

I N D E X

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S.No.	Date	Title	Page No.	Teacher's Sign/Remarks
Disclaimer: Use this note for revision purposes only.				
		Writers		
		→ MS Shetty		
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		Masonry		
		→ A S Arya		
		→ P. Dayazatham		
		Concrete technology (52)		
6+4		1. Introduction to concrete and concrete Materials.		
6		2. structure of concrete		
8		3. Mix Design of concrete and property of Green concrete		
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		Masonry Structure (28)		
		1. Introduction to Masonry Structure		
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		3. Masonry structure under lateral loads.		
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https://www.surendrasharma0001.com.np/				

w/c
 agg & adm
 Bogues

1 Introduction to concrete and concrete materials

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History Of use of concrete in structures

- Jungle edge: cave for safety and from effect of sun, rain, wind
- Got the concept of agriculture → huts of plant
- started using dry stone
- Bricks and concept of lime was introduced
- Joseph Aspdin in 1824 developed OPC cement.
- Cement replaced lime.

Concrete: It is properly mixed composite material consisting of

- Binding material (cement or lime), 10-15%
- Aggregate (fine and coarse) - 70-75%
- Water: 15-20%

• Admixtures (optional ^{add as material} added to improve ^{of material} property) Concrete Technology (deals with concrete and its properties)

→

cement + water
↓
Binding cement paste

+
Fine aggregate

↓
Mortar

+
coarse aggregate

↓
Concrete

* Advantages of concrete

- easily availability of ingredient ^{why?}
- High compressive strength
- can be manufactured to desired strength

- versatile in shape and monolithic character (no need to attach two concrete with the help of nailing, riveting, etc. is monolithic character)
- Durability, water resistance, temperature resistance.
- Easy handling and transportation

* Disadvantages of concrete

- low tensile strength (is brittle)
- Need skilled workmanship and the formwork
- Joint are required for long structure.
- Soluble salts in concrete cause efflorescent
- prone to creep and shrinkage

Types of concrete

(1) Based on binding material

- (a) Cement concrete - cement is used as binding material
- (b) Lime concrete - lime is used as binding material

2) Based on design

- Plain Cement concrete (P.C.C.)
- Reinforced cement concrete (R.C.C.)
- Prestressed Cement concrete - compressive strength artificially introduced before use

(iii) Based on density: Light weight ($1000-1800 \text{ kg/m}^3$) and heavy weight concrete ($2200-3000 \text{ kg/m}^3$)

(iv) Based on purpose - Fibre reinforced concrete
 - Fibre resistance concrete
 - vacuum concrete (excess water removed by vacuum)
 - Aerated concrete (aluminum used as admixture)

(v) Based on setting: Green (wet)
 Just (dry)

Aggregates:

Aggregates are inert material (chemically inactive) occupying 75% of the concrete volume. Such as sand, gravel, slag, crushed stone, etc. They act as filler only. They do not react with cement and water

* Type of aggregate:

(i) Based on source

Natural and artificial aggregate (crushed aggregate, blast furnace aggregate)

(ii) Based on size

coarse and fine aggregate ($4.75 \text{ mm} \pm 5$ sieve)
 (retain on 4.75 mm sieve)

(iii)

Based on shape → Rounded (33% voids, require minimum cement paste, poor bond, less interlocking. unsuitability for high strength concrete)

Irregular (35-39% voids, require more cement paste, better interlocking than round, unsuitable for high strength concrete)

Angular (38-45% voids, round texture, crushed rock, require more paste, good bonding, better for high strength concrete)

Flaky and elongated particle

(IS 383 recommends not more than 10-15% of aggregate mass)

Flaky → If the least dimension of particle is less than 0.6 times mean sieve size

elongated → If the longest dimension is greater than 1.5 times the mean sieve size

Note: Mean size: If particle pass through 40mm sieve and retain in 20mm sieve then mean sieve size is $\frac{40+20}{2} = 30\text{mm}$

• Flakiness index: $\frac{\text{Mass of flaky particles}}{\text{mass of sample}} \times 100\%$

• Elongation index: Also a closer size, control is necessary, the sieve considered are not standard

• Texture: visual estimation; quite reliable, depends on hardness, grain size, pore characteristics.

mean sieve size → arithmetic mean of sieve size at which aggregate just pass & retain.

concrete based on
4. type of texture

(a) Glassy: conchoidal fracture, shell like surface

(b) Smooth: better worn or smooth due to fracture

(c) Granular:

(d) rough:

(e) crystalline:

(f) Honeycomb:

(5) Density (Normal weight (2.2 to 2.6) sp.)

(b) Surface (a) very dry (c) saturated surface dry (d) wet

Surface dry → preferred for construction

Shape parameters:

→ Angularity number

→ Sphericity.

Aspect of shape of coarse aggregates:

1. Angularity Number: The degree of packing of particles all of one size depends on their shape, the angularity of aggregate can be estimated from proportion of voids among particles.

Angularity number of aggregate is amount (to the higher whole number) by which the percentage of voids in it after compacting in prescribed manner exceed 33 (voids in rounded aggregate)

In angularity no. test, a quantity of single sized aggregate is filled into metal cylinder of 3lt capacity.

If the void content of aggregate is 33% the angularity of such aggregate is considered 0. If void is 44% the angularity no. of such aggregate is considered 11. (Normally should be 0-11)

BS 812: 67 minw the percentage of solid volume in vessel filled with aggregate in a standard manner. The no. 67 in the expression for angularity number represents the solid volume of the most rounded gravel.

2. Sphericity:

Ratio of surface area to its volume is called sphericity. Particle with high ratio of surface to volume are of particular interest as they lower the workability of mixture. Elongated and flaky particles are of this type.

High sphericity detrimentally affects durability as they tend to cause orientation in one plane with water and air voids forming underneath.

3. Shape index = $\frac{\text{Mass of both flaky and elongated particle}}{\text{Mass of sample}}$

4. Properties of Aggregate:

(i) Physical property

(a) Specific gravity $\rightarrow$ Absolute $\rightarrow$ weight of aggregate to wt. of same vol^m of water.

Absolute
mass of agg. dried in oven
mass of water occupying vol^m
equal to solid excluding pores

Apparent
mass of agg. dried in oven
mass of water occupying vol^m
equal to solid including intermediate pores

Apparent $\rightarrow$ volume of solids including impenetrable pores but not capillary ones.

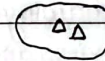
Test: Pycnometer test, wire-basket method

(c) Porosity and Absorption:

Influences bonding between aggregate and cement paste, resistance to freezing and thawing, chemical stability, resistance to abrasion, specific gravity

(d) Moisture content

Bone dry



Absorbed moisture

Air dry

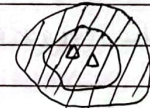


Saturated surface dry



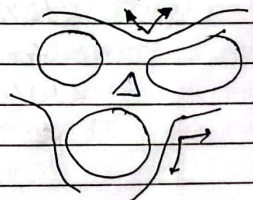
Free moisture

Wet



(e) Bulking

$\rightarrow$ Interparticle repulsion is cause of bulking
 $\rightarrow$ Process by which fine aggregates increase in volume upon increment of moisture upto threshold.

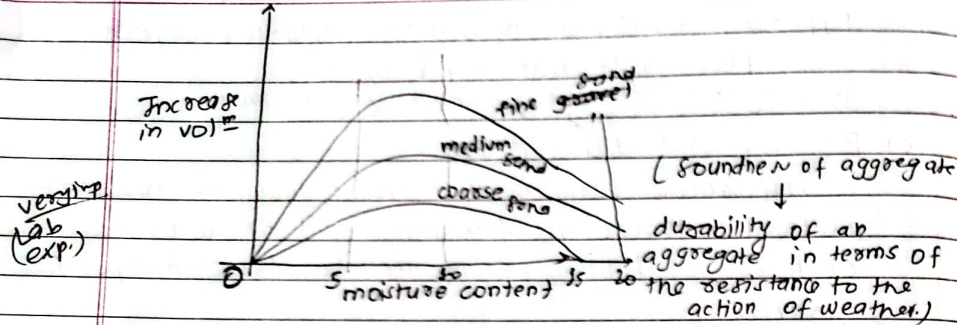


$\rightarrow$ When water is added to dry sand a thin film forms around the particle increasing capillary interaction b/w water films.

(water added to dry sand $\rightarrow$ thin film forms around sand particles which generated surface tension and creates a state of interparticle repulsion resulting in increase in vol^m.)

20, consider effect of volume batching

Maximum Bulking threshold



(f) Soundness: Resistance to excessive change in volume of aggregate due to physical changes (freezing and thawing, variance in temperature, alternative drying and wetting)

- Testing done by alternative immersion and drying in sulphate solution

- These action cause disruption of particles due to pressure generated by the formation of salts crystal i.e. crystallization of sulphate salts occur inside the aggregate and deteriorates it

- The change in mass of aggregate after 10 cycles with respect to initial mass in percentage

<12% and 18% for Na_2SO_4 and MgSO_4 for coarse aggregate.

<10% and 15% for Na_2SO_4 and MgSO_4 for fine aggregates

① Mechanical properties
① Bond strength

② Crushing strength

Crushing strength of single aggregate is always greater than that of concrete. So, crushing strength of bulk aggregate is calculated rather than single aggregate

→ Normal wt- aggregate considered 10x stronger than crushing strength of concrete

→ Stronger aggregate have lesser A.C.V.

→ A.C.V. should not be greater than 45% for non-wearing surface and 30% for wearing surface.

[A.C.V. → Aggregate crushing value]

③ Toughness:

Resistance of aggregate to failure by impact (suddenly applied load) is called toughness.

→ As per IS 383-1970 (CI 3.4) toughness is measured by aggregate impact value

→ Impact is provided by standard hammer of wt. 14kg falling freely 15 times from a height of 38cm.

→ Other same as crushing strength (25% for heavy duty concrete floor)

[finish]

→ Dry in oven → sieve 2.36mm → % pass to whole mass after impacted

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(IV) Hardness: Resistance of aggregate to wear due to constant rubbing action like in highways is called hardness. Hardness of aggregate is tested by following method

- Los Angel's Abrasion test
- Devil Abrasion test
- Dorry Abrasion test

• Los Angel's Abrasion test

Aggregate is placed in L.A.A. machine which contains cylindrical rotating drum mounted horizontally with abrasive charge (steel balls)

→ The drum is turned for 500 revolutions at the rate of 30-35 rev/min

→ The tumbling and dropping of aggregate and of the balls result in damage to aggregate

→ Then sample is passed through 1.7mm sieve and % passing is calculated.

→ Not greater than 50% for non-wearing ($\geq 50\%$) and 30% for wearing surface ($\geq 30\%$)

(V) Thermal properties

(i) coefficient of thermal expansion

(ii) Specific heat

(iii) conductivity

The specific heat and conductivity are of interest in mass concrete where rigorous control of temperature is necessary (also in case of light weight concrete used for insulation)

coefficient of thermal expansion of agg. interacts with coeff. of cement paste in body of cement concrete.
→ The coeff. of thermal expansion of agg. determines the value of concrete but its influence depends on agg. content of mix & on mix proportion in general.

but usually not in ordinary structural works.

→ The coefficient of thermal expansion of aggregate differs by more than 5×10^{-6} degree Celsius from that of cement paste than durability of concrete subjected to freezing and thawing may be determinately affected.

(IV) Chemical properties of aggregate

→ There should be no aggregate-alkali reaction

→ Good concrete should contain aggregate with theoretically no active silica content

→ Silicious material reacts with alkaline hydroxide (K_2O, Na_2O) from cement and forms alkali silica gel

→ Gel swells by absorbing water and creates internal pressure which leads to cracking and deterioration.

Imp. • Factor affecting aggregate alkali reaction

→ reactive type of aggregate

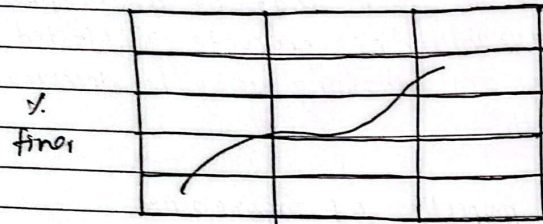
→ high alkali content in cement

→ Availability of moisture (on surface more deterioration and less in interior of mass concrete, applying water proofing agent on surface)

→ Temp^{re} condⁿ (Temp^{re} of 10 to 38°C is ideal)

Gradation of Aggregate: Aggregate is said to be graded if it contains particles of various sizes in different proportion. The act of doing gradation (particle size distribution) of an aggregate as determined by sieve analysis is known as grading of aggregate

Sieve analysis: largest at top to smallest at bottom
 → weight of sample taken and sieving is done



Grading curve: → well graded
 → poorly graded
 → Gap graded

* Advantages of gap graded curve:

- (i) Sand required will be of order about 25% as against about 40% in the case of continuous grading.
 - (ii) Specific surface area of gap graded aggregate will be low, because of high percentage of C.A. and low percentage of F.A.
 - (iii) Requires less cement and lower water/cement ratio.
 - (iv) Because of point contact between C.A. to C.A. and also an account of lower cement and mortar content the drying shrinkage is reduced.
- Inc. compaction resulting in denser & robust final product & higher strength to durability.
 → Improves drainage in road construction
 → Reduced content of fine particles can lead to lower shrinkage rate.
 → Gap graded mix tends to reduce segregation of different particles during handling & placement ensuring more uniform mix.
 → Specific selection of particle size may lead to reduce cost
 → Unique texture & appearance can be desirable in decorative concrete application.

CEMENT

is a binding substance used for constⁿ, that sets & hardens and adheres to material to bind them together.
 → has property of adhesion & cohesion when mixed with water.

oxide composition of portland cement, components element in raw materials like O_2 , Si, Ca, Al, Fe are present in cement. The main constituent of raw material in cement are lime, Al_2O_3 , Mn_2O_3 , Na_2O or K_2O .

* Manufacture of portland cement

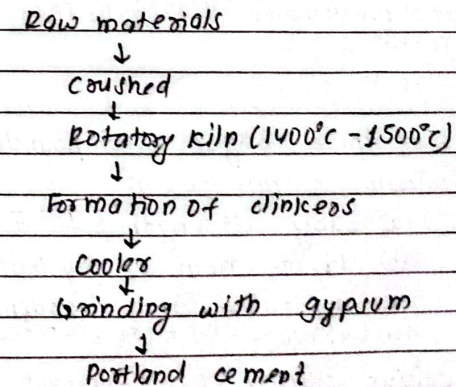
(i) Primary constituent → Calcium Silicate

(ii) Raw materials - calcium: limestone, chalk ($CaO + CO_2$)

Silica: clay and shales ($SiO_2 + Al_2O_3 + Fe_2O_3 + H_2O$)

$\frac{2}{3}$ of calcium + $\frac{1}{3}$ of clay → well mixed and homogenized before use.

(iii) Flow diagram can be drawn as shown



* Important of Oxide constituent (Self-study from book)

- i. CaO → control strength & soundness, helps in formation of silicate, aluminate of calcium.
- ii. Silica (SiO_2) → imparts strength & increases setting time.
- iii. Alumina (Al_2O_3) → provide quick setting property, lowers strength of raw materials.
- iv. Fe_2O_3 → gives color, hardness & strength. Helps in fusion of raw materials.

- v. MgO → helps in shrinkage compensation, provides heat
 vi. SiO₂ → makes cement dense
 vii. Na₂O, K₂O → excess of it cause efflorescence & cracking (soda, potash)

Compound constituent/composition of portland cement

The main constituent of raw materials in cement are lime, silica, alumina, and iron oxide

$\text{CaO} = \text{C}$ symbol
 $\text{SiO}_2 = \text{S}$
 $\text{Al}_2\text{O}_3 = \text{A}$
 $\text{Fe}_2\text{O}_3 = \text{F}$

Bogue's compounds:

Compound	Formulae	Symbol	% (in portland cement)
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Tricalcium silicate (Alite)	3CaO.SiO ₂	C ₃ S	20-50%
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Dicalcium silicate (Belite)	2CaO.SiO ₂	C ₂ S	20-45%
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Tricalcium Aluminate (Celite)	3CaO.Al ₂ O ₃	C ₃ A	2-12%
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Tetracalcium Aluminoferrite (Felite)	4CaO.Al ₂ O ₃ .Fe ₂ O ₃	C ₄ AF	6-12%
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Role of these Bogue's compound:

① Tricalcium silicate (C₃S):

- Early strength (1st 7 days)
- More heat of hydration is generated
- Hydrates and hardens quickly.
- Less resistant to chemical attack.

② Dicalcium silicate (C₂S) - impart ultimate strength to cement.

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

Hydration (begins after 28 days) & takes 2-3 yrs for complete hydration

9. Manufacture of cement.

(III) Tricalcium aluminate (C₃A)

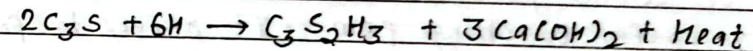
- Generates high heat of hydration
- Less resistant to sulphate attack
- Contributes a little to strength of cement
- Causes initial setting of cement.

(IV) Tetracalcium Aluminium Ferrite (C₄AF): ^{poor cementing value}

- Hydrates rapidly liberating much heat
- Less resistant to sulphate attack
- Contributes to sulphate attack
- Contributes little to strength
- Reacts slowly during setting & generates small amount of heat.

Hydration of Cement

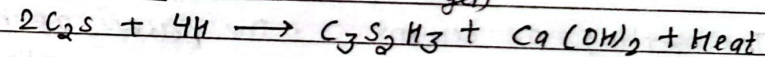
For ~~C₃S~~ C₃S



(100) (24) (75) (49)

Calcium silicate

For ~~C₂S~~ C₂S. Hydrate (Cementitious gel)

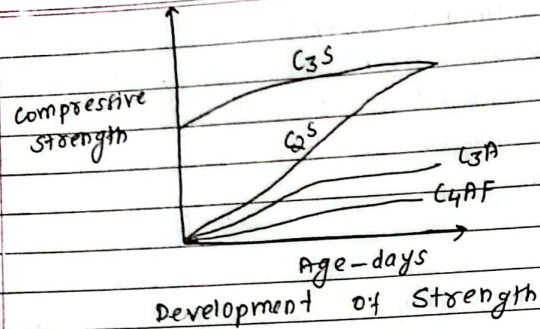


(100) (21) (99) (22)

* C₃S and C₂S require almost equal amount of water but produce more heat of hydration and Ca(OH)₂

* Ca(OH)₂ is soluble in water and gets leached but making concrete porous (not good for hydraulic structure)

Answering model
 ↳ pointwise to the point
 ↳ Graph, fig, schematic diagram.



- # Setting of Cement Hardening of Cement
- setting is term used to describe the setting of cement paste.
 - It refers to change from fluid to rigid state.
 - The setting of cement starts after 30 minutes from instant when water is added to cement and completed within 10 hours.
 - To know the setting of cement, initial setting time test and final setting time test are conducted.
 - Hardening refers to gain of strength at set of cement paste.
 - It refers to formation of solid mass possessing good compressive strength.
 - The process of hardening of cement continues for a period more than 1 years.
 - To know the hardening of cement, compressive strength test is conducted.
- types of cement (read yourself).

* Bogue's Equation

↳ Gives percentage of major compound in cement

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

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

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

$$C_4AF = 3.04(Fe_2O_3)$$

Eg: If $CaO = 68.2\%$, $SiO_2 = 22.4\%$, $Fe_2O_3 = 0.3\%$, $Al_2O_3 = 4.6\%$, $SO_3 = 2.4\%$ & Free lime = 3.3% .

$$\begin{aligned} C_3S &= 4.07 \times CaO - 7.60 \times SiO_2 - 6.72 \times Al_2O_3 - 1.43 \times Fe_2O_3 - 2.85 \times SO_3 \\ &= 4.07 \times 68.2 - 7.60 \times 22.4 - 6.72 \times 4.6 - 1.43 \times 0.3 - 2.85 \times 2.4 \\ &= 69.15\% \end{aligned}$$

$$\begin{aligned} C_2S &= 2.87 SiO_2 - 0.754 C_3S \\ &= 2.87 \times 22.4 - 0.754 \times 69.15 \\ &= 12.15\% \end{aligned}$$

$$\begin{aligned} C_3A &= 2.65 \times Al_2O_3 - 1.69 \times Fe_2O_3 \\ &= 2.65 \times 4.6 - 1.69 \times 0.3 \\ &= 11.68\% \end{aligned}$$

$$\begin{aligned} C_4AF &= 3.04 Fe_2O_3 \\ &= 3.04 \times 0.3 \\ &= 0.912\% \end{aligned}$$

* Testing of Cement

(1) • Lab Test

(a) Fineness test

(b) Consistency test

(c) Setting time (imp)

↳ Initial setting time

↳ Final setting time

(d) Compressive strength test

(Cube size 50cm³)

(2) • Field test

(i) Open the bag and take a good look at the cement. There shouldn't be any visible lumps.

