1.2.2. Cement- Manufacturing of cement, compound composition of Portland Cement, structure and reactivity of compounds.

Cement can be defined as a material having adhesive and cohesive properties which make it capable to bond mineral fragments into compact mass. The principal constituent of the cement are compounds of lime. On adding water to cement, a chemical reaction called hydration take place with release of large quantity of heat. Due to this, gel is formed that binds aggregates together and provides strength and water tightness on hardening.

Classification of Cement

Cement is mainly classified into two groups:-

i) Natural cement

ii) Artificial cement or portland cement.

Manufacturing of Portland Cement.

Manufacturing of portland cement is done by either wet process or dry process.

In dry process, raw materials are mixed in required proportion, crushed, grind and then fed into the klin in dry state while in wet process, the raw materials are crushed in mills, mixed with water in proper proportion to form slurry and is fed to the klin.

The dry mixture (in dry process) ~~and~~ or slurry (in wet process) is burnt in rotatory klin to temperature of about 1400°c - 1500°c to form clinkers or nodules of diameter 5mm to 25mm. These clinkers are cooled and ground to the required fineness to produce a materreal known as cement. During grinding, gympsum ($CaSO_4$) is added to retard the setting time. The amount of gympsum added is 2-3% by weight of clinker. The cement thus obtained is finally bagged and transported to stockists and construction sites. Simple flow chart of cement manufacturing process is as shown below:-

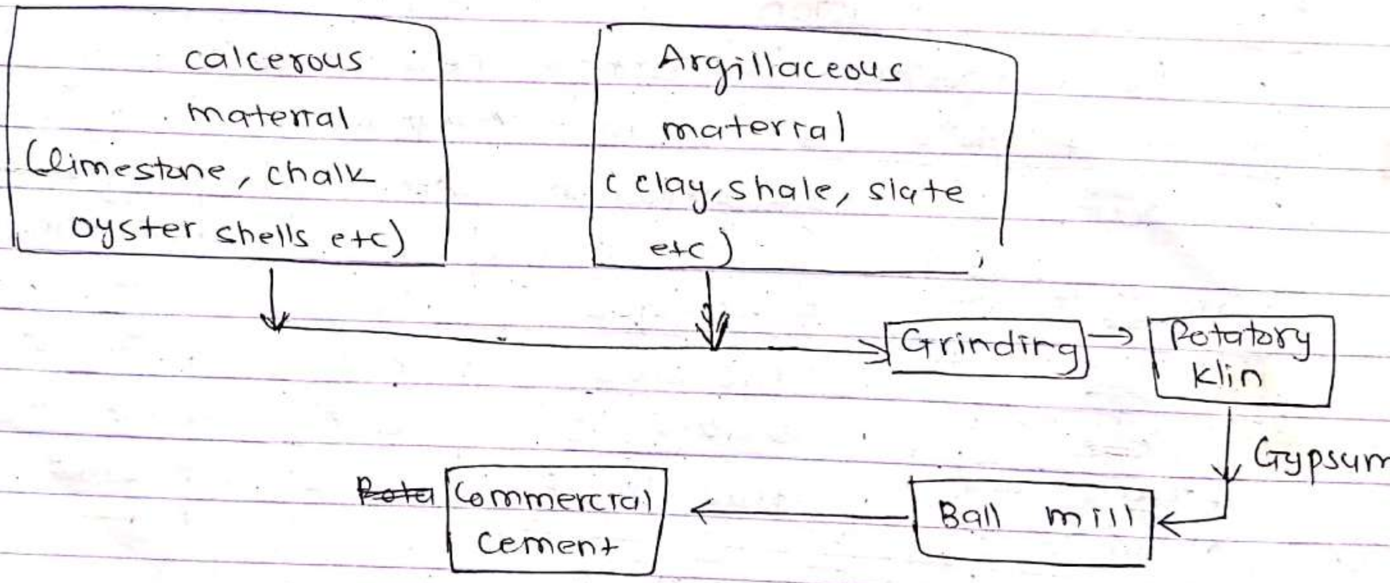

Fig:- 1.3 Manufacturing of Cement.

Approximate composition of raw materrals used in manufacturing of ordinary portland cement is Table No:

Ingredients	Function	Composition (%)
lime (CaO)	controls strength & soundness	60-65
Silica (SiO_2)	Gives strength. Excess of it causes slow setting	17-25
Alumina (Al_2O_3)	provides quick setting setting. of it causes lowers the strength	3-8
Ferrous oxide (Fe_2O_3)	Gives color and helps in fusion.	0.5-6
Magnesium oxide (MgO)	provide color, hardness. Excess of it causes cracks in concrete and mortar	0.5-4

Sulphur trioxide (SiO_3)	Makes cement sound. Excess of it causes unsound	1 - 2
Soda and Potash (Na_2O & K_2O)	Excess of it causes efflorescence & cracking	0.5 - 1.3

Compound Composition

The composition of Portland cement ~~is~~ basically consists of following four main compounds

Compound	Oxide Composition	Abbreviation	% by ~~wt of~~ mass in Cement.
Tricalcium Silicate ~~C3S~~	$3CaO \cdot SiO_2$	C_3S	25-50
Dicalcium Silicate ~~C2S~~	$2CaO \cdot SiO_2$	C_2S	20-45
Tricalcium Aluminate ~~C3A~~	$3CaO \cdot Al_2O_3$	C_3A	5-12
Tetracalcium ~~&~~ Aluminoferrite	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	C_4AF	6-12

Table No :-

Properties of Cement Compounds:-

(i) Tricalcium Silicate (C_3S)

- Develops early strength and hardness.
- It generate more heat of hydration.
- Less resistant to sulphate attack
- Hydrates and hardens rapidly.

(ii) Dicalcium silicate (C_2S)

- Hydrates and hardens slowly
- Generate less heat of hydration
- More resistant to sulphate attack
- Responsible for ultimate strength.

iii) Tricalcium aluminate (C3A)

- Hydrates rapidly
- less resistant to sulphate attack
- Contribute to little strength of cement.
- Reacts rapidly with water and generate high heat of hydration resulting initial set.

iv) Tetracalcium aluminoferrite (C4AF)

- It has less cementing value.
- It reacts very slowly and responsible for increase the volume of cement and reduce cost.

(Space for graph)

Bogue's Equation.

The four major compounds of cement are called Bogue's compounds.

The percentage of major compounds in a cement may be obtained from Bogue's equation given below:-

$C_3S = 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3)$

$C_2S = 2.87(SiO_2) - 0.754(C_3S)$

$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3)$

$C_4AF = 3.04(Fe_2O_3)$

<u>Example</u>

From Bogue's equations, calculate the different compounds of cement, whose oxide composition is as follows:-

$CaO = 61.0\%$, $SiO_2 = 25.0\%$, $Fe_2O_3 = 3.0\%$,

$Al_2O_3 = 4.0\%$, $SO_3 = 2.5\%$, free lime $= 1.0\%$.

<u>Solution</u>

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we have,

$C_3S = 4.07 * (CaO) - 7.60 (SiO_2) - 6.72 (Al_2O_3) - 1.43 (Fe_2O_3)$
$- 2.85 (SiO_2)$
$= 4.07 (61.0) - 7.6 (25.0) - 6.72 (4.0) - 1.43 (3.0)$
$- 2.85 (2.5)$
$= 248.27 - 190.0 - 26.88 - 4.29 - 7.125$
$= 19.975 = 20\%$

$C_2S = 2.87 (25) - 0.754 (20) = 71.75 - 15.08$
$= 56.67\%$

$C_3A = 2.65 (4.0) - 1.69 (3) = 10.60 - 5.07 = 5.53\%$
$C_4AF = 3.04 \times 3 = 9.12\%$. Ans .

Reaction of Cement with Water (Hydration of Cement)

Anhydrous cement doesnot bind fine and coarse aggregate. It acquires binding property only when mixed with water. The chemical reaction between cement and water is called hydration of cement.

when water is added to cement, C_3S undergoes hydrolysis first producing $C_3S_2H_3$ (calcium silicate hydrate) and $Ca(OH)_2$ is released. Then, hydrates C_2S.

In equation form:

$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3\,Ca(OH)_2$
(100) (24) (75) (49)

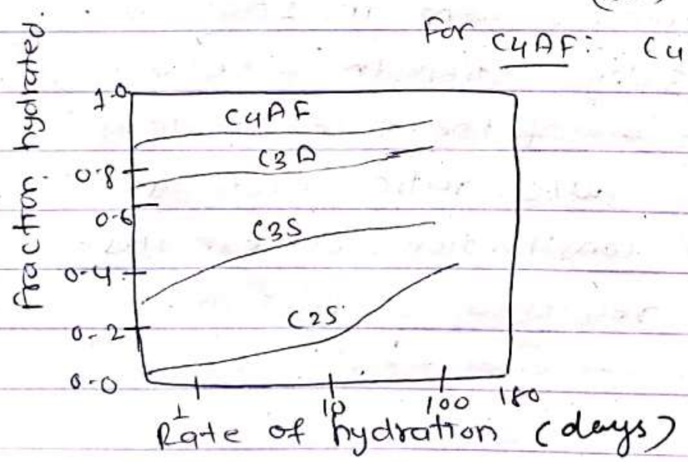
$2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca(OH)_2$
(100) (21) (99) (22)

From above equations, it is clear that both silicate require the same quantity of water for hydration but C2S produce $Ca(OH)_2$ less than half which is produced by C3S. $Ca(OH)_2$ is not a desirable product in concrete mass as it can get leached during service, making concrete porous. So, in hydraulic structures, cement with higher C2S content should be used.

The reaction of C3A with water is very violent and leads to immediate stiffening of paste which is called flash-set. To prevent flash-set, 2-3% of $CaSO_4$ is added to cement clinker. Gypsum reacts with C3A to form insoluble calcium sulfoaluminate which deposite on surface of C3A to form a protective colloidal membrane and thus retard direct hydration reaction.

for C3A: $C_3A + 6H \longrightarrow C_3AH_6$
(100) (40) (140).

For C4AF: $C_4AF + 2CH + 10H \longrightarrow C_3AH_6 + C_3FH_6$



The above graph shows the rate of hydration of C2S is lesser than that of C3S. The order of rate of reaction is C3A, C3S, C2S and C4AF. The order of gain of strength is C3S, C2S, C3A and C4AF.

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1.2.93 Introduction to special types of cement.

~~Types of cement~~:

(i) Ordinary Portland Cement:- It is suitable for general concrete construction wherever it is not exposed to sulphate in soil or in ground water. It has medium rate of strength development and heat generation. It is generally available as 33 grade OPC, 43 grade OPC and 53 grade OPC cement. Its' specific surface area is 2250 cm^2/gm.

(ii) Rapid Hardening Cement:-

Rapid Hardening cement develops strength rapidly. It has higher content of C_3S which is the main reason for increased rate of gain of strength. Its' specific surface area is 3250 cm^2/gm of cement. Initial and final setting time is same as that of OPC. The strength developed by rapid hardening cement in 1 day is of the order as that of 3 days strength of OPC and 3 days strength of RHC is of the order of strength of 7 days of OPC with same w/c ratio. It is used in cold weather, for road constructions or in those areas where form work is required to be removed early.

iii) Extra rapid hardening portland cement.

This type of cement is manufactured by addition of $CaCl_2$ to the Rapid Hardening cement. The $CaCl_2$ added should not be more than 2%. It is used when very high early strength is required or in cold weather. Its' strength is about 25% higher than RHC at 1 or 2 days and 10 to 20% higher at 7 days but the gain of strength disappears at the age of 90 days. Setting time is also short from 5 minutes to 30 minutes depending upon the temperature at the time of placement. It's' shrinkage is also higher than RHC and should not be stored for more than one month after manufacturing.

IV) Low heat portland Cement:-
In this type of cement, C_3S and C_3A content is reduced and C_2S content is increased. Thus, the rate of strength development is lower initially, but the ultimate strength is unaffected ie it is same as that of OPC. specific surface area of this cement is 3200 cm^2/gm. The setting and hardening times of this cement are nearly same as that of ordinary portland cement. It's' strength after 7 days is 50% that of OPC and after 28 days 66%. This cement is not suitable for ordinary work instead it is used in mass construction works like dams, bridges etc.

(V) Sulphate resistance Cement:- A portland cement with low C_3A (less than 5%) and C_4AF contents is very effective against sulphate attack. such a cement having high silicate content is called sulphate resisting cement. An ordinary portland cement is susceptible to attacks of sulphates in solution which permeate in the hardened concrete and react with free $Ca(OH)_2$, hydrate of calcium aluminate and even hydrated silicates to form calcium sulphoaluminate having volume of approx. 227% of volume of original aluminates. This expansion in hardened structure will cause cracks and subsequent disruption takes place. It is called sulphate attack. This process is accelerated in wetting and drying condition like that ~~of~~ of marine environment.

So, this type of cement is used for the construction of structure in marine environment, beneath reactive/aggressive soils, sewage treatment plants and in marshy regions.

vi) Water proof portland cement:- To ordinary portland cement, waterproof substance is added during mixing. The common admixtures are calcium stearate, aluminium stearate and the gypsum treated with tannic acid. It is used in structures like tanks, reservoirs etc.

~~vii)~~

vii) White Portland Cement:- The manufacturing process of white cement is same as that of ordinary portland cement except the amount of ~~o~~ iron oxide is kept less than one percent. For architectural purposes white ~~cemen~~ concrete is required and to achieve this, it is better to use white cement. White cement has slightly lower value of specific gravity than OPC (3.05 to 3.10) and strength of white cement is also lower than ordinary portland cement.

viii) Colored portland cement:- To OPC cement, upto 10% coloring pigments are added during grinding of cement clinker. A good pigment should be permanent. For architectur purposes, colored portland cement is required.

1.2.4 Use of water in Concrete.

Water is most important and least expensive ingredient of concrete. A part of mixing water is utilized for hydration and remaining part is used as a lubricant between fine and coarse aggregate and makes concrete workable. Besides mixing, water is also used for curing and washing aggregates.

Quality of mixing water.

The quality of mixing water should conform to the following:-

(i) The water suitable for drinking is fit for concrete mare as well. But water containing 0.05% of sugar by weight of water is quite fit for drinking but it retards cement's initial setting time by 4 hours. So, water used for concrete production should be free from acids, oils, carbonates, bicarbonates, alkalis, sugar, silt and organic materials that will have adverse effect on green and hardened concrete.

ii) PH value of concrete mixing water should be between 6 and 8.

iii) Algae, if present ~~in~~ in mixing water, combines with cement and reduces bond ~~st~~ between aggregates and cement paste. So, water should be free from algae.

iv) Water should be free from chlorides (generally in sea water) which results in corrosion of reinforcement.

v) If the compressive strength of concrete is 90% of the strength with distilled water than this water is acceptable for concrete.

Water for washing of Aggregates:-

- The most important effect of the use of impure water for washing aggregate is the deposition of coating of salts and silt, organic matter etc on the surface of aggregate particles. The coating of impurities form a layer betweel gel and aggregate surface thus there will be poor bond between aggregate and cement past which ultimately reduce the strength of ~~aggrego~~ concrete. Thus, water used should not contain such impurities.

Water for curing of concrete:-

- Water suitable for mixing concrete, is also suitable for curing of concrete. However, following points should be noted regarding the use of water for curing of concrete:-

1) Iron or organic matter:- The presence of these matters may cause staining of concrete particularly if the flow of water over the concrete is slow and evaporation is rapid.

(2) Water should be free from carbondioxide (CO_2) as it attacks hardened concrete.

3) Water formed by melting ice or by condensation should not be used for curing as it contains little CO_2. This CO_2 in water dissolves $Ca(OH)_2$ and causes surface erosion. Sea water is also prohibited for curing purposes.

1.2.5 Admixtures - Classification of admixtures, Introduction to commonly used admixtures (superplasticizer, water proofing agent and Retarders), Use of Mineral admixtures in concrete.

Admixtures are the chemical compounds in concrete other than hydraulic cement, water and aggregates, and mineral ~~aggregate~~ additives that are added to the concrete mix immediately before or during mixing to modify one or more properties of fresh or hardened concrete. The use of admixture should offer improvement in the properties of concrete which cannot be economically attained by adjusting the proportions of cement, aggregate and water. But, admixtures are no substitute for good workmanship. An admixture should be used only after assessing its effects on the concrete to be used under a intended situation. The properties commonly modified are the rate of hydration, dispersion, air-entrainment and workability.

Function of Admixtures

Admixtures are used for the following purpose:-

i) To speed up the strength development rate at early ages.

ii) To retard the initial setting of concrete.

iii) To improve workability of concrete.

iv) To reduce segregation in grout and concrete mixes.

v) To increase strength of concrete by reducing water content and densification of concrete

vi) To enhance the durability property of concrete

vii) To help in curing of concrete.

viii) To reduce shrinkage during setting of concrete.

ix) To reduce bleeding of concrete.

x) To impart colour to concrete

xi) To reduce heat of hydration.

xii) To enhance bond of concrete to steel reinforcement.

xiii) To increase the resistance to chemical attack.

xiv) To increase imperviousness of concrete.

xv) To decrease weight of concrete per cubic meter.

xvi) To control the alkali - aggregate reaction.

xvii) To produce cellular concrete.

xviii) To ~~pr~~ impart colour to the concrete surface etc.

Classification of Admixture

Admixture can be classified into following two category:-

(i) chemical admixture.

(ii) Mineral admixtures.

(i) chemical admixture

- chemical admixtures are listed as following:-

(a) Accelerating Admixture / Accelerator.

(b) Retarding Admixture / Retarder

(c) Air - entraining admixture

(d) water/reducing admixture. (d) Plasticizers

(e) Plasticizers (e) Superplasticizers.

(f) Superplasticizers.

(ii) Mineral admixtures

- Some of the mineral admixture are listed as:-

(a) Fly ash

(b) Granulated blast furnace slag

(c) Silica fume.

(d) Rice husk

(e) Metakaoline

(i) Chemical admixture.

chemical admixture are those admixture which are in form of powder or fluids added to concrete to improve or impart specific properties of fresh or hardened concrete.

(a) Accelerating admixture :-

- It is also called as accelerator. An admixture used to accelerate the initial set of concrete is called an accelerator. Acceleration of setting facilitates early removal of forms, reduction of required period for curing and earlier placement of structure in service. It is also used when concrete is to be done at low temperatures. It ~~m~~ is useful in repairing ~~want~~ waterfront structures in tidal zone, underwater concreting, basement water proofing operation.

Most commonly used accelerator is $CaCl_2$.
Besides it, $NaOH$, Na_2SO_4, $NaCl$, Na_2CO_3, KOH, K_2SO_4 etc are also used as accelerator. As per IS 456-1964, 1.5% of $CaCl_2$ by wt. of cement is sufficient for the purpose but upto 2% $CaCl_2$ may be used. When 2% $CaCl_2$ is used, it increases compressive strength by 17% at 1 day, 30% at 7 day and about 10% at 28 days. and continued upto 2 years.

(b) Retarders:

Retarder increases the setting time of the concrete mix by slowing down the initial rate of hydration. Retarders are used primarily to offset the accelerating and damaging effect of high temperature and keep concrete workable during the whole period of placing so that construction joints may not develop. Retarder are used in the following situations:-

(i) ~~use~~ Pumping cement grouts in oil wells.

(ii) In situations where concrete is to be transferred for long distance for placement.

Most common retarder is Gympsum. Sugar is also used as retarder. 0.05% addition of ~~cem~~ sugar by mass of cement retards the setting time by 4 hrs. Some other retarders are calcium borate, hydroxides of zinc and lead etc.

(c) Air-entraining admixture:- Air-entraining admixture incorporates controlled amount of air throughout the body of concrete, without significantly ~~a~~ changing the setting rate of concrete. It aims to improve workability, durability, resistance to frost action, reduction in bleeding and segregation and easier placing and finishing. However, due to incoorporation of air, the strength of hardened concrete decreases. It is also helpful to produce light-weight aggregate concrete as well. It also increases the chemical resistance of the concrete and also improves permeability characteristics. Desirable entrained air content is 3 to 6%. The compounds used for air-entrainment are olive oil, tallow, stearic and oleic acids, abietic and pimeric acid salts etc.

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(d) Plasticizers:- It is also known as water reducing admixture. Its' function is to reduce water/cement ratio by maintaining the workability or to increase workability at constant water/cement ratio. when water/cement ratio is decreased, the concrete thus obtained will have higher strength at the same workability. plasticizer are normal or mid range water reducer. Normal water reducer reduces water by 5 to 10 percent while mid range water reducer reduces water by 10 to 15%.
for eg. derivatives of lignosulfonic acids and their salts, hydroxylated carboxylic acid etc.

(e) Superplasticizers:- These are high range water reducer that reduces water upto 20 to 40%. superplasticizers are used for producing flowing concrete to be used in inaccessible locations, floors or where very quick placing is required. A self levelling and self compacting concrete is called flowing concrete. Super plasticizers are also used for the production of high strength and high performance concrete with ~~water content~~ water/cement ratio ~~to~~ being 0.25 or less, super plasticizers can be used to produce flowing concrete with strength 120MPa or more.
For eg. sulphonated melamine formaldehyde condensate (SMF).
sulphonated napthalene formaldehyde condensate (SNF).
Modified lignosulphonates (MLS) etc

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ii) Mineral admixtures:-

These are supplementary cementing materials. They are finely ground siliceous material which do not possess cementing property in themselves, but react chemically with $Ca(OH)_2$ released from the hydration of portland cement at normal temperature to form compounds of low solubility having cementing properties. These are added to concrete to make mixtures more economical, reduce permeability, increase strength or influence other concrete properties. Some mineral ~~addi~~ admixtures are:-

a) Fly Ash:- It is the residue obtained from the combustion of powered coal. It is a waste product from coal fired power stations. The fly ash particles are spherical and have same fineness as that of cement. The unburnt carbon content in fly ash should be less than 5%. Use of right quantity of fly ash reduces the water content required for the production of concrete with desired slump which finally reduces drying shrinkage, bleeding.

b) Silica fume:

It is a by product produced during the manufacture of silicon metal and found to be not only pozzolanic in character but also capable of producing very dense concrete.

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(c) Rice husk ash: It is waste product of rice mills. It is highly reactive pozzolanic admixture. It is produced by controlled combustion of husk - retaining silica in the crystalline form, with cellular structure.

(d) Metakaoline: It is obtained by calcination of pure or refined dry clay at temperatures of 650°c - 850°c and by grinding it subsequently to achieve fineness. It is highly reactive pozzolana.

(e) Ground granulated blast furnance slag:-
chemical composition of ground granulated blast furnance slag indicates the presence of silica glass which contains calcium, magnesium and aluminium. It produces concrete with improve resistance to chemical attack.

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Gypsum = $CaSO_4 \cdot 2H_2O$.   Ettringite :- $6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$

Reaction Involves in C_3A:

Case I:

When Gypsum is not added:

$C_3A + 6H \longrightarrow C_3AH_6$ (Calcium Aluminates Hydrates, It is
[100] [40] Cubic Crystalline & reaction is rapid leads to flash set of cement).

To avoid the flash set of cement, Specific amount of gypsum ($CaSO_4 \cdot 2H_2O$) should add.

Case II: (When ~~ample~~ ample amount of Gypsum is added)

The primary initial reaction of C_3A, when ample amount of Gypsum is present, then;

$C_3A + 3C\bar{S}H_2 + 26H \longrightarrow C_6A\bar{S}_3H_{32}$

$3C\bar{S}H_2$ ↓ $CaO \cdot SO_3 \cdot 2H_2O$ ↓ $CaSO_4 \cdot 2H_2O$ (Gypsum ~~of~~ or Calcium Sulphate)

$C_6A\bar{S}_3H_{32}$ ↓ ($6CaO \cdot Al_2O_3 \cdot 3SO_3 \cdot 32H_2O$) (Ettringite:- Composed of Calcium, sulphate, ~~ao~~ alumina, and water)

If all the Sulphate is Consumed before C_3A has completely hydrates, then ettringite become unstable ~~to~~ and changes into Mono-sulphate Aluminates.

$C_3A + C_6A\bar{S}_3H_{32} + 4H \longrightarrow 3C_4A\bar{S}H_{12}$
(Mono sulpho - Aluminates)

Chapter 2: Structure of the Concrete:

2.1 Concrete as a three phase system.

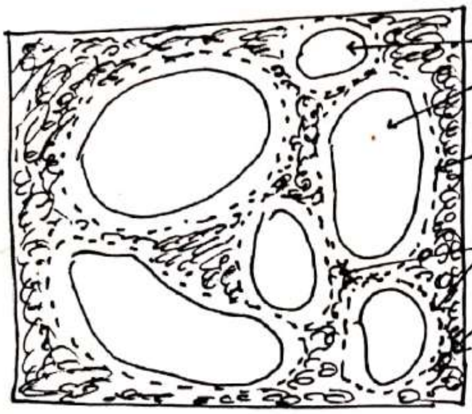
Type, amount, size, shape and distribution of the phases present in the solid state is called as the structure of the concrete.

Macrostructure :- Gross structure is visible to human being. (200 um) → (Only two phase System is seen)

Microstructure :- Microscopically magnified portion of Macrostructure. (Roughly < 100 um) → (Three phase System).

Three phase of Concrete

1) Aggregate phase (Aggregate of different size).
2) Binding Medium phase (Cement paste/Mortar phase).
3) Transition zone phase (Between Aggregate & Binding Medium phase).



2.2 Structure of the Aggregate phase:

- Responsible for the unit weight, elastic modulus, dimensional stability of Concrete because these properties are based on the physical characteristics.
- (60-70)% of the volume of solids in most of the Concrete.
- The chemical or mineralogical Composition of the solid phase in aggregate is usually less important than the physical characteristics such as Volume, size and distribution of pores.
- It is stronger than other two phases.

→ Size and Shape affect the Strength of Concrete.

→ Larger the Size of Aggregate in concrete, higher will be the tendency for water films to accumulate next to the aggregate Surface, thus result in weakening the cement paste aggregate transition zone. (Internal Bleeding).

Bleeding: free water in the mix rises upward to the Concrete Surface due to the Settlement of Solid particles by the gravity action. This process is known as Bleeding of Concrete.

Internal Bleeding: In certain Situation though bleeding water doesnot Come up to the Surface but bleeding does take place. The bleeding water get trapped on the underside of Coarse aggregate or of reinforcements. This is known as internal Bleeding.

2.3: Structure of Hydrated cement paste phase (HCP).

It is the most important phase of the Concrete as it influence the overall behaviour of hardened concrete. strength, durability, creep, shrinkage and elastic properties of the Concrete is greatly affected by the paste structure of Concrete.

a) Solids in Hydrated cement paste.
- i) Calcium silicates Hydrates (C-S-H)
- ii) Calcium Hydroxide ($(Ca(OH)_2)$)
- iii) calcium Sulpho-aluminales
- iv) Unhydrates clinker grain

i) Calcium Silicates Hydrates :(C-S-H)

→ Generally known as C-S-H gel or tobermorite gel.

→ Most important to generate the ~~cementious~~ Cementitious property in cement.

→ It covers approximately (50-60)% of total volume of Solid.

→ Exact structure of the C-S-H is not known.

→ strength is due to venderwall force.

ii) Calcium-Hydroxide ($(Ca(OH)_2)$)

→ Minor role in structural property relationship.

→ It is also called as portlandite

→ Calcium hydro-oxide crystal Constitute 20 to 25% of volume of hydrated Cement paste.

→ It tends to form large crystal with distinctive hexagonal prism morphology.

→ strength Contribution potential of calcium hydrates is limited as compared to C-S-H.

→ Adverse effect due to solubility.

iii) Calcium Sulpho-aluminates:

→ It occupy (15-20)% Solid volume of hcp.

→ Minor role in structural property relationship.

→ Ettringites and Monosulphate

→ presence of Monosulphate hydrates in concrete is vulnerable due to sulphate attack.

iv) Unhydrate clinker grain:

→ Depends upon the particle size of cement and degree of hydration

→ clinker particles size range between 1 to 50 um.

→ Smaller particles hydrates first and larger become smaller due to hydration.

→ Some unhydrates clinker grains may be found in the micro-structure of hcp, even long after hydration.

b) Voids in Hydrated cement paste:

i) Inter layer space in C-S-H.

→ powers determined that it accounts for 28% porosity in solid C-S-H.

→ Suggested that space may very from 5 to 25 Å

→ This void is too small to have adverse effect on the strength and permeability of hcp.

→ water in small voids can be held by hydrogen bonding and is removal ~~of~~ under certain condition may contributes to drying shrinkage and creep.

ii) Capillary voids:

→ space not filled by solid component of hcp.

→ The capillary voids may range from 10 to 50 um and more.

→ Size and Amount of Capillary voids is related to w/c and degree of hydration.

→ void larger than 50um, reffered to as macropores are assumed to be determental (हानिकारक) to strength and permeability.

→ while voids smaller than 50nm, ~~reffr~~ referred to as micro-pores and assumed to be more important to drying shrinkage and creep.

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iii) Air voids:

→ Capillary voids are generally irregular in shape, where as air voids are spherical.

→ Entrained air voids are usually 50 to 200 µm.

→ Entrapped air voids may be as large as 3mm.

→ Capable of adversely affecting its strength and Impermeability.

Strength of HCP:

→ Strength in solid product of hcp is due to Venderwaals force of attraction.

→ Small crystal of C-S-H possess enormous surface area and adhesive capability tends to adhere strongly not only to each other, but also to low surface solid such as calcium hydroxide, anhydrous clinker grains and fine & coarse aggregate particles.

→ Inverse relationship between porosity and strength.

→ Voids in hcp is the function of amount of mixed and degree of hydration.

~~Dimensitional~~ Stability (Dimensional Stability)

→ Saturated hcp is not dimensionally stable.

→ When hcp is exposed to the environmental humidity material will began to loose water and shrinks.

→ As soon as Relative Humidity (RH) drops below 100%, free water held in large cavity (>50nm) began to escape to the environment. There is little shrinkage at that point.

→ Mechanisms which are responsible for drying shrinkage are also responsible for creep of hcp.

→ In case of creep sustained external stress become the driving force for the movement of the movement of physically absorbed water.

→ Creep strain can occur even at 100% Relative Humidity.

Durability of Hcp:

- → Hcp is alkaline, therefore exposure to acidic water is determental.
- → permeability is the prime factor for durability.
- → strength and permeability of hcp are two sides of same coins in the sense that both are closely related to the capillary porosity or the solid/space ratio.
- → In hcp direct relationship was noted between the permeability and the volume of pores larger than about 100nm.

2.4 Transition Zone phase:-

The transition phase is the region between larger aggregate particles and hydrated cement paste (hcp). It exist as the thin cell, typically (10-50) micron thick. .. results to poor formation of transition zone can be. cracking and formations of water films around the larger particles during mixing

Owing to higher w/c, the transition zone is more porous than the mortar matrix. Due to the low strength, microcracking often forms within the transition zone even before the loading is applied. The transition zone is usually weaker than both the aggregate and paste zone. .. Although transition zone occupy much less volume than other two phase.

→ Cement paste or mortar will always be stronger than the concrete provided that they have the same w/c and be tested in same age.

→ permeability of concrete is more higher than the cement paste

→ Under the same loading component of concrete (Aggregate and hcp) can shows the linear behaviour while the concrete itself shows the non-linear Behaviour).

(fig:- Three phase of Concrete)

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Chapter 3 :- Mix design of Concrete and property of Green Concrete

3.1 Workability and its test

As per the IS Code, workability of the freshly mixed Concrete is the property which determines the easy and homogenity with which it can be mixed, placed, compacted and finished.

According to the Road research laboratory, uk, the strict defination of workability is " Amount of useful internal work necessary to provide the full compaction. This compaction energy is required to

→ overcome the internal friction between individual particles in the Concrete.

→ Overcome the surface friction between concrete and formwork.

factor Involving the workability are:.

(1) water cement ratio :- Increase in w/c higher will be the workability

(2) Aggregate cement ratio :- Low aggregate cement ratio means rich mix, which produces more paste, which makes the mix Cohesive and gives the better workability.

(3) Shape, size and texture of Aggregate :- Round and cubical shape aggregate have lesser surface area than the angular & flaky aggregate, Hence workability increases. Rough texture have more area than the smooth texture so, smooth texture gives higher workability.

(4) Use of Admixtures :- Admixture reduces the internal friction which causes the high workability.

(5) Grading of Aggregate :- A well graded aggregate is one which has least amount of voids in a given volume. when the voids are less, excess paste is available to give the better workability.

Test of workability:

There are different test available to check the workability which are as follow.

(1) slump test
(2) Compaction factor test
(3) flow table test
(4) Vee Bee (Consistometer test)
(5) Kelly Ball test.

Among these all test slump test is commonly use due to easyness and can be used in laboratory as well as in site also.

In IS 456, 2000 clause 7, page 17, Recommended to following guideline.

(a) Compaction factor test :- for very low degree of workability
(b) slump test :- for low, medium and High degree of workability.
(c) flow table test :- for very high degree of workability.

1) Slump test:

- Most commonly used Method.
- Not suitable for very wet and very dry concrete.
  (very wet: flow table; very dry: Compaction factor)
- Use conveniently as a control test and gives an indication of uniformity of concrete from Batch to Batch.
- The apparatus for conducting the slump test consists of the metallic mould in the form of frustum of cone having dimension as below.

  Bottom dia (ϕ_b) = 200mm
  Top dia (ϕ_t) = 100 mm
  Height = 300mm

- Thickness of the metallic sheet for mould should not be thinner than 1.6mm.
- For the tamping of the concrete a steel tamping rod 16mm dia and 0.6m long with bullet end is used.

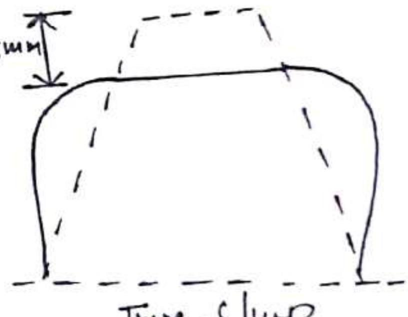
procedure for slump test:-

The mould is placed in smooth, horizontal, rigid and non-absorbent surface, inner surface of mould should be clean throughly, which must be clean and free from adherence of any old set concrete.

- Fill the mould with fresh concrete in 3 or 4 equal height layer.
- Each layer is tamped 25 times by the tamping rod. After the top layer is tamped, the concrete is stuck off level with the trowel.
- The mould is removed immediately by raising it slowly and carefully in a vertically direction to allow the concrete to subside.
- This subsidence is referred as the slump of the concrete in mm or decrease in the height of the center of slump concrete is called as slump.

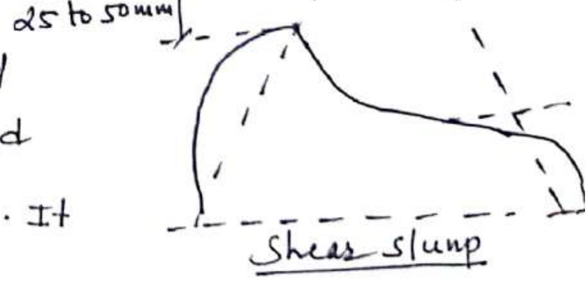
As in the figure, it indicates that the characteristic of concrete in addition to the slump value.

If the concrete slumps evenly, then it is called as True slump.



True Slump

If the one half of the cone slides down, then it is called shear slump. In this case the slump value is measured as the different in height of mould and the average value of subsidence. It also shows that the concrete is non cohesive and indicates segregation characteristics.



Shear slump

If the concrete spreads then it is called as collapse slump.

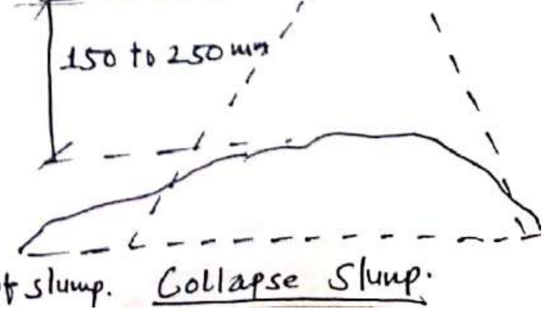


fig: different type of slump. Collapse Slump.

② Compaction factor test:

This test is designed primarily to determine the workability of concrete in lab where maximum size of Aggregate doesnot exceed 38mm. However ~~are~~ it may also used in field. It is more sensitive and precise ~~and~~ than the slump test and is particularly useful for concrete mixes of very low workability as are normally used for concrete to be compacted by vibration. Such a concrete may fail to slump.

The workability is defined as the amount of work required to place and compact the concrete fully. The degree of compaction is called as the compaction factor and measured by the density ratio. It is the ratio of actually achieved density in the test to the density of same fully compacted concrete. Thus compacting factor can be defined as the ratio of actual density obtained during the test to the density of fully compacted concrete.

$$\text{Compaction factor (CF)} = \frac{\text{wt of partially compacted concrete}}{\text{wt of fully compacted concrete}}$$

for equal volume.

procedure:

- Take fully concrete in upper hopper (A)
- open the trap door of upper (A) hopper to fall the concrete into lower hopper (B).
- open the trap door of lower hopper (B) and concrete is allowed to fall into the cylinder.
- Excess of concrete in the cylinder is cut off by the help of two trowels sliding across the top of the cylinder and take wt of the concrete in the cylinder which is called as partially compacted concrete.

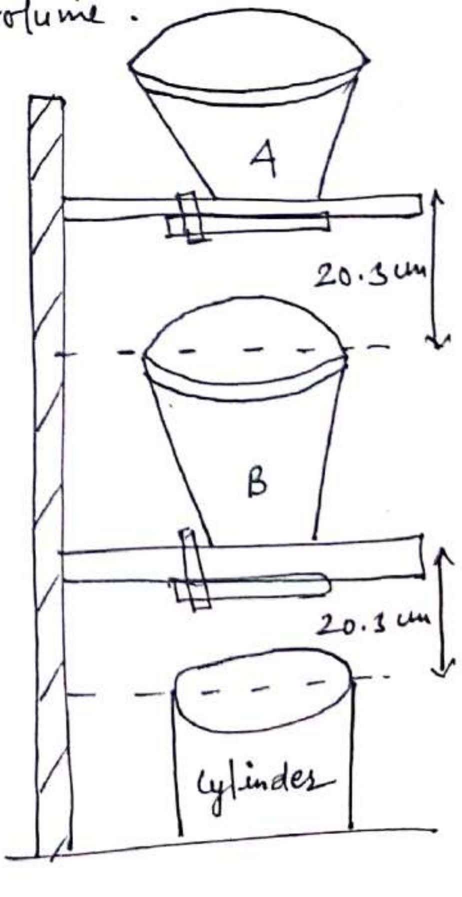


Fig:- Compaction factor apparatus.

→ Empty the cylinder and then refilled with Concrete with the same sample in 5 cm layes each with heavy vibration or ramming for fully Compaction then take the weight of fully compacted concrete.

Dimension :

Upper hopper A	Dimension in cms.
1. Top internal dia	25.4
2. Bottom internal dia	12.7
3. Internal height	(27.9 – 28.0)

Lower hopper B	Dimension in cms
1. Top Internal dia	22.9
2. Bottom Internal dia	12.7
3. Internal height	22.9

cylinder C	Dimension in cms
1. Internal dia	15.2
2. Internal height	30.5
3. Distance between bottom of A and top of B	20.3
4. Distance between bottom of B and top of C	20.3

Water Cement Ratio (W/C)

Water cement ratio (w/c) can be expressed interm of weight and volume too. In term of ~~vol~~ weight, the quantity of water to be used per unit weight of cement (1kg) is known as the water cement ratio. In term of volume water used in liter per bag of cement (50kg) is taken as the water cement ratio by volume.

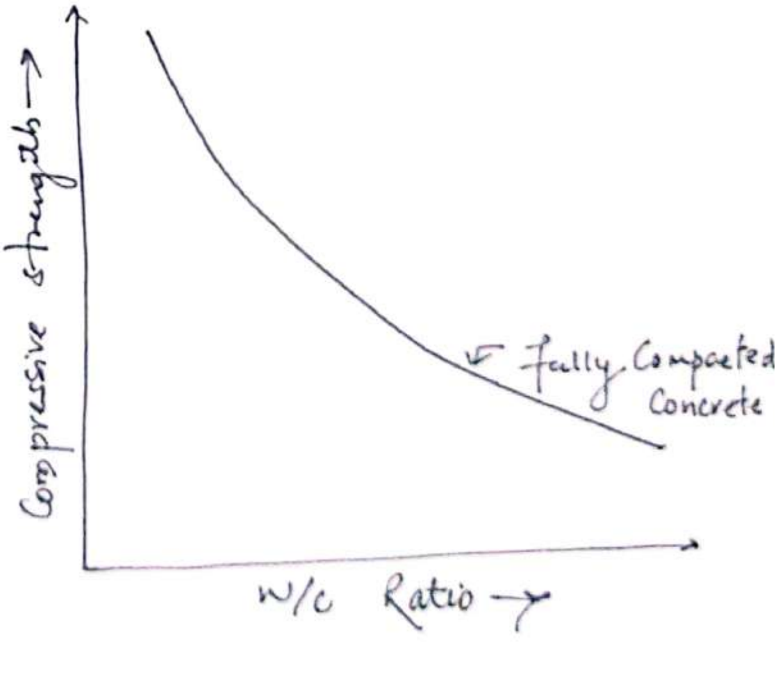
→ Water cement ratio is an index of strength of concrete.

→ for fully compacted concrete, strength is inversly proportional to w/c. The typical curve is shown as below.

→ Minimum w/c is 0.38, required for concrete for the complete reaction (hydration).

→ w/c can be reduced by using the plasticizer and superplastizer.

W/c have significant influence on workability. Higher w/c will result on fludity of concrete which increases the workability.



3.3 Introduction to the nominal mix

→ A mix having fixed Cement Aggregate ratio which insure the adquate strength is called as the nominal mix design. It is generally used for M_{25} or less strength of Concrete.

- Mix design is the process of selecting the suitable ingradients of Concrete and determine the relative quantity with the purpose of producing a economic concrete which has Certain minimum properties (durability strength, workability) etc.

Information required for mix design:

→ Grade of Concrete
→ Types of Cement to be used
→ Type and maximum size of Aggregate
→ Minimum cement Content
→ Max^m w/c by weight
→ Degree of workability
→ Exposure Condition
→ Types of admixture of used
→ Max^m temperature of fresh Concrete
→ Method of placing
→ Method of Supervision etc.

