Modified

CBCS SCHEME

15CV831

USN

Eighth Semester B.E. Degree Examination, June/July 2019
Earthquake Engineering

Time: 3 hrs. Max. Marks: 80

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. IS1893-2016 code is permitted.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages. 2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Explain the concept of plate tectonic theory and with a neat figure explain the concept of elastic rebound theory. (06 Marks)

b. What are the seismic waves? Explain the significant characteristics of seismic waves. (06 Marks)

c. How the classifications of earthquakes are made? (04 Marks)

OR

2 a. Explain the difference between magnitude and intensity. What are the isoseismals? (08 Marks)

b. What are the different earthquake ground motion characteristics? (04 Marks)

c. A seismograph located 1200km from the epicenter of an earthquake, records a maximum ground displacement of 15.6mm for surface waves having a period of 20 seconds. Determine the surface wave magnitude. (04 Marks)

Module-2

3 a. Derive and plot the response for SDOF system with free vibration undamped case. (08 Marks)

b. Derive and plot the vibration DAF with damping and frequency ratio of an SDOF system subjected to harmonic excitation. (08 Marks)

OR

4 a. Explain the dynamic step by step dynamic response procedure for linear acceleration method. (08 Marks)

b. What is response spectrum? And what are the steps involved in construction of design spectrum. (08 Marks)

Module-3

5 a. Explain the different vertical irregularities. (05 Marks)

b. What are the lessons learnt with references to seismic behaiour of structural damages during past earthquakes. (05 Marks)

c. Illustrate with the neat sketches the problems associated with the configuration of building and its possible remedial measures. (06 Marks)

OR

6 a. Summarize the different philosophy adopted in seismic design. (06 Marks)

b. What are the different types of structural modules to simulate the seismic behaviour of a framed building? (05 Marks)

c. Explain the different code-based methods for seismic design. (05 Marks)

Module-4

7 For an RCC-SMRF building frame for office, the seismic weights on the floors are W_1(roof) = 3000 kN, W_2 = W_3 = W_4 = 42000kN. The storey heights are ground storey = 4.2m, other storey each of 3.2m. The building is founded on hard soil and situated in zone-IV. Find the seismic force by equivalent lateral force procedure. **(16 Marks)**

OR

8 For the RCC-SMRF frame building with importance factor = 1. Founded on soft soil and situated in Zone-V. Seismic weights on the floors are W_3(Roof) = 392 kN, W_2 = 784 kN, W_1 = 1568 kN. Determine the seismic forces by dynamic analysis method. The free vibration results for the buildings are. **(16 Marks)**

Natural Period	Mode – 1	Mode – 2	Mode – 3
(sec)	0.883	0.404	0.302
Roof	1.000	1.000	1.000
2^{nd} FL	0.791	0.000	-0.791
1^{st} FL	0.250	-1.000	0.250

Module-5

9 a. Explain with neat figure of typical failure of RC framed structure. **(06 Marks)**
b. Explain with neat sketches of the ductile detailing provisions for columns as per IS-code methods. **(06 Marks)**
c. Explain the different methods of retrofitting of structures. **(04 Marks)**

OR

10 a. Explain the different elastic properties of masonary structures. **(06 Marks)**
b. Explain the major steps of the lateral load analysis of masonary building. **(06 Marks)**
c. How to make stone masonry buildings earthquake resistant. **(04 Marks)**

* * * * *

Subject – Earthquake Engineering
Code – 15CV831
Semester – 8
Max marks – 80
Faculty – Prof. Laxmi. H

Module-1

1 a) Plate tectonic theory

According to this theory Earth's crust i.e Lithosphere is divided into number of plates called as crustal plates or Lithospheric plates. These plates are about 70-100km deep in ocean basin & 100-150km deep under continents.

These plates are actually floating on Asthenosphere. since these plates are floating on magma the convection currents generated in magma are responsible for movement of plates. plates move in different direction with different speed.

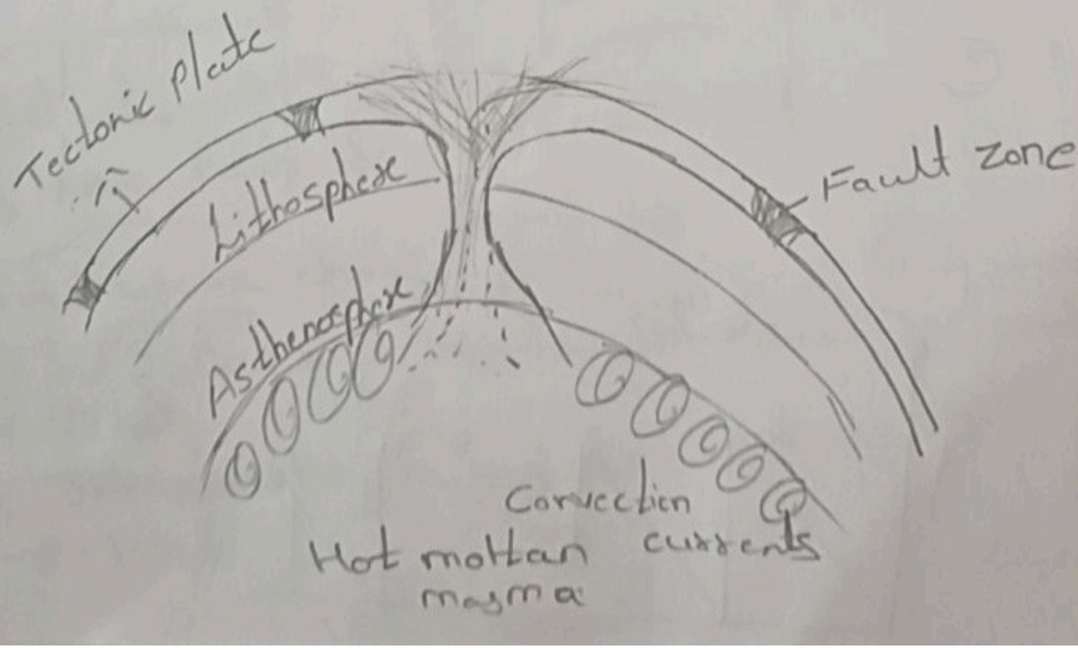


Plate Boundaries

1) Divergent Boundaries
2) Convergent Boundaries
3) Transform Boundaries.

