ज्ञान ज्योति से मार्गदर्शन
To Beam As A Beacon of Knowledge

CONCRETE TECHNOLOGY



November 2024

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING
PUNE 411 001

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FOREWORD TO THE THIRD EDITION

A lot of new developments have taken place in the field of Concrete Technology in last 10 years. Use of mineral and chemical admixtures, RMC etc have transformed concrete production manifold. Revisions have been issued in various BIS codes related to concrete work. BIS codes for Cement and Design mix have been revised with added provisions. Also, the need was felt to include provisions of IRS Concrete Bridge Code in the book, which are relevant for Railway Bridge Construction. Many references, relevant to the subject, have also been included.

In view of all these developments, the book on "Concrete Technology" has been thoroughly revised, incorporating the latest provisions of IRS Concrete Bridge Code and various BIS codes.

I hope this third edition of book will be a useful source of information and knowledge in the field of'Concrete Technology' for field engineers, dealing with concrete for bridge and Building construction activities.

Pune
November, 2024

Sunil Kumar Jha
Director General,
IRICEN, Pune

PREFACE TO THE THIRD EDITION

The second edition of book "Concrete Technology" was published in January-2014. In last 10 years, there were a lot of new developments in the field of Concrete production, quality control etc. Therefore, the need was felt to revise the book, incorporating all the new updates.

It is seen that many revisions/ amendments have been effected in BIS codes. IS:269:Code of cement has been revised with introduction of new cement grades such as 43S and 53S. IS:456 has also issued amendments on concrete grades and acceptance criteria. BIS code for concrete mix design i.e. IS: 10262 was revised in 2019. All these changes have been included in the relevant chapters of this book.

Many provisions of IRS Concrete Bridge code, which are applicable for bridge constructions in Railways, were left out in earlier editions. Now they have been included, to make the book more relevant for Railway field Engineers, dealing with the concrete production for bridge works.

Use of mineral admixtures and chemical admixtures with cement has increased significantly in last 2 decades. Use of cement with mineral admixtures has increased from 20% to 70% and it has now been widely accepted as part replacement of OPC. Its properties and performance on quality front have been elaborated.

High performance concrete and detailing of its use of chemical admixtures in it, has been elaborated. PCE based High Range Water Reducing Admixtures and other modern developments in the field of chemical admixtures, have been included in the book, with the provisions of Concrete Bridge code and BIS codes.

Use of various concrete mixers, provisions of IS: 1791 and testing procedure of cubes have been detailed for more clarity for field engineers. Introduction to Ultra

High Performance Concrete and extracts of RDSO BS-136 report, have also been included in the book.

All efforts have been made to make this edition more useful for the readers. Although care has been taken to include details as per references, still there may be some errors and omissions. We shall be grateful to the readers, for their suggestions, which may be sent to IRICEN at **mail@iricen.railnet.gov.in**. This will be helpful in further refinement and rectification of errors/ omissions.

Lastly, we are thankful to Shri Sunil Kumar Jha, Director General, IRICEN for his encouragement and guidance, in bringing out this revised publication.

Pune
November, 2024

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FOREWORD TO THE FIRST EDITION

Concrete has become the most popular construction material. Even common people have started using concrete in a big way. Its popularity and ease with which it can be prepared, has led to many innovations in the field of concrete. Now the words 'High Performance Concrete', 'Ready Mix Concrete', 'Self Compacting Concrete' are commonly heard not only among the civil engineering community but common people also. With so much of awareness about concrete all around, there is a need that civil engineers should be more aware and informed about concrete technology. They should keep themselves abreast with the latest developments, new technological advances and future prospects.

This book is an effort in this direction, in which the latest developments have been described in addition to the basic concrete technology. This book will be quite handy for the officers engaged in concrete works and others in general too. Though a large number of books on this subject are available in the market, yet what makes this book stand out is that it has been written in a concise manner for better assimilation. I hope this book written by Shri Ghansham Bansal, Professor (Bridges) of this Institute will be very useful for the Railway officers.

Although every effort has been made to present the book in error free manner, yet if there is any suggestion or discrepancy, kindly do write to us.

Pune
October, 2007

Shiv Kumar
Director
IRICEN, Pune

ACKNOWLEDGEMENT TO THE FIRST EDITION

With the invention of cement, there has been a revolution in the field of construction. The popularity graph of this material is ever rising since then. Concrete has travelled a long path and reached a stage where it is not sufficient to call it only concrete, but has to be mentioned with some or the other characteristics like 'High Performance', 'Ready Mix' or 'Self Compacting', etc.

With so much development all around, the engineers can't afford to be ignorant of the latest developments in the field of concrete. With this intention in mind, this book was conceived which should not only give the basic knowledge about concrete, but also should incorporate the latest technological advancements in this area. An effort has been made to make this book crisp and concise so as not to be read as a text book.

I am thankful to Shri Shiv Kumar, Director/IRICEN for constant inspiration and for his valuable guidance. I am thankful to Shri Ganesh Srinivasan, PS for prompt and accurate typing work, Shri Sunil Pophale, SE/Drg. for drawing neat figures. I am also thankful to my family members for their support and encouragement.

Suggestions are invited to make the book better.

Pune
October, 2007

Ghansham Bansal
Professor/Bridges
IRICEN, Pune

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CHAPTER 1
GENERAL

Introduction

Concrete is the most commonly used manmade construction material. It has become very popular not only among civil engineers but among common people also. The secret of its popularity lies in the simple fact that except cement, all other ingredients of concrete are commonly available local materials like aggregate and water. Therefore, it is no surprise that the concrete is being used as a construction material from small pavements to run-ways and express-ways, from small hutments to multi- storied buildings and from small culverts to long multi span bridges.

Developments in Concrete

Popularity of concrete has resulted into many developments and innovations in this field. Earlier we were thinking of M-20 grade concrete only; today we are producing well above M-100. Earlier we were struggling for normal concrete; now we are producing concrete with new characteristics i.e. High Performance Concrete (HPC), Ready Mixed Concrete (RMC), Self-Compacting Concrete (SCC), Ultra High Performance Concrete etc. In the same way, earlier we were using 'Ordinary Portland Cement' (OPC) only, today we are using 'Cementitious' material instead, which is OPC blended with Pozzolanic fly-ash, Ground Granulated Blast Furnace Slag and Micro Silica. Earlier we knew only about the conventional ingredients of concrete like cement, aggregate and water, but today we are well conversant with the importance of admixtures too.

This progress has been possible in the field of concrete because we have accepted concrete as an ideal construction material.

There has been a continuous improvement in the method of concrete production called 'process'. Today we have become more aware about selection of materials and their proportioning. We have now understood the importance of quality control in 'compaction' and 'curing' of concrete and therefore implemented these in the actual structures too. There has been a marked difference in the concrete quality as a result of this awareness.

There was a time when we used to give importance only to the compressive strength of concrete. But today we know that durability is also an important parameter in addition to compressive strength. In fact,

durability is nothing but the long term guarantee for the serviceability of the structure including its compressive strength. The service life of a structure depends upon durability which depends upon various factors such as water-cement (w/c) ratio, compaction and curing. Water-cement ratio should be kept minimum and compaction and curing should be ensured to the fullest extent so as to reduce the permeability and increase the durability.

A concept of concrete which has significantly improved the quality of concrete is 'Ready Mix Concrete' (RMC). RMC is manufactured in controlled conditions at batching plants, where it has to pass through the strictest quality control measures. Then it is transported to the destination through Transit Truck Mixers ensuring the required workability.

Continuing the series of improvements in the quality of concrete, we have developed a new category of concrete called 'Self Compacting Concrete' (SCC). This was originally developed in Japan due to shortage of manpower. But its use has proved to be a boon for the construction industry because it has come out as the most modern type of concrete. No vibration is required for the compaction of this concrete and the concrete automatically flows into the formwork. Since it flows like fluid, it can easily reach every nook and corner of the formwork and the full compaction is ensured automatically. This results into not only the higher compressive strength but drastic increase in durability also. In order to increase the durability of concrete, we have also started the use of blended cement in place of normal OPC. The blended cement is obtained by adding mineral admixtures like fly-ash, slag and silica fumes to OPC. Micro Silica or Silica Fume has a major role to play in the manufacturing of High Performance Concrete (HPC). Its fineness is much higher as compared to OPC so that it can penetrate into the micro spaces of the concrete resulting into a highly compact mass with very little permeability. This results into high cube strength as well as improved durability of concrete.

As a result of many developments and improvements in the concrete technology, we have come a long way in production of concrete and concrete has eventually been established as a reliable construction material.

Production of concrete

The production of concrete involves two distinct but equally important activities. One is related to 'material' required for concrete and the other 'process' involved in its production.

Material

The activity related to materials involves their-

(1) Selection and

(2) Proportioning

Process

The activity related to process involves :

(1) Mixing

(2) Transportation

(3) Placement

(4) Compaction and

(5) Curing

Out of above activities, more often than not, it is the 'process' which is responsible for quality of the concrete, though the cost of the concrete is mainly governed by the cost of the materials. The selection of materials and their proportioning is usually well taken care of at higher levels but the process is left to the lower levels. The expenditure incurred on materials goes waste if the process is not taken care of. Ignorance and lack of appreciation of good practices are the main reasons for the poor quality of concrete. Therefore, if we are able to control the process, we can obtain far better quality of concrete at no extra expenditure.

Ingredients of concrete

The basic ingredients of concrete are as given below:

1. **Cement -** It is the most important and costliest ingredient of concrete. The mix-design of concrete indirectly means optimising the use of cement for obtaining the desired properties of concrete in fresh as well as in hardened state. It affects the overall economy of the structure too. Different types of cements are available for different type of structures with different use and exposure conditions. Judicious selection of cement is necessary for the longevity of the structure.

   Cement may be OPC or any other cementitious material mixed with OPC. As per clause 2.1 of Concrete Bridge Code, Cementitious Material means cement or cement mixed with mineral admixtures like Pozzolanic Fly Ash (PFA), Ground Granulated Blast Furnace Slag (GGBFS), micro silica etc.

2. **Aggregate -** The aggregates give volume to the concrete because these occupy maximum space in the total volume of concrete. Efforts should be made to use maximum quantity of aggregates

as they increase the volumetric stability of concrete and make the mix-design more economical.

3. **Water -** It is indispensable because it is required for reaction of hydration. But its use should be restricted to minimum possible considering the requirement for chemical reaction with cement and workability. Any excess water is destined for evaporation, leaving capillary pores in the concrete. Eventually, strength and durability both will be adversely affected when water is excessive.

4. **Admixture -** It is an optional ingredient which is used only for some specific purpose. It is used to modify some of the properties of concrete like setting time, workability or surface finishing characteristics. But admixture should not be used to compensate the bad quality of concrete, instead it should be used as a supplement to good construction practices. In the newer versions of concrete i.e. HPC, RMC and SCC, the use of admixtures has become indispensable.

All these ingredients are explained in the following chapters in greater details.

***

CHAPTER 2
CEMENT

History of Cement

In general, cement is described as a material used to bind the mineral fragments called aggregates. The cement paste acts as glue which makes a cohesive mass with all the aggregates. This bonding is very important as the concrete normally fails not because of less strength of aggregates but mainly due to failure of bonding.

Production of cement is only a recent development. It was conceived in 1824 by William Aspidin, but it was developed in the form of present day cement by Isaac Charles Johnson in 1845. He produced this modern cement by burning a mixture of chalk, clay and silica up to a temperature of 1400-1450^{o}C. At this temperature, the basic raw materials i.e. lime, clay and silica fuse together forming 'clinkers' in the shape of spherical balls of 3 to 25 mm in diameter. Due to high temperature, approximately 20-30% of the material becomes liquid and crystallises into spherical balls on cooling.

The cement may be a recent development, but the use of cementing material is quite old. Lime and gypsum were used in as early as 2500 BC by the Egyptians in making Great Pyramids. Similarly, the Greek and the Romans also used calcined lime stone. The basic raw materials of these cementing materials were the same as of today's cement but the only difference is the temperature up to which these are heated. Prior to production of modern cement, a temperature of 1400-1450^{o}C was not heard of and the ingredients used to be mixed at atmospheric temperature.

The cement was produced as a product by combining lime with volcanic ash containing active silica and aluminium, at normal temperature. This product was known as 'pozzolanic cement' because the volcanic ash used in this was obtained from a village called 'Pozzuoli'.

Present day cement is called 'Hydraulic Cement' by virtue of its property of setting and hardening even under water.

Composition of modern cement

The modern cement is also called 'Ordinary Portland Cement' because after setting, it resembles in colour and quality with the 'Portland Stone' quarried in Portland (Dorset)-UK.

Portland cement primarily consists of

(1) Calcareous material : Limestone or chalk

(2) Silicious material : Silica

(3) Argillaceous material : Clay/Shale

The process of manufacturing of cement essentially involves the following activities:

a) Proportioning of raw material,

b) Grinding, intimate mixing and

c) Burning in a large rotary kiln at 1400-1450°C.

Due to intense heat, 20 to 30% of material fuses together forming spherical balls known as 'clinkers'. The 'clinker' is only one step short of cement. The cement is obtained by grinding the clinkers up to the desired fineness.

The raw material is always available in the form of oxides in nature. Oxide and compound composition of a typical Portland cement is given in Table – 1 & 2.

Table-1

(Source : Properties of concrete by A M Neville)

Oxide	Percent
Calcium Oxide (CaO)	63%
Silica Oxide (SiO_2)	20%
Aluminium Oxide (Al_2O_3)	6%
Ferric Oxide (Fe_2O_3)	3%
Magnesia (MgO)	1.5%
SO_3	2%
K_2O	1%
Na_2O	

When the raw material is heated in the kiln, the oxides get converted into silicates and aluminates in addition to some other compounds. The percentages of all important compounds in a typical portland cement are as given in Table-2.

Table-2

(Source : Properties of Concrete by A.M. Neville)

Compound	Short form	Chemical Formula	% age
Tri-calcium Silicate	C_3S	$3CaO.SiO_2$	54.1%
Di-calcium Silicate	C_2S	$2CaO.SiO_2$	16.6%
Tri-calcium Aluminate	C_3A	$3CaO.Al_2O_3$	10.8%
Tetra-calcium Alumino Ferrite	C_4AF	$4CaO.Al_2O_3.Fe_2O_3$	9.1%

Out of the above compounds, the strength of cement is contributed mainly by silicates. Silicates react with water and produce a gel called Calcium Silicate Hydrate or 'C-S-H' gel. This gel is initially weak and porous, but with the passage of time it becomes stronger and less porous. Since it is an exothermic reaction, a lot of heat is generated. The chemical reaction involved in this process is as under.

$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH + 114$ KJ/mole

(61%) (39%)

$2C_2S + 4H \rightarrow C_3S_2H_3 + CH + 43$ KJ/mole

(82%) (18%)

where

C = CaO

S = SiO_2

H = H_2O

CH = $Ca(OH)_2$

This reaction of cement with water is called 'reaction of hydration'. As a result of this reaction, the silicates produce gel. But Di-calcium Silicate (C_2S) is considered superior as compared to Tri-calcium Silicate (C_3S) because it produces superior and large quantity of C-S-H gel. C_3S produces only 61% of C-S-H gel and 39% CH, but C_2S produces 82% of Calcium Silicate Hydrate C-S-H gel and only 18% of CH. In addition to this, the heat generated is also less in case of Di-calcium Silicate. Less heat means fewer thermal cracks and more durable concrete. CH occupies the space in produced concrete mass and may lead to various ill effects in concrete like carbonation, leaching or adding to porosity. Hence less CH is desirable.

Initially when the gel is porous, the pores are completely filled-up with water. About 15% water by weight of cement is required to fill up the gel pores and it is called 'gel water'. In addition to this 23% extra water

is required for continuing the chemical reaction which is called 'bound water'. Therefore, theoretically speaking, the total requirement of water should not exceed 38% in normal concrete.

Any extra water causes capillary formation in the concrete which increases the permeability of concrete. If only 38% water is added to the concrete, no extra water will be available for capillary formation and therefore concrete will be more compact, stronger and more durable.

The extent of reaction of cement with water is called 'degree of hydration'. Since the reaction is associated with evolution of heat, the degree of hydration can indirectly be estimated by measuring the heat evolved during the reaction. Approximately 50% of the total heat evolution occurs during the first 3 days of hydration and a continuous record of liberation of heat during this period is a very useful indicator for estimation of strength gain.

In the total volume of cement paste, about 50-60% volume is occupied by C-S-H gel, 20-25% by $Ca(OH)_2$ and the rest by water, pores etc.

Analysis of Reaction

A schematic diagram showing the cement compounds and reaction with water is shown in Figure- 1.

Basic elements of cement

Ca	O_2	Si	Al	Fe

Oxides of Elements

CaO	SiO_2	Al_2O_3	Fe_2O_3

Cement Compounds

C_3S	C_2S	C_3A	C_4AF

Reaction of cement with water

C-S-H gel	$Ca(OH)_2$	Heat

Figure - 1 : Reaction of cement with water

Strength of cement is mainly contributed by silicates i.e. C_3S and C_2S, whereas C_3A is responsible for setting. In the order of reaction with water, C_3A is the first to react with it and imparts setting to the cement paste. Strength contribution by C_3A is negligible and therefore can very well be neglected. In the category of silicates, C_3S is quicker in reacting with water as compared to C_2S. Therefore, the initial strength up to 7

days is mainly given by C_3S. After 7 days when most of C_3S is exhausted, C_2S also start reacting with water. The strength between 7 and 28 days is contributed mainly by C_2S and a part is contributed by C_3S too.

Hydration of various compounds

1) Hydration of Silicates

Since the heat of hydration is proportional to the rate of hydration reaction, initially most of the heat is generated by C_3S. As described in earlier paras, although the products of reaction are same in both the cases, i.e. C-S-H gel and $Ca(OH)_2$, yet quality wise, C_2S is considered superior to C_3S because it requires less water for reaction and produces more C-S-H, less $Ca(OH)_2$ and less heat. All the four parameters are favourable for good quality of concrete in C_2S as compared to C_3S. The C_3S requires 24% water by weight of cement whereas C_2S requires only 21% water for complete hydration. In addition to this, the density and the quality of gel formed by C_2S is also superior. Therefore, higher percentage of C_2S is desirable in cement.

2) Hydration of C_3A

C_3A reacts very fast with water forming a compound C_3AH_6 which triggers flash set in the cement. Since it is not desirable that cement should set immediately, the quantity of C_3A in the cement has to be controlled. For this purpose, gypsum is generally added at the time of grinding of clinkers. Hydrated Calcium Aluminate (C_3AH_6) doesn't contribute anything to the strength of cement.

3) Hydration of C_4AF

C_4AF is a minor constituent of cement which reacts with water and produce C_3FH_6 or Hydrated Calcium Ferrite. Its volume is insignificant and it doesn't contribute to strength. C_4AF acts as a flux in cement making and helps in reduction of melting temperature of silica from 1650^oC or so to 1400^oC or so.

Reaction of Hydration and Gain of Strength

The major portion of the strength of cement is achieved during first three weeks after casting, however the process continues for ever. It has been found from the experimental studies that the full strength potential of cement is never achieved because the hydration process never gets completed in reality. In fact, after initial reaction with cement particles, the water is not readily accessible to some of the particles of C_3S & C_2S which get surrounded by a layer of already hydrated silicates. These hydrated silicates are relatively impervious to water and therefore come in the way of some particles of cement and renders

further reaction slow. It is very much possible that even less reactive C_2S crystals present on the surface of a cement grain may get hydrated first and a more reactive C_3S crystals buried in the interiors of a cement grain may hydrate late or may not get hydrated at all.

Therefore, in practice, the full strength potential of cement is never utilised, and therefore the water requirement will also be proportionately less than 38% for the reaction. But in most of the cases, the requirement of water is guided by the requirement of workability and not by the chemical reaction.

Different types of cement

Same type of cement may not be suitable for different locations and climatic conditions. Therefore, various types of cement have been developed as per the actual requirements. The necessary changes have been achieved by different methods like :

(a) Changing oxide composition

(b) Changing fineness

(c) Using additives or mineral mixtures like slag, fly-ash or silica fumes etc.

Different types of cement should not be mixed. If more than one cement type is used (e.g., OPC 53 Grade, OPC 43 Grade, PPC, or others), a record shall be kept showing the location of use.

CBC (Concrete Bridge Code) specifies that cement shall be used with the prior approval of Engineer.

The various types of cements generally used in various locations are as given below:

1. Ordinary Portland Cement (OPC)

OPC is the most commonly produced and used cement. The name 'Portland' was derived from lime stone called 'Portland stone' quarried in Dorset-UK, due to its resemblance with the set cement.

In OPC category, we have five grades of cement available in Indian market (IS 269-2015).

(a) Grade 33

(b) Grade 43

(c) Grade 53

(d) Grade 43 S

(e) Grade 53 S

The numerical value in grade indicates the minimum 28 days compressive strength of cement.

2. Rapid Hardening Cement (RHC) (IS 8041-1990)

It is also called 'Early Strength Cement' because its 3 days strength is almost equal to 7 days strength of OPC. It is different from quick setting cement which only sets quickly whereas in RHC, strength development is very fast. This is because of following reasons:

(1) Higher fineness of cement. The specific surface of this cement is increased to 325 m^2/ kg as compared to 225 m^2/kg for OPC.

(2) Higher quantity of C_3S in cement as compared to C_2S. C_3S is more reactive in comparison to C_2S.

As a result of these changes, the rate of reaction in the early period is considerably increased and so is the heat generated. Therefore, this cement should be used only where the early strength requirement is there. At the same time, it should not be recommended where surface/volume ratio is less and the large heat that will be liberated, may not be dissipated effectively. If it is not ensured then there are chances of temperature cracks.

This cement is recommended:

(1) In pre-fabricated construction

(2) When the form work is to be removed early

(3) In road repair works

(4) In cold weather where heat generation will be helpful in preventing freezing.

3. Sulphate Resistant Cement (SRC) (IS 12230-1988)

The normal OPC is susceptible to sulphate attack – particularly magnesium sulphate. The sulphate present in the soil or surrounding environment reacts with free $Ca(OH)_2$ available in the concrete and $CaSO_4$ is formed. There is no dearth of free $Ca(OH)_2$ as it is available in abundance in the set cement. The $CaSO_4$ thus produced, reacts with hydrate of calcium aluminate and form an expansive compound called Calcium Sulpho Aluminate which causes expansion and cracks in the set cement. Sulphate attack is further accelerated if it is accompanied by alternate wetting and drying also, which normally takes place in marine structures of the tidal zone.

The cement can be made sulphate resistant if quantities of C_3A and C_4AF are controlled as given below :

$C_3A < 5\%$ (Normally it is 8-12% in OPC), and

$3\ C_3A + C_4AF < 25\%$

While controlling the quantities of C_3A and C_4AF, a precaution is to be taken when chloride attack is also perceived in addition to the sulphate attack. In this situation, the quantity of C_3A should be limited to 5-8%. Similarly, when only chloride attack is there and no sulphate attack, then sulphate resistant cement (SRC) should never be used.

The quantity of C_3A in OPC can be controlled by blending it with slag (GGBFS) i.e. slag cement.

SRC is recommended in-

(1) Marine condition where both sulphate and chloride attacks are there

(2) Construction of sewage treatment plants

(3) Foundations and basement in soil having sulphate

(4) Chemical factories

4. Blast Furnace Slag Cement (IS 455 : 2015)

This cement is also known as 'ground granulated blast furnace slag (GGBFS) cement. It is produced by blending OPC clinkers with blast furnace slag in suitable proportion (generally 25-65%) and grinding together. A small quantity of gypsum is also added which acts as a retarder. The slag can be separately grinded and mixed with OPC in the mixer during concreting also. But in the conventional drum mixers, it is difficult to achieve proper mixing. The fineness specified for GGBFS is 320 sq.m/kg minimum (IS 16714 : 2018) and for Slag cement is 225 sq.m/kg minimum (IS 455 : 2015).

The slag is a waste product in the manufacture of steel from open hearth blast furnace. Earlier this waste was thrown outside the plants and huge stacks of slag were lying unused creating disposal problem. It was later found that the constituents of slag were similar to that of cement and the so called 'waste product' was rechristened as 'by-product'. Its extensive use now has resulted in saving of enormous energy and raw material in addition to prevention of pollution.

The only word of caution while using this cement is that the early strength is less as compared to OPC. Therefore, the form-work removal should be adjusted accordingly. The early strength of blended cement is due to OPC fraction and the slag fraction joins in strength contribution later on.

Earlier there was a considerable resistance and suspicion in the minds of the users in using the slag cement mainly because the good quality of slag was not available. In fact, earlier the thrown out air-cooled slag was being used which is not considered of good quality for concrete. Instead of air cooling, if the slag is rapidly cooled by pouring water over it, then the process of crystallisation is prevented and it solidifies as granules. This slag is ideal for cement. That is the reason why it is now called 'granulated slag'.

Physical properties of slag cement are similar to those of OPC in terms of fineness, setting time, soundness and strength etc, but the initial reaction with water is slower due to which the heat of hydration is low. It is a better resistant to sulphate, alkali and acid also.

Recommended use of Slag cement

(a) In sewage disposal works

(b) In water treatment plants

(c) Where low heat cement is required

(d) Where high chloride and sulphate attack is there

Mixing of 50% blast furnacess slag conforming to IS:16714 with OPC cement at the site shall not normally be permitted. However, in exceptional cases for bridges requiring higher levels of durability using blended cement, which is not available from manufacturers, blending at site may be permitted subject to ensuring dedicated facilities and complete mechanized process control to achieve specified quality with the special permission of PCE/CE (Co-ordination) or CAO/C (Clause 4.1.1 of CBC)

5. Portland Pozzolana Cement (PPC) (IS 1489 : Part-1 : 2015)

'Pozzolana' essentially means a silicious material having no cementing properties in itself. But in finely divided form, it reacts with $Ca(OH)_2$ in presence of water at ordinary temperature and forms compounds possessing cementing properties. In this process $Ca(OH)_2$ is also utilised which otherwise is destined to leaching out of concrete leaving a porous and weaker concrete.

The chemical reaction which takes place is as given below:

$2C_3S + 6H \rightarrow C_3S_2H_3 + 3\ CH$

$3CH + 2SiO_2 \rightarrow C_3S_2H_3$

Generally, fly-ash, shale, volcanic ash, opaline, diatomaceous earth etc. are used as Pozzolanas. It is easier to grind together OPC

clinkers with pozzolana than mixing the pozzolana afterwards. Mixing afterwards is difficult because of Pozzolana being finer than cement. Fineness for PPC cement is 300 m^2/kg (Minimum) as compared to 225 m^2/kg for OPC.

Fly-ash is a waste product of thermal plants which is collected by electro-statically precipitating the exhaust fumes of coal-fired power stations. The use of fly-ash is an ecofriendly process as precipitation of fly-ash reduces the pollution. The quality of fly ash is tested as per IS : 3812 (Part-1). The code specifies that percentage of silica plus alumina should be at least 70% and maximum loss on ignition should be 12%. Generally, much better quality is available from power plants as compared to the codal specifications. The obvious advantage of using PPC is that the impermeable and denser concrete is produced by blending OPC with fly-ash.

The early strength of PPC is contributed by OPC fraction and Pozzolana also starts contributing after some time. The strength should normally be not less than 22 MPa in 7 days and not less than 33 MPa in 28 days. Other properties of PPC like soundness, setting time etc. are same as OPC.

Advantages of Pozzolana cement

1. Less heat of hydration
2. Reduced leaching of $Ca(OH)_2$ as it is utilised in reaction with pozzolana.
3. It can be used at almost all the places where OPC is used.

Clause 4.1.1 of CBC stipulates that Portland Pozzolana cement shall not be used for PSC works. When Portland Pozzolana cement is used in plain and reinforced concrete, it is to be ensured that proper damp curing of the concrete is done for at least 14 days, and supporting formwork shall not be removed until the concrete attains at least 75% of the design strength.

6 Air entraining cement

Air is entrained in the concrete in the form of bubbles which modify the properties of fresh concrete i.e. workability, segregation, bleeding and finishing characteristics. It also modifies the properties of hardened concrete i.e. resistance to frost action and permeability. Air bubbles act like flexible ball bearings so that friction between the various ingredients of concrete is reduced and workability is improved without additional water. The desirable air

content is 3-6%. The various air entraining agents used are :

(a) Alkali salts of wood resin

(b) Synthetic detergents

(c) Calcium ligno-sulphate

(d) Aluminium powder, animal fats etc.

These are also available under commercial names such as vinsol resin, airalon, darex, teepol etc. Just for clarity, entrained air is different from entrapped air. The difference between them is given in the Table-3.

Table-3

Difference between entrained and entrapped air

Entrained Air	Entrapped Air
1. Entrained air is intentional and it is distributed evenly	1. Entrapped air is due to insufficient compaction and unevenly distributed.
2. The size of bubbles in entrained air is very small ranging from 5μ to 80μ.	2. The size of entrapped air pockets may vary from 10μ to 1000μ or even bigger.
3. The shape is nearly spherical.	3. Entrapped air may be of any shape as it follows the contours of aggregate surface.
4. It is a desirable process.	4. It is an undesirable inclusion.

Air entraining cement is not so popular in India and it is not elaborated by any of the IS Codes. However, it is being used for project specific requirements since long time. In 1950s, it had been used in some of the very big dams in India like Hirakud dam, Koyna dam and Rihand dam. For these works the air entraining agents like Vinsol and Darex were imported from the USA.

7. Quick Setting Cement

The setting time of ordinary cement is very less if gypsum is not added at the clinkering stage. Therefore, when quick setting cement is required, the gypsum is deliberately added in less quantity or not added at all. This type of cement is useful in flowing water and some typical grouting operations.

8. Expansive Cement

Generally, there is a tendency of shrinkage in green concrete due to drying. Shrinkage is associated with reduction in volume which may cause cracking in the concrete. In these cements, expansive compound like sulpho-aluminate is added. The expansion due to sulpho-aluminate will counter the shrinkage of concrete. This cement is used for repair works where the change in volume is not desirable.

9. High alumina cement

This cement has a very high rate of strength development. In this type of cement, up to 80% of total strength is achieved in one day only. Lime and bauxite are used as raw material for producing this cement. Because of large proportion of bauxite, this cement is called high alumina cement. The rate of heat generation is also proportionately high i.e. 2.5 to 3 times of rapid hardening cement. The form work should be stripped-off as early as possible to prevent built-up of high temperature. This cement is resistant to sulphate attack due to inert quality of alumina gel and absence of $Ca(OH)_2$.

Tests of Cement

Clause no 11(g) of IS:269-2015 stipulates the need for testing of cement more than 3 months old to check conformity before its use.

Normally two types of cement tests are conducted as given below:

A) Field Tests

There are some field checks which give some basic idea about the quality of the cement without elaborate facility of laboratory in the field. These checks are as given under:

(a) Date of manufacture - It is important because the strength of cement may be reduced with age depending upon the storage conditions.

(b) Open the bag and see that lumps should not be present in the bag. It will ensure that no setting has taken place.

(c) Thrust your hand into the cement bag and it should give cool feeling. It indicates that no hydration reaction is taking place in the bag.

(d) Take a pinch of cement between the fingers. It should

give smooth feeling.

(e) Throw handful of cement on water. It should float initially before finally settling.

(f) Take 100 g of cement and make a stiff paste. Prepare a cake with sharp edges and put on the glass plate. Immerse this plate in water. Observe that the shape shouldn't get disturbed while settling. It should be able to set and attain strength. Cement is capable of setting under water also and that is why it is also called 'Hydraulic Cement'.

B) Laboratory tests

Although most of the tests are conducted in the laboratories of producers and a certificate is also provided by the supplier along with the supply, yet some of the tests are also conducted by the user in their own laboratories for confirmation and also to assess the deterioration of strength potential during transit. The various tests which are generally conducted on cement are as given under :

a) Fineness of cement

Fineness of cement determines the rate of hydration reaction. Finer cement reacts faster with water and the rate of development of strength and corresponding heat of hydration is higher. IS Codes prescribe only the values of minimum fineness which are required for different types of cements.

Fineness can be determined either by specific surface using Blains air permeability test or it can be determined by actual sieving as per IS 4031 (Part-I and Part-II). In order to ensure the adequate fineness, 100g of cement is hand sieved through 90μ IS sieve for 15 minutes. The limits of residue on sieve should be as given under

For OPC, < 10%

For PPC, HSPC < 5%

As per IS:269 the minimum specific surface for OPC should be 225 m^2/kg and for PPC, 300 m^2/ kg.

Effect of fineness of cement

(1) Due to increased fineness, the surface area of cement increases and reaction with water becomes quicker.

Therefore, the gain of strength also becomes faster but the ultimate strength remains almost unaffected. This will be clear by observing the trend of relation between specific surface and strength as shown in Figure-2.

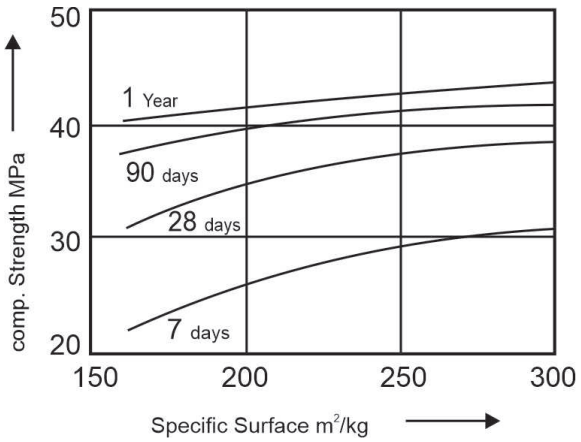


Figure - 2 : Relation between specific surface and strength

From this figure it is evident that 7 days or 28 days strength may be higher for finer cement but 1 year strength is almost same even for higher fineness. In fact, it will be exactly same if we compare the ultimate strength at infinity.

(2) Chance of bleeding reduces in the concrete if finer cement is used.

(3) Shrinkage and cracking in the concrete increases with fineness.

Note: 'Bleeding' is the separation of water from cement paste and 'segregation' means separation of aggregates from the concrete.

b) Standard Consistency Test

This test in itself doesn't give any quality parameter of cement but it ascertains the volume of water which is to be added for other tests like initial setting time, final setting time, soundness and strength etc. 'Vicat's Apparatus' is used for this test as shown in the Figure-3.

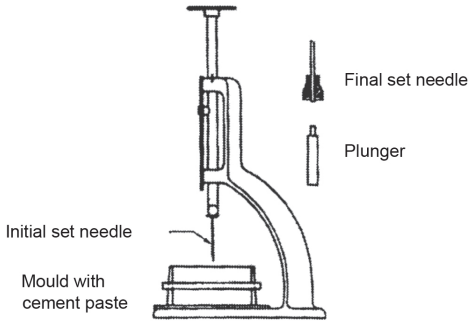


Figure - 3 Vicat's Apparatus

Procedure

About 500 g of cement is taken and paste is made by adding about 24% water by weight of cement. Cement and water are correctly measured before adding because the quantity of water needs to be adjusted to achieve normal consistency of paste.

Within 3 to 5 minutes of adding water at 27$\pm$2^{o}C, the paste is filled in the mould of 80 mm dia and 40 mm height. After keeping the mould in position, the Vicat's plunger of 10 mm dia and 50 mm height is fitted to the apparatus and it is kept in touching position with top of the paste in the mould. Then plunger is quickly released and its penetration in the paste is recorded. The quantity of water is adjusted in such a manner that the penetration achieved becomes 33-35 mm.

The percentage of water by weight of cement which causes the penetration of 33-35 mm is called 'Standard Consistency' and it is designated by 'P'. This value is useful in standardization of other tests of cement as shown in Table-5.

Table-5

S.N.	Test	Addition of water
1.	IST & FST	85% of P
2.	Soundness test	78% of P
3.	Strength test	(P/4)+3 %

c) Setting Time Tests

Setting time means the time required for stiffening of cement paste to a defined consistency. There are two important limits on time scale which are important for setting of cement :

(i) Initial setting time

By definition it is the time from addition of water to a time when the paste starts losing its plasticity. The test is conducted using 'Vicat's apparatus'. A needle of size 1 mm^2 is used for measuring the penetration. 500 g of cement is taken and water equal to 0.85 'P' is added to make paste and the test is conducted at 27±2^{O}C and relative humidity 65±5%. The needle is lowered till it touches the top surface of paste in the mould and then tightened. The needle is then quickly released and penetration is recorded. Initially it may go down and touch the bottom. As the time passes and the paste stiffens, the penetration of the needle will reduce. The test is repeated till such time when the needle is 5 mm (±0.5 mm) above bottom of mould. This time is called 'Initial Setting Time (IST)'. When the test is repeated, the mould should be slightly displaced so that the needle doesn't penetrate at the same location again.

(ii) Final setting time

It is the time from addition of water to the time when paste completely loses its plasticity. The test is conducted with the changed needle. This needle has special attachment such that when the penetration is more than 0.5 mm, there will be two impressions on cement paste, one of main needle and second of a circular cutting edge. But there will be only one impression of main needle when penetration is less than 0.5 mm.

Therefore 'final setting time (FST)' is the time from addition of water to the time when the penetration is just less than 0.5 mm or when the circular cutting edge fails to make an impression on the cement paste.

d) Soundness Test

This test is conducted to find out the presence of excess unburnt lime in the cement. Due to this lime, cracks may develop in the set cement because of increase in volume. When excess lime is present in the raw material, there is a possibility that entire lime may not combine with acidic oxides at the time of burning in the kiln and some free lime may be left in the cement. This free or hard burnt lime hydrates very slowly and some of it will hydrate only when the cement has already set. Due to this delayed hydration of lime, expansion will take place in the set cement as the hydrated lime or $Ca(OH)_2$ occupies more volume as compared to quick lime or CaO. Since no space is available for expansion after setting of cement, this expansion causes cracks in the set cement which is called 'unsoundness' of cement. In fact there may be three main reasons for this excess free lime in the cement as given below :

- Inadequate burning of raw material
- Insufficient grinding of raw material
- Insufficient mixing of raw material

The test to find out the expansion due to free lime will indicate the presence of free lime and limit of expansion will be a guiding factor for the soundness of cement. The cement will be considered 'sound' if the expansion is within the permissible limits otherwise it will indicate 'unsoundness'. The expansion is measured using 'Le Chatelier Apparatus' and it should be limited to 10 mm for cements except for 43S & 53S where this limit is 5 mm.

Test Procedure for soundness test

Step 1: Cement paste with water equal to 0.78 x P (Standard Consistency) by weight of cement is prepared and filled up in the mould. The mould is 30 mm in dia, 30 mm in height and splitted along height. It is provided with a 165 mm length indicator for magnification of expansion as shown in Figure-4. This is called 'Split Brass Cylinder'. After filling the mould, glass plates are put at top as

well as at bottom. Then the assembly is put in water at a temp. of 27±2^{O}C. After 24 hours it is taken out and distance between pointers is recorded at the extreme end. Let it be 'x'. Till now, the free lime present in the cement has not contributed any expansion.

