heat during the hydration process, making this cement type more resistant to sulfates and less reactive than other types of cement. It may be suitable for mass concrete construction or projects to help prevent cracking due to heat. However, low-heat cement may have a longer initial setting time than other types.

7. Sulfate-resisting cement

Sulfate-resisting cement helps reduce the risk of sulfate side effects on concrete. Its most common use is for constructing foundations in soil with high sulfate content. This concrete type can also be beneficial for projects like canal linings, culverts and retaining walls.

8. Blast furnace slag cement

Manufacturers make blast furnace slag cement by grinding clinker with up to 60% slag. This creates cement with many of the same properties as OPC. However, it may be less expensive to produce than other types, making it a good choice for financially conscious projects.

9. High-alumina cement

High-alumina cement is a type of rapid-hardening cement created by melting bauxite and lime together and grinding it with clinker. It has high compressive strength and may be more flexible and workable than OPC. Construction teams can use high-alumina cement for projects where cement is subject to extreme weather like high temperatures or frost.

10. White cement

White cement is a type of OPC that's white instead of gray. It's prepared from raw materials that don't include iron oxide and may be more expensive than other cement types. It's often useful in architectural projects and interior and exterior decorative projects like designing garden paths, floors, swimming pools and ornamental concrete products.

11. Colored cement

Colored cement has properties similar to OPC and white cement. Manufacturers mix 5% to 10% mineral pigments with OPC to achieve the desired color. Like white cement, contractors often use this type for decorative purposes and projects to enhance their designs.

12. Air-entraining cement

Air-entraining cement is more workable with a smaller water-cement ratio than OPC and other types of cement. Manufacturers add air-entraining agents like glues, sodium salts and resins to the clinker during the grinding process to create this cement. A common use for this type of cement is for frost resistance in concrete.

13. Expansive cement

Expansive cement can grow slightly over time without shrinking during the hardening process. It may be beneficial for projects like grouting anchor bolts or concrete ducts. Teams can also use it in structure joints or to reinforce other concrete structures.

14. Hydrographic cement

Manufacturers create hydrographic cement by mixing in water-repelling chemicals. This cement type has high workability and strength and also repels water to prevent weather damage. Teams can use hydrographic cement for projects such as dams, water tanks, spillways and water retaining structures.

15. Portland-limestone cement (PLC)

Portland-limestone cement is a blend of Portland cement and 5% to 15% fine limestone. Its properties are similar to Portland cement for general use. However, it also has about 10% lower greenhouse gas emissions, which can help increase sustainability

What is Cement?

Cement is a binding agent that holds aggregates and reinforcing elements together. For all forms of construction, including dwellings, roads, schools, hospitals, dams, and ports, as well as for decorative purposes and objects like tables, sculptures, or bookcases, cement is mostly employed as a binder in concrete.

What are the Different Types of Cement?

Different types of cement are used in the construction sector. The differences between each type of cement are its properties, uses, and composition materials used during the manufacturing process. The following list includes the most common types of cement used in construction.

- Ordinary Portland Cement
- Quick Setting Cement
- Rapid Hardening Cement
- Low Heat Cement
- Portland Pozzolana Cement
- Portland Blast Furnace Slag Cement
- High Alumina Cement
- Sulphate Resisting Cement
- Hydrophobic Cement
- Super Sulphated Cement
- Expansive Cement
- Air Entraining Cement
- White Cement
- IRS-T40 Cement

Ordinary Portland Cement (OPC)

Ordinary Portland cement is the most extensively manufactured and used cement worldwide, which is suited for all types of concrete construction. It is made of Calcareous materials containing calcium carbonate (limestone, marl) and Argillaceous materials containing clay (clay, shale). Main constituents of OPC are lime (62-67%), silica (17-25%), alumina (3-8%), calcium sulphate (3-4%), iron oxide (3-4%) and magnesia (1-3%).

When cement ingredients are inter-grinded and burned, they fuse together, forming complex compounds known as Bogues compounds. In addition to water, these compounds react with it causing the cement to set and harden. These compounds are listed below –

- Tricalcium Aluminate(C_3A) – It is responsible for the flash setting of cement, i.e., it is the first to harden and set.
- Tricalcium Silicate(C_3S) – It is responsible for the development of strength in the early stages.
- Dicalcium Silicate(C_2S) – It is responsible for the progressive strength of cement in later stages.
- Tetra Calcium Alumino Ferrate(C_4AF) – It does not impart any property in the cement and hence, is of no engineering significance.

Types of Ordinary Portland Cement – 33 grade, 43 grade, and 53 grade. The grade signifies the compressive strength of cement at 28 days.
For example, 33 grade means the compressive strength of cement at 28 days is 33 N/mm^2.
Properties – OPC resists cracking and dry shrinkage well but is less resistant to chemical attack. Some of the important properties of OPC are listed below -

- Specific Gravity – 3.15
- Density – 1440 kg/m^3
- Setting time – Initial setting time should not be less than 30 minutes whereas the final setting time should not be more than 10 hours.

- Fineness – As measured by Blaine's method, the specific surface area should not be less than 225 m^2/kg.

Uses – It is employed in general construction works as well as in the majority of masonry projects.

Quick Setting Cement

Quick Setting Cement is obtained by adding a small percentage of alumina in finely ground cement clinkers and reducing the proportion of gypsum (calcium sulphate). As the name suggests, this type of cement sets very quickly. The initial setting time is just 5 minutes and the final setting time is 30 minutes.
Quick setting cement finds its application in construction where cement is required to set quickly such as:

- Underwater concreting
- In cold and rainy weather conditions
- Grouting operations

Rapid Hardening Cement

Rapid Hardening Cement is a type of cement that has a higher rate of gain of strength as compared to OPC. This cement attains the same strength in 3 days that OPC may attain in 7 days. However, the ultimate strength of the rapid hardening cement is the same as OPC. Higher strength in the early stages is obtained by finely grinding the cement for higher fineness (specific surface area should not be less than 325 m^2/kg) and increasing the proportion of C_3S.
This type of cement is used in construction works where speedy construction is required. Rapid Hardening Cement finds its application in:

- Pavement construction
- Cold weather concreting
- Repair works in roads and bridges
- Where formworks are to be reutilized for rapid constructions as it allows early formwork removal

Low Heat Cement

Low Heat Cement produces low heat of hydration as compared to normal cement. This type of cement is produced by reducing the proportion of C_3A and C_3S which causes a reduction in heat of hydration of the cement and reduces early strength. The quantity of C2S is increased to compensate for the loss of strength. Reduction in the proportion of C_3A also results in increased initial setting time (60 minutes). This type of cement is resistant to sulphate attacks and is less reactive.

Low heat cement is used for mass concreting in dams and other hydraulic structures, bridge abutments, massive retaining walls, piers, etc. It is also used in the construction of chemical plants.

Portland Pozzolana Cement (PPC)

Portland Pozzolana Cement is prepared by inter-grinding pozzolanic materials with Portland cement. Pozzolanic materials are compounds that do not possess any cementitious property. When finely ground in the presence of water, react with calcium hydroxide released during the hydration of cement and lead to the formation of a cementitious compound. Some examples of Pozzolanic materials are blast furnace slag, rice husk, fly ash, surkhi, etc. This type of cement exhibits the following properties:

- Low cost
- Low heat of hydration
- Higher plasticity
- Reduced permeability
- Higher resistance against expansion
- Higher resistance against chloride and sulphate attacks

Portland pozzolana cement is widely used for the construction of marine and hydraulic structures. Due to its high chemical resistance, this type of cement is also used for the construction of pipes for sewage works.

Portland Blast Furnace Slag Cement

Portland Blast Furnace Slag Cement is prepared by inter-grinding granulated blast furnace slag with OPC clinkers. This type of cement can be utilized for projects where the economy is a major consideration as it is of low cost as compared to OPC. Further advantages include lower heat of hydration and higher durability. It offers high resistance against attacks of sulphur and chlorides, so it can be used in marine works. It also offers lower permeability and hence can be used in water retaining structures.

High Alumina Cement

High Alumina Cement is manufactured by calcination of limestone and bauxite (ore of alumina). This type of cement offers a higher initial setting time (3.5 hours) and a lower final setting time (5 hours). It offers higher early strength. High alumina cement is generally used in furnace lining as it can resist high temperature. It is also utilized where concrete has to resist frost and acidic action.

Sulphate Resisting Cement

OPC is highly susceptible to the attack of sulphates which causes volume change. This volume change leads to the formation of cracks in the structure. Sulphate Resisting Cement is a type of cement in which proportions of C_3A are reduced to make the cement more resilient to sulphate attack. This type of cement finds its use in constructions such as marine structures, sewerage systems, foundation works, and pipes laid in marshy areas.

Hydrophobic Cement

Hydrophobic Cement is produced by inter-grinding ordinary cement clinkers with water repellant film-forming substances such as stearic acid and oleic acid. The water repellant film formed around the cement particles reduces the rate of deterioration of the cement due to prolonged storage under unfavorable conditions.

Super Sulphated Cement

Super Sulphated Cement is prepared by inter-grinding granulated blast furnace slag and a small amount of Portland cement clinkers with the addition of gypsum. The cement offers very high resistance against the attacks of chlorides and sulphates. This type of cement is used when the construction must be done under aggressive conditions. This includes marine works, reinforced concrete pipes in groundwater, mass concreting works to resist the attack by aggressive water, concrete construction in sulphate-bearing soil, and in chemical works subjected to a high concentration of sulphates.

Expansive Cement

Expansive Cement is produced by mixing sulpho-aluminated clinker with Portland cement with a stabilizer. This type of cement expands slightly over time but does not shrink during or after the hardening process. Expansive cement is frequently used as an essential part of sealing joints for expansion joint cement. It is also used in grouting anchor bolts and the construction of prestressed concrete ducts.

Air Entraining Cement

Air Entraining Cement is prepared by an inter-grinding mixture of OPC clinkers and air-entraining agents such as calcium ligno-sulphate, salts from wood resins, glues, etc. Air entraining cement forms tiny air bubbles which improve workability and reduce the water-cement ratio and in turn cause less shrinkage. It also enhances the frost resistance of concrete.

White Cement

White Cement is obtained by lowering the iron oxide content in OPC. Except for the color, white cement is very identical to ordinary Portland cement. This cement is expensive as compared to OPC and hence, not used for ordinary works. It is used for decorative works, tile grouting, swimming pools, and terrazzo flooring.

IRS-T40 Cement

IRS-T40 Cement is a special type of cement used mainly for manufacturing railway sleepers. This unique cement is made according to specifications specified by the Indian Railways Ministry. This cement comprises a high percentage of C_3S, which is finely ground to achieve high early strength.

3 Aggregate, Water and Admixtures:

3.1

Classification and characteristics of aggregate:

Classification of Aggregates

Aggregates form an essential part of many construction projects, from large-scale commercial to smaller domestic works. Whether you need aggregates to form a sub-base for foundations or paving, decorative aggregates for driveways and

footpaths – or simply need something to fill in unsightly holes – you should know which kind of aggregates will work best.
the different classifications of aggregates, based on their varying properties.
Contents:

Classification of aggregates based on: Grain Size

If you separate aggregates by size, there are two overriding categories:

Fine

Coarse

The size of **fine aggregates** is defined as 4.75mm or smaller. That is, aggregates which can be passed through a number 4 sieve, with a mesh size of 4.75mm. Fine aggregates include things such as sand, silt and clay. Crushed stone and crushed gravel might also fall under this category.

Typically, fine aggregates are used to improve workability of a concrete mix.

Coarse aggregates measure above the 4.75mm limit. These are more likely to be natural stone or gravel that has not been crushed or processed. These aggregates will reduce the amount of water needed for a concrete mix, which may also reduce workability but improve its innate strength.

Classification of aggregates based on: Density

There are three weight-based variations of aggregates:

Lightweight

Standard

High density

Different density aggregates will have much different applications. Lightweight and ultra lightweight aggregates are more porous than their heavier counterparts, so they can be put to great use in green roof construction, for example. They are also used in mixes for concrete blocks and pavements, as well as insulation and fireproofing.

High density aggregates are used to form heavyweight concrete. They are used for when high strength, durable concrete structures are required – building foundations or pipework ballasting, for example.

Classification of aggregates based on: Geographical Origin

Another way to classify aggregates is by their origin. You can do this with two groups:

Natural – Aggregates taken from natural sources, such as riverbeds, quarries and mines. Sand, gravel, stone and rock are the most common, and these can be fine or coarse.

Processed – Also called 'artificial aggregates', or 'by-product' aggregates, they are commonly taken from industrial or engineering waste, then treated to form construction aggregates for high quality concrete. Common processed aggregates include industrial slag, as well as burnt clay. Processed aggregates are used for both lightweight and high-density concrete mixes.

Classification of aggregates based on: Shape

Shape is one of the most effective ways of differentiating aggregates. The shape of your chosen aggregates will have a significant effect on the workability of your concrete. Aggregates purchased in batches from a reputable supplier can be consistent in shape, if required, but you can also mix aggregate shapes if you need to.
The different shapes of aggregates are:

Rounded – Natural aggregates smoothed by weathering, erosion and attrition. Rocks, stone, sand and gravel found in riverbeds are your most common rounded aggregates. Rounded aggregates are the main factor behind workability.

Irregular – These are also shaped by attrition, but are not fully rounded. These consist of small stones and gravel, and offer reduced workability to rounded aggregates.

Angular – Used for higher strength concrete, angular aggregates come in the form of crushed rock and stone. Workability is low, but this can be offset by filling voids with rounded or smaller aggregates.

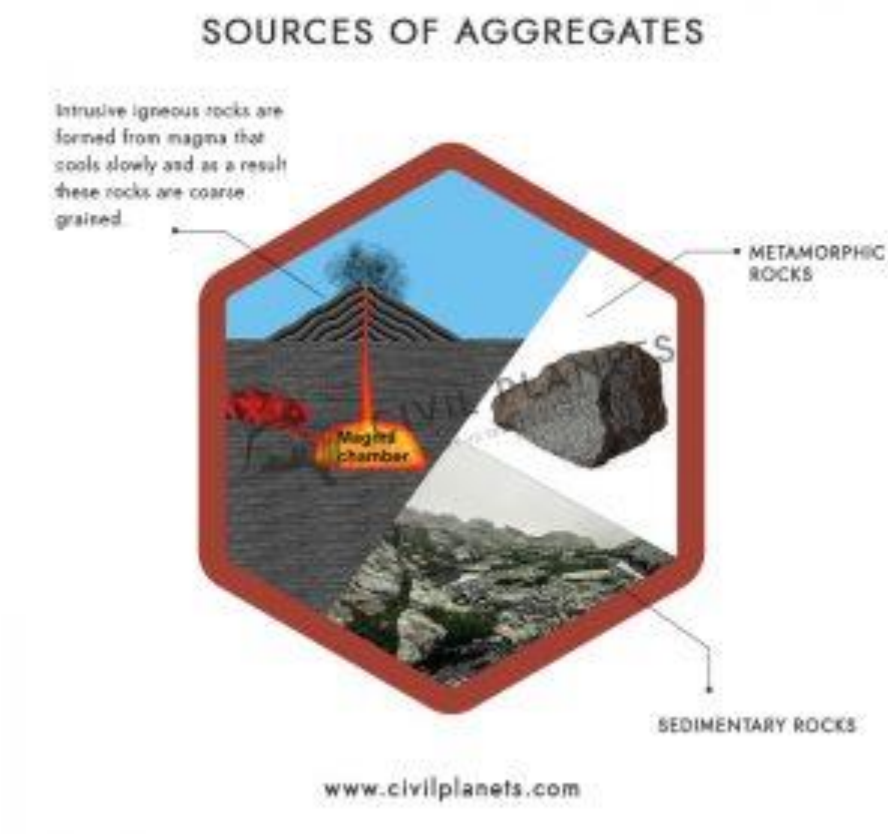
Flaky – Defined as aggregates that are thin in comparison to length and width. Increases surface area in a concrete mix.

Elongated – Also adds more surface area to a mix – meaning more cement paste is needed. Elongated aggregates are longer than they are thick or wide.

Flaky and elongated – A mix of the previous two – and the least efficient form of aggregate with regards to workability.

Origin of Aggregates

Aggregates are gained from the natural deposited rocks. Based on the mode of formation, the rocks are classified into three categories



- Igneous rock
- Sedimentary rock
- Metamorphic rock

Due to the natural geothermal activity & weathering process, the aggregates are produced from those types of rocks. Then the aggregates are involved in quality tests, whether it is safe to use in concrete or other construction activity.

Classification of Aggregates

There are so many options for the classification of aggregates,

- Grain Size

- Density
- Shape
- Geographical Origin

Let’s discuss this in detail!

Classification of aggregates based on Grain Size

Based on the grain size, the aggregates are classified into two types.

- Fine Aggregate
- Coarse Aggregate

The fine aggregates are used in concrete as a filler material to fill the voids. The coarse aggregates are used in concrete to develop the strength of the element. The difference between the fine & coarse aggregate are listed below.

Sl	Fine Aggregates	Coarse Aggregates
1	Naturally deposited in the river bank by the disintegration of rock particles.	The crushing of disintegrated rocks manufactures Coarse Aggregates.

2	The particle size is less than 4.75mm.	The particle size is greater than 4.75mm.
3	Fine Aggregates are used in concrete as filler material to fill the voids that are formed between the coarse aggregate.	Coarse aggregates are used in concrete to produce the shape & strength for concrete.
4	Fine aggregates are used in plastering work and also a filling material.	The coarse aggregates are mainly used in concrete.
5	Increases the workability of concrete.	Decreases the workability of concrete.

Classification of aggregates based on density

The aggregates are classified according to the density as

- Lightweight Aggregates
- Normal Weight Aggregates
- Heavy Weight Aggregates

Category	Unit Weight of Dry-rodded Aggregate (kg/m^3)	Unit Weight of Concrete (kg/m^3)	Typical Concrete Strengths (MPa)	Typical Applications
Ultra lightweight	<500	300-1100	<7	Nonstructural insulating material
Lightweight	500-800	1100-1600	7-14	Masonry units
Structural Lightweight	650-1100	1450-1900	17-35	Structural
Normal weight	1100-1750	2100-2550	20-40	Structural
Heavyweight	>2100	2900-6100	20-40	Radiation shielding

Lightweight Aggregates

The density of lightweight aggregates ranges between 800 to 1100 Kg/Cum. The lightweight aggregates will have a high absorption value compared to other aggregates. So the slump loss happening in lightweight concrete instantly due to the absorption.

The lightweight aggregates are used as a filling material in flooring, deck slab & insulating the fireline pipes, etc.,

Normal Weight Aggregates

The normal weight aggregates are such as sand, gravel material, which we regularly use in construction.

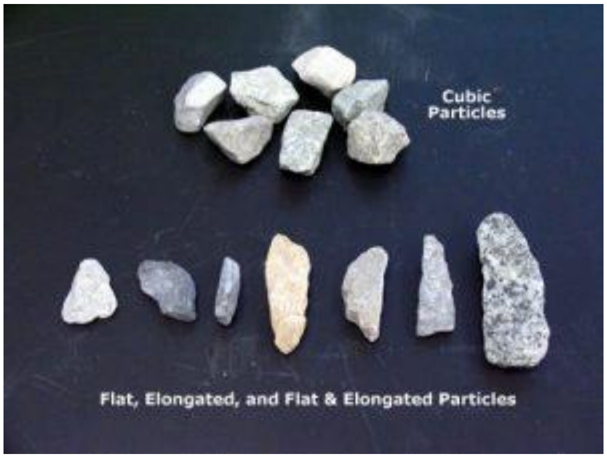
The normal weight aggregates are used for column, beam & slab concrete. The density of normal weight aggregates in ranges between 1520 to 1680 Kg/Cum.

Heavy Weight Aggregates

The heavyweight aggregates are mostly used in construction to protect the radiation room.

The main drawback of heavyweight aggregates is it produces very low workability in concrete. The density of heavyweight aggregates range between 2100 to 2900 Kg/Cum.

Classification of aggregates based on the shape

- **Rounded aggregates –** You may see the rounded aggregates mostly in the seashore or riverbank area. It produces high workability & fewer voids in concrete, but mostly it was not recommended for high strength concrete elements because of its poor interlocking properties. Primarily it is used lintel concrete and also a filler material.
- **Angular aggregates –** The angular aggregates are low in workability. But it is mostly suitable for high 

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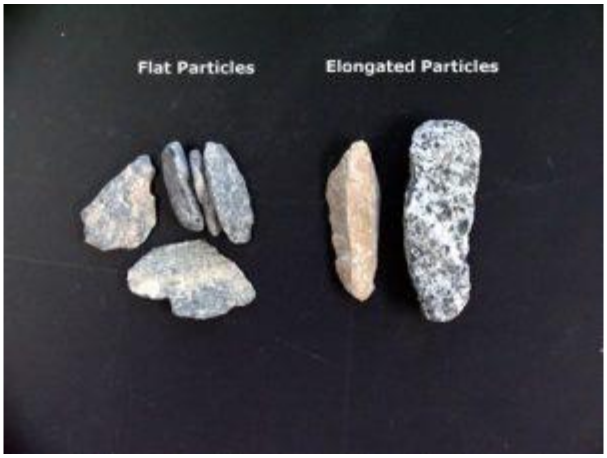
- strength concrete elements because of its angularity & it produces high strength. Due to its angularity, it easily interconnects with other aggregates & fewer voids are forming in concrete.
- **Irregular aggregates –** The irregular aggregates will develop strength slightly lower than the angular aggregates. The irregular shapes are formed due to friction between the aggregates. The bondage between the aggregates is very low due to its irregular shape & it develops low workability in concrete.
- **Elongated aggregates –** In elongated aggregates, the length of the aggregates is higher than its width.

- 

- It is having low compressive strength and not recommended for concrete. If we use the elongated aggregates in concrete, the voids ratio will become high compared to the other aggregates.
- **Flaky aggregates –** The flaky aggregates are having a very light thickness, and it can easily crack. Due to its lower workability, it is not used in concrete, and also it quickly gets broken due to its minor thickness.
- **Flaky & elongated aggregates –** The flaky & elongated aggregates are having less thickness & high in length. It is also not used in concrete due to its lower compressive strength.

Classification of aggregates based on Geographical Origin

Based on the source of aggregates, it can be classified into two types, namely natural aggregates and manufactured aggregates.

Natural aggregates

The natural aggregates are available in river banks, seashore, & pits mines. The natural aggregates are used in construction work after involving some quality tests. The river sand, gravel, mud, etc., naturally available.

Manufactured Aggregates

All aggregates are developed from natural resources only.

But the manufactured aggregates means the natural aggregates are processed to produce new size & quality aggregates which are suitable for different construction activities.
The coarse aggregates are manufactured in different sizes like 10 mm, 12 mm, 20 mm, and now manufactured sand is also available instead of river sand.

Classification of Aggregates Based on Shape

We know that aggregate is derived from naturally occurring rocks by blasting or crushing etc., so, it is difficult to attain required shape of aggregate. But, the shape of aggregate will affect the workability of concrete. So, we should take care about the shape of aggregate. This care is not only applicable to parent rock but also to the crushing machine used. **Aggregates are classified according to shape into the following types**

- Rounded aggregates
- Irregular or partly rounded aggregates
- Angular aggregates
- Flaky aggregates
- Elongated aggregates
- Flaky and elongated aggregates

Rounded Aggregate

The rounded aggregates are completely shaped by attrition and available in the form of seashore gravel. Rounded aggregates result in the minimum percentage of voids (32 – 33%)

hence gives more workability. They require a lesser amount of water-cement ratio. They are not considered for high-strength concrete because of poor interlocking behavior and weak bond strength.

Irregular Aggregates

The irregular or partly rounded aggregates are partly shaped by attrition and these are available in the form of pit sands and gravel. Irregular aggregates may result 35- 37% of voids. These will give lesser workability when compared to rounded aggregates. The bond strength is slightly higher than rounded aggregates but not as required for high strength concrete.

Angular Aggregates

The angular aggregates consist well defined edges formed at the intersection of roughly planar surfaces and these are obtained by crushing the rocks. Angular aggregates result maximum percentage of voids (38-45%) hence gives less workability. They give 10-20% more compressive strength due to development of stronger aggregate-mortar bond. So, these are useful in high strength concrete manufacturing.

Flaky Aggregates

When the aggregate thickness is small when compared with width and length of that aggregate it is said to be flaky aggregate. Or in the other, when the least dimension of aggregate is less than the 60% of its mean dimension then it is said to be flaky aggregate.

Elongated Aggregates

When the length of aggregate is larger than the other two dimensions then it is called elongated aggregate or the length of aggregate is greater than 180% of its mean dimension.

Flaky and Elongated Aggregates

When the aggregate length is larger than its width and width is larger than its thickness then it is said to be flaky and elongated aggregates. The above 3 types of aggregates are not suitable for concrete mixing. These are generally obtained from the poorly crushed rocks.

Classification of Aggregates Based on Size

Aggregates are available in nature in different sizes. The size of aggregate used may be related to the mix proportions, type of work etc. the size distribution of aggregates is called grading of aggregates. Following are the classification of aggregates based on size:
Aggregates are classified into 2 types according to size

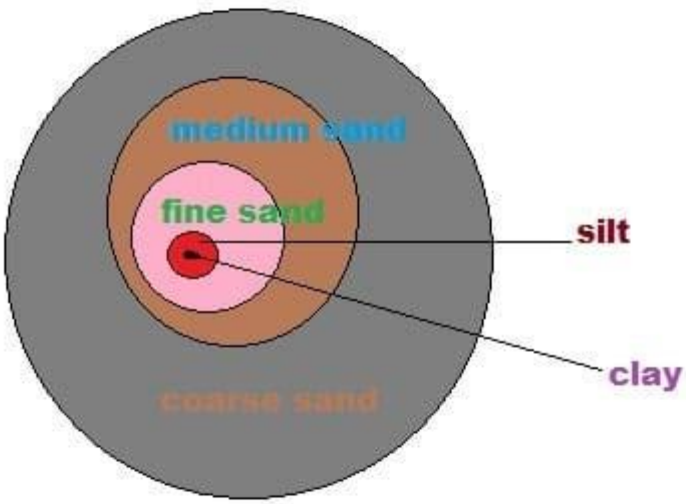
- Fine aggregate
- Coarse aggregate

Fine Aggregate

When the aggregate is sieved through a 4.75mm sieve, the aggregate passed through it called fine aggregate. Natural sand is generally used as fine aggregate, silt and clay also come under this category. The soft deposit consisting of sand, silt, and clay is termed as loam. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

Fine aggregate	**Size variation**
Coarse Sand	2.0mm – 0.5mm
Medium sand	0.5mm – 0.25mm

Fine sand	0.25mm – 0.06mm
Silt	0.06mm – 0.002mm
Clay	<0.002



Coarse Aggregate

When the aggregate is sieved through 4.75mm sieve, the aggregate retained is called coarse aggregate. Gravel, cobble and boulders come under this category. The maximum size aggregate used may be dependent upon some conditions. In general, 40mm size aggregate used for normal strengths, and 20mm size is used for high strength concrete. the size range of various coarse aggregates given below.

Coarse aggregate	**Size**
Fine gravel	4mm – 8mm

Medium gravel	8mm – 16mm
Coarse gravel	16mm – 64mm
Cobbles	64mm – 256mm
Boulders	>256mm

FINENESS MODULUS OF AGGREGATE

FINENESS MODULUS OF AGGREGATE – WHAT, WHY & HOW

HAT IS FINENESS MODULUS OF AGGREGATE?

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by 100.


Fineness Modulus of Sand

WHY TO DETERMINE FINENESS MODULUS?

- Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.
- Fineness modulus of different type of sand is as per given below.

Type of Sand	Fineness Modulus Range
Fine Sand	2.2 – 2.6
Medium Sand	2.6 – 2.9
Coarse Sand	2.9 – 3.2

- Generally sand having fineness modulus more than 3.2 is not used for making good concrete.

- Fineness modulus can also be used to combine two aggregate to get the desirable grading.

HOW TO DETERMINE FINENESS MODULUS?

Following procedure is adopted to calculate fineness modulus of aggregate.

PROCEDURE

- Sieve the aggregate using the appropriate sieves (80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron & 150 micron)
- Record the weight of aggregate retained on each sieve.
- Calculate the cumulative weight of aggregate retained on each sieve.
- Calculate the cumulative percentage of aggregate retained.
- Add the cumulative weight of aggregate retained and divide the sum by 100. This value is termed as fineness modulus
- Refer the following example calculation

FINENESS MODULUS OF SAND – WORKED OUT EXAMPLE

Example Calculation of Fineness Modulus of Fine Aggregate

Sieve Size	**Weight of sand Retained (g)**	**Cumulative weight of sand retained (g)**	**Cumulative percentage of sand retained (%)**
80 mm	–	–	–
40 mm	–	–	–
20 mm	–	–	–
10 mm	0	0	0

4.75 mm	10	10	2
2.36 mm	50	60	12
1.18 mm	50	110	22
600 micron	95	205	41
300 micron	175	380	76
150 micron	85	465	93
Pan	35	500	
Total amount =	500		Total = 246

So **Fineness Modulus = 246/100 = 2.46**

What is Fineness Modulus of Coarse Aggregates?

Fineness modulus of coarse aggregates represents the average size of the particles in the coarse aggregate by an index number. It is calculated by performing sieve analysis with standard sieves. The cumulative percentage retained on each sieve is added and subtracted by 100 gives the value of fine aggregate. Higher the aggregate size higher the Fineness modulus hence fineness modulus of coarse aggregate is higher than fine aggregate. Coarse aggregate means the aggregate which is retained on 4.75mm sieve

when it is sieved through 4.75mm. To find fineness modulus of coarse aggregate we need sieve sizes of 80mm, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm. Fineness modulus is the number at which the average size of particle is known when we counted from lower-order sieve size to higher-order sieve. So, in the calculation of coarse aggregate we need all sizes of sieves.

Determination of Fineness Modulus of Coarse Aggregates

To find fineness modulus we need to perform sieve analysis and for that above mentioned sieve sizes, mechanical shaker and digital weigh scale are required.

Sample preparation

Take a sample of coarse aggregate in pan and placed it in dry oven at a temperature of 100 – 110^{o}C. After drying take the sample weight to nearest gram.

Test Procedure for Fineness Modulus of Coarse Aggregates

Arrange the sieves in descending order and put the arrangement on mechanical shaker. It is suggested that, to know the exact value of fineness modulus for coarse aggregate, mechanical shaker will give better value than hand shaking because of more no. of sieves and heavy size particles. After proper sieving, record the sample weights retained on each sieve and find out the cumulative weight of retained particles as well as cumulative % retained on each sieve. Finally add all cumulative percentage values

and divide the result with 100. Then we get the value of fineness modulus.

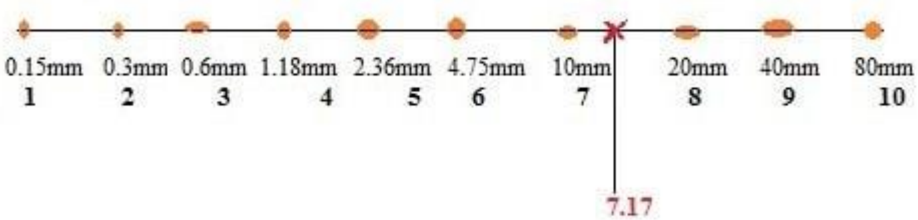
Example for Fineness Modulus Calculation

Let us say dry weight of coarse aggregate = 5000g Values after sieve analysis are

Sieve size	Weight retained(g)	Cumulative weight retained (g)	Cumulative % retained (g)
80mm	0	0	0
40mm	250	250	5
20mm	1750	2000	40
10mm	1600	3600	72

4.75mm	1400	5000	100
2.36mm	0	5000	100
1.18mm	0	5000	100
0.6mm	0	5000	100
0.3mm	0	5000	100
0.15mm	0	5000	100
	Sum	=	717

Therefore, fineness modulus of coarse aggregates = sum (cumulative % retained) / 100 = (717/100) = 7.17 Fineness modulus of 7.17 means, the average size of particle of given coarse aggregate sample is in between 7th and 8th sieves, that is between 10mm to



20mm.

Limits of Fineness Modulus

Fineness modulus of coarse aggregate varies from 5.5 to 8.0. And for all in aggregates or combined aggregates fineness modulus varies from 3.5 to 6.5. Range of fineness modulus for aggregate of different maximum sized aggregates is given below.

Maximum size of coarse aggregate	Fineness modulus range
20mm	6.0 – 6.9
40mm	6.9 – 7.5
75mm	7.5 – 8.0
150mm	8.0 – 8.5

grading of aggregate,I.S.383

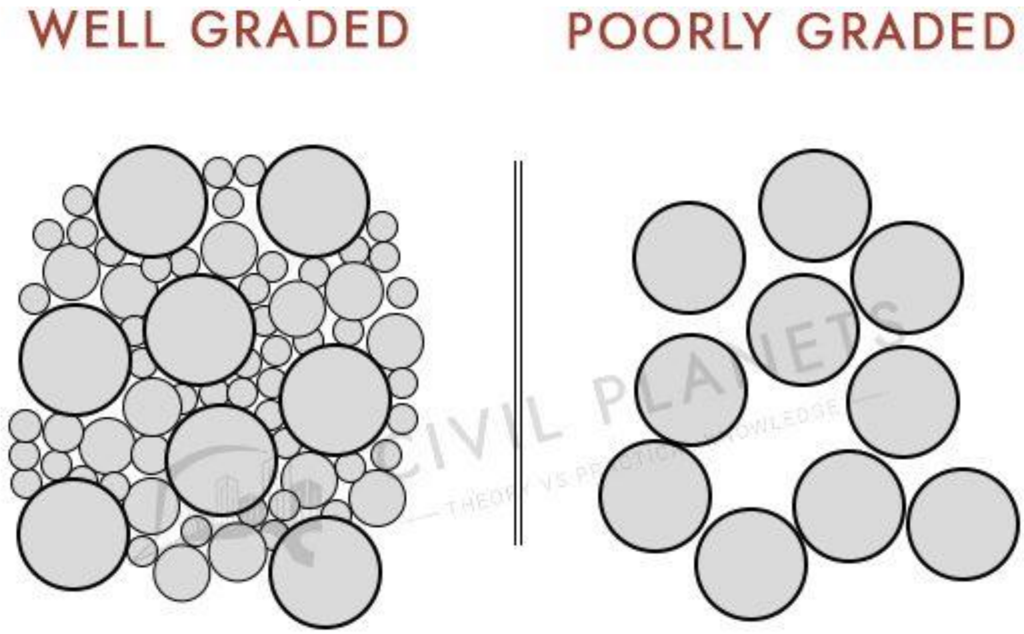
What is Grading of Aggregates?

You are all aware that aggregates occupy 70 to 80% of the total volume of concrete.
The fine aggregates are used as filler material & the coarse aggregate are used in concrete to increase the compressive strength of the concrete.
The size of the aggregates influences the bondage of the concrete ingredients. Improper size & quality of aggregates impacts the strength & durability of aggregate.

What is the grading of aggregates?

The grading of aggregates is the determination of the aggregate size used for construction works.

The coarse aggregate is graded as per its size (10mm, 12mm & 20mm). The selection of the right coarse aggregate size depends on the specific construction activity.



You will understand how grading of aggregates influences the bondage in concrete from the above picture. In well-graded concrete, two or more different aggregate sizes are used to influence the good bondage.

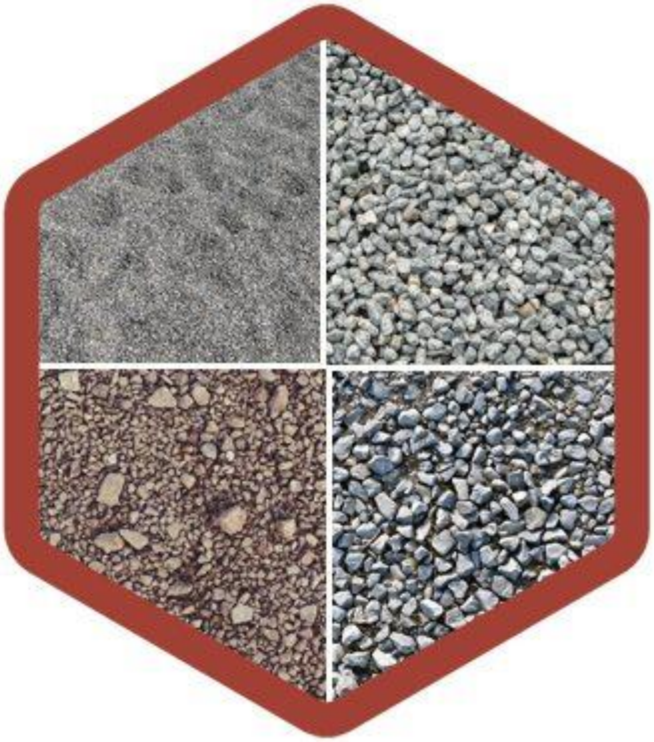
In poorly graded concrete, single size aggregates are used in concrete. So cement paste can't induce good bondage between the material. The result is that the concrete loses its strength & it is easily breakable.

Significance of Grading

The aggregates are graded as per IS code 383, when the aggregate size is less than 4.75mm is called **fine aggregate** & more than 4.75mm is called **coarse aggregate**.

The aggregate gradation is determined by the fineness modulus method where aggregates are passing through the sieve as per IS standard to classify its size.

- Based on the aggregate gradation, we can choose the right aggregates for construction. For example,



- 40mm aggregates are used in PCC & 20mm aggregates are RCC.
- The smaller size of aggregates gives a larger surface area which provides good bonding to the material and increases the strength of the concrete.
- It helps to find the flaky & irregular shape aggregates which are not suitable for concrete that decreases the strength of the concrete.
- The bonding between the aggregates is not good when the single size of aggregates used in concrete.
- To determine the quality of the aggregates.

The aggregates are classified based on,

- Size
- Density
- Shape
- Geographical origin

We have discussed the classification of aggregates already.

Grading Limit for Single Sized Coarse Aggregates

The grading limit for single sized coarse aggregate and graded coarse aggregate of nominal size has been listed as per IS standard.

- The single sized aggregate usage in concrete makes more voids but it has good resistance against sudden impact.
- The grade aggregates contain different particle sizes of coarse aggregate which reduce the voids in concrete & increase the bondage between the aggregates & cement paste.

IS Sieve Designation	Percentage passing for single sized aggregates of nominal size(mm)					Percentage passing for single sized aggregates of nominal size(mm)				
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	40 mm	20 mm	16 mm	12.5 mm

80 mm	100	–	–	–	–	–	100	–	–	–
63 mm	85–100	100	–	–	–	–	–	–	–	–
40 mm	0–30	85–100	100	–	–	–	95-100	100		

20 mm	0–5	0–20	85–100	100	–	–	30–70	95–100	100	100
16 mm	–	–	–	85–100	100	–	–	–	90–100	–
12.5 mm	–	–	–	–	85–100	100	–	–	–	90–100

10 mm	0–5	0–5	0–20	0–30	0–45	85–100	10–35	25–55	30–70	40–85
4.75 mm	–	–	0–5	0–5	0–10	0–20	0–5	0–10	0–10	0–10
2.36 mm	–	–	–	–	–	0–5	–	–	–	–

Grading Limits for Fine Aggregates

The grading of fine aggregates has been listed as per the IS code standards

IS Sieve Designation	Percentage Passing			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100

2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100
600 microns	15 – 34	35 – 59	60 – 79	80 – 100
300 microns	5 – 20	8 – 30	12 – 40	15 – 50
150 microns	0 – 10	0 – 10	0 – 10	0 – 15

Characteristics of aggregate

ENGINEERING PROPERTIES OF AGGREGATES

Aggregates are used in concrete to provide economy in the cost of concrete. Aggregates act as filler only. These do not react with cement and water.
But there are properties or characteristics of aggregate which influence the properties of resulting concrete mix. These are as follow.

1. Composition
2. Size & Shape
3. Surface Texture
4. Specific Gravity
5. Bulk Density
6. Voids
7. Porosity & Absorption
8. Bulking of Sand
9. Fineness Modulus of Aggregate
10. Surface Index of Aggregate
11. Deleterious Material
12. Crushing Value of Aggregate
13. Impact Value of Aggregate
14. Abrasion Value of Aggregate

1. COMPOSITION

Aggregates consisting of materials that can react with alkalies in cement and cause excessive expansion, cracking and deterioration of concrete mix should never be used. Therefore it is required to test aggregates to know whether there is presence of any such constituents in aggregate or not.

2. SIZE & SHAPE

The size and shape of the aggregate particles greatly influence the quantity of cement required in concrete mix and hence ultimately economy of concrete. For the preparation of economical concrete mix on should use largest coarse aggregates feasible for the structure. IS-456 suggests following recommendation to decide the maximum size of coarse aggregate to be used in P.C.C & R.C.C mix.
Maximum size of aggregate should be less than

- One-fourth of the minimum dimension of the concrete member.
- One-fifth of the minimum dimension of the reinforced concrete member.
- The minimum clear spacing between reinforced bars or 5 mm less than the minimum cover between the reinforced bars and form, whichever is smaller for heavily reinforced concrete members such as the ribs of the main bars.

Remember that the size & shape of aggregate particles influence the properties of freshly mixed concrete more as compared to those of hardened concrete.

3. SURFACE TEXTURE

The development of hard bond strength between aggregate particles and cement paste depends upon the surface texture, surface roughness and surface porosity of the aggregate particles.
If the surface is rough but porous, maximum bond strength develops. In porous surface aggregates, the bond strength increases due to setting of cement paste in the pores.

4. SPECIFIC GRAVITY

The ratio of weight of oven dried aggregates maintained for 24 hours at a temperature of 100 to 110^{0}C, to the weight of equal volume of water displaced by saturated dry surface aggregate is known as specific gravity of aggregates.
Specific gravities are primarily of two types.

- Apparent specific gravity
- Bulk specific gravity

Specific gravity is a mean to decide the suitability of the aggregate. Low specific gravity generally indicates porous, weak and absorptive materials, whereas high specific gravity indicates materials of good quality. Specific gravity of major aggregates falls within the range of 2.6 to 2.9.
Specific gravity values are also used while designing concrete mix.

5. BULK DENSITY

It is defined as the weight of the aggregate required to fill a container of unit volume. It is generally expressed in kg/litre.
Bulk density of aggregates depends upon the following 3 factors.

- Degree of compaction
- Grading of aggregates
- Shape of aggregate particles

6. VOIDS

The empty spaces between the aggregate particles are known as voids. The volume of void equals the difference between the gross volume of the aggregate mass and the volume occupied by the particles alone.

7. POROSITY & ABSORPTION

The minute holes formed in rocks during solidification of the molten magma, due to air bubbles, are known as pores. Rocks containing pores are called porous rocks.
Water absorption may be defined as the difference between the weight of very dry aggregates and the weight of the saturated aggregates with surface dry conditions.
Depending upon the amount of moisture content in aggregates, it can exist in any of the 4 conditions.

- Very dry aggregate (having no moisture)
- Dry aggregate (contain some moisture in its pores)

- Saturated surface dry aggregate (pores completely filled with moisture but no moisture on surface)
- Moist or wet aggregates (pores are filled with moisture and also having moisture on surface)

8. BULKING OF SAND

It can be defined as in increase in the bulk volume of the quantity of sand (i.e. fine aggregate) in a moist condition over the volume of the same quantity of dry or completely saturated sand. The ratio of the volume of moist sand due to the volume of sand when dry, is called bulking factor.
Fine sands bulk more than coarse sand
When water is added to dry and loose sand, a thin film of water is formed around the sand particles. Interlocking of air in between the sand particles and the film of water tends to push the particles apart due to surface tension and thus increase the volume. But in case of fully saturated sand the water films are broken and the volume becomes equal to that of dry sand.

9. FINENESS MODULUS

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by 100.
Fineness modulus is generally used to get an idea of how coarse or fine the aggregate is. More fineness modulus value indicates that the aggregate is coarser and small value of fineness modulus indicates that the aggregate is finer.

10. SPECIFIC SURFACE OF AGGREGATE

The surface area per unit weight of the material is termed as specific surface. This is an indirect measure of the aggregate grading. Specific surface increases with the reduction in the size of aggregate particle. The specific surface area of the fine aggregate is very much more than that of coarse aggregate.

11. DELETERIOUS MATERIALS

Aggregates should not contain any harmful material in such a quantity so as to affect the strength and durability of the concrete. Such harmful materials are called deleterious materials. Deleterious materials may cause one of the following effects

- To interfere hydration of cement
- To prevent development of proper bond
- To reduce strength and durability
- To modify setting times

Deleterious materials generally found in aggregates, may be grouped as under

- Organic impurities
- Clay , silt & dust
- Salt contamination

12. CRUSHING VALUE

The aggregates crushing value gives a relative measure of resistance of an aggregate to crushing under gradually applied compressive load. The aggregate crushing strength value is a useful factor to know the behavior of aggregates when subjected to compressive loads.

13. IMPACT VALUE

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact. The impact value of an aggregate is sometime used as an alternative to its crushing value.

Also read: Impact Value Test of Aggregates

14. ABRASION VALUE OF AGGREGATES

The abrasion value gives a relative measure of resistance of an aggregate to wear when it is rotated in a cylinder along with some abrasive charge.

Characteristics of aggregate

The characteristics of aggregate have different parts of Particle Size, shape and Texture, Specific Gravity and Bulk density, the strength of aggregate Porosity, absorption, and Moisture Content, Bulking of Sand, Soundness of Aggregate.

The properties of the aggregate have a significant effect on concrete properties in both the fresh and hardened concrete state. The test sample should be a larger sample taken from all parts of the pile and should retain the same properties as the bulk of the aggregate. The different characteristics of aggregate are as follows

Characteristics of aggregate

Particle Size, shape and Texture

The maximum practical size of aggregate is used for the proportion of concrete. It reduces the cement content, water requirement, and drying shrinkage. However it should not exceed one-fourth of the minimum thickness of member, 5mm less than the minimum cover to reinforcement and 5 mm less than the minimum clear distance between main reinforcement for reinforced concrete work. Method of mixing handing and placing o concrete will restrict the maximum size of aggregate. The size of aggregate bigger than 4.75 mm is considered as coarse aggregates and less as fine aggregate or sand. The nominal sizes of coarse aggregate are 10 mm, 20 mm, etc.

The shape of the particle depends on strength and abrasion resistance of the parent rock and the amount of wear to which it has been subjected. The classification of shape is subjective and it as follows-

Shape of Aggregate

The shape and texture of aggregate influence workability, water required of the mix, the flexural and compressive strength of the concrete mix

Group	**Surface Texture**	**Characteristics**	**Examples**
1.	Glassy	Conchoidal fracture	Black flint vitreous slag.
2.	Smooth	Water-worn, or smooth fracture of fine-grained rock or laminated rock	sandstone.
3.	Granular	Fracture showing more or less uniform rounded grains.	Granite gabbro, gneiss.

4.	Crystalline (coarse crystalline fine	Easily visible crystalline constituents. Rough fracture of fine or medium-grained rock containing no easily visible crystalline constituents.	Basalt trachyte.
5.	Honeycombed and porous	With visible pores and cavities	Brick, Pumice, foamed slag, clinker, expanded clay

Strength of aggregate

The compressive strength of the majority of rock aggregates commonly used is in the range of 45 to 550 N/mm. In general, igneous rocks are very much stronger than sedimentary and metamorphic rocks. The strength of concrete is generally between 15 to 50 N/mm2.

It indicates that the strength of concrete is based on the quality of cement paste as well as the bond between cement paste and the aggregate.

When the quality of cement paste and its bond with the aggregate is good, then only the mechanical properties of aggregate will influence the strength of concrete especially in the case of ultra-high-strength concrete.

The strong aggregates need not yield strong aggregate need not yield strong concrete but for high strength concrete, strong aggregates are essential.

Toughness and hardness of the aggregate

They are important for concrete used in road pavements. Toughness is its resistance to failure by the impact.

Modulus of Elasticity

Modulus of elasticity of aggregate depends on its composition, texture, and structure. It affects the elastic properties of concrete, shrinkage properties, and to a small extent creep behavior of concrete.

Specific Gravity and Bulk density

Porosity, absorption and Moisture Content

Bulking of Sand

Soundness of Aggregate

The soundness of aggregate is the ability of an aggregate to resist excessive change in volume as a result of changing in physical conditions.

The Physical conditions like freezing and thawing, variation in temperature, alternate wetting, and drying, ensues large or permanent volume change in unsound aggregate.

These changes result in the deterioration of the concrete. The deterioration may vary from an impaired appearance due to local scaling to a structurally dangerous situation due to disintegration over a considerable depth.

Thermal Properties

Coefficient of thermal expansion, specific heat, and conductivity is significant thermal properties of the aggregate, the higher the coefficient of thermal expansion of the aggregate of the coefficient of the concrete.

If the cement paste differs too much a large change in temperature may introduce a break in the bond between the aggregate and surrounding cement paste. Thus durability of concrete is affected.

3.2

Quality of water for mixing and curing.

Quality of Water for Concrete Used as Mixing Water & Curing Water

Concrete consists of cement, sand, aggregate, and water. Out of the constituents, water is the least expensive, but it plays a major role in all the concreting processes. Water is an essential requirement for the hydration of cement. To know water requirements during hydration of cement, **visit Water Requirement of Concrete**.

Table of Contents

Why is Quality of Water for Concrete Important?

If the quality is not considered, and if impurities are present in the water, then, these impurities –

- interfere with setting of concrete
- stains the surface of concrete
- adversely affects the strength of concrete
- causes corrosion in reinforcement

Quality of Mixing Water

Generally, the potable water is taken as the mixing water.
However, if the potable water has a higher content of potassium and sodium, then it is unfit for use as mixing water. As the presence of these salts promotes alkali-aggregate reaction.
Sometimes, unprocessed surface water or well water is also used to reduce the cost. But the impurities present can affect set time, strength, or durability.
If water has higher silt content, then it can be allowed to settle in a settling basin.
Following are the characteristics of Mixing Water:

- pH of mixing water should be between 6-8
- The taste of mixing water should not be saline
- Slightly acidic natural water is okay for use as mixing water. However, water containing humic or organic acids affects the hardening of concrete hence it should be avoided.

Acceptable Criteria for Mixing Water

Average compressive strength of mortar cubes at 7 days	≮ 90% of avg strength of cubes made with distilled water
Set time of mortar cubes by Vicat apparatus	≮ 1 hr as compared that of the cubes made with distilled water ≯ 1-1.5 hr as compared that of the cubes made with distilled water

Acceptable Criteria for strength and setting time for mixing water

Impurities and their Tolerable Concentration in Mixing Water

Sr. No.	Impurity	Tolerance Limit (concentration)
1	Silt & Suspended particles	2000 ppm
2	Carbonates & Bicarbonates of Na/K Bicarbonates of Mg	1000 ppm 400 ppm
3	Chlorides	10,000 ppm
4	Calcium chloride	2% by wt. of cement (non-prestressed concrete)
5	Sulphates	20,000 ppm
6	Sulphuric anhydride	3,000 ppm
7	Sodium sulphide	< 100 ppm (Tests to be performed at 100 ppm)
8	Sodium hydroxide	0.5% by wt. of cement (without quick set)

9	Dissolved salts	15,000 ppm
10	Organic matter	3,000 ppm
11	pH	6-8
12	Iron salts	40,000 ppm
13	Acids (HCl, H_2SO_4)	10,000 ppm
14	Sugar	500 ppm

Impurities and their Tolerable Concentration in Mixing Water

Permissible Limits as per IS: 456 – 2000:

laterial	ested as per IS	ermissible Limit in mg/l (Max)

rganic	025 (part 18)	00
norganic	025 (part 18)	000
ulphates as SO_3^-	025 (part 24)	00
hlorides as Cl^-	025 (part 32)	000 (for PCC) 500 (for RCC)
uspended	025 (part 17)	000

Permissible Limits as per IS: 456 – 2000

1. Suspended Particles

If suspended particles exceed 2000ppm, the water is allowed to settle in a settling basin before using it as mixing water.

2. Inorganic Salts

Effects of salts of different elements are tabulated below:

Salts	**Effect**
Salts of zinc tin copper lead	Considerable reduction in strength of concrete

odium phosphate odium borate odium iodate	cts as retarders onsiderable reduction in strength of concrete
odium sulphide	etrimental to concrete (tests needs to be carried out even if it is found in 100 ppm concentratior
inc chloride	educes setting of concrete -day test for determining the strength of concrete cannot be performed
alcium chloride	ncreases setting of concrete

	ncreases hardening of concrete
odium carbonate	apid setting of concrete
otassium carbonate	eduction in strength of concrete
icarbonates	ccelerates/Retards setting of concrete

Effects of Salts on Concrete

2. Acids

The pH of the water used for mixing is limited to the range of 6-8.

Limit of acidity is determined by-

The amount of 0.1N NaOH required to neutralize 100 ml sample of water using phenolphthalein as indicator $\ngtr$1ml

This acidity is equivalent to

- 49 ppm of H_2SO_4
- 36 ppm of HCl

Limit of alkalinity is determined by-

The amount of 0.1N HCl required to neutralize 100 ml sample of water < 5ml

This alkalinity is equivalent to

- 265 ppm of carbonates
- 420 ppm of bicarbonates

3. Sugar

The concentration of sugar alters its effect on concrete as tabulated below:

oncentration (by weight of cement)	ffect

Up to 0.05%	No considerable effect
0.15%	Reduces setting Decreases early strength Increases 28-day strength
0.2%	Increases setting Reduces 28-day strength

Effect of Sugar on Concrete

4. Oil Contamination

The presence of mineral oil (petroleum) causes lesser ill effects than the presence of animal oil or vegetable oil.

- If mineral oil is present by < 2% by weight of cement, then it can reduce the compressive strength of concrete by > 20%.
- Vegetable oil is quite detrimental to concrete, especially during later stages.

5. Algae

Algae can enter concrete through mixing water or from the surface of aggregates.

Harmful effects caused by Algae:

- Reduces **bond strength** of cement with aggregates
- Reduces **compressive strength** by entraining large amount of air in concrete

Effect of Mixing Water from Different Sources

1. Ground Water

Ground Water as Mixing Water

Groundwater can be used as mixing water after checking its iron content.

Fe < 20-30 ppm.

2. Sea water as Mixing Water for Concrete

Seawater as Mixing Water

Seawater is salty and has a typical total salinity of 3.5 %, out of which 78% of dissolved solids contain NaCl while the remaining 15% contain $MgCl_2$ and $MgSO_4$.

Seawater is used only if freshwater *is not available or its availability is too costly.*

Using seawater as mixing water slightly increases the early strength of concrete but the long-term strength is reduced. The loss of strength up to 15% is tolerated.

Concrete mixed by seawater causes dampness as well as efflorescence (Efflorescence is contributed by chlorides). Hence, it is not used where the appearance of the concrete surface is important.

Seawater is not recommended for reinforced cement concrete owing to the increased risk of corrosion to the reinforcement steel.

Again, if this RCC work is totally immersed in water, then seawater can be used as mixing water.