Proportion of nominal mix

Grade	Ratio	Uses
M_{10}	1:3:6	→ for mass Concrete work
M_{15}	1:2:4	→ for RCC, Beam, Columns etc.
M_{20}	1: ½ :3	→ for hydraulic structure, piles & foundations.
M_{25}	1: 1: 2	

3.4 probabilistic Concept in mix design approach:

During the process of Construction, there may have Certain amount of variability both in material as well as in the Construction Method. There is variation of strength from Batch to Batch and also within the Batch also. It is very difficult to asses the strength of final product

∴ The basis of acceptance of the Sample is that a reasonable Control of the Concrete is provided, by ensuring that the probability of test result falling below the design strength is not more than the specific tolerence limit. Thus the aim of the quality Control is to limit the variability as much as practicle.

If a number of cube test ~~are~~ result are plotted on histogram, the results are found to be follow a bell shaped curve known as the "Normal distribution Curve".

The results are said to be follow a normal distribution curve if they are equally spaced about the mean value and if the largest number of cube have the strength closer to the mean value, and very few number of result have the very much greater or lesser than the mean value.

This deviation in the strength value represent the quality Control in the field. The following ~~curve~~ curve shows how good quality of concrete can be achieved.

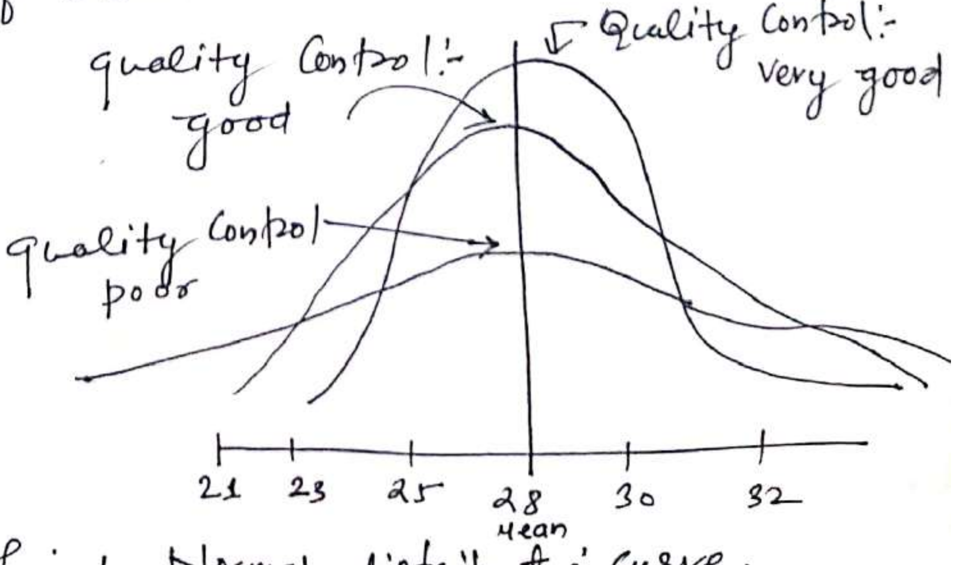


fig:- Normal distribution curve.

The arthematic mean of sample $x_1, x_2, x_3, x_4 \ldots x_n$ is denoted by $\bar{x} = \frac{x_1 + x_2 + \ldots x_n}{n}$

Standard deviation $\sigma = \sqrt{\frac{\Sigma (x_i - \bar{x})^2}{(n-1)}}$

Coefficient of variation = $\frac{\text{Standard deviation}}{\text{Mean}} = \frac{\sigma}{\bar{x}} * 100\%$

Target mean strength

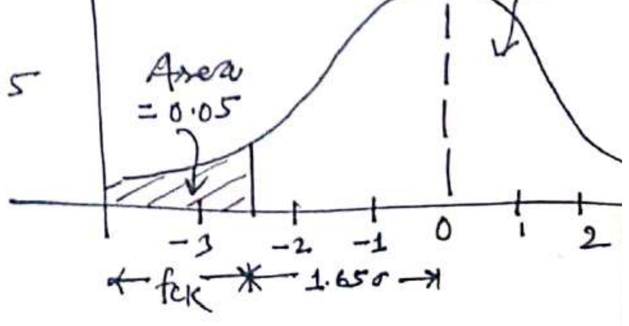
From the behaviours of normal distribution curve it is clear that when we are testing large no of cubes, all the cubes may not have a same strength even if they are cast and tested in a identical condition. Some of them have higher than the mean value and some will have the lower. Then the deviation from the mean value is indicated by the "Standard deviation".

It is clear that if we required the strength equal to the mean value, probability is that only 50% cube will have equal or more than the mean strength. If we want to increase the % of equal or more than the required strength, we have to target for the higher strength. for this we have to place on left side of the Mean value by the distance $K\sigma$ where K is a Constant value.

As per IS 456:2000 this % is 95%,
Hence desired strength to be placed 1.65 times σ Left to the mean.

$TMS = f_{ck} + 1.65 * \sigma$

for 5% risk factor $K = 1.64 \simeq 1.65$
for 1% risk factor $K = 2.33$



Characteristics strength:. (Minimum strength).

While ~~des~~ designing the mix we have to target for the higher strength, which is called as the "Target strength", so that not more than 5% test result falls below the ~~designed~~ desired strength called as fck ie characteristic strength.

$$f_{mean} = f_{ck} + \cancel{ks}\, k\sigma \text{ or } (k \cdot s)$$

$$\therefore f_{ck} = f_{mean} - k\sigma$$

where fck is called as characteristic strength.

Grading of Concrete:.

M_{20}:- The numbers 20 refers to characteristic compressive strength of 15 * 15 * 15 cm^3 at 28 days expressed in N/mm^2 or Mpa.

DOE Method of mixed design:

Step 1: find the target mean strength, $f_{target} = f_{ck} + 1.65\sigma$

Step 2: select the water cement ratio from curve (W/C) and check W/C for durability condition.

Step 3: Estimate the water content based on slump value / Vebee, maximum size of aggregate and type of aggregate.

Step 4: Calculate the cement content using $\frac{w}{c}$ = water cement ratio and check cement content for the durability condition.

Step 5: Determine the wet density of concrete using free water content & bulk specific gravity of aggregate. Also find total aggregate. (Total aggregate = Wet density − cement − water).

Step 6: Determine the fine aggregate based on the maximum size of aggregate, slump value, W/C and grading zone of sand from curve.

Step 7: Make necessary adjustment for moisture content in aggregate.

— x — x — x — x — x — x — x —

ACI Method:

· American Concrete Institute

Deals with both air entrained and non- air entrained Concrete.

Steps:

1. Find the mean Compressive Strength as per

$$f(t) = f_{ck} + 1.65\sigma \qquad \sigma = \begin{cases} 3.5 \rightarrow (M_{10} - M_{15}) \\ 4 \rightarrow (M_{20} - M_{25}) \\ 5 \rightarrow > M_{30} \end{cases}$$

2) find the water cement ratio from the table for the target compressive strength considering air entrained or non-air entrained concrete. Also check w/c for check for durability condition.

3) Determine the max^m size of aggregate to be used that is economically available and consistent with the dimension of the structure.

Generally; RCC work → 20 mm;
other work → 10 mm.

4) Determine the slump depending upon the degree of workability and placing condition.

5) Total water content of the concrete is determine from the given slump and max^m size of aggregate. Also find the percentage of entrapped air.

6) Cement Content is determine from.

$$\frac{w}{c} = \frac{\text{water Content}}{\text{Cement Content}}$$

7) The dry Bulk volume of Coarse aggregate per unit volume of concrete is selected for a particular max^m size of Coarse aggregate & F.M of fine aggregate.

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8) weight of Coarse Aggregate per meter cube of Concrete is calulated by multiplying the bulk volume with the bulk density.

9) Estimate the density of fresh Concrete, for given maximum Size of Aggregate & Air entrained or Non- air entrained Concrete.

10) find the weight of fine aggregate. It can be done by two diffrent technique.

i) a) By the method of density of fresh concrete:

∴ Fine Aggregate (Kg/m³) = Density of Concrete − wt of cement/m³ − wt of water/m³ − wt of C.A/m³

b) By the method of absolute volume; which is more accurate.

→ Solid volume of cement, water, C.A in one cubic meter of concrete can be calulated by knowing the Specific gravity of cement, water, C.A respectively.

→ The Solid volume of f.A is calulated by subtracting the solid volume of cement, C.A, water and entrapped air from total volume of Concrete.

→ finally weight of fine Aggregate is calulated by multiplying the Solid volume of fine Aggregate by Specific gravity of fine Aggregate.

→ Adopt Higher value of two above.

11) Make necessary adjustment for moisture Content in fine and Coarse Aggregate.

12) perform the Trial mix until the desired ~~test~~ result is acheived.

ACI Method:

Design a Concrete Mix for a Construction of an elevated ~~tank~~ Water tank from the following data.

a) Strength of Concrete $f_{ck} = 35$ Mpa at 28 days.

b) Specific gravity of f.A = 2.65

c) Specific gravity of CA = 2.75

d) Maximum size of C.A = 20mm

e) Dry rodded bulk density of C.A = 1600 Kg/m^3

f) fineness Modulus of fine Aggregate = 2.8

g) Slump = 50mm

h) Ordinary portland Cement is used. Coarse aggregate is found to absorb upto 1% and free surface moisture in sand is found as 2%. Assume any data required.

Soln: let the Concrete be Non-air entrained Concrete:

1) Target Mean strength of $F_{Target} = f_{ck} + K \cdot s$

$= 35 + 1.65 * 5$

$= 43.25$ Mpa

2) from the table given in Code, by the method of Interpolation.

$W/C = 0.41$ (strength point of view)

$W/C = 0.5$ (Durability Condition, Exposure to fresh water)

Adopt Min of (0.41 & 0.5) ie $W/C = 0.41$

3) Calculation of water Content;

for slump = 50mm

Maximum Size of Aggregate = 20mm,

for Non-air entrained Concrete

Water Content = 185Kg/m^3

& Entrapped air Content % = 2%.

4) Cement Content:

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

$$\therefore \text{Cement} = \frac{\text{water}}{w/c} = \frac{185}{0.41} = 45\cancel{8}\ \text{kg/m}^3$$

for ~~from~~ durability Consideration, we dont check ~~for~~ In ACI Method, but ~~we~~ if we ~~are~~ intrested to ~~the~~ check, then use the IS guideline,

(By using IS Guideline) Cement = 340 kg/m³

∴ Adopt Maximum of both; Cement = 453 kg/m³

5) for maximum ~~φ~~ size of 20 mm C.A & F.M of fine aggregate of 2.8, the ~~dry~~ bulk volume of C.A = 0.62

∴ wt of Coarse ~~aggregate~~ = 0.62 * 1600 = 992 kg/m³

6) Estimate ~~the~~ density of fresh Concrete for 20mm maximum Size of ~~Aggregate and~~ for non ~~air~~ Entrained Concrete = 2355 kg/m³

7) weight of all ingredients of Concrete except fine Aggregate are known. Then find the wt of fine aggregate.

ie; wt of water = 185 kg/m³

wt of cement = 453 kg/m³

wt of Coarse Aggregate = 992 kg/m³

∴ wt of fine Aggregate = 2355 − 185 − 453 − 992
= 725 kg/m³

The weight of fine aggregate may also be found from Absolute Volume method which is more accurate as follow.

Ingradient	wt (Kg/m³)	Absolute Volume (cm³)
1. Cement	453	$\frac{453}{3.15} * 1000 = 143.8 * 10^3$
2. water	185	$\frac{185}{1} * 1000 = 185 * 10^3$
3. C.A	992	$\frac{992}{2.75} * 1000 = 361 * 10^3$
4. Air	–	$\frac{2}{100} * 10^6 = 20 * 10^3$

$$\text{Total} = 709.8 * 10^3$$
$$= 710 * 10^3 \ cm^3$$

∴ Absolute volume of fine Aggregate $= (1000 - 710) * 10^3$
$= 290 * 10^3 \ cm^3$

∴ weight of fine Aggregate $= 290 * 2.65 = 768.5 \ kg/m^3$

Hence, Adopt Highes value of two ie $768.5 \ kg/m^3$

8) Estimated quantity of Material per meter cube of Concrete are;

a) Cement = 453 Kg
b) fine Aggregate = 768.5 Kg
c) Coarse Aggregate = 992.0 Kg
d) water = 185 Kg

9) proportions.

C.	F.A	C.A	water
453	768.5	992	185
1	1.69	2.19	0.41

ie 1 : 1.69 : 2.19 with $W/c = 0.41$ //

The above quantity are on the basic of F.A & C.A are in SSD Condition. These has to be adjusted as per the field Condition as follow.

f.A has surface moisture of 2%.

∴ Total free Surface moisture in f.A = 2% of 768.5 kg/m³
= 15.37 kg/m³

∴ wt of fine Aggregate in field = 768.15 + 15.37 = 783.87
= 784 kg/m³

Again:
C.A absorbs 1% of moisture Content = 1% of 992
= 9.92 kg/m³

∴ wt of C.A = 992 − 9.92 = 982.8 ≃ 982 kg/m³

To account for the Surface moisture of fine aggregate and absorption of Coarse Aggregate, quantity of water in the Concrete = 185 − 15.4 + 9.9
= 179.5 kg
= 180 kg

∴ Quantity of material to be used in field are;

a) Cement = 453 kg/m³
b) F.A = 784 kg/m³
c) C.A = 982.0 kg/m³
d) Water = 180 kg/m³

from these quantities, trial mix is prepared, Sample cast and tested at 28 days to judge the suitability of Concrete for desired work. If need arises, adjusted in quantities be made.

IS Method of Mix design:

Indian Standard Method.
Deals with non-air entrained concrete

Steps:
1) find the mean or target strength as, $f(t) = f_{ck} + 1.64\sigma$.
2) water cement ratio (w/c) for the mean strength is chosen from the graph of w/c and 28 days strength.
and check for the durability condition.
3) Estimate the air content from the table for max^m size of the aggregate.
4) water content and % of fine aggregate in total aggregate by absolute volume are selected from table for medium (<M35) and High (>M35) strength concrete. Also necessary adjustment are to be made in water content & % of sand.
5) Cement content is calculated as; $\frac{w}{c} = \frac{\text{water content}}{\text{Cement content}}$.
It should be checked against the durability condition
6) Aggregate content may be calculated from following relation.

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p} * \frac{f_a}{S_{fa}} \right] * \frac{1}{1000}$$

Coarse aggregate $C_a = \frac{1-p}{p} * f_a * \frac{S_{ca}}{S_{fa}}$

where; V = Absolute value of fresh concrete, which is equal to the volume of concrete in m^3 minus volume of entrapped air.
W = Mass of water (kg) per m^3 of concrete.
C = Mass of cement (kg) per m^3 of concrete.
S_c = Specific gravity of cement.
p = Ratio of fine aggregate to total aggregate by absolute volume.

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fa = total mass of F.A (kg) per m^3 of Concrete.
Ca = Total mass of Coarse aggregate (kg) per m^3 of Concrete.
Sfa = Specific gravity of fine aggregate.
Sca = Specific gravity of Coarse aggregate.

7) The proportion calculation above are based on the assumption that ~~aggregate~~ aggregate are Saturated and Surface dry. for any change in this moisture Condition, Correction is to be made.

Example on IS Method of mixed design:

Using IS Method of Concrete mixed design for reinforced Concrete structure for the following requirement.

Design Data:

Characteristics compressive strength = 20 N/mm²

Maximum size of Aggregate = 20mm (Angular).

Degree of workability = 0.9 C.F

Degree of quality control = Good

Type of exposure = Mild

Test data for Material

Cement used = Ordinary portland cement of grade 43 with 28 days strength = 51 N/mm²

S.G of Cement = 3.15

Bulk density = 1450 kg/m³

Aggregate:	fine Aggregate	Coarse Aggregate:
S.G	2.66	2.75
Bulk density	1700	1800
water absorption	1	0.5
free Moisture	2	Nil

Soln: Target mean Strength = $F_{tar} = f_{ck} + k \cdot s$

Step (1)

$$= 20 + 1.65 * 4$$

$$= 26.6 \text{ N/mm}^2 \text{ (Mpa)}$$

Step (2) Selection of w/c

from fig (i) of IS code, free water cement ratio required for target strength of 26.6 is 0.5

from fig (ii) of IS Code 28 days strength of cement 51 N/mm² for curve 'D', the free water cement ratio is 0.52.

from Durability Condition for mild exposure, maximum free water cement Ratio = 0.5

Hence Adopt w/c as minimum of all above

ie $w/c = 0.5$

Step III:

Estimation of Air Content

for maximum Size of Aggregate of 20mm, air Content is taken as 2%.

Step-4: Selection of water and Sand Content:

from table '4' Given in IS Code for 20 mm nominal maximum Size of Aggregate, water Content = 186 kg/m^3

& Sand Content as % of Total Aggregate = 35% by Absolute volume.

Step 5: Adjustment in water Content & percentage of Sand in total Aggregate for diffrent Condition of w/c, Compaction factor and Sand belonging to Zone III.

Condition Change:	water Content	% of Sand in Total Aggregate
1) for decrease in water cement ratio $(0.6-0.5) = 0.1$; $\frac{0.1}{0.05} * 1 = 2.0$	0	-2
2) for Increase in Compaction factor $(0.9-0.8) = 0.1$; $\frac{0.1}{0.1} * 3 = 3$	+3	0
3) for Sand Conforming Zone III	0	-1.5
4) Angular aggregate	0	0
Total	+3%	-3.5%

$\therefore$ water Content Required $= 186 + 3\%$ of 186
$= 186 + 5.58$
$= 191.6\ \cancel{6}\ kg/m^3$

Sand ~~for~~ Content % by total Aggregate by Absolute Volume $= 35 - 3.5$
$= 31.5\%$.

Step 6: Determination of Cement Content:

$W/C = 0.5$

water $= 191.6$

$$\frac{\text{water}}{\text{Cement}} = W/C$$

$$\frac{191.6}{0.5} = \text{Cement}$$

$\therefore$ Cement $= 383.4\ kg/m^3$

from durability Consideration, Minimum Cement Content $= 300\ kg/m^3$

$\therefore$ Cement Content $=$ (Max of $383.4, 300$).
$= 383\ kg/m^3$

Step 7: Determination of fine & Coarse Aggregate:

Absolute volume of fresh concrete $= 1 - 2\%$
$= 1 - 2/100$
$= 0.98\ m^3$

With the quantity of water and Cement per unit volume of Concrete and ratio of fine to total aggregate already determined, total Aggregate Content per unit volume of Concrete may be calculated from following equation.

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p} * \frac{fa}{S_{fa}} \right] * \frac{1}{1000}$$ for fine Aggregate

$$0.98 = \left[191.6 + \frac{383}{3.15} + \frac{1}{0.315} * \frac{fa}{2.66} \right] * \frac{1}{1000}$$

$$980 = 313.187 + 1.19\, fa$$

$\therefore fa = 558.75\ kg/m^3$ of fine Aggregate

And: $$V = \left[W + \frac{C}{S_c} + \frac{1}{(1-P)} * \frac{Ca}{S_{ca}} \right] * \frac{1}{1000}$$ for Coarse-Aggregate

$$0.98 = \left[191.6 + \frac{383}{3.15} + \frac{1}{(1-0.315)} * \frac{Ca}{2.75} \right] * \frac{1}{1000}$$

$$980 = 313.187 + 0.5308\, Ca$$

$\therefore Ca = 1256.24\ kg/m^3$ of C.A.

Step 8: proportion of Ingradients:

Cement	F.A	C.A	water	
383 kg	558.75 kg	1256.24 kg	191.6 kg	By Mass.
1	1.46	3.28	0.5	

Cement:	F.A	C.A	water:	
$\frac{383}{1450} = 0.264$	$\frac{558.75}{1700} = 0.328$	$\frac{1256.24}{1800} = 0.698$	$\frac{191.6}{1000} = 0.19$	By volume
ie; 1	1.242	2.644	91.6 liters	

Adjustment of Aggregate Moisture:

	Cement (kg)	F.A (kg)	C.A (kg)	water (kg)
By Mass	383	558.75 kg ≃ 559	1256.24 ≃ 1256	191.6 ≃ 192
Moisture Content	–	2% = +2% of 559 = +11.18	Nil = 0% = 0	= −2% of 559 = −11.18 = −0% of 1256 = −0 = +1% of 559 = +5.59 = +0.5% of 1256 = +6.28 Total = +0.69
water Absorption		1%	0.5%	
Adjusted weight		570 kg	1256 kg	= 192.69 kg

3.6 Segregation and Bleeding:

Segregation :- It is defined as the seperation of the constituent of heterogeneous mixture so that their distribution is no longer uniform. The main cause of segregation is difference in size of aggregate (specific gravity of aggregate) ~~as~~. It can be contol by proper grading and careful handling.

Two forms of segregation

(1) Coarser particles tends to seperate out since they travel along a slope or settle more than finer particles. This types of segregation occur if mix is too dry.

(2) Seperation of grout (cement + water) from the mix. This types of segregation occur if mix is too wet.

When correct method of handling, transporting and placing the likely hood of the segregation can be greatly reduced.

Bleeding :- Bleeding is the form of segregation in which some of the water in the mix tends to rise to the surface of the freshly ~~mixed~~ placed concrete. In other words seperation of cement paste from the mix is termed as bleeding.

- This is caused by inability of solid constituent of the mix to hold all the mixing water

As a result of bleeding, top layer of the concrete may become too wet and porous, weak and less durable concrete results.

- In some cases bleeding may creats capillary channels which increases the permeability of concrete.

ASTM standard for the measurement of Bleeding

- A sample of concrete is placed in a container of 250 mm dia and 280 mm height.
- The bleeding water is accumulated on the surface is withdrawn at 10m interval during 1st 40min ~~interval at~~ and at 30min interval. Bleeding is expressed in term of amount of accumulated water as the percentage of net-mixing water. in sample.

$$\text{Bleeding} = \frac{\text{Total sum of Bleed water}}{\text{Net mixing water}}$$

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3.7 Quality control in site, Mixing, handling, placing, Compaction and curing.

Quality control in site:

Variation in batch to batch is depends upon following factor.

* Variation in quality of constituents.
* Variation in mix proportion.
* Variation in mixing.
* Quality of overall workmanship and supervision.

The aim of quality control is to reduce the variations and to produce uniform desirable concrete.

Advantages of Quality control

(1) Quality control maintain the rational use of available resources after testing their characteristics, resulting in the reduction of material cost.

(2) Quality control reduces the maintenance cost.

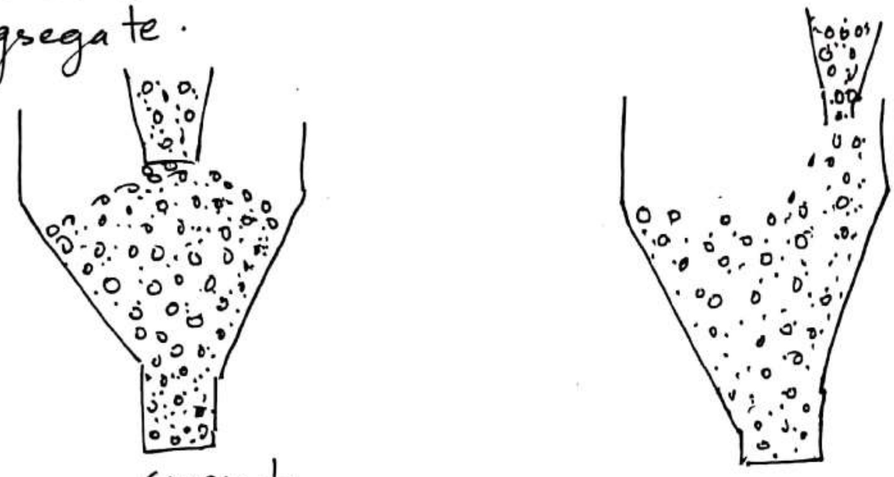
(3) In the absence of quality control of site the designer is attempt to over design, so as to minimized the risk which adds to overall cost.

Mixing:- The mixing operation essentially consists of rotation or stirring, the objective of mixing is to coat the surface of all the aggregate particles with the cement paste and to bind all the ingredient of concrete into a uniform mass & this uniformity must not be disturbed by the process of discharging from the mixture.

The usual type of mixture is a batch mixture, which means that one batch of concrete is mixed and discharge before any more material are put into the mixture. There are four types of Batch mixers.

(i) A tilting drum mixer
(ii) A non-tilting drum mixer
(iii) A pan-type mixer

Handling:- There are many methods of transporting concrete from the mixture to the site. ~~and infact~~ The choice of method obviously depends upon the economic consideration and on the ~~quality~~ quantity of concrete to be transported. There are many possibilities, ranges from wheelbarrows, buckets, skips and belt conveyors etc. In all the cases the important requirement is that the mix should be suitable for the particular method chosen ie it should remain cohesive and should not segregate.

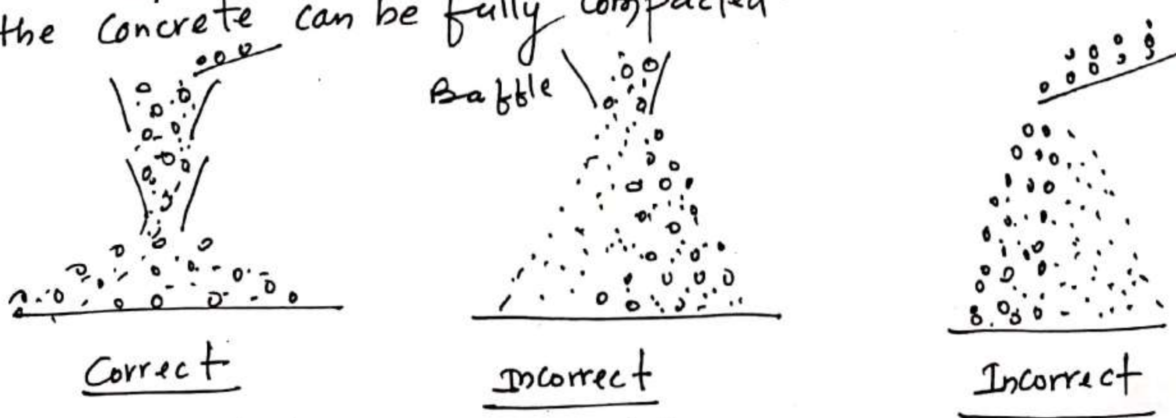


Correct Incorrect

fig:- Control of segregation on filling concrete bucket

placing and Compaction:-

The operation of placing and compaction are interdependent and are carried out almost simultaneously. They are most important for the purpose of ensuring the requirements of strength, impermeability and durability of the hardened concrete in the actual structure. ~~As far as~~ The main objective is to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted.



Correct Incorrect Incorrect

fig:- Control of segregation for fully compaction

Curing: Maintenance of satisfactory moisture content and temperature in a concrete during a definite period, Immediately after placing and finishing. Curing is done to ensure the degree of hydration is of sufficient to reduce the porosity level.

- Curing strongly influenced strength, durability, water tightness, abrasion resistance, volume stability and resistance to freezing and thawing action.

objective of curing:

- To prevent the loss of moisture from the Concrete.
- To maintain the favourable Concrete temperature for a defined period.

factor affecting the curing of concrete:

(1) Curing period:- strength development is depends upon the period for which the concrete is moist cured. The same age of Concrete having smaller curing period ~~atten~~ attain lower strength than for larger curing period.

(2) Interruption in ~~cret~~ concrete curing:

When the moist curing is interrupted, the development of strength is continues for the short period and then stops after the concrete relative humidity drops about 80%. Thus it is best to moist cured the concrete continously from the time of placing until the sufficient strength is gained.

(3) Curing Temperature:

Curing temperature below 50°F is unfavourable for the early strength development, and below 40°F the development of early strength is greatly retarded at or below the freezing temperature and finally when temperature is below 14°F no strength is developed.

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Cusring Method and Material:

① Maintain the presence of mixing water in a Concrete during the early hardening period.
- ponding or immersion, sprayaing or fogging and Saturation wet.

② prevent loss of mixing water from the concrete by sealing the surface.
It can be done by Covering the Concrete with impervious paper or plastic sheet by applying memberance forming Cusing compound.

③ Method that accelerate strength gain by supplying heat and additional moisture to the concrete.
- "steam Cusing" is advantageous where the develop-ment of early strength in concrete is desired or where additional heat is required to accomplish hydsatio as in the Cold weather.

Method of Cusing Can be summarized as:

① Sprinkle of water
② steam Cusing
③ Compounding of concrete
④ Member Cusing
⑤ Shading of Concrete work.

3.8 Concrete in extreme temperature

ⓐ Concreting in hot weather:- Any operation of Concreting done at a atmospheric temperature above 40°c or where the temperature of Concrete at the time of placement is expected to beyond 40°c may be categories in hot weather Concrete.

- A higher temperature of fresh Concrete result in more rapid hydration of Cement and therefore accelerated setting time and may reduce long term strength
- The rapid hardening of Concrete before the compaction accelerated the chemical activities result in rapid setting and rapid evaporation of mixing water.
- Due to rapid evaporation, plastic shrinkage in concrete occurs and would cause cracking.

while Concreting in a hot weather the following prevention may be adopted.

(i) The temperature of Concrete may kept low by shading aggregate and mixture.
(ii) The temperature of aggregate may be lowered by sprinking water over them.
(iii) Temperature is lowered by shading pipelines or water tanks.
(iv) The Crushed ice can be used.
(v) It can be maintain by working at night also.
(vi) for curing moisture retaining material are used.

The effect of hot weather Concreting may be as follow:

(i) accelerated setting
(ii) Reduction in strength.
(iii) Increase tendency to cracking
(iv) Rapid evaporation during curing.

Concreting in Cold weather:

→ Any Concreting operation done at a temperature below the 6°c is termed ~~as~~ the cold weather concreting.

→ If the Concreting is done at the freezing temperature it will have harmful effect on the properties of Concrete.

The effects are:

(i) Setting is suspended if the Concrete freezes immediately after it has been placed.

(ii) If the concrete freezes before it has attain the sufficient strength, the expansion due to formation of ice-Causes disruption and irrepairable loss in the strength.

(iii) If the concrete has acquired the sufficient strength before the freezing it can withstand the internal pressure generated by the formation of ice from the remaining mixture of water.

While Concreting in cold weather following precaution are adopted.

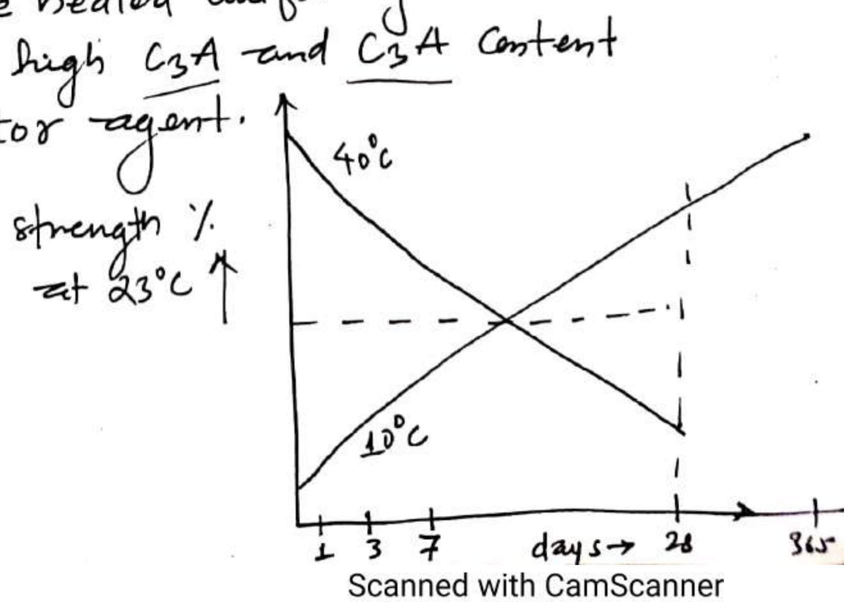
(i) To increase the temperature of fresh Concrete, mixing water may be heated but not above 80°c as more hot water will Cause flash set of the cement.

(ii) If heating of water doesnot rise the temperature of concrete to a desired value aggregate can also be heated not above 25°c.

(iii) Aggregate should be heated uniformly.

(iv) Use of Cement with high C_3A and C_3A Content

(v) By using accelerator agent.



Chapter-4

Properties of Hardened Concrete.

~~Introduction~~.

Introduction

The principal properties of hardened concrete which are of practical importance are those concerning its strength; stress-strain characteristics, shrinkage and creep deformations, response to temperature variation, permeability and durability. Of all these, strength of concrete is of prime importance as it denotes the standard/quality of concrete. The strength of concrete is directly dependent on w/c ratio and compaction. The voids found in cement have major impact on the strength so effect of gel/space ratio is also discussed in this chapter. Besides this, impact on the concrete due to impact, fatigue and dynamic loading is also discussed thoroughly in this chapter.

4.1 Deformation of hardened concrete, Moduli of elasticity.

Deformation of hardened concrete.

In the theory of reinforced concrete, it is assumed that concrete is elastic, isotropic, homogeneous and obeys Hooke's law. In fact, none of these assumptions are strictly true and concrete is not perfectly elastic material. If stress is applied on concrete strain appears and if a curve is drawn between these two parameters, we obtain a stress-strain curve. If this curve is straight as shown in fig 4.1, then material is elastic and if the curve is non-linear then the material is not perfectly elastic.

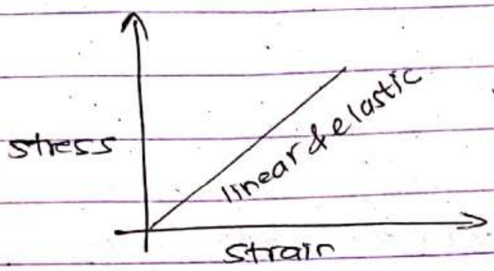


Fig: 4-1

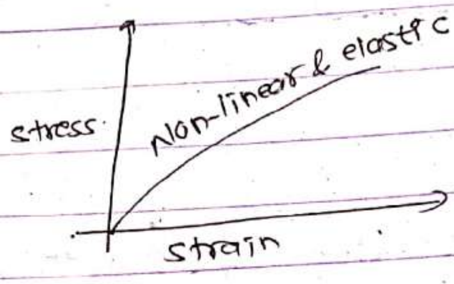


fig: -4-2

stress-strain response.

In case of concrete, it deforms on the application of load, but deformation depends upon the magnitude of load, rate of applying load and time elapsed after which the observations are made. Thus, the deformation of concrete is quite complex.

Non linearity of stress-strain relationship of concrete.

The stress-strain curve of aggregate and cement paste alone shows a farily good straight line. But the stress-strain curve of concrete, which is a combination of aggregate and cement paste gives a curved curve. Perphaps, this is due to the development of fine or micro cracks at the interface of the aggregate and cement paste. Stress-strain curve of aggregate, cement paste and concrete are shown in figure 4.3.

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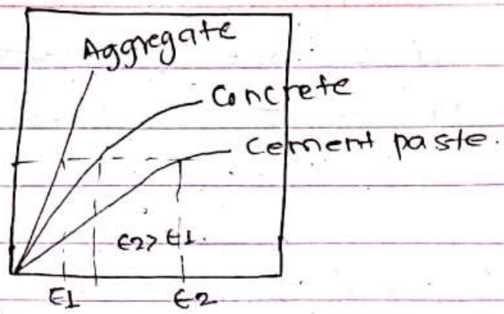


Fig. 4.3 : stress-strain curves for aggregate, cement paste & concrete.

Behavior of concrete at various stress level.

Microcracks already exists in concrete in transition zone. But these cracks remains stable upto 30% of ultimate stress level. Therefore, the stress-strain curve is therefore linear in this region.

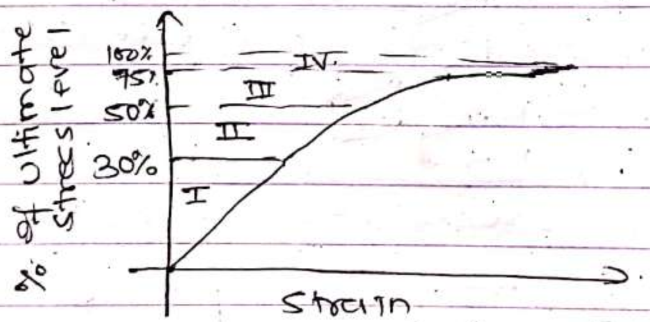


Fig: 4.4 stress-strain curve for concrete at various level of loading.

As the stress increases between 30-50% of ultimate loading, micro-cracks starts to increase in both length and width. But they are still confined within the transition zone and this microcracking system is still considered as a stable one. No ~~paste ph~~ cracks occurs in paste phase ~~B~~ but curve shows non linear behaviour.

Upto (50-75)% of ultimate loading, cracts starts in paste phase too. further propagation of crack in both transition zone and paste zone leads the system to be under unstable stage. stress-strain curve is strongle non-linear.

upto (75-100)% of ultimate loading, crack reaches to its critical stage with the increase in crack and failure of specimen occur at its ultimate stage.

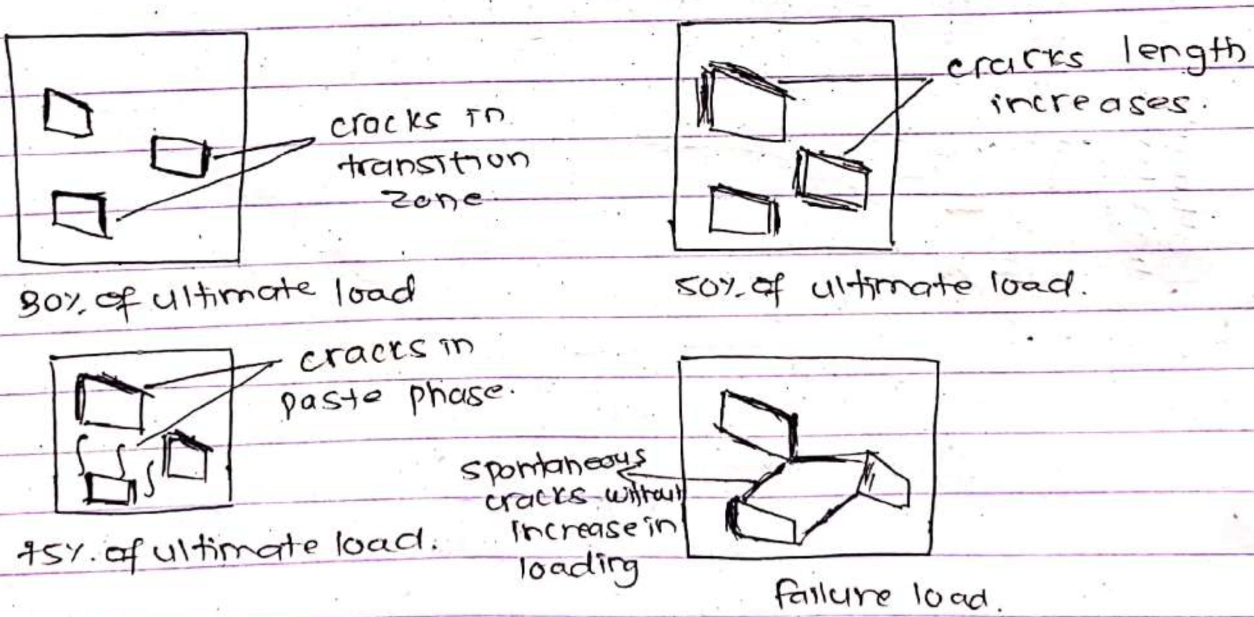


Fig:- 4.5 formation of continuous cracks.

Moduli of Elasticity.

Modulus of elasticity is slope of stress-strain curve of concrete ~~is~~. It may be computed by the following relation.

$$\text{Modulus of elasticity} = \frac{\text{unit stress}}{\text{corresponding strain}}$$

It is a measure of stiffness or resistance to deformation of a material. The term elastic modulus or Young's Modulus of elasticity can only be applied to the straight part of the stress - strain curve. The modulus of elasticity is determined by subjecting a cylinder of 15cm dia. and 30cm length or 15cm cube to uniaxial compression usually in UTM and measuring the strains or deformations by strain gauges or dial gauges fixed at certain gauge length. The value of strain is then obtained by dividing the gauge reading by gauge length. The stress is obtained by dividing load by area of cross-section of specimen. Then, the stress-strain curve is drawn with the help of values of stress and strain obtained.

Types of Modulus of Elasticity

Modulus of Elasticity of concrete can be classified into two main groups as:-

i) Static modulus

ii) Dynamic Modulus.

1) Static Modulus:- The modulus of elasticity obtained from actual loading is called static modulus of elasticity. As concrete is an imperfect elastic material,

stress strain diagram is a curved line. Different types of modulus of elasticity are explained below:-

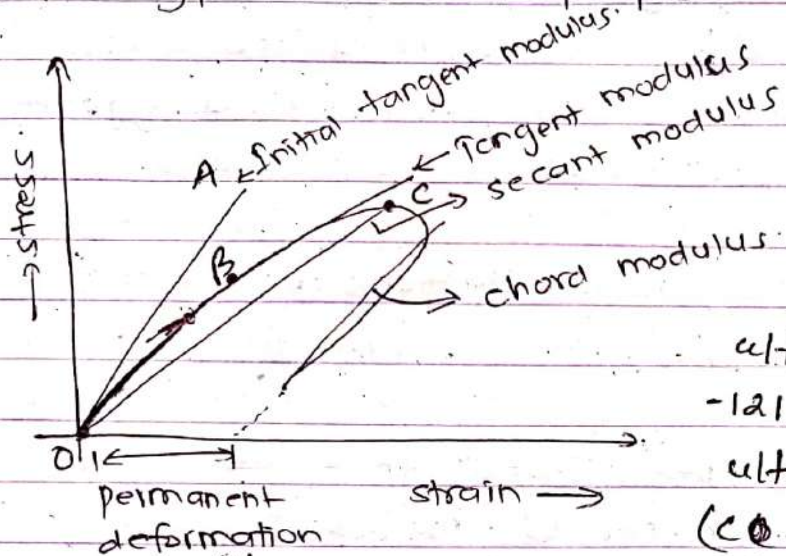
a) Initial tangent modulus.

It is represented by the slope of a tangent to the stress-strain curve drawn passing through origin. This modulus has significance only for low stresses and thus is of limited value and not easy to determine. It is represented by line OA in the Fig 4.6.

b) Tangent modulus:- It is represented by the slope of line drawn tangent to the stress-strain curve at any point on the curve, but this modulus applies only to very small changes in load above or below the load at which the tangent modulus is considered. secondly, it is difficult to determine tangent modulus with accuracy as the tangent to the curve is drawn by eye judgement.