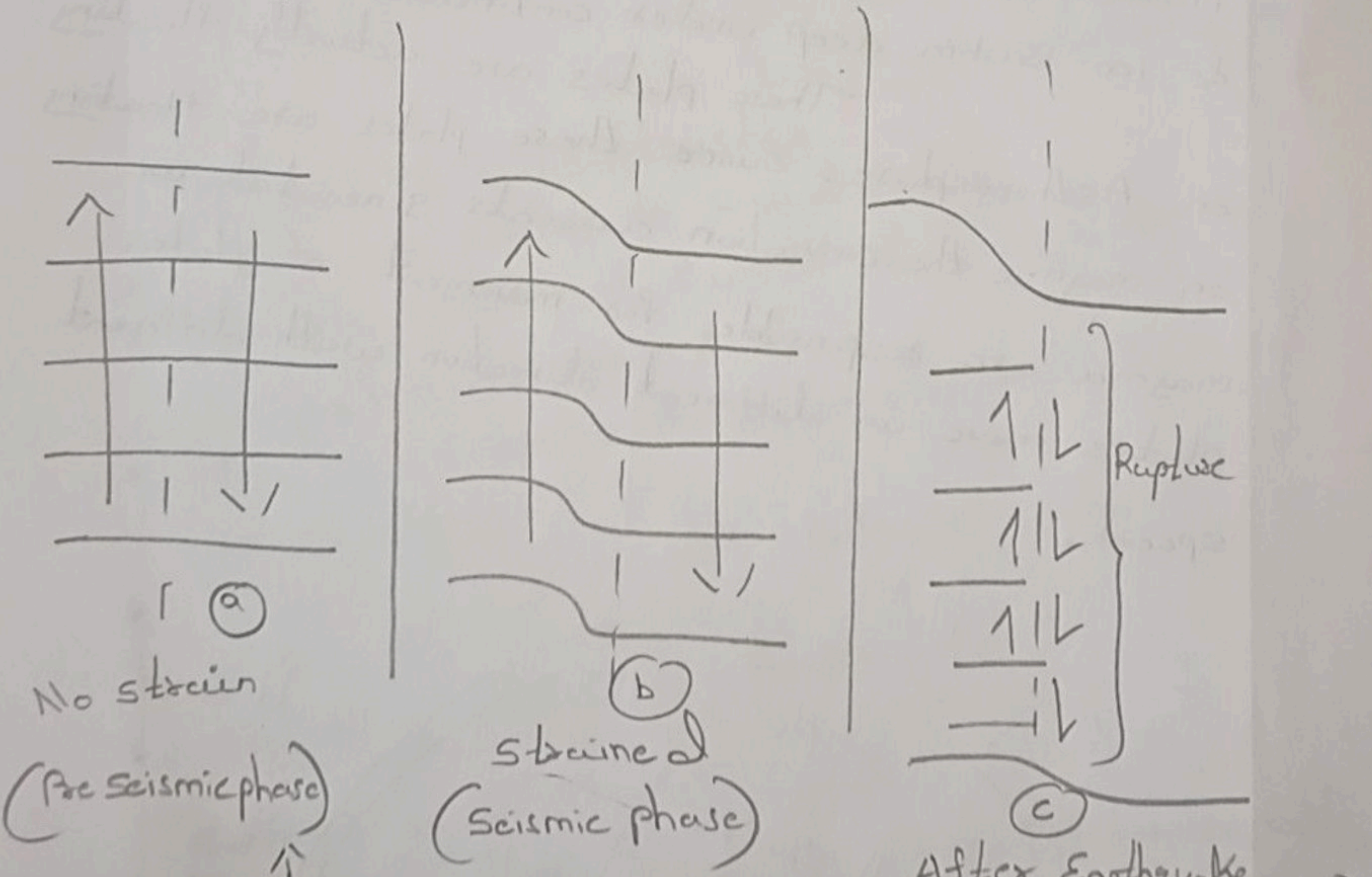
Elastic Rebound Theory.

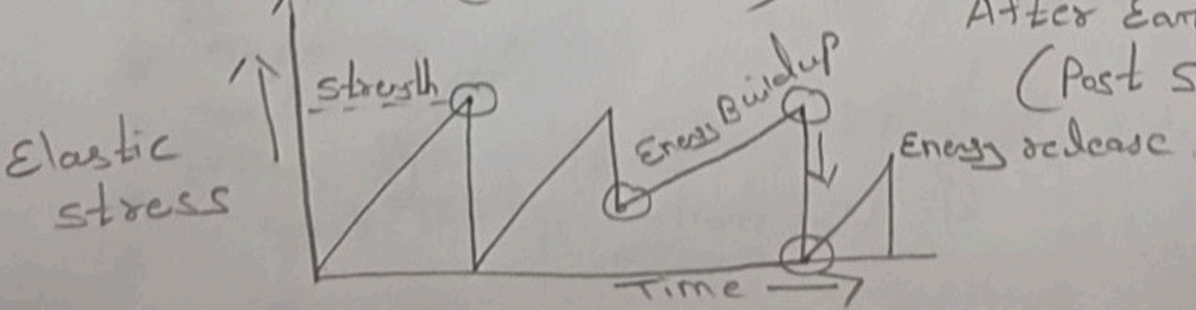
Theory Proposed by M. F Reid. The gradual accumulation & release of stress & strain is referred as "Elastic Rebound Theory".

Fig a) continuous Increase in shear force are acting on Two Blocks

Fig b) Blocks are distorted. Initial straight line have become oblique.

Fig. c) weakest part of fault slips suddenly.





1 b) Seismic waves & its charecteristics.

Seismic waves are waves of energy that travel through Earth layer & are result of Earthquakes, Volcanic eruptions etc. Also called shock waves.

Two Types

1) Body waves
↳ Travel through Interior of Earth
↳ Primary waves
↳ Secondary waves

2) Surface waves
↳ Travel along the Earths surface
↳ Love waves
↳ Rayleigh waves

Body wave charecteristics.

* These are similar to sound waves.
* Particle motion of P wave is in direction of propogation of wave.
* They cause volume change in material But no shape change
* P wave Travel in all states of matter solid liquid & gasses.
* They have Push & Pull movement.

S~~urface~~ wave charecteristics.

* Transverse waves & may be Polarized Horizontally or vertically.
* They travel through solids
* 3-8 Km/s.

Surface waves

* Love waves
  - Dispersive waves
  - Particle motion is in horizontal plane & transverse to propogation of wave.

* Rayleigh waves
  - motion of Particle - retrograde elliptical orbits
  - velocity of wave is dependent on Poissons Ratio
  - Amplitude of particle displacement decreases Exponentially.

1 c) Classification of Earthquake.

I Based on Location
- ↳ Interplate Earthquake.
- ↳ Intraplate Earthquake.

II Based on Focal Depth
- ↳ shallow Depth
- ↳ Intermidiate Depth
- ↳ Very Deep.

III Based on Epicentral Distance.
- ↳ Local shock
- ↳ Near shock
- ↳ Distant shock
- ↳ Telescopic

IV Based on magnitude
- ↳ Micro Earthquak
- ↳ Intermidiate "
- ↳ Moderate "
- ↳ strong "
- ↳ Major "
- ↳ Great "

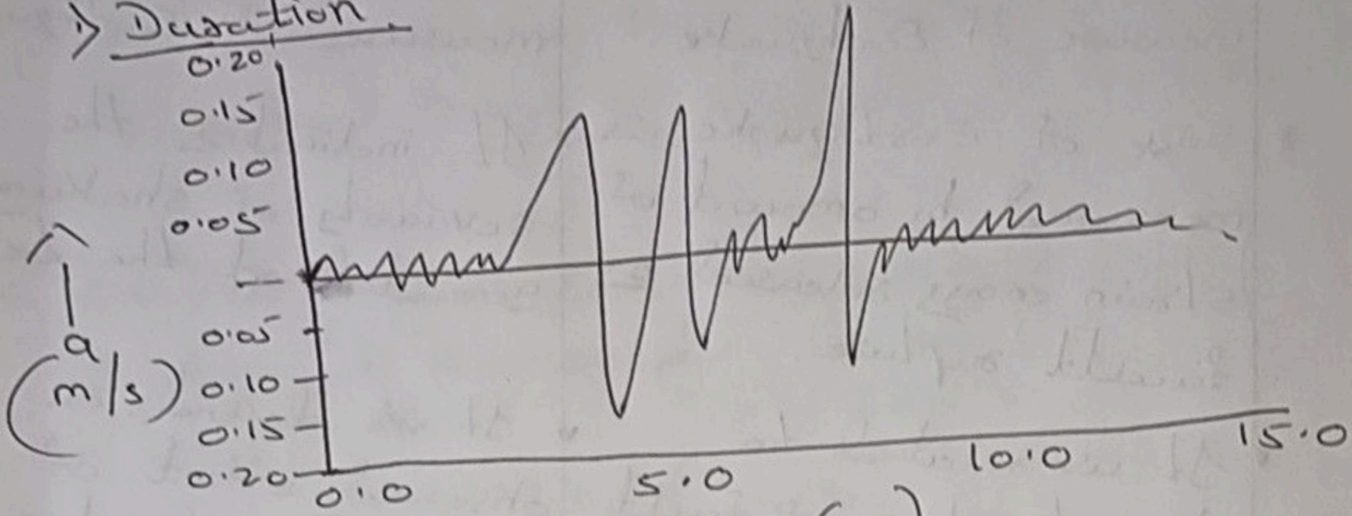
2 a)

Magnitude	Intensity.
* It is quantitative measure of Earthquake	* It is qualitative measure of Earthquake.
* Size of Earthquake is measured by amount of strain energy released by fault rupture.	* It indicates the seviarity of shaking generated at the Location.
* It is related to characteristics of fault. Extent of relative displacement suffered by Two sides of fault.	* It is depends on observed effect of Landscape, structure, Loss of Life.
* It is single value for a given Earthquake	For a Perticular Earthquake. It veries from place to place, Geological area, Type of structure.
* Assigned in Numbers.	Assigned as Roman capital Numbers.

Isoseismals-map It is the map of Lines showing equal felt Intensity.

2b Earthquake ground motion characteristics.

1) Duration



* usually time Interval b/w 5-95% contribution of energy of vibration is considered as significant duration of strong motion.
* Longer Duration of Earthquake gives rise to yielding and repeated loading into plastic range followed by deterioration of strength & stiffness.

2) Frequency Content

A typical strong motion accelerogram can be thought of as a superimposition of simple constant amplitude sinusoidal waves. Each with different frequency amplitude & phase. Dominent frequency ~~gives~~ are Important

3) Amplitude

Peak ground acceleration PGA is presently considered as measure of strength of ground shaking as it relates directly to maximum Inertia forces generated in structure. Seismic force on structure are estimated Based on amplitude of Response.

2.c Circumferance of Earth $= 4 \times 10^7 m$ @ 360°

Distance of seismograph $=$ 1200 Km $= 1.2 \times 10^6 m$

$$A = \frac{12.2 \times 10^6}{4 \times 10^7} \times 360^\circ$$

$$A = 10.8^\circ$$

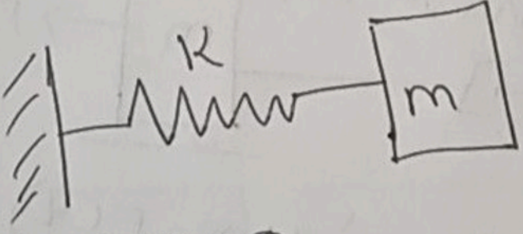
& $A' = 15.6 mm = 15600 \mu m$

$$M = \log A' + 1.66 \log \Delta + 2$$

$$= \log 15600 + 1.66 \log 10.8 + 2$$

$$M = 7.9$$

3 a)



$$mx'' + Kx = 0$$

$$x'' + \left(\frac{K}{m}\right)x = 0 \quad \text{— Eq (1)}$$

$$x'' + \omega^2 x = 0$$

where $\omega = \sqrt{\frac{K}{m}}$

Solution of Eq (1)

$x(t) = A\cos\omega_n t + B\sin\omega_n t$ A & B constants.

To find

BC

(1) $t = 0$, $x = x_0$, $x' = x_0'$

$$\boxed{x_0 = A}$$

(2) when $t = 0$, $x' = x_0'$

$$x' = -A\omega_n \sin\omega_n t + B\omega_n \cos\omega_n t$$

$$x_0' = B\omega_n$$

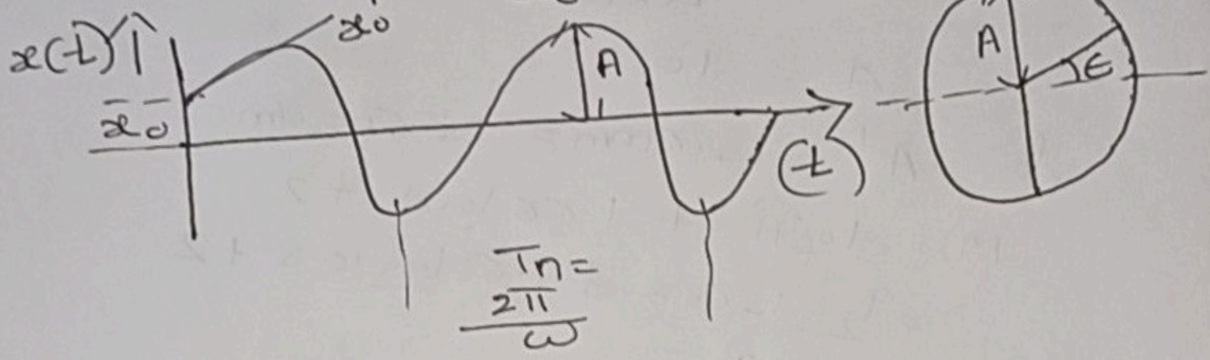
$$\boxed{B = \frac{x_0'}{\omega_n}}$$

Final Equation

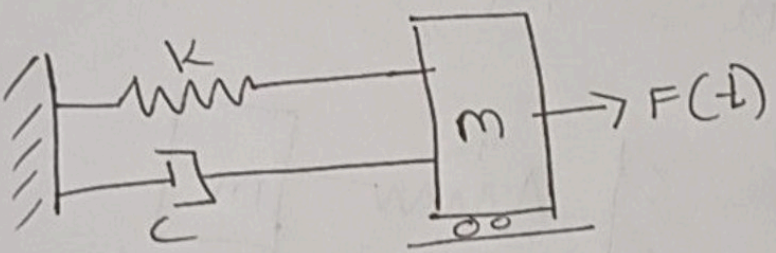
$$x(t) = x_0 \cos\omega_n t + \left(\frac{x_0'}{\omega_n}\right)\sin\omega_n t$$

$$A = \sqrt{x_0^2 + \left(\frac{x_0'}{\omega_n}\right)^2}$$

$$\tan\epsilon = \frac{(x_0'/\omega)}{x_0}$$



3 b)



$$mx'' + cx' + kx = F(t)$$

$$x'' + 2nx' + \omega_n^2 x = \left(\frac{F_0}{m}\right)\sin\omega t$$

$$x(t) = e^{-\xi\omega_n t}\left[x_0 \cos\omega_d t + \frac{x_0' + \xi\omega_n x_0}{\omega_d}\sin\omega_d t\right]$$

