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Introduction:

→ Concrete is a composite mixture of binder, aggregate, water & sometimes admixtures too.

→ Cement Concrete: The uniform mixture of well proportioned amount of cement, sand (fine aggregate), crushed stone (Coarse aggregate), water & sometimes other admixtures is called cement concrete.

→ On allowing sufficient time to gain the strength, the plastic mixture (called as fresh Concrete) yields a solid strong hard mass, known as hardened concrete.

※ Structural Uses of Concrete:

→ Cement concrete is widely used in almost every civil engineering constructions like buildings, bridges, canals, dams, tunnels, tanks etc.

→ It is commonly used construction material due to following reasons.

(a) Resistant to weather / fire resistant
(b) Strength increases with time
(c) Can be casted into various shapes & sizes.
(d) Constituents are cheap & readily available.
(e) Economical & energy efficient.
(f) Optimum environmental performance.
(g) Durable

→ The major area of use of cement concrete are

(i) Building
(ii) Bridges
(iii) Foundation / Abutment of steel structures
(iv) Tunnel, sewer & underground structure.
(v) Slope stabilization / Soil improvement by shortcreting, retaining structures etc.
(vi) Offshore structures.
(vii) Nuclear shield
(viii) Refractory & fire proofing
(ix) Reinforced Concrete, prestressed Concrete, Precast concrete etc.

Fineness Modulus (FM) of aggregate = $\frac{\text{(Total cumulative weight retained \%)}}{100}$

[For Gradation of Concrete]

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※ Constituents of Concrete:

→ Cement Concrete is made by mixing four major constituent cement, fine aggregate (sand), coarse aggregate (crushed stone) & water.

→ The properties of the concrete can be changed using other different materials which are termed as admixtures.

(a) Aggregates:

→ chemically inactive, inert material
→ Obtained from disintegration of relatively strong rocks eg: pebbles, gravels, brokenstones, sands etc.
→ Contributes 70-80% of volume of hardened concrete.

• Properties of Good aggregate

(a) Must be clean, hard, strong, dense, durable, properly shaped, well graded, free from veins & adherent coatings, chemically stable, free from injurious amount of disintegrated pieces, alkali, vegetable matter.
(b) Inertness & Soundness
~~(c) Inertness & soundness.~~
(d) Strength - / Toughness
(e) Bond strength
(f) Shape - angular aggregate are best due to good interlocking.

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(b) Cement:
→ Material having property of adhesion & cohesion between different materials to form a strong bond betⁿ them.
→ Main constituent of concrete / need water for hydration rxn.
→ Manufacturing by dry & wet process.
→ Composition of cement
(i) Lime (CaO) (ii) Silica (SiO_2)
(iii) Alumina (Al_2O_3) (iv) Calcium Sulphate / Gypsum ($CaSO_4$)
(v) Iron Oxide (Fe_2O_3) (vi) Magnesia (MgO)
(vii) Sulphur Trioxide (SO_3) (viii) Alkalies.

※ Bouge Compounds ⇒ Compounds formed during the hydration of cement.

(a) Tri-calcium Silicate ($3CaO.SiO_2$), C_3S, 48%, Alite
• Responsible for initial set & early strength.
$2C_3S + 6H \rightarrow C_2S_3H_3 + 3Ca(OH)_2 + 502$ (J/gm)

(b) Di- Calcium Silicate ($2CaO.SiO_2$), C_2S, 25%, Belite
• Provide good ultimate strength
$2C_2S + 4H \rightarrow C_3S_2H_3 + Ca(OH)_2 + 260$

(c) Tri- Calcium Aluminate
• C_3A, 10%, Celite, $3CaO.Al_2O_3$
• First compound which reacts with water when cement is mixed with water.
• Responsible for initial setting. $C_3A + 6H \rightarrow C_3AH_6 + 867$

(d) Tetra-Calcium Alumino Ferrite ($4CaO.Al_2O_3.Fe_2O_3$)
• C_4AF, 10%, Felite, poor cementing value
• Comparatively inactive
$C_4AF + 2CH + 10H \rightarrow C_3AH_6 + C_3FH_6 + 416$ (J/gm)

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※ Types
- Ordinary portland cement
- Portland pozzolana cement
- Rapid Hardening Cement
- ~~Rapid~~ High Alumina Cement
- White cement
- Low heat cement
- Colored Cement
- Blast furnace slag cement
- Water Repellent Cement
- Hydrophobic Cement
- Acid Resistant Cement
- Quick setting cement

※ Test of cement
- Fineness
- Normal Consistency
- Setting Time
- Soundness
- Specific gravity
- Tensile strength
- Compressive strength

※ Admixtures:-
→ A material other than basic ingredients (sand, cement, agg. & water) which are used to alter the properties of concrete for specific purpose such as workability, water content, setting time, strength etc can be changed.
→ Types:- (can be added in powder & liq. form)
(a) Chemical Admixture (b) Mineral Admixture
• Accelerator → Increase rate of hydration
• Retarder → Slow down the rate of hydration
• Plasticizer & Super-plasticizer → Increase workability of fresh concrete
• Air-entraining Admixtures → Insert air bubbles in concrete. When the fresh concrete begin to cure, the bubbles within it become mineralized & become an integral part of it. In this way, an additional space is created inside the concrete structure inside which the freezing water expands. This prevents an increase in internal pressure, which is responsible for the formation of cracks during low temperatures. The presence of air bubbles in

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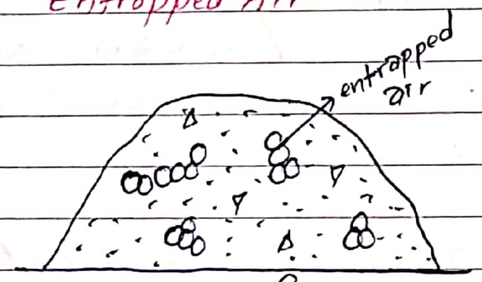
concrete mix also improves the workability. Bubbles act as bearings that increase plasticity without having to change the w/c ratio. Air bubbles also reduce the friction that occurs during the concrete pumping stage.

* Purpose of Admixtures:

(a) To modify fresh Concrete
- Increase the workability without increasing the water cement ratio or decrease the water content at same workability.
- Retard or accelerate time of initial setting.
- Modify rate of bleeding.

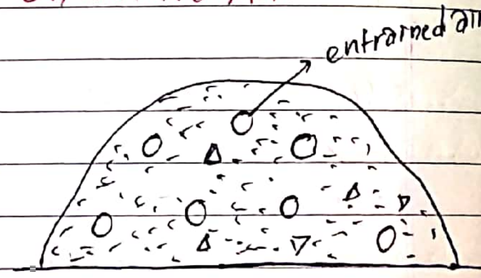
(b) To modify harden property:-
- Reduce heat of hydration
- Accelerate the rate of strength development at early stages.
- Increase the durability
- Decrease the permeability of Concrete.

Entrapped Air



Air bubble is formed inside concrete unintentionally due to less compaction.

Entrained Air.



Air bubble is inserted inside concrete intentionally to change the properties of concrete.
[used when concrete is subjected to thawing & freezing action]

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Properties of Fresh Concrete:-

* Fresh Concrete / Green Concrete:-

→ As we know, concrete is prepared by mixing cement, sand, coarse aggregate & water with or without other admixtures. The mix in its initial stage is plastic in nature that can be easily handled & casted as required. The concrete in such fresh stage is known as fresh concrete.

* Hydration of Cement:-

→ When cement comes in contact of water, a chemical actron occurs between them that result in formation of new compounds responsible for gain of strength of hardened cement of cement concrete. This reaction of cement with water is called hydration of cement.

- Heat of Hydration:-

→ The chemical reaction between cement & water is exothermic. Hence, certain amount of heat is produced during reaction that depends on compound in cement that is taking part in hydration.

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3Ca(OH)_2 + 502\ J/gm$$
$$2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca(OH)_2 + 260\ J/gm$$
$$C_3A + 6H \longrightarrow C_3AH_6 + 867\ J/gm$$
$$C_4AF + 2Ca(OH)_2 + 10H \longrightarrow C_3AH_6 + C_3FH_6 + 419\ J/gm$$

Where,
$C_3S_2H_3$ denotes $3CaO \cdot 2SiO_2 \cdot 3H_2O$ also called C-S-H gel that gives the strength to the hardened cement paste.

→ C_3A → More heat of hydration → High rate of hydration

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Water Cement Ratio:

→ In concrete, major function of water is to react with cement to form hard and strong compound. As the aggregate is inert, the amount of water required is directly related to amount of cement used in the concrete. Hence, the ratio of amount of water to amount of cement (usually by weight) called as w/c ratio, is very important for hydration of cement & quality of concrete.

→ More the water cement ratio, more the cement hydrated more is the compactness of paste & more is the strength. However, if too much water is used, some voids remain unoccupied resulting in low strength Concrete.

→ Though use of more water in concrete makes it easy to handle but degrades the strength of Concrete. Hence, minimum water, but sufficient for hydration of cement gives the most strong concrete.

→ Water/Cement Ratio → (0.45 - 0.6) Generally
For higher strength Concrete → lower ratio are used along with plasticizer to increase flow ability

→ In 1918, Abram's gave a eqn for strength of Concrete as,

$$S = A/B^{x}$$, provided the mix is workable.

S → Strength of Concrete
A = Constant = 96.53 Mpa
B = 4 for 28 days & 7 for 7 days

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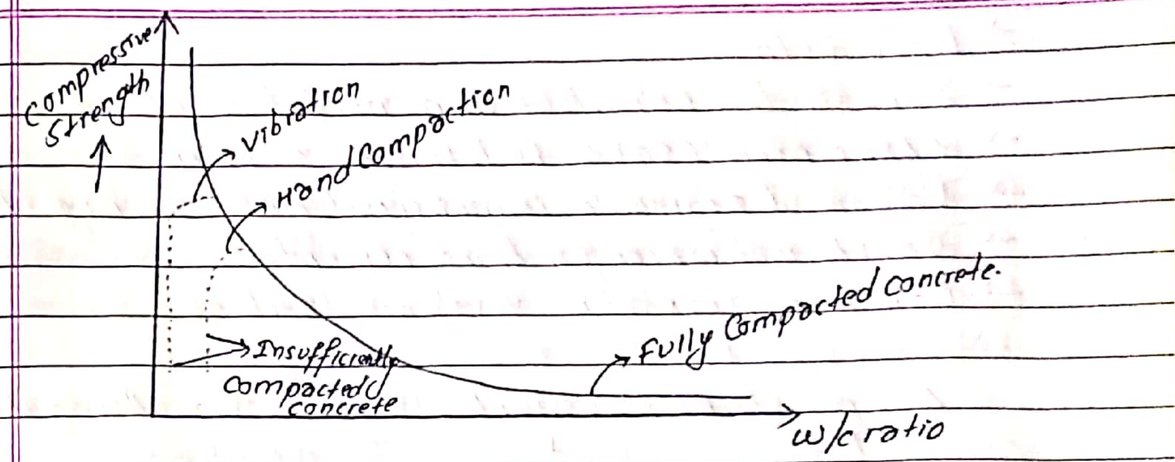


Fig: Relation between strength versus w/c ratio in concrete.

Stages of Concreting work:-

→ Concrete is firstly prepared in plastic form, which is casted to required shape using formworks & cured to allow for hydration and development of strength. Different stages of concreting work are

i) Batching (ii) Mixing
iii) Handling (iv) Placing
v) Compaction (vi) Curing (vii) Finishing

* Batching:-

→ The right proportioning of ingredients to be mixed for preparation of concrete is called batching of materials for concrete production.

→ Can be done in two ways
- Volume Batching
- Weight Batching

(a) Volume Batching:-

→ In this method, the proportioning of materials is done by measuring their volume.

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→ Easy method
→ Done for less important or minor job.
→ 1 bag cement (50kg) is taken as 35 liters.
→ Volume of aggregate is measured by measuring box.
→ 25 liters of water per bag of cement.
→ Common proportion of volume batching

Desired Strength	Cement	Sand	Coarse Aggregate
M10	1	3	6
M15	1	2	4
M20	1	1.5	3

→ For higher strength, volume batching shall not be done.
→ W/C ratio shall be around 0.5 - 0.55.

(b) Weight Batching:
→ In this method, proportioning of ingredients is done by measuring the weight of individual materials.
→ Correct method
→ Requires weighing arrangement
→ Moisture content in aggregate shall be adjusted in proportioning.
→ Most common method & done for any type of job.

* Mixing:
→ Through mixing of materials is essential for uniform & homogeneous Concrete.
→ Methods of mixing
  (a) Hand mixing
  (b) Machine mixing.

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* Hand Mixing:
→ Mixing is done by using tools but with power of hands of workers.
→ Suitable for small works.
→ Additional 10% cement is required to compensate loss of strength than machine mixing.

* Machine Mixing:
→ In this method, power of machine is used for mixing of concrete.
→ Used for medium to large works.
→ Economical for large works.
→ Give more homogeneous & uniform mix at lower w/c.

* Transportation:
→ Concrete shall be moved from mixing site to formworks.
→ Due attention shall be given to avoid loss of homogeneity & workability during transportation.
→ Some method of transportation are by means of
  (i) pump/pipeline
  (ii) Helicoptar
  (iii) Mortar pan
  (iv) Wheel Barrow / Cart
  (v) Bucket & Rope, Skip & Hoist
  (vi) Truck mixer / Transit mixer
  (vii) Belt Conveyor
  (viii) Chute

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* Placing:
→ After transportation, the concrete shall be placed to the right shape and size.
→ Depending upon the site, different things shall be considered during placing.

(a) For foundation (on earth)
→ Any vegetation or organic matter shall be removed.
→ Loose earth should be removed or compacted.
→ The earth shall be damped.

(b) For slab:
→ Concrete shall be dumped not dragged
→ For high thickness, concrete shall be done in two layers, compacting each layer.
For RCC works, thickness of each layer shall be 15-30cm.
For mass concreting, thickness of each layer shall be 35-45cm.
→ During compaction of layered concrete, vibrator needle shall penetrate to previous layer too.

(c) Concreting on previous layer:-
→ Cold joint shall be avoided
→ The joint shall be well cleaned with wire-brush & waterjet. Sand blasting can be used where necessary.
→ The surface shall be thoroughly wetted & a thin layer of cement slurry may be applied to the surface before concreting.
→ If further concreting is necessary, the top surface shall be left rough for proper bonding.

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(d) For RCC,
→ The placement & cover of the rebar shall be checked before placing concrete.
→ Mould releasing agent (plastic, grease, other chemical) shall be applied on surface of formwork.

(e) For column
→ Tremie or can shall be used.
→ Special formworks with opening on one side at different height shall be used.
→ Consideration shall be made to avoid segregation.

* Compaction:
→ The concrete shall be appropriately compacted in place right after placing.
→ The primary objective of compaction is to remove the air/voids that might be trapped during mixing, transporting or placing of concrete.
→ As the air/voids drastically reduces the strength of concrete compaction is very necessary to achieve the desired strength.
→ The method of compaction are
(a) Hand Compaction:
- Can be done for concrete of upto 15-20cm layers.
- Concrete of high consistency is required for hand compaction
- It can be done in three ways.
  (i) Rodding
  (ii) Ramming
  (iii) Tamping

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(b) Compaction by Vibrator:-
→ Suitable in genetal purpose concreting.
→ It can compad concrete of even lower w/c ratio.
→ Vibration set particles in motion, reducing the friction causing temporary liquefaction. It makes the particle settle well.
→ Types of Vibrator,
(i) Needle / Immersion Vibrator - For common concreting
(ii) Formwork Vibrator - For thin layer of concreting
(iii) Table Vibrator - In labs.
(iv) Platform Vibrator - In precast Industry
(v) Surface Vibrator - For thin concrete section / Road
(vi) Vibratory Roller - in mass concrete.

※ Curing:-

→ Providing favourable environment for concrete to gain strength in desired time without harmful changes is called curing.
→ The strength of concrete is achieved by hydration of cement.
→ The water required for curing is greater than required because it is evaporated from the surface, leaving dry top layer of concrete, that may cause rapid shrinkage & insufficient hydration.
→ Curing is done to keep the concrete moist & warm enough so that the hydration of cement continues at optimum level for best gain in strength without any adverse effects.
→ Method of Curing:-
(i) Immersion - precast
(ii) Ponding - slabs, pavements
(iii) Sprayings - plasters, vertical concrete
(iv) Wet-Covering (saw-dust, sand, jute etc.) - vertical surface, concrete in difficult position.

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* Finishing:-

→ Concrete can be given desired finishing during casting, during partially hardened state or after fully hardened state. Finishing can be given to concrete in major three ways.
- Formwork finish
- Surface finish
- Applied finish

※ Workability & its tests:-

→ Workability is the measure of ease in mixing, transporting, placing & compaction of concrete due to the property of concrete itself.
→ Workability can also be defined as the amount of useful internal work necessary to produce full compaction.
→ With increase in w/c ratio, workability will increase but strength decrease. Hence, strength of concrete is inversely proportional to the workability and too much workability should be avoided.
→ Factor affecting workability of concrete
(a) Water content
(b) Size of aggregate
(c) Mix proportions
(d) Shape of aggregate.
(e) Surface texture of aggregate
(f) Grading of aggregate
(g) Use of admixtures.
(h) Time & temperature

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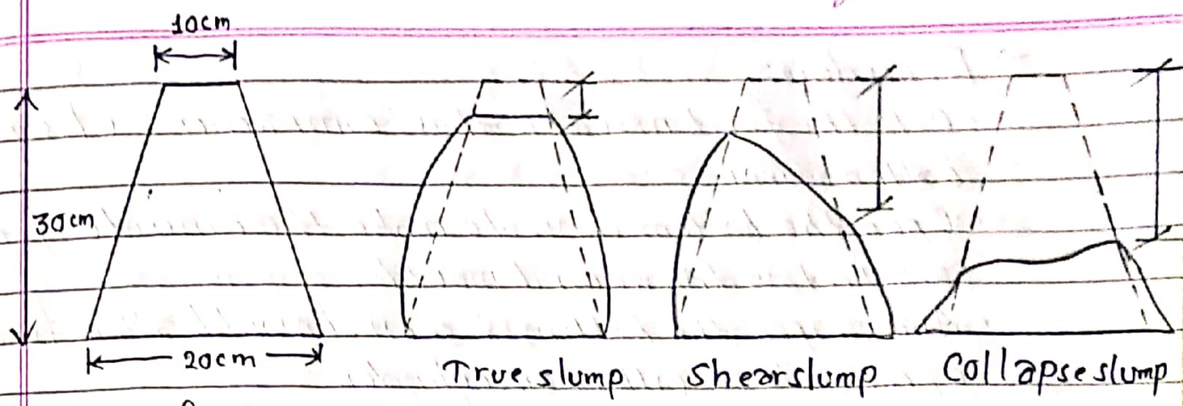
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* Workability Tests
(i) Slump Test
(ii) Compaction Factor Test
(iii) Flow Test
(iv) Kelly ball test
(v) Vee Bee Consistometer test.

Slump Test:

→ This test measures the consistency property of concrete
→ It is not suitable for very dry or very wet concrete.
→ It is simple & easy to use in lab as well as on site.
→ It is most widely used method.
→ This method uses a special metallic mould in shape of truncated circular pyramid with internal diameter of 10cm & 20cm at two ends. The height of mould is 30cm that has a flat non-absorbent metal base.
→ Procedure
(a) The mould is erected over plate with smaller dia. side on top.
(b) Mould is filled with fresh concrete in 3-4 layers, each layer being compacted by tamping 25 times with 60cm long tamping steel rod of 16mm dia.
(c) The top surface is leveled. The height of concrete equals height of mould (i.e 300 mm)
(d) Then, the mould is lifted vertically, that allows concrete to subside.
(e) The new height is measured & the height of subsidence is calculated.
(f) The subsidence height in mm is taken as slumpless or slump value.

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Mould for slump test

→ If the concrete slumps evenly, it is called true slump.
→ If one half of the cone slides down, it is called shear slump.
→ If w/c ratio is high, all concrete gets collapsed such type of slump is called collapse slump.
→ Degree of workability, Low → 25-50, Medium → 50-100, High → 100-150 } slump value.

Compaction Factor Test:

→ This test is performed to measure the level of compaction in concrete an application of fixed amount of energy for compaction by free-fall.
→ It utilizes three moulds, two are frustum of cone & one is cylinder

Mould	diameter	Height
Upper hopper	25.4cm, 12.7cm	27.9 cm
Lower hopper	22.9cm, 12.7cm	22.9 cm
Cylinder	15.2cm	30.5 cm

→ The moulds are so arranged that, concrete from first mould falls on second mould & to the third one.