(c) Secant Modulus:- It is represented by the slope of a line drawn from origin to any point C on the curve. This method is most pratical and is in most general use as it represents the actual deformation at the selected point and no uncertainities are invowed in its determination. Secant modulus decreases with increase in stress, hence stress at which it has been determined should be stated.

d) Chord modulus:- It is the slope of line drawn between the two points on stress-strain curve. This is mainly used for typical research purpose.



point 'c' is at 33% of ultimate stress in BS (1881-121:1983) and 40% of ultimate stress in ASTM (C469-02).

Fig 4-6:- Typical stress-strain diagram.

Relation betn Modulus of elasticity and strength.

As per IS 456:2000, the static modulus of elasticity (E_c) and the characteristics strength of concrete is related as $E_c = 5000\sqrt{f_{ck}}$ ------ (4.2)

where E_c is in N/mm^2

f_{ck} is characteristics strength of concrete.

Factors affecting Modulus of elasticity of concrete.

(i) Strength of concrete: Higher the strength of concrete, higher will be its modulus of elasticity.

ii) State of wetness of concrete:- The value of modulus of elasticity of wet specimen is found to be more than that of dry specimen but the strength of wet concrete is found to be less than that of dry concrete.

3) Properties of aggregate: Higher the modulus of elasticity of aggregate higher will be the value of modulus of elasticity of concrete. Greater the volume of aggregate, higher is the modulus of elasticity of concrete.

4) Age of concrete: Modulus of elasticity of concrete increases more rapidly with age than the strength.

5) Mix proportion:- It has been found that ~~rof~~ richer the mixes of concrete, higher will be its modulus of elasticity. The value of modulus of elasticity of concrete of mix proportion 1:1.67:2 is found ~~31.9 N/mm²~~ 31.9 GPa while for a mix 1:2.5:3 is 25 GPa for same age and wet conditions. The stress-strain curve for concrete of different mixes is as shown below:-

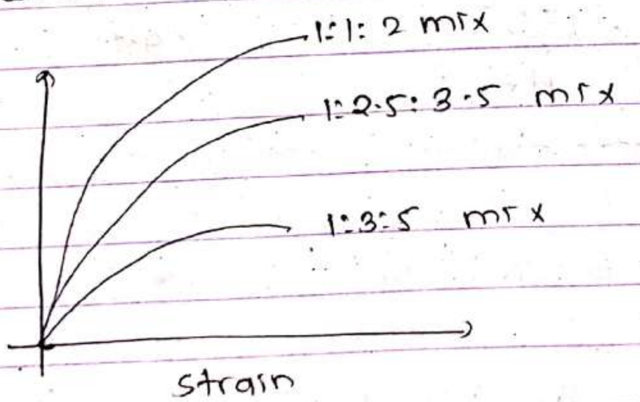


Fig 4.7:- stress-strain curve for different mixes.

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ii) Dynamic Modulus of elasticity:-

Static modulus of elasticity is determined by destructive method but dynamic modulus of elasticity is ~~dete~~ determined by non destructive method of testing. In this case, the specimen is subjected to longitudinal vibration at their natural frequency. Then, either resonant frequency through a specimen of concrete or pulse velocity travelling through the concrete is measured. From the known values of length of specimen, density of concrete and resonant frequency, the value of dynamic modulus in S.I. units is determined from the relation.

$$E_d = k \cdot n^2 \cdot L^2 \rho \quad \text{------} \quad (4.2)$$

where E_d = dynamic modulus of elasticity

k = a constant

n = resonant frequency

L = length of specimen

ρ = density of concrete.

~~Uses~~ Uses of modulus of elasticity:-

- Modulus of elasticity of concrete is used in the calculation of structural deformations.
- In case of reinforced concrete structures, it is used to determine the stresses developed in simple elements and also to determine moments, deflections & stresses.
- Dynamic modulus is used to determine the relative durability of concrete when exposed to severe climatic conditions.

4.2 Shrinkage and Creep.

Shrinkage

Shrinkage is the reduction in the volume of concrete due to loss of water or moisture due to evaporation or by hydration of cement or by carbonation. The reduction in volume is equal to 3 times the linear contraction. In practice, the shrinkage is simply measured as linear strain. Its unit are thus mm per mm, usually expressed in 10^{-6}.

Classification of shrinkage

Shrinkage can be classified into following categories:-

(a) Plastic shrinkage:- The hydration of cement causes a reduction in volume of system of cement plus water to an extent of about one percent of the volume of dry cement. This contraction is plastic strain and is aggravated due to loss of water by evaporation from the surface of concrete, particularly under hot climates and high winds. This results in surface cracking. Also, with increase in cement content, plastic shrinkage is found to have increased.

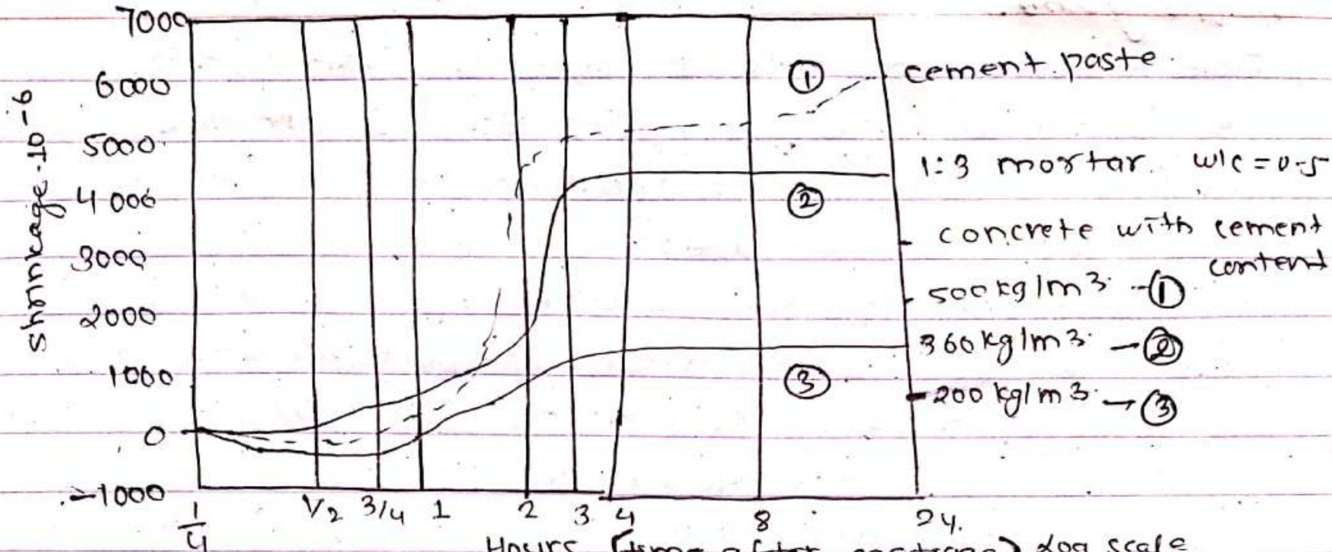

Fig 4.8: Influence of cement content of the mix on the plastic shrinkage in air at 20°c.

b) Drying shrinkage :- Withdrawal of water from concrete stored in unsaturated air void causes drying shrinkage. A part of this movement is irreversible and should be distinguished from the reversible part or moisture movement. In case of reversible moisture part, if concrete allowed to dry in air of given relative humidity is placed in water, or at a higher humidity later on, the cement paste will absorb and will swell. This phenomenon is shown in the figure 4.9.

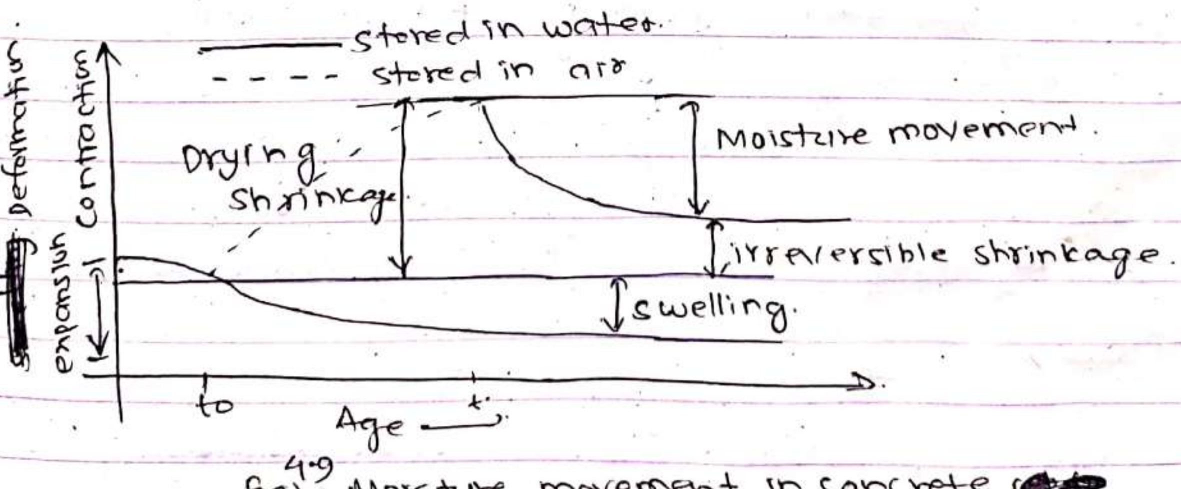

fig 4.9 :- Moisture movement in concrete

Note: The rate of shrinkage decreases with time. The test indicates that (14 to 34)% of 20 years shrinkage occurs in two weeks, 40 to 70% occurs in three months & 66 to 80% in one year.

The reversible moisture movement is about 40 to 70% of drying shrinkage but it depends on the age before the start of first drying. With the increase in age, shrinkage decreases.

In the absence of other reliable data, shrinkage can be estimated from Schorer's formula:

$$\epsilon_s = 0.00125\,(0.9 - h) \quad \text{---- (4.3)}$$

where ϵ_s = shrinkage strain.

h = relative humidity expressed as fraction.

If relative humidity is 50% then $h = 0.5$

If relative humidity is 100%, then $h = 1$ and in that case ϵ_s is $-ve$. This indicates swelling.

The drying shrinkage is affected by

1) W/C ratio:- The shrinkage increases with increase in W/C ratio.

2) Cement Content:- Shrinkage increases with increase in cement content as shown in fig. 4.8.

3) Ambient humidity:- The shrinkage increase with decrease in humidity.

4) Type of aggregate:- The aggregate which exhibit moisture movement themselves and having low modulus of elasticity cause large shrinkage.

d) Autogeneous shrinkage:-

This type of shrinkage occurs due to self-dessication. Self-dessication is the phenomena by virtue of which concrete with low water cement ratio begin to dry out due to internal consumption of water during hydration. This type of shrinkage doesnot occur due to locs of water by evaporation.

Creep:-

The increase of strain in concrete with time under sustained stress is termed creep. The shrinkage and creep occur simultaneously and they are assumed to be additive for simplicity. When the sustained load is removed, the strain decreases immediately by an amount equal to the elastic strain at given age. This instanteneous recovery is then followed by a gradual decrease in strain, called creep recovery which is a part of total creep suffered by concrete.

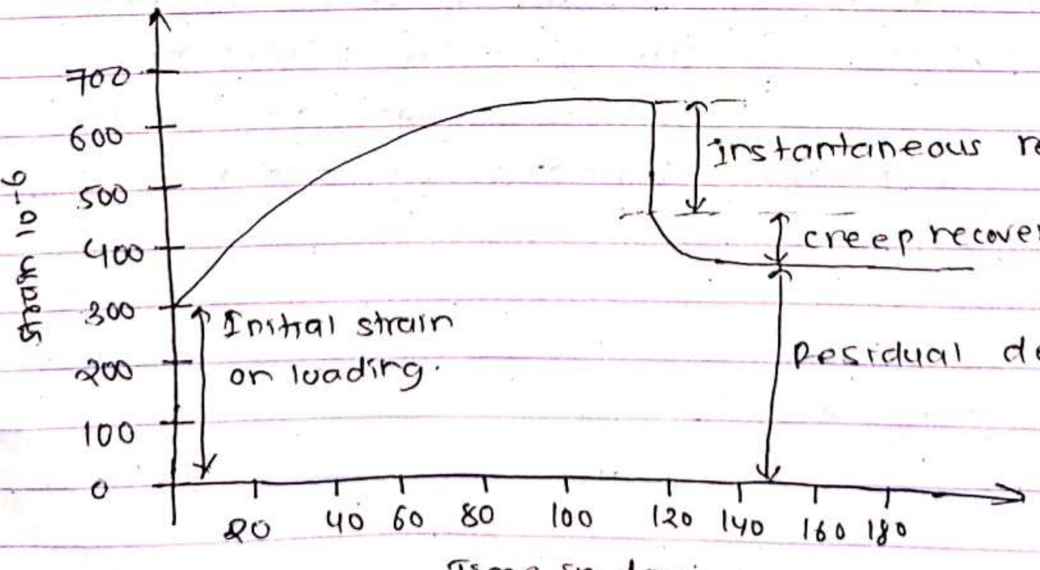

fig: 4.10: Creep and creep recovery of concrete.

creep effects may also be seen from other point of view. If a loaded concrete specimen is restrained so that it is subjected to a constant strain, creep will show itself as a progressive decrease in stress with time. This phenomenon is called stress relaxation and shown in fig 4.11

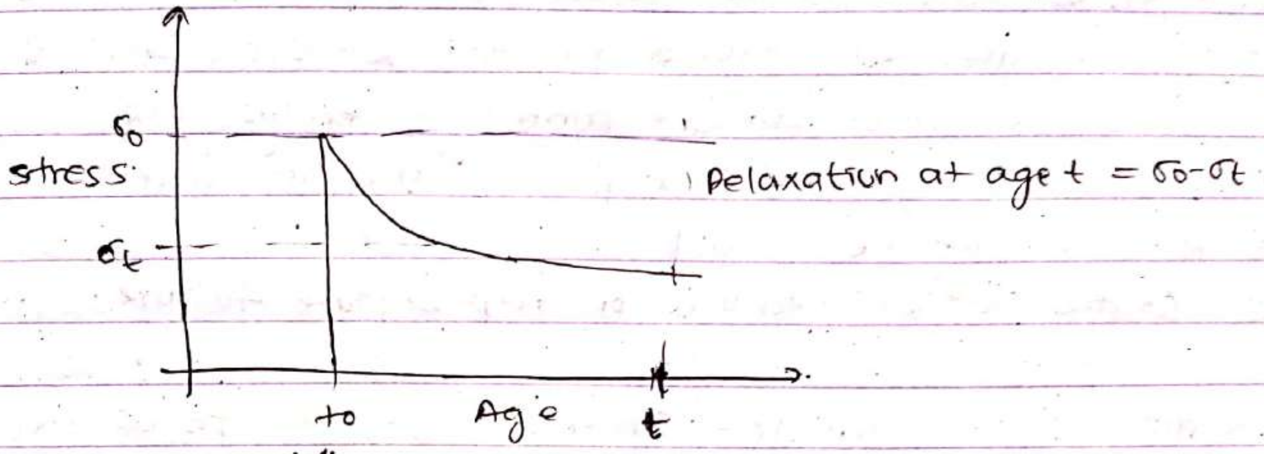

fig 4.11:- stress relaxation after age t of concrete.

The rate of creep decreases with time and the creep strains attained at a period of 5 years are usally taken as terminal values. 75% of creep strains occur in 12 months. All the factors influencing shrinkage influence creep in a similar manner. Types of aggregate, cement and admixtures, entrained air, mix proportions, mixing time and consolidation, age of concrete, level of sustained stress, ambient humidity, temperature, and the size of specimen are among the important factors influencing creep.

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4.3 Fatigue, impact and dynamic loading.

Fatigue

When a material fails under a number of repeated loads, each load being smaller than the static compressive strength of concrete, then failure taken place is called fatigue failure. Such type of repeated loads are applied in road pavements, airport runways, bridges etc.

There are two types of fatigure failure in concrete:

a) Simple fatigure failure

b) static fatigue failure or Creep Supture failure.

a) Simple fatigue failure:- In this case, failure of concrete structure takes place under cyclic or repeated loading.

b) static fatigue failure:- In this type of failure, failure occurs under a sustained or slowly increasing load near or below the strength under an increasing load, as in a standard test. This failure is known as static fatigue or creep rupture failure.

Impact

Impact force is the product of mass of a body and its velocity. Impact strength is the ability of specimen to withstand blows and to absorb energy. Knowledge of impact strength is necessary as the concrete (as in pile driving) may get subjected to a repeated falling object or a single impact of a large mass at high velocity.

As we know, impact strength is ability to withstand repeated blows and to absorb energy, thus the number of blows which the concrete can withstand before reaching the no rebound condition, indicates a definite state of damage. for a given type of aggregate, higher the compressive strength of concrete, lower the energy absorbed per blow befor cracking, but the number of blows increases to reach no rebound condition. Thus, with increase in compressive strength and age, impact strength increases. The relationship between strength of concrete and number of blows to no rebound condition is shown in Fig: 4.12

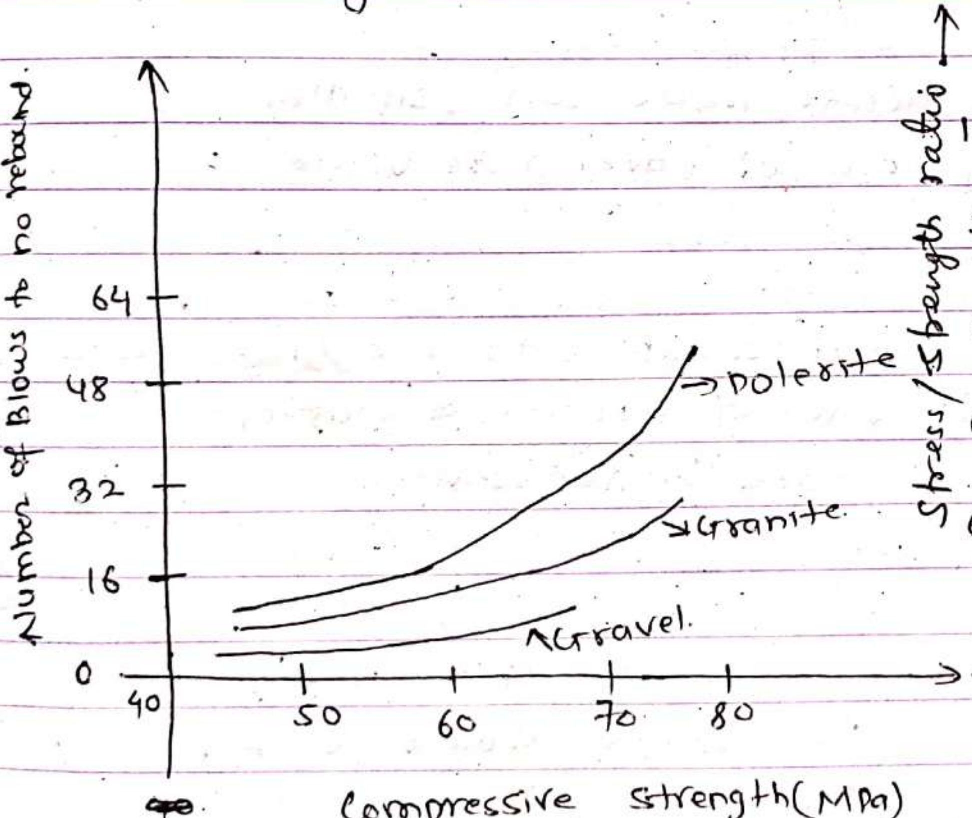

Fig: 4.12 Relation between compressive strength & No. of blows to no rebound condition.

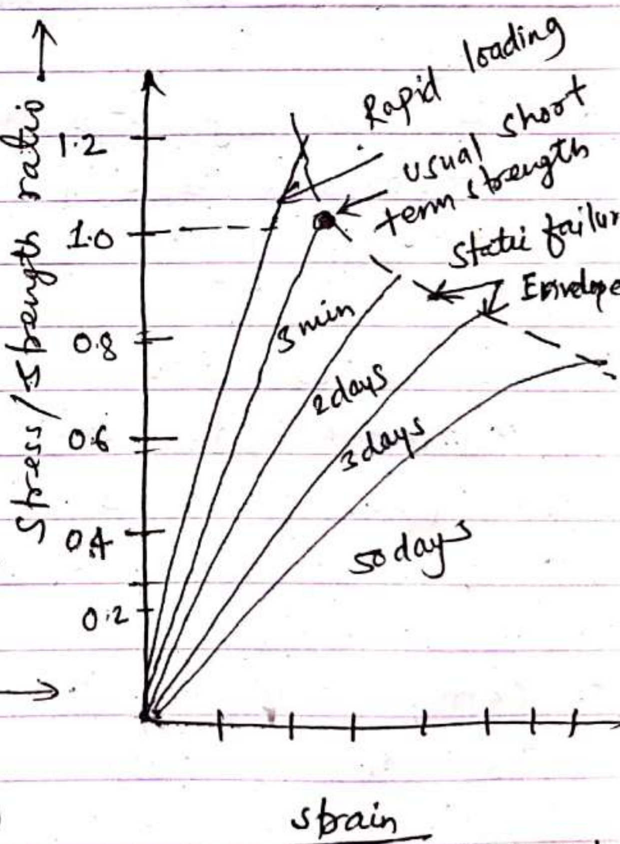

fig: stress & strain variation with rate of loading.

Factors affecting the impact strength.

Impact strength is affected by following factors:-

1) Types of coarse aggregate:- Impact strength depends upon the bond between mortar and coarse aggregate. So, the concrete made with crushed aggregate will have better and stronger bond between mortar and aggregate and will have greater impact strength than that made with natural gravel.

2) Storage condition of concrete:- Impact strength of moist or water stored concrete is less than that of dry concrete.

3) Size of aggregate:- Concrete made with smaller maximum size of aggregate will have more value of impact strength.

4) Modulus of elasticity and poisson's ratio of aggregate:- Aggregate with lower value of modulus of elasticity and poisson's ratio will have higher value of impact strength and vice-versa.

5) Cement content:- To get the concrete of satisfactor impact strength, the cement content should be less than 400kg/m^3.

6) Effect of rate of loading: Impact load can be considered as the application of the uniform stress extremely rapid, in which strength measured will be high.

It has been observed that, if the rate of application of stress exceed 5×10^6 Mpa/sec, static compressive strength obtained is more than double static compressive strength at normal rate of loading (0.25 Mpa/sec).

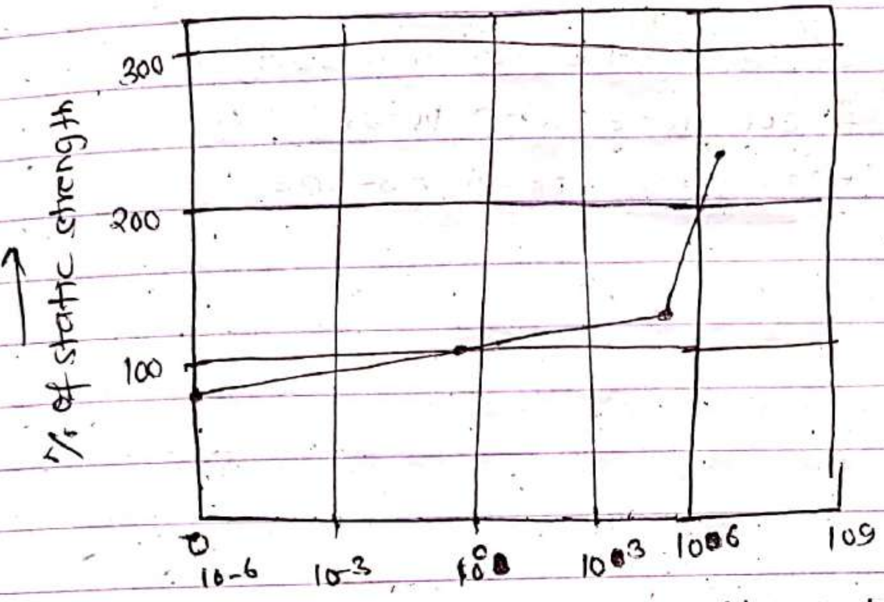

Fig: 4.13:- Rate of loading (log scale) Mpa/sec).

4.4 Effect of porosity, water-cement ratio and aggregate size.

Effect of porosity.

The strength of concrete is fundamentally a function of voids in it. So, strength of concrete is influenced by the volume of all voids: entrapped air, capillary pores, gel pores, and entrained air, if present. Porosity is defined as the ratio of total volume of pores in concrete to the volume of concrete. With increase in porosity, the density of concrete decreases and hence the strength also reduces.

The influence of the volume of pores on strength can be expressed by a power function of the type

$$f_c = f_{co}(1-p)^n \quad ---- (4.4)$$

where p = porosity, that is, the volume of voids expressed as a fraction of total volume of concrete.

f_c = strength of concrete with porosity p.

f_{co} = strength of concrete with porosity 0.

n = a coefficient, which need not be constant.

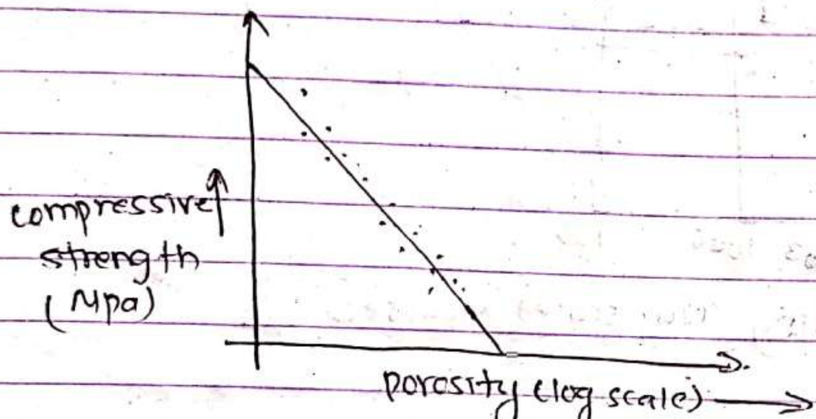

Fig: 4.14 → Relation betn strength & porosity

This relation shows that with increase in porosity, strength of concrete decreases.

Effect of water/cement ratio.

The strength of concrete at a given age and cured in water at a prescribed temperature is assumed to depend primarily on two factors only: w/c ratio and degree of compaction. And when the concrete is fully compacted, its strength is taken to be inversely proportional to the w/c ratio. This relation was proposed by

Duff Abram and is known as water/cement ratio law.
This relation is represented as

$$fc = \frac{k_1}{(k_2)^x} \quad \text{- - - - (4.5)}$$

where fc = concrete cylinder (15×30 cm) strength at 28 days after proper curing.
k1 & k2 = constants
x = water/cement ratio.

He suggested empirical values for k1 as 984 and k2 as 7 in MKS units.

thus $$fc = \frac{984}{(7)^x} \quad \text{- - - (4.6)}$$

The compressive strength given by eqn 4.6 can be assumed as 7 days strength & 28 days strength can be assumed as $fc = \frac{984}{(4)^x}$.

Thus, ABRAM's water/cement ratio law states that the strength of concrete is only dependent on w/c ratio provided that the mix is workable.

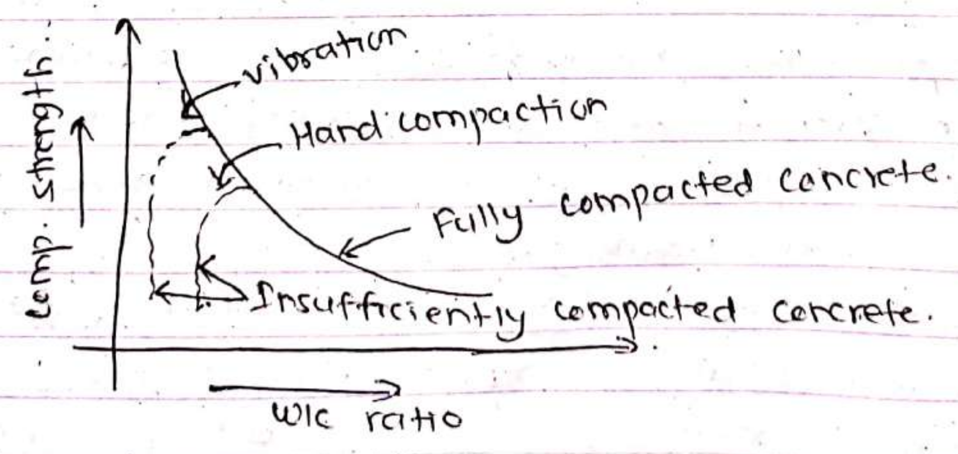

fig: 4.15 Relation betn w/c ratio and comp. strength.

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Effect of aggregate size:-

With increase in the size of aggregate, the surface area to be wetted per unit weight of aggregate ~~increase~~ decreases. Thus, it lowers the water requirement of min, for a specified workability and richness. Hence, with decrease in water, strength of concrete increases ~~decreases~~. But researchers have found that the aggregates with maximum size more than 38.1mm, if used in concrete, reduces the strength. The reason behind this is that with increase in size, more than 38.1mm, the bonding area decreases and concrete becomes grossly heterogeneous and results in lower strength.

Hence the adverse effect of increase in the size of the largest aggregate particles in the mix exists throughout the ranges of sizes, but below 38.1mm, the effect of size on the decrease in water requirement is dominant.

For larger sizes, the balance between maximum size and strength depends on richness of mix as shown in fig: 4.16. The best maximum size of aggregate from strength point of view is a function of richness of mix, specially in lean concrete, the use of 150 mm aggregate is most advantageous. However, in the structural concrete of usual proportion, from strength point of view, use of greater size aggregate than 25mm or 38mm has not been found advantageous.

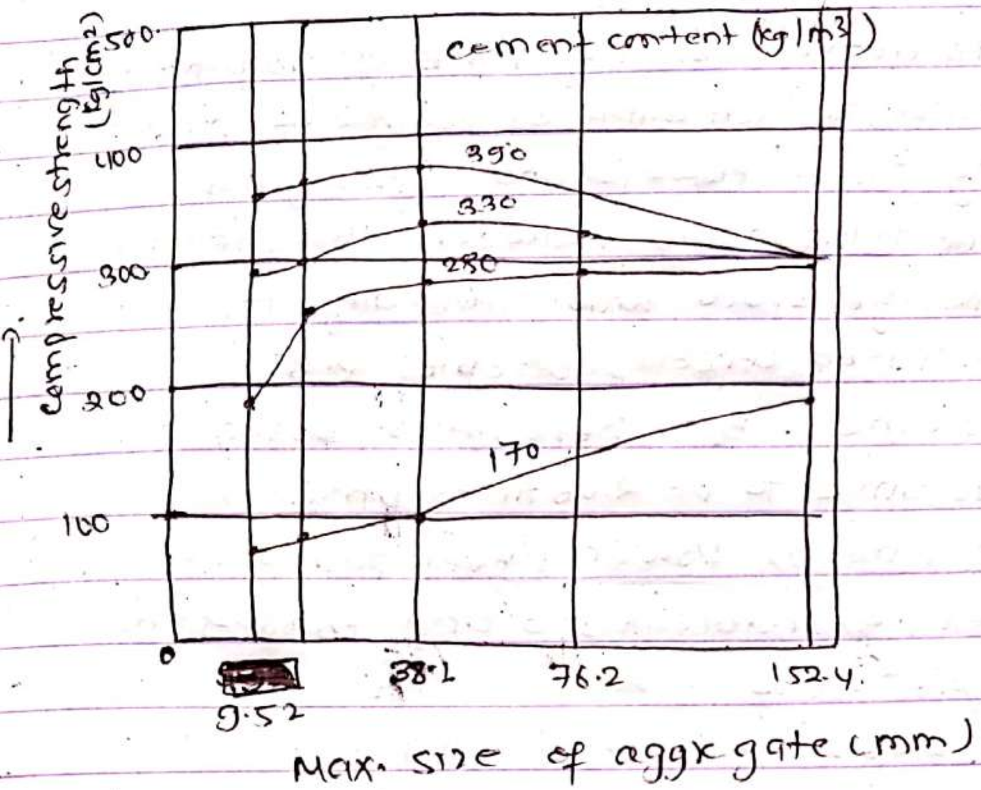

Fig. 4.16 Influence of max. size of aggregate on 28 day comp. strength of concrete of different mixes

Note: There are structural limitations also on the size of aggregate. As per IS 456-1964 the maximum size should not be greater than 1/5 to 1/4 of thickness of concrete section. Secondly, the maximum size of aggregate should be at least 5mm smaller than the spacing of reinforcement. Thirdly, maximum size should be at least 5mm smaller than the cover given to the concrete reinforcement.

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4.5 Effect of gel/space ratio.

Gel/space ratio is defined as the ratio of volume of hydrated cement paste to the sum of volume of hydrated cement and capillary pores. Powers and Brownyard have established the relationship between the strength development and the gel/space ratio. Normally, it is known that hydrated cement occupies 2.15 times its original volume. But, here, it is assumed the increase of volume to be 2.06 times only.

Through his experiment, Power developed a relation between gel/space ratio and compressive strength and the relation is

$$f_c = 240x^3 \quad \text{------} (4.7)$$

where f_c = compressive strength of concrete

x is gel/space ratio

The relation represented graphically is as shown below:-

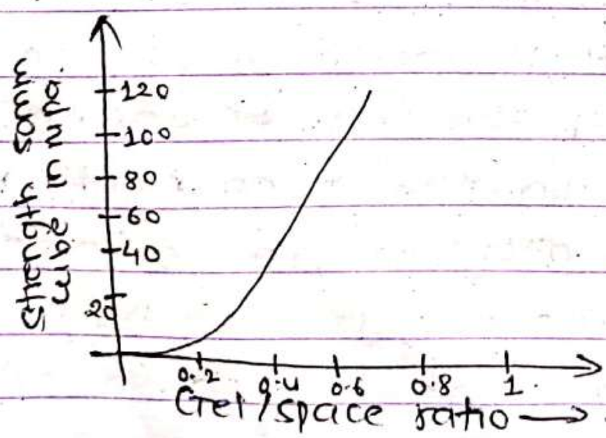

Fig: 4.17 Relation between compressive strength of mortar & gel/space ratio.

→ calculation of gel/space ratio for complete hydration:-

let c = wt. of cement in grams.

V_c = specific volume of cement = 0.319 ml/gram.

w = volume of mixing water. in ml.

Assuming that on hydration 1 ml cement will produce 2.06 ml of gel.

Then, volume of gel = $c \times 0.319 \times 2.06$

$= 0.657c$

Total space available = vol. of cement + vol. of water

$= 0.319c + w$

∴ Gel/space ~~available~~ ratio (x) = $\frac{\text{total volume of gel}}{\text{vol. of space}}$

$$= \frac{0.657c}{0.319c + w} = \frac{0.657}{0.319 + (w/c)} \quad \text{---} (4\text{-}8)$$

If 'α' fraction of cement is hydrated then,

Gel spac ratio (x) = $\frac{2.06 \times 0.319 \times c \times \alpha}{c \times 0.319 \times \alpha + w}$

$$\therefore x = \frac{0.657 \times \alpha}{0.319\alpha + (w/c)} \quad \text{-----} (4\text{-}9)$$

Now for capillary porosity

Volume of solid = volume of unhydrate cement + Volume of hydrate cement.

$= (c \times V_c - \alpha . c V_c) + (2.06 \times \alpha . c . V_c)$

∴ volume of solid $= (1 + 1.06\alpha)\, c V_c$.

capillary porosity = $\frac{\text{Total space} - \text{volume of solid}}{\text{Total space}}$

$$= \frac{(cV_c + w) - (1 + 1.06\alpha)c \cdot V_c}{cV_c + w}$$

$$= \frac{w - 1.06\alpha \cdot c \cdot V_c}{c \cdot V_c + w}$$

$$= \frac{w/c - 1.06\,\alpha \cdot V_c}{V_c + w/c}$$

$\therefore$ capillary porosity $= \frac{w/c - 1.06 \cdot \alpha \cdot V_c}{V_c + w/c}$ - - - (4-10)

Example 4.1 Calculate the gel/space ratio, theoretical strength and capillary porosity of a concrete sample made with 600gram of cement with 0.5 w/c ratio on full hydration and at 70% hydration.

Solution

Case I: On full hydration.

from equation (4.8)

Gel/space ratio $(x) = \frac{0.657}{0.319 + (w/c)}$

w/c ratio = 0.5

so, $x = \frac{0.657}{0.319 + 0.5} = 0.80$ Ans.

$\therefore$ Theoritical strength of concrete $(f_c) = 240\,x^3$ (from eqn 4.7)

$= 240 \times (0.8)^3$

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$= 122.88$ Mpa. Ans.

capillary porosity $= \frac{w/c - 1.06 \cdot \alpha \cdot V_c}{V_c + (w/c)}$ [from eqn 4.10]

for complete hydration $\alpha = 1$. and $V_c = 0.319$ ml/gram

$$= \frac{0.5 - 1.06 \times 1 \times 0.319}{0.319 + 0.5}$$

$= 0.198 \approx 0.2$. Ans

case II At 70% hydration. ($\alpha = 0.7$)

from eqn 4.9

Gel/space ratio $(x) = \frac{0.657 \times \alpha}{0.319 \times \alpha + w/c}$

$= \frac{0.657 \times 0.7}{0.319 \times 0.7 + 0.5} = 0.636$

≈ 0.64 Ans

Theoritical strength $(f_c) = 240 \times (0.64)^3$

$= 63.0$ Mpa. Ans

And

capillary porosity $= \frac{w/c - 1.06 \cdot \alpha \cdot V_c}{V_c + (w/c)}$

$$= \frac{0.5 - 1.06 \times 0.7 \times 0.319}{0.319 + 0.5}$$

$= 0.32$ Ans

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Chapter - 5

Testing of Concrete and Quality Control.

Introduction

To ascertain that concrete has developed the desired properties or not, it is required to test the concrete in both fresh and hardened state. fresh concrete is tested for workability to determine its capacity for satisfactory placing. The workability tests have been discussed earlier in chapter 3. In this chapter, tests on the hardened concrete will be discussed. The testing of hardened concrete specimens is required for checking the quality and compliance with the specifications. Though there are many methods to test the properties of hardened concrete, but the most common of all tests on hardened concrete is the compressive strength test, partly because it is an easy test to perform and maily due to the basic importance of compressive strength of concrete in construction.

5.1 Various strength of concrete: Tensile, compressive, shear and Bond.

Various strength of concrete are

(i) Compressive strength
(ii) Tensile strength
(iii) Shear strength
(iv) Bond strength
(v) Bearing strength.

Tensile strength.

Concrete is not designed (normally) to resist direct tension, but the knowledge of tensile strength is of value in estimating the load under which cracking will develop. Cracking problems occur when diagonal tension arising from shearing stresses develops, but the most frequent case of cracking is due to restrained shrinkage and temperature gradient.

The tensile strength of concrete varies from 7% to 11% of the compressive strength but on average, it is taken as 10% of compressive strength. Also, As per IS 456 : 2000, Tensile strength of concrete $= 0.35\sqrt{f_{ck}}$ where f_{ck} is characteristics compressive strength.

There are three types of test for strength in tension:

(a) Direct tension test

(b) Flexure test and

(c) Splitting tension test.

These tensile strength test for concrete are discussed later in the chapter.

Compressive strength

Concrete structures are mainly designed to resist the compressive loads. ~~The~~ for structural design, the compressive strength is taken as the criterion of quality of concrete. ~~and~~ The compressive strength is determined by compressive strength test using cylinder and cube. This test give quick and much accurate data and this test can easily be ~~applied~~ carried out in comparison to other tensile, shear ~~or~~ tests. so, compressive strength test of concrete is used as a popular means to known the quality of concrete. The 28 days compressive strength of concrete determined by un-axial compressive test is taken as a general index of concrete strength.

Shear strength.

Shear is the action of two equal and opposite parallel forces applied in planes a short distance apart. Direct determination of shear strength is very difficult. Hence, 12% of compressive strength is generally taken as the shear strength of concrete.

Bond strength:

It is defined as the resistance to slipping of the steel reinforcing bars which are embedded in concrete. This resistance is provided by the friction and adhesion between concrete and steel friction between concrete and lugs of deformed bars. Bond involves not only the property of concrete, but also the mechanical properties of steel and its position in concrete member. In general, bond strength is approximately proportional to the compressive strength of concrete upto 200 kg/cm². For higher strengths of concrete, increase in bond strength become progressively smaller.

Bond strength is also a function of specific surface of gel. cement having higher percentage of C_2S will give higher surface of gel, giving higher bond strength. On the other hand, cement having higher percentage of C_3S or cured at higher temperature gives smaller value of specific surface of gel, resulting in lower bond strength. It has been observed that concrete cured at high pressure steam produces gel of about 1/20th specific surface of the gel surface produced at normal curing temperature. Thus, the bond strength of high pressure steam cured concrete is lower.

Further, it has been observed that bond strength increases with delayed vibration. It is higher for dry concrete than for wet concrete. It's value reduces at high temperature. At 200°C to 300°C, bond strength has been found 50% of bond strength at room temperature. Bond strength is also reduced by alternate drying and wetting. Its value is determined by pull out test.

$$\text{Bond strength, } \sigma_{bond} = \frac{T}{\pi D L_d}$$

where T is pull force, D is diameter of steel bar L_d is length of embedded steel.

As per IS 456:2000 permissible bond stresses for plain and deformed bars is given as

Table: 5.1 : Bond strength for plain bars in tension for different Grade of concrete (LSD Method)

Grade of concrete	M15	M20	M25	M30	M35	M40 and above
Design Bond Stress, N/mm^2	1	1.2	1.4	1.5	1.7	1.9

Bearing strength:-

Sometimes, heavy concentrated loads are applied directly on concrete elements within very limited area. In such a case, the loaded area of concrete can be punched inside ~~to bear the direct load on~~ The resulting stress is bearing stress and the resistance to that punching is termed bearing strength.

Bearing stresses develop especially at the base of the column and the anchorage area of the tensions in the pre-stressed concrete member. In order to make the concrete safe in such situation, the bearing strength of the concrete should be sufficient.

According to IS 456:200, the WSMD, the permissible bearing stress ($\sigma_{bearing}$) on full area of concrete shall be taken as $0.25 f_{ck}$.

For LSD, its value should be $0.45 f_{ck}$.

where f_{ck} is characteristics compressive strength of concrete.