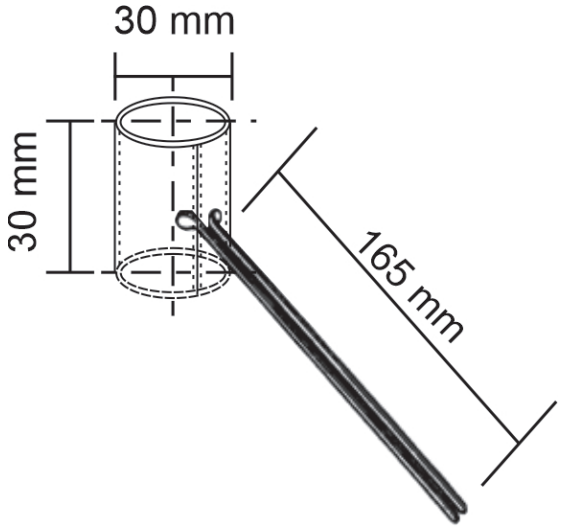


Figure - 4 : Split Brass Cylinder

Step-2: Assembly is again submerged in water and water is heated up to boiling point in about 30 minutes. It is kept in boiling water for 3 hours. Again, distance between pointers is recorded at the extreme end. Let it be 'y' which will be obviously more than 'x' because now expansion due to free lime has occurred due to boiling water. Therefore,

Net expansion due to free lime = y - x

The above test is suitable for detection of expansion due to free lime only. However, expansion in cement can be due to presence of magnesia also. When free lime and magnesia both are present, a test called 'Autoclave Test' is recommended which is explained below :

Autoclave Test

A cement specimen of 25 x 25 mm^2 section and 250 mm length is prepared and cured in humid air for 24 hours. It is then placed in autoclave which is a high-pressure steam-boiler. The temperature is raised to 215.7±1.7^{O}C and steam pressure increased to 2.1 ± 0.01 MPa for approximately 60 to

75 minutes and maintained for 3 hrs. The autoclave is then cooled and the length of the specimen is measured again.

The expansion of bar should not be more than 0.8 %, which indicates that the presence of free lime & magnesia in cement are within the limits.

e) Strength Test

The test is conducted on a cube of cement and sand in the ratio of 1:3. Sand is used to prevent excessive shrinkage. The paste is prepared with 200 g cement, 600 g sand and water (P/4 + 3.0)% of combined weight of cement and sand. The paste is mixed for 3-4 minutes and filled-up in cube moulds of 7.06 cm sides. The moulds are vibrated on a standard vibrating table and then kept for 24 hours at 27 ± 2^{O}C, at 90% relative humidity. Cubes are then taken out and submerged in clean fresh water at 27 ± 2^{O}C and tested after 3, 7 and 28 days. 3 cubes constitute one sample and an average of 3 cubes is taken as compressive strength. 3, 7 and 28 days test strength for different grade of cements have been given in table-3 of IS:269 as given below-

	Strength in N/mm2 (IS: 269, Table-3)				
Age at testing	Grade 33	Grade 43	Grade 43 S	Grade 53	Grade 53 S
72 ± 1 hrs	16	23	23	27	27
168 ± 2 hrs	22	33	37.5	37	37.5
672 ± 4 hrs	33 (min) 48 (max)	43 (min) 58 (max)	43	53	53

f) Loss on Ignition Test

1.0 g of cement is taken on platinum crucible and heated up to a temperature of 900-1000^{O}C for 15 minutes. The loss due to evaporation of moisture and CO_2 causes weight loss which should not be more than 5% for all cements. Moisture and CO_2 are normally present in combination with free lime and magnesia.

Storage of cement

Since cement is hygroscopic is nature, it loses strength with time depending upon its exposure to moisture. Therefore, in order to minimize the loss of strength, the following precautions should be taken while storing the cement in godown.

(1) Godown should be air tight and moisture proof and above the ground level.

(2) Bags should be stacked on raised platform

(3) Different stacks should be made for different cement company, date of manufacture, type and grade of cement. In addition, identification tags should be displayed on each stack showing all above details.

(4) There should be a clearance of about 0.6 m between adjacent stacks and also outer walls and the stacks.

(5) Normally not more than 8-10 bags should be stacked vertically. Up to 15 bags can be permitted temporarily.

Efforts should be made to remove additional bags as early as possible.

(6) During rainy season, the stacks should be covered with suitable polythene sheets.

(7) For general purpose 'First in - First out' policy should be adopted.

Gain of strength in cement

Initially the rate of gain of strength in the cement is very high but it reduces with time. However, the process of strength gain continues forever. The strength gain is faster in the beginning mainly because of the following reasons :

(1) Prompt response of more active constituents

(2) Rapid hydration of finer particles of the cement

(3) Ready availability of a lot of free water

As outer layers start setting, the availability of water reduces for the inner particles and the rate of gain of strength decreases.

Advantages of Blended Cement

Blended cement is obtained by mixing OPC with mineral admixtures or additives like fly-ash, slag or silica fumes. Blended cements are now being considered superior as compared to conventional OPC category of cements. The advantages of using the blended cement can broadly be divided in two categories i.e.

1) Technical advantages and

2) Environmental advantages

Technical advantages

(a) Blended cement generates less heat of hydration, thus reduces risk of thermal cracking and hence it is more suitable for mass concrete works like dams, retaining walls, large foundations, plastering works etc.

(b) Blended cement generally has a lower alkali content than OPC, hence it is better in sulphate resistance.

Environmental advantages

The production of OPC requires a lot of energy and raw material. At the same time a lot of 'green house gases' are emitted during the process, polluting the atmosphere.

Production of cement is an energy intensive activity. Its energy consumption is highest after steel and aluminium production. The energy required for one ton of cement is 4 GJ and at the same time it produces 1 ton of CO_2.

Blending mineral admixtures with OPC is one step in the direction of eliminating both the above problems. In fact, all the mineral admixtures which are used for blending with cement are the waste products of one or the other industrial processes.

As blended cements are obtained by adding mineral admixtures with OPC, the energy, which would have otherwise been utilised for production of OPC, is thus saved. By reducing the production of cement, pollution is also controlled as cement is an energy intensive product.

20 years back in India about 30% of the total production was blended cement. Now the figure is 70% with the increase in awareness of use of blended cement. In UK & USA, the usage of blended cement is nearly 90% of the total production. Durability problem can be effectively tackled by reducing the permeability of the concrete using blended cement.

CHAPTER 3
AGGREGATE

Aggregates give body to the concrete. They also reduce shrinkage and effect overall economy. Since aggregate is cheaper than cement, it is economical to put as much aggregates as practically possible. Not only the use of more volume of aggregate in concrete is economical, it also provides higher volume stability to the concrete. Generally, they occupy 60-70% of the total volume of concrete. At the same time the aggregates should be strong because the weak aggregates can't make strong concrete and they may limit the strength of concrete. Therefore, the selection of aggregate becomes very vital.

Aggregates shall comply with the requirements of IS:383. Where required by the engineer, aggregates shall be subjected to the tests specified in IS:383. These tests shall be done in accordance with IS: 2386 (Part I) to IS: 2386 (Part VIII).

Aggregate resulting from the natural disintegration of rock are called as natural or uncrushed aggregates and aggregates produced by crushing hard stone/natural gravel are called as crushed aggregates. Aggregate produced by Blending natural and crushed stone or gravel in suitable proportion are called mixed aggregates.

Aggregates manufactured from other than natural sources, by processing materials, using thermal or other process such as separation, washing, crushing or scrubbing are called as manufactured aggregates.

IS 383-2016 deals with aggregates derived both from natural sources and manufactured aggregates produced from other than natural sources. As per Clause 4.2.2, of IS:383, manufactured aggregates shall not be permitted for use in prestressed concrete.

Earlier, aggregates were viewed as an inert ingredient of concrete but now their importance has been understood and these are no more considered inert. Their physical, chemical as well as thermal properties greatly influence the properties of concrete.

Types of Aggregates

In terms of size, there are two broad categories of aggregate as given below :

1. **Fine Aggregate –** most of which passing through 4.75 mm sieve
2. **Coarse Aggregate** – most of which retained over 4.75 mm sieve

Within a particular category also, aggregates would have representation of all standard sizes as per relevant IS codes. The different sizes of the aggregates are mixed for making concrete assuming that voids created by the larger size will be filled up by the next immediate lower size. Again, some voids would be created, which would accommodate the next lower size. This assumption holds good from coarse aggregate to fine aggregate and then finally up to cement paste. At the end we should get a compact mass of concrete with minimum voids.

Properties of aggregates

The properties of aggregates can broadly be categorised as under :

1. Inherited properties

These properties are inherited by the aggregate from the parent rock. These are as given below :

(i) Chemical and mineral composition

(ii) Specific gravity

(iii) Hardness

(iv) Strength

(v) Colour etc.

2. Acquired properties

These properties are acquired by aggregates in the process of crushing. These properties are :

(i) Aggregate shape

(ii) Aggregate size

(iii) Surface texture

(iv) Water absorption

(v) Gradation

If we closely observe the above two categories of properties, we can easily infer that not only the source or parent rock is important in influencing the properties of aggregate, but the properties which have been acquired by the aggregate are also equally important. All the acquired properties greatly influence the properties of fresh as well as hardened concrete. Therefore, all the acquired properties need to be closely studied before the aggregate is selected for concrete. These are elaborated as under :

(i) Aggregate Shape

The shape acquired by aggregate can't be defined by any

regular geometrical shape. It can approximately be put in following categories :

(a) Rounded

(b) Angular

(c) Elongated

(d) Flaky

(e) Irregular

The shape can also be defined by a mathematical entity called Angularity Number. It measures the percentage of voids in excess of 33%. This 33% represents the percentage of voids in most rounded gravels.

Mathematically

Angularity No. = 67 – (Bulk Density/Sp. Gr.) x 100

Here 67 represents percentage of solid in total volume of the most rounded gravel. It has been found that if gravels are most angular, the percentage of solid in total volume will reduce to 56%. Therefore angularity number will vary from 0 to 11 depending upon roundness. Higher the angularity no. more angular will be the aggregate.

Flaky aggregates have thickness less than 0.6 times mean sieve size to which particles belong. Similarly elongated aggregates have length dimension more than 1.8 times mean sieve size. Flaky and elongated aggregates should be avoided in concrete. The combined value of Flakiness and Elongation Index should not be more than 40% for crushed and uncrushed aggregates.

The shape of aggregate is influenced by the type of crusher as well as its reduction ratio.

According to the field experience, the rounded aggregates are preferred for the low grade of concrete where w/c ratio is more than 0.4, but angular aggregates are preferred for higher grade of concrete and where the requirement of flexure strength and interlocking is higher.

(ii) Aggregate size

Larger size of aggregate is preferred in concrete because of the following reasons :

(a) It reduces the cement requirement

(b) It reduces the water requirement

(c) It reduces shrinkage of concrete

But practically, there are a number of factors which limit the use of higher size aggregates in the concrete.

- For most works, 20 mm nominal size aggregate is suitable. Where there is no restriction to the flow of concrete into sections, 40 mm or larger sizes may be permitted, but in no case greater than one fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty.
- For heavily reinforced concrete members like the ribs of main beams, the nominal maximum size of the aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum clear cover to the reinforcement, whichever is smaller.
- For Plain Concrete called 'Plum Concrete', even rubbles of size up to 160 mm have been used. For normal RCC works, MSA of 20 mm is generally used. For special requirements like pumped concrete, PSC works, this size may be further reduced.
- In general, marine aggregate shall not be used for reinforced concrete and Prestressed concrete bridges. However, IRS Concrete Bridge Code, in special cases, permits the use of marine aggregates after washing, with some stipulations for Chloride and Sulphate content.

(iii) Surface texture

It is the surface quality of aggregate in terms of roughness. Texture of aggregate depends upon its hardness, grain size, pore structure and degree to which it has been polished by the external forces like wind and water. There can be two types of texture for aggregate as given below :

(a) Smooth texture

Generally hard, dense and fine grained aggregates are smooth textured. The surface area is less due to less irregularities, therefore these require less quantity of paste for lubrication. But as smoothness increases, the bonding area with matrix also reduces. Therefore, although more compressive strength may be achieved due to less requirement of water, the flexure strength

decreases due to poor bonding and interlocking.

(b) Rough texture

Rough textured aggregates exhibit higher strength in tension as compared to smooth aggregates, but compressive strength is less because higher w/c ratio is required for the same workability. The impact of texture of aggregate can be understood by the sample shown in the Table-1 given below :

Table-1

Particle Percentage		w/c ratio	28 day flexural strength (MPa)	28 day compressive strength (MPa)
Smooth	Rough			
100	0	0.54	4.3	34.8
50	50	0.57	4.6	32.1
0	100	0.64	4.8	29.5

(iv) Water Absorption

In mix-design calculations, we assume aggregate to be saturated and surface dry (SSD). Actually, it may be in a different state of dryness as given under.

(a) Bone dry

(b) Air dry

(c) Saturated and surface dry

(d) Moist

If aggregate is drier than SSD, it will absorb water from concrete and reduce the workability. On the other hand, if it moist, it will contribute water in the concrete reducing the strength. The different stages can be as given in Figure-1.

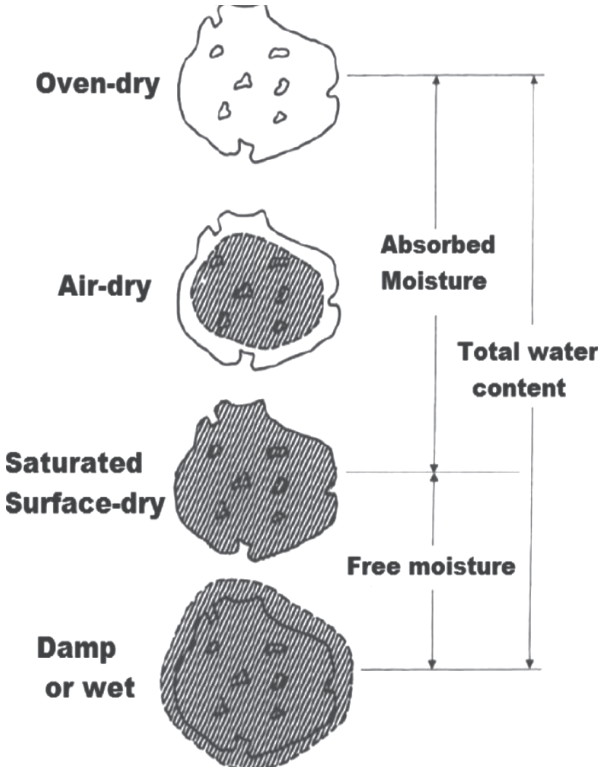


Figure - 1 : Water Absorption

(v) Gradation

In the total concrete volume, there are two important phases viz;

(i) Paste phase

(ii) Aggregate phase

In most of the cases of concrete failure, it is the paste phase which is a weaker link. The paste phase of concrete has the following characteristics :

(i) It is weaker than aggregate

(ii) It is vulnerable to most of the ill effects on concrete

(iii) It is more permeable than any of the mineral aggregates

(iv) It is susceptible to aggressive chemicals

Therefore, effort should be made to use minimum volume of paste in the concrete. It should just be sufficient to fill the voids left out by the aggregates and lubricate them properly. This can be

achieved by using 'well graded aggregates' so that the voids are minimum.

Sieve Analysis of Aggregates

It is a process of dividing a sample of aggregates into various fractions, each consisting of particles of same nominal size. The resultant 'particle size distribution' is called the gradation.

As per IS: 383, sizes of the sieve are:-

80, 40, 20, 16, 12.5, 10, 4.75, 2.36, 1.18, 600µ, 300µ, 150µ

The gradation of aggregate is very important not only for concrete strength but for workability also. In fact, the gradation of FA has much greater effect on concrete qualities. FA should not be very coarse as it may cause segregation or bleeding and also result into harsh concrete. It should not be very fine also, otherwise it will have more water demand. Quantity of fine aggregates also affects the workability of concrete.

The gradation of FA can be represented by a mathematical index called 'Fineness Modulus' (FM) which determines the relative fineness of material.

Mathematically,

FM = Cumulative percentage of aggregates retained on each standard sieves

Larger the value of FM, coarser will be the aggregate as given in Table-2 below :

Table-2

Sand	FM
Fine Sand	2.2 – 2.6
Medium Sand	2.6 – 2.9
Coarse Sand	2.9 – 3.2

FM more than 3.2 is generally considered unsuitable for concrete.

On the basis of gradation, FA have been divided into four zones i.e. Zone-I, Zone-II, Zone-III & Zone-IV. The grading limits for different zone of sands as per IS:383 are shown in Table-3.

Table-3

IS Sieve	Percentage Passing			
	Zone-I	Zone-II	Zone-III	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 µ	15-34	35-59	60-79	80-100
300 µ	5-20	8-30	12-40	15-50
150 µ	0-10	0-10	0-10	0-15

* The Percentage Passing values for 600 µ size are unique and not overlapping for different zones. It is used for confirming the zone of FA.

Zone-I represents the coarse and zone-IV represents the finer sand. Fine aggregates belonging to Zone-IV should not be used in RCC works unless tests have been made for suitability of mix proportion. This is due to the fact that fine sand will have more voids, thus needs more water and affect durability and in RCC it may adversely affect the performance of embedded steel.

Quality of Aggregates

The aggregate should be free from impurities like deleterious material, salt contaminations and alkali reaction. These are elaborated as under :

(a) Deleterious Material

Impurities and deleterious material like clay, silt, coal, lignite, mica, shale etc. interfere with the process of hydration and prevent bonding of aggregates with cement matrix. Limits of various deleterious materials have been given in Table 2 of IS 383-2016

(b) Salt contamination

This problem is more prevalent in sea dredged aggregates.

As given in para 4.22 of 'Concrete Bridge Code' (CBC). in general, marine aggregate shall not be used for reinforced concrete and prestressed concrete bridges. However, in special cases, use of marine aggregates may be permitted thoroughly washed and the limits for chloride content and sulphate content in aggregates after washing should be as under:

Limit of chloride - 0.04% by weight for FA and 0.02% by

weight for CA

Limit for sulphate- 0.4% by weight of Aggregates

(c) Alkali Reaction

Some aggregates contain active silica which may react with alkalies present in cement like sodium oxide, potassium oxide etc. Alkaline hydroxide derived from alkalies in the cement may attack these constituents and gels of 'unlimited swelling' is formed which results in cracking. This problem can be overcome if:

1. Low alkali cement (cement with alkali content < 0.6%) is used.
2. Ground Pozzolana is added to the cement so that Pozzolana react with alkalies before they attack aggregates.

Bulking of Sand

It is the property of sand by virtue of which its apparent volume increases when some water is added to it. It happens mainly due to surface tension. This increase in volume will not take place when the sand is either dry or fully saturated. The bulking depends both on moisture content as well as on particle size. Fine sand bulks more and very fine sand may bulk even up to 38-40%. The bulking of a particular sand is maximum at a particular moisture content as presented in the Figure-2.

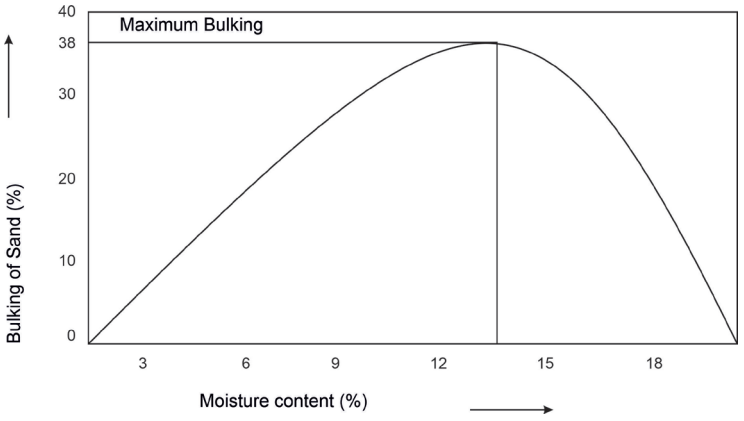


Figure - 2 : Bulking of sand

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CHAPTER 4
WATER & ADMIXTURE

Water

The quality of water is very important for making good concrete. The quality of water has great influence on strength as well as durability of concrete. There is a general understanding that water fit for drinking purpose can be used for concrete. But technically speaking various chemicals in water should be within the prescribed limits. Following general aspects may be followed for use of water in concrete:-

(1) pH value of water should be between 6 and 8. The value less than 6 means acidic in nature which may lead to corrosion of reinforcement.