↳ solution for Homogenous Part

Trial solution

$$x_p = A\cos\omega t + B\sin\omega t$$

Substituting A & B

$$x_p = \frac{(F_0/K)}{\sqrt{(1-r^2)^2 + (2\xi r)^2}} \times \sin(\omega t - \phi)$$

$$x(t) = x_c + x_p$$

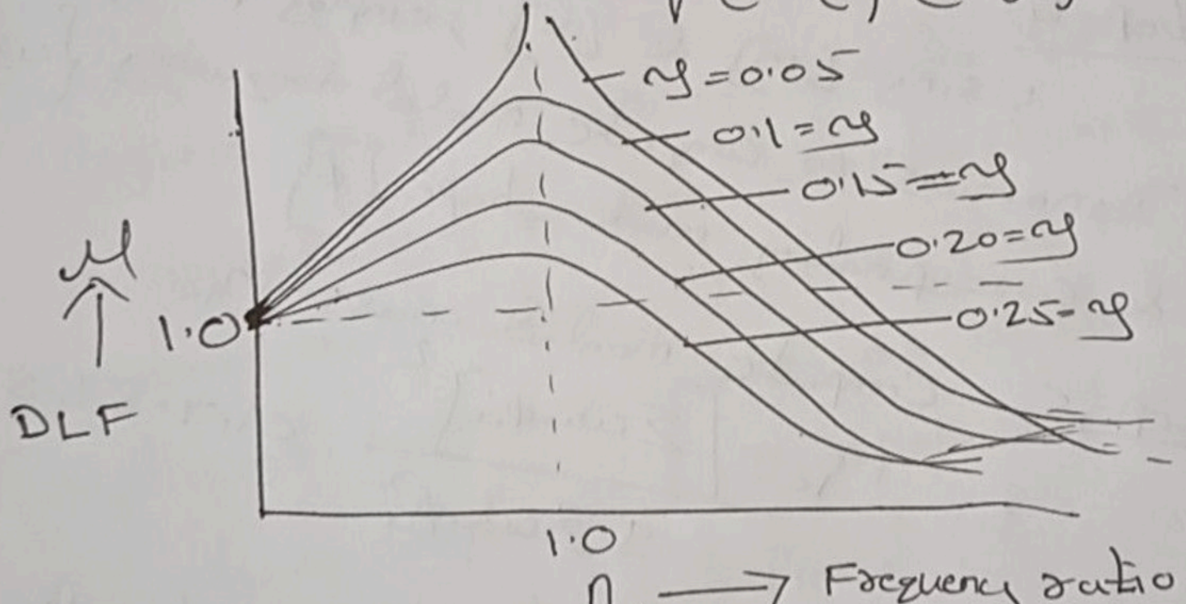
$$\eta = \frac{\omega}{\omega_n}$$

$$x_c = e^{-\xi\omega t}\left[x_0 \cos\omega_d t + \frac{x_0' + \eta\xi\omega x_0}{\omega_d}\sin\omega_d t\right]$$

Steady state motion

$$x = \frac{(F_0/K)}{\sqrt{(1-\eta^2)^2 + (2\eta\xi)^2}}\sin(\omega t - \phi)$$

$$\mu = \frac{x_{max}}{\delta_{st}} = \frac{1}{\sqrt{(1-\eta^2) + (2\eta\xi)^2}}$$



4. a) Dynamic response procedure.

step 1 Depending on location of Building site, identify seismic zone & assign zone factor

step-2
Compute seismic weight of Building (W)
Cl. 7.4.2 IS 1893-2002

step-3 Establish mass [m] & stiffness [K] matrices of Building using mass lumped @ floor

step-4
Using [m] & [K], employ principles of Dynamics to compute modal frequency {ω} & corresponding mode shape [ϕ]

step-5 Compute modal mass M_K

$$M_K = \frac{\left[\sum w_i \phi_i\right]^2}{g \sum w_i \phi_i^2} \quad Cl. 7.8.4.5$$

step-6
Compute modal participation factor P_K.

$$P_K = \frac{\sum w_i \phi_{iK}}{\sum w_i \phi_{iK}^2} \quad Cl\ 7.8.4.5b$$

step 7 Compute Lateral force

$$\phi_{iK} = A_K \times \phi_{iK} \times P_K \times W_i$$

Cl. 7.8.4.5c

A_K = Horizontal acceleration spectrum.

4a) Compute storey shear

$V_{ik} = \Sigma Q_{ik}$ cl. 7.8.4.5 d

<u>step. 9</u>

Compute storey shear force due to all modes considered by CQC method or SRS method

<u>step - 10</u>

Finally compute design lateral force at each storey

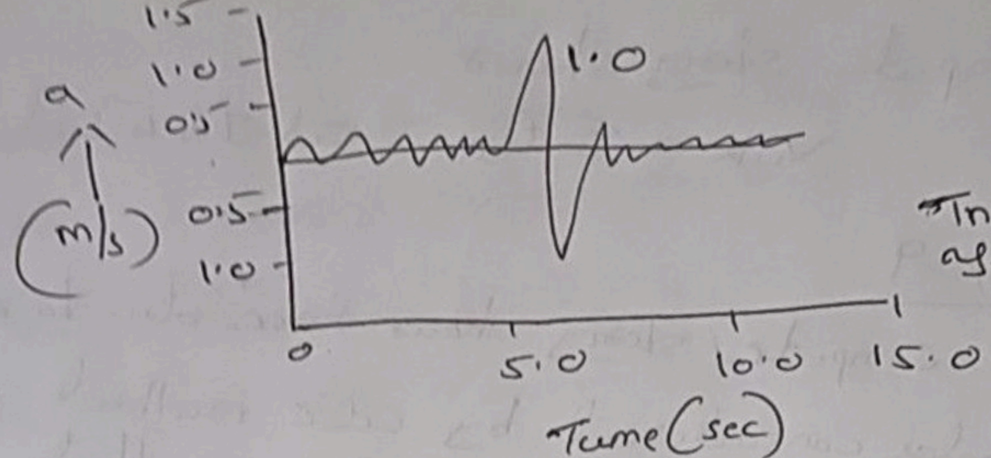
$F_{roof} = V_{roof}$ cl 7.8.4.5 f.

$F_{i} = V_{i} - V_{i+1}$

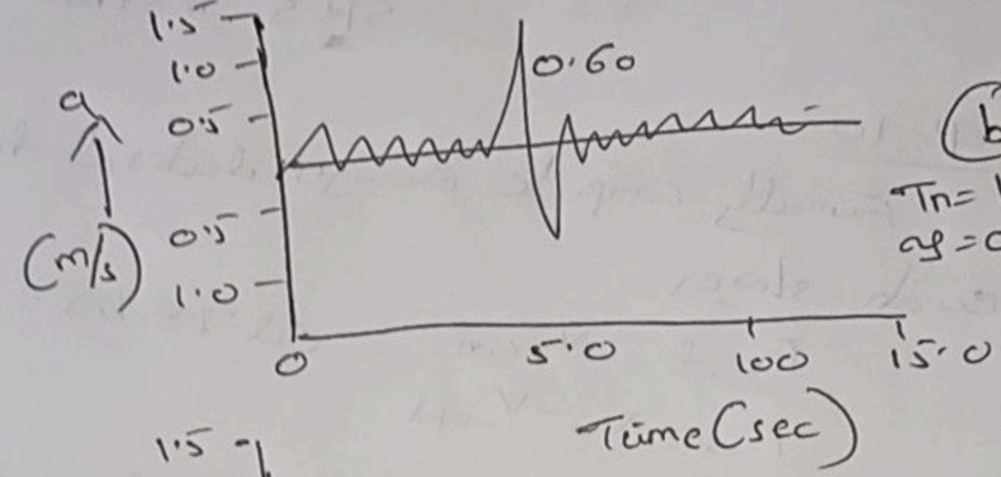
4.b) Response spectrum is a standard method of representing response of structures to ground acceleration. It is a plot of peak value of response quantities as acceleration, velocity or displacement of SDOF system as a function of Natural Period (T_n) with Particular Damping Ratio.

<u>Construction</u>

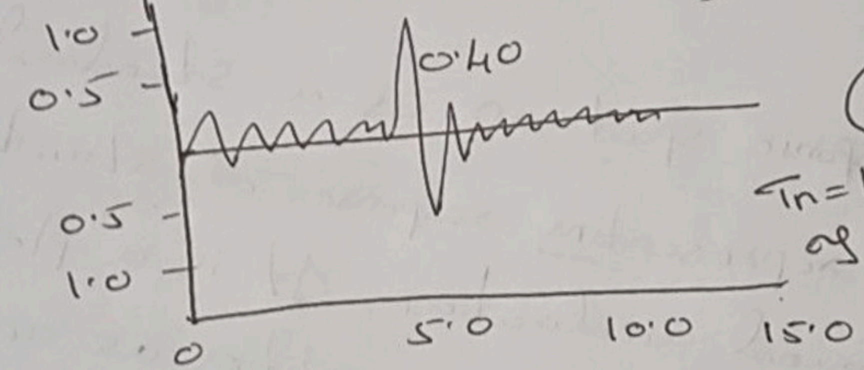
Response history is recording of an accelerograph providing value of acceleration, velocity & displacement as function of Time for a given ground motion.



(a)
Tn = 0.5 s
ξ = 0.5%

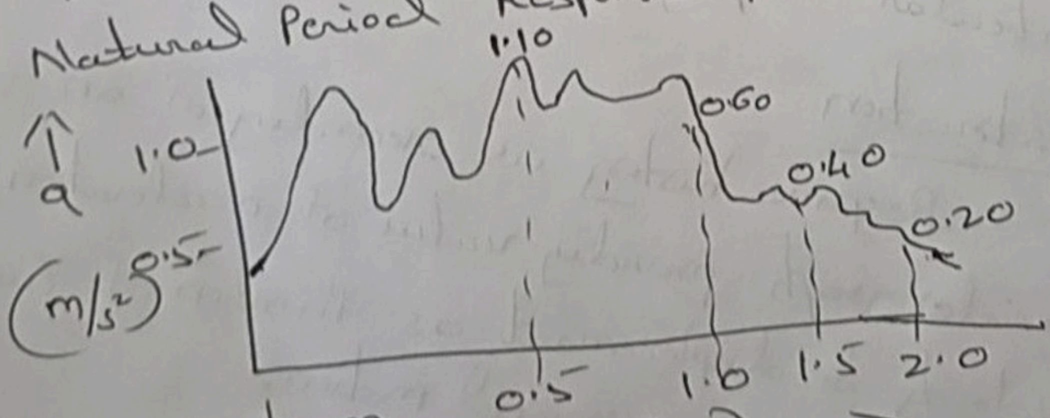


(b)
Tn = 1.0 s
ξ = 0.5%



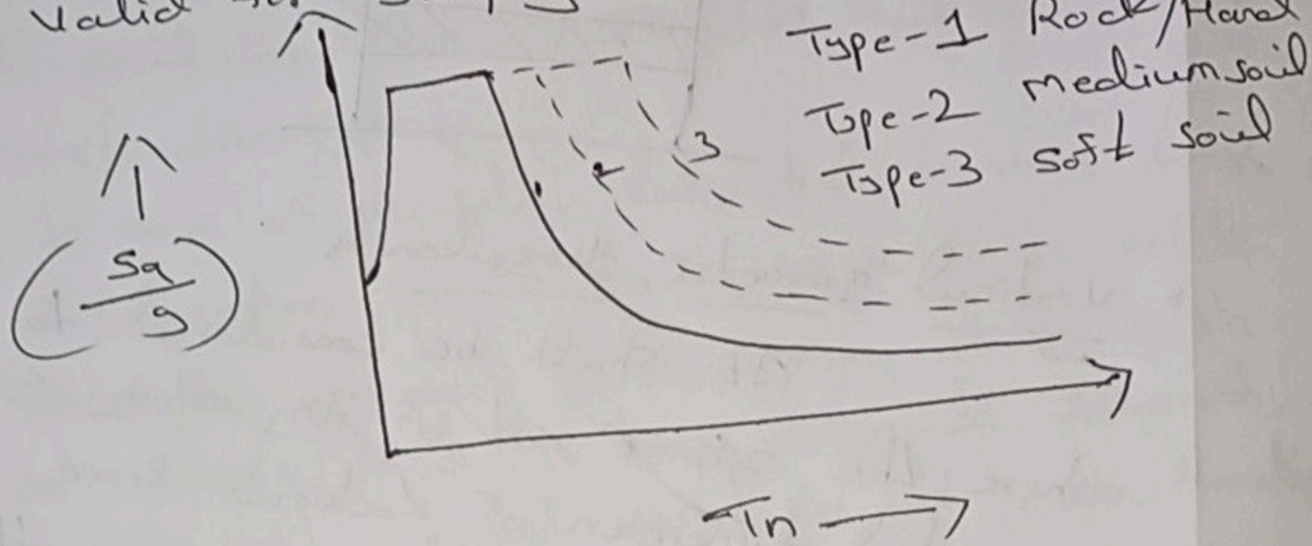
(c)
Tn = 1.5 sec
ξ = 0.5%

- Response of SDOF system of different Natural Period are different & hence Peak response are also different.
- By taking all Peak values of different Natural Period Response spectrum is ploted.



<u>Response Spectrum</u>   Tn (sec) →

* Response spectrum obtained should be Normalised to get Design response spectrum.
* Design spectrum holds good for all time Period & all 3 soil types are considered.
* valid for Damping 5%.



Design Response Spectrum.

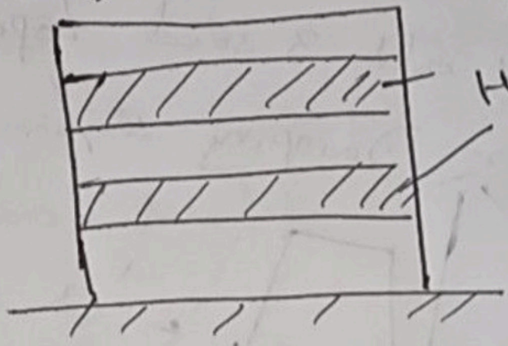
5. a) Vertical Irregularities

① Stiffness Irregularity
soft storey - Lateral stiffness is Less than 70% the Lateral stiffness of storey above or Less than 80% of avg Lateral stiffness of 3 storey above.

② Extreme soft storey
Lateral stiffness is Less than 60% of Lateral stiffness of storey above or Less than 70% of avg Lateral stiffness of 3 storey above.

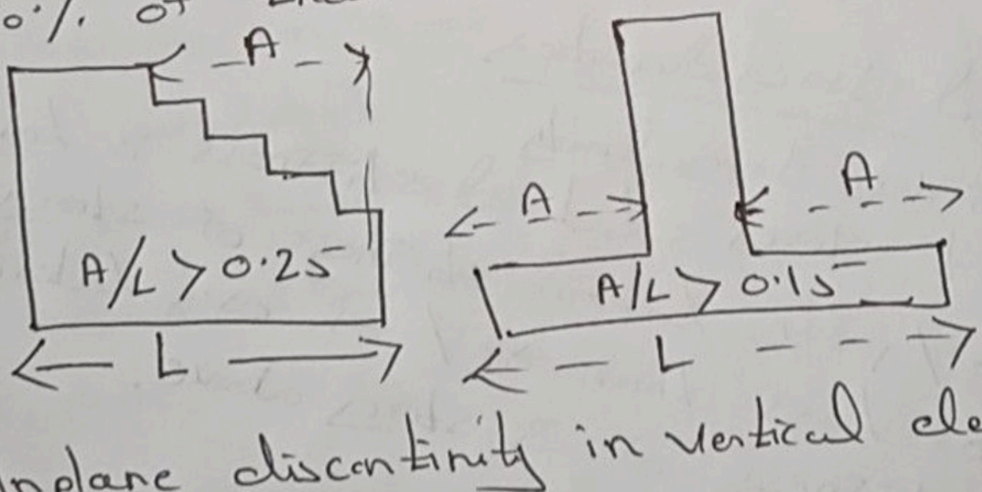
* **Mass Irregularity**

It shall be considered to exist where the seismic wt of any storey is more than 200% of that of adjacent



* **Vertical geometric Irregularity.**

It shall be considered to exist where the ~~seismic wt of any storey is more~~ Lateral force
Horizontal dimension of lateral force resisting system in any storey is more than 150% of that in its adjacent storey.



* Inplane discontinuity in vertical elements
* Discontinuity in capacity.

5.b Lessons Learnt from Past Earthquake.

* Human casualities in Earthquake are mostly due to collapse of structure then by events themselves.
* Damages caused by Earthquake depend on number of aspect such as Intensity duration & frequency content of ground motion, geological & soil condition, quality of material used for construction etc.
* In case of Building subjected to very Large deformation its integrity as a single entity must be ensured by designing it in such a manner that it has adequate strength, high ductility, enough resistance to cyclic loading
* From Investigation in china after wenchuan earthquake in 2008 it was found that among available stock 63% of Building constructed using raw soil, 36% Brick wood structure, 25% of masonry structure & 11% of RC framed structure were damaged during Earthquake.
* Masonry Building are more prone to damage During Earthquake.
* However masonry constructed with good quality stone & Bricks can perform well.

5 c)

- The Behaviour of a Building during Earthquake depends critically on its overall shape, size & geometry. Hence Architects should work on its planning stage.
- If we have a poor configuration to start with all Engineer can do is to provide a Band-aid as best as he can Improve a Basically poor solution &
- If we start with good configuration & reasonable framing system, even a poor engineer cannot harm its ultimate performance too much.

Size of Building

- A Building too long, too tall, too Large in plan do not perform well during Earthquake
- Horizonal Layout

  simple geometric plan Building have performed well during strong Earthquake.

  Building with reentrent corners like U, V, H shape have sustained significant Damage.
- Vertical Layout of Building

  Any deviation or discontinuity in load path leads to poor performance of Building.

  a) Building with vertical Set Backs
  b) Few column in Perticular stores
  c) open ground stores

  are more prone to damage.

6 a) <u>Seismic Desijn Phylosophy</u>.

a) Under minor But frequent shaking the
main members of Building that carry
Vertical & Horizontal forces should not be
damaged. However Building parts that do
not carry load may sustain reparable
damage.

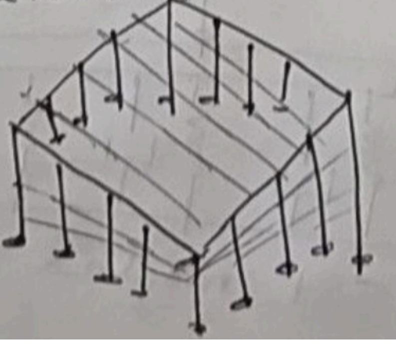
b) under moderate But occasional shaking
the main members may sustain repairable
damage, while other parts of Building may
be damaged such that they may even have
to be replaced after Earthquake.

c) under strong But rare shaking the main
members may sustain severe (even irreparable)
damage But Building should not collapse.

6b). <u>structural Models</u> 1

(i) 3-Dimenstional model

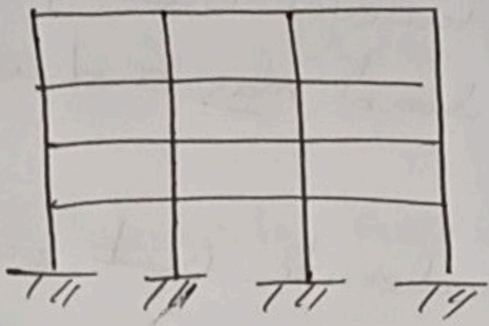
It has independent displacement
at Each node & can stimulate any
type of behaviour.



3D frame model

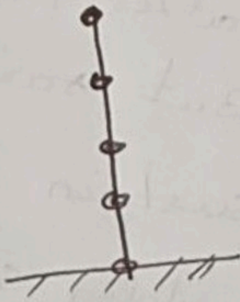
2-D frame Model

Used for Building having symmetric Plan & torsional response are Expected to be Small. This model connects all frame in one Principal direction.



③ Lumped mass model

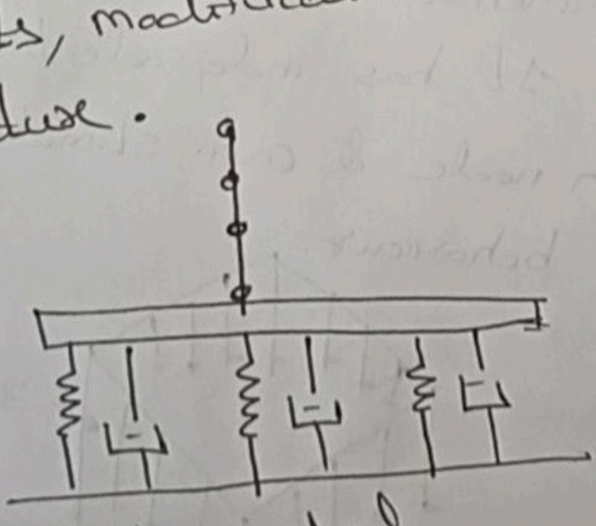
most frequent used in early times for practical design of multistory Building.



Lumped mass model

4) Soil structure Interaction.

Takes account possibility of having different Horizontal & Vertical motion of supports, modification of Natural Period of structure.



SSI model.

6.c) Code Based Seismic Design methods.

① Lateral strength Based Design.

It is Based on providing the structure with minimum Lateral strength to resist seismic loads assuming that structure will behave adequately in non linear range.

② Displacement/Ductility Based Desirn.

It is very well recognized now that Becz of economic reason the structure is not designed to have sufficient strength to remain Elastic in severe Ed. The structure is designed to posses adequate ductility so that it can dessipate energy by yielding. method directly operates on displacement.

③ Capacity Based Desirn.

It is a desirn approach in which structure are designed in such a way that hinges can only form in predetermined positions & sequencies.

④ Energy Based Desirn.

Here Total Energy input E_I can be resisted by sum of Kinetic Energy E_K & E_{ES} Elastic strain Energy.

$$E_I = E_K + E_{ES} + E_H + E_y$$

7) Natural Period $T_n = 0.075 h^{0.75}$ $h = 13.8m$

$T_n = 0.537 sec$

$Z = 0.24$

$\frac{S_a}{g} = 2.5$

$I = 1$

$R = 5$

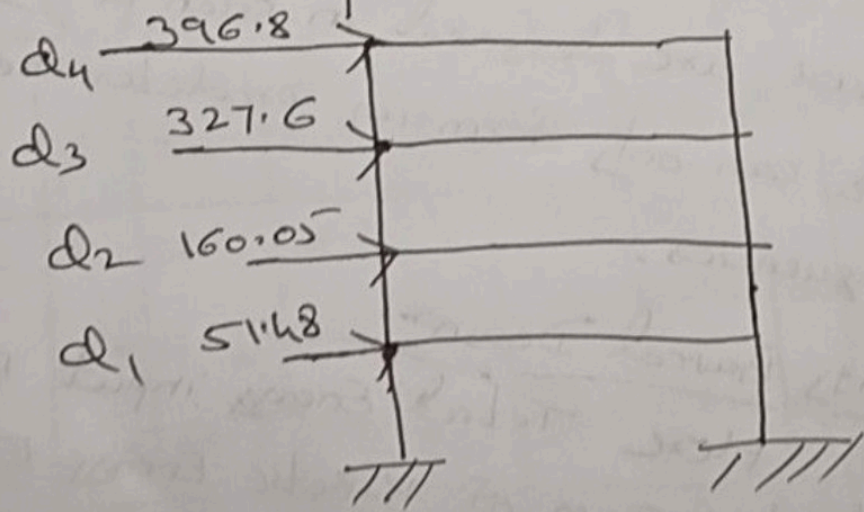
$A_h = \frac{Z}{2} \frac{I}{R} \frac{S_a}{g} = 0.06$

Seismic wt $W = (3 \times 4200) + 3000 = 15600$ KN

Base shear $V_B = A_h \times W = 0.06 \times 15600$
$= 936$ KN

Lateral force.

story	wt KN	h_i m	$w_i h_i^2$	$\frac{w_i h_i^2}{\Sigma w_i h_i^2}$	$Q_i = V_B \times \left(\frac{w_i h_i^2}{\Sigma w_i h_i^2}\right)$
4	3000	13.8	571320	0.424	396.86
3	4200	10.6	471912	0.350	327.6
2	4200	7.4	229992	0.171	160.05
1	4200	4.2	74088	0.055	51.48
Σ	15600	Σ	134312	Σ	936 KN



8)

Storey	wt KN	mode-1 φ	$w_i\phi_i$	$w_i\phi_i^2$	mode-2 φ	$w_i\phi_i$	$w_i\phi_i^2$	mode-3 φ	$w_i\phi_i$	$w_i\phi_i^2$
3	392	1	39.2	392	1	392	392	1	392	392
2	784	0.791	620	491	0	0	0	-0.79	-620	491
1	1568	0.15	392	98	-1	-1568	1568	.25	392	98
Σ	2744		1404	981		-1126			164	981

	mode-1	mode-2	mode-3
M_K	2049711kg	71927kg	2791kg
P_K	1.432	-0.6	-0.167

Horizontal acceleration.

mode	K=1	K=2	K=3
Ta	0.883	0.404	0.302
Sa/g	1.891	2.5	2.5
Z	0.36	0.36	0.36
I	1	1	1
R	5	5	5
A_{hK}	0.0681	0.09	0.09

$A_{hK} = \frac{Z}{2} \times \frac{I}{R} \times \frac{S_a}{g}$

Lateral Load SRSS method.

Storey	wt KN	mode-1 φ	Q_{i1}	V_{i1}	mode-2 φ	Q_{i2}	V_{i2}	mode-3 φ	Q_{i3}	V_{i3}	SRSS $V=\sqrt{V_i^2}$
3	392	1	38.2	38.2	1	-21.1	-21.1	1	5.8	5.8	44.082
2	784	0.791	60.4	98.6	0.0	0.0	-21.1	-0.79	-9.3	-3.4	100.93
1	1568	0.25	38.2	136.8	-1	8.46	68.5	0.25	5.8	2.4	150.91

$Q_{iK} = A_{hK} \times \phi_{iK} \times P_K \times w_i$.

$Q_3 = V_3 = 44.082\,KN$

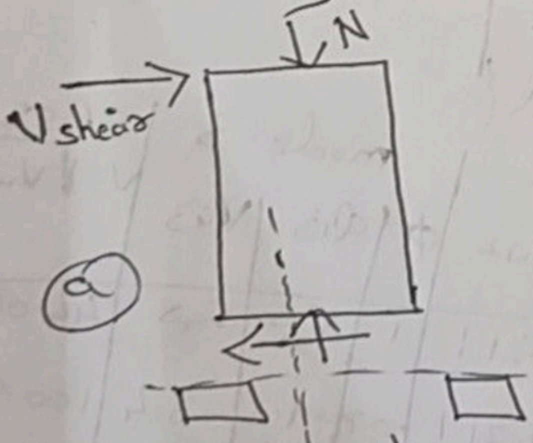
$Q_2 = V_2 - V_3 = 56.89\,KN$

$Q_1 = V_3 - V_2 = 49.01\,KN$

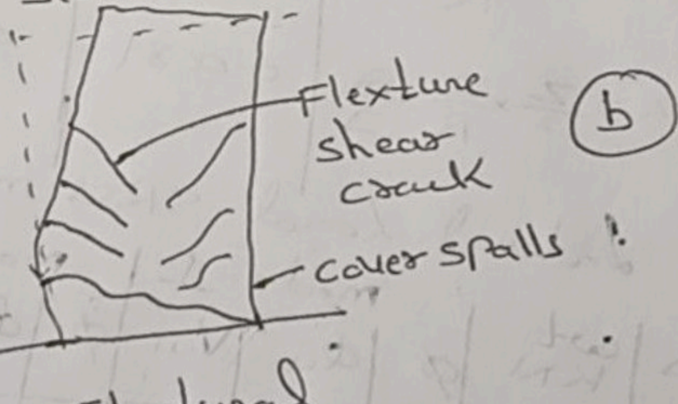
9. a) <u>Typical failure of RC framed Building.</u>

* It is evident that root cause of failure of even well-reinforced concrete members is the cracking of concrete which leads to degradation in cracked zone. Reinforcement Elongates Permanently in crack & tensile stress drops. Later cracks do not close & interlocking of aggregate is destroyed.
* In hinges & joints reversal cracking breaks down the concrete Between cracks completely & sliding shear failure occurs

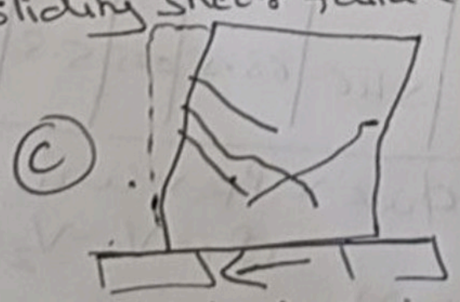
Apart from this
- a) Bond failure
- b) Direct shear failure
- c) shear cracking in Beam-Column zone
- d) Diagnol cracking of shear wall
- e) Tearing of slabs at discontinuities.



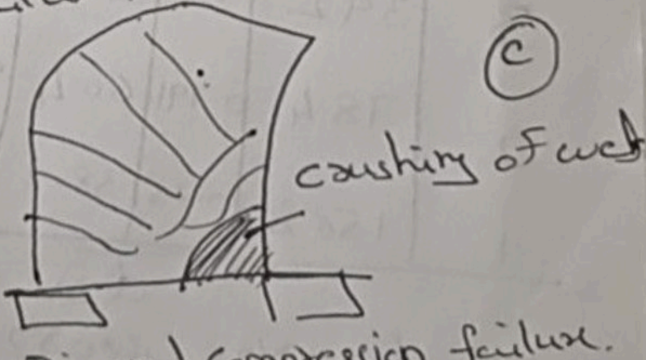
sliding shear failure.



Flextural failure.



Diagnol Tension failure.



Diagnol Compression failure.

9b) Ductile Detailing Provision for column.

Longitudinal Reinforcement

1) Top as well as Bottom reinforcement shall consist of at least two Bars of minimum 12mm diameter throughout the member length to ensure minimum resistance against reversible nature of stress under seismic Loading.

2) Tension steel ratio on any face at any section not to be Less than

$$\rho_{min} = \frac{0.24\sqrt{f_{ck}}}{f_y}$$

(3) maximum steel ratio on any face at any section is 0.025 that is 2.5%.

$$\rho_{max} = 0.025$$

(4) Positive steel at Joint face must be atleast equal to half the negative steel at that face as indicated. This stipulation is to provide minimum flexural resistance for reversible stress due to seismic loading.

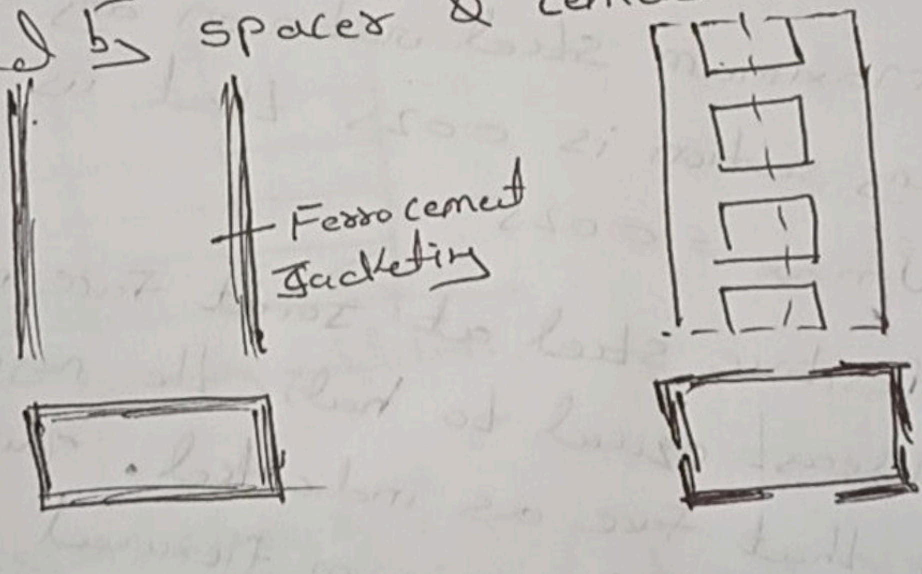
9. c) Methods of Retrofitting of structure.

Stabilization strategy.

This consist of strengthening existing structural components to cater for seismic forces if structure is designed only for gravity loading or to retrofit the damaged structure.

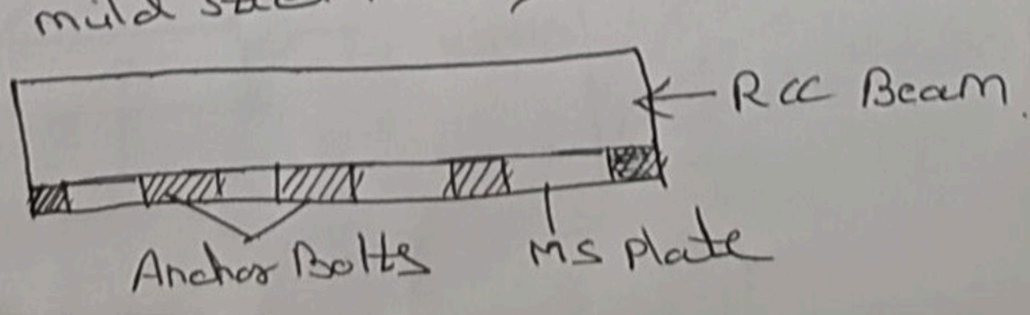
a) Ferro cement Jacketing

It is a thin wall type composite composed of minimum two layers of continuous & relatively small diameter orthogonally woven seperated by spacer & cement mortar.



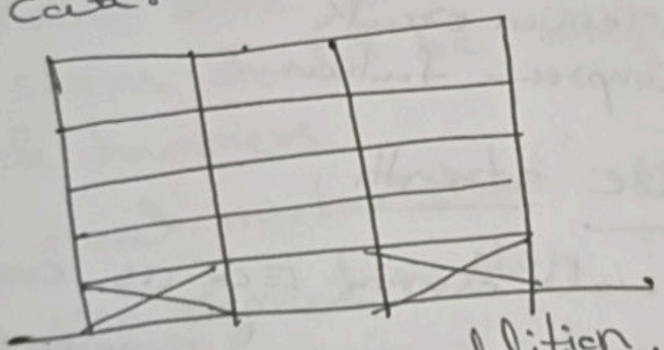
b) Bonding of Plates

Plate Bonding is an inexpensive versatile & advanced technique for rehabilition of concrete structure by mechanically upgradation of concrete structure by Bolting & gluing connecting mild steel plate by Bolting & gluing



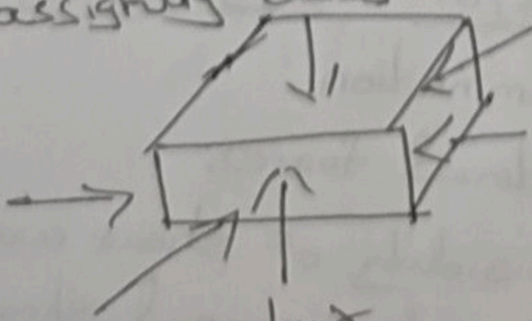
(x) Replacement strategy.
Consist of replacing energy dissipating devices or vibration isolation system or Damaged Bracing system.

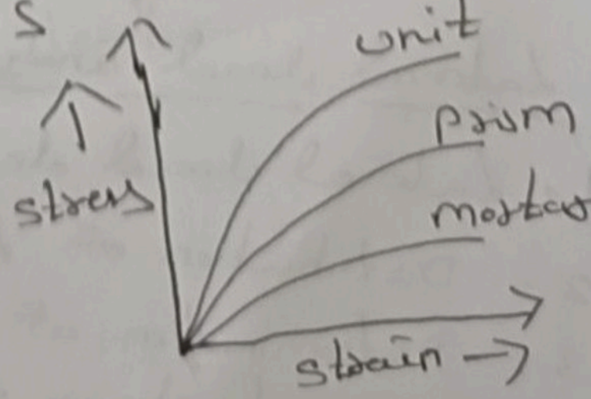
(b) Augmentation strategy.
Addition of Lateral load resisting structural system such as Bracing, shear wall, energy dissipating devices or vibration isolation system to cater for seismic forces.



Bracing addition.

10.a) x) compressive strength
plays a Important role in load bearing structure. compressive strength of masonry is often used as Basis of assigning design stress





* Flextural Tensile strength.

Bending about vertical axis produces flexture Tension normal to Bed Joints (f_m) & Bending about Horizontal axis produces flexture Tension parallel to Bed Joint (f_{tb}).

* shear strength

Combined Loading axile compression, flexture, shear gives complex stress in walls & becomes one of the cause to its failure. shear failure modes
  * shear slip failure
  * Diagnol Tension crack
  * shear Compression failure

* Diagnol Tensile strength

Failure of wall during EQ is caused by Combined effect of normal Compressive & shear stress which is represented by principal Tensile stress & when it exceeds Diagnol Tensile strength of masonry failure will Takes place.

$$f_t = 0.707 P/A$$

10b) Lateral load analysis of masonry Building.

1. Lateral load determination
2. Distribution of Lateral forces
3. Determination of Rigidity of shear wall
4. Direct shear force & Torsional shear force.

* Increase in axial load due to overturn.

→ ① Lateral load

$V_B = \alpha_h \times W$

$T_a = 0.09h/\sqrt{d}$

$Q_i = V_B \times \frac{W_i h_i^2}{\sum w_i h_i^2}$

② Distribution.

③

10 c) * Ensure proper wall construction

↳ wall thickness should not exceed 450mm.

↳ Round stone Boulders should not be used

↳ stones should be shaped using chisels & hammers.

↳ mud mortar should be avoided

↳ use cement mortar 1:6 or 1:3

* Ensure proper Bond in masonry course.

* should be build in construction lifts not exceeding 600mm.

* Through stones or pair of overlapping Bond stones must be used at every 600mm along height & maximum spacing of 1.2m along length.