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5.2 Compressive strength test.

Compressive strength test is a destructive test carried out to determine the compressive strength of concrete. It is the most popular test out of other tests (tensile test, shear test) etc due to following reasons:-

(i) Most of the structure are designed to resist the compressive loads. Hence, to provide adequate safety to those structure minimum standards have been set out and to check whether our built structure, onsite, ~~conf~~ satisfy that standards or not, compressive test are carried out.

ii) This test give quick and much accurate data regarding the strength of concrete.

iii) Compressive loads can be easily applied than other loads (tensile, shear, etc.).

iv) Main measure of structural quality of concrete is the compressive strength.

v) Tensile, shear, ~~et~~ strength, etc. can be derived by using suitable empirical relations from compressive strength.

Compressive strength of concrete is determined using following types of specimes:-

1) cubes 2) cylinders.

1. Cube tests:

- For cube test, specimens are casted in steel or cast iron moulds of dimensions 150 mm x 150mm x 150mm.
- The dimensions and planeness should be within the limits of tolerance.
- The mould and its base must be clamped together during casting in order to prevent leakage of mortar.
- Thin layer of mineral oil should be applied to the inside surfaces of moulds to prevent the development of bond between the mould and concrete.
- The cube is filled in three layers and each layer should be compacted either by vibrator or by standard tamping rod.
- After compaction, top surface is made flush with the edges of mould and is finished with trowel.
- The finished surface is stored undisturbed for 24 hours at temperature 20±5°C and relative humidity not less than 90%.
- After 24 hours, mould is stripped and specimen is stored in water for ~~upto~~ 28 days.
- After 28 days, the specimen ~~is~~ are removed from water and then tested by uni-axial compression testing machine by appling load at the rate of 140 kg/cm² per minute till the specimen fails.
- The compressive strength of specimen is given by the ratio of load at failure to cross-section area.

ie compressive strength = $\frac{\text{load at failure}}{\text{Area over which load is applied}}$

Note:- → At least three specimen should be used for testing.
→ when cubes are ~~satisfactory~~ surface dry, or have not been cured, immerse them in water for a minimum of 5 minutes, before testing. They must be tested while they are still wet.

→ It must be noted that If the concrete cubes of sizes less than 150mm x 150mm x 150mm are prepared, their strength would be greater than that of cubes of size 100mm x ~~100mm~~ 100mm x 100mm. Following table gives the relative strength of concrete cubes (as compared to the cubes of size 150mm x 150mm x 150mm).

Table: 5.2: Relative strength of cubes.

cube size (mm)	100	150	200	250
Relative strength	1.05	1	0.95	0.87

2) Cylinder test

- The specimen is prepared using the cylindrical mould of 150mm diameter and 300mm height
- The base and its mould must be clamped together in such a way that no leakage of mortar takes place.
- The inner surface of mould must be oiled with mineral oil to prevent the bond formation between mould and concrete.
- Concrete mix of required proportion is prepared and is

filled in the mould in three layers and each layers are compacted by 16 mm diameter tamping rod for 25 times.

- Once the mould is filled, its top is flushed with top of mould and is finished with help of trowel.
- Then, mould is left for 24 hours at temperature $20 \pm 5°C$ and relative humidity not less than 90%.
- After 24 hours, mould is removed and specimen is immersed under water and is left for curing for 28 days.
- After 28 days, the ~~Unixatl~~ uniaxil compression test is carried out ~~ta~~ by keeping the specimen under uni-axial compression testing machine.
- The load at failure is recorded. Before that, load is applied at the rate of 350kN/min till failure.
- The compressive strength of specimen is given by $q_u = \frac{\text{load at failure}}{\text{Area of specimen}}$

~~At~~

- If the specimen length to diameter ratio is less than 1.8, correct the result obtained by multiplying the appropriate correction factor shown in following table. 5.3:

L/D	2	1.75	1.5	1.25	1
factor	1	0.98	0.96	0.93	0.87

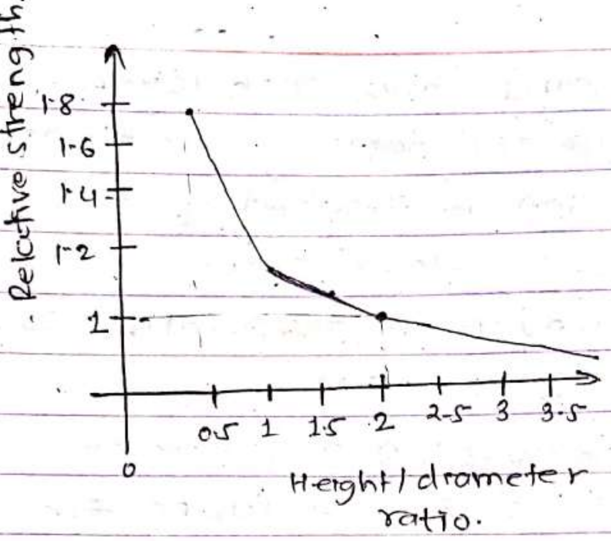

Fig: 5.1 ~~the~~ General pattern of influence of H/D ratio on strength of cylinder.

Fig: 5.1 shows the general pattern of the influence of the height diameter ratio on the compressive strength of cylinder. for the values H/D ratio smaller than 1.5, the measured strength increases rapidly. for H/D between 1.5 to 4.0 strength variation is very little and for H/D between 1.5 and 2.5, the variation of strength is within 5% of H/D. ratio 2.0. For H/D ratio above 5, strength falls rapidly. Hence, the choice of H/D ratio of 2 is suitable.

Note:- IS 516-1964 suggested that the cylinder strength is 80% of the cube strength, both made up of same concrete.

5.3) Tensile strength test.

There are many difficulties in the direct measurement of tensile strength of concrete. Following are the major difficulties in the direct determination of tensile strength of concrete:-

a) Difficulty in gripping the specimen :- Proper and satisfactory gripping equipments are not available in market which may assure the uniform distribution of pull applied to the concrete.

b) There should be no eccentricity of applied load. The stresses are changed due to eccentric loading that may introduce major error on the stress development.

Due to the above reason, direct tensile strength test is difficult. The tensile strength of concrete is determined by indirect methods :-

1) Flexure test
2) Splitting tension test.

1) Flexure test.

In flexure test, the theoretical maximum tensile stress reached in the bottom of fibre of a test beam is determined and it is known as the modulus of rupture. This is tensile strength under bending. Central point loading and two points loading are two loading schemes to determine the modulus of rupture. The modulus of rupture is calculated by using bending equation.

Modulus of rupture $f_{cr} = \frac{M}{Z}$, M = Maximum bending moment

Z = section modulus $= \frac{I}{y}$.

(a) Central point loading.

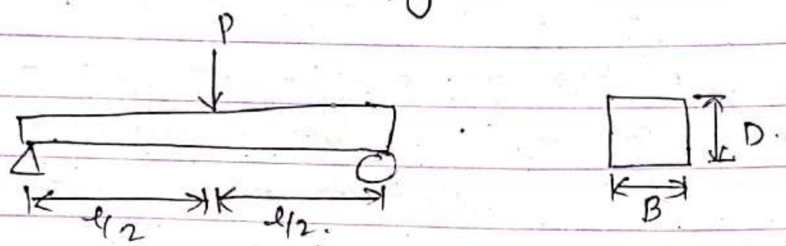

Fig:- 5.2 Central point loading

$$\therefore \quad Z = \frac{I}{y} = \frac{1}{12}\frac{BD^3 \times 2}{D} = \frac{BD^2}{6}$$

So, Modulus of rupture, $f_{cr} = \frac{M}{Z} = \frac{Pl}{4} \times \frac{6}{BD^2}$

$$= \frac{3}{2}\frac{Pl}{BD^2}$$

$$\therefore \boxed{f_{cr} = \frac{3}{2}\frac{Pl}{BD^2}}$$

b) ~~Third point loading~~.

Thus, in this system, load is applied at the central point of test specimen, which gives triangular B.M. Maximum fibre stresses will be below the point of loading where BM is maximum.

b) Third point loading:-

In this system of loading, two points loads produce constant bending moment between them, so that one third of span is subjected to maximum stress and thus in this region cracking is likely to take place. An simple illustrative figure of two point loading is shown below:-

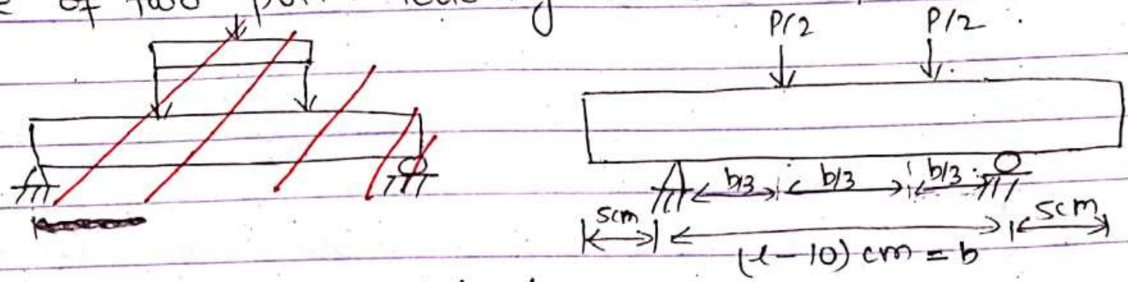

Fig: 5.3 Third point loading.

Two sizes of specimen are generally used depending upon the maximum size of coarse aggregate.
for the coarse aggregate greater than 20mm, size of specimen used is (150x150x700)mm.
for the coarse aggregate of size less than 20mm, the size of specimen used is (100x100x500) mm

The load application rate also depends on size of specimen. for the specimen of size (150x150x700) mm load application rate is 400 kg/min and for the specimen of size (100x100x500) mm, the load application rate is 180 kg/min.

when a > 20, for 15cm specimen and a > 13.33 cm for 10cm specimen, flexural strength $(f_{cr}) = \frac{Pl}{BD^2}$.

And, if $a < 20\,cm$ and $a > 17\,cm$, for 15cm specimen
and if $a < 13.33\,cm$ and $a > 11\,cm$, for 10cm specimen

$$\text{flexural strength } (f_{cr}) = \frac{3Pa}{BD^2}$$

where a is the distance from support to point of failure as per IS 516 – 1959.

2) Splitting tension test.

This test was developed in Brazil in 1943. Sometimes this test is also called as Brazilian test.

Test procedure

This test is carried out in a cylindrical specimen by placing it horizontally between the platens or loading surfaces of the testing ~~procedure~~ machine and the load is increased untill the failure of the specimen takes place by splitting in the plane containing the vertical diameter of the specimen. The figure for the test is shown in fig 5.4

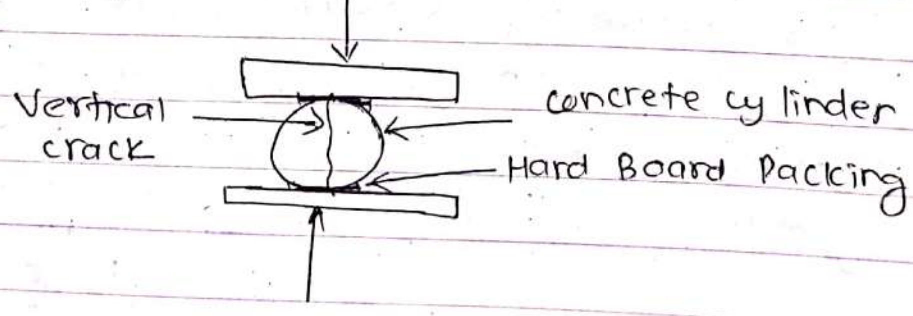

fig: 5.4 Cylinder splitting test.

Even though the load applied is compressive, almost 5/6 of the depth is subjected to a uniform tensile stress as shown in the figure 5.5.

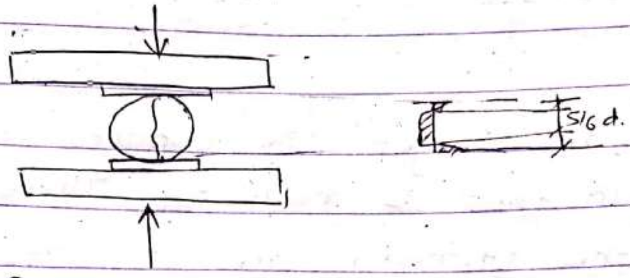

Fig: 5.5 cylinder splitting test.

The horizontal and vertical component of compressive stress are

(a) Horizontal component of compressive stress $= \frac{2P}{\pi L D}$

b) Vertical component of compressive stress $= \frac{2P}{\pi L D}\left[\frac{D^2}{r(D-r)} - 1\right]$

5.4 Variability of concrete strength and acceptance criteria.

It is not possible to get the samples of concrete with the strength that is made for. There is variability in the strength and properties of concrete and this is common. The variability may occurs due to various reasons. It may be due to the variation in the properties of materials used to construct the sample or it may be due to bad workmanship or it may be due to change in the proportion of ingredients etc. Hence, the concrete sample with strength more or less than the designed strength will be produced. so, there are certain criteria that the group of concrete and individual sample have to satisfy.

Acceptance criteria:-

(1) For compressive strength.

→ The mean strength determined from any group of four consecutive test result complies with appropriate limit in column 2 Table 5.4

→ The individual test result complies with the appropriate limit in column 3 in Table 5.4 (IS code 456:2000

Table 5.4: Characteristics Compressive Strength compliance requirement.

(1) Specified Grade	(2) Mean of group of 4 Non-overlapping consecutive test results (N/mm^2) (f_{mean})	(3) Individual test results in (N/mm^2) (f_i)
M15	$\geq f_{ck} + 0.825 *$ established S.D. (rounded off to the nearest $0.5\ N/mm^2$ or $f_{ck} + 3N/mm^2$ whichever is greater.	$\geq f_{ck} - 3N/mm^2$
M20 or above	$\geq f_{ck} + 0.825 *$ established S.D. or $f_{ck} + 4N/mm^2$ whichever is greater.	$\geq f_{ck} - 4N/mm^2$.

(ii) for flexural strength:

Acceptance criteria for flexural strength are:-

→ The mean flexural strength determined from any group of four consecutive test results should exceeds the specified characteristics strength by at least $0.3N/mm^2$ i.e. $f_{mean} \geq f_{ck} + 0.3$

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→: The flexural strength determined by any test result should not be less than the specified characteristics strength less than $0.3 N/mm^2$ ie $f_f \geq f_{ck} - 0.3$

5.5 Non Destructive test of Concrete.

In case of destructive test of concrete, concrete samples are destroyed to determined the properties of concrete like strength, elastic parameters, durability etc. Destructive test is good method for evaluating the various properties of concrete to be built. But for evaluating the properties of existing concrete structures, this test is not considered good. so, NDT [Non-Destructive Tests] methods are used for this purpose. These ~~Non~~ non-destructive testing methods are a powerful means for evaluating the strength, durability and quality control of the existing concrete structure. In addition to above, the depth of cracks, micro cracks and progressive deterioration can also be studied by this method.

In these methods, some other properties are measured and from these properties strength, durability and elastic parameters are estimated. Some of such properties are hardness, resistance to penetration of projectiles, ability to allow ultrasonic pulse velocity to propagate through it etc.

Some of the general non-destructive testing methods are as follows:-

1) Visual inspection
2) Rebound hammer test / Schmidt's hammer test
3) Ultrasonic pulse velocity test.
4) Impact echo test.

Non-destructive testing (NDT) methods are techniques used to obtain information about the properties or internal condition of an object without damaging the object. The above mentioned methods are described as follows:-

1) Visual inspection:- This is an essential precursor to any intended non-destructive test. An experienced civil or structural engineer may be able to establish the possible cause(s) of damage to a concrete structure and hence identify which of the various NDT methods available could be most useful for any further investigation of the problem.

2) Rebound / Schmidt's hammer test:-

Hardness of surface is actually determined by rebound hammer test. The rebound hammer was developed by Swiss Engineer named Ernst Schmit in 1948. The weight of hammer is 2kg and its impact energy 2.2 Nm. The hardness is measured by the rebound of an elastic mass. This rebound number is then expressed in terms of compressive strength of the concrete.

The test is used for the following applications:-
a) for checking the uniformity of concrete quality.
b) Approximate estimation of strength
c) Comparing a given concrete with a specified quality concrete.

Equipment and its working.
A typical rebound test hammer is shown in fig 5.6

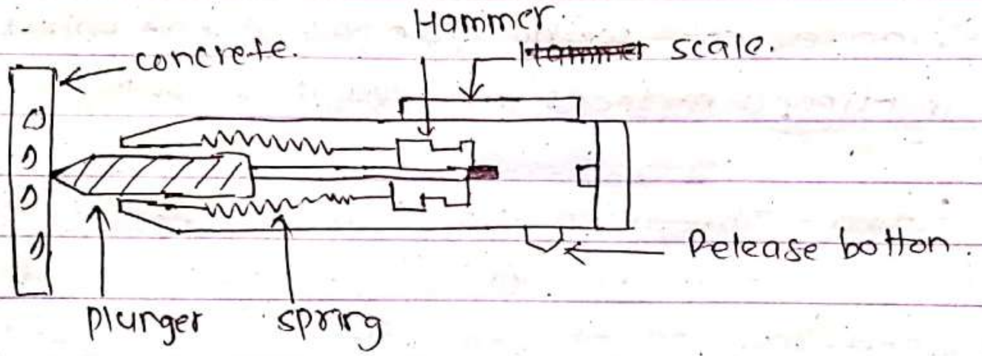


fig: 5.6 Schmidt's rebound hammer.

It consists of a spring controlled hammer mass that slides on a pluger with in a tubular casing as shown in fig: 5.6. when the plunger, is pressed against the surface of the concrete, the mass rebounds from the plunger. It retracts against the force of the spring. This spring is automatically released when fully tensioned, causing the hammer mass to impact against the concrete through the plunger. when the spring controlled mass, rebounds, it takes with it a rider which slides along a graduated scale and can be seen through a small window in the side of the casing. The rider can be held in any position on the scale by depressing the locking button to record the reading. The distance travelled by the mass is called rebound number. It is indicated by the rider moving along a graduated scale.

The equipment can be operated vertically or horizontally. The plunger is pressed hard and steadily against the concrete surface to be tested at right angles, till the spring loaded mass is triggered off from its locked position. After impact, the scale index is read while the hammer still is in the test position. The measurement of the distance taken is an arbitary quantity, known as rebound number.

Fig:- 5.7 shows the relationship between rebound number of test hammer and compressive strength of concrete. taking into account the moisture condition and direction (ie whether placed vertically or horizontally).

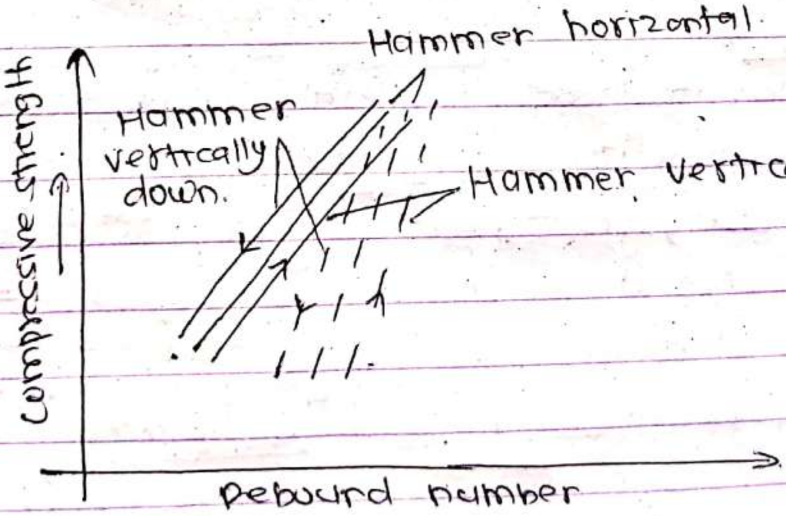


Fig: 5.7:- figure showing relation between Rebound No., compressive strength, direction and moisture condition of specimen.

3) Ultrasonic Pulse velocity Method.

The ultra sonic pulse velocity method basically consists of measuring the velocity of electronic pulse passing through the concrete from a transmitting transducer to a receiving transducer. The pulse velocity method have been used to evaluate the concrete structures and attempts have been made to corelate the pulse velocity with strength and other properties of concrete. Variou uses of the pulse velocity methods are discussed below:-

a) Establishing the uniformity of concrete:-

b). Establishing the quality of concrete based on the observation confirming with the following table.

Table 5.5. Quality criteria as suggested by central water and power research Khadakwasla (India)

Velocity in km/sec	classification of quality	Overall insitu compressive strength in MPa.
4.0 and above	Very good	30 to 35
3.5 to 4.0	Good	25 to 30
3.0 to 3.5	Medium	20 to 25
3.0 and below	Poor.	15 to 20

Techinque for measuring pulse velocity

-> The transducer is kept in contact with the concrete so that the vibration travel through it and is picked by other transducer in contact with the opposite face or adjacent face or same face.

-> The transducer generate an electrical signal which is fed through an amplifier to a plate of cathode ray tube. A second plate supplies time marks at fixed intervals. Thus, from the measurement of displacement of pulse signal and time of travel, the velocity of pulse may be calculated.

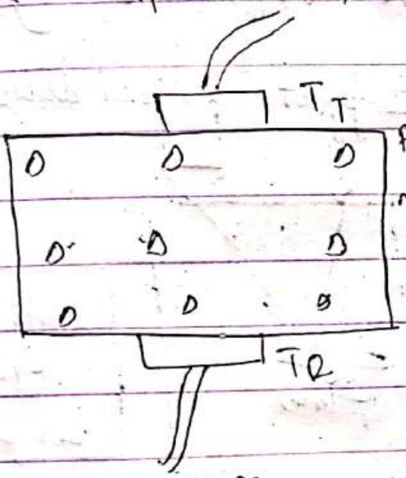


fig:- 5.8 Direct transmission.

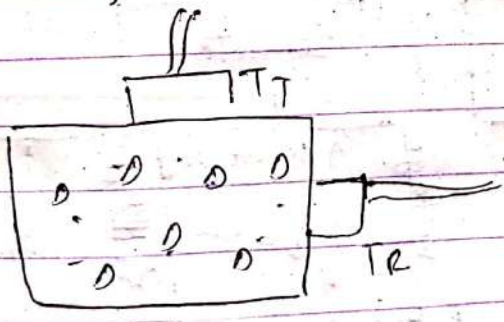
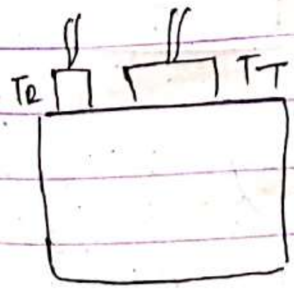


fig: 5.9 Semi-direct transmission



T_T = Transducer transmitter

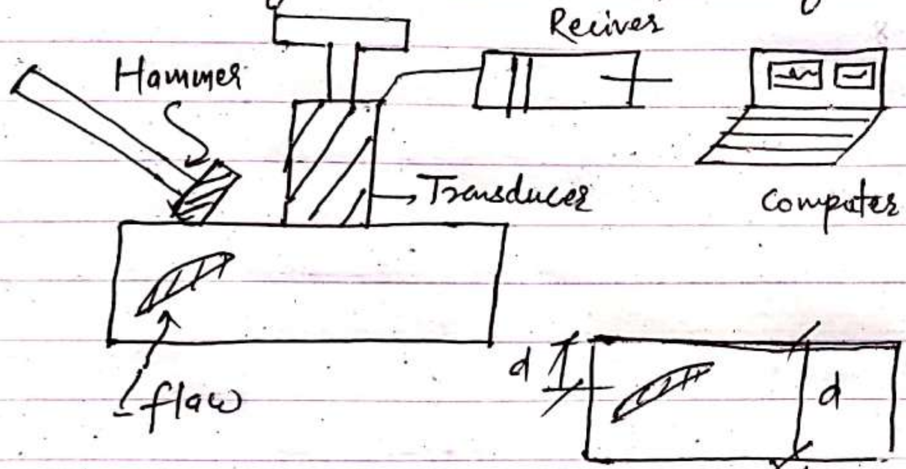
T_R = Transducer receiver.

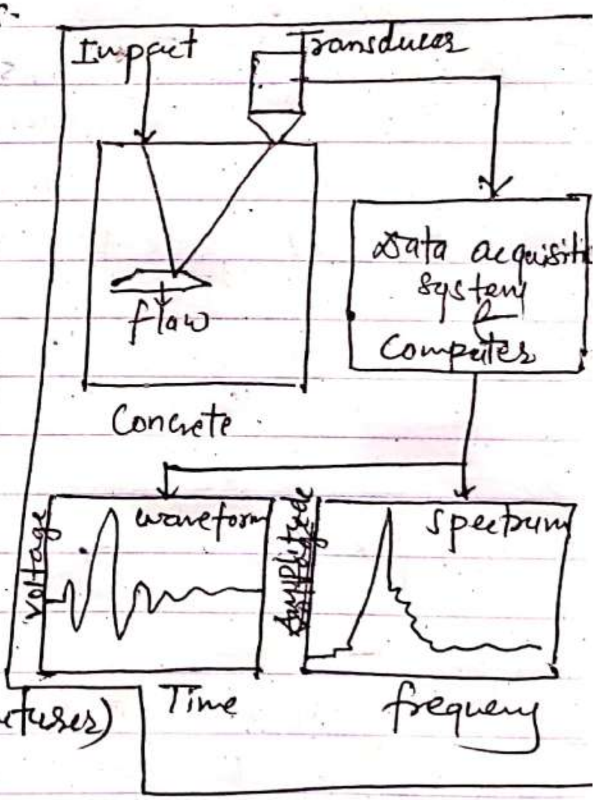
fig. 5:10:- surface transmission.

Impact Echo test:

→ Impact echo test is used to determine the location of cracking, voids & delamination.

→ It is based on the Impact generated stress. Waves that propagate through the structure ~~are~~ reflected by internal flaws & external surfaces.





→ Depth of stress wave are reflected 'd'

$$d = \frac{c}{2f}$$

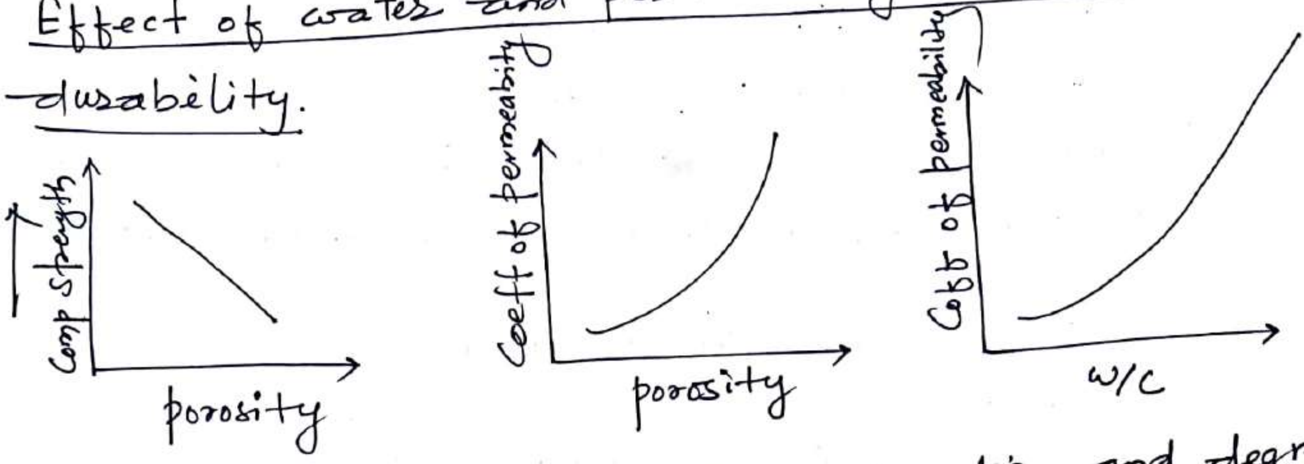
where, c = wave speed (Device Manufacturers provide)

f = Dominant frequeny.

→ It is reliable method for ~~velocity of~~ determing the variety of Defects in Concrete.

Chapter - 6 Concrete Durability

6.1 Effect of water and permeability on a Concrete durability.



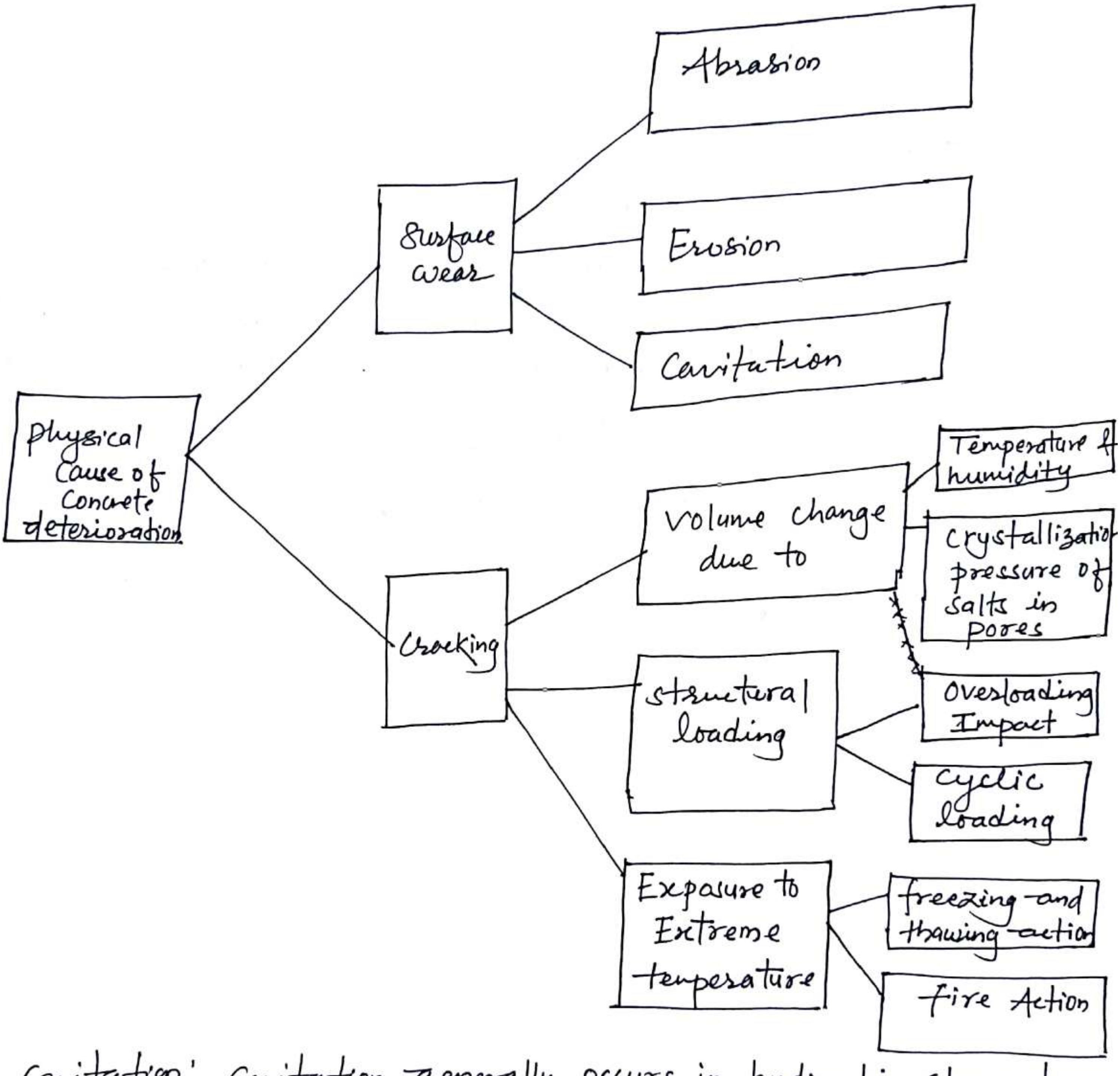
The capillarity "u" is given by the w/c ratio and degree of hydration. for the given degree of hydration permeability is lower for the paste with lower w/c. permeability also increases if more porous aggregate are used. From the durability point of view it may be important to achieve low permeability as quickly as possible. to

To reduce the permeability
(i) A mix with low w/c ratio is advantageous.
(ii) Concrete must be dense so better to use well graded aggregate.

6.2 physical and chemical Causes of Concrete deterioration

6.2: physical & chemical Cause of Concrete deterioration:

a) physical Cause of Concrete deterioration



Cavitation: Cavitation generally occurs in hydraulic channel or pipe where flow velocity is high typically over 10m/sec at normal temperature. this liquid creats the low pressure resulting the formation of vapour pocket. When this vapour pocket enters into the region of high pressure it Collapses and gives the impact load on Concrete Surfaces, Hence concrete get damage.

⑤ Chemical cause of Concrete deteriosation.

i) Deteriosation by carbondioxide
ii) Deteriosation by sulphates
iii) Deteriosation by chlorides
iv) Deteriosation by Aggregate Alkali reaction

i) Deteriosation by carbon-dioxide – Carbonation

→ The atmospheric CO_2 reacts with calcium hydroxide ie lime, forming calcium carbonate

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

→ Calcium carbonate is slightly soluble in water and destroying the permeability system of the concrete

→ In the presence of moisture carbondioxide (CO_2) forms carbonic acid, which reacts with $Ca(OH)_2$ forming the calcium carbonate. In this process cement compound are decomposed.

→ The pH value of pore water in the hardened concrete usually vary between 12.5 to 13.5 depending upon the alkali content of cement. This high alkalinity of cements forms a thin protective layer around the steel reinforcement and potect it from the action of water and oxygen. As long as steel is in the high alkalinity zone, it is not going to be corroded. Such a condition is known as a passivation.

→ when all the carbon hydrooxide $Ca(OH)_2$ has been carbonated, the pH value reduces from about 13 to 8.3. In such a low pH value the protective layer get dissolved or destroyed and the steel is exposed to Corrosion.

→ The corrosion product occupies much greater volume than original metal, which result to surrounding concrete to burst.

ii) Deterioration by sulphates:

→ Source of sulphates (salts of ester or a sulpheric acid) in the environment are calcium, potassium, sodium and magnesium sulphates. Sulphates are found in industrial effluents, sea water and ground water.

→ sulphates converts the calcium hydroxide to large volume of calcium sulphate ie Gypsum

$Na_2SO_4 \cdot 10H_2O + Ca(OH)_2 = CaSO_4 \cdot 2H_2O + 2NaOH + 8H_2O$

→ Later tri-calcium aluminates hydrates reacts with the sulphate solutions to form sulpho aluminates hydrate (ettringite)

→ This sulpho aluminates hydrates is larger in volume that leads to formation of internal stresses.

→ The internal stress leads to deformation, cracking and eventually loss of cohesion.

→ As the concrete cracks the moisture get easy entry thus aggravating the reaction again.

preventive measures:

i) use sulphate resistance portland cement.
ii) Use low water cement ratio & dense concrete
iii) provide expansion joint
iv) use minimum cement.

iii) Deterioration by chlorides

→ Chlorides attack is one of the most important aspect while dealing with the durability of the concrete. It primarily causes corrosion of reinforcement. Statistics have indicated that over 40% of failure of structure is due to corrosion of steel.

Chlorides can be introduced into concrete by

→ sea water
→ Chlorides present in mixed water
→ chlorides present in aggregate.
→ chlorides present in admixture
→ from atmosphere.

Mechanism:

→ If the concrete is permeable to such a extend that solute chlorides penetrates right upto the reinforcement and water & oxygen is also present, then the corrosion of steel will take place.

→ The Bureau of Indian standard has specified the maximum chloride content in cement is 0.1%.

→ The amount of chlorides required for initiating corrosion is partly depend upon the pH value of the pore water in concrete. At a pH value less than 11.5 corrosion may occur without presence of chloride.

iv) Deterioration by Alkali-aggregate reaction:

→ It is also called as AAR

→ In this reaction alkali present in the cement reacts with a silicious material present in the aggregate to form gel like substances.

→ This ~~get~~ gel further expands leading to the crack formation, deterioration, decrease in strength and modulus of elasticity.

preventive measures:

→ Use low alkali cement

→ Use Non reactive aggregates.

6.3: Carbonation:

See previous note in 6.2:

6.4 :- Corrosion of steel in Concrete :-

Corrosion in a steel is electrochemical process, which usually takes place when two dis-similar metal are in electrical contact in presence of moisture & oxygen. This same process takes place in the steel alone due to the difference in electrochemical potential on the surface which forms anodic & cathodic region, connected by the electrolyte in the form of the salt solutions in hydrated cement.

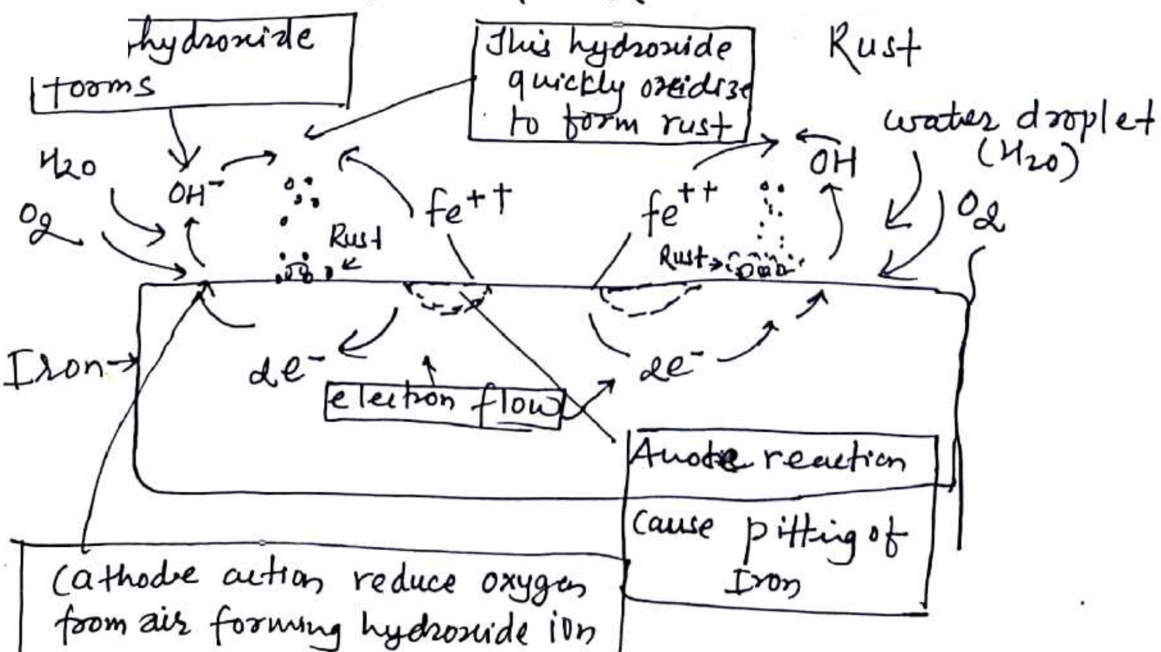
The positively charged ferrous ions fe^{++} at the anode pass into solutions, while negatively charged free electrons e^- along the steel into cathode, where they are absorbed constituents of the electrodes and combines with water and oxygen to form hydroxyl ions (OH^-). Then they combines with ferrous ion to form ferric hydroxide. This hydroxide is converted into rust by further oxidation. The reaction can be written as follow.

$$fe \rightarrow fe^{++} + 2e^- \quad \text{(Anodic reaction)}$$

$$4e^- + O_2 + 2H_2O \rightarrow 4(OH) \quad \text{Cathodic reaction}$$

$$fe^{++} + 2(OH) \rightarrow fe(OH)_2 \quad \text{ferrous hydroxide}$$

$$4fe(OH)_2 + 2H_2O + O_2 \rightarrow \quad \text{ferric hydroxide}$$



→ When the relative humidity below 40%, no corrosion can take place. It is noticed that not much corrosion of reinforcement take place if the concrete is fully immersed in water.

→ 70 to 80% relative humidity is most-conginial for the development of corrosion of reinforcement. At higher than 80% relative humidity, the diffusion of oxygen is reduced considerably and atmospheric condition along the steel are more uniform.

→ product of the corrosion occupy volume about six times the original volume of steel. ~~de~~ thus cause the damage in ~~con~~ surrounding concrete.

Scanned with CamScanner

Impact of Corrosion:

→ The corrosion products are more volumetric than the parent metal and their formation and deposition on the bar leads to the surrounding concrete being subjected to excessive pressure and since concrete is relatively weak in tension, longitudinal cracks along the bar are initiated, such cracks also accelerate further corrosion by allowing the passing of chloride, oxygen and water through the concrete and change the structural behaviour of concrete.

Effect of Corrosion:

- Development of longitudinal ~~cor~~ cracks along a bar.
- By corrosion, change the structural behaviour.
- Spalling of concrete cover
- Appearance of rust stains at the surface of concrete
- → Reduction c/s of bars.

Prevension measures ~~of~~ against corrosion:

- → first and formost precausion is to provide dense concrete
- → provide adequate cover to reinforcement bar.
- → Use of ~~a~~ slage cement or portland pozzalane cement
- → By controlling the permissible crack width.

Masonry structures

Chapter 7,8,9,10

Chapter 7

Introduction to masonry structures

- **Masonry structures** are those structures which are made/ built from individual units laid and bound together by mortar.
- **Mortar** is a bonding agent which is generally produced by mixing cementing or binding material (lime or cement) and fine aggregate (sand, surki, sawdust, etc.) with water. **Mortar** is used to bind different building blocks like bricks, stones, etc. It can also add a decorative pattern in brick or stone masonry.

- Masonry units

- Oldest & simplest
- Common materials : Bricks, Stone, Marble, Concrete block, glass block.
- Economic in comparison to steel and RCC structure but not fully earthquake resistant.
- Mortar can be - mud, lime, cement, surkhi.

- Masonry durability affected by
- quality of materials
- Workmanship
- Patterns assembling way.

7.1 Use of masonry structure

- Uses
- Arches, partition walls, retaining walls, coffer dams
- For finishing work of buildings, cladding and roofing.
- As a building material.
- Examples
- Hanging garden
- Great wall of china

- Advantages
- Increase thermal mass of the building.
- Finishing is not required in masonry which reduces life cycle costs.
- Are noise resistant and provides good fire resistance
- Masonry structure built in compression preferably with lime mortar can have a successful life of more than 500 years as compared to 30 to 100 for structure of steel or reinforcement concrete.