Adverse Effects of Seawater:

- Efflorescence (∵ of Cl^-)
- Staining of concrete surface
- Corrosion of reinforcement steel
- Volume instability
- Decreased durability

Precautions to be Undertaken to Reduce Corrosion Risk:

- Decrease permeability of concrete
- Providing adequate cover to reinforcement
- Inducing adequate entrained air

Seawater should never be used for Prestressed Concrete. Prestressed concrete contains small diameter wires. It may cause disaster if these are corroded.

3. Industrial Waste Water

Most of the wastewater generated from industries contains total solids < 3000 ppm. The decrease in compressive strength due to the presence of these solids is generally < 10 %.

Harmful impurities are present in wastewater from paint factories, coke plants, chemical, and galvanizing plants. Hence, water from these sources should be avoided.

4. Waste Water from RMC plants

This is discussed in the later part of this article, **Disposal and Reuse of Concrete Wash Water**.

Quality of Curing Water

Water, which is satisfactory for mixing, is normally suitable for curing water too.

Iron or organic matter if present in curing water can cause staining on the concrete surface, especially if the flow of water is slow over the concrete surface with rapid evaporation.

If discolouration is not an issue, then water with more inferior quality as compared to that of mixing can be used.

It should be noted that curing water should not have substances that attack hardened concrete. For example, free CO_2 is present in the curing water. Water formed by the melting of ice or condensation contains free CO_2. This free CO_2 reacts with dissolved calcium hydroxide present in the cement causing surface erosion.

Disposal and Reuse of Concrete Wash Water from RMC Plants

Disposal of wastewater generated from RMC plant operations was a great concern for the producers of RMC.

Sources of wastewater in RMC Plant:

- from truck wash system
- washing of central mixing plant
- from water sprayed for dust control
- conveyor wash down
- storm water runoff from RMC plant yard

As most of the water generated from the various operations contains potash and caustic soda, it is considered as hazardous as per the Water Quality Act, Part 116. And the disposal of this water is regulated by Environment Protection Agency.

Conventional Disposal of Wastewater

- dumping at jobsite
- dumping at landfill
- dumping in to concrete wash water pit at RMC plant

The availability of dumping sites for landfills has been greatly reducing in recent years. This is because the current environment protection limits or restricts conventional practices.

Hence, the RMC plant developed an operation configuration to manage their own wash water.

Alternatives for Disposal of Wastewater

- settling ponds
- storm water detention/retention facilities
- water reuse systems
- as mixing water for concrete (studies have shown that the water from stabilized wash water does not affect the quality of water)

Key Take Away

Potable water should be preferred for use during the mixing of concrete and curing of concrete.

Permissible Limits as per IS: 456 – 2000

laterial	**ested as per IS**	**ermissible Limit in *mg/l* (Max)**

)rganic	025 (part 18)	00
norganic	025 (part 18)	000
ulphates as SO_3^-	025 (part 24)	00
hlorides as Cl^-	025 (part 32)	000 (for PCC) 500 (for RCC)
uspended	025 (part 17)	000

Effects of Impurities on Concrete

mpurity	**ffect**
lkali carbonate & bicarbonate	romote alkali-aggregate reaction
hloride	orrosion of reinforcement steel is the primary issue
ulphate	auses expansive reaction

	Causes deterioration of concrete
Other salts	Not much harm is caused if present within tolerance limits
Seawater	Accelerates early strength gain Reduces ultimate strength Promotes alkali-aggregate reaction Not recommended for RCC

	IEVER use for prestressed concrete
.cid water	Jot much harm is caused if present within tolerance limits
.lkaline water	Can increase alkali-aggregate reaction the concentration of NaOH > 0.5%, the quick set may occur reducing the strength the concentration of KOH > 1.2% may reduce 28-day strength in some types c ement

ugar	oncentration > 500 ppm → reduces setting time
ils	ineral oil (petroleum) concentration > 2.5% by wt of mix reduces strength by 20%
lgae	educes hydrationInduces entrained air lot recommended for use as mixing water

Water for Mixing can be taken from-

- Ground water (check for iron content)
- Seawater (only if fresh water is unavailable)
- Wash water from RMC plants

FAQ

What is quality of mixing water?

Mixing water used in concrete should normally be potable water, fit for drinking. Impurities present may adversely affect the concrete like-

- Alkalis can promote alkali aggregate reaction.
- Chloride causes corrosion to reinforcement
- Sulfate causes expansive reaction and deterioration of concrete.
- Seawater reduces the ultimate strength of cement and also promotes alkali aggregate reaction. (It should not be used for RCC and prestressed work.)
- Alkaline water may cause quick setting, reducing strength.
- Sugar and mineral oil reduce the strength of concrete.
- Algae reduces hydration and bond strength of concrete. It also entrains air.

3.3

classification of admixtures

Types of Admixtures of Concrete

Types of Admixtures of Concrete

Chemical admixtures - Accelerators, Retarders, Water-reducing agents, Super plasticizers, Air entraining agents etc.

Mineral admixtures - Fly-ash Blast-furnace slag, Silica fume and Rice husk Ash etc

Chemical admixtures

1. Water-reducing admixture / Plasticizers:

These admixtures are used for following purposes:

1. To achieve a higher strength by decreasing the water cement ratio at the same workability as an admixture free mix.
2. To achieve the same workability by decreasing the cement content so as to reduce the heat of hydration in mass concrete.
3. To increase the workability so as to ease placing in accessible locations
4. Water reduction more than 5% but less than 12%
5. The commonly used admixtures are Ligno-sulphonates and hydrocarbolic acid salts.
6. Plasticizers are usually based on lignosulphonate, which is a natural polymer, derived from wood processing in the paper industry.

Actions involved:

1. **Dispersion:**

Surface active agents alter the physic chemical forces at the interface. They are adsorbed on the cement particles, giving them a negative charge which leads to repulsion between the particles. Electrostatic forces are developed causing disintegration and the free water become available for workability.

2. **Lubrication:**

As these agents are organic by nature, thus they lubricate the mix reducing the friction and increasing the workability.

3. **Retardation:**

A thin layer is formed over the cement particles protecting them from hydration and increasing the setting time. Most normal plasticizers give some retardation, 30–90 minutes

2. Super Plasticizers:

These are more recent and more effective type of water reducing admixtures also known as *high range water reducer.* The main **benefits** of super plasticizers can be summarized as follows:

Increased fluidity:

- Flowing
- Self-leveling
- Self-compacting concrete
- Penetration and compaction round dense reinforcement

Reduced W/C ratio:

- Very high early strength, >200% at 24 hours or earlier
- Very high later age strengths, >100 MPa or 15000 psi.
- Reduced shrinkage, especially if combined with reduced cement content.
- Improved durability by removing water to reduce permeability and diffusion.

The commonly used Super Plasticizers are as follows:

- **Sulphonated melamine formaldehyde condensates** (**SMF**)

Give 16–25%+ water reduction. SMF gives little or no retardation, which makes them very effective at low temperatures or where early strength is most critical. However, at higher temperatures, they lose workability relatively quickly. SMF generally give a good finish and are colorless, giving no staining in white concrete. They are therefore often used where appearance is important.

- **Sulphonated naphthalene formaldehyde condensates (SNF**)

Typically give 16–25%+ water reduction. They tend to increase the entrapment of larger, unstable air bubbles. This can improve cohesion but may lead to more surface defects. Retardation is more than with SMF but will still not normally exceed 90 minutes. SNF is a very cost-effective.

- **Polycarboxylate ether superplasticizers (PCE)**

Typically give 20–35%+ water reduction. They are relatively expensive per liter but are very powerful so a lower dose (or more dilute solution) is normally used.

In general the dosage levels are usually higher than with conventional water reducers, and the possible undesirable side effects are reduced because they do not markedly lower the surface tension of the water.

3. Accelerators:

An admixture which, when added to concrete, mortar, or grout, increases the rate of hydration of hydraulic cement, shortens the time of set in concrete, or increases the rate of hardening or strength development. Accelerating admixtures can be divided into groups based on their performance and application:

1. **Set Accelerating Admixtures**,

Reduce the time for the mix to change from the plastic to the hardened state. Set accelerators have relatively limited use, mainly to produce an early set.

2. **Hardening Accelerators**,

Which increase the strength at 24 hours by at least 120% at 20ºC and at 5ºC by at least 130% at 48 hours. Hardening accelerators find use where early stripping of shuttering or very early access to pavements is required. They are often used in combination with a high range water reducer, especially in cold conditions. Calcium chloride is the most effective accelerator and gives both set and hardening characteristics. However, is limited due to acceleration of **corrosion of steel reinforcement** and decrease resistance of cement paste in a **sulfate environment**. For this reason, it should not be used in concrete where any steel will be embedded but may be used in plain unreinforced concrete. Chloride-free accelerators are typically based on salts of **nitrate, nitrite, formate and thiocyanate**. Hardening accelerators are often based on high range water reducers, sometimes blended with one of these salts.

Accelerating admixtures have a relatively limited effect and are usually only cost effective in specific cases where very early strength is needed for, say, access reasons. They find most use at low temperatures where concrete strength gain may be very slow so that the relative benefit of the admixture becomes more apparent. In summary, a hardening accelerator may be appropriate for strength gain up to 24 hours at low temperature and up to 12 hours at ambient temperatures. Beyond these times, a high range water reducer alone will usually be more cost-effective.

4. Set Retarders:

The function of retarder is to delay or extend the setting time of cement paste in concrete. These are helpful for concrete that has to be transported to long distance, and helpful in placing the concrete at high temperatures.

When water is first added to cement there is a rapid initial hydration reaction, after which there is little formation of further hydrates for typically 2–3 hours. The exact time depends mainly on the cement type and the temperature. This is called the **dormant period** when the concrete is plastic and can be placed. At the end of the dormant period, the hydration rate increases and a lot of calcium silicate hydrate and calcium hydroxide is formed relatively quickly. This corresponds to the setting time of the concrete. Retarding admixtures delay the end of the dormant period and the start of setting and hardening. This is useful when used with plasticizers to give workability retention. Used on their own, retarders allow later vibration of the concrete to prevent the formation of cold joints between layers of concrete placed with a significant delay between them.

The mechanism of set retards is based on absorption. The large admixture anions and molecules are absorbed on the surface of cement particles, which hinders further reactions between cement and water i.e. retards setting. The commonly known retards are **Calcium Ligno-sulphonates** and **Carbohydrates derivatives** used in fraction of percent by weight of cement.

5. Air Entrained Admixtures:

An addition for hydraulic cement or an admixture for concrete or mortar which causes air, usually in small quantity, to be incorporated in the form of minute bubbles in the concrete or mortar during mixing, usually to increase its **workability** and **frost resistance.** Air-entraining admixtures are **surfactants** that change the surface tension of the water. Traditionally, they were based on fatty acid salts or vinsol resin but these have largely been replaced by synthetic surfactants or blends of surfactants to give improved stability and void characteristics to the entrained air. Air entrainment is used to produce a number of effects in both the plastic and the hardened concrete. These include:

- Resistance to freeze–thaw action in the hardened concrete.
- Increased cohesion, reducing the tendency to bleed and segregation in the plastic concrete.
- Compaction of low workability mixes including semi-dry concrete.
- Stability of extruded concrete.
- Cohesion and handling properties in bedding mortars.

Mineral Admixtures of Concrete

Types of Mineral Admixtures

1. Cementitious Admixtures of Concrete

These have cementing properties themselves. For example:

- Ground granulated blast furnace slag (GGBFS)

2. Pozzolanic Admixtures of Concrete

A pozzolan is a material which, when combined with calcium hydroxide (lime), exhibits cementitious properties. Pozzolans are commonly used as an addition (the technical term is "cement extender") to Portland cement concrete mixtures to increase the long-term strength and other material properties of Portland cement concrete and in some cases reduce the material cost of concrete. Examples are

- Fly ash
- Silica Fume
- Rice Husk Ash
- Metakaolin

Pozzolanic Action:

The additive act in three ways

1. Filler
2. Nucleating
3. Pozzolanic

1. Filler:

These additives/admixtures are finer than cement, so when added to concrete they occupy the small pores previously left vacant.

2. Nucleating:

These fine particles accelerate the rate of hydration and precipitation starts.

3. Pozzolanic:

When cementing material reacts with water the following reaction take place:

C2S + H CSH + CH

C3S + H CSH + CH

CSH is responsible for strength while CH is a soluble material reacts and dissolves in water leaving behind pores. So when admixture is added

SiO3 or Al2O3+CH CSH

Thus it reduces the amount of CH & increase CSH

Conditions to Declare a Material Pozzolan:

- Having silica + Alumina oxide+ ferrous oxide more than 70%.
- Surface area on normal admixture is more than 300m²/kg.
- Surface area should be more than cement used.

Pozzolans are used to improve the workability and quality of concrete, to effect economy, and to protect against disruptive expansion caused by the reaction between different constituents of mass concrete. A pozzolan is defined as a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Natural pozzolanic materials occur in the form of obsidian, pumicite, volcanic ashes, tuffs, clays, shales, and diatomaceous earth. Most of these pozzolans require grinding. Fly ash (fuel dust from power plants burning coal) too can be an excellent pozzolan as it has a low carbon content, a fineness about the same as that of Portland cement, and occurs in the form of very fine glassy spheres.

3. Ground Granulated Blast Furnace Slag (GGBFS)

Ground granulated blast-furnace slag is the **granular material** formed when molten iron blast furnace slag (a by-product of iron and steel making) is rapidly chilled (quenched) by immersion in water. It is a granular product, **highly cementitious** in nature and, ground to cement fineness, hydrates like Portland cement. **(Blast-Furnace Slag:** A by-product of steel manufacture which is sometimes used as a substitute for Portland cement. In steel industry when iron ore is molted, then in the molted state all the impurities come at its surface which are removed called slag. It consists mainly of the silicates and aluminosilicates of calcium, which are formed in the blast furnace in molten form simultaneously with the metallic iron. Blast furnace slag is blended with Portland cement clinker to form PORTLAND BLASTFURNACE SLAG CEMENT).

GGBFS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. GGBFS has been widely used in Europe, and increasingly in the United States and in Asia (particularly in Japan and Singapore) for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years. Concrete made with GGBFS cement **sets more slowly** than concrete made with ordinary Portland cement, depending on the amount of GGBFS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in **lower heat of hydration** and **lower temperature rises**, and makes avoiding **cold joints** easier, but may also affect construction schedules where quick setting is required. Use of GGBFS significantly reduces the risk of damages caused by alkali-silica reaction (ASR), provides higher resistance to chloride ingress, reducing the risk of reinforcement corrosion, and provides higher resistance to attacks by sulfate and other chemicals.

Benefits:

1. **Durability**
2. GGBFS cement is routinely specified in concrete to provide protection against both sulphate attack and chloride attack
3. GGBFS is also routinely used to limit the temperature rise in large concrete pours. The more gradual hydration of GGBFS cement generates both lower peak and less total overall heat than Portland cement.
4. **Appearance**
5. In contrast to the stony grey of concrete made with Portland cement, the near-white color of GGBFS cement permits architects to achieve a lighter colour for exposed fair-faced concrete finishes, at no extra cost.
6. **Strength**
7. **Co**ncrete containing GGBFS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength. Concrete made with GGBFS continues to gain strength over time, and has been shown to double its 28 day strength over periods of 10 to 12 years.

4. Fly Ash:

The finely divided residue resulting from the combustion of ground or powdered coal. Fly ash is generally captured from the chimneys of coal-fired power plants; it has POZZOLANIC properties, and is sometimes blended with cement for this reason. Fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Toxic constituents include arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium.

Class F Fly Ash:

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). The glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds.

Class C Fly Ash:

Fly ash produced from the burning of younger lignite or subbituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes. In addition to economic and ecological benefits, the use of fly ash in concrete improves its workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulfate resistance. Even though the use of fly ash in concrete has increased in the last 20 years, less than 20% of the fly ash collected was used in the cement and concrete industries. One of the most important fields of application for fly ash is PCC pavement, where a large quantity of concrete is used and economy is an important factor in concrete pavement construction.

5. Silica Fume

- By-product of semiconductor industry

The terms condensed silica fume, microsilica, silica fume and volatilized silica are often used to describe the by-products extracted from the exhaust gases of silicon, ferrosilicon and other metal alloy furnaces. However, the terms microsilica and silica fume are used to describe those condensed silica fumes that are of high quality, for use in the cement and concrete industry. Silica fume was first ‘obtained’ in Norway, in 1947, when environmental restraints made the filtering of the exhaust gases from the furnaces compulsory. Silica Fume consists of very fine particles with a surface area ranging from 60,000 to 150,000 ft^2/lb or 13,000 to 30,000 m^2/kg, with particles approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, Silica Fume is a highly effective pozzolanic material. Silica Fume is used in concrete to improve its properties. It has been found that Silica Fume improves compressive strength, bond strength, and abrasion resistance; reduces permeability of concrete to chloride ions; and therefore helps in protecting reinforcing steel from corrosion, especially in chloride-rich environments such as coastal regions.

6. Rice Husk Ash:

This is a bio waste from the husk left from the grains of rice. It is used as a pozzolanic material in cement to increase durability and strength. The silica is absorbed from the ground and gathered in the husk where it makes a structure and is filled with cellulose. When cellulose is burned, only silica is left which is grinded to fine powder which is used as pozzolana.

4 Properties of fresh concrete:

4.1

Concept of fresh concrete

What Is Fresh Concrete?

When concrete is its **plastic state, it is known as fresh concrete**. Fresh concrete can be **easily molded to a durable structural member**. It can be prepared on the spot and may give a wide range of properties from easily available raw materials.

Workability of Fresh Concrete

The diverse requirements of **transportability, compatibility, mobility, stability, mixability, playability, and finish ability of fresh concrete** mentioned above are collectively referred.

To as workability. The **workability of fresh concrete is thus a composite property**. It is difficult to define precisely all the aspects of the workability in a single definition.

IS 6461 (Part-VII)-1973 defines workability as that Property of freshly mixed mortar or concrete that determines the ease and homogeneity by which it could be **mixed, placed, compacted, and completed**.

Factors Affecting Workability

- **Influence of Mix Proportions**
- **Influence of Aggregate Properties**
- **Influence of Admixtures**
- **Effect of Time**

Test of Workability for Fresh Concrete

- **Slump Test**
- **The Competing Factor Test**
- **The Vee-Bee Consistency Test**
- **The Flow Test**
- **Spread / Flow Table**
- **Kelly Ball**
- **Ouimet**
- **K- Slump**
- **Visual Assessment**

compacting factor test

Compaction Factor Test of Concrete

The compactability of concrete is measured using the compaction factor test, which is an important feature of workability. The compaction factor is the weight difference between partially compacted and fully compacted concrete.

The compacting factor test was established in the United Kingdom and documented in BS 1881-103: 1993. It is suitable for aggregate sizes up to 40mm. This test operates on the principle of determining the amount of compaction achieved by a standard amount of effort done by letting the concrete to fall through a specified height.

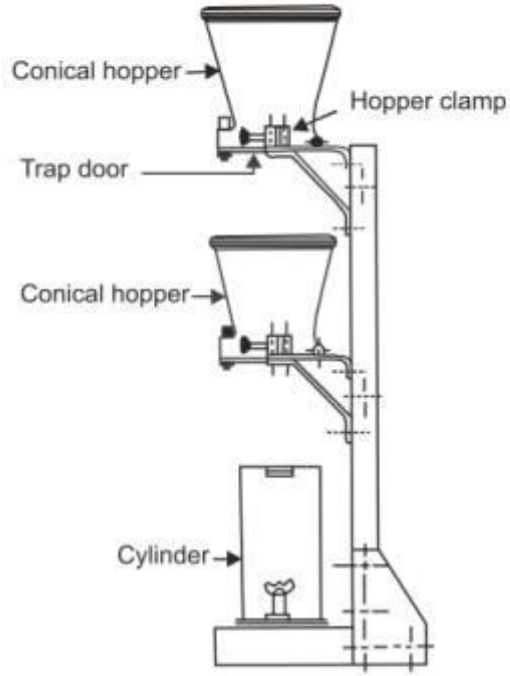
It's especially effective for concrete mixes with medium and low workabilities, which are often used when concrete is compacted by vibration; these dry concretes aren't affected by the slump test.

The test is not acceptable for concrete with a very low workability of 0.7 or below, because this concrete cannot be thoroughly compacted for comparison in the manner stated in the test.

This test is more accurate than the slump test, especially for medium and low workability concrete mixtures. In laboratories, the compaction factor test is more commonly used to measure the workability of concrete mixes.

Apparatus Used in Compaction Factor Test

Two hoppers and one cylinder mould are stacked in three layers to make up the compacting factor device. The device stands between 1.2 and 1.4 metres tall. To release the concrete, the first two hoppers have small hinged doors at the bottom.



compaction factor test apparatus

You'll also require some additional equipment, such as a concrete mixing pan, steel rod, and weighing machine.

Procedure

- **The concrete sample to be analysed is gently placed in the upper hopper.**
- **The hopper is loaded to the top with concrete, and the hinged door is opened to let the concrete fall into the lower hopper.**
- **Certain combinations have a natural tendency for clogging one or both hoppers.**
- **If this happens, the concrete can be pushed through by gently pushing the rod into the concrete from above.**
- **Trowels should be used to cover the cylinder throughout this process.**
- **The cylinder is uncovered, the trapdoor of the bottom hopper is opened, and the concrete is allowed to fall into the cylinder immediately after it has come to rest.**
- **The extra concrete that remains above the top of the cylinder is then cut away.**
- **The weight of partially compacted concrete is calculated by rounding the weight of the concrete in the cylinder to the nearest 10 g.**
- **The cylinder is replaced with concrete from the same sample in 50 mm layers, which are vigorously rammed or preferable vibrated to achieve complete compaction.**
- **The fully compacted concrete's top surface is carefully struck off level with the cylinder's top.**
- **The weight of partially compacted concrete divided by the weight of fully compacted concrete is known as the compacting factor.**
- **It is usually expressed to the second decimal place.**
- **The compaction factor ranges from 0.78 to 0.95 in most cases, while concrete with high fluidity has a greater compaction factor.**

Observation

- **Unlike the slump test, changes in the workability of dry concrete are reflected in a considerable shift in the compacting factor, indicating that the test is more sensitive at the low end of the workability scale than at the high end.**
- **The ratio of the height of the cylinder while full of compacted concrete to the height of the compacted concrete after vibration determines the degree of compactibility.**

Below table shows the different workability values :

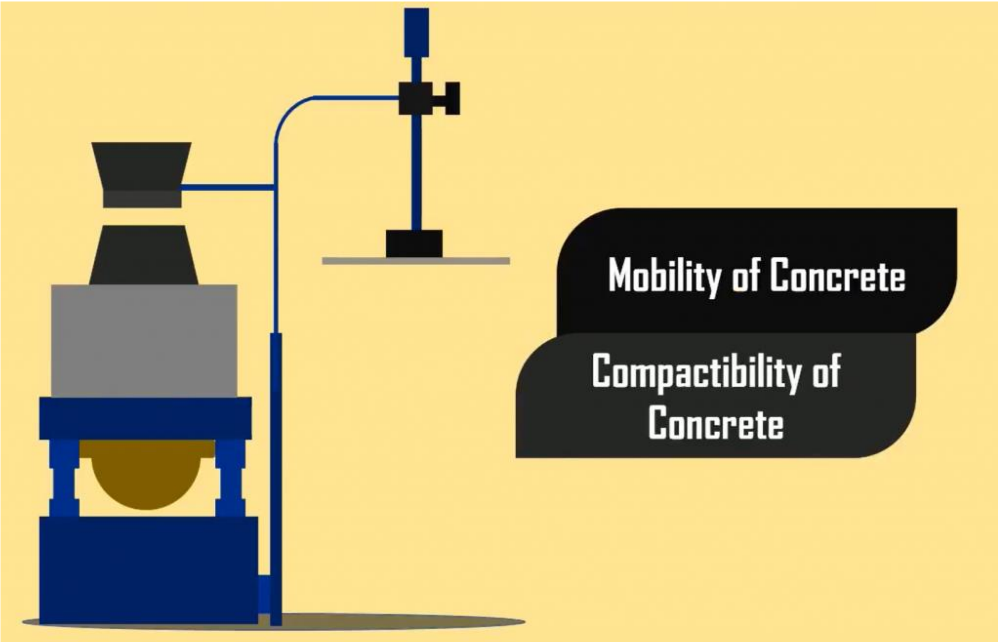
Degree of Workability	**Compacting Factor**
Very Low	**0.7 – 0.8**
Low	**0.8 – 0.85**
Medium	**0.85 – 0.95**
High	**0.95 – 1**

Points to be Noted While Performing Compaction Factor Test of Concrete

- **This test is sensitive enough to detect changes in workability resulting from the cement's first hydration phase.**
- **If strictly comparable findings are to be obtained, each test is carried out at a fixed time interval after the mixing is done.**
- **After the concrete has finished mixing, 2 minutes has been determined to be a reasonable time to release it from the higher hopper.**

What is Vee Bee Consistometer Test?

The test used to find out the workability of freshly mixed concrete by the consistometer apparatus is known as Vee Bee Test.



Contents of the Article show

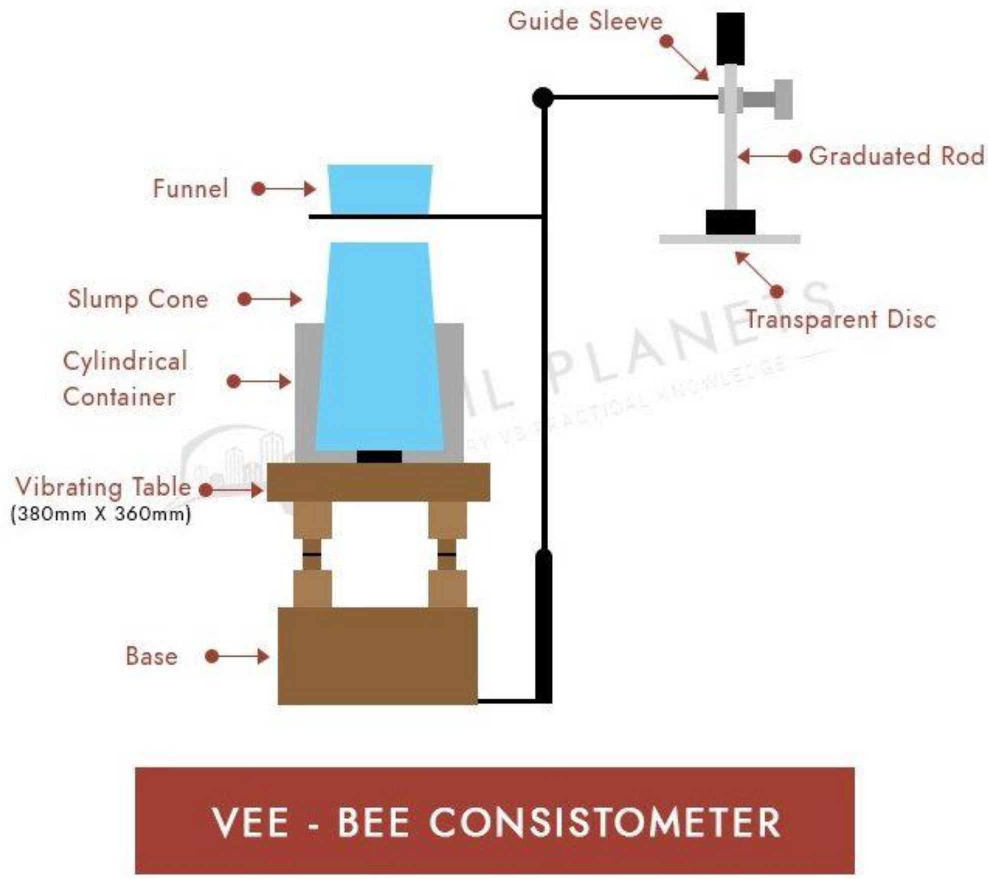
Principles of Vee Bee Test

Vee bee test is conducted at the laboratory. This test gives results based on the mobility and compatibility of the concrete.
In Simple Words,

This test measures the relative effort & time that is required to convert the concrete mould from one shape to another.
The effort taken to convert the mould from one shape to another is known as remoulding effort.
The time that has been taken for the concrete to settle down in cylindrical shape is measured in seconds, which is known as vee bee seconds.
This test is suitable for the concrete slump value lower than 50 mm. If it has more than 50 mm value, then the concrete settles quickly on the container pot, which is hard to measure in seconds.

Please watch the video and read the principles once again for a better understanding.

Apparatus Required



Vee-Bee Consistometer
Tamping rod 500 mm long & 20 mm dia.
The vibrator table should be 380mm long & 260mm width, which rests on elastic support at height 305mm above floor level.
The table should be mounted on a base which is equipped with an electrically operated vibrometer.
The sheet metal cone should be 30 cm height, and the diameter should be 20 cm and 10 cm at the bottom and top, respectively.
The graduated rod is fixed in a whirling arm. A glass disc is screwed at the end of the arm.
The division scale records the slump cone value of concrete in centimeters.

Vee Bee Test Procedure

Step 1 – Place the slump cone in the consistometer machine.
Step 2 – Fill the cone with concrete in four layers.
Step 3 – Each layer should be tamped 25 times by the tamping rod.
Step 4 – Remove the excess concrete from the slump cone & level it.
Step 5 – Now, rotate the glass disc, which is attached to the whirling arm and place it over the slump cone concrete level & measure the initial reading from the graduated rod.
Step 6 – Rotate the glass disc to its original position. Then remove the slump cone slowly in a vertical direction. You can see the concrete slightly changed from its shape.
Step 7 – Now again, rotate the glass disc and measure the final reading.
Step 8 – Now turn on the electrical vibrator table & eventually switch on the stopwatch, continue the vibration until the concrete remoulded, and the surface of the concrete becomes horizontal.
Step 9 – Once the concrete surfaces come horizontal in the cylindrical pot, stop the vibration & the watch.
Step 10 – Record the time – Vee Bee Seconds.

Test Result

Slump value = Initial Reading on the graduated scale (a) – Final Reading on the graduated scale (b)
Consistency of concrete is measured in Vee Bee Seconds

Workability Description Table

Description	Vee-Bee Seconds
Extremely Dry	32-18
Very Stiff	18-10
Stiff	10-5
Stiff Plastic	5-3
Plastic	3-0

How it differs from other workability tests?

According to the concrete workability and time availability, each test has been listed below.

#	Test Name	Suitable Workability	Performed @
1	Slump Test	High	Field / Lab
2	Kelly Ball Test	High	Field / Lab
3	Compaction Factor	Low	Lab
4	Flow Table test	Low	Lab
5	Vee – bee test	Low & very low	Lab

Requirements of Workability

The Requirements of Workability are:

The workability of the concrete must be such a way that it can be properly mixed, placed in the formwork and properly compacted with less effort without the chances for segregation and bleeding.

The workability is chosen based on the compacting equipment, section size and reinforcement concentration

Workability is high for sections that are heavily reinforced or when they have inaccessible parts

The workability requirement should be dealt with situation. Minimum workability with satisfactory placement and compaction must be followed.

The Table -1 shows the requirements of workability for different conditions of concrete placement.

Table.1: Requirements of workability for different conditions of concrete placement.

Degree of Workability	Slump, mm	Compaction Factor	Suitability
Very Low	0-25	0.78	Roads that are vibrated by power operated machines
Low	25-50	0.85	Roads that are vibrated with hand operated machines, light reinforced sections with vibrations, mass foundation without vibration
Medium	50-100	0.92	Flat slabs, less workable, manually compacted areas
High	100-180	0.95	Sections of Congested Reinforcement. Not for Vibration

Concrete Slump Test

The **concrete slump test** is an on-the-spot test to determine the consistency as well as workability of fresh concrete. This test plays a vital role in ensuring immediate concrete quality in a construction project. It is used almost in every construction sites.

The slump test is very simple and easy to handle. It also demands comparatively less equipment and can be done in a short period of time. These advantages of slump test have made it very popular all over the world. In the slump test, workability of concrete is not measured directly. Instead, consistency of concrete is measured which gives a general idea about the workability condition of concrete mix.

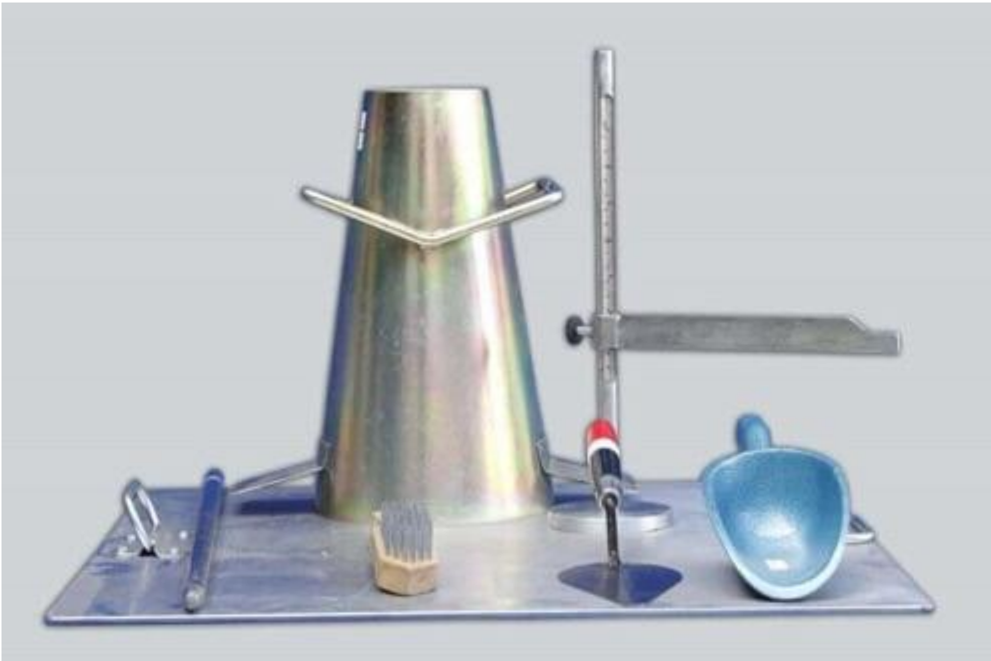
Concrete Slump Test International Standard

Various international codes have specific testing standards for concrete slump test. These standards specify methods, equipment for determining the consistency of fresh concrete by the slump test. For acceptance and reliability, It is essential to maintain strict compliance with these standards during the slump test for concrete. The standards for the concrete slump test are followings.

- American Society for Testing and Materials (ASTM): ASTM slump test standards are **ASTM C 143**, **ASTM C143M**.
- The American Association of State Highway and Transportation Officials (AASHTO): AASHTO slump test standards are **AASHTO T119**, **AASHTO BS1881.**
- British & European standard: British & European slump test standard is **BS EN 12350-2**.
- Indian standard: **IS 1199 – 1959**

Concrete Slump Test Equipment

Slump test requires some equipment to perform the test. One can easily find these test kit set in the market. The test equipment must comply with the standards mentioned above. The equipment mainly used for slump test are followings.


Concrete Slump Test Kit Set. Source: panairsan.com

- **Mould**: Shape of the mould is a frustum of a cone. The cone is known as slump cone or Abrams cone. Slump cone is made of steel, plastic, etc. Its height is 12 inches (30 cm). The diameter of the base opening is 8 inches (20 cm) and the top opening is 4 inches (10 cm).
- **Base plate:** Base plate may be made of Aluminum, polymer, steel, etc. It may be equipped with a holding attachment.
- **Tamping rod:** Temping rod used in the slump test is made of steel. Tamping Rod is usually 24" long and has a diameter of 5/8" diameter. Temping rod used in the slump test is made of steel. Tamping Rod is usually 24" long and has a diameter of 5/8" diameter.
- **Tape measure:** Standard tap should be used for measurement.

Concrete Slump Test Procedure

Step 1

Firstly, the internal surface of the mould is cleaned carefully. Oil can be applied on the surface.

Step 2

The mould is then placed on a base plate. The base plate should be clean, smooth, horizontal and non-porous.

Step 3

The mould is filled with fresh concrete in three layers. Each layer is tamped 25 times with a steel rod. The diameter of this steel rod is ⅝ inch. The rod is rounded at the ends. The tamping should be done uniformly.

Step 4
After filling the mould, excess concrete should be removed and the surface should be leveled. When the mould is filled with fresh concrete, the base of the mould is held firmly by handles.
Step 5
Then the mould is lifted gently in the vertical direction and then unsupported concrete will slump. The decrease in height at the center point is measured to nearest 5mm or 0.25 inch and it is known as 'slump'.

Cautions Required During Concrete Slump Test

To get the proper result, some cautions must be taken during the test. Following are the list of major caution that can be maintained.

- Inside of the mould and base should be moistened before every test. It is necessary to reduce surface friction.
- Prior to lifting mould, the area around the base of the cone should be cleaned from concrete which may be dropped accidentally.
- The mould and base-plate should be non-porous.
- This test should be performed in a place free of vibration or shocks.
- The concrete sample should be very fresh, the delay must be avoided and the test should be done just after mixing.

Measurement of workability from the Slump Test

If shear slump or collapse slump occurs, the test should be repeated. We can get the result from the only true slump. We can classify the result within some ranges according to the slump value.

1. Very low workability: slump value 0-25mm or 0-1 inch
2. Low workability: slump value 25-50mm or 1-2 inch
3. Medium workability: slump value 50-100mm or 2-4 inch
4. High workability: slump value 100-175mm or 4-7 inch

According to 'Fresh Concrete' by P. Bartos, slump results can be classified as given below:

1. No slump: slump value 0 mm or 0 inch
2. Very Low: sump value 5-10 mm or 0.25-0.5 inch
3. Low: sump value 15-30 mm or 0.75-1.25 inch
4. Medium: sump value 35-75 mm or 1.5-3 inch
5. High: sump value 80-155 mm or 3.25-6 inch
6. Very High: sump vaue180 mm or 6.25 inch to collapse

According to European Standard ENV 206: 1992, workability is classified in 4 categories of S1, S2, S3, and S4. Slump ranges are:

- S1: 10-40 mm
- S2: 50-90 mm
- S3: 100-150 mm
- S4: more than 160 mm

Though there are different types of workability classification, the main rule is that low slump value indicates less workability and high sump value indicates high workability.

Uses and Drawbacks of slump test

This test does not give good results for very wet and dry concrete. Also for stiff-mix, it is not sensitive. The table below shows the various values of slump with the workability of concrete. Following chart shows the Slump Value of concrete for different **Degree of workability** for various placing conditions:

Degree of workability	**Placing Conditions**	**Slump(mm)**
Very Low	Binding concrete (member of concrete by spreading, shallow sections, Pavements using pavers (mixer with spreading arrangements)	Compaction factor 0.75 – 0.8
Low	Mass concrete, lightly reinforced slab, beam, wall, column sections, canal lining, strip footing (ling wall with smaller width)	25 – 75
Medium	Heavily reinforced sections in slab, beams, walls, columns. Slip formwork (slope concrete), pumped concrete.	50-100
High	Trench fill, in-situ piling	100-150

Very high	Tremie concrete (concreting in water by using water tight pipe to pour concrete.)	Flow test.

Table: Value of Slump at different degree of Workability

Much **research** shows that for the **“very high”** category of workability, the **flow test** is more suitable for workability measurement.

For **large construction projects**, a slump test is a very useful tool to check **day-to-day** or **hour-to-hour** variation of the quality of the concrete mix, and by observing slump reading, we can easily change the **moisture (water) content** and grading of concrete. Due to that reason, it is the most common method of test.

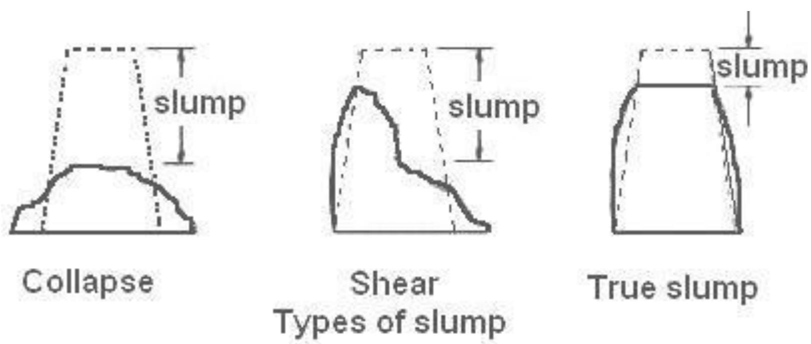


Fig. 3. Shapes of Concrete Slump

Shape of concrete slump

When the metal mould is removed from the concrete cone, the slump takes the following shapes:

- **True Slump:** True shape of a slump is only a verified slump. This shape is measure as the difference between the top layer of the cone to the top of the slump concrete.
- **Collapse Slump:** It shows that due to a high water-cement ratio, the shape of a slump is not a clear dimension. It means, concrete is very high workability, for which slump test is not suitable.
- Shear Slump: This shape of slump is the same as shear failure of soil. This is an indication of a lack of cohesion of the concrete mix ingredients. So, a fresh sample is taken and the ***test is repeated***.

Factors influencing Slump Cone:

Followings factors influence concrete Slump value:

1. Water –cement ratio of concrete.

2. The quality of coarse and fine aggregates, their shape, moisture content, texture, and grading.
3. The use of plasticizer, superplasticizer admixture, and the sequence of their mixing.
4. The void ratio of concrete and air content of concrete.
5. The time of the test after mixing of concrete.

Results of Slump Test on Concrete

Slump for the given sample= _____mm When the slump test is carried out, following are the shape of the concrete slump that can be observed:

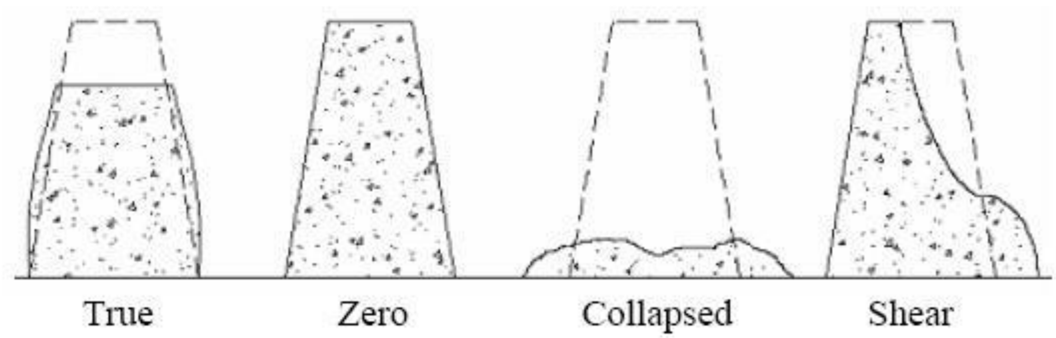


Figure-3: Types of Concrete Slump Test Results

- **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown in figure-1.
- **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. These type of concrete is generally used for road construction.
- **Collapsed Slump** – This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
- **Shear Slump** – The shear slump indicates that the result is incomplete, and concrete to be retested.

Properties of Fresh Concrete

1. **Workability**
2. **Segregation**
3. **Bleeding**
4. **Plastic shrinkage**
5. **Setting**

6. **Temperature**
7. **Water Cement Ratio**
8. **Hydration**

5 Properties of hardened concrete:

5.1

COMPRESSIVE STRENGTH OF CONCRETE CUBE VS CYLINDER

Compressive Strength of Concrete Cube vs Cylinder

What is Compressive Strength of Concrete?

The compressive strength test is the most crucial of the several tests conducted on the concrete since it provides information about the properties of the concrete. Compressive strength can be defined as the capacity of concrete to withstand loads before failure.

Compressive Strength of Concrete Cube vs Cylinder

In testing concrete for compressive strength, the shape of specimen may differ depending on you location and the code you are working according to.

The shape of the specimen can be a cylinder or a cube. So, what is the difference between the two cases?

Do you expect the shape of specimen to affect the value of the strength even if they may have the same mixture design?

The answer is Yes!

The compressive strength of a cube is larger than the compressive strength of a cylinder for specimens prepared from the same mixture design.

Compressive Strength of Concrete Cube vs Cylinder

Why is Cube strength larger than Cylinder Strength?

The primary cause responsible for this variation is the different length to diameter ratios for cubes and cylinders.

For the previous image, the length to diameter ratio for cube is 1:1, while for cylinders, the ratio is 2:1. That is why cubes are stronger.

In addition, the compressive testing machine's top platen has greater surface area to interface with the cube than the cylinder, increasing confinement to the cube specimen.

Thus, because there is more confinement for the cubes by platens of the compressive testing machine, the cube sample will require higher stress to fail compared to the cylinder.

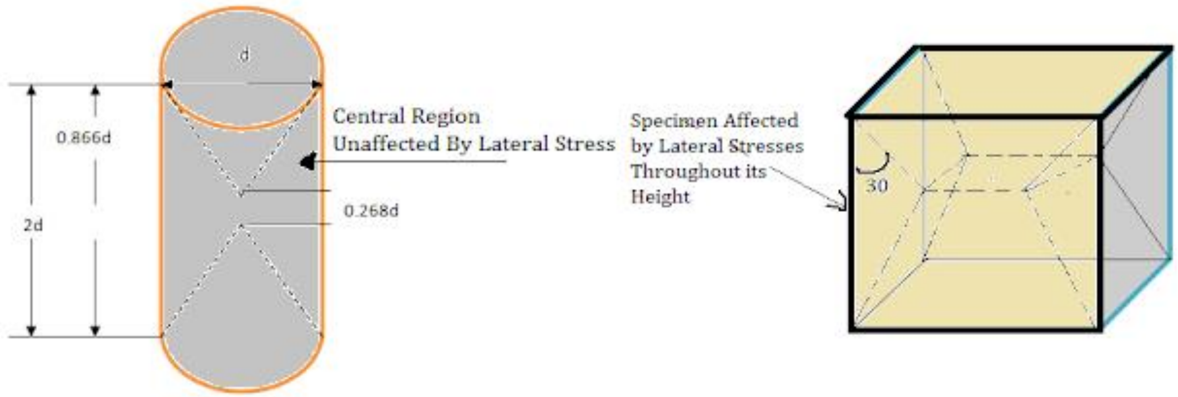
Before the specimen (a cube or cylinder) is loaded, the steel plates are positioned above and below the specimen. In contrast to the concrete specimen, there is no lateral expansion at all in the steel plates. This implies that the steel will prevent concrete from expanding laterally as a result. Thus steel platens will prevent the concrete specimen from expanding laterally. This is a common occurrence in the specimen's concrete structure, which is located close to the plate's end. As a result, in addition to the compressive stress brought on by the imposed compressive force, frictional tension develops between the plate and the specimen..

As a result, an element inside the specimen will experience "shear stress". This is as a result of two acting stresses on the specimens.

- **Friction stress between the steel plates and concrete specimens.**
- **Compressive force on the specimens.**

It has been noted that the interaction of Stresses 1 and 2 will cause an axial load failure. A greater compressive strength number will be provided as a result of this.

Look at the below figure.



Areas affected by lateral stresses

It has been noted that the cube's overall height is affected by the restraint caused by friction between the specimen and the platens. The cylinder, on the other hand, has unaffected parts in this situation. The cubes and cylinders fail by shearing at 45 and 60 degrees, respectively, from the horizontal.
As a result, it is obvious that the cube specimen will experience greater overall stress than the cylinder specimen. Even with the same concrete mix, this will lead to a higher compressive strength in cubes than in cylinders.
There is an equation that approximately governs the relationship between the cube and cylinder strengths, which is as follows:
Compressive Strength of Cube = 1.25 x (Compressive Strength of Cylinder)
As long as the mixture design is the same for both specimens.

- **compressive strength of the concrete cube test**
- **The compressive strength of the concrete cube test provides** an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. Concrete compressive strength for general construction varies from 15 MPa (2200 psi) to 30 MPa (4400 psi) and higher in commercial and industrial structures.
- Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, quality control during the production of concrete, etc.
- Test for compressive strength is carried out either on a cube or cylinder. Various standard codes recommend a concrete cylinder or concrete cube as the standard specimen for the test. American Society for Testing

Materials ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

- **Contents:** [show]

Compressive Strength Definition

- Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates.

Compressive Strength Formula

- Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.
    - **Compressive Strength = Load / Cross-sectional Area**

Procedure: Compressive Strength Test of Concrete Cubes

- 
- For cube test two types of specimens either cubes of 15cm X 15cm X 15cm or 10cm X 10cm x 10cm depending upon the size of aggregate are used. For most of the works cubical molds of size 15cm x 15cm x 15cm are commonly used.
- This concrete is poured in the mold and appropriately tempered so as not to have any voids. After 24 hours, molds are removed, and test specimens are put in water for curing. The top surface of these specimen should be made even and smooth. This is done by placing cement paste and spreading smoothly on the whole area of the specimen.
- These specimens are tested by compression testing machine after seven days curing or 28 days curing. Load should be applied gradually at the rate

of 140 kg/cm2 per minute till the Specimens fails. Load at the failure divided by area of specimen gives the compressive strength of concrete.

- 

Following are the procedure for testing the Compressive strength of Concrete Cubes

Apparatus for Concrete Cube Test

- Compression testing machine

Preparation of Concrete Cube Specimen

- The proportion and material for making these test specimens are from the same concrete used in the field.
- **Specimen**
- 6 cubes of 15 cm size Mix. M15 or above

Mixing of Concrete for Cube Test

- Mix the concrete either by hand or in a laboratory batch mixer
- **Hand Mixing**
- Mix the cement and fine aggregate on a watertight none-absorbent platform until the mixture is thoroughly blended and is of uniform color.
- Add the coarse aggregate and mix with cement and fine aggregate until the coarse aggregate is uniformly distributed throughout the batch.
- Add water and mix it until the concrete appears to be homogeneous and of the desired consistency.

Sampling of Cubes for Test

- Clean the mounds and apply oil.
- Fill the concrete in the molds in layers approximately 5 cm thick.
- Compact each layer with not less than 35 strokes per layer using a tamping rod (steel bar 16mm diameter and 60cm long, bullet-pointed at lower end).
- Level the top surface and smoothen it with a trowel.

Curing of Cubes

- The test specimens are stored in moist air for 24 hours and after this period the specimens are marked and removed from the molds and kept submerged in clear freshwater until taken out prior to the test.

Precautions for Tests

- The water for curing should be tested every 7 days and the temperature of the water must be at 27+-2oC.

Procedure for Concrete Cube Test

- Remove the specimen from the water after specified curing time and wipe out excess water from the surface.
- Take the dimension of the specimen to the nearest 0.2m
- Clean the bearing surface of the testing machine
- Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast.
- Align the specimen centrally on the base plate of the machine.

- Rotate the movable portion gently by hand so that it touches the top surface of the specimen.
- Apply the load gradually without shock and continuously at the rate of 140 kg/cm^2/minute till the specimen fails
- Record the maximum load and note any unusual features in the type of failure.
- ***Note:***
- Minimum three specimens should be tested at each selected age. If the strength of any specimen varies by more than 15 percent of average strength, the results of such specimens should be rejected. The average of three specimens gives the crushing strength of concrete. The strength requirements of concrete.

Calculations of Compressive Strength

- Size of the cube =15cmx15cmx15cm
- Area of the specimen (calculated from the mean size of the specimen)=225 cm^2
- Characteristic compressive strength(f ck)at 7 days =
- Expected maximum load =fck x area x f.s
- Range to be selected is ....
- Similar calculation should be done for 28 day compressive strength
- Maximum load applied =..........tones = ...N
- Compressive strength = (Load in N/ Area in mm^2)=..............N/mm^2
- =...........................N/mm^2

Reports of Cube Test

- Identification mark
- Date of test
- Age of specimen
- Curing conditions, including date of manufacture of specimen
- Appearance of fractured faces of concrete and the type of fracture if they are unusual

Results of Concrete Cube Test

- Average compressive strength of the concrete cube = ...N/ mm^2 (at 7 days)

- Average compressive strength of the concrete cube =.......... N/mm2 (at 28 days)

Compressive Strength of Concrete at Various Ages

- The strength of concrete increases with age. The table shows the strength of concrete at different ages in comparison with the strength at 28 days after casting.

• **Age**	• **Strength percent**
• 1 day	• 16%
• 3 days	• 40%
• 7 days	• 65%
• 14 days	• 90%
• 28 days	• 99%

Compressive Strength of Different Grades of Concrete at 7 and 28 Days

• **Grade of Concrete**	• **Minimum compressive strength N/mm2 at 7 days**	• **Specified characteristic compressive strength (N/mm2) at 28 days**
• M15	• 10	• 15
• M20	• 13.5	• 20
• M25	• 17	• 25

• M30	• 20	• 30
• M35	• 23.5	• 35
• M40	• 27	• 40
• M45	• 30	• 45

Some Facts on Concrete Strength Test

- Why Compressive Strength Test of Concrete is Important?
- The compressive strength of the concrete cube test provides an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not.
- What is compressive strength of commonly used concrete?
- Concrete compressive strength for general construction varies from 15 MPa (2200 psi) to 30 MPa (4400 psi) and higher in commercial and industrial structures.
- What is compressive strength after 7 days and 14 days?
- Compressive strength achieved by concrete at 7 days is about 65% and at 14 days is about 90% of the target strength.
- Which test is most suitable for concrete strength?
- A concrete cube test or concrete cylinder test is generally carried out to assess the strength of concrete after 7 days, 14 days or 28 days of casting.
- What is the size of concrete cubes used for testing?
- For cube test two types of specimens either cubes of 15cm X 15cm X 15cm or 10cm X 10cm x 10cm depending upon the size of aggregate are used. For most of the works cubical molds of size 15cm x 15cm x 15cm are commonly used.
- Which machine is used for concrete strength test?
- The compression testing machine is used for testing the compressive strength of concrete.
- What is the rate of loading on compression testing machine?

- Load should be applied gradually at the rate of 140 kg/cm2 per minute till the Specimens fails.
- Which ACI Code is use for Concrete Strength Test?
- American Society for Testing Materials ASTM C39/C39M provides Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

Flexural Strength of Concrete

Flexural strength of Concrete, also known as **Modulus of rupture,** is an indirect measure of the tensile strength of unreinforced concrete. Modulus of rupture can also be defined as the measure of the extreme fibre stresses when a member is subjected to bending. Apart from external loading, tensile stresses can also be caused by warping, corrosion of steel, drying shrinkage and temperature gradient.

One-point loading test and the Two-point loading test For Flexural Strength of Concrete.jpg – EngineeringCivil.org

Concrete is strong in compression but weak in tension because of which the flexural strength accounts for only 10% to 20% of the compressive strength.

Determination of Flexural Strength of the Concrete

Experimental Estimation of Flexural Strength using One-point loading test and the Two-point loading test

Unlike compression, tensile strength of a member can not 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.