(2) It should be free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials and other substances that may be deleterious to the concrete and steel.

(3) Permissible limits for solids shall be as per clause 5.4 of IS: 456 as given in Table below:

Permissible Limit for Solids			
SN		**Tested as per**	**Permissible Limit, Max**
1	Organic	IS 3025 (Part 18)	200 mg/l
2	Inorganic	IS 3025 (Part 18)	3000 mg/l
3	Sulphates (as SO_4)	IS 3025 (Part 24)	500 mg/l
4	Chlorides (as Cl)	IS 3025 (Part 32)	500 mg/l for Pre-stressed Concrete Work. 2000 mg/l for Plain Concrete Work.
4	Suspended Matter	IS 3025 (Part 17)	2000 mg/l

(4) Potable water is generally considered satisfactory for washing of aggregates and mixing and curing of concrete.

(5) Water found satisfactory for mixing is also suitable for curing of concrete. However, the water used for curing should not produce any objectionable stain or unsightly deposit on the concrete

surface. The presence of tannic acid or iron compounds is objectionable.

(6) Sulphates have adverse effect in concrete and chlorides accelerates corrosion. Excess amount of sulphate and chloride in water makes it unsuitable for RCC.

Effect of Impurities of water

(1) Carbonates and bicarbonates affect setting time of cement. Sodium carbonate causes quick setting.

(2) If bicarbonate is more than 1000 ppm, tests for setting time and strength should be carried out.

(3) Turbidity should be limited to 2000 ppm. This is due to silt and other suspended material which interfere not only with setting, but also with hardening and bond characteristics.

(4) Algae, if present in water, entraps a large amount of water which causes reduction in strength.

Generally, the source of water should be reliable. In case of doubtful source, e.g. coastal area, marshy land and other places where brackish water is suspected, we should compare the cube strength at 7 days and 28 days made with available water and distilled water. This will give an overall effect of the source water. If strength achieved with available water is up to 90% of the strength achieved with distilled water, and no other problem is reported, then the source of water may be accepted. But the tests should be conducted at regular intervals.

Effect of Sea Water

Salinity of sea water is approximately 3.5%. If sea water is used, the main concern will be the corrosion of steel and reduction in strength. The strength reduction is about 10-15%. In addition, it also accelerates the setting time of cement, causes efflorescence and persistent dampness. Therefore, use of sea water should be avoided for concrete works.

Admixture

Admixtures may be Mineral or Chemical which can be used for getting the desired properties of mix. As per clause 4.4 of CBC, Chief Engineer may permit the use of admixtures for imparting special characteristics to the concrete or mortar on satisfactory evidence that the use of such admixtures does not adversely affect the properties of concrete or mortar particularly with respect to strength, volume change, and durability and has no deleterious

effect on reinforcement.

(1) Mineral Admixtures:

Mineral admixtures may be blended with cement to replace the cement in specified proportion. This has been discussed in earlier chapter under blended cement. Any of the following mineral admixtures may be used along with Ordinary Portland Cement. Uniform blending of the mineral admixtures with the cement should be ensured by having dedicated facility and complete mechanized process control at the site to achieve specified quality.

(i) Fly ash: Fly ash when permitted, shall conform to IS: 3812 (Part-1).

(ii) Metakaoline: Metakaoline conforming to IS: 16354, when permitted, may be used as part replacement of Ordinary Portland Cement.

(iii) Silica Fume: Silica fume, when permitted, shall conform to IS: 15388.

(iv) Ground Granulated Blast furnace Slag: Granulated Blast furnace Slag (GGBS) conforming to IS: 16714 when permitted, may be used as part replacement of Ordinary Portland Cement.

(v) For High Strength Mixes the recommended percentage of Mineral Admixtures shall be in accordance with IS: 10262.-2019.

(2) Chemical Admixtures:

It is an optional ingredient of concrete which is added to modify the properties of fresh as well as hardened concrete and grout material as per some specific requirements. Addition of admixture may alter workability, pumping qualities, strength development, appearance etc. in fresh concrete and permeability, strength, durability etc. in hardened concrete. Use of chemical admixture is necessary for producing high grade and high performance concrete.

Categories of Admixtures

Various categories of admixtures are available in the market as given below:

(i) Water reducing admixtures

(ii) Retarding admixtures

(iii) Accelerating admixtures

(iv) Air entraining admixtures

(i) Water reducing admixtures

These admixtures reduce the requirement of water for a given workability. For full hydration, a w/c ratio of 0.23 is sufficient but generally much higher w/c ratio is adopted due to the requirement of workability. Workability is an equally important design parameter in addition to strength because inadequate workability leads to honeycombing and non-uniform strength. Excess water is used to overcome the internal friction between solid particles of concrete and facilitate mixing, placing, transportation and compaction of concrete. There are two categories of water reducing admixtures.

(a) Plasticizers

(b) Super-plasticizers

Super-plasticizers are improvised version of conventional plasticizers. They reduce water requirement significantly. These are, therefore, also called 'High range water reducers'. Plasticizers reduce water requirement up to 8-12% whereas super plasticizers can reduce this requirement up to 15-30%.

There are three possible improvements that can be achieved, which are as follows:

(a) Increase workability without increasing water content to facilitate placement and compaction.

(b) Increase strength without affecting workability by reducing the water-cement ratio.

(c) Achieve economics by reducing consumption of cement without any detrimental effect on workability or strength.

Mechanism of water reduction

Water reducers are surface active chemicals called surfactants. In absence of water reducer, cement particles, being very fine, cling together and flocculate when water is added to cement. Due to flocculation, a lot of water is entrapped by cement particles and it becomes unavailable for workability. Water reducer admixtures induce negative charge on cement particles due to which the flocculated cement particles get

dispersed as a result of repulsion. The entrapped water now becomes free and available for workability. This is purely a physical action. But it may be associated with chemical interaction also which results in slump retention. The admixtures get absorbed on hydrated phase containing silicates and aluminates and thus delay the gel formation. Thus, the slump is retained.

(ii) Retarding admixtures

These admixtures are used where setting time of concrete needs to be delayed. Retarders delay the hydration process but don't affect the eventual process. Initial setting time can be delayed by more than 3 hours. The main application of retarding admixtures is in controlling the setting of concrete and eliminating the cold joints.

(iii) Accelerating admixtures

These are used to accelerate the setting time and hardening process of cement in concrete. These are used in concreting under flowing water and in road repair works so that work can be put to use earliest as possible.

(iv) Air entraining admixtures

These are also surface active agents that form stable air bubbles of very small size ranging from 5μ to 80μ. The main function of air bubbles is to break capillary structure within the concrete and to act like roller ball bearings so that the particles in the mix move freely against each other, thus improving the workability of concrete without adding more water.

Among all above admixtures, water reducing agents or super-plasticizers are the most commonly used admixture for high performance concrete. There are four types of super-plasticizers which are generally used for concrete as explained below:

(a) Sulphonated melamine

- It is more suitable in low temperature areas

(b) Sulphonated naphthalene

- It is more suitable in high temperature areas

(c) Ligno sulphates

- Calcium, Sodium and Ammonium lignosulphonates are commonly used. Mostly they are obtained from wooden pulp as byproduct from paper industries.

They can be used for moderate water reduction and to improve cohesiveness in highly workable concrete and are suitable for Indian conditions where temperature variation is high.

(d) Carboxylated

- It is suitable where workability is required to be retained for large duration.

Polycarboxylated Ether (PCE) based admixture are used as High Range Water Reducing Admixtures (HRWA) or Superplasticizers to reduce water requirement upto 30% or even more. These are used in lower dosages and are particularly suitable for high strength concrete and for self-compacting concrete.

PCE based retarders are also available which can increase the initial setting time by 2-3 hrs.

Factors affecting the performance of Admixture

The various factors affecting the performance of admixture are as given below :

1. Type of super-plasticizer

The admixture will be more effective if molecular weight of the super-plasticizer is high.

2. Dosages

The quantity of admixture should be optimum. Excess of admixture may cause segregation or bleeding. It may also cause excessive retardation. The optimum dose should be estimated by trials.

3. Compatibility with cement

All admixtures may not produce same results with different cements. Therefore, before using any admixture, its compatibility with cement has to be established. Properties of cement like fineness, chemical-composition, C_3A content etc. affect the performance of admixture. Therefore, trials have to be made before finalising an optimum dose of admixture.

4. Mix Design

All the constituents of mix affect the performance of the super-plasticizer as given below:

(a) Water: More water in the mix improves the

physical interaction and dispersion of admixtures.

(b) Coarse Aggregate: Proportion and grading of CA influence the performance of admixture.

(c) Fine Aggregate: Proportion, grading and silt content also influence the performance.

(d) Cement: Its fineness, C_3A content influence the performance. Higher C_3A reduces efficiency of admixture.

(e) Other Admixtures: Presence of other admixtures also influence the performance of admixtures.

5. Other factors

Certain other factors like temperature and humidity at the time of concreting also affect the performance of the admixtures. High temperature and less humidity lower the efficiency of admixtures. Drum mixers are not considered ideal for mixing admixtures. Pan or compulsive shaft mixers perform in better way in this regard.

Recommended Methods for better performance of admixtures

(a) All aggregates, cement and approximately 2 litre less water should be fed into the mixer and mixed properly for 2 minutes.

(b) Admixture is mixed in balance 2 litre of water and added in the mixer. Continue mixing for one more minute.

(c) When transit mixer is used for transportation of RMC, add plasticizer only few minutes before loading into the transit mixer.

(d) Add plasticizer in smaller dosages at regular interval. It will improve its effectiveness.

(e) Initial overdose of plasticizer is required for initial high workability and additional dosage just before placement.

The effect of super-plasticizer can be understood in a better way by analysing the results of Table-1.

Table-1 A – Effect on Workability (keeping w/c same)

Mix	Cement kg/m³	w/c	Slump (mm)	Strength (N/mm²)	
				7 days	28 days
Mix with cement only	440	0.37	25	39	54
Cement + 0.4% Admixture	440	0.37	100	41.1	54.1

B – Effect on Strength (keeping workability same)

Mix	Cement kg/m³	w/c	Slump (mm)	Strength (N/mm²)	
				7 days	28 days
Mix with cement only	315	0.60	95	21.8	29.1
Cement + 0.4% Admixture	315	0.53	95	28.5	37.5

Note : The percentage of admixture is by weight of cement.

The adverse effects on slump loss, delayed setting time of concrete and additional air entrapment shall be kept in mind while deciding type and dosage of various admixtures. Sometimes problems due to cement admixture incompatibility are experienced. An admixture that produces all the desired effects with one cement may not do the same with another cement. This problem is particularly experienced when the supply of cement and/or admixture is changed midway through a project.

Cement admixture incompatibility may result in rapid loss of workability, bleeding and segregation of concrete, acceleration/ retardation of setting, low rates of strength gain and entrapment of air. Compatible combinations of cement and superplasticizer may be selected by trials or by simple tests like Marsh cone test as mentioned in Annexure-G of IS:10262

As per Clause 10.3.3 of IS:456, Dosages of retarders, plasticisers and superplasticisers shall be restricted to 0.5, 1.0 and 2.0 percent respectively by mass of cementitious materials. The dosages of polycarboxylate based admixtures shall not exceed 1.0 percent. However, a higher value of above admixtures may be used, if agreed upon between the manufacturer and the constructor based on performance test related to workability, setting time and early age strength.

Concrete Bridge Code specifies that Calcium chloride or admixtures containing calcium chloride shall not be used in structural concrete containing reinforcement, prestressing tendons, or other embedded metal.

The admixture containing Cl and SO_3 ions shall not be used. Admixtures containing nitrates shall also not be used. Admixtures based on thiocyanate may promote corrosion and therefore shall be prohibited.

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CHAPTER 5
PRODUCTION OF CONCRETE

Production of concrete involves two distinct activities. One is related to 'material' and the other to 'process'. The material part is generally taken care by everybody, but the involved processes in the production of concrete are often neglected. Therefore, no wonder that it is the 'process' which is responsible for good or bad quality of concrete. If we take care of processes, the quality of concrete will be improved automatically without incurring any extra expenditure as the major expenditure has already been made in procurement of material. In order to ensure the quality, it is very important to have a knowledge of each and every process.

A competent person who understands the relevant aspects of concreting, shall supervise all stages of the production of concrete. The preparation of the test specimen and tests conducted on site shall be properly supervised.

Process for Concrete Production

The various stages of concrete production are as given below :

(1) Proportioning
(2) Mixing
(3) Transportation
(4) Placement
(5) Compaction
(6) Curing

(1) Proportioning

It is the relative quantity of each ingredient to make the desired concrete. It is decided based upon the calculations of mix-design. The proportioning should be such that the resultant mass should be compact with minimum voids and the required strength should be achieved. This should be done by weight so that change of volume due to moisture etc. does not affect the proportioning.

The accuracy of the measuring equipment shall be within ±2 percent of the quantity of cement and mineral admixtures being measured and within ±3 percent of the quantity of aggregate, chemical admixtures and water being measured.

(2) Mixing

The purpose of proper mixing is to ensure that mass should become homogeneous, uniform in colour and uniform in consistency.

There are two types of mixing that are adopted in the field i.e. Hand Mixing and Machine Mixing

(a) Hand Mixing

It is done manually and inferior to machine mixing. It is adopted only for small quantum of work where machine mixing is not economically viable.

(b) Machine Mixing

It is an efficient and economical way of mixing in which homogeneous and uniform mixing can be ensured. It can further be divided into two categories as given below :

(i) Batch Mixing – The mixing of concrete is done in batches.

(ii) Continuous Mixing – The mixing is done continuously till the plant is working. All the ingredients are fed through screw feeder in a continuous manner. It is used in large works where large quantity of concrete is required.

Type of Batch Mixers

1. Pan Type Mixers:

It consists of a circular pan rotating about a vertical axis with one or two star scraper blades rotating about a vertical axis which is not matching with the axis of the pan. Scraper blades prevent sticking of mortar to the sides of pan. The pan mixers are particularly efficient for stiff and cohesive mixes.

These are mainly used in central batching plant on large projects or at pre-cast manufacturing units. A smaller version is generally available in laboratories too.

2. Drum Type Mixers:

There are three types of drum mixers as given below :

(a) Tilting – The rotating drum is able to tilt. This type of mixer is normally used in the field.

(b) Non-Tilting - The rotating drum is not able to tilt, therefore separate entry and exit for concrete is

provided.

(c) Reversing or Forced Action - It is similar to non-tilting but entry and exit of concrete is provided on the same side.

These mixers are shown in Figure-1.



Reversing Tilting Non-Tilting

Figure - 1 : Drum Mixers

As per IS: 1791-2020, the mixers are designated by capacity as given below :

Tilting : 100T, 140T, 200T

Non-Tilting : 200NT, 280NT, 375NT, 500NT and 1000NT

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

Here Figure represents capacity in litre which can be prepared in one batch and words represent like: T for Tilting, NT for Non-tilting & R for Reversing.

Mixers can mix upto 10% more than the nominal capacity.

Sequence of charging ingredients

As enumerated in para 2.6 of IS: 516-1959 (Re-affirmed in 2018) following sequence of charging for machine mixing should be adopted in the field for achieving homogeneous and uniform mixing.

(i) Full quantity of water

(ii) Half the quantity of CA

(iii) Full quantity of FA

(iv) Full quantity of cement

(v) Remaining quantity of CA

Mixing time

It is the time required to mix the ingredients so as to obtain a homogeneous and uniform consistency mass of concrete. The time is reckoned from the moment when all the ingredients including water has been added. Generally, 25 to 30 revolutions of drum mixer are sufficient for proper mixing. The drum mixer rotate @ 15-20 rpm, therefore it will take approximately 2 minutes for proper mixing.

Mixing time also depends upon the grade of concrete. Richer mix requires more time. Similarly mixing time will depend upon type of aggregate also and more time will be taken for crushed aggregates as compared to smooth aggregates. In case of doubt, it is always better to mix for a longer time.

Concrete shall be mixed in a mechanical mixer. The mixer should comply with IS: 1791. It shall be ensured that stationary or central mixers and truck mixers shall comply with the performance criteria of mixing efficiency as per IS: 4634. Mixing efficiency test shall be performed at least once in a year. The mixing shall be continued until there is a uniform distribution of the materials in the mass and it is uniform in colour and consistency. If, there is segregation after unloading from the mixer, the concrete should be remixed.

In hot weathers, ice is added in the water to maintain the temperature below $35^{o}C$.

(3) Transportation

Transportation of concrete is an important activity in the production of concrete. The time taken in transit should be a design parameter as it depends on the initial setting time as well as the requirement of workability at the destination. The method of transportation adopted at site should be decided in advance so that suitable admixtures can be used. Mixed concrete shall be transported from the place of mixing to the place of final deposition as rapidly as practicable by methods which prevent the segregation/loss of ingredients. The various prevalent methods of transportation are as given below:

(a) Mortar pan

It is a labour intensive method and generally used for small works. There are less chances of segregation of concrete in this method. However in hot weather, there is a substantial loss of water due to more exposure of concrete to environment.

(b) Wheel barrow or hand cart

It is normally used for ground level transportation i.e. road construction and other similar works. Segregation can occur if transportation is done on rough roads however this problem can be minimized if pneumatic tyres are used.

(c) Bucket and ropeway

It is suitable for works in valley, over high piers and long dam sites. Excessive free fall of concrete should be avoided to avoid segregation.

(d) Truck mixer and dumper

It is an improved and better method for long lead concreting. The concrete is covered with tarpaulin if it is transported in open trucks. If long distance is involved, agitators should be used.

(e) Belt conveyor

It has limited application due to chances of segregation on steep slopes, roller points and change in direction of belt. It also involves over-exposure of concrete to environment.

(f) Chute

It is generally used for concreting in deep locations. When concrete is conveyed by chute, there should be continuous flow in the chute. Slope of the chute shall be so adjusted that the concrete flows without the use of excessive quantity of water and without any segregation of its ingredients. Normally the slope should not be flatter than 1V : 2.5H, otherwise concrete will not slide down. The delivery end of the chute shall be as close as possible to the point of deposit. The chute shall be thoroughly flushed with water before and after each working period and the water used for this purpose shall be discharged outside the formwork.

(g) Skip and hoist

It is a widely used method for high rise structures. Concrete is fed into the skip which travels vertically on rails like a lift.

(h) Pump and Pipe-line method

It is the most sophisticated method particularly suitable for limited space or when a large quantity of concrete is to be poured without cold joints. Pumping of concrete can be done @ 8 to 70 cum per hour up to a horizontal distance of 300 m and vertical distance of 90 m. Pipe dia is generally

8-20 cm and it is made of steel, plastic or aluminium. The workability for pumped concrete should have a minimum of 100-150 mm of slump or 0.90-0.95 CF. At delivery point, the workability may be reduced by upto 25% due to compaction during transport and this factor should be kept in mind while designing the mix.

At the end of day's work, the pipe should be cleaned by passing a special ball called 'go devil' forcing through the pipe by air pressure.

(4) Compaction

Compaction is a process of expelling the entrapped air. If we don't expel this air, it will result into honeycombing and reduced strength. It has been found from the experimental studies that 1% air in the concrete reduces the strength approximately by 6%. The strength as well as durability gets reduced significantly if compaction is not fully ensured in the concrete. It is necessary that compaction should be ensured throughout the structure with equal precision. Figure-2 shows the effect of w/c ratio and compaction on strength of concrete.