(ii) Color of cement is normally greenish grey.

(iii) Thrust your hand into the cement bag. It must give you cool feeling. There should not be any lump or granule inside.

(iv) Take a pinch of cement and fell b/w the fingers. It should give a smooth and not a gritty feeling.

(v) Take a handful of cement and throw it on bucket full of water, the particles should float for some time before sinking.

(vi) Take about 100gm of cement and a small qty of water and make stiff paste. From stiff paste make a flat cake with sharp edges. put it on a glass plate and slowly take it under the water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of bucket. It should retain shape, set and attain some strength in 24 hr.

(अवस्था) → कठोर - यह प्रक्रिया - कठोर फलने

• Use of water in concrete

- It is an imp. constituent of concrete. Plays vital role in the strength of concrete (hydration)
- Quality of water is important because impurities in it (drinkable)

→ May interfere with setting of cement

→ May adversely affect the strength of concrete

→ May cause staining of its concrete surface

→ May lead to corrosion of reinforcement

→ May retard the setting time (sugar in water)

- In many specifications, quality of water is covered by a clause saying that water should be fit for drinking

- As a rule, any water with 6-8 pH value which does not taste saline or brackish is suitable for use but a dark color - -

• Water is used for

- Washing Aggregate
- to prepare concrete mix, i.e. hydration and lubricant
- For curing (time for concrete)
- (saturated surface dry aggregate)

- For hydration min w/c ratio is 0.3

- Ex- water cause laitance i.e. thin layer of chalk material (cement water) that comes on surface which weakens the bond of aggregate and paste and forms planes of weakness

- Ex- water can leak thr. joints of formwork and introduce honey comb.

- Water for curing penetrates to surface concrete through pores which through diffusion may be transported to inner part.

Harmful Water:

Mash - or imp. sugar ^{retard setting time} } Algae water → loss of water.
sulphate _{react with aggregate} } carbonate _{lowers setting}

• Test on Water

- A simple way of determining the suitability of water for mixing is to compare the setting time of cement and strength of mortar cubes using the water in question with the corresponding results obtained using known "good" water or distilled water

- BS 3148: 1980 suggests a tolerance of 10% in strength variation

Additives → added during cement manufacturing process

AD MIXTURE → added later during mixture of cement

↳ optional

↳ to get desired properties

Special cement: availability, cost → difficult.
↳ optional ingredient of concrete usually used to enhance some specific property.

Types of admixture: chemical Admixture and Mineral Admixture

Chemical Admixture (small amount: 3% by mass of cement)

• Accelerator

- accelerates development of early strength
 CaCl_2

- About 1% of CaCl_2 (by mass of cement) added to concrete vol^m increased about 6°C at rise in temperature.

- CaCl_2 CaOH (Calcium formate) used instead of CaCl_2 (it causes corrosion of bars and shrinkage of concrete) but has less accelerating ability.

• Set retarder

- this delay the setting of concrete

- sugar derivative

- 0.05% of sugar by mass of cement will delay the setting time by about 4 hours.

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• Plasticizer

✓ - water reduces

✓ - To achieve a higher str. by decreasing w/c ratio at the same workability.

- induce negatively charged particles around the cement particles which cause interparticle repulsion and enhance mobility
- water can be reduced to 5-15%.

• Superplasticizers

- high range water reducing agent

- used to produce flowing concrete or where early placing is required like slab, staircase, etc.

- sulphonated naphthalene formaldehyde condensate
- less used.

Mineral Admixture

↳ finely divided material which are added in large amount (20-60% of cement).

> Raw or calcinated natural pozzolana

- pozzolanic cement

> Fly Ash

- burning powdered or bituminous coal

- reduces H₂O (heat of hydration)

> Silica Fume

- ultra fine material whose size is about 10 times smaller than that of cement particles

- fills fine voids b/w cement particles and make concrete denser

- > ggbs (ground granulated blast furnace slag)
- are byproduct of iron production
 - ② contains silicates and aluminates of calcium
 - reducer H_2O

> surkhi

- powdered broken brick
- mixed with lime for more strength
- used as fine aggregate with lime.

Chapter 2:

Structure of concrete

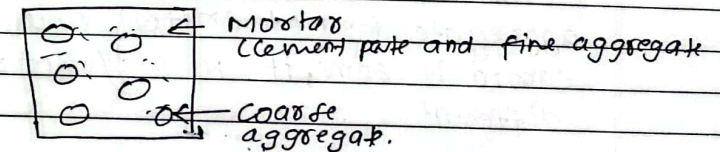
- 2.1. Concrete as Three phase system
- 2.2. Structure of aggregate phase
- 2.3. Structure of hydrated cement paste
- 2.4. Transition zone in concrete

* Concrete as three-phase system

- Macroscopic & microscopic

- Aggregate phase: Binding medium phase (hydrated cement phase): Transition phase (interface).

- aggregate suspended in mortar



* Phase model

Series:

→ Both mortar and coarse aggregate carry same load thus stresses in mortar and coarse aggregate are same. The strain in mortar and coarse agg. are different (depend on modulus of elasticity.)

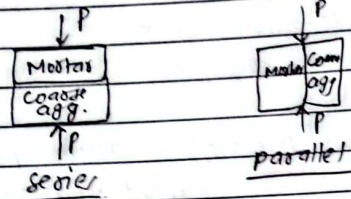
Parallel (strain compatible → carry diff force change)

→ Both mortar and coarse aggregate are subjected to same level of strain

→ If level of strain is same then load they carry which is related to stress is different.

→ write phase model even if not stated.

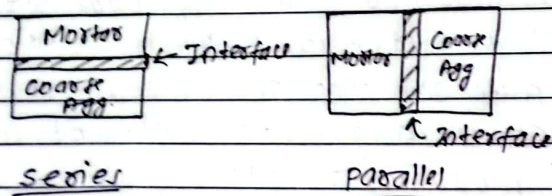
- ⇒ Concrete in real sense is neither a truly parallel system nor is a truly series system. The actual behaviour is b/w series and parallel mechanism of load transfer



* Interface:

Series: The interface b/w mortar and coarse aggregate is not critical since load being carried is same, it is only deformation is different

Parallel: The interface is critical. Bond b/w coarse aggregate and mortar phase is important to ensure strain compatibility.



Q. Explain 3-phase system of concrete.

- * Structure of aggregate phase
 - The physical prop. of agg. phase is more imp. than chemical or mineralogical composition (inert material)
 - Shape, size affect the properties of concrete adversely
 - Stronger than other two phase
 - Larger the size of agg. in concrete and higher prop. of elongated and flaky particles, the water film accumulate more around aggregate surface weakening cement paste bonding
 - Occupies: 70-80%

* Structure of Hydrated cement phase

→ Hydrated cement paste consists of

- solids
- voids

• Solids:

→ calcium silicate hydrate phase (C-S-H)

- it is the binding gel

→ It has a layered geometry with calcium silicate sheet structure and some degree of crystallinity. However exact structure not known.

- The state of chemically and physically bound water in its structure is not well known.

- 50-60% of volⁿ of solids

Calcium Hydroxide

- 20-25% of solid
- tends to form large crystals with distinct hexagonal prism
- soluble in water and get leached out making concrete porous

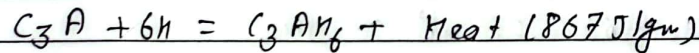
Calcium sulfo aluminates

- 10-15% of solid HCP
- generally needle shaped prismatic crystal
- formation of ettringite is harmful due to high change in volume.

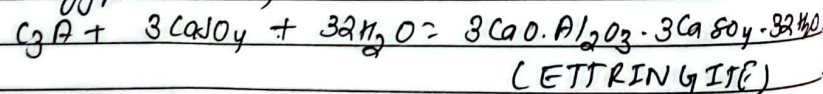
Unhydrated Clinker grains

- smaller particles hydrate first and some large size particle may remain unhydrated.
- size of grain depends upon cement particles and hydration.
- formation of dense concrete may lead to ~~explosion~~ expansion and deterioration.
(curing)

Exn



when gypsum added,



For C₄AH₁₃ / C₄AH₁₁

9. Adsorbed water
1. Adsorbed water

• Voids:

Interlayer space in calcium silicate hydrate (C-S-H)
- these voids are too small to have adverse affect on strength and permeability of hydrated cement paste.

Capillary voids

- space not filled by solid components of HCP
- larger voids affect strength and permeability while smaller voids affect dry shrinkage

Air voids

- for easy workability during mixing
- Entrained air — forcefully added to make porous concrete.
- Entrapped air (are larger than entrained)

• Water:

→ capillary water

→ Adsorbed water to solid surface

→ Interlayer surface water

→ chemically combined water

- chemically bonded water is not lost during drying while other water are lost depending on drying.

* Structure of Transition Phase

→ Difficult to obtain structure of transition zone

→ Explained as the film around the aggregate

→ More porous structure around the vicinity of aggregate.

→ Is the weakest structure

(Overall strength determined by transition phase)

Chapter - 3 Mix - Design

Nominal mix

Design mix

Gwt. based.

Nominal mix $\rightarrow$ Standard ratio
 $\rightarrow$ volume based

eg: Nominal mix M15 has ratio

1:2:4

Nominal mix M10 has ratio

1:3:6

Nominal mix M20 has ratio

1:1.5:3

Nominal mix M25 has ratio

1:1:2

Information
M10 3:6
M15 2:4
M20 1.5:3
M25 1:2

* Minimum M20 concrete required
for construction of building
(residential)

$\rightarrow$ Part day $\rightarrow$ Min^m M15

Design mix

$\rightarrow$ In large project (like hydropower)

$\rightarrow$ weight based

$\rightarrow$ Based on various criterion mix ratio
is computed.

② We use 20mm aggregate generally

20mm agg $\rightarrow$ 20mm down aggregate $\rightarrow$ 20, 10, 5 mm

* Information required for mixed proportion:-
(i) Concrete grade

Surendra Sharma

- # Characteristic strength of concrete
- (M20) → characteristic strength
 ↳ It has strength of 20 N/mm² (stress)
- (20) → strength of concrete in N/mm²
 ↳
- (M20) → 95% C.T.

- Characteristic strength of concrete, is the strength of concrete below which not more than 5% of test result are expected to fail
- Strength of concrete is variable quantity
- A Designer specifies minimum required from structural point of view so that mean strength is higher and mostly all part of structure have adequate strength.
- For 5% risk, probability factor (K) = 1.65
 For 1% " " " " K = 2.33
 For 2.5% " " " " K = 1.96

→ Characteristic strength, (f_{ck})
 $[f_{ck} = f_t - K\sigma]$

K → probability factor = 1.65

σ → standard deviation

(Calculate from test result)

(Number of test = 30)

→ If can't test / don't have test result

M10, M15 ⇒ $\sigma = 3$ N/mm²

M20, M25 ⇒ $\sigma = 4$ N/mm²

Normal distribution curve (ND)

$$M_{30} - M_{50} \Rightarrow \sigma = 5 \text{ N/mm}^2$$

M20

What is 20?

20 indicates compressive strength of standard cube of $15 \times 15 \times 15 \text{ cm}^3$ at 28th days expressed in N/mm² or MPa.

What is coefficient of variation (C.V.)?

→

Standard deviation formula:

→

If stand cube size not given

Cube size (mm)	100	150	200	300
Relative factor	1.05	1	0.95	0.87

→ Multiply by relative factor to get standard value

→ Compute for give size say 100 mm then * by 1.05 to get standard value

Steps to design # Numerical

Department of Environment

Imp # Design mix

- British standard (DOE Method)
- American standard (ACI Method)
- Indian standard (IS Method)

(Q) Design the concrete mix from all 3 methods for a RCC structure from the following data.

$f_{ck} = 30 \text{ MPa}$ $\Rightarrow$ (M30)
Required characteristic strength

Exposure condition = severe

Slump required = 30 to 60

Nominal max size of aggregate = 20mm crushed

Specific gravity of coarse aggregate

S_{ca} (SCA) = 2.7

Sp. gravity of fine agg (S_{fa}) = 2.65

Sp. gravity of cement (S_c) = 3.15

sand = 25% passing thr 600 micron sieve

(IS zone I)

(I) DOE Method

Steps:

(i) Target mean strength

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

$$f_m = 30 + 1.65 \times 5 = 38.25 \text{ N/mm}^2$$

(M30)

(ii) W/C ratio: (water: cement)

Adopt min of $\Rightarrow$ (a) $\rightarrow$ 28 days, $\Rightarrow$ fig 1 = 0.48

(b) $\rightarrow$ Durability consideration $\Rightarrow$ severe $\Rightarrow$ table 4 $\Rightarrow$ 0.45 (depends on exposure condition)

(iii) Free water content

Exposure condition	RCC (W/C)	RCC (W/C)
severe	0.5	0.45

Thus, from both

(a) & (b)

adopt w/c

ratio as

0.45

(ii) Free water content $\Rightarrow$ Table 5

20mm crushed

crushed/uncrushed $\rightarrow$ crushed

size of aggregate $\rightarrow$ 20mm

Workability $\rightarrow$ Slump

Thus, $W_w = 210 \text{ kg/m}^3$

(iv) Cement content $\left[W_c = \frac{W_w}{(W/C)} \right]$

$$\hookrightarrow W_c = \frac{\text{water}}{\text{cement}} = 0.45 \Rightarrow \text{cement } (W_c) = \frac{210}{0.45} = 467 \text{ kg/m}^3$$

$\hookrightarrow$ Exposure condition (table 4), $W_c = \text{Min} = 320 \text{ kg/m}^3$

Thus, we use $\Rightarrow$ adopt, $W_c = 467 \text{ kg/m}^3$.

(v) Agg Total Aggregate content

$\hookrightarrow$ combined SSD condition aggregate $\Rightarrow S_{fa} + S_{ca}$

$$= \frac{2.7 + 2.65}{2}$$

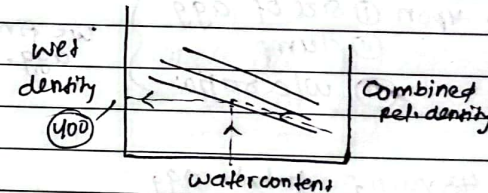
$$= 2.68$$

Figure (2)

Wet density of concrete

$$= \gamma_0 = 2400 \text{ kg/m}^3$$

(vi) Aggregate content



(vii) Proportion

Total aggregate content in SSD condition

$$= \gamma_0 - W_w - W_c$$

$$= 1723 \text{ kg/m}^3$$

VII Aggregate content

(5th page onwards)

↳ look at max. aggregate size

Here, max agg. size = 20mm

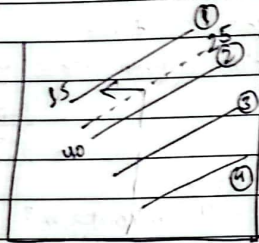
Grade: 1 → 15-40

2 → 40-60

3 → 60-80

4 → 80-100

we have, w/c → 0.45



Depending upon ① size of agg

② slump

③ w/c ratio

we find
agg. content

$$W_{fa} = 43\% \text{ of total agg.}$$

$$= 0.43 \times 728$$

$$= 741 \text{ kg/m}^3$$

$$W_{ca} = 982 \text{ kg/m}^3 [T - W_{fa}]$$

VII Proportion

Constants

$$C : F : A : C : A : W/C$$

$$467 : 741 : 982 : 0.45$$

↓

$$1 : 1.58 : 2.1 : 0.45$$

ACI Method.

Design the concrete mix from all 3.

Finess modulus (FM) = 3

Unit wt. of dry - rodded coarse aggregate
= 1600 kg/m³

Non-air entraining concrete

→ Soln:-

(I) Target mean strength

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

$$= 30 + 1.65 \times 5$$

$$= 38.25 \text{ N/mm}^2$$

(II) w/c ratio

↳ 28 days → fig 1 = 0.48

↳ Durability consideration ⇒ severe ⇒ Table 4 ⇒ 0.45 (max.)

Don't miss
durability
approach

adopt w/c ratio as 0.45

value $\rightarrow$ interpolation
 Range $\rightarrow$ curve

Surendra Sharma

Date _____
 Page _____

Free water content $\Rightarrow$ table 5
 coursed $\Rightarrow$ 20mm $\Rightarrow$ (30-60) slump.
 (19mm) (air entrained)

PCF
 table 6 $W_w = 210 \text{ kg/m}^3$ 179 kg/m^3

IV cement content $(w/c) = \frac{W_w}{W_c}$

$$\hookrightarrow W_c = \frac{179}{0.45} = 467 \text{ kg/m}^3 \quad 398 \text{ kg/m}^3 (> 320)$$

$\hookrightarrow$ exposure condition, $W_c = \min = 320 \text{ kg/m}^3$

Apodpt $\Rightarrow W_c = 467 \text{ kg/m}^3$ 398 kg/m^3

V Total Aggregate:-

table 7 FA table 7

FM $\rightarrow$ 3

max size $\rightarrow$ 20mm

3
 20 $\rightarrow$ 0.6 B_v

Bulk volume $(B_v) = 0.6$

Amount of C.A. $(W_{ca}) = B_v \times \gamma_{dc}$

$$= 0.6 \times 1600$$

$$= 960 \text{ kg/m}^3$$

6 Mix Proportion

1st Method (Based on estimated unit wt. of concrete per unit volume)

(i) table 8 Unit wt. of fresh concrete = 2355 kg/m^3
 (W_{fc})

(ii) Amount of fine aggregate

$$W_{fa} = W_{fc} - (W_w + W_c + W_{ca})$$

$$= 2355 - (1000 + 398 + 960)$$

$$= 897 \text{ kg/m}^3$$

Proportion
 $C : FA : CA : W_c$
 $398 : 897 : 960 : 0.45$
 $1 : 2.26 : 2.41 : 0.45$

6 Second method

(Based on calculation of absolute volume occupied by concrete ingredients)

(i) Determination of vol. of water $(V_w) = \frac{W_w}{\gamma_w} = \frac{179}{1000}$

$$= 0.179 \text{ m}^3$$

(ii) Determination of solid volume of cement

$$(V_c) = \frac{W_c}{S_c \times \gamma_w} = \frac{398}{3.15 \times 1000}$$

$$= 0.126 \text{ m}^3$$

(iii) Determination of solid volume of coarse aggregate, $(V_{ca}) = \frac{W_{ca}}{S_{ca} \times \gamma_w} = \frac{960}{2.7 \times 1000}$

$$= 0.356 \text{ m}^3$$

(iv) Determination of volume of entrapped air (V_a) Table 6 = 2%

$$= 0.002$$

(v) Determination of total vol. of ingredient except F.A.

$$V_{ef} = V_w + V_c + V_{ca} + V_a$$

$$= 0.681 \text{ m}^3$$

(vi) Determination of req. vol. of fine aggregate

$$(V_f) = 1 - V_{ef} = 1 - 0.681 = 0.319 \text{ m}^3$$

9. Workability; factors affecting workability

(vii) Determination of weight of FA (w_f)

$$= V_f \times (S_f \times \gamma_w)$$

$$= 0.319 \times (2.65 \times 1000)$$

$$= 845 \text{ kg}$$

Proportion: (on basis of wt)

Cem. : FA : CA : W/C

0.126 : 0.319 : 0.356 : 0.45

398 : 845 : 960 : W/C

1 : 2.12 : 2.41 : 0.45

IS Method

Workability = 0.85 — compaction factor test

Cement grade E

Free Moisture content in fine agg, $m_{fa} = 2\%$

Free Moisture content in coarse agg, $m_{ca} = 1.5\%$

(I) Target Mean strength (f_{m0}) = $f_{ck} + 1.65\sigma$

$$= 38.25 \text{ N/mm}^2$$

(II) acc. to grading & durability fig (4a)

W/C ratio $\rightarrow$

$\hookrightarrow$ for grade E $\Rightarrow 0.43$

$\hookrightarrow$ Durability $\Rightarrow 0.45$ (max)

Thus, adopt 0.43.