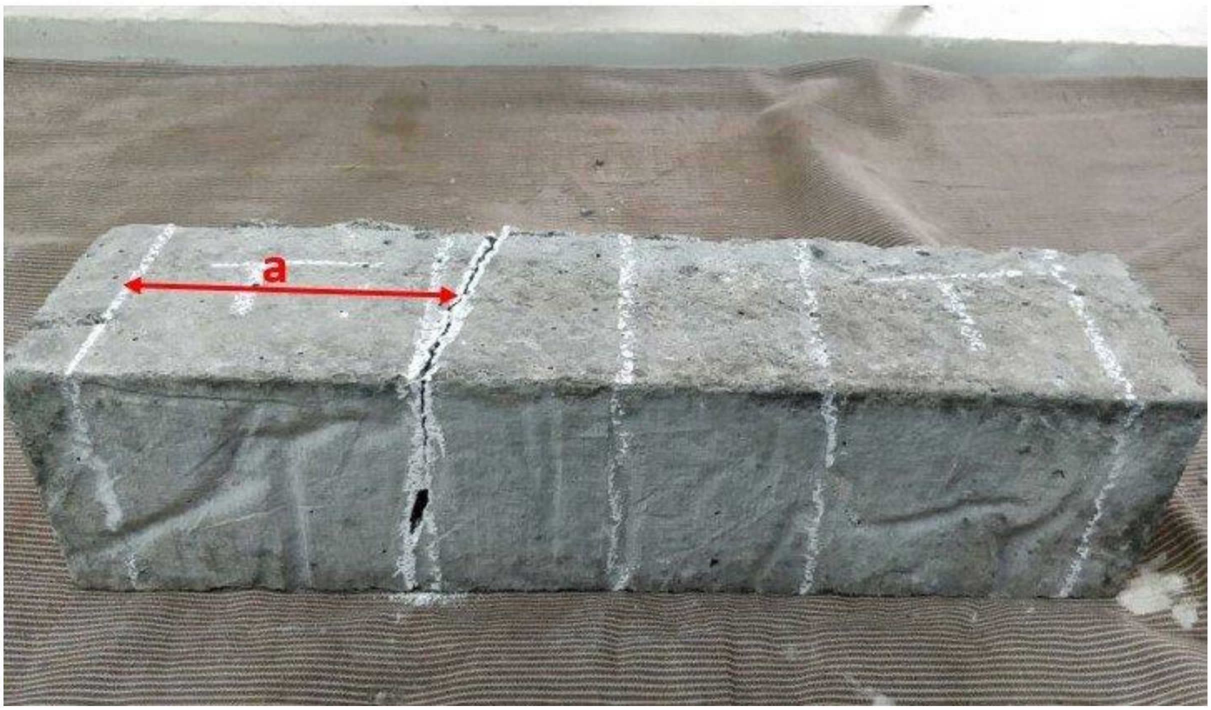
Principle / Mechanism

Modulus of rupture is the measure of extreme fibre stresses in a member under flexure where the beam can be loaded using One-point loading or the symmetrical Two-point loading. When a simply supported beam is subjected to bending, tensile stresses are developed at the bottom of the beam and once the tensile stresses exceed the flexural strength of the beam, cracks start to occur at the point of maximum bending moment. The load causing the crack and the pattern of the crack can be used to calculate the flexural strength of the given concrete member.

Procedure for Calculating Flexure Strength of Concrete

1. Unreinforced concrete specimens of size 400 mm x 100 mm x 100 mm are casted using the desired concrete grade and cured properly for 28 days.
2. The test specimens are allowed to rest in water for 2 days at a temperature of 24˚C to 30˚C before testing.
3. The testing is done immediately after removal of the specimen from the water and while the specimens are **in wet condition.**
4. Reference lines are drawn using chalks at 5 cm from the edges of the specimen on either side to indicate the position of the roller supports
5. The prismatic specimens are supported on rollers of the testing machine. These rollers provide a simply supported condition for the test.
6. The load is gradually applied through two symmetrical rollers on the axis of the beam.

7. Further, load is applied without shock and increased continuously at a rate such that the stress in the extreme fibre increases at approximately **$7 kg/cm^2$/minute.**
8. Finally, the load is applied until the specimen fails and the maximum load is noted.



Specimen after Failure for Testing Flexural Strength of Concrete

Calculation of Flexural Strength from Lab Test

The Flexural Strength or Modulus of Rupture (f_b) is given by

$f_b = Pl/bd^2$ (when a > 13.3 cm)

$f_b = 3Pa/bd^2$ (when a < 13.3 cm)

Where,

a = the distance between the line of fracture and the nearest support, measured on the center line of the tensile side of the specimen (cm)

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

P = Maximum Load taken by the specimen (kg)

Empirical Formula for Estimating Flexural Strength of Concrete

As per IS 456 2000, the flexural strength of the concrete can be computed by the characteristic compressive strength of the concrete

Flexural strength of concrete = 0.7 sqrt(*fck*)

Where**,** *fck* is the characteristic compressive strength of concrete in MPa.

Characteristic compressive strength (MPa)	**Flexural Strength (MPa)**
20	3.13
25	3.50
30	3.83
35	4.14
40	4.43
45	4.70

50	4.95

Flexural strength of various grades of concrete as per IS code

Significance of Flexural Strength

Though the modern construction practice uses reinforcement steel to increase the tensile strength of the concrete, the computation of the flexural strength is significant as the steel reinforcement can only take care of the extreme fibre stresses in the member.

The tensile stress caused by **warping, corrosion of steel, drying shrinkage and temperature gradient** can also cause failure. The determination of flexural strength is an important factor in **the design of pavements** especially when there is inadequate subgrade support. If you're **planning to hire a contractor** it's important that they understand the importance of flexural strength dynamics and how to increase the flexural strength of the concrete to meet the specific needs of the project.

How to Increase the Flexural Strength of Concrete?

The use of **crushed aggregates** in the place of rounded aggregates increases the bond strength between the aggregates and the cement matrix and therefore increases the flexural strength. When reactive aggregates like the **Calcareous aggregates** are used, it reacts with the excess calcium hydroxide among the products of hydration to yield by-products which increases the flexural strength of the member.

Another way of increasing the flexural strength is by replacing a part of cement with **pozzolanic additives** like fly ash or Ground Granulated Blast Furnace Slag (GGBS). The pozzolanic additives play a major role in reducing the size and concentration of the Calcium Hydroxide crystals and invoking the formation of the most vital **Calcium Silicate Hydrate Gel** (CSH gel).

The other ways of increasing the flexural strength includes the overall strengthening of the member by reducing the total **porosity** and by reducing the **water cement ratio** of the concrete mix.

FAQ

What is characteristic compressive strength?

Characteristic compressive strength of concrete is the strength below which not more than 5% of the test results should fall. It is denoted by *fck***.**

For example, the characteristic compressive strength of M20 grade of concrete is 20 MPa.

Stress strain curve of concrete

Stress strain curve of concrete is a graphical representation of concrete behavior under load. It is produced by plotting concrete compress strain at various interval of concrete compressive loading (stress). Concrete is mostly used in compression that is why its compressive stress strain curve is of major interest. The stress and strain of concrete is obtained by testing concrete cylinder specimen at age of 28days, using compressive test machine. The stress strain curve of concrete allows designers and engineers to anticipate the behavior of concrete used in building constructions. Finally, the performance of concrete structure is controlled by the stress strain curve relationship and the type of stress to which the concrete is subjected in the structure.

Contents: [show]

Stress-strain Curve for Concrete

Fig. 1 and Fig. 2 shows strain stress curve for normal weigh and lightweight concrete, respectively. There is a set of curves on each figure which represents the strength of the concrete. So, higher curves show higher concrete strength. Fig. 3 shows how the shape of concrete stress strain curve changes based on the speed of loading. Despite the fact that, speed of testing and concrete density influences the shape of the stress-strain curve, but it can be noticed that, all curves show nearly the same character. i.e. they undergo the same stages under loading. Various portions of concrete stress stain curve are discussed below:

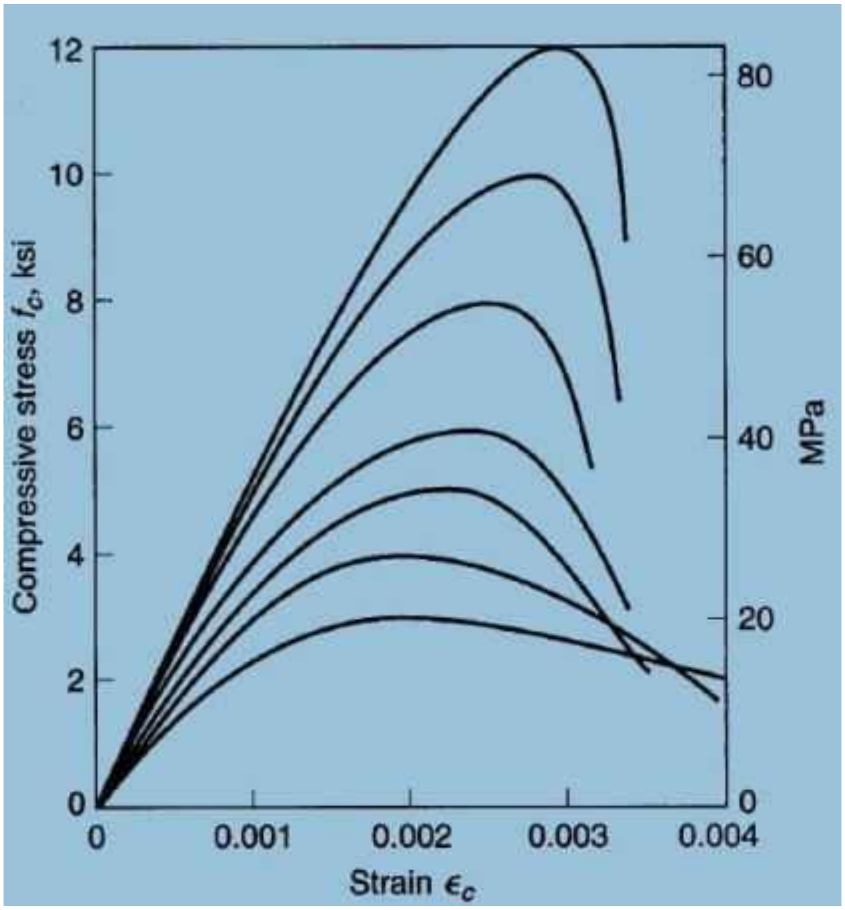


Fig. 1: Set of Stress Strain Curve for Normal Density Concrete

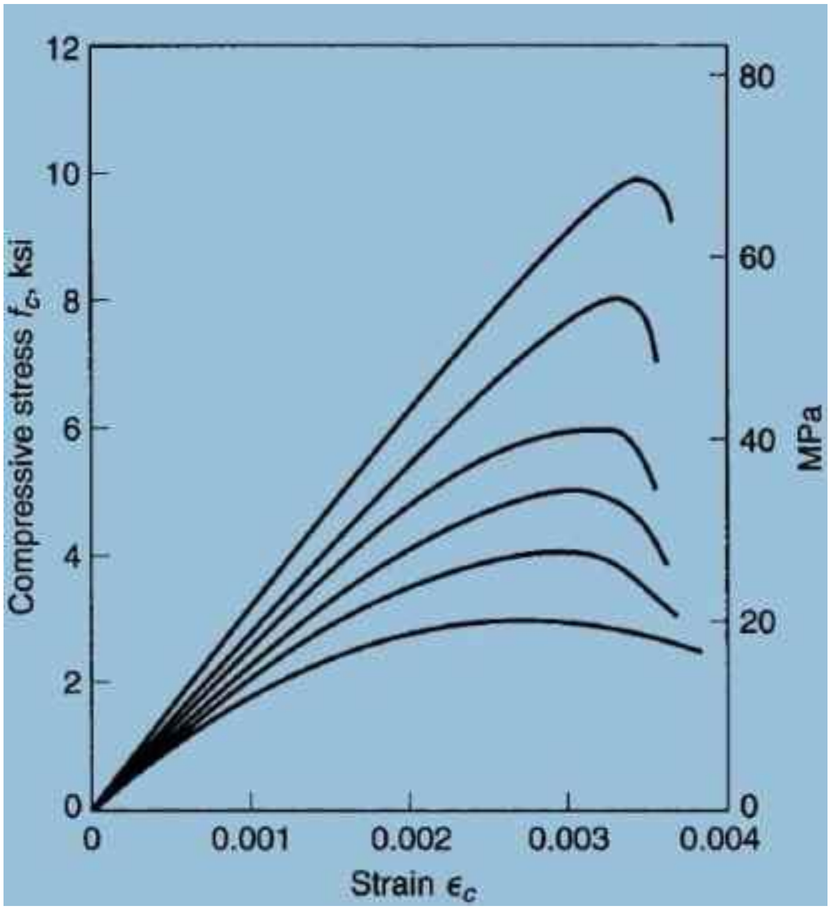


Fig. 2: Stress Strain Curve for Lightweight Concrete

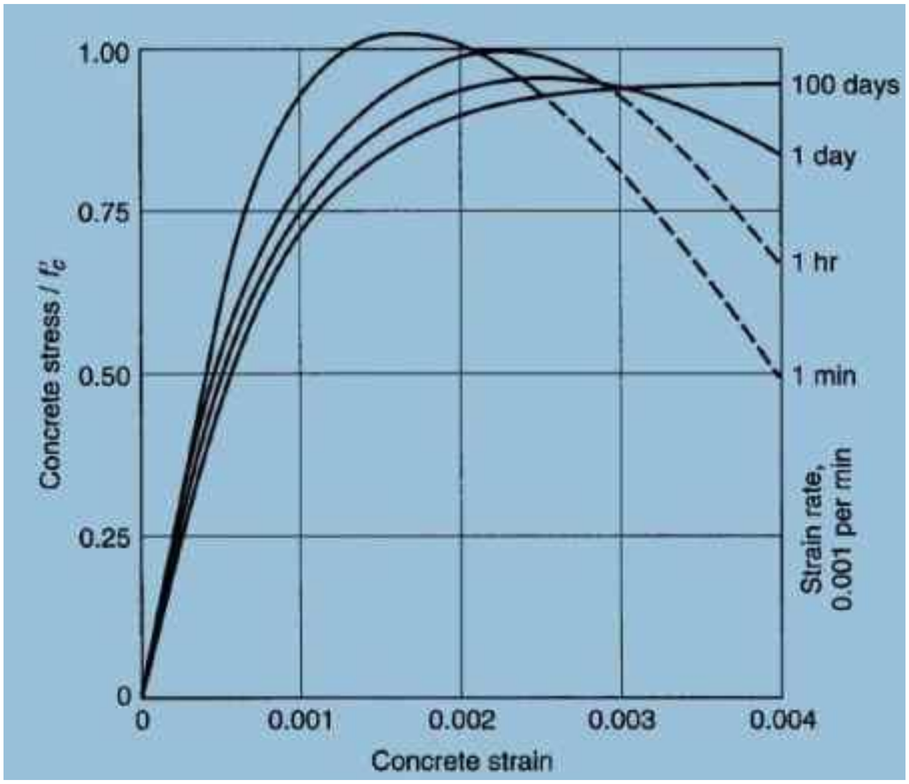


Fig. 3: Stress Strain Curve of Concrete Varies Based on Speed of Testing

1. Straight or Elastic Portion

Initially, all stress strain curves (Fig.1 and Fig. 2) are fairly straight; stress and strain are proportional. With this stage, the material should be able to retain its original shape if the load is removed. The elastic range of concrete stress strain curve continues up to 0.45fc' (maximum concrete compressive strength). The slope of elastic part of stress strain curve is concrete modulus of elasticity. The modulus of elasticity of concrete increases as its strength is increased. ACI Code provides equations for computing concrete modulus of elasticity.

2. Peak Point or Maximum Compress Stress Point

The elastic range is exceeded and concrete begin to show plastic behavior (Nonlinear), when a load is further increased. After elastic range, the curve starts to horizontal; reaching maximum compress stress (maximum compressive strength). For normal weight concrete, the maximum stress is realized at compressive strain ranges from 0.002 to 0.003. however, for lightweight concrete, the maximum stress reached at strain ranges from 0.003 to 0. 0035.The higher results of strain in both curves represent larger strength. For normal weight concrete, the ACI Code specified that, a strain of 0.003 is maximum strain that concrete can reach and this value used for design of concrete structural element. However, the European Code assumes concrete can reach a strain of 0.0035, and hence this value is used for the design of concrete structural element.

3. Descending Portion

After reaching maximum stress, all the curves show descending trend. The characteristics of the stress strain curve in descending part is based on the method of testing. Long stable descending part is achieved if special testing procedure is employed to guarantee a constant strain rate while cylinder resistance is decreasing. However, if special testing procedure is not followed, then unloading after peak point would be quick and the descending portion of the curve would not be the same.

Creep in Concrete and Effects of Creep of Concrete

Creep Definition

Concrete creep is defined as: deformation of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. When a load is applied to concrete, it experiences an instantaneous elastic strain which develops into creep strain if the load is sustained.

Creep is factored in when concrete structures are designed.

Factors Affecting Creep

1. Aggregate
2. Mix Proportions
3. Age of concrete

The magnitude of creep strain is one to three times the value of the instantaneous elastic strain, it is proportional to cement-paste content and, thus, inversely proportional to aggregate volumetric content. The magnitude of creep is dependent upon the magnitude of the applied stress, the age and strength of the concrete, properties of aggregates and cementitious materials, amount of cement paste, size and shape of concrete specimen, volume to surface ratio, amount of steel reinforcement, curing conditions, and environmental conditions.

1. Influence of Aggregate

Aggregate undergoes very little creep. It is really the paste which is responsible for the creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by aggregate which do not creep. The stronger the aggregate the more is the restraining effect and hence the less is the magnitude of creep. An increase from 65 to 75 % of volumetric content of the aggregate will decrease the creep by 10 %.

The modulus of elasticity of aggregate is one of the important factors influencing creep. It can be easily imagined that the higher the modulus of elasticity the less is the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate.

2. Influence of Mix Proportions:

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. Therefore, it can be said that creep increases with increase in water/cement ratio. In other words, it can also be said that creep is inversely proportional to the strength of concrete. Broadly speaking, all other factors which are affecting the water/cement ratio are also affecting the creep.

3. Influence of Age:

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves with time. Such gel creeps less, whereas a young gel under load being not so stronger creeps more. What is said above is not a very accurate statement because of the fact that the moisture content of the concrete being different at different age also influences the magnitude of creep.

Effects of Creep on Concrete and Reinforced Concrete

- In reinforced concrete beams, creep increases the deflection with time and may be a critical consideration in design.
- In eccentrically loaded columns, creep increases the deflection and can load to buckling.
- In case of statically indeterminate structures and column and beam junctions creep may relieve the stress concentration induced by shrinkage, temperatures changes or movement of support. Creep property of concrete will be useful in all concrete structures to reduce the internal stresses due to non-uniform load or restrained shrinkage.
- In mass concrete structures such as dams, on account of differential temperature conditions at the interior and surface, creep is harmful and by itself may be a cause of cracking in the interior of dams. Therefore, all precautions and steps must be taken to see that increase in temperature does not take place in the interior of mass concrete structure.
- Loss of prestress due to creep of concrete in prestressed concrete structure.
- Because of rapid construction techniques, concrete members will experience loads that can be as large as the design loads at very early age; these can cause deflections due to cracking and early age low elastic modulus. So, creep has a significant effect on both the structural integrity and the economic impact that it will produce if predicted wrong.

Creep & Shrinkage Explained

Throughout the course of time, structural concrete may undergo wear and tear, which may cause cracking, stresses or deflections that will affect the in-service behavior of the reinforced concrete structures. This time-dependent phenomenon in concrete that we observed is called the creep and shrinkage. These circumstances are already part of the life cycle of a structure that should be taken into consideration in the design. But before doing so, it is important to understand the difference between the two, to be able to come up with a favorable design.

Creep

Creep is the gradual increase in a strain of a structural member which is subjected to certain loading over a period of time. When the concrete is loaded in compression, an elastic strain develops as shown in figure A. If this load remains on the member, creep strain developed with time.The main factors affecting creep strain are the concrete strength and mixture, the type of aggregate, curing, the relative humidity and the duration of the sustained loading.

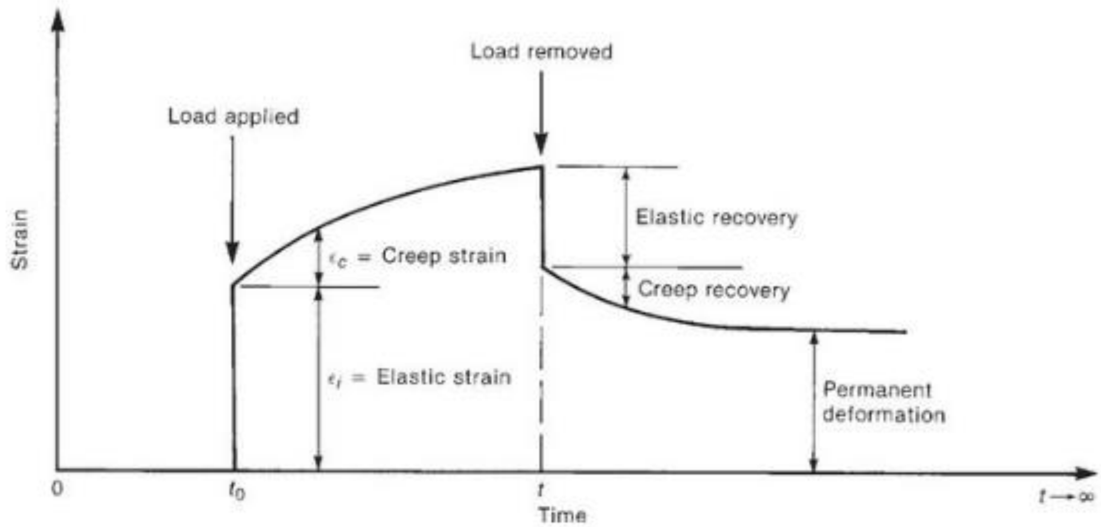


Figure A: Creep Strains due to Loading at time, t_0 and unloading at time *t*

The values from creep strain are used in the deflection calculation. According to BS8110: Part 2 section 7.3, the creep strain in concrete, ϵ_{cc} can be predicted from:

$$\epsilon_{cc} = \frac{stress}{E_t}\phi$$

where:

- Et: is the modulus of elasticity of concrete at the age of loading *t*
- Φ is the creep coefficient which can be taken from figure 7.1 of BS8110: Part 2

Shrinkage

Shrinkage is the contraction that occurs in concrete when it dries and hardens due to moisture content evaporation. The amount of shrinkage increases with time as shown in figure B. The aggregate contents present in concrete are the most important factors influencing shrinkage. This is because the larger the aggregate, the lower is the shrinkage and the higher is the aggregate content, the lower the water-cement ratio and workability are. A decrease in ambient humidity also increases shrinkage.

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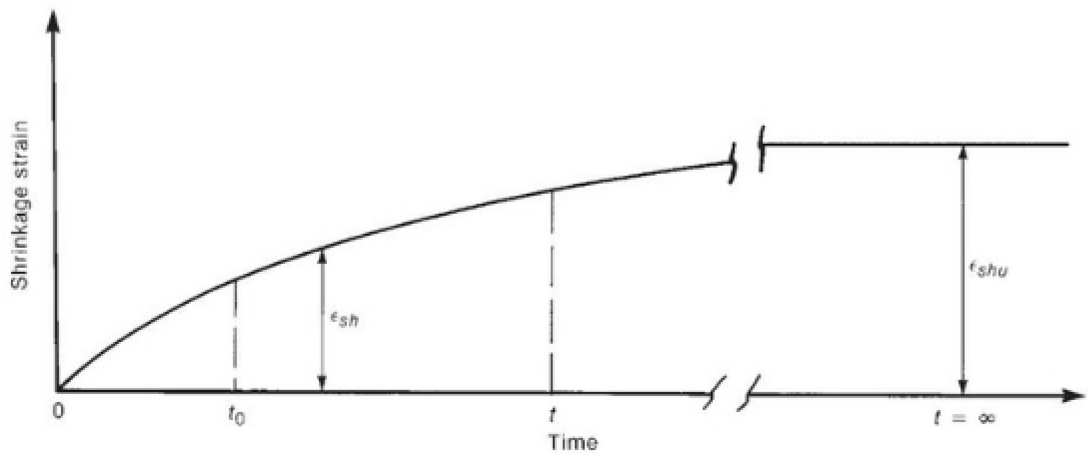


Figure B: Shrinkage Diagram of an Unloaded Specimen

On the other hand, Shrinkage has been discussed in BS8110: Part 2, section 7.4. The values obtained from the shrinkage strain are used in the deflection calculation. An estimate of the shrinkage of the symmetrically reinforced concrete section may be obtained from:

$$\frac{\varepsilon_{sh}}{1 + K_\rho}$$

where:

- ϵ_{sh} is the shrinkage of the plain concrete
- ϱ is the area of steel relative to that of concrete
- K is a coefficient, taken as 25 for internal exposure and as 15 for external exposure.

Deflection Calculations

The values obtained from the creep and shrinkage strain are used in the calculation of deflection. For further details, the Calculation of deflection can be found in section 3.7 of BS8110: Part 2.

Note: The above formula are based on BS8110, ACI had a different approach on obtaining the values of creep and shrinkage strain.

Shrinkage of Concrete

Shrinkage of Concrete, Types and Factors of Shrinkage in Concrete

Shrinkage of Concrete

Presently we shall discuss the volume change on account of inherent properties of concrete "shrinkage". One of the most objectionable defects in concrete is the presence of cracks, particularly in floors and pavements. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage.

It is difficult to make concrete which does not shrink and crack. It is only a question of magnitude. Now the question is how to reduce the shrinkage and shrinkage cracks in concrete structures. As shrinkage is an inherent property of concrete it demands greater understanding of the various properties of concrete, which influence its shrinkage characteristics.

It is only when the mechanism of all kinds of shrinkage and the factors affecting the shrinkage are understood, an engineer will be in a better position to control and limit the shrinkage in the body of concrete.

The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons. To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage, (b) Drying Shrinkage; (c) Autogeneous Shrinkage, (d) Carbonation Shrinkage.

Types of shrinkage of concrete
a) Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by aggregate or subgrade is believed to be the reasons of plastic shrinkage.
The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement

b) Drying Shrinkage

Just as the hydration of cement is an everlasting process, the drying shrinkage is also an everlasting process when concrete is subjected to drying conditions. The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen.
The loss of free water contained in hardened concrete does not result in any appreciable dimension change. It is the loss of water held in gel pores that causes the change in the volume

c) Autogeneous Shrinkage

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when the temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as an autogenous shrinkage.
Autogenous shrinkage is of minor importance and is not applicable in practice to many situations except that of a mass of concrete in the interior of a concrete dam. The magnitude of autogenous shrinkage is in the order of about 100 x 10–6.

d) Carbonation Shrinkage

Carbonation shrinkage is a phenomenon very recently recognized. Carbon dioxide present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide [Ca(OH)2] gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide in the normal atmosphere.

Carbonation penetrates beyond the exposed surface of concrete only very slowly. The rate of penetration of carbon dioxide depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase in weight of the concrete and by shrinkage.
Carbonation shrinkage is probably caused by the dissolution of crystals of calcium hydroxide and deposition of calcium carbonate in its place. As the new product is less in volume than the product replaced, shrinkage takes place

Factors affecting of Shrinkage of Concrete

One of the most important factors that affect shrinkage is the drying condition or in other words, the relative humidity of the atmosphere at which the concrete specimen is kept. If the concrete is placed in 100 percent relative humidity for any length of time, there will not be any shrinkage, instead, there will be slight swelling.
The magnitude of shrinkage increases with time and also with the reduction of relative humidity. The rate of shrinkage decreases rapidly with time. It is observed that 14 to 34 percent of the 20-year shrinkage occurs in 2 weeks, 40 to 80 percent of the 20-year shrinkage occurs in 3 months and 66 to 85 percent of the 20-year shrinkage occurs in one year.
Another important factor which influences the magnitude of shrinkage is water/cement ratio of the concrete. As mentioned earlier, the richness of the concrete also has a significant influence on shrinkage.
The grading of aggregate by itself may not directly make any significant influence. But since it affects the quantum of paste and water/cement ratio, it definitely influences the drying shrinkage indirectly. The aggregate particles restrain the shrinkage of the paste.
The harder aggregate does not shrink in unison with the shrinking of the paste whereby it results in higher shrinkage stresses, but the low magnitude of total shrinkage. But a softer aggregate yields to the shrinkage stresses of the paste and thereby experiences the lower magnitude of shrinkage stresses within the body, but the greater magnitude of total shrinkage.

Permeability of Concrete: Function, Factor Affecting, Importances, Preventive Measures

Table of Contents

we will discuss the permeability of concrete.

1. Introduction

Concrete is the composite material that is composed of a mixture of fine and coarse aggregates bonded together with biding material which hardens over time. The binding material mostly includes fluid cement paste, lime putty, lime, etc. In simple language, Concrete is a mixture of cement, sand, aggregates, and water.

The **permeability of concrete** may be defined as a measure of the quantity of water, air, and other substances that increase through concrete, which is the ability of concrete to withstand the penetration of any material that accesses the concrete matrix, the concrete has voids that can permit these materials to access or depart.

Concrete has tiny voids whose diameter changes from 0.01 to 10 μm in cement pastes whereas it may be between 1 mm to 10 mm when the cement paste is kept on the aggregate.

The commonly utilized methods for testing the permeability of concrete contain water permeability, air permeability, soaking chlorine pools, and electric quantity.

2. Function of Permeability

a. Permeability controls the rate of moisture penetration.

b. Higher permeability will have lower durability.

c. Also, if the permeability is high, the water-tightness will be decreased.

d. If good quality **aggregates** are utilized then permeability is low.

3. Factors Affecting The Permeability of Concrete

The factors that affect the permeability of concrete are as follows:

a. Cement Content:

It is important to give enough material to prepare impermeable concrete.
The permeability of concrete decreases with the fineness of the cement.

b. Quality of Aggregate:

If best quality aggregates are utilized then permeability is decreased.
If higher porous aggregates are utilized, the permeability of the concrete will increase.
The larger-sized aggregate use also raises the permeability of concrete.

c. Pore structure:

The lowering quantity of paste is advantageous in lowering permeability.
Permeability is very less at and below porosity(η) of 30%.
The porosity of more than 30% will increase the permeability of concrete.

d. Water cement Ratio:

The water mixture is indirectly proportionally responsible for the permeability of the hydrated cement paste.
The loss of water mixture is responsible for the high permeability of concrete.

e. Age of concrete:

As the age of **concrete** is high, permeability will be low.

f. Degree of Compaction:

The permeability of concrete raises due to incomplete compaction and voids.
It is therefore necessary that concrete should be reasonable and sufficiently compacted.

g. Adequacy of treatment:

The curing will progress the process of hydration, which stays in the pore space making the concrete more impermeable. **Concrete** is high permeable with **steam curing**.

4. Importance of Permeability

In **reinforced concrete**, access to water and air will cause steel erosion causing the concrete to increase in size, crack, and break up.
The access of solute into the solution may highly affect the durability of concrete.
Ca (OH_2) leaches and aggressive fluids charge the concrete.
If the concrete set off saturated with water because of permeability, it is additionally vulnerable to frost action.
It is important in the case of liquid retaining structures like water tanks and dams where water tightness is necessary.

5. Measures To Reduce The Permeability of Concrete

To decrease the permeability of concrete, the steps of the following way should be taken as follows:

a. To decrease the permeability of concrete utilizing pozzolana or slag **cement** should be done.

b. Precast members must be provided preference, plastering should be neglected.

c. Neglect the utilization of pieces of bricks, soft limestone, or other porous aggregates.

d. Increase the cover over rebars.

e. A **concrete** mixture with a low water/cement ratio will produce concrete with low permeability.

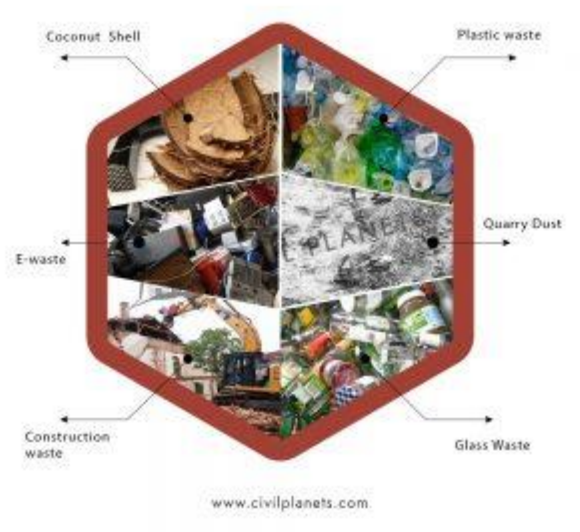
What is Durability of Concrete?

Ten decades ago, the usage of concrete was very few in construction. The old method of construction manners has followed to build a structure. But the conventional way does not give stability & longer life for the structure.
So the usage of concrete increases gradually in construction fields. Since 1830 concrete has come a long way of development and become a vital material in modern construction.

What is the durability of concrete?

In simple words, the life span of the concrete is called **durability**.
In technical terms, the resistance capacity of concrete against the chemical attack, weathering action & environmental changes is called durability of concrete—generally, a concrete structure designed at a minimum lifespan of 100 years.
Durability is one of the most important properties of concrete. It depends on the compressive strength & tensile strength of the concrete.

Why is concrete durability important?



Everyone wants to build a long-lasting structure which does not require frequency maintenance work
Already the construction materials are in short supply & scientists researching replaceable material. By increasing the lifespan of the structure, we could avoid the over usage of natural materials.

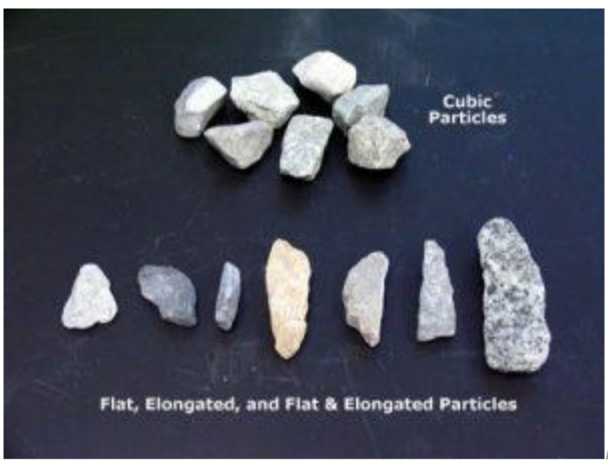
Factors affecting the durability of concrete

The strength of the concrete depends on many factors, as described below.

- Quality & Shape of Coarse Aggregates
- Quality of Fine Aggregate
- Quantity of Cement
- Mix Ratio
- Water Cement Ratio
- Cover Provision
- Compaction of Concrete
- Workmanship
- Curing Period
- Moisture content
- Sulphate Attack
- Chloride attack
- Environmental Conditions

Quality & Shape of Coarse Aggregates

The quality of coarse aggregates is significant for the durability of concrete. The coarse aggregate, which occupies 70-80% of the concrete volume, is responsible for its compressive strength.



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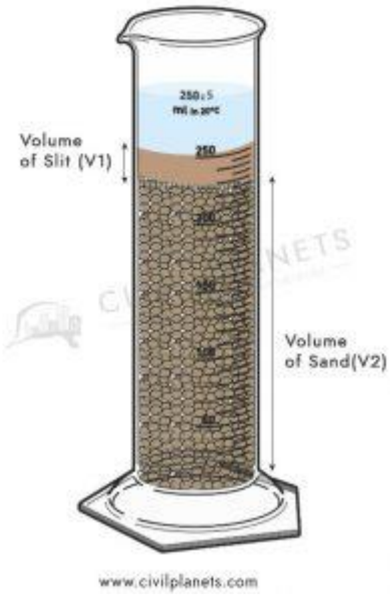
So choosing the right classification & grading of aggregates plays a vital role. If the shape of the aggregates is flaky or elongated, then it is easily broken due to sudden impact.

- The irregular shape of aggregates makes more voids in concrete.
- The angular aggregates make bonding with each other, and it helps develop the strength of the concrete.

Quality of Fine Aggregate

The river sand is used as filler material in concrete. It should be free from silt & other marine impurities. The silt content test for sand has to be performed to measure the silt particles in sand. The allowable silt in the sand in the ranges between 6 to 8%.



Or we could use M Sand, which is free from silt and other impurities.

Quantity of Cement

The durability of concrete will be affected by the shrinkage of concrete.

- If the cement content is exceeded, it leads to shrinkage happening in concrete.
- The lower cement content decreases the bondage between the concrete materials, reducing concrete strength.

So using the proper amount of cement content is essential.

Mix Ratio

The proper recommended mix ratio should be used for any construction work. Improper mix ratio directly affects the compressive strength of the structure. Eventually, it led to structural failure.

Water cement Ratio

A high amount of water increases the porosity in concrete then the water molecules easily penetrate the concrete and rust the steel bar.

In the case of low water content in concrete, it affects the workability of concrete. The recommended water-cement is 0.45 to 0.65 as per IS standards.

Concrete Cover

The steel embedded in concrete to increase its tensile strength. The exposure of the steel rod must be avoided else; it can be easily corroded by the atmospheric moisture.

The recommended clear cover steel has been given below based on concrete exposure.

Exposure	Nominal Concrete Cover

Mild	20
Moderate	30
Severe	45
Very Severe	50
Extreme	75

Compaction of Concrete

Improper compaction severely impacts the durability of concrete. There is a chance for voids formation on the concrete surface due to the improper compaction, which induces crack on concrete and, finally, will disintegrate quickly.

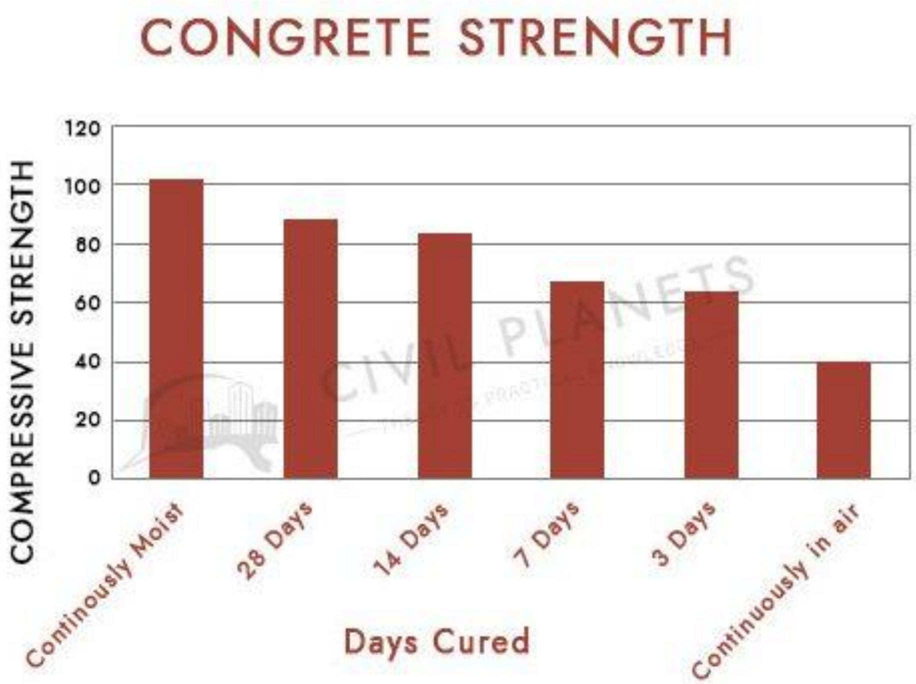
The concrete should be placed in the formwork without bleeding & segregation.

Workmanship

Even if you carefully selected the materials and cautiously implemented the standards, if the workmanship is poor, then the structure's strength & durability will be affected severely. So keep on eye on proper workmanship while concrete pouring.

Curing Period

Curing of concrete increases the durability of the concrete. Improper or delayed curing induce shrinkage cracks. Proper curing helps to reduce the permeability of the concrete.



The recommended curing period for concrete, as per IS code 456.

Nature of Work	Curing Period
Portland Cement used in concrete	7 to 14 days
Rapid hardening cement used in concrete	7 to 10 days

In cold weather conditions	14 days

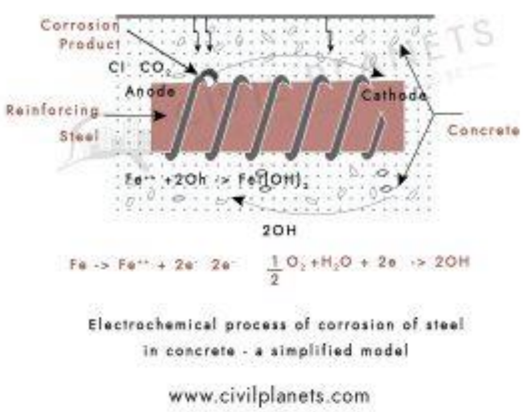
Moisture Content

Sometimes you may see white patches on concrete surfaces called **Efflorescence**.
The moisture content present in surroundings forms white patches on the surface. If the concrete surface does not resist permeability, it penetrates the surface and reacts with the steel to corrode.

Sulphate Attack

Sulphate Attack is the most damaging cause of concrete deterioration and affects the durability severely. It causes the concrete to expand and deformation.
When the structure comes in contact with water, it will undergo sulphate attack.
Also, cement & other aggregates contain some limited volume of sulphate content. If it exceeds the limitation, it may lead to crack formation on concrete. To avoid this, the sulphate content in concrete should not be exceeded by 4% by the mass of cement in concrete.

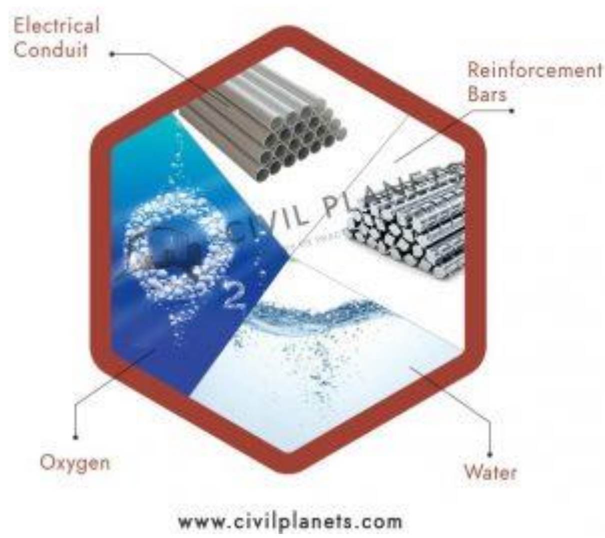
Chloride Attack



Same as sulphate attack, the concrete surface may be contaminated by external environment chloride. It causes corrosion, primarily in reinforcement. By using epoxy coated rebar, we can prevent reinforcement from chloride attack.

So the volume of chloride content must be controlled in construction materials.

Environmental Conditions



Environmental conditions play a crucial role in the structure's durability.
Sometimes the concrete structure may be built near the seashore area, or the structure may be built-in cold weathering conditions. It may result in chemical attacks or freeze-thaw. It affects concrete durability because of steel corrosion.

How to test the durability of concrete?

IS code 516 has described the tests conducted to determine the strength & durability of concrete.

- **Water absorption Test –** By immersing the concrete sample into the water for a certain period, the resistance against water penetration will be derived. The concrete has excellent durability when its absorption value is low.
- **Rapid Chloride Permeability Test –** This test is conducted to determine the concrete resistance against chloride ion penetration in concrete. The electric charge passed in the concrete for a certain period to find the resistance of concrete. The electrical charges passed a benchmark level indicating the strength of concrete.
- **Water Penetration Test –** Using hydrostatic pressure after completion of 28 days curing period, the concrete will be tested for its water permeability. The specimen will be cut in half vertically after three days & measured.

How can you increase the durability of concrete?

- Ensure to use proper mix ratio & workmanship.
- Admixture can be used in concrete to reduce the quantity of water in the concrete.
- Ensure the quality of material used in concrete and do some field tests to check the material quality.
- Use the right type of cement for construction work.
- Use special concrete for special environmental conditions.
- The water-cement ratio should not be exceeded from the permissible limit.
- Proper compaction required for concrete settlement.
- Use self-compacting concrete where the concrete poured location is not possible to compaction by vibration.

Durability of Concrete and Effects of Durability of Concrete

Definition

The ability of concrete to withstand the conditions for which it is designed without deterioration for a long period of years is known as durability.
OR
Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties.
Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than indoor concrete.
Concrete will remain durable if:

- The cement paste structure is dense and of low permeability
- Under extreme condition, it has entrained air to resist freeze-thaw cycle.
- It is made with graded aggregate that are strong and inert

- The ingredients in the mix contain minimum impurities such as alkalis, Chlorides, sulphates and silt.

Factors affecting durability of concrete

Durability of Concrete depends upon the following factors

Cement content

Mix must be designed to ensure cohesion and prevent segregation and bleeding. If cement is reduced, then at fixed w/c ratio the workability will be reduced leading to inadequate compaction. However, if water is added to improve workability, water / cement ratio increases and resulting in highly permeable material.

Compaction

The concrete as a whole contain voids can be caused by inadequate compaction. Usually it is being governed by the compaction equipments used, type of formworks, and density of the steelwork

Curing

It is very important to permit proper strength development aid moisture retention and to ensure hydration process occur completely

Cover

Thickness of concrete cover must follow the limits set in codes

Permeability

It is considered the most important factor for durability. It can be noticed that higher permeability is usually caused by higher porosity. Therefore, a proper curing, sufficient cement, proper compaction and suitable concrete cover could provide a low permeability concrete

Types of Durability

There are many types but the major ones are:

1. **Physical durability of concrete**
2. **Chemical durability of concrete**

Physical Durability

Physical durability is against the following actions

1. Freezing and thawing action
2. Percolation / Permeability of water
3. Temperature stresses i.e. high heat of hydration

Chemical Durability

Chemical durability is against the following actions

1. Alkali Aggregate Reaction
2. Sulphate Attack
3. Chloride Ingress
4. Delay Ettringite Formation
5. Corrosion of reinforcement

Causes for the Lack of Durability in Concrete

1. External Causes:

1. Extreme Weathering Conditions
2. Extreme Temperature
3. Extreme Humidity
4. Abrasion
5. Electrolytic Action
6. Attack by a natural or industrial liquids or gases

2. Internal Causes

a) Physical

- Volume change due to difference in thermal properties of aggregates and cement paste
- Frost Action

b) Chemical

- Alkali Aggregate Reactions
  i. Alkali Silica Reaction
  ii. Alkali Silicate Reaction
  iii. Alkali Carbonate Reaction
- Corrosion of Steel

Sulphate attack on concrete

Sulphate attack on concrete is a chemical breakdown mechanism where sulphate ions attack components of the cement paste. The compounds responsible for sulphate attack on concrete are water-soluble sulphate-containing salts, such as alkali-earth (calcium, magnesium) and alkali (sodium, potassium) sulphates that are capable of chemically reacting with components of concrete.

Contents: [show]

Forms of Sulphate Attack on Concrete

Sulphate attack on concrete might show itself in different forms depending on:

- The chemical form of the sulphate
- The atmospheric environment which the concrete is exposed to.

What happens when sulphates get into concrete?

When sulphates enters into concrete:

- It combines with the C-S-H, or concrete paste, and begins destroying the paste that holds the concrete together. As sulphate dries, new compounds are formed, often called **ettringite**.
- These new crystals occupy empty space, and as they continue to form, they cause the paste to crack, further damaging the concrete.

Sources of Sulphates in Concrete

Following are the sources of sulphates which are responsible for sulphate attack:

1. Internal Sources

This is more rare but, originates from such concrete-making materials as hydraulic cements, fly ash, aggregate, and admixtures.

- Portland cement might be over-sulphated.
- presence of natural gypsum in the aggregate.
- Admixtures also can contain small amounts of sulphates.

2. External Sources

External sources of sulphate are more common and usually are a result of high-sulphate soils and ground waters, or can be the result of atmospheric or industrial water pollution.

- Soil may contain excessive amounts of gypsum or other sulphate.
- Ground water be transported to the concrete foundations, retaining walls, and other underground structures.
- Industrial waste waters.

Reactions of Sulphate Attack on Concrete

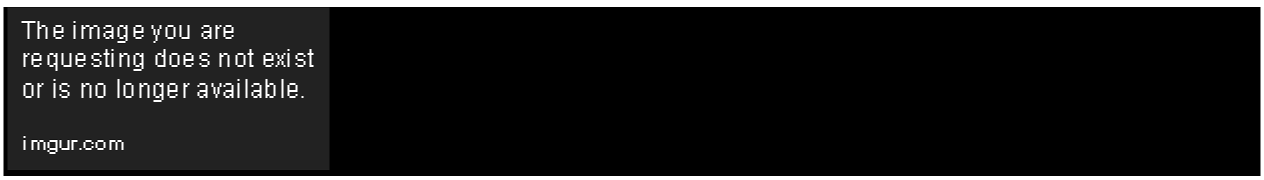
Nature of reaction: Chemical and physical reactions Sulphate attack process decrease the durability of concrete by changing the chemical nature of the cement paste, and of the mechanical properties of the concrete.

1. Chemical Process of Sulphate Attack

The sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = ettringite (calcium sulphoaluminate hydrate)

$C_3A.Cs.H_{18} + 2CH + 2s + 12H = C_3A.3Cs.H_{32}$

Play Video



$C_3A.CH.H_{18} + 2CH + 3s + 11H = C_3A.3Cs.H_{32}$

The sulphate ion + hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste + water = gypsum (calcium sulphate hydrate)

$Na_2SO_4 + Ca(OH)_2 + 2H_2O = CaSO_4.2H_2O + 2NaOH$

$MgSO_4 + Ca(OH)_2 + 2H_2O = CaSO_4.2H_2O + Mg(OH)_2$

Two forms of chemical reaction occurs depending on:

- Concentration and source of sulphate ions .Diagnosis
- Composition of cement paste in concrete.

2. Physical Process of Sulphate Attack

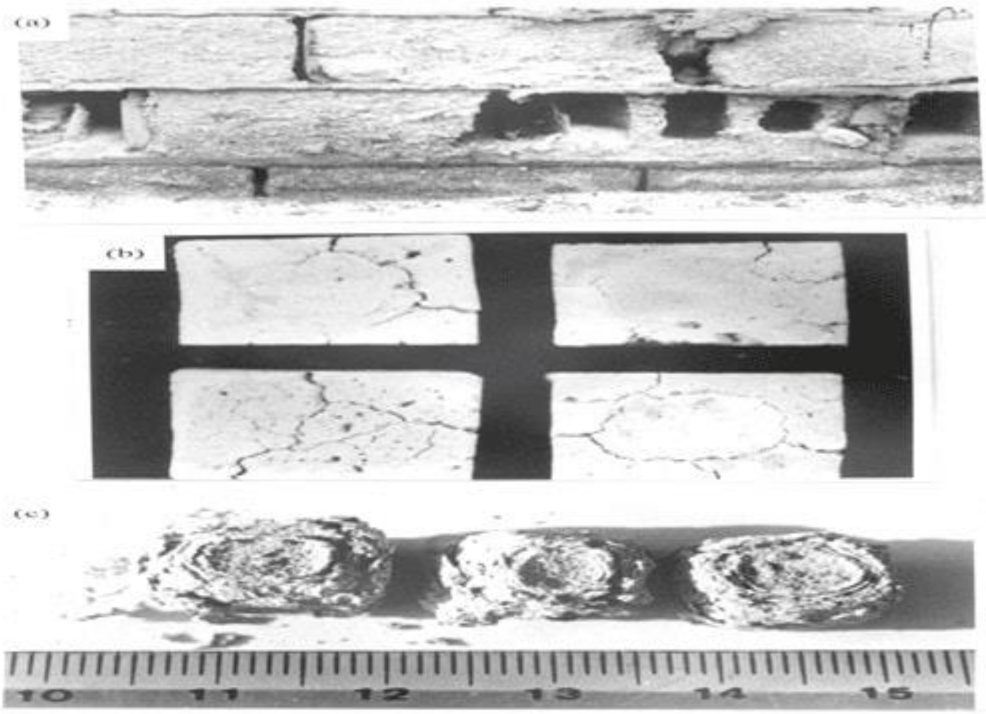
- The complex physicochemical process of "sulphate attack" are interdependent as is the resulting damage.
- physical sulphate attack, often evidenced by bloom (the presence of sodium sulphates Na_2SO_4 and/or $Na_2SO_4.10H_2O$) at exposed concrete surfaces.
- It is not only a cosmetic problem, but it is the visible displaying of possible chemical and microstructural problems within the concrete matrix.

Both chemical and physical phenomena observed as sulphate attack, and their separation is inappropriate.

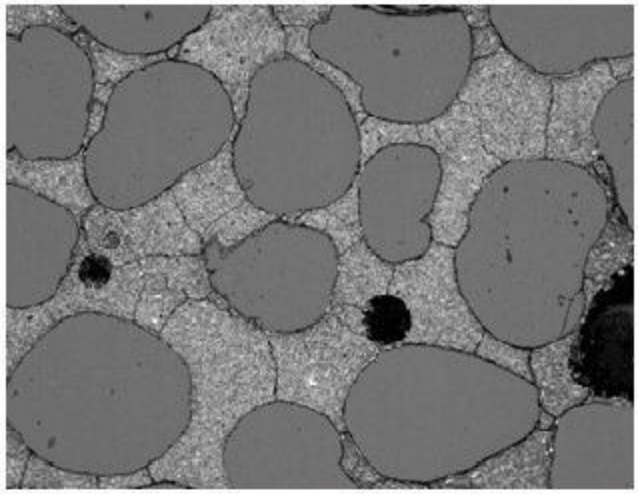
Diagnosis of Sulphate Attack on Concrete

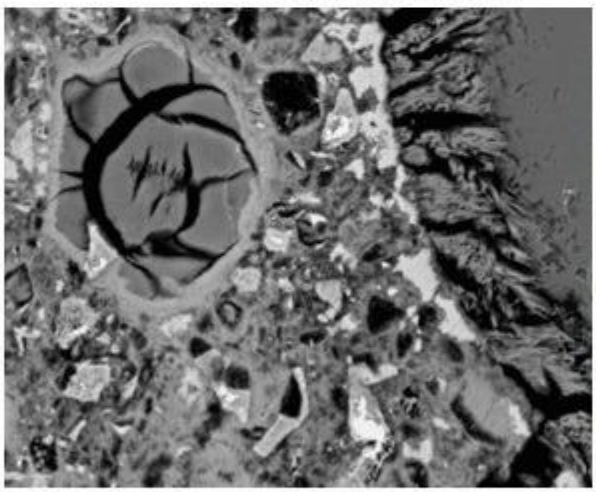
- Spalling of concrete due to sulphate attack.


Spalling due to
Sulfate Attack


(a)
(b)
(c)
10 11 12 13 14 15

Microscopical Examination of Sulphate Attack





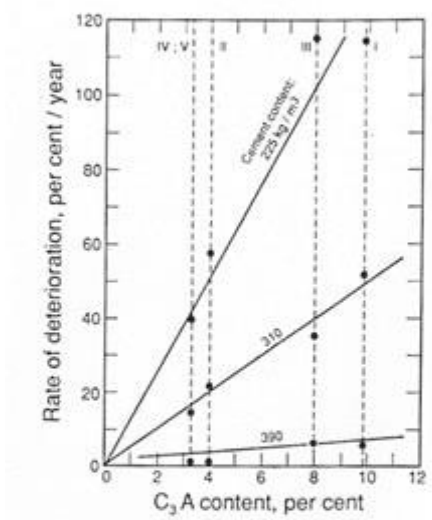
Prevention of Sulphate Attack on Concrete

To prevent the sulphate attack on concrete, we must understand the factors which affect the sulphate attack.