- Disadvantages

- Extreme weather causes degradation of masonry wall surfaces due to frost damage.
- Masonry requires strong foundation because they are heavy.
- Requires more skilled manpower.

Structural limitations:

- It has high compressive strength but has lower tensile strength. So should be reinforced to make it strong in tensile strength.

7.2 Construction technology

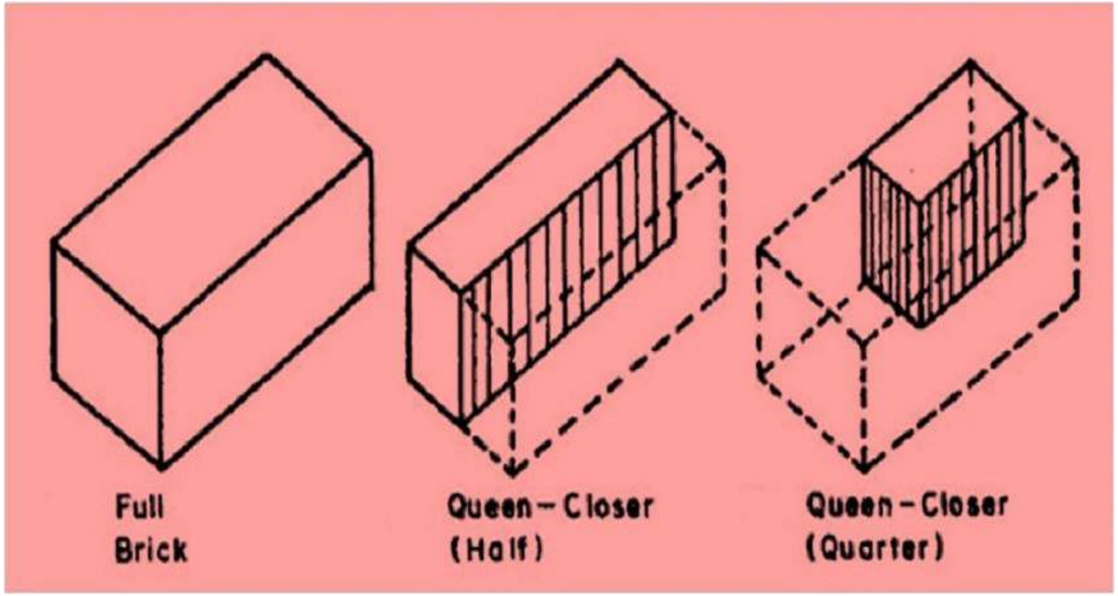
- Size and weight of bricks

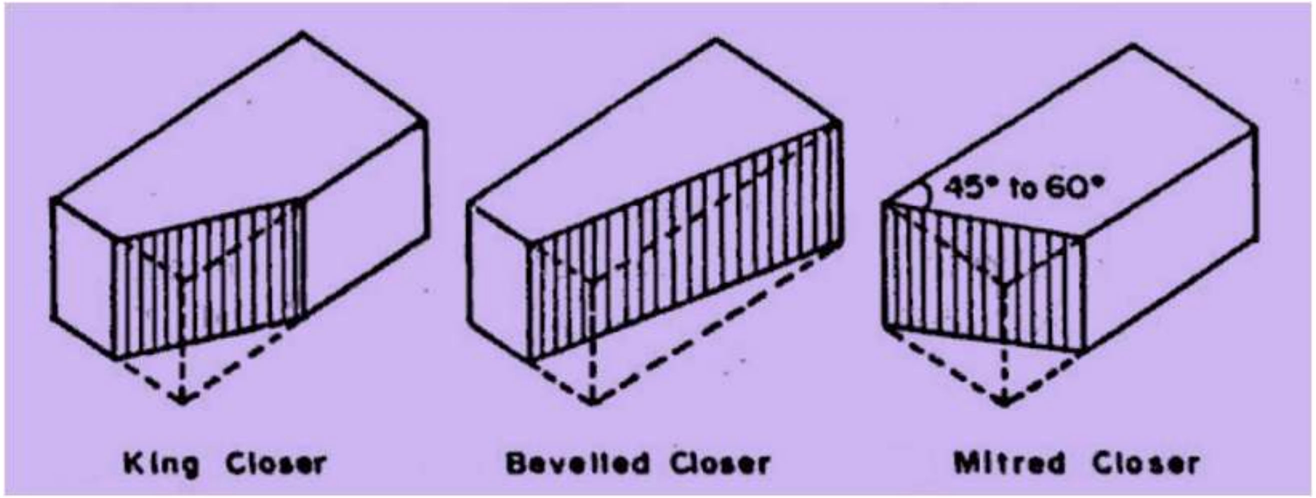
- The bricks without standard size are traditional bricks .
- If bricks are large - no proper burning is possible and is difficult during placing.
- If bricks are small more quantity of mortar is required.
- Bricks with uniform size are modular bricks.
  - 190 mm * 90 mm *90 mm
  - According to BIS (Bureau of IS)
- When mortar used
  - 200 mm * 90 mm * 90 mm
  - Normal size

- Wt. of single brick - 3 to 3.5 kg
- NBC size - 240*115*57 (10mm vertical mortar Joint)

Closer: It is the portion of the brick cut along the length in such a way as one long face remains intact.

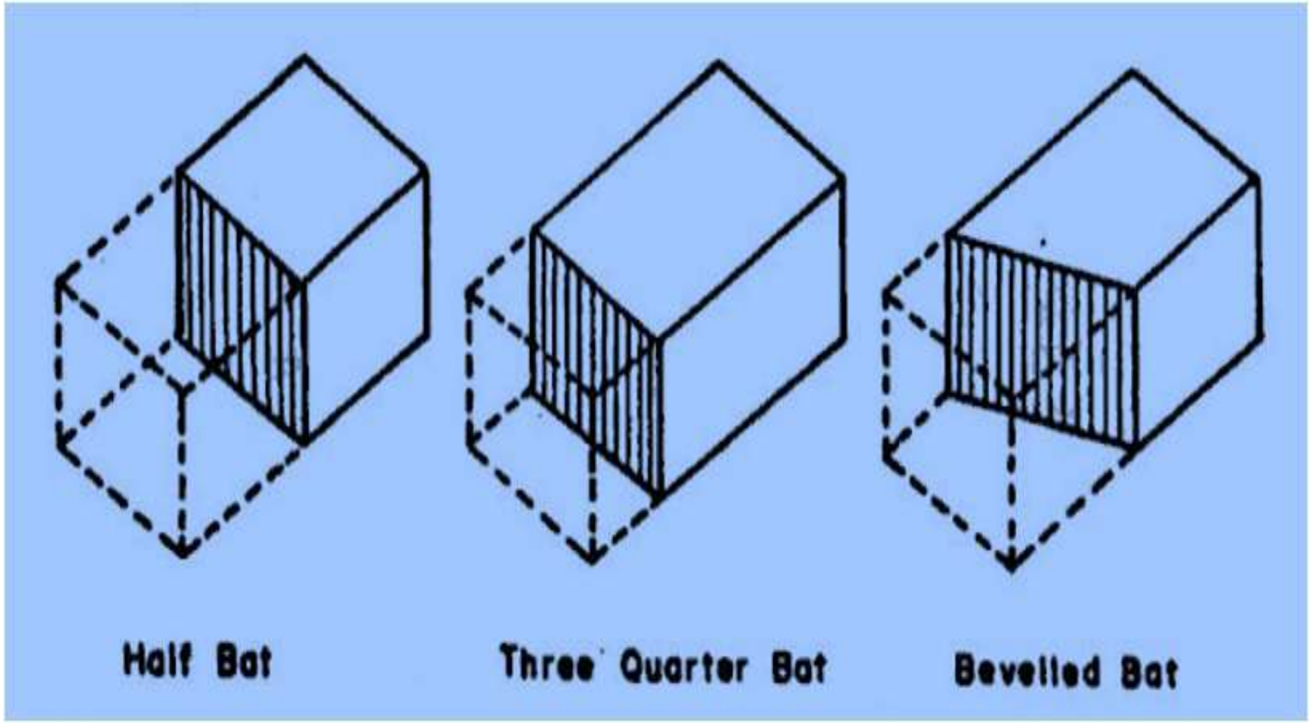
- Queen Closer
- King Closer
- Beveled Closer
- Mitred Closer





Bat: When a brick is cut across the width, the resulting piece is called bat..

- Half Bat
- Three Quarter Bat
- Beveled Bat



Brick Faces and Quoins

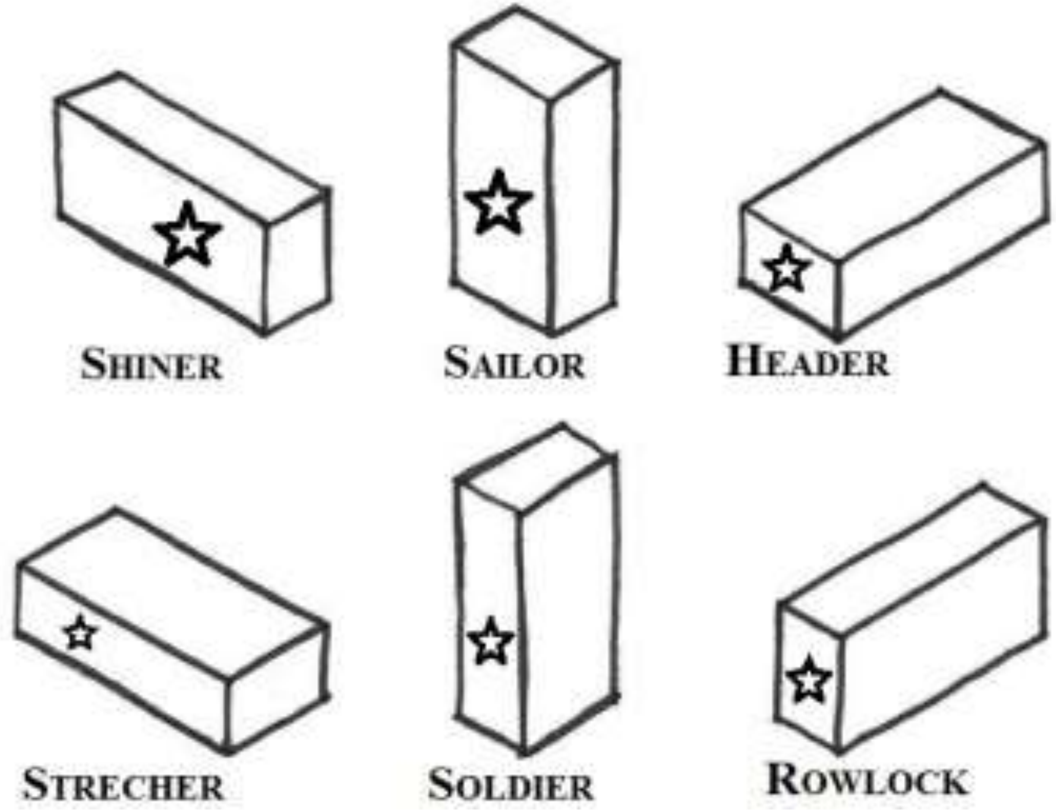


Fig: Brick Faces

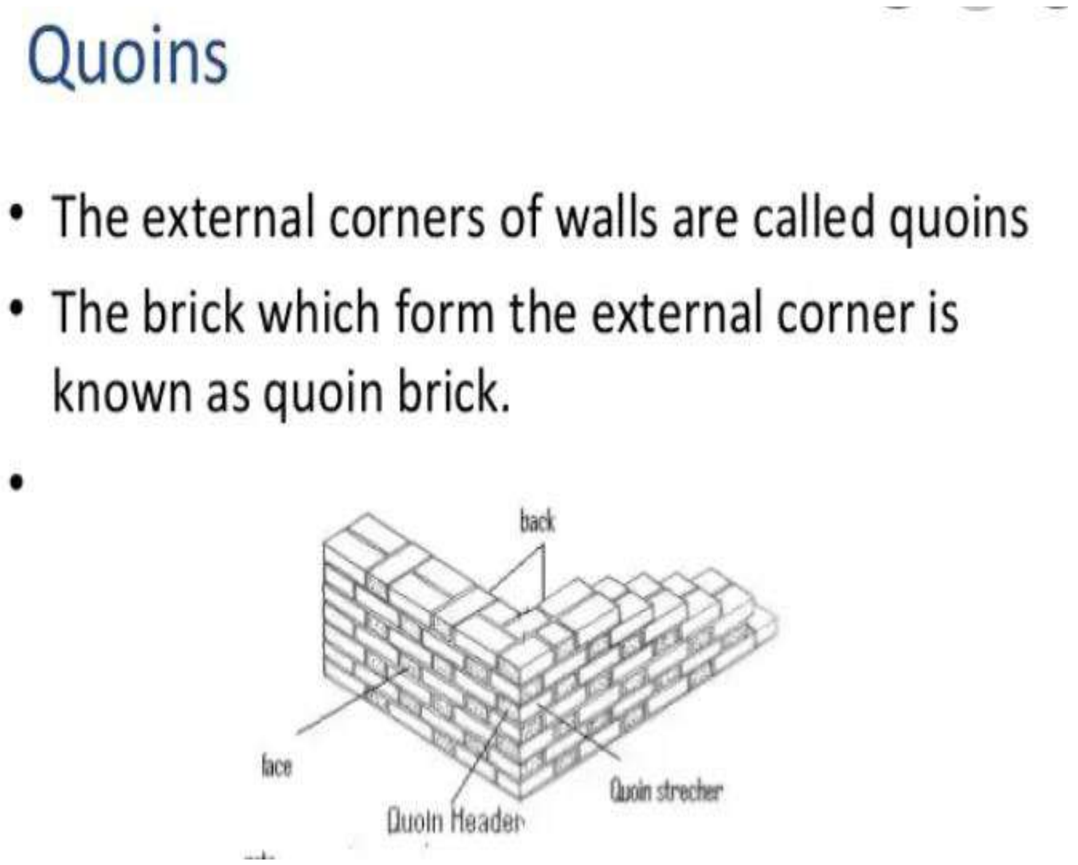


Fig: Quoins

- **Some definitions:**

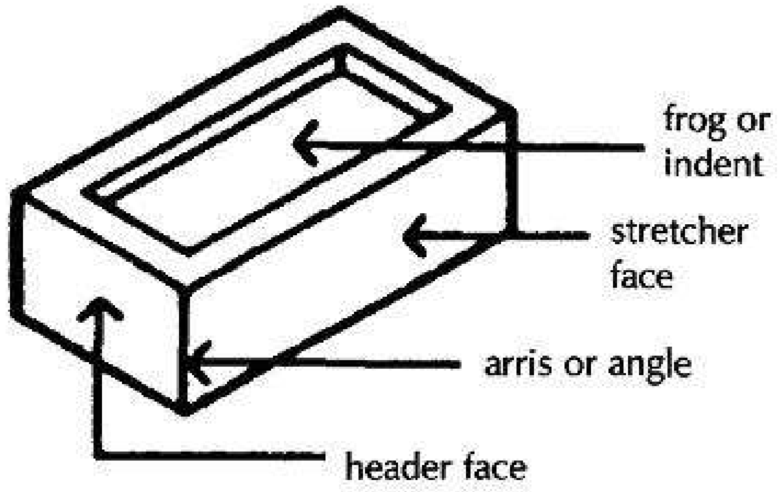


Fig. 51 Brick faces.

1. Stretcher -Laid length parallel to face or front direction of wall.
2. Header -Laid width or breadth.
3. Arris- Edges formed by intersection of plane surfaces of brick, should be sharp, square, free from damage.
4. Bed- Lower surface of brick when laid flat.
5. Bed joint - mortar at bed.

6. Perpend- Vertical joints
7. Lap distance- Distance between vertical joints
8. Closer - piece of brick used at ends to end brick course
9. Frog- depression on the face of brick: 10 mm - 20 mm deep.

- **Bond in brickwork:**

- Bricks being uniform in size can be arranged in a variety of forms.

- **Types of Bond:**

1. Stretcher bond
2. Header bond
3. English bond
4. Flemish bond
5. Rat trap bond
6. Garden-wall bond

7. Raking bond
8. Dutch bond
9. Brick-on-edge bond
10. English cross bond
11. Facing bond

Bonding means the arrangement of bricks in such a way that no vertical joint of one course is exactly over the joints in next course. This means that the brick is laid in such way that it overlaps and breaks the joint below.

1. Stretcher bond

- Stretcher bond, also called as running bond, is created when bricks are laid with only their stretchers showing, overlapping midway with the courses of bricks below and above.
- used for the construction of walls of half brick thickness

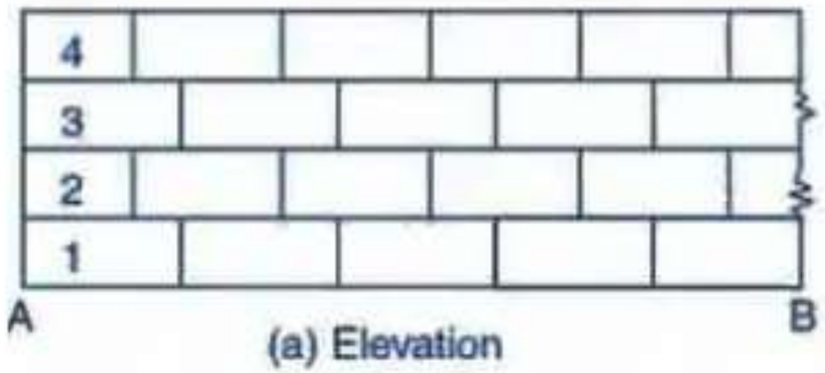


Fig-1: Stretcher Bond

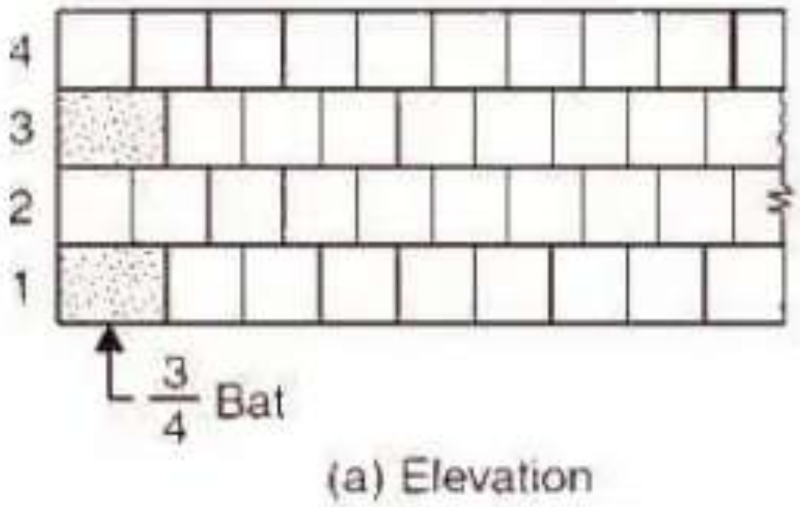


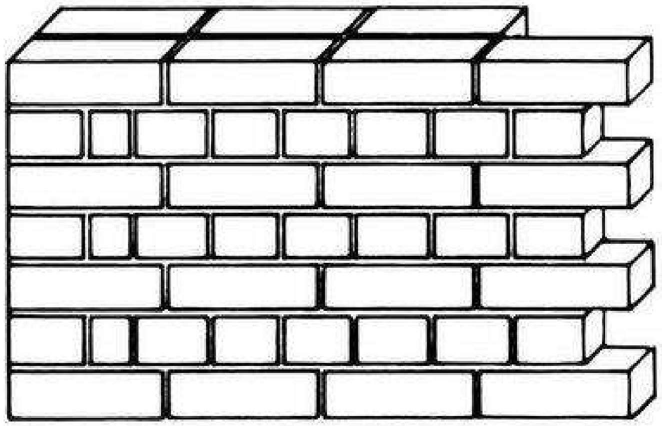
Fig. 2: Header bond

2. Header bond

- Header bond is also known as heading bond. In header bonds, all bricks in each course are placed as headers on the faces of the walls.
- used for the construction of walls with full brick thickness.
- In header bonds, the overlap is kept equal to half width of the brick. To achieve this, three quarter brick bats are used in alternate courses as quoins.

3. English bond

- Generally used
- Strongest bond
- Consists of stretcher and header in alternate course.



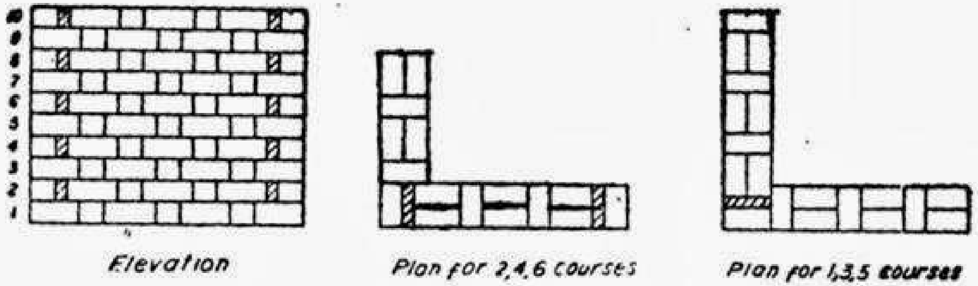
English bond

- Features of English bond

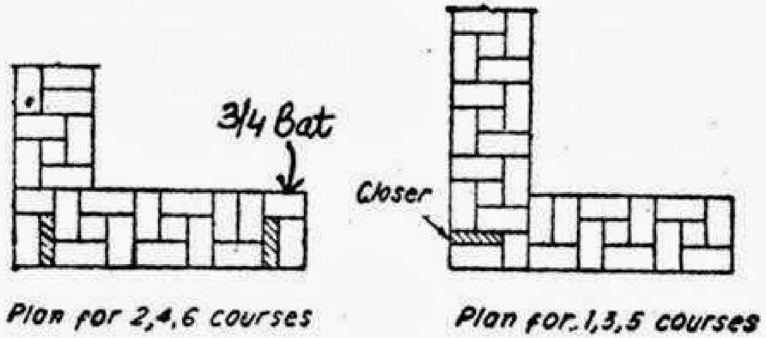
- Alternate header and stretcher courses.
- In this bond, the continuous vertical joint is not formed.
- The quoin closer is kept next to header to develop the face lap.
- The quoin closer is not required in stretcher course.
- Each alternate header is centrally supported over a stretcher.

4. Flemish bond

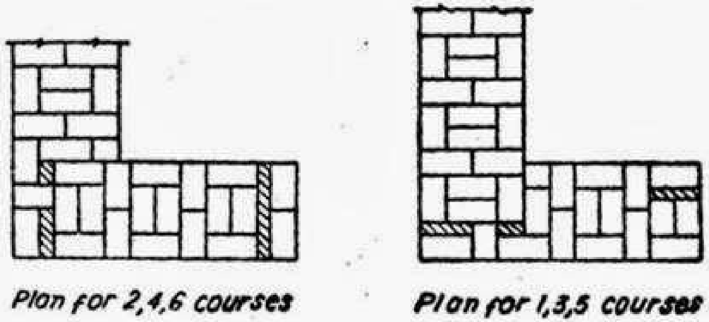
- In this type of bond, header and stretcher are placed alternatively in each course.
- It creates a better appearance than the English bond.
- The queen closer is put next to the queen header in alternate courses to develop the face lap.
- Short continuous vertical joints are formed.



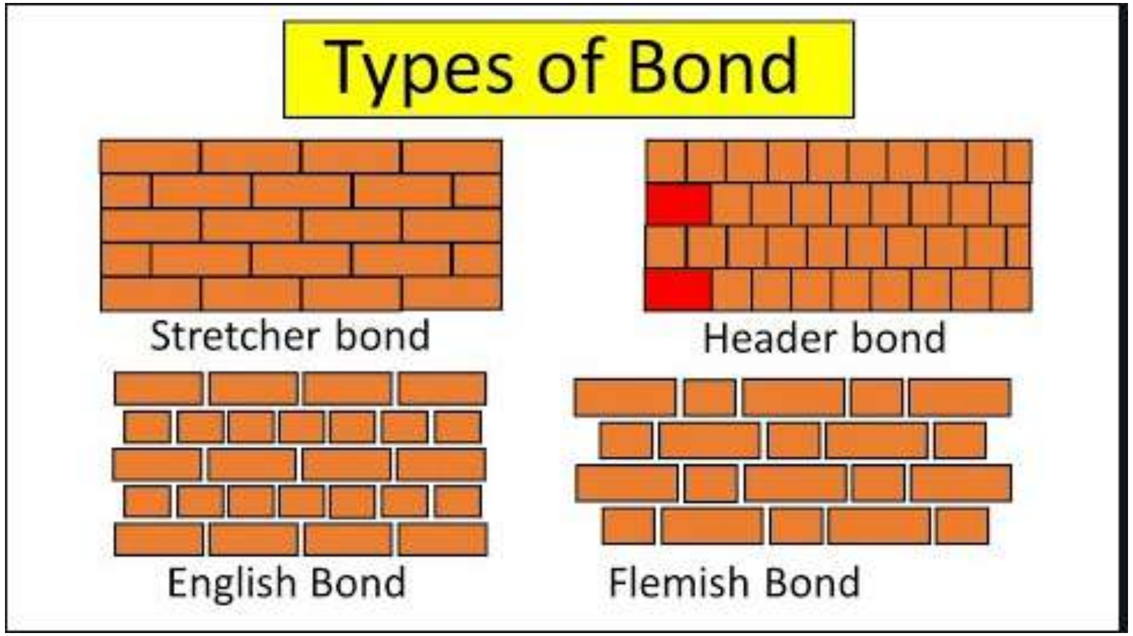
One-brick wall double flemish bond.

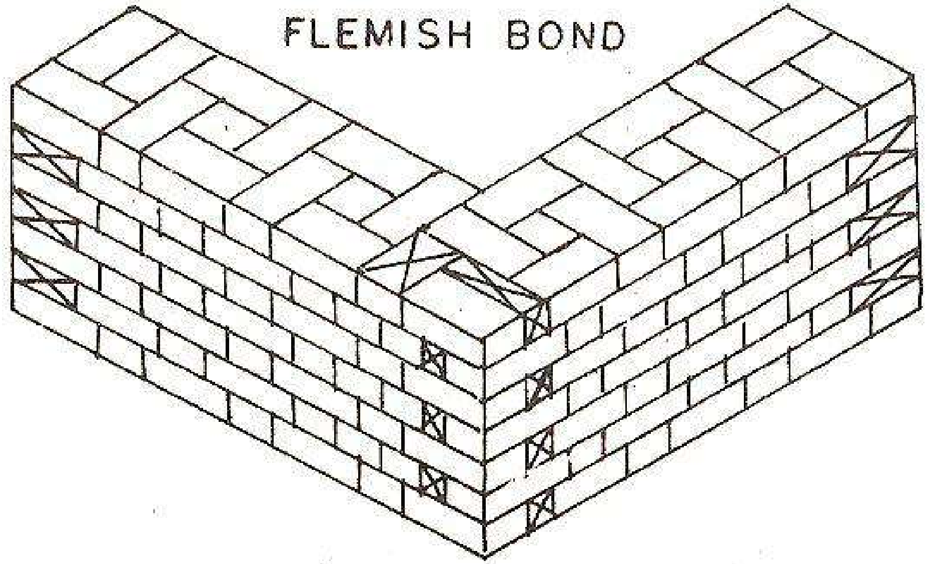


One-and-a-half-bricks double fl:mish bond.



Two-bricks double flemish bond.



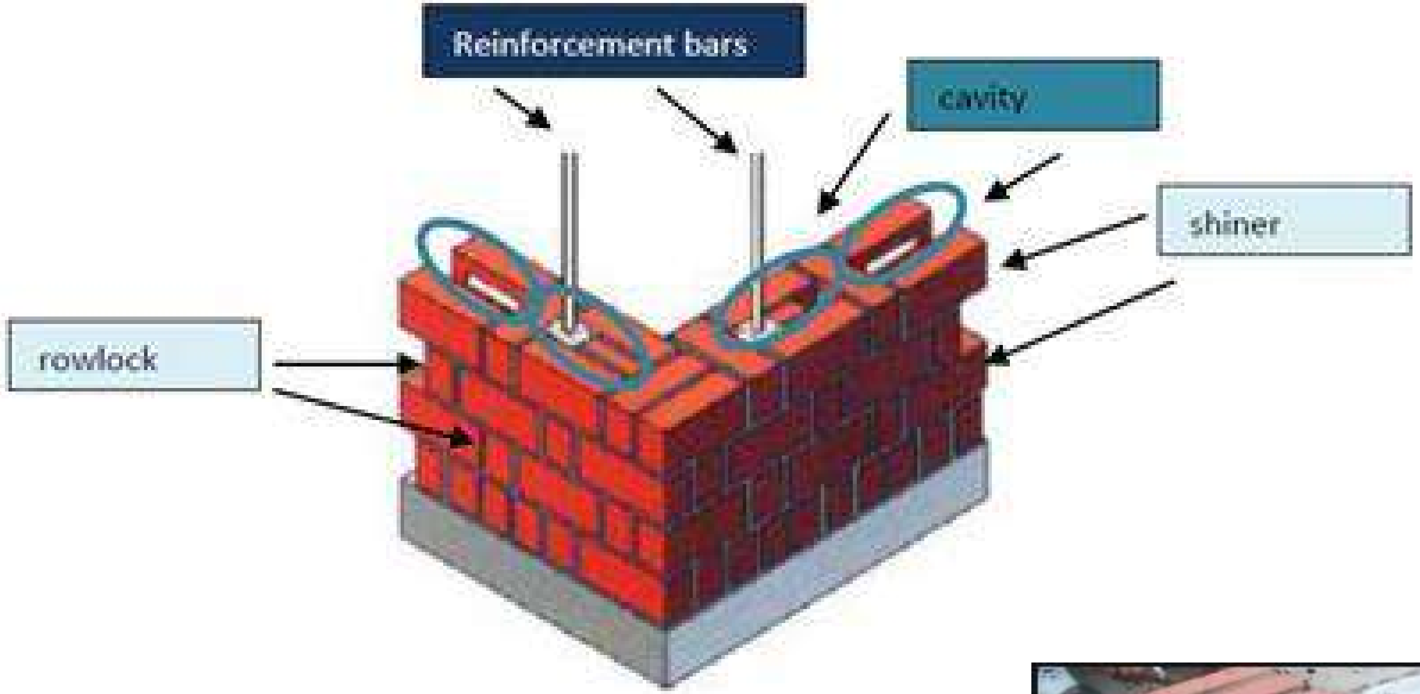


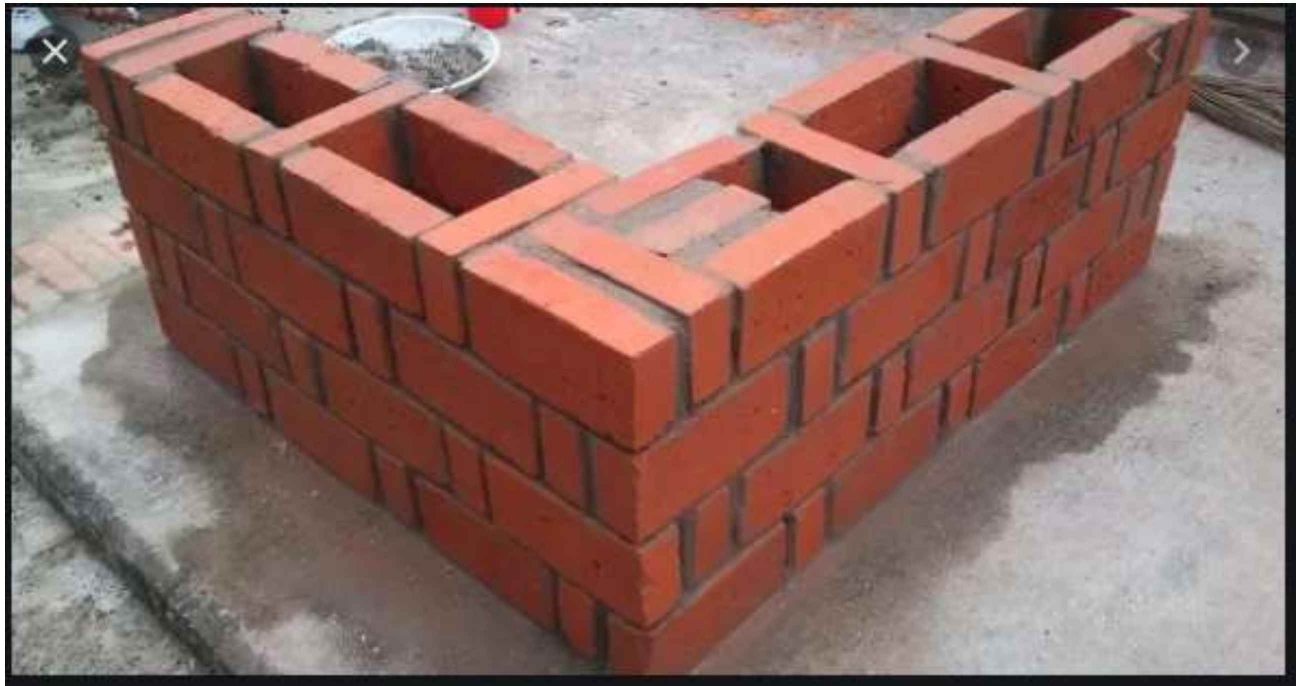
$1\frac{1}{2}$ BRICK WALL

5. Rat trap bond

- **Rat trap bond** is a brick masonry method of wall construction, in which bricks are placed in vertical position instead of conventional horizontal position and thus creating a cavity (hollow space) within the wall

- It is a type of brick masonry in which bricks are laid on edge such that the shiner and rowlock are visible on the face of masonry resulting an internal cavity bridged by rowlocks.


Reinforcement bars
cavity
shiner
rowlock



- **Advantages**

- Economic use of bricks i.e. nearly 35% bricks reduced, 50% less mortar and overall 30% cost reduction.
- Strength is equal to a standard solid brick wall.
- Cavity induced in wall provides advantage of thermal comfort. Makes the interior cooler in summer and warmer in winter.
- Dead load reduced by 20% so foundation size is reduced.
- Aesthetically pleasing finishing without plastering can be obtained.
- Vertical wiring and plumbing can be done easily.
- Reduction in wastages of bricks (no cutting done to fit in).
- Can be used as thick partition wall as well as load bearing wall.
- For more structural safety, reinforcement bars can be inserted through the cavity until the foundation.

- Disadvantages

- It does not provide good sound insulation.
- Extra care must be taken while designing the wall length and heights for a structure.
- It requires trained masons, otherwise wastage of mortar falling into the cavity.

7.3 Hollow block and compressed earth block

- They are precast concrete units made from mixture of cement, aggregate and water.
- Can be produced in different shape and size for wall construction to fit different construction needs and designs.
- They are of different sizes:

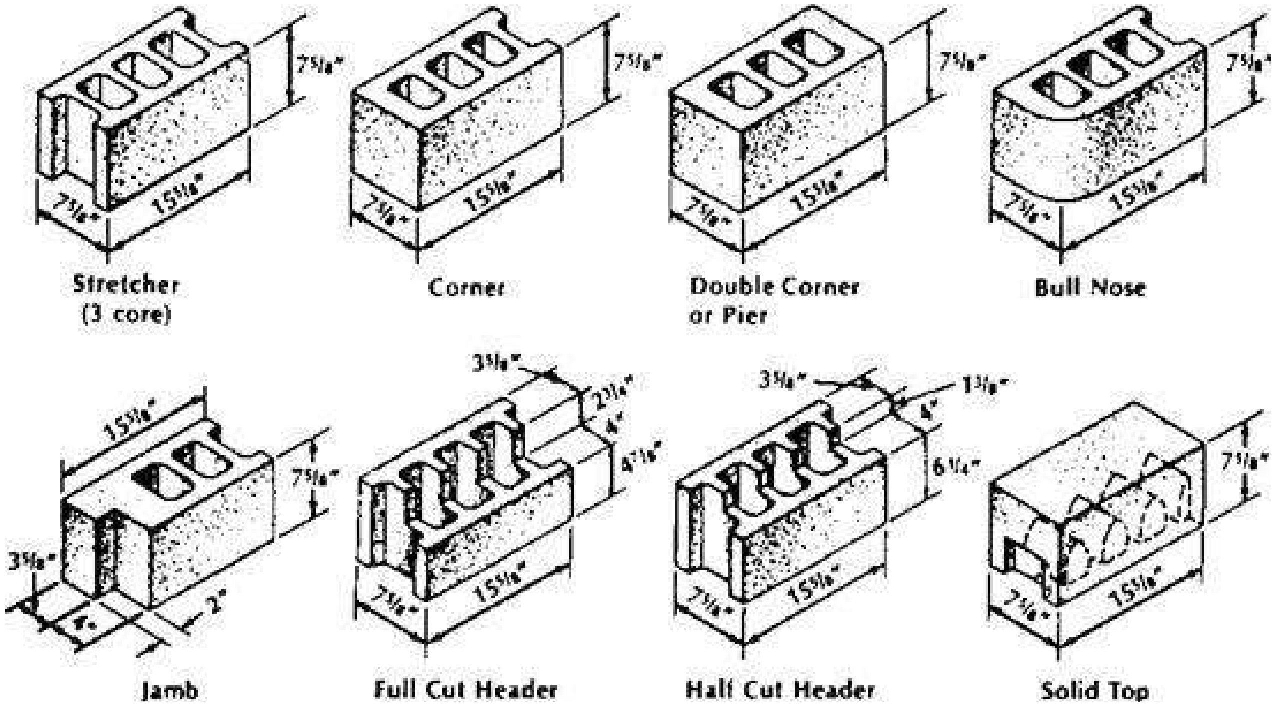
- Size: 300 mm * 200 mm * 150 mm

- Compressive strength: 50 - 100 kg/cm2
- They are made in full or half units.
- They are prepared by concrete block technology.

- **Concrete block technology**

- It is based on the principle of densification of lean concrete mix to make regular shaped, uniform high performance masonry units.
- Concrete block technology can be easily adopted to suit special needs of user by modifying design parameter such as mix proportion, water cement ratio, etc.

- The technology has high performance in area where raw materials are easily available.



- Advantages of Hollow concrete blocks:

- Reduce the investment cost at least 30% and energy consumption more than 50% compared to fired clay brick.
- Easy and speedy in construction.
- Good thermal and sound insulator.
- Reduced dead load.
- Reduces maintenance cost, durable.
- Acts as damp proofing due to low water absorption capacity.
- Can be produced in different shape and size to fit different construction needs and design.

- Technical specifications of concrete blocks

- Typical size: 300*200*150 mm
- Average compressive strength: 50-100 kg/cm^2 in 28 days.

- Mix proportion- 1:(12-14) (1 part cement: 12-14 part well graded aggregate)
- Water absorption in 24 hrs: <10% by weight of block.

- **Compressed earth blocks**

- The cuboidal shaped masonry unit manufactured by compacting raw material earth mixed with stabilizer (e.g. cement, lime) under pressure of 20 -40 kg/cm2 are compressed earth blocks.
- Also termed as stabilized compressed earth block.
- The basic principle of all the machines is the compaction of raw earth to attain dense, even sized masonry.
- Some of the hydraulic machines can even manufacture interlocking blocks.
- These interlocking blocks are highly suitable for speedy and mortar less construction.
- Constructed manually or by hydraulic machines.

- **Advantages**

- Construction at site using local material.
- Speedy and mortar less construction.
- Environment friendly as firing is not required.
- Has minimum maintenance so economic.
- Transferable technology(No skilled manpower is required).
- Fire resistant, sound insulation.

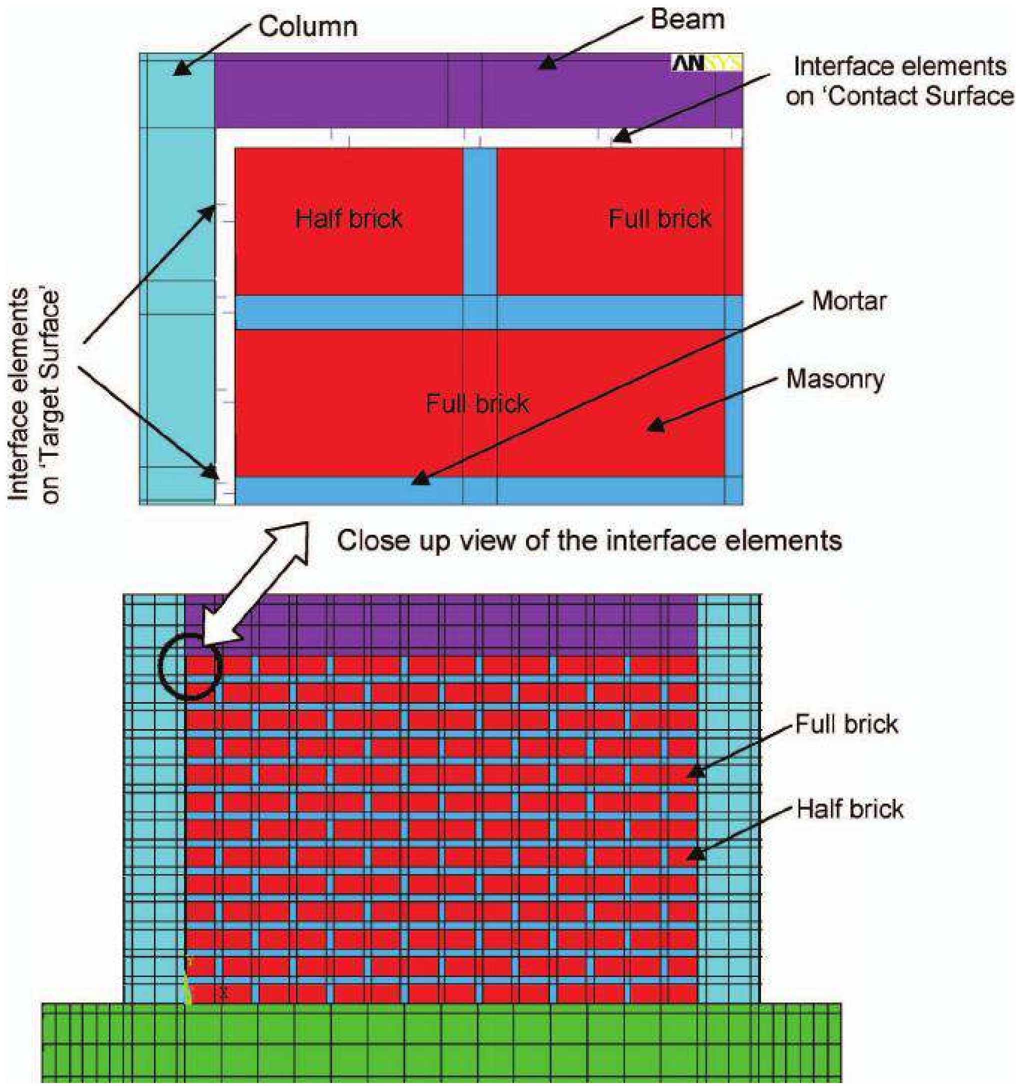
- **Disadvantages**

- Proper soil identification is required.
- Low technical performance compared to concrete.
- Over stabilization through fear or ignorance implying outrageous acts.