(III) Determination of water content

(W_w)_{initial} = 186 kg/m³ (table 10)

upto M35

(R)_i = 35%

(W/C & workability fix)
(size of agg. & sand % fix)

(IV) Adjustment parameters Adjustment required

Parameter	Water content	% of sand
(i) Decrease in w/c from 0.6 to 0.43	0	$\frac{-1}{0.05} \times 0.17 = -3.4$
(ii) Increase in workability factor from 0.8 to 0.85	$\frac{3}{0.1} \times 0.05 = 1.5\%$	nil
(iii) For sand confining to zone I	nil	+1.5%
(iv) For crushed aggregate	nil	nil
	$W_w = +1.5\%$	$P_{sa} = -1.9\%$

✓ ~~5.5~~ * Compare the mix design by ACI 211S & IS 10262

Adjustment $\Rightarrow$ Actual values

$$W_w = 186 + 1.5\% \text{ of } 186 = 188.79 \text{ kg/m}^3$$

$$\% \text{ Sand} = 35\% - 3\% = 33.1\%$$

$$\frac{\text{FA}}{\text{Total aggregate}} (P) = \frac{P_s}{100} = \frac{33.1}{100} = 0.331$$

Adjustment $\Rightarrow$

(V) Cement content

$$W_c = \frac{W_w}{(w/c)} = \frac{188.79}{0.43} = 439.05 \text{ kg/m}^3$$

Durability, $W_c, \text{ min} = 320 \text{ kg/m}^3$

Adopt 439.05 kg/m^3

(VI) Entrapped air $\rightarrow$ table 9

$$(V_{ea}) = 2\% \text{ volume of concrete (20mm down)}$$

(VII) Determination of net vol^{ts} of fresh concrete

$$V_f = 1 \text{ m}^3 - V_{ea} = 1 - 0.02 = 0.98 \text{ m}^3$$

(VIII)

$$V = \frac{1}{1000} \left(W_w + \frac{W_c}{S_c} + \frac{1}{S_{fa}} W_{fa} \right)$$

$$\text{or } 0.98 = \frac{1}{1000} \left(188.79 + \frac{439.05}{3.15} + \frac{1}{0.331} \times \frac{W_{fa}}{2.65} \right)$$

Solving

$$\therefore W_{fa} = 571.75 \text{ kg/m}^3$$

WT in IS.

DURABILITY Adjustment (Table 10.1.11) $\rightarrow$ free moisture content

Also, For coarse

$$V = \frac{1}{1000} \left(W_w + \frac{W_c}{S_c} + \frac{1}{(1-P)} \frac{W_{ca}}{S_{ca}} \right)$$

$$\text{or } 0.98 = \frac{1}{1000} \left(188.79 + \frac{439.05}{3.15} + \frac{1}{(1-0.331)} \times \frac{W_{ca}}{2.7} \right)$$

Solving,

$$W_{ca} = 1177.40 \text{ kg/m}^3$$

(IX) Actual values

(Correction for moisture)

$$\begin{aligned} \text{Actual Amt. of F.A. (a } W_{fa}) &= W_{fa} (1 + m_f) \\ &= 571.75 (1 + 0.02) \\ &= 583.19 \text{ kg/m}^3 \end{aligned}$$

$$\begin{aligned} \text{Actual amt. of C.A. (a } W_{ca}) &= 1177.4 (1 + 0.015) \\ &= 1195.06 \text{ kg/m}^3 \end{aligned}$$

$$\begin{aligned} \text{Amount of water (a } W_w) &= W_w - (m_f \times W_{fa} + m_c \times W_{ca}) \\ &= 188.79 - (0.02 \times 571.75 + 0.015 \times 1177.4) \\ &= 159.7 \text{ kg/m}^3 \end{aligned}$$

Ratio:

$$C : FA : CA : W : C$$

$$439.05 : 583.19 : 1195.06 : 159.7$$

$$\text{or } 1 : 1.33 : 2.72 : 0.36$$

Workability

→ Workability of a fresh concrete is the property which determines the ease and homogeneity with which a freshly mixed concrete or mortar can be mixed, compacted, transported, placed and finished.

→ Workability is

mixability = low effort for homogeneous mix

stability = stable w/o segregation and bleeding

mobility = ability to flow w/o losing homogeneity

compactability = ability to compact with less energy input

finishability = ability to attain satisfactory surface finish

placeability = ability to be placed easily

→ Workability is amt. of useful internal work necessary to provide full compaction (Road research lab, UK)

100% compaction

The work or energy is used to overcome the internal friction b/w the individual particles in concrete and to overcome the surface friction b/w concrete and formwork.

Factors affecting Workability

> Water content of Mix

Addⁿ of water increases interparticle lubrication but it also lead to segregation and bleeding. Fine particles require more water to wet their large surface. (FA more surface area)

M.S. Shetty: Workability

> Aggregate-cement ratio

For a const. w/c ratio, workability inc as the agg. cement ratio is reduced. Lower agg. cement ratio means more paste which gives more workability.

> Size of Aggregate

High vol^{ts} of coarse to fine aggregate results in lower workability and segregation and over increases the workability but overrounded mix makes concrete less durable.

> Shape and texture of aggregate

Irregular and rough texture aggregate demand more water than round aggregate due to high surface area.

> Admixture (Plasticizer)

> Time

Freshly mixed concrete stiffens with time as

> Temperature

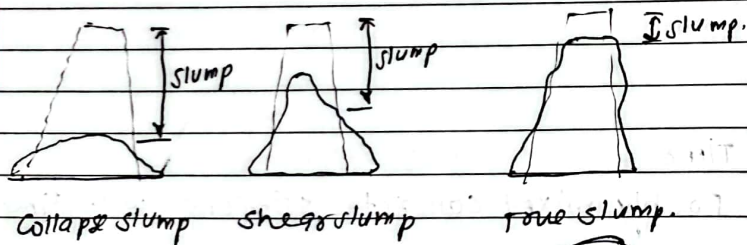
High temp. reduces workability and increases slump loss.

Workability Test

> Slump test

- Formation of cone
- 3 layers tamped 25 times
- Tamping rod 16mm dia
- Mold firmly held (handlev. & footrest)
- After filling, cone lifted slowly & the unsupported concrete will now slump - hence the name.
- as smoothly as possible.

Very low	0-25
Low	25-50
Medium	50-100
High	100-175



max. used in Asian countries

Slumpor' Compacting Factor Test:

- The % degree of compaction achieved by a standard amt. of work.
- Ratio of density after test to density of fully compacted concrete is the compacting factor.
- Two hoppers with hinged doors at bottom (frustum of cone) and cylinder.
- Top hopper gently filled and allowed to fall in lower hopper and to cylinder.

Very low	0.78
Low	0.85
Medium	0.92
High	0.95

Vee-Bee Test

- Vibrating table (± 0.85 mm vertical amplitude) with empty cylinder (60 mm dia. and 200 mm height) graduated and connected with transparent glass disc (sides) and a standard slump cone.
- Concrete filled in slump cone, removed (slump can be measured) and a disc placed on top of concrete.
- The vibration is started and time is noted.
- Concrete will spread in the container, vibration is continued until the concrete is remolded and the surface of concrete becomes horizontal. Stop the vibration and time.
- Another way: the transparent sides is totally covered with concrete and all cavities in the surface of concrete have disappeared i.e. concrete completely adheres uniformly to disc.
- Difficulty in establishing end point may be the source of error.

very low	20-10
low	10-5
medium	5-3
high	3-0 sec.

Flow table test

- Generally useful for flowing concrete made with superplasticizer to know the fluidity of concrete.
- Const. of sq. wooden board (700 mm) covered by steel plate (total mass abt. 16 kg).
- Board: upper and lower (base) and two boards hinged at one side and other side free, provides with stop and can be lifted upto 40 mm (rise).
- Table cleaned and frustum of cone (TD: 180, BD: 200, H: 200 mm) is placed and filled with concrete.
- Before lifting, excess concrete removed.
- Table is then lifted and dropped 15 times, each cycle taking approx. 4 sec (approx).
- Concrete spreads, the max^m spread parallel to the two edge of table is measured and average is taken i.e. in two perpendicular direction.
- Medium workability: 400 mm,
high workability: 500 mm.

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Q. Compare 3 tests Vee-Bee, Slump test & Compacting factor test (Graphs & tables) (To measure workability)

	Slump Test	Vee-Bee Test (Consistometer)	Compacting Factor test
1			
Purpose:	determines consistency of concrete	Measures flow consistency of concrete	Evaluates workability of concrete
Procedure	A cone-shaped mould is filled with fresh concrete, compacted and then removed. The height of slump (subsidence) is measured, indicating workability	A vibrating table compacts the concrete in a cylindrical container. The time taken for the concrete to flow and close a gap is recorded. (Vee-Bee time)	Compacts concrete in a standard mould using a tamping rod. The ratio of compacted concrete volume to original volume gives compaction factor.
Applicability:	suitable for medium to high workability concrete (slump range: 25 to 125mm)	suitable for concrete with slump value lower than 50mm.	Used for low-workability concrete (eg. mass concreting of foundations)
Limitation:	Not effective for low-workability concrete (slump < 50mm)	Not ideal for higher slump values.	Adv: Effective when slump values are very low (< 50mm)
Range:	Very-low = 0-25 Low = 25-50 Medium = 50-100 High = 100-175	(Time in sec) Very-low = 18-10 Low = 10-5 Medium = 5-3 High = 3-0	(Ratio) Very low = 0.78 Low = 0.85 Medium = 0.92 High = 0.95

Segregation

- Separation of constituents of concrete heterogeneous mixture so that their distribution is no longer uniform.
- Diff. in size of particles in concrete (and sometimes in specific gravity of mix constituent) is the primary cause.

- Two forms of segregation

- (1) First: The coarser particles tend to separate out since they travel farther along a slope or settle more than finer particles (in dry mix).

Second: The grout (cem. & water) tends to separate from mix (in wet mix).

- The actual extent of segregation occurs in handling and placing of concrete (dropping from considerable ht.; changing the direction while passing through chute, discharging against a obstacle, prolong vibration).

- Difficult to measure quantitatively but can be seen in lab when vibrated about 10 min for cube or cylinder.

* Process of hand mix of concrete.

Bleeding (water gain)

- Also some forms of segregation in which water in the mix tends to rise to the surface of freshly placed concrete.
- (1) - It is because water has low sp. gravity, than all constituents and also because of inability of solid constituents of the mix to hold all of the mixing water when they settle downward.
- The top of every lift (layer of concrete placed) may become too wet and is trapped b/w two layers of concrete making concrete porous and weak. Even in top surface, if bleeding water is removed during finishing, wear wearing surface is formed. If rising water carries fine particles of cement than laitance is formed which creates weak bond b/w lifts.
- (2) - On the other hand, if evaporation of water from the surface of concrete is faster than the bleeding rate, plastic shrinkage may result.
- The bleeding water can also be trapped on underside of large aggregate or below reinforcement, creating zones of poor bond.
- Bleeding in lower with fines cement or with high C/A or rich mixes or air entrainment.

Date _____
Page _____

Quality control in site (Mixing, Handling, Placing, Compacting and Curing)

Mixing

- Is done thoroughly to produce uniform concrete
- Hand mixing: small scale and non-important work (10% cement extra)
- Machine mixing: large scale, Batch mixers and continuous mixers.
- Generally, 15 to 20 rev. per min and 25-30 rev. done.

Handling

- care during transportation from mixer to site.
- There are possibilities like wheel barrow, buckets, belt conveyor, pumping, etc. but the mix should remain coherent and should not segregate.
- Bad handling methods which promote segregation must obviously be avoided.

Date _____
Page _____

* Placing

- Process of keeping concrete in position

Objective: to deposit the concrete as close as possible to its final position so that segregation is avoided and the concrete can be fully compacted.

- concrete is placed in layers (with compaction), not in large heaps or sloping layers (15-30 cm in RCC, max concrete layer 35-45 cm thick). Moving concrete by vibrator should be avoided.
- Each layer should be made rough and in plastic stage so that monolithic construction

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* Compacting

- process of removing the entrapped air from concrete.
- obj:

Process of Hand-mixing of concrete (for mixing a small batch)

1. Spread a plastic sheet/GI sheet on the ground
 - ↳ lay down plastic sheet to keep working area clean & prevent concrete mix from sticking on the ground.
2. Measure out the materials:
 - ↳ Gather materials: cem, sand, CA & water.
 - ↳ pile up CA & sand on plastic sheet.
3. Layer the ingredients:
 - ↳ put cement on top of pile of sand & CA
 - ↳ shovel the materials with shuffling action in the pile on new side. Repeat this step 3-4 times to ensure thorough mixing & aggregate surface is coated with cement.
4. create a deep crater and Add water:
 - ↳ Make a deep crater in the center of pile.
 - ↳ Gradually add water into the crater.
 - ↳ Begin folding the mix in from the side incorporating the water.
 - ↳ Use a chopping action/motion to distribute water evenly through the mix.
 - ↳ sprinkle little water to make good mix if necessary.

V. Imp

* concrete in Extreme temperature

• Hot weather concreting

- Hydration of cement is faster at higher temp. which produce early strength and low long term strength.
- At high temperature, water evaporates faster and drying shrinkage cracks can result.
- It is desirable to keep temp. of concrete from 16° to 28°C.
- Preventive measures
 - providing shades to aggregate, cement and concrete mix
 - sprinkling cold water to agg. surface.
 - using small pieces of crushed ice as mixing water while mixing
 - concreting at night (env. temp is low), no direct sunlight
 - continuous water curing
 - Thermally insulating mixing water tanks, pipes etc & admixture used.

Cold Weather concreting

- When temp. at concreting is very low, cement setting is hampered if freezing happens immediately after concreting. If freezing occurs at premature stage, the concrete is damaged.
- Preventive measures:
 - mixing water may be warmed
 - If heating water is not sufficient,

Chapter-6

Concrete Durability.

6 marks

Effect of water and permeability on concrete durability.

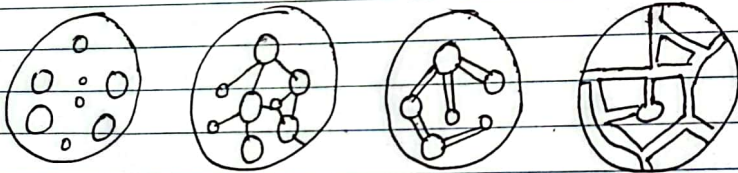
- Durability

Ability of concrete to resist any process of deterioration such as weathering action, chemical attack, abrasion, etc.

(ACI committee 201)

i.e. If the concrete retains its original form, quality and serviceability when exposed to the designed environment, the concrete is durable.

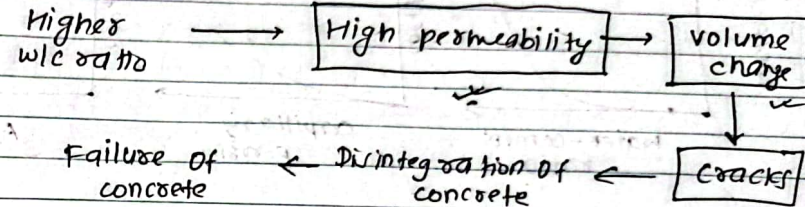
→ With low w/c ratio, the permeability decreases to such a level that these concretes are impervious to water i.e. inter connected network of capillaries are so fine that water cannot flow through them



- (a) Highly porous, no permeable
(b) High porous, low permeable
(c) High porous, high permeable (capillary pores interconnected by large pores)
(d) Low porous, high permeable

a, b, c → same porous but diff permeability

- Higher w/c ratio is the fundamental cause of higher permeability. Permeability is the contributing factor for volume change. Volume change results in cracks and cracks are responsible for disintegration of concrete.



- Difficulty to pin point which of these are primarily responsible for affecting durability.
- permeability of concrete is often, referred as the root cause for lack of durability. (But volume change in impervious concrete due to heat or internal manifestation can crack the concrete making durable)

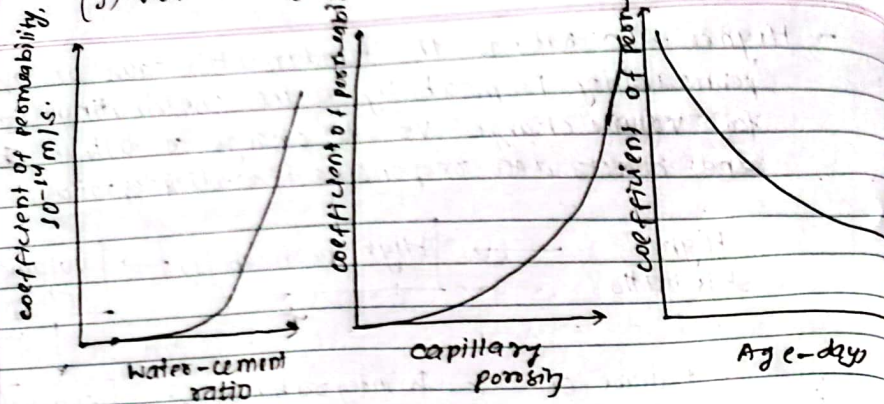
Acceptance:

is having the faith despite the circumstances that all is well

These three factors, one follows the other two, like, "DAY" follows the "NIGHT" are responsible for affecting durability.

- Water permeability: expressed as coefficient of permeability (laboratory)
- Darcy's equation: $\frac{1}{A} \frac{dQ}{dt} = k \frac{\Delta h}{L}$
 - cross-sectional area of sample, Rate of flow of water, Coefficient of permeability, Drop of hydraulic head through sample, thickness of sample

- Durability & permeability
 (8) → Physical & chemical causes of concrete deterioration
 (9) vol^m change & crack



Physical causes of concrete deterioration:

(a) Surface wear due to

- Abrasion (resistance due to wear or rubbing off)
- Erosion (scum)
- Cavitation (formation of cavity-hollow within solid body)

(b) Cracking due to

1. Volume caused by

- ↳ Normally temperature and humidity gradient
- ↳ Crystallization pressure of salt in pores

2. Structural loading as

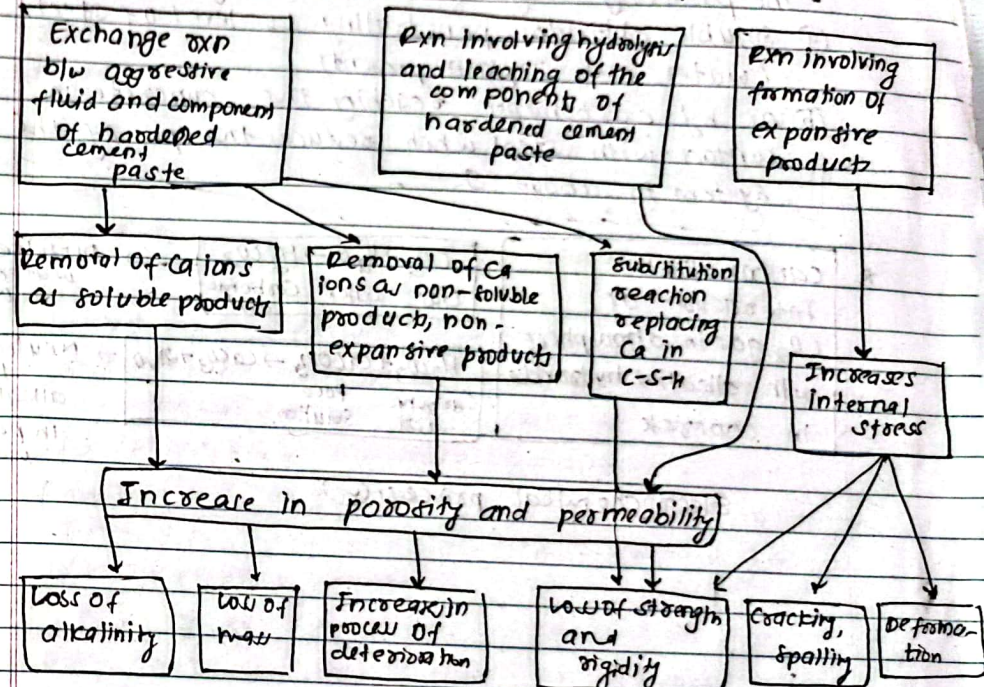
- ↳ Overloading and impact
- ↳ Cyclic-loading.