Main factors affecting sulphate attack are:

1. Type of Cement and its Content

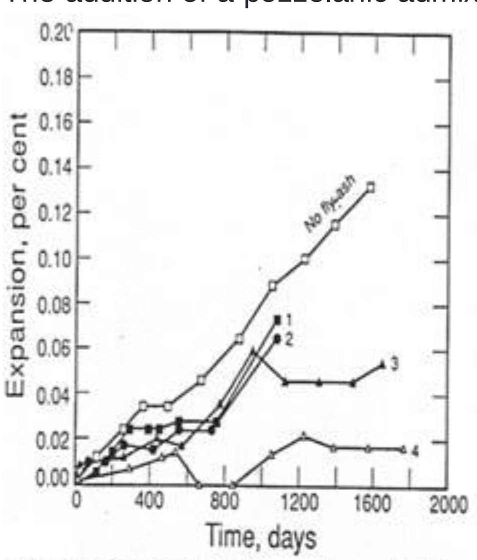
The most important mineralogical phases of cement that affect the intensity of sulphate attack are: C3A, C3S/C2S ratio and C4AF.



Effect of the C_3A content in Portland cement on the rate of deterioration of concrete exposed to sulphate bearing soils

2. Fly ash addition

The addition of a pozzolanic admixture such as fly ash reduces the C3A content of cement.



Sulphate expansion of concrete containing low-calcium fly-ash of different compositions marked 1 to 4.

3. Types of Sulphate and its Concentration

The sulphate attack tends to increase with an increase in the concentration of the sulphate solution up to a certain level.

4. Chloride ions

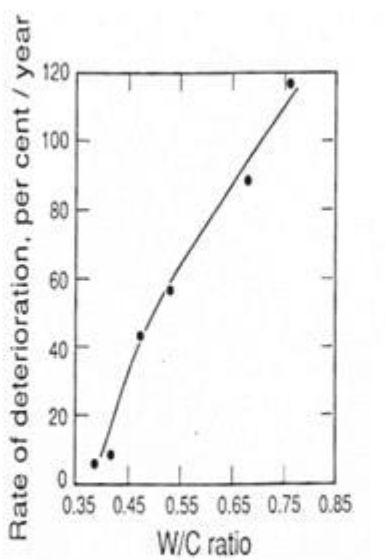
Other factors:

- The level of the water table and its seasonal variation
- The flow of groundwater and soil porosity
- The form of construction
- The quality of concrete

Control of Sulphate Attack on Concrete

Following measures help to control sulphate attack”": 1. The **quality of concrete**, specifically a low permeability, is the best protection against sulphate attack.

- Adequate concrete thickness
- High cement content
- Low w/c ratio
- Proper compaction and curing



Effect of W/C ratio on rate of deterioration of concrete made of ordinary Portland cement and exposed to sulphate bearing soils.

Fig: Effect of water-cement ratio on sulphate attack

2. The **use of sulphate resisting cements** provide additional safety against sulphate attack

Exposure	Concentration of water-soluble sulphates in soil percent	Concentration of water-soluble sulphates in water ppm

Mild	<0.1	<150
Moderate	0.1 to 0.2	150 to 1500
Severe	0.2 to 2	1500 to 10000
Very severe	>2	>10000

Chloride Attack on Concrete

Chloride Attack on Concrete Structures is one of the most important phenomena we consider when we deal with the durability of concrete. Among all sources of failure of concrete structures, the chloride attack accounts 40% contribution. The main effect of chloride attack is the corrosion of reinforcement that induces the strength of the structure drastically.

Contents: [show]

Causes of Chloride Attack on Concrete Structures

The attack of chloride on concrete structures can be happened either from inside of the concrete or through the ingress of chloride from outside to the inside of concrete structures. The chlorides exist in concrete during the casting process due to the following reasons:

1. Use of seawater for the concrete mixing process
2. Use of calcium chloride as an additive to increase the setting time
3. Use of aggregates that contained chlorides which were not washed for mixing
4. Aggregates with chloride content more than the limit stated in the specification

The chlorides enter the concrete from the exterior environment to concrete interior due to the following reasons:

1. Exposure of concrete to seawater
2. Use of salt to melt the ice
3. Presence of chlorides in the substances placed for storage

Comparing both the means of chlorides, the chances of exterior chloride action are high. Most of the offshore structures are subjected to extreme chloride attacks. This induces reinforcement corrosion of structures. In reality, the action of chloride in inducing corrosion of reinforcement is more serious than any other reasons. One may understand that Sulphates attack the concrete whereas the chloride attacks steel reinforcements.

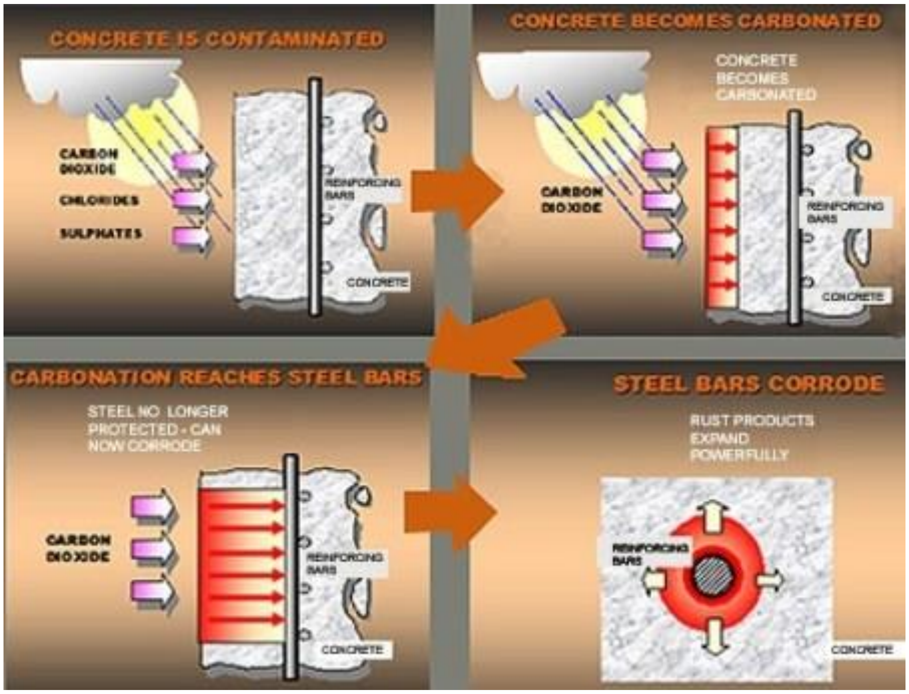


Fig.1. The process of Corrosion of Reinforcement from Chloride Attack

A protective oxide film is present on the surface of the steel reinforcement due to the concrete alkalinity. This layer is called passivity. The process of carbonation will affect this protective passivity layer. This layer can also be affected by the presence of chlorides in water or in oxygen. The reinforcement corrosion process is shown in figure-1.

Prevention of Chloride Attack on Concrete Structures

Several methods are available in order to prevent the effect of chlorides on concrete structures. Some of them are:

1. Increasing the cover over the reinforcement bar. This is the simplest way to prevent chloride attack. Studies have shown that an increase in cover by one inch can increase the life period of the structure by double.
2. The rate of deterioration of the reinforcement under extreme conditions of chlorides can be prevented by having a rebar coated by epoxy, having cathodic protection or by use of stainless steel-clad rebar.
3. Another important way is to decrease the chloride ion ingress into the concrete by decreasing the permeability of the concrete. This will decrease the durability and the time, cost of expensive repairs.

Chloride Content Limit in Concrete Structures

The chloride content limit is the amount of chloride that must be present in concrete along with oxygen and moisture in order to facilitate corrosion. Table-1 below shows the ACI 318-95 code limits of water soluble chlorides. These are limits that must be met when designing the mix proportions.

Table.1: Water -Soluble Chloride -ion Limits in ACI 318-95

Type of Member	Maximum Water-soluble chloride ion(Cl^-) content in concrete, percent by weight of cement	Percent of Water-soluble chloride corrosion threshold (0.15% by weight of cement)
Prestressed Concrete	0.06	40
Reinforced Concrete exposed to chloride in service	0.15	100
Reinforced concrete that will be dry or protected from moisture in service	1	666
Other reinforced concrete construction	0.30	200

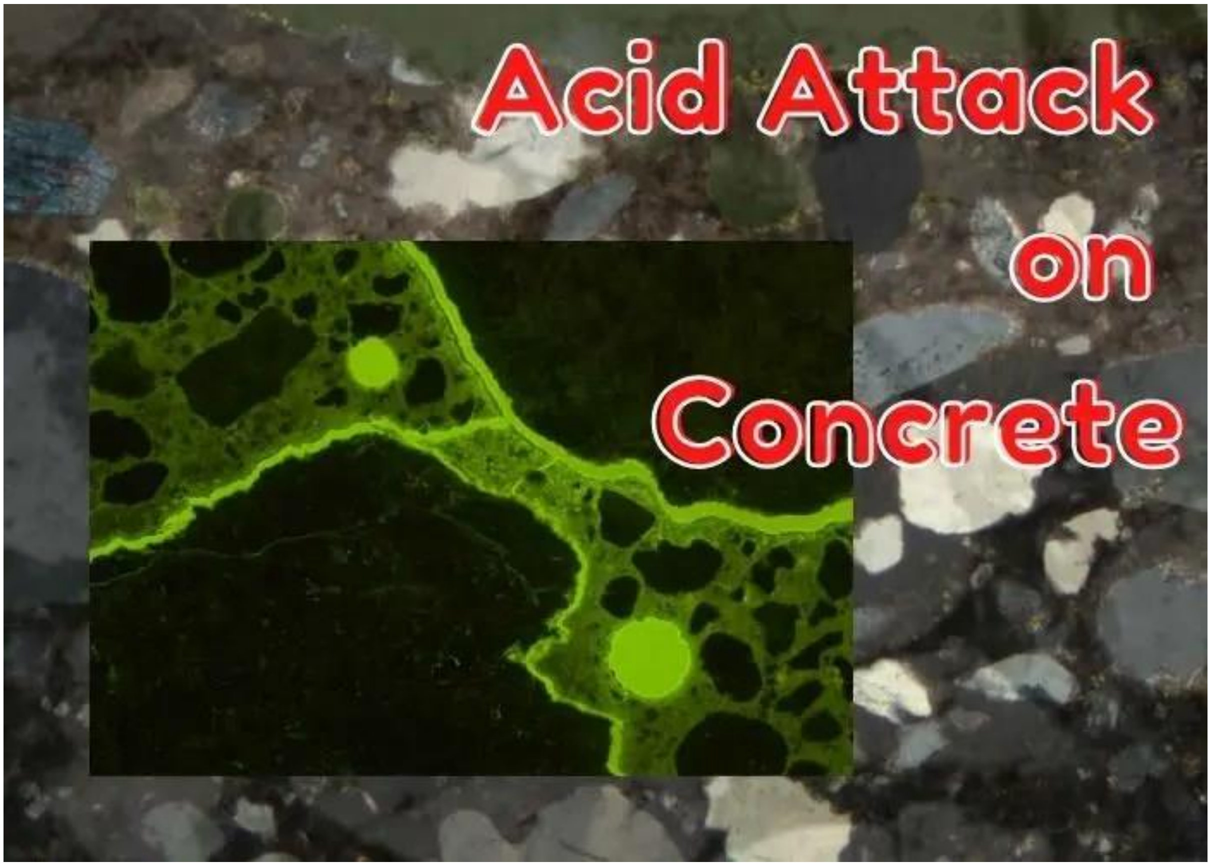
Table.2: Maximum Chloride content in concrete in percent by weight of cement as per ACI Committee 222

Category	Acid-soluble (ASTM C 1152)	Water-Soluble (ASTM C 1218)	Water -Soluble (ACI 222.1)

Prestressed (Pretensioned or post-tensioned)	0.08 (40%)	0.06 (40%)	0.06 (40%)
Non-prestressed Water conditions	0.10 (50%)	0.08 (53%)	0.08 (53%)
Non-prestressed, Dry Conditions	0.20 (100%)	0.15 (100%)	0.15 (100%)

The amount of chloride required for initiating corrosion is partly dependent on the pH value of the pore water in concrete. At a pH value, less than 11.5 corrosion may occur without the presence of chloride. At a pH value greater than 11.5 a good amount of chloride is required.

Acid Attack on Concrete | Is there Remedy for Acid Attack on Concrete?



Acid attack on concrete is caused by most of the acids like sulphuric acid, acetic acid, hydrochloric acid, and nitric acid in solution form. Oxalic acid and phosphorous acid do not attack concrete.The hydrated products of cement are vulnerable to the acid attack in concrete. Acid mostly attacks $Ca(OH)_2$. C-S-H gel can also be attacked sometimes.

Table of Contents

Causes of Acid Attack on Concrete

Following are the causes of acid attack on concrete:

1. Intrusion of low pH solutions:

Acid can attack concrete only when the pH of the liquid drops below 6.5. The following table shows the acid attack at different pH:

< 6.5	acid attack starts
< 5.5	severe acid attack
< 4.5	very severe acid attack

Acid Attack at Different pH

2. Calcareous aggregates:

Aggregates of calcareous origin are more vulnerable to acid attack. Siliceous aggregates show more resistance to acid attack as compared to calcareous aggregates.

3. Presence of SO_2, CO_2 and other acid fumes in a damp atmosphere

SO_2 can form sulphuric acid dissolving in the water while CO_2 can form carbonic acid.

4. Sewerage water:

Anaerobic bacteria release hydrogen sulphide while breaking down organic materials containing sulphur.

H2S (hydrogen sulphide) is produced, which is not so destructive. However, it is dissolved in the moisture films formed on the concrete surface. Anaerobic bacteria oxidises H_2S into sulphuric acid.

Hence, the acid attack takes place in sewers above the water level.

5. Moorland water or Water from ice melting:

Melted water from ice or moorland water contains free CO_2. If the concentration of CO_2 is 15-60 ppm, then it may cause acid attack.

If the concentration of CO2 > 60 ppm, then the pH of its solution may be as low as 4.4. Hence, a very severe acid attack will be caused.

Mechanism of Acid Attack on Concrete

From hardened concrete, the acidic constituents react with the hydrated products of cement. To know which are the hydrated products of cement, READ Products of Hydration of Cement.

Calcium sulphate is first attacked followed by C-S-H gel.

The rate of acid attack depends upon the ability of hydrogen ions to diffuse through the C-S-H gel after dissolved $Ca(OH)_2$ is leached out.

Hydration of cement:

$$calcium\ silicate + water \rightarrow calcium\ silicate\ gel + calcium\ hydroxide$$

$$Ca(SO)_4 + H_2O \rightarrow C - S - H\ gel + Ca(OH)_4$$

Above reaction illustrates the hydration of cement. Out of the two products of hydration, calcium hydroxide is first attacked.

Reaction with calcium hydroxide $(Ca(OH)_2$

$$acid + calcium\ hydroxide \rightarrow acid\ salt + water$$

Soluble calcium salt is formed, which is easily removed from the concrete. Thus, the concrete structure weakens as a whole.

Acids with low solubility- Weaker acids like phosphoric acid or humic acid produce less soluble salt, which can even inhibit the whole process of acid attack.

Acids with high solubility- Aggressive acids like hydrochloric, acetic, nitric, and sulphuric acids form highly soluble calcium salts.

For instance, sulphuric acid produces calcium sulphate, a highly soluble salt. It increases the rate of attack.

$$H_2SO_4 + Ca(OH)2 \rightarrow CaSO_4 + H_2O$$

Reaction with calcium silicate hydroxide (C-S-H gel):

After calcium hydroxide is consumed, the dissolution of calcium silicate gel starts. This will cause severe damage to concrete.

Sometimes, the precipitation of the insoluble salts formed causes expansion in concrete.

Calcium, iron, aluminium, and silicate ions can form complexes with acids increasing the concentration of these ions. Thus, the process of acid attack is intensified.

Effect of Acid Attack on Concrete

Due to acid attack on concrete, all the cement compounds get broken down. With any carbonate material, the broken cement constituents are leached away.
Another effect of acid attack is the corrosion of reinforcement. Acid can reach the reinforcement by penetrating the concrete (high porosity) or by traversing through cracks.
When acid comes in contact with steel, it causes corrosion leading to cracks in concrete.

Effect of Sulphuric Acid Attack on Concrete

Sulphuric acid attack on concrete can also occur if SO_2 (sulphur dioxide) fumes are present in the damp atmosphere. SO_2 dissolves forming sulphuric acid and removes a part of set cement.
Reaction of H_2SO_4 with calcium hydroxide:

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4.2H_2O$$

Reaction of H_2SO_4 with calcium silicate hydroxide gel:

$$3CaO.2SiO_2.3H_2O + H_2SO_4 \rightarrow CaSO_4.2H_2O + Si(OH)_4$$

Soft and weak mass of concrete is left as a result of acid attack. This phenomenon of acid attack can occur at chimneys and dairy floors.
Effect of sulphuric acid attack on concrete mechanism:

- **Calcium hydroxide formed as a result of hydration of cement reacts with calcium aluminates, which is another product of hydration of C_3A.**
- **Calcium sulphoaluminate is formed from this reaction.**
- **Crystallisation of calcium sulphoaluminate takes place.**
- **As a result, expansion is caused in concrete, which leads to disruption of concrete.**

Effect of Hydrochloric Acid Attack on Concrete

Hydrochloric acid will form both insoluble and soluble salts while reacting with hydrated cement products.
Calcium hydroxide reacts with HCl forming calcium chloride as shown below:

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

Effect of Nitric Acid Attack on Concrete

Nitric acid is produced from artificial manure, plants manufacturing explosives, etc. from nitrogen dioxide as shown below:

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

Calcium nitrate is formed from nitric acid's reaction with hydration products, which is highly soluble. It leaches inside the concrete and causes corrosion followed by shrinkage.
Visible cracks form across the corroded layer. Cracks, in turn, allow penetration of more nitrates. Hence, the acid attack phenomenon increases.

Effect of Acetic Acid Attack on Concrete

Calcium acetate is formed after acetic acid reacts with the products of hydration of cement.
Reaction of CH_3COOH with calcium hydroxide:

$$2CH_3COOH + Ca(OH)_2 \rightarrow Ca(CH_3COO)_2 + 2H_2O$$

Reaction of CH_3COOH with calcium silicate hydroxide gel:

$$2CH_3COOH + 3CaO.2SiO_2.3H_2O \rightarrow SiO_2 + Ca(CH_3COO)_2 + 2H_2O$$

Calcium acetate formed is highly soluble. It leaches inside the concrete and causes corrosion followed by shrinkage.
Visible cracks form across the corroded layer. Cracks, in turn, allow penetration of more nitrates. Hence, the acid attack phenomenon increases.
Thus, the process is similar to that of nitric acid, but the rate of attack is slower.
Acetic acid may be found in agricultural waste along with lactic acid.

How to Prevent Acid Attack on Concrete?

Acid attack on concrete may be prevented by fixing calcium hydroxide- $Ca(OH)_2$.
As we have seen, acid attack occurs as the acidic solution attacks calcium hydroxide. Therefore, reducing or fixing it can reduce the risk of acid attack.
Calcium hydroxide can be fixed by:

- **A treatment with diluted water and sodium silicate (glass) can be done so that calcium silicates are formed inside the pores in concrete.**
- **Another method of fixing $Ca(OH)_2$ is the surface treatment. Coal tar pitch, rubber or bituminous paints, epoxy resins, and other such agents can be used for surface treatment.**

Remedy of Acid Attack on Concrete

Acid attack on concrete can be remedied by:
1. Using fly ash and silica fume in concrete

Fly ash helps in decreasing the porosity of concrete as it packs the aggregates and cement densely. To know how fly ash helps in achieving this, READ Effects of Fly Ash on Hardened Concrete and Durability.
Microsilica exhibits pozzolanic reactions and consumes calcium hydroxide, the constituent responsible for acid attack.
If microsilica is used alone without fly ash, microcracks may form in the concrete, which will then pave way for acid inside the concrete.
2. Entraining air in concrete
Entraining air can improve the workability and allow the dense packing of concrete making it homogenous.
Air voids block the capillaries in concrete preventing acid intrusion.
3. Using siliceous aggregates
Calcareous aggregates are more prone to acid attack. Hence, siliceous aggregates should be used as their resistance to acid attack is better.
4. Applying surface treatments to concrete
Acid attack occurs at a pH of less than 6.5. if the concrete is exposed to an environment with a pH of less than 4.5, then surface treatment is provided to concrete.

Key TakeAway

Acid attack on concrete is because of the reaction between the acids and the products of the hydration of cement. Aggressive acids like sulphuric acid, acetic acid, hydrochloric acid, and nitric acid in solution form cause much damage to concrete.
In an acidic environment, the acid reacts with calcium hydroxide and forms soluble salts. After calcium hydroxide is consumed, the more aggressive acids like sulphuric and acetic acid react with C-S-H gel. Thus, the solids in concrete start to break down and concrete is weakened.
Moreover, when acids come in contact with the steel reinforcement, they pave the risk of corrosion.
Effects of Acid Attack on Concrete:

1. **Corrosion**
2. **Increase in volume or shrinkage**
3. **Formation of cracks**
4. **Increase in capillary porosity**
5. **Loss in cohesiveness**
6. **Loss of strength**

Remedy of Acid Attack on Concrete:

1. **Using fly ash and silica fume in concrete**
2. **Entraining air in concrete**
3. **Using siliceous aggregates**
4. **Applying surface treatments to concrete**

EFFLORESCENCE IN CONCRETE

EFFLORESCENCE IN CONCRETE – WHAT, WHY & HOW?

WHAT IS EFFLORESCENCE IN CONCRETE?

Efflorescence in concrete simply means appearance of white colored powdered material on the concrete surface. Efflorescence is the formation of salt deposits, usually white, on or near the surface of concrete after it has been finished and causing a change in the appearance.
Light-coloured concrete shows the deposit much less than darker coloured concrete.
Note: With time, efflorescence becomes less extensive and should eventually cease to occur, unless there is an external source of salt.

Efflorescence in concrete – what, why & how

WHY EFFLORESCENCE IN CONCRETE OCCUR? (CAUSES)

Efflorescence is usually caused by a combination of the following factors:

- One or more of the constituents of concrete may contain salts
- A high water-cement ratio resulting in a more porous concrete that allows movement of water and salt solutions
- Inadequate curing which may leave un-hydrated products near the surface of the concrete
- Exposure to rain or other water sources (moisture allows salts to be transported to the surface where they accumulate as the water evaporates)
- Slow rate of evaporation of water allowing time for salts to permeate to the surface (this is why efflorescence tends to be more of a problem during the winter months; in summer, high temperatures may cause evaporation and hence depositing of salts within the concrete rather than on the surface)
- Variability of concrete (e.g. from compaction or curing) can result in localised problems where water can permeate more easily through the concrete.

HOW TO PREVENT EFFLORESCENCE IN CONCRETE?

Measures to prevent/control the occurrence of efflorescence include:

- Use ingredients containing as little soluble salt as possible.
- Use waterproofing admixtures to reduce permeability of concrete/mortar. Note that as some of these products may cause efflorescence themselves (e.g. water-soluble soaps) always check with the manufacturer.
- Use a denser concrete, again to reduce permeability. However, this may increase the shrinkage.
- Use **cement : lime : sand** mortars no stronger than required for the application to minimise possible soluble salt levels.
- Lime should be hydrated lime free from calcium sulphate.
- Avoid premature drying.
- Apply curing compounds or same-day sealers to reduce exposure to wetting.
- Protect hardened concrete from exposure to moisture by maintaining surface sealers and site drainage, and from rising groundwater by placing a plastic membrane under slabs.
- For masonry, ensure flashings, damp-proof courses and copings are detailed correctly, cover the top course at the end of each day’s work, tool joints with a ‘V’ or concave shaped jointer to compact the mortar at exposed surfaces, provide wide eaves and avoid wetting from sources such as sprinklers.

HOW TO REPAIR CONCRETE SURFACE AFFECTED BY EFFLORESCENCE?

Prior to removing efflorescence, the things that may be causing the problem should first be corrected so as to limit or reduce the risk of re-occurrence.

METHOD-1 (BRUSHING)

Soluble salt deposits can be removed with a stiff-bristle broom. Note that all brushed-off material should be totally removed by vacuum cleaning or other means. If the result is not satisfactory, scrub with clean water then lightly rinse the surface. Note that adding water may result in further deposits. Repeated dry brushing as the deposits appear is probably the best treatment.

Insoluble salt deposits (hard, white, scaly or crusted) cannot be removed by water washing, although the use of a high-pressure water jet is effective.

METHOD-2 (USING DILUTE ACID SOLUTION)

The application of a dilute acid solution is also effective in most cases, and in some cases, may be the only way (as explained below).

Extreme care is required when handling acids. When diluting hydrochloric acid always add the acid to the water, never the reverse. Ensure good ventilation and avoid contact between the acid and the reinforcement. Use only diluted acid to clean the concrete surface.

The recommended proportions are **1 part hydrochloric acid to 20 parts water**. Always saturate the surface with water before applying the dilute acid solution. When applying the solution, ensure that the surface is moist but without any free water being present. The applied solution should be allowed to react on the concrete surface for **10 to 15 minutes**. The surface should then be thoroughly rinsed and scrubbed with lots of clean water. Repeat rinsing at least twice or until all traces of the acid solution have been removed. The process may be repeated if necessary to produce the required surface finish.

Note: Washing with acid may cause colour variations and alter the surface texture. For coloured finishes a more dilute acid solution (**2% or 1 part acid to 50 parts water**) may be required. A small trial area should be done first to assess the results.

Efflorescence in concrete is a whitish coloured powdered deposition of salts on the concrete surface that is formed due to evaporation of water from the concrete. It is caused when water soluble salts are present in the concrete material, which comes on to the surface while evaporation of water from the concrete.


Fig 1: Efflorescence in concrete wall.

Contents: [show]

Causes for Formation of Efflorescence in Concrete

The formation of efflorescence in concrete is factored by many external factors.

1. Presence of salts in one of the materials of concrete. Commonly salts are found in the fine aggregate or sand taken from the river beds.
2. If the concrete is not cured properly, the hydration process is incomplete on which the un-hydrated products near the surface form the efflorescence on the surface of concrete.
3. Slow rate of evaporation of water allowing time for salts to permeate to the surface (this is why efflorescence tends to be more of a problem during the winter months; in summer, high temperatures may cause evaporation and hence depositing of salts within the concrete rather than on the surface)
4. If the water content in the concrete mix is more, it makes the concrete porous. Thus allowing the path for water and salts to come to the surface and for efflorescence.
5. In wet conditions such as rainy season, the surplus water acts as a medium for the salts to transport to the surface of concrete and form crystalline white powder.
6. Variability of concrete (compaction or curing) can result in localised problems where water can permeate more easily through the concrete.

Type of Salts in Efflorescence

1. **Calcium Sulphate**
   A common efflorescence salt source in brick
2. **Sodium Sulphate**
   Often seen in cement-brick reactions
3. **Potassium Sulphate**
   Noticeable in many cement-brick reactions
4. **Calcium Carbonate**
   May be discovered in mortar or concrete backing
5. **Sodium Carbonate**
   Frequently seen in mortar
6. **Potassium Carbonate**
   Like sodium carbonate, commonly found in mortar
7. **Vanadyl Sulphate**
   Usually found in brick
8. **Manganese Oxide**
   Often present in brick.

Prevention of Efflorescence in Concrete

The preventive methods that can be used to avoid efflorescence in concrete are,

1. Inclusion of Class-F fly ash or metakaolin can lock up significant amounts of calcium hydroxide in the concrete.
2. Installing vapour barrier to prevent the movement of moisture from the sub grade to the surface of a slab.
3. Application of sealers and coatings can prevent surface water from penetrating slabs.
4. Waterproofing agents to be used to reduce permeability of concrete.
5. Making the concrete denser will reduce the permeability of concrete to a greater extent.
6. Preventing the hardened concrete from exposure to moisture by maintaining surface sealers and site drainage, and from rising groundwater by placing a plastic membrane under slabs.
7. Avoiding the concrete from premature drying.
8. Use of concrete ingredient such as aggregate, cement and sand which contains very less amount of salts in it.

Removal of Efflorescence in Concrete

Before removal of efflorescence in concrete, the source for the cause for the efflorescence must be found out and tried to mitigate it. Further the removal of efflorescence can be done in 3 methods,

1. Pressurised Water

Efflorescence in the concrete can be removed using the pressurised water jet. Applying pressurised water may dissolve efflorescence quickly. But care must be taken that the water after removing of efflorescence is completely dried off. If not dried, the same water can cause efflorescence to reappear.

Fig 2: Removal of efflorescence using pressurised water.

2. Brushing

Some type of efflorescence that are easily removable can be easily removed using a stiff?bristle broom or brush. If the result is not satisfactory by dry brushing, scrub with clean water then lightly rinse the surface.

3. Dilute Acid Solution

Concentrated acid is not recommended to be applied on concrete, diluted proportion of 1:20 is used. the surface in which the acid is applied must be moist but without any free water. The applied solution should be allowed to react on the concrete surface for 10 to 15 minutes. The surface should then be thoroughly rinsed and scrubbed with lots of clean water. Repeat rinsing at least twice or until all traces of the acid solution have been removed.

Fig 3: Removal of efflorescence using diluted acid and brush.

Washing with acid may cause colour variations and alter the surface texture. For coloured finishes a more dilute acid solution (2% or 1 part acid to 50 parts water) may be required. A small trial area should be done first to assess the results.
Proper safety to be followed while doing this procedure. Ensure good ventilation and avoid contact between the acid and the reinforcement.

Acids used in Removal of Efflorescence in Concrete

- Hydrochloric acid.
- Phosphoric acid.
- Phosphoric acid.
- Prepackaged efflorescence removers.

Applying of Coating to Prevent Efflorescence in Concrete

Clear water repellents, silicone and acrylic coatings also may help you remove efflorescence as well. The coating will absorb water across a masonry surface and

prevent efflorescence from recurring. Plus, the combination of warm water and white wine vinegar has been shown to eliminate efflorescence.
Application of sealant coat is done in 3 steps,

1. Rinsing of Concrete

Rinse the building surface with water. If the surface is outdoors, you can use a hose to spray down the surface. Or, if the surface is indoors, you can use a spray bottle filled with water to rinse the surface thoroughly.

2. Applying the Solution

Spray the cleaning solution onto the building surface and allow it to sit for several minutes. If necessary, you may apply multiple coats of the cleaning solution to the surface for optimal results.

3. Rinsing of Concrete Again

Rinse the building surface with water one last time. Then, use a fresh, dry cloth to clean the surface. Ensure the surface is dry to minimize the risk of ongoing efflorescence.
Apply coatings roughly 1/8 in. to 1/4 in. below the surface of the building material. This will prevent water from evaporating and passing through the treated area as vapour and soluble salts.

6 Concrete mix Design

6.1

Data Required for Mix Design of Concrete | Concrete Technology

For the mix design of concrete following data is required: 1. Characteristic (Targeted) Compressive Strength at 28 days 2. Degree of Workability (Selection of Water-Cement Ratio) 3. Estimation of Entrapped Air 4. Selection of Water-Cement and Fine to Total Aggregate Ratio 5. Calculation of Cement Content 6. Calculation for Aggregate Content and a Few Others.

1. Characteristic Compressive Strength at 28 Days:

The target mean compressive strength f_t, at 28 days is given by the relation-

$f_t = f_c$ + K.S. ...(i)

where f_t is the target mean strength at 28 days, f_c is the characteristic strength at 28 days. As per IS-456- 2000 and IS-1343-1980, the characteristic strength of the concrete is that value of the concrete, below which not more than 5% results are expected to fall.

where,

S = standard deviation. For the initial value of mix design the value of standard deviation may be adopted from table 20.32 below.

K = a statistical coefficient known as tolerance factor or risk factor. The value of K may be adopted from table 20.33.

From table 20.33, the value of K is taken as 1.65, putting the value of K is equation (i) we get.

$\therefore f_t = f_c + 1.65$ S...(ii)

Table 20.32. Value of standard deviation as suggested by IS 456-2000

Grade of Concrete	*Assumed standard deviation N/mm²*	*Remark*
M_{10}	3.5	These values relate to the site control as below
M_{15}	do	
M_{20}	4.0	(*i*) Proper storage
M_{25}	do	
M_{30}	5.0	(*ii*) Weight batching of all materials
M_{35}	do	(*iii*) Controlled addition of water
M_{40}	do	(*iv*) Regular checking of all materials
M_{45}	do	(*v*) Periodcal checking of workability and strength
M_{50}	do	

Table 20.33. Values of tolerance factor

Tolerance level / *No. of samles*	1 in 10	1 in 15	1 in 20	1 in 40	1 in 100
10	1.37	1.65	1.81	2.23	2.76
20	1.32	1.58	1.72	2.09	2.53
30	1.31	1.54	1.70	2.04	2.46
Infinite	1.28	1.50	1.64	1.96	2.33

Note. Under major concreting jobs, where large no. of samples are tested, the tolerance factor should be adopted corresponding to infinite no.

2. Selection of Water-Cement Ratio:

Even when the water-cement ratio is fixed, the compressive strength of concrete is influenced by various factors such as type of cement and aggregate, maximum size of aggregate, surface texture of aggregate etc. Thus it is desirable to establish relation between the strength of concrete and free water/cement ratio for the materials to be used and site conditions. If it is not possible to establish such relation, then for the targeted strength of the concrete the free water/cement ratio may be obtained from the curve 20.7 given below.

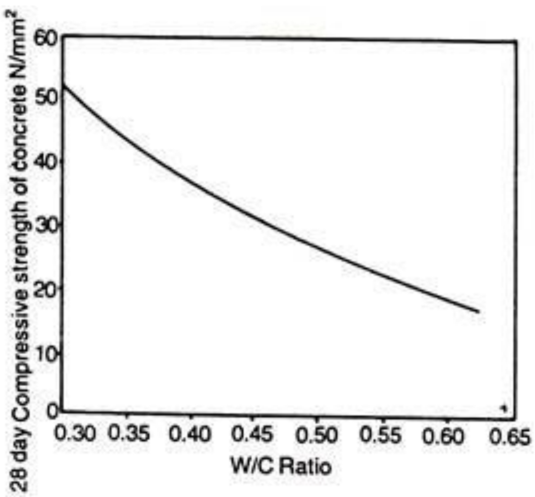
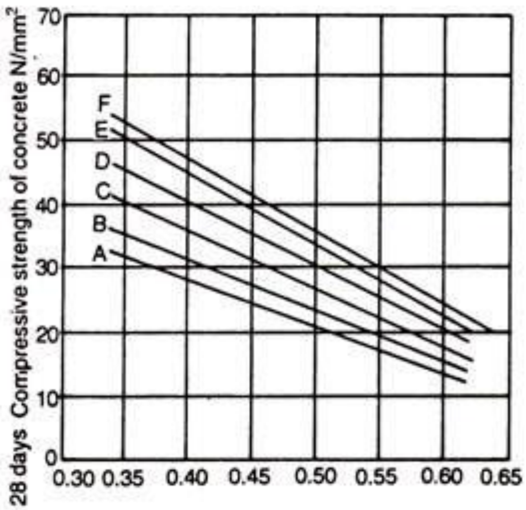


Fig. 20.7. General relation between free water/cement ratio and compressive strength of concrete

In this method of mix design, the strength of cement has been incorpo-rated. By incorporating the strength of cement, it is possible to effect economy in the concrete mix.

If the 28 days cement strength is known then for more accurate estima-tion of water/cement ratio curves shown in Fig. 20.8 can be used. However adoption of these curves will delay the work as for testing the 28 days strength; at least a delay of 28 days will be there in the whole process.

To cut down this delay, accelerated strength tests may be adopted. Since 1982 the quality and strength of Indian Cement has improved considerably. Hence for determining the water/cement ratio curve of Fig. 20.9 may be adopted instead of Fig. 20.8. The curves of Fig. 20.9 are not a part of the IS recommended method. They are taken from practice in Germany and may be more useful for getting better results.



A = 31.9 – 36.8 N/mm²
B = 36.8 – 41.7 N/mm²
C = 41.7 – 46.6 N/mm²
D = 46.6 – 51.5 N/mm²
E = 51.5 – 56.4 N/mm²
F = 56.4 – 61.3 N/mm²

Fig. 20.8. Relation between free w/c ratio and concrete strength for different cement strength

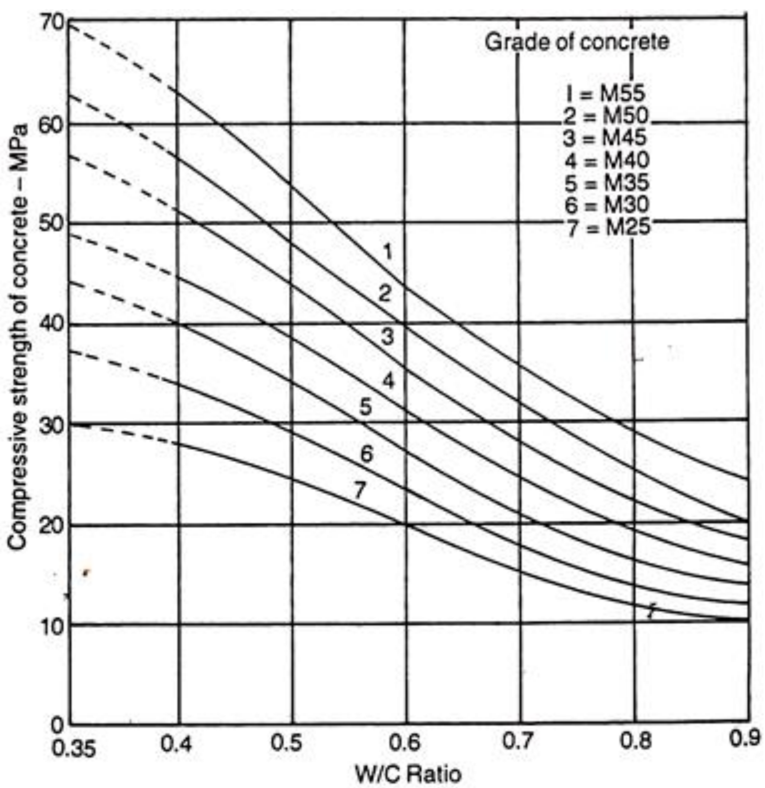


Fig. 20.9. Relation between w/c ratio and compressive strength used in Germany

The free water/cement ratio thus selected as discussed above, should also be checked from durability requirements as shown in Table 20.34, the lower value of the two should be adopted.

Table 20.34. Minimum Cement content, Max. w/c ratio, and minimum grade of concrete for different exposure with nominal weight aggregate of 20 mm nominal max. size as per IS 456-2000

S. No.	Exposure	Plain concrete			Reinforced concrete		
		Min. cement contents in kg/m³	*Max. Free w/c ratio*	*Min. grade of concrete*	*Min. cement contents in kg/m³*	*Max. Free w/c ratio*	*Min. grade of concrete*
1.	Mild	220	0.60	—	300	0.55	M_{20}
2.	Moderate	240	0.60	M_{15}	300	0.50	M_{25}
3.	Severe	250	0.50	M_{20}	320	0.45	M30
4.	Very severe	260	0.45	M_{20}	340	0.45	M35
5.	Extreme	280	0.40	M_{25}	360	0.40	M40

3. Estimation of Entrapped Air:

The air content is estimated as shown in Table 20.35 for the nominal aggregate used.

Table 20.35. Approximate amount of entrapped air

Max. size of aggregate in mm	*Entrapped air as % of volume of concrete*
10	3.0
20	2.0
40	1.0

4. Selection of Water Content and Fine to Total Aggregate Ratio:

For medium strength concrete i.e. below M_{35} grade concrete and high grade concrete i.e. higher than M_{35} grade, the water content and percentage of sand in total aggregate by absolute volume basis can be determined from table 20.36 and 20.37 respectively.

Both tables are based on the following conditions:

(a) Crushed coarse aggregates conforms to IS 383-1970

(b) Fine aggregate consisting of natural sand conforms to the grading of zone II of IS 383-1970.

(c) Workability corresponding to slump of about 30 mm (compacting factor 0.80).

The water/cement ratio of table 20.36 is 0.6 by mass and that of Table 20.37 as 0.35 by mass. For departure from above noted conditions corrections have to be applied as suggested in table 20.38.

Table 20.36. Approximate sand and water content per cubic metre of concrete w/c = 0.6, workability, C.F. = 0.8 and slump = 30 mm app., applicable for concrete upto grade M35

Maximum size of aggregate (mm)	*Water content including surface water per cubic metre of concrete in kg.*	*Sand as % of total aggregate by absolute volume*
10	200	40
20	186	35
40	165	30

Table 20.37. Approximate sand and water content per cubic metre of concrete, w/c ratio 0.35, workability slump about 30 mm, C.F. = 0.8. For concrete strength above 35 MPa or M35 grade

Max. size of aggregate in (mm)	*Water content including surface water per cubic metre of concrete in kg.*	*Sand as % of total aggregate by absolute volume*
10	200	28
20	180	25

Table 20.38. Adjustment in water content and sand percentage for other conditions

S. No.	*Change in conditions stipulated for tables*	*Adjustments required in*	
		Water content	*% sand in total aggregate*
1.	For sand conforming to grading zone I Zone III or Zone IV table 4 IS-383-1979	0	+ 1.5% for zone I – 1.5% for zone III – 3.0 for zone IV
2.	Increase or decrease in the value of compacting factor by 0.1	± 3.0%	0
3.	Each 0.5% increase or decrease in w/c ratio	0	± 1.0%
4.	For rounded aggregate	– 1.5 kg	— 7%

5. Calculation of Cement Content:

The cement content per unit volume of concrete may be calculated from free water/cement ratio and the quantity of water per unit volume of concrete as-

Cement by mass = [(water content)/(w/c ratio)]

The cement content so calculated should by checked for durability requirement Table 20.34. Greater of the two values should be adopted.

6. Calculation for Aggregate Content:

Aggregate content may be calculated from the following relation:

$$V = \left[W + \frac{C}{S_c} + \frac{1}{P} \times \frac{f_a}{Sf_a} \right] \times \frac{1}{1000} \qquad \text{...(1)}$$

Coarse aggregate $$C_a = \frac{1-P}{P} \times f_a \times \frac{S_{c_a}}{Sf_a} \qquad \text{...(2)}$$

where,

V = Absolute volume of fresh concrete, which is equal to vol. of concrete in m^3 minus the volume of entrapped air.

W = mass of water (kg.) per m^3 of concrete

C = mass of cement (kg) per m^3 of concrete

S_c = specific gravity of cement

p = ratio of fine aggregate (F.A.) to total aggregate by absolute volume

f_a = total mass of F.A. (kg.) per m^3 of concrete

C_a = total mass of coarse aggregate (kg) per m^3 of concrete

Sf_a & S_{ca} = sp. gravities of fine and coarse aggregate respectively.

7. Actual Quantities Required for the Mix:

The mix proportions calculated by the above noted method are based on the assumption that aggregates are saturated and surface dry. For any change than these conditions, i.e., when aggregates are moist or air dry or fully dry. Corrections in the quantity of mixing water as well as in aggregates have to be made.

8. The Calculated Mix Proportion should be Checked by Trial Batches:

For each trial, the mix should be sufficient to prepare at least three 150 mm cubes and workability should be as per IS 1199-59. If any change is required to be done, it should be done as per table 20.38.

The method is illustrated by following examples:

Example:

(a) Design Stipulation (Requirements):

(i) Characteristic compressive strength at 28 days in the field required = 25 MPa

(ii) Maximum size of crushed aggregate = 20 mm (angular)

(iii) Degree of workability = Medium, compacting factor 0.90 or slump 75 mm

(iv) Degree of quality control Good

(v) Type of exposure Mild

(vi) Grading zone of sand III (I.S. 385-1970)

(b) Characteristics of materials

Cement:

(i) Type of cement Ordinary port-land cement

(ii) Specific gravity 3.15

(iii) Bulk density of cement 1450 kg/m3

(iv) Compressive strength at 7 days Satisfies the requirements of IS 269-1989

Aggregate	*Fine aggregate*	*Coarse aggregate*	*Remark*
Sp. gravity	2.60	2.75	C.A. Conforming to Table 2 IS-383-1970
Bulk density (kg/m^3)	1700	1600	
Free moisture	1.5%	1.0%	
Fineness modulus	2.2	6.0	
Water absorption	2%	0.5%	

Sieve analysis of coarse aggregate is given below

Coarse aggregate

Sieve size in mm	*Fractions passing*		*% of different fractions*		*Conbined*	*Remark*
	I	II	I 60%	II 40%	100%	
20	100	100	60	40	10	Conform to Table 2 IS-383-1970
10	0	72.2	03	29.5	29.5	
4.75	—	8.7	—	4.7	4.7	
2.36						

(c) Mix Design. Target Mean Strength:

$f_t = f_c + K\,S$ The values of K and S are taken from tables 20.32 and 20.33

= 25 + 1.6 x 4 = 25 + 6.4 = 31.4 Ma

(d) Selection of Water/Cement Ratio:

As the seven days strength is specified, use of Fig. 20.8 has been made.

For a targeted mean strength of 31.4 MPa, the w/c ratio is 0.48

This is lower than specified value of 0.55 for R.C.C. from durability consideration for mild exposure. Hence adopt w/c ratio as 0.48.

(e) Selection of Water and Sand Contents:

For 20 mm maximum aggregate size, sand conforming to the grading of zone II, from table 20.36, water content per cubic metre of concrete = 186 kg.

Sand content % of total aggregate = 35% For change in w/c ratio, compacting factor, for sand belonging to zone III, following adjustments must be made as per table 20.38

S. No.	Changes As per table 11.38	Percent adjustments required	
		Water content	Sand in total aggregate
1.	For decrease in Water/Cement ratio by (0.60-0.48) *i.e.* 0.12	0	– 2.0
2.	For increase in compacting factor from 0.8 to 0.9 *i.e.* 0.10	+ 3.0	0
3.	For sand conforming to zone III of table 4, IS 383-1970	0	– 1.5
	Total change	+ 3.0	– 3.5%

Thus required sand as percentage of total aggregate by absolute value 35.0 – 3.5 = 31.5%

Required water content = 186 + 3% of 186 kg = 186.0 + 5.58 = 191.58 kg = 191.6 kg.

(f) Determination of Cement Content:

Water/cement ratio = (0.60 – 0.12) = 0.48

Amount of water = 191.6 kg

= 191.6

Cement = [(Amount of water)/(w/c ratio)] = 191.6/0.48

= 399.2kg/m^3 app.

Cement content from durability considerations from table 20.34 for mild exposure is adequate.

(g) Determination of Coarse and Fine Aggregate Contents:

From table 20.35, for the specified maximum size of aggregate of 20 mm, the amount of entrapped air is 2%.

$$V = \left[W + \frac{C}{S_c} + \frac{1}{P} \times \frac{f_a}{Sf_a} \right] \times \frac{1}{1000} \qquad \ldots(1)$$

Coarse aggregate $$C_a = \frac{1 - P}{P} \times f_a \times \frac{S_{c_a}}{Sf_a} \qquad \ldots(2)$$

Taking this into account and using equation no. 1 and 2 we get-

Absolute volume of concrete = 1 – 0.02 = 0.98%

$$\therefore \quad 0.98 = \left[191.6 + \frac{3.992}{3.15} + \frac{1}{0.315} \times \frac{f_a}{2.6}\right] \times \frac{1}{1000}$$

$$= \left[191.6 + 126.73 + \frac{f_a}{0.819}\right] \times \frac{1}{1000}$$

or $$980 = \left[318.33 + \frac{f_a}{0.819}\right]$$

or $$\frac{f_a}{0.819} = 980 - 318.33$$

$$= 661.67$$

or $$f_a = 661.67 \times 0.819$$

$$= 542.57 \text{ kg. say } 543.0 \text{ kg.}$$

Mix. Proportion is

Water	*Cement*	*Fine aggregate*	*Coarse aggregate*
191.6	399.0	543.0	1118
0.48	1	1.36	2.8

For 50 kg of cement, the quantities worked are as follows:

Cement = 50 kg

Fine aggregate = 68 kg

Coarse aggregate = 140 kg fraction I 60% = 84 kg

fraction II 40% = 56 kg

(ii) Water:

1. For w/c ratio 0.48, water = 24 kg

2. Extra water for absorption by coarse aggregate 0.5% of mass = 0.70 litres.

(iii) Quantity of Water:

Quantity of water to be deducted for moisture present in sand at 2% by mass = 1.38 litres

∴ Actual quantity of water to be added = 24 + 0.7 – 1.38 = 23.3 litres

Actual quantity of sand after adding water content = 68 + 1.38 = 69.38 kg. Thus after allowing for free mass of moisture, sand quantity = 69.4 kg.

(iv) Actual Quantity of Coarse Aggregate:

Fraction (i) 84 – 0.42 = 83.68 kg Fraction

(ii) 56 – 0.28 = 55.72 kg.

Thus actual quantities of materials to be used are:

Water = 23.3 litres

Cement = 50.0 kg

Sand = 69.9 kg

Coarse aggregate fraction I = 83.58 kg

Coarse aggregate fraction II = 55.72 kg. Ans.

Concrete mix Design

6.1 a) Introduction

Concrete Mix Design as per IS Code

Concrete is a heterogeneous and hardened mass obtained from a mixture of cement, sand, coarse aggregate and water, in a certain proportion.

The grade of concrete varies greatly in accordance with the changing proportion of its constituent materials. The proportion and the ratio, in which the materials should be mixed

together to obtain a certain grade of the concrete, has already been specified by IS 456:2000.
But the limitation of the code is, that it specifies the ratios of the materials, up to a certain grade, which is M25, beyond which, no certain proportion has been industrially approved.

S.No	Grade	Proportion (cement: sand: coarse aggregate)
1	M5	1:5:10
2	M7.5	1:4:8
3	M10	1:3:6
4	M15	1:2:4
5	M20	1:1.5:3
6	M25	1:1:2

These are called Nominal Mix.
In the era of industrial and infrastructural developments, to cater the need for high strength concrete and overall improvement of the concrete properties, various high strength concrete has been introduced, taking it way more than M100.
Due to the limitation of IS:456, a new procedure have been adopted in all around India, which is to properly design the mix, from the scratch, and thus finding the required ratio for that particular Concrete.
This is known as Mix Design of Concrete, which follows some certain principles, devised by **IS:10262,2009.** In this article, I'd like to mention some useful notes on designing the mix, as well as factors dependent on mix design, as a clear understanding of mix design processes is what a civil engineering firm expect from a fresher.

Contents hide

1. Target Mean Strength:
2. Water-Cement Ratio:
3. Water Content Determination:
4. Cement Content Determination:
5. Determining the amount of Course and fine aggregates:
6. Determination of Total volume of all the materials:
7. Taking out the ratio:
8. Preparation of trial mixes:

Factors Dependent on Mix Design:

While Designing a concrete mix, there is a wide range of factors, involved throughout the process, which largely contributes to the end product, which is Concrete and all of its properties. So considering all of these factors, and carefully maintaining it to it's desired level, would add significant value to the quality and strength of the concrete. Some of these factors have been mentioned following-

- Grade of Cement
- Size and shape of aggregates
- Grading Zone of Aggregate
- Water absorption by the aggregate
- The specific gravity of the materials
- Type of Admixture added
- Slump value of the concrete
- W/C Ratio of concrete
- Degree of supervision provided
- Method of transportation of concrete
- Concreting Methods(such as Tremie or underwater concreting).

Concrete Mix Design Procedure:

The concrete mix is designed while taking into consideration the above factors. After properly designing the structure by a structural designer, the concrete technologists stipulate certain minimum strength of the concrete, that should be used in casting the structural members. After that, the site engineer prepares the concrete at site, by closely following the parameters, which overall contributes to the long term durability and strength of the concrete. So a properly designed mix is very much needed for the structure to safely withstand all the loads which are expected to act on it, during its lifespan.

1. Target Mean Strength:

Before designing concrete Mix, the grade of the concrete, for which the design will be performed, should always be known beforehand. That is known as a characteristic strength of the concrete (in M45 concrete, the characteristic strength of the concrete is 45Mpa). From the characteristic strength, the target mean strength is found out, for that specific concrete, from the given formulae-

Target Mean Strength = Characteristic strength + t x s

Where, t is the tolerance factor which is equal to 1.65, taking 5% of the test results are expected to fall below it

And s is the standard deviation whose value can be found out of a separate grade of concrete, from “Standard Deviation chart” from any concrete book.

2. Water-Cement Ratio:

After the Target Mean Strength has been found out, the water-cement ratio is being determined, either using the chart specified by IS:456,2000 on the basis of the Exposure condition and Grade of concrete or by using some experience used for the similar construction executed recently. W/C Ratio is one of the most important factors of the concrete, which controls overall quality, as well as have a direct or indirect effect on different properties of concrete.

3. Water Content Determination:

After the W/C ratio has been determined, the amount of water required for mixing that specific grade of concrete may be found out through a chart, which is based on the size of aggregates used for making that concrete.

- For 10 mm aggregates: 208 kg
- 20 mm aggregates: 186 kg
- 40 mm aggregates: 165kg

The above value Is for the aggregates of angular course type and slumps range of 25-50mm. For different shapes of aggregates, as well as for slump ranges, the water content can be adjusted proportionately.

The amount of water content can be reduced by 10 kg for sub-angular aggregates, 20 kg for gravel and 25 kg for rounded gravel. The water content can also be adjusted depending upon the slump value. For every 25 mm increased slump, the water content can be increased by an amount equal to 3 per cent.

4. Cement Content Determination:

After the required water content is determined, then from the water-cement ratio, and obtained water content, the cement content can easily be found out.

W/C Ratio = Water Content/Cement Content

5. Determining the amount of Course and fine aggregates:

The coarse and fine aggregates are then Determined. The weight of the coarse aggregate depends upon the size of the course Aggregates used and grading zones of the aggregate, namely, there are four grading zones of the aggregates, I, II, III and IV. The value can be found out from the respective charts in the" Design Mix" chapter of any concrete book. The value obtained from the chart is the volume of the coarse aggregate, per unit volume of total aggregates. After, the volume of the fine aggregates is found out by deducting the volume of course aggregate, from number 1.

6. Determination of Total volume of all the materials:

The volume of all the materials can be obtained from the following formulae-

Volume= Weight obtained/specific gravity× 1/1000

If Admixture is used, then the volume of Admixture is also being determined. It can be determined by the following formulae-

Volume= dosage of Admixture× Cement content× 1/1000

Considering the total volume of concrete produced as 1 cubic metre, the volume of cement, water, and Admixtures are determined. Then the remaining value is the volume of the total aggregates. By multiplying the volume of the total aggregates with the volume of the coarse and fine aggregates per unit volume of the aggregate, specific gravity of respective aggregates and the value 1000.

7. Taking out the ratio:

After the volume and weight of all the materials are found out, then the ratio of the respective materials are determined. It is generally done by making the value of the cement as 1 and dividing all the weight of elements by the weight of cement.