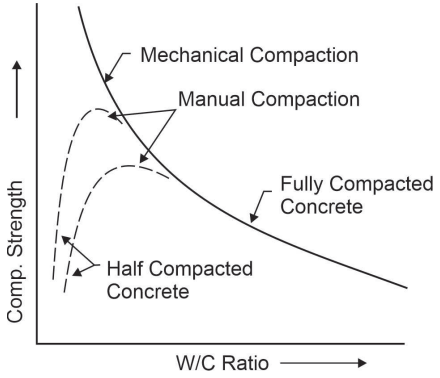


Figure - 2 : Importance of Compaction

There are two methods of compaction adopted in the field as given below:

(a) Hand Compaction

Hand compaction is used for ordinary and unimportant structures. Workability should be decided in such a way that the chances of honeycombing are minimum. It is very primitive and inferior way of compaction. The various methods of hand compaction are as given below:

(i) **Rodding –** It is a method of poking with 2 m long, 16 mm dia rod at sharp corners and edges. The thickness of layers for rodding should be about 15-20 cm.

(ii) **Ramming –** It is generally used for compaction on ground in plain concrete. It is not used either in RCC or on upper floors.

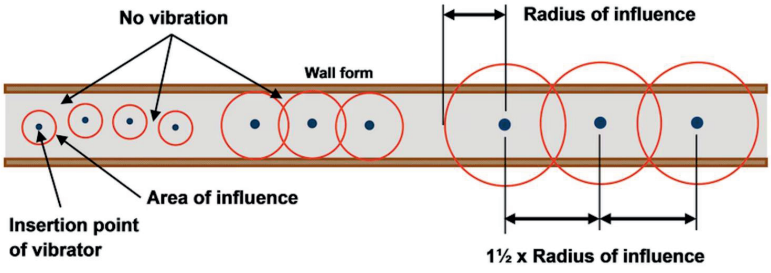
(iii) **Tamping –** It is a method in which the top surface is beaten by wooden cross beam of cross section 10 cm x 10 cm. Both compaction and levelling are achieved simultaneously. It is mainly used for roof slabs and road pavements.

(b) Mechanical Compaction

Vibration is imparted to the concrete by mechanical means. It causes temporary liquefaction so that air bubbles come on to the top and expelled ultimately. Mechanical vibration can be of various types as given under :

(i) Internal vibration

It is the most commonly used technique of concrete vibration. The needle diameter varies from 25 mm to 90 mm and its length varies from 30 cm to 65 cm. The frequency range adopted is normally 100 - 270 Hz (Ref. IS: 2505). The correct and incorrected methods of vibration using internal vibration needles are shown in Figure-3(a) and 3(b).



Incorrect (very small needle) | Incorrect (small needle) | Correct (exact size needle)

Figure - 3 (a) :

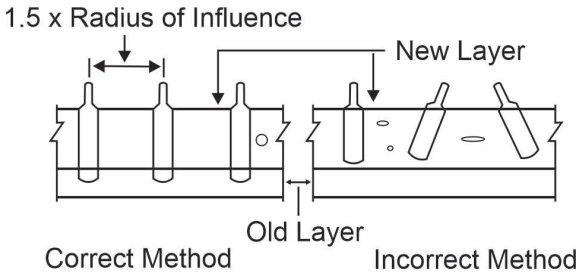


Figure - 3 (b) :

Radius of influence of needle is approximately 10 times of needle diameter. For effective compaction, spacing between vibrator insertions should be around 1.5 times of radius of influence. Vibrator withdrawal should also be gradual so that space left by it, is properly filled up.

(ii) External vibration

This is adopted where internal vibration can't be used due to either thin sections or heavy reinforcement.

External vibration is less effective and it consumes more power as compared to the internal vibration. The formwork also has to be made extra strong when external vibration is used.

(iii) Table vibration

It is mainly used for laboratories where concrete is put on the table.

(iv) Platform vibration

It is similar to table vibrators but these are generally used on a very large scale production, normally precast members like electric poles, railway sleepers etc.

(v) Surface vibration

These are also called screed board vibrators. The action is similar to that of tamping. The vibrator is placed on screed board and vibration is given on the surface. It is mainly used for roof slabs, road pavements etc. but it is less effective beyond 15 cm depth and should not be used for layer thickness beyond 25-30 cm.

Vibration shall be done continuously during the placing of each batch of concrete until the expulsion of air has practically ceased and in a manner that does not promote

segregation. No concrete shall be allowed without vibration except under-water concreting or tremie concreting or in specific cases. Concrete shall be thoroughly compacted and fully worked around the reinforcement, around embedded fixtures and into corners of the formwork.

(5) Curing

Curing is a procedure of promoting the hydration of cement for development of concrete strength and controlling the temperature. As a result of curing, we can achieve higher strength and reduced permeability which is very vital for the long term strength and durability. The effect of curing has been depicted in Figure-4.

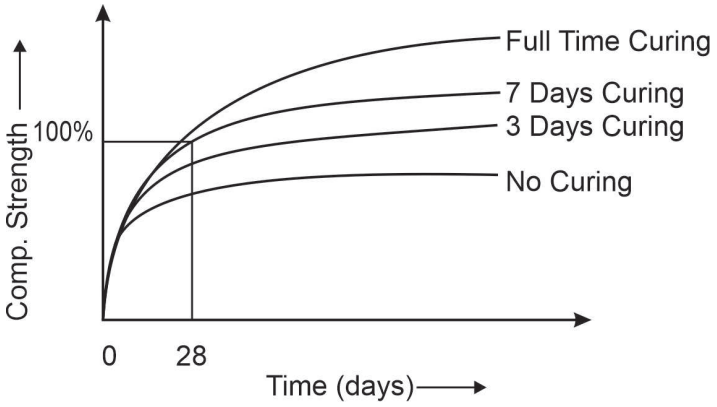


Figure - 4 : Effect of curing

The curing is required for full development of strength. Initially the entire concrete has sufficient quantity of water for hydration. But over the passage of time, the water is lost due to evaporation or it is consumed due to reaction of hydration. The relative humidity, thus, falls below 80% level and the hydration process eventually stops.

Methods of curing

Various methods of curing are adopted in the field as given below :

(a) Replenishing the lost water

(i) By immersion in water

(ii) By ponding

(iii) By sprinkling

(iv) Using saturated coverings, e.g. jute bags etc.

(b) Preventing loss of moisture

(i) Using curing compounds

(ii) Using impermeable membrane coverings

Out of above methods, immersion may be the ideal method of curing but it is not practicable always. It is restricted to laboratories or pre-cast units where small units like cubes or PSC sleepers etc. can be immersed in water. Ponding is suitable only for flat surfaces but not for vertical or overhead surfaces. Sprinkling is the most commonly used method in the field but it requires a large quantity of water. Saturated covering is a better method which requires less quantity of water but needs close monitoring. Curing compounds are effective for concrete with high initial w/c ratio. Approved curing compounds can be used in lieu of moist curing with the permission of the Engineer. Such compounds shall be applied to all exposed surfaces of the concrete along with stripping of form work. Impermeable membrane is also having the same effect as of curing compounds. Out of these methods, the most widely used method in the field is saturated coverings using jute bags.

Important factors regarding curing

(i) Curing should be started as early as possible. It should be started when the concrete is still wet.

(ii) For the portion of concrete which is covered with formwork, the curing should be started as soon as the formwork is removed.

(iii) On exposed surface, it should be started when concrete has just sufficiently hardened such that it doesn't get disturbed by curing.

(iv) Ensure uninterrupted curing. If it is discontinued for any reason, the reaction of hydration may be stopped permanently. The partial hydration makes the capillary pores discontinuous and water can't enter the concrete even if the curing is started again.

(v) High strength concrete should be cured at an early age.

(vi) There is a widespread belief that humid climate is sufficient and curing is not required in rainy season. But it is not fully correct. Wet curing is desired for continuous hydration.

(vii) It can't be made a measurable item in the contract. The best way to ensure proper curing is to educate the person responsible for curing.

(viii) The person generally entrusted for curing is the most unskilled person. He doesn't appreciate the importance of curing. In fact, he believes that curing is a process of wastage of water, time and money. Therefore, the best and practical method to ensure proper curing is the education of the person who is responsible for curing. Once he understands the importance of curing, he would certainly ensure it.

(ix) When air temperature is expected to drop below 5°C during the curing period, additional covering of cotton/gunny bags, straw or other suitable blanketing material shall be provided so that concrete temperature at surface does not fall below 10°C.

(x) **Steam Curing-** Steam curing can be used advantageously along with moist curing of concrete for transfer of pre-stress. Optimum steam curing cycle to be determined by trial. However, it has been found satisfactory to use a pre-steaming period of 4 to 5 hours or rate of temperature rise between 22-33^{o}C per hour and a maximum curing temperature of 66-82^{o}C for a period such that entire curing cycle does not exceed 18 hours.

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CHAPTER 6
MIX DESIGN

Concrete Mix Design

In preparation, concrete looks very simple. Only three ingredients viz Cement, Aggregate and Water need to be mixed to make concrete. But its performance is not so simple, rather complex. By adding same ingredients, we can make different varieties of concrete, like different grade, different workability, different finish etc. It is possible by selecting its ingredients in different proportions. We have to set a correct proportion of its ingredients for desired properties of concrete, means we have to design the correct proportion of its ingredients. That is why it is called Concrete Mix Design.

Designing concrete mix is a process of selecting suitable ingredients and determining their relative proportions with the objective of producing concrete of having certain minimum workability, strength and durability as economically as possible.

Design of a mix not only needs the knowledge of properties of all ingredients and the properties of concrete in plastic condition, but it also requires wider knowledge and experience of concreting.

Types of Mix Design

A mix can be designed in two ways as explained below :

1. Nominal Mix

It is used for relatively unimportant and simpler concrete works. In this type of mix, all the ingredients are prescribed and their proportions are specified. Therefore, there is no scope for any deviation by the designer. Nominal mix concrete may be used for concrete of M-20 or lower. The various ingredients are taken as given below in Table-1 (Ref : IS 456-2000)

Table-1

Grade	Max. Qty of Dry Aggregates per 50 kg of cement	FA : CA by mass	Max. quantity of water in litres
M-5	800	Generally 1:2 but may vary from 1:1.5 to 1:2.5	60
M-7.5	625		45
M-10	480		34
M-15	330		32
M-20	250		30

As per Concrete Bridge Code, Nominal Mix of concrete may be used for concrete of Grade M-20 for bridge works as above with the condition that water should not be more than 25 litres.

2. Design Mix

It is a performance based mix where choice of ingredients and proportioning are left to the designer. The user has to specify only the requirements of concrete in fresh as well as hardened state. The requirements in fresh concrete are workability and finishing characteristics, whereas in hardened concrete these are mainly the compressive strength and durability.

Designation of concrete

Concrete is generally characterized by 'compressive strength' and designated by 'Grade of concrete'. As per IS: 456-2000, the grade of concrete is 28 days characteristics compressive strength of concrete cube of 15 cm size expressed in N/mm^2.

Grades of Concretes as per Table 2 of IS 456-2000

Group	Grade Designation	Specified Characteristic compressive strength of 150 mm Cube at 28 days N/mm^2
(1)	(2)	(3)
Ordinary Concrete	M10	10
	M15	15
	M20	20

Standard Concrete	M25	25
	M30	30
	M35	35
	M40	40
	M45	45
	M50	50
	M55	55
	M60	60
High Strength Concrete	M65	65
	M70	70
	M75	75
	M80	80
	M85	85
	M90	90
High Strength Concrete	M95	95
	M100	100

NOTES

1. In the designation of concrete mix M refers to the mix and the number to the specified characteristic compressive strength of 150 mm size cube at 28 days, expressed in N/mm^2.
2. For concrete of grades above M 60, design parameters given in the standard may not be applicable and the values may be obtained from specialized literatures and experimental results.

Sampling

1. The number of samples to be taken depends upon the quantity of concrete as shown below in Table-2.

Table-2 (Ref.: IS 456-2000 Cl.15.2.2)

Quantity of concrete (m^3) in the work	No. of samples
1 – 5	1
6 – 15	2
16 – 30	3
31 – 50	4
51 & above	4 + 1 for each 50 m^3 or part thereof

2. However, a minimum of one sample should be taken from each shift. Where concrete is produced at continuous production unit, such as ready-mixed concrete plant, frequency of' sampling ln a day be agreed upon mutually by suppliers and purchasers.

   These shall be made for testing at 28 days. Additional samples may be required for various purposes such as to determine the strength of concrete at 7 days or at the time of striking the formwork, or to determine the duration of curing etc.

3. The samples should be taken at random and it should be representative sample. Approximately 0.02 cum concrete should be collected from the sampling mass from 4-5 places and thoroughly mixed on non-absorbent flat surface to prepare one sample (IS: 1199, Part-1).

Cube Casting

Cubes are casted with the same concrete which is being used in the structure. Concrete is filled up in the mould in three equal layers, each layer being tamped with the help of a bullet headed tamping rod of 16 mm ϕ and 600 mm length by giving 35 strokes in each layer. Alternatively, the compaction can also be done using needle vibrator or table vibrator but instead of inserting the needle into the mould, the vibration should be given indirectly by placing a wooden piece over the cube and touching the needle at middle of the wooden piece.

Marking of sample number for identification of sample is made on the green concrete. The cube in the mould is covered with a damp cloth. It is stripped after 16-24 hours and then submerged in clean water pond till the testing is done.

Damaged specimens shall not be tested. Specimens that are badly honeycombed shall not be regarded as being representative of the quality of concrete supplied. When such specimens are tested, the test report shall include the fact that the specimen was honeycombed.

Cube Testing

3 cubes constitute one sample. At the time of testing, the cube should be so placed on the machine such that smooth faces should be on top and bottom.

The load shall be applied without shock and shall be increased continuously at a constant rate of 14 N/mm^2/min until no greater load can be sustained. The maximum load indicated shall be recorded.

The test results of the sample shall be the average of the strength of three specimens. The individual variation should not be more than ±15 percent of the average. If more, the test results of the sample are

invalid. (Clause 15.4 of IS 456-2000).

Assessment of Type of Failure-

For cube specimens, if the failure is satisfactory (see Figure-1), this fact shall be recorded. If the failure pattern is unsatisfactory (see Figure-2), this fact shall also be recorded.

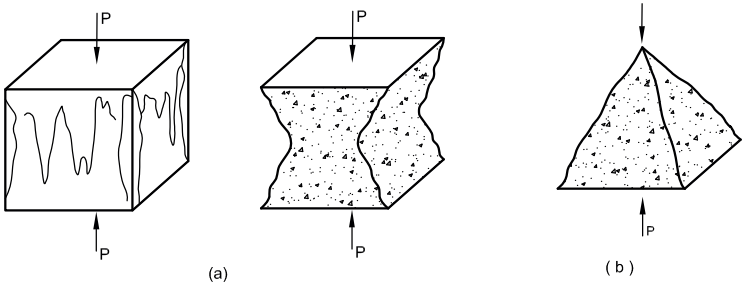
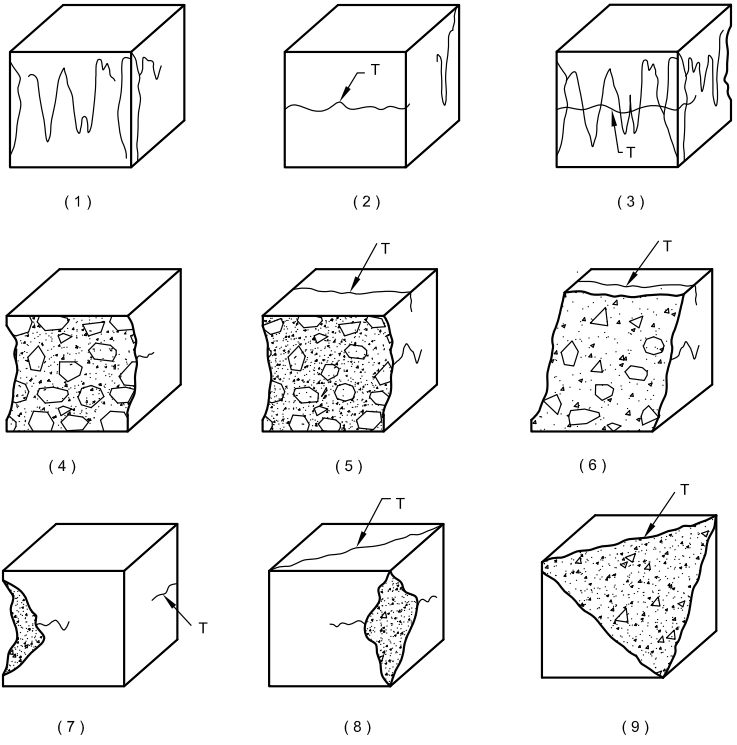


FIG. 1 SATISFACTORY FAILURE OF CUBE SPECIMENS



NOTE: T = TENSILE CRACK

FIG. 2 UNSATISFACTORY FAILURE OF CUBE SPECIMENS

The compressive strength is given by the equation: $f_c = F/A_c$

where

f_c = compressive strength, in MPa;

F = maximum load, in N; and

A_c = cross-sectional area, in mm^2, of the specimen on which the compressive force acts.

The compressive strength shall be expressed to the nearest 0.5 MPa. (Cl.3.6 of IS 516 part I Sec 1 : 2021)

The actual dimensions of test specimens shall conform to IS 10086. If the actual dimensions are within the tolerance limits as mentioned in IS 10086, the strength may be calculated on the basis of designated size. If the actual dimensions are outside this tolerance, the strength calculation shall be based on the actual dimensions of the test specimen, however, perpendicularity of the surface of specimens should be maintained as per IS 10086.

Importance of Cube Test

Although cube strength does not represent the actual strength of concrete in the structure because of many reasons as explained in the forthcoming paragraphs, yet the importance of cube testing can't be underestimated because of the following reasons:

(i) It indicates the potential strength of the mix.

(ii) It detects the variation in quality control at site.

(iii) It helps in determining the rate of gain of strength of concrete.

(iv) It helps in determining the time of removal of form work.

However as mentioned above, the cube strength does not guarantee the same strength in the structure because of the following reasons:

(i) The concrete in cubes does not pass through the misadventures of transportation, placement, compaction and curing. All these processes are much superior in cube as compared to the structure.

(ii) Its shape is different from the shape of structures. Therefore, the shape factor also plays an important part in strength.

Statistical interpretation of cube results

A number of factors can influence the results of the cube test like material, their proportions, various processes like mixing, compaction and curing and finally the testing procedure of cubes. Even the results of different cubes cast from the same concrete at the same time, cured and tested in similar way may also show different results. Therefore, for evaluation of the test results, the help of statistical approach is required.

When the test results of a large number of cubes, prepared under similar conditions, are plotted on a histogram, the results are found to follow a definite 'bell shaped curve' known as 'Normal Distribution Curve'. It will be further observed that a large number of cubes will have the strength near the mean value and the no. of cubes having more or less strength will reduce progressively depending upon the difference from the mean value. This deviation in strength represents quality control in the field. As shown in Fig-3, the quality control of curve 1 is very good, for curve 2, it is good and for curve 3, it is poor.

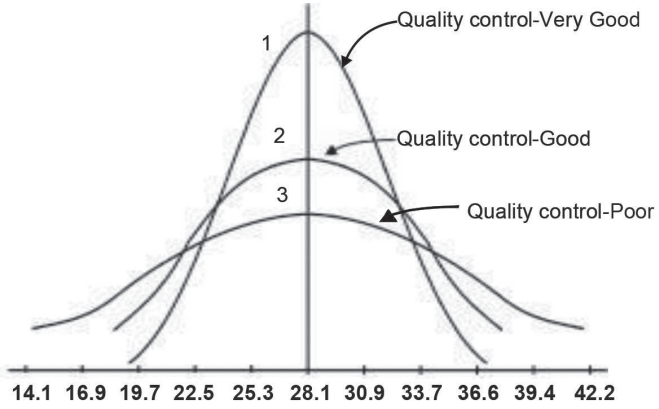


Figure - 3 :

Statistically this deviation is known as 'Standard Deviation' and it can be calculated by the formula given below.

$$S.D.\ (\sigma) = \sqrt{\frac{\sum (x - \mu)^2}{n - 1}}$$

Where

x = value for individual cube

n = total number of cubes.