- **Manufacturing process: Proportioning, mixing, compressing & drying.**

7.4 MASONRY AS INFILL WALLS:

- The **infill wall** is the supported wall that closes the perimeter of a building constructed with a three-dimensional framework structure (generally made of steel or reinforced concrete).
- So, masonry infill walls are the walls which are confined on all four sides with the reinforced concrete member or reinforced masonry as vertically and horizontally confining element.
- Therefore, the structural frame ensures the bearing function, whereas the infill wall serves to separate inner and outer space, filling up the boxes of the outer frames.
- These walls are not intended to carry vertical or horizontal load (no load bearing capacity).
- A non-structural element.
- Masonry infills are very often constructed as the non-structural element after the completion of the main R.C. structure.


Column
Beam
Interface elements
on 'Contact Surface
Half brick
Full brick
Mortar
Masonry
Full brick
Interface elements
on 'Target Surface'
Close up view of the interface elements
Full brick
Half brick

- **Confined Masonry** is a **construction** system where the walls are built first, and the columns and beams are poured in afterwards to enclose (confine) the wall.
- Walls are anchored to the frames
- Masonry walls are intended to carry all vertical and seismic loading and act as a structural member.

- As the experimental investigation and experiences obtained form earthquakes have shown, confining the masonry wall with beam and column results in:

- Improvement in connection between structural walls.
- Improvement in the stability of slender structural wall.
- Improvement in strength and ductility of masonry panels.
- Reduction in the risk of disintegration of masonry panel damaged by earthquake.

Confined Masonry versus Infilled RC frames:

-construction sequence
- integrity between masonry and frame

Confined Masonry

- Walls first
- Concrete later

Source: Tom Schacher

Reinforced Concrete Infilled Frame

- Concrete first

7.5 Reinforced and unreinforced masonry

7.5.1 Reinforced masonry

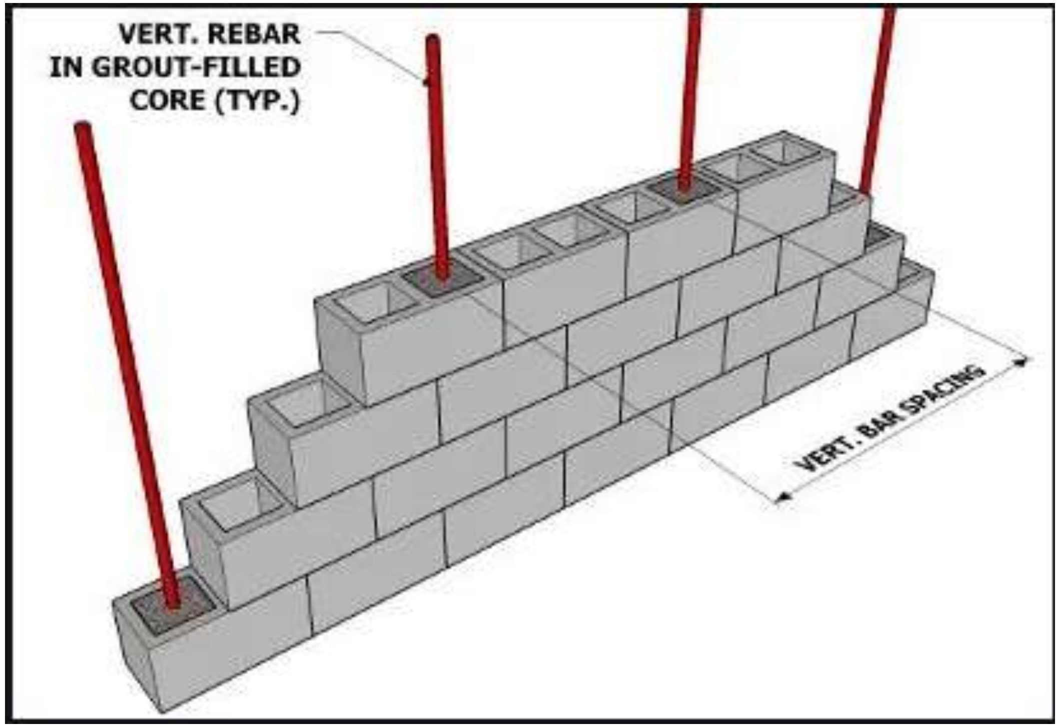
- Reinforced Masonry is a construction system, where steel reinforcement in the form of reinforcing bars or mesh is embedded in the mortar or placed in the holes and filled with concrete or grouted.
- Reinforcement increases tensile strength of wall.
- It resists seismic loads and improves energy dissipating capacity.
- To achieve this, reinforcement should be integrated with masonry so that all the material of reinforced masonry system acts monolithically when resisting gravity and seismic loading.
- There are various ways in which steel reinforcement can be used in reinforced masonry structural system

Types of Reinforcement masonry structure:

1. Reinforced hollow unit masonry.
2. Reinforced cavity masonry.
3. Reinforced pocket type walls.
4. Reinforced confined wall.

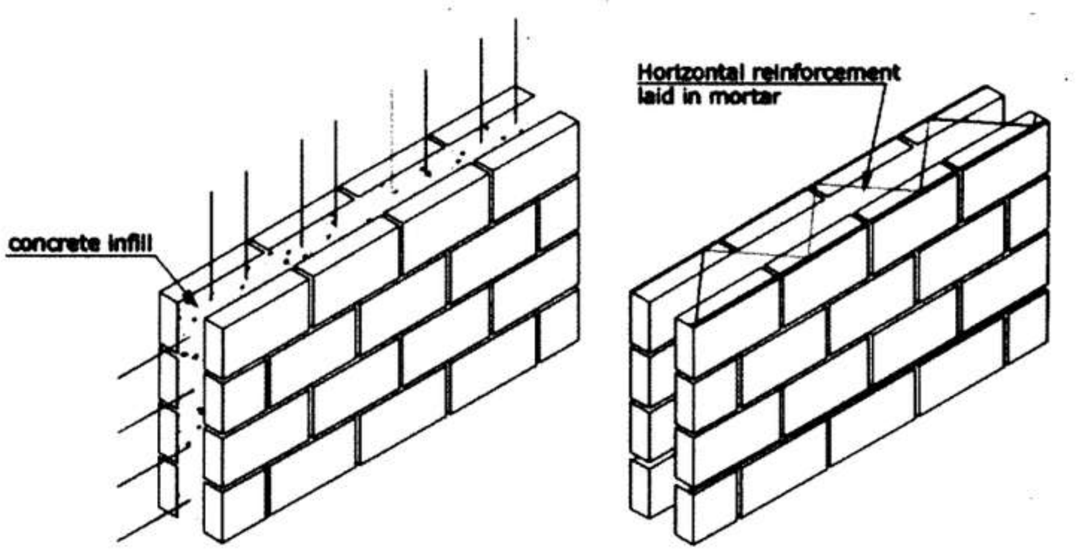
1. Reinforced hollow unit masonry.

- It is a basic form of reinforcement masonry construction.
- Special shaped units with vertical holes, where vertical reinforcement is placed and filled with infill concrete or grout, with or without grooves to accommodate horizontal, bed joint reinforcement.
- 1st - Vertical reinforcement is placed.
- 2nd - First course of units laid.
- 3rd - Horizontal bars or bed joint placed in grooves or mortar.
- Holes - grouting or filled with concrete infill.


VERT. REBAR
IN GROUT-FILLED
CORE (TYP.)
VERT. BAR SPACING

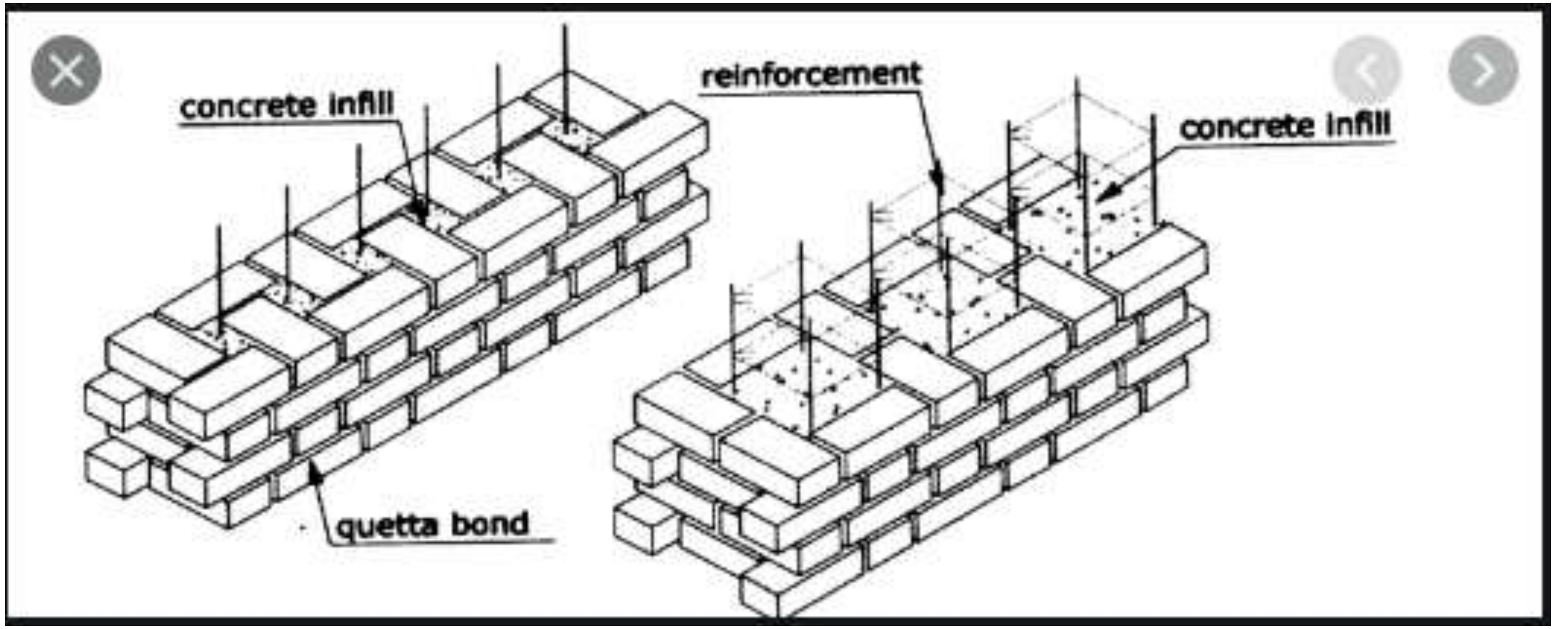
2. Reinforced cavity masonry

- Diff. technology, structure characteristics
- It consists of two leaves of masonry units, separated by a cavity into which the vertical and Horizontal reinforcement is placed and grouted with either concrete infill or grout.
- The two leaves of a cavity wall are tied together with wall besides or connector which is designed to resist earthquake or lateral loads.
- Grout before or during work mason



3. Reinforced pocket type walls

- Sometimes vertical reinforcement is placed in the pocket formed in the wall by special bonding arrangement.
- This **type** of construction is so named because the main **reinforcement** is concentrated in vertical **pockets** formed in the masonry.
- Placing same as in RCC hollow unit masonry.
- This **type** of **wall** is primarily used to resist lateral forces in retaining or wind loading situations.



7.5.2 Unreinforced masonry

- An unreinforced masonry is a construction system where load bearing walls, non load bearing walls or other structure such as dam, retaining wall, etc. are made of bricks, blocks, tiles adobes or other masonry unit which are not braced by the reinforced bars or beams.
- This term is used for earthquake engineering.
- Vulnerable to collapse in earthquake.
- Most mortar used to hold bricks together is not strong enough so masonry elements may peel from the building and fall on the occupant outside.

Chapter 8

Design of masonry walls for gravity loads

8.1 Introduction to codal provisions

- The most effective use of masonry construction is seen in load bearing structures wherein it performs a variety of functions, namely supporting loads, subdividing space, providing thermal and acoustic insulation as well as fire resistance and weather protection which normally in a framed building has to be accounted for separately.
- Until 1950'sthere were no engineering methods of designing masonry for buildings and thickness of walls were based on Thumb-rule.
- As a result walls used to be very thick and masonry structures were found to be very uneconomical beyond 3 or 4 stories.
- Since1950's intensive theoretical and experimental research has been conducted on various aspects of masonry in advanced countries.
- Factors affecting strength, stability and performance of masonry structures have been identified, which need to be considered in design and code of practice was developed in different countries which specify all necessary specification and criteria for masonry design.

- There are various design codes for masonry design.

1. Building code requirement for masonry structure (ACI-530-02/ASCE5-02/TMS402-02).

2. International Building code 2000

3. New Zealand standard-code for practice for the design of concrete and masonry structures (NZ4230:PART1:1990)

4. Euro code 6: Design of masonry structure (DDENV 1996-1-1:1996)

5. Indian standard-code of practice for structural use of unreinforced masonry (IS:1905-1987)

6. Nepal Building code : NBC 109

- We are mainly concerned with IS 1905-1987 and NBC 109.

8.2 Design example for gravity loads:

8.2.1 Solid wall

- Design steps:

i) Assume the thickness of wall (e.g. 100 mm), mortar ratio (e.g. 1:5 m1) and crushing strength (e.g. 10 Mpa)

ii) Calculate the total load on the wall.

a. Weight of the slab = ………………………………kN/m

b. weight of surface finish=………………….kN/m

c. live load=…………………………………kN/m

d. self-weight of wall=………………….KN/m

$\therefore$Total load = (a+b+c+d) kN/m

iii) Find total stress = Total load/ (Thickness of wall*1) (kN/m ^{2})

iv) Find permissible stress

fca= fb*ka*ks*kp

Where,

- fb=basic compressive stress. It is function of mortar type and crushing strength and is given in table 8 (IS 1905-1987)
- ka=area reduction factor as per clause 5.4.1.2 (IS 1905-1987)
- ks=stress reduction factor as per clause 5.4.1.1

  =f (slenderness ratio, eccentricity) and given in table 9
- kp=shape modification factor as per clause 5.4.1.3 and is given in table 10

v) Check

- if total stress < fca

  Design is ok.

- Else, redesign the wall using another wall thickness and repeating all above procedure. Mortar type and crushing strength can also be changed.

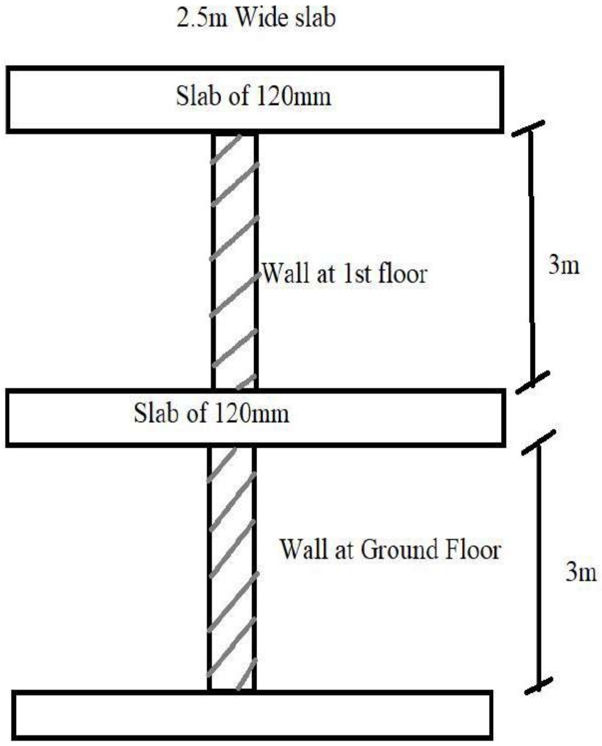
- Example-1:

Design the wall of two story building to carry 120 mm thick RCC slab with 3 m ceiling height. The wall is unstiffened and supports a 2.5 m wide slab on both sides.

Live loads on roof = 1.5 kN/m2

Live loads on floor = 2.0 kN/m2

Weight of surface finish = 1.2 kN/m2



➢ Solution:

Step 1: Assume, the thickness of wall = 110 mm

Mortar ratio = 1:5 (M1)

and crushing strength = 10 Mpa

Step 2: Load calculation,

- **Load from roof:**

a) Wt. of slab = unit wt. of RCC*thickness of slab*width of slab

=25kN/m3*0.12m*2.5m

=7.5kN/m

b) Weight of surface finish = unit wt. of surface finish*width of slab

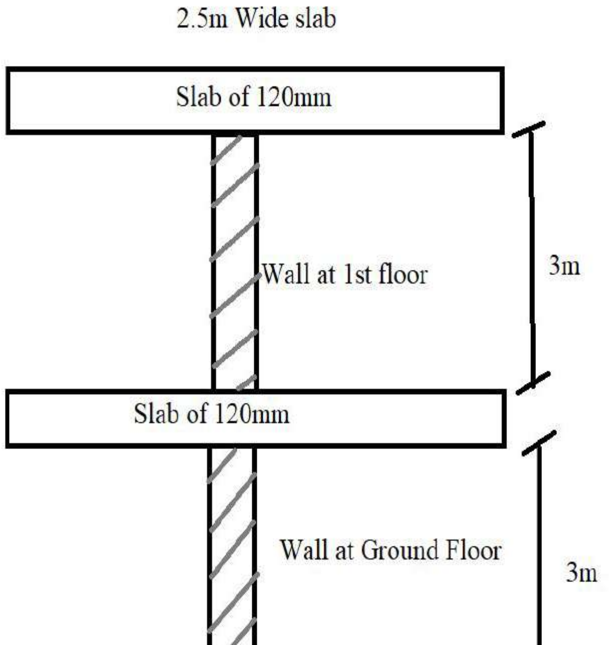
=1.2kN/m2*2.5m =3kN/m

c) Live load = 1.5kN/m2*width of slab

= 1.5*2.5m

=3.75 kN/m

So, Total load = (7.5+3+3.75)KN/m = 14.25kN/m



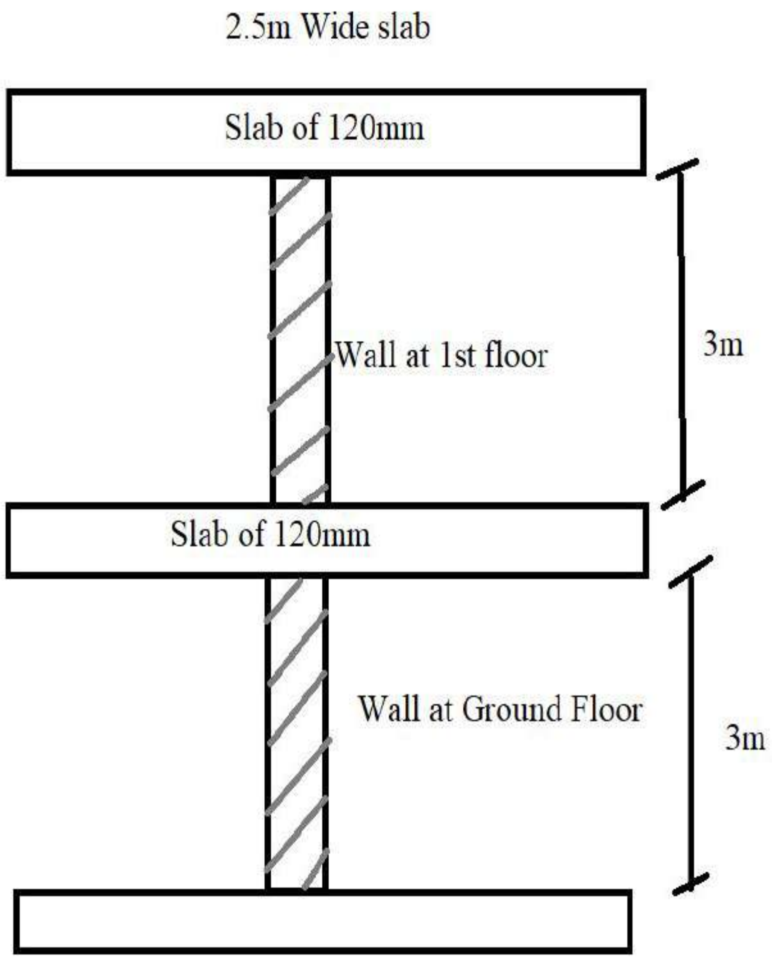
- Load from 1st floor:

a) Wt. of 120 mm slab = 7.5 kN/m

b) Wt. of surface finish = 3 kN/m

c) live load = 2*2.5 = 5kN/m

So, total load = (7.5+3+5)KN/m = 15.5KN/m



- Self-wt. of the wall = unit wt. of the wall*height of the wall*thickness of wall*no of storey

= 20kN/m3*3m*0.11m*2

= 13.2 kN/m

So, Total load: = (14.25+15.5+13.2) =42.95 kN/m

Step 3:

Total stress = Total load/Thickness of wall =42.95/(0.11*1) =0.39045 N/mm2

Step 4:

Permissible stress ,fca =fb*ka*ks*kp

Where, fb= 0.96 N/mm2 (from table 8)

Area reduction factor (ka):

Area of wall = 0.11*2.5 =0.275 (>0.2m2)

So, ka =1 as per clause 5.4.1.2

Stress reduction factor (ks)

e (eccentricity) =0

Slenderness ratio (SR) = h h / h

Effective height = 0.75 H as per clause 4.3.1

= 0.75*(3000+120*2/2)mm

=2340 mm

Effective thickness = 110 mm as per clause 4.5.1

So, SR = 2340/110 = 21.27 < 27 OK (see clause 4.6.1)

From table 9, by interpolation, for e=0 & SR = 21.27

ks = 0.5819

Shape modification factor (kp)

h h / h = 55/110 =0.5

from table 10, kp = 1

∴ fca = 0.96*1*0.5819*1 =0.5578 N/mm2

- Step 6: Check

fca > total stress, so design in OK.

- Hence provide, thickness of wall = 110 mm

  Mortar type = M1

  Crushing strength = 10 Mpa

- 8.2.2 **Walls with openings:**

- It also follows the same design steps as explained in article 8.2.1.

- Example 2:

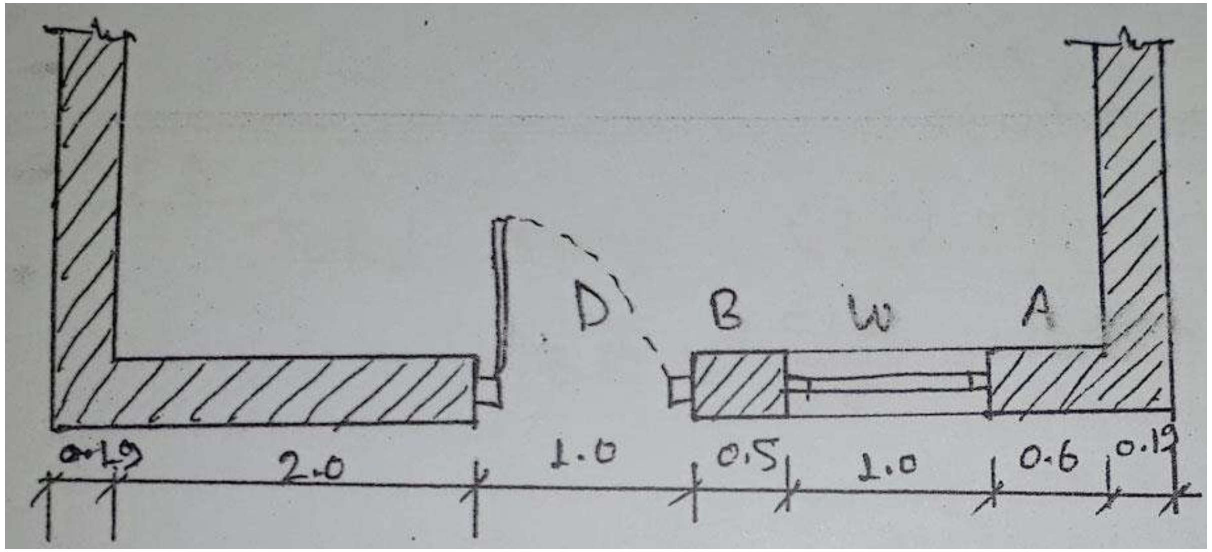
External wall of a single storeyed house is 19 cm thick, and has door and window opening as shown in fig. Plinth level is 1.2 m above the top of foundation footing and floor to ceiling height is 2.8 m. One way RCC slab of 3 m clear span bears on the wall and is 10 cm thick. Determine the maximum stress in the wall and calculate strength of bricks and grade of mortar required for the wall . There is a 20 cm thick parapet wall of 0.8 m height above the roof slab wall and both wall and parapet is plastered on both sides. Assume joint are racked joint type.

Live load = 1.5 kN/m^2

Lintel level = 2.0 m

Sill level of window = 0.5 m

All dimensions are in m.



- Solution:

As thickness of wall is given, We start from load calculation

- Load calculation

Thickness of wall = 19 cm

Thickness of wall with both side plaster = 19 + 3 = 22 cm (plaster of 1.5cm on both side)

Parapet Load

Load from parapet = thickness of wall * height of wall * unit wt.

= 0.22 m * 0.8 m * 20 kN/m3 = **3.52 kN/m**

Roof Load:

Wt. of 10 cm RCC slab = 0.1 * 25 kN/m3 = 2.5 kN/m2

Assuming 1.5 cm plaster on both side

Wt. of plaster = 0.015 * 2 *20 kN/m^3

= 0.6 kN/m^2

Total = (2.5+0.6) = **3.1 kN/m^2**

Clear span of slab = 3 m

So, Effective span = 3 + 0.1*2 = 3.2 m (0.1 m bearing width)

Roof load on wall = (3.1 kN/m2 * 3.2 m)/2 = **4.96 kN/m** (as roof load distributes on two walls, slab being on one way slab)

- Self weight of wall up to plinth level:

  = 0.22 * 2.8 * 20

  = 12. 32 kN/m

Portion A of wall:

Length of wall = 0.6+(0.19/2) = 0.695 m (up to center of cross wall)

Load on wall = load from parapet + roof load + self wt.

=(3.52 + 4.96 + 12.32) *(0.69+(1.0/2))

= 20.65*(0.69+(1.0/2)) = 24.75 kN

(Since loads from the half window length, bears wall A.)

- Since wall is plastered on both sides, it may be assumed to have raked joints on both sides.

Thus effective thickness of wall = 19 - 2 = 17 cm (see clause 5.5.1.1)

Compressive stress at plinth level = / = 24.75/(0.17*0.69) = 210.99 kN/m2 =0.2109 N/mm2 = 0.211N/mm^2

- Slenderness Ratio:

From consideration of height:

SR = effective *height*/effective thickness = 0.75(1.2+2.8+0.05)/0.17 = 17.87

(See Clause 4.3.1 & 10cm of slab=10/2=0.05m)

As length of wall A (69 cm) >4t(4*17= 68 cm)

So, it is not a column. (Clause 2.3.1)

Effective length = 2 L (from clause 4.4)

=2*0.69 (table 5)

=1.38 m

SR = 1.38/0.17 = 8.12

Since, SR, lengthwise < SR height wise.

SR lengthwise governs the design. [Clause 4.6.1]

Let us consider that basic compressive stress for masonry=fb

∴ Permissible compressive stress (fca) = fb*ka*ks*kp

Area reduction factor Ka

A = 0.17*0.69 = 0.117 m2< 0.2 m2

So, ka= 0.7 + 1.5 A =0.876 (clause 5.4.1.2)

Shape modification factor (kp):

(h/b)unit = *90/90* = 1 (modular brick)

Assuming crushing strength = 10 Mpa

kp = 1.1 (clause 5.4.1.3)

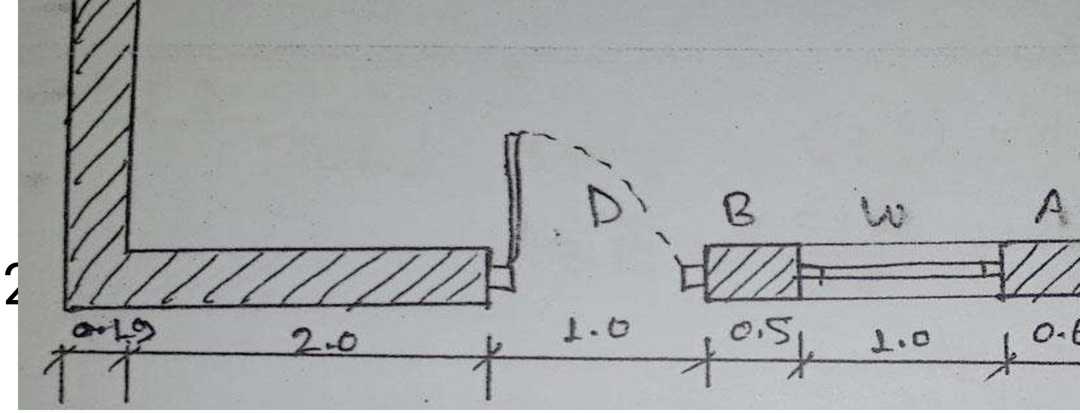
Stress Reduction factor (ks)

for eccentricity = 0 and SR = 8.12

Ks = 0.95 (from table 9)

∴ Basic compressive stress:

fb = /(* *) = *0.211/(0.876*0.95*1.1)* = 0.2



- Portion B of wall:

Length = 0.5 m < (4t=68cm) so it behaves as **a column (as per clause 2.3.1.)**

This portion of wall has opening on both sides, therefore total load on the wall at plinth level

= (3.52+4.96+12.32)*((1/2)+0.5+(1/2)) = 31.2 KN (half length from both the opening)

So, Compressive stress in wall at plinth level=31.2/(0.17*0.5)=367.05 KN/m ^{2} =0.367N/mm^2

- Stress reduction factor (ks):

Effective ht. of column for the direction perpendicular to the plane of the wall (clause 4.3.3)

heff = 0.75 H + 0.25 H1

= 0.75 (1.2 + 2.8 + 0.05)+0.25*2

= 3.04+0.5

= 3.54 m

Effective height of column for direction parallel to the wall,

heff = H = 1.2+2.8+0.05

= 4.05 m

SR perpendicular to plane of wall = *3.54/0.17* = 20.82=21

SR, parallel to plane of wall = *4.05/0.5* = 8.1

Thus SR = 21 will govern the design (clause 4.6.2)

ks=0.59 from table 9 for SR = 21 & e = 0

Area reduction factor: (ka)

A = 0.5*0.17 = 0.085 m2< 0.2 m2

∴ ka = 0.7+1.5*0.085 (clause 5.4.1.2)

= 0.83

Shape modification factor (kp):

For crushing strength 10 Mpa

And *h/* of unit = 1

kp = 1.1

∴ Basic compressive stress (fb)

= /(. .)

fb=*0.367/(0.83*0.59*1.1)* = 0.68 N/mm2>fb for wall portion A.

- Thus from table 8, M3 mortar can be used with basic compressive stress 0.75 N/mm2, as wall portion B governs the design.
- Hence, provide crushing strength = 10 Mpa

Grade of mortar = M3

8.2.3 Wall with eccentric loading:

- Calculation of stress for eccentric loading
- Consider a masonry section b*d as shown in fig. subjected to axial load 'w' at point ‘P’

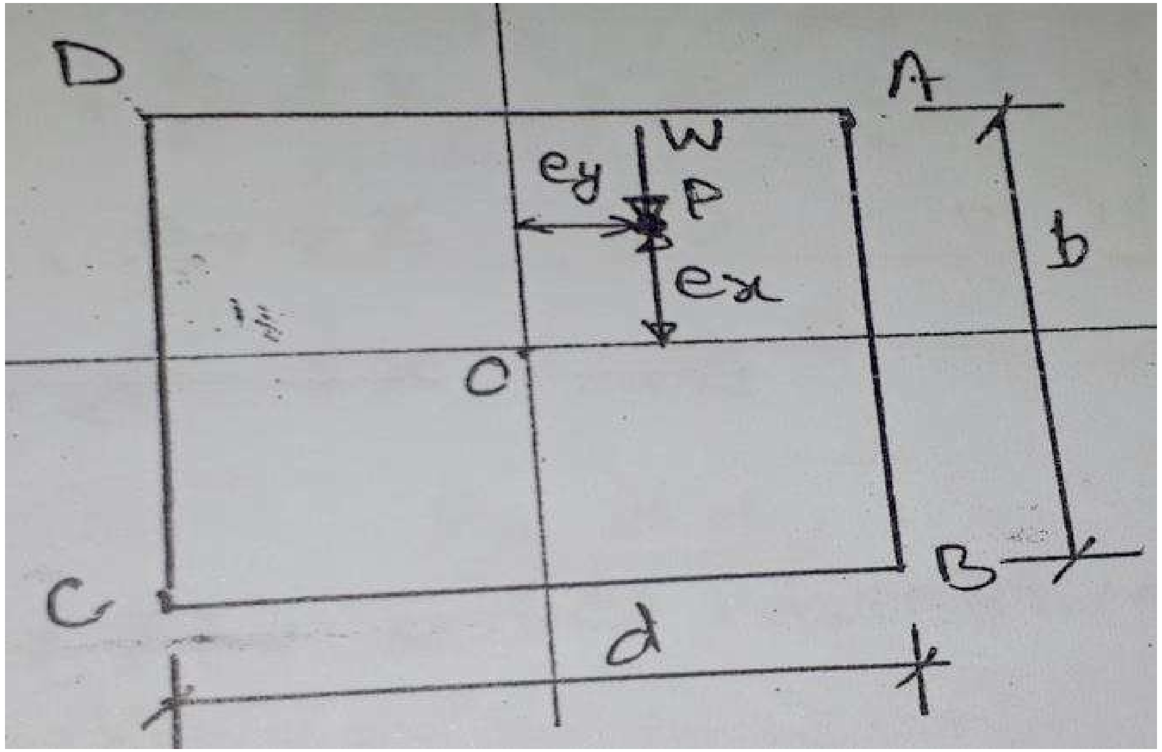


Fig:

- The load equivalent at P = load 'w' at point O + moment (w*ex) + moment (w*ey)
- Area, A = b.d

- $I_{xx} = db^3/12$
- $I_{yy} = bd^3/12$
- Let. f(x,y) be any point on masonry section.
- The stress due to load w = / = /( )
- Stress due to moment $w.e_x$ (sigma)= (/)*y = $[(w.e_x)/(db^3/12)]*y = (12we_x.y)/(db^3)$ [*M/I= σ/y , bending equation]*
- Stress due to moment $w.e_y$ (sigma)= $(12we_y x)/(bd^3)$
- Hence, total Stress:

$$\sigma = w/(bd)+(12we_x y)/(db^3)+(12we_y x)/(bd^3)$$

$$\therefore \sigma=w/(bd)[1+(12e_x y)/b^2+(12e_y x)/d^2] \quad \text{.............. equation 8.1}$$

For point A, x=d/2 & y=b/2

B, x=d/2 & y=-b/2

C, x=-d/2 & y=-b/2

D, x=-d/2 & y=b/2

- Minimum stress will be at point C.

  i.e. $\sigma_C = \sigma_{min} = \ / \ [1-6 \ _x/ \ - 6 \ _y/ \ ]$ ....equation 8.2

- Maximum stress will be at point A.

  i.e. $\sigma_A = \sigma_{max} = \ / \ [1+6 \ _x/ \ +6 \ _y/ \ ]$ ......equation 8.3

<u>Middle third rule:</u>

- If e_x and e_y are large, the stress at point C becomes negative (i.e. tensile). So it is required to keep e_x and e_y limited for stresses to be compressive always.

- When, σc just becomes zero.

  i.e. $\sigma_c = 0$

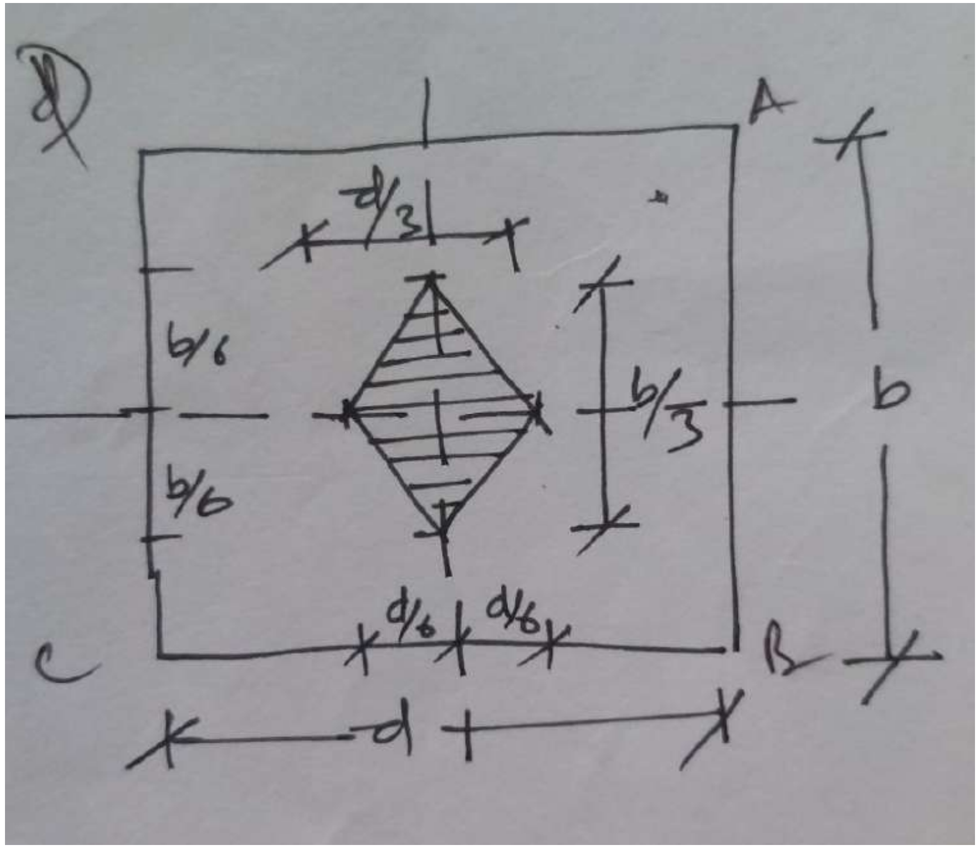
/ [1-*6* x/ - *6* y/]=0

Or, 1-*6* x/ - *6* y/ =0

If e_x=0 then e_y=d/6

If e_y=0 then e_x=b/6

Hence the stress at 'c' does not become tensile so long as the load remains in the shaded area.



<u>Definition of Middle Third rule</u>

For no tension on the section of wall the resultant thrust should be with in the middle third of the axis.

- In some cases cracking of masonry structures may be allowed on the tension face provided that the compressive stress is within the safe limit. The maximum compressive stress may be determined as follows.