8. Preparation of trial mixes:

Generally, four trial mixes are prepared to check the desired strength and all other properties. The second trial mix is done by constant w/c ratio of the first one, and varying water/Admixture content. Trial mix 3 and 4 is done by keeping the water content as preselected value and varying W/C ratio by 10 per cent.

These are the eight steps involved in the calculation of Mix Design. I would recommend seeing an example of Design Mix from any concrete book, as an example would be very helpful in remembering these points as well as properly understanding them. A properly designed concrete mix offers around improvement of various characteristics, which not only resists all the loads expected on that concrete, it also offers greater stability throughout its lifespan as well as beyond the lifespan.

Concrete Mix design as per IS (Indian Standard) Method

The following points should be remembered before proportioning a concrete mix a per IS-10262-2009.

- This method of concrete mix proportioning is applicable only for ordinary and standard concrete grades.
- The air content in concrete is considered as nil.
- The proportioning is carried out to achieve specified characteristic compressive strength at specified age, workability of fresh concrete and durability requirements.

Concrete Mix Design

This method of concrete mix design consist of following 11 steps

1. Design specification
2. Testing of materials
3. Calculating target strength for mix proportioning
4. Selecting water/cement ratio

5. Calculating water content
6. Calculating cement content
7. Finding out volume proportions for Coarse aggregate & fine aggregate
8. Mix calculations
9. Trial mixing and

10. Workability measurement (using slump cone method)
11. Repeating step 9 & 10 until all requirements is fulfilled.

Let us discuss all of the above steps in detail

STEP-1. DESIGN SPECIFICATIONS

This is the step where we gather all the required information for designing a concrete mix from the client. The data required for mix proportioning is as follows.

- Grade designation (whether M10, M15, M20 etc)
- Type of cement to be used
- Maximum nominal size of aggregates
- Minimum & maximum cement content
- Maximum water-cement ratio
- Workability
- Exposure conditions (As per IS-456-Table-4)
- Maximum temperature of concrete at the time of placing
- Method of transporting & placing
- Early age strength requirement (if any)
- Type of aggregate (angular, sub angular, rounded etc)
- Type of admixture to be used (if any)

STEP-2. TESTING OF MATERIALS

The table given below shows the list of most necessary tests to be done on cement, coarse aggregate, fine aggregate and admixture. After doing the test, store the test data for further calculation.

Concrete Ingredients	**Tests to be done**

Cement	Specific gravity	—	—	—
Coarse aggregate	Specific gravity	Water absorption	Free surface moisture	Sieve analysis
Fine aggregate	Specific gravity	Water absorption	Free surface moisture	Sieve analysis
Admixture(if any)	Specific gravity	—	—	—

STEP-3. TARGET STRENGTH CALCULATION

Calculate the target compressive strength of concrete using the formula given below.
$f_{ck}' = f_{ck} + 1.65s$
Where,
f_{ck}' = Target compressive strength at 28 days in N/mm^2.
f_{ck} = Characteristic compressive strength at 28 days in N/mm^2. (same as grade of concrete, see table below)
s = Standard deviation
The value of standard deviation, given in the table below, can be taken for initial calculation.

Sl.No	**Grade of Concrete**	**Characteristic compressive strength (N/mm^2)**	**Assumed standard deviation (N/mm^2)**
1.	M10	10	3.5
2.	M15	15	

3.	M20	20	4.0
4.	M25	25	
5.	M30	30	5.0
6.	M35	35	
7.	M40	40	
8.	M45	45	
9.	M50	50	
10.	M55	55	

STEP-4. SELECTION OF WATER-CEMENT RATIO

For preliminary calculation, water cement ratio as given is IS-456-Table 5 (also given below) for different environmental exposure condition, may be used.

Note: Use **Table-1** for finding out water-cement ratio of **Plain Concrete** and use **Table-2** for finding out water-cement ratio of **Reinforced Concrete**.

Table -1		
Sl.No.	**Environmental Exposure Condition**	**Plain Concrete**

Minimum Cement Content (kg/m3)	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete		
1	Mild	220	0.60	—
2	Moderate	240	0.60	M 15
3	Severe	250	0.50	M 20
4	Very Severe	260	0.45	M 20
5	Extreme	280	0.40	M 25

Table -2

Sl.No.	Environmental Exposure Condition	Reinforced Concrete
Minimum Cement Content (kg/m3)	**Maximum Free Water-Cement Ratio**	**Minimum Grade of Concrete**

1	Mild	300	0.55	M 20
2	Moderate	300	0.50	M 25
3	Severe	320	0.45	M 30
4	Very Severe	340	0.45	M 35
5	Extreme	360	0.40	M 40

Refer the table given below (As per IS-456) to choose right type of environment depending upon different exposure conditions to concrete.

Sl. No	**Environment**	**Exposure condition**
1	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal areas.
2	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wetConcrete exposed to condensation and rainConcrete continuously under waterConcrete in contact or buried under non aggressive soil/ground waterConcrete surfaces sheltered from saturated salt air in coastal area

3	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensationConcrete completely immersed in sea waterConcrete exposed to coastal environment
4	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing condition whilst wetConcrete in contact with or buried under aggressive sub-soil/ground water
5	Extreme	Surface members in tidal zoneMembers in direct contact with liquid/solid aggressive chemicals

STEP-5. SELECTION OF WATER CONTENT

Selection of water content depends upon a number of factors such as

- Aggregate size, shape & texture
- Workability
- Water cement ratio
- Type of cement and its amount
- Type of admixture and environmental conditions.

Factors that can reduce water demand are as follows

- Using increased aggregate size
- Reducing water cement ratio
- Reducing the slump requirement
- Using rounded aggregate
- Using water reducing admixture

Factors that can increase water demand are as follows

- Increased temp. at site
- Increased cement content
- Increased slump

- Increased water cement ratio
- Increased aggregate angularity
- Decrease in proportion of the coarse aggregate to fine aggregate

The quantity of maximum mixing water per unit volume of concrete may be selected from the table given below.

Maximum water content per cubic meter of concrete for nominal maximum size of aggregate		
Sl.No.	Nominal maximum size of aggregate	Maximum water content
1	10	208
2	20	186
3	40	165

The values given in the table shown above is applicable only for angular coarse aggregate and for a slump value in between 25 to 50mm.
Do the following adjustments if the material used differs from the specified condition.

Type of material/condition	**Adjustment required**
For sub angular aggregate	Reduce the selected value by 10kg
For gravel with crushed stone	Reduce the selected value by 20kg

For rounded gravel	Reduce the selected value by 25kg
For every addition of 25mm slump	Increase the selected value by 3%
If using plasticizer	Decrease the selected value by 5-10%
If using super plasticizer	Decrease the selected value by 20-30%

Note: Aggregates should be used in saturated surface dry condition. While computing the requirement of mixing water, allowance shall be made for the free surface moisture contributed by the fine and coarse aggregates. On the other hand, if the aggregate are completely dry, the amount of mixing water should be increased by an amount equal to moisture likely to be absorbed by the aggregate

STEP-6. CALCULATING CEMENTIOUS MATERIAL CONTENT

From the water cement ratio and the quantity of water per unit volume of cement, calculate the amount of cementious material. After calculating the quantity of cementious material, compare it with the values given in the table shown in Step-4. The greater of the two values is then adopted.

If any mineral admixture (such as fly ash) is to be used, then decide the percentage of mineral admixture to be used based on project requirement and quality of material.

STEP-7. FINDING OUT VOLUME PROPORTIONS FOR COARSE AGGREGATE & FINE AGGREGATE

Volume of coarse aggregate corresponding to unit volume of total aggregate for different zones of fine aggregate is given in the following table.

Sl. No.	NominalMaximum Size ofAggregate(mm)	Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate

Zone IV	Zone III	Zone II	Zone I		
1	10	0.50	0.48	0.46	0.44
2	20	0.66	0.64	0.62	0.60
3	40	0.75	0.73	0.71	0.69

The values given in the table shown above is applicable only for a water-cement ratio of 0.5 and based on aggregates in saturated surface dry condition.

If water-cement ratio other than 0.5 is to be used then apply correction using the rule given below.

Rule: For every **increase or decrease** by **0.05** in **water-cement ratio**, the **above values** will be **decreased or increased** by **0.01,** respectively.

If the placement of concrete is done by a pump or where is required to be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined as above, upto 10 percent.

After calculating volume of coarse aggregate, subtract it from 1, to find out the volume of fine aggregate.

STEP-8. MIX CALCULATIONS

The mix calculations per unit volume of concrete shall be done as follows.

a	Volume of concrete=	$1m^3$
b	Volume of cement=	(Mass of cement/specific gravity of cement)*(1/1000)
c	Volume of water=	(Mass of water/specific gravity of water)*(1/1000)
d	Volume of admixture=	(Mass of admixture/specific gravity of admixture)*(1/1000)
e	Volume of total aggregate (C.A+F.A)=	[a-(b+c+d)]
f	Mass of coarse aggregate=	e*Volume of coarse aggregate*specific gravity of coarse aggregate*1000
g	Mass of fine aggregate=	e*Volume of fine aggregate*specific gravity of fine aggregate*1000

STEP-9. TRIAL MIX

Conduct a trial mix as per the amount of material calculated above.

STEP-10. MEASUREMENT OF WORKABILITY (BY SLUMP CONE METHOD)

The workability of the trial mix no.1 shall be measured. The mix shall be carefully observed for freedom from segregation and bleeding and its finishing properties.

STEP-11. REPEATING TRIAL MIXES

If the measured workability of trial mix no.1 is different from stipulated value, the water and/or admixture content shall be adjusted suitably. With this adjustment, the mix proportion shall be recalculated keeping the free water-cement ratio at pre-selected value.
Trial-2 – increase water or admixture, keeping water-cement ratio constant
Trial-3 – Keep water content same as trial-2, but increase water-cement ratio by 10%.

Trial-4 – Keep water content same as trial-2, but decrease water-cement ratio by 10%
Trial mix no 2 to 4 normally provides sufficient information, including the relationship between compressive strength and water-cement ratio.

7 Production of concrete:

7.1

Batching of materials:

Batching

Batching is the process of measuring concrete mix ingredients either by volume or by mass and introducing them into the mixture. Traditionally batching is done by volume but most specifications require that batching be done by mass rather than volume. Percentage of accuracy for measurement of concrete materials as follows.

Cement:

When the quantity of cement to be batched exceeds 30% of scale capacity, the measuring accuracy should be within 1% of required mass. If measuring quantity is less than 30% i.e. for smaller batches then the measuring accuracy should be within 4% of the required quantity.

Aggregates:

If the measurement is more than 30% of the scale capacity then the measuring accuracy should be within 1%. If measurement is less than 30% then the measuring accuracy should be within less than 3%.

Water:

Water is measured in volumetric quantity as 1 litre = 1kg. In case of water, the measuring accuracy should be within 1%.

Admixtures:

For mineral admixtures same accuracy as that required for cement.For chemical admixtures same accuracy as that required for water. Mineral admixtures accuracy is same as that of cement because it is used as partial replacement of cement. As chemical admixtures are liquid or added to water therefore its accuracy is same as that of water.

mixing of concrete materials:

The mixing operation consists of rotation or stirring, the objective being to coat the surface the all aggregate particles with cement paste, and to blind all the ingredients of the concrete into a uniform mass; this uniformity must not be disturbed by the process of discharging from the mixer.

Batch mixer

The usual type of mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer. There are four types of batch mixer.

Tilting drum mixer:

A tilting drum mixer is one whose drum in which mixing take place is tilted for discharging. The drum is conical or bowl shaped with internal vanes, and the discharge is rapid and unsegregated so that these mixers are suitable for mixes of low workability and for those containing large size aggregate.

Non tilting drum mixer:

A non tilting drum is one in which the axis of the mixer is always horizontal, and discharge take place by inserting a chute into the drum or by reversing the direction or rotation of drum. Because of slow rate of discharge, some segregation may occur.

Pan type mixer:

A pan type mixer is a forced–action mixer, as distinct from drum mixer which relies on the free fall of the concrete inside the drum. The pan mixer consist of a circular pan rotating about its axis with one or two stars paddles rotating about vertical axis of pan.

Dual drum mixer:

A dual drum is sometimes used in highway construction. Here there are two drums in series, concrete being mixed part of the time in one and then transferred to the other for the remainder of the mixing time before discharging.

Continuous mixers:

These are fed automatically by a continuous weigh-batching system.

Charging the mixer:

There are no general rules on the order of feeding the ingredients into the mixer as this depend on the properties of the mixer and mix. Usually a small quantity of water is fed first, followed by all the solids materials. If possible greater part of the water should also be fed during the same time, the remainder being added after the solids. However, when using very dry mixes in drum mixers it is necessary to feed the coarse aggregate just after the small initial water feed in order to ensure that the aggregate surface is sufficiently wetted.

Uniformity of Mixing

In any mixer, it is essential that a sufficient interchange of materials occurs between parts of the chamber, so that a uniform concrete is produced. The efficiency of the mixer can be measured by the variability of the samples from the mix. ASTM prescribes samples to be taken from about points 1/6 and 5/6 of the discharge of the batch and the difference in the properties of the two samples should not exceed any of the following:

1. Density of concrete 1 lb/ft^3
2. Air content 1%
3. Slump 1" when average is less than 4"
4. 1.5" when average is less than 4 to 6"
4. % of aggregate retained on 4 No. sieve 6%
5. Compressive strength 7 day, 3 cylinders 7.5%

Mixing time:

It is important to know the minimum mixing time necessary to produce a concrete of uniform composition, and of reliable strength.

The mixing time or period should be measured from time all the cementing materials and aggregates are in mixer drum till taking out the concrete.

Mixing time depends on the type and size of mixer, on the speed of rotation, and on the quality of blending of ingredients during charging of the mixer. Generally, a mixing time of less than 1 to 1.25 minutes produces appreciable non-uniformity in composition and a significant lower strength; mixing beyond 2 minutes causes no significant improvement in these properties.

Table: Recommended minimum mixing times

Capacity of mixer (yd^3)	Mixing time (Minutes)
Up to 1	1
2	1.25

3	1.5
4	1.75
5	2
6	2.25
10	3.25

Prolong mixing:

If mixing take place over a long period, evaporation of water from the mix can occur, with a consequent decrease in workability and an increase in strength. A secondary effect is that of grinding of the aggregate, particularly if soft; the grading thus becomes finer and the workability lower. In case of air entrained concrete, prolong mixing reduces the air content.

Ready mixed concrete:

If instead of being batched and mixed on site, concrete is delivered for placing from a central plant. It is referred to as ready-mixed or pre-mixed concrete. This type of concrete is used extensively abroad as it offers numerous advantages in comparison with other methods of manufacture:

1. Close quality control of batching which reduces the variability of the desired properties of hardened concrete.
2. Use on congested sites or in highway construction where there is little space for a mixing plant and aggregate stockpiles;
3. Use of agitator trucks to ensure care in transportation, thus prevention segregation and maintaining workability
4. Convenience when small quantities of concrete or intermittent placing is required.

There are two categories of ready-mixed concrete: central-mixed and transit mixed or truck mixed. In the first category, mixing is done in a central plant and then concrete is transported in an agitator truck. In the second category, the materials are batched at a central plant but are mixed in a truck.

What Is Batching of Concrete?

Batching of Concrete stands for the method of estimating and mixing the required concrete ingredients with both weight or volume according to the mix design and transplanting them into the mix to create a consistent quality of concrete.

Batching of Concrete is usually done with volume. Precision is very important in batching. It is better to do weight batching instead of volume batching. Before making a concrete mixture, the concrete material must be properly and accurately batched or proportioned to achieve excellent quality of the concrete.
Concrete Batching helps improve the practicality of concrete to achieve a smooth surface of concrete and increase the speed of construction and reduce the wastage of concrete components. Thus, batch-making of concrete components is an essential process when making concrete

Methods Of Batching Concrete

Following the three types of batching of concrete

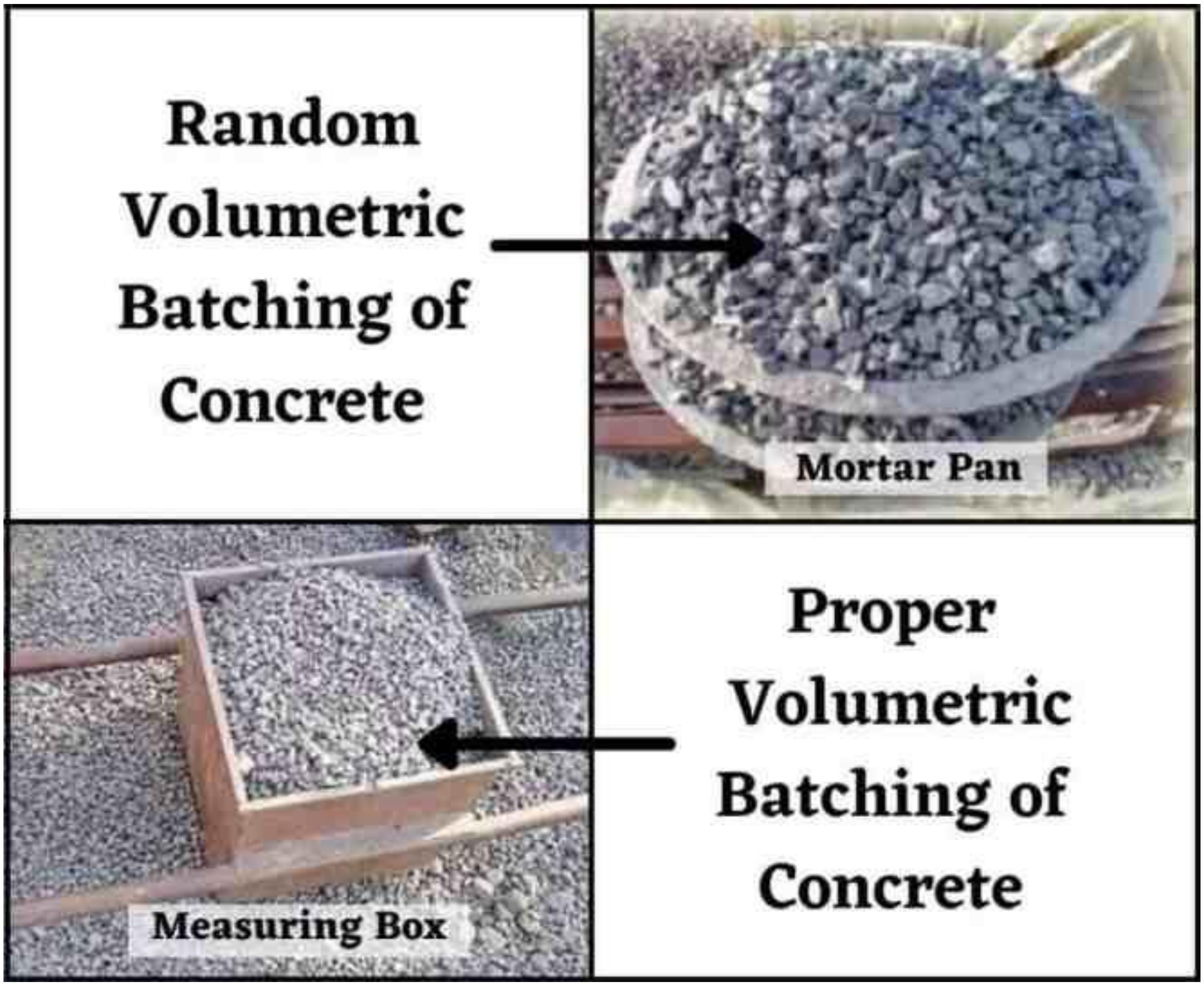
1. Random volumetric batching
2. volumetric batching
3. Weigh batching of concrete

1. Random Volumetric Concrete Batching

Devoid of any control over the size and shape of the applied containers causing major disturbances and deviations numbers. This method is completely unscientific, and unsophisticated, and should not be recommended even for a small project.

2. Proper Volumetric Batching

Volume batching of concrete is accomplished with the use of a **measurement box**, locally named **"farma or gauge".** Concrete components such as aggregates (Karachi + sand) and cement are calculated with farms or gauge boxes and proper precaution must be taken to ensure that the form of the gauge box is excessively filled.
To calculate the amount of water, a water meter should be used when there is a certain amount of water cans or uses.



Random and Proper Volumetric Batching

3. Weigh Batching of Concrete

Weigh Batching of Concrete is accomplished by using a batch wet batch or a weighting system. On large projects, automated batching plants are set up to facilitate the optimization of quality and uniformity.

Water is a very important material and therefore, maximum water should be used for batching. If the amount of water is small, the performance of the concrete will be interrupted while the surplus water will reduce the strength of the concrete. Water must be fully calculated in liters.


Automatic Weigh Batching of Concrete

Read More: Site Mix Concrete Vs Ready Mix Concrete – Which is Better

Various Factors Affecting the Choice of Batching system

The following factor affects the choice of batching system:

1. Job size: The choice of method of batching concrete depends on how big is the work to be done with the method of batching.
2. Concrete production rate: It depends on the required concrete production rate per house or day.

3. Accuracy of weight measurement and based on standard batching performance
4. Weighing batches operate electronically or mechanically.
5. Nowadays electronic weight batches are more trending than mechanical weight batches, but some plants still use mechanical weight batches to serve as backups for electronic weight batches.
6. Mechanical weight batches have dial-type scales that use a spring to measure the weight of concrete components. Electronic weight batches have electronic scales that are suspended by load cells that convert force into a measurable electrical quantity. The load cell is supported by hoppers, tanks, or other vessels that convert the stress to an electrical signal. Electronic scales measure accurately and often do not require repair.
7. Electronic weighing batches are available in various types. Depending on the type of batch plant, weight batches should be used i.e., high-silo, low-profile, or underground batch plant. The batches may be stationary individuals that are not moving while weighing, or they may be non-stationary batches that weigh as transport materials.

Types of Concrete Batching Plants

Following the types of concrete batching plants:

1. Manual Weight Batching.
2. Semi-Automatic Weigh Batching.
3. Fully Automatic Weigh Batching.

1. Manual Weigh Batching

In manual batching, all solid ingredients are weighed manually. Manual-weight batching systems can be used for small jobs.

Manual Batching

2. Semi-Automatic Weigh Batching

In semi-automatic weight batching, aggregate bin gates are opened by manually operated switches and the gates are automatically closed when the material has been delivered.

Semi-Automatic Weigh Batching

3. Fully Automatic Weigh Batching

It is an automated tool for batching concrete materials, requiring qualified and experienced engineers. These systems have automated microprocessor-controlled batching systems. Not only are the aggregates batch in the correct proportions, but their moisture is also measured automatically and necessary corrective action must be taken so that the mixture has the desired stability

Fully Automatic Weigh Batching

Concrete Batching Process:

The concrete batching process involves a series of steps that ensure the accurate and consistent mixing of the raw materials that make up the concrete. These steps can be summarized as follows:

Aggregate Storage and Weighing: The first step in the batching process involves the storage of aggregates such as sand, gravel, and crushed stone in silos or bins. These materials are then weighed using a belt conveyor or hopper scale to ensure that the correct amount is used in the mix.

Cement Storage and Weighing: Cement is stored in silos and weighed using a scale or weigh batcher to ensure the correct amount is used in the mix.

Water Measurement: Water is measured using a meter or calibrated tank to ensure that the correct amount is used in the mix.

Admixture Measurement: Admixtures such as accelerators, retarders, and plasticizers may be added to the mix to improve its properties. These materials are measured and added to the mix according to the manufacturer’s specifications.

Mixing: Once all the materials are measured and in the mixer, the mixing process begins. The mixer can be a stationary mixer or a truck mixer, depending on the batching plant’s design. The mixing time and speed are carefully controlled to ensure that the mix is homogeneous and consistent.

Transport and Delivery: Once the mixing is complete, the concrete is transported to the construction site using mixer trucks. The concrete must be delivered and placed within a specific time frame to ensure that it retains its desired properties.

Quality Control: Quality control measures, such as testing the concrete’s slump, air content, and strength, are carried out at various stages of the batching process to ensure that the concrete meets the desired specifications.

FAQs:

What is batching of concrete?

Batching is the process of measuring and combining the raw materials that make up concrete, such as cement, aggregates, water, and admixtures, in the correct proportions to produce a consistent and uniform mix.

Why is batching important in concrete production?

Proper batching is important for ensuring consistency and uniformity in the quality of the concrete. This ensures that the concrete meets the desired strength, workability, and durability requirements, and helps to reduce costs associated with the production of concrete.

What are the raw materials used in concrete batching?

The raw materials used in concrete batching include cement, aggregates (such as sand, gravel, and crushed stone), water, and admixtures (such as accelerators, retarders, and plasticizers).

What is the difference between volumetric and weight batching?

Volumetric batching involves measuring the volume of the materials used in the mix, while weight batching involves weighing the materials using scales or weigh batchers. Weight batching is more accurate and consistent, and is typically used in larger batching plants.

Concrete Placing and Compaction of Concrete

The operation of placing and compaction are interdependent and are carried out simultaneously. They are most important for the purpose of ensuring the requirements of strength, impermeability and durability of hardened concrete in the actual structure. As for as placing is concerned, the main objective is to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted. The aim of good concrete placing can be stated quite simply.

It is to get the concrete into position at a speed, and in a condition, that allow it to be compacted properly.

To achieve proper placing following rules should be kept in mind:

1. The concrete should be placed in uniform layers, not in large heaps or sloping layers.
2. The thickness of the layer should be compatible with the method of vibration so that entrapped air can be removed from the bottom of each layer.
3. The rate of placing and of compaction should be equal. If you proceed too slowly, the mix could stiffen so that it is no longer sufficiently workable. On no account should water ever be added to concrete that is setting. On the other hand, if you go too quickly, you might race ahead of the compacting gang, making it impossible for them to do their job properly.
4. Each layer should be fully compacted before placing the next one, and each subsequent layer should be placed whilst the underlying layer is still plastic so that monolithic construction is achieved
5. Collision between concrete and formwork or reinforcement should be avoided.
6. For deep sections, a long down pipe ensures accuracy of location of concrete and minimum segregation.
7. You must be able to see that the placing is proceeding correctly, so lighting should be available for large, deep sections, and thin walls and columns.

Compaction

Once the concrete has been placed, it is ready to be compacted. The purpose of compaction is to get rid of the air voids that are trapped in loose concrete.

Why is compaction of concrete necessary?

It is important to compact the concrete fully because:

- Air voids reduce the strength of the concrete. For every 1% of entrapped air, the strength falls by somewhere between 5 and 7%. This means that concrete containing a mere 5% air voids due to incomplete compaction can lose as much as one third of its strength.
- Air voids increase concrete's permeability. That in turn reduces its durability. If the concrete is not dense and impermeable, it will not be watertight. It will be less able to withstand aggressive iquids and its exposed surfaces will weather badly.
- Moisture and air are more likely to penetrate to the reinforcement causing it to rust.
- Air voids impair contact between the mix and reinforcement (and, indeed, any other embedded metals). The required bond will not be achieved and the reinforced member will not be as strong as it should be.
- Air voids produce blemishes on struck surfaces. For instance, blowholes and honeycombing might occur.

Summing up, fully compacted concrete is dense, strong and durable; badly compacted concrete will be porous, weak and prone to rapid deterioration. Sooner or later it will have to be repaired or replaced. It pays, therefore, to do the job properly in the first place.

Stiff mixes contain far more air than workable ones. That is one of the reasons why a low-slump concrete requires more compactive effort than one with a higher slump - the compaction needs to continue for a longer time, or more equipment has to be used.

Even air-entrained concrete needs to be compacted to get rid of entrapped air voids. The difference between air voids and entrained air bubbles should be noted at this stage. The air bubbles that are entrained are relatively small and spherical in shape, increase the workability of the mix, reduce bleeding, and increase frost resistance. Entrapped air on the other hand tends to be irregular in shape and is detrimental to the strength of the mix. It is to remove this air that the concrete must be properly compacted. There is little danger that compaction will remove the minute air bubbles that have been deliberately entrained, since they are so stable.

Methods of Compaction of concrete

Vibration:

To compact concrete you apply energy to it so that the mix becomes more fluid. Air trapped in it can then rise to the top and escape. As a result, the concrete becomes consolidated, and you are left with a good dense material that will, after proper curing, develop its full strength and durability. Vibration is the next and quickest method of supplying the energy. Manual techniques such as rodding are only suitable for smaller projects. Various types of vibrator are available for use on site.

Poker Vibrators

The poker, or immersion, vibrator is the most popular of the appliances used for compacting concrete. This is because it works directly in the concrete and can be moved around easily.

Sizes:

Pokers with diameters ranging from 25 to 75mm are readily available, and these are suitable for most reinforced concrete work. Larger pokers are available - with diameters up to 150mm - but these are for mass concrete in heavy civil engineering.

Radius of action:

When a poker vibrator is operating, it will be effective over a circle centred on the poker. The distance from the poker to the edge of the circle is known as the radius of action.

However, the actual effectiveness of any poker depends on the workability of the concrete and the characteristics of the vibrator itself. As a general rule, the bigger the poker and the higher its amplitude, the greater will be the radius of action. It is better to judge from your own observations, as work proceeds on site, the effective radius of the poker you are operating on the concrete you are compacting.

The length of time it takes for a poker vibrator to compact concrete fully depends on:

1. The workability of the concrete: the less workable the mix, the longer it must be vibrated.
2. The energy put in by the vibrator: bigger vibrators do the job faster.
3. The depth of the concrete: thick sections take longer.

Different between Weight batching and Volume Batching

S.N	Weight Batching	Volume Batching
1	Ingredients are batched / Proportioned based on weight.	Ingredients are batched/proportioned based on volume.
2	Concrete is of uniform and consistent quality.	Its quality is not uniform than weight batching.
3	Use weigh batching machine/ plant.	Use farma (Mould) for proportioning the materials according to various mixed proportions
4	It is more precise method	It is the less precise method.
5	Weight batching need skilled labours and man power.	No need to required skilled labors

6	This method is expensive.	This method is cheaper and economical

Formwork-requirements and types:

What is Formwork and Requirements of a Good Formwork

Formwork by name means “The Mold” which means it is the casing into which the casting material, usually concrete, is poured to obtain the desired structural shape.

In construction industry formwork is similar to a mold to cast concrete member in different shape and sizes using different types of materials such as timber, steel, aluminum, plastic, etc. Shuttering is a synonym term used for form-work. Form work should have sufficient strength to carry dead load and live load coming on it during casting operation and after that till concrete gets hard and gain some percentage of design strength.

Requirements of good Formwork

It must be capable to withstand all types of dead and live

It is practically good to have water proof character, so that it won't absorb water from concrete.

Entire formwork should be rigidly constructed and propped, so that there should be no deformation in the shape and retain its original shape.

Deflection and shrinkage should be minimum.

The joins should be tight enough to minimize the leakage of cement grout.

The formwork should be constructed with different segments. So that while removing the formwork it should not damage the concrete

The material of the formwork should be cheap, easily available and should be suitable for reuse.

The formwork should be set accurately to the desired line and levels should have plane surface.

It should be as light as possible. So that it is easy to transfer and erect.

The material of the formwork should not warp or get distorted when exposed to the elements.

Different Types of formwork - Based on Material

1. Timber formwork

The Timber formwork is one of the mostly used type in construction industry, fabricated on site using timber. It is easy to produce but time-consuming for larger structures. We can't produce curved shapes economically. Timber shuttering should satisfy the following requirement:

Lightweight

Well-Seasoned

Free from termite attacks

Easily Workable

2. Plywood Formwork (In Combination with Timber)

Plywood is an artificially manufactured wooden material available in different thickness and size used in formwork for concrete member. It is strong enough, durable and light weight. The main advantage of this forms from timber forms is we get smooth cement surface with this form.

3. Steel Formwork

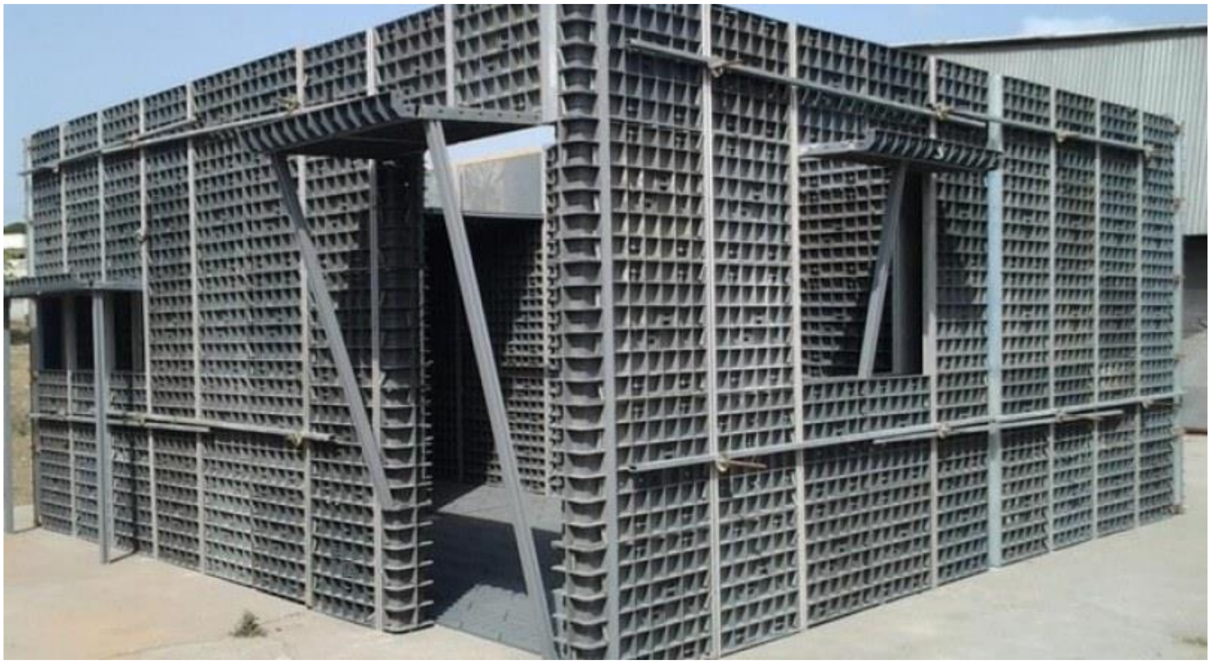
Steel formwork is now becoming popular due to its long-life time and multiple time reuses. Steel formwork is costly but can be used for large number of projects. Steel shuttering give very smooth finishes to concrete surface. It is suitable for circular or curved structures such as tanks, columns, chimneys, tunnel and retaining wall.

4. Aluminium Formwork

Aluminum formwork is almost similar to those made of steel. Aluminum forms are lighter than steel forms due to low density and this is their primary advantage when compared to steel. The shuttering is economical if large numbers of repeating usage are made in construction. The disadvantage is that no alteration is possible once the formwork is constructed.

5. Plastic Formwork

Plastic formwork is lightweight, posses interlocking mechanism and could be used for multiple times. Plastic shuttering is mostly useful where similar construction shape structures are required.



6. Coffor Formwork

Coffor is a structural stay-in-place shuttering used in concrete construction. Coffor is made of two filtering grids, in which vertical stiffeners are reinforced. After the placement of coffor formwork, concrete is poured between the grids and excess water is drained through grids due to gravity.

7. Fabric Formwork

Fabric formwork is used for construction of complex and irregular shaped member. Usage of fabric formwork provides an opportunity for construction of efficient and architecturally marvellous structural members of any shape and sizes.

Different Types of Formwork - Based on Structural member they are used for

1. beam formwork

Beam formwork consists of pre-assembled form sheeting parts. A method for cover straps is used for nailing of sheeting boards together for providing sheeting base and side panels. The extent of work is dependent upon width and thickness of sheeting base and cover straps and the width of thrust board.

A whaler is mounted at the upper edge of side sheeting to hold together the forms by wire ties. The whaler and segments are propped by diagonal sheets.

2. Coloumn Formwork

The sheeting of column formwork is prefabricated, depending upon required column dimensions. Steel bolts are used to anchor the sheeting panels in foot rim. Vertical arch timbers are placed to take the forces from cover straps of formwork sheeting. The diagonal board braces are used to tie the column in formwork laterally

3. Wall Formwork

Wall shuttering consists of vertically arranged upright formwork bearers and sheeting boards are nailed to it, at concrete side. Moreover, upright timbers are braced diagonally by using boards at both sides. The opposite whalers must be tied at specific distances and cleaning holes are to be allocated at the foot of formwork.

4. Foundation Formwork

Foundation formwork are designed differently for different foundation types and sizes. Formwork specifications will be different for isolated and strip foundation. The design of formwork is mainly dependent on size and depth of foundation. Metal screws and tie wires are used as formwork ties and generally sheeting panels are used along with formwork bearers for foundation formwork.

5. Slab Formwork

System of ceiling shuttering provides ease in transport, assembling and stocking. Ceiling formwork has optimum stability and time is saved while assembling and disassembling. The basic elements of ceiling shuttering are wooden beam beams and steel supports and it doesn't require much expertise.

Technical requirements of Good Formwork

Formwork should be exactly designed of the required shape and size so that it fits at the designed position.

According to the desired concrete surface the material of the formwork will be selected.

Formwork should be strong enough to withstand the pressure of fresh concrete and working loads and should not distort or deflect from their position during the concrete placing operation.

Formwork should support the designed horizontal and vertical loads. It should also support the other unusual loads also during the construction period.

The formwork should not disturb the structure or concrete surface during the removal time.

The segments of the formwork should be tightly fitted to minimize the gaps between them which prevents the leakage of cement material.

Sr. No	Structural Member	OPC (Ordinary Portland Cement)	Rapid Hardening Cement
1	Beam sides, walls & Columns	2-3 Days	2 Days
2	Slab (Vertical Supports remains intact)	4 Days	3 Days
3	Slab (Complete Formwork removal)	10 Days	5 Days
4	Beams (Removal of Sheeting, Props remains intact)	8 Days	5 Days
5	Beams & Arches (Complete formwork removal) (up to 6 m span)	14 Days	5-8 Days
6	Beams & Arches (Complete formwork removal) (more than 6 m span)	21 Days	8-10 Days

Functional Requirements of Formwork

Form segments should be of suitable size so that they can be transported and stored easily and reused at another place.

Formwork should be easy to dismantle and fit so that construction of building process advances.

Formwork segments should have symmetry so that they can be interchangeable and can be used at different places.

Forms should be simple to build.

Formwork should be as lightweight but with enough strength required to withstand the loads and pressure.

Forms should be made such that workers can handle them without any safety issue, respecting the Health, Safety, and Hygiene Regulation in effect.

stripping of forms. (Concepts only):

The **removal of concrete formwork** also called as strike-off or stripping of formwork should be carried out only after the time when concrete has gained sufficient strength, at least twice the stress to which the concrete may be subjected to when the formworks are removed. It is also necessary to ensure the stability of the remaining formwork during formwork removal.

Contents: [show]

Concrete Formwork Removal Time

The rate of hardening of concrete or the concrete strength depends on temperature and affects the formwork removal time. For example, time required for removal of concrete in winter will be more than time required during summer.

Special attention is required for formwork removal of flexural members such as beams and slabs. As these members are subjected to self-load as well as live load even during construction, they may deflect if the strength gained is not sufficient to handle to loads.

To estimate the strength of concrete before formwork removal, the tests on concrete cubes or cylinders should be carried out. The concrete cubes or cylinders should be prepared from the same mix as that of the structural members and cured under same circumstances of temperature and moisture as that of structural member.

When it is ensured that the concrete in the structural members has gained sufficient strength to withstand the design load, only then formworks should be removed. If possible, the formworks should be left for longer time as it helps in curing.

Removal of formwork from the concrete section should not make the structural element to:

- Collapse under self load or under design load
- deflect the structural member excessively in short or the long term
- physically damage the structural member when formwork is removed.

The following points must be kept in mind during formwork removal whether the structure will be prone to:

- freeze thaw damage
- cracks formation due to thermal contraction of concreteafter formwork striking.

If there is a significant risk of any of the above damages, it is better to delay the removal time of formwork. If formwork have to removed for optimising the concrete construction activities, then these structures must be insulated well to prevent such damages.

Calculation of Safe Formwork Striking Times:

Structural members are constructed based on designed load. But before a structure is complete and subjected to all loads assumed during structural design, the structural members are subjected to its self weight and construction loads during construction process.

So, to proceed with construction activities at a quicker rate, it is essential to calculate the behaviour of structure under is self load and construction load. If this can be done and structural member is found to be safe, formwork can be stripped-off.

If these calculations are not possible, then following formula can be used for calculation of safe formwork striking times:

Characteristic strength of cube of equal of maturity to the structure required at time of formwork removal

$$= \frac{\text{Dead load + construction load}}{\text{Total design load}} \times \text{grade of concrete}$$

This formula was given by Harrison (1995) which describes in detail the background of determination of formwork removal times.

Other method to determine the strength of concrete structure is to conduct the non-destructive tests on structural member.

Factors Affecting Concrete Formwork Striking Times

The striking time of concrete formwork depends on the strength of structural member. The strength development of concrete member depends on:

- **Grade of concrete** – higher the grade of concrete, the rate of development of strength is higher and thus concrete achieves the strength in shorter time.
- **Grade of cement** – Higher cement grade makes the concrete achieve higher strength in shorter time.
- **Type of Cement** – Type of cement affects the strength development of concrete. For example, rapid hardening cement have higher strength gain in shorter period than the Ordinary Portland Cement. Low heat cement takes more time to gain sufficient strength than OPC.
- **Temperature** – The higher temperature of concrete during placement makes it achieve higher strength in shorter times. During winter, the concrete strength gain time gets prolonged.
- A higher ambient temperature makes the concrete gain strength faster.
- Formwork helps the concrete to insulate it from surrounding, so longer the formwork remain with concrete, the less is the loss of heat of hydration and rate of strength gain is high.
- **Size of the concrete member** also affects the gain of concrete strength. Larger concrete section members gain strength in shorter time than smaller sections.
- **Accelerated curing** is also a method to increase the strength gain rate with the application of heat.

Generally following values of concrete strength is considered for removal of formwork for various types of concrete structural members.

Table – 1: Strength of concrete vs. Structural Member Type & Span for Formwork Removal

Concrete Strength	**Structural Member Type and Span**

2.5 N/mm^2	Lateral parts of the formwork for all structural members can be removed
70% of design strength	Interior parts of formwork of slabs and beams with a span of up to 6m can be removed
85% of design strength	Interior parts of formwork of slabs and beams with a span of more than 6m can be removed

Table – 2: Formwork Stripping Time (When Ordinary Portland Cement is used):

Type of Formwork	**Formwork Removal Time**
Sides of Walls, Columns and Vertical faces of beam	24 hours to 48 hours (as per engineer’s decision)
Slabs (props left under)	3 days
Beam soffits (props left under)	7 days
Removal of Props of Slabs:	
i) Slabs spanning up to 4.5m	14 days

ii) Slabs spanning over 4.5m	14 days
Removal of props for beams and arches	
i) Span up to 6m	14 days
ii) Span over 6m	21 days

Important Note:

It is important to note that the time for formwork removal shown above in Table -2 is only when Ordinary Portland Cement is used. In normal construction process Portland Pozzolana cement is used. So, the time shown in Table-2 should be modified.

For cements other than Ordinary Portland cement, the time required for formwork removal should be as:

- Portland Pozzolana Cement - stripping time will be 10/7 of the time stated above (Table-2)
- Low heat cement - stripping time will be 10/7 of the time stated above (Table-2)
- Rapid Hardening Cement - stripping time of 3/7 of the time stated above (Table-2) will be sufficient in all cases except for vertical sides of slabs, beams and columns which should be retained at least for 24 hours.

Concrete Formwork Removal Specification

During stripping of formwork, following points must be remembered:

- Formwork should not be removed until the concrete has developed sufficiently strength to support all loads placed upon it. The time required before formwork removal depends on the structural function of the member and the rate of strength gain of the concrete. The grade of concrete, type of cement, water/cement ratio, temperature during curing etc. influence the rate of strength gain of concrete.
- The formwork parts and connections should be arranged in a way that makes formwork removal easy and simple, prevents damage to concrete and formwork panels so that it can be reused without extensive repair.
- The formwork removal procedure should be supervised by the engineer to ensure that quality of hardened concrete in structural member, i.e. it should be free from or has minimum casting defects such as honeycombing, size and shape defects etc. These defects in concrete influence the strength and stability of structure. Thus immediate repair works can be done or the members can be rejected.
- The separation of forms should not be done by forcing crowbars against the concrete. It may damage the hardened concrete. This should be achieved by using wooden wedges.
- Beam and joist bottoms should remain in place until final removal of all shoring under them are done.
- Joist forms should be designed and removed so that the shores may be removed temporarily to permit removal of joist forms but must be replaced at once. The shores and joists will be dismantled beginning from the middle of the member’s span, continuing symmetrically up the supports.

- The approval from the engineer should be obtained for the sequence and pattern of formwork removal.

Reference:

- ACI (1995) *In-place methods to estimate concrete strength.* ACI 228.1R-95.
- ASTM (1987) *Standard practice for estimating concrete strength by the maturity method.* ASTM C1074–87
- BS 8110 - code of practice for the structural use of concrete
- IS-456 – Plain and Reinforced Concrete – Code of Practice

FAQs

When should formwork be removed?

The **removal of concrete formwork** also called as strike-off or stripping of formwork should be carried out only after the time when concrete has gained sufficient strength, at least twice the stress to which the concrete may be subjected to when the formworks are removed. It is also necessary to ensure the stability of the remaining formwork during formwork removal.

What are the factors affecting concrete striking time?

The striking time of concrete formwork depends on the strength of the structural members. The strength development of concrete member depends on:
1. Grade of concrete
2. Grade of cement
3. Type of Cement
3. Temperature
4. Size of the concrete member
5. Accelerated curing

FAQs:

What is the Curing of Concrete?

The method of shielding concrete against the steady loss of moisture in order to retain it for carrying out hydration is maintained within the required temperature range, this process is called Curing of Concrete. It is a practice to keep concrete moist until the end of hydration.

What Is Formwork?

Formwork is a type of casting mold or box, like a container into which fresh concrete is poured and compacted. It is kept for several days until concrete acquires its strength and stability.

How many days is the curing of concrete?

Min. 7 days are required for curing concrete at a temperature above 5oC. However, a greater time might be required for curing some concerts with Higher Strength. 70% of compressive or flexural strength must be acquired by concrete in its curing span.

When to Remove Forms From Concrete Slab?

Slabs, with their props left under them, can typically be removed after 3-4 days. Props supporting slabs under 15 feet can be removed after 1 week.

When to Remove Forms from Quikrete?

The formwork of cover can be removed after its achieved sufficient strength of taking load or it is usually safe to remove after 24 hrs of curing.

What do you mean by Deshuttering Time?

Deshuttering is also called a strike-off of forms in which concrete is poured. The formwork should be removed only after when concrete component achieves sufficient strength. This process is called de shuttering Time. Care should be taken during the removal of formwork to ensure the stability of the remaining formwork.

When strip concrete forms?

1. For Concrete Forms, Concrete walls and concrete columns can be removed after about 24 to 48 hours.
2. Slabs, with their support left under them, can be normally removed after 3 to 4 days.
3. The Soffits, with their remaining supports under them, can be removed after 1 week.

How long before removing concrete forms?

Walls and columns can be removed after **about 24-48 hours**. Slabs, with their props left under them, can typically be removed after 3-4 days.

Soffits, with their props left under them, can be removed after one week.
Props supporting slabs under 15 feet can be removed after one week.

Q/A 74 RCC FORMWORK CHECKLIST

The following checking should be done for formwork of RCC –

1. Check the Formwork is properly aligned.
2. Check it is cleaned.
3. Check it is oiled (if steel formwork)
4. Check inner face of formwork is smooth (if wooden formwork).
5. Check if the formwork is water-tight.
6. Check supports are properly placed and fixed.
7. Check width and depth/height of formwork.
8. Check thin metal sheets are provided along joints of wooden formwork.
9. Check foam is provided along the joint of steel formwork.


EUROPROP

Slab Formwork Removal

Formwork Removal with Crowbar

Column Formwork made of Steel

Slab Formwork made of Wood

Curing of concrete

Curing of cement concrete is defined as the process of maintaining the moisture and temperature conditions of concrete for hydration reaction to normally so that concrete develops hardened properties over time. The main components which need to be taken care of are moisture, heat, and time during the curing process.

Contents: [show]

Why the curing of cement concrete is required?

Curing of cement concrete is required for the following reasons:

- To prevent the concrete from drying out prematurely due to solar radiation and wind. This prevents plastic shrinkage of concrete.
- It helps to maintain the concrete temperature by allowing the hydration process. The hydration process requires water to carry on and releases heat.

- Curing helps the concrete to harden and bond with internal materials and reinforcement. This helps to prevent damage to the bond between concrete and reinforcement due to vibration and impact.
- This helps the development of impermeable, crack-free, and durable concrete.

Fig 1: Curing of Concrete Roof Slab by Ponding.

What is the right time for the curing of concrete?

The time to start the curing of concrete depends on the evaporation rate of moisture from the concrete. The evaporation rate is influenced by wind, radiant energy from sunshine, concrete temperature, climatic conditions, relative humidity. The evaporation of moisture is driven by the difference in vapor pressure on the concrete surface and the surrounding air. When the difference is high, the evaporation rate is high.

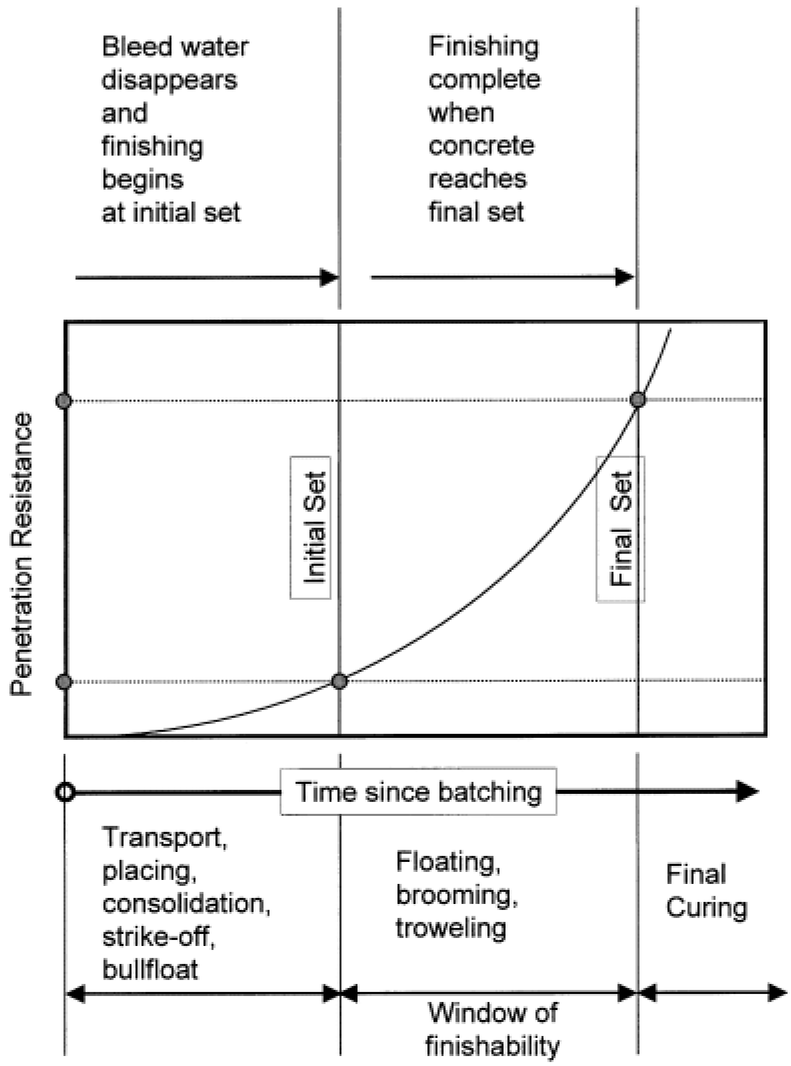


Fig 2: Three phase of concrete curing

ACI 308 – Guide to Curing Concrete suggests three phases of concrete curing. These phases are shown in figure 1.6 of ACI 308.

The right time of curing of concrete depends on:

1. Initial Curing

When the concrete is placed and compacted, bleeding of water occurs and rises through the surface of concrete due to the settlement of concrete. The rate and duration of bleeding depend on many factors, including concrete mix properties, depth or thickness of concrete, method of compaction of concrete, etc.

These bleed water starts to evaporate from the surface. When all the bleeding water has disappeared from the surface, the drying of concrete starts, then the initial curing of concrete is required to minimize the moisture loss and prevent plastic shrinkage cracks to the concrete before and during finishing operations.

The initial curing of concrete can be done by techniques such as fogging or using the evaporation reducers, or by providing the sunshades and windscreens.

2. Intermediate Curing

Intermediate curing is done when the concrete surface finishing operations have been carried out before the final set of concrete. This happens when the required surface texture of the concrete members is achieved rapidly or when the setting of concrete is delayed.

3. Final Curing

When the concrete is finished after the final set of concrete, the final curing of concrete should be done. This helps to prevent surface drying of concrete because the loss of moisture from the concrete surface occurs immediately.

What is the duration of cement concrete curing?

Curing of concrete for longer duration increases the strength and durability of concrete structural members. The following figure explains how the compressive strength of concrete increases with time when it is cured for a longer duration.

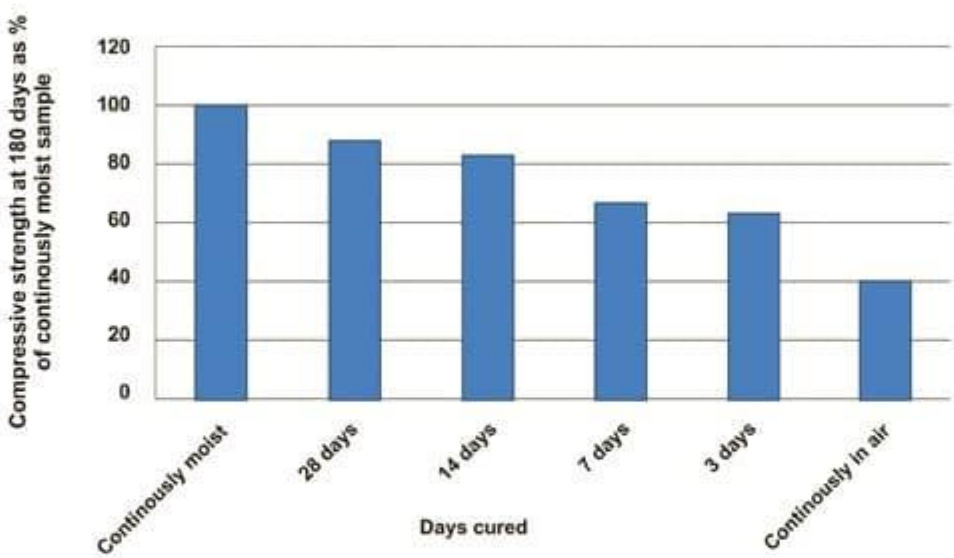


Fig 3: Effect of duration of water curing on strength of concrete

The curing duration of concrete depends on

1. The reason for curing, i.e. to prevent plastic shrinkage, temperature control, strength, and durability of concrete.
2. The size of a concrete structural member
3. The type of concrete grade and rate of hardening of concrete
4. The temperature and moisture conditions of surroundings
5. The exposure conditions of the concrete surface during and after curing
6. The requirement of curing duration as per the specification of concrete

The **American Concrete Institute (ACI) Committee 301** recommends a minimum curing period corresponding to concrete attaining 70 percent of the specified compressive strength. The often specified seven-day curing corresponds to approximately 70 percent of the specified compressive strengths.
The **Indian Standard IS 456 – 2000** recommends that curing duration of concrete must be at least seven days in case of ordinary Portland Cement, at least ten days for concrete with mineral admixtures or blended cements are used. It also recommends that the curing duration should not be less than ten days for concrete exposed to dry and hot weather conditions and 14 days for concrete with mineral admixtures or blended cement in hot and dry weather.

