MAHALAKSHMI
ENGINEERING COLLEGE
TIRUCHIRAPALLI – 621213

DEPARTMENT: CIVIL **SEMESTER: VII**

SUB.CODE/ NAME: CE2403/ BASICS OF DYNAMICS AND ASEISMIC DESIGN

UNIT – IV

RESPONSE OF STRUCTURES TO EARTHQUAKE

Response and design spectra – Design earthquake – concept of peak acceleration – Site specific response spectrum – Effect of soil properties and damping – Liquefaction of soils – Importance of ductility – Methods of introducing ductility into RC structures.

Two Marks Questions and Answers

1. What do you understand by response spectrum?

A Response spectrum is the plot of the maximum response (maximum displacement, velocity, acceleration or any other quantity of interest) to a specified load function X_a (t) for all possible SDOF systems (having different natural frequencies or time periods T and a constant damping ratio).

2. What is mean by soil liquefaction?

Soil liquefaction during an earthquake is a process that leads to loss of strength or stiffness of the soil. This could result in the settlement of structures, cause landslides, precipitates failures of earth dams or cause other types of hazards. Soil liquefaction has been observed to occur most often in loose saturated sand deposits.

3. Write a short note on liquefaction of clay soil.

Certain clayey soils are vulnerable to serve strength loss due to earthquake shaking. A clayey soil would be considered liquefiable if all of the following criteria are met:

i. The weight of the soil particles finer than 0.005mm is less than 15% of the dry weight of the soil.

ii. The liquid limit of the soil is less 35%.

iii. The moisture content of the soil is less than 0.9 times the liquid limit.

4. How the liquefaction – induced Ground failures?

If a soil becomes liquefied and loses its shear strength, ground failures may result. When structures are founded over or near these soil deposits, they may get damaged. The ground failures caused by liquefaction may be classified into the following categories:

i. Lateral Spreading

ii. Flow Failures

iii. Loss of Bearing Capacity

5. What do you understand by lateral spreading?

Lateral spreading is the movement of surfacial soil layers, which occur there is a loss of shear strength in a subsurface layer due to liquefaction. Lateral spreading usually occurs on very gentle slopes (< 6%). If there is differential lateral under a structure, there could be sufficient tensile stresses developed in the structures that it could literally tear apart. Flexible buildings have been observed to better withstand extensional displacement than more stiff or brittle buildings.

6. What are the methods available on site Modification?

Several site modification methods have been devised and adopted to reduce the potential or susceptibility of the soils beneath a site to liquefy. Some of them include

i. Excavation and Replacement of liquefiable soils

ii. Densification of in – situ soils

iii. In –stu improvement of soils by alteration

iv. Grouting or chemical Stabilization.

7. Write a short note on Soil Alteration?

The third major category of site improvement methods is alteration of the soil to reduce the potential for liquefaction. The soil may be made more resistant by the construction of mixed – in place solidified piles or walls to provide shear resistance which would confine an area of liquefiable soils to prevent flow.

8. What is mean by Grouting?

The fourth category of soil improvement methods is soil grouting or chemical stabilization. These would improve the shear resistance of the soils by injection of particulate matter, resins or chemicals into the voids. Common applications are jet grouting and deep soil mixing.

9. What is mean by Structural Damping?

Damping of structural systems plays a major role in determining the response of the structure for ground motions induced by earthquakes. The actual stiffness of foundation and damping co – efficient are dependent on the frequency of vibration.

10. What are the effects of Damping on soil – structure interaction?

Simple single degree of freedom (SDOF) system is considered for the analysis. The system is mounted on a rigid, mass-less and L-Shaped foundation which in turn is supported on an elastic foundation.

11. Define Ductility.

The ability of a structure or its components or of the materials used to offer resistance in the inelastic domain of response in described by the term ‘ Ductility”. It includes the ability to sustain large deformations, and a capacity to absorb energy hysteretic behavior.

12. What are the basic concepts for ductile performance structures?

i. Selection of sound structural configuration with a well defined lateral load resisting system.
ii. Systematic placement of stiff elements with a view to minimize increase in member forces due to torsion.
iii. Availability of direct load path for force transfer from superstructure to soil medium.

iv. Proper detailing of members and joints is very much necessary

13. Write a short note on Push over analysis.

Pushover analysis is a static analysis procedure for assessing the capacity of structural members against seismic forces. A number of widely used procedures (FEMA 273, ATC – 40) compare these demands with the recommended values of member capacities varying with the level of the performance objectives employed. Each member is classified as either force based or displacement based, depending on its mode of behavior.

14. Mention the different Variable affecting sectional ductility.

The variables that affect sectional ductility include,

i. Material variables such as the maximum usable compressive strain in concrete and grade of reinforcement.
ii. Geometric variables such as the amount of tension and compression reinforcement and the shape of the section.
iii. Loading variables such as the level of axial load accompanying shear.

15. What do you understand by Response reduction factor (R)?

It is the factor by which the actual base shear force, that would be generated if the structure were to remain elastic during its response to design basis Earthquake shaking, shall be reduced to obtain the design lateral force. Ductile buildings are designed for seismic forces that are R times lower than the elastic behavior would require.

16. Write a Short notes on the Analysis of structural Response Based on Soil properties.

Analysis of soil structure interaction can be either using the direct method or the multiple – step method. In the direct method, finite element model of the soil – foundation system is generated and solved in a single step. Multi – step method of analysis uses the principle of superposition to isolate the two primary causes of soil – structure interaction,

a) the inability of the foundation to match free field deformation; b) the effect of dynamic response of foundation – structure system on the movement of the supporting soil.

17. What is zero period acceleration?

Zero period acceleration implies maximum acceleration experienced by a structure having zero natural period (T =0). An infinitely rigid structure has zero natural period (T = 0). It doesn't deform. Thus relative motion between its mass and its base, Mass has same acceleration as of the ground. Hence ZPA is the same as peak ground acceleration.

18. What is a design spectrum?

Response spectrum developed for displacement, pseudo-velocity and pseudo acceleration in a combined manner for elcentro earthquake (1940) for various damping ratios. This type of spectrum called tripartite response spectrum. For design purpose, local peaks and valleys should be ignored, since natural period can't be calculated with accuracy. Hence smooth cure plotted by considering the average number of elastic response spectrums corresponding to various possible earthquakes at particular site. It is known as design spectrum.

19. What is peak ground acceleration (PGA)?

PGA is a measure of earthquake acceleration. Unlike Richter scale, it is not a measure of the total size of the earthquake, but rather how hard the earth shakes in a given geographical area. PGA is what is experienced by a particle on the ground.

20. Enumerate site specific response spectrum.

A site specific response spectrum is plotted by taking the average of each record of site specific ground motions. This results in smooth means spectrum. The recorded earthquake motions clearly show that response spectrum shape differs for different types of soil profile at the site. Seed, Ugas and Lysmer (1985) plotted the average shape of response of spectrum.

21. What are the methods to reduce liquefaction?

(a) Avoid liquefaction-susceptible soils
(b) Build liquefaction-resistant structures
(c) Shallow foundation aspects
(d) Deep foundation aspect

(e) Improve the soil

(f) Drainage techniques

(g) Verification of improvement

22. List out the effects of liquefaction.

(a) Loss of bearing strength

(b) Lateral spreading

(c) Sand boils

(d) Flow failures

(e) Ground oscillation

(f) Flotation

(g) Settlement.

23. Name two type of liquefaction.

Liquefaction has two types they are

(i) Flow liquefaction

(ii) Cyclic mobility.

24. What is pounding?

Pounding is another important issue in the construction of multistory frame in urban areas. That is when two multistory frames are constructed too close to each other; they may pound on each other during strong ground motion which leads to collision. To avoid collection, adjacent buildings should be separated by minimum gab. These factors imply that nowadays there is a need of earthquake resistance architecture in highly seismic areas.

25. Name the four techniques of aseismic design.

The following four techniques of aseismic design or earthquake resistant building are:

(a) Structural configuration

(b) Lateral strength

(c) Good ductility

(d) Light weight mass.

16 MARKS

1. **Explain the Importance of Ductility in Earthquake Resistant structure?**

   It is defined as the ability of a structure to undergo inelastic deformation beyond initial yield deformation with no decrease in load resistance.

- ✓ Concept of earthquake design philosophy is achieved by introducing ductility at the predetermined position 0.3ns in the structure. This will enable the structure to absorb energy during earthquakes to avoid sudden collapse of the structure.

- ✓ The term ductility is defined as the ability of a structure to undergo inelastic deformations beyond the initial yield deformations without increase in load resistance.

- ✓ The magnitude of the earthquake forces induced in a structure will mainly depend on ductility of the structure. By introducing the ductility in earthquake resistant buildings, they have the ability to reverse large lateral deformations before failure during an earthquake and to withstand earthquake effects with some damage but without collapse.

- ✓ This is beneficial to the users of the structure as in case of earthquake if the structure is to collapse, it will undergo large deformation before failure. This gives a warning to the occupants and provides sufficient time for taking preventive measures. Hence it is important for the structure to behave as a ductile structure.

- ✓ Buildings with lateral load resisting system consisting of (i) a ductile moment resisting frame as given by Figure (a), and (ii) a dual system consisting of ductile moment resisting frame and ductile flexural wall as shown in Figure (b).

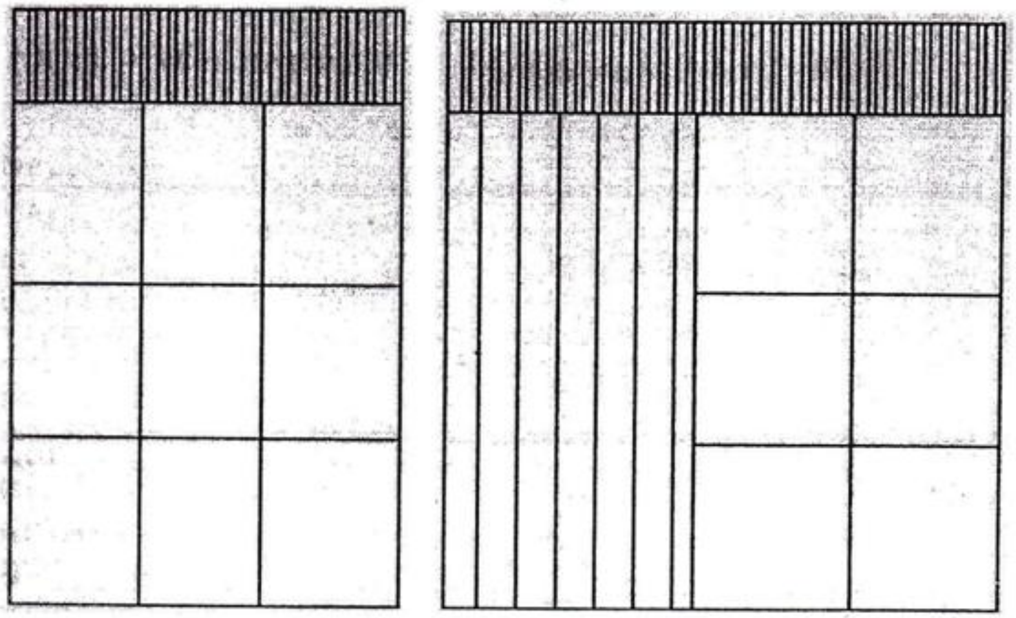


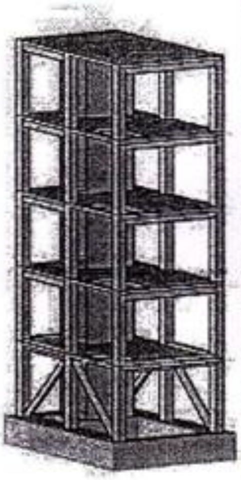
Fig (a) Moment resisting frame

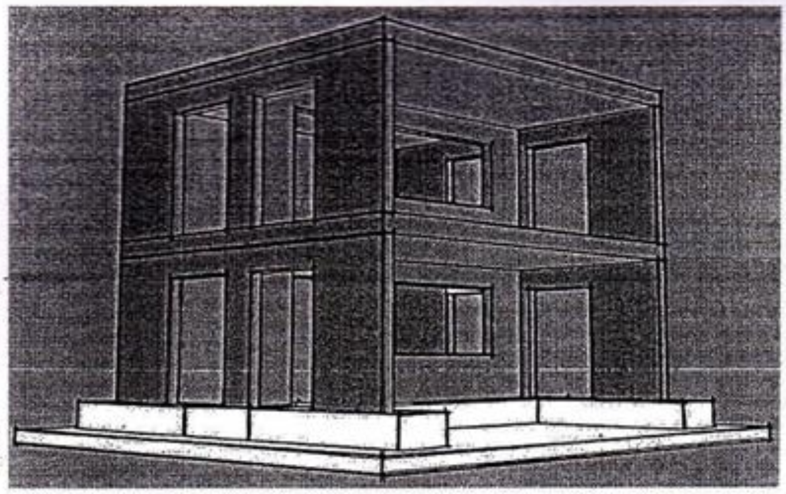
(b) Building with dual system

- ✓ A frame of continuous construction, comprising flexural members and columns designee and detailed to accommodate reversible large lateral displacements after the formation of plastic hinges without decrease in strength is known as ductile Moment Resisting Frame.

- ✓ **Shear walls** arereinforced concrete structural walls cantilevering vertically from the foundation, and designee and also detailed to be ductile and to resist seismic forces. They are used to dissipate energy through flexural yielding at one or more plastic hinges during earthquake.

  - o The shear wall is resisting the lateral forces.
  - o The properly designed shear needs to be connected to columns and beams, so that it can have a closed form actions or box action.





2. **Explain the various liquefaction induced failure in structure with sketches?** May/June 20

- ✓ Liquefaction is one of the most important and complex problem in earthquake engineering.
- ✓ Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading.
- ✓ Liquefaction occurs when the structure of loose, saturated sand breaks down due to some rapidly applied loading. As the structure breaks down, the loosely packed individual soil particles attempt to move into a denser configuration.
- ✓ In an earthquake, however, there is not enough time for the water in the pores of the soil to be squeezed out. Instead, the water is trapped and prevents the soil particles from moving closer together.
- ✓ This is accompanied by an increase in water pressure which reduces the contact forces between the individual soil particles, thereby softening and weakening the soil deposit.

In an extreme case, the pore water pressure may become so high that many of the soil particles loose contact with each other.

1. When liquefaction occurs, the strength of the soil decreases and, the ability of a soil deposit to support foundations for buildings and bridges are reduced. Liquefied soil also exerts higher pressure on retaining walls, which can cause them to tilt or slide.

2. This movement can cause settlement of the retained soil and destruction of structures on the ground surface. Increased water pressure can also trigger landslides and cause the 'collapse of dams.

3. Write short notes on the two main categories of liquefaction of soil Nov | June 2017

TYPES OF LIQUEFACTION

The mechanisms causing them, however, are different. These phenomena can be divided into two main categories:

1. Flow liquefaction
2. Cyclic mobility.

1. Flow liquefaction:

- Flow liquefaction is a phenomenon in which the static equilibrium is destroyed by static or dynamic loads in a soil deposit with low residual strength.
- Residual strength is the strength of a liquefied soil. It occurs when the static shear stresses in the soil exceed the shear strength of the liquefied soil. This will cause large deformations in the soil.
- For example, static loading can be applied by new buildings on a slope that exerts additional forces on the soil beneath the foundations.
- Earthquakes, blasting, and pile driving are all examples of dynamic loads that could trigger flow liquefaction. Once triggered, the strength of a soil susceptible to flow liquefaction is no longer sufficient to withstand the static stresses that were acting on the soil before the disturbance.
- Flow failures, can involve the flow of considerable volumes of material, which undergoes very large movements that are actually driven by static stresses.

2. Cyclic mobility:

- Cyclic mobility is a liquefaction phenomenon, triggered by cyclic loading, occurring in soil deposits with static shear stresses lower than the soil strength.

- Deformations due to cyclic mobility develop incrementally because of static and dynamic stresses that exist during an earthquake. Lateral spreading, a common result of cyclic mobility, can occur on gentle sloping and on flat ground close to rivers and lakes.

4. Briefly describe any five methods to reduce liquefaction of soil May | June 2013

EFFECTS OF LIQUEFACTION

Typical effects of liquefaction include:

1. **Loss of bearing strength:**
   - The ground can liquefy and lose its ability to support structures.
2. **Lateral spreading:**
   - The ground can slide down very gentle slopes as shown in Fig.1 or toward stream banks riding on a buried liquefied layer. It is mainly caused by cyclic mobility.
   - Lateral spreading cause's damage to foundations of buildings, pipelines, railway lines and cause shaking at piles due to increased lateral loads.

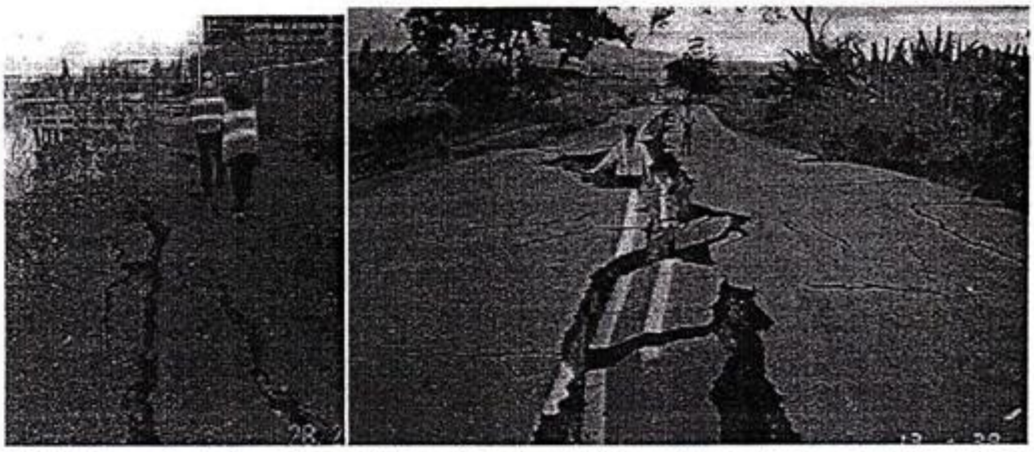


Fig.1 lateral spreading induced fissures in the main east-west highway between Siquerres and Puerto Limon.

3. **Sand boils:**
   - Sand-laden water can be ejected from a buried liquefied layer and erupt at the surface to form sand volcanoes; the surrounding ground often fractures and settles.

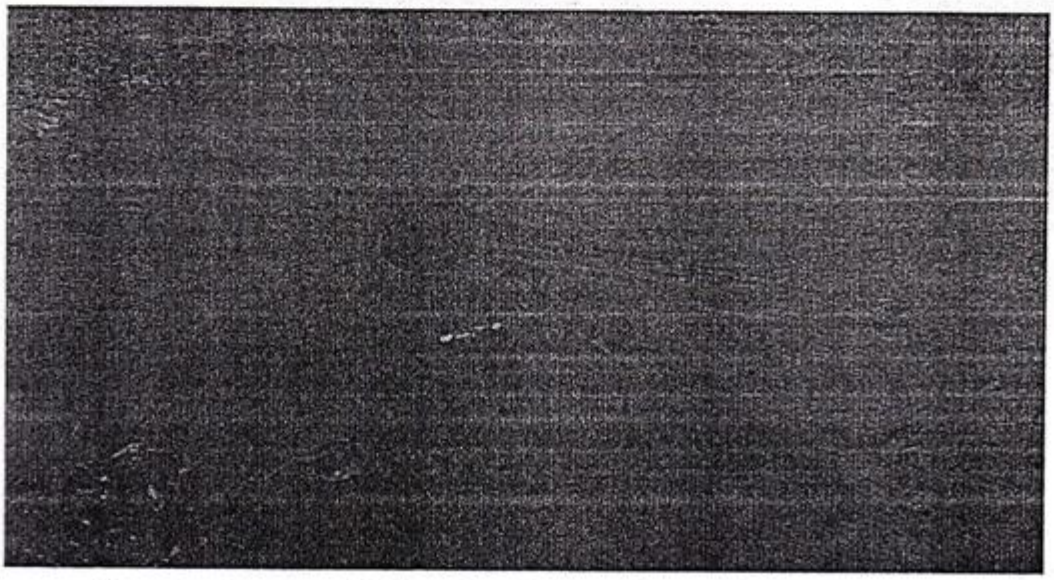


Figure 2 a view of a sand boil near Ranbir village, 2001 Bhuj earthquake.

4. **Flow failures:**

   - Here earth moves down steep slope with large displacement and much internal disruption of material as shown in Figure 3. This is caused by flow liquefaction.

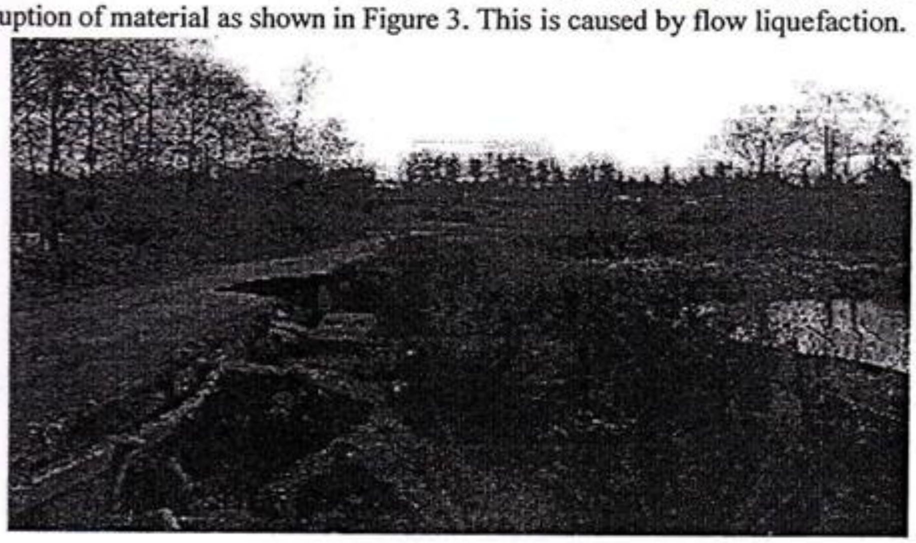
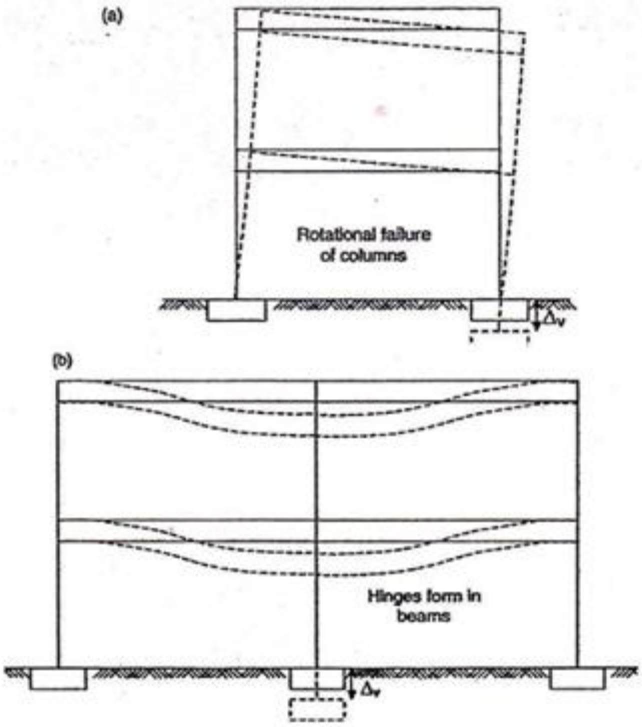


Figure 3 Flow failures in highway fill, Lake Merced, 1957 Daly City earthquake.

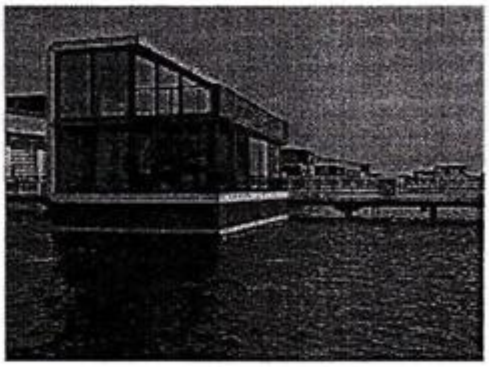
5. **Ground oscillation:**

   - This affects flat ground. The liquefied sediment starts to slosh into waves as shaking continues. Whatever is on top of the sediment gets broken and thrown around. Cracks in the ground open and close, and water or mud may erupt from them.



6. **Flotation:**

- Light structures that are buried in the ground (like pipelines, sewers and nearly empty fuel tanks) can float to the surface when they are surrounded by liquefied soil.



7. **Settlement:**

- Liquefied ground reconsolidates following an earthquake, the ground surface may settle or subside as shaