# 1

# Introduction

## 1·1. Concrete, Reinforced Concrete and Prestressed Concrete

Concrete is a stonelike material which is obtained by carefully mixing in proportion cement, sand and gravel or other aggregate, and water to harden in forms of the shape and dimensions of the desired structures. The bulk of the material consists of fine and coarse aggregate. Cement and water interact chemically to bind the aggregate particles into a solid stonelike material. Additional water, over and above that is needed for chemical reaction, is necessary to give the mixture workability which enables it to fill the forms and surround the embedded reinforcing steel before hardening. Concrete of various strength properties can be obtained by appropriate proportions of the constituent materials. Special cements such as high-early strength cements, and special aggregates such as light weight or heavy weight aggregates and special curing methods such as steam curing permit an even wider variety of properties to be obtained. Before being placed in form this material is referred to as concrete mix. Concrete mixed in a concrete factory *i.e.* central mixing plant and supplied to the user ready for use is called ready-mixed concrete.

Production takes place by mixing the materials in concrete mixers, which ensure homogeneity of the product on completion of mixing the ingredients measured in definite quantities for the given concrete composition.

The properties of concrete depend to a very large extent on the proportions of the mix, on the thoroughness with which the various constituents are intermixed, and on the conditions of humidity and temperature in which the mix is maintained from the moment it is placed in the forms untill it is fully hardened The process of controlling these conditions is known as curing.

(*a*) **Cement.** According to the purpose for which the concrete is required, the mix may contain cement from one of the following groups ; all kinds of ordinary Portland cement, Portland blast-furnace cement, pozzolanic cement, and sand-Portland-cement, high alumina cement, expanding cement and non-shrinking cement, super-sulphate cement or slag sulphate cement.

(*b*) **Aggregates.** In ordinary structural concretes the aggregates occupy about 70 to 75 percent of the volume of the hardened mass. The remainder consists of hardened cement paste, uncombined water and air voids. The uncombined water and air voids do not contribute to the strength of concrete. The more densely the aggregate can be packed, the better the strength, weather resistance and enconomy of the concrete. The gradation of the particle sizes in the aggregates to produce dense concrete is very important. It is also important that the aggregate should have good strength, durability and weather resistance. It should be free from impurities such as loam, silt and organic matter which may weaken the bond with cement and have unfavourable chemical reaction with cement.

Natural aggregates are generally classified as fine and coarse. The size of a fine aggregate shall not exceed 4·75 mm gauge. Aggregates of bigger sizes are called coarse aggregates. When favourable gradation is desired, aggregates are separated by sieving into two or three size groups of sand and several size groups of coarse aggregate. These are then combined to get a densely packed aggregate. The maximum size of coarse aggregate in reinforced concrete is governed by the requirement that it shall easily fit into the forms and between the reinforcing bars. For reinforced concrete work, aggregates having a normal size of 20 mm are generally considered satisfactory. For heavily reinforced concrete members as in the case of ribs of main members, 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 cover to the reinforcement whichever is smaller.

Crushed rock or gravel in the form of a mixture of several fractions can be used as coarse aggregate. The fine aggregate *i.e.* sand is used as far as possible in two fractions. For preparing the concrete mix the fractions of the aggregates are measured separately.

Plums above 160 mm upto any reasonable size may be used in plain concrete work upto a maximum limit of 20 percent by volume of concrete. The plums shall be distributed evenly and shall be not closer than 150 mm from the surface.

(*c*) **Concrete.** The unit weight of stone concrete *i.e.* concrete with natural stone aggregates varies from 23,000 N/m$^3$ to 24000 N/m$^3$.

For special purposes lightweight concretes and heavy concretes are being used. A variety of lightweight aggregates consist of pumice or cinders used for insulating concretes, processed aggregates like expanded shales, clays, slates, slags or pelletized fly ash for structural light weight concrete. These are light in weight due to the individual aggregate particles are porous or cellular which is achieved by using gas or steam in processing the aggregates in rotary kilns at as high temperature as 1100 °C.

Three classes of lightweight concretes are

(*i*) low density concretes which are employed for insulation with unit weight not exceeding 8000 N/m$^3$.

(*ii*) Moderate strength concretes with unit weights from 9500 N/m$^3$, to 1300 N/m$^3$, having compressive strength of 7 N/mm$^2$ to 15 N/mm$^2$ chiefly used as fill.

(*iii*) Structural concretes with unit weight of 14,000 N/m$^3$ to 19,000 N/m$^3$ and compressive strenghts equal to those of stone concretes.

Heavy weight concrete is required for shielding gamma and X-radiation in nuclear reactor and similar installations, for protective structures, as counterweight of lift bridges. Heavy aggregates such as heavy iron ores or barium sulfate rock crushed to suitable sizes. Steel in the form of scrap, punchings or fines is also used. Unit weights of heavy-weight concretes with natural heavy rock aggregates range from 30,000 N/m$^3$ to 32,000 N/m$^3$. If iron punchings are added to high density ores unit weight can be as high as 38,000 N/m$^3$. The weight may be as high as 52,000 N/m$^3$ if ores are used for the fines and steel for the coarse aggregate.

(*d*) **Water-cement ratio.** Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing concrete.

For complete hydration of a given amount of cement, an amount of water equal to about 25 percent of that cement by weight, is needed for chemical reaction. An additional 10 to 15 percent is added to provide mobility for the water in the cement paste during the hydration process so that it can reach the cement particles. This makes for a total minimum water-cement ratio of 0·35 to 0·40 by weight. Water-cement ratios in concretes are generally considerably larger than this minimum, to provide the necessary workability of the concrete mix. Any amount of water above the 25 percent consumed in the chemical reaction produces pores in the cement paste. Since only the solids and not the voids resist stress, strength increases directly as the fraction of the total volume occupied by the solids increases. Thus the strength of cement paste decreases directly with increasing water-cement ratio.

The chemical process involved in the setting and hardening liberates heat, known as heat of hydration. In large concrete masses, such as dams, this heat gets dissipated very slowly and therefore there will be rise in temperature consequently increase in volume of concrete during hydration and subsequently on cooling there will be contraction and cracking. To avoid the serious cracking and weakening, special measures must be taken and low heat Portland cement be used.

(*e*) **Workability**. The concrete mix proportions chosen should be such that the concrete is of adequate workability for the placing conditions of the concrete and can be properly compacted with the means available.

The workability is measured by two methods—

(*i*) Slump test (*ii*) Compaction factor test.

In slump test, a slump test cone is filled one fourth at a time with concrete and compaction is done with a 16 mm rod by stroking evenly with 25 strokes. After the whole cone is filled and compacted, the cone is removed without disturbing the concrete. The vertical settlement of the concrete is called the slump. The slump required for various works is—

(*a*) Concrete for road work......25 mm to 50 mm

(*b*) Concrete for beams and slabs......50 mm to 100 mm

(*c*) Concrete for walls, thin vertical members and columns......75 mm to 125 mm

(*d*) Vibrated concrete......15 mm to 25 mm

(*e*) Mass concrete......25 mm to 50 mm.

In compacting factor test, concrete is poured into top hopper and then the door is opened at the bottom so as concrete to fall into the second hopper, kept at some distance from first hopper. The door of second hopper is opened so as the concrete to fall into a cylinder kept at distance from second hopper. Extra concrete in the cylinder is scraped off. The weight of concrete in cylinder is ascertained and let it be $W_1$. Then the same cylinder is emptied and filled with concrete mix and compacted so as there are no voids and the weight of voidless concrete is ascertained and let it be $W_2$. The ratio $W_1/W_2$ is called compaction factor. A compaction factor of 0·95 represents good workability and factor 0·92 represents medium workability and factor 0·85 represents low workability. The compaction factor required for various placing conditions are as given below :

| | *Compaction factor* |
|---|---|
| (*a*) Concreting of shallow sections with vibration | ...0·75 to 0·8 |
| (*b*) Concreting of lightly reinforced sections with vibration | ...0·80 to 0·90 |
| (*c*) Concreting of lightly reinforced section without vibration, or heavily reinforced section with vibrations | ...0·85 to 0·92 |
| (*d*) Concreting of heavily reinforced section without vibration | ...Above 0·92 |

(*f*) **Durability.** The durability of concrete depends on the resistance to deterioration and the environment in which it is placed. The resistance of concrete to weathering, chemical attack, abrasion, frost and fire depends upon quality of constituent materials.

One of the main characteristics influencing the durability of concrete is its permeability. With strong, dense aggregates, a suitably low permeability is achieved by having a sufficiently low water-cement ratio by ensuring as thorough compaction of the concrete as possible, and by ensuring sufficient hydration of cement through proper curing methods.

Therefore for given aggregates, the cement content should be sufficient to provide adequate workability with a low water-cement ratio so that concrete can be completely compacted with the means available.

(*g*) **Transporting, Placing, Compacting and Curing.** Concrete shall be transported from the mixer to the form work as rapidly as possible by methods which will prevent the segregation or loss of any of the ingredients and maintaining the required workability.

The individual components of concrete tend to segregate because of their dissimilarity. If the concrete is very wet, standing in containers or forms, the heavier gravel components tend to settle and the lighter materials particularly water tend to rise. Lateral movement such as flow in the forms, tends to separate the coarse gravel from the finer components of the mix. The previously common methods of conveying such as chutes and conveyer belts have been discarded because they cause segregation of components Now a days concrete is conveyed by bottom dump buckets or in wheelbarrows or pumping through steel pipelines.