References

1. ACI 308, American Concrete Institute – Guide to Curing Concrete
2. BS 8110 – British Standard for the Design and Construction of Reinforced and Prestressed Concrete Structures
3. IS 456 – 2000: Indian Standard Code of Practice for Plain and Reinforced Concrete

1. What is curing of concrete?

Curing of cement concrete is defined as the process of maintaining the moisture and temperature conditions of concrete for hydration reaction to normally so that concrete develops hardened properties over time.

2. **Why the curing of cement concrete is required?**

The curing of cement concrete is required for the following reasons-
1. To prevent the concrete from drying out prematurely due to solar radiation and wind.
2. To maintain the concrete temperature by allowing the hydration process.
3. To harden and bond with internal materials and reinforcement. This helps to prevent damage to the bond between concrete and reinforcement due to vibration

and impact.
4. To the development of impermeable, crack-free, and durable concrete.

3. **What is the right time for the curing of concrete?**

The time to start the curing of concrete depends on the evaporation rate of moisture from the concrete. The evaporation rate is influenced by wind, radiant energy from sunshine, concrete temperature, climatic conditions, relative humidity.

4. **What is the duration of cement concrete curing?**

The curing of concrete for longer duration increases the strength and durability of concrete structural members. However, after 28 days of the casting of a concrete, 99% of the hydration process of the concrete is completed. Further to which continuation of curing is of no use.

5. Which are the standard codal references for curing concrete?

1. ACI 308, American Concrete Institute – Guide to Curing Concrete.
2. BS 8110 – British Standard for the Design and Construction of Reinforced and Prestressed Concrete Structures.
3. IS 456 – 2000: Indian Standard Code of Practice for Plain and Reinforced Concrete.

10 Inspection and Quality Control of Concrete

10.1

Quality control of Concrete as per I.S.456:

What Is Quality Control Of Concrete?

Concrete is one of the most important and widely used materials in the construction industry. Concrete consists of raw materials including cement, sand, aggregates, admixtures, and water. All these raw materials are mixed up in a certain proportion to form concrete, according to the requirements.

Concrete is widely used for the construction of elements like columns, beams, walls, lintels, slabs, copings, and foundations so on. The prepared concrete, as a material, should maintain a certain level of quality standards to get accepted for its utilization for the construction of various elements of concrete.

The quality of concrete should be checked, maintained, and also should be corrected if the level of quality standards does not match the required level of quality. If the quality of concrete is inferior, it may have an adverse effect on the construction.

The quality of concrete is checked in three different stages of construction. They are as follows:

1. Quality control of concrete before concreting,
2. Quality control of concrete during concreting, and
3. Quality control of concrete after concreting (or after construction of an element).

Let us study all the three stages of quality control of concrete in detail.

Stage 1: Quality Control Of Concrete Before Concreting

Before the concrete is even prepared, the quality of raw materials shall be checked, and only then they are mixed in a required proportion to form fresh concrete. The quality of raw materials is directly related to the quality of concrete.

The quality control of concrete in this stage is done in two different steps. They are as follows:-

Step -1: Test for quality of materials used in concrete

Step – 2: various tests on fresh concrete for its quality check.

Step – 1: Quality Tests Of Concrete Materials

Concrete is made up of cement, sand, aggregates, and water, respectively. So it is necessary to have a check for the quality of all of these materials.

Cement

The quality of cement is usually diagnosed by carrying out tests for compressive strength on cement cubes. There are a few points which are important and should be taken care of to control the quality of cement before the commencement of concreting. They are:-

Cement should be tested before it's added to the concrete mix.

The cement should be subsequently checked once every two months.

Cement should be kept far away from moisture.

Cement should be retested after every three months if it is stored for a longer period.

If large lumps of cement are found in the cement bags, it should not be accepted.

Aggregates (Fine and Coarse)

Aggregates have different properties such as shape, size, grades, water absorption, durability, specific gravity, etc. All of these properties should be checked for the sample of aggregates which are to be used while preparing the concrete. Also, impurities are to be removed before mixing them into the concrete mix.

Some points to remember while checking the coarse aggregates.

The coarse aggregates having a rough surface are preferable over the smooth aggregates for better bonding.

The aggregates should be hard and strong enough to provide proper strength to toes concrete.

If the aggregates are submerged underwater for 24 hours, the water content should not exceed 10%.

The quantity of flaky and elongated aggregates shall be equal to or lesser than 35 percent of the total quantity of aggregates in the concrete.

20 mm and 10 mm aggregates shall be taken in the ratio of 70:30 or 60:40 to allow better compaction and to achieve a higher density of concrete.

Some points to remember while checking the quality of sand or fine aggregates.

Sand used for making concrete shall retain on 150-micron sieve and should pass 4.75 mm sieve.

Sand should have a lesser amount of clay in it, as the presence of clay makes the sand cohesive. The amount of clay should be less than 8%.

Sand containing more than 5 % moisture is not preferable for concrete.

Water

Water is an important element of concrete. The quantity and quality of water decide the quality of concrete. The quality of water should be checked for:

- Chemically harmful substances.
- Impurities in water.

To ensure the quality of water, at least three cubes of concrete should be cast using that particular sample of water, and the compressive strength of concrete after 28 days should be measured. If the compressive strength is less than 90 %, it is advised to reject the sample of water.

Stage 2: Quality Control Of Concrete During Concreting

For quality control of concrete during concreting, the following points are kept in mind:

The design mix of concrete should not differ from the mix design given in the specification.

The ingredients of concrete in a concrete mixture should be properly mixed.

Approximately 15 to 20 revolutions of mixture machine are recommended to give them a proper mix.

It should be taken care that segregation should not take place.

Slump test shall be conducted after every 25 m3 of concreting done, to ensure the perfect workability of concrete.

The dropping height of concrete should not exceed 1m, to avoid segregation.

Once the concrete is poured, proper vibration shall be done so that the voids in the concrete are removed.

After the hardening of concrete, proper curing for 7 days should be done.

Stage 3: Quality Control Of Concrete After Concreting

After the concrete is hardened, the quality of concrete is tested in the following ways:

Chemical tests and analysis of concrete are done.

Core is obtained from the concrete element and they are tested for the strength of concrete.

Non-destructive test like rebound hammer test is performed on the concrete structure.

The concrete structure is tested for its dimensions and shapes.

Also, a check for clear cover is done. If, in some parts, the reinforcements are visible, that particular part of the structure is rejected.

Acceptance criteria according to Indian standards

As per the IS code (Clause 16 of IS 456:2000), for a given set of tests, the compressive strength is taken as the average of three tests, no one test differing from the average by more than 15%. The strength requirements are deemed to meet standards in the following conditions are satisfied.

Compressive strength:

Mean of 4 test results > f_{ck} + 0.825 σ, or f_{ck} + 4 MPa (whichever is greater)

Individual strength result > f_{ck} – 4 MPa

Flexural strength (f_t is the characteristic flexural strength):

Mean of 4 test results > f_t + 0.3 MPa

Individual strength result > f_t – 0.3 MPa

Quality factors

For a good quality concrete construction, one must ensure the four Cs:

- **Ensure design Cover is maintained**
- **Ensure sufficient Cement and proper w/c**
- **Ensure adequate Compaction so there is no honeycombing**
- **Ensure good Curing so that design strength is obtained**

Factors causing the variations in the quality of concrete

How to Control Variation in the Quality of Concrete ?

Generally at site concrete is produced in batches with the locally available materials of variable characteristics. Thus concrete of one batch is likely to be different from the other.

The magnitude of this variation depends upon many factors as follows:

(a) Variation in the quality of the constituent materials.

(b) Variation in the mix proportions due to batching.

(c) The quality of overall workmanship and supervision at site.

Further concrete has to go under a number of operations such as:

(i) Transportation,

(ii) Placing,

(iii) Compaction,

(iv) Curing etc.

During all these operations considerable variation may develop partly due to the quality and efficiency of machinery and plants available and partly due to the difference in the efficiency of techniques used. Thus there is no single feature to define the quality of concrete. Under such conditions concrete generally is referred as good, fair or poor quality con-crete. This interpretation is subjective.

Thus it is necessary to define the quality of concrete in terms of desired performance characteristics, economics, safety and other such factors. Due to the large number of variables influencing the performance of concrete, quality control is essential. As the concrete serves the needs of safety and serviceability including durability, which vary from one situation and type of construction to another. Therefore uniform standards for general application to all the works are not practical.

Thus the aim of quality control is to reduce the above noted variations and produce uniform material of desired characteristics for the envisaged job. Therefore the quality control is a dynamic corporate pro-gramme to assure that all aspects of equipment, materials and workmanship are looked after well.

Factors Causing Variations in the Quality of Concrete:

The main factors which cause variations in the quality of concrete are as follows:

1. Personnel.

2. Material.

3. Aggregates.

4. Equipment.

1. Personnel:

Personnel are the basic key for the successful execution of any plan or job. Therefore the basic require-ment for the success of any quality control plan is the availability of trained and experienced personnel at all levels of concrete production and its execution. The designer must be well versed with the construction operations and the site engineer must be able to understand the statements of specifications fully and clearly. In quality control everything cannot be specified and much depends on the skill and experience of the people involved in it.

2. Material:

For producing concrete of uniform quality, its ingredients play a major role. Thus the ingredients used in concrete must be from the same source as far as possible, specially the cement. When ingredients from different sources are used, the strength and other qualities of the materials are likely to change.

Thus the ingredients from different sources must be tested before use, the same type of cement from different sources and at different times from the same source exhibits variation in its properties, especially the compressive strength.

Thus cement received from each source must be tested initially, once from each source of supply and after wards every two months as the variation in compressive strength is related to the composition of raw materials and the variation in the process of manufacturing. Cement should be protected from moisture. Set cement with hard lumps should be rejected.

3. Aggregates:

The maximum size, moisture content, grading and shape of coarse aggregate are major source of varia-bility in the concrete. Hence aggregates should be stock piled separately in single sizes. The graded aggre-gate should not be allowed to segregate.

Rule for Grading of Aggregate:

i. For fine aggregate long and continuous grading's are preferable. The material passing through 300 micron (0.3 mm) sieve and 150 micron (0.15 mm) sieve should be minimum.

ii. The grading's that are at the coarser end of the range are more suitable for rich mixes and those at finer end of the range are suitable for lean mixes.

4. Equipment:

The equipment used for batching, mixing and compaction should be of the right type. The weight batchers should be checked frequently for their accuracy. Generally weight batching should be preferred than volume batching. If volume batching has to be adopted, the volume measures should be checked frequently for the weight volume ratio.

Mixer's performance also should be checked to the requirements of the relevant standards. Concrete should be mixed for the stipulated time as under mixing and over mixing both affect the compressive strength of concrete and should be avoided. The vibrators should be of required frequency and amplitude.

The green concrete should be handled, transported and placed in such a manner that it does not segregate. The time interval between mixing and placing should be as minimum as possible. The targeted strength, impermeability and durability can be achieved only by thorough compaction. 1% voids left due to incomplete compaction will reduce the compressive strength by 5%.

Quality Control of Concrete:
Field Control:

It consists of inspection and testing. They play a vital role in the overall quality control plan.

Inspec-tion may be divided into the following two groups:

1. Quality control inspection.

2. Acceptance inspection.

1. Quality Control Inspection:

For repeated type activities or operations an early inspection is impor-tant. After the plant is stabilized, occasional checks may be sufficient to ensure the continued satisfactory results. On the other hand for the activities or operations which are not of repetitive type more constant checks are necessary.

Apart from the tests of concrete material, concrete should be tested at the fresh or green and hardened stages. Tests in the green stage of concrete offer an opportunity for necessary corrective steps to be taken before it is too late. These tests include unit weight, air content and workability test. The accelerated strength tests from which a reliable idea of the 28 day strength can be obtained with in few hours are effective quality control tools.

2. Acceptance Test:

The tests whose results are at universal acceptance level are known as accepted tests. The 28 day concrete strength test is the only acceptance test on the basis of which the acceptance or rejection of concrete mix depends.

Advantages of Quality Control in Concrete:

Following are the advantages of quality control:

i. Quality control is the rational use of available resources after testing their characteristics resulting in the reduction of material cost.

ii. Quality control reduces the maintenance cost.

iii. In the absence of quality control there is no guarantee that the weakness of a certain area can be compensated by over spending in other areas. For example the loss of strength due to incomplete compaction or in adequate curing of concrete cannot be compensated by adding more cement in concrete at some other place.

iv. In the absence of quality control at the site, the designer may be tempted to overdesign to minimise the risk. This will result in more cost.

v. Checks at every stage of production of concrete and rectifications of defects at the proper time will result in early completion of work reducing the delay and cost.

Statistical Quality Control:

Cement concrete is a mixture of cement, aggregate, and water and thus have certain amount of variabi-lity in materials as well as in construction methods. This results in variation of concrete strength from batch to batch as well as in the same batch. To assess the strength of the final product is very difficult. To evaluate the strength of end product requires a very large number of destructive tests, which is very costly and time consuming.

Thus we have to resort to sample tests. To adopt very rigid criteria to reject a structure on the basis of a single or few standard samples will prove very costly. Thus to have a reasonable control on con-crete work, the acceptance test basis of samples may be adopted, by ensuring that the probability of test result falling below the design strength is not more than a specified tolerance level.

The aim of quality control is to limit the variability of concrete as much as possible. Statistical quality control method provides a scientific approach to concrete designer to understand the realistic variability of materials. With the knowledge of variability of materials, he may lay down the design specifications with proper tolerance to provide for the unavoidable variations. The acceptance criteria are based on statistical evaluation of the test results of samples taken at random during the execution period of the work. For this purpose various statistical techniques are available.

The quality control of concrete will be of great im-portance on large contracts, where the specifications insist on certain minimum requirement. The efforts put in will be more than the benefits from the resulting savings in the overall concreting operations.

The control over the quality of concrete generally is carried out by testing 150 mm cubes or 150 x 300 mm cylinders prepared at site from the concrete used in the structure. These tests measure the potential strength of the concrete but do not indicate any variation in the compaction or curing conditions of the concrete in the structure. The compressive strength of tests cubes from random sampling of a mix show variations. These variations are inherent in the various operations involved in the preparation and testing of concrete. The variation is shown in Fig. 21.1. This Fig. has been drawn on the basis of table 21.1.

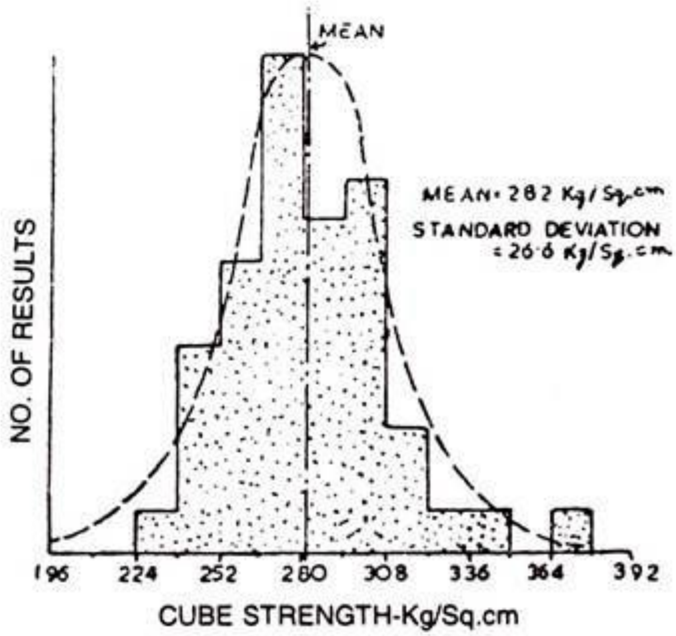


Fig. 21.1. A Histogram of strength values

Table 21.1.

Range of variation in strength	*Frequency f*	*Mid value*	*Difference d*	*f · d*	*f · d²*	*Remark*
371 — 378	4	374.5	– 56.0	– 224.0	12545	
378 — 385	3	381.5	– 49.0	– 147.0	07203	
385 — 392	7	388.5	– 42.0	– 294.0	12384	
392 — 399	1	395.5	– 35.0	– 35.0	01225	
399 — 406	4	402.5	– 28.0	– 112.0	03136	
406 — 413	2	409.5	– 21.0	– 42.0	00882	
413 — 420	5	416.5	– 14.0	– 70.0	00980	
420 — 427	6	423.5	– 7.0	– 42	00294	
427 — 434	4	430.5	0.0	00	000	
434 — 441	2	437.5	+ 7.0	+ 14.0	00098	
441 — 448	1	444.5	+ 14.0	+ 14.0	00196	
448 — 455	1	451.5	+ 21.0	+ 21.0	0044!	
455 — 462	1	458.5	+ 28.0	+ 28.0	00784	
462 — 469	2	465.5	+ 35.0	+ 70.0	02450	
469 — 476	0	472.5	+ 42.0	+ 00.0	0000	
476 — 483	2	479.5	+ 49.0	+ 98.0	04802	
483 — 490	2	486.5	+ 56.0	+ 112.0	06272	
	N = 47			$\Sigma fd = -609$	$\Sigma fd^2 = 53691$	

In the Fig. 21.1, the strength interval is taken constant along the x-axis and no of specimens in each interval (called frequency, along y-axis. The figure obtained is called histogram. The area under the curve represents the total number of specimens to an appropriate scale.

If the number of specimen is very large and at the same time the size of the interval is decreased to a limiting value of zero. The histogram would become a continuous curve known as the distribution curve. Such a distribution curve is called a Normal or Gaussian distri-bution curve. The assumptions of this distribution are very close to reality and are an extremely useful tool in the computation.

The doted smooth curve of Fig. 21.1 is normal distribution curve. The curve is described in terms of mean strength f_m and standard deviation σ or S. The standard deviation is the measure of the scatter or disper-sion of strength about the mean.

The theoretical normal distribution is represented in Fig. 21.2. It can be seen from the Fig. 21.2 that the curve is symmetrical about the mean value and extends to plus and minus infinity. Actually in practice, very low and very high values of strength do not occur, but these extremes can be ignored as most of the area under the curve (99.6%) lies with in ± 3.0 S or σ. In practice this area can be taken to represent all the strength values of concrete.

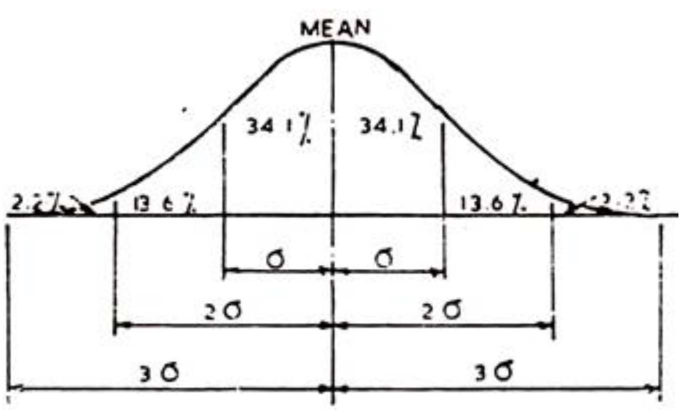


Fig. 21.2. Normal distribution curve

In other words, it can be said that the probability of a value of strength failing with in ± 3 5 from the mean value is 99.6%. Similarly the probability of a value falling between any given limits about the mean value (f_m + K.S.) can be stated. The values of probability for various values of probability factor K together with the probability of falling strength below (f_m – KS).

Table 21.2. Probability strength in the range $f_m + Ks$ and below $f_m - K.S.$ for normal distribution

Probability factor K	*Probability of strength in the rnage f_m + K.S. %*	*Probability of strength below f_m – K.S. (Risk factor) % Risk percent*
1.0	68.2	15.9 (1 in 6)
1.64	90.0	5.0 (1 in 20)
1.96	95.0	2.5 (1 in 40)
2.33	98.0	1.0 (1 in 100)
3.00	99.7	0.15 (1 in 700)

In the mix design the mean strength can be calculated by the following relation:

$f_m = f_{min}$ + K.S. ...(21.1)

where $f_{min.}$ = minimum strength which is also known as specified characteristics strength or specified design strength.

The probability factor K usually is chosen as 1.64 or 2.33, i.e. there is a probability that 1 in 20 or 1 in 100 respectively of the strength values will fall below the minimum strength. The term K.S. is known as margin. In the calculation of the margin, the standard deviation 'S' or σ should be based on the results obtained using the same plant, materials and supervision.

In the absence of such data, the value of S may be taken depending upon the number of available results V and the characteristic strength f_{min} as follows:

If	$n \leq 20$	
then	$S = 0.4 f_{min}$, for $f_{min} \leq 20$ MPa	...(21.2)
	$S = 8$ MPa for $f_{min} \geq 20$ MPa	
(*ii*) If	$n \geq 20$	
	$S = 0.2 f_{min}$ for $f_{min} \leq 20$ MPa	
	$S = 4$ MPa for $f_{min} \geq 20$ MPa	...(21.3)

Note:

The above values of standard deviation should be used till the sufficient data for the calculation of standard deviation is not available.

In the British method of mix design for air entrained concrete, it is assumed that a loss of 5.5% in com-pressive strength results for each 1% air entrained by volume in the mix.

This reduction is compensated by aiming for a higher strength as:

$$f_m = \frac{f_{min} + K.S.}{1 - 0.055\, a} \qquad \text{...(21.4)}$$

where a is the percentage of air entrained.

Himsworth has suggested the value of coefficient of probability K as shown in Table 21.3.

Table 21.3. Value of K. Coefficient of probability (Himsworth constants)

Percentage of results allowed to fall below the minimum	*Value of K*
0.1	3.09
0.6	2.50
1.0	2.53
2.5	1.96
6.6	1.5
16.0	1.0

In the table 21.2 the value of K is shown as 1.64 if 5% results are allowed to fall below the minimum value, but generally it is taken as 1.65.

Table 21.2. Probability strength in the range $f_m + Ks$ and below $f_m - K.S.$ for normal distribution

Probability factor K	*Probability of strength in the rnage $f_m + K.S.$ %*	*Probability of strength below $f_m - K.S.$ (Risk factor) % Risk percent*
1.0	68.2	15.9 (1 in 6)
1.64	90.0	5.0 (1 in 20)
1.96	95.0	2.5 (1 in 40)
2.33	98.0	1.0 (1 in 100)
3.00	99.7	0.15 (1 in 700)

Example 1:

Find the mean strength of concrete for an overhead tank concrete from the following data:

1. The characteristics strength of concrete = 18 MPa

2. The number of test results available = 75

3. Probability factor K = 2.33.

Solution:

$f_m = f_{min} + K.S.$

As the value of n is greater than 20, and f_{min} is less than 20 MPa, the standard deviation 5 is taken as-

$S = 0.2 \times f_{min} = 0.2 \times 18 = 3.6$

Then $f_m = f_{min} + K.S.$

$= 18 + 2.33 \times 3.6 = 18 + 8.388 = 26.388$ say

$= 26.4$ MPa Ans.

Example 2:

From the following data, find the mean strength if air entrainment is 4%:

1. The characteristics strength of concrete = 18 MPa

2. The number of test results available = 75

3. Probability factor K = 2.33.

Solution:

From Eq.21.4,

$f_m = [(f_{min} + K.S)/(1 – 0.055\ a)]$

the value of f_{min} + K.S. from example (1) is 26.4 MPa

the f_m = [26.4/(1 – 0.220)] = 26.4/0.78 = 33.85 MPa (app.) Ans.

Sampling of Concrete:

1. Sampling Procedure:

To ensure that each concrete batch should have a reasonable chance of being tested, random sampling procedure should be adopted. Thus the sampling should be spread over the total period of concreting to cover all mixing units and all the batches.

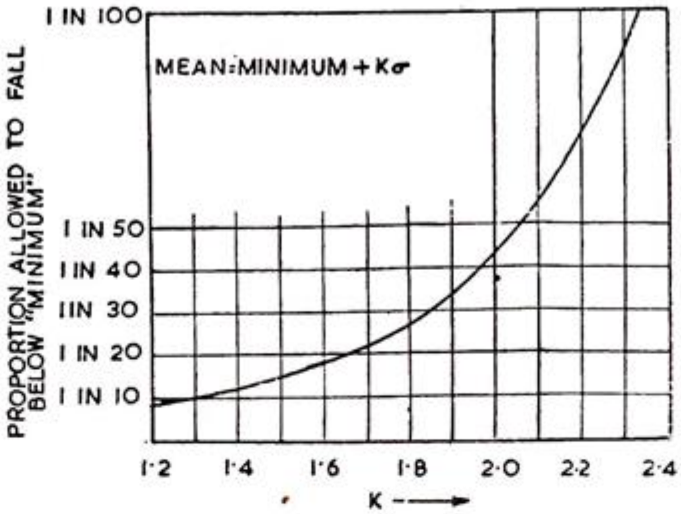


Fig. 21.3. Values of K for various tolerance.

2. Frequency of Sampling:

The minimum frequency of sampling of concrete of all grades should be as follows as per IS 456-1978 shown in table 21.4.

Table 21.4. No. of samples to be taken

Quantity of concrete work in m^3	*No. of samples*
1 — 5	1
6 — 15	2
16 — 30	3
31 — 50	4
51 and above	4 plus one additional sample for each addional 50 m^3 concrete or part there of.

Note:

At least sample should be taken from each shift.

Test Specimens for Concrete:

Three specimens should be prepared from each sample to be tested at 28 days. Additional cube specimens may be prepared for determining the strength at 7 days or at the time of stripping the shuttering or to determine the duration of curing etc. The specimens should be tested as per IS 516-1959 or latest edition.

Test Strength:

The test strength of sample should be the average of the strength of three specimens. The individual variation in strength should not be more than 15% of the average strength.

Application:

As stated above, statistical methods may be used to analyse the variation in strength. The standard deviation and coefficient of variation are the most accepted methods. The procedure of the calculation of standard deviation and coefficient of variation is illustrated with the help of test results of a site-shown in Table 21.1.

Acceptance Criteria for Concrete:
Concrete is considered to comply the requirement of strength if it fulfills the following conditions as per IS 456-1978:

1. The test strength of every sample is not less than the characteristic value.

2. The strength of one or more samples may be less than the characteristic value but in each case it is not less than the greater value given by the following relations:

(a) Characteristic strength minus 1.35 times the standard deviation.

(b) 0.8 times the characteristic strength.

(c) The average strength of the sample is not less than the characteristic strength plus.

$$\left[1.65 - \frac{1.65}{\sqrt{\text{No. of samples}}}\right] \text{times the standard deviation.}$$

Thus the compressive strength of any sample of concrete should not be less than the greater value given by relation- (a) and (c) above.

1. Compliance:

To obtain the 28 day specified strength with in the permissible range of limits is called the compliance of specification. According to BS 5328 1990, the compliance of the characteristic strength is based on groups of consecutive test results, as well as on single results. Each result is the average of two cubes, made in the specified manner from concrete which is sampled at a prescribed rate and normally tested at 28 days.

The compliance is assumed to be met, if both of the following requirements are satisfied:

i. The average strength determined from the first two, three or four consecutive test results or from any group of four consecutive results, complies with the results of the following table 21.7

ii. No individual test result should fall short of the specified characteristic strength more than the value given in table 21.7.

Table 21.7. Compliance requirements for compressive strength as per B.S. 5328-Part-4-1990

Specified characteristic strength (grade) MPa	*Group of results MPa*	*Minimum value by which the mean strength of the group of test results should exceed the grade strength MPa*	*Max. value by batch any individual test result falls short of the grade strength MPa*
7.5 to 15	First 2	0	2
	First 3	1	2
	4*	2	2
20 and above	First 2	1	3
	First 3	2	3
	4*	3	3

4* Any consecutive four

2. Flexural Strength:

The compliance with respect to flexural strength of concrete is met when the following both condi-tions are satisfied:

i. The mean strength determined from any group of four consecutive test results exceeds the speci-fied characteristic strength by at least 0.3 MPa (0.3 N/mm^2).

ii. The strength determined from any test result is not less than the specified characteristic strength less than 0.3 MPa (0.3 N/mm^2).

Establishing the Compressive Strength of Concrete:

Concrete is a very useful and faithful material. If due care is taken of all the ingredients and workman-ship of the concrete structure, it generally does not fail to give the specified results.

1. Core Test:

The selection of point from where the core is to be taken depends upon the discretion of the inspecting authority or it can be decided from the cube testing register. The number of test specimens (cores) should not be less than three and they should represent the whole section of the doubtful concrete.

The core strength should be converted to equivalent cube strength. If the strength of equivalent cube obtained is at least 85% of the characteristic strength of the concrete grade, no strength of an individual core is obtained less than 75%, then strength of the concrete may be considered satisfactory.

In case such core tests are not possible or core test results are not found satisfactory then load test may be conducted.

2. Load Tests for Flexural Members:

To verify the performance of the structure i.e., the characteristic strength of the concrete, load tests may be carried out after the expiry of 28 days from the time of placing the concrete.

i. The structure should be subjected to a load equal to full dead load of the structure plus 1.25 times the live load for a period of 24 hours. After 24 hours the live load should be removed.

ii. The deflection due to live (imposed) load should be recorded. If within 24 hours of removal of live load, the structure does not recover at least 75% of the deflection under super impose load, the test should be repeated after 72 hours of the first test. If the recovery is less than 80% the structure should be rejected.

iii. If the max. deflection in mm shown in 24 hours under load is less than $40\ l^2/D$, where I is the effective span in metres and D the overall depth of the section in mm, then it is not necessary to measure the recovery and the recovery criteria is not applicable.

3. Non-Destructive Tests:

Nondestructive testing provides alternative method to core testing for the estimation of the strength of the concrete in the structure. It can also be used to supplement the data obtained from limited number of cores.

Use of Standard Deviation or Coefficient of Variation:

The use of standard deviation or coefficient of variation is based on the following argument. If the control over all materials and operations involved in the production of concrete including sampling and testing was perfect, then every result would be the same and would correspond to the mean value. In practice to have each operation fully perfect is impossible.

The more uniform the operations; closer will be the result to the mean value. Hence lower will be the value of standard deviation. Thus the quality of concrete can be changed by standard deviation. At site it is observed that it is more difficult to achieve consistent results with high strength concrete and the value of standard deviation is higher for high strength concrete than medium or low strength concrete.

Coefficient of variation = standard deviation/mean strength = a constant

It is seen that with a constant coefficient of variation, the standard deviation increases with the strength and is larger for higher strength.

On the basis of their research work Murdock and Erntroy have shown that the coefficient of variation more nearly represent a particular standard of control at relatively low strengths, while standard deviation more nearly represent the standard of control at high strength. Thus Indian standard method has adopted the standard deviation method.

American Concrete Institute (ACI) has recommended following values of standard deviation for different.

Control standards as shown in Table 21.8:

Table 21.8. Showing control standard and standard deviation

S. No.	*Control standard*	*Expacted standard deviation in MPa (N/mm²)*	
		General construction	*Laboratory trial mixes*
1.	Excellent	< 3.0	< 1.5
2.	Very good	3.0 – 3.5	1.5
3.	Good	3.5 – 4.0	1.5 – 2.0
4.	Fair	4.0 – 5.0	2.0 – 2.5
5.	Poor	> 5	> 2.5 to 3.5

IS 456-1978 has suggested the following values of standard deviation for different grades of concrete:

Table 21.9. Values of standard deviation for different grades of concrete

Grade of Concrete MPa	M_{10}	M_{15}	M_{20}	M_{25}	M_{30}	M_{35}	M_{40}
Assumed standard deviation MPa	2.3	3.5	4.6	5.3	6.0	6.3	6.6

Table 21.10. Suggested values of coefficient of variation for different grade of control

Degree of content	Well controlled as in lab	Excellent near that of lab	Excellant	Good	Fair	Fair (minus)	Bad
Coefficient of variation percent	5%	10%	12%	15%	18%	20%	25%

10.2

Mixing, Transporting, Placing &curing requirements of Concrete as per I.S.456.

Mixing, transporting, placing, and curing are important aspects of the concrete construction process. The Indian Standard Code of Practice for Plain and Reinforced Concrete (IS 456:2000) provides guidelines for these activities.

Mixing of Concrete:

1. Mixing of concrete should be done in a mechanical mixer or a batch mixer. The mixer should be capable of producing a uniform mix of concrete. The mix proportions should be as per the design mix or as approved by the engineer.

Transporting of Concrete:

2. Concrete should be transported from the mixing location to the point of placing within 30 minutes of the completion of mixing. The transportation should be done in a way that prevents segregation or loss of ingredients. The concrete should be transported in a truck mixer, dumpers or other suitable means.

Placing of Concrete:

3. Concrete should be placed in position within 30 minutes of the arrival of the concrete at the site. The concrete should be placed in horizontal layers of uniform thickness. The concrete should be compacted by means of vibrators, internal or external, to remove the voids and to achieve a dense concrete.

Curing of Concrete:

4. Concrete should be cured for a period of at least 7 days after placing. The curing should be done by keeping the concrete moist by spraying water, covering with wet jute bags, or other suitable methods. The curing should be continued until the concrete has achieved the desired strength.

In addition to the above requirements, it is important to ensure that the quality of the materials used for the construction of concrete is as per the specifications mentioned in the code of practice. The quality of reinforcement and formwork used for the construction of concrete should also be as per the specifications mentioned in the code.

As per the Indian standard code for reinforced concrete design, IS 456:2000, the following are the mixing, transporting, placing, and curing requirements for concrete:

Mixing Requirements:
a. The concrete mix should be designed to achieve the required strength, workability, and durability based on the site conditions and application.
b. The materials used for concrete, such as cement, fine aggregate, coarse aggregate, and water, should be of good quality and conform to the relevant standards.
c. The mixing should be done mechanically using a concrete mixer, and the mix should be uniform in color and consistency.

1. d. The mixing time should not be less than two minutes or more than five minutes, depending on the type of mixer used.

Transporting Requirements:
a. The transportation of concrete should be done as quickly as possible to avoid segregation and loss of workability.
b. The transportation should be done in suitable containers such as trucks or wheelbarrows, and the containers should be clean and free from any debris or contaminants.

2. c. The transportation should be done in such a way that the concrete is not subjected to any shock or vibration.

Placing Requirements:
a. The concrete should be placed in layers not exceeding 15 cm in thickness, and each layer should be compacted thoroughly using suitable vibrators.

b. The concrete should be placed at the location where it is required, and it should be placed within 30 minutes of mixing, or else the mix should be discarded.
c. The concrete should not be allowed to free-fall more than 1.5 meters or be placed from a height exceeding 1.5 meters above the point of final deposition.

3. d. The concrete should be placed as near to its final position as possible and should not be re-handled or disturbed after initial placement.

Curing Requirements:
a. The concrete should be cured immediately after placement to prevent rapid evaporation of water, which could lead to shrinkage and cracking.
b. The curing should be done by covering the concrete with suitable materials such as wet gunny bags or hessian cloth and keeping them moist for a minimum of seven days.

4. c. The curing should be done in such a way that the concrete temperature does not exceed 50°C at any time during the curing period.

10.3

Inspection and Testing as per Clause 17 of IS:456.

Clause 17 of I.S.456 outlines the inspection and testing requirements for reinforced concrete structures. The clause covers the following aspects:

1. Inspection of reinforcement: Before the reinforcement is placed in the formwork, it should be inspected for its quality, size, shape, and dimensions. The reinforcement should be free from any rust, oil, grease, or other contaminants that can affect the bond between the reinforcement and concrete.
2. Inspection of formwork: The formwork should be inspected before pouring concrete to ensure that it is properly aligned, braced, and capable of withstanding the pressure of the wet concrete.
3. Inspection of concrete: The concrete should be inspected for its workability, consistency, and slump before pouring. The slump test should be performed to ensure that the concrete has the desired consistency.
4. Sampling of concrete: Concrete samples should be taken from each batch for testing. The number of samples and the frequency of testing depend on the quantity of concrete, the method of transportation, and the placement location.
5. Testing of concrete: The concrete samples should be tested for its compressive strength, flexural strength, and other properties as per the relevant Indian Standard.

6. Non-destructive testing: Non-destructive testing techniques such as ultrasonic testing, rebound hammer testing, and core testing should be used to assess the quality of concrete.
7. Inspection of finished structure: The finished concrete structure should be inspected for its surface finish, dimensions, and other visual defects.
8. Record keeping: All inspection and testing activities should be recorded and maintained for future reference.

Overall, clause 17 of I.S.456 emphasizes the importance of proper inspection and testing to ensure that reinforced concrete structures meet the required quality standards.

Clause 17 of IS:456 outlines the requirements for inspection and testing of concrete in reinforced concrete structures. The following are the key points to consider:

1. Inspection during Production: The producer of concrete should maintain records of the materials used, the proportions of the mix, the batching and mixing equipment used, and the date of production. The concrete should be inspected for consistency, workability, and segregation, as well as for the presence of foreign materials.
2. Sampling of Concrete: Samples of concrete should be taken from each batch, at least once every 50 cubic meters, or once every day, whichever is the lesser quantity. The samples should be tested for compressive strength, slump, air content, and other properties as required.
3. Testing of Concrete: Testing of concrete should be carried out as per relevant Indian Standards. The compressive strength of concrete cubes should be tested at 7 days and 28 days, and the results should be reported to the engineer-in-charge.
4. Non-Destructive Testing: Non-destructive testing (NDT) of concrete can be carried out to assess the quality and integrity of the concrete. Methods such as ultrasonic pulse velocity, rebound hammer, and core testing can be used to determine the strength and durability of the concrete.
5. Inspection during Placing: The concrete should be inspected for consistency, workability, and segregation during placement. The placing should be carried out as per the requirements of the design and the engineer-in-charge.
6. Curing of Concrete: The concrete should be cured properly to achieve the desired strength and durability. Curing can be carried out by methods such as wet hessian, ponding, spraying, and curing compounds.
7. Records: The producer of concrete should maintain records of all the inspection and testing carried out, as well as the results of the tests. These records should be made available to the engineer-in-charge as and when required.

In summary, Clause 17 of IS:456 provides comprehensive guidelines for the inspection and testing of concrete in reinforced concrete structures. It is important to adhere to these guidelines to ensure the quality and durability of the structure.

10.4

Durability requirements of Concrete as per I.S:456.

The Indian Standard code of practice for reinforced concrete, I.S:456, provides guidelines for the durability requirements of concrete in reinforced concrete structures. The following are the key points to consider:

1. Exposure conditions: The durability of concrete depends on the exposure conditions to which it is subjected. The exposure conditions are classified into four categories, namely mild, moderate, severe, and very severe. The designer should select the appropriate exposure condition based on the type of structure, the environment, and the service conditions.
2. Minimum grade of concrete: The minimum grade of concrete for different exposure conditions is specified in the code. For mild exposure conditions, M20 grade concrete is recommended, while for moderate and severe exposure conditions, M25 and M30 grade concrete, respectively, is recommended.
3. Maximum water-cement ratio: The maximum water-cement ratio for different exposure conditions is also specified in the code. For mild exposure conditions, the maximum water-cement ratio is 0.55, while for moderate and severe exposure conditions, it is 0.50.
4. Use of admixtures: The use of admixtures such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume can improve the durability of concrete. The code recommends the use of such admixtures to reduce the permeability of concrete and enhance its resistance to chemical attack.
5. Cover to reinforcement: The cover to reinforcement is an important factor in ensuring the durability of concrete. The minimum cover to reinforcement for different exposure conditions is specified in the code. For mild exposure conditions, the minimum cover is 20 mm, while for moderate and severe exposure conditions, it is 30 mm.
6. Quality control: Proper quality control measures should be adopted during the production of concrete to ensure its durability. The code recommends the use of good quality materials, proper mix design, and adequate curing to achieve the desired strength and durability of concrete.

In summary, I.S:456 provides comprehensive guidelines for the durability requirements of concrete in reinforced concrete structures. It is important to adhere to these guidelines to ensure the long-term durability and service life of the structure.

The durability of concrete is an important consideration for the long-term performance of reinforced concrete structures. The Indian Standard code of practice for reinforced concrete, I.S:456, provides guidelines for ensuring the durability of concrete. The following are the key requirements:

1. Quality of Materials: The materials used for concrete, including cement, aggregates, water, and admixtures, should be of good quality and free from harmful impurities. They should comply with the relevant Indian Standards.
2. Concrete Mix Design: The concrete mix should be designed to achieve the desired strength and durability requirements. The mix should be designed to provide adequate cover to the reinforcement, which is a critical factor in ensuring durability.
3. Water-Cement Ratio: The water-cement ratio should be kept low to reduce the porosity of concrete and improve its durability. The maximum permissible water-cement ratio for different exposure conditions is specified in the code.
4. Minimum Cement Content: The minimum cement content should be specified based on the exposure conditions and the strength requirements. The minimum cement content for different exposure conditions is specified in the code.
5. Use of Admixtures: Admixtures such as fly ash, silica fume, and superplasticizers can be used to improve the durability of concrete. They can reduce the permeability of concrete and improve its resistance to chemical attack and corrosion.
6. Compaction and Curing: The concrete should be compacted properly to reduce the voids and ensure good bonding between the cement paste and aggregates. The curing should be carried out properly to prevent the loss of moisture and to ensure the development of strength and durability.
7. Maintenance: Regular maintenance of the structure is essential to ensure its durability. Any damage or deterioration should be identified and repaired promptly.

In summary, I.S:456 provides comprehensive guidelines for ensuring the durability of concrete in reinforced concrete structures. It is important to follow these guidelines to ensure the long-term performance of the structure.

Durability of Reinforced Concrete in Different Environmental Conditions

Some precautions to be taken care while constructions of reinforced concrete structure for durability are:

1. Proper amount of minimum cover specified by the code should be provided.
2. Minimum cement content in concrete mix and maximum water-cement ratio guidelines based on type of environment provided by the code should be followed.
3. Using good quality lab tested coarse and fine aggregates suitable for construction and free from (or within permissible limits) impurities such as dust, alkalies, chlorides, sulfates etc. should be used.
4. Based on environment attack on structure, suitable type of cement, concrete admixtures and water-cement ratio should be used.
5. Good placement and compaction of concrete.
6. Following formwork removal schedule as per type of construction as per guidelines given by standard codes.
7. Proper curing of concrete for the required period of time.

Some of the major durability problems caused by environment are:

1. Corrosion of steel reinforcement:

This corrosion of steel reinforcement can be controlled by:

- Cover to reinforcement (IS 456, Cl.25.4)
- Minimum cement content (IS 456, Table-19)
- Proper water-cement ratio
- Proper compaction and curing
- Using epoxy coated reinforcement.

2. Deterioration of Concrete:

Due to chemical attacks such as sulfates present near chemical industries atmosphere, soil and ground water, the concrete even without reinforcement steel deteriorates. Concrete in plant drains or sewers are also exposed to such environment and deteriorates due to sulfate action. To overcome the problem of such deterioration of concrete, following points should be followed:

- Using proper cement types such as sulphate resistant cement or cement with low C3A content
- Using minimum cement content as specified by the code
- Using proper water-cement ratio for the concrete

- Using protective coating to concrete surface buried under the soil.

Table - Classification of Exposure Conditions (According to IS 456- Table-19)

Type of Exposure	**Environment Description**
Mild	Protected concrete surface
Moderate	Sheltered from rain or permanently under water or in contact with non-aggressive soils
Severe	Alternate wetting and drying or exposed to sea water
Very severe	Exposed to sea water spray or corrosive fumes
Extreme	Exposed to abrasive action like sea water carrying solids

Table – Nominal Cover for Durability (BS 8110)

Exposure Condition	**Concrete Grade (Size of aggregate – 20mm)**				
	25	30	35	40	45

Mild	25	20*	20*	20*	20*
Moderate	-	35	30	25	20
Severe	-	-	40	30	25
Very Severe	-	-	50	40	30
Extreme	--	-	-	60	50

Notes:

1. Minimum grade of concrete for Reinforced concrete work is 25 (According to BS 8110).
2. Grades of concrete shown in Table include a relaxation of 5 MPa.
3. The cover specified is the nominal cover to reinforcement, including links.
4. Cover may be reduced to 15mm in places marked by * when the aggregate size does not exceed 15mm.

Table – Increased cover for special conditions for concrete below M25 Grade (IS456-Cl.25.4)

Condition	**Additional Cover (mm)**
Members totally immersed in sea water	40

Members periodically immersed in sea water or subjected to sea water spray	50
Members exposed to harmful chemicals and in contact with earth faces contaminated with chemicals	15 to 50 (Average value =35)

Notes: For concrete grade M25 and above, the additional cover specified may be reduced to half. In all cases, the cover to reinforcement should not exceed 75mm.

Table – Minimum cement content and water-cement ratio for Durability (IS 456, Table-19)

Exposure Condition	**Minimum Cement Content (kg/m3)**		**Maximum water cement ratio**	
	IS	**BS**	**IS**	**BS**
Mild	250	275	0.65	0.65
Moderate	290	300	0.55	0.6
Severe	360	385	0.45	0.55

11 Special Concrete

11.1

Introduction to ready mix concrete:

Ready-mix concrete (RMC) is a type of concrete that is manufactured in a batching plant according to a set recipe and then delivered to a construction site in a transit mixer truck. The concrete is already mixed and ready to use, hence the name "ready-mix". RMC is preferred over on-site mixed concrete due to its consistent quality, reduced construction time, and increased efficiency.

In a ready-mix concrete plant, the ingredients such as cement, aggregates, water, and admixtures are batched and mixed together in a concrete mixer truck. The batching process is computer-controlled to ensure accurate proportions and consistency of the mix. The mix is then transported to the construction site in transit mixer trucks, which have rotating drums to keep the concrete fresh and mixed during transportation.

At the construction site, the RMC is discharged from the transit mixer truck into the required location, such as the foundation, column, or slab. The concrete can be placed directly into the formwork or pumped to the required location using a concrete pump.

RMC offers several advantages over on-site mixed concrete. Firstly, the quality and consistency of the mix can be maintained throughout the project. Secondly, the batching and mixing process is efficient and reduces the construction time. Thirdly, RMC can be produced in large quantities, making it suitable for large construction projects. Finally, the use of RMC reduces the need for on-site storage of raw materials and reduces the environmental impact of construction activities.

In conclusion, ready-mix concrete is a type of concrete that is manufactured in a batching plant and delivered to the construction site in a transit mixer truck. It offers several advantages over on-site mixed concrete and is preferred by construction professionals for its consistent quality, efficiency, and reduced construction time.

Ready-mix concrete (RMC) is a type of concrete that is manufactured in a factory or a batching plant, according to a set recipe, and then delivered to the construction site in a transit mixer truck. It is also known as "factory-produced concrete" or "manufactured concrete".

In the traditional method of concrete production, the raw materials are mixed on-site in a batch plant or mixer truck. However, with the introduction of RMC, the process of concrete production has been revolutionized, making it more efficient, consistent and of higher quality.

The production process of RMC involves the use of a central batching plant, which is responsible for preparing a pre-determined mix of concrete, consisting of cement, aggregates, water, and admixtures. The ingredients are precisely measured and mixed in the plant, and the resulting mixture is then transported to the construction site in specially designed transit mixer trucks.

The advantages of using RMC over traditional concrete production methods are numerous. Firstly, it eliminates the need for on-site mixing, which reduces the time and effort required for concrete preparation. Secondly, the use of RMC ensures consistency in the quality of the concrete, as the mix is prepared under controlled conditions in the factory. This reduces the risk of errors in the mix design or incorrect batching.

Another advantage of RMC is that it reduces the wastage of raw materials, as the precise amount of materials required for each batch is measured accurately. It also reduces the dust and noise pollution associated with on-site concrete production.

In conclusion, ready-mix concrete is a type of concrete that offers numerous advantages over traditional concrete production methods. It provides a consistent, high-quality product, reduces wastage of raw materials, and minimizes dust and noise pollution on the construction site.

high performance concrete:

High-performance concrete (HPC) is a type of concrete that has superior properties in terms of strength, durability, workability, and aesthetic appeal, compared to conventional concrete. The development of HPC is based on advanced technologies and innovative mix designs, which incorporate the use of high-quality materials, chemical admixtures, and advanced production techniques.
The main properties of HPC include:

1. High Compressive Strength: HPC has a compressive strength of more than 50 MPa, which is significantly higher than conventional concrete. This makes it suitable for use in high-rise buildings, bridges, and other structures that require high strength.
2. High Durability: HPC has superior durability properties, which make it resistant to various environmental factors such as freeze-thaw cycles, chemical attack, and abrasion. This makes it ideal for use in marine structures, industrial buildings, and other structures that are exposed to harsh environments.
3. High Workability: HPC has excellent workability, which makes it easy to place and finish. This allows for the production of complex shapes and structures with high precision and accuracy.
4. Aesthetic Appeal: HPC can be designed to have different colors, textures, and finishes, which make it suitable for architectural applications where appearance is important.

The production of HPC requires careful mix design, which involves the use of high-quality materials such as cement, aggregates, water, and chemical admixtures. The mix design is based on the desired performance requirements and environmental conditions of the structure.
Overall, HPC offers numerous advantages over conventional concrete, including superior strength, durability, workability, and aesthetic appeal. Its properties make it ideal for use in high-performance structures, where strength, durability, and appearance are critical factors.

High-performance concrete (HPC) is a specialized type of concrete that is designed to meet specific performance requirements, such as increased strength, durability, and resistance to environmental factors. HPC is typically used in demanding applications such as high-rise buildings, bridges, dams, and other critical infrastructure.

The key characteristics of HPC include:

1. High Strength: HPC has a compressive strength of up to 150 MPa, which is much higher than that of traditional concrete.
2. High Durability: HPC has excellent resistance to environmental factors such as freeze-thaw cycles, chloride penetration, and chemical attack.
3. Reduced Permeability: HPC has low permeability, which reduces the ingress of water and other harmful substances into the concrete.
4. Improved Workability: HPC has improved workability, which allows it to be easily placed and consolidated into complex forms and shapes.
5. Reduced Heat of Hydration: HPC has a lower heat of hydration, which reduces the risk of thermal cracking in large structures.

The production of HPC involves the use of specialized materials, such as high-grade cement, high-quality aggregates, and chemical admixtures such as superplasticizers and fly ash. The proportion of these materials is carefully controlled to achieve the desired performance characteristics.

HPC requires careful quality control during production and placement to ensure that the desired performance characteristics are achieved. It also requires specialized equipment and expertise for mixing, placing, and curing.

In summary, HPC is a specialized type of concrete that offers exceptional performance characteristics, including high strength, durability, reduced permeability, improved workability, and reduced heat of hydration. It is used in demanding applications where the performance requirements of traditional concrete cannot be met.

silica fume concrete:

Silica fume concrete is a type of high-performance concrete that is made by adding silica fume to the mix. Silica fume is a byproduct of the production of silicon and ferrosilicon alloys, and it is composed of very fine particles that are much smaller than those of cement. When silica fume is added to concrete, it fills the gaps between the cement particles, making the resulting concrete denser and more compact.

The addition of silica fume to concrete has several benefits. First, it increases the strength and durability of the concrete, making it more resistant to cracking, abrasion, and chemical attack. Second, it improves the workability of the concrete, allowing it to be pumped and placed more easily. Finally, silica fume concrete has a smoother surface finish than regular concrete, making it ideal for architectural applications.

However, because silica fume is a highly reactive material, it can be difficult to handle and mix with other concrete ingredients. It is also more expensive than regular concrete, which can make it less practical for some applications. Nevertheless, silica fume concrete is an excellent choice for projects that require high strength, durability, and aesthetic appeal.

Silica fume concrete is a type of concrete that contains a high percentage of silica fume, which is a byproduct of the production of silicon and ferrosilicon alloys. Silica fume is a very fine powder that is added to the concrete mix in order to improve its properties.

When used in concrete, silica fume acts as a filler and as a pozzolan, which is a material that reacts with calcium hydroxide in the presence of water to form cementitious compounds. This results in a denser, stronger and more durable concrete with a lower permeability, higher abrasion resistance and better resistance to chemical attack.

Silica fume concrete is commonly used in high-performance concrete applications, such as bridges, tunnels, high-rise buildings, and other structures where strength, durability, and resistance to harsh environmental conditions are critical. However, due to its high cost and the technical expertise required to use it properly, silica fume concrete is not commonly used in everyday construction projects.

silica fume concrete

Silica fume concrete is composed of cement, silica fume, fine aggregate, coarse aggregate, and water. Fresh and hardened properties of silica fume concrete is superior to conventional concrete. For instance, it has higher compressive and flexural strength.
The durability of this type of concrete is superior to conventional concrete. Resistance against freezing and thawing and chemical attacks is better than concrete without silica fume. Segregation and bleeding is low in silica fume concrete, and the mixture is adhesive compared to traditional concrete.
The applications of the silica fume concrete in construction are seen in high-rise buildings, parking structure, dam structure, nuclear waste storage facility, and shotcrete rehabilitation.

Contents: [show]

Chemical Composition of Silica Fume Material

- It contains more than 90 percent of silicon dioxide.
- Other constituents are carbon, sulfur, oxides of aluminum, iron, calcium, magnesium, sodium, and potassium.

Physical Properties of Silica Fume Material

- The diameter of the silica fume particle ranges from 0.1 micron to 0.2 micron.
- The surface area is about 30,000 m^2/kg.
- Density varies from 150 to 700 kg/m^3 but when it is about 550 kg/m^3, it is best suited as a concrete additive.