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→ Procedure:-

- Fill the first mould without compaction, closing the bottom door.
- Open the bottom door, to make the concrete free fall & collect on the second mould.
- Again, open the bottom of second mould, allow free fall of concrete & collect on cylinder.
- Cut the extra concrete in the cylinder to level.
- Determine the weight of partially compacted concrete due to free fall in the cylinder. (By weighing with concrete & once empty)
- Remove the concrete from cylinder & refill the cylinder in 5cm layers, each layer being compacted with tamping rod or by vibration.
- Then, compactor factor is calculated as,

$$C.F = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted Concrete.}}$$

→

Workability	C.F
Very low	0.78
low	0.85
Medium	0.92
High	0.95

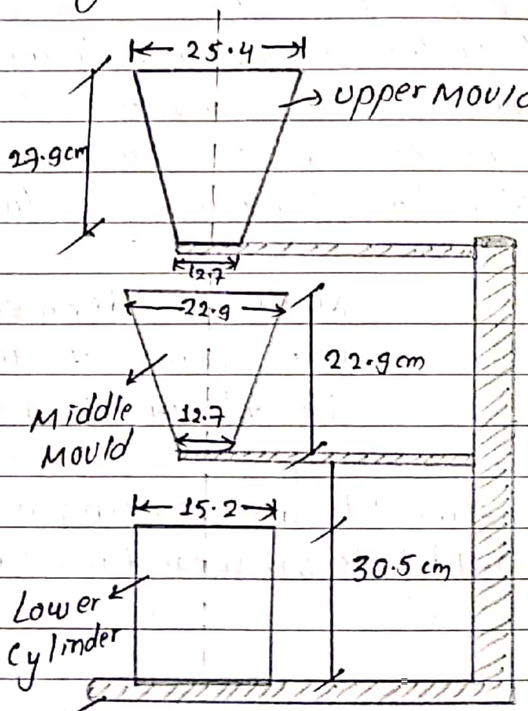


Fig: Compacting Factor Test Apparatus (All dimensions in cm)

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** Flow Test:-

→ It is another method ~~det~~ of determining workability of concrete in which, concrete is allowed to flow or spread by subjecting to jolting.

→ The amount of flow indicates the quality of concrete with respect to consistency, cohesiveness & proneness to segregation.

→ It consists of mould in shape of frustum of cone with diameters of 17cm at top & 25cm at bottom, that rest on a larger diameter plate with arrangement of jolting the plate, by raising to 12.5mm & suddenly dropping.

→ Procedure

(a) Put the mould over the impervious plate with smaller dia. on top.

(b) Fill the mould in two layers rodding each layer 25 times with 16mm diameter & 61cm long steel tamping rod.

(c) Level the top surface

(d) Gently lift the mould vertically up & remove it.

(e) Jolt the plate by raising & dropping through 12.5 mm, 15 times in about 15 seconds with a jolting arrangement provided in the table. It will spread the concrete to larger area.

(f) The diameter of flowed concrete is measured.

(g) The flow is determined as,

$$\% \text{ flow} = \frac{\text{Spread dia. in cm} - 25\text{cm}}{25} \times 100\%$$

→ Common value ranges from 0-150%.

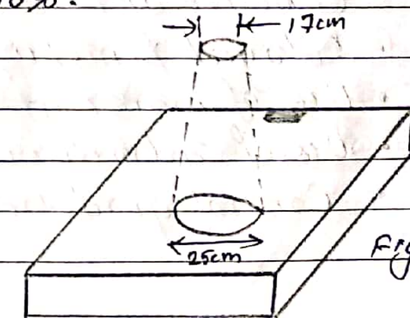


Fig: Flow Table Test

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✻ Segregation & Bleeding:

* Segregation:

→ Separation of constituents of materials of concrete is called segregation. It breaks the homogeneity of the concrete causing strength degradation & other undesirable effects. Due to variation of specific gravity of different constituents, they tend to separate under influence of gravity. Segregation can be categorized in three types

(a) Coarse aggregate separating out or settling down from rest of the concrete.
(b) Paste/Matrix separating away from coarse aggregate
(c) Water separating out from the rest of material.

→ Factors promoting Segregation
a) Badly proportioned mix
b) Insufficient mixing
c) Excess water
d) Dropping of concrete from height
e) Transporting through long distance.
f) Over-vibration
g) Quickly working on surfaces.

→ Remedies of segregation:-
- Remixing of concrete for short time after long transportation.
- Cohesive or rich mix shall be prepared.
- Delayed finishing
- Use of more cement / finer cement
- Use of admixtures like air-entraining agent.
- Control gradation on fine & coarse aggregate.

* Bleeding:

→ It is the particular forms of segregation in which water moves in the concrete. Usually, water comes out to the surface & accumulates. Bleeding occurs more in wet mix or when laid in thin sections.
→ Badly proportioned or insufficiently mixed concrete has also higher bleeding problem.
→ The effects of bleeding are
a) Top layer - weak & generates dusts/muds
b) Reduce the strength of concrete
c) If evaporation > Bleeding rate, development of shrinkage crack
d) Creates zone of poor bonding
e) Decrease durability of Concrete.

→ $\% \text{ Bleeding} = \frac{\text{Quantity of water bleeded}}{\text{Total water in concrete}} \times 100\%$

→ Control of bleeding
- Proper proportioning of ingredients of concrete.
- Late finishing
- Use of fine cement
- Decrease w/c ratio
- Air entrainment admixture.

✻ Concreting in extreme temperatures:-

→ The rate of hyration of concrete is very dependent on temperature on which it is cured. These arise different problems while concreting in very cold or very hot temperatures, both during concreting & curing.
- Concreting in cold weather
- Concreting in hot weather.

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* Concreting in cold Weather:-

→ The major effects of cold weather in concreting are as follows.

(a) Delay in setting & hardening
- Rate of hydration decreases with decrease in temperature.
- It increases the time for formworks & curing.
- The progress of work will be slow, that affects the economy.
- It also makes the concrete more vulnerable to frost action.

(b) Freezing of Concrete in early stage:
- If water is frozen, then the hydration stops.
- The expansion of water in concrete during freezing includes induces crack on low strength concrete, as the hardening process is not sufficient.
- Affects the durability.

(c) Freezing & thawing Cycle:
- The alternate freezing & thawing causes early disintegration & fatigue in the concrete.

→ The common precautions for concreting in cold weather are as follows.

a) Shielding of wind in working area & insulating with insulators around plant.
b) The site shall be well managed for quick delivery. finishing & covering of concrete with insulator like straw, jute sacks, plastic sheets, water proof paper etc.
c) The material for concrete can be preheated. Water in container, coarse aggregate in closed steam coils under stock pile, or by steam or hot air, sand in steel plates while cement shall not be heated.
d) Formwork & subgrade can also be heated.

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e) Special type of cement like RHC, High Alumina Cement etc. can be used that have high rate of hydration & high heat of hydration & keeps the concrete warm.
f) Accelerating admixtures is also commonly used that increase the rate of hydration. $CaCl_2$ is a good accelerator, but use in higher amount increases the corrosion in steels embedded in RCC.
g) Electrical heating for curing

* Concreting in Hot weather:

→ While concreting in very hot weather also, certain problems arises. Typically, if the temperature exceeds 40°C, then these problems are high.

→ The major problem in hot weather concreting are
(i) Rapid rate of hydration & setting causing early stiffening of concrete.
(ii) Rapid evaporation & loss of water from surface & formwork
iii) Higher plastic shrinkage due to faster drying.
iv) Less time for finishing
v) Difficulty in air-entrainment & curing.

→ Different precautions can be employed for hot-weather concreting, which are listed below

a) Management of Material
- Aggregate shall be stock piled in shade.
- Regular sprinkling of water to aggregate.
- Using cold water (upto 5°C)
- Use low heat cement
- Use of retarding admixtures.

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(b) Management of Concreting Work:
- Scheduling the concreting work in evening (but with sufficient lighting)
- Use of more masons for quickly finishing the work.
- Transporting the concrete in deep container.
- Covering of concrete with moist materials as early as possible.

(c) Curing of Concrete:-
- The concrete shall be cured with cold water.
- The surface shall be continuously made wet either by ponding or using water absorbing materials in surface like cloth, jute, sand etc.

Types of Admixtures:-

(a) Plasticizer (Water-Reducer)
→ The workability of concrete can be increased by improving gradation of coarse aggregate, using higher proportion of fine aggregate & using more cement & water.
→ However, these methods have only little impact & use of higher cement is uneconomical too. Thus, special type of chemical compound which can be used with concrete for increasing the workability of concrete is called plasticizer.
→ Reduce the water content for given workability.
→ These plasticizers are used in amount of 0.1% to 0.4% by weight of cement & can reduce water by 5-15% or increase slump by 30-150 mm.

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(b) Superplasticizer:-
→ They are improved & more powerful version of plasticizers with high water reducing capacity.
→ They are used when high degree of water reduction is required maintaining the required workability especially for flowing concrete, self leveling concrete, self-compacting concrete, high performance concrete etc.
→ Upto 30% water reduction is achievable with use of superplasticizers maintaining water cement ratio of just 0.25.

(c) Retarders:-
→ They are such admixtures that delay the setting time of concrete. As it slows down the hydration rate, it keeps concrete workable for long period of time giving additional time for mixing, placing, compaction & finishing.
→ They are used in very small quantity. 0.05% by weight of cement has noticeable retarding effect, while more than 0.2% may virtually prevent setting.
→ Common Retarders:-
Calcium sulphate (Gypsum), Starch/Sugar, cellulose etc.

(d) Accelerators:-
→ These admixtures increase the rate of hydration thus shorten the setting & hardening time.
→ They are used in urgent-repair work, in cold weather concreting or under water concreting.
→ They are also used in pre-cast industry for early formwork removal or when rapid construction is required.
→ However, they reduces the strength of concrete to some extent, hence their use shall be limited.
→ Eg: calcium chloride, calcium nitrate etc.

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→ Though chloride admixtures are economic & effective admixture as accelerator, its use is limited to 0.15% of cement for RCC & 0.06% for pre-stressed concrete as it promotes corrosion in reinforcing steel.

* Quality Control at Site:-

→ Good design is not sufficient but its actual implementation is required for fully quality of work & performance of structure as expected. Hence, quality control at site is very important for expected outcome.

→ For overally quality of concreting works, quality shall be maintained on each steps of works (workmanship) & materials.

→ The major requirements for quality work are

(a) Using quality material
(Cement, aggregate, sand, water, admixtures, Reinforcement)

(b) By maintaining the workability (check slump value)

(c) Appropriate Storage of material (storage of material shall be done as per IS 4082)

(d) Good Concreting practice
- Give consideration in mix proportion, method of batching & mixing as per specification.
- Regular monitoring of workability & strength by slump & cube test.
- Not dragged / thrown from height greater than 1m.
- Compaction, Curing, weather condition etc.

(e) Good formwork & Reinforcement laying practice.

(f) Following Good Quality Assurance plan

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Properties of Hardened Concrete:-

* Deformation of Hardened Concrete:

→ Concrete deforms on application of loads. Concrete is mostly used to resist the compressive load as its compressive strength is relatively very high than its tensile strength.

→ The deformation characteristics in compression can be studied from the stress-strain relation of concrete.

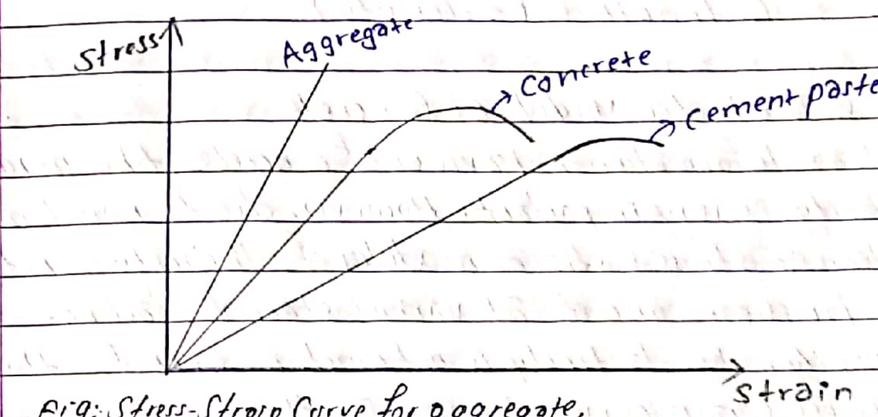


Fig: Stress-Strain Curve for aggregate, concrete & cement paste.

→ The stress-strain of concrete is obtained by testing concrete cylinder specimen at age of 28 days, using Compressive Test Machine.

→ The elastic range of concrete stress-strain curve continues upto $0.45f_c'$ (f_c' → Max^m compressive strength of concrete)

→ Due to progression of cracks, the concrete is failed under loading.

* Modulus of Elasticity of Concrete:-

→ The modulus of elasticity represents the deformability of concrete. Higher modulus indicates stiffer concrete with lesser deformation at same load.

→ The modulus of elasticity of concrete can be determined in different ways.

(a) By subjecting cube/cylinder to uniaxial compression
Stress = P/A & strain = D/L

(b) By conducting bending test,

$$E = \frac{Pl^3}{48EI}$$ [For mid-point loading of simply supported concrete beam]

(c) By subjecting concrete to longitudinal vibration

$$E = kn^2L^2\rho$$

(K = 4×10^{-15} Gpa, n = Resonating Frequency, L = length & ρ = density)

✳ Types of Elastic Moduli of Concrete

→ For load deformation behaviour of concrete, the modulus of elasticity is very important. However, due to non-linear relation of stress & strain, modulus of elasticity is not constant even for same concrete at various stage of loading.

→ Typically, the elasticity is ~~not constant even for~~ the slope of stress-strain curve. Hence, as the curve is non-linear the elasticity is also changing.

→ The types of elastic modulus of concrete are,

(a) Initial Tangent Modulus:-

→ It is determined by taking tangent at origin for stress strain curve. It is suitable while using concrete in low stress.

(b) Tangent Modulus

→ It is determined at any point of curve by taking tangent with the stress-strain curve at that point. The value is dependent on the stress level, & varies from point to point. It is important when more accurate analysis is required.

(c) Secant Modulus:-

→ It is determined from the slope of secant joining origin & a fixed point on curve. This is most common modulus in use as it indicates an average value for stress level in use. It is determined by taking secant passing through point in curve corresponding to 15, 25, 33 or 50% of stress level.

(d) Chord Modulus:-

→ This modulus is determined by taking slope of chord joining two points in stress-strain curve corresponding to two different stress levels. Hence, it is useful, if concrete is subjected to stress within some fixed range. It is mainly used in research purpose only.

✳ Creep:-

→ Creep is defined as gradual increase in strain (deformation) under sustained stress (or load). The creep is mainly dependent on quality of cement paste & age of concrete.

→ Creep is believed to occur due to movement of pore water due to stress.

→ The major factor that affects the creep are,

(a) Stress on Concrete → More stress, more creep

(b) Age during loading → Lesser age, higher creep.

(c) Duration of loading → Higher the duration of loading, more creeping

(d) Mix proportion → Rich mix with low w/c has lower creep.

(e) Aggregate properties

(f) Other factors like size of member, environmental condition.

→ The amount of creep is generally expressed in terms of creep coefficient.

$$\text{Creep coefficient } (C_c) = \frac{\text{Creep strain } (\epsilon_{creep})}{\text{Elastic strain } (\epsilon_{elastic})}$$

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→ IS 456:2000, recommends the following value of creep coefficient for different age of loading.

Age of loading	7 days	28 days	1 year
C_c	2.2	1.6	1.1

※ Shrinkage:

→ Contraction in volume (or length) of concrete due to various phenomenon is called shrinkage. The total shrinkage depends upon constituents of concrete, size of member & environmental condition

→ For given humidity & temperature, total shrinkage is most influenced by the total amount of water present during concrete mixing & higher cement content results in higher shrinkage. In absence of test data, IS 456:2000 recommends taking the total shrinkage value 0.0003 approximately.

→ The total shrinkage in concrete can be divided into four types as follows

(a) Plastic Shrinkage:-

→ It is the shrinkage due to loss of moisture at plastic stage.

→ Moisture loss due to evaporation mostly occurs on exposed surface of slabs, Road pavements etc.

(b) Drying Shrinkage:-

→ It is the shrinkage due to loss of pore water over a long period, in dry condition.

→ It depends upon amount of gel relative to aggregate.

(c) Autogeneous Shrinkage

→ It is the shrinkage without moisture movement, possibly due to consumption of water during hydration. It is of very small quantity.

(d) Carbonation shrinkage:-

→ It is the shrinkage which occurs while the carbondioxide in atmosphere reacts with calcium hydroxide of concrete to produce calcium carbonate.

→ It is also of very low quantity & can be considered good for concrete as $Ca(OH)_2$ will be used up at compromise of very small shrinkage.

※ Thermal Expansion:-

→ Concrete expands on increase in temperature and vice-versa. The coefficient of thermal expansion depends upon nature of cement, aggregate, relative humidity, size of concrete section etc. Under normal circumstances, the expansion mainly depends on aggregate.

→ IS 456:2000 recommends the value for linear coefficient of thermal expansion of concrete with different aggregates as follows.

Sn	Aggregate material	α ($\times 10^{-5}$/°C)
1	Quartzite	1.2 - 1.3
2	Sandstone	0.9 - 1.2
3	Basalt	0.8 - 0.95
4	Granite	0.7 - 0.95
5	Limestone	0.6 - 0.9

→ Expansion of concrete in structure results in secondary stresses. Hence, normally structure exceeding 45m in length are designed with one or more expansion joints.

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Impact loading:

→ The load that is applied suddenly at short time interval is called impact load & the strength shown for impact load is called impact strength.

→ With increase in load, microcracks are first developed at transition zone that propagates to cement paste. Hence, under impact loading, concrete shows increased strength due to lesser available time for propagation of crack.

→ The impact strength is found to increase with
(a) Increase in rate of loading
(b) Increase in surface roughness of aggregate
(c) Decrease in aggregate size
(d) Increase in tensile strength.
(e) Improved Transition zone

→ The CEB-FIP Model Code (1990) recommends following relation for impact strength.

$$f_{c,imp} = f_c * \left(\frac{\sigma_s}{\sigma_0}\right)^{\alpha}$$

where,
$f_{c,imp}$ = Impact Compressive Strength
f_c = Compressive strength of Concrete
σ_s = Impact strength rate
σ_0 = 1 Mpa

$$\alpha = \frac{1}{5 + 9 * \frac{f_c}{f_{co}}} \quad \text{where, } f_{co} = 10\,\text{MPa}$$

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Cyclic loading & fatigue

→ Loading that is applied & removed repeatedly is called cyclic loading. On application of cyclic load, material shows reduced strength at higher cycles of load.

→ The phenomenon of reduction of strength of material due to ~~progressive microcracking~~ repeatedly acting load (or cyclic load) is called fatigue.

→ Fatigue occurs due to progressive microcracking at interfacial transition zone and past matrix in mutiple cycles of load causing strength & stiffness degradation.

→ Fatigue is found to be more if the acting load is high, very near to Ultimate stress level. Generally speaking, cyclic loading exceeding 50% of Ultimate stress has pronounced adverse effect. Typical test shows that, at 5000 cycles of load, concrete fails at only 70% of its ultimate monotonous stress.

→ John Hanson has proposed an equation for possible number of cyclic load within fixed range, a concrete specimen with certain strength can bear as follows.

$$\log(N) = \frac{1 - \frac{f_{max}}{f_c}}{\beta * \left(1 - \frac{f_{min}}{f_{max}}\right)} - 1.9, \quad \text{where, } \beta = 0.0685$$

f_c = Strength of concrete

→ An example with f_c = 20MPa, f_{min} = 5MPa & different f_{max} shows following results.

f_c (N/mm²)	20	20	20	20	20
f_{max} (N/mm²)	18	16	14	12	10
f_{min} (N/mm²)	5	5	5	5	5
Number of cycle (N)	2	302	47,000	1.2 Million	1.1 Billion

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✳ Effect of Porosity, Water-Cement Ratio & Aggregate Size

* Effect of porosity:-

→ Higher pores reduces the strength of concrete. Higher water content and insufficient compaction results in porous concrete that has relatively low strength.

→ Typically, the capillary pores in concrete shall be filled with hydrated products of cement (gel) over time causing filling of pores and increase in strength with time.

→ Gel space Ratio:- The hydrated product of cement is gel & the available volume in concrete for gel is termed as space. It has been found that, the strength of concrete is highly dependent on the ratio of gel to space called gel-space ratio.

If 'S' be the strength of concrete with gel space ratio 'x', then strength can be related to gel-space ratio as,

$$S = 240x^3$$

$$x = \frac{\text{Volume of gel}}{\text{Volume of space}} = \frac{0.319\alpha C * 2.06}{0.319\alpha C + W + A} \quad ---(1)$$

α = Fraction of hydrated cement
C = Weight of cement
W = Volume or Weight of water.
A = Volume of air / Volume of voids

For full compaction, eqn (1) reduces to

$$x = \frac{0.319\alpha C * 2.06}{0.319\alpha C + W}$$

$$x = \frac{0.319\alpha \times 2.06}{0.319\alpha + W/C} = \frac{0.657\alpha}{0.319\alpha + w/c}$$

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✳ Effect of water Cement Ratio:-

→ Higher the water-cement ratio during concrete mix results in concrete with poor strength. Basically, more pores (space) will be formed in such concrete resulting in lesser gel relative to space, that cannot be fully filled by hydrated products.

→ Abram has given a relationship of strength with water-cement ratio by volume,

$$S = \frac{A}{B^x}$$

Where, S = Strength in lbs/sq. inch
A = 14,000 lbs/sq. inch
B = 7 for 28 days strength
x = Water cement ratio by volume

→ High w/c ratio increases the porosity & permeability of concrete & reduces its durability. Higher w/c ratio also increases shrinkage & creep of concrete & reduces the resistance to cyclic loading as it deteriorates the transition zone.

✳ Effect of Aggregate size:-

→ The most important properties of concrete are shape, texture & size of aggregate.

→ Maximum size affects the strength in several ways. Larger particle reduces the specific surface area of aggregate which treads a reduction in bonding. Also, larger particles tend to more strain, volume change in cement paste and therefore induced more internal stress. Which will weaken the concrete. Aggregate effects can be offered by reducing the water content. In general, at a constant w/c ratio, higher strength can be obtained by using line of mixture.

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→ If constant workability is maintained, strength will increase with cement content.
→ In rich mix concrete/ high strength concrete, when large sized aggregate is used, due to internal bleeding in the transition zone, it will become much weaker by developing micro-cracks with lower compressive strength.

* Durability of Concrete:-

→ A durable concrete is one that performs satisfactorily in the working environment during its anticipated exposure conditions during service. The materials & mix proportions specified & used should be such as to maintain its integrity and if applicable, to protect embedded metal from corrosion.
→ The factors influencing the durability of concrete are
(a) Environment
(b) Cover to embedded steel
(c) Type & quality of constituents material.
(d) Cement content & w/c ratio
(e) Workmanship, to obtain full compaction & efficient curing
(f) Shape & size of member.

* Requirements for Durability:-

(a) Shape & Size of member:-
→ promote good drainage of water & to avoid standing pools & rundown of water.
→ Member profiles & their intersections with other members shall be designed & detailed in a way to ensure easy flow of concrete & proper compaction during concreting.
→ The life of structure can be lengthened by providing extra-

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cover to steel, by chamfering the corners or by using circular cross sections or by using surface coatings which prevent or reduce the ingress of water, CO_2 or aggressive ~~material~~ chemicals.

(b) Exposure Condition:-
→ The general environment to which the concrete will be exposed during its working life is classified into five levels of severity, which shall be considered during concrete mix design & detailing.
(Mild, Moderate, Severe, Very severe & Extreme)

(c) Concrete Cover:-
→ The protection of steel in concrete against corrosion depends upon an adequate thickness of good quality concrete.

Exposure	Mild	Moderate	Severe	Very Severe	Extreme
Nominal Cover (not less than)	20	30	45	50	75

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(d) Concrete Mix Proportions:-
→ The free water-cement ratio is an important factor in governing the durability of concrete & should always be the lowest practical value.

Exposure	Minimum Cement Content (kg/m³)	Maxm free water cement ratio	Minimum grade of Concrete	Minimum cement content (kg/m³)	Maxm ~~Cement~~ ~~content~~ free w/c ratio	Minimum Grade of Concrete.
Mild	220	0.60	—	300	0.55	M20
Moderate	240	0.60	M15	300	0.50	M25
Severe	250	0.50	M20	320	0.45	M30
Very Severe	260	0.45	M20	340	0.45	M35
Extreme	280	0.40	M25	360	0.40	M40

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(e) Mix Constituents:

→ Deleterious consituents in aggregate shall not exceed the specified limits (IS 456:2000, clause 3.2.1

→ The amount of solids present in mixing water shall be within limits. (Clause 5.4, IS 456: 2000)

→ The amount of chloride content in the concrete at the time of placing shall be limited.

→ The total water soluble sulphate content of the concrete mix should not exceed 4% by mass of concrete in mix.

→ Precautions in selection of mix constituents.

(f) Protection against Aggressive soils & water:-

→ Drainage shall be appropriately maintained to lower ground water specially where alkali concentrations are high.

→ Adequate workability & compaction without segregation.

→ Good finishing practices are essential for durable concrete.

→ Use proper & adequate curing techniques to reduce the permeability of concrete.

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Ch-4 Introduction to Special Types of Concrete:-

* Light Weight Concrete:-

→ Normally, density of concrete is 2200 to 2600 kg/m³, while that of timber is only around 800 kg/m³. Heavier the material of construction more will be the self weight, hence low density members are economical. Being contained with higher percentage of air, they are commonly used for sound adsorption, sound proofing, thermal insulation & fire resistant materials. Similarly, there are various other areas of use where light weight concrete is preferred both as structural member or non-structural member. Hence, use of light weight concrete is rapidly increasing in modern days, with concrete as light as upto 300 kg/m³

→ Light weight concrete can be prepared, mainly by three different ways

a) By replacing usual mineral aggregate by cellular porous or light weight concrete. (Light wt. aggregate Conc.)

b) By introducing gas or air bubbles (Aerated Concrete)

c) By omitting fraction of sand from concrete (No fines concrete)

* Light weight Aggregate Concrete

→ Light weight aggregate concrete is a light weight concrete made by replacing usual mineral aggregates in concrete by cellular porous or light weight natural or artificial aggregated.

→ Natural light weight aggregates:-
Pumice, diatomite, Scoria, Volcanic Cinders, Sawdust, Rice husk, groundnut-huk, bassage etc.

→ Artificial Light weight aggregates
Artificial cinders, coke breeze, foamed slag, bloated clay

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expanded shale & slate, sintered fly ash, exfoliated vermiculite, expanded perlite, thermocoal beads etc.
→ Natural light weight aggregate are rare & are not of uniform quality wheras by product of a large number of industry are being used for artificial light weight aggregate.
→ Light weight aggregate being porous usually produce harsh concrete & absorbs water. Hence, consideration shall be made for required workability, prevention of water absorption & strength of concrete. Being porous special consideration shall be made for durability of concrete.

✱ Aerated Concrete:-

→ It is light weight concrete prepared by introducing large volume of air into the slurry of cement (with or without lime), fine sand & water. Such concrete generally don't have coarse aggregates and are very light. Such concrete is called gas concrete / foam concrete cellular Concrete.
→ Different ways of manufacturing aeras follows:
a) Using chemical in mix that forms gas during mixing
b) Mixing preformed stable foam with the cement sand slurry.
c) Glacification by using metal powders
→ Aerated Concrete can be produced in density range of 300-800 kg/m³ having excellent thermal insulation property. They can be produced in wide range of density & strength making it suitable for different purposes like sound insulation, thermal insulation building blocks, load bearing walls & even pre-cast reinforced concrete.

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✱ No fines Concrete:

→ It is the concrete made by omitting the fine aggregate in the concrete. Very often, single sized coarse aggregate (passing through 20mm sieve & retained in 10mm sieve) are used.
→ They have large proportions of voids & lightin weight with a density of 1600-1900 kg/m³. It can even be reduced upto 360 kg/m³ using lightweight concrete.
→ Having low thermal conductivity, sufficient strength to be used as load bearing walls, it is commonly used as partition or load bearing walls. Being rough texture, in some places, it offers architecturally attractive look, while in other place, it provides good base for plastering.
→ Precise control in water cement ratio & aggregate cement ratio is necessary to produce cohesive mix sufficient to get smeared with aggregate but preventing settling of paste at bottom & with sufficient strength.
→ No fines concrete has relatively low compressive strength (3.4-14 MPa) & very low bond strength. However, as the aggregates are in contact with each other, its compaction can be easily done by rodding & have much lower drying shrinkage.

✱ High Density Concrete:

→ Concrete with density greater than 3360 kg/m³ is called high density concrete. Concrete of upto 5280 kg/m³ can be obtained using iron as both fine & coarse aggregate. High density concrete finds its special usefulness in shielding the radiations (specially nuclear particles & electromagnetic waves like x-ray, γ-ray etc) harmful for living beings in related industries.

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→ Where high density concrete are used as shielding, generally, they also have to withstand high loads & high temperatures. Thus strength, heat resistant and durability is also very important for such concrete which is obtained by using dense aggregate, strictly controlling w/c ratio, maintaining sufficient workability and using good compaction technique for full compaction. It is also found that concrete with higher amount of hydrogen molecules have better shielding ability for nuclear particles.

→ Common heavy weight aggregate are, barite, magnetite, Ilmenite, Hematite, Limonite, Geonite, Serpentine, steel shots, punching scarp.

→ Due to heavier height of aggregate, high density concrete has higher tendency of segregation. Hence, care shall be taken while proportioning to make rich paste & during mixing, transporting, placing & compacting concrete to avoid segregation. Consideration shall be done for heavier-weight of concrete for formwork design & stripping of formwork.

* Fibre Reinforced Concrete:-

→ Fibre reinforced concrete is produced by uniformly dispersing suitable type of discontinuous & discrete fibres in mixture of concrete. Concrete is a brittle material inherently consisting microcracks. On application of load, these cracks openup & propagates. It causes non-linear and inelastic deformation of concrete causing brittle failure.

→ Addition of closely spaced & uniformly dispersed fibres act as crack arrester, checks the widening & propagation of cracks and substantially improve the properties of concrete. These fibres are small piece of strong material with its length to diameter ratio (called aspect ratio) of 30 to 150. The properties of fiber reinforced concrete are dependent on volume of fibres, aspect ratio of fibres, orientation of fibres, size of coarse aggregates, workability, mixing & Compaction of concrete.

→ Common fibres used for fibre reinforced concrete are: steel fibre, polypropylene & nylon fibre, asbestos, organic fibres like jute & canesplits, glass fibre, carbon fibre, basalt fibre etc.

→ The fibre reinforced concrete has improved static & dynamic properties, tensile strength, toughness & fatigue resistance. Similarly, it is much easier & faster method for where it substitutes RCC. It is been used for air-field, road-pavement, flooring, bridge-deck, canal lining & various precast works like wall panel, roof panel, blocks, beams etc.

* Self Compacting Concrete:-

→ It is special type of concrete that has ability to flow under its own weight through heavily congested reinforcements and thin sections retaining the homogeneity of mix without segregation. Hence, the concrete is homogeneous and fully compacted everywhere under self weight without necessity of vibration or other measures. A good SCC has following properties.

a) Filling ability
b) passing ability
c) Segregation Resistance.

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→ SCC is made in three ways.
a) Increasing powder content
b) Using VMA (Viscosity modifying admixture) or superplasticizers.
c) Combined.

→ The advantage of SCC over normal concrete are
a) Faster construction
b) Reduction in site manpower
c) Better surface finish
d) Easier placing
e) Improved durability
f) Greater freedom in design
g) Thinner concrete sections.
h) Safer working environment
i) Reduced noise level.

→ In SCC, high flowability is required maintaining high strength. Thus, relatively higher dose of admixture, & more than one admixtures (usually VMA & superplasticizer) are required to obtain such concrete with very high workability, which may have other side effects. Similarly, relatively greater amount of powder is used in SCC that may lead to higher heat of hydration, greater shrinkage & more creep. Thus, different aspects shall be considered while producing SCC.

* Shortcrete :-

→ It is concrete with small sized coarse aggregate that is conveyed through hose & pneumatically projected at a high velocity. The momentum of the concrete itself is sufficient to support & compact itself. Similar application of mortar is generally referred as Gunite.

→ Shortcrete can be produce by dry or wet process. In dry process, water is mixed only just before setting of concrete from hose while in wet process, water is mixed to prepare wet concrete which is later conveyed the hose by pressure. Both method has their own advantage but in general, wet method is simple, easy & uniform, while dry method can produce concrete of high compaction & strength with low w/c ratio.

→ They are commonly used in tunneling works & overhead concreting. Due to high cost of application, they are only used when normal concreting is feasible. The properties of shortcrete are similar to normal concrete, but it is very difficult to obtain high-strength concrete. Suitable admixtures & fibres may be used to increase the strength & modify other properties of shortcrete as required.

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Testing of Concrete & Quality Control:-

Various Strength of Concrete:-

→ Concrete shall bear various types of load depending on its use. Hence, different types of strength of concrete like compressive strength, tensile strength, shear strength, bond strength etc. are established & accordingly concrete shall be used.

→ However, concrete is normally designed with its 28 days strength. Hence, it is very difficult to test the concrete during the casting to conform its strength & perform required adjustment. Generally, samples are casted during concreting work with same concrete & cured according to recommended norms & tested.

Compressive strength & its test:-

→ Compressive strength of concrete is a measure of concrete's ability to resist compressive loads.

→ It is used to define different properties of concrete such as elastic modulus, water tightness or impermeability, tear & wearing resistance etc.

→ The preparation of sample for compressive strength test is as follows:

a) preparation of moulds
b) Sampling of Concrete
c) Casting & compaction
d) Removal of mould & Curing
e) Preparation for testing

→ Two common types of compressive strength test are
a) Cube test
b) Cylinder Test

Concrete Cube Test:-

→ The test is carried out using 150mm concrete cubes on a universal testing machine.

→ Standard size of cube = 150mm * 150mm * 150mm
But, if max^m size of aggregate does not exceed 20mm, cubes of 100mm * 100mm * 100mm can be used provided corresponding correction for observed strength.

→ The concrete cube is applied with an axial compressive force from its smooth faces at a uniform rate of 0.2 Mpa/s. The load at which sample fails is noted. Dividing the failure load by area of cube on which load is acted gives the ultimate strength of concrete.

→ If the cube of size other than standard size (150mm) is taken, then the observed strength shall be corrected by following factors.

Cube size	100	150	200	300
Strength Correction factor	1.05	1	0.95	0.87

→ Hence, it is seen that, higher strength is observed in smaller cube & lesser strength is observed in large cube.

Concrete Cylinder Test:-

→ The test is carried out using concrete cylinder of diameter of 150mm and 300mm height.

→ The apparent strength of test cylinder is found to be dependent on its height to diameter ratio (h/d). Due to effect of friction on face, there is some restraints towards ends affecting the true strength. Hence, a correction shall be done to determine strength of concrete from cylinder other than standard ratio.

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* Comparison of Cube test & Cylinder test:-

→ Cylinder specimen gives lower strength than cube strength.
→ Cylinder specimen gives more uniform strength than cube test - because cylinders have less end restraint and a more uniform distribution of stress over the cross-section. For these reasons, the cylinder strength is probably closer to the true uniaxial Compressive strength of concrete than the cube strength.
→ British standard (BS 1881:1970) has given relation between cylinder strength & Cube test strength for general purpose concrete as,

$$\text{Cylinder strength} = \frac{4}{5} * \text{Cube strength}$$

※ Tensile Strength & its test:-

→ Concrete is strong in compression but relatively weak in tension. Normally, tensile strength of concrete is neglected in design of RCC, however concrete has to resist some tension. Even plain cement Concrete has to resist some tension due to shrinkage, temp change & some external forces.
→ When steel is embeeded in RCC, over a long period, steel may get rusted which also produces tensile stress in concrete.
→ There are different methods for tensile strength test. However, each of them have some limitations & difficult to conduct as well.
→ As per IS 456:2000, tensile strength of concrete ~~fcr~~ (f_{cr}) can be related with characteristic strength of concrete as,

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

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→ The most common tensile strength test are
i) Direct tension
ii) Flexural Test
iii) Cylindrical Splitting test

※ Shear strength & its test:-

→ A shear force is such force that tends to produce sliding failure on a material along a certain plane. The sliding force parallel to that plane per unit area of that plane is called shear stress. And the strength of concrete against shear failure is called shear strength.
→ Concrete structures often encounter high shear stresses. In most cases, additional reinforcements are provided to resist a portion of shear that cannot be resisted by concrete alone.
→ The shear strength can also be related with characteristic compressive strength of concrete. As per IS 456:2000,

(N/mm^2)

Sn	Grade of Concrete	Design shear strength	
		LSM	WSM
1	M15	0.28	0.18
2	M20	0.28	0.18
3	M25	0.29	0.19
4	M30	0.29	0.20

※ Bonding Strength & its test:-

→ A good concrete shall have good bonding ability. Bond exists bet^n the aggregate and cement paste of concrete & also bet^n concrete & reinforcements (if any). Bond strength is provided by strong adhesion property of cement paste. Thus, the bond mainly depends upon the quality of cement paste and compaction of concrete. Normally,

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higher strength concrete has higher bond strength.
→ Accordingly, the bond strength is commonly specified in terms of compressive strength. As per IS456:2000, the design bond strength of concrete with embedded reinforcements can be taken as follows.

Sn	Concrete Grade	Design Bond Strength	
		LSM	WSM
1	M20	1.2	0.6
2	M25	1.4	0.8
3	M30	1.5	0.9

→ The bond test can be performed by pullout test.

Non-Destructive Tests:-

→ It is a method to test existing concrete in place without causing any damage to it. Generally, such test is done to determine the strength of concrete, but most often, it is also used to determine depth, cover to rebar, cracks in the concrete and size and position of rebar inside the concrete.
→ However, very realistic results are difficult to obtain from such test with commonly available tools & instruments. The results are not uniform & its interpretation requires in depth knowledge & analytical skills. They are more often used for qualitative analysis & comparison of results from place to place.
→ Normally carried out
a) Periodically to evaluate the performance of building.
b) To gather information on old building in order to ascertain the method of repair or to demolish.

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→ Different methods of non-destructive test are
a) Rebound Test
b) Penetration and pullout test
c) Dynamic or vibration test
d) Combined test (Dynamic + Rebound)
e) Radioactive & nuclear method
f) Electrical & Magnetic Method
g) Acoustic Emission Test etc.

* Rebound Test:-

→ The rebound test is non-destructive testing method of concrete which is done to estimate the compressive strength of concrete.
→ Also known as schmidt hammer test.
→ Rebound hammer is most easy, quick and commonly used equipment.
→ In this test, a plunger is pressed against concrete surface that charges the spring inside the hammer. When sufficiently pressed, a mass within the hammer gets dropped against the concrete automatically with the spring force & rebounds back, taking a rider along with it in guide scale. With display arrangement, the amount of rebound is displayed in terms of a number called rebound number.
→ This test is affected by following factors like
a) Smoothness of concrete surface
b) Size, shape & rigidity of specimen
c) Age of specimen
d) Moisture Condition
e) Type & dists of Coarse aggregate
f) Type of cement & Mould

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→ Such test usually gives the result with the error of about 15-20%. proper calibration before use reduces such error. These test are commonly employed for comparing of concrete rather than to determine absolute value of strength.

✱ Variability of Concrete strength & acceptance criteria:-

→ The strength of concrete varies from batch to batch & even on same batch too. Hence, a value of standard deviation is to be established for mix design purpose that represents an estimation of deviation of actual strength from mean strength.

→ The variation in strength of concrete is due to
a) Material properties
b) Material proportions like w/c ratio
c) Variation in batching & mixing process
d) Compaction quality
e) Testing methods
f) variation in testing
g) Variation in delivering & handling procedure.
h) Variation in climatic condition.

→ Test Result & acceptance Criteria:

⇒ The test result of a sample is an average strength of three test specimens. The individual variation shall not exceed 15% (+-) of average strength. The concrete is liable to be rejected if it is porous or honeycombed or contain other defects.

⇒ If test results show unexpected values, the load test shall be performed to verify strength. If the member fails in load test also, then the structure is deemed to be unacceptable.

→ The frequency of sampling as specified by IS 456: 2000 is as follows:

SN	Quantity of Concreting (m^3)	Min^m no. of Sample
1	1 to 5	1
2	6 to 15	2
3	16 to 30	3
4	31 to 50	4
5	above 51	4 + Qty/50

→ As per IS 456: 2000, the concrete is deemed to comply with the compressive strength requirements if it satisfies the criteria given in table below.

Specified Concrete Grade	Mean of group of 4 non-overlapping Consecutive test results		Individual Test Results
M15	>= f_{ck} + 0.825 * SD (rounded to 0.5)	whichever is greater	≥ f_{ck} - 3
	f_{ck} + 3		
M20 & above	≥ f_{ck} + 0.825 SD (rounded to 0.5)	whichever is greater	≥ f_{ck} - 4
	f_{ck} + 4		

→ An attempt should be made to obtain results of 30 samples as soon as possible to establish value of standard deviation

→ As per IS 456: 2000, the concrete is deemed to comply with the flexural strength requirements if
i) The mean strength determined from any group of four consecutive test results exceed the specified characteristic strength by at least 0.3 N/mm^2 &
ii) The strength determined from any test result is not less than specified characteristic strength less 0.3 N/mm^2

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→ If test result shows unacceptable values, load test shall be performed to verify strength. If the member fails in load test also, then the structure is deemed to be unacceptable.

* Quality Control & Quality assurance:-

→ Quality means "degree of excellence." Good design is not sufficient but its actual implementation is required for fully quality of work & performance of structure as expected.

→ For overall quality of concreting works, quality shall be maintained on each steps of works & materials.

→ The quality can be controlled by
(i) Using quality material
(ii) By maintaining workability
(iii) Appropriate storage of material
(iv) Testing of material before use.
(v) Care on transportation & pouring (less than 1m height not dropped from)
(vi) Proper compaction, curing
(vii) Control in w/c ratio.
(viii) Good quality assurance plan.

→ Quality assurance is a set of planned & systematic activities which are laid out before a building project starts. The aim of this activity plan is to give confidence that quality requirements will be fulfilled. We can put it simply like this, Quality Assurance is planning to do the right things at right time & right way. It shall cover all the activities of all parties involved in the project.

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* Gel Space ratio:-

→ Gel is liquid form of solid substance. Means when water added to cement powder, then it is called Gel.
Space means pores in Gel. (Empty space in powder that are not filled by water)

→ It is the ratio of volume of hydrated cement paste to the sum of volumes of the hydrated cement and of capillary pores.

Mathematically, $x = \frac{\text{volume of Gel}}{\text{volume of Gel + volume of pores}}$

* Calculation of Gel/Space ratio for complete hydration

Let,
C = Weight of cement in gram
V_c = Specific volume of cement = 0.319 ml/gm
W_o = Volume of mixing water in ml
Assuming that 1ml of cement on hydration will produce 2.06ml of gel
volume of gel = $C * V_c * 2.06 = C * 0.319 \times 2.06$
$= 0.657C$
Total space available = $C * V_c + W_o = C * 0.319 + W_o$
Gel space ratio (x) = $\frac{\text{Volume of gel}}{\text{Space available}} = \frac{0.657C}{0.319C + W_o}$
& Theoretical strength of concrete = $240 * x^3$ MPa.

* Calculation of gel/space ratio for partial hydration

Let C = Weight of cement in gram
V_c = Specified volume of cement = 0.319 ml/gm
W_o = Volume of mixing water in ml.
Assuming that 1ml of cement on hydration will produce 2.06 ml of gel
volume of gel = $C * \alpha * V_c * 2.06 = 0.657C\alpha$
Total space available = $C * \alpha * V_c + W_o = 0.319C\alpha + W_o$
Gel space ratio (x) = $\frac{0.657C\alpha}{0.319C\alpha + W_o}$
& Theoretical strength of concrete = $240 * x^3$ MPa

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Q Calculate the gel space ratio and theoretical strength of sample concrete made with 500gm of cement with 0.5 water cement ratio on full hydration & 60% hydration.

→ Here,

$C = 500gm$, $W_0 = 0.5 \times 500 = 250 ml.$

For full hydration,

$$\alpha = \frac{\text{volume of gel}}{\text{Space available}} = \frac{0.657C}{0.319C + W_0}$$

$$\alpha = \frac{0.657 * 500}{0.319 \times 500 + 250} = 0.802$$

Theoretical strength of concrete $= 240 * x^3 = 240 \times 0.802^3$
$= 123.8 MPa.$

For 60% hydration,

$\alpha = 0.6.$

$$x = \frac{0.657C\alpha}{0.319C\alpha + W_0} = \frac{0.657 \times 500 \times 0.6}{0.319 \times 500 \times 0.6 + 250} = 0.57$$

Theoretical strength of concrete $= 240x^3 = 44.45 MPa$

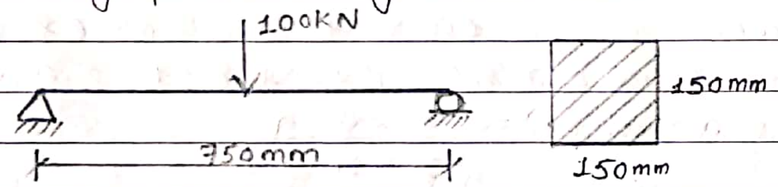
Q Calculate modulus of rupture of concrete beam under single and two point loading for following data; size of beam 150 * 150 mm, length of beam = 750 mm, failure loads for single point load is 100kN & two point loading for each is 50kN.

→ Given,

Size of beam = 150 * 150 mm

Length of beam = 750 mm

(i) For single point loading.



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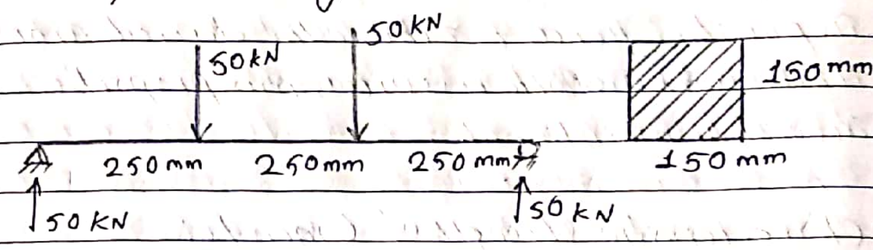
$$M = \frac{P}{2} \times \frac{L}{2} = \frac{PL}{4} = \frac{100 \times 10^3 \times 3750}{4} = 18750000 Nmm$$

$$I = \frac{150 \times 150^3}{12} = 42187500 mm^4$$

$y = d/2 = 75 mm$

Modulus of rupture $(\sigma) = \frac{M}{I} \times y = \frac{18750000}{42187500} \times 75$
$= 33.33 N/mm^2$

(ii) For two point loading:



$M = 50 \times 250 = 12500 kNmm = 1.25 \times 10^7 Nmm$

$I = 42187500 mm^4$

$y = 75 mm$

Then,

Modulus of rupture $(\sigma) = \frac{M}{I} * y = \frac{1.25 \times 10^7}{42187500} \times 75$
$= 22.22 N/mm^2$

Sumit Paudel (NEC)

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ch-5 Mix Design of Concrete:-

Outline:-
1) Introduction to nominal mix
2) Probabilistic concept in mix design approach
3) Concrete mix design as per DOE and IS method.

* Mix proportioning Concept
Ingradients of concrete have to mixed in certain proportion to make the concrete. In doing so, certain workability, surface finish, strength, durability & other properties are desired as economically as possible. Hence, to achieve the desired properties economically with available resources, mix proportion shall be accurately maintained.

* Characteristic Strength of Concrete:-
→ The characteristic strength of concrete is defined as that value of strength, below which, not more than 5% of the test results are expected to fall.
→ The distribution of test result for compressive strength is often assumed to follow standard normal curve. Hence, based on statistics, the mean strength & characteristic strength determined from test of large samples of concrete can be related as,

$$f_{mean} = f_{ck} + 1.65\sigma$$

Where, f_{mean} = Mean strength
f_{ck} = characteristic strength
σ = Standard deviation of test results of concrete.

** Concrete Grade:-
The strength of concrete is specified in term of grade. Hence, particular grade of concrete is representing its strength & corresponding properties. The grade designation of concrete as per IS 456: 2000 is as follows.

Group	Grade Designation	Specified characteristic strength of 150mm cube at 28 days in N/mm^2
Ordinary Concrete	M10	10
	M15	15
	M20	20
standard Concrete	M25	25
	M30	30
	--- M55	-- 55
High strength Concrete	M60	60
	--- M80	-- 80

→ In designation of concrete, 'M' refers to mix and "the number" refers to specified characteristic strength of 150mm cube at 28 days in N/mm^2.

** Probabilistic Concept in mix design approach:-
→ Usually, strength of concrete is specified in terms of characteristic compressive strength. However, the characteristic strength is not only dependent on the average (or mean) strength of the concrete but also the standard deviation in strength of concrete. In other words, the characteristic strength depends on the variation of strength of different concrete samples that may again depend on the material quality and degree of supervision & control. Such variation is higher in higher grade concrete.
→ As per IS456:2000, in absence of test data, the assumed standard deviation ~~deviation~~ for initial design maybe taken as per table-8.
(i) For M10, M15, $\sigma = 3.5\ N/mm^2$
(ii) For M20, M25, $\sigma = 4\ N/mm^2$
(iii) For M30, M35, M40, M45, M50, $\sigma = 5\ N/mm^2$

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→ Hence, to obtain certain specified characteristic strength, i.e to obtain concrete whose at least 95% samples can show certain specified strength, the concrete mix shall be made to target some higher value of mean strength. Assuming standard normal distribution of test results of concrete, the target mean strength of concrete shall be calculated as,

$$f_{mean} = f_{ck} + 1.65\sigma,$$

→ As such, statistics has been used to appropriately account for the probability that, at least 95% samples has test result higher than the characteristic strength. Hence, with 95% confidence level, it can be said that the concrete mix targeted for f_{mean} will have at least the strength of f_{ck}. The standard normal curve showing the position of mean value & characteristic values are shown in figure above.

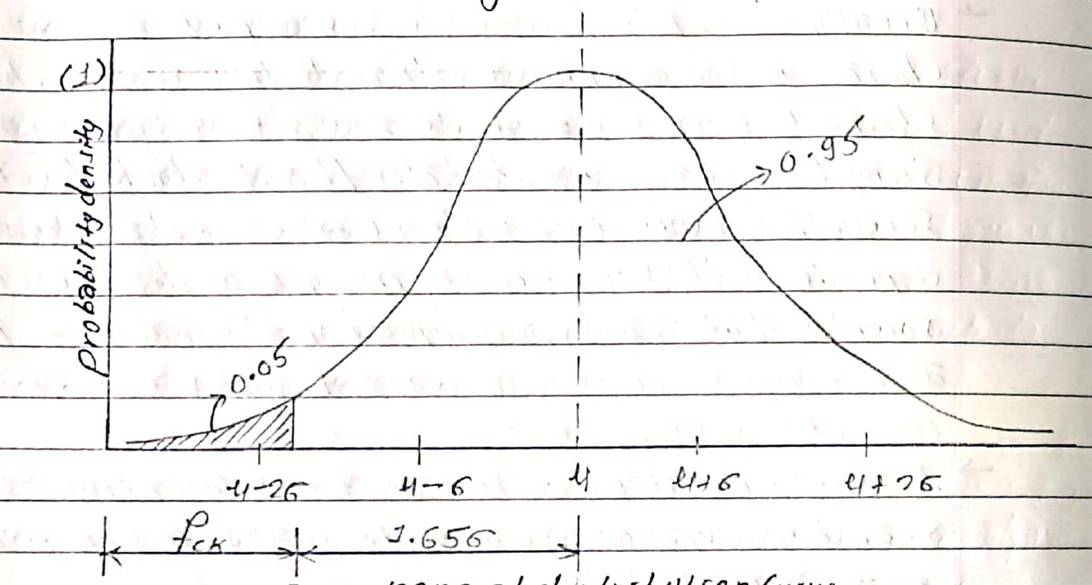


Fig:- normal distribution curve

where, f_c = Strength test value
μ = Mean strength
σ = Standard deviation

Lean Concrete ⇒ having less cement
M60, M80 → High strength Concrete

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* Introduction to nominal mix

→ Nominal mix specifies the fix proportion of cement, sand & aggregates.
→ Ingradient of concrete are mixed on the basis of volume.
→ It is a site level mixing of ingradients to prepare concrete mix.
→ Such type of concrete mix is generally used in small quantity or where load is not high.
→ Nominal mix is used for M20 or less strength of Concrete.
→ Nominal mix, proportion & uses are given below.

Grade of Concrete		Proportion (Cement: Sand: Agg)	Uses.
Lean Concrete	M5	1:5:10	To provide uniform surface to foundation concrete & prevent direct contact with soil
	M7.5	1:4:8	
Ordinary grade of concrete	M10	1:3:6	PCC
	M15	1:2:4	PCC
	M20	1:1.5:3	RCC (beam, slab, column, footing)
Standard Grade of concrete	M25	1:1:2	RCC (slab, beam, column)

* Design Mix:- Design mix is a process to prepare concrete by testing all necessary properties (like properties of cement, fine aggregate & coarse aggregate) of concrete ingradients.
→ Ingradients of concrete are mixed on the basis of weight.
→ It is generally designed from ready mix concrete (RMC) plant.
→ Used in heavy structure construction.
→ When the proportion of its ingradients are decided after trial & error of various options in laboratory. After carrying out tests on individual ingradients with the objective of producing concrete of certain minimum strength & durability as economically as possible. The proportions of ingradients in the design mix differ from project to project.
→ Used for M25 & above grades of Concrete.

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* Factors affecting choice of concrete mix design:-
- Grade of Concrete
- Type & grade of cement
- Maxm nominal size of aggregate
- Grading of combined aggregate
- W/C ratio
- Workability
- Durability
- Quality Control

* Grade of Concrete:
→ The grade of concrete gives characteristic compressive strength of concrete. Depending upon the degree of control available at site, the concrete mix is to be designed for a target mean compressive strength (f_{ck}) applying suitable standard deviation.

* Type & Grade Cement:-
→ The rate of development of strength of concrete is influenced by the type of cement. Higher the strength of cement used in concrete, lesser will be the cement content. The use of 43 grade & 53 grade of cement, gives saving in cement consumption as much as 15% & 25% respectively, as compared to 33 grade of cement. For concrete of grade M25, it is advisable to use 43 & 53 grade of cement.

* Maximum Nominal Size of ~~Carrnate~~ Aggregate
→ The maximum size of C.A is determined by sieve analysis. It is designated by the sieve size higher than larger size on which 15% or more of the aggregate is retained. The maximum nominal size of C.A should not be more than one forth of minimum thickness of member.

→ For heavily reinforced concrete members as in the case of ribs of main beams, the nominal maximum size of the aggregate should usually be restricted to not more than the minimum clear distance between the main bars or 5mm less the minimum cover to the reinforcement, whichever is smaller.
→ The workability of concrete increases with an increase in maximum size of aggregate. But the smaller size of aggregates provide larger surface area for bonding with the mortar matrix which gives higher strength.

* Grading of Combined aggregates:
→ The relative proportions of fine & coarse aggregate in a concrete mix is one of the important factors affecting strength of concrete.
→ For dense concrete, it is essential that the fine & coarse aggregate be well graded. In the case when the aggregate available from natural sources do not confirm to the specified grading, the proportioning of two or more aggregate become essential.

* Water-cement ratio:-
→ According to Abram, the strength of workable concrete mix is dependent only on water/cement ratio. Lower the w/c ratio, greater is the compressive strength.

* Workability:-
→ Workability of fresh concrete determines the ease with which a concrete mixture can be mixed, transported, placed, compacted and finished without harmful segregation & bleeding.

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* Durability:-

→ Durability require low water/cement ratio. It is usually achieved not by increasing the cement content, but by lowering the water demand at given cement content.

→ Water demand can be lowered by through control of the aggregate grading & by using water reducing admixtures.

※ Concrete Mix Design Methods

(a) DOE Method [Department of Engineering]
(b) ACI Method [American Concrete Institute]
(c) IS Method [Indian standard]

※ British Mix Design Method / DOE Method

steps

1) Find target mean strength

$$f_t = f_{ck} + ks$$

Where, f_t = target mean strength
f_{ck} = characteristic strength
k = Risk factor or probability factor
s = standard deviation

2) Determine curve of cement based on the strength.
3) Determine w/c ratio
4) Determine fine & coarse aggregate
5) Determine trial mix ratio.

Q) Using the DOE mix design method, a pcc concrete mix for an application requiring characteristic strength of 35 Mpa at 28 days & slump of 10-30 mm. The materials available are OPC, uncrushed fine & coarse aggregate of sp. gr. 2.65. The maximum nominal size 10 mm (CA), grading zone II (FA), moderate climate & standard deviation 6 & defective rate 5%, probability factor 'k' = 1.65.

from IS456:2000, Max

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→ Solution

1) Determination of target mean strength

$$\sigma_t = \sigma_{ck} + ks$$
$$= 35 + 1.65 \times 6$$
$$= 45 \text{ MPa}$$

2) Determination of free water cement ratio.

For OPC cement & uncrushed C.A with free w/c ratio 0.65, the compressive strength at age of 28 days, $\sigma_{28} = 42$ MPa

From figure 1, for $\sigma_t = 45$ MPa

$$w/c = 0.46$$

Also, from table 2, for moderate climate, PCC

Minimum cement = 240 kg/m³
Max^m free w/c ratio = 0.6
Min^m grade of concrete = M15

Adopt lesser value of w/c. so, w/c = 0.46

3) Determination of water content

For slump of 10-30 mm, Max^m size of aggregate 10mm & uncrush type aggregate, from table 3

Water content = 180 kg/m³

4) Determination of cement content

$$\text{Cement content} = \frac{\text{water content}}{w/c} = \frac{180}{0.46} = 391 \text{ kg/m}^3$$

From table 2, Minimum cement content = 240 kg/m³
Take maximum of above two, cement content = 391 kg/m³

5) Determination of total aggregate.

From figure two, for free water content of 180 kg/m³, specific gravity 2.65 & uncrushed aggregate,

wet density of concrete = 2400 kg/m³

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Therefore, total aggregate in SSD condition = 2400 - 391 - 180
= 1829 kg/m³

Alternative by absolute volume basis,

Total aggregate = 1000 × Sa × $\left(1 - \frac{\text{cement Content}}{Sc \times 1000} - \frac{\text{water cont.}}{1000}\right)$

= 1000 × 2.65 $\left(1 - \frac{391}{3.15 \times 1000} - \frac{180}{1000}\right)$

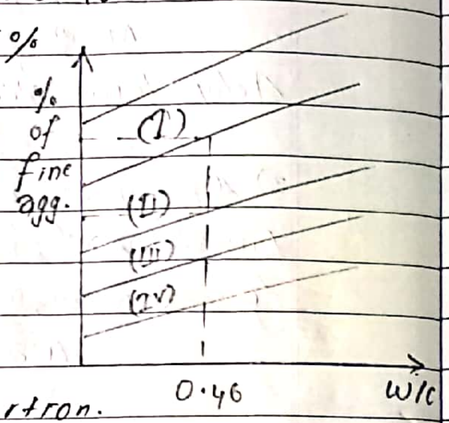
= 1844 kg/m³

∴ Total aggregate = 1829 kg/m³

6) Determination of fine & Coarse aggregate.

For slump value of 10 - 30mm, Maxm size of C.A = 10 mm, grading zone III for FA & w/c ratio 0.46

proportion of fine aggregate = 35%



So, fine aggregate = 0.35 * T.A
= 0.35 × 1829
= 640.15 kg/m³

Coarse aggregate = 1829 - 640.15
= 1188.85 kg/m³

7) Design mix ratio / Final proportion.

Water = 180 kg/m³
Cement = 391 kg/m³
Fine aggregate = 640.15 kg/m³
Coarse aggregate = 1188.85 kg/m³

To obtain ratio, divide all value by cement content.
(Because, while writing mix ratio, we write 1 : -- : ---)

So, cement = 1, Sand = $\frac{640.15}{391}$ = 1.64, aggregate = $\frac{1188.85}{391}$ = 3.04

So, M35 with mix ratio 1 : 1.64 : 3.04
& w/c ratio = 0.46

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* Limitation of DOE method:-

→ The fine aggregates content calculated from DOE method often is on the higher side resulting in oversandy mixes. For zone I, coarse and (600 micron fraction 15 to 20%) the sand content may exceed 50% for moderate workability of 30mm to 60mm slump.

→ The fine aggregate content cannot be adjusted for different cement contents. Hence, a rich mix with cement of 400 kg/m³ will have the same fine aggregate proportion, as a lean mix with 300 kg/m³ cement for given sand. Thus, richer mixes may not be as workable because of higher fines when compared to mixes obtained from IS method.

→ The DOE method also doesnot take into account the effect of the surface texture & flakiness of aggregate on sand & water content although it distinguishes between crushed stone aggregates & natural aggregates.

→ The DOE method doesnot have a specific method of combining 10 mm aggregates with 20 mm aggregates.

→ No specific graphs are available for maximum size of aggregates betn 20mm & 40mm.

* IS Method:-

→ IS 10262:2009 is used for concrete mix proportioning.

→ Data required for mix proportioning

- Grade of Concrete
- Maxm temp^r at pouring point
- Maximum size of aggregate
- Early age strength
- Minimum Cement Content
- Grading zone of FA
- Maximum w/c ratio.
- Type of aggregate
- Workability in terms of slump
- Maxm cement content
- Exposure condition
- Specific Gravity of all materials

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Design Steps:-

1) Target Mean strength:-

$f_{ck}' = f_{ck} + t * s$

t = Tolerance factor

s = Standard Deviation (Table 8 of IS 456:2000)

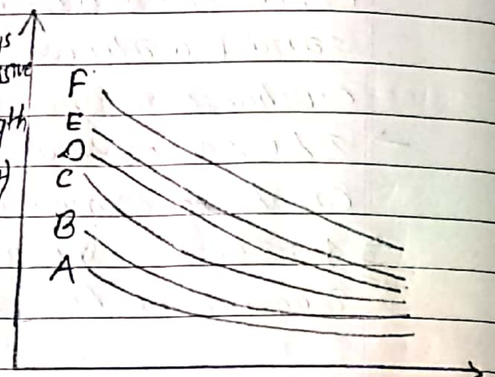
Assuming 5% of the site results are allowed to fall below the characteristic strength, then t = 1.65.

So, $f_{ck}' = f_{ck} + 1.65s$

2) Selection of w/c ratio:-

- w/c ratio is calculated from ABCDEF curves drawn in graph of strength of Concrete & w/c ratio. ABCDEF curves refer to strength of various cement.

A: 31.9 - 36.8 N/mm²
B: 36.8 - 41.7 N/mm²
C: 41.7 - 46.6 N/mm²
D: 46.6 - 51.5 N/mm²
E: 51.5 - 56.4 N/mm²
F: 56.4 - 61.3 N/mm²



- Also find maximum w/c ratio from durability Criteria. (Tables of IS 456:2000) (Table 4 of PU code)
- Lower of two values must be adopted.

3) Selection of water Content:

→ The quantity of maximum mixing water per unit volume of concrete is given in Table 2 of IS 10262:2009.

Nominal size of aggregate (mm)	10	20	40
Maxm water Content (kg)	208	186	165

Upto M35 grade, refer next table for > M35

4) Calculation of Cement Content:-

$$w/c \text{ ratio} = \frac{\text{Water used}}{\text{Cement Content}}$$

$$\Rightarrow \text{Cement Content} = \frac{\text{Water used}}{w/c \text{ ratio}}$$

→ This cement content is to be checked against minimum cement content given in table 5 of IS 456 for durability requirement.
→ Greater of two values must be adopted.

5) Calculation of Coarse & fine aggregate Content:-

→ Coarse Aggregates of different sizes may be combined in different proportions so as to get overall gradings conforming to gradings given in Table 2 of IS 383.
→ From all the above steps, we have estimated the proportions of all the ingredients except CA & FA. As a next step, find out the absolute volume of all the so far known ingredients. Deduct the sum of all the known absolute volume from unit volume (1 m³). The result will be the absolute volume of coarse & fine aggregates put together.

Then, Volume of FA = Combined volume of Agg. − volume of CA.

6) Trial Mixes:

→ With the last step, the weight of all the ingredients in kg/m³ can be found out.
→ Depending upon the absorption characteristics or presence of surface moisture, make the field corrections.

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Q. Design a Concrete mix for M45 grade of concrete with following data

(a) Type of cement	OPC 43 Grades
(b) Maxm Size of Aggregate	20mm
(c) Exposure Condition	Severe (RCC)
(d) Workability	125mm slump
(e) Minimum Cement Contat	320 kg/m³
(f) Maxm w/c ratio	0.45
(g) Method of placing Concrete	Pumping
(h) Degree of Supervision	Good
(i) Type of Aggregate	Crushed Angular Agg.
(j) Superplasticizer will be used	
(k) Sp. gr of Coarse Aggregate	2.80
(l) Sp. gr of Fine Aggregate	2.70
(m) Water absorption:	
Coarse Aggregate	0.5%
Fine Aggregate	1%
(n) Free Surface moisture	
CA & FA	Nil
(o) Grading Zone II	

→ Here,
Characteristic Strength of Concrete (f_{ck}) = 45 N/mm²
Target mean strength (f'_{ck}) = f_{ck} + 1.65 x S
= 45 + 1.65 x 5
= 53.25 N/mm²

[For M45 concrete, S = 5 N/mm², Table 8, IS 456: 2000]

→ Water-Cement Ratio,
For RCC work, exposure condition Severe,
Maxm free w/c = 0.45

~~[Target mean strength = 53.25 N/mm² ... Grade of OPC (Page 3)]~~

For 43 grade Cement, from figure 6,
w/c = 0.42 [Experience of mix designer]
[Here 43 grade ⇒ (41.7 - 46.6) N/mm², Curve c)

∴ Adopted w/c ratio = 0.42

→ Selection of water Content:
For grade of concrete above M35, & for Maxm nominal size of aggregate 20mm,
~~Adopted~~ water content = ~~180~~ kg/m³.
Assume, efficiency of Super-plasticizer = 25%.
So,
Actual water to be added = 0.75 x ~~180~~ = 150 litre

→ Calculation of Cement Content
Cement content = $\frac{\text{Water Content}}{\text{w/c}}$
= $\frac{150}{0.42}$ = 357.14 kg/m³

From IS 456:2000,
For severe exposure, RCC work,
Minm Cement = 320 kg/m³
∴ Adopt. cement Content = 357.14 kg/m³

→ Calculation of Coarse & Fine Aggregate Content:
From Table 3 of IS 10262:2009, for nominal size of aggregate 20mm, Zone II for w/c ratio of 0.5 is found out to be 0.62.
In present Case, w/c ratio is 0.42. The coarse aggregate is ~~red~~ increased at the rate of 0.01 for every decrease in w/c ratio of 0.05.

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Volume of Coarse Aggregate = $0.62 + \frac{0.08}{0.05} \times 0.01$

$= 0.686\ m^3$

Since, it is angular aggregate of concrete is to be pumped, the coarse aggregate can be reduced by 10%

Final volume of CA = 0.9×0.636

$= 0.572\ m^3 \approx 0.57\ m^3$

Volume of fine Aggregate = $0.43\ m^3$.

→ Calculation of Mix proportions.

Volume of concrete = $1\ m^3$

Absolute volume of cement = $\frac{357.14}{3.15 \times 1000}$

$= 0.113\ m^3$

Volume of water = $0.15\ m^3$

Volume of Admixture = $\frac{1.2 \times 357.14}{100 \times 1.1 \times 1000} = 0.00389\ m^3$

[Assuming dosage of 1.2% by weight of cementitous material & Specific gravity of admixture as 1.1]

Total Aggregate volume = $1 - (0.113 + 0.15 + 0.00389)$

$= 0.733\ m^3$

Weight of Coarse aggregate = $0.733 \times 0.57 \times 2.8 \times 1000$

$= 1169.88\ kg/m^3$

Weight of FA = $0.733 \times 0.43 \times 2.7 \times 1000$

$= 851\ kg/m^3$

→ Mix proportion

Cement → ~~360 kg/m³~~ $357.14\ kg/m^3$

Water → $150\ kg/m^3$

FA → $851\ kg/m^3$

CA → $1169.86\ kg/m^3$

Chemical Admixture → $4\ kg/m^3$

$W/C = 0.42$

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→ Site Correction.

Absorption of fine Aggregate = 1%

$= \frac{1}{100} \times 851 = 8.51$ litre

Absorption of CA = 0.5%

$= \frac{0.5}{100} \times 1169.86 = 5.84$ litre.

Total absorption = 14.35 Litre.

So,

Amount of water to be used = $150 + 14.35 = 164.35$ Litres

Actual wt of Fine aggregate = $851 - 8.51 = 842.49$ kg

Actual wt of CA = $1169.86 - 5.84 = 1164.02$ kg

∴ Cement : FA : CA = $357.14 : 842.49 : 1164.02$

$= 1 : 2.358 : 3.259$

With water = 164.35L & $W/C = 0.46$

Chapter-7, Introduction to Masonry Structure

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✻ Composition of Masonry & different types of masonry units (Bonding)

→ A masonry structure is one made by joining multiple number of building blocks (like brick, stone, block etc) usually with cohesive material called mortar. The mortar may be mud mortar, lime mortar, cement mortar etc. Sometimes, based on requirement, dry masonry is also built without any mortar.

* Different types of masonry units:-

(a) Burnt clay building bricks
(b) Sand lime Bricks
(c) Laterite stone
(d) Granite stone
(e) Concrete Block :- • Hollow (25-50% cavity)
• Solid
• Load bearing light weight
• Autoclaved Cellular
(f) Burnt clay Hollow Bricks
(g) Gypsum partition blocks
(h) Stone rubble

✻ Advantage of Masonry Structure:-

→ strength: Strong in compression
→ Heat Absorber:- Resists temperature fluctuation
→ Maintenance Free:- Most of the wall not require painting
→ Fire Resistant:- Fire protection due to formation of non-combustible material.
→ Environmental Friendly
→ Great Sound proofing
→ Use of locally available material.
→ Economic

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✻ Disadvantage of Masonry Structure

→ Moisture Absorber:- Absorbs moisture when raining.
→ Color Deterioration:- Extreme weather causes masonry to degrade. material such as wall surface decolorize due to frost damage.
→ Strength:- Masonry structure have low tensile strength
→ Opening:- Problem in large opening
→ Education:- Lack of education in masonry.
→ Need heavy foundation:- Due to heavy weight, large foundation is required. Also cracking & settlement may occur.

✻ Construction Technology:-

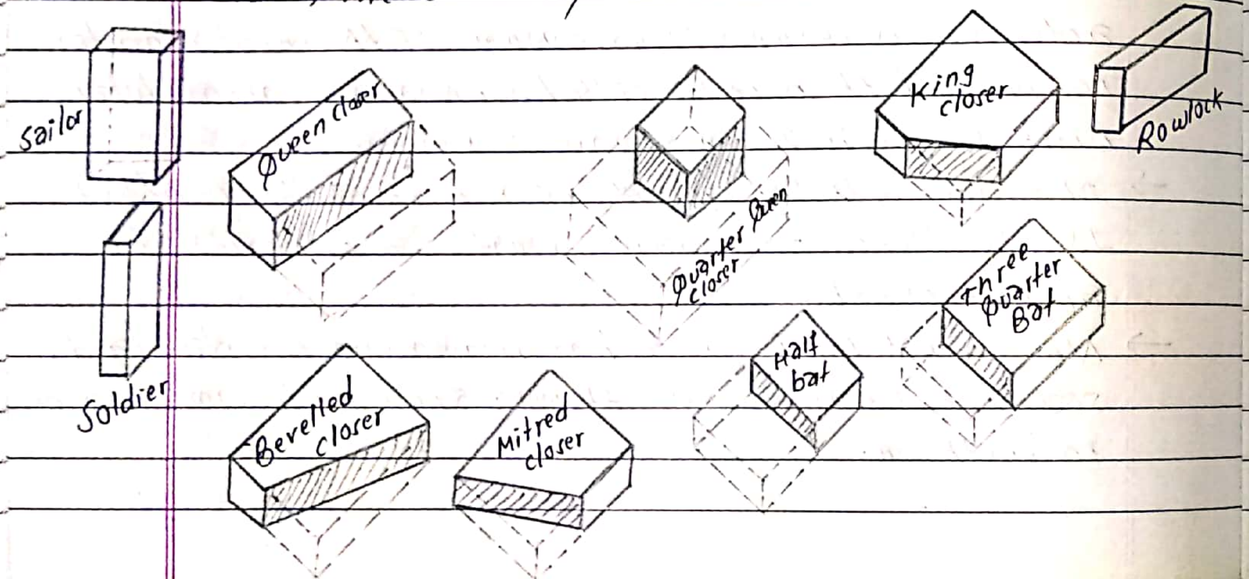
* Size and Weight of Brick:-

→ Bricks which are not standardized are called traditional bricks. If the bricks are large it is difficult to burn them properly & they become too heavy to be placed.
→ On the other hand, if bricks are small, more quantity of mortar is required.
→ Hence, BIS (Bureau of Indian Standard) has recommended the bricks of uniform size, called modular bricks & the actual size is 190 mm × 90mm × 90mm. If thickness of mortar is included then it is called nominal size of modular brick & size is 200mm × 100mm × 100mm.
→ It is found that weight of $1m^3$ of brick earth is about 1800kg. Hence, average weight of a brick will be about 3 to 3.5kg.
→ NBC (Nepal Building Code) has recommend the standard size of brick as 240mm × 115mm × 57mm with 10mm mortar in length side.

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* Basic Terms in Masonry:-

→ Course - Horizontal layer of bricks/stones
→ Bed - Lower surface of bricks/stones in each course which is perpendicular to line of pressure.
→ Backing - Unexposed wall
→ Facing - Exposed to weather
→ Hearting - Between backing & facing.
→ Header - Face of brick when length is perpⁿ to face of wall.
→ Stretcher - Face of brick when length is parallel to face of wall.
→ Bond - Individual brick units are tied together with mortar is called as bond.
→ Closer - A piece of brick obtained after cutting across its length
→ Bat - A piece of brick obtained after cutting a brick across its width.
→ Soldier - Laid vertically with the long narrow side of brick exposed.
→ Sailor - Laid vertically with the broad face of the brick exposed.
→ Rowlock :- Laid on the long narrow side with the short end of the brick exposed.



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* Bonding in Brickworks:-

→ Bonding is the method of arranging the bricks in courses so that individual units are tied together & vertical joints of successive courses do not lie in same vertical line.
→ The unbonded wall has less strength & durability.

Consideration in Brick Masonry

→ Lap should be minimum 1/4th brick along the length of wall & 1/2 brick across the thickness of wall.
→ Bricks bats should be discouraged, except in special locations.
→ The vertical joint in the alternate courses should be along the same perpend.
→ Brick should be of uniform size.
→ All the finished masonry walls should be cured for at least 7 days.
→ Thickness of mortar joint should be uniform & not more than 13mm in any case.
→ Height of Brick masonry in one day should not exceed 1.5m.

✱ Types of Brick Bond:-

(a) Stretcher Bond:-

This bond is formed when stretcher of bricks are laid along the face of wall. Used in partition wall.

(b) Header Bond:-

This bond is formed when head of bricks are laid along the face of wall. 3/4 Bat is provided in each alternative course in corners. Unsuitable for load bearing structures.

c) English Bond:-

It consists of alternative courses of header & stretchers. Queen closer after first header in each heading course.

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d) Flemish Bond:-

→ In this type of bond, each course is comprised of alternative headers & stretchers. Every alternate course starts with header at corner. Quion closer are placed next to the quion header in alternate courses to develop face lap.

(e) Facing Bond:-

This bond is used where bricks of different thickness are to be used in facing & backing of wall.

(f) Dutch Bond:-

Alternative courses of header & stretched bond as in english bond but every stretcher course starts at corner with three quarter bat & header placed after three quarter bat.

(g) Raking Bond:-

The bond formed when bricks are laid on inclination to the direction of walls.

- Diagonal bond (Brick in same direction)
- Herring Bone Bond (Opposite direction)

(h) Zigzag Bond:-

Bricks are laid in zigzag fashion.
Used in brick flooring.

(i) Garden Wall Bond:-

→ In garden wall english bond, header course is provided only after three to five stretcher courses.

→ In garden wall flemish bond, each course contain one header after three to five stretcher.

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* Difference between english & flemish bond:-

English Bond	Flemish Bond
① Headers & stretchers are laid in alternate courses.	① Header & stretcher are laid alternatively in each course.
② stronger	② less strong
③ Provide rough apperance.	③ Provide good apperance
④ Absence of vertical joints	④ Partly continuous vertical joints
⑤ Special attention is not requrred for this joint.	⑤ Special attention is required for this joint.
⑥ Progress of work - fast	⑥ Progress of work - slow
⑦ Costly	⑦ Economic
⑧ Skill labor is not required.	⑧ Skill labor is required.
⑨ less mortar is used.	⑨ More mortar is used.

(j) Rat trap bond:-

→ Bricks are placed in vertical position which creates a cavity in the wall while maintaining the same wall thickness as that of conventional brick masonry wall.

→ Also known as chinese brick bond.

→ Advantage

- Reduce number of brick
- Thermal insulation
- Decrease dead load of building
- For structural safety, reinforcement bar can be inserted.
- Cavity can be used for plumbing, sanitary, wire, cable etc.

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Load Bearing & Non-load Bearing Masonry:-

(a) Non-Load Bearing Masonry:-

→ Such masonry walls are used for partition or similar purpose only. They have to support self weight and wind pressure or seismic force if any. Panel-wall is a non-bearing wall supported by beams & columns in a framed structure.
→ Also known as curtain wall.
→ They are built lighter to reduce dead load of structure.
→ One can remove any non-load bearing walls without endangering the safety of the building.
→ Types
  (a) Hollow Concrete Block wall
  (b) Facade Bricks Wall
  (c) Hollow Bricks Wall
  (d) Bricks wall

(b) Load Bearing Masonry:-

→ These are the masonry walls that have to support considerable vertical loads & lateral loads other than its self weight. Normally, loads are applied on top of the wall from floors or roofs in building structure.
→ Load bearing walls transfer loads to the foundation or other suitable frame members.
→ It may be interior or exterior wall.
→ Types
  - Pre-cast concrete wall
  - Retaining wall
  - Masonry wall
  - Pre-panelized load bearing metal stud walls
  - Engineering Brick wall
  - Stone wall

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Reinforced & Un-reinforced Masonry:-

* Reinforced Masonry:-

→ These are special type of masonry structures which are strengthened by suitably embedding strong & continuous material within the masonry. Such strong material include steel bars, reinforced concrete bands, bamboo, timber & other new materials.
→ These reinforcements are capable of maintaining integrity of masonry units even in large lateral loads & resists a part of forces like tension & shear. In other words, it increases the ductility & strength of structure.
→ It is classified as,
  (a) Reinforced Hollow unit masonry
  (b) Reinforced Grouted Cavity Masonry
  (c) Reinforced pocket type walls.

(a) Reinforced hollow unit masonry:-

→ Vertical Reinforcement is inserted inside brick / block & filled with infill concrete or grout.

(b) Reinforced Grouted Cavity Masonry

→ It consists of two leaves of masonry units separated by a cavity into which the vertical & horizontal reinforcement is placed & grouted with either concrete infill or grout.

(c) Reinforced pocket type walls:-

→ Vertical reinforcement is placed in the wall by special bonding arrangement. In reinforced hollow unit masonry, vertical reinforcing bars are placed in mortar jointed position before laying of masonry unit but in reinforced pocket type walls, the reinforcing bars are placed in mortar joint as the construction of wall progresses.

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* Unreinforced Masonry:-
→ The reinforcing bar is not placed in such type of masonry
→ Likely to be damaged during earthquake.
→ Mortar holding the masonry together is generally not strong enough to resist earthquake forces.
→ Anchorage of walls to the floor & roof is critical.
→ These houses are weak & can break apart.
→ Walls may fall away or buckle, resulting in damage.

** Properties and strength of Cement-Mortar:-
For good masonry work, good mortar is required. The properties of good mortar are

(a) Good Workability:-
→ A good mortar shall be sufficiently workable such that it can be laid to right thickness with sufficient easiness by mason. Addition of small quantity of lime in cement mortar improves the workability without compromising strength.

(b) Sufficient strength:-
→ In general, mortar shall have sufficient strength to resist the load in structure, but shall not be greater than that of masonry units. It shall be confirmed that, the failure of masonry shall be initiated from mortar, not the masonry units in order to make the failure ductile. NBC 109:1995 recommendation in selection of mortar is as follows.

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SN	Masonry Unit Strength (N/mm^2)	Recommend Mortar Type
1	24 and above	H_1
2	15 - 24.9	H_2
3	5 - 14.9	M_1
4	Less than 5	M_2

(c) Water Retaintivity:-
→ A good mortar shall be able to retain the mixed water for longer time so as to maintain the workability during its use. Also after use, it ~~shall~~ shall be able to retain the water (prevent high loss) so as to fascilitate the hydration process. Otherwise, proper hydration may not occur resulting in greater loss in strength.

(d) low Drying Shrinkage:-
→ Generally, the volume of mortar reduces slightly on drying or setting. Such shrinkage may cause cracks in stiffened masonry, especially around the edges. In some case, due to shrinkage, the whole masonry wall may settle slightly, creating debonding from the frame at top & sides. Hence, mortar shall have low drying shrinkage. Good mix proportion, use of properly graded sand, optimum use of water, & good quality cement reduces the shrinkage. For special case, shrinkage resistant cement (or mortar) are also available, especially for grouting

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Masonry Walls under lateral loads:

* Earthquake:-
→ Earthquake cause shaking of ground, so a building resting on it will experience motion at its base.
→ The roof has a tendency to stay in its original position and the roof experiences a force, called inertia force.
→ Inertia force is multiplication of weight of building & acceleration. So, larger the weight of building more the earthquake shaking.

** Masonry Structures:-
→ Masonry is brittle and tensile & shear strength is very low.
→ Due to large masonry structures, heavy weight attracts large amount of seismic forces.
→ Wall to wall connection & roof connection is generally weak. Stress concentration occurs at the corners of windows & doors.

** Lateral loads:-
→ Lateral loads are live loads that are applied parallel to the ground. That means, lateral loads represents the horizontal loads acting on a structure.
→ Common lateral loads
i) Wind load
ii) Seismic load
iii) Water & earth pressure

* Elements of Lateral Load Resisting Masonry System:
(a) Horizontal bands:-
• Plinth band: Band provided at plinth level
• Sill Band- Band provided at the bottom of opening
• Lintel Band: Band provided just above the opening.
• Dowel band (Stitches):- At the corner of walls
• Roof band / floor beam - Roof band shall be provided at the eaves level of trussed roof
• Parapet band: This band shall be provided at top of parapet wall
• Gable band: Bands provided in triangular portion of masonry.
→ The reinforcement in these bands must be provided as per NBC 202:2015, Guidelines on load bearing masonry.

→ Splint:
Vertical band provided on sides of opening & unsupported wall.

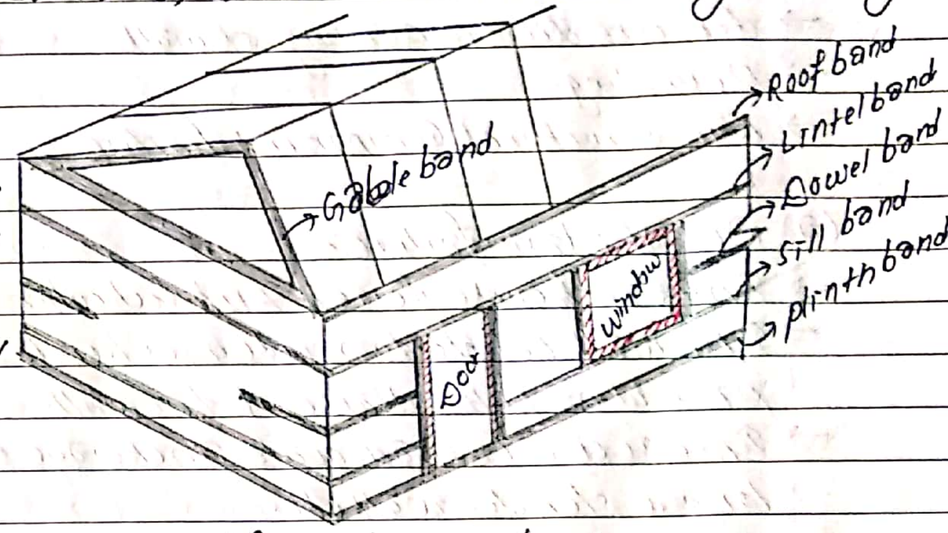


Fig: Different bands in building

(b) Dowels at Corners & Junctions:
→ Steel dowel bars shall be used at corners & T-junction to integrate the box action of walls.

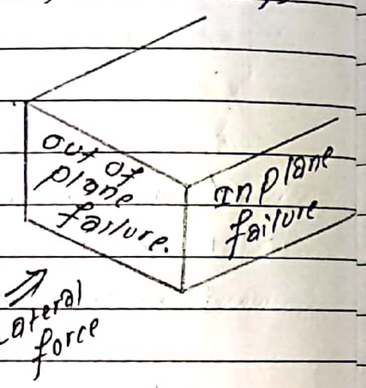
(c) Vertical Reinforcement in Walls:
→ Vertical reinforcement shall be installed at the critical sections like corners of walls & junctions of walls right from foundation concrete, jambs of opening.

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(d) Floors & Roofs:-
→ As a general rule, heavy floors & roofs are source of seismic hazards. Hence, roofs as well as floors should be made as light as possible structurally & functionally.

✻ Failure modes of masonry building:-
→ Out of plane failure
→ In plane failure
→ Diaphragm failure
→ Connection failure
→ Failure due to opening of wall
→ Pounding
→ Non-structural Component failure.

(a) Out of plane failure:-
→ The earthquake force is perpendicular to the plane
→ The wall tends to overturn or bend. This causes the partial or full collapse of the wall.
→ This is due to inadequate anchorage of wall & roof, long & slender wall etc.
→ Characterized by vertical cracks at corner, cracks at lintel, roof level, gable wall etc.



(b) In plane failure:-
→ The earthquake force is parallel to the plane.
→ The wall is shear off or bend & cross crack occurs.
→ Characterized by vertical cracks at wall intersection, separation of corners of two walls, spalling of materials etc.

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→ Types of inplane failure
i) Shear failure
ii) Sliding shear failure
iii) Bending failure.

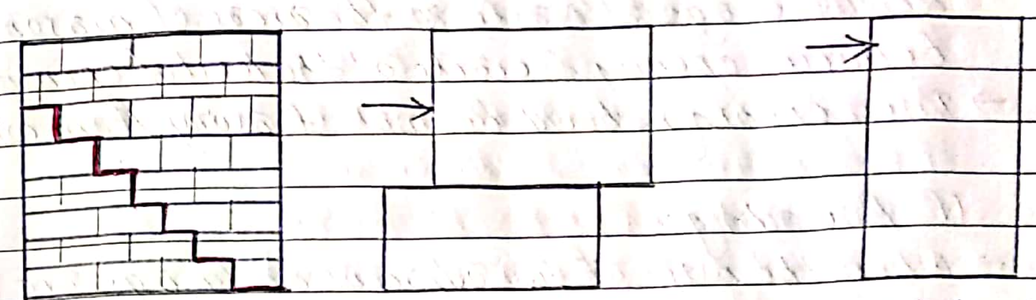


Fig: Shear failure Fig: Sliding Shear failure Fig: Bending failure

(c) Diaphragm failure:-
→ Lack of anchoring produce a push of diaphragm against the wall.
→ Absence of good shear transfer betⁿ diaphragms & reaction walls account for damage at corner of wall.
→ Rare phenomenon in the event of seismic motion
→ Separation of wall & diaphragm cause collapse of buildings.

(d) Connection failure:-
→ For given direction of earthquake, one wall acts as shear wall (In plane failure) & another wall acts as flexural wall (out of plane failure).
→ If the walls are not tied together, shear wall will slide & flexural wall will bend or overturn & collapse occurs. So, masonry units must tied properly.
→ The masonry units can be tied using different bands & reinforcements.

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(e) Failure due to opening in walls:-
→ Opening will obstruct the flow of forces from one wall to another.
→ Large openings in shear wall reduces the strength of wall against the inertia forces.
→ Results diagonal cracks in the areas of masonry between opening & cracks at the level of opening.
→ Thus, opening should be small & away from corners.

(f) Pounding:-
→ When the roofs of two adjacent buildings are at different levels, during earthquake two buildings strike against each other is called pounding
→ Pounding results into cracking of the walls.

(g) Non-structural Component failures:-
→ Falling of plaster from walls & spanning ceiling.
→ Cracking & overturning of parapets, chimneys, partition walls etc.
→ Cracking of glasses
→ Falling of loosely placed objects.

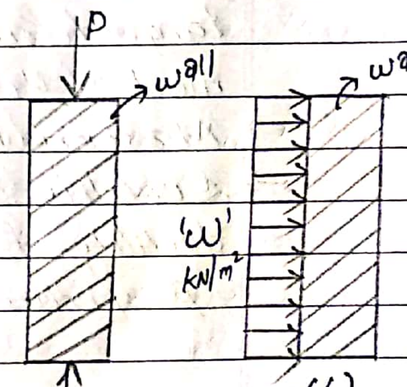
* Failure behaviour of masonry wall in lateral loads
→ The cause of failure of unreinforced masonry building is due to structural defects such as a lack of proper joints, scarcity of walls in one direction and asymmetric layout of resisting elements.
→ The various failure in masonry structure are
1) Diagonal shear cracks
2) Horizontal shear cracks
3) Bending cracks at lintel
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 roof eave.

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* Analysis of stresses on masonry wall under lateral loads:-
→ When wall is subjected to lateral loads such as wind, earthquake etc. bending will occur depending on support condition.
→ Consider a wall subjected to uniformly distributed vertical load 'p' at the centre line in one axis as shown in figure. This force may be by self weight of wall, other external loading & applied uniform compressive stress across the section.
Compressive stress due to load 'p' = P/A ------(1)
→ Again, consider a lateral load 'w' kN/m² applied to the section of wall & the corresponding stress is given by,

$$\frac{\sigma_b}{y} = \frac{M}{I} \Rightarrow \sigma_b = \frac{M}{I/y} = \frac{M}{Z}$$

where, σ_b = bending stress
$M = Max^m BM$
I = MOI about length of wall
Z = Section modulus
y = distance of considered layer from N.A.



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→ The loaded wall will be in compression side & other will be in tension side. Hence, cracks will develop on the tensile side with a minor load. To prevent cracking on tension face, the tensile stresses should not be greater than the applied precompression stresses. ($P/A > M/Z$)

→ Also, for shear stress calculation, consider a wall having length 'l' & thickness 't'.
The shear stress can be calculated as,

$$\tau = \frac{P}{(l * t)}$$

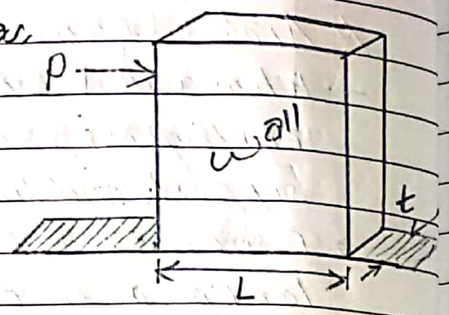


Fig (c)

For combined loading System,

$$\tau = \frac{V}{Ib} * A'\bar{y}$$

where, V = shear force
b = width of section
I = MOI about NA
A' = Area of considered sedion
$\bar{y}$ = distance of CG of considered section from NA.

* Ductile Behaviour of reinforced & unreinforced Masonry structures:-

→ It is the capacity of an element or structure to undergo large deformation beyond yield level while maintaining most of its load bearing capacity.
→ Masonry is brittle in nature.
→ Ductility of masonry structure is governed by the ductility of masonry units and ~~of masonry~~ mortar properties of mortar

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→ Unreinforced masonry cannot withstand tension so cracks develops.
→ In plane and out of plane failure is also due to ductility of masonry.
→ To improve ductility, reinforcing bars are embedded in the masonry, called reinforced masonry which can resist the seismic force more than unreinforced masonry.

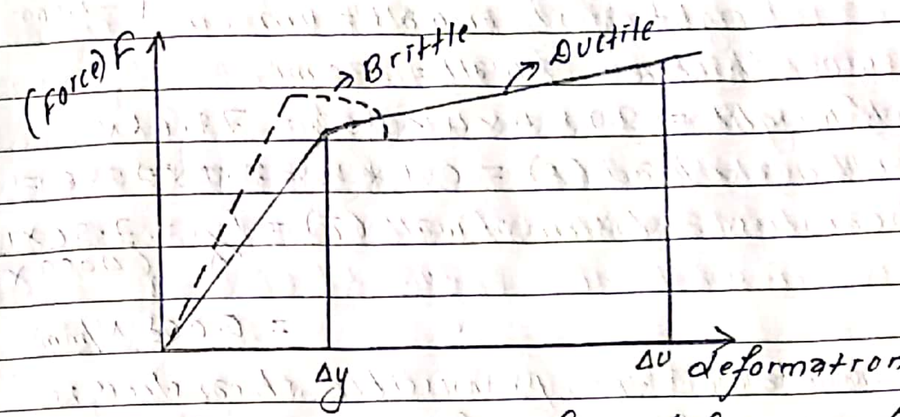


Fig: Brittle and ductile force deformation behavior.

* Major Causes of failures of masonry buildings:-

→ Non-integrity of wall floor & roof
→ Configuration - Irregularity of building causes torsional effect
→ Large opening of the building
→ Inappropriate position of opening
→ Lack of cross wall in large length of walls.
→ Lack of reinforcement make the masonry building brittle.
→ Pounding effect
→ Lack of anchoring element b/t two walls.

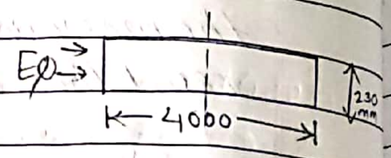
* Delamination: Mode of failure in thick masonry walls in which the wall is separated into number of layers due to poor binding b/t materials & thick section of masonry.

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9. A shear wall is 4m long and 4m high to resist horizontal earthquake force in its plane. The wall is tied at the top and bottom by beam. The ground acceleration is 0.1g. Calculate the thickness, crushing strength & mortar type for wall.

→ Solution,

Given, length of shear wall = 4m
Height of shear wall = 4m



Assume, thickness of wall = 230 mm

Self weight = $20 * 4 \times 4 \times 0.23 = 73.6\ kN$

Earthquake load (F) = $0.1 * W = 0.1 \times 73.6 = 7.36\ kN$

Shear stress at bottom of wall (τ) = $\frac{F}{A} = \frac{7.36 \times 10^3}{(4000 \times 230)}$

$= 0.008\ N/mm^2$

From clause 5.4.3, permissible shear stress is

$f_s = 0.1 + \frac{f_d}{6}$

Here, $f_d = \frac{73.6 \times 10^3}{400 \times 230} = 0.08\ N/mm^2$

So, $f_s = 0.1 + \frac{0.08}{6} = 0.113\ N/mm^2 > \tau$ [shear stress within limit]

→ The bending moment due to lateral load,

$M = \frac{F \times H}{2} = \frac{7.36 \times 4}{2} = 14.72\ kNm$

Bending stress, $\sigma_b = \frac{M}{Z} = \frac{14.72 \times 10^6}{230 \times 4000^2} \times 6 = 0.024\ N/mm^2$

→ Stress reduction factor: (Ks)

$S.R = \frac{h_{eff}}{t_{eff}} = \frac{4000}{230} = 17.39$

eccentricity (e) = $\frac{M}{W} = \frac{14.72 \times 10^6}{73.6 \times 10^3} = 200\ mm$	not necessary

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For e/t = 0 and slenderness ratio = 17.39

From table 9,

16	0.73
17.39	K_s
18	0.67

$K_s = 0.73 + \frac{0.67 - 0.73}{18 - 16} \times (17.39 - 16) = 0.688$

→ Area reduction factor (Ka)

$A = 4m * 0.23m = 0.92m^2 > 0.2m^2$

Hence, Ka = 1

→ Shape modification factor (Kp).

$\left(\frac{Height}{Width}\right)_{brick} = \frac{57}{115} = 0.49 < 0.75$

Assume brick crushing strength is 10 N/mm² & Mortar type M.

Hence, Kp = 1.

Also, Basic Compressive stress (f_b) = $0.96\ N/mm^2$

The permissible compressive stress,

$\sigma_{per} = K_s * K_a * K_p * f_b$

$= 0.688 * 1 * 1 * 0.96$

$= 0.66\ N/mm^2$

But, Actual combined compressive stress:

$\sigma_{act} = \frac{73.6 \times 10^3}{(0.23 \times 4) \times 10^6} + 0.024 = 0.104\ N/mm^2 < \sigma_{per}$

So, provide

Crushing strength of brick = 10 N/mm²
Mortar type = M1
Wall thickness = 230mm

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6. Design an exterior wall of a single storey warehouse of 3.5m height. The vertical load on wall is 30 kN/m from the roof and wind pressure of 100 N/m². The load is tied with metal anchor at floor and roof levels.

→ Let, the thickness of wall = 230 mm

Load from roof = 30 kN/m

Self weight of wall = $0.23 \times 3.5 \times 20 = 16.10$ kN/m

Total load (W) = 46.10 kN/m

Bending Moment (M) = $\frac{pH^2}{10} = \frac{1000 \times 3.5^2}{10} \times 1000$

$= 1225000$ Nmm

Cross sectional area (A) = $230 * 1000 = 230000$ mm²

section modulus (z) = $\frac{bt^2}{6} = \frac{1000 \times 230^2}{6} = 8816666.67$ mm³

Compressive stress (σ_c) = $\frac{W}{A} + \frac{M}{z}$

$= \frac{46100}{230000} + \frac{1225000}{8816666.67}$

$= 0.2 + 0.14 = 0.34$ N/mm²

Effective height (heff) = 3500 mm

Effective thickness (teff) = 230 mm

Hence,

$SR = \frac{heff}{teff} = \frac{3500}{230} = 15.22$

Equ. Eccentricity (e) = $\frac{M}{W} = \frac{1225000}{46100} = 26.57$ mm

$\frac{e}{t} = \frac{26.57}{15.22} = 0.115 \simeq \frac{1}{6}$

For SR = 15.22 and e/t = 1/6, from table 9

14	0.7
15.22	K_s
16	0.63

$K_s = 0.7 + \frac{0.63 - 0.7}{16 - 14} \times (15.22 - 14) = 0.657$

⇒ Area reduction factor

$A = 1 \times 0.23 = 0.23 m^2 > 0.2 m^2$

So, $K_a = 1$

⇒ Shape modification factor.

Let, crushing strength of brick = 10MPa & M1 type mortar

Also, size of brick = 230 * 115 * 57

$\left(\frac{Height}{Width}\right)_{brickunit} = \left(\frac{57}{115}\right) = 0.49 < 0.75$

From table 10, for (h/b) < 0.75 & Crushing strength 10MPa

$K_p = 1$.

Also,

basic compressive stress (f_b) = 0.96 N/mm²

So, permissible stress due to axial load = $f_b \times K_s \times K_a \times K_p$

$= 0.96 \times 0.657 \times 1 \times 1$

$= 0.63$ N/mm² > 0.2 N/mm²

Combined Compressive stress due to axial & bending

$= 1.25 * K_s \times K_a \times K_p \times f_b$

$= 0.63 \times 1.25$

$= 0.788$ N/mm² > 0.34 N/mm²

[safe]

Ch-8 Design of Masonry walls for Gravity Loads:-

* Introduction to Codal Provision:-
→ In the past, there was no any code for designing masonry construction & at that time design is based on thumb rule. The thickness of wall is found very large & uneconomical beyond 3 to 4 stories.
→ Since 1950's intensive theoretical & experimental research has been conducted & code of practice were developed.
→ Code for design of masonry:-
1) IS 1905:1987 → Code of practice for structural use of unreinforced masonry
2) NBC 202:2015 → Guidelines on load bearing masonry
3) NBC 109:1994 → Masonry: Unreinforced.

→ "NBC 109:1994", This code should be read in conjuction with the Indian Standard IS 1905:1987, Code of practice for structural use of unreinforced masonry (third revision).
⇒ This NBC 109:1994 cannot be applied for walls constructed in mud mortar.

* Walls:-
→ Most essential component of building
→ Enclose or divide space of building.
→ provide privacy, afford security & protection against heat, rain and cold.
→ Design wall should have strength & stability, weather resistance & thermal insulation, durability & fire resistance, sound insulation etc.
→ Vertical load bearing member, width of which exceeds 4 times the thickness.
→ loadbearing wall - Designed to carry superimposed load & self weight
→ Non-load bearing wall - Design to carry self weight only.

* Types of Wall
a) Freestanding wall:- Compound wall / paraped on building
b) Retaining wall:- Wall constructed to retain soil pressure.
c) Shear wall:- Wall that carry vertical as well as large in plane loads
d) partition wall:- Interior non-load bearing wall
e) panel wall:- Exterior non-load bearing wall in framed construct
f) Faced Wall:- It is wall in the facing & backing of two different materials are bounded together to ensure common action under load.
g) Veneered Wall:- It is a wall in which facing is attached to the backing but not so bonded as a result in a common action under load.
(h) Cavity Wall:- Wall comprising two leaves separated by cavity.
(i) Curtain wall:- Self supporting wall carrying no other vertical load but subjected to lateral loads.
(ii) Cross wall:- Load bearing walls constructed, in which all loads are carried by internal walls, running at right angles to the length of building.
(k) Buttress wall:- A pier of masonry built as an integral part of wall & projecting from either or both surfaces, decreasing in cross sectional area from top to bottom

* Design Consideration:-
→ Masonry structures gain stability from the support offered by cross walls, floors, roof, piers, buttress etc. Load bearing walls are structurally more efficient when the load is uniformly distributed & structure is so planned that

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eccentricity of loading on the members is as small as possible.

* Lateral Supports & Stability
Lateral supports for a masonry are intended to
i) Limit slenderness of a masonry element so as to prevent or reduce possibility of buckling of member due to vertical loads
ii) Resist horizontal components of forces so as to ensure stability of a structure against overturning.

* Selection of Mortar:-
→ Requirement of mortar for masonry structure workability, strength, water retentivity & low drying shrinkage.
→ Mortar strength in general should not be greater than that of masonry unit.
→ H: High strength, M: Medium & L: Low strength Mortar

Masonry unit strength (N/mm^2)	Mortar type
Below 5	M2
5 to 14.9	M1
15-24.9	H2
25 or above	H1

* Effective Height:-for walls:-
→ The height of a wall or column to be considered for calculating slenderness ratio.
→ Effective height of wall shall be taken from table 4.
(i) Lateral as well as rotational restraint at top & bottom - ~~EE~~
→ 0.75H

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(ii) Full restraint (Lateral & Rotational restraint) at one end & partial restraint (lateral only) at other end → 0.85H
(iii) Partial restraint (Lateral only) at both ends → 1H
(iv) Lateral restraint as well as rotational restraint at bottom but have no restraint at the top → 1.5H
• Where, H ⇒ Height of wall between centres of supports in case of RCC slabs, in case of footing, H is measured from top of footing.

* Effective length:-
→ The length of a wall or column to be considered for calculating slenderness ratio.
→ The effective length of wall is given in Table 5.

* Effective Height for column:-
→ Effective height shall be taken as actual height for the direction it is laterally supported & as a twice the actual height for the direction it is not laterally supported

* Effective Height for opening in walls:-
When openings occur in a wall such that masonry between the opening is by definition a column, effective height of masonry between the openings shall be reckoned as follows.
(a) When wall has full restraint at top
(i) For direction perp^n to plane of wall; $H_{eff} = 0.75H + 0.25H_1$
H_1 ⇒ Height of taller opening
(ii) For direction parallel to wall, $H_{eff} = H$
(b) When wall has partial restraint at top
(i) For direction perp^n to plane of wall
$H_{eff} = H$, when neither opening exceeds 0.5H
$H_{eff} = 2H$, when height of any opening exceeds 0.5H

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(ii) For the direction parallel to plane of wall

$H_{eff} = 2H$

* Effective thickness

→ The thickness of wall or column to be considered for calculating slenderness ratio.

→ For solid walls, faced walls or columns, effective thickness shall be the actual thickness.

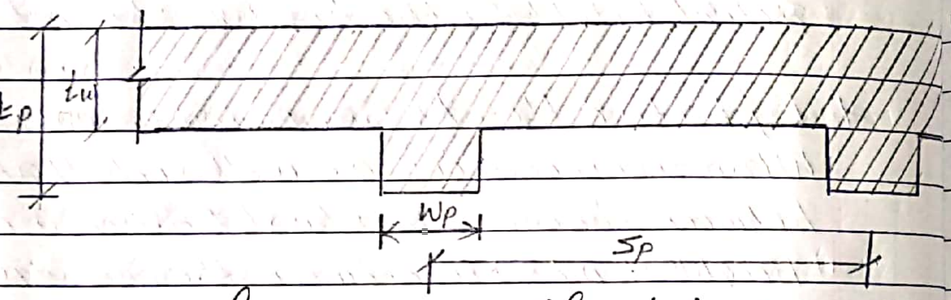
→ For solid walls bonded into pier/buttress, teff is actual thickness of wall multiplied by stiffening coefficient given in table 6. No modification in effective thickness, when slenderness ratio is based on effective length of walls.

S_p = Centre/centre spacing of pier/cross wall

t_p = thickness of pier

t_w = Actual thickness of wall

W_p = width of pier in the direction of wall.



→ For solid walls or faced walls, stiffened by cross walls, appropriate stiffening coefficient may be determined from table 6 on the assumption that the cross walls are eqvt. to piers of width equal to thickness of cross wall & thickness equal to three times the thickness of stiffened wall.

→ For cavity walls with both leaves of uniform thickness throughout, teff shall be taken as two thirds of the sum of actual thickness of two leaves.

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* Load dispersion:

→ The angle of dispersion of vertical load on walls shall be taken as not more than 30° from the vertical.

→ In Intel. length of bearing at each end shall not be less than 9cm or one tenth of span whichever is more.

→ For concentric loading, maximum spread of a concentrated load on a wall may be taken to be equal to (b+4t) (b is width of bearing & 't' is thickness of wall), or stretch of wall supporting the load or c/c distance betⁿ loads whichever is less.

* Permissible Compressive Stress:

The permissible compressive stress is,

$$\sigma_{per} = f_b * k_s * k_a * k_p \quad \text{---------- (1)}$$

Where, f_b = basic compressive stress, depends upon masonry units strength & mix of mortar [Table 8]

[Basic compressive stress → 28 days strength of masonry in compression]

k_s = Stress Reduction factor, depends on SR & e/t ratio [Table 9]

k_a = Area reduction factor, When sectional area of element is less than $0.2 m^2$, $k_a = 0.7 + 1.5A$, otherwise, $k_a =$

k_p = Shape modification factor, depends upon height width ratio of masonry unit & crushing strength. Applicable for units of crushing strength upto 15N/m [Table 10]

* Increase in permissible compressive stresses allowed for eccen vertical loads & lateral loads under certain conditions:-

(i) When $e > \frac{1}{24}$ but $e < \frac{1}{6}$, 25% increase in σ_{per}.

(ii) When $e > \frac{1}{6}$, 25% increase in σ_{per} but area of sectio under tension shall be disregarded for computing the lo carrying capacity of member.

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(iii) When resultant eccentricity ratio of loading is 1/6 or less, compressive stress due to bending shall be ignored & only axial stress need be computed for purpose of design.

* Permissible Tensile stress :-

→ In general, design of masonry is based on assumption that masonry is not capable of taking any tension. However in case of lateral loads normal to the plane of wall which causes flexural tensile stress.

→ Grade M1 mortar → 0.07 N/mm² for bending in vertical direction where tension developed is normal to bed joints. 0.14 N/mm² for bending in longitudinal direction where tension developed is parallel to bed joints. Provided crushing strength of masonry units is not less than 10 N/mm²

→ Grade M2 mortar → 0.05 N/mm² for bending in vertical direction where tension developed is normal to bed joints. 0.10 N/mm² for bending in longitudinal direction where tension developed is parallel to bed joints, provided crushing strength of masonry unit is not less than 7.5 N/mm²

* Permissible shear stresses :-

For walls built in mortar not leaner than grade M1 & resisting horizontal forces in plane of wall, τ permissible calculated on area of bed joint, shall not exceed the value obtained by formula given below, subject to maximum of 0.5 N/mm²;

$$f_s = 0.1 + f_d/6$$

where, f_s = permissible shear stress in N/mm²

f_d = Compressive stress due to dead loads in N/mm²

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* Walls with eccentric loading :-

Consider a masonry section b*d shown in figure subjected to axial load 'W' at point 'p'.

total load eqvt at point p = load 'W' at point 'o' + W * e_x + W * e_y

Area (A) = b × d

$I_{xx} = \frac{db^3}{12}$ & $I_{yy} = \frac{bd^3}{12}$

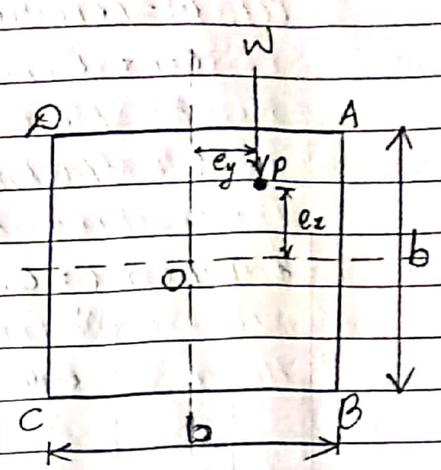


Fig: Eccentric loading

Let, P(x,y) be any point on masonry section.

Stress due to load $W = \frac{W}{A} = \frac{W}{bd}$

Stress due to moment $W \cdot e_x = \frac{M}{I_{xx}} xy = \frac{We_x \times 12 \times y}{db^3}$

Stress due to moment $W \cdot e_y = \frac{M}{I_{yy}} * x = \frac{We_y \times 12 \times x}{bd^3}$

total stress, $\sigma = \frac{W}{bd} + \frac{12We_x y}{db^3} + \frac{12We_y x}{db^3}$

$$\sigma = \frac{W}{bd}\left[1 + \frac{12e_x}{b^2}xy + \frac{12 \times e_y \times x}{d^2}\right]$$

Coordinates,

A $(d/2, b/2)$, B $(d/2, -b/2)$, C $(-d/2, -b/2)$ & D $(-d/2, b/2)$

$$\sigma_{min}\ (at\ c) = \frac{W}{bd}\left[1 - \frac{6e_x}{b} - \frac{6e_y}{d}\right]$$

$$\sigma_{max}\ (at\ A) = \frac{W}{bd}\left[1 + \frac{6e_x}{b} + \frac{6e_y}{d}\right]$$

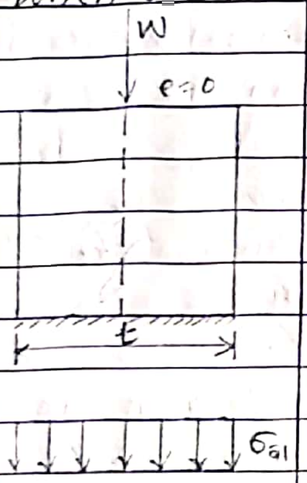
* Stress distribution in eccentrically loaded wall :-

→ Eccentrically loaded wall consists of an axial load & bending moment. These two can be combined into single resultant load acting at a distance which is known as equivalent eccentricity.

$$\sigma = \underset{\text{direct}}{\frac{W}{A}} \pm \underset{\text{bending}}{\frac{M}{Z}} = \frac{W}{Lt} \pm \frac{W \times e}{Lt^2/6} = \frac{W}{Lt}\left(1 \pm \frac{6e}{t}\right)$$

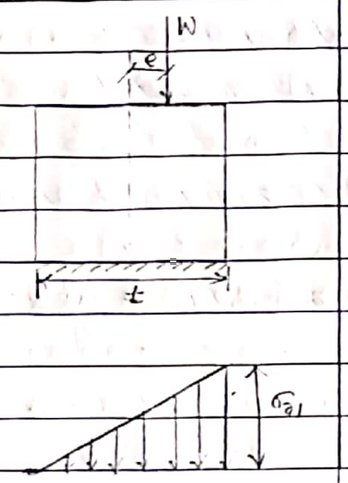
Let, W = permissible load per unit length of masonry
σ_{al} = Permissible compressive stress of masonry
e = Resultant eccentricity of loading
t = thickness of wall

(a) When e = 0,



$\sigma_{al} = W/Lt$

(b) When e = t/6

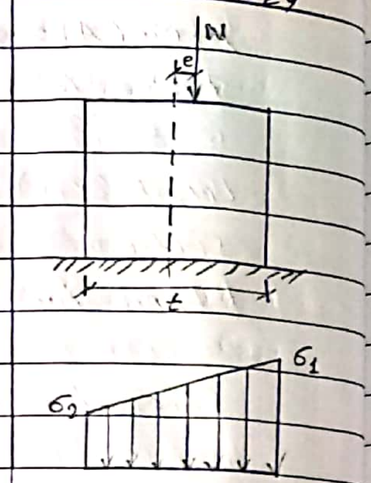


$\sigma_{a1} = \frac{W}{Lt} \times \left(1 + 6 \times \frac{1}{6}\right)$

$\sigma_{a1} = 2W/Lt$

$(\sigma_{a1})_{left} = \frac{W}{Lt}\left(1 - 1\right) = 0$

(c) When e = t/24



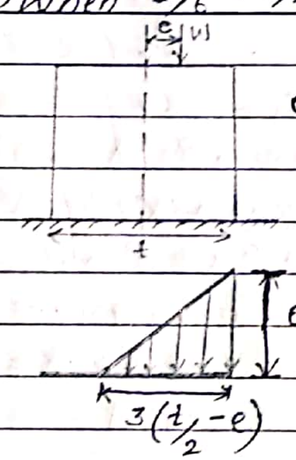
$(\sigma_{a1})_1 = \frac{W}{Lt}\left(1 + 6 \times \frac{1}{24}\right)$

$(\sigma_{a1})_1 = 1.25\,W/Lt$

$(\sigma_{a1})_2 = W/Lt\left(1 - 6/24\right)$

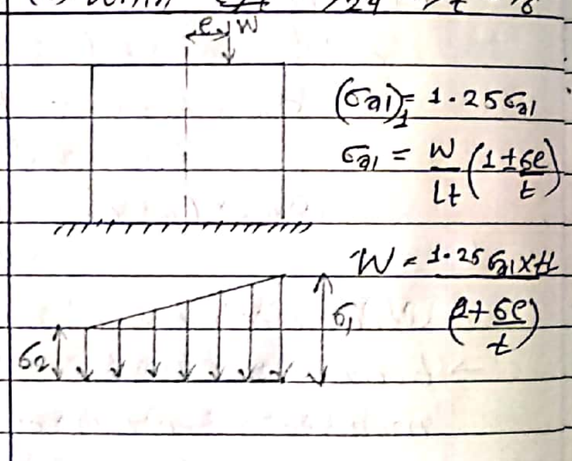
$= 0.75\,W/Lt$

(d) When $1/6 < e/t < 1/2$



$\sigma_{a11} = \frac{2W}{3(t/2 - e)}$

(e) When $1/24 < e/t < 1/6$



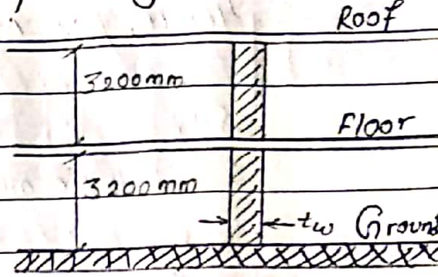
Sumit Paudel (NEC)

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Q. Design an interior cross wall, a two storeyed building to carry 100mm thick RCC slabs with 3.2m ceiling height. The wall is unstiffened & its supports 3m wide slab. Live load from roof = 2.5 kN/m², Live load on floor = 3 kN/m², Weight of 80mm thick terrace = 2 kN/m², weight of floor finish = 0.2 kN/m²

→ Let, wall thickness = 110 mm

Crushing strength of brick = 10MPa & M1 type mortar.



Load Calculation

For roof,

Weight of slab = 0.1 × 25 = 2.5 kN/m²

Weight of 80mm terrace = 2 kN/m²

Live load from roof = 2.5 kN/m²

Total load from roof = 7.0 kN/m²

For floor;

Weight of slab = 0.1 × 25 = 2.5 kN/m²

Floor finish load = 0.2 kN/m²

Live load = 3 kN/m²

Total floor load = 2.5 + 0.2 + 3 = 5.7 kN/m²

Unit weight of masonry = 20 kN/m³

Self weight of wall = 2 (0.11 * 3.2 * 20) = 14.08 kN/m

Total load on wall = (5.7 + 7) * 3 + 14.08 = 52.18 kN/m.

Actual stress (comp.) $\Rightarrow \sigma_{act} = \frac{P}{A} = \frac{52.18}{0.11} \times \frac{1000}{1000 \times 1000} = 0.474\ N/mm^2$

For permissible Compressive stress,

$H_{eff} = 0.75H = 0.75 \times 3200 = 2400$ mm

$t_{eff} = 110$ mm

$S.R = \frac{H_{eff}}{t_{eff}} = \frac{2400}{110} = 21.82 < 27$ [For two storey building, SR < 27]

Eccentricity (e) = 0.

Now, from table 9, for e/t = 0 & S.R = 21.82

20	0.62
21.82	ks
	0.55

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$K_s = 0.62 + \frac{0.56-0.62}{(22-20)} \times (21.82-20) = 0.565$

$\left(\frac{Height}{Width}\right)_{brick} = \frac{57}{115} = 0.49 < 0.75$

For crushing strength 10 N/mm², $K_p = 1$

Also,

$A = 0.23 \times 1 = 0.23 m^2 > 0.2 m^2$. So, $K_a = 1$.

Hence, for M1 type mortar & 10 N/mm² crushing strength

$f_b = 0.96 N/mm^2$

So,

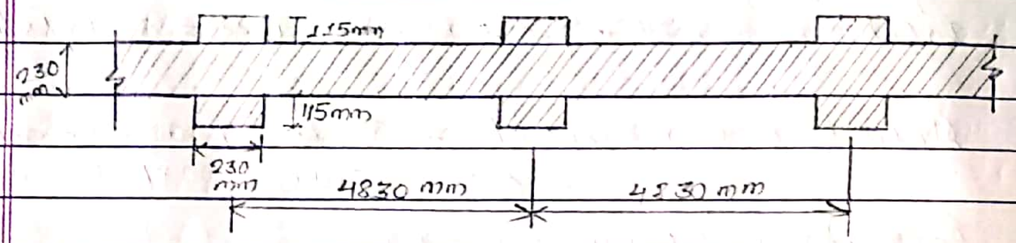
$f_{permissible} = f_b * K_s * K_a * K_p$

$= 0.96 * 0.565 * 1 * 1 = 0.542 N/mm^2$

$> \sigma_{act}$

Hence, wall is safe.

Q) Design an interior wall of a single storeyed workshop of height 5.4m supporting a RCC roof. The bottom of wall rests over a foundation block. Assume roofload = 45 kN/m.



→ Let, the size of brick ⇒ 230 * 115 * 57 mm

Width of pier (Wp) = 230 mm

Spacing of pier (Sp) = 4830 mm

thickness of pier (tp) = 115 + 230 + 115 = 460 mm

thickness of wall (tw) = 230 mm

Now, $\frac{tp}{tw} = \frac{460}{230} = 2$ & $\frac{Sp}{Wp} = \frac{4830}{230} = 21$

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From table 6, stiffening coefficient = 1.

So, Effective thickness of wall = stiffening coeff. * tw

$t_{eff} = 1 \times 230 = 230$ mm

Effective Height (H_{eff}) = $0.75H = 0.75 \times 5400 = 4050$ mm

Load Calculation.

load from roof = $\frac{4830 * 45}{1000} = 217.34$ kN

Self weight of wall = $(4.83 * 0.23 * 5.4 + 2 * 0.23 \times 0.115 * 5.4) * 20$

$= 125.69$ kN

Total load per bay = 217.34 + 125.69 = 343.04 kN

X-sectional area per bay = $4830 \times 230 + 4 \times 115 * 115$

$= 1163800 mm^2$

Actual compressive stress (σ_{act}) = $\frac{343.04 \times 10^3}{1163800} = 0.2947 N/mm^2$

$(S.R)_H = \frac{H_{eff}}{t_{eff}} = \frac{4050}{230} = 17.6$

$(S.R)_L = \frac{L_{eff}}{t_{eff}} = \frac{0.8 \times 4830}{230} = 16.8 \approx 17$

For wall, smaller of above taken. So, SR = 17

For SR = 17 & e/t = 0,

stress reduction factor (K_s) = 0.7

Area of single brick unit (A) = $1.1638 m^2 > 0.2 m^2$

So, $K_a = 1$

Also, $K_p = 1$.

Assume, Mortar type M1 & crushing strength of brick = 10MPa

$f_b = 0.96 N/mm^2$ (Table 8)

$\sigma_{per} = f_b \times K_a K_p K_s$

$= 0.96 \times 1 \times 1 \times 0.7$

$= 0.672 N/mm^2 < \sigma_{act}$.

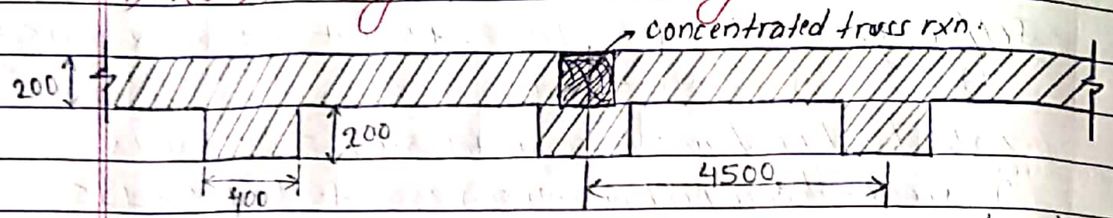
So, Designed wall is safe.

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Q Design an exterior wall of a workshop building 3.6m high carrying steel trusses at the top at 4.5m spacing. The wall is securely tied at roof & floor level. The following shall be assumed as follows.

i) Concentrated reaction from roof truss = 30kN acting at centre of wall

ii) Roof loading = 7kN/m iii) Ignore wind load

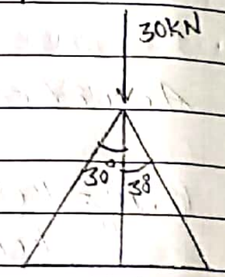


→ Let wall thickness (tw) = 200 mm

Wp = 400 mm & tp = 400mm

Assume, bearing area = 200 x 200

= 4 x 10⁴ mm²



→ For bearing stress,

Concentrated load (P) = 30 kN

$$\text{Bearing stress} = \frac{P}{A} = \frac{30 \times 10^3}{4 \times 10^4} = 0.75\ N/mm^2$$

Let M1 type mortar with 7.5 MPa brick strength,

$f_b = 0.74\ N/mm^2$ (Table 8)

Permissible bearing stress = 1.5 * 0.74 = 1.11 N/mm² > 0.75 N/mm²

[50% increase for bearing] [OK]

→ Check for compressive strength:

Maxm spread of concentrated load = b + 4t

= 200 + 4 x 200

= 1000 mm

$$\text{Self weight of wall} = 20 * 4.5 \times 0.2 \times 3.6 + \left(20 \times 0.2 \times \frac{0.2 \times 3.6}{2}\right)$$

= 70.56 kN

Roof load = 7 * 4.5 = 31.5 kN

$$\sigma_{act} = \frac{30 \times 10^3}{(1000 \times 200) + (400 \times 200)} + \frac{(70.56 + 31.5) \times 10^3}{(4500 \times 200) + (200 \times 200) \times 2}$$

$= 0.214\ N/mm^2$

effective height (Heff) = 0.75H = 0.75 x 3.6 = 2.7m

Here,

$\frac{Sp}{Wp} = \frac{4500}{400} = 11.25$ & $\frac{tp}{tw} = \frac{400}{200} = 2$

From table 6,

10	1.2
11.25	S_c
15	1.1

$$S_c = 1.2 + \frac{1.1 - 1.2}{15 - 10} \times (11.25 - 10) = 1.175$$

Effective thickness (teff) = Stiffening coefficient * tw

= 1.175 * 200 = 235mm

$$SR = \frac{Heff}{teff} = \frac{2.7}{0.235} = 11.489$$

For SR = 11.489 & e/t = 0, from table 9

10	0.89
11.489	K_s
12	0.84

$$K_s = 0.89 + \frac{0.84 - 0.89}{12 - 10} \times (11.489 - 10)$$

= 0.852

So, permissible Compressive stress,

$\sigma_{per} = f_b * K_s$

= 0.74 x 0.852

= 0.631 N/mm² > 0.214 N/mm²

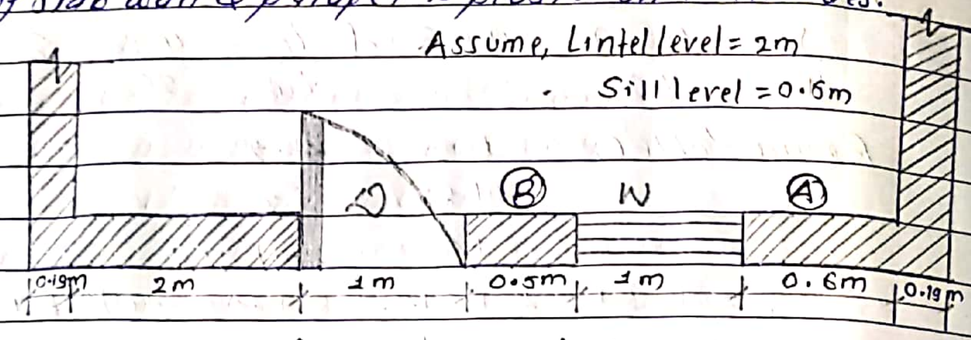
Hence, the designed wall is safe.

Q External Wall of Single storred house is 20cm thick & has door & window opening as shown in figure. plinth level is 1.2m above the top of foundation footing & floor to ceiling height is 2.8m, one way RCC slab of 3m clear span

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bears on the wall & is 10cm thick. Determine the maximum stress in the wall & calculate strength of bricks & grade of mortar required for wall. There is a 20cm thick parapet wall of 0.8m height above the roof slab wall & parapet is plaster on bothsides.

→



Here, thickness of wall with plaster = 19 + 3 = 22cm

Load from parapet = 0.22 * 0.8 * 20 = 3.52 kN/m

Weight of slab = 0.1 × 25 = 2.5 kN/m²

Assuming 1.5cm plaster on bothside.

Weight of plaster = 0.015 * 2 * 20 = 0.6 kN/m²

Total load = 3.1 kN/m²

clear span of slab = 3m

Effective span = 3 + 0.1 = 3.1m (bearing width 10cm)

Roof load on wall = 3.1 × 3.1 / 2 = 4.81 kN/m ↘ (load distribute in two wall)

→ Self weight of wall upto plinth level = 0.22 × 2.8 × 20 = 12.32 kN/m

Total load = 3.52 + 4.81 + 12.32 = 20.65 kN/m

⇒ For wall A,

Length of wall = 0.6 + 0.19/2 = 0.69 m (window side)

Load on wall = 20.65 * (0.69 + 1/2) = 24.57 kN

Since, wall is plastered on bothsides, it may be assumed to have raked joints on bothsides.

Effective thickness of wall = 19 − 2 = 17cm [clause 5.5.1]

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Compressive stress at plinth level = load on wall / Area = 24.57 / 0.17 * 0.69

= 209.46 kN/m²

= 0.2095 N/mm²

Slenderness ratio from consideration of height.

S.R = Effective height / Effective thickness = 0.75 (1.2 + 2.8 + 0.05) / 0.17 = 17.87

Slenderness ratio from consideration of length

S.R = l_eff / t_eff = 2 * 0.69 / 0.17 = 8.32

Since, SR lengthwise < SR heightwise.

SR lengthwise governs the design. [clause 4.6.1]

Area of cross section (A) = 0.17 * 0.69 = 0.117 m² < 0.2 m²

K_a = 0.7 + 1.5A = 0.876

Assume brick of size 190 * 90 * 90 with M1 type mortar.

So, (Height / Width) = 90 / 90 = 1

From table 10, K_s = 1.1

Also, from table 9, for e/t = 0 & SR = 8.32

8	0.95	
8.32	x	x = 0.9404 = K_s
10	0.89	

Basic compressive stress = 0.2095 / (0.876 × 1.1 × 0.9404) = 0.252 N/mm²

⇒ For wall B [∵ t = 76 cm > 0.5m, act as column]

Load on wall at plinth level = 20.65 * (0.5 + 0.5 + 0.5)

= 30.975 kN

Compressive stress in wall at plinth level = 30.975 / 0.17 × 0.5 = 364.41 kN/m²

Effective height of column perp^n to wall = 0.75 H + 0.25 H_1

= 0.75 (1.2 + 2.8 + 0.05) + 0.25 × 2

= 3.54m

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Effective height of column in direction parallel to wall
$H_{eff} = 1.2 + 2.8 + 0.5 = 4.05\ m$

S.R perp^n to wall $= \frac{3.54}{0.17} = 21$

SR parallel to wall $= \frac{4.05}{0.5} = 8.1$

Thus, SR = 21 will govern the design.

For $e/t = 0$ & SR = 21, $K_s = 0.59$

Area reduction factor (k_a) -

$A = 0.5 \times 0.17 = 0.085\ m^2 < 0.2\ m^2$

$K_a = 0.7 + 1.5 * 0.085 = 0.83$

Shape modification factor (k_p)

$k_p = 1.1$

Basic compressive stress (f_b) $= \frac{0.364}{0.83 \times 0.59 \times 1.1}$

$= 0.68\ N/mm^2$

Hence, from table 8, for M1 type mortar with crushing strength 7.5 N/mm^2, $f_b = 0.74\ N/mm^2$.
Hence, design will be safe.

Q) A masonry wall 230 mm thick carries an axial load 30 kN/m from wall above & eccentric load 22 kN/m from RCC floor acting at a distance 45 mm from centreline of the wall. Determine the resultant eccentricity of loading & eccentricity ratio.

→ Let, W = Total vertical load
$\bar{e}$ = Resultant eccentricity of all loads

Here, $W_1 = 30\ kN/m$
$W_2 = 22\ kN/m$
$W = W_1 + W_2 = 52\ kN/m$

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Taking Moment about Centre line of wall

$W \times \bar{e} = W_1 * 0 + W_2 * 45$

$\bar{e} = \frac{30 \times 0 + 22 \times 45}{52} = 19\ mm$

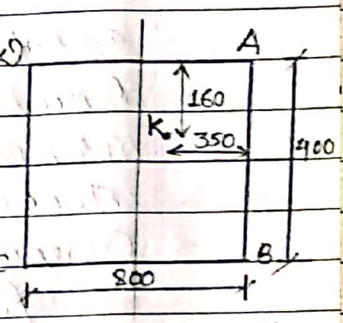
Resultant eccentricity ratio,

$\frac{e}{t} = \frac{19}{230} = 0.08$

Q) A column 400mm * 800mm carries load 250 kN acting at 160 mm from the 800 mm face & 350 mm from 400 mm. At all corners of column, determine the stress intensities.

→ Here,

$b = 400\ mm$, $W = 250\ kN$
$d = 800\ mm$
$e_x = \frac{400}{2} - 160 = 40\ mm$
$e_y = \frac{800}{2} - 350 = 50\ mm$



Stress at points given by, $\sigma = \frac{W}{bd}\left[1 + \frac{12 e_x * y}{b^2} + \frac{12 e_y \times x}{b^2}\right]$

Coordinates, A(0.4, 0.2), B(0.4, −0.2), C(−0.4, −0.2) & D(−0.4, 0.2)

Then,

$\sigma_A = \frac{250}{0.8 \times 0.4}\left(1 + \frac{12 \times 40 \times 200}{400^2} + \frac{12 \times 50 \times 400}{800^2}\right)$

$= 1542.96\ kN/m^2$

Similarly,

$\sigma_B = 605.46\ kN/m^2$
$\sigma_C = 19.53\ kN/m^2$
$\sigma_D = 957.03\ kN/m^2$

From here, it is seen that, stress is maximum @ A & minimum at C.

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Q Design a cavity wall of two storey building with height 3.5m each consists of RCC slab with total UDL from roof is 20kN/m & from floor is 30kN/m.

→ Let, overall thickness of cavity wall be 250mm with each leaf being 100 mm thick.

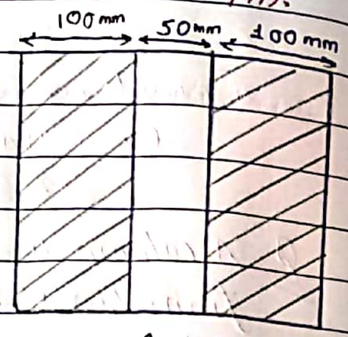


Fig: Cavity wall

Load from roof = 20 kN/m
Load from floor = 2 × 30 = 60 kN/m
Load from wall = 2 * (20 * 0.2 * 3.5)
= 28 kN/m

Total load = 108 kN/m.

Since, nothing is given on the eccentricity of load. We assume load is applied at centre of wall.

Area of each leaf = $100 \times 1000 = 10^5 \text{ mm}^2$

Compressive stress due to axial load on each half is,

$$f_{ca} = \frac{108}{2 * 0.1} = 540 \text{ kN/m}^2 = 0.540 \text{ N/mm}^2$$

$$t_{eff} = \frac{2}{3}(100 + 100) = 133 \text{ mm} \quad [4.5.4 \text{ clause}]$$

$$H_{eff} = 0.75H = 0.75 \times 3.5 = 2.625 \text{ m}$$

$$SR = \frac{H_{eff}}{t_{eff}} = \frac{2.625}{0.133} = 19.736$$

For SR = 19.736 & e/t = 0

$K_s = 0.626$.

Also, $A = 0.1 * 1 = 0.1 \text{ m}^2 < 0.2 \text{ m}^2$

$k_a = 0.7 + 1.5 \times 0.1 = 0.85$

$k_p = 1$, Let M1 be mortar type & Crushing strength = ~~10~~ 12.5 MPa

Basic compressive stress (f_b) = 1.06 N/mm²

Then, permissible comp. stress = $1.06 \times 0.85 \times 0.626 \times 1$
= 0.564 N/mm² > 0.540 N/mm²

Hence, provide M1 mortar with crushing strength = 12.5 MPa

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Ch-10 Testing of Masonry Elements:-

Outline:-
→ Compressive strength of masonry units & masonry walls
→ Diagonal shear test
→ Non Destructive Tests (Elastic Wave Tomography, Flat Jack & Push shear Test)

⇒ Masonry is composed of masonry units & mortars with or without additional reinforcing materials. The property of masonry wall directly depends upon properties of masonry units & mortar.

Compressive Strength Test of Masonry Units:-

a) First sufficient number of samples are taken by appropriate sampling procedure.
b) Remove unevenness observed in bed faces to provide two smooth parallel faces by grinding.
c) Immerse in water at room temperature for 24 hours.
d) Remove the specimen & drain out any surplus moisture at room temperature.
e) Fill the frog & all voids in the bed faces flush with cement mortar (1:1, sand being clean & grade 3mm or down)
f) Store it under the damp jute bags for 24 hours filled by immersion in clean water for 3 days. Remove & wipe out any traces of moisture.
g) The sample is placed in compression testing machine with flat faces horizontal & mortar filled face upward, between two 3-ply plywood sheets each of 3mm thickness, & centered between plates of testing machine.
h) Load is increased at uniform rate of 14 N/mm² per minute till failure occurs.
i) The maximum load at failure is noted.

$$\sigma_c = \frac{\text{Max}^m \text{ load at failure}}{\text{Avg. area of bed faces.}}$$

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(ii) The average of above result gives the average strength of masonry unit in compression.

* Compressive Strength Test of Masonry Walls:-

→ The strength of masonry in compression can be calculated/determined by following two methods
  i) Unit Strength method
  ii) prism test method

* Prism Test Method:

→ Assembled prism specimen shall be at least 40cm high & shall have height to thickness ratio (h/t) of at least 2 but not more than 5. The prism shall be tested after 28 days between sheets of nominal 4mm plywood in testing machine the upper platform of which is spherically seated. The load shall be applied evenly distributed over the whole top & bottom surfaces at the uniform rate of 350 to 700kN per minute. The load at failure shall be recorded.

→ The compressive strength of masonry from test is the ultimate load per unit bed area of masonry. The obtained strength shall be corrected by multiplying with a factor as indicated below.

Correction factors for different h/t ratios

h/t ratio	2	2.5	3	3.5	4	5
Correction for brickwork	0.73	0.8	0.86	0.91	0.95	1
Correction for blockwork	1	0.5	1.2	1.25	1.30	1.37

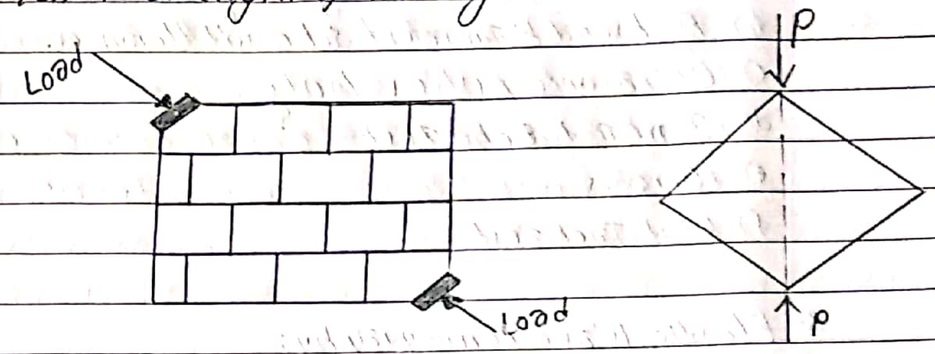
→ Interpolation is valid for intermediate values.

* Purpose of testing of masonry

1) Periodically, to evaluate the performance of building
2) To gather information on old building in order to ascertain the methods of repair or to demolish
3) To ascertain strength of concrete if cube tests failed.

* Diagonal Shear Test:

→ In load bearing masonry walls, shear walls carry vertical loads and resist lateral in plane loads. This combined loading creats principal tension stresses in the wall leading to tensile cracking when the tensile strength of masonry is exceeded.



→ To evaluate masonry shear strength (diagonal tension) & shear elastic modulus, this test is performed on rectangular masonry specimen representing actual masonry structure with diagonal axis in vertical direction & loaded in compression along this direction.

→ Then shear stress obtained is calculated as,

$$\tau = \frac{0.707P}{An}$$

Where, P = load applied by jack

An = Net specimen area = $[(w+h)/2] \times t * n$

where, w, h & t = width, height & thickness of masonry

n = proportion of solid of masonry unit (1 for solid unit)

Shear modulus, (G) = τ/γ

where,

τ = Diagonal shear stress | Pd = applied comp. load

γ = Shear strain | Pdu = Maxm value of Pd

Shear strength = $\frac{Pdu}{\sqrt{2} \times A}$ { $\tau_{max} = 1.1\frac{Pd}{A}$

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* Non-Destructive Test:-

→ Non-destructive test is such test which does not impact the structural strength, stability or integrity of the structure under test.

→ Such method is very useful for assessing the old structure for its strength & to suggest if strengthening is required.

→ The major non-destructive test (NDT) are,

a) Elastic Wave Tomography
b) Rebound Hammer/ Schmidt Hammer.
c) Ultrasonic pulse velocity
d) Impact Echo Test
e) X-rays
f) Flat Jack Test

* Elastic Wave Tomography:

→ Technique used for locating shallow delaminations, cracks and voids.

→ Elastic wave tomography is based on two basic principles from heat transfer: Conduction & radiation. Sound materials with no voids, gaps or cracks are more thermally conductive than materials that are delaminated or contain moisture.

→ This allows rapid areal mapping of internal conditions. It should be noted that the IT method is most useful for the detection of shallow defects & flaws.

→ Tests for: Voids, Cracks, Moisture

* Flat Jack Test:-

→ Flat Jack Testing is a non-destructive test of evaluating existing masonry structure. It does not require removal of masonry units, only the removal of small portions of mortar is enough.

→ The flat jack test uses small, thin, hydraulic jacks to apply a force to a section of an existing masonry wall, and the method uses measuring devices to determine the resulting displacement of the masonry.

→ Flat jack testing has many useful applications:-

(i) It can be used to determine masonry compressive modulus, which is the stress/strain relationship of the masonry, or axial stress by applying axial load & measuring resulting axial deformation.

(ii) It can be used to estimate compressive strength & measure the shear strength.

(iii) If the destruction of the masonry units is acceptable, it can be used to directly measure the compressive strength by testing the masonry to failure.

→ Two types of flat jack test

a) Single flat test or insitu stress test
b) Double flat jack test or insitu deformability test.

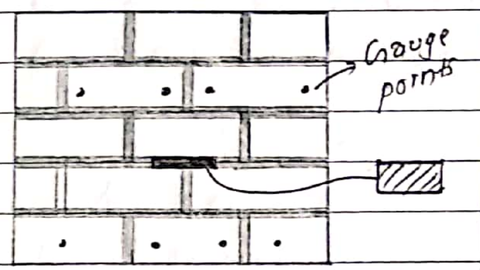


Fig:- Single flatjack test

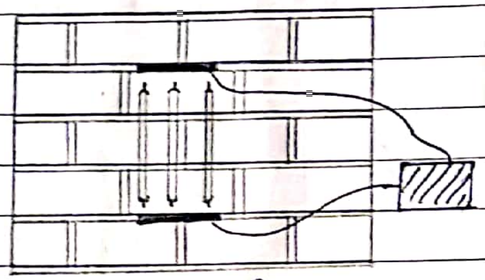


Fig:- Double flat jack test.

* Push Shear Test:-

→ Prepare the test location by removing the brick including the mortar, on one side of the brick to be tested. The head joint on the opposite side of the brick to be tested is also removed. Care must be exercised so that the mortar joint above or below the brick to be tested is not damaged.

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→ The hydraulic ram is inserted in space where the brick was removed. A steel loading block is placed bet" the ram and the brick to be tested so that the ram will distribute its load over the end face of the brick. The dial gauge can also be inserted in the space.

→ The brick is then loaded with ram until the first indication of cracking or movement of the brick.

→ The ram force & associated deflection on the dial gauge are recorded to develop a force deflection plot on which the first cracking or movement should be indicated. A dial gauge can be used to calculate a rough estimate of shear stiffness.

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Q what will be the 28 days strength of concrete having w/c = 0.4 as per Abhrams eqn. Assume, $k_1 = 14000$ lbs/sq.in & $k_2 = 7$ lbs/sq.in

→ Here,

$w/c\ (x) = 0.4$

$k_1 = 14000$ lbs/sq.in

$k_2 = 7$ lbs/sq.in

Strength of Concrete in 28 days $= \frac{A}{B^x} = \frac{k_1}{k_2^x}$

$\Rightarrow S = \frac{14000}{7^{0.4}} = 6428.19$ lbs/sq.in

$\Rightarrow S = \frac{6428.19 \times 0.45 \times 9.81\ N}{(2.54 \times 10)^2\ (mm^2)}$

$\Rightarrow S = 43.984\ N/mm^2$

$\Rightarrow S \approx 44$ Mpa.

Sumit Paudel (NEC)

The End

Best of Luck