Placing is the process of transferring the fresh concrete from the conveying device to its final place in the forms. The concrete shall be deposited as nearly as practicable in its final position to avoid rehandling. Prior to placing, loose rust must be removed from the reinforcement, forms must be cleaned and hardened surfaces of previous concrete lifts must be cleaned and treated appropriately. Placing and compacting are critical in their effect on the final quality of the concrete. Proper placement must avoid segregation, displacement of forms or of reinforcement in the forms, and poor bond between successive layers of concrete.

Immediately after placing, the concrete should be compacted by means of hand tools or vibrators. The concrete should be worked around the reinforcement, around embedded fixtures and into corners of the formwork. Such compacting prevents honey combing, assures close contact with forms and reinforcement and serves as a partial remedy to possible prior segregation. Compacting is achieved by hand tamping with a variety of special tools, but now more commonly and successfully with high frequency power driven vibrators. The vibrators may be internal type which are immersed in concrete or the external type which are attached to the forms.

Over-vibration or vibration of very wet mixes is harmful and should be avioded. Under-vibration is also harmful.

Whenever vibration has to be applied externally, the design of formwork and the disposition of vibrators should receive special consideration to ensure efficient compaction and to avoid surface blemishes.

The internal vibrators are preferable but must be supplemented by the external vibrators where narrow forms or other obstactles make immersion impossible.

Fresh concrete gains strength most rapidly during the first few days and weeks. Structural design is generally based on the 28 days strength, about 70 percent of which is reached at the end of the first week after placing. The final strength depends greatly on the conditions of moisture and temperature during this initial period. The maintenance of proper conditions during this time is known as curing. Thirty percent or more of the strength can be last by premature drying out of the concerte. Similarly strength may be lost to the extent of thirty percent if the outside temperature falls to 2°C or lower during the first few days unless the concrete is maintained continuously moist for a long time thereafter. Freezing of fresh concrete may reduce its strength by as much as 50 percent.

To prevent such damage, the concrete should be protected from loss of moisture for at least 7 days and in case of more sensitive work upto 14 days. When high-early-strength cements are used, curing periods can be cut in half.

Curing can be achieved by keeping exposed surfaces continuously wet through sprinkling, ponding, covering with wet burlap, or the like. Recent methods include the use of sealing compounds, which when properly used, form evaporation retarding membranes, and water proof papers. Besides strength, proper moist curing provides better shrinkage control.

To protect the concrete against low temperature during cold wauther, the mixing water and occasionally, the aggregates are heated, temperature insulation is used where possible and special [illegible]temperature[illegible]ly calcium chloride are used. When air temperatures are very low, external heat may have to be supplied in addition to insulation.

(*h*) **Under-water Concreting.** When it is necessary to deposit concrete under water, the following points should be noted :

(*i*) Such concrete should not be considered as 'Design mix concrete'.

(*ii*) The concrete shall contain atleast 10 percent more cement than that required for the same mix placed in the dry, the quantity of extra cement varying with conditions of placing. The volume of mass of the coarse aggregate shall be not less than one and a half times, not more than twice that of the fine aggregate. The materials shall be so proportioned as to produce a concrete having a slump of not less than 100 mm and not more than 180 mm.

(*iii*) Cofferdams or forms shall be sufficiently tight to ensure still water if practicable, and in any case to reduce the flow of water to less than 3 metres per minute through the space into which concrete is to be deposited. Cofferdams or forms in still water shall be sufficiently tight to prevent loss of mortar through the walls. Dewatering by pumping shall not be done when concrete is being placed or until 24 hours thereafter.

(*iv*) Cencrete shall be deposited continuously until it is brought to the required height. While depositing the top surface shall be kept as nearly level as possible and the formation of seams avoided. The methods to be used for depositing concrete under water shall be one of the following :

(*I*) *Tremie*. When concerete is to be deposited under water by means of tremie, the top section of the tremie shall be a hopper, large enough to hold one entire batch of the mix or the entire contents of the transporting bucket if any. The tremie pipe shall be not less than 200 mm in diameter and shall be large enough to allow a free flow of concrete and strong enough to withstand the external pressure of the water in which it is suspended, even if a partial vacuum develops inside the pipe. Preferably flanged steel pipe of adequate strength for the job should be used. A separate lifting device shall be provided for each tremie pipe with its hopper at the upper end Unless the lower end of the pipe is equiped with an approved automatic check valve, the upper end of the pipe shall be plugged with a wadding of the gunny sacking or other approved material before delivering the concrete to the tremie pipe through the hopper, so that when the concrete is forced down from the hopper to the pipe, it will force the plug along with any water in the pipe, down the pipe and out of the bottom end, thus establishing continuous stream of concrete.