Properties of Fresh Silica Fume Concrete

- Silica fume concrete requires higher water content, for the same workability as of conventional concrete.
- Low workability
- Low slump value
- Possibility of bleeding and segregation is low

- The mixture is cohesive
- High plastic shrinkage

Properties of Hardened Silica Fume Concrete

- The compressive strength of silica fume concrete is higher than ordinary concrete (62 – 80 MPa), Fig. 1. Similarly, the flexural strength is also higher, Fig. 2.
- The modulus of elasticity is substantially higher than that of ordinary concrete.
- Creep of silica fume concrete is lesser than conventional concrete

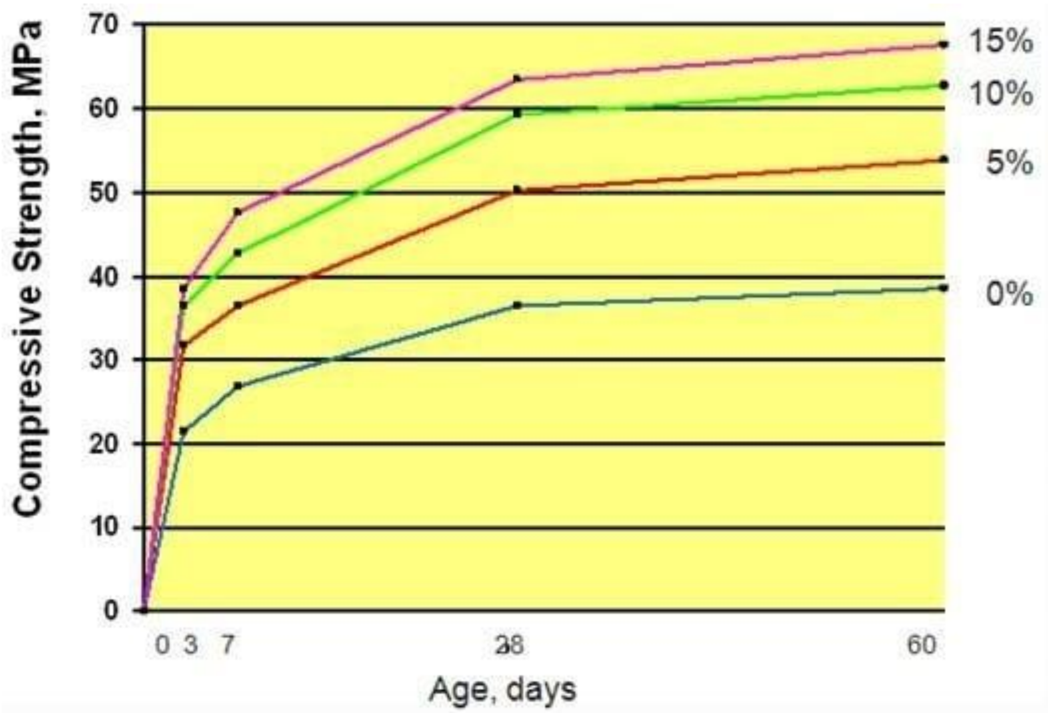


Fig. 1: Strength Development of Silica Fume Concrete

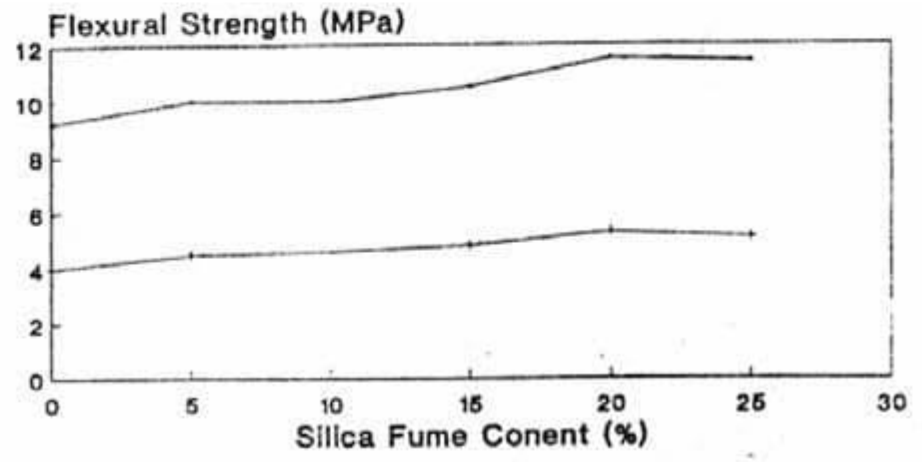


Fig. 2: Flexural Strength of Silica Fume Concrete

Durability

- Permeability of silica fume concrete is low; hence, penetration of sulfate ions is low.
- Abrasion resistance and corrosion resistance are high.
- The reaction of silica fume with lime in the paste matrix improves durability. Lime material reacts with different chemicals and cause expansion.

Advantages

- Silica fume enhances the properties of fresh and hardened concrete.
- Silica fume reduces segregation and bleeding.
- High durability
- The finishing process is efficient due to low bleeding.
- High early compressive strength
- High flexural strength and modulus of elasticity
- High bond strength
- Suitable for mass concreting since it prevents thermally induced cracking.

Disadvantages

- Availability issue
- High cost

Applications

- High rise buildings, Fig. 2.
- Parking structure, Fig. 3.
- Dam structure, Fig. 4.
- Nuclear waste storage facility
- Shotcrete rehabilitation


Fig 3: High rise Building

Fig. 4: Parking Structure

Fig. 5: Dam Structure

FAQs on Silica Fume Concrete

What is silica fume concrete?

Concrete made from cement, silica fume, fine and coarse aggregate, and water.

What are the desirable properties of silica fume concrete?
Compressive strength, flexural strength, and bond strength of silica fume is better than normal strength concrete. In addition, the durability of this type of concrete fend off most aggressive chemical attacks.
What are the properties of fresh silica fume concrete?
Low workability, considerably cohesive, low bleeding and segregation, and low slump value.
What are the advantages of silica fume concrete?
High durability, segregation and bleeding, efficient finishing process, high early compressive strength., high flexural strength and modulus of elasticity, high bond strength., and suitable for mass concreting since it prevents thermally induced cracking.
What are the applications of silica fume concrete is civil engineering?
The applications of the silica fume concrete in construction are high rise buildings, parking structure, dam structure, nuclear waste storage facility, and shotcrete rehabilitation.

shot-crete
concrete or gunitting (Concepts only).
Shotcrete is a method of applying concrete or mortar through a high-pressure hose onto a surface, typically using compressed air to project the material at a high velocity. It is commonly used in construction for a variety of applications, including creating walls, floors, and roofs. Shotcrete is sometimes referred to as "gunite," which is a specific type of dry-mix shotcrete.

There are two primary methods of shotcrete application: wet-mix and dry-mix. In wet-mix shotcrete, the concrete or mortar is pre-mixed with water and then pumped through a hose to the nozzle where compressed air is introduced to spray the material onto the surface. In dry-mix shotcrete, the dry materials are fed into a hopper at the nozzle where water is added and mixed as the material is projected onto the surface.

Shotcrete has several advantages over traditional concrete placement methods. It can be applied in a variety of shapes and forms, can be applied quickly, and can be used to repair and strengthen existing concrete structures. It is also highly durable and resistant to water and weathering.

Shotcrete, also known as sprayed concrete or guniting, is a construction method in which concrete or mortar is pneumatically projected or sprayed onto a surface, usually with a high-pressure hose. This process is typically used for building walls, swimming pools, tunnels, and other structures.

The term "shotcrete" can refer to both wet-mix and dry-mix processes. In the wet-mix process, the concrete mix is prepared with water and then pumped through a hose to the nozzle, where compressed air is used to spray the mixture onto the surface. In the dry-mix process, dry ingredients are mixed together and then fed into a hopper, where compressed air is used to project the mixture onto the surface, and water is added at the nozzle.

Shotcrete has several advantages over traditional cast-in-place concrete, including faster construction times, reduced labor costs, and the ability to create complex shapes and structures. It is also often used in repair and rehabilitation work, such as repairing cracked or damaged concrete structures or reinforcing existing structures.

However, shotcrete requires skilled workers and specialized equipment, and proper safety measures must be taken to protect workers from the high pressure of the spraying process.

Difference Between Shotcrete And Gunite

As we know, both gunite and shotcrete work by spraying wet cement onto the walls and floor surfaces. But they are not the same. In this article, we will explain the differences between shotcrete and gunite.

In guniting, the water is added to dry concrete as you spray it. And in shotcrete, it already comes with wet concrete, so you don’t need to add any extra water while spraying.

Below we have mentioned both gunite and shotcrete advantages and disadvantages. So, by that, you will understand the differences between gunite and shotcrete. In short, we can say that both will produce a high-quality, watertight, durable concrete layer if you do the processes correctly. It all depends on the workmanship.

What Is Shotcrete?

Shotcrete is similar to gunite, which is also made of cement, sand, water. The prepared mixture is sprayed on the surface just like guniting.

In guniting, water is added to the material to form concrete onsite. While in shotcrete, a “wet mix” is prepared by mixing the water and dry mix before arrival. This pre-mixed cement is shot out or sprayed of a nozzle to form the pool.

In shotcrete, the water-cement ratio usually ranges from 35 to 0.50 by mass which is somewhat lower than most conventional concrete mixes. Shotcrete can be used as both wet mix and dry mix.

Advantage Of Shotcrete

The various advantages of the shotcrete process are as follows.

- The shotcrete process forms a uniform and strong layer of concrete on the surface.
- Like the guniting process, the shotcrete process is more economical than conventional concrete, which requires wooden or steel formwork.
- Shotcreting can be used in construction where the formwork cannot be installed.
- The concrete can be applied to one nozzle from a safe distance.

- The required materials in this process can be accessible in most places.
- Specialized admixtures can be added to the concrete to achieve more efficiency
- As it is pre-mixed, there is no additional need for water while applying.
- Shotcrete helps to achieve high production rates.
- No Need for skilled workers. As it is a pre-mixed mixture.
- In terms of pressure application, shotcrete is faster than guniting.
- Material requirements are fewer.

Disadvantages Of Shotcrete

- If the hose gets blocked, It will be very tough to clear it, which could be dangerous for the crew and property.
- Though it does not need any additional water during its application, some water is required for pumping.
- The hoses are very heavy, which would be more challenging to use for the crew
- Like guniting, You can’t start and stop the application. Doing so may create weak points in the concrete.
- The application process is quick. As the mixture is pre-mixed.
- Chances of developing cracks are more if the excess water is added to the pre-mixed concrete.
- This process is not so economical when compared to guniting.

Applications Of Shotcrete

- Dome construction
- Retention walls
- Tunneling
- Artificial Ponds
- Mining Applications
- Dikes and Dams
- Ditches and Channels
- Water tanks and Ponds
- Slope Stabilization

What Is Gunite?

Gunite is a mixture made of cement, sand, and water. Gunite is similar to concrete, but the traditional pouring method is not adopted here; instead sprayed with a gun in several layers. Hence it is named gunite.

While preparing the mixture, water is added to the dry concrete mix at the gun-shaped nozzle opening. Generally, concrete is made in the air just before hitting the target.

As per pool professionals, gunite is a "dry mix" because the water is added to the material to form concrete onsite, and it is also known as Dry shotcrete.

Advantages of Guniting

The advantages of guniting are as follows:

- Guniting is highly durable and gives the flexibility to create structure in any shape.
- Gunite gives a more variety of finishes. Plaster finishes come in an array of shades from which we can choose according to the outdoor living area and house design.
- The preparation process of dry mix is speedy compared to wet shotcrete mix.
- The guniting process helps to achieve a high compressive strength of concrete.

- The guniting process is mostly used in artificial caves and swimming pools to create unique shapes and features.
- Gunite also makes it easy to design and build features like waterfalls and customs steps.
- The guniting process is less expensive than shotcrete.

Disadvantages Of Guniting

The various disadvantages of the Guniting process are as follows.

- During the application of dry mix concrete, the Chance of clogging or blockage of a hosepipe is more.
- Skilled workers are needed for the guniting process.
- Skill workers are directly proportional to the quality of work. That means the quality of the job depends upon the operator.
- In the guniting process, there may be chances of wastage of concrete.

Applications Of Guniting

- Dome construction
- Tunneling
- Artificial Ponds
- Mining Applications
- Dikes and Dams
- Ditches and Channels
- Water tanks and Ponds
- Slope Stabilization

Lets check the differences in detail.

Difference Between Shotcrete And Gunite
Shotcrete Vs Gunite

Sl. No	**Gunite**	**Shotcrete**
1	The guniting process is economical	While shotcrete is a bit more expensive.
2	The guniting process involves only dry mix, hence it is also called dry shotcrete.	The Shotcrete process involves both dry mixes as well as wet mixes.
3	The guniting process is most suitable for small works.	The shotcrete process is most suitable for large works.
4	The guniting process requires skilled workmanship.	The shotcrete process requires less skilled workmanship.
5	The waste generated while applying in guniting is more.	The waste generated while applying shotcrete is less.

6	The guniting process requires more time duration.	The shotcrete process requires less time duration.
7	There are no shrinkage cracks in guniting.	High chances of shrinkage cracks in shotcrete.
8	Higher compressive strength (from 7,000 to 9,500psi)	Less compressive strength (6,500 to 7,500psi)
9	Guniting has low production rates.	Shotcrete has high production rates.
10	The process can be halted in between and can be continued without any problem.	In shotcrete the application process must not be halted, doing so may result in weak points in concrete.

12 Deterioration of concrete and its prevention:

12.1

Deterioration of Concrete - Types and Causes

Different Types of Deterioration observed are:

1. Spalling
2. Cracking
3. Debonding of the Joints
4. Erosion
5. Corrosion of Concrete Through Chemical Attack
6. Sagging of Beams and Floors, bowing or inclination
7. Excessive Efflorescence, staining or discoloration
8. Damages Due to Vibration
9. Faults in Design, Material, and Workmanship

Spalling of Concrete

The spalling in concrete is caused due to

1. Corrosion of steel reinforcement or other embedded metal
2. The freezing of the porous or the cracked concrete
3. The chemical attack on concrete
4. Concrete that is of poor quality
5. Overloading or insufficient reinforcement
6. The thermal shock creating fire or firefighting activities
7. Mechanical damage due to accidents
8. The bearing of the concrete member or another with joint that is insufficient or that is choked
9. The bearing edge forming too close to the edge or at the end of a concrete member

Cracking

The safety or the bearing capacity of the structure is not endangered by the cracks formed in the concrete. All the possible effects of cracks are considered in the context of the cause, location, statical system and environment and the structure utilization. The cracks caused may be the effect of fault or the both. The reinforced concrete is not wholly monolithic.

The hypothesis that is followed during the design and the structural analysis of reinforced concrete structure is that the concrete will crack in the tension zone before the reinforcement bars will take the tension. Hence the cracks formed in this part of the member will have no direct effect on the immediate load bearing capacity of the member, even if the cracks are of considerable width.

The cracks formed in the cover will result in the penetration of the corrosion accelerating agents to reach steel. This will affect and break the corrosion protection of the reinforcement.

Note: Special Consideration must be given to sealing by injection the cracks that are wider than those allowed by the area's building code standards.

It has to be considered that the cracks will influence the stiffness and the dynamic response of the structure, wherever this criterion is not considered in the design. The possibilities of unforeseen cracks in the prestressed concrete structures will result in fatigue failure when subjected to repeated loading.

The cracks in the compression zone of a load bearing member indicate the lack of shear resistance, this will result in the ultimate failure of the structure.

Cracks can be classified into different types. Principle method of classification is based on the primary cause of cracks.

Types of Cracks

1. Cracks in Fresh Concrete
2. Thermal Cracks
3. Shrinkage Cracks
4. Durability Cracks
5. Cracks formed From Loading
6. Other Cracks

Before choosing a specific repair method, the cause of crack identified have to be determined. It is essential to find whether the cracks are active or dormant. The periodic observations by utilizing tell-tales helps to check the crack behaviour at intervals.

The functional requirements and the cause of cracking is the factors on which the acceptable width of a crack is dependent. The National codes -design codes worldwide limit the crack width. For theoretically calculated values they are admissible limits. These will differ from the observed values practically.

Debonding Of the Joints

This problem of deterioration is found where there is a large change in the cross-sectional area or where dissimilar materials are bonded to concrete. The examples include:

1. At the epoxy resin expansion, joint nosings
2. Areas where the mastic asphalt waterproofing material is used
3. In areas where a thin topping layer like granolithic flooring is laid
4. Areas where sealants are used

Erosion

This is mechanical action due to the usage, weather and the water which leads to abrasive wear formed due to sliding, scraping or percussion. The erosion that is caused by the jet of water with a very high velocity can have the same mechanism as in the cavitation.

Corrosion of Concrete Through Chemical Attack

The cement paste which is highly alkaline in nature (due to hydration reaction and products) is subjected to chemical attack. This can occur only through the dissolution into the pore water of the cement paste. Hence, the resistance of the concrete to chemical attack will depend on the:

Ø Permeability of the concrete
Ø Type and size of the pore system
Ø Type of the cement

This will involve the following types:

1. The attack in the form of dissolution: Here, the compounds that are easily soluble can be washed out of the concrete or from the cement paste by the continuous access of the water.
2. The attack in the form of expansion: Compounds that are heavy soluble remain in the cement paste pores and crystallizes. If these compounds more space, they will create additional expansive stresses that will result in the bursting of the structure of cement paste.
3. Chemical or the electrochemical attack: These are caused by the acids, organic and the inorganic salts, alkali-carbonate reactions, soft water, aggressive gases or due to the electrochemical attack.

Sagging of Beams and Floors, Bowing or Inclination of Vertical Members

Settlement, overloading, deterioration or the failure of the concrete, corrosion or detachment of the tendons or the reinforcement or the conversion of the high alumina cement may cause the problems of bowing in walls or columns, opening or the closing of the joints or the sagging of the floors or the beams.

Excessive Efflorescence, Staining or Discolouration

The main reasons for these types of deterioration are the:
1. Undergone Chemical Attack
2. Presence of salts in the concrete constituents
3. Porosity in the concrete
4. Have Passage of water
5. Conversion of high-alumina cement
6. The concrete cover is small
7. The concrete permeability
8. Incomplete grouting of the ducts of tendons

Vibration Caused Damages

The vibration will bring seldom problems for the concrete. But checks is very necessary where heavy industrial processes is carried out.

Faults Found in Design, Material, and Workmanship

Faults found in design, the materials used and workmanship increases the risks of excessive deterioration. A proper and thorough investigation of the statistical calculation and drawings shows that whether a structural component has reserved or whether it requires any strengthening or repair.

The Faults can be Caused due to the Failure of Design, which will Include:

Ø Reduction of the dimension of concrete members (below the permitted minimum value
Ø Inadequate concrete cover
Ø Error in the calculation and human incompetence
Ø Inadequate assessment of the construction stages and temporary scaffoldings and the formwork used
Ø Incorrect design consideration for the tendon curvature
Ø Complex interaction of the numerous parameters for the impact and the impulse loading
Ø Difficulty in the prediction of structural response to these loads

The Faults in Materials include:

Ø Poor Quality Cement, aggregate, admixture, water
Ø Incorrect type of cement, aggregate, admixture, water

The faults in Workmanship include:

Ø Materials Storage
Ø Installation of formwork and scaffolding
Ø Batching
Ø Mixing
Ø Compaction
Ø Placing
Ø Curing

Types of Concrete Defects - Causes, Prevention

Various types of defects which can be observed in hardened concrete surface and their prevention methods are explained below:

1. Cracking

Cracks are formed in concrete due to many reasons but when these cracks are very deep, it is unsafe to use that concrete structure. Various reasons for cracking are improper mix design, insufficient curing, omission of expansion and contraction joints, use of high slump concrete mix, unsuitable sub-grade etc. To prevent cracking, use low water – cement ratio and maximize the coarse aggregate in concrete mix, admixtures containing calcium chloride must be avoided. Surface should be prevented against rapid evaporation of moisture content. Loads must be applied on the concrete surface only after gaining its maximum strength.

Fig 1: Cracking

2. Crazing

Crazing also called as pattern cracking or map cracking, is the formation of closely spaced shallow cracks in an uneven manner. Crazing occurs due to rapid hardening of top surface of concrete due to high temperatures or if the mix contains excess water content or due to insufficient curing. Pattern cracking can be avoided by proper curing, by dampening the sub-grade to resist absorption of water from concrete, by providing protection to the surface from rapid temperature changes.

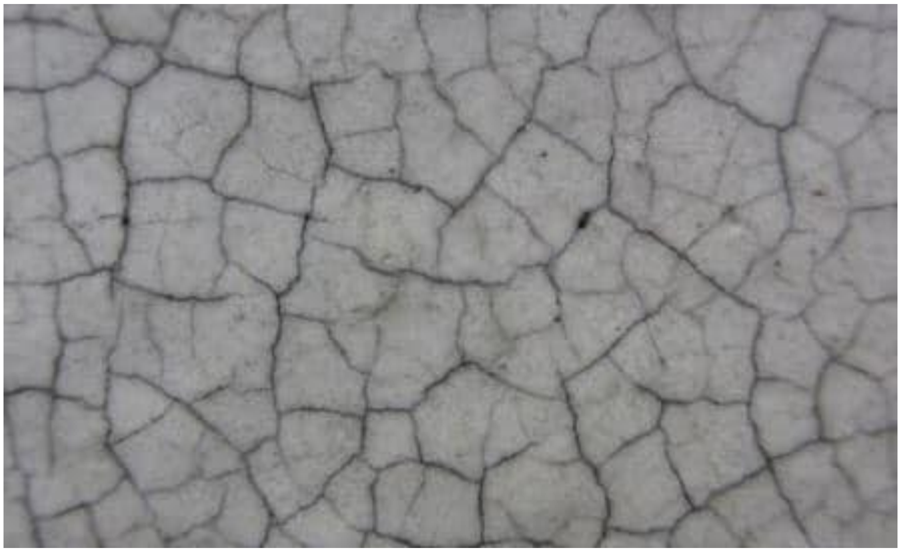


Fig 2: Crazing or Pattern Cracking

3. Blistering

Blistering is the formation of hollow bumps of different sizes on concrete surface due to entrapped air under the finished concrete surface. It may cause due to excessive vibration of concrete mix or presence of excess entrapped air in mix or due to improper finishing. Excessive evaporation of water on the top surface of concrete will also cause blistering. It can be prevented by using good proportion of ingredients in concrete mix, by covering the top surface which reduces evaporation and using appropriate techniques for placing and finishing.

Fig 3: Concrete Blisters

4. Delamination

Delamination is also similar to blistering. In this case also, top surface of concrete gets separated from underlying concrete. Hardening of top layer of concrete before the hardening of underlying concrete will lead to delamination. It is because the water and air bleeding from underlying concrete are struck between these two surfaces, hence space will be formed. Like blistering, delamination can also be prevented by using proper finishing techniques. It is better to start the finishing after bleeding process has run its course.

Fig 4: Delamination

5. Dusting

Dusting, also called as chalking is the formation of fine and loose powdered concrete on the hardened concrete by disintegration. This happens due to the presence of excess amount of water in concrete. It causes bleeding of water from concrete, with this fine particles like cement or sand will rise to the top and consequent wear causes dust at the top surface. To avoid dusting, use low slump concrete mix to obtain hard concrete surface with good wear resistance. Use water reducing admixtures to obtain adequate slump. It is also recommended to use better finishing techniques and finishing should be started after removing the bleed water from concrete surface.

Fig 5: Dusting

6. Curling

When a concrete slab is distorted into curved shape by upward or downward movement of edges or corners, it is called curling. It occurs mainly due to the differences in moisture content or temperature between slab surface (top) and slab base (bottom). Curling of concrete slab may be upward curling or downward curling. When the top surface is dried and cooled before bottom surface, it begins to shrink and upward curling takes place. When bottom surface is dried and cooled due to high temperature and high moisture content, it will shrink before top surface and downward curling occurs. To prevent curling, use low shrink concrete mix, provide control joints, provide heavy reinforcement at edges or provide edges with great thickness.

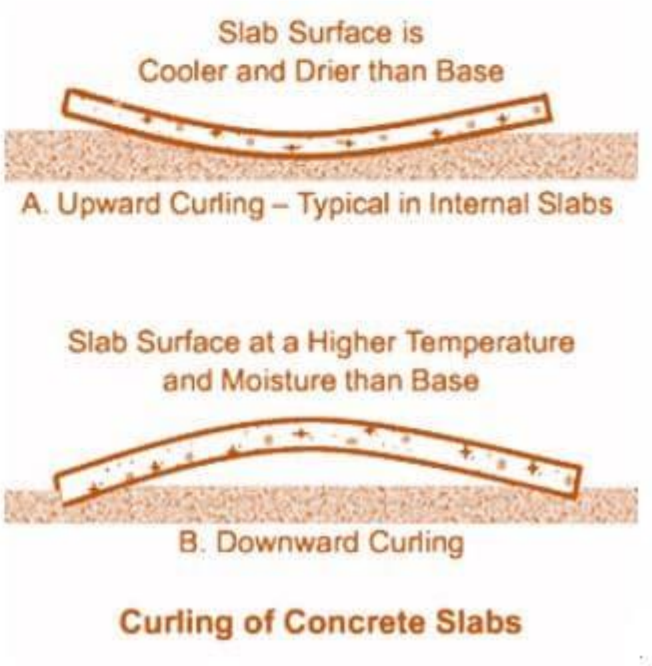


Fig 6: Curling of Concrete Slab

7. Efflorescence

Efflorescence is the formation of deposits of salts on the concrete surface. Formed salts generally white in color. It is due to the presence of soluble salts in the water which is used in making concrete mix. When concrete is hardening, these soluble salts gets lifted to the top surface by hydro static pressure and after complete drying salt deposits are formed on the surface. It can be prevented by using clean and pure water for mixing, using chemically ineffective aggregates etc. And make sure that cement should not contain alkalis more than 1% of its weight.

Fig 7: Efflorescence

8. Scaling and Spalling

Scaling and spalling, in both the cases concrete surface gets deteriorated and flaking of concrete occurs. The main cause for this type of cases is penetration of water through concrete surface. This makes steel gets corroded and spalling or scaling may occurs.

Fig 8: Scaling

Some other causes are use of non-air entrained concrete mix, inadequate curing and use of lo strength concrete etc. This type of defects can be prevented by, using well designed concrete mixes, by adding air entrainment admixtures, proper finishing and curing, providing good slope to drain water coming on to the surface etc.

Fig 9: Spalling

prevention of concrete deterioration

3 Ways to Prevent Concrete Deterioration

There are many factors that will cause concrete deterioration. Although it is an incredibly durable and reliable material, it won't last forever, not without the proper initial installation and maintenance. Follow these concrete tips to ensure the integrity and strength of your structures.

- **Concrete Reinforcement**

Steel reinforcement is often used in concrete applications to make the resulting structure that much more sound, strong, and secure. But, steel can be susceptible to corrosion, especially in the winter and cold climates. Once corrosion starts to spread, it's almost impossible to stop and therefore, repairing an isolated area likely won't solve the problem. Prevent steel reinforcement corrosion by ensuring that you have at least 1.5 to 2 inches of concrete over the reinforcements. An impermeable concrete mix that consists of a low water-to-cement ratio is best for protecting the steel. In addition, other corrosion-inhibiting materials like an epoxy coating and penetrating sealers help ensure that the steel will remain effective.

- **Sulfate Tests**

Exposure to water that contains a high number of dissolved sulfates leaves your concrete vulnerable to cracks. A sulfate attack comes from sulfate-containing water entering the concrete, crystallizing, and expanding. The other option is that the sulfate salts will cause the cement paste to dissolve, soften, and ultimately erode. Prevent this type of deterioration by testing the sulfate content of the water and soil, and then creating a resistant concrete mix by limiting the water to cement ratio.

- **Cement-Aggregate**

In certain conditions, a reaction of alkali-silica will create an expansive gel that will cause concrete to crack. You'll notice this reaction by the presence of "map cracking" and white or gray gel-like deposits. Minimize this reaction by testing the combination of cement-aggregate for the cement alkalinity limit, expansion, and petrographic, or rock and mineral, characteristics. Consider adding slag or low-alkali fly ash to the cement and reduce the amount of alkali in the concrete.

Concrete Care and Maintenance from Concrete Visions

Concrete Visions has over 12 years of experience and expertise in concrete scanning and we know how to detect any problems lurking beneath the surface. We use ground penetrating radar accurately and expertly and are familiar in many other methods that can be used when appropriate like concrete x-ray and electromagnetic conductivity.

MECHANISM OF DETERIORATION OF CONCRETE BASED STRUCTURES OR SYSTEMS AND REMEDIES

In the civil engineering field concrete is a construction materials is extensively used in construction work. Generally it is mixture of cement, fine aggregate (normally termed as sand) coarse aggregate (termed as stone chips or broken stones), water and some times admixture . It is used to develop or construct different type of structures or systems. These structures are generally two types , they are P.C.C and R.C.C. P.C.C stands for Plain Cement Concrete and R.C.C stands for Reinforced Cement Concrete. Now P.C.C structures are developed by mixing cement, sand, stone chips and water where admixtures are optional. In case of R.C.C along with P.C.C ingredients steel bars embedded into it. Performance of concrete in P.C.C and R.C.C is quite satisfactory from the strength point of view as well as many other aspects. One of the important performance of concrete in R.C.C is prevention of steel bars from external hazards. Both of the type of systems at early stage offers considerable resistance but as the time passes the degree of resistance of systems reduces. Thus resulting unsatisfactory performance of structural systems. Structural systems those are experiencing such type of adverse situations if not provided selective or necessary treatments. Most of the concrete structures or systems deteriorate through four different ways. Those are classified as –

1. **Chemical deterioration**

This type of deterioration takes place due to chemical reaction at the concrete covers of R.C.C members. This reaction may take place in several ways –

3. *Carbonation*: Generally reinforced steel bars are surrounded by a particular grade of concrete. Harden concrete made up of calcium silicate gel and calcium hydroxide (Ca $[OH]_2$). Ca $[OH]_2$ ensure high alkaline nature of concrete to fight against corrosion and save steel from rust by creating a passive film around the

steel bars. Due to this film, O_2 and H_2O fail to reach the main steel bars. Thus corrosion avoided. But if environment surrounding concrete covers, contains carbon dioxide(CO_2) in air it may be vulnerable to RC members. CO_2 in moisture enter in concrete cover through concrete pores. It reacts with Ca $[OH]_2$ and produces calcium carbonate ($CaCO_3$) and water (H_2O). Thus reduces pH value of concrete and formation of acidic substance i.e, $CaCO_3$. Due to this acidic substance passive film decays and open up the entry of O_2 and H_2O to main steel bars. This initiate the corrosion of steel and in tern resulting damage of RC structures.

Remedy – Application of different types of polymer based coating, stabilising primers on concrete surfaces offers protective barrier against concrete carbonation and slow down this adverse process. Adoption of epoxy coating on steel bars, safe guard the passive layer of steel bars also controls the carbonation process.

1. *Alkali-Aggregate Reaction* : If aggregates containing reactive silica are used in concrete making, it is observed that alkaline solution reacts with silica present in aggregates and produces alkali-silica gel. The product volume is quite higher and bring out all the undesirable properties in concrete. Due to higher volume internal stresses generates and cracks develop in concrete structures or systems.

Remedy – Avoid use of reactive silica based aggregates in concrete making to control the Alkali-Aggregate Reaction.

1. *Sulphate attack* : It is also one of the important cause of concrete based structure's deterioration. Sulphate may exists in nature e.g, in ocean water, ground water and industrial pollution etc in different soluble forms like calcium, sodium, magnesium etc. Sulphate attach may takes place by two reactions. When concrete structures come in contact with water contaminated by sulphates, then Ca $[OH]_2$, sodium based sulphate salt and water. Therefore produces gypsum thus reduces pH value due to loss of Ca $[OH]_2$ from concrete. In the other way sulphate ion react with tri-calcium aluminate (C_3A) and produces calcium sulphoaluminate hydrate (termed as ettringite) as major product. Both gypsum and ettringite posses higher volume expansion resulting internal stresses in concrete body. Finally concrete surfaces spall of from the actual concrete.

Remedy – Use of sulphur resisting cement, fly ash based cement, adequate compaction of concrete etc prevent this type of attack in concrete systems.

1. *Chlorine attack* : Another adverse situation that happens to concrete when RC element's constituents or environment contaminated by chlorine. Resulting corrosion of steel in RC structures or systems. If concrete come in contact of sea water or sea water used to produce concrete, higher chloride content in aggregate

so on and so forth. Chlorides reached to passive layer surrounding steel bars and destroy it and then the bars are exposed fully to the environment. So corrosion initiates and reduces the cross sectional area of bars. Therefore tension carrying capacity of systems or structures reduces. While rusting occurs in bars, its volume immensely increases causing internal thrust in whole system and cracks generates that further accelerates corrosion process. Finally failure of structures or systems takes place.

Remedy – The best possible and easiest way to slow down this attack is to increase concrete cover, epoxy coating on steel bars and surface coating on concrete systems.

2. Mechanical deterioration

Mechanical decay of concrete systems may occur through several ways like erosion, abrasion and cavitation. Concrete used to construct hydraulic structures are often subjected to the action of abrasion by fluid flow containing solid substances. Wearing of concrete surfaces due to this flow of fluid results erosion of systems termed as erosion. Sometimes movement of solid substances over concrete surfaces develops friction between each other. Some of the examples related to this type of friction are – acceleration and de-acceleration of moving vehicle's wheels, movement of heavy machine over the industrial floors etc made up of concrete. Therefore considerable amount of material loss from system will occur. In the other way loss of materials from surface of concrete systems may occur as a result of irregular flow of fluid/water , change in the direction of flow creating vapour bubbles. This in turn show up as decay of concrete surfaces.

Remedy – Ensuring elimination of solid materials in fluid flow, treatment of concrete surfaces, use of higher grade of concrete can avoid and prevent this type of deterioration.

3. Physical deterioration

This is a type of deterioration takes place mainly due to freezing and thawing. Locations where cold and hot weather conditions occurs frequently, in cold situation freshly produced concrete having adequate quantity of water free zed and converted into ice. Therefore volume of water increases and creates internal stresses into the system. While during in hot weather concrete thaws i.e, ice converted to water. Again freezing occurs and followed by thawing in repeated cycles. Thus resulting disruption of system and reduces the strength.

Remedy – Application of air entraining agents during concrete making dissipate internal stresses in concrete systems.

4. Deterioration due to constructional errors

Constructional errors may occur through different ways those are given below :

a. During production of concrete if water-cement ratio maintained is higher than specified value and adequate compaction is not achieved in concrete then it will show up in the form of tiny holes, honey combing etc over the concrete surfaces. This will not only interrupt the performance of concrete systems but the appearance of surfaces as well.
Remedy – To avoid this error adequate care should be ensured during concrete making from the point of view of compaction and proportions of ingredients.
b. Inappropriate placing of reinforcing steel bars in form work of RC members may also cause errors which finally become the reason of deterioration.
Remedy – Placing of bars according to the codal guidelines help to avoid this type of error.
c. Dislocation of form work and insufficient strength of temporary supports to form work during concrete placing resulting variation of dimensions of concrete structural members as well as violate design stipulations. As a result of which stress distribution throughout the members become non uniform and finally causes deterioration of systems.
Remedy – Continuous supervision throughout the construction work ensure avoidance of this errors and deterioration.
d. Also improper finishing and curing of concrete systems whether it is P.C.C or R.C.C, results deterioration of systems. Because if curing is not ensured properly, hydration reaction and production of calcium- silicate-hydrate (C-S-H) gel will not be adequate. Thus directly affects the performance of structures from the strength as well as durability point of view.
Remedy – Based on the situation of construction sites (i.e, whether member is vertically or horizontally placed, temperature-atmospheric conditions and availability of resources etc.) finishing and curing (periodically) techniques should be adopted.

Methods of Protecting Concrete Surfaces from Damages and Deterioration

Following are the surface protection measures that may be taken to minimize or stop the damage to concrete structures:

1. Hydrophobation
2. Painting

3. Impregnation
4. Sealers
5. Coating

The degree of surface protection for concrete structures achieved from these measures increases in the order as they have been listed above. The difference between various methods of surface protection lies in the process of how the protection of concrete surface is achieved. In the impregnation system, the protection is achieved through prevention of capillary absorption of water by the concrete. Depending upon the material used for surface protection, the prevention of capillary absorption of water by concrete will be achieved by hydrophobation of the pores at the walls or by narrowing of the capillary ducts, which result due to film formation on these walls. Sealers or coatings lead to a closed thin film on the surface of concrete and thus have higher degree of surface protection.

Materials for concrete surface protection

(a) The materials used for impregnation, hydrophobation methods for concrete surface protection are:

- Silicon organic solutions
- Resins
- Oils

(i) Silicon organic impregnation materials are:

- Siliconates
- Silanes
- Siloxanes and
- Silicon resins

(ii) Resins: The resins provides protection to concrete surface by forming a thin film on the surface of the pores and narrowing of the capillaries. Types of resin materials used for this are:

- Polymethylmetacrylates (PMMA) and
- Epoxy resins

(iii) Oils: Oil is a low molecular, organic compound and is used for impregnation. Linseed oil is most widely used oil for impregnation. Linseed oil may be used in the following types:

- Boiled (linseed) oil
- Linseed stand oil and
- Mixture products of boiled (linseed) oil or
- Linseed stand oil with not more than 15% unsaturated organic compounds.

(b) Sealers:

In contrast to impregnation and hydrophobation, sealers are more effective is protecting the concrete surface by forming a film on the surface. Sealing of concrete surface is achieved by increasing the applied quantity of an impregnation agent, which tends to form a film, or through the choice of suitable resins. The following plastics are commonly used as sealers for concrete surface:

- Epoxy resins (EP)
- Polyurethane resins (PU)
- Polymethyl Methacrylate resins (PMMA); and
- Unsaturated polyester resins (UP)

Sealers can also serve as a primer for coatings.

(c) Coatings:

Coatings provides additional protection to concrete surface as compared to sealers. Consideration should also be given to the fact that coatings, as compared to sealers, have an increased resistance to the diffusion of internal moisture. There are two types of coatings used, thin coating and a thick coating. Thin coatings follows the contour of any unevenness of the concrete surface. Thick coatings is used to form as much as possible a plain surface with a thickness of 1mm or larger. Therefore, a thick coating will smooth out any unevenness of the surface.

A good coating materials should have following properties:

- Resistance against chemical attacks,
- Resistance against temperature changes,
- Good adhesion to the surface,
- Sufficient tensile strength and elasticity,
- Sufficient abrasive resistance,
- Capability to bridge cracks; and
- Coefficient of thermal expansion comparable to that of concrete.

Coatings suitable for protection at concrete surfaces are epoxy resin, bituminous compound linseed oil, silicon preparation, rubber emulsion or even mere cement coating. Coatings are also used for sealing of the cracks in concrete structures. For this, high elasticity coating materials is used. The epoxy systems are known to change their properties with variations in temperature and exposure to sun rays. For thinner layers bridging of cracks can only be achieved when a limited debonding of the coating adjacent to the crack is possible. With such coating, it is possible to bridge cracks up to 0.2mm in width. Bridging of larger crack widths can be achieved by the insertion of a fiber material into the coating, e.g. in the form of textile fabrics. Recently, two component liquid sealers have been developed which can be sprayed onto the concrete surface. They have the ability to bridge larger cracks as a result of their low modulus of elasticity and their improved elongation.

Methods of Using Surface Protection Materials

Concrete surface is first prepared for the impregnation of surface protection materials. The surface is prepared based on the depth of impregnation required on the concrete surface. Then the impregnation liquid is placed on the concrete surface in an amount to fill the voids on surface, then is sprayed on the concrete surface with the help of brush, lambskin roller or by spraying. Depending on the absorptive capacity of the concrete surface, several repetitions may be necessary. For the first application on the concrete surface, thin solvent containing impregnation systems may be required to achieve a deeper penetration. Penetration depth of surface protection material is especially important where wearing of concrete surface is expected. Therefore, impregnation protection systems are only suitable where the concrete surface will not be removed by abrasion, damaged or locally disturbed by the formation of crack. While impregnation with resins may be successfully used on horizontal surfaces, hydrophobizing impregnations are not suitable for horizontal surfaces where water will stay on the surface. Therefore, the primary field of application of hydrophobizing impregnation is on vertical or sloped surfaces, where the water can flow off easily.

corrosion of reinforcement in concrete:

Corrosion in Concrete

As we all know, the reason behind using reinforcement in concrete.

***Recap** – The concrete is strong against compressive force & weak against tensile force. So we use reinforcement bars to increase its tensile strength.*

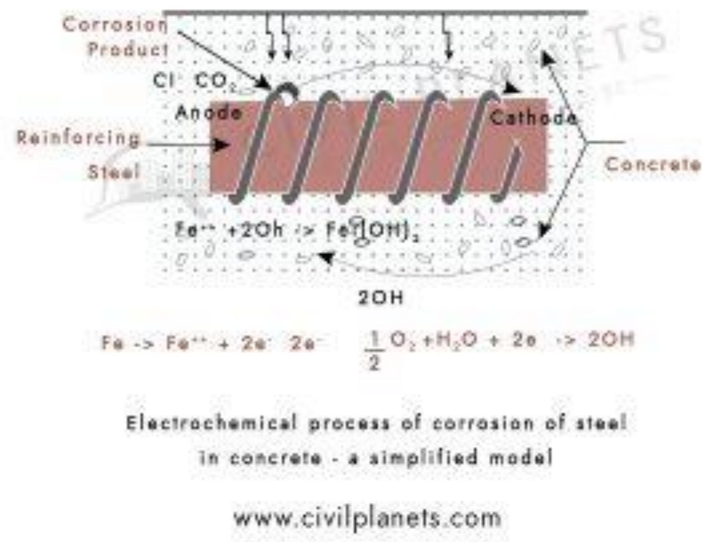
The reinforced concrete is used in construction because of excellent durability, workability & high strength. It doesn't mean that it will sustain any chemical reactions. The concrete also has some defects and the corrosion is one among them.

What is corrosion of reinforcement in concrete?

The chemical & electrothermal reaction induced by environmental circumstances over a long period which causes the reinforcement bars to get rusted and disintegrated is known as corrosion in concrete.

The reinforcement corrosion severely affects concrete strength & durability.

Corrosion Process in Concrete



The chemical reaction happens in the following manner,

When two or more materials get in contact, which has distinct surface characteristics such as electric conduit and reinforcement, it forms concentrated cells.

Those concentrated cells will be formed near reinforcement bars due to the differences in the concentrated, dissolved ions like salt, alkalis, acid & chloride, etc. It creates an oxide layer over the reinforcement.

Process

Like an electric battery plus & minus point when two or more materials are used in concrete, it acts as an

electrochemical cell.

The one end becomes the anode, and the other end becomes the cathode. Then the electrothermal reaction happens in the electrolytic cell.

<— You can skip the next two headings if you are not interested in the chemical formation 😵 —>

Anode Reaction – The iron cells lose the electrons and pass on the concrete & turn as Ferrous ions.

$2Fe \rightarrow 2Fe^{2+} + 4e^-$

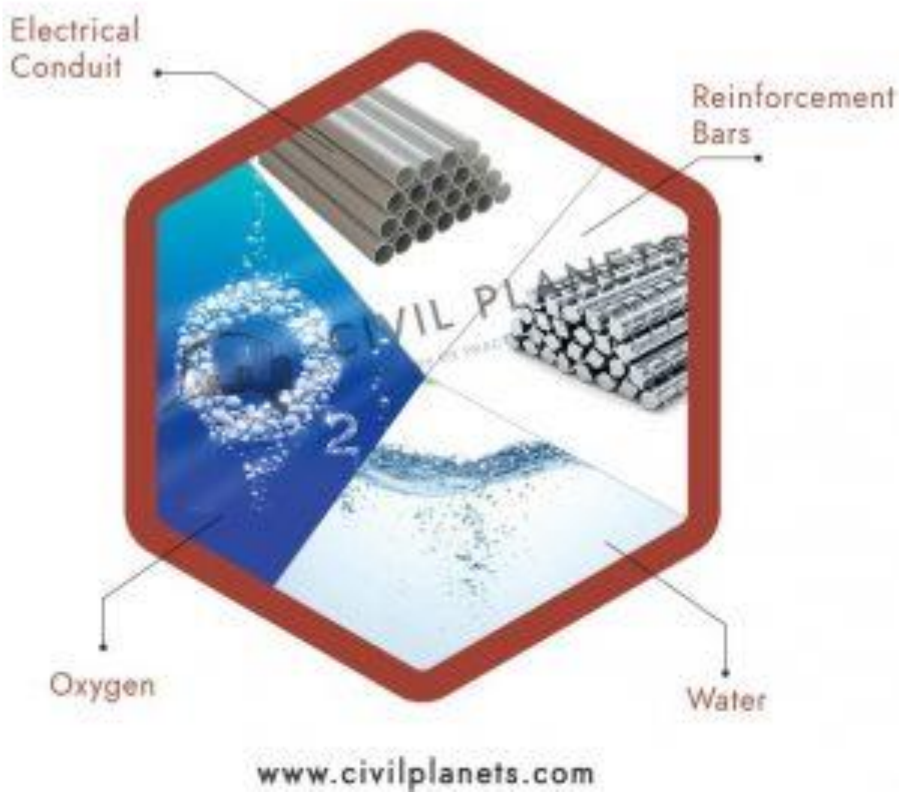
Cathode Reaction – The remaining electrons are **mixed with water & oxygen**, which flow into the concrete.

$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$

Finally, an oxide layer is formed on the reinforcement & it becomes rust for over a long period. At last, the corrosion affects concrete strength.

What causes concrete corrosion?

If you read the process above, you probably found that without oxygen and water, the corrosion layer does not acquire on the reinforcement.



Any defects that allow water or oxygen to enter the reinforced concrete leads to corrosion.

- **Water cement ratio** – The high water-cement ratio for concrete increases the rate of porosity. So the water molecules enter into the concrete & rust the steel bars.
- **Shrinkage in concrete** – The shrinkage cracks start to appear on the surface due to the moisture evaporation without any external load. In the future, it exposes the reinforcement bar and gets corroded.
- **Quality of Material** – The silt or other marine impurities may mix in concrete and develop the cracks on the concrete surface. In the future, the embedded rods are corroded due to its alkalinity.
- **Permeability of concrete** – The concrete should be poured properly, and compaction is needed to avoid the permeability.
- **Moisture** – Sometimes, the concrete element may be wet by the surrounding nature. Thus the moisture content may end up to the steel surface through the voids & affect the reinforcement bars.

- **Strength of concrete –** The concrete structure should be designed well to sustain the load. In the case of low tensile strength or compressive strength of concrete, the cracks can quickly appear on the concrete surface. It makes way to oxygen and water.
- **Alkalinity loss due to carbonation –** If the reinforcement bars are visible, then the environmental gases react with alkali & make an ion oxide layer on the steel. Finally, the steel will be corroded.
- **Sulphate –** The cement & other aggregates contain some limited volume of sulphate content. If it exceeds the limitation it may lead to cracks on concrete. To avoid this, the sulphate content in concrete should not be exceeded by 4% by the mass of cement in concrete.
- **Chloride –** The concrete surface may be contaminated by external environment chloride, such as the salt from the construction material. So the volume of chloride content must be controlled. The quantity of chloride content in the concrete at the time of pouring is given below the table as per the Indian Standard Code IS 456.

SI	**Types of Concrete**	**Maximum Total Acid Soluble Chloride Content in concrete Kg/Cum**
1	Prestressed Concrete	0.4

2	RCC or PCC containing embedded metal	0.6
3	Concrete not containing embedded metal or any material requiring protection from chloride	3

Effects of corrosion in concrete

- **White Patches –** The reaction between carbon dioxide & calcium hydroxide makes calcium carbonate. The calcium carbonate penetrates the concrete surface with the help of atmospheric moisture and forms a white patch on the concrete's external surface. It appears on the bricks also. We have discussed in detail the quality checking of bricks at the site.
- **Brown Patches –** The brown patches form on concrete surfaces because of the iron oxide layer formed and start corroding the reinforcement bar. After the formation of brown spots, the concrete surface will peel off quickly in some time.
- **Cracks –** Due to the corrosion, the size of the steel bar may increase (bulge), and on the external surface initially, a minor crack appears. However, after some days, it will become a huge crack which directly affects the stability of the structure.
- **Snapping of reinforcement bars –** The size of the steel will be reduced due to the continual corrosion. Finally, the steel bars will be snapped, which will affect the concrete element's alignment.

How do you prevent rebar corrosion on concrete?

- **Quality – **There is no compromise in the quality of the concrete material. The concrete ingredients should be free from silt or other harmful impurities.
- **Clear cover –** Sufficient clear cover should be provided for the reinforcement to avoid the chances of exposure.
- **Epoxy Coating –** The epoxy-coated steel reinforcement shall be embedded in concrete to resist corrosion.
- **Polymeric Fibre –** The usage of polymeric fibres in concrete can prevent steel from corrosion.
- **Proper Workmanship –** Ensure that the concrete should be poured with proper compaction without bleeding and segregation (Honeycomb)to avoid the voids happening on the surface.

13 Repair technology for concrete structures:

13.1

Symptom, cause and prevention and remedy of defects during construction:

There are various techniques available for repair and rehabilitation of concrete structure for failure and defects in concrete. These techniques and materials for repair of concrete is described. Concrete is the most widely used and versatile construction material possessing several advantages over steel and other construction materials. However very often one come across with some defects in concrete. The defects may manifest themselves in the form of cracks, spalling of concrete, exposure of reinforcement, excessive deflections or other signs of distress. On many occasions, corrosion of reinforcement may trigger off cracking and spalling of concrete, coupled with deterioration in the strength of the structure. Such situations call for repairs of affected zones and sometimes for the replacement of the entire structure.

Contents: [show]

Causes for Failures or Defects in Concrete Structures

The following are the major causes for failures of concrete structures:

- Structural deficiency arising out of faulty design and detailing as well as wrong assumptions in the loading criteria.
- Structural deficiency due to defects in construction, use of inferior and substandard materials, poor workmanship, and negligence in quality control and supervision.
- Damages caused due to fire, floods, earthquakes, etc.
- Chemical deterioration and marine environments.
- Damages caused due to abrasion, wear and tear, impact, dampness etc.
- Movement of concrete caused due to settlement of foundation, thermal expansion etc.

Identification of Failures and Defects in Concrete Structures

A correct diagnosis establishing the cause, nature and extent of damage, and the weakness or deterioration caused in the structure is very essential, since a faulty diagnosis may lead to improper selection of materials and repair techniques leading to the failure of the repaired zone again. It may also be necessary that the serviceability of the structure is checked after carrying out the necessary repairs.

Need for Repair and Rehabilitation of Concrete Structure

The need of structural repairs can arise from any of the following:

- Faulty design of the structure
- Improper execution and bad workmanship
- Extreme weathering and environmental conditions
- High degree of chemical attack
- Ageing of the structure

Techniques for Repairs and Rehabilitation of Concrete Structure

The technique to be adopted for repair or restoration of the structure depends on the cause, extent and nature of damage, the function and importance of the structure, availability of suitable materials and facilities for carrying out repair, and a thorough knowledge of the long-term behavior of the materials used for the repair work. Depending upon the requirement, the repairing technique may be of a superficial (cosmetic) nature or, in some cases, may involve the replacement of part or whole of the structure. **The repairing techniques can be classified into three major groups:**

1. Injection into cracks, voids or honey-combed areas.
2. Surface treatment
3. Removal and replacing of defective or damaged material / area.

A variety of new materials have been developed for the repair and restoration of damaged structures by following any one of the above methods. These are briefly described below.

Materials for Repairs and Rehabilitation of Concrete Structure

Cement, Cement Grouts, etc.

In most cases, the repair material may be cement-based, since cement is the only active ingredient in concrete. Dry pack consisting of rich cement concrete or cement grouting may be suitable for sealing damaged areas and cracked portions. Spraying of concrete or cement sand grout by means of high pressure nozzles, usually termed as ‘shotcrete’ or ‘guiniting’, respectively, may prove effective in many cases where a large surface area is to be repaired.

The guiniting or shotcrete may be carried out with or without the use of steel reinforcing mesh or steel fibers.

Resin based Repairs of Concrete

The resins normally used are from epoxide, polyester, acrylic or polythene families. The application of resins for repair work requires a thorough understanding of their chemical and physical properties and their performance in the structure, particularly with the passage of time and under unfriendly environs. Epoxy resin systems find application in civil engineering works such as grouting of cracks, repairs of eroded concrete structures, emergency repairs of bridges, aqueducts, chemically corroded columns and beams. Generally, resin materials are used in repair and restoration work where properties such as, high strength (hence thin sections), excellent adhesion (hence small patches), quicker curing (hence saving in time), and high chemical resistance are required. One of the most commonly adopted resins is from epoxide. A brief description of the properties and applications of epoxy based resins is given below.

Epoxy Resins for Concrete Repair

The resin mortar may be obtained by adding fillers such as coarse sand or calcined bauxite grit. The chemical reaction begins as soon as the resin and hardener are combined. Most combinations have a pot-life between 30 and 60 minutes. They develop excellent strength and adhesive properties and are resistant to many chemicals besides possessing good water proofing. Epoxy resin when cured with different hardeners offer wide range of properties. Once cured, they form irreversible system (thermosetting). **The characteristic properties of cured epoxy resin systems repair and rehabilitation of concrete structure are**

- High adhesive strength to almost all materials
- Low shrinkage during curing
- Exceptional dimensional stability
- Natural gap filling properties
- Thermosetting (does not melt)
- Resistance to most chemicals and environments
- Ability to cure in wet conditions and underwater (for selected grades)
- Ease of application

Procedure of epoxy resin grouting

- Locating the cracks
- Cleaning of the cracked surface
- Drilling and fixing of nozzles for grouting at suitable intervals with epoxy putty
- Grouting of epoxy mixture with the help of the grout pump
- Sealing of nozzles through which grouting is done

A grout vessel essentially consists of a pressure vessel (to withstand 10 – 15 kg/cm^2 pressure) with inlet and outlet for resin mixture, pressure gauge, connection for compressed air with regulator for pressure grouting. A pre-mixed resin + hardener is filled in the grouting vessel and through the nozzle the activated resin is pumped in the cracks. When cracks get filled in, the grouting is carried in the next nozzle and so on till all the cracks are filled in. When cured, the epoxy resin improves the load carrying capacity of the cracked structure.

Bonding Old to New Concrete

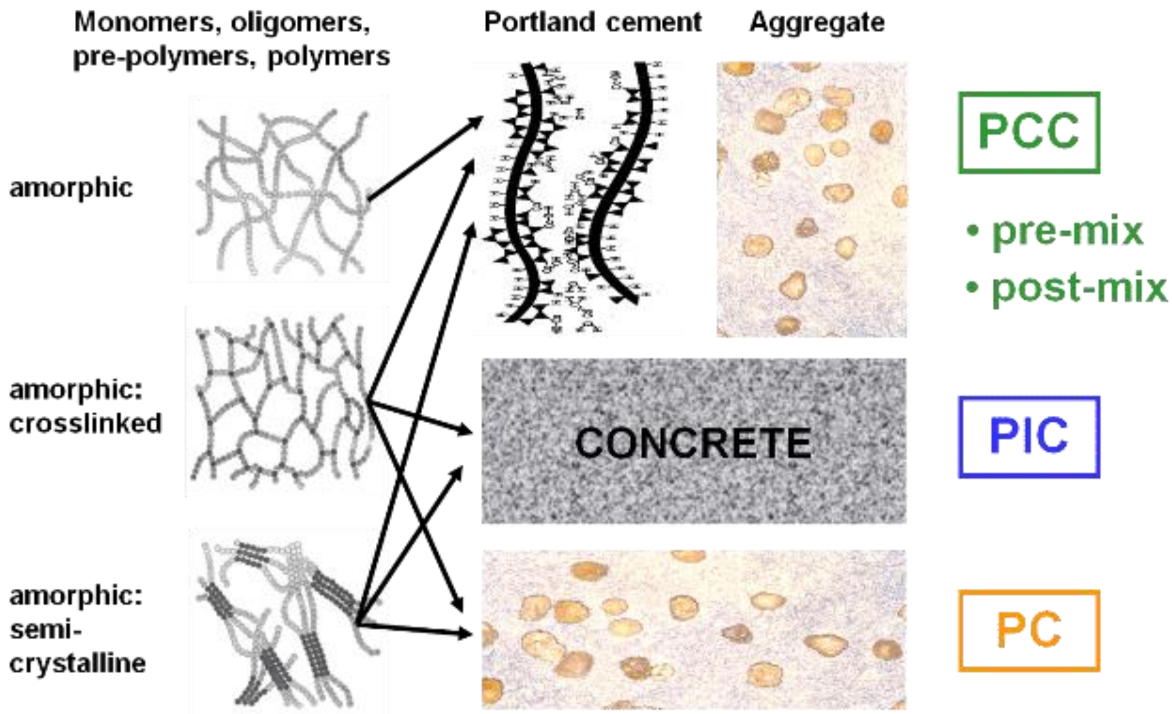
Epoxy resin with a special polyamide hardener combination is successfully used for bonding old to new concrete. **The process consists of —**

- Removal of all loose and damaged concrete using mechanical means or water jet
- Surface to be dried
- A suitable epoxy resin [unmodified solvent less epoxy resin + polyamide hardener (special grade)] is applied with stiff nylon brush
- The fresh concrete should be poured when epoxy coating has become just tack free
- Care should be taken not to completely dry the coating.