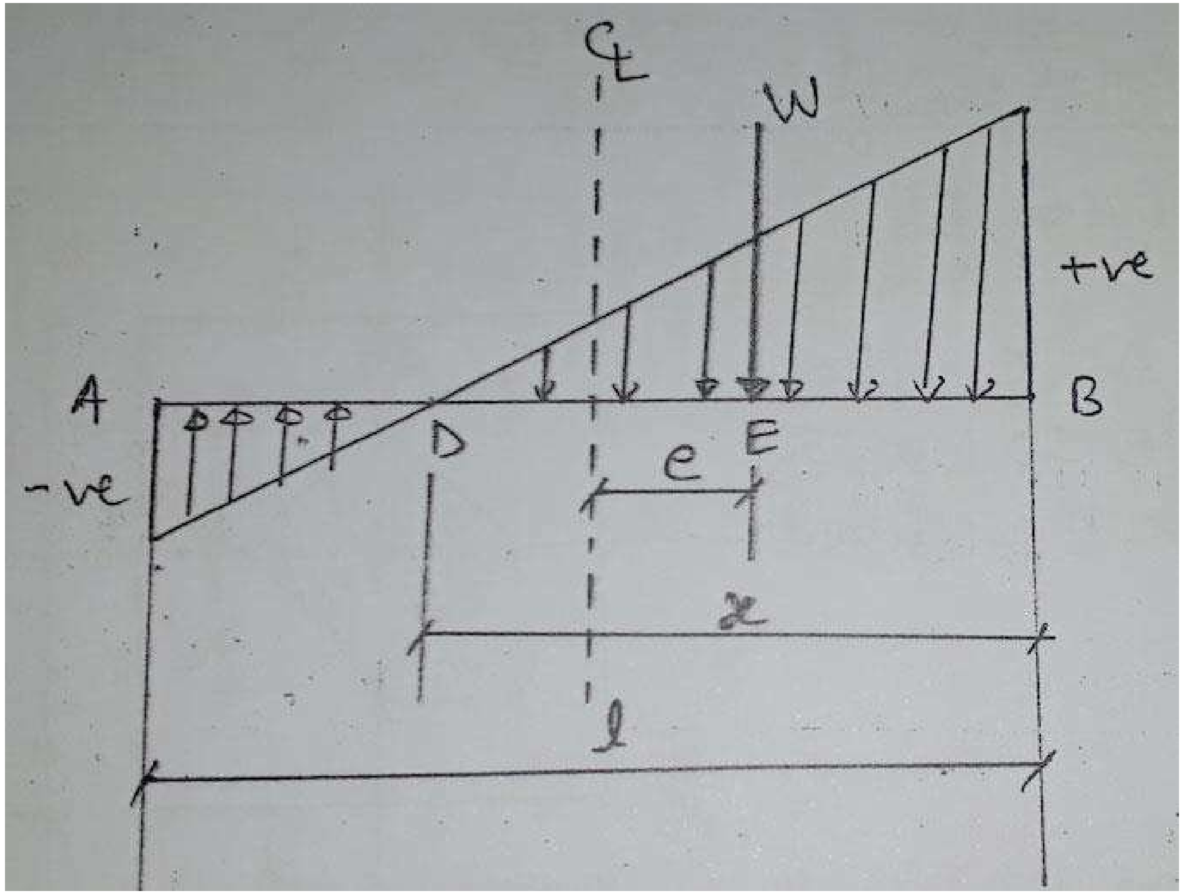


Fig: 8.6

- Since, tension is induced at A, it will crack and reduced width x will remain in contact. Since resultant weight 'w' should lie on the outer third point so that point D should carry zero stress (middle third rule)

$\therefore$ BE = /3 or, x = 3 BE =3(l/2-e)

$\therefore$ x= 3(l/2-e) .... equation 8.4

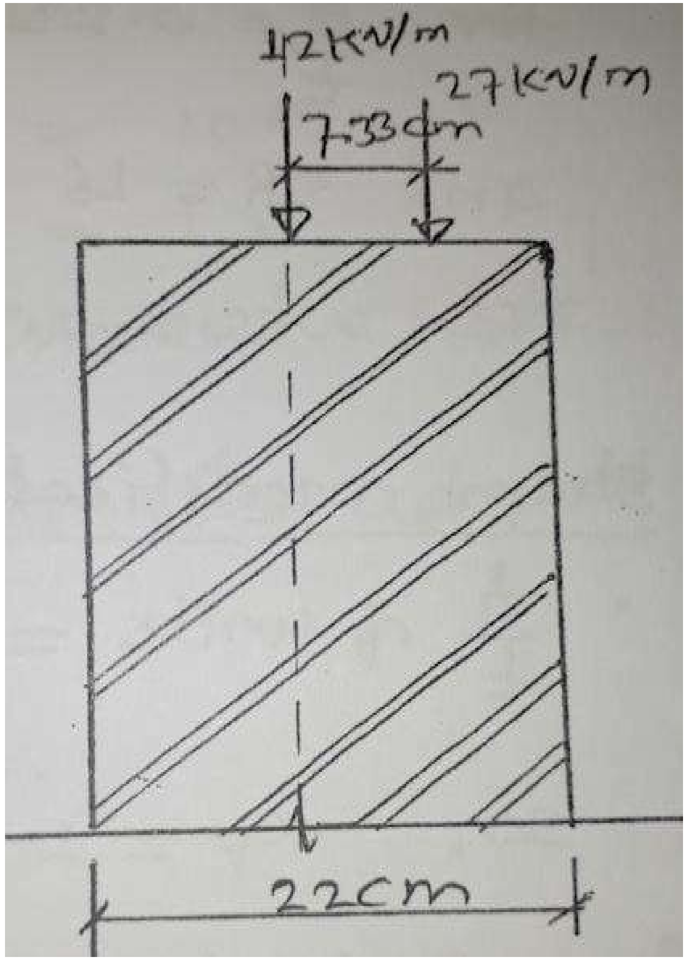
- So, the maximum pressure,

As $(1/2 * \sigma_{max} * x) * b = W$

$\sigma_{max} = 2$ / .... equation 8.5

Example 3:

A brick masonry wall having 22 mm effective thickness carries an axial load of 12kN/m and eccentric load of 27 KN/m acting at a distance of 7.33 cm from the axis of wall as shown in the fig. Design the masonry for the wall if its slenderness ratio is 16. Assume that joint is not raked.



➢Solution:

- Effective thickness (t)= 22 cm = 0.22 m
- Resultant eccentricity

$e= (\ _1 * \ _1 + \ _2 * e_2)/(\ 1 + \ 2) = (12*0+27*0.0733)/(12+27)$

$= 5.07$ cm [weighted average]

Eccentricity Ratio = / $= 5.07/22 = 0.23 > 1/6$

[For no tension case:

e<(t/6)

i.e. (e/t)<(1/6)]

& (1/6)=0.167]

- So there will be tension on one face and thickness of wall supporting the load will get reduced. (Clause 5.4.1.4.(b))
- Thickness of wall in compression.
- x=3(/*2* - e) =3(*22/2* - 5.07) = 17.8 cm
- Maximum compression stress in masonry

$$\sigma_{max} = 2\ \ /(\ \ *1) = 2*(12+27)/0.178 \qquad = 0.44\ N/mm2$$

- Stress reduction factor (ks):

For, / = 0.23 and SR = 16

ks= 0.59 by interpolation (see table 9)

- Shape modification factor (kp):

h/ of units = *55/110* = 0.5 < 0.75

So, kp = 1 from table 10

- Area reduction factor (ka):
- ka = 1 (say) as length wall is not given assuming A > 0.2 m2
- As per clause 5.4.1.4(b), 25% increase in permissible stress is allowed.
- We have,

Permissible stress (fca) = fb*ka*ks*kp*1.25

$\therefore$fb = fca/(ka∗ks∗kp∗1.25) = 0.44/(1*0.59∗1∗1.25) = 0.6 N/mm^2

From tabe-8. It can be seen that,

crushing strength of brick = 7.5 N/mm2

and mortar type = M1

corresponding to basic compressive stress = 0.74 N/mm2

- OR,

Crushing strength of brick = 10 N/mm2

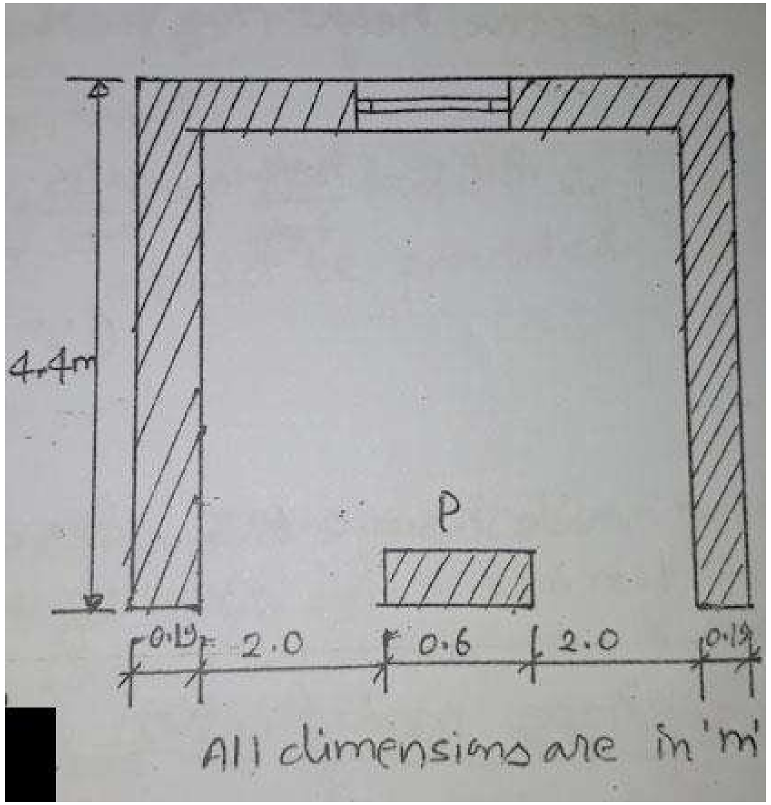
And mortar type = L1

Corresponding to basic compressive stress = 0.67 N/mm2

- Any of above two results can be adopted.

8.2.4 Walls acting as columns:

Example 4:In a car garage walls are 20 cm thick, height of the floors is 3.0 m, plinth is 0.7 m above the foundation footing. Roof is constructed with RCC of 12 cm thick. If masonry elements P in the garage (see fig.) carries a load of 44 kN at the base inclusive of self-load, what should be the strength of bricks and grade of mortar for masonry elements 'P'. Assume that joints are not raked.



Solution:

t= effective thickness wall = 20-1 = 19 cm (10mm sized modular mortar is reduced)

Length of masonry elements (P) = 0.6 m <(4t=4*19 =76 cm)

So by definition it behaves as a column, (see clause 2.3.1)

Load on the wall = 44 kN

Stress on base of wall = / $= 44$ $/(0.19*0.6)$

= 385.96 kN/m2= 0.386 N/mm2

- Area reduction factor (ka):

Area plan 'P' (A) = 0.19*0.6 =0.114 m2< 0.2 m2

∴ ka= 0.7 + 1.5 A =0.7 + 1.5 * 0.114 =0.871

- Stress reduction factor (ks):

Eccentricity (e) = 0

Effective height (heff) = H = 0.7+3.0 + 0.06 = 3.76 m as per clause 4.3.2

∴SR = h_{eff}/ eff =*3.76/0.19* = 19.8 (∴ SR is governed by height and not by lengths in column)

∴ ks = 0.625 from table 9. By interpolation.

- Shape modification factor (kp):

h h / h of modular brick unit=*0.9/0.9* = 1

As crushing strength of unit is Unknown.

Let us assume the brick with crushing strength = 7.5 N/mm2

Then kp = 1.1

∴ Basic compressive stress should be = *0.386/(0.871*0.625*1.1)* = 0.65 N/mm2

From table - 8.

For mortar grade= M1

And crushing strength = 7.5 Mpa

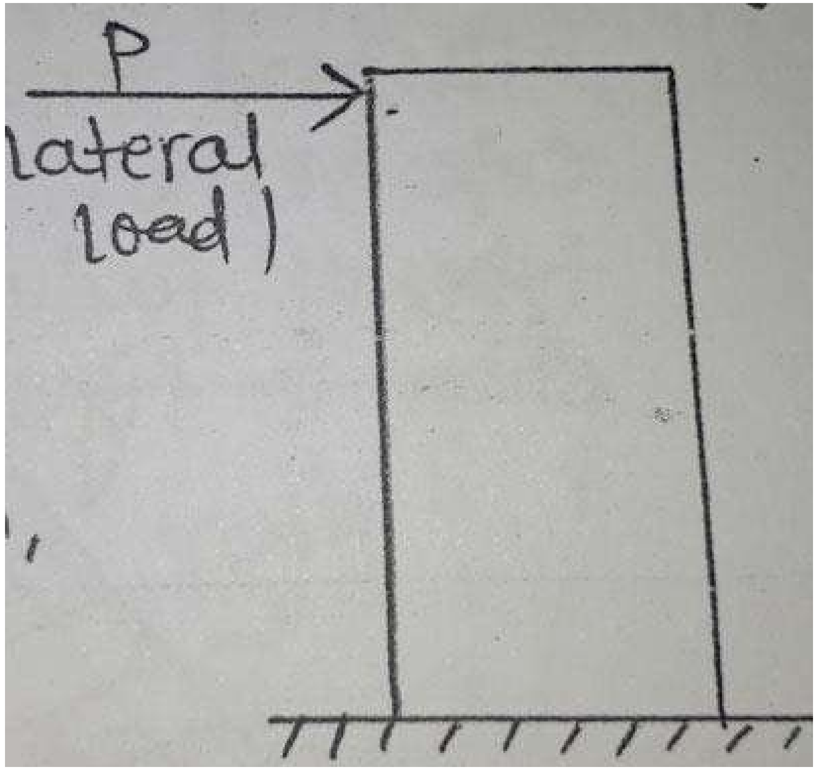
∴ Basic compressive strength = 0.74 > 0.65 N/mm^2

So design is okay.

CHAPTER 9
MASONRY STRUCTURE UNDER LATERAL LOADS

9.1 Performance of masonry structure in lateral loads:

- In general, masonry structure is very good in resisting gravity loads, but don't perform well when subjected to lateral loading, such as seismic loads caused by earthquake. As Indonesia is located in a high risk seismic region, many masonry houses experienced severe damage during past earthquakes that caused many injuries and death. The houses collapsed gradually in brittle failure without ductility.



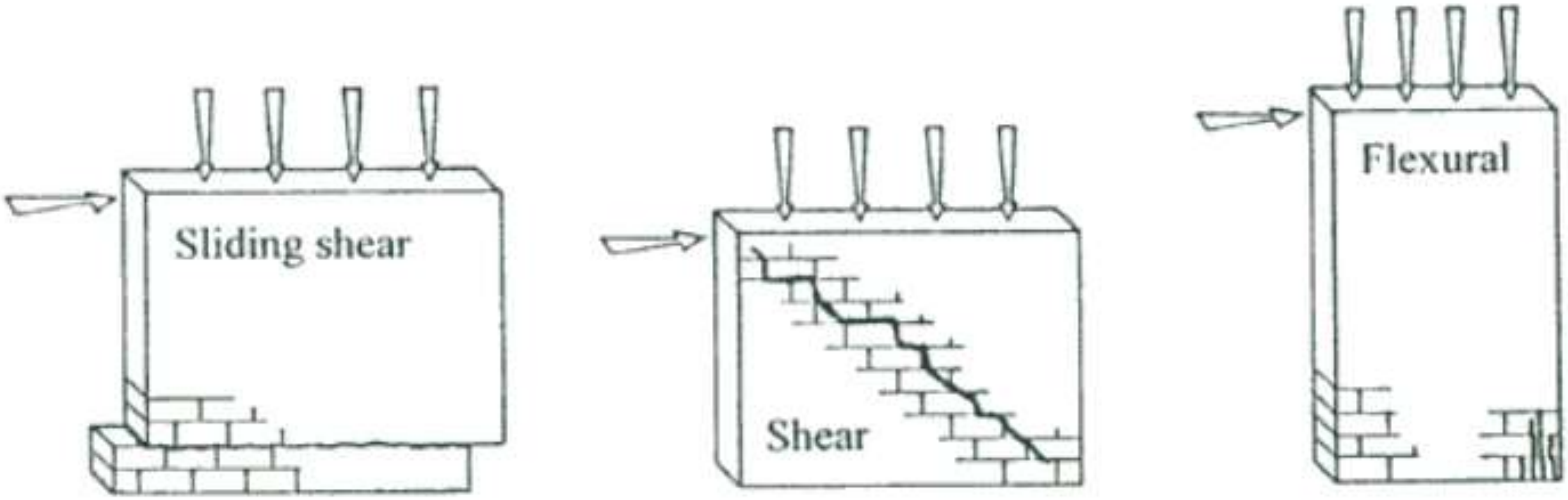
Masonry walls resisting in plane loads usually exhibit the following three modes of failure.

i) Sliding shear: a wall with poor shear strength, loaded predominantly with horizontal loading exhibits this failure mechanism. Aspect ratio for such wall is usually 1:1 or 1:1.5.

ii) Shear: a wall loaded with significant vertical load as well as horizontal forces can fail in the most common mode of failure. Aspect ratio for such walls is usually about 1:1. Shear also occurs for panels with bigger aspect ratio i.e. 2:1, in case of big vertical load.

iii) Bending: This type of failure can occur if walls are with improved shear resistance. For the ratio i.e. 2:1 bending failure can occur due to small vertical loads, rather than high shear. In this mode of failure the masonry panel can rock like a rigid.

Seismic behavior of masonry construction has been very frequently unsatisfactory and it is often unfavorable compared with the performance of steel and concrete structures.



Typical failure modes of unreinforced masonry walls, subjected to in-plane loads: a) Sliding Shear failure; b) Shear failure; c) Flexural failure, with masonry crushing at the corner (Tomaževič 2000)

9.2 Failure behavior of masonry structures in lateral loads:

- Masonry buildings designed and constructed according to requirement of modern seismic codes, behaved adequately. Cases of collapse were rare and were limited to buildings where the requirements of codes, especially those related to the quality of construction, were only partly met. Although the structural behavior of masonry buildings varies in different regions, their damage resulting from earthquakes can be classified in an uniform way. Structural elements, such as walls, columns and beams are only bearing the weight of the building and the live load under normal conditions, mostly compression forces for the walls and columns and vertical bending for the beams. Under dynamic load, they also have to withstand horizontal bending and shear forces and extra vertical compression forces.
- The following typical types of failure behavior of masonry structure are shown in figure below.

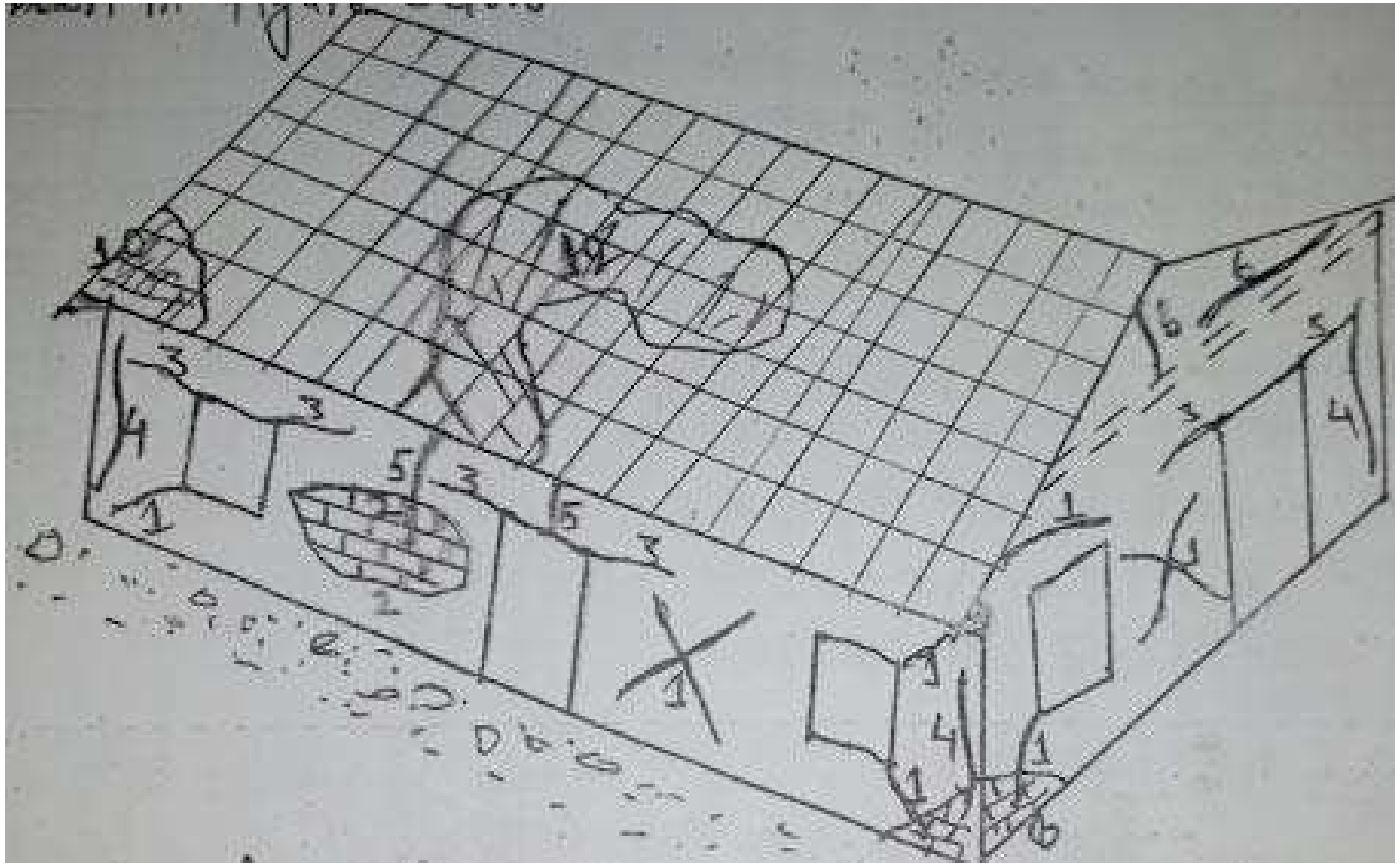
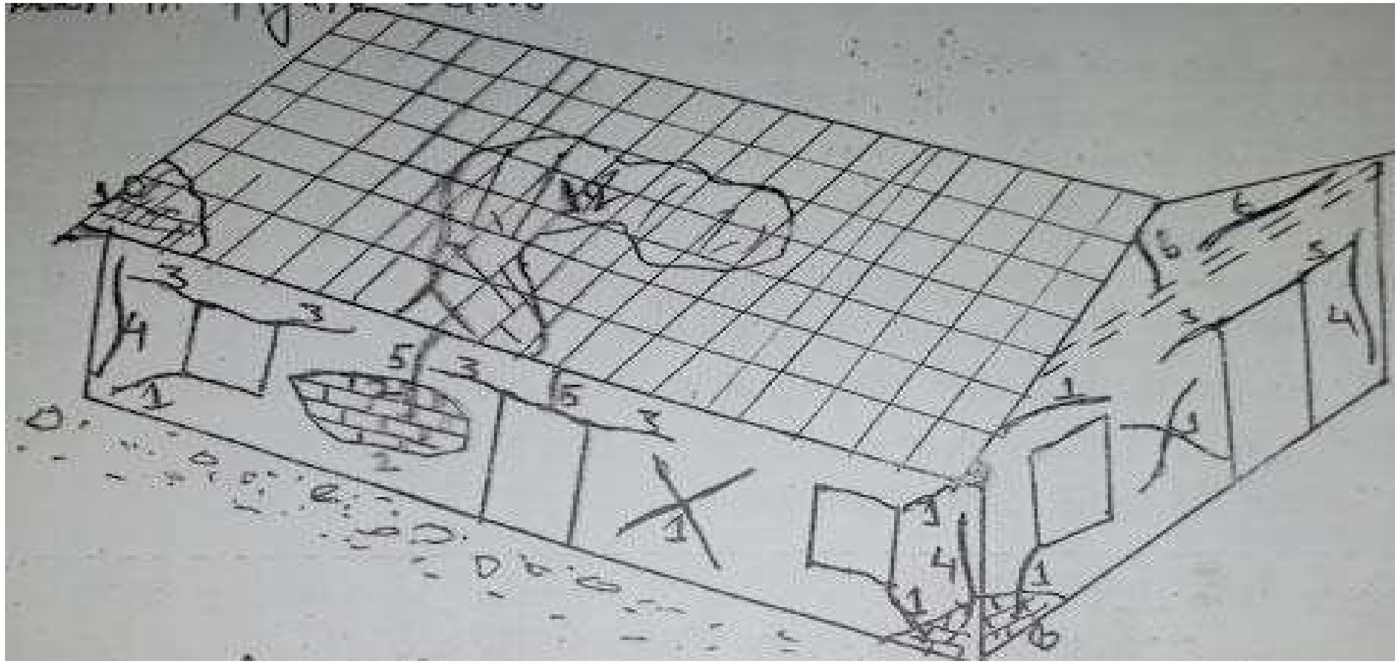


Fig: Typical failure in a masonry structure

1. Diagonal shear cracks
2. Horizontal shear cracks
3. Bending cracks at lintels and feet
4. Bending cracks at corners
5. Bending cracks at spandrel
6. Bending cracks at gable
7. Plaster peeling off
8. Crushing of weak masonry under vertical ground motion
9. Badly anchored roof, pulled out by vertical ground motion
10. Falling of tiles from the roof eave

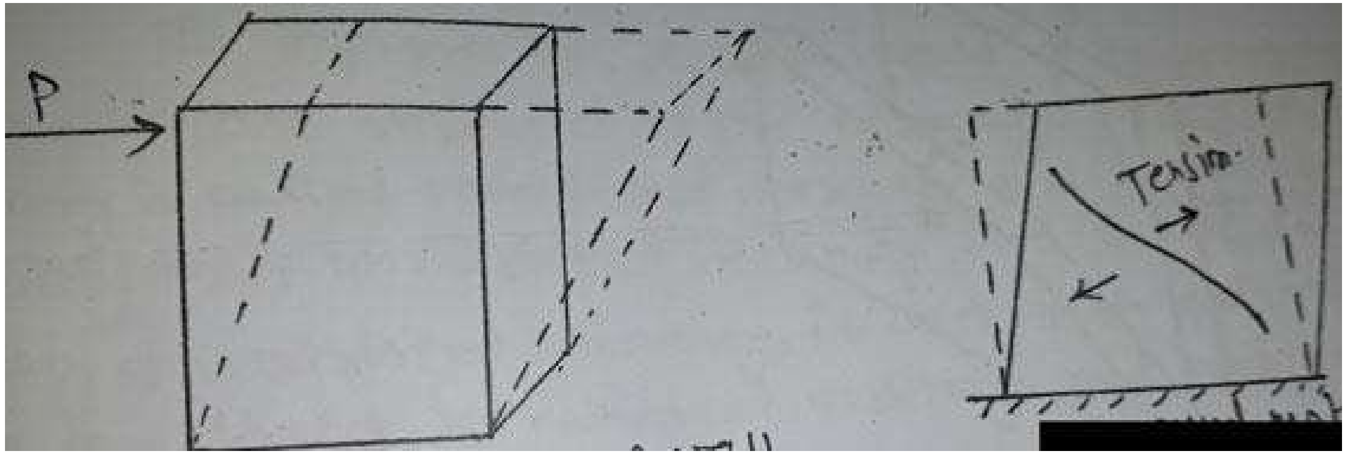


9.3 In-plane and out of plane behavior of masonry structures

- In plane and out of plane behavior of masonry structures also called the failure mechanism of walls.

1. In-plane failure

- The failure which is pushed in the direction of the plane of wall is called In-plane failure.



Pushed in the plane of wall, Ground motion in the wall plane.

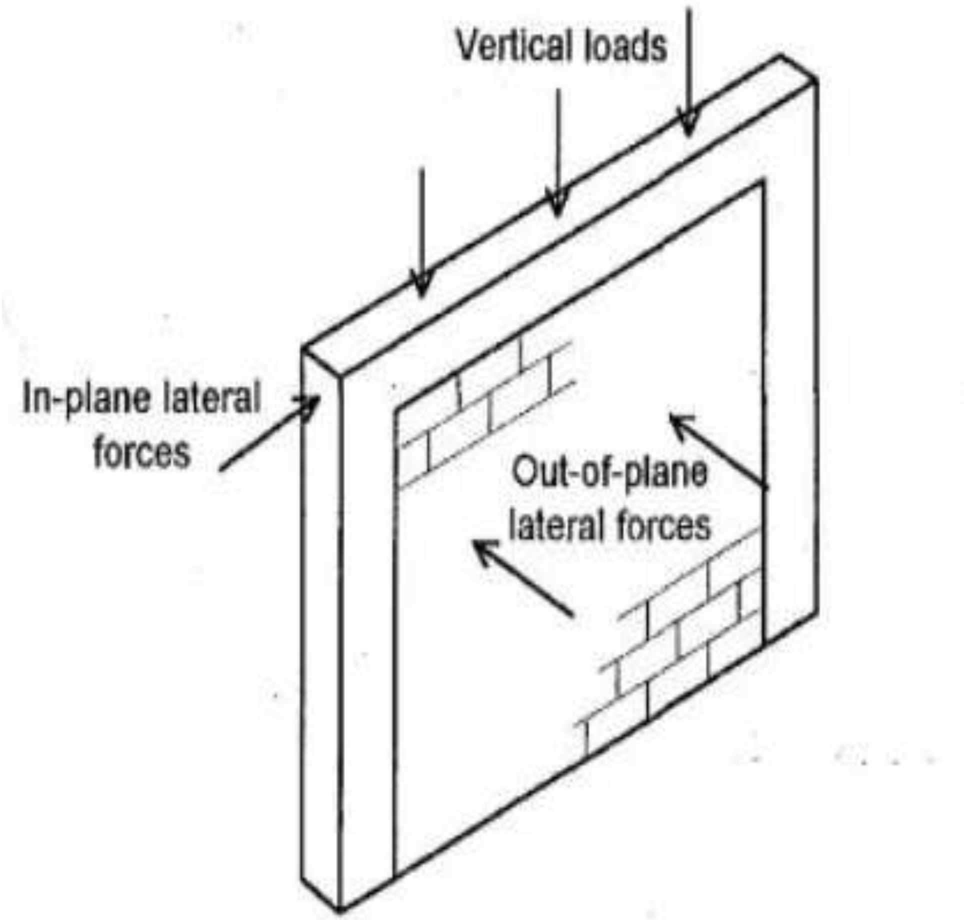
Fig: Failure patterns in plane failure

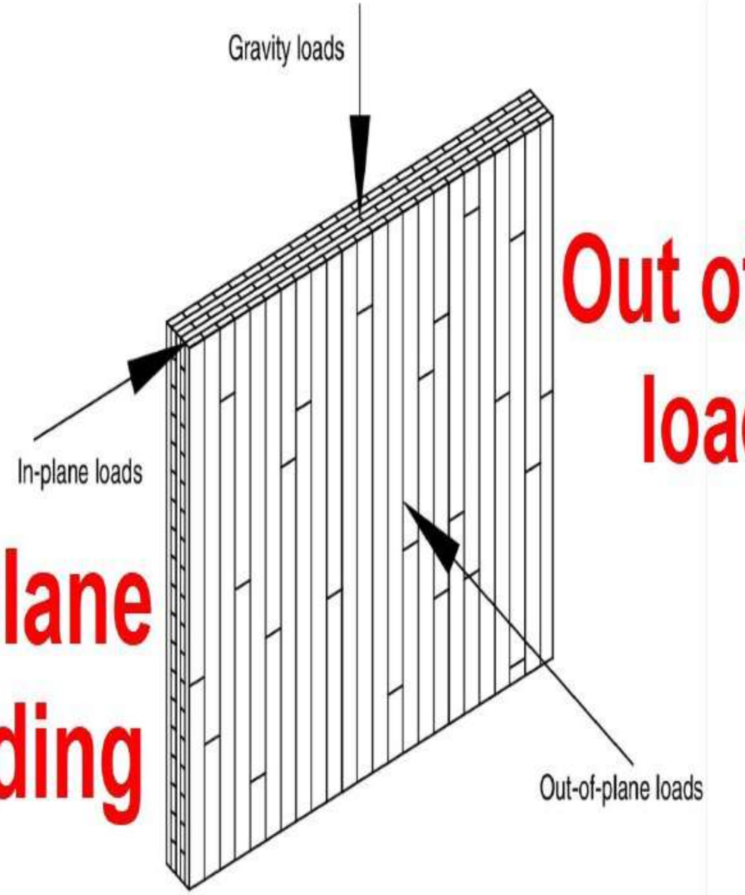
A masonry wall joints with the bed in horizontal direction is supported at the lower side and the upper side loaded in -plane by a horizontal force (P). The failure of wall is caused by combine effect of normal compressive and shear stresses, which is represented by the principal tensile stresses and when it exceeds, the diagonal tensile strength of the masonry failure will take place which is shown in figure above.

2. Out - of plane failure

- The failure, which is pushed in the direction perpendicular to the wall is called out -of plane failure.

Difference between





In plane loading

Out of plane loading

9.4 Ductile behavior of reinforced and unreinforced masonry structures:

- As we know that masonry structures are very weak in tension and strong in compression. This is due to the structure ductile property of masonry. The ductility of masonry structures depends up on the ductility of masonry units properties of mortar. Saying about masonry (unreinforced) these are brittle in nature instead of ductile. Due to this property, unreinforced masonry cannot with stand any tensile and cracks are formed in the portion of tension in masonry. The main cause of in-plane and out-plane failure is also due to the ductility of masonry.
- To improve the ductile nature of masonry, reinforcements are embed in the masonry. This type of masonry is called reinforced masonry and have higher ductility than unreinforced masonry. Due to the ductile property of reinforced masonry, it can resist seismic load more than that of unreinforced masonry and perform well in earthquake. The damage due to in-plane and out-plane failure in reinforced masonry is very little as compared to unreinforced masonry due to the same property the reinforcement in masonry also increases the compressive strength and shear strength and improves the connection between structural walls.

9.5 Calculation of stresses for lateral loads:

When a wall is subjected to a lateral load such as that resulting from wind pressure, bending will occur depending on the lateral supported conditions. In typical construction vertical and horizontal supports are provided by elements such as cross walls and concrete floors or roofs respectively.

Consider a wall with a uniformly distributed force 'P' applied at each end along the center line in one axis. This force is caused by self-weight of wall and other external loading and applies uniform compressive stress across the section.

Compressive stress due to load 'P' = $\frac{P}{A}$ —— (9.1)

Where,

A = cross-section area of wall.

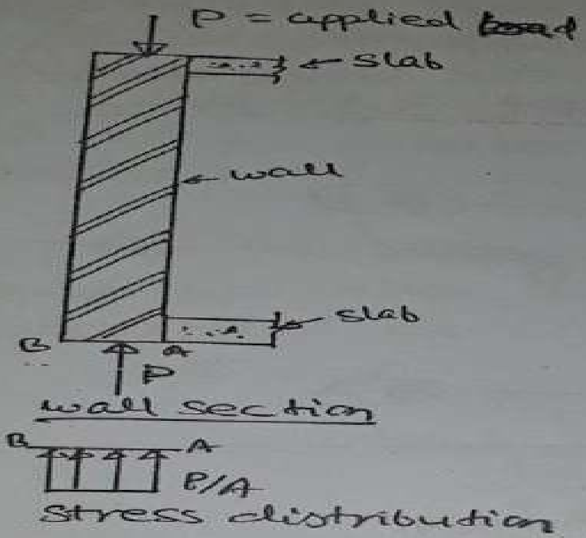


Fig. 9.6 (a). wall subjected to pre-compression

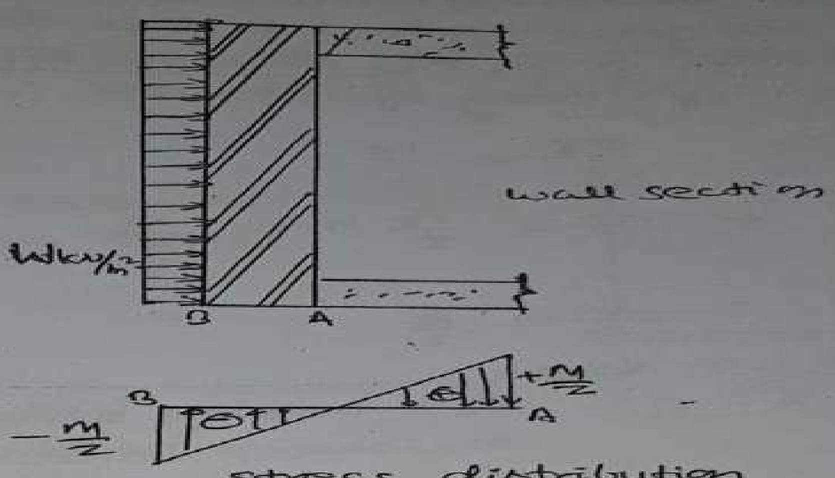


Fig 9.6 (b) : wall subjected to lateral load

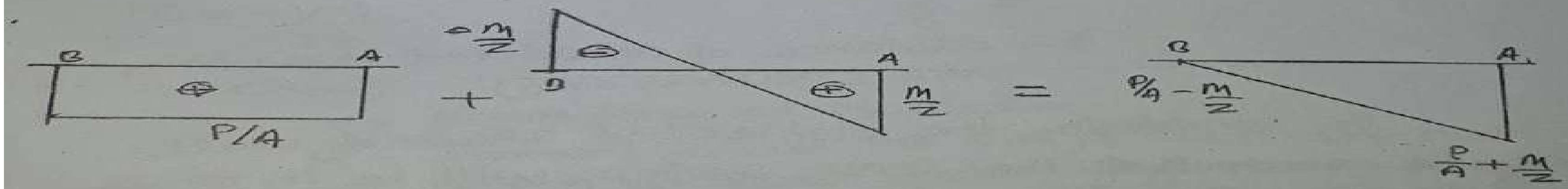


Fig. 9.7. simplified stress diagram for pre-compression and lateral loading.

- The stress distributed is theoretically uniform throughout but depends on the uniformity of the masonry and the mortar.
- Subsequently, consider a lateral load 'w' kN/m2 applied to the section of wall and the corresponding bending moments diagram applied to this alone. The stress distribution from the flexure of wall is calculated from equation of theory of flexure.

i.e. $\sigma_b/ \quad = \quad //$ … … … … … … … … … … … … … equation 9.2

or, $\sigma_b = (\quad / \ ) y = \quad /(\ / \ )$

$\therefore \ \sigma_b = \quad /$ … … … … … … … … … … … … … ..equation 9.3

- Where,

σ_b = bending stress

M = maximum bending moment

I = moment of intertia about the length of wall.

z = section modulus

= /

y = distance of considered layer from N.A (Neutral axis)

- By considering the deflected shape of wall, it can be seen that the inner surface will be in tension and a corresponding stress diagram can be drawn. The simplified stress diagrams for the masonry wall indicate that tension is theoretically eliminated when combining the stress distributions from pre-compression with those from the out plane loading (see fig 9.7).
- A wall restrained from the top and bottom only will fail by cracking on tension side following minor deflections when subjected to lateral loads. Explained in simple terms, the loaded wall will be in compression on the side of the loading and in tension on the other face. Hence cracks will develop on the tensile side with a minor load. To prevent cracking on tension face, the tensile stresses should be greater the applied pre-compression stresses.
- For the loading as shown in fig. 9.8 shear stress can be calculated as:

Shear stress τ=P/(L*t)

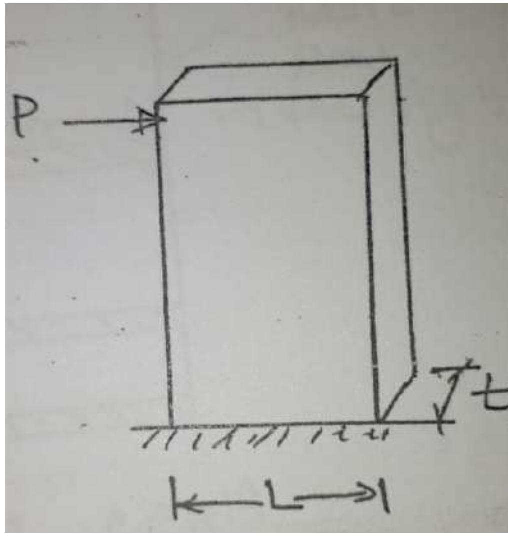


Fig: 9.8

For combined loading system the shear stress is can be calculated as

- $\tau =$ /
- Where

V = shear force at the section

Q = moment about the N.A of section of that portion of cross-section

I = moment of internal about N.A.

b = width of section, (for detail see theory of flexure in any book of theory of structure).

Design of Transversely Loaded wall

Design a exterior wall of a single storey ware house of 4m height. The vertical load on the wall is 30KN/m and wind pressure is 1000KN/m^2. The wall is fixed at the bottom and supported by slab at the top.

Solution:

Let the thickness of the wall=230mm

Loading on the wall

Load from the roof =30KN/m

Self weight of the wall=0.23*4*20=18.40KN/m

Total vertical load ‘P’=30+18.4=48.4KN/m

Bending moment due to wind pressure (Considering as propped cantilever) will be maximum at the bottom and its value =PH^2/8

Therefore Moment =M=1000*4^2/8=2000Nm/m=2000000N-mm/m

Sectional Properties:

Area of the cross-section A=230*1000=230000mm^2/m

Section Modulus: Z=bt^2/6=1000*230^2/6=8816667.7mm^3/m

Compressive stress under axial load and Bending Sigma=P/A+M/Z

=48.4*1000/230000+2000000/881666.7=0.437Mpa

Calculation of Permissible Stress:

Effective height =heff=0.85*H=0.85*4=3.4m

Effective thickness=actual Thickness=230mm

Slenderness ratio, SR=3400/230=14.78

Equivalent Eccentricity=e=M/p=2000000/484000=41.32mm

e/t=41.32/230=0.18

Stress reduction factor Ks=0.64

Area reduction factor Let A>0.2m^2

Ka=1

Shape modification factor Kp, Let height of Brick/ Width of brick=55/110=0.5

Select the brick unit strength =10Mpa

Kp=1

Basic Compressive strength ‘fb’for brick unit of strength 10 Mpa and Mortar Type M2=0.81N/mm^2

Hence,

Permissible stress under axial and Bending Moment =1.25*fc*Ks*Ka*Kp

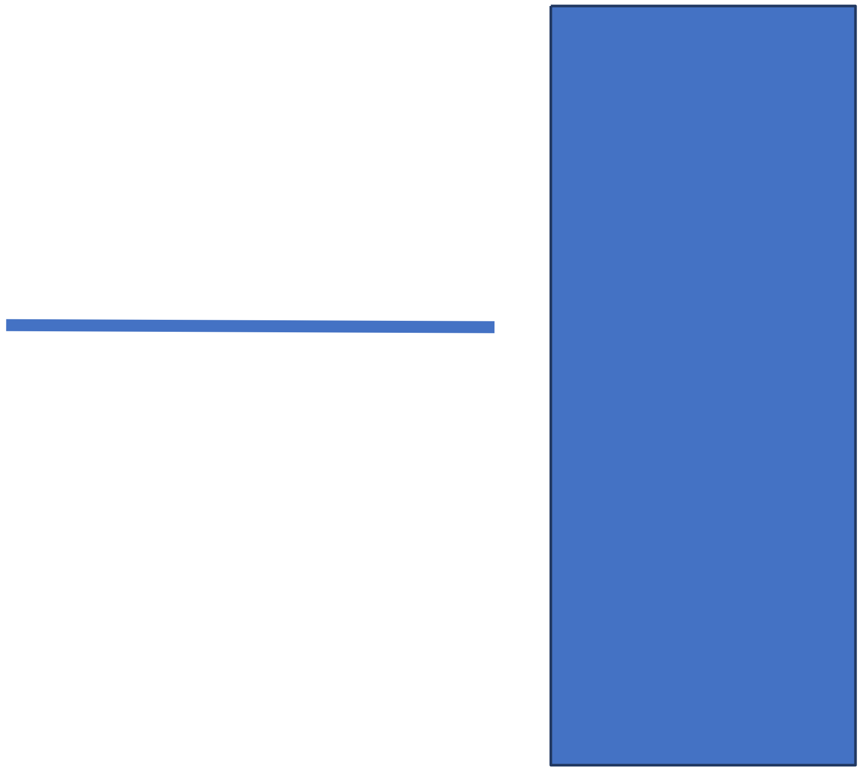
=1.25*0.81*0.64*1*1

=0.648Mpa> 0.437

Hence design okay

Design of Laterally Loaded Wall (shear wall)

Design a wall of 5m long and 4m Height to resists the horizontal seismic force in its plane. Assume the seismic load to be uniformly distributed across the height of the wall. Earthquake acceleration =0.1g. The wall is fixed at the base and free at the Top.