It will be necessary to raise slowly the tremie in order to cause a uniform flow of the concrete, but the tremie shall not be emptied so that water enters the pipe At all times after the placing of concrete is started and until all the concrete is placed, the lower end of the tremie pipe shall be below the top surface of the plastic concrete. This will cause the concrete to build up from below instead of flowing out over the surface, and thus avoid formation of laitance layer. If the charge in the tremie is lost while depositing, the tremie shall be raised above the concrete surface, and unless sealed by a check valve it shall be plugged at the top end, as at the beginning, before refilling for depositing concrete.

(*II*) *Drop bottom bucket*. The top of the bucket shall be covered with a canvass flap. The bottom doors shall open freely downward and outward when tripped. The bucket shall be filled completely and lowered slowly to avoid backwash. The bottom doors shall not be opened until the bucket rests on the surface upon which the concrete is to be deposited and when discharged, shall be with drawn slowely until well above the concrete.

(*III*) *Bags*. Bags of atleast 0·028 $m^3$ capacity of jute or other coarse cloth shall be filled about two thirds full of concrete, the spare end turned under so that bag is square ended and securely tied. They shall be placed carefully in header and stretcher courses so that the whole mass is interlocked. Bags used for this purpose shall be free from deleterious materials.

(*IV*) *Grouting*. A series of round cages made from 50 mm mesh of 6 mm steel and extending over the full height to be concreted shall be prepared and laid vertically over the area to be concreted so that the distance between centres of the cages and also to the faces of the concrete shall not exceed one metre. Stone aggregate of not less than 50 mm nor more than 200 mm size shall be deposited outside the steel cages over the full area and height to be concreted with due care to prevent displacement of the cages.

A stable 1·2 cement sand grout with a water-cement ratio of not less than 0·6 and not more than 0·8 shall be prepared in a mechanical mixer and sent down under pressure (about 0·2 $N/mm^2$) through 38 to 50 mm diameter pipes terminating into steel cages, about 50 mm above the bottom of the concrete. As the grouting proceeds, the pipe shall be raised gradually upto a height of not more than 600 mm above its starting level after which it may be withdrawn and placed into the next cage for further grouting by the same procedure.

After grouting the whole area for a height of 600 mm, the same operation shall be repeated, for the next layer of 600 mm and so on.

The amount of grout to be sent down shall be sufficient to fill all the voids which may be either ascertained or assumed as 55 percent of the volume to be concreted.

## 1·2. Design Considerations

In past four decades or so reinforced cement concrete (RCC) has established itself as a very satisfactory construction material. Reinforced concrete has reached very advanced stage both in design and construction techniques. Reinforced concrete has been success fully used in construction of buildings, bridges, dams, bunkers, silos, water tanks and many other structures.

The first basic step in the design of any structure is layout. The layout of a structure is governed by the functions to be performed by the structure.

The design of RCC structures will depend on the layout. The layout depends on the functions to be performed by the structure. Planning and proportioning a structure is called structural design. Some of the factors which will govern the design are :

(*i*) Adequate strength and rigidity.

(*ii*) Should not interfere with the functions for which the structure is intended.

(*iii*) Be economical in first cost and maintenance.

(*iv*) Should be strong enough to last for the design service life.

(*v*) Be readily adaptable to future extension.

The design will consist of :

(*i*) Working out the forces and loads which the structure has to carry.

(*ii*) Arrangement of various beams, columns etc. to support the structure.

(*iii*) Computation of stresses, shears, moments etc. in the members of the structure.

(*iv*) Providing adequate sections to resist the stresses in the members.

## 1·3. Loads

For the purpose of computing the maximum stresses in any structure or member of structure the following loads should be taken into account :

(*i*) *Dead loads.* The weight of the RCC and all the material supported by it permanently.

(*ii*) *Live loads.* These are the loads which temporarily rest at one place such as—

(*a*) The goods stored on a warehouse floor.

(*b*) The furniture and occupants of an office.

(*c*) The snow load on the roof or deck of a bridge.

(*d*) Material stored in bunkers and silos.

(*e*) Moving loads on bridges.

(*iii*) *Dynamic effects.* Live loads which produce vibrations by impact such as moving trains, trucks and cranes, produce greater effects than would be produced by the same loads if stationary. The additional effect is called the dynamic effect.

(*iv*) *Wind loads.*

(*v*) *Seismic loads.*

(*vi*) *Erection loads*. Storage of construction material and erection equipment including all loads due to operation of such equipment.

(*vii*) *Temperature effects*. The provisions for maximum expansion and contraction has to be allowed in the structure.