Epoxy resins are a not primary construction material. A judicious use of these resins is required in view of the high cost of these resins. The resins should be used in emergencies. Properties of epoxy resin systems can be advantageously exploited, when other materials cannot be used due to strength or other considerations. Epoxy resins are finding many new applications in pressing conditions such as underwater repairs of dams, ships, etc. Many new applications will be found using epoxy and other synthetic resins in future.

Polymer Concrete Composites

Most of the deficiencies found in ordinary structural concrete are removed using polymer concrete composites either in the form of a surface coating over the structure or by impregnating it into the structure. Polymer concrete composites are relatively new developments and have been used in structural applications since 1950. They possess very high strengths and are more durable and resistant to most chemicals and acids. There are three types of polymer concrete composites, namely polymer impregnated concretes (PIC), polymer concretes (PC), and polymer cement concretes or polymer modified concretes (PCC or PMC). In PICs the monomers (usually styrene, methyl-methacrylate (MMA), polymethyl methacrylate (PMMA), etc.) are impregnated into the pore system of the hardened concrete, thereby filling up the pores and making them impermeable and resistant to chemical attack; In PCs the polymer is the sole binder in lieu of cement and water. In PCCs and PMC s, a polymeric additive (latex or pre-polymer) is added to the normal cement composite during the mixing stage itself.



All the three types of polymer concrete composites are useful for carrying out repairs and restoration work in damaged structures. The use of these composites for post-distress and post-failure applications is steadily increasing because of their superior durability, excellent bond to parent concrete structure, superior abrasion and wear-resistant properties, a high degree of resistance to chemicals like chlorides and acids, and their very low water absorption. Repairs of cracks can be easily carried out by injecting the polymer concrete damaged by corrosion of reinforcement can be chipped off and replaced by polymer concrete.

Sealants

Many commercial sealants are available for sealing of cracks in concrete structures. Joint sealants should ensure structural integrity and serviceability. They should also serve as protection against the passage of harmful liquids, gases, and other undesirable substance which would impair the quality of concrete. In the case of repair of a cracked surface, the cracks are first enlarged along their exposed face and are pointed up with the sealants.

Surface Treatment to Concrete

The durability of the concrete can also be increased particularly on the surface by applications of different materials which make it waterproof, hardened and resistant to chemical attack.

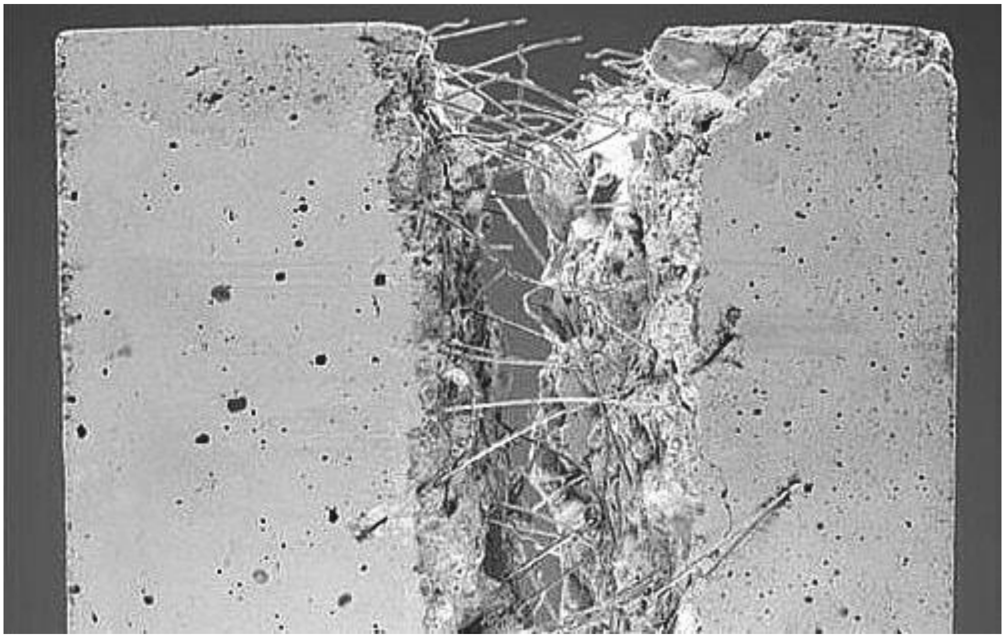
Some of the commonly used surface treatments are:

- Sodium silicate, magnesium or zinc fluoride
- Drying oils like Tung or Linseed oil
- Chlorinated rubber paints and neoprene paints
- Epoxy paints
- Silican Fluoride treatment

The surface of the hardened and dry concrete can be made abrasion resistant and less dust generating by application of solutions of sodium silicate, magnesium or zinc sulphates or silico fluorides. Drying oil like tung oil or linseed oil can be used. Alternatively, carborundum or fused alumina or finely divided iron aluminum chloride preparations may be added in the surface layer while placing the fresh concrete. Floor paints also provide reasonable durability if the traffic on floor is not heavy. Paints containing synthetic resins particularly polyurethanes or epoxies or chlorinated rubber provide greater resistance to wear. They also protect against solutions of salts and dilute acids. Sodium silicate and silico fluoride applications provide protection against mild conditions of attack by aqueous solutions or organic liquids. Bitumen and coal tar gives protection against insects and borers. Some plastic materials, rubber latex glass fiber coatings and PVC linings have also been successfully employed to improve durability of concrete.

Steel Fiber Reinforced Concrete

Use of small diameter steel fibers in concrete has been found to improve several properties of concrete and particularly its tensile strength and impact and wear resistance. One of the uses of steel fiber reinforced concrete (SFRC) is in the area of repairs and restoration of concrete structures.



The damaged portions of a concrete structure can be removed and can be made good by placing of SFRC to the sides and bottom of damaged structures by guiniting or shotcrete techniques. Because of its improved wear and tear and abrasion resistance, SFRC has been successfully employed for the repair of industrial floors and bridge decks with or without the use of polymer concrete.

Other Materials for Repair and Rehabilitation of Concrete

There are several other materials which can also be used for repairs of certain structures. For repairs to existing foundations, special chemical grouts have been developed which will ensure the compaction of the soil below and provides protection to the reinforcing steel in the foundations. Superplastized fiber reinforced concrete has been used in carrying out repairs to machine foundations and underground structures. Certain chemicals and surface coatings marketed under brand names are said to seal the cracks in structures like water tanks and afford sufficient protection to the steel from corrosion. Special paints (latex or bitumen based) have also been developed for applying to the concrete surface or to the bars for making them resistant to aggressive environs. With the increasing number of cases of damages being observed on structures built in the past, repairs and rehabilitation of such structures have assumed greater importance. Some of the techniques and materials found useful to reinstate some affected structures. Table below shows the materials generally recommended for repair of concrete structures. Epoxy resins and concrete composites show high potential as promising repair materials. Timely detection of deficiencies in concrete and steel of an existing structure and execution of immediate remedial measures will prevent further deterioration of the structure and will result in huge savings in the maintenance cost. The old dictum, ‘prevention is better than cure’ is applicable to concrete structures, both at the time of constructing the structures and at a time when the structure has shown signs of initial distress.

Materials for Repair of Concrete

Repair Operation	Material	Comments
Sealing of fine cracks	Epoxy resins	- Good bonding properties even in the presence of moisture
Sealing of large cracks and joints	Portland cement Mortar Polymer mortar Putties and caulks	- Well – compacted - Good bonding properties - Based on synthetic polymers and tars
General sealing of surface	Synthetic polymers and asphalt coatings	
Localized patching of surfaces	- Concrete or mortar using Portland cement - Rapid-setting cements - Polymer resins; epoxies; polyesters	- Calcium aluminate and regulated-set cements - Good bonding

Repair Operation	Material	Comments

Overlays and shotcrete	- Portland cement concrete - Steel fiber reinforced concrete - Latex modified concrete - Polymer concrete - Asphaltic concrete	- Quick-setting admixtures - Resistance to cracking - Good bonding

cracking of concrete due to different reasons.

Major Reasons of Cracks in Concrete Construction

The crack in concrete construction can be a major issue. It can be prevented by taking the right measure well in advance.
There are various reasons for which cracks can be developed in concrete construction.

Causes for which Cracks developed in Concrete Structures

- **Quality of Concrete** – Quality of concrete depends upon its material. Therefore, it is needed to use only **best quality construction material** that reduces the risk of Cracks.
- **Temperature Fluctuation** – During the contraction materials heated up and gradually it cools down. This expansion and contraction with temperature change takes place of all structures cross sectional area.
- **Creep Movement** – If any slope is covered with loose it causes slow downward movement within. With the modern technologies frost heaving gets implemented to restrain cracks.
- **Moisture** – In construction due to differences in vapor pressure moisture movement happens in between moves through a porous medium. This movement affects concrete and result cracks.
- **Reinforcement Corrosion** – In due course of time it is natural to develop corrosion in reinforcement due to atmospheric reaction to it. There are other reasons to it too – Carbonation, High Chloride, Moisture reaction, Lack of proper measure during storage.
- **Maintenance** – If the proper care is not taken time to time then due to lack of maintenance can be another major cause for it.
- **Design** – Poor structural design & specification can be another major cause of it.
-

Different Types of Cracks in Concrete Structure

Plastic Settlement Cracking

At initial level when the concrete mix is not solid during that time this type of cracks form at the surface. After some hours of placement only it can be identified.

How to Prevent Plastic Settlement Cracking?

There are few ways that can prevent this type of Cracks in Concrete.

- By using High Quality Concrete Mix
- Using Shrinkage Compensating Admixture into Concrete Mix
- Controlling the vibration during construction
- Re-vibration of concrete after they are formed

Plastic Settlement cracking is a common error but it can be eliminated if the points mentioned above are followed properly.

Thermal Contraction Cracking

Thermal Cracking causes for massive temperature deviation in mass concrete. It appears on surface level after few days of formwork.

How to Prevent Thermal Contraction Cracking?

Thermal Cracking happens due to huge difference between the maximum temperature and minimum temperature range that occurs in concrete. The Designer and Contractors are mainly responsible to minimize this type of cracking by following the specifications limits and doing the temperature control on time.

- Usage of Port land Cement that generates relatively low heat.
- Avoid specifying an excessively low w/cm (water-cementitious materials ratio)
- Thermal Control measures has to be decided before starting the construction
- Using the cooling pipes if necessary during the cooling process.

Drying Shrinkage Cracking

Drying Shrinkage mainly occur for usage of more water in concrete mix. It can be reduce during the design stage:

How to Prevent Drying Shrinkage Cracking?

Drying Shrinkage Cracking can be reduced during the design stage.

- Provide sufficient movement joints
- Sufficient Crack Control Reinforcement can also reduce this type of cracking in concrete
- During the placement avoid adding additional water to the mix

Reinforcement Corrosion

Reinforcement bars are the main component that strengthens the structure because of superior bonding with concrete. Corrosion of TMT Rebar can be one of main issue if that is not taken care on time.

How to Prevent Reinforcement Corrosion?

Reinforcement corrosion can be one of the major issues that cause cracking to the structure. There are some methods that can stop developing corrosion in reinforced steel that are:

- **Anti-Corrosion Coating on TMT Rebars** before applying it to the construction site
- Corrosion Inhibitor Admixtures
- Cathodic Protection

But above all 2 things are most important to prevent corrosion. Water penetration and choosing the **best quality TMT Bar** those are highly corrosion resistant.
These are the major reason to develop cracks in concrete structure. It is important to take the precaution before it goes wrong. It is important to use only **best quality construction material** that strengthen the structure forever.

Reasons Why Concrete Cracks

1. **Excess water in the mix** – A common malpractice when treating concrete is adding excess water to the concrete mix. Concrete needs a certain capacity of water to strengthen its core, but anything above the standard limit causes more harm than good. When this excess water evaporates from the concrete, it leads to further shrinkage. It's best that your construction team is aware of the exact proportions of water and concrete to be mixed.
2. **Rapid drying of the concrete** – While excess water causes harm to concrete, so does rapid drying. This drying then leads to excess evaporation of water from the surface, leading to map cracking. While this usually affects the aesthetics of the structure, if not controlled, it can affect the deeper layers leading to cracks within the building. A process called curing usually prevents rapid drying. Here moisture levels in concrete are regulated by adding proportionate amounts of water.
3. **Improper strength concrete poured on the job** – Every structure needs a certain weight-bearing capacity. From skyscrapers to small houses – every building has a different requirement for concrete. This concrete often comes in a range of different 'strength capacities'. A common error is to use a lower or higher grade strength concrete without matching it with the structural requirements of the building. This then leads to cracks and eventual damage.
4. **Lack of control joints** – Control joints are used in concrete to strategize the cracks. These joints are placed in areas where temperature, shrinkage, and other factors will lead to cracks. This gives the builders control over deciding where the concrete will crack while minimizing damage. When these control joints are missing, the concrete will crack in fragments that will cause heavy damage.

Types of Cracks in Concrete

Concert develops cracks because of varied reasons and each such crack can be identified because of its unique characteristics. In this section, we will explore more about the types of cracks in concrete and what each type indicates. Identifying the causes of cracks can help you think of preventative steps.

1. **Cracks caused by deformation** – There are many forces that act upon concrete. The most common are tensile, compressive, and shear forces. It is because of these forces that deformation occurs, which leads to cracking. To identify such cracks, you must see the geometry of the crack. For instance, parallel cracks are caused due to compression, whereas perpendicular cracks are caused due to applied forces or tensile forces.
2. **Cracks caused by hydraulic shrinkage** – The process of hardening often causes exposed concrete to shrink. This shrinkage is a natural phenomenon. Yet when the forces of this shrinkage become greater than the concrete's inherent strength, it causes deformation. These cracks are usually seen in concrete joints or in areas where reinforcements were done.
3. **Cracks caused by thermal shrinkage** – Cracks due to thermal shrinkage are often seen in large structures. Here, as the name thermal suggests, the variation in temperature leads to deformations. As we know, concrete undergoes a drying process where the heat usually dissipates. Sometimes when there is an unequal distribution of heat in the structure, it causes cracks to occur.
4. **Cracks caused by swelling** – Concrete can swell due to multiple reasons. The most common ones are presence of sulfates presence in the earth. Apart from that, freezing of water in the concrete leads to an expansion of the entire concrete. Oxidation is another reason for the swelling of concrete. These all lead to one occurrence – an increase in internal tensile force which reduces the strength of concrete.

Cracks caused by corrosion of the steel reinforcement – TMT bars are often used to strengthen concrete. When these TMT rebars corrode over time, it leads to development of cracks in the concrete structure.

How to Limit the Cracking Phenomena?

You can prevent the different types of cracking in concrete by following a few simple but effective methods. Let's explore these reasons in depth in this section.

1. **Start with a sound subgrade** – When overlaying concrete with other elements, it's essential to ensure the 2 elements layer and bond properly. This is what's

known as a sound subgrade. If these aren't layered well, then the material will detach from the concrete, leaving it exposed to wear and tear.

2. **Modify the concrete mix –** Understand the proportions of water you need before adding it to the concrete mix. Consult the manufacturer, who will accurately inform you about the right proportions to be added. If the mix is smooth, it means you have added enough water. In case you feel the mix is crumbly, then add more water. Keeping this simple trick in mind can help prevent damage.

3. **Install Steel Joints** – Add steel joints in potential crack areas. This will help control the cracks and also minimize the damage caused due to them. With this method in place, the cracks will be restricted to vulnerable areas instead of the whole slab.

Properly cure the concrete – Constant hydration of the slab will help curb the rapid drying due to evaporation. Besides adding water, curing also involves covering the concrete with cotton mats soaked in water. This process, if carried out properly, will cause fewer deformations and cracks.

Key Takeaway

Concrete forms the spine of any structure and needs to be well protected. As covered in the article, this can be done right at the initial stage by strengthening the concrete with strong raw materials and processes. Sree Metaliks Limited offers just these materials that will strengthen your concrete structures and safeguard them for years to come. The brand is a renowned name in the construction industry and offers quality products at an affordable range. So, if you want your structures to remain strong, then invest in right materials.

Repair of cracks for different purposes:

8 Different Methods of Concrete Crack Repair | How to Select Suitable Method of Concrete Crack Repair

Introduction of Concrete Repair Method

Concrete is one of the most widely used building materials in the construction industry all over the world. Concrete is a versatile construction material that possesses various advantages as compared to other construction materials.

There are many defects that occur in the concrete with time due to an aggressive environment. There are many old structures that have reduced the strength in due time. If further use of such buildings continues it will endanger the lives of the people and the surrounding habitat.

Here In this article, we will learn about the various **concrete repair methods** in detail which are used to repair concrete damage. Concrete repair is basically a modification of the concrete due.

How to Select a Suitable Method of Concrete Crack Repair?

The concrete repair method which is adopted for the restoration of this structure mainly depends upon the cause and the extent of the damage.

The concrete repair method is selected based on the evaluation of the crack that occurred in the structure. While treating any damage or crack in the concrete structure it is very necessary that we should know the main cause of that defect.

Knowing the cause of the damage and reducing or eliminating that cause will repair last longer. The selection of the concrete repair method also depends upon the various factors which are as follows. Importance of the structure.

- **Availability of Suitable Material.**
- **The Function of the Structure.**
- **Nature of the Damage.**
- **Availability of the Fund.**

Methods of Concrete Crack Repair

There are various **concrete repair methods** which are used to repair various types of cracks and damages which generally occur in the concrete.

1. Method of Concrete Crack Repair: Stitching

In the technique of stitching the crack is a bridge up with u shaped metal, you need stitching dogs before being repaired with the rigid resin material.

This can establish restoration of the strength and integrity of the correction due to care is to be given to make an analysis check to ensure that this will perform well under applied loads.

Stitching is the best **concrete repair method** for Major cracks and it is suitable when tensile strength must be re-established across the major cracks.

Stitching will not close the crack but it is a way of stopping the further movement of active cracks. Stitching will help to prevent cracks from spreading.

Stitching dogs should be of variable length and orientation and so located that the tension transmitted across the crack is not applied to a single plane within the section but is spread over an area.

2. Method of Concrete Crack Repair: Grouting

Grouting is also one of the common and widely used **concrete repair methods**. Grouting is defined as the process in which the injection of liquid grouting material into the concrete under pressure.

During the process of grouting, the cracks and pores in the concrete get filled with the grouting material which will get subsequently Hardened.

Grouting can be performed the same as the injection of epoxy.

The Procedure of the Process of Grouting

The step-by-step procedure for grouting are as follows.

1. First upon holes are drilled along the crack in this structure and in and around hollow spots.
2. If there are several cracks the holes can be drilled in a staggered manner at **500 mm to 750 mm** spacing in both directions covering adequately the area proposed to be grouted.
3. The holes spacing can be changed as per the requirement and the site conditions.
4. The Galvanized Iron pieces (12 to 20 mm diameter X 200 mm) with one end threaded or PVC nozzles are fixed in the holes with rich cement mortar.
5. All the cracks and annular space around G.I. pipes are filled with rich cement mortar.

6. All the cracks are cut open to a ‘V’ shaped groove, cleaned, and sealed with rich cement mortar.
7. All the ground holes will be closed with water using the same equipment a day before grouting.
8. All holes are first plugged with proper wooden logs are locked in the case of PVC nozzles. The bottom-most plug and the two adjacent plugs are removed and cement water injected in the bottom-most hole under pressure.
9. When the cement water comes out through the adjacent holds the injection of cement mortar is stopped and the plugs in the bottommost hole and the one immediately above are restored.
10. The process of grouting of concrete cracks is repeated with other holes till all the holes are covered properly.
11. It is important that on the day of routing all the flags should be removed in order to drain out the excess amount of cement water and restore before starting the process of grouting.
12. The grout should be kept fully stirred under pressure throughout the process of Grouting. The grouting is carried out till refusal and till crowd starts flowing from the hole present at its adjacent.
13. A proper record of the quantity of grout injected into each hole should be maintained.
14. After the process of grouting, it is very necessary that proper curing should be done for or at least 14 days. All the equipment which are used in the process of grouting should be clean thoroughly after its use.

Precautions Should Be Taken During the Process of Grouting of Cracks in Concrete

1. In the case of the arch masonry of the bridges, the grouting is done to strengthen the structure. Some load tests may be carried out in selected structures to satisfy that grouting has helped to reduce the deflection of the crown and spread at the springing to within permissible limit.
2. After completing the grouting work, all the equipment which are used in grouting including the slurry and mixing drums, nozzles should be thoroughly washed otherwise cement will get set.

3. After the grouting work is completed it should be inspected thoroughly by the expert and should be kept under observation for a period of 6 to 12 months for its behavior after grouting.

3. Method of Concrete Crack Repair: Epoxy Injection

The epoxy injection is the most widely used **concrete repair method** for cracks which generally develops in beams and columns. The injection of a low viscosity epoxy is a possible repair method for cracks.
This concrete repair method proves to be effective to completely fill the cracks. The epoxy injection is a concrete repair The method is suitable for the treatment of cracks between 0.02 mm and 6mm.
While treating the cracks, care should be taken that the crack must be free of dirt grease, and other types of contamination. This is the best **method of crack sealing of concrete**.
The use of low modulus and flexible attitude in the treatment of crack will not allow significant movement of the concrete structures.
Before starting this process it is very necessary that the dust should be cleaned by using vacuum cleaning. Compressed air or blasting with water can also be used to remove dust and other contamination from the crack.
If the dust and other contamination are not removed from the crack, then epoxy resin will not form a strong bond in a crack. Epoxy injection is a concrete repair

method in which the epoxy concrete is prepared by the addition of epoxy resin with a hardener in the appropriate proportion.

For epoxy injection, high skilled workmanship is required for its application. The injection should start from the bottom and continue until resin appears at the next port.

Next

Stay

The injection nozzle is removed from the seal and the nozzle moved up to the next port. It is very just that the pumping pressure should be properly maintained in the cracks.

At the end, when the injected resin gets cured properly the sealing adhesive should be removed by using grinding or cutting.

The various methods of providing entry ports are as follows

- Bonded flush fitting which is attached by the sealing adhesive.
- The drill holes with the systematic fitting inserted and bonded with the adhesives which are used for the purpose of sealing.
- The interrupted seal using a gasket that covers the unsealed portion.

4. Method of Concrete Crack Repair: Grooving and Sealing

Grooving and sealing is the most common and simple **Concrete repair method**. This technique can be executed with relatively unskilled personnel and can be used to seal both fine pattern cracks and larger isolated cracks.

The system can be used to repair dormant cracks that are of no structural significance and is used to seal the cracks against the increase of moisture and carbon dioxide.

This **concrete repair method** involves enlarging in the crack along with its export face and sealing it with crack fillers. The care should be taken to ensure that the entire crack is routed and sealed.

5. Method of Concrete Crack Repair: Guniting

Guniting is the **concrete repair Method** in which the mortar is conveyed through a hose pneumatically to protect at a high velocity onto a surface.

This technique has been developed by introducing a small-size coarse aggregate into the mix. This process is made economical by reducing the cement content. The force of Jet impact on the surface compact the material.

6. Method of Concrete Crack Repair: Shotcreting

The shotcrete process is used for the application of mortar of less thickness. It is also a **concrete repair method** that is used to repair various damages in concrete structures. Shotcreting works on the same principle of greeting for achieving greater thickness with a small coarse aggregate.

Step by step procedure of shotcreting are as follows.

- **Shotcreting** is a concrete repair method. The first one removes the Plaster and finishes all around the distressed concrete surface.
- Remove concrete all around the reinforcement in order to get an average **25mm** air gap.
- Put the additional information wherever the reinforcement diameter has been reduced by more than **15 to 20%.**
- Fix shear key bars of appropriate diameter at a specified spacing in both directions over the surface to be covered with repair materials.
- Apply appropriate passivating and Bond Court over the reinforcement and prepared RCC surface.
- Shotcreting should be done with a 6mm thick finishing coat. It is also necessary to do wet curing over the finished surface of the shotcrete for a minimum period of **7 days.**

7. Method of Concrete Crack Repair: Dry Packing Method

Dry packing is a **concrete repair method** for filling holes and cracks whose depth is at least equal to the smallest surface dimension of the repair area.

The dry pack method is generally used on a small hole in the concrete. The holes should be at least 25 mm deep the dry packing method is not suitable for shallow depressions. The holes go right through the concrete section where the filling cannot be properly rammed.

Dry pack mortar is normally a mix of one part of ordinary Portland cement to 2.5 part of fine sand. The correct measure of the water will produce a mortar that is at the point of becoming rubbery when it is solidly packed.

The holes should be prepared so that they are sharp and Square at the surface edge. The interior surface is to be rubbed and if possible undercut marginally. All repairs and effects to concrete must be removed and the surface of the hole left clean.

Dry should be packed in a layer that has a compacted thickness of about 10 mm. The compacting effort should be directed at a slight angle towards the sides of the hole. The holes should not be overfilled and can be done by pounding on a piece of hardened laid on the surface.

The holes are vertical or overhead surface or not likely to be prepared effectively by this method and epoxy mortar is may be needed. The area to be prepared properly by cleaning and roughened and it should be kept wet for some time.

Repair mortar should be mixed to a plastic consistency and a small quantity of cement mortar should be scrubbed into the surface with the wire brush.
Repair mortar compacted should be a tight Filling around the edges of the hole. It is necessary that proper curing should be done for at least 7 days.
A strong and good bond will get developed between old concrete and repair. The expansive cement or admixtures have been advocated for replacement mortar repair. Generally, the expansive admixtures are used for grouting purposes.

8 . Method of Concrete Crack Repair: Drilling and Plugging

This concrete repair method consists of drilling down the length of the crack and Grouting it to form a key. This concrete repair method is used to repair vertical cracks in the retaining walls.
The hole should be drilled on the crack and the grout key prevents transverse moments of the section of the concrete adjacent to the crack. The key will also help to reduce the heavy leakage through the crack and loss of soil from behind a leaking wall.

Conclusion of Method of Concrete Crack Repair

The above Concrete repair methods are used for repairing concrete defects and cracks which generally occur in concrete structures. The use of the particular concrete repair method varies upon the types.

FAQ

How to Select a Suitable Method of Concrete Crack Repair?

Appropriate **repair** materials include epoxies, urethanes, silicones, polyureas, and polymer mortars. For slabs, designers must choose a material with suitable flexibility and hardness or stiffness properties to accommodate both the anticipated floor traffic and future **crack** movements.

Method of Crack Sealing of Concrete.

Epoxy injection **method** is used for **cracks** as narrow as 0.002 inch (0.05 mm). The **technique** generally consists of establishing entry and venting ports at close intervals along the **cracks**, **sealing** the **crack** on exposed surfaces, and injecting the epoxy under pressure.

Concrete Repair Method

- Removing the deteriorated **concrete**,
- Forming the sections to be repaired,
- Prepacking the **repair** area with coarse aggregate, and.
- Pressure grouting the voids between the aggregate particles with a cement or sand-cement mortar.

How to Fix Cracks in Concrete?

1. Use a small sledgehammer and chisel to undercut the edges of the **crack.**
2. Clean the area in and around the **crack** with a wire brush and broom.
3. Mix vinyl **patching** compound as directed by the manufacturer and trowel the compound into the **cracks**.
4. Smooth the mixture with a trowel.
5. When the patch has set (see manufacturer’s instructions for the patch compound you’re using), smooth or brush the surface to match the surrounding area.

Repairing Crack in Concrete

Wide **cracks in concrete** are best patched and sealed with a **concrete patching** compound. Smaller **cracks**, less than 1/4 inch wide, can be **repaired** with a **concrete** caulk or liquid filler. **Patching** compounds typically are mixed with water and applied with a trowel.

What Are the Best Concrete Crack Repair Products?

- Bluestar flexible concrete crack filler.
- Ezr hairline crack sealer.
- Red devil pre-mixed concrete patch.
- Pc-concrete two-part epoxy adhesive paste.
- Drylok fast plug hydraulic cement.
- Dalton enterprises 35099 pli-stix.
- Damtite concrete superpatch.

Can You Fill Concrete Cracks with Epoxy?

Epoxy Concrete Repair Crack Treatment and Concrete Crack Filler: A traditional epoxy system to effectively treat static cracks in concrete or minimize their return inactive, structural cracks, and patching concrete.

Will Concrete Sealer Fill Cracks?

To **repair** the **crack**, the **sealer** (or other **filler** material) needs to penetrate into the **crack** and **fill** it completely. Ideally, the **sealer** has a low surface tension so it readily wets out the **concrete** and a low viscosity. Keep in mind that materials like epoxy are effective because they wet out the **concrete.**

Should Concrete Cracks Be Sealed?

Every **concrete** slab has **cracks**. Due to the rigid nature of **concrete**, **cracks** are inevitable. Uneven drying, shrinkage, and temperature changes can all cause fractures in your slab. Once a **crack** develops, it’s important to **seal** it to prevent water seepage and further damage.

Are Hairline Cracks in Concrete Slabs Normal?

Hairline cracks in a **concrete slab** are rarely a cause for concern. They can be controlled, but not eliminated. A **crack** in a **slab** of 1/8 inch or less is typically a **normal** shrinkage **crack** and not a cause for concern.

Should I Worry About Hairline Crack?

Hairline cracks in a **concrete slab** are rarely a cause for concern. They can be controlled, but not eliminated. A **crack** in a **slab** of 1/8 inch or less is typically a **normal** shrinkage **crack** and not a cause for concern.

How Do You Fix a Crack in a Concrete Patio?

Patch all **cracks**, crevices, and holes in the old **concrete** surface. For hairline **cracks** up to 1/8 inch wide, mix four parts of Ardex **Concrete** Dressing to one part water. Force the thick paste into the **cracks** with a putty knife. For larger **cracks** up to 1/2 inch wide, use **concrete–repair** caulk.

How to Repair Concrete Cracks?

1. Use a small sledge hammer and chisel to undercut the edges of the crack. Undercutting the crack makes it wider at the base than at the surface, providing a mechanical method of keying the concrete patch in place for a more secure and permanent repair. For more information, see How to Break Up Concrete.
2. Clean the area in and around the crack with a wire brush and broom. Wash the area with a stream of water.
3. Mix vinyl patching compound as directed by the manufacturer and trowel the compound into the cracks. Tamp the mixture to remove air pockets with a tamper. If you use patching mortar instead of vinyl concrete crack sealer, either mix it with a bonding agent instead of water or coat the edges of the surface to be repaired with a bonding agent.
4. Smooth the mixture with a trowel.
5. When the patch has set (see manufacturer's instructions for the patch compound you're using), smooth or brush the surface to match the surrounding area.

How to Fill Cracks in Concrete?

Narrow **cracks** can be filled with a masonry **concrete crack** filler that comes in a cartridge designed to be used in a **caulking** gun. Alternatively, you can create a **concrete patch** with a vinyl **concrete patching** compound applied and smoothed with a putty knife.

How to Seal Cracks in Concrete?

Quikrete Self-Levelling Polyurethane **Sealant** may be used. Widen the **crack** using a chisel and hammer to a minimum of ¼ inch and break away any deteriorating **concrete** (the edges of the **crack** should be vertical or bevelled in an inverted "v").

How Do You Repair Cracked Concrete Outside?

Patch all **cracks**, crevices, and holes in the old **concrete** surface. For hairline **cracks** up to 1/8 inch wide, mix four parts of Ardex **Concrete** Dressing to one part water. Force the thick paste into the **cracks** with a putty knife. For larger **cracks** up to 1/2 inch wide, use **concrete**–**repair** caulk.

Types of Cracks in Concrete

- Plastic shrinkage concrete cracks.
- Expansion concrete cracks.
- Heaving concrete cracks.
- Settling concrete cracks.
- Concrete cracks caused by overloading the slab.
- Concrete cracks caused by premature drying.

How to Patch Cracks in Concrete?

Wide **cracks in concrete** are best patched and sealed with a **concrete patching** compound. Smaller **cracks**, less than 1/4 inch wide, can be repaired with a **concrete** caulk or liquid filler. **Patching** compounds typically are mixed with water and applied with a trowel.

Can Cracked Concrete Be Repaired?

Wide **cracks** in **concrete** are best patched and sealed with a **concrete** patching compound. Smaller **cracks**, less than 1/4 inch wide, **can** be **repaired** with a

concrete caulk or liquid filler. Patching compounds typically are mixed with water and applied with a trowel.

Should You Fix Hairline Cracks in Concrete?

This less evasive crack repair technique breaks the rules for concrete repair. Hairline cracks are not worth the trouble fixing. You have to cut open a hairline crack if you want to actually repair it.

Concrete Wall Repair Methods.

1. Scrub it clean.
2. Use a nail to align injection points.
3. Mix the two-part epoxy crack sealer.
4. Spread the sealer onto base.
5. Mix and apply a larger batch of epoxy sealer.
6. Dispense the LCR epoxy.
7. Fill up the ports.
8. Cut necks of the ports.

Crack Repair Techniques.

There are several **methods** of concrete **crack repair** such as epoxy injection, routing, and sealing, grouting, stitching, drilling and plugging, and gravity filling of **cracks** in concrete. Details of these **methods** for the selection of suitable **methods** for different types of **cracks** in concrete are discussed.

Concrete Slab Repair Methods.

Repair methods and solutions common ways to **repair** a **slab** are to surface fill or inject with epoxy or polyurethane. Filling and bonding the **slab** back together with a high strength epoxy is a great way to seal the crack.

Polymer Modified Cement Motor (PMI): –

This type of Mortar is used only for repairing the open surface of the old concrete. **Polymer Modified Cement Mortar** should be used if the repair area is large and the thickness of the repair is more than 50 mm.

In addition to **cement, sand, water, polymers** are added to this type of motor. The polymer is available in the following form.

- **Polymer latexes**
- **Redispersible polymer powders**
- **Water-soluble polymer**
- **Liquid resins**

How To Make Polymer Modified Cement Mortar

- To make polymer modified mortar,
- First a cement, the sand motor in the ratio of 1: 3 to 1: 2 is prepared.
- Then add polymer, 50% to 20% of the weight of cement.
- As per the need for **Workability**, select the water-cement ratio between **0.3 to 0.6.**
- Polymer Modified Cement Mortar now ready to use.
- This mortar is spread in thin layers.

Polymer-Based Solution:

Several materials and procedures have been developed to repair cracks on concrete roads. Generally, the best treatment option is a flexible, polymer-based solution that adheres to the crack. Apart from being easy to use, polymer-based solution possesses an exceptional crack bridging ability. Not to miss, it is economical, has excellent adhesion, restricts water penetration, allows the surface to breathe while retaining the potential to expand and contract. There's more! The polymer blended solution is fast setting and doesn't need any time for curing. After just two hours of final compaction, the road provides a running surface for vehicular traffic without any hazards of failure. Last but not the least, it offers a durable, finished surface which has a visually pleasing appearance.

Common Types of Concrete Repair Mortar, Chemicals and other Repair Material

Common Types of Concrete Repair Mortar, Chemicals and other Repair Material

In this blog, we explain different types of building repair mortar and chemicals which are commonly used for building repairing. Explain portland cement mortar, polymer-modified cement mortar, epoxy mortar, polymer chemicals, latex chemicals, polyester resins and so more.

Table of Contents

a) Epoxy Resins

b)Epoxy Hardner (Curing Agent):

2. Polymer and Latex: –

3. Acrylic Polymer:

4. Polyester Resins:

Types of Concrete Repair Mortars Used for repairing of Structure:

Many types of mortars are used to repair structures.

1. **Portland cement mortar**
2. **Polymer modified cement mortar**
3. **Epoxy mortar**

1. Portland cement mortar:

Portland cement mortar is generally used only for repair of exposed surfaces and new concrete surfaces, when the defective part is too wide for dry packing and thickness is less than this type of mortar will be used for repairing purposes. This mortar is not used for repair.

Image By :- Pinstrest

Portland Cement Mortar, Ordinary Portland Cement (Grade-43), is a mixture of water and clean sand. The proportion of cement and sand are similar to repair surface cement, sand proportion.

2. Polymer Modified Cement Mortar (PMI): –

This type of Mortar is used only for repairing the open surface of the old concrete. **Polymer Modified Cement Mortar** should be used if the repair area is large and the thickness of the repair is more than 50 mm.

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3. Epoxy mortar:

Epoxy the mortoar is made from a mixture of Epoxy resin, hardener, and sand. On an old surface of concrete, first applied **Epoxy Bond coat** then apply Epoxy Mortar on concrete surface and repair.

Such a mortar acquires Strength in a few hours. Such mortars have

- high strength.
- The barrier against wear and tear is high.
- Moisture barrier,
- can be applied in fairly thin layers.

This type of mortar can be used in such a condition.

- Where the epoxy bonded concrete Couldn't be used
- The thickness of repair (like,**cracks)** is not more than **40mm**.
- Repair area is less than **0.1 square**meter.

Types of Concrete Repair Chemicals Used for repairing of Structure:

Chemicals are essentially used in the construction and maintenance of the building. Different types of concrete repair chemicals are given below.

1. **Epoxies**
2. **Polymer and Lates**
3. **Acrylic Polymers**
4. **Polyester resins**
5. **Others**

1. Epoxies:

Epoxy is one type of organic chemical. In order for it to be polymerized, it is needed the two material

- Epoxy Resins
- Curing Agent (Hardner).

IMAGE BY – GUFIXING

a) Epoxy Resins

Epoxy resins is a natural material which is obtained by plants and tree. It can also be made in the factory. They are organic adhesive substances that are insoluble in water.

Example:**- M – Seal** which is available in two parts in one packet in the market is used to seal tank leakage of Car Radiator, to seal cracks between doors and walls, to seal **broken ceramic pieces**, etc.

Properties of Epoxy Resins:

- Good Mechanical Strength
- Good Chemical Resistance
- Ease of Working
- High Tensile Strength

It has low viscosity. It can also be ejected into small cracks.

High viscous epoxy resins are used for surface coating as well as for filling large cracks or holes.

b)Epoxy Hardner (Curing Agent):

Epoxy hardner combines with its epoxy resin to convert it from liquid to solid. The main Epoxy Hardner is as follows:

- Aliphatic and aromatic amines
- Polyamides, etc.

IMAGE BY : – WOODIMPROVE

Uses of Epoxy:

- **Epoxy grout, mortar, coatings,** etc. are widely used for repair. It gives Good Strength and Adhesive Property. It also gives toughness, which increases durability and resistance to cracks.
- Epoxy coated steel bars are used in RCC works to protect steel against corrosion, **IS: 13620 – 2004, giving specifications of epoxy coated steel bars.**
- Epoxy based chemicals are also used to prevent leakage. Epoxy grout was first used in India in 1968 to seal cracks caused by earthquakes in **Koyna Dam**. Epoxy grout was used to prevent leakage of the **tunnel at Bangalore ISRO**.

2. Polymer and Latex: –

Polymer is an organic compound with high molecular weight. It can be made by combining many small monomers or by removing water from small molecules and cooling it. (E.g. nylon).

Thus, polymers are long molecules made up of a combination of many monomers. The process of combining small molecules is called **polymerization.**

Rubber trees produce natural rubber (latex) in the presence of sunlight. If the rubber is manufactured in a factory, it is called synthetic rubber.

Polymer is available in the following forms:

- Polymer latexes
- Redispersible polymer powders,
- Water soluble polymer
- Liquid resins,

Well-known polymers used in construction are as follows:

- Styrene Butadiene Rubber (SBR)
- Styrene Acrylic Ester (SAE) derived from acrylic acid and resins

3. Acrylic Polymer:

Acrylic is created from acrylic acid. It is one special type of polymer.

Acrylic polymer emulsions are water-based polymers that can be produced from methyl methacrylate, butyl acrylate, 2-Ethylhexyl acrylate, acrylic acid, methyl acrylate, etc.

4. Polyester Resins:

Polyester is one type of polymer. In which monomer units are joint with Coo-group. It's used to make the polymer resins.

cracking of concrete due to different reasons.

Major Reasons of Cracks in Concrete Construction

The crack in concrete construction can be a major issue. It can be prevented by taking the right measure well in advance.

There are various reasons for which cracks can be developed in concrete construction.

Causes for which Cracks developed in Concrete Structures

- **Quality of Concrete** – Quality of concrete depends upon its material. Therefore, it is needed to use only **best quality construction material** that reduces the risk of Cracks.
- **Temperature Fluctuation** – During the contraction materials heated up and gradually it cools down. This expansion and contraction with temperature change takes place of all structures cross sectional area.
- **Creep Movement** – If any slope is covered with loose it causes slow downward movement within. With the modern technologies frost heaving gets implemented to restrain cracks.
- **Moisture** – In construction due to differences in vapor pressure moisture movement happens in between moves through a porous medium. This movement affects concrete and result cracks.
- **Reinforcement Corrosion** – In due course of time it is natural to develop corrosion in reinforcement due to atmospheric reaction to it. There are other reasons to it too – Carbonation, High Chloride, Moisture reaction, Lack of proper measure during storage.
- **Maintenance** – If the proper care is not taken time to time then due to lack of maintenance can be another major cause for it.
- **Design** – Poor structural design & specification can be another major cause of it.

Different Types of Cracks in Concrete Structure

Plastic Settlement Cracking

At initial level when the concrete mix is not solid during that time this type of cracks form at the surface. After some hours of placement only it can be identified.

How to Prevent Plastic Settlement Cracking?

There are few ways that can prevent this type of Cracks in Concrete.

- By using High Quality Concrete Mix
- Using Shrinkage Compensating Admixture into Concrete Mix
- Controlling the vibration during construction
- Re-vibration of concrete after they are formed

Plastic Settlement cracking is a common error but it can be eliminated if the points mentioned above are followed properly.

Thermal Contraction Cracking

Thermal Cracking causes for massive temperature deviation in mass concrete. It appears on surface level after few days of formwork.

How to Prevent Thermal Contraction Cracking?

Thermal Cracking happens due to huge difference between the maximum temperature and minimum temperature range that occurs in concrete. The Designer and Contractors are mainly responsible to minimize this type of cracking by following the specifications limits and doing the temperature control on time.

- Usage of Port land Cement that generates relatively low heat.
- Avoid specifying an excessively low w/cm (water-cementitious materials ratio)
- Thermal Control measures has to be decided before starting the construction
- Using the cooling pipes if necessary during the cooling process.

Drying Shrinkage Cracking

Drying Shrinkage mainly occur for usage of more water in concrete mix. It can be reduce during the design stage:

How to Prevent Drying Shrinkage Cracking?

Drying Shrinkage Cracking can be reduced during the design stage.

- Provide sufficient movement joints
- Sufficient Crack Control Reinforcement can also reduce this type of cracking in concrete
- During the placement avoid adding additional water to the mix

Reinforcement Corrosion

Reinforcement bars are the main component that strengthens the structure because of superior bonding with concrete. Corrosion of TMT Rebar can be one of main issue if that is not taken care on time.

How to Prevent Reinforcement Corrosion?

Reinforcement corrosion can be one of the major issues that cause cracking to the structure. There are some methods that can stop developing corrosion in reinforced steel that are:

- **Anti-Corrosion Coating on TMT Rebars** before applying it to the construction site
- Corrosion Inhibitor Admixtures
- Cathodic Protection

But above all 2 things are most important to prevent corrosion. Water penetration and choosing the **best quality TMT Bar** those are highly corrosion resistant.

These are the major reason to develop cracks in concrete structure. It is important to take the precaution before it goes wrong. It is important to use only **best quality construction material** that strengthen the structure forever.

Reasons Why Concrete Cracks

1. **Excess water in the mix** – A common malpractice when treating concrete is adding excess water to the concrete mix. Concrete needs a certain capacity of water to strengthen its core, but anything above the standard limit causes more harm than good. When this excess water evaporates from the concrete, it leads to further shrinkage. It's best that your construction team is aware of the exact proportions of water and concrete to be mixed.
2. **Rapid drying of the concrete** – While excess water causes harm to concrete, so does rapid drying. This drying then leads to excess evaporation of water from the surface, leading to map cracking. While this usually affects the aesthetics of the structure, if not controlled, it can affect the deeper layers leading to cracks within the building. A process called curing usually prevents rapid drying. Here moisture levels in concrete are regulated by adding proportionate amounts of water.
3. **Improper strength concrete poured on the job** – Every structure needs a certain weight-bearing capacity. From skyscrapers to small houses – every building has a different requirement for concrete. This concrete often comes in a range of different 'strength capacities'. A common error is to use a lower or higher grade strength concrete without matching it with the structural requirements of the building. This then leads to cracks and eventual damage.
4. **Lack of control joints** – Control joints are used in concrete to strategize the cracks. These joints are placed in areas where temperature, shrinkage, and other factors will lead to cracks. This gives the builders control over deciding where the concrete will crack while minimizing damage. When these control joints are missing, the concrete will crack in fragments that will cause heavy damage.

Types of Cracks in Concrete

Concert develops cracks because of varied reasons and each such crack can be identified because of its unique characteristics. In this section, we will explore more about the types of cracks in concrete and what each type indicates. Identifying the causes of cracks can help you think of preventative steps.

1. **Cracks caused by deformation** – There are many forces that act upon concrete. The most common are tensile, compressive, and shear forces. It is because of these forces that deformation occurs, which leads to cracking. To identify such cracks, you must see the geometry of the crack. For instance, parallel cracks are caused due to compression, whereas perpendicular cracks are caused due to applied forces or tensile forces.

2. **Cracks caused by hydraulic shrinkage** – The process of hardening often causes exposed concrete to shrink. This shrinkage is a natural phenomenon. Yet when the forces of this shrinkage become greater than the concrete's inherent strength, it causes deformation. These cracks are usually seen in concrete joints or in areas where reinforcements were done.
3. **Cracks caused by thermal shrinkage** – Cracks due to thermal shrinkage are often seen in large structures. Here, as the name thermal suggests, the variation in temperature leads to deformations. As we know, concrete undergoes a drying process where the heat usually dissipates. Sometimes when there is an unequal distribution of heat in the structure, it causes cracks to occur.
4. **Cracks caused by swelling** – Concrete can swell due to multiple reasons. The most common ones are presence of sulfates presence in the earth. Apart from that, freezing of water in the concrete leads to an expansion of the entire concrete. Oxidation is another reason for the swelling of concrete. These all lead to one occurrence – an increase in internal tensile force which reduces the strength of concrete.

Cracks caused by corrosion of the steel reinforcement – TMT bars are often used to strengthen concrete. When these TMT rebars corrode over time, it leads to development of cracks in the concrete structure.

How to Limit the Cracking Phenomena?

You can prevent the different types of cracking in concrete by following a few simple but effective methods. Let's explore these reasons in depth in this section.

1. **Start with a sound subgrade** – When overlaying concrete with other elements, it's essential to ensure the 2 elements layer and bond properly. This is what's known as a sound subgrade. If these aren't layered well, then the material will detach from the concrete, leaving it exposed to wear and tear.

2. **Modify the concrete mix –** Understand the proportions of water you need before adding it to the concrete mix. Consult the manufacturer, who will accurately inform you about the right proportions to be added. If the mix is smooth, it means you have added enough water. In case you feel the mix is crumbly, then add more water. Keeping this simple trick in mind can help prevent damage.

3. **Install Steel Joints** – Add steel joints in potential crack areas. This will help control the cracks and also minimize the damage caused due to them. With this method in place, the cracks will be restricted to vulnerable areas instead of the whole slab.

Properly cure the concrete – Constant hydration of the slab will help curb the rapid drying due to evaporation. Besides adding water, curing also involves covering the concrete with cotton mats soaked in water. This process, if carried out properly, will cause fewer deformations and cracks.

Key Takeaway

Concrete forms the spine of any structure and needs to be well protected. As covered in the article, this can be done right at the initial stage by strengthening the concrete with strong raw materials and processes. Sree Metaliks Limited offers just these materials that will strengthen your concrete structures and safeguard them for years to come. The brand is a renowned name in the construction industry and offers quality products at an affordable range. So, if you want your structures to remain strong, then invest in right materials.

Defects in Construction: How to Identify and Avoid Them

Construction defects are common, though most defects are minor and fairly inconsequential. However, the most dangerous defects could risk damage to either people or the property itself.

Regardless of whether a defect is major or minor in nature, a problem remains: defects typically aren't discovered until long after completion of the work, and defending against defect claims is a tall (and expensive) task.

Table of Contents

What Is a Construction Defect?

Generally, construction defects refer to a deficiency in the construction process – be that in design, materials, or workmanship – which leads to a failure in some aspect of the structure being built, and that causes damage to a person or property (financial or otherwise). To put it another way, a construction defect must include all 3 of the following:

- a deficiency in the construction process itself (resulting from poor design, materials, or workmanship);
- the deficiency must lead to a failure in the structure (that’s being built during the project);
- that failure must cause damage to a person or property (financial damages or otherwise.

Sometimes, a defect might be as simple as falling short of an owner’s expectations. Other times, it could be as serious as a structural defect in the property. Obviously, construction defects and the resulting fallout will vary greatly based on the source and severity of the issue at hand.

What are the Main Types of Construction Defects?

After distinguishing the ***type*** of construction defect, they're commonly classified as being either a patent or latent. Patent defects are those that are known or readily obvious upon inspection. They're the ones that a contractor, sub, or other trade *should* find during normal inspections. Latent defects, on the other hand, are those that are concealed or otherwise not readily observable. Latent defects probably won't be found even by someone who inspects the work pretty thoroughly.

Patent defects are obvious – and often, that means there's an easy fix. These defects are surface-level, and often merely aesthetic, so accessing and repairing the issue is typically not that invasive. On the other hand, since latent defects aren't obvious, that usually means they're below the surface or even a defective system in the guts of a project. As a result, latent defects tend to be a little more problematic.

Let's break down the **big three construction defect types** a bit more:

Design Defects

These defects result from a design professional's failure to produce accurate and well-organised construction documents. Design defects occur by error or omission. Errors usually require some sort of redesign and replacement of a component part, while omission can be remedied by adding to a contractor's scope of work through **change orders**.

Material Defects

Defects that arise due to damaged or inadequate building material are called "material defects". When these defects come from the manufacturer, the parties using these materials usually won't become aware of the defect until after they've already been incorporated into the project. This makes material defects particularly expensive because they may require additional labour and new materials.

Workmanship Defects

When people think of construction defects, typically, workmanship defects are what come to mind. These defects occur when a contractor fails to build a structure or component part in accordance with the construction documents. Workmanship defects can range from simple aesthetic issues to structural integrity problems. Allocating liability and determining how (and even *who*) failed to abide by the property standard of care can be extremely complex.

What Is “Standard of Care?”

Every project participant needs to perform their contractual obligations up to a designated “standard of care”. This means their work should be done in accordance with all of the contract and design documents. For example, the AIA **general conditions** require a contractor to:

- visit the site to become familiar with the local conditions;
- review the contract documents to facilitate coordination onsite;
- to perform work in accordance with the acceptable **standards of workmanship.**

How Does Construction Defects Litigation Work?

The biggest problem with construction defects is the amount of litigation involved. Construction defect litigation is a long, complex, and costly process – not unlike other types of **construction litigation**. Depending on the defect, a lawsuit can include numerous defendants, varying insurance policy coverages, anti-indemnity statutes, and fact-intensive discovery procedures. Basically, construction defects litigation is *great*… for the bottom lines of **construction lawyers**, but it can be a nightmare for the construction businesses themselves.

Determining Damages

If you’re sued based on an alleged construction defect, not only do you have to pay to defend *yourself*, but you might also be on the hook for any number of damages. Determining the scope of damages is particularly challenging, because of the number of factors that can affect the award. For instance: *what was the extent of the damage?* The court can include the cost of repairs, the decline in property value, loss of use, court costs, and, in some cases, even punitive damages (if gross negligence or recklessness was present). If there are multiple defendants, then the court will need to determine how to spread liability amongst everyone.

Timeline to File Suit

The other challenge with construction defect litigation is *time*. Most defects are discovered long after the completion of a project. Whether a lawsuit can be filed once the defect is discovered will be determined by the state’s statute of repose. It’s similar

to a statute of limitations, which limits the amount of time someone has to file a lawsuit. However, a statute of repose works a little differently.
Instead of starting the clock when the "harm" occurred, it starts at a particular event (typically the project completion date). Depending on your state, this timeline can be as short as 4 years or as long as 20 years! Construction businesses could find themselves defending a lawsuit from a project that's been long since closed in their books. Gathering all the documentation required to prove your case could prove tricky.

How to Minimise Construction Defects – and Their Impact

Everyone on a project is responsible for minimising construction defects. There are proactive measures everyone can take to decrease the chance of encountering one.

Review the Contract Terms and Policy Coverage

With so many people involved on a project, there are a lot of places where blame could land. For all project stakeholders (designers, contractors, subs, and suppliers, etc.), the contract should clearly assign accountability and confirm that everyone is responsible for their own work. Also keep an eye out for provisions concerning responsibilities, liabilities, and any risk-shifting language. A clear understanding of your liability coverage will also help minimise your exposure to defect claims. Plus, it's a good idea to confirm that everyone else on the project has sufficient coverage as well.

Implement Quality Control Programs

Involve all the project participants early on and form some sort of quality assurance group. Everyone is ultimately responsible for avoiding defects, so this should be a collaborative effort. This group should meet regularly, review plans and make occasional site assessments. Speaking of site assessments, another helpful tool to avoid defects is a solid **daily report** system in place. Conducting daily inspections of the work and materials can help detect issues early on. Furthermore, keeping these well documented and organised can assist you later on when an old project presents a defect claim.

Act Quickly

If a defect is discovered, perform a walk-through. Determine what the issue is and present it to the owner, contractor, or management team as soon as possible. Then you can decide how to proceed in the most cost-effective way. Having a quality control program provides an opportunity to repair the defective work prior to completion, which can reduce monetary damages and prevent future litigation.

Construction defects can quickly turn a project upside down, and, with so many parties working on the job, they're not always easy to identify or manage. Everyone involved with a project – from both the design team *and* the construction team – must do their part to avoid defects. Quality control programs, communication, and documentation are an easy, yet effective way to minimise defective work which can help both your bottom line and your reputation.