(c) Exposure to extreme condition such as

- ↳ free zing & thawing
- ↳ Fire

Corrosion of Steel in concrete

Chemical causes of concrete deterioration



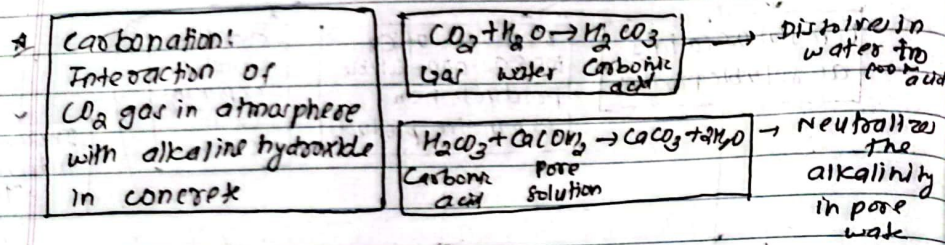
Corrosion in steel

- The pH of pore water in the hardened concrete is generally b/w 12.5 to 13.5 depending upon the alkali ($\text{Ca}(\text{OH})_2$) content in concrete.
- The high alkalinity forms a thin passivity layer around steel reinforcement and protects it from the action of oxygen and water. This prevents the corrosion of reinforcement. For corrosion, this passivity layer must first be destroyed.

9. Explain Carbonation

* Imp Carbonation & Factors affecting Carbonation: [6 marks]

- The passivity layer can be destroyed either by
 - soluble chlorides penetrating to level of steel. (water and oxygen present)
 - or by carbonation reaching the concrete in contact with steel which reduces the pH of the system to about 9



Electrochemical process ☺

Spalling ; cracking ; Delamination

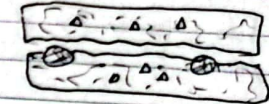
Damage caused by penetration of concrete



Spalling



Cracking



Delamination.

- * Preventive measure against corrosion
 - Impermeable concrete mix design with max^m limit on w/c and min^m limit on cement content for different exposure condition
 - Provision of adequate clear cover for durability
 - Permissible crack width limit, (0.3mm general, 0.1mm extreme), IS 85
 - Using epoxy coated bar
 - Using surface seal coating on concrete surface and a membrane water proofing

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Chapter-5

Testing of concrete (28m)

Various strength types in concrete

- (1) Compressive strength
- (2) Tensile strength
- (3) Shear strength
- (4) Bond strength
- (5) Bearing strength

Destructive Test
(For quality control)

(1) Compressive strength (Imp. for concrete test)

↳ by compressive strength test

↓
② (i) cube test (Gen in Indian subcontinent)

(ii) Cylinder test (Gen in US, France, Japan)

Cube test

↳ 150mm x 150mm x 150mm (150mm cube)

↳ mould made of Cast Iron

↳ smoothing & cleaning of internal surface (greasing)

↳ keep concrete in 3 layers.

↳ layer by layer filling & compaction

↳ level maintained (levelling)

↳ (Labelling)

↳ top surface smoothing.

↳ 24 hrs : air dried in shade (RH $\approx$ 90%
to maintain Temp: 66°F - 70°F)

↳ taking sample out of mould & curing

↳ left for 3 days, 7 days, 28 days

for testing 3 day, 7 day, 28 day strength.

↳ 0.2 - 0.4 MPa : compression

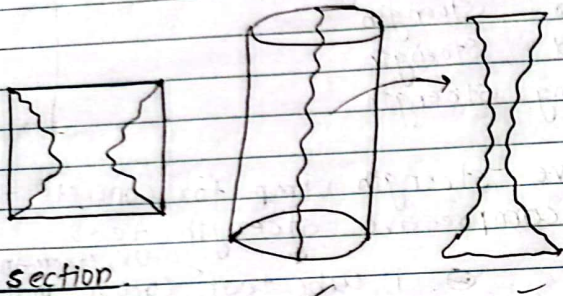
Cube Test Strength = $1.25 \times$ (S_4)

(#) Cylindrical Test

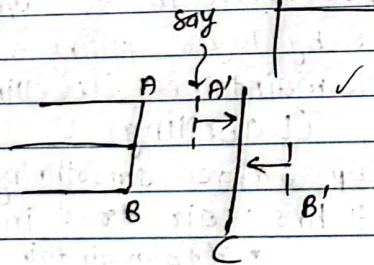
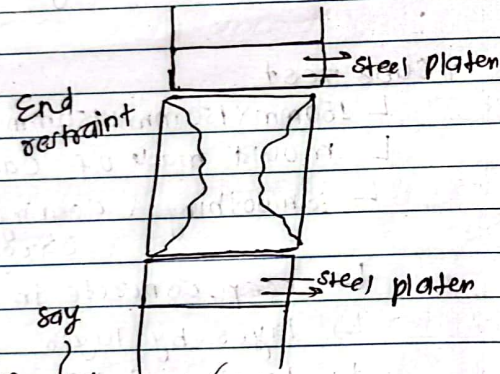
Cylinder Test Strength

Platen effect
(5-marks)

(Neville)



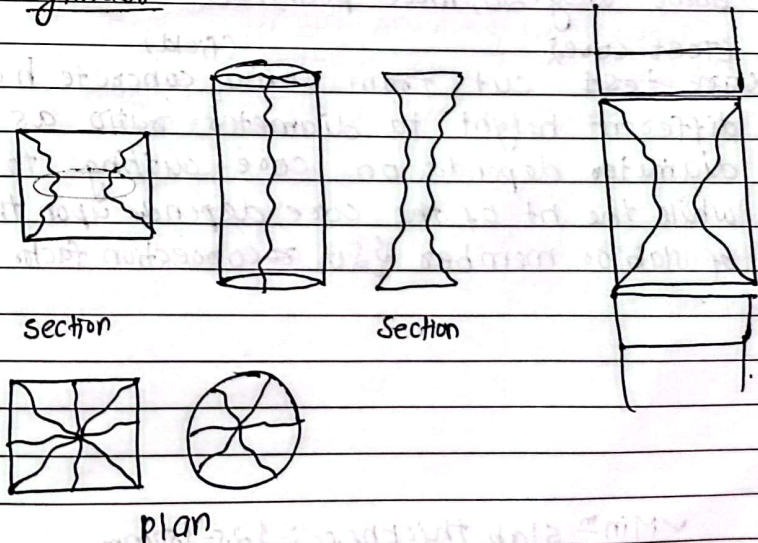
Platen effect
↳ 3D effect

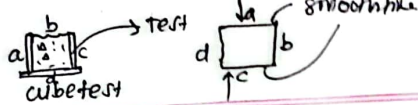


A' & B' → final position of A & B after elongation
But as two platens are compressive strain remains same then ultimately goes to position C

→ The compression test imposes a more complex system of stress due to lateral force developed b/w the end surface of the concrete specimen and adjacent steel platens of testing machine. The degree of platen restraint on the concrete section depends on the friction developed at the concrete-platen interface and distance from end surface of the concrete. The steel is stiffer than concrete. Due to additional lateral constraint, consequently, in addition to imposed uniaxial compression there is a lateral shearing stress. Due to the lateral shearing stress, there is increase in apparent compressive strength of concrete. This effect of shear stress decreases towards the center.

The influence of platen restraint can be seen from typical failure modes of test cubes/cylinder.





- When the ratio of height to width of specimen increases the influence of shear becomes smaller.
- Stress distribution is uniform of cylinder & plate effect is less seen in it. So, it is more practical.

* Advantage of cylinder test

- less plate-restraint effect.
- More uniform distribution of stress over cross-section.

So, cylinder test is said to be more realistic than cube test. It gives closer to true result. Thus, its use in research laboratory is increasing.

- In cube test, casting and loading is done in different way. So, it is not practical.

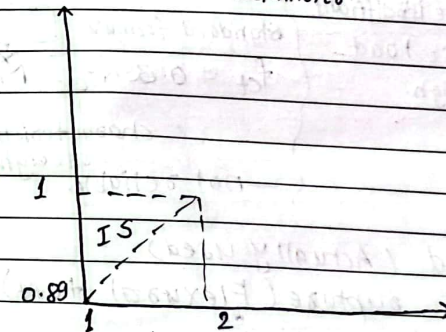
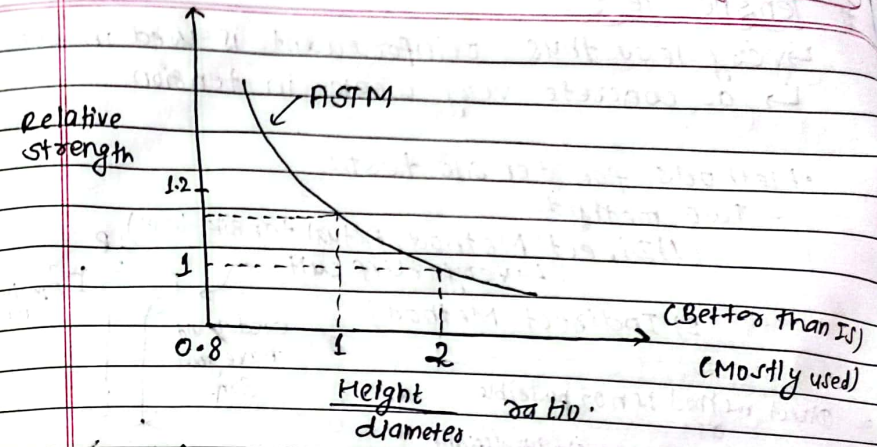
By in cylinder, casting & loading is done in same way. So, more practical.

(Test core)

(field)

- Core test cut from in situ concrete have different height to diameter ratio as diameter depends on core cutting tool while the ht. of the core depends upon thickness of slab or member. So, correction factor required.

✓ Min^m slab thickness: 125-150mm

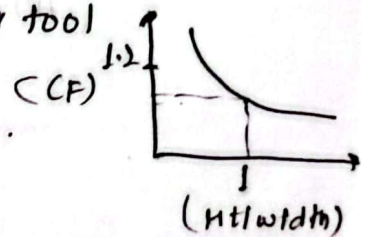


	H/D	2	1.75	1.5	1.25	1
Correction Factor	ASTM	1	0.98	0.96	0.93	0.87
	IS	1	0.98	0.96	0.94	0.92

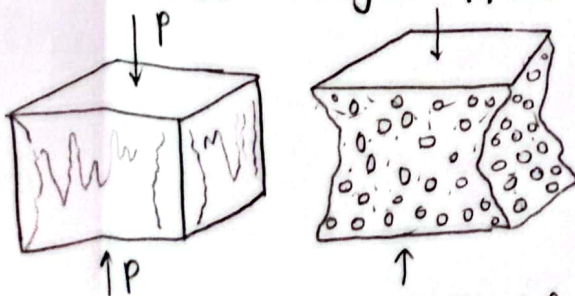
The compression test imposes a more complex system of stress, mainly because of lateral forces developed b/w the end surfaces of the concrete specimen and adjacent steel platens of the testing machine. These forces are induced by the restraint of the concrete, which attempts to expand laterally (Poisson effect), by the several-times stiffer steel, which has a much smaller lateral expansion. The degree of platen restraint on concrete section depends on friction developed at the concrete-platen interfaces, and on the distance from the end surfaces of the concrete.

Consequently, in addition to imposed uniaxial compression, there is a lateral shearing stress, the effect of which is to increase apparent compressive strength of concrete.

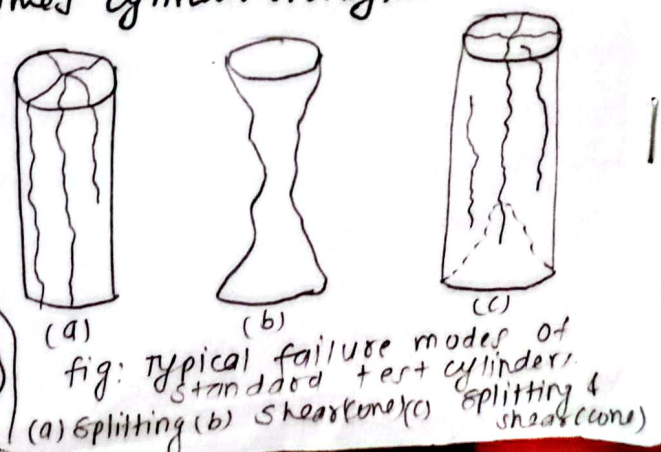
- ✓ one face touching the platen cracks and disintegrates so as to leave a pyramid or cone.
- ✓ $ht/width \uparrow \rightarrow$ influence of shear $\downarrow \rightarrow$ so central part of specimen may fail by lateral splitting.
- ✓ For standard cylinder test $ht/width = 2$.
- ✓ May encounter diff ht/dia ratio (insitu test codes)
 - ↳ dia depends on core-cutting tool
 - ↳ $ht/thickness$ of core.
 - ↳ need to apply correction factor.



- ✓ Since influence of platen restraint on mode of failure is greater in a cube than in a standard cylinder, cube strength approx. 1.25 times cylinder strength.



(Satisfactory failure modes of test cubes acc. to BS1881: Part 116: 1983)
Non-explosive



Gen. 10% of compressive test (Direct tension)

Tensile Test

→ Very less thus reinforcement is used in concrete
→ as concrete very weak in tension

• Methods for tensile test:

- Two methods

(1) Direct Method (Actual tensile test)

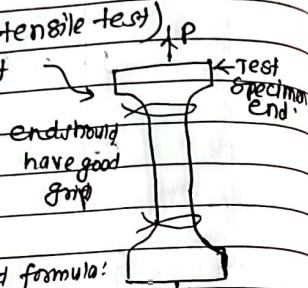
→ very difficult

(2) Indirect Method

Direct method is not possible as:

- Gripping of concrete is difficult
- Chances of eccentric load being applied is high.

Standard formula:
 $f_{ct} = 0.35 \sqrt{f_{ck}}$ MPa.
characteristic strength.
= not reliable.



(2) Indirect Method (Actually used)

(a) Modulus of rupture (Flexural test)

(b) Splitting Test

(a) Modulus of rupture (Flexural test)

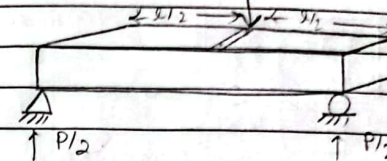
→ (i) central point loading

(ii) Third-Point loading (2-Point loading)
(xx threeex)

Ductility = $\frac{\phi_{ultimate}}{\phi_{yield}}$ - Strain / Deformation

② Determine tensile and Max Bending compression strength

(i) Central-Point Loading



$$\frac{\sigma}{y} = \frac{M}{I}$$

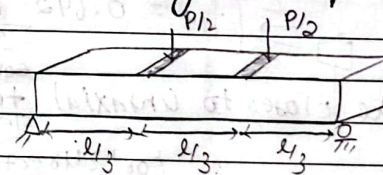
$$[\sigma = \frac{M}{I} \times y]$$

$$[f_{cr} = \frac{M}{I} \times y]$$

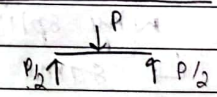
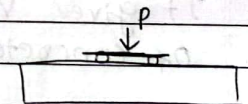
$$f_{cr} = \frac{\frac{Pl}{4}}{\frac{150 \times 150^3}{12}} \times 75 = 333.33 \frac{P}{\text{KN/m}^2} \quad [\text{if } P \text{ in 'KN'}]$$

* Normal size of Beam: 150mm x 150mm x 750mm

(ii) Two-point loading (Third point loading)



In lab



Generally,

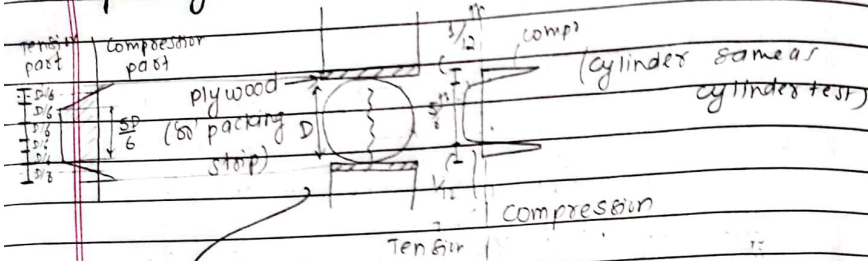
$$f_{cr} = \frac{f_{cr}}{1 + 2 \left(\frac{h}{h_0} \right)^{0.7}}$$

h → depth of the beam

h₀ = 100mm (Standard value)

cylinders used mostly

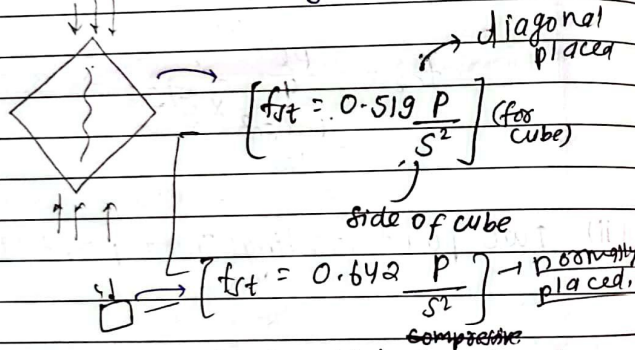
(b) Splitting-Test (Brazilian test)



$$[f_{st} = \frac{2P}{\pi DL}] \quad \text{cube (used rarely)}$$

Biaxial stress state

cube?



$$[f_{st} = 0.519 \frac{P}{S^2}] \quad (\text{for cube})$$

$$[f_{st} = 0.642 \frac{P}{S^2}] \quad \rightarrow \text{normally placed, compressive}$$

It gives value close to uniaxial tensile strength of concrete (or direct tensile)

Why splitting test? (Advantages)

→ same specimen can be used for compression test.

→ gives value close to uniaxial tensile strength of concrete.

✓ Shear is the action of two equal and opposite parallel forces applied in plane which is some distance apart.
✓ Direct determination of shear strength is difficult.
Shear strength.

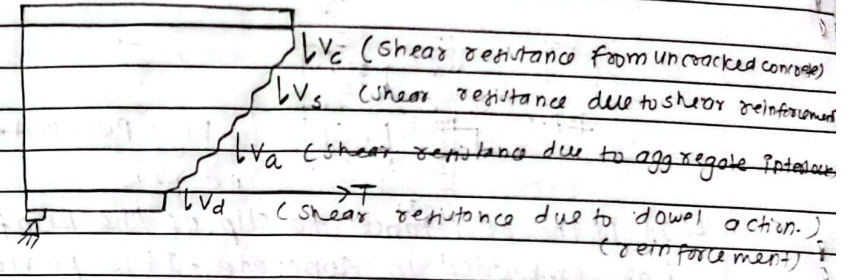


fig: Internal stresses at flexural shear crack

Concrete when uncracked has some resistance or strength against shear force at the section. Even the cracked concrete has some resistance to shear due to aggregate interlock. It is difficult to determine shear carrying capacity of concrete. In case of reinforced concrete the tension reinforcement also provides shear resistance called dowel action. Shear strength of concrete is function of compressive strength (Approximately 1% of f_{comp}).

✓ f_{st} (or f_{comp}) kept for shear strength.

IS 456:2000

	M15	M20	M25	M30
τ (N/mm ²)	1.6	1.8	1.9	2.2

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Bond strength.

- ↳ due to bonding b/w reinforcement & concrete
- ↳ by pull-out test

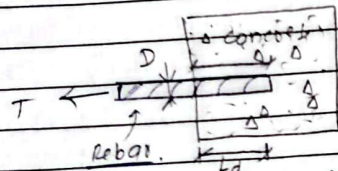


Fig: Pull-out test.

- ↳ It is the resistance to slip of the reinforcing bar embedded in concrete. It is provided by adhesion, friction, and mechanical resistance.

(chemical bonding) (reinforce bar)

Tension applied.

$$\sigma_{\text{bond}} = \frac{T}{\pi D l_d}$$

Development length
Dia of reinforcement

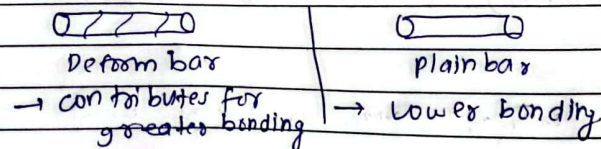
- ↳ Depends on strength of concrete.

IS 456:2000

Grade	M20	M25	M30	M35	M40
Bond strength	1.2	1.4	1.6	1.8	2.0

smooth bar

For deformed bar increase by 60% (with lugs)



→ De form bar = 60% more i.e. 1.6x plain bar bonding

(Destructive test) ← Test confirmed for quality control

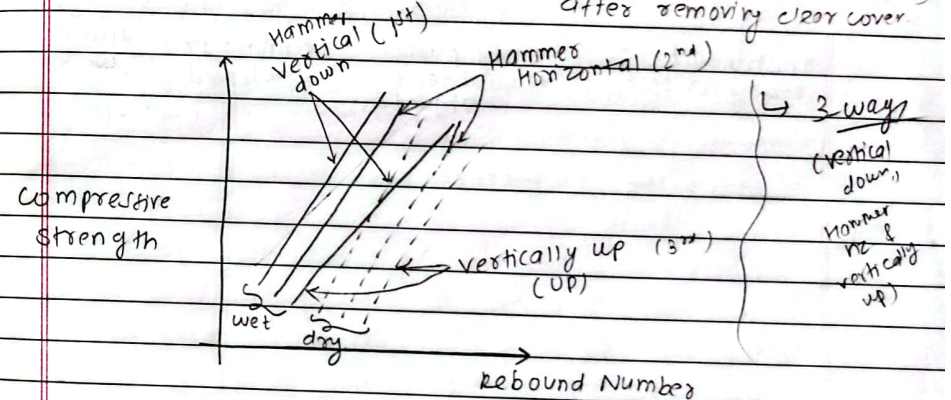
Bearing strength

- ↳ When heavy concentrated load are applied directly on concrete element within very limited area, the loaded area of concrete can be punched inside. The resisting stress for punching is the bearing strength.
- ↳ IS 456:2000 gives permissible bearing stress on full area of concrete as $0.45 f_{ck}$ (for limit-state method)

NON-DESTRUCTIVE TEST { Supervision tests }

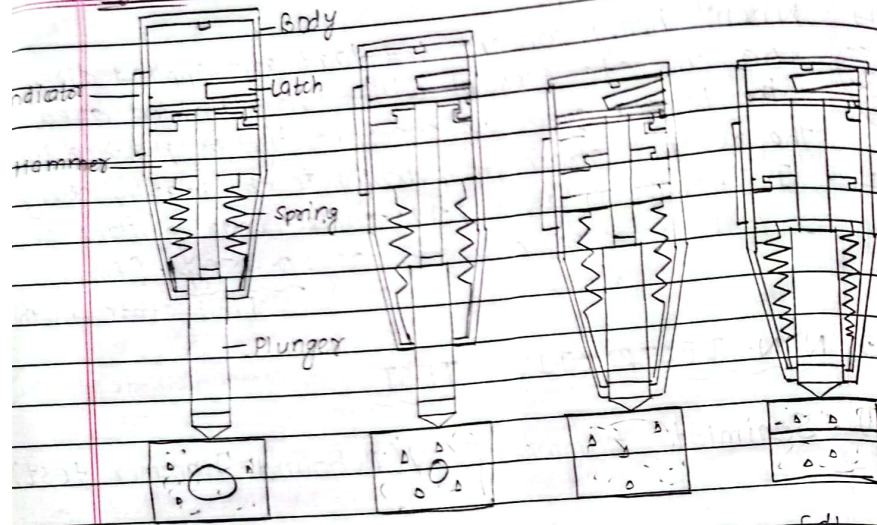
Schmidt Hammer Test (Rebound hammer test)

- ↳ pure concrete (core concrete test with smooth outer) after removing clear cover



- ↳ 1x to surface
- ↳ Multiple data/reading
- ↳ Mark area → Scrap off → smooth surface → take multiple data → Averaging
- ↳ Again Mark next area & mean
- ↳ honeycomb str → not good strength
- ↳ Location → Multiple column → Multiple
- ↳ not at end of str

Figure (U state & section) of plu



(a) Instrument ready for test

(b) Body pushed toward test object

(c) Hammer is released

(d) Hammer rebounds

- It consists of a spring-controlled hammer that slides on a plunger within a tubular housing.
- The hammer is forced against the surface of the concrete by the spring and distance rebounds are measured on the scale.
- ↳ Test surface to be horizontal, vertical or at any angle but the instrument must be calibrated in this position.

#

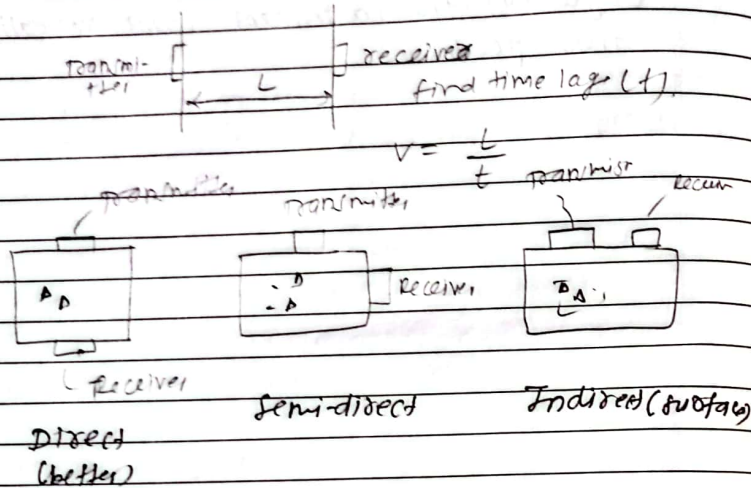
(2) Ultrasonic Pulse velocity test

↳ ultrasonic pulse transmitted through transmitter.

↳ & receiver receives the pulse.

↳ time lag of passing & receiving of ultrasonic pulse is noted.

↳ Two methods — Direct Method (ATPR)



↳ It is assessed by measuring the velocity of ultrasonic pulse passing through concrete.

↳ Pulse velocity = $\frac{\text{width of structure}}{\text{Time taken}}$

* Factors affecting

(i) Path length

(ii) Temperature (works good at 5-30°C)

(iii) Moisture condition (vel ↑ with moisture content)

(iv) Presence of reinforcing steel (Differ for RCC & RCC)

(Pulse vel): Steel = $(1-21.9) \times \text{concrete}$

(iii) L (saturated & dry) → 2% difference

(moisture content)

Acceptance criteria for concrete

↳ (IS 456:16) (IS 456:2000 clause 16)

(A) ~~★~~ The concrete is acceptance for compressive strength if

(a) The mean strength determined from any group of 4 non-overlapping consecutive test results fulfill following conditions:

$$f_{\text{mean}} \geq \text{greater of (a) } f_{ck} + 0.8255$$

(b) $f_{ck} + a$

where, $a = 3.44 \text{ N/mm}^2$ for M15 &

$S = \text{established standard deviation}$

(rounded off nearest to 0.5 N/mm^2)

(b) Individual test ~~avg~~ result complies with the appropriate limits as shown:

$$f_{\text{mean}} \geq f_{ck} - 3 \text{ N/mm}^2 \text{ for M15}$$

$$f_{\text{mean}} \geq f_{ck} - 4 \text{ N/mm}^2 \text{ for M20 \& above}$$

(B) Flexural Strength

When both the following conditions are met, the concrete complies with the specified flexural strength

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

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

✓ The quantity of concrete represented by a group of four consecutive test results shall include the batches from first and last samples were taken together with all intervening batches.

✓ Three test specimens shall be made for each sample for testing at 28 days. Additional specimens may be required for 7 days strength. In all the cases 28 days strength shall alone be the criterion for acceptance or rejection of the concrete.

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

Ch-5. # Properties of Hardened Concrete

Introduction

Explains with suitable diagram

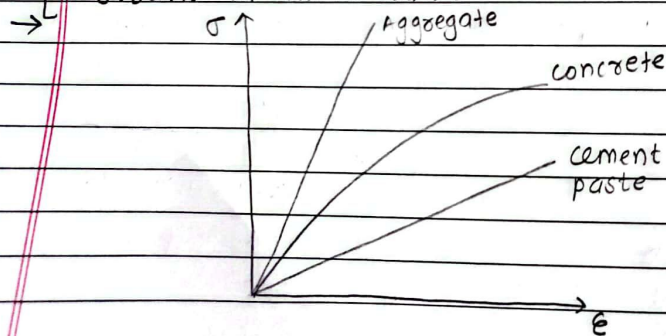
- Linear and Elastic (Steel)
- Non-Linear and Elastic (Plastic, timber)
- Linear and Inelastic (Brittle material: glass, rock)
- Non-linear and Non-elastic (concrete)

(9) The aggregate and cement paste separately subjected to loading shows linear stress-strain relationship. But, the stress-strain (σ - ϵ) relationship of concrete is Non-linear. Why?
→ as there is another layer of microcracking in interface layer in concrete.

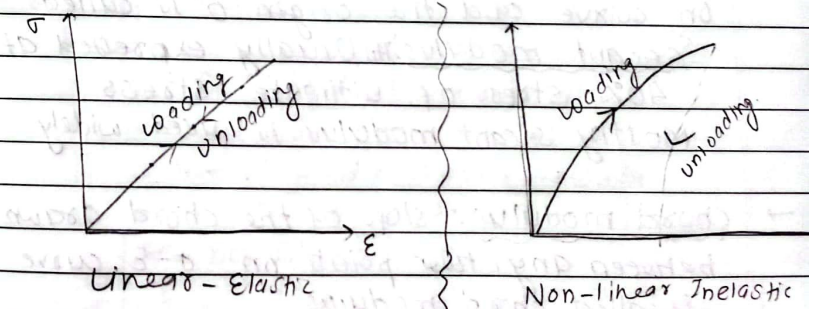
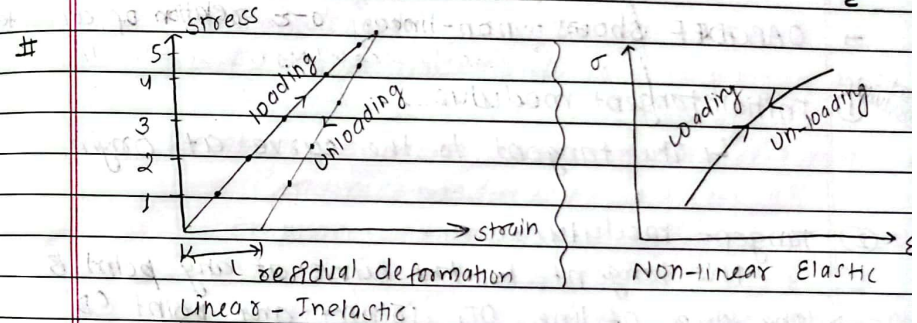
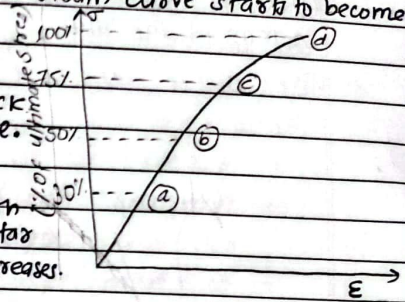
Interface of microcracking σ & ϵ (different strength / Modulus of Elasticity of cement & concrete) &

→ It shows the presence of 3rd phase ITZ (Interfacial-Transition-Zone) which contains microcracking i.e. microcracking exists in ITZ of concrete on normal curing or even before loading.

The drying ~~shrinkage~~ shrinkage, thermal stress causes differential strain b/w aggregate & paste. as they have different modulus of elasticity and result in microcracks.



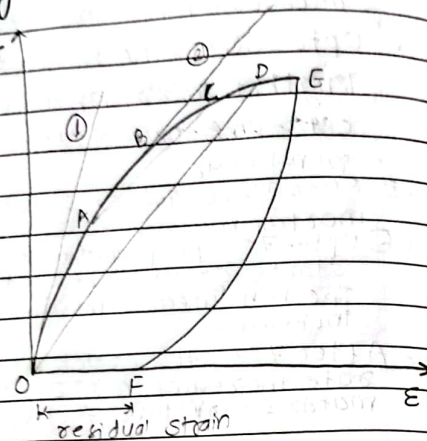
- 30% >50%
- Upto 30% of compressive strength of concrete the initial microcracking are stable. (do not extend further)
 - Upto 50% ; the microcracking start to multiply in length, number and width. no microcracks in cem-paste mortar, stress-strain curve starts to become non-linear
 - 50-60% : cracking starts in mortar matrix
 - Upto 75% propagation of crack starts, cracks are unstable. The non-linear curvature increases.
 - After 75%, the crack growth rate increases in ITZ & mortar matrix & curvature further increases.



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Modulus of Elasticity (Types of modulus of Elasticity)

- ① Initial tangent modulus
- ② Tangent modulus
- ③



→ OAB CDEF shows non-linear σ - E relation of concrete.

Static modulus

① Initial tangent modulus

↳ The tangent to the curve at origin

② Tangent modulus

The tangent to the curve at any point B

→ The slope of line OD joining any point 'D' on curve and the origin 'O' is called 'Secant modulus'. Usually expressed at 40% stress of ultimate stress.

Mostly secant modulus is used widely.

→ Chord modulus: slope of the chord drawn between any two points on σ - E curve is called chord modulus.

→ When the concrete is loaded and afterwards unloaded completely then certain strain remains in concrete which is called residual strain.

permanent strain / plastic strain / Inelastic strain.

* Dynamic modulus

↳ vibration

↳ determined by applying vibration rather than static loading

$$E_d = k n^2 L^2 S$$

where,

k = constant (depend on unit)

n = resonant frequency

L = Length of specimen

S = density

E_d = Dynamic modulus.

↳ Relation between static modulus (E_c) and dynamic modulus (E_d)

Empirical formula,

$$[E_c = 1.25 E_d - 19]$$

expressed in GN/m^2 or GPa

↳ Also,

$$E_d = \frac{3V^2(1+\nu)(1-2\nu)}{(1-\nu)}$$

V → longitudinal pulse velocity

ν → poisson's ratio

[For normal concrete, ν =

For steel, ν =

↳ According to IS,

$$E_c = 5700\sqrt{f_{ck}} \text{ (MPa)} \quad \text{--- (i)}$$

(If do not have other test data
or in design above eqⁿ is used)

Shrinkage and Creep

* Shrinkage

↳ volume reduction after setting and
↳ volumetric hardening of concrete after
w.t. time.

↳ volumetric strain

Types of shrinkage

↳ (i) Plastic shrinkage

↳ (ii) Drying shrinkage

(iii) Autogenous shrinkage

(iv) Carbonation shrinkage

(v) Thermal shrinkage

(i) Plastic shrinkage

→ This type manifests ^{itself} soon after the concrete
is placed in the form while the concrete
is still in plastic state.

→ Loss of water by evaporation from surface
of concrete or by absorption by aggregate
or sub-grade is the reason of plastic shrinkage.

(ii) Drying shrinkage

↳ Contraction due to loss of surface water by
evaporation (after setting)

↳ continuous process (as hydration is continuous process)
(as left timber in dry)

↳ It induces tensile strength in concrete.

↳ As hydration of cement is an everlasting
process, the drying process is also an everlasting
process, when concrete is subjected to drying
concrete

→ The drying shrinkage is analogous to the mechanism
of drying of timber specimen.

(iii) Autogenous shrinkage

→ Contraction due to loss of water used up in
hydration (due to loss of water by evaporation)

→ Value smaller than drying shrinkage

→ Occurs due to self-desiccation

→ Self-desiccation is the phenomenon by virtue of which
concrete with low water-cement ratio begins to dry out
due to internal consumption of water during hydration

(iv) Carbonation shrinkage.

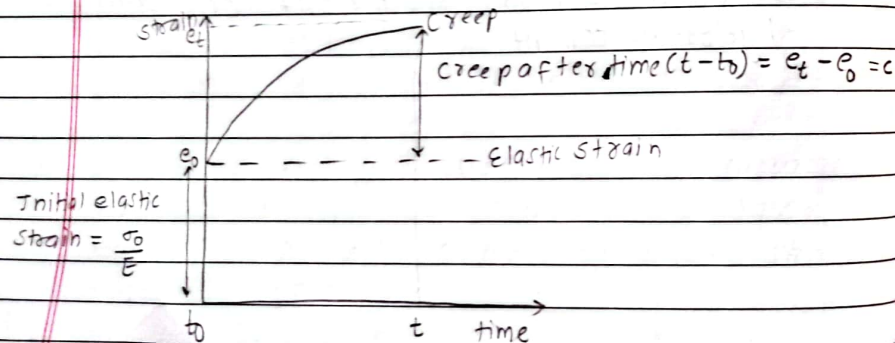
→ Contraction due to reaction of CO_2 and
hydrated cement

(v) Thermal shrinkage

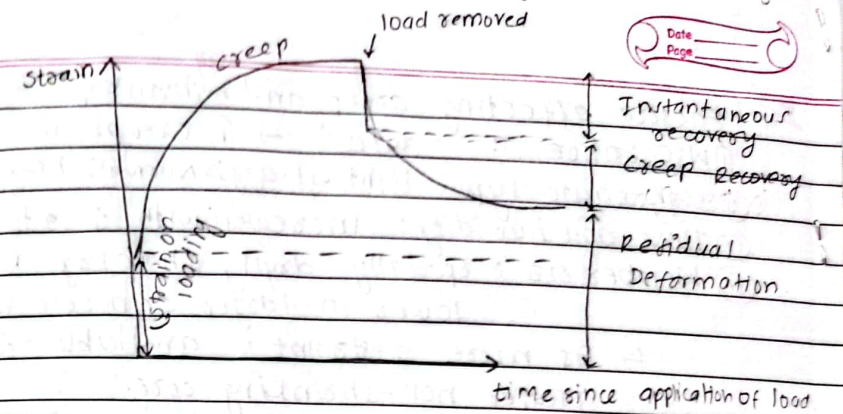
- ↳ Concrete can be subjected to volumetric change with decrease of temperature.
- ↳ Roof slab or pavement expand during day and undergoes thermal shrinkage at night.

Creep

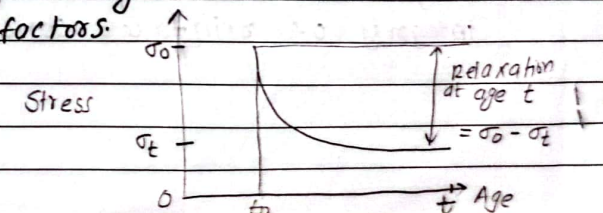
- ↳ When concrete is subjected to everlasting loading then it undergoes deformation called creep.
- ↳ It is time dependent inelastic strain
- ↳ Its rate decreases with time



Explain creep & its recovery with suitable diagrams



- If the sustained load is removed, the strain decreases immediately, called instantaneous recovery ($=$ elastic strain)
- Followed by gradual decrease in strain called creep recovery
- ⇒ The increase of strain in concrete with time under sustained stress is termed as creep. The shrinkage and creep occurs simultaneously and they are assumed to be additive for simplicity. When the sustained load is removed, the strain decreases immediately by an amount equal to the elastic strain at given age. This instantaneous recovery is followed by a gradual decrease in strain, called creep recovery which is a part of total creep strain suffered by concrete. If a loaded concrete specimen is viewed as being subjected to a constant strain, the creep decreases the stress progressively with time, which is called relaxation. eg: In prestressed concrete, stress relaxation occurs in the steel tendons (wires or strands) used for prestressing. These tendons gradually lose tension over time due to combination of factors.



- day
- * Factors affecting creep and shrinkage
- (i) W/C ratio: $w/c \uparrow \rightarrow \uparrow \text{ creep \& sh.}$
 - (ii) aggregate type: light wt. agg > normal > heavy
 - (iii) Time and humidity: increases with $\uparrow$ in time
 - (iv) Member size: specially drying shrinkage is lower in larger concrete member
- ↳ As more restraint is available for greater non-shrinking core.

Fatigue (failure)

↳ Failure under long-term effect

Two types

↳ If it is under sustained load or slowly increasing load it is called static fatigue or creep rupture

↳ If it is under cyclic load / repeated load it is normally called fatigue

↳ In both instances, time-dependent failure occurs only at stresses which are greater than a certain threshold value but smaller than short-term static load strength.

↳ Fatigue results in compromising overall structural integrity of reinforced concrete elements

V.V. Imp effect of porosity, aggregate size and w/c ratio on strength

Impact and dynamic loading. (Note)

Effect of water/cement ratio

→ Strength of concrete primarily depends upon the strength of cement paste. Strength of cement paste depends upon dilution of paste i.e.

Strength of paste increases with cement content and decreases with air and water content.

→ In 1918, Abrams presented his classic law in the form:

$$S = \frac{A}{B^x} \quad \text{S = strength of concrete.}$$

where, x = water/cement ratio by volume & for 28 days results the constants A and B are 14,000 lbs/in² and 7 respectively. [984 kg/cm²]

→ Abrams w/c ratio law states that the strength of concrete is only dependent upon water/cement ratio, provided the mix is workable.

→ Earlier according to Feset (1897),

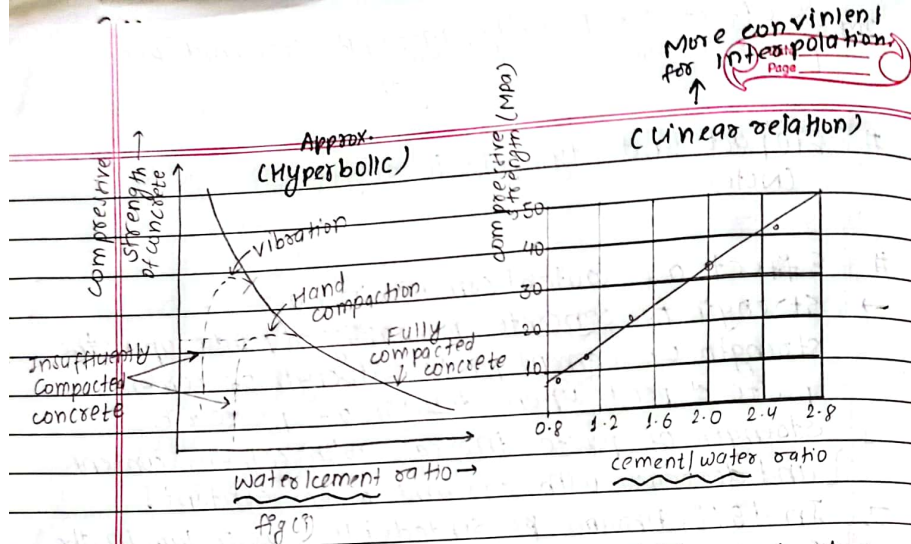
$$S = K \left(\frac{C}{C+e+a} \right)^2 \quad \text{e = water}$$

where, S = strength of concrete

$C, e, \& a$ = volume of cement, water and air

K = a constant

• In this expression, volume of air is also included because it is not only w/c ratio but also degree of compaction, which indirectly means the volume of air filled voids in concrete is taken into account in estimating the strength of concrete.



- Lower water/cement ratio could be used when concrete is vibrated to achieve higher strength, whereas comparatively higher w/c ratio is required when concrete is hand-compacted.
- In both cases when w/c ratio is below practical limit the strength falls rapidly due to introduction of air voids.

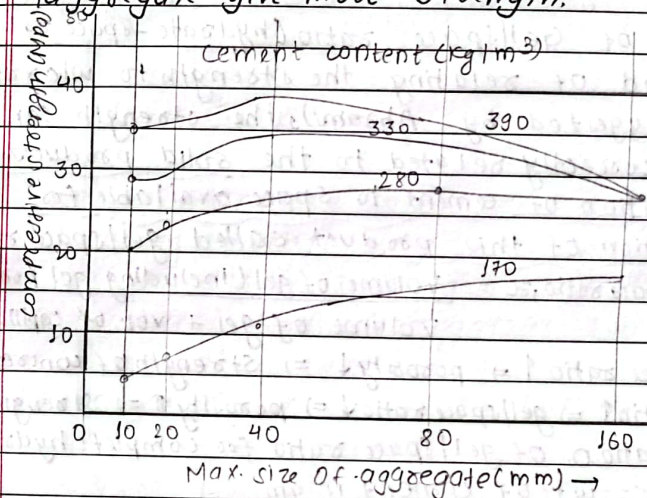
Effect of aggregate size on strength

- At one time it was thought that, larger size of aggregate, lowers the total surface area and lower is the requirement of water for given workability. Thus, lower w/c ratio can be used leading to higher strength.
- But later, it was found that larger size of aggregate did not contribute to higher strength due to following reasons:
 - Larger maximum size aggregate gives lower surface area for developments of gel bonds which is responsible for lower strength of concrete.

(ii) Larger aggregate cause more heterogeneity in concrete which will prevent uniform distribution of load when stressed.

(iii) Larger size aggregate used, then, due to internal bleeding, the transition zone will become much weaker due to development of microcracks which result in lower compressive strength.

Note: In lean mixes larger aggregate gives highest strength while in rich mixes, smaller aggregate give more strength.



Effect of porosity

- Porosity refers to the presence of voids or empty spaces within concrete matrix. The strength of concrete (compressive) decrease with increase in porosity, as larger pores create stress concentration points, making the material more susceptible to failure.

- Voids: entrapped air, entrained air, capillary pores, gel pores, entrained air
- For every 1% increase in volume of air voids, there's approx. 5% reduction in concrete strength
- Porosity ↑ → density of concrete ↓ → strength ↓
- Influence of vol% of pores on strength given by

$[f_p = f_c (1 - p)]$ (2)

p → porosity = $\frac{\text{vol of voids}}{\text{vol of concrete}}$

f_p = strength of concrete with porosity p

f_c = strength of concrete, $S = 240 \times \alpha$ } $240 \rightarrow$ intrinsic strength of concrete

Effect of GellSpace ratio (hydrate-space ratio)

- Instead of relating the strength to w/c ratio (as suggested by Abrams), the strength can be more correctly related to the solid products of hydration of cement to space available for formation of this product called gellspace ratio.

→ GellSpace ratio, $\alpha = \frac{\text{Volume of gel (including gel pores)}}{\text{Volume of gel + vol. of capillary pores}}$

- gellSpace ratio ↑ ⇒ porosity ↓ ⇒ strength of concrete ↑
- w/c ratio ↑ ⇒ gellSpace ratio ↓ ⇒ porosity ↑ ⇒ strength ↓
- Calculation of gellSpace ratio for complete hydration:

Let C = wt. of cement in gm

$V_c = \frac{C}{\rho_c} \times \text{vol. of cement} = 0.319 \text{ ml/gm}$

W_0 = vol. of mixing water in ml

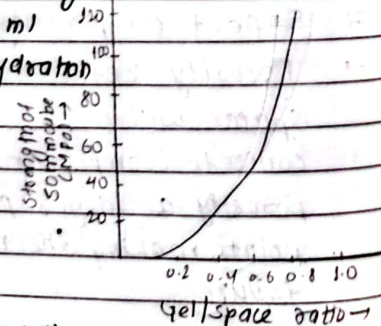
Assuming 1ml of cement on hydration produces 2.06ml of gel.

vol% of gel = $C \times 0.319 \times 2.06$

space available = $C \times 0.319 + W_0$

∴ GellSpace ratio, $\alpha = \frac{C \times 0.319 \times 2.06}{C \times 0.319 + W_0}$

$\alpha \rightarrow$ fraction of cement that is hydrated C for complete hydration, $\alpha = 1$



DUBC

Masonry codes (गवन विज्ञान)

we codes: NBC & IS

Masonry codes

202 & 203

(low & high str.)

mud

cement

→ Masonry unit & Mortar

- Brick
- Cement
- Rock
- mud

- Faces of brick
- Bonds in brick

* Use of masonry structure

→ Masonry structure

'made from individual units laid in and bound together by mortar'

History

* Egypt (w/o mortar)

* Great wall of China

* arc bridge of Meler river, Turkey

* First code: BS code of practice 1948 'load bearing wall'

* India: 1960, Nepal: NBC 109:1999 'unreinforced masonry'

* wall, low height structure, retaining wall, bridge, etc.

NBC 108:1994 $\Rightarrow$ IS 1905:1987

refer



* Use of Masonry structures:

Advantages:

- $\rightarrow$ No painting or finishing required
- Fire resistant
- $\rightarrow$ raw materials readily available
- $\checkmark \rightarrow$ thermal mass due to large size
- high compressive strength.

Disadvantages:

- low tensile strength
- large size (lateral balancing by weight)
- Efflorescence occurs on wetting and drying.

* Masonry Units

Bricks

- $\rightarrow$ solid with frog ($< 20\%$ frog br), perforated (small holes $> 25\%$), hollow (holes $> 20\%$ but holes larger than 20mm).

NBC

code

$\rightarrow 240\text{mm} \times 115\text{mm} \times 57\text{mm}$ (length $2 \times$ width + vertical joint)

- water absorption: 15-25% in 24hrs when immersed in cold water.
- Efflorescence: presence of grey/white deposit
- Size: standard size, sharp edge
- Hardness: No scratch with finger nail
- Soundness: metallic/ring sound
- Compressive str.: 24hr immersed in water, take out, frog filled, 1 day put, 3 day immersed, 14N/mm^2 per min

- 1. Compressive strength test of masonry
- 2. field testing of brick
- 3. laboratory test of brick

Compressive str.



perforated

Surendra Sharma

Bank consideration on stone masonry (Min size of (NBC 203 & 204)

Stones

- variable sizes
- stone masonry wall: thickness 450mm,
- ★ max storey ht 2.7m, wall span 5m, through stones, distance of opening from junction 2ft. (w/o proper design) door/window.

Hollow concrete blocks:

- material: com. and aggregate (sand, gravel, crushed stone)
- strength: can be changed i.e. mix proportion can be changed.
- hollow: reduce wt, insulation, easy to incorporate, reinforcement.
- variable shape & size.
- can be ~~to~~ locally produced, no skilled manpower, easy & fast construction, no finishing required.

block & shape

short note

diff. form rammed earth.

Compressed earth block (CEB)

- building material primarily made from damp soil by compacting (compressing) at high pressure using ~~st~~ manual soil press called Balam.
- cheaper than concrete blocks.
- ② - if cement & lime used then, compressed stabilized earth block
- ★ - environmental and energy efficient (no burning)
- solid & hollow compressed block (reinforcement embed easy)
- strength can be changed (depending on raw material)
- locally made (on-site soil used)
- low skilled manpower.

Disadv: Soil identification, no tensile capacity, low performance than concrete blocks

CEB → not for partition

Bar
concrete
structure

Mortar >> Mortar
unit

Mortar
unit

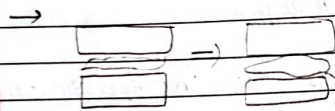
fall
C, from unit
(dangerous)

loose

- proportion (Cement: Sand)
H1 (1:3), H2 (1:4), M1 (1:5), the
proportion is changed if lime is used.
Mortar (Cement, lime, cement-lime, mud)
Mortar strength should not be greater than
that of masonry unit (unit failure)

→ compressive strength test (70mm cube)

Why brick curing is
done?
(before use)?



stable

shape of
mortar
after
it consumes
water

Masonry Unit Strength (N/mm ²)	Mortar Type
below 5	M2
5 to 14.9	M1
14 to 24.9	H2
25 & above	H1

so wall & of addition
(300)

Construction Technology

- Lap should be minimum $\frac{1}{4}$ th brick along the length of wall and $\frac{1}{2}$ nd brick across the thickness of wall.
- Bricks bat should be discouraged, except in special locations.
- The vertical joint in alternate courses should be along same perpendicular.
- All finished masonry walls should be cured for at least 7 days.
- Thickness of mortar joint should be uniform and not more than 10mm in any case.
- Height of brick masonry in one day should not exceed 1.5m.

* Brick construction technology:
Terminology

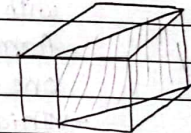
- Bond: a pattern in which brick is laid
- Lap: distance b/w vertical joint
- Closer: piece of brick used to close up the bond at the end of brick course (done by mason)



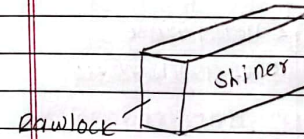
Queen closer



King closer
closer



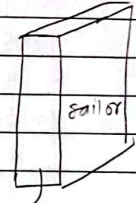
Beveled
closer



Rawlock



Stretcher



Soldier

Brick laying pattern

- Bonds
- Since masonry consists of a large number of individual units jointed together with mortar so as to form one mass, it is necessary to lay units in such a way that under load, the units act jointly.
- The most important rule to be observed in this connection is that vertical cross-joints in any course should be staggered and there should not be more than a quarter of brick length from those in the course below or above that course.

Bahr

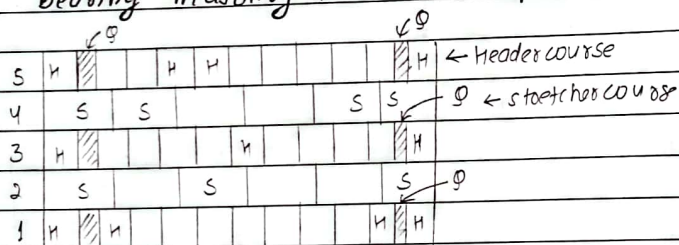
Practical Joint note
Sample

Trp: 1 brick (1st 1/2) brick

- English Bond (सकर Joint)
- Alternate course of header and Stretcher

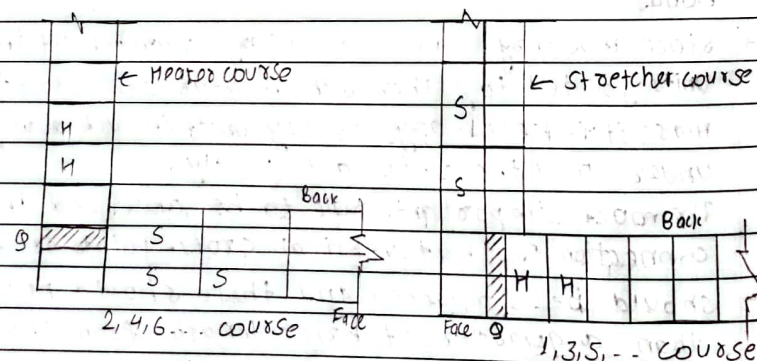
along height

- lap: min one fourth brick length
- Bricks in same course do not break joint
- Generally centrally located header in stretcher
- The header course is commenced with a queen header followed by a queen closer and continued with successive headers. The stretcher course is formed of stretchers, having a minimum lap of one quarter brick length.
- This bond considered to give the best strength in masonry and is mostly adopted in all load bearing masonry that is to be plastered over.



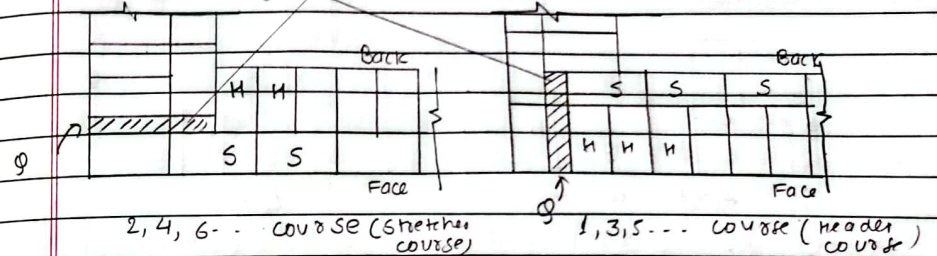
S = Stretcher; H = Header; Q = Queen closer

Elevation



Plan for 1 brick thick wall (English bond)

Quarter queen closer (Q) Queen Bat



Plan for 1 1/2 Brick thick wall (English bond)

- Flemish Bond (Dutch)

- (Alternate header and stretcher in each course.)

- Two types study with figure
- The queen closer is put next to the queen header in alternate course to develop the face lap.

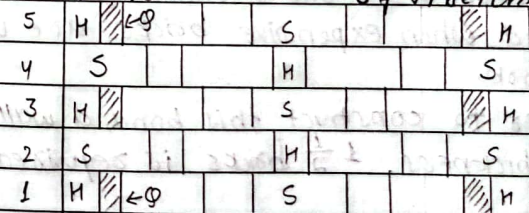
- (1) Double Flemish Bond

- Header and stretchers are placed alternately in front as well as back elevations.

- For odd number of half bricks, half bats and three-quarter bats used.

- For even number of half bricks, no bats required.

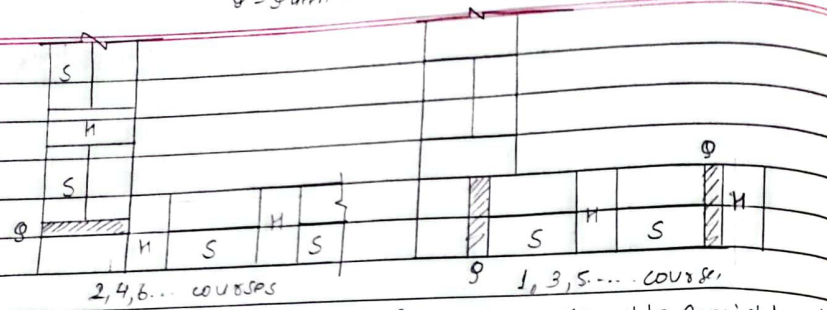
- This bond gives better appearance than English bond. But it is not so strong as English bond as it contains more number of stretchers.



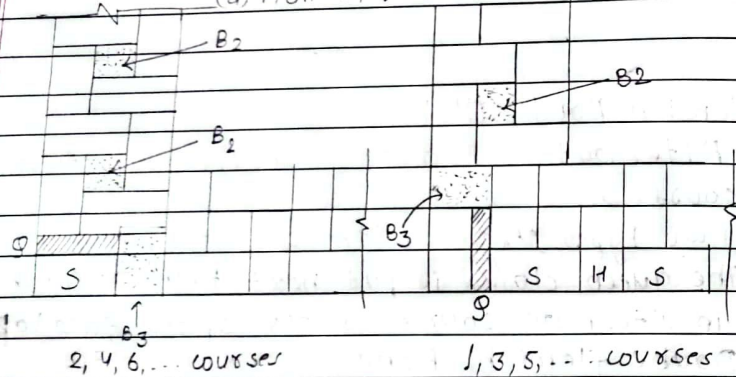
Elevation

S = Sattler
H = Header
Q = Quarter

B₂ → Half brick
B₃ → 3/4 brick
B₁ → Quarter



(a) Plan of 1 Brick thick (Double Flemish bond)



(b) Plan of 1 1/2 Brick thick (Double Flemish bond)

(ii) Single Flemish Bond

↳ In single Flemish Bond, the face elevation of a Flemish Bond and the setting as well as backing are of English bond.

↳ Thus, in this type of bond, an attempt is made to combine the strength of the English bond with the appearance of the Flemish bond. This type of bond is used when expensive bricks are used for the face work.

↳ But in order to construct this bond, a wall of minimum thickness 1 1/2 bricks is required.

- Rat-trap Bond
- Alternate shiner and row lock in each course
- centrally located cavity
- 35% less bricks than other bond
- Two possible layout
 - Alternate course start: 3/4th shiner, intermediate course with row lock.
 - Alternate course: shiner, intermediate start with row lock.

Surendra Sharma

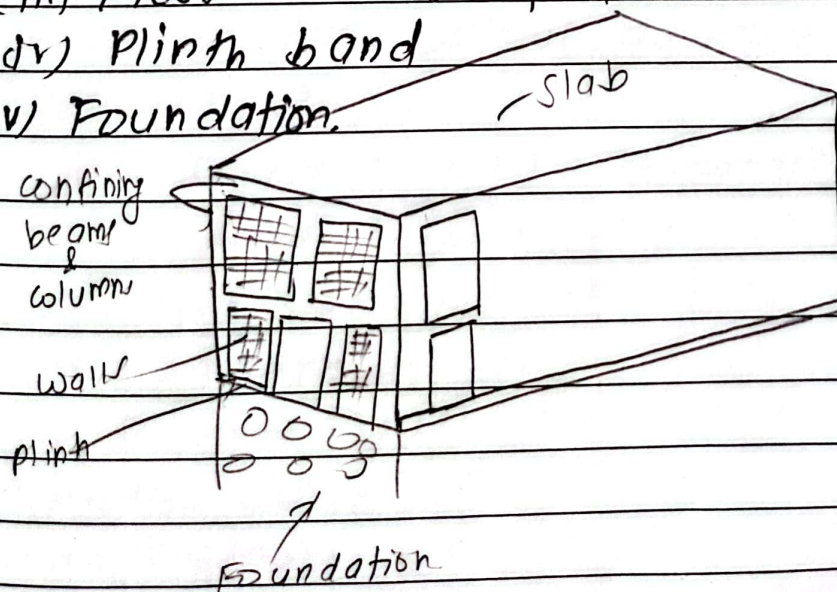
Isolation b/w column & brick.

* Explain Masonry as infill material
Equivalent strut model Adv. & disadvantages.

* Confined masonry

↳ brick.

- Masonry walls carry seismic loads and concrete is used to confine the walls.
- Construction system where masonry walls are surrounded on all four sides with reinforced concrete.
- Confinement should be in vertical and horizontal both direction to resist lateral and gravity loads.
- The confining members are effective for:
 - (i) Enhancing stability and integrity of masonry walls for in-plane and out-of-plane EQ loads.
 - (ii) Enhancing strength of masonry wall under EQ.
 - (iii) Reducing brittleness of masonry improving EQ performance.
- Structural components of confined masonry:
 - (i) Masonry wall
 - (ii) Confining elements (tie-beams and tie-columns)
 - (iii) Floor and roof slab.
 - (iv) Plinth band
 - (v) Foundation.



Now min 125mm

Date _____
Page _____

(Q) Design an interior cross wall of two-storey building to carry 100 mm thick RCC slab with 3m ceiling height. The wall is unstiffened and it supports a 2.65m wide slab. Live load on roof and floor is 1.5 kN/m^2 and 2 kN/m^2 . Wt. of floor finish is 0.2 kN/m^2 . Wt. of 80mm thick terrace 1.96 kN/m^2 .

→ Solution

(a) select wall thickness = 110mm



Question 21

We can assume all dead load incorporated in self wt. (if not given)

$$\text{Actual stress} = \frac{\text{Total load}}{\text{thickness}}$$

→ Solution:-

(a) select thickness = 110mm

compressing strength of brick = 10 N/mm^2

Mortar type = M1

(b) critical section at bottom

IS: 875 part 1
 $\gamma_{\text{ecc}} = 25 \text{ kN/m}^3$

Roof: swt. of slab = $0.10 \times 25 = 2.5 \text{ kN/m}^2$
Dead load: Wt. of terrace = 1.96 kN/m^2

Live load = 1.5 kN/m^2 { IS 875 part II }
 5.96 kN/m^2

Floor:

(if not given assume 1 kN/m^2)
Wt. of slab = 2.5 kN/m^2
Wt. of floor finish = 0.2 kN/m^2

Live load = 2 kN/m^2
 4.7 kN/m^2

Dead load & self weight = $1.96 \times 3.05 \times 0.11 \times 2$ (wall at 1st UDL section)

$\gamma_{\text{masonry unit}}$ (brick) H_t (effective taken) thickness of wall (110mm)

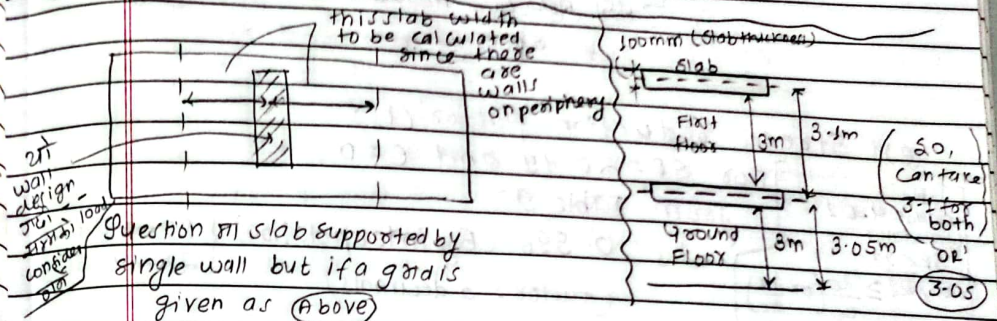
2 storey

= 12.88 kN/m

If joints are selected and

Brick
mortar
Brick
taken (1 cm on each side)

→ overall wall thickness decrease and.



(c) Total load = $(5.96 + 4.7 + 12.88)$
 $\rightarrow = (5.96 + 4.7) \times 2.65 + 12.88$
 $= 41.129 \text{ kN/m}$

length of slab of which the wall supports wt.

(c) Effective height, $h_e = 0.75 H = 0.75 \times (3 + 0.1)$ { can take (3+0.1) }
 $= 2.2875 \text{ m}$ (table 4)

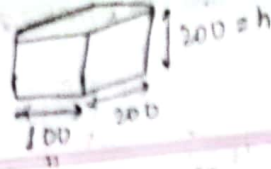
Effective thickness, $t_e = 110 \text{ mm} = 0.11 \text{ m}$ [clause 4.5]

Slenderness Ratio (SR) = $\frac{h_e}{t_e} = \frac{2.2875}{0.11} = 20.79$ (check must) (OK)

Max^m slenderness ratio = 27 (As per clause 4.6.1)

eccentricity, $e = 0$ (Assume)

What if bricks are
 $\frac{ht.}{wd.} = \frac{200}{100} = 2$ then
 $k_p \neq 1$
 depend on
 crushing strength



(d) basic compressive strength, $f_b = 0.96 \text{ MPa}$ (Table 8)

↳ depends on mortar and masonry unit strength

(e) Stress reduction factor (k_s)

Tips:

clause 4.6.1

(for walls)

$SR \leq 27$

$20, 27 \geq \frac{le}{te} \text{ (or } \frac{he}{te})$

For $SR = 20.79$ and $e = 0$
 from Table 9

$k_s = 0.596$ (By interpolation) $\left\{ \begin{array}{l} 20 \rightarrow 0.62 \\ 22 \rightarrow 0.56 \end{array} \right\}$
 (factor: 3 decimals)

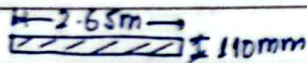
सूचना नें ध्यान देनी

Assume जिन

Area reduction factor (k_a)

⊙ Assuming length of wall: 2.65m

Look at plan of wall Area of wall = $\frac{0.11}{\text{thickness}} \times \frac{2.65}{\text{length}}$



$= 0.29 > 2$ (clause 5.4.1.2)

So, k_a not applicable

take, $k_a = 1$

[If $A_a < 0.2$ then, $k_a = 0.7 + 1.5 A_a$]

Shape modification factor (k_p)

$\frac{ht. \text{ of brick unit}}{\text{width of brick unit}} = \frac{55}{110} = 0.55 (< 0.75)$

check wall thickness too, if it is 100mm

width of brick to be 100mm

(Table 10: clause 5.4.1.3)

So, take, $k_p = 1$

(f) Actual stress, $= \frac{\text{total load}}{\text{thickness}} = \frac{41.29}{0.11} = 373.9 \text{ kN/m}^2$

(g) Permissible stress, $f_{all} = f_b \times k_s \times k_a \times k_p$
 $= 0.96 \times 0.596 \times 1 \times 1$
 $= 572.16 \text{ kN/m}^2$

Actual stress < Permissible stress
 (OK)

eccentricity $\rightarrow$ also increases chances of buckle

Increase the tendency of masonry element to buckle and reduce load carrying capacity. Thus these are related to permissible stress through stress reduction factor (K_s)

So, AS, SR $\uparrow$ & eccentricity $\uparrow \rightarrow$ load carrying capacity $\downarrow$

So, ($K_s < 1$)

(SR < 6) $\rightarrow$ ($K_s = 1$)

Numerical:

(SP-20) code $\Rightarrow$ Newton of Masonry.

①
Explanatory of IS: 1905

Has numerical

Pg: 40-67

(Pg 31 $\rightarrow$ numerical) - (No compound with)

Area reduction factor (K_a)

$\rightarrow$ Small-area of the member is based on the concept that there is statically greater probability of failure of a small section as compared to larger element. This is necessary if there is appreciable variation in strength of individual unit.

Shape reduction factor (K_p)

$\rightarrow$ It is based on the general principle that lesser the number of horizontal joints in masonry, greater its strength or load carrying capacity

Ht/width $\uparrow \rightarrow$ NO of joints $\downarrow \rightarrow K_p \uparrow$
(as crushing strength $\uparrow$)

Masonry as infill wall

→ The wall which is confined on all four sides with reinforced concrete or steel frame which are not intended to carry either vertical loads or horizontal loads & are consequently not designed to perform moment resisting frame.

→ Masonry infill wall serves as non-structural elements.
Role: as partition wall (but while using as partition wall has both defects & benefits)

↳ Mass ↑ (mass-modeling) → seismic force & mass
↳ Load ↑ → stability ↑ (need in load-bearing but not much necessary in RC)

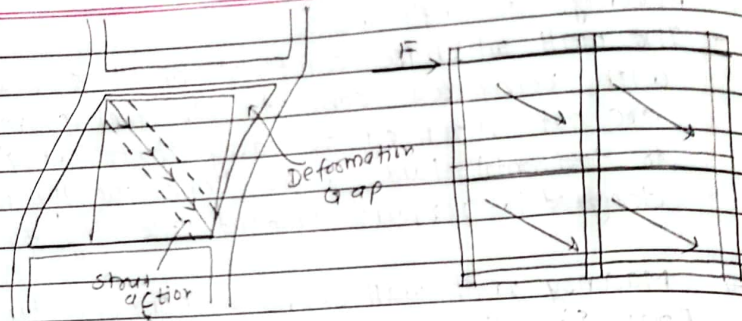
↳ so, infill wall thickness ↓ (< 9 inch)

↳ When infill wall interacts with a structure, the effect may be favourable or unfavourable.

• Equivalent strut

→ The dissimilar deformation of masonry infill and frame causes increase in compression i.e. compression strut is formed and it is the resisting mechanism once the interaction gets activated.

→ And if every panel is looked as equivalent strut it has stiffening effect on bare frame, and panel itself can have different failure (sliding, crushing) depending on aspect ratio, overall geometry, material strength, etc.



V.V. Imp

• Aspect ratio

- ↳ Area of wall w.r.t plan area of building
- ↳ why imp? In masonry str. walls are important for bearing loads if mass of wall isn't sufficient then masonry str. fails. So, aspect ratio imp. in case of masonry str.

V.V. Imp

• Benefits

(i) with reference to deformation

- ↳ Infill panels reduce seismic deformation demand at storey and member level due to and member their in-plane stiffness

↳ It incre

(ii) w.r.t strength

- ↳ It increases ^{storey} lateral force resistance through their inplane strength (as act as shear wall so, in-plane strength is increased)

Stiff (increased area)

Moment resisting capacity $(M_R) = \frac{\sigma_c I}{y}$

Mom of inertia $(I) \propto \rightarrow M_R$

(iii) energy dissipation

→ When panel is damaged then it contribute to global energy dissipation capacity.

Negative

→ But, there is a problem if when panel is strong stout, it gives stout action in framed joint which results in failure of frame due to increased stress concentration.

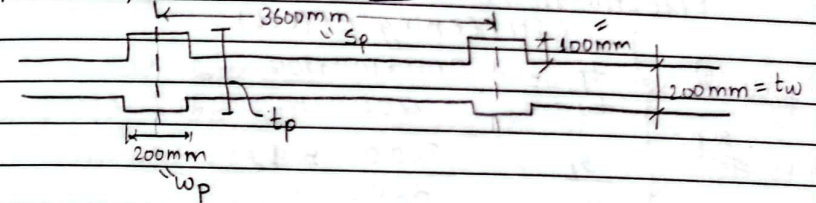
Surendra Sharma

Numerical - II

single
A 1 storey workshop of height 5.4 m supporting
RCC roof. If roof load is 45 kN/m and bottom
of the wall rest over foundation block. ~~At~~
Design interior walls with piers.

- (1) wall thickness = 200 mm
width of pier = 300 mm ~~Stiffening effect~~
Spacing of piers = 3600 mm
Thickness of pier on each side of wall = 100 mm

→ Solution, (pier: code) - dim.



(I) det brick · 10 N/mm² M1 mortar

$$f_b = 0.96 \text{ N/mm}^2$$

(II) Loading

$$\text{Roof} = \frac{3600 \times 45}{1000} = 162 \text{ kN}$$

$$\text{Self weight} = (3.6 \times 0.2 + 2 \times 0.2 \times 0.1) \times 5.4 \times 20 = 82 \text{ kN}$$

$$\text{Total load/Bay} = 162 + 82 = 244 \text{ kN}$$

$$\text{Cross-sectional area} = 3600 \times 200 + 2 \times 200 \times 100 = 76 \times 10^4 \text{ mm}^2$$

$$f_{actual} = \frac{244 \times 10^3}{76 \times 10^4} = 0.321 \text{ N/mm}^2$$

$$(3) \text{ Effective height } (h_e) = 0.75 \times 5400 = 4050 \text{ mm}$$

Effective thickness
(stiffening effect)

$$\text{tabu } (6) \left\{ \begin{array}{l} \frac{t_p}{t_w} = \frac{200+100+100}{200} = 2 \\ \frac{s_p}{s_w} = \frac{3600}{800} = 4.5 \end{array} \right.$$

$$\text{stiffening coefficient} = 1.04$$

$$\text{effective thickness} = 1.04 \times 200 = 208 \text{ mm}$$

$$\left[\text{Effective thickness} - \frac{\text{Stiffening} \times t_w}{\text{coeff}} \right]$$

(4) Slenderness ratio

$$\text{Based on height} = \frac{4050}{208} = 19.5$$

$$\text{Based on length} = \frac{2880}{208} = 13.85 \approx 14$$

continuous wall supported by pier/buttress

(5) stress reduction factor

$$K_s = 0.67$$

$$\text{Area reduction factor } (A = 0.208 \times 3.6)$$

$$A > 0.2$$

$$= 1$$

Cavity wall 4.5.2

Shape modification factor

$$\frac{55}{110} \Rightarrow 0.5$$

(take brick 230 x 110 x 55)

= 1 or take similar

(6) permissible stress

$$= 0.67 \times 0.96$$

$$= 0.64 > 0.321$$

Q. Design an interior wall with 2 storey carrying concrete slab with a storey ht. of 3m. The wall is stiffened by 100mm thick intersecting walls at 3600mm c/c. Also, a wall has door opening of size 900 x 2000mm at a distance of 200mm from one of the intersecting wall. Assume roof loading 15 kN/m, floor loading 12.5 kN/m

(Avg thickness method)

→ Solution:-

(1) wall thickness = 200mm

$$\text{Self wt} = 24 \text{ kN/m}$$

$$\text{total load} = 15 + 12.5 + 24 = 51.5 \text{ kN/m}$$

$$\text{Effective height} = 0.75 \times 3000 = 2250 \text{ mm}$$

• Effective thickness:

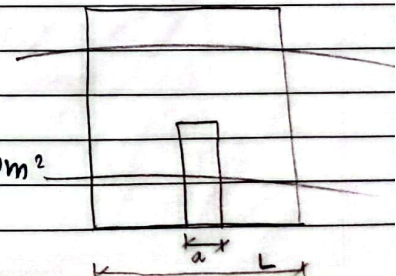
At level of opening,

$$\text{Effective area} = (L-a)t$$

$$= 540000 \text{ mm}^2$$

$$\text{Effective thickness} = \frac{540000}{3600}$$

$$= 150 \text{ mm}$$



(check must work)
 ~ Always pab design
 ~ by hand

Above level of opening,
 effective thickness = 200mm

$$\therefore \text{Average} = \frac{200 + 150}{2} = 175 \text{mm}$$

Slenderness ratio = 13 (< 27) okay

$$k_s = 0.715$$

$$\text{factual} = \frac{51500 \times 3.6}{540000} = 0.34$$

Using brick 7.5 N/mm² f mortar L₁

$$f_{a1} = 0.53 \times 0.715 (> 0.34)$$

$$= 0.38 \text{ N/mm}^2$$

OK

Masonry column

- ~~max~~ Design a brick column to carry axial load of 60kN from a roof consisting of RCC beam and slab. Take effective height of pillar 3.8m.

any way

→ Mortar = M₂

crushing strength = 7.5 N/mm²

$$SR = \frac{\text{eff ht}}{\text{eff t}} \quad \times 12 \quad \downarrow \quad 4.6.27$$

Again,

(Take 12)

$$\text{Minimum dimension of column} = \frac{3800}{12} = 316.67$$

Use 350mm width (1.5 thick brick wall)

$$SR = 10.85$$

$$f_b = 0.74 \text{ N/mm}^2$$

$$k_f = 0.86$$

$$k_a = \frac{(0.7 + 1)}{2} = 0.85 \quad (\text{avg. of min \& max})$$

$$k_p = 1 \quad (\text{based on masonry unit})$$

$$\left(\frac{55}{110} = 0.5, k_p = 1 \right)$$

Now,

$$f_{a11} = f_b \times k_f \times k_p \times k$$

$$\text{or, } \frac{60 \times 10^3}{350 \times 350} = 0.74 \times 0.86 \times 0.85 \times 1$$

$$\Rightarrow l = 319.75$$

(but l > 316.67)

Adopt 350 x 350 column size.

Pass ~~अक्स~~ now, actual value.

Actual capacity

$$A = 0.35 \times 0.35 = 0.1225 \text{ m}^2 \text{ (0.2)}$$

$$k_a = 0.7 + 1.5A$$

$$= 0.7 + 1.5 \times 0.12 = 0.88$$

∴ Actual capacity

$$f_{all} = (0.7 + 1.5 \times 0.88 \times 0.8 \times 1)$$

$$= 0.56$$

(Modular bricks)
width/ht. ratio
of brick = 1

$$\frac{60 \times 10^3}{350 \times 350}$$

(Okay)

✓ V.V.T # (Eccentric Loading) using modular bricks

(Q) A wall 20cm thick, carries at a top, a load of 80 kN/m having resultant eccentricity ratio $e = \frac{1}{12}$. Wall is 5m long b/w cross-walls

and is of 3.4m clear height b/w RCC slab at top and bottom. What should be the strength of brick and grade of mortar?

ext to moment

$$\sigma = \frac{P}{A} + \frac{M}{Z}$$

→ 50%!

$$h_e = 2.55 \text{ m}$$

$$h_g = 5 \text{ m}$$

SR

$$\sigma = \frac{P}{A} + \frac{M}{Z}$$

Axial (direct) Bending (stress)

Stiffening coeff = 1

Total wt = W

$$\text{sectional-modulus} = Z \text{ (???) } = \frac{I}{y}$$

See For eccentricity ratio $\frac{1}{24}$, take only axial loading

B/w $\frac{1}{24}$ & $\frac{1}{6}$, multiply by 1.25.

Greater than $\frac{1}{6}$, Redesign (increase wall thickness)

$$M = \text{total load} \times \text{eccentricity}$$

$$f_{all} = 1.25$$

(fall can be increased by 25% for eccentric loading 5.4.1.4)

$$\rightarrow SR = \frac{h_e}{l_e} \text{ or } \frac{l_e}{h_e} \text{ whichever is less}$$

$$\text{Here, } l_e > h_e \text{ (so, } SR = \frac{0.75 \times 3.4}{(20-1) \times 10^{-2}} = 13.4$$

$$\text{Axial stress in masonry due to loading at top} = \frac{80 \times 10^3}{\frac{19 \times 100}{1000}} = 4.2 \text{ N/cm}^2 = 0.42 \text{ N/mm}^2$$

Actual thickness

$$\text{Axial stress due to self load at wall at bottom of support} = \frac{\gamma_m \times A \times H_e}{A}$$

$$= \frac{20 \times 3.4 \times 1000}{(1000)^2}$$

$$= 0.068 \text{ N/mm}^2$$

Bending stress due to eccentricity of load at top

$$= \frac{80 \times 10^3 \left(\frac{1}{12}\right) \times 0.2 \times 6}{1 \times 0.22^2 \times 0.19^2}$$

$$= 0.222 \text{ N/mm}^2$$

Max. compressive strength = Axial stress + bending stress on one face

$$= 0.42 + 0.068 + 0.222 = 0.71 \text{ N/mm}^2$$

K_s (for $SR = 13.4$ & $FR = 1/12$) = 0.761 (Table 9 by interpolation)

Acc to 5.4.3.2 (10), $f_{all} = f_b \times 0.75 = 0.89 \text{ N/mm}^2$

Taking, $K_p = 1$ & $K_a = 1$ (element being fairly long)

(say) $f_b \leq f_{all}$ or, $f_b \times K_p \times K_a \leq 0.89$

[Crushing strength of brick = 7.5 N/mm^2] $\Rightarrow f_b = \frac{0.89}{0.761 \times 1 \times 1} = 1.17 \text{ N/mm}^2$

But, for modular bricks $f_b = 7.5 \text{ N/mm}^2 \rightarrow I_{cp} = 1.1$

(9) A masonry wall 230mm thick carries on axial load 30kN/m from the wall above and eccentric load of 22kN/m from RCC floor acting at a distance 45mm from center-line of the wall. Determine resultant eccentricity and eccentricity ratio $\rightarrow \frac{\text{eccentricity}}{\text{thickness}}$

→ Solⁿ:

$$W_1 = 30 \text{ kN/m}$$

$$W_2 = 22 \text{ kN/m}$$

$$W = W_1 + W_2 = 52 \text{ kN/m}$$

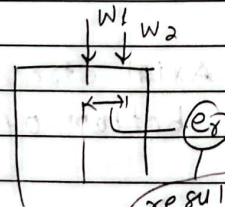
Taking moment about center line.

principle of superposition

$$52 \times 10^3 \times e = 30 \times 10^3 \times 0 + 22 \times 10^3 \times 45$$

$$[e = 19 \text{ mm}]$$

resultant eccentricity



resultant eccentricity

must

Eccentricity ratio = $\frac{\text{eccentricity}}{\text{thickness}}$

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

$$4 \times 0.23$$

$$0.92$$

$$\text{But } L = 0.6$$

(check wall or column)
But question of column

9. A masonry wall have thickness 230mm and length 0.6m carries a load of 55kN at the base inclusive of self wt. The effective ht. is 2.8m having RCC roof. What should be the strength of brick and grade of mortar?

→ Solution:-

(I) Check:

$$\text{length} = 0.6\text{m} > (4 \times 0.23) \text{ [clause: 2.3.1]}$$

So, the masonry structure is ~~wall~~ column.

(II) Wall thick:

$$\text{Column thickness} = 230\text{mm}$$

$$\text{size: } 230\text{mm} \times 230\text{mm} \times 600\text{mm}$$

For column,

$$\text{effective height} = \text{actual ht.} \text{ [4.3.2]}$$

$$h_e = 2.8\text{m}$$

$$\text{Also, considering effective length, } L_e = 0.6\text{m}$$

$$\text{Effective thickness, } t_e = 0.23\text{m} \text{ [4.5.1]}$$

$$\text{Assume, crushing strength} = 12.5\text{N/mm}^2$$

$$\text{Mortar} = \text{M1}$$

Then,

(III) Basic compressive strength, $f_b = 1.16\text{N/mm}^2$ [Table 8].

(IV) Actual compressive stress,

$$f_{ac} = \frac{55}{0.23 \times 0.6} = 0.40\text{N/mm}^2$$

(V)

$$\text{Slenderness ratio, } SR = \frac{2.8}{0.23} = 12.17 (> 12)$$

Not okay

[Form 4.6.2]

$$\text{Again, } SR = \frac{2.8}{0.6} = 4.67 (< 12)$$

okay.

Since, $SR < 6$,

$$\text{Stress reduction factor, } K_s = 1$$

[Table 9]

(VI)

Consider each masonry brick unit of size,

$$230\text{mm} \times 110\text{mm} \times 55\text{mm}$$

Then,

$$\frac{\text{ht.}}{\text{width}} = \frac{55}{110} = 0.5 (< 0.75)$$

$$\text{So,}$$

$$\text{Shape modification factor, } K_p = 1$$

[Table 10]

(VII)

$$\text{Area of section, } A = 0.23 \times 0.6 = 0.138\text{m}^2 (< 0.2\text{m}^2)$$

Thus,

From clause, 5.4.1.2,

$$\text{Area-Reduction Factor, } K_a = 0.7 + 1.5A$$

$$= 0.7 + 1.5 \times 0.138$$

$$= 0.907$$

(VIII)

$$f_{all} = f_b \times K_s \times K_p \times K_a = 1.16 \times 1 \times 1 \times 0.907 = 1.05\text{N/mm}^2$$

Since,

$$f_{all} > f_{ac}, \text{ the design is okay}$$

But to make more economical design,

Let's consider, crushing strength = 7.5N/mm^2

$$4 \text{ Mortar} = \text{M1.5}$$

[Table 8]

Thus,

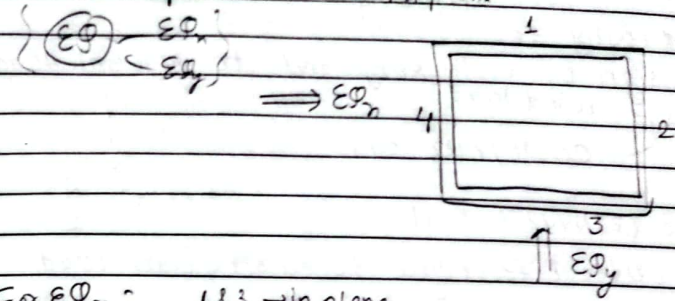
$$f_{all} = 0.74 \times 1 \times 1 \times 0.907 = 0.67\text{N/mm}^2$$

$$\text{Then, } f_b = 0.74\text{N/mm}^2$$

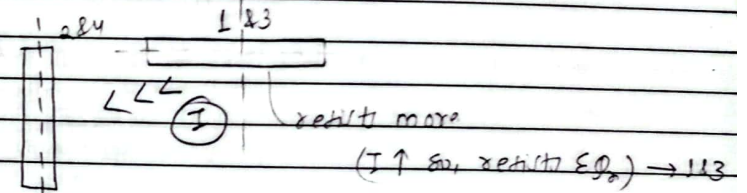
(will not change, K_s, K_p & K_a value)

Design of wall under Lateral load

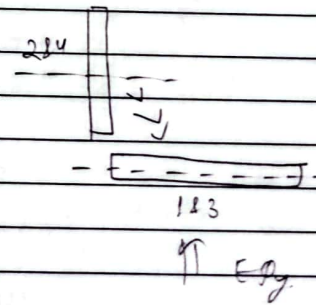
or In-plane & out of plane



For $E P_x$: 1 & 3 → in plane
2 & 4 → out of plane



For $E P_y$: 1 & 3 → out of plane
2 & 4 → In plane



- (c) Explain in plane & out of plane str.
- (9) Deficiencies & failure in masonry structures
- (9) Earthquake resisting element in masonry building
- (9) Why to

Design of wall subjected to lateral loads

wind load

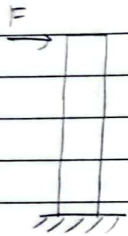
earthquake load

• Earthquake load:

Lateral force due to earthquake load
 $= 0.5 \times W$

(Gen. $\alpha_h = 0.1g$)

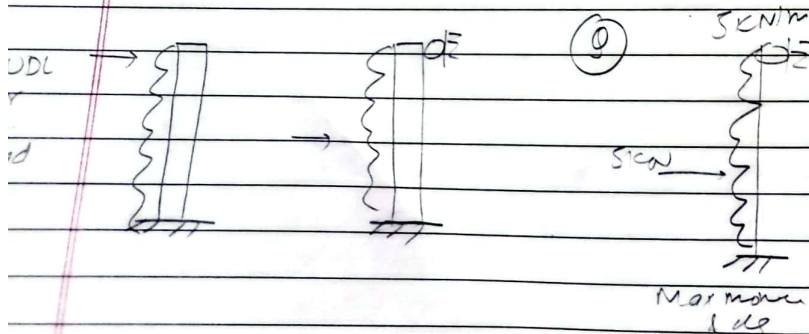
For any wall $\rightarrow$ restrained at top & bottom
 must be known at top
 (propped, cantilever, fixed, tie)



$$M = F \times H$$

$$\sigma = \frac{M}{I} \times y$$

$$\{ \text{allowable} = f_b \times K_s \times K_a \times K_p \}$$

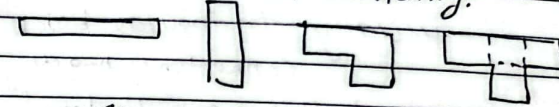


Deficiencies

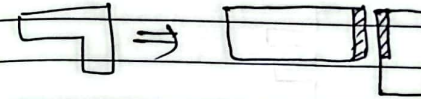
• Failure in masonry structure:

(1) Configuration problem

Arrangement of building.

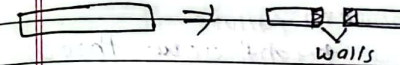


$\rightarrow$ Symmetrical (as far as possible) $\rightarrow$ else



torsion effect comes into play.

$\rightarrow$ Large building: heat transfer problem



(So, separation is done).

(structurally diff. buildings)

(2) Large door and window openings.

$\rightarrow$ since aspect ratio decreases.

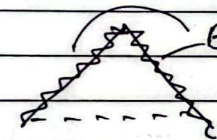
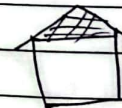
(3) Openings at corner

$\rightarrow$ min $\approx$ at 2ft. from corner.

opening $\uparrow \rightarrow$ wall stiffness $\downarrow \rightarrow$ Failure due to lateral loads

(4) Gable wall

$\rightarrow$ most vulnerable as cantilever effect.



Bands are provided.

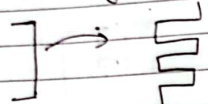
(5) Long wall failure

↳ out of plane failure
↳ to cross-wall provided to minimize it.

(6) Lack of connection between walls

↳ usually triangular brick unit connection is made

↳ 'oo' nothing can be done



better

↳ adjacent walls might fail through triangular toothing.

(7) Delamination

↳ to avoid through stones ($\frac{3}{4}$ th of total thickness can be kept).



through stone

else



separation

Major causes of failure of Masonry Building.

- (i) Non-integrity of wall, floor and roof.
- (ii) configuration - irregularity of building causes torsional effect.
- (iii) Large opening of building.
- (iv) Inappropriate position of opening.
- (v) Lack of cross wall in large length of wall.
- (vi) Lack of reinforcement make the masonry building brittle.
- (vii) Pounding effect
- (viii) Lack of anchoring element b/w two walls.

Masonry Pounding → when roofs of two adjacent buildings are at different levels during earthquake, two buildings strike against each other called pounding.

(8) Lack of earthquake resisting element.

(9) Weak wall-roof connection.

In-Plane and Out-of-Plane

[Force | Behaviour | Pattern]

• Out-of-plane

→ The structural walls perpendicular to seismic motion are subjected to out of plane forces

④ → The resulting flexural stresses due to bending moment caused by out-of-plane forces create a tensile stress in masonry causing rupture. These forces cause bending of wall in both horizontally and vertically in long and tall walls.

→ causes:

(i) Inadequate anchorage between wall-to-wall and also in wall-to-roof.

Crack effect:

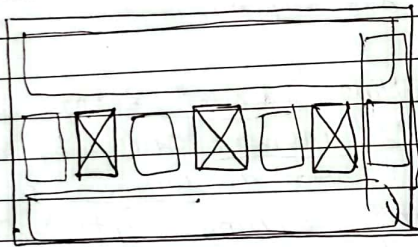
- (i) Vertical crack at corner, T-junction,
- (ii) Horizontal crack at parapet wall
- (iii) with separation / delamination
- (iv) Crack at lintel

→ happens to be worst at upper stories and is critical in flexible floor compared to rigid floor.

Flexible $\rightarrow$ Timber
RCC slab $\rightarrow$ Rigid.

In-plane

- The structural walls parallel to seismic motion are subjected to in-plane forces.
- Due to in plane forces masonry walls are grouped into small sized elements like spandrel, pier, etc.



Failure pattern

(i) Rocking of piers



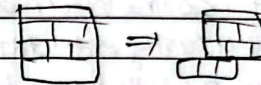
- The subunits rock back & forth developing contact at opposite diagonal, causing crushing of masonry at corner. (fig $\rightarrow$ Google)
- more susceptible for greater ht. or if wt. above wall is less then more movement occurs.
- when masonry is slender and wt. of the structure above is small.

(ii) Diagonal shear crack.



(iii) sliding

$\hookrightarrow$ masonry str. to layer & slide.



Diaphragm Diaphragm failure

$\hookrightarrow$ lack of anchoring produces a push of diaphragm against the wall.

$\hookrightarrow$ due to absence of good shear transfer b/w diaphragms and reaction wall accounts for damage at corner of wall.

Summary

Earthquake resisting element in masonry

$\rightarrow$ Two types: $\rightarrow$ Band

(like bandage)

① Horizontal Bands

① $\rightarrow$ Gable Band

② $\rightarrow$ Roof Band

③ $\rightarrow$ Lintel Band

④ $\rightarrow$ Sill Band

⑤ $\rightarrow$ Plinth Band.

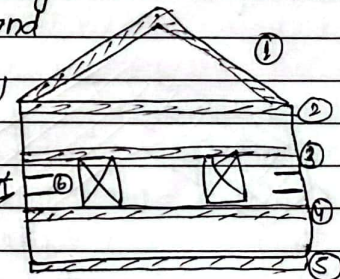
⑥ corner stretch

$\rightarrow$ min thickness of Band

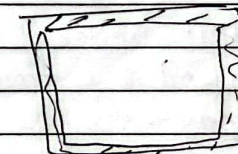
$\hookrightarrow$ 75mm to 150mm.

(NBC 202/2003)

$\hookrightarrow$ Band continuous throughout the walls.



Elevation.



1. Compressive strength of Bricks and walls

- Important property for structural application
- Load carrying capacity of brick and wall depends on it.

① → Increasing comp. strength of unit will increase the masonry assemblage and elastic modulus.

② → The factor governing the strength of brick structure (walls) includes compressive strength of brick unit, mortar strength and elasticity, brick layer i.e. type of bond used, workmanship and brick uniformity.

* Procedure (for brick)

- Apparatus → Universal testing machine.
- Specimen → At least 3 nos. of whole brick.
- Sampling:
 - Remove unevenness observed in the bed faces to provide smooth parallel faces by grinding.
 - Immerse in water at room temp² for 24 hrs.
 - Remove specimen and drain out any surplus moisture at room temperature.
 - Fingers and voids are filled by cement mortar and then (1:1, clean coarse sand of 3mm and down).
 - Store it under damp jute bag for 24 hours followed by immersion in clean water for 3 days.
 - Remove and wipe out traces of moisture.
 - Specimen ready to test.

Procedure

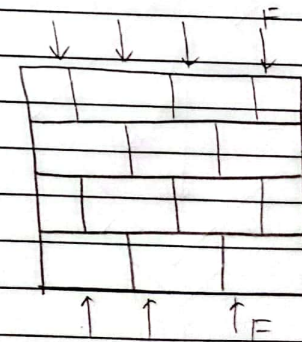
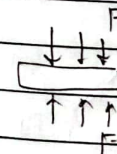
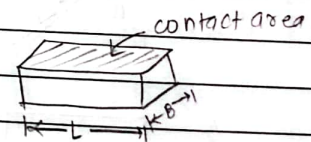
- Place specimen in compressive testing machine with frog facing upward in between plates.
- Load is gradually and uniformly applied (140 kg/cm^2 / min)
- Load at which specimen fails is noted and calculated as
crushing / compressive strength = $\frac{\text{Max. load at failure}}{\text{Loaded area of brick.}}$

* Procedure (for wall)

- UTM
- 3 nos. (with certain bond type)
- Sampling
 - Prepare walls (3 to 5 nos. brick) with specific bond
 - Fill the top and bottom of walls by placing mortar in frogs and gaps.
 - If cement mortar is used cover the wall by jute bags for 24 hours and cured by clean water for 3 days.
 - Remove jute bags after 3 days and wipe out any traces of moisture and specimen is ready to test.

procedure

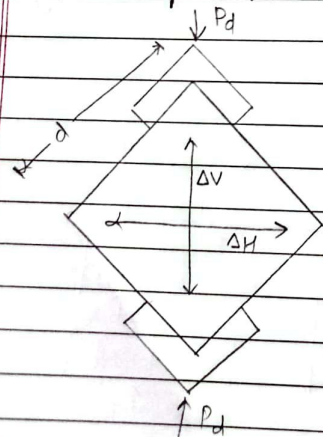
- Similar as brick.



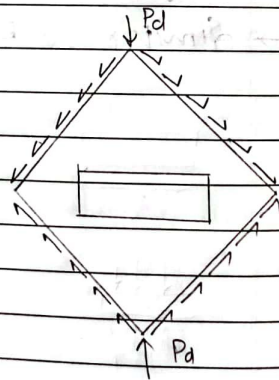
2. Diagonal shear test

- The failure of walls during earthquake is caused by combined effect of normal compressive and shear stresses, which is represented by principle tensile stress and which when exceeds diagonal tensile strength of the masonry, failure will take place.

- Diagonal shear test is based on subjecting a $1.2\text{m} \times 1.2\text{m}$ square section of wall by the thickness of wall, to diagonal compression through loading shoe at two diagonally opposite corners of specimen as shown in figure.
- Failure mode of test is through formation of diagonal crack parallel to the line of action of compression force.

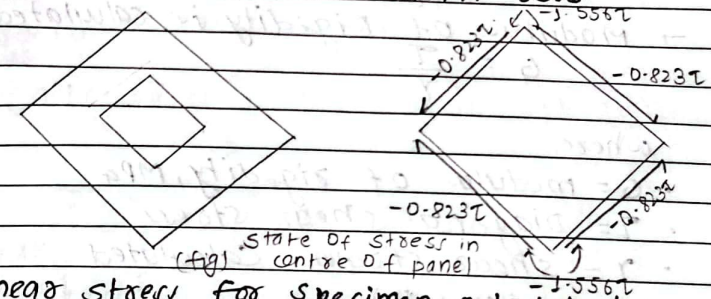


(a) Diagonal compression test



(b) Diagonal test

- Test was introduced to simulate a pure shear stress.
- Procedure is based on ASTM E519.



- Shear stress for specimen calculated as

$$\tau = \frac{P_d}{\sqrt{2}A} \quad (1)$$

P_d → Applied load (N)

A → Net area of specimen along the bed and head joint in mm^2 .

$$A = (w+h) \times t \times \frac{n}{2}$$

w → width of specimen in mm

h → height of specimen in mm

t → total thickness of specimen in mm

n → % of gross area of unit that solid, expressed in decimal.

Surendra Sharma

Shear strain is given as follows:-

$$\rightarrow \gamma = \frac{(\Delta V + \Delta H)}{g}$$

→ Modulus of rigidity is calculated as

$$G = \frac{\tau}{\gamma}$$

where,

- G = modulus of rigidity, MPa
- τ = Diagonal shear stress
- γ = shear strain calculated

$$= \frac{(\Delta V + \Delta H)}{g}$$

- ΔV = Vertical shortening (mm)
- ΔH = Horizontal shortening (mm)
- g = vertical gauge length (mm)

} Based on gauge