## 1·4. Concrete and Reinforced Concrete

**Concrete.** Concrete is a material obtained by cementing together inert materials like sand, gravel broken stone or some other suitable materials. Cementing material generally used is portland cement. Cement and water react chemically to bind sand, known as fine aggregate and gravel or broken stone known as coarse aggregate. The resulting product is like an artificial stone. When the aggregates, cement and water are mixed in proper proportions, the resulting product after some time is hard, strong in compression and shear, brittle and weak in tension. These properties of concrete are affected by several factors like proportions of cement, coarse aggregate and fine aggregate ; amount of water, temperature at the time of mixing, humidity at the time of moulding of concrete in forms and temperature and humidity maintained subsequently. This process of maintaining desired temperature and humidity is known as curing of concrete.

The plain concrete, being strong in compression is suitable for massive construction, where it is subjected to compressive stresses. It is not suitable at places where it is subjected to tensile stresses.

**Reinforced concrete.** As discussed above, concrete is strong in compression and weak in tension, so steel reinforcement is used to take up tensile stresses at places where section is subjected to tensile stress. Such a concrete is known as reinforced concrete. Cement concrete shrinks a little and grips very fast on the steel reinforcement. This produces bond between cement concrete and steel, and thus tensile stresses are transferred to steel reinforcement.

Concrete has good resistance to damage by fire and protects steel bars from buckling and twisting at high temperature. Also concrete offers very good resistance to atmospheric adverse conditions and thus stops steel reinforcement from rusting.

## 1·5. Advantages of RCC Construction

Following are the advantages of RCC construction :

1. Concrete can be easily moulded to any desired shape.
2. The materials for RCC are easily available.
3. It is easy to make.
4. It is durable.
5. By proper proportioning of mix, concrete can be made water-tight.

6. Its monolithic character gives it more rigidity.
7. It is fire resisting.
8. Its maintenance cost is practically nil.

## 1·6. Steel as Reinforcement

Steel is used as reinforcement to take up tensile stresses in RCC structures because of the following reasons :

(1) Its tensile strength is high.
(2) It can develop good bond with concrete.
(3) Its coefficient of expansion is nearly same as that for concrete.
(4) It is easily available.

The steel bars used for reinforcing concrete are generally of plain round mild steel with diameters between 5 mm and 50 mm. It is only in very heavy structures that bars of diameter larger than 40 mm are used. There is a growing practice to use high yield point steel bars which are usually mild steel bars that have been old drawn to increase their strength : but the difficulty of placing and bending these bars may outweigh the initial saving in the weight of steel required.

Mesh fabric is used frequently as reinforcement in concrete roads, walls and floor slabs. It can also be used in column footings. It is used in place of bar reinforcement only when there are definite advantages in cost and placing. The common types of mesh fabrics in use are welded fabric, expanded metal and ribbed metal lathing. The fabric is made in standard size lengths and widths.

Deformed bars conforming to IS : 1130—1966 and cold-twisted steel conforming to IS : 1566—1967 are being widely used.

All reinforcement in RCC construction shall be clean and free from loose mill scales, dust, loose rust and coats of paints, oil or other coatings which may destory or reduce bond.

## 1·7. S.I. Units

S.I. units have been used in revised code of practice for plane and reinforced concrete IS 456—1978. The stresses are given in $N/mm^2$, *i.e.* Newtons per millimetre square.

$$1 \text{ N/mm}^2 = \frac{100}{9{\cdot}81} \text{ kg/cm}^2$$

$$= 10{\cdot}19 \text{ kgf/cm}^2 \qquad [1 \text{ kgf} = 9{\cdot}81 \text{ N}]$$

Newton is defined as a force to produce acceleration of 1 $metre/sec^2$ in a mass of 1 kg. Unit of mass is kg.

By this revised code the stresses are taken as :

(*i*) *The modulus of elasticity of steel* shall be taken as 200 kN/mm$^2$.

(*ii*) *The characteristic strength of concrete* is defined as the strength of materirl below which not more than 25 percent of the least results are expected to fall.

**Table 1·1**

| *Grade designation* | *Specified charaeteristic compressive strength of 28 days $f_{ck}$ ($N/mm^2$)* |
|---|---|
| M 10 | 10 |
| M 15 | 15 |
| M 20 | 20 |
| M 25 | 25 |
| M 30 | 30 |
| M 35 | 35 |
| M 40 | 40 |

Letter 'M' refers to the mix and the number to the specified characteristic compressive strength of 15 cm cube at 28 days, expressed in N/mm$^2$.

Grades of concrete less than M 15 shall not be used in reinforced concrete.

M 5 and M 7·5 grades of concrete may be used for lean concrete bases and simple foundations for masonry walls.

(*iii*) *Increase in strength of concrete with age.* Where it can be shown that a member will not receive its full load within a period of 28 days after the casting of the member, the characteristic compressive strength given in Table 1·1 may be increased by factor as given in Table 1·2.

**Table 1·2**

| *Minimum age of member when full design load is expected months* | *Age factor* |
|---|---|
| 1 | 1·0 |
| 3 | 1·10 |
| 6 | 1·15 |
| 12 | 1·20 |

(*iv*) *Tensile strength of concrete.* The following formula should be used to arrive at the tensile strength from the compressive strength.

Flexural strength,

$$F_{cr}=\sqrt{f_{ck}}\ \text{N/mm}^2$$

where $f_{ck}$ is the characteristic compressive strength of concrete.

(*v*) *The modulus of elasticity for structural concrete* may be assumed as

$$F_c=5700\sqrt{f_{ck}}\ \text{N/mm}^2$$

where $F_c$ is the short term static modulus of elasticity.

(*vi*) *Shrinkage strain of concrete* may be taken as 0·0003.

(*vii*) *Creep of concrete.* Creep of concrete depends on stress in the concrete, age at loading and the duration of loading besides water content at the time of mixing and cement content. The creep coefficient defined as ultimate creep strain by elastic strain at the age of loading may be taken as given in Table 1·3

**Table 1·3**

| *Age of loading* | *Creep coefficient* |
|---|---|
| 7 days | 2·2 |
| 28 days | 1·6 |
| 1 year | 1·1 |

(*viii*) *Thermal expension,* The coefficient of thermal expansion depends upon the aggregate used and the nature of cement, cement content the relative humidity and the size of sections. Table 1·4 gives thermal coefficient for various aggregates.

**Table 1·4**

| *Type of aggregate* | *Coefficient of thermal expansion for concrete/°C* |
|---|---|
| Quatzite | 1·2 to $1·3\times10^{-5}$ |
| Sandstone | 0·9 to $1·2\times10^{-5}$ |
| Granite | 0·7 to $0·95\times10^{-5}$ |
| Basalt | 0·8 to $0·95\times10^{-5}$ |
| Limestone | 0·6 to $0·9\times10^{-5}$ |

(*ix*) *Design of concrete mix.* The mix shall be designed to produce that grade of concrete having the required workability and a characteristic strength not less than appropriate value as given in Table 1·2.

As long as the quality of materials does not change, a mix design done earlier may be considered adequate for later work.

Nominal concrete mix may be used for concrete of grades M 5, M 7·5, M 10, M 15 and M 20. The properties of materials for nominal concrete mix shall be in accordance with Table 1·5.

**Table 1·5**

| *Grade of concrete* | *Total quantity of dry aggregate by mass per 50 kg of cement to be taken as the sum of individual mass of fine and coarse aggregate mix (kg)* | *Proportion of fine aggregate to coarse aggregate (by mass)* | *Quantity of water per kg of cement max litres* |
|---|---|---|---|
| M 5 | 800 | Generally 1 : 2 | 60 |
| M 7·5 | 625 | but subject to an | 45 |
| M 10 | 480 | upper limit of | 34 |
| M 15 | 350 | 1 : 1½ and a lower | 32 |
| M 20 | 250 | limit of 1 : 2½ | 30 |

The cement content of the mix specified in Table 1·5 for any nominal mix shall be proportionately increased if the quantity of water in a mix has to be increased to overcome the difficulties of placement and compaction, so that the water cement ratio as specified is not exceeded.

In the case of vibrated concrete, the limits specified may be suitably reduced to avoid segregation.

The quantity of water used in concrete mix, for reinforced concrete work should be sufficient, but not more than necessary to produce a large concrete of adequate workability for its purpose, which will surround and properly grip all the reinforcement. Workability of the concrete should be controlled by maintaining a water content that is found to give concrete which is just sufficiently wet to be placed and compacted without difficulty with the means available.

(*x*) *Modular ratio* $m=\frac{280}{3\sigma_{cbc}}$

where $\sigma_{cbc}$ is permissible compressive stress due to bending in concrete in $N/mm^2$ as specified in Table 1·6.

(*xi*) *Permissible stress in concrete.* Permissible stresses for the various grades of concrete $\sigma_{cbc}$ shall be taken as given in Table 1·6.

**Table 1·6**

| Grade of concrete | Permissible stress in compression | | Permissible stress in bond (average) for plain bars in tension $\tau_{bd}$ | m |
|---|---|---|---|---|
| | Bending $\sigma_{cbc}$ | Direct $\sigma_{cdc}$ | | |
| M 10 | 3·0 | 2·5 | — | — |
| M 15 | 5·0 | 4·0 | 0·6 | 18 |
| M 20 | 7·0 | 5·0 | 0·8 | 13 |
| M 25 | 8·5 | 6·0 | 0·9 | 11 |
| M 30 | 10·0 | 8·0 | 1·0 | 9 |
| M 35 | 11·5 | 9·0 | 1·1 | 8 |
| M 40 | 13·0 | 10·0 | 1·2 | 7 |

(*xii*) *Permissible stresses in concrete in direct tension.* For members in direct tension, when full tension is taken by the reinforcement alone, the tensile stress shall be not greater than the values given in Table 1·7. The tensile stress shall be calculated as $\frac{F_t}{A_c+mA_{st}}$.

**Table 1·7**

| Grade of concrete | M 10 | M 15 | M 20 | M 25 | M 30 | M 35 | M 40 |
|---|---|---|---|---|---|---|---|
| Tensile stress $N/mm^2$ | 1·2 | 2·0 | 2·8 | 3·2 | 3·6 | 4·0 | 4·4 |

where $F_t$=Total tension on the member minus pretension in steel if any, before concreting

$A_c$=Cross-sectional area of concrete excluding any finishing material and reinforcing steel

$m$=Modular ratio

$A_{st}$=Cross-sectional area of reinforcing steel in tension.

(*xiii*) *Bond stress for deformed bars.* In the case of deformed bars, the bond stresses as given in Table 1·7 may be increased by 40 per cent.

(*xiv*) *Permissible stresses in steel reinforcement.* Permissible stresses in steel reinforcement shall not exceed the values given in Table 1·8.

**Table 1·8. Permissible stresses in N/mm²**

| *Type of stress in steel reinforcement* | *Mild steel bars conforming to grade I of IS : 432 or deformed mild steel bars IS : 1139* | *Medium tensile steel conforming to IS : 432, or deformed medium tensile steel bars IS : 1139* | *High yield strength deformed bars IS : 1139 or IS : 1786* |
|---|---|---|---|
| Tension $\sigma_{st}$ | | Half the guaranteed yield stress subject to max of 190 | |
| (*a*) Upto 20 mm | 140 | | 230 |
| (*b*) Over 20 mm | 130 | | 230 |
| Compression in columns $\alpha_{sc}$ | 130 | 130 | 190 |
| Compression in bars in a slab beam, resistances of concrete taken into account | The calculated compressive stress in the surrounding concrete multiplied by 4·5 times the modular ratio or $\sigma_{sc}$ whichever is lower. | | |
| Compression in bars, resistances of concrete not taken | | Half the guaranteed yield stress subject to a maximum | |
| (*a*) Upto 20 mm | 140 | 190 | 190 |
| (*b*) Over 20 mm | 130 | | 190 |

(*xv*) *Permissible stress in long columns.* The maximum permissible stress in a reinforced concrete column or part thereof having a ratio of effective column length $l_{ef}$ to least lateral radius of gyration $i_{min}$, above 40 shall not exceed the appropriate permissible stresses multiplied by $C_r$ given by

$$C_r = 1{\cdot}25 - \frac{l_{ef}}{160\, i_{min}}$$

For approximate value, $C_r = 1{\cdot}25 - \dfrac{l_{ef}}{48\, b}$

where $b$ is least dimension, for $\dfrac{l_{ef}}{b} > 12$.

(*xvi*) *Density of concrete.* The unit weight of plain concrete and reinforced concrete made with sand and gravel and crushed stone aggregate may be taken as 24,000 N/m³ and 25,000 N/m³ respectively.

(*xvii*) *Design shear strength of concrete.* The permissible shear stress in concrete in beams without shear reinforcement is given in Table 1 9.

**Table 1·9**

| $\frac{100\,A_s}{bd}$ | Permissible shear stress in concrete $\tau_c$ $N/mm^2$ for grade of concrete | | | | | |
|---|---|---|---|---|---|---|
| | M 15 | M 20 | M 25 | M 30 | M 35 | M 40 |
| 0·25 | 0·22 | 0·22 | 0·23 | 0·23 | 0·23 | 0·23 |
| 0·50 | 0·29 | 0·30 | 0·31 | 0·31 | 0·31 | 0·32 |
| 0·75 | 0·34 | 0·35 | 0·36 | 0·37 | 0·37 | 0·38 |
| 1·00 | 0·37 | 0·39 | 0·40 | 0·41 | 0·42 | 0·42 |
| 1·25 | 0·40 | 0·42 | 0·44 | 0·45 | 0·45 | 0·46 |
| 1·50 | 0·42 | 0·45 | 0·46 | 0·48 | 0·49 | 0·49 |
| 1·75 | 0·44 | 0·47 | 0·49 | 0·50 | 0·52 | 0·52 |
| 2·00 | 0·44 | 0·49 | 0·51 | 0·53 | 0·54 | 0·55 |
| 2·25 | 0·44 | 0·51 | 0·53 | 0·55 | 0·56 | 0·57 |
| 2·50 | 0·44 | 0·51 | 0·55 | 0·57 | 0·58 | 0·60 |
| 2·75 | 0·44 | 0·51 | 0·56 | 0·58 | 0·60 | 0·62 |
| 3·00 | 0·44 | 0·51 | 0·57 | 0·60 | 0·62 | 0·63 |

$A_s$ is that area of longitudinal reinforcement which continues at least one effective depth beyond the section being considered except at supports where the full area of tension reinforcement may be used.