9.6 Elements of lateral load resisting masonry system:

- The elements of masonry structure resisting lateral load are listed below:

i> Tie beam

ii> Sill band

iii> Lintel band

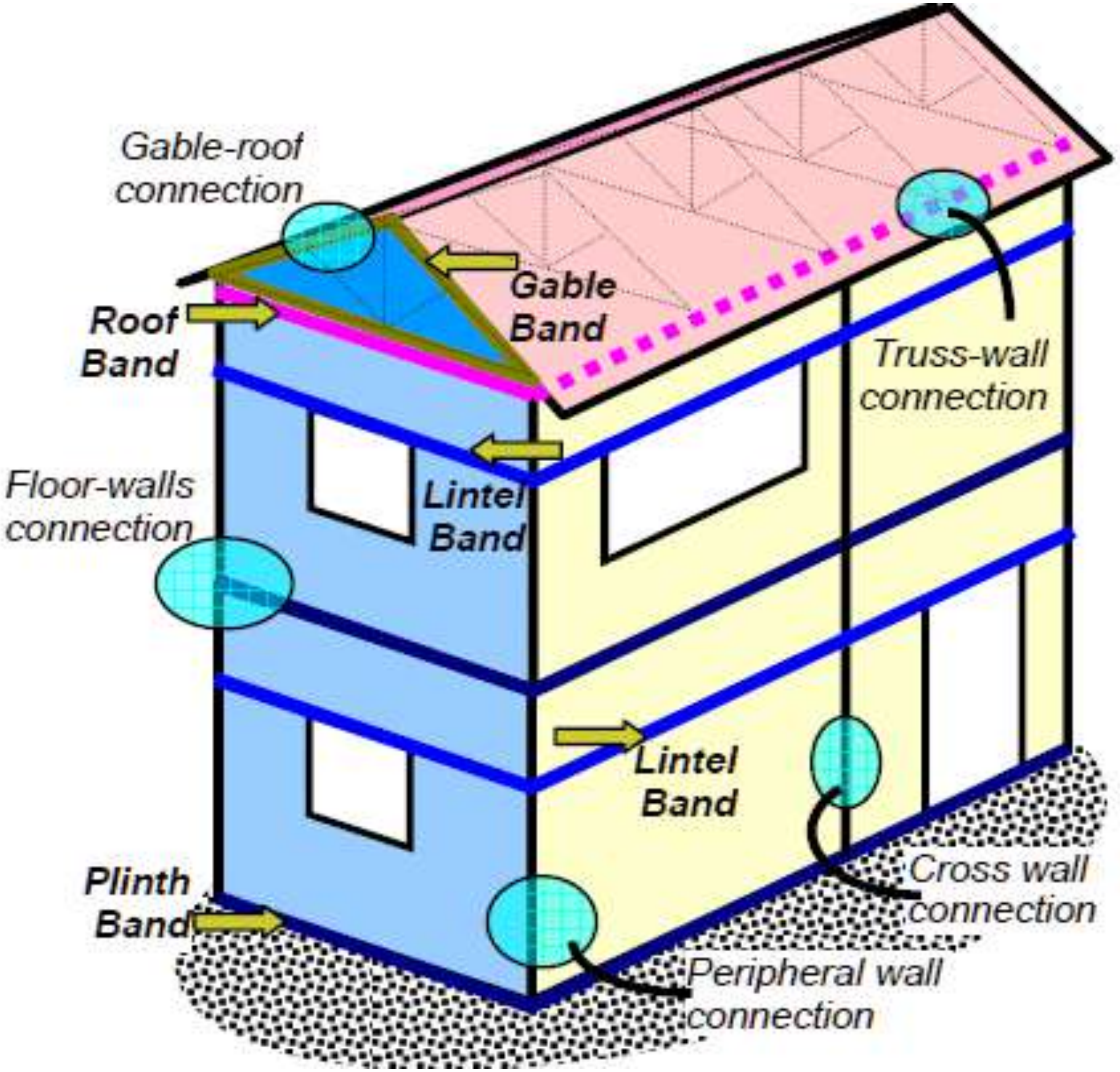
iv> Roof band

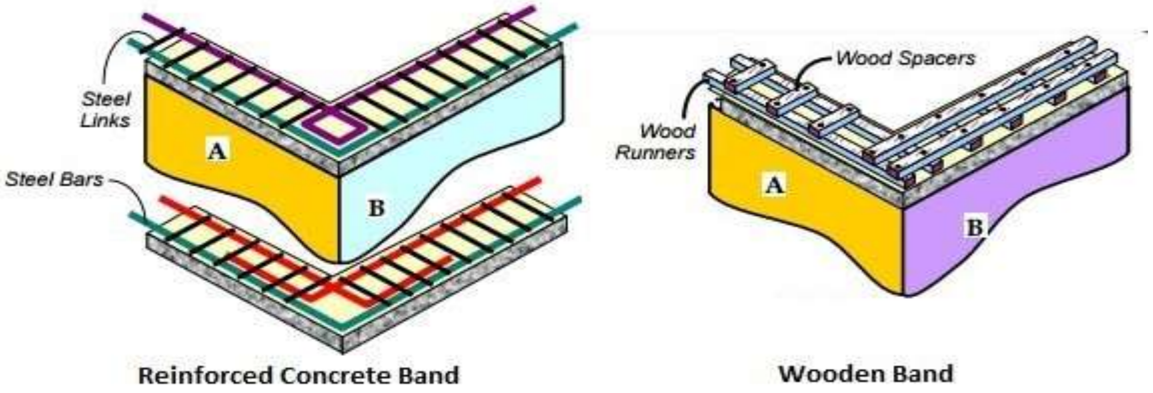
v> Gable band

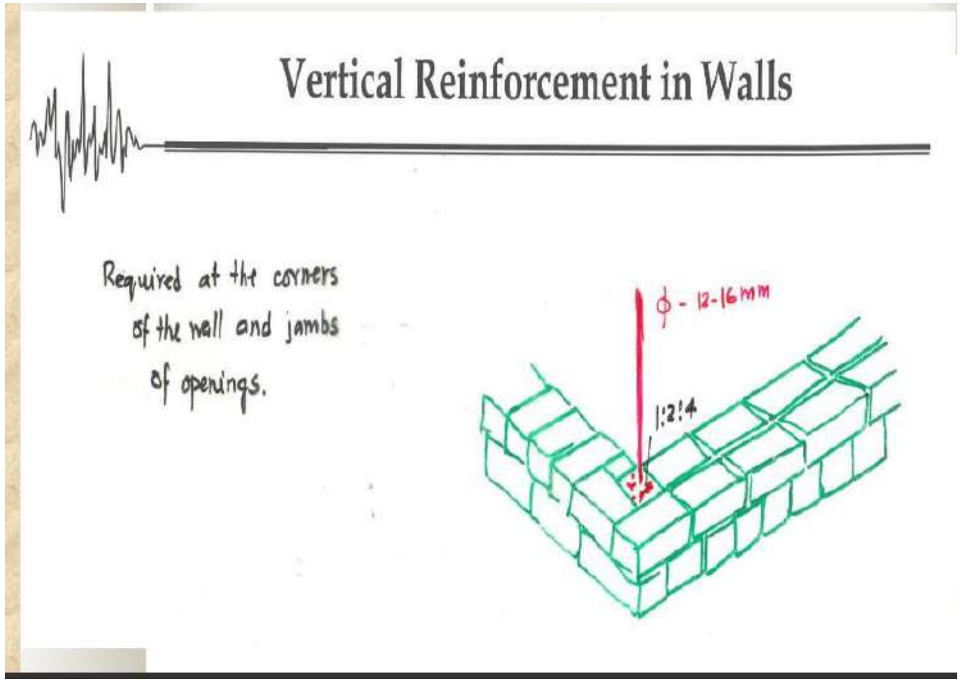
vi> Anchorage with walls

vii> Shear wall

viii> Anchorage between slabs and wall etc.


Gable-roof connection
Gable Band
Roof Band
Truss-wall connection
Floor-walls connection
Lintel Band
Lintel Band
Plinth Band
Cross wall connection
Peripheral wall connection


Steel Links
Steel Bars
A
B
Wood Spacers
Wood Runners
A
B
Reinforced Concrete Band
Wooden Band


Vertical Reinforcement in Walls
Required at the corners of the wall and jambs of openings.
ϕ - 12-16 mm
1:2:4

Testing of masonry elements

Chapter 10

10.1 Compressive strength of bricks and walls:

- Compressive strength of brick is an important material property for structural applications.
- In general, increasing the compressive strength of unit will increase the masonry assemblage compressive strength and elastic modulus.
- The compressive strength of bricks depends upon the type of soil (material) used and method of manufacturing and uniformity of brick.
- The factors governing the strength of a brick structure (walls) includes compressive strength of brick unit, mortar strength and elasticity, brick layer (i.e. type of bond used).
- The compressive strength of individual bricks or wall is tested in lab by using compression testing machine or universal testing machine. To test the compressive strength of brick or wall, samples should be prepared.

- Sampling:

1. **Brick**

- Remove unevenness observed in the bed faces to provide two smooth parallel faces by grinding.
- Immerse in water at room temperature for 24 hours.
- Remove the specimen and drain out any surplus moisture at room temperature.
- Fill the frog and all voids in the bed faces flush with cement mortar (1 cement : 1 clean course sand of grade 3 mm and down)
- Store it under the damp jute bags for 24 hours followed by immersion in clean water for 3 days. Remove and wipe out any traces of moisture.
- Now specimen is ready to test.

2. Wall

- Prepare the walls (at least 3 in number) with a specific bond.
- Finish the top and bottom of the wall by placing mortar in the frogs and gaps.
- If cement mortar is used cover the wall with jute bags for 24 hours and cured by clean water for 3 days.
- Remove the jute bags after and wipe out any traces of moisture and specimen is ready now.

• Procedure:

- Place the specimen with flat faces between the plates of testing machine.
- Apply load axially at a uniform rate of 140 kg/cm2 per minute till failure occurs and note down the maximum load at failure.
- The load at failure is maximum load at which the specimen fails to produce any further increase in the indicator reading on the testing machine.

- Calculation:
- Compressive strength = /

- Contact area should be calculated by measuring length and breadth of brick and length and thickness of wall, before testing the specimen.

∴ Compressive strength = / (= N/mm2 or kg/cm2)

- The average of compressive strength

  of samples tested will be the required compressive strength.

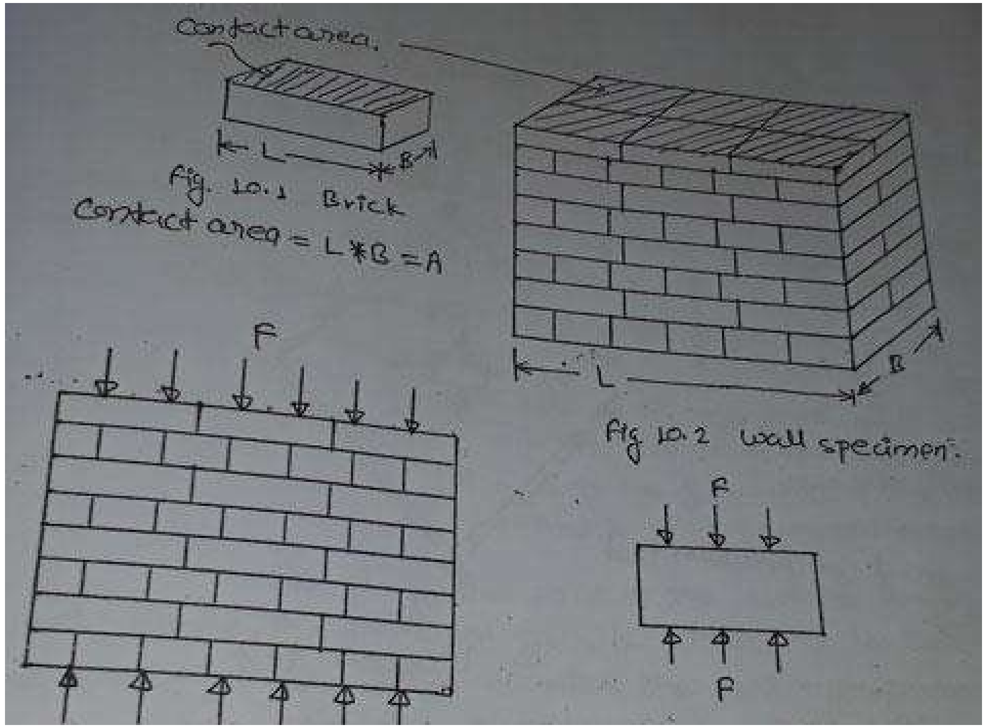


Fig: 10.3 loading sample specimen

10.2 Diagonal shear test

- The failure of walls during earthquake is caused by combined effect of normal compressive and shear stresses, which is represented by the principal tensile stress and when it exceeds the diagonal tensile strength of the masonry, failure will take place.
- The diagonal shear test is based on subjecting a 1.2 m *1.2 m square section of wall by the thickness of the wall type to diagonal compression through loading shoes at two diagonally opposite corners of the specimen as shown in fig. 10.4 (a).
- The failure mode of the test is through formation of diagonal crack parallel to the line of action of the compression force.

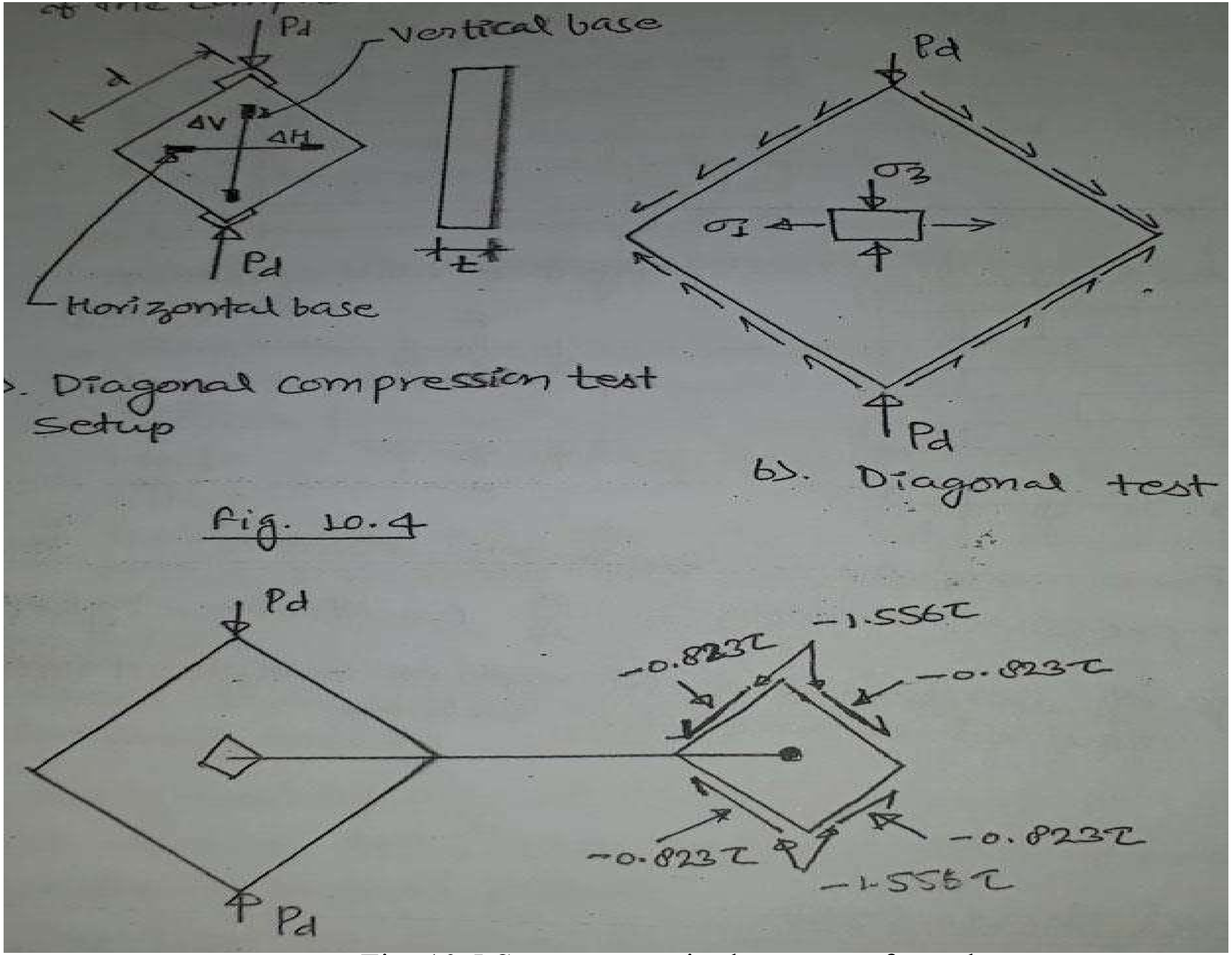


Fig: 10.5 State stresses in the center of panel.

Procedure is Based on ASTM E519

- Shear stress for the specimen on the basis of net area. Calculate the shear stress of the specimen as follow.
- $\tau = 0.707*P/$ ---------------------equation 10.1
- Where, Pd = applied load (N)
- A = Net area of the specimen mm^2. Calculated as follow

  $An=(w+h)* t*n /2$
- Where,

  w= Width of specimen in mm

  h= Height of specimen in mm

  t = total thickness of specimen in mm

  n = % of the gross area of the unit that is solid, expressed in a decimal

Shear strain is given as follow

$=(\Delta \quad +\Delta \quad)/$

And Modulus of Rigidity is calculated as follow.

$G = \tau/$

Where,

- G = modulus of rigidity, Mpa
- τ = Diagonal shear stress
- = shear strain calculated $=(\Delta \quad +\Delta \quad)/$
- Δ = vertical shortening (mm)
- Δ = Horizontal shortening (mm)
- g = vertical gauge length (mm) (Δ must be based on the same gauge as for Δ)

10.3 Non-destructive tests - Elastic wave tomography, flat jack, push shear test and others

- Non-destructive test is the test used to determine the strength of the specimen(masonry) without failure of the specimen (i.e. without destruction of specimen).
- There are so many types of Non-destructive tests available to test masonry.

1. Elastic wave tomography
2. Flat jack test
3. Push shear test
4. Impact echo test
5. Ultrasonic pulse velocity test
6. Schmidt hammer/ rebound hammer test, etc.

1. Elastic wave tomography:

- Elastic wave tomography is a non-destruction testing technique for masonry or concrete or other material.
- This technique is used for locating shallow delamination, cracks and voids.
- Elastic wave tomography is based on two basic principals from heat transfer: conduction and radiation.
- Sound materials with no voids, gaps or cracks are more thermally conductive than materials that are delaminated or contain moisture.

2. Flat Jack test:

- Flat jack testing is a non-destructive, versatile and powerful technique of testing existing masonry structures that provides significant information on mechanical properties of historical construction (masonry).

- Flat jack testing is direct and in-situ testing method that requires only removal of a portion of mortar form the bed joints. So it is considered non-destructive because the damage is temporary and is easily repaired after testing.

- Description of flat jack:

- Flat jack is a "thin envelope-like bladder with inlet and outlet ports which may be pressured with hydraulic oil". Some typical configurations are shown in fig.
- Flat jack may be manufactured in many shapes and sizes. The actual dimensions are determined by its function, slot preparation technique and properties of the masonry being tested.
- Flat jacks with curved edges are designed to fit in a slot cut by a circular saw.
- Rectangular jacks (type a,b) are used where mortar must be removed by hand or with stitch drilling.

- An ideal flat jack will completely fill the slot in the mortar joint. However, if such flat-jack is not available, then shims are used together with the flat jack to completely fill the slot thickness.

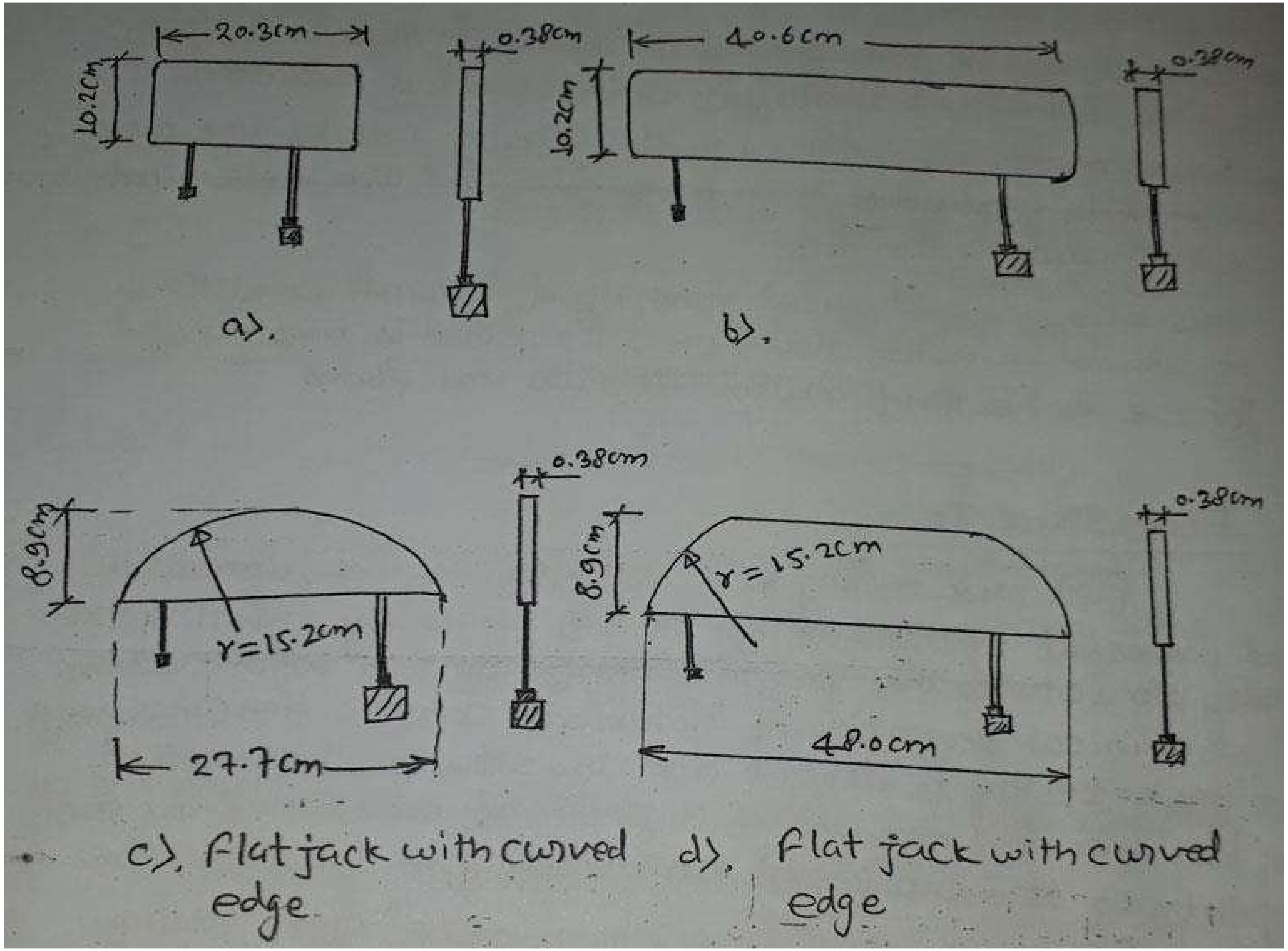


Fig.: Different flat jack configurations

- There are basically two types of flat jack tests:

1. In-situ stress test (single flat-jack test)
2. In-situ deformability test (two flat-jack test)

1. In-situ stress test (single flat-jack test)

- The simple flat jack test allows determining the level of stress installed at a given point of structure.
- This test is based on the principal of partial stress release and involves the local elimination of stresses followed by controlled stresses compensation (see fig 10.7)
- The reference field of displacements is first determined by measuring distances between the gauge points fixed to the surface of the masonry (distance di in fig 10.7 (b).
- Then a slot is cut in a plane normal to the direction of measured stresses.
- Distance between gauge points decreases (i.e. distance d in fig 10.7 (c) is less then di) cutting the slot causes partial stress relief in masonry above and below.

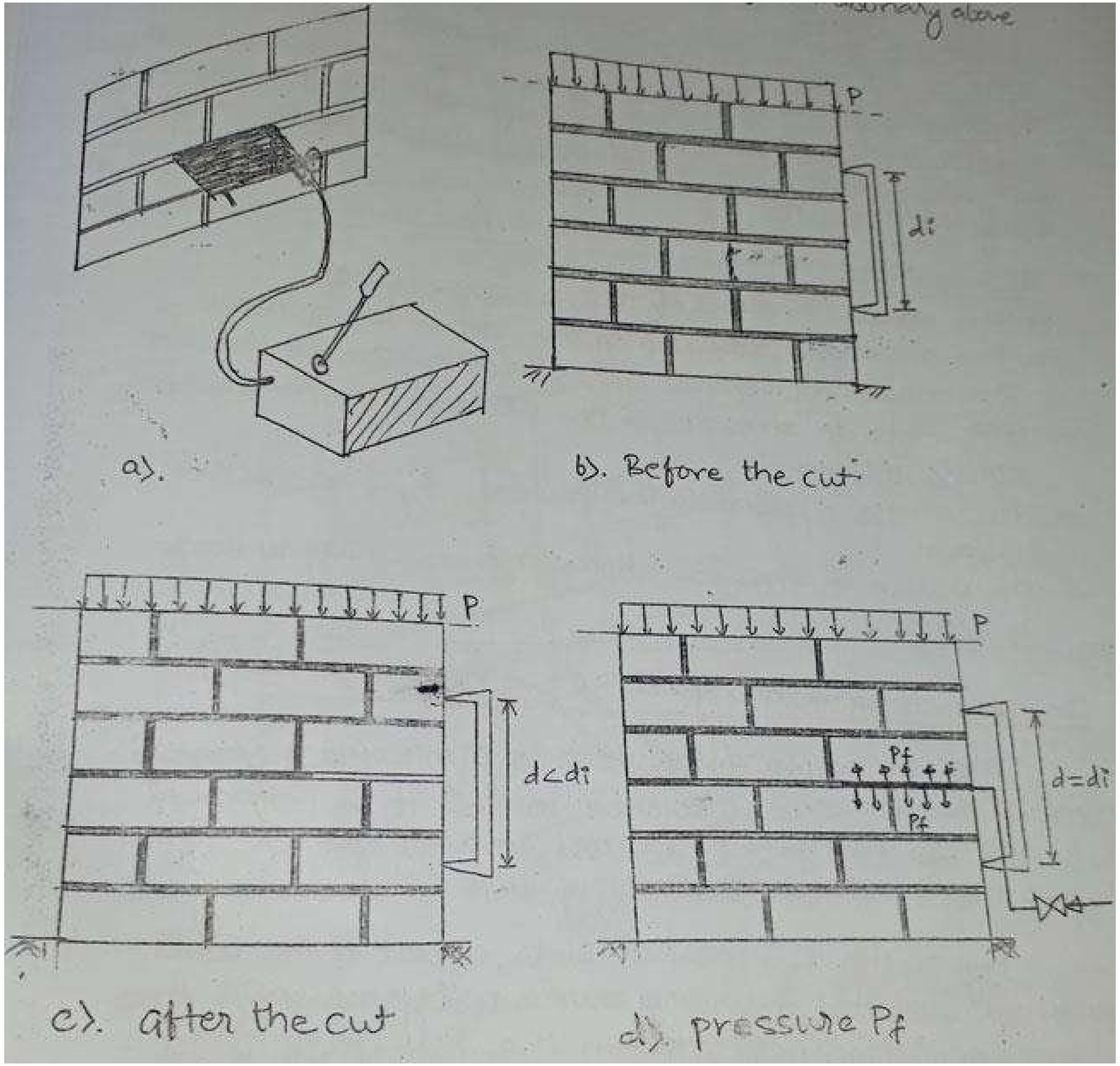


Fig: 10.7 Phases of Flat-jack test ($p=p_f$ when $d=d_i$)

- Afterwards, a thin flat jack is introduced into the slot. With the aid of this device, pressure is applied to the masonry.
- This causes a partial restoration of the initial displacement field; the displacement some point reach previously measured value (see fig.10.7 (d).
- The necessary pressure pf (called cancelling pressure) can be related to the compressive stress in the direction normal to the slot.

• Assumptions:

- The stress in place of test is compressive.
- The masonry surrounding the slot is homogeneous.
- The masonry deforms symmetrically around the slot.
- The state of stresses in the place of the measurement is uniform.
- The stress applied to the masonry by flat-jack is uniform.
- The value of stresses allows the masonry to work in elastic regime

2. In-situ deformability test (two flat-jack test)

- The principal of the test is similar to a standard compressive test. The difference is that it is performed in-situ and two flat jacks are used to apply load. A typical set up of the in-situ deformability test is shown is fig. 10.8.
- By cutting two parallel slots, a part of the wall is isolated from the surrounding masonry forming a "specimen".
- Masonry between the flat-jack is assumed to be unstressed. The flat jacks are assumed to be unstressed.
- The flat jacks are then introduced into both slots and the initial distance between gauge points are measured

- By pressurizing flat-jacks through hydraulic pump the load is applied to the specimen creating an approximately uniaxial state of compressive stress.
- With the pressure increase in the flat jacks, the distance between gauge point pairs decrease.
- By gradually increasing the pressure, the stress-strain relationship can be determined. Loading and unloading cycles can also be performed.
- Based on experimental stress-strain curve, the value of Young's modulus of elasticity can be calculated.
- If extended damage in the specimen is acceptable, the compressive strength of masonry can be obtained.
- During testing, the load-displacement diagram is monitored and when it becomes highly non-linear (indicating imminent failure) loading is usually terminated.

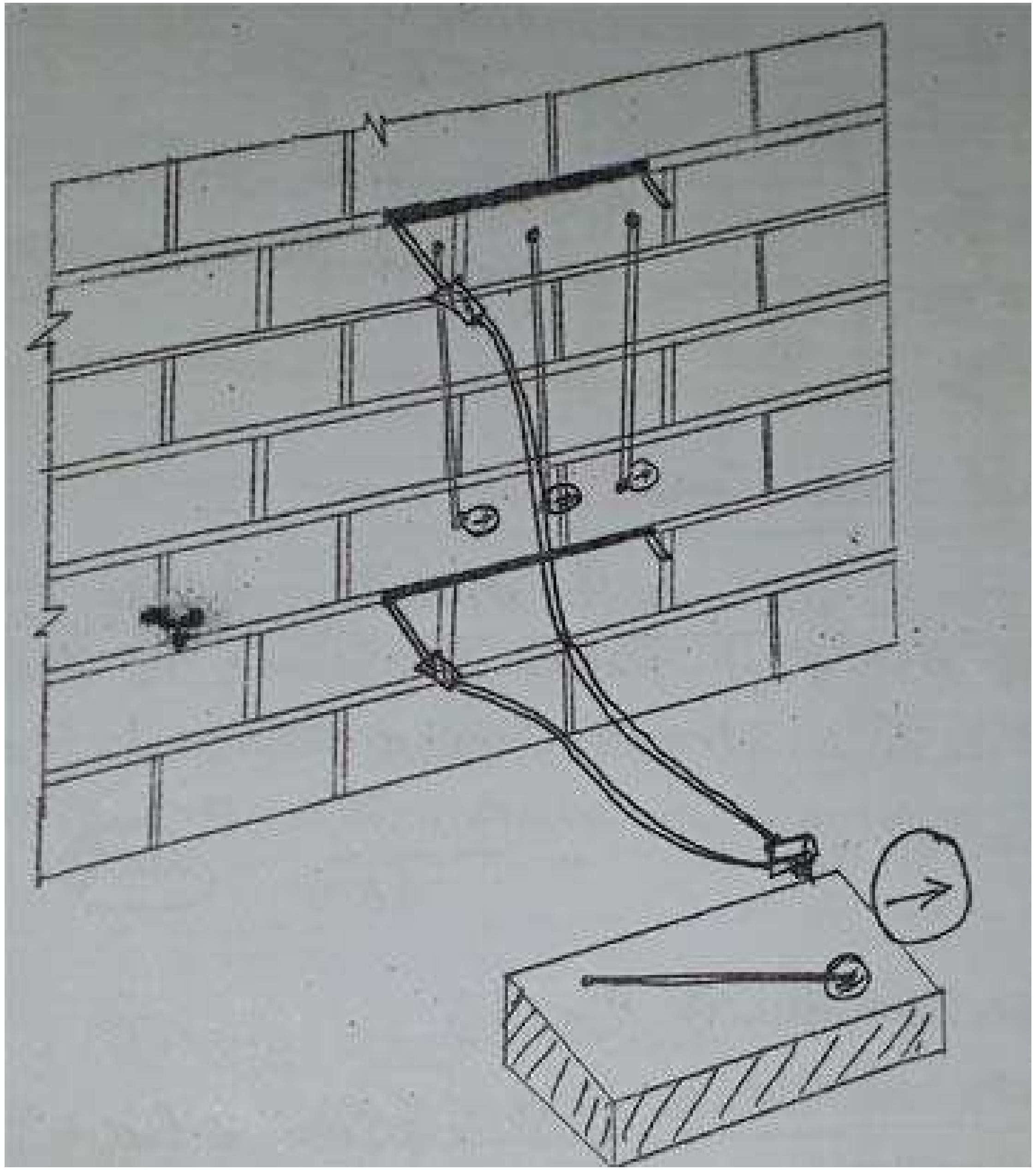


Fig: 10.8 typical set-ups for in-situ deformability

- Assumptions:

- Masonry structures surrounding the slot are homogeneous.
- The stress applied to the masonry by flat-jack is uniform and the state of stress in test specimen is uniaxial i.e. a lateral constraining effects of adjacent masonry can be neglected.
-

- Interpretation of test results:

- For both the stress and deformability tests it is necessary to convert the flat-jack pressure to the actual compressive stress. The stress can be calculated by

σm = kmkaÞ

where,

σm= Stress (in-situ)

km = calibration factor of Jack (<1)

ka = – / . = (<1)

Þ = flat-jack pressure

3. Push shear test

- Push shear test is minimally destructive technique that is used for in-situ measurement of masonry mortar joint strength index.
- This test uses a calibrated hydraulic ram and pressure gauge to measure the actual shear strength of a traditional brick wall, and thus its seismic resistance.
- A single brick beside the brick being tested is removed to accommodate the hydraulic ram(and is replaced in the wall after completion of test).
- This test is suitable for masonry that has relatively strong units and weak mortar so that shear cracks form in the typical stair step pattern along mortar joints and the units remain un-cracked.
- In this type of construction, the shear strength of mortar joints limits the shear strength of masonry wall.

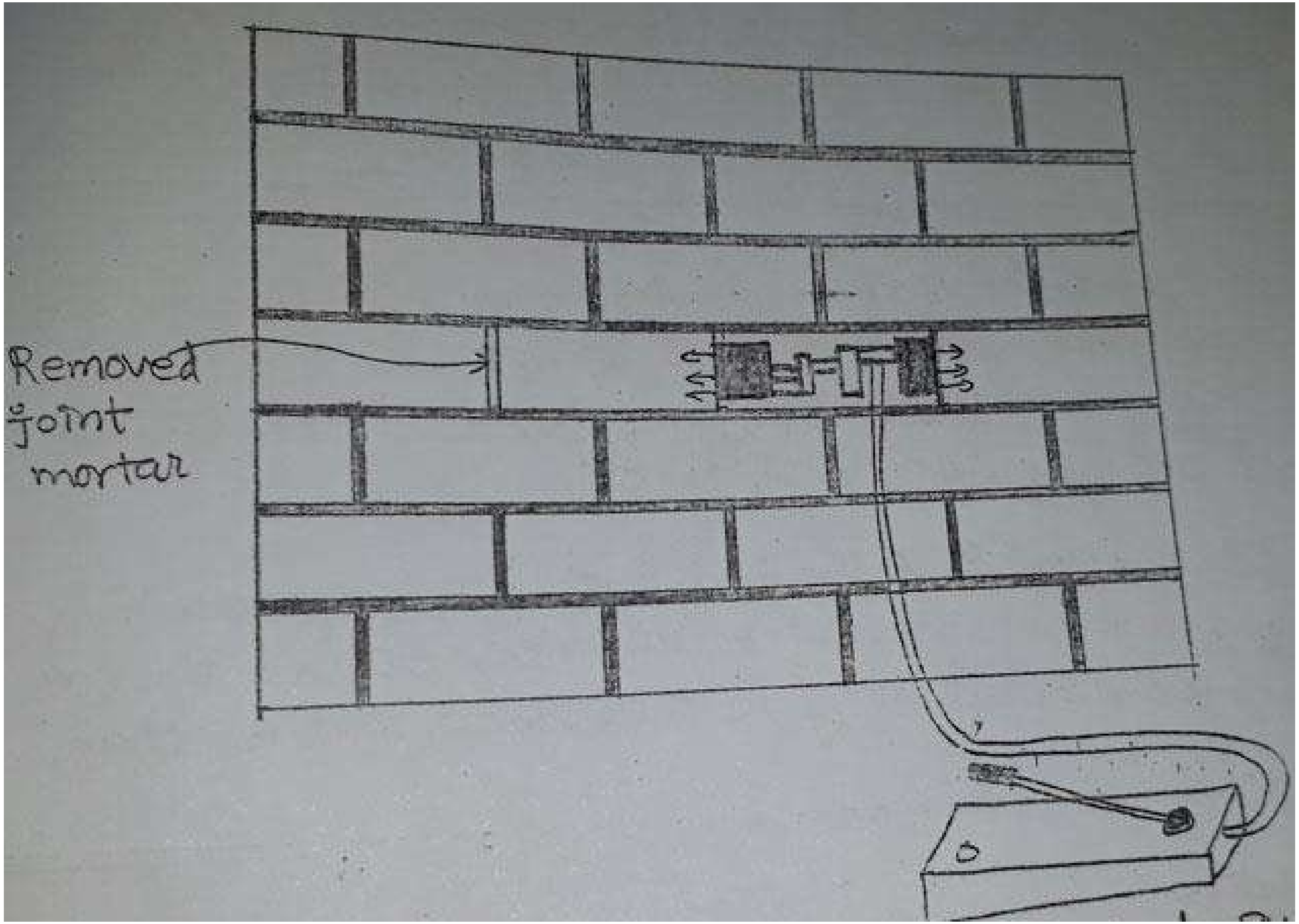


Fig: 10.9 A complete arrangement of push shear test:

- Displacing a single unit horizontally relative to the surrounding masonry use in a hydraulic ram.
- The maximum horizontal force recorded during the test divided by the gross area of the upper and lower bed joints is the mortar joint shear strength index.
- The mortar joint shear strength is directly affected by the magnitude of vertical load at the point of measurement.
- The load must be determined before testing.

units the shear strength of masonry

* joint in opposite side of the test brick is removed
* But the mortar joint above or below the tested sample should not be disturbed.

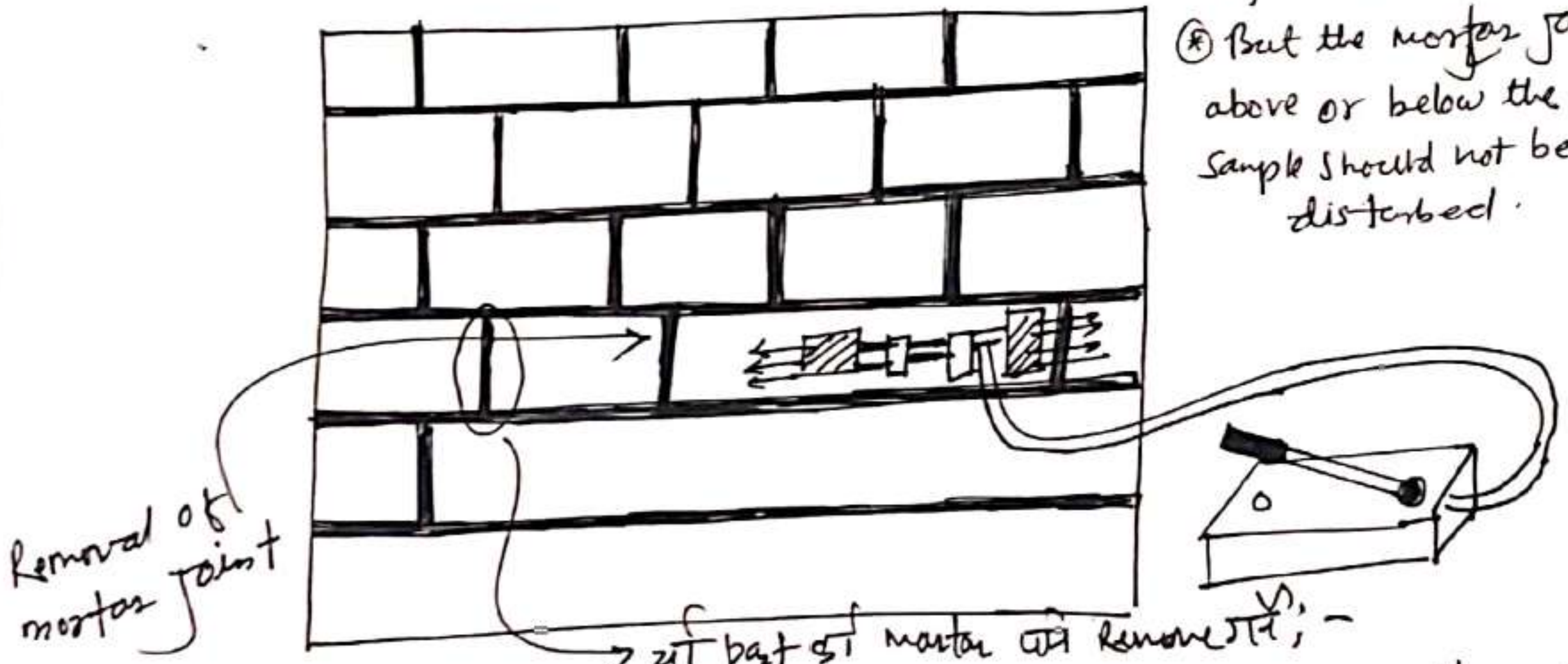


fig:- Complete arrangement of push shear test.

4. Impact Echo testing

- This is versatile testing technique to locate top and bottom delamination caused by corrosion at the top and bottom reinforcement.
- In this test an Impact Echo scanner is used to scan on the top of the balcony deck.
- 'A point by point' impact Echo test is used from the underside to confirm the top delamination.
- **Impact**-**Echo** is a nondestructive **test** method for evaluating concrete and masonry structures. The **test** utilizes stress waves (sound) that is normally generated through striking concrete by an impactor (**Impact**), and recording the reflections and refraction from internal flaws and other boundaries (**Echo**).

• $D=c/2f$

Where,

D= depth from which stress waves are reflected

c= wave speed

F=dominant frequency of the signal (peak)

By determining the D, presence of flaws in structure is calculated.