μ = Arithmetic mean of 'n' cubes

S.D. will be less if the 'Quality Control' at site is better and most of the cube results will be clustered near the mean value. If quality control is poor, the test results will have value much different from mean value and therefore, Standard Deviation will be higher.

Target Mean Strength

From the behaviour of the 'Normal Distribution Curve', it is clear that when we are testing a large number of cubes, all the cubes will not have the same strength even if these are cast and tested in identical conditions. Some cubes will have higher strength than mean value whereas other cubes will have lower strength. The deviation from the mean value is indicated by 'Standard Deviation'. It has been found from the experiments that the area under the 'Normal Distribution Curve' will follow certain behaviour such that the area covered within a distance equal to one S.D. on either side from mean will be equal to 34.1% of total area. Similarly, second and third S.D. on each side will cover additional area of 13.6% and 2.2% respectively. Combined together, approximately 99.9% area will be covered within distance equal to 3 x S.D. on each side from mean value as shown in Fig-4.

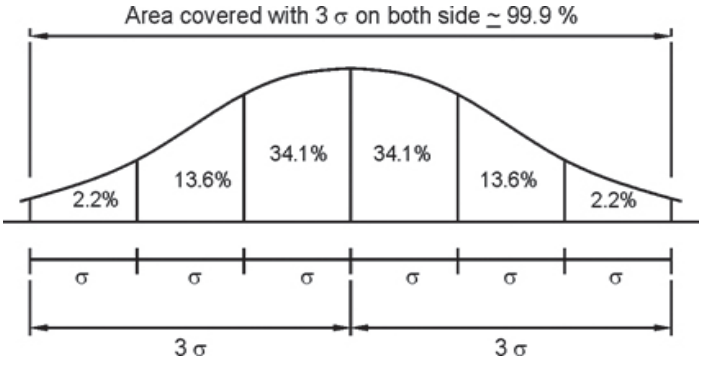


Figure - 4

From this figure it is also clear that if we target the strength equal to mean value, the probability is that only 50% cubes will have strength equal to or more than the required strength. If we want to increase the percentage of cubes having strength equal or more than the required strength, we will have to target for higher strength. So instead of placing the desired strength at mean value, place it on the left side of mean value by a distance equal to k x S.D. where k will depend upon the percentage of cubes we want to have strength equal to or more than the desired strength. This is depicted in Fig-5.

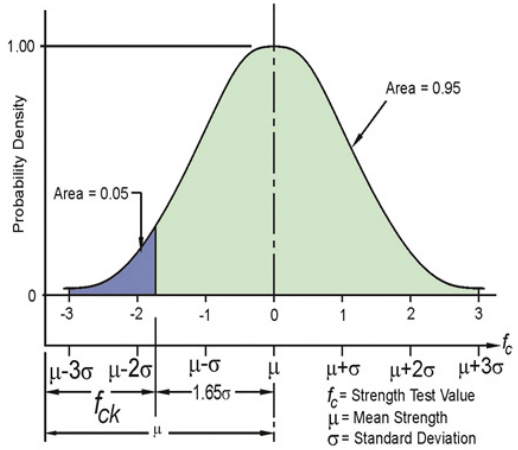


Figure - 5

As per the definition of characteristic strength as per clause 6.1.1 of IS : 456:2000, this percentage is 95% and therefore the desired strength has to be placed at 1.65 times S.D. left of mean, such that now mean = desired strength + 1.65 x S.D.

In fact, the desired strength is called 'Characteristic Strength (fck)'. The value of 1.65 is based upon the provision that 5% of the test results can be accepted having lower than the required strength. The mean value is called 'Target Mean Strength (TMS)'. Therefore,

TMS = fck + 1.65 x S.D.

Understanding the Normal Distribution Curve

The ordinate, 'Probability Density' as given in Fig-5 represents the number of cubes at a particular strength. In fact, it shows the probability of concentration of test results at this strength as shown in Fig-6.

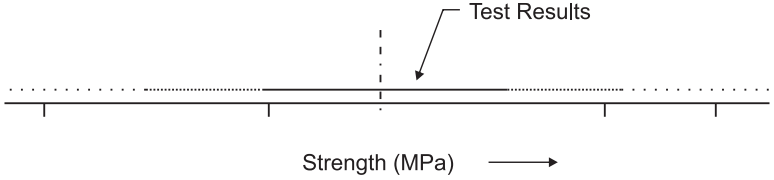


Figure - 6 : Probability Density of cube results

The concentration at mean value depends upon 'quality control' and S.D. If value of S.D. is less, the probability of concentration of test results will be higher at the mean value and therefore, the curve will shrink from both side and rise at centre as shown by 'curve 1' in Fig-3.

Design of Mix - Target Strength for Mix Proportioning

While designing the mix, we have to target for a higher strength called 'Target Mean Strength (f'ck)' so that not more than 5% test results fall below a desired strength called 'fck' i.e. Characteristics Strength (CS).

As per IS 10262 the margin over characteristic strength is given by the following relation:

$f'ck = fck + 1.65\ S$

or

$f'ck = fck + X$ whichever is higher.

Where,

f'ck = target mean compressive strength at 28 days, in N/mm^2;

fck = characteristic compressive strength at 28 days, in N/mm^2;

S = standard deviation, in N/mm^2; and

X = factor based on the grade of concrete, as per Table-1 of IS 10262.

Standard deviation is to be mathematically calculated when minimum 30 test results of compressive strength are available.

Where sufficient test results for a particular grade of concrete are not available, the value of standard deviation given in Table-2 of IS 10262-2019 may be assumed for the proportioning of mix in the first instance. As soon as the results of samples are available, actual calculated standard deviation shall be used and the mix may be proportioned suitably.

Assumed Standard Deviation as per Table-2 of IS 10262-2019 is as under-

S N	Grade of Concrete	Assumed Standard Deviation N/mm^2
(1)	(2)	(3)
i)	M10 M15	3.50
ii)	M20 M25	4.0
iii)	M30 M35 M40 M45 M50 M55 M60	5.0

iv)	M65 M70 M75 M80	6.0

NOTES

1. The above values correspond to good degree of site control having proper storage of cement, weigh batching of all materials, controlled addition of water, regular checking of all materials, aggregate grading and moisture content and regular checking of workability and strength. Where there are deviations from the above, the site control shall be designated as fair and the values given in the above table shall be increased by 1 N/mm2.
2. For grades M65 and above, the standard deviation may also be established by actual trials based on assumed proportions before finalizing the mix.

X factor as per Table 1 of IS 10262-2019 is as under-

S N	Grade of Concrete	Value of X
(1)	(2)	(3)
i)	M10 M15	5.0
ii)	M20 M25	5.5
iii)	M30 M35 M40 M45 M50 M55 M60	6.5
iv)	M65 and above	8.0

Assumed Standard Deviation values have also been stipulated in Cause 8.7.5.3 of IRS: CBC as given below-

Grade of Concrete	Assumed Standard Deviation N/mm^2
M20	4.6
M25	5.3
M30	6.0
M35	6.3
M40	6.6
M45	7.0
M50	7.4
M55	7.6
M60	7.8

Acceptance Criteria (As per IS-456:2000)

(1) Compressive Strength

The concrete shall be deemed to comply with the strength requirements when both the following condition are met:

a) The mean strength determined from any group of four consecutive test results compiles with the appropriate limits in col 2 of Table-11 of IS:456

b) Any individual test result complies with the appropriate limits in col 3 of Table 11 of IS:456.

Table-11 of IS:456 is reproduced as under-

Table-11 Characteristic Compressive Strength Compliance Requirement (Clause 16.1 and 16.3 of IS:456)		
Specified Grade	Mean of the Group of 4 non-overlapping Consecutive Test Results in N/mm^2 (minimum)	Individual Test Results in N/mm^2 (minimum)
(1)	(2)	(3)
M15 and above	fck + 0.825 x established standard deviation (rounded off to nearest 0.5 N/mm^2) or fck + 3 N/mm^2, whichever is greater	fck – 3 N/mm^2

NOTES :

1. In the absence of established value of standard deviation, the values may be assumed [as discussed above] and attempt should be made to obtain results of 30 samples as early as possible to establish the value of standard deviation.
2. For concrete quantity upto 30 m^3 (where the number of samples to be taken is less than four as per the frequency of sampling), the mean of the test results of all such samples shall be f_{ck} + 4 N/mm^2, minimum and the requirement of minimum individual test results shall be f_{ck} – 2 N/mm^2, minimum. However, when the number of sample is only one, the requirement shall be f_{ck} + 4 N/mm^2, minimum.

(2) Flexural Strength

The concrete shall be deemed to comply with the flexural strength requirements when both the following conditions are met:

a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 0.3 N/mm^2.

b) The strength determined from any test result is not less than the specified characteristic strength less 0.3N/mm^2.

Specified Characteristic Flexural Strength = $0.7\sqrt{fck}$ N/mm^2

Where,

f_{ck} = Characteristic Compressive Strength of Concrete

Example :

Check the following test results according to Acceptance Criteria assuming f_{ck} = 20 N/mm^2 and established standard deviation of 3.4 N/mm^2.

22, 25, 23, 22.9, 22.75, 24.75, 25.50, 19.50, 24.9, 26.2, 23.75, 18

(All in N/mm^2)

Solution :

In above results, we should not worry even if some of the test results are having value less than fck. We have to check the test results as per Acceptance Criteria as given below :

(i) The mean of 4 consecutive test results should be

≥ fck + 0.825 x 3.4 or ≥ 22.81 N/mm^2

or

≥ fck + 3 or ≥ 23 N/mm^2

(ii) Individual result should not be less than fck – 3, i.e 20 – 3 = 17 N/mm^2

Calculating mean of set of four cubes

Mean of 1st set= (22 + 25 + 23 + 22.90)/4 = 23.23

Mean of 2nd set= (22.75+24.75+25.50+19.50)/4 = 23.13

Mean of 3rd set= (24.9 + 26.2 + 23.75 + 18)/4 = 23.21

The mean of all the three sets are more than or equal to 23N/mm^2, therefore, first criteria is satisfied and since no test result is having value less than 17 N/mm^2, the second criteria is also satisfied.

Therefore, even if the two results are having value less than 20 N/mm^2, the above results have passed the criteria for acceptance.

Acceptance criteria as per Clause 8.7.6.1 of CBC

In CBC, the values are for M-20 and above only. The criterion is as under:

(a) The mean of 4 consecutive test results should exceed 'fck' by at least 3 N/mm^2.

(b) Any individual test result should not be less than 'fck' by 3 N/mm^2.

Mix Design Example

(As per IS : 12062-2019)

Input Data :

(a) Concrete Requirements :

-Grade of concrete = M-40 (for R.C.C.)

-Workability = 75 mm slump

-Exposure condition = Severe

(b) Material

-Grade of cement = PPC satisfying IS:1489 Part-1

-Max. Size of Aggregate (MSA) = 20 mm

-Sand = Zone-II (As per IS : 383)

-Type of Aggregate : Angular

-Superplasticiser to be used which can give water reduction of 23% while using at the rate of 1% by weight of cement.

-Specific Gravity of :

Cement = 2.88

Coarse Aggregate = 2.74

Sand = 2.65

Admixture = 1.145

Solution :

Step-1 Target Mean Strength

TMS = f_{ck} + 1.65 x Standard Deviation (S.D.) where f_{ck} = Characteristic strength of concrete

SD depends upon Grade of Concrete and 'Quality Control' of concrete. The assumed S.D. as per IS : 10262 for M40 with Good degree of site quality control is 5.0 and X value for M-40 Grade of concrete is 6.5.

Therefore, TMS = 40 + 1.65 x 5.0 = 48.25 N/mm^2

OR

40 + 6.5 = 46.5 N/mm^2

Whichever is more

Say 48.25 N/mm^2

Step- 2 Water–Cement Ratio

A graph between 28 days compressive strength in N/mm^2 and w/c ratio is available in IS:10262 as Figure -1 for different grades of cement. For PPC and Slag Cement, graph applicable for 43 grade cement is used. From this graph, w/c ratio may be adopted for initial design calculations corresponding to Target Mean Strength. However, if designer has his own experience and idea about any other value of w/c ratio, that also can be adopted for initial design trial calculations.

In our case, for PPC, we have to use Curve no-2 and according to it, for TMS 48.25 N/mm^2, w/c ratio is 0.36. This value should be in conformity with the durability requirements as per table-5 of IS:456 where maximum limit of w/c ratio has been prescribed for different exposure conditions from durability point of view.

Table-5 of IS:456 is as under-

Table-5 Minimum Cement Content, Maximum water-cemet Ratio and Minimum Grade of Concrete for different exposures with nomal weight aggregate of 20 mm Nominal Maximum size

(Clauses 6.1.2, 8.2.4.1 and 9.1.2 of IS:456)

S N	Exposure	Plain Concrete			Reinforced Concrete		
		Min. Cement Content kg/m³	Max. Free water-cement Ratio	Min. Grade of Concrete	Min. Cement Content kg/m³	Max. Free water-cement Ratio	Min. Grade of Concrete
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
i	Mild	200	0.60	-	300	0.55	M 20
ii	Moderate	240	0.60	M 15	300	0.50	M 25
iii	Severe	250	0.50	M 20	320	0.45	M 30
iv	Very severe	260	0.45	M 20	340	0.45	M 35
v	Extreme	280	0.40	M 25	360	0.40	M 40

Cement content given in above table is adjusted as +40 kg/ -30 kg for 10/40 mm aggregates respectively (Table-6, IS:456).

Clause 5.4 of CBC also specifies similar durability conditions viz-a-viz Minimum Cement Content, Maximum water-cemetitious Ratio and Minimum Grade of Concrete for different exposures in table 4(a), 4(b) and 4(c).

Our durability case is “Severe” for which limiting value of w/c ratio for RCC is 0.45. Hence, w/c rato as 0.36 is acceptable.

Step- 3 Estimation of air in concrete

The entrapped air in concrete depends on nominal size of aggregate. More air is entrapped in smaller size aggregates as compared to larger size. Value of approximate entrapped air is to be taken from Table-3 of IS 10262 which is as under -

Table-3 of IS 10262

Nominal Maximum Size of Aggregates	Entrapped Air (% volume of concrete)
10 mm	1.5%
20 mm	1.0%
40 mm	0.8%

In our case, for 20 mm size of aggregate, the entrapped air will be 1%.

Step- 4 Estimation of water in concrete

The quantity of water in concrete depends upon MSA. Less water is required for higher size of aggregates.

The values of water requirement have been given in Table-4 of IS 10262 which is as under :

Table-4 of IS 10262

MSA (mm)	Quantity of water for each m^3 of concrete (In Litre)
10	208
20	186
40	165

In instant example, MSA = 20 mm

Therefore, quantity of water = 186 kg per m^3 of concrete.

This water requirement is for 'Angular" aggregates. If aggregates are 'Sub angular', 'Gravel' or 'Round', these requirements will be reduced by 10kg, 15kg and 20 kg respectively (Clause 5.3 of IS:10262).

In our case, aggregates are 'angular', so we keep water requirement as 186 litre.

This water requirement is for Slump value of 50 mm. For Slump requirement more than 50 mm, water content is increased by 3% for every increase of 25 mm in slump (Para 5.3 of IS:10262).

In our case, Slump requirement is 75mm, so water requirement will be adjusted as under-

186 + 3*186/100 = 191.58 lit

This water requirement can be reduced by using plasticisers. In our case, superplasticiser at the rate of 1% of the weight of cement can give water reduction by 23%.

Hence modified water requirement = 191.58 * 0.77 = 147.52 lit; say 148 litre per m^3 concrete.

If designer has his own experience and idea about any other value of water quantity, then he can adopt that also for initial design trial calculations.

Step-5 Calculation of cement quantity

C = w/(w/c) = 148/0.36 = 412 kg

This quantity of cement needs to be checked against requirement

from durability consideration given in table-5 of IS:456. As per this, for 'severe' exposure condition for RCC, minimum cement content should be 320 kg. Hence 412 kg is acceptable.

Step-6 Calculation of Aggregate content

We have already calculated water and cement for one cubic meter of concrete.

Gross volume of concrete = Volume of water + Volume of cement + Volume of admixture + Volume of total aggregates + Volume of entrapped air in concrete.

Ratio of Course Aggregate to the Total Aggregates by volume for different combination of CA and FA have been given in Table-5 of IS:10262 which is reproduced as under-

Table-5 of IS:10262

Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate for Water-Cement / Water-Cementitious Materials Ratio of 0.50

S N	Nominal Maximum Size of Aggregate mm	Volume of Coarse Aggregate per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate			
		Zone-I	Zone-II	Zone-III	Zone-IV
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.54	0.52	0.50	0.48
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.73	0.72	0.71	0.69

1. Volumes are based on aggregates in Saturated Surface Dry condition.

2. These volumes are for crushed (angular) aggregates and suitable adjustments may be made for other shapes of aggregates.

3. Suitable adjustments may also be made for fine aggregates from other than natural sources, normally, crushed sand or mixed sand may need lesser fine aggregate content. In that case, the coarse aggregate volume shall be suitably increased.

4. It is recommended that fine aggregates conforming to Grading Zone IV, as per IS 383 shall not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions. It is because in fine sand, the percentage of voids is more, and concrete formed with this sand will be more permeable than coarse sand. Embedded reinforcement is more susceptible to corrosion in permeable concrete.

In our case, for 20 mm aggregates and zone-II sand, this ratio is 0.62.

This ratio is suitable for w/c ratio 0.5. For other value of w/c ratio, it is to be changed by -/+0.01 for every change of +/-0.05 in w/c ratio value (Para 5.5.1 of IS 10262).

In our case, w/c ratio is 0.36, so corrected ratio will be -

0.62 + 0.01*(0.50-0.36)/0.05 = 0.648

For Pumpable concrete, this ratio should be reduced by 10% (Para 5.5.2 of IS 10262). In our case, the concrete is not pumpable, hence no modification is required.

Thus adopted CA / Total Aggregate ratio value = 0.648

Ratio of FA = 1-0.648 = 0.352

Total Volume of Aggregates = Volume of Concrete - Volume of water - Volume of cement - Volume of admixture - Volume of entrapped air in concrete

- Total Volume of Concrete = Say 1 m^3
- Volume of Cement = 412/(2.66*1000) = 0.143 m^3
- Volume of water = 148/1000 = 0.148 m^3
- Volume of admixture 1% of 412 kg/(1.145*1000) = 0.0036 m^3
- Volume of Entrapped Air = 1% = 0.01m^3

Hence,

- Total Volume of Aggregates = 1- 0.143 – 0.148 – 0.0036 – 0.001 = 0.695 m^3

Hence,

- Qty of CA = 0.695 * 0.648 * 2.74 * 1000 = 1233.98 Kg
- Qty of FA = 0.695 * 0.352 * 2.65 * 1000 = 648.29 Kg

So, Mix proportion for Trial Mix TM-0 is as under :-

Cement = 412 kg

Water content = 148 kg

Fine aggregate = 648 kg

Coarse aggregate = 1234 kg

Admixture = 4 kg

Step-7 Trial Mixes

Prepare the concrete mix with the above proportion of ingredients and find out the workability. If the workability is exactly same as required i.e. 75 mm slump, then no further adjustment is made. But if the measured

workability is different from initially assumed, then water content adjustment will be made accordingly. Water requirement which suits to our workability requirement will be corrected water requirement (say W1) as per workability requirements and this will be the final value considered for further design calculations. Keeping the water cement ratio same, the quantity of cement will also be adjusted with corrected water requirement. Now the final quantities of other materials will again be calculated using the equations as above as the water and cement quantities have changed now. Let us call this trial mix as TM-1.

Two more trial mixes TM-2 & TM-3 will be made, one with 10% less w/c ratio and other with 10% more w/c ratio but keeping the water content same as corrected above as final water requirement. All these trial mixes will be as under-

	Water (kg)	**Cement (kg)**	**w/c**	**FA (kg)**	**CA (kg)**
TM-0	W=148	C=412	0.36	648	1234
TM-1	W1	C1	0.36	FA1	CA1
TM-2	W1	C2	1.1x0.36	FA2	CA2
TM-3	W1	C3	0.9x0.36	FA3	CA3

Now we will cast one sample (three cubes) with each trial mix, TM-1, TM-2 and TM-3 and find out the 28 days' compressive strength. This strength is plotted against w/c ratio and a curve will be obtained as given under in Figure - 7.

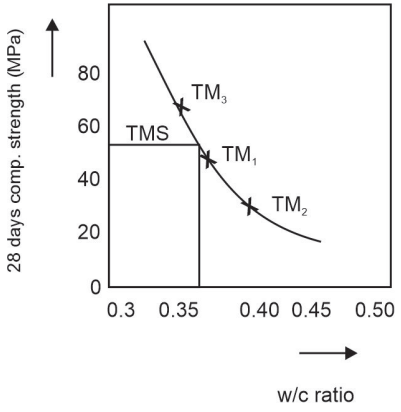


Figure - 7 : Strength v/s w/c ratio

From the above curve we can determine the w/c ratio for the required TMS i.e. 48.25 N/mm^2 in our case. This w/c is used to calculate again the

ingredient quantities using above equations with same corrected water requirement as calculated above. Final quantities to be verified as per the durability requirement of table-5 of IS : 456. If it does not, then, it is to be further modified to follow the limiting values as per table-5 of IS:456 from durability point of view.

Final values so arrived will be the design mix which satisfies the durability, workability and strength requirements as per the TMS and can be followed in field.

However, in field, moisture correction is required as per site condition.

Moisture Correction in Fields

Design mix is prepared by assuming aggregates in Saturated Surface Dry (SSD) condition. Means aggregates are assumed to have moisture content as equal to water absorption values. Water absorption is the moisture content in aggregates at which all the pores of aggregates are completely saturated and there is no free/excess moisture on the surface. However, in fields, actual moisture content may vary. If aggregates are in different state of moisture content than SSD condition, field moisture correction becomes essential.

In summer season, there is a possibility that pores are not completely saturated. In this case, extra water has to be added to the extent of making aggregate pores fully saturated. Otherwise, concrete will become stiff and less workable. Similarly, in rainy season, when there is excess moisture in aggregates, addition of water should be reduced.

Limitations of Maximum Cement Content in Concrete

High cement content increases risk of –

(a) Cracking due to drying shrinkage in thin sections.

(b) Early thermal cracking.

(c) Damage to concrete due to alkali silica reactions.

Due to these reasons, maximum cement content in concrete has been restricted.

As per IS:456, cement content not including fly ash and ground granulated blast furness slag in access of 450 kg/m^3 should not be used unless special consideration has been given in design to the increased risk of cracking due to drying shrinkage in thin sections or to thermal cracking and to the increased risk of damage due to alkaly silica reaction.

As per Concrete Bridge Code provisions, maximum cementitious material content in concrete shall be limited to 500kg/m^3.

Data for Mix Proportioning.

As per Clause 4 of IS 10262-2019, following data are required for mix proportioning of a particular grade of concrete:

(a) Grade designation;

(b) Type of cement, and grade of cement (if applicable);

(c) Maximum nominal size of aggregate;

(d) Minimum cement/cementitious materials and maximum water-cement/ cementitious materials ratio to be adopted; or Exposure conditions as per Table 3 and Table 5 of IS 456;

(e) Workability required at the time of placement;

(f) Transportation time - On account of long distances over which concrete needs to be carried from batching plant/ RMC plant, the concrete mix is generally designed for a higher slump initially than the slump required at the time of placing. The initial slump value shall depend on the distance of transport and loss of slump with time.

(g) Method of placing- like pumpable concrete

(h) Degree of site control (good/fair) or value of established standard deviation, if any;

(i) Type of coarse aggregate (angular/sub angular/gravel with some crushed particles/ rounded gravel/ manufactured coarse aggregate);

(j) Type of fine aggregate (natural sand/ crushed stone or gravel sand/manufactured sand/ mixed sand)- Zone of sand as per IS 383

(k) Maximum cement content – from durability point of view to limit Alkali-Silica reaction

(l) Whether a chemical admixture shall or shall not be used and the type of chemical admixture and the extent of use;

(m) Whether a mineral admixture shall or shall not be used and the type of mineral admixture and the extent of use; and

(n) Any other specific requirement like early age strength requirements.

In absence of complete and correct input data, incorrect inferences may be drawn by the designer and mix design may not be appropriate.

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CHAPTER 7
DURABILITY OF CONCRETE

Today durability of concrete has become the greatest concern of civil engineers. In the recent past, a few bridges have collapsed, highlighting the need for durability. Mandovi road bridge of Goa collapsed in 1986 within 15 years of construction and Poonam Chambers Bridge of Mumbai collapsed in 1997 within 25 years of construction. Similarly, many other bridges like Thane Creek road bridge Mumbai, Vasai creek road bridge Mumbai and Zuari bridge Goa have become distressed. All these bridges are on coastal regions, therefore, the needle of suspicion points to the corrosion of reinforcement. In most of the cases the primary reason for distress is not the quality of construction, but the lack of awareness of 'durability' concept.

Till recent years, our main concern was the strength of concrete indicated by cube strength. Now we have realised that in addition to cube strength, the durability of the structure is also an important parameter which should be taken care of. In fact the cube strength only indicates the strength of the structure at the time of testing which may reduce with the age whereas the durability is the long term guarantee of same strength and serviceability of the structure. Corrosion of reinforcement steel and disintegration of concrete are the main culprits responsible for less durability.

Mechanism of Corrosion

Concrete provides an ideal protective environment to steel from corrosion. Fresh concrete is highly alkaline in nature due to presence of Na, K and Mg hydroxides. Due to the high initial alkalinity, an extremely thin passive film of ferric-oxide (Fe_2O_3) is formed on the surface of steel. This layer, though extremely thin, effectively protects the steel from corrosion. But unfortunately, this layer is effective as long as the surrounding concrete remains alkaline. Therefore, if we can manage to keep the environment alkaline, the corrosion of steel can effectively be prevented and the durability of the structure can be ensured. The alkaline medium can be maintained for a longer period by making the concrete impermeable.

Corrosion is an electro chemical process in which one part of steel becomes anode and the other cathode. Fortunately, anode reaction can't start till the passive ferric oxide film is destroyed by the acidic medium or it is made permeable by the action of chloride ions. Similarly,

the cathode reaction can't start till sufficient supply of oxygen and water is available at the surface of steel. It can, therefore, be concluded that corrosion of steel can be prevented if the concrete is sufficiently impermeable so as to keep air, water and other such agents out of its reach.

Process of change in pH value

Alkalinity and acidity are measured on a pH value scale as given below.



Initially, cement in the hydrated form is alkaline in nature due to production of abundance of $Ca(OH)_2$, presence of $Mg(OH)_2$ and NaOH. Normally OPC contains approximately 20% alkalies by weight in the pore fluid, which is sufficient to maintain a high pH value in the range of 12-13. But due to permeability in the concrete, this alkalinity is either destroyed due to carbonation or neutralised by acidic medium caused by various agents. Consequently, the pH value of concrete falls below the value 11.5 which is the value below which the corrosion process in the reinforcement starts. The atmospheric agents which are responsible for reduction in pH value are CO_2, Cl^- and SO_2^- in presence of oxygen and water. A lot of CO_2 is available in the atmosphere ranging from 0.04% in rural areas to 0.4% in urban areas. This CO_2 penetrates the hydrated concrete and neutralises the alkaline medium bringing the pH value down. When the carbonation penetrates the full cover depth, it attacks the reinforcement and the passive film of ferric-oxide is destroyed. All these enemies attacking the concrete are shown in Figure-1.

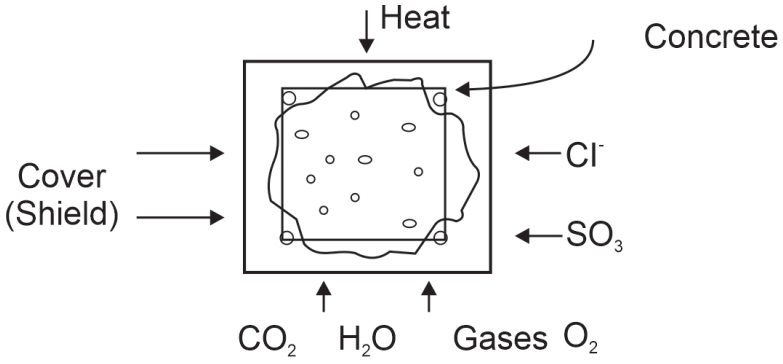


Figure - 1 : Enemies attacking concrete

Now the steel surface becomes active acting as anode and the other inactive surface becomes cathode. Due to this development the electro-

chemical reaction starts as shown in Figure-2.

At Anode

$Fe \rightarrow Fe^{2+} + 2e^{-}$

At Cathode

$2e^{-} + H_2O + ½\ O_2 \rightarrow 2(OH)^{-}$

At Anode

$Fe^{2+} + 2(OH)^{-} \rightarrow FeO.H_2O$ (Rust)

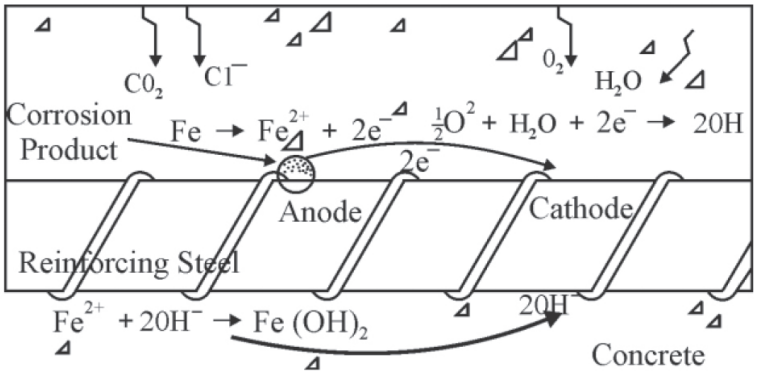


Figure - 2 : Electro-chemical Process of Corrosion

These reactions can take place when concrete is permeable and allow oxygen, moisture, CO_2, SO_3^{-} and Cl etc. to reach up to reinforcement. Further oxidation of rust also takes place and its volume progressively increases with each level of oxidation. Finally, the volume of rust becomes nearly 6 times the volume of steel oxide layer, as shown in Table-1 which obviously can't be accommodated in the set concrete and cracking and spalling of concrete is eventually started.

Table-1

Different Levels of Oxidation	FeO	Fe_3O_4	Fe_2O_3	$Fe(OH)_2$	$Fe(OH)_3$	$Fe(OH)_3 3H_2O$
Volume Increase	**1**	**2**	**3**	**4**	**5**	**6**

It can be concluded from the above discussion that if the concrete is made impermeable and supply of various agents which are responsible for the reaction are effectively prevented from reaching the reinforcement then the process of rusting will automatically be avoided.

Process of Carbonation

Carbonation is the reaction of CO_2 with hydrated concrete.

Carbonation Phenomenon is explained below-

$CO_2 + H_2O \rightarrow H_2CO_3$ (Carbonic Acid)

$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + H_2O$

$CaCO_3$ make the concrete acidic and also causes volume increase. Carbonation is more predominant when humidity is between 40-80%. Too wet and in too dry atmospheric conditions are less conducive for carbonation.

Due to this reaction the alkaline nature of concrete gets neutralised and it paves the way for corrosion of reinforcement. The most common method to detect carbonation is to spray a cut or broken concrete section with a phenolphthalein alcoholic solution. The solution remains clear on carbonated concrete, but turns pink at non-carbonated areas. The test is actually an indicator of pH of concrete surfaces, but as carbonation reduces pH, this test also provides an indirect indication of carbonation. This reaction starts at the surface of the concrete and penetrates into the concrete. The rate of penetration depends upon the permeability of concrete. The time taken for carbonation to reach the level of reinforcement depends upon permeability as well as the cover of concrete.

$D = k\sqrt{t}$ or $t \alpha D^2$

where t is concrete exposure time, D is depth of carbonation and 'k' is a carbonation constant.

If the cover is more, the carbonation time will also be more. The factor 't' depends upon concrete permeability. As per 'Concrete Bridge Code', the permeability test is mandatory for all major bridges in all exposure conditions and for all RCC/PSC bridges when exposure condition is severe/very severe or extreme. It has further been stipulated that even in mild or moderate exposure conditions, it is desirable to conduct permeability test for other than major bridges also. The procedure of permeability test of concrete is as explained below and shown in Figure-3.

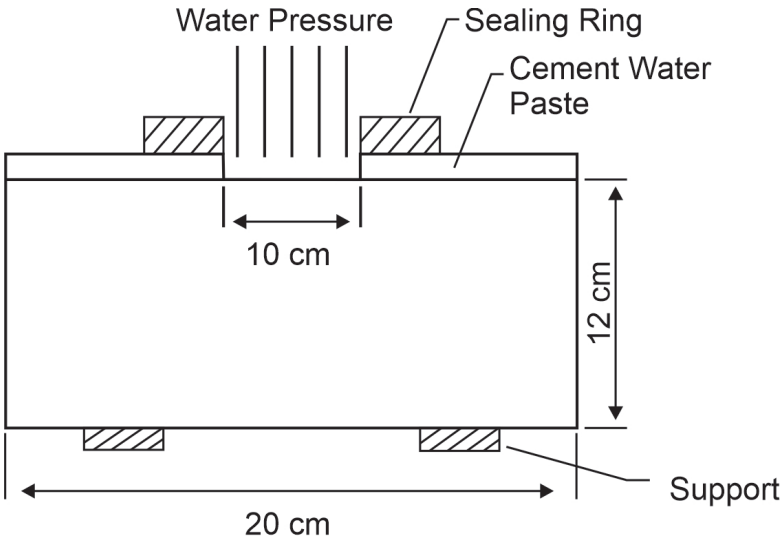


Figure - 3 : Permeability Test

Permeability Test

1. Three concrete specimens, each of 200 mm dia and 120 mm height are cast.
2. After 24 hrs, the middle portion of 100 mm dia is roughened and the remaining portion is sealed with cement paste.
3. The specimen is cured for 28 days and then water pressure is applied on the middle roughened portion so that water can penetrate inside the concrete. The water pressure is maintained as given under.
   (a) 1 bar (1 kg/cm^2) for 48 hours.
   (b) 3 bars for next 24 hours
   (c) 7 bars for next 24 hours.
4. After this, the specimen is split to know the penetration of water. The specimen is split in compression machine by applying concentrated load at two diagonally opposite points slightly away from central axis. The average of three maximum values of penetration is calculated. The depth of penetration of water should not be more than 25 mm otherwise the specimen is considered to be failed in permeability test.

   Permeability of concrete can be minimized by adopting low w/c ratio, ensuring proper compaction and curing of concrete.

Good Construction Practices

In order to improve the workmanship of concrete, the following good practices to be adopted in field :

1. Sequencing of concrete work should be finalised in advance so that the first layer does not set before the next layer is placed over it. The concrete shall be placed before initial setting of concrete has commenced and shall not be subsequently disturbed. Fresh concrete shall not be placed against concrete which has already been started setting, unless a proper construction joint is formed. Concrete shall be deposited in horizontal layers to a compacted depth of not more than 450 mm when internal vibrators are used and not exceeding 300 mm in case of surface vibrators. This can be ensured by carefully planning the following items :
   (a) Capacity of mixers and vibrators
   (b) Initial Setting Time of cement
   (c) Man power to be deputed
2. Cold joints should be avoided by forward flowing method of concreting as shown in Figure - 4.

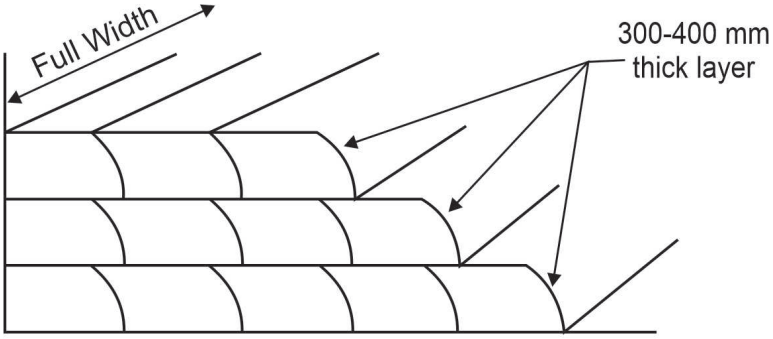


Figure - 4 : Step Placing in Concrete

3. The concrete shall be deposited as nearly as practicable to its final position to avoid rehandling. Concrete shall be placed so as to avoid segregation of material or displacement of reinforcement. Concrete should not be dropped from a height more than 1.5m.
4. Provide proper construction joint at the end of days' work. Laitance of cement, which has risen up to the surface due to vibration, should be removed before next days' concreting because it is highly permeable. It should be removed by wire

brush and aggregates should be exposed without dislodging in such a manner that 1/3 of aggregates should be visible on the surface. This is called 'Hacking of joints'. Never sprinkle cement slurry before next days' concrete.

5. To prevent leakage of cement slurry through shutter plate joints, 10 mm thick sponge should be used.
6. Cover block should have the comparable strength, durability and permeability as that of the main concrete.
7. Excess water is detrimental to the strength and durability. Addition of water should be controlled. Only specified quantity of water as per design mix should be added. Moisture correction as and when necessary, should be done.

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CHAPTER 8
HIGH PERFORMANCE CONCRETE

The simplistic definition of High Performance Concrete (HPC) can be given as 'Concrete having high workability, high strength and high durability'.

With the development of concrete strength beyond M- 120, concrete as a building material has started competing with the strength of ordinary reinforcement steel at least in compression. One major breakthrough responsible for this feat is the use of admixtures i.e. chemical admixture like super-plasticizer and mineral admixtures like fly-ash, blast furnace slag and micro silica. Chemical admixtures increase the strength of concrete by reducing the w/c ratio, whereas mineral admixtures play an important role in increasing the durability of the concrete.

HPC era began with the use of M-50 in the year 1965 for 'Lake Point Tower' in Chicago. After that two 'Union Square' Buildings in Seattle were constructed with M-120 concrete column. Now the use of HPC has become very common the world over.

Ready Mix Concrete

Ready Mixed Concrete (RMC) is the Concrete produced by completely mixing cement, aggregates, admixtures, if any, and water at a Central Batching and Mixing Plant and delivered in fresh condition at site of construction. It is a concrete which is readily available in the mixed form so that it can directly be placed in the formwork. Therefore, the various processes involved in the conventional concrete are accomplished in the factory condition and therefore much superior concrete is obtained in comparison to conventional concrete. The processes which are done away with are as given below:

(a) Storage of material

(b) Proportioning

(c) Mixing

(d) Transportation

All above processes are taken care of by the producers, who are committed to supply the concrete of desired strength and required properties. Based upon the requirement of the user, the proportioning and mixing is done in the central batching plant and then it is transported to the site of placement on truck mounted rotating drum mixers so that the concrete reaches the destination with the required properties in

green state and a commitment for the desired strength in the hardened state.

Truck-mounted Drum Mixer

These mixers have a revolving drum with the axis inclined to the horizontal. There is a pair of blades, inside the drum, in helical configuration from the head to the opening of the drum. This configuration helps in discharging the concrete when the drum revolves in a particular direction. During the transit period, the drum is continuously turned at a speed of approximately 2-6 revolutions per minute (rpm).

Traditionally, the truck mounted mixers discharge the material from rear end but now the front discharging units are also becoming popular. In this type of unit, the driver of the truck can control the unit in a better way and the concrete can directly be discharged at a desired place without taking help of other personnel.

In addition to transportation, sometimes these mixers are used for mixing the concrete also. The drums are designed for a maximum rated capacity of 67% of the gross drum volume when mixing is also done in the truck mixers otherwise this capacity is generally 80-90% of the drum volume.

The lead of concrete should be a design parameter because it is a perishable item which may undergo 'slump loss' depending upon temperature and time taken in delivery at the site. Normally, the concrete shall be discharged at the job site within 90 minutes and before 300 revolutions after water has been added to the cement. When the long delivery time and high temperatures are involved, some admixture such as air entraining, water reducing, retarding or high range water reducers are used.

Types of Ready Mix Concrete

There are three types of RMC depending upon the mixing of the various ingredients as given below :

a) Transit mixed concrete

b) Shrink mixed concrete

c) Central mixed concrete

a) Transit Mixed Concrete

It is also called dry batched concrete because all the basic ingredients including water are charged directly into the truck mixer. The mixer drum is revolved fast at charging speed during the loading of the material and after that it continues rotating at a normal agitating speed. In this type of RMC, three variations are

possible as given below :

(i) Concrete mixed at job site

While being transported towards the destination, the drum is revolved at a slow or agitating speed of 2 rpm but after reaching the site just before discharging the material, it is revolved at maximum speed of 12 to 15 rpm for nearly 70 to 100 revolutions for ensuring homogeneous mixing.

(ii) Concrete mixed in transit

The drum speed is kept medium during the transit time, i.e. approximately 8 rpm for about 70 revolutions. After 70 revolutions, it is slowed down to agitating speed i.e. 2 rpm till discharging the concrete.

(iii) Concrete mixed in the yard

The drum is turned at high speed of 12 to 15 rpm for about 50 revolutions in the yard itself. The concrete is then agitated slowly during transit time.

b) Shrink Mixed Concrete

The concrete is partially mixed in the plant mixer and then balance mixing is done in the truck mounted drum mixer during transit time. The amount of mixing in transit mixer depends upon the extent of mixing done in the central mixing plant. Tests should be conducted to establish the requirement of mixing in the drum mixer.

c) Central Mixed Concrete

It is also called 'central batching plant' where the concrete is thoroughly mixed before loading into the truck mixer. Sometimes the plant is also referred as 'wet-batch' or 'pre-mix plants'. While transporting the concrete, the truck mixer acts as agitator only. These agitators revolve at a speed of 2-6 rpm. Sometimes when workability requirement is low or the lead is less, non-agitating units or dump trucks can also be used.

Advantages of RMC

- Better quality control during production as large quantity is handled at one place and close supervision is possible.
- As a result of use of advanced equipment, dependency on labour is minimised.
- Better quality concrete is produced as a result of minimising human error and consistency in production.

- No need to handle construction materials at the job site, thus Air and Noise pollution at the job site is reduced.
- Large scale handling reduces wastage of basic materials at the site.
- Speedy production facilitates faster construction for major projects like dams, roads, bridges, tunnels, etc.
- Environment-friendly.

Self-Compacting Concrete

Self-Compacting Concrete (SCC) was first developed in 1988 for eliminating human error associated with compaction and also to make it a labour free activity. In Japan where labour is just not available easily, it was developed as a necessity. However, it has been proved to be better in terms of durability, aesthetics and ease of handling for large and important projects.

Mechanism of Self Compaction

Before going through the literature on self compacting concrete, it will be interesting to imagine how it may be possible to achieve self compaction without any external vibration. Similarly, what may be different requirements with respect to ingredients and what problems may be encountered in achieving self compaction with their possible solutions?

As a layman, the SCC should be something like a flowing concrete which should be able to flow up to every nook and corner of the formwork only under gravity. Is it only increasing the workability of concrete? No. Had it been so, then it would not have been so special about SCC because the workability can merely be increased by increasing the w/c ratio or adding suitable plasticizers. In fact, it is the viscosity of the concrete which needs to be modified in addition to increasing the workability. In order to achieve this, one more admixture is also added which is called 'Viscosity Modifying Agent' (VMA).

When concrete is expected to reach every corner of the structure only due to its own weight, some problems are sure to be expected. It has to pass through many obstacles in the form of closely spaced reinforcement and sharp corners etc. The concrete reaching the far end after conquering all these obstacles should have the same consistency as that of original concrete. The obstacles should not be able to block the aggregates and pass the cement mortar alone. In other words, the viscosity of the mortar should be sufficient to carry with it all the ingredients of concrete without any segregation.

In addition to above, the normal size of the aggregates and their proportions adopted in conventional concrete are also not suitable for

SCC. Since the concrete has to travel through a network of reinforcement which is acting like a sieve, the size of coarse aggregates has to be comparatively smaller and their proportion to be reduced. This will help in conquering the blockades smoothly without segregation. Therefore, 'Self Compaction' involves achieving high deformability of mortar so that no segregation occurs when concrete flows through the confined zones of reinforcing bars. The credit for this type of concrete goes to Okamura, Ozawa and Malkawa of Japan.

Problems in achieving self compaction

When concrete is passing through various obstacles, the relative distance between the particles decreases and the frequency of collision and contact between aggregate particles increases. Due to this collision, some extra energy is required to maintain the flow. This extra energy requirement can be controlled by limiting the size and content of coarse aggregates because consumption of energy is maximum in coarse aggregates. In addition to this, if the viscosity of the paste is increased, the latent energy stored in the paste in the form of momentum will be utilised in overcoming the loss of energy.

The viscosity of the mortar is increased by adding 'Viscosity Modifying Agent' and keeping w/c ratio as low as possible. Due to high viscosity, deformability of paste becomes high and it prevents localised increase in internal stresses due to approach of coarse aggregates towards the obstacles. In order to achieve this, the degree of packing of CA is kept less at approximately 50% to reduce the interaction between CA at the time of deformation. Similarly, the degree of packing in fine aggregate is also limited to 60% so that shear deformity is controlled.

Advantages of SCC

(i) Since concrete is capable of filling the formwork completely under its own weight, there is no requirement of vibration. Full compaction is ensured without making elaborate arrangements of internal or external vibration.

(ii) There is no need of finishing the green concrete as very good finish is obtained using SCC. Similarly, there is no need of repairs to hardened concrete as there are no chances honeycombing.

(iii) There is a remarkable improvement in the performance and durability of concrete.

(iv) There is almost no noise pollution as no vibrations required.

(v) It is advantageous to use SCC when the normal placement of concrete is difficult e.g. tunnel linings, heavily reinforced structures, PSC structures and other inaccessible places.

Requirement of Admixtures

Two types of admixtures are required for obtaining Self Compacting Concrete.

1. High Range Water Reducing Agents (HRWRA)
2. Viscosity Modifying Agents (VMA)

1. High range water reducing Agents (HRWRA)

High range water Reducing Agents or Super Plasticizers have been explained in earlier chapter - 4.

2. Viscosity Modifying Agents (VMA)

These are added in the concrete for the following purposes:

(a) To reduce bleeding, segregation and retention of water in the skeleton. In short, they improve the stability of the concrete mix.

(b) To reduce creep and shrinkage of SCC. Normally the proportion of fine aggregates in SCC should be increased at the cost of coarse aggregates so that it can perform better while passing through the maze of reinforcement bars. Addition of VMA will enable reducing the requirement of FA and thus reduction in creep and shrinkage of SCC.

Use of Mineral Admixtures in SCC

It has been found from experiments that in order to improve the stability of the mix in SCC and also to prevent segregation and bleeding, fine powder with particle size less than 0.125 mm is required in the range of 400-600 kg/m^3. OPC has 99% of its particles less than 0.090 mm size and almost 100% smaller than 0.125 mm. Hence OPC qualifies as the primary material for SCC. But the quantity of cement is not sufficient to meet the demand of SCC. Hence in order to fulfil this requirement, supplementary powder materials like fly-ash, blast furnace slag etc. are added in the concrete. Fly-ash has its particle size exactly in the desired range whereas in blast furnace slag, some milling is required. Therefore, fly-ash is the popular mineral admixture, used in SCC.

Tests for Self Compacting Concrete

Conventional workability tests such as slump cone, compacting factor etc. are not suitable for SCC because these can't detect the tendency of segregation and bleeding. Therefore, different tests necessary to characterize the suitability of SCC have been explained in IS: 10262 as given under :

(a) Filling ability or flowability

This is the ability of fresh concrete to flow into and fill all spaces within the formwork up to the farthest ends including sharp corners under its own weight. Flowability is tested by Slump Flow Test performed through slump cone apparatus as per IS:1199 (Part-6). Concrete is filled up in cone and when cone is lifted, concrete spread diameter is measured as Slump Flow (SF) value. There are three classes of slump flow values-

SF 1 $\rightarrow$ Slump Flow 550 mm-650 mm

SF 2 $\rightarrow$ Slump Flow 660 mm-750 mm

SF 3 $\rightarrow$ Slump Flow 760 mm-850 mm

Higher slump flow value indicates more fluidity of concrete.

(b) Passing ability

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation.

L-Box test is performed to check the passing ability as per IS: 1199 (part-6).

In this test, concrete is poured in the vertical column and allowed to pass through the opening of height H1 as shown in Figure - 1 The height of concrete at the other end will give an idea about passing ability of concrete.

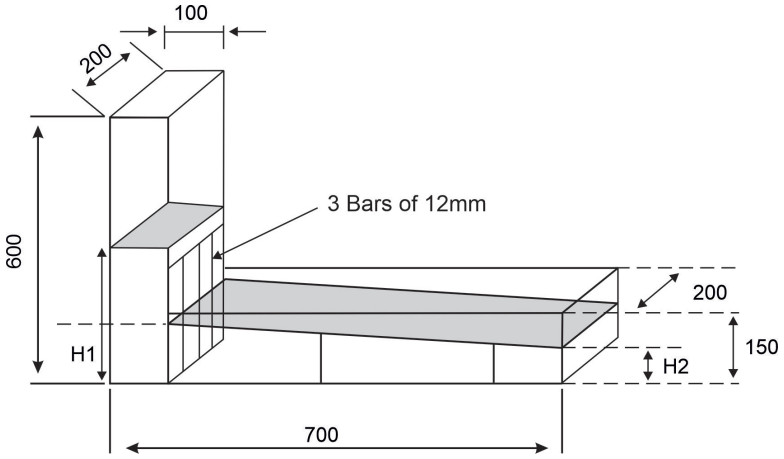


Figure - 1 : L - Box Test

$$\text{Passing ratio} = \frac{H2}{H1}$$

Minimum passing ratio required for SCC is 0.8.

(c) Segregation Resistance (Stability)

The SCC should remain homogeneous in composition during the flow. This can happen only if the concrete is not segregated and flows with all its ingredients as a homogeneous mass.

To check segregation resistance, sieve test is performed as per IS:1199. Fresh concrete mass is allowed to stand for 15 min time and any separation of bleed water is noted. Sample then placed on 4.75 mm square sieve for 2 min time and percentage passing is noted as Segregation Resistance (SR) value.

Less SR value is recommended for better segregation resistance. For normal work where flow distance is up to 5m and confinement gap is greater than 80mm, SR value 15-20% is desired. If flow length is more than 5m, less than 10% SR value is recommended.

(d) Viscosity

Concrete with low viscosity will have a very quick initial flow and then stop. Concrete with high viscosity will be able to flow over an extended time. V-Funnel Test is used to assess the viscosity of SCC as per IS:1199 (Part 6).

V - Funnel Test

In this test, concrete is poured in a rectangular shape funnel which is having top dimension of 515 mm x 75 mm and bottom dimension as 65 mm x 75 mm. Its total height is 600 mm out of which 150 mm bottom portion is straight as shown in Figure - 2. Funnel is filled-up completely with concrete and then bottom door is opened. The time required for entire concrete to flush out is called V-flow time.

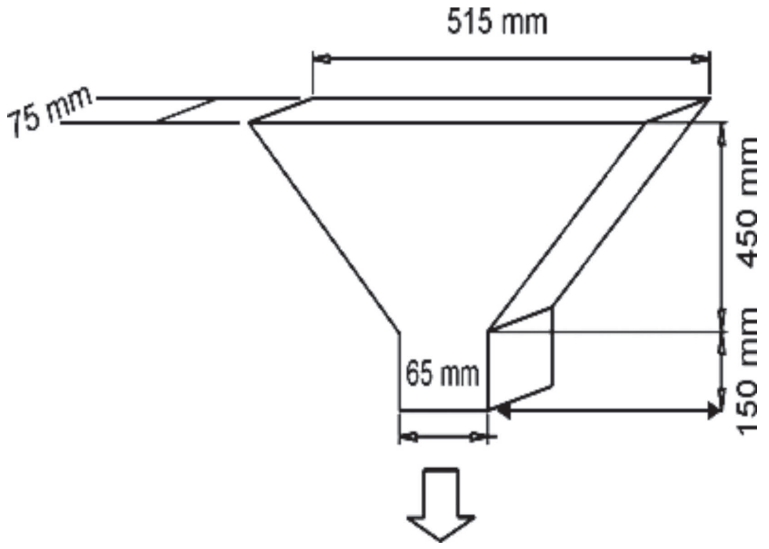


Figure - 2 : Funnel Test

Viscosity V1 class has flow time less than 8 seconds and is considered good filling ability even in congested reinforcements. Viscosity V2 class has flow time between 8-25 seconds and suitable for normal SCC.

Vacuum Dewatered Concrete

It is a well known fact that excessive w/c ratio is detrimental for concrete. We always try to restrict the w/c ratio in order to achieve higher strength. The chemical reaction of cement with water requires a w/c ratio of less than 0.38, whereas the adopted w/c ratio is generally much more than that mainly because of the requirement of workability. Workability is also important for concrete, so that it can be placed in the formwork easily without honeycombing.

After the requirement of workability is over, this excess water will eventually evaporate leaving capillary pores in the concrete. These pores result into high permeability and less strength in the concrete. Therefore, workability and high strength don't go together as their requirements are contradictory to each other.

Vacuum dewatered concreting is the effective technique used to overcome this contradiction of opposite requirements of workability and high strength. With this technique both these requirements are possible.

In this technique, the excess water after placement and compaction of

concrete is sucked out with the help of vacuum pumps. This technique is effectively used in industrial floors, parking lots, deck slabs of bridges etc. The magnitude of applied vacuum is usually about 0.08 MPa and the water content is reduced by upto 20-25%. The reduction is effective up to a depth of about 100 to 150 mm.

Technique and Equipment

The main aim of the technique is to extract extra water from concrete surface using vacuum dewatering after placement of concrete. As a result of dewatering, there is a marked reduction in effective w/c ratio and the performance of concrete improves drastically. The improvement is more on the surface where it is required the most.

Mainly four components are required in vacuum dewatering of concrete, which are given below:

(1) Vacuum pump

(2) Water separator

(3) Filtering pad

(4) Screed board vibrator

Vacuum pump is a small but strong pump of 5 to 10 H.P. Water is extracted by vacuum and stored in the water separator. The mats are placed over fine filter pads, which prevent the removal of cement with water. Proper control on the magnitude of the applied pressure is necessary. The amount of water removed is equal to the contraction in total volume of concrete. About 3% reduction in concrete layer depth takes place. Filtering pad consists of rigid backing sheet, expanded metal, wire gauge or muslin cloth sheet. A rubber seal is also fitted around the filtering pad as shown in Figure-3. Filtering pad should have minimum dimension of 90 cm x 60 cm.

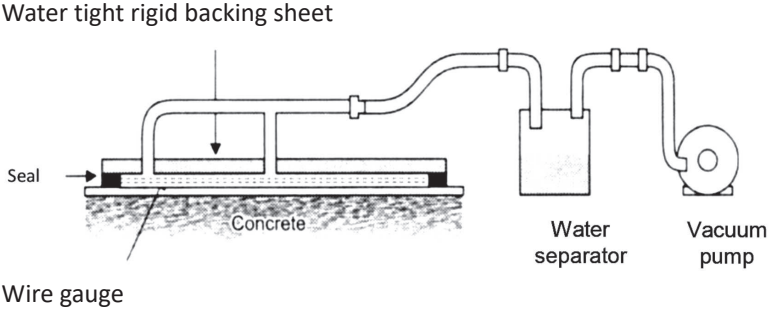


Figure - 3 : Vacuum Dewatering

Advantages of vacuum concreting

(i) Due to dewatering through vacuum, both workability and high strength are achieved simultaneously.

(ii) Reduction in w/c ratio may increase the compressive strength by 10 to 50% and lowers the permeability.

(iii) It enhances the wear resistance of concrete surface.

(iv) The surface obtained after vacuum dewatering is plain and smooth due to reduced shrinkage.

(v) The formwork can be removed early and surface can be put to use early.

However, the advantages of vacuum dewatering are more prominent on the top layer as compared to bottom layer as shown in Figure-4. The effect beyond a depth of 150 mm is very less.

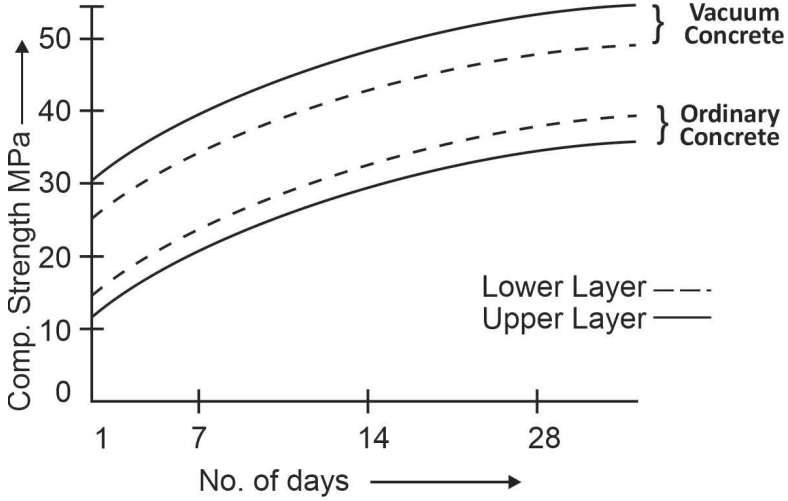


Figure - 4 : Effect of Vacuum De-watering

Ultra High Performance Concrete (UHPC)

Ultra-high performance concrete (UHPC) is a new generation of high-performance concrete with extremely high strength, ductility, and durability, making it a promising material for a variety of applications.

This type of concrete is generally considered to be characterized by a compressive strength above 120 MPa. It exhibits lack of brittleness, allowing for the design and production of structural members without the need for reinforcing steel.

Use of Ultra High Performance Concrete is permitted for trials in design

and construction as per RDSO guideline (BS-136). The design shall be approved by RDSO and validated after the trials. UHPC is made with high-strength steel fibres, fine sand, cement, fly ash, a large volume of Silica Fume and a low amount of water (a w/cm ratio less than 0.20)

Common features of UHPC are-

- Compressive strength : 140 MPa to 220 MPa
- Use of Steel fibers about 0.2 mm and 13 mm length.
- 50 % Weight reduction of structural elements
- Low Reinforcing Steel
- Sleek Structural elements
- Ultra-High wear and impact resistance
- Rapid development of strength : 40 MPa in 24 hours, 100 MPa in 7 days



Figure - 5 : Sleek design of girders with UHPC

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6. IS 456-2000 Plain and Reinforced Concrete – Code of practice.
7. Other IS codes as mentioned.

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