(*xviii*) For solid slabs (excluding flat slabs) the permissible shear stress in concrete shall be $k\tau_c$, where $k$ has the values as given in Table 1·10.

**Table 1·10**

| *Overall depth of slab in mm* | 300 or more | 275 | 250 | 225 | 200 | 175 | 150 or less |
|---|---|---|---|---|---|---|---|
| $k$ | 1·00 | 1·05 | 1·10 | 1·15 | 1·20 | 1·25 | 1·30 |

(*xix*) *Permissible shear stress in flat slabs.* When shear reinforcement is not provided, the calculated shear stress at the critical section shall not exceed $k_s\,\tau_c$.

where $k_s=(0\cdot5+\beta_c)$ but not greater than 1, $\beta_c$ being the ratio of short side to long side of the column a capital.

and $\tau_c=0\cdot25\sqrt{f_{ck}}$ in limit state method of design and

$0\cdot16\sqrt{f_{ck}}$ in working stress method of design.

When the shear stress exceeds $k_s\,\tau_c$ shear reinforcement is provided In case actual shear stress is greater than $1\cdot5\,\tau_c$, the flat slab shall be redesigned.

(*xx*) *Permissible loads in compression members*. The axial load $P$ for pedestal or short column reinforced with longitudinal bars and lateral ties shall not exceed that given by the following formula :

$$P=\sigma_{cc}A_c+\sigma_{sc}A_{sc}$$

where $\sigma_{cc}$=Permissible stress in concrete in direct compression

$A_c$=Cross-sectional area of concrete excluding any finishing material and reinforcing steel

$\sigma_{sc}$=Permissible compressive stress for column bars

$A_{sc}$=Cross-sectional area of the longitudinal steel.

Short-column with helical reinforcement such as the ratio of the volume of helical reinforcement to the volume of the core shall not be less than $0{\cdot}36\left(\frac{A_g}{A_c}-1\right)\frac{f_{ck}}{f_y}$

where $A_g$=Gross area of the section

$A_c$=Area of core of the helically reinforced column measured to the outside diameter of the helix

$f_{ck}$=Characteristic compressive strength of the concrete

$f_y$=Characteristic strength of the helical reinforcement but not exceeding 415 N/mm$^2$.

The permissible load in short column satisfying above helical reinforcement requirements shall be 1·05 times the permissible load for similar member with lateral ties or rings.

## 1·8. Formwork

Formwork is a temporary structure in which the wet concrete is placed to harden till it reaches required strength. It may be constructed of timber steel, asbestos or plastic. Formwork is one of the major cost items in reinforced concrete structures.

The following types of formwork are in common use :

1. *Timber*. This is most commonly used material in the construction of formwork. It can easily be put into required shape and can easily be fixed and dismantled. Mostly commercial soft woods can be used.

2. *Plywood*. Resin bonded plywood panels are sometimes used instead of timber planks, especially where large exposed areas of concrete are to be constructed *e.g.* faces of retaining walls and the under sides of floor slabs. Compared to timber, shuttering of this type reduces labour costs in fixing and dismantling because of use of large panels. This type eliminates joint marks and with careful fixing of panels, the hardened concrete surface will not require any finishing treatment.

3. *Steel*. Steel formwork is in the form of panels made by welding steel sheets to angle framing. Steel shuttering is initially

more expensive than timber formwork but because it can be continually re-used, it is eventually more economical. This type is most suitable for curved construction as circular chimneys and columns. This type of shuttering is extensively used in precast concrete industry because it can be constructed with a high degree of accuracy.

4. *Moulds.* This type of formwork is made in steel, asbestos or glass fibre. They are precisely made and, therefore, produce a very smooth surface to the hardened concrete. This type of shuttering is mostly used to form the underside or ribbed floor slabs.

5. *Permanent formwork.* The moulds described above are sometimes left in place after the concrete has hardened and such a formwork is called as permanent formwork. Any shuttering that is left in place after concrete has hardened is called permanent formwork.

6. *Travelling formwork.* This is an economical way to forming certain types of structures. This type of formwork travels along the path of the structure to be formed. The type of structures where this type of formwork is used are tall chimneys, silos and bunkers where plan shape is constant throughout the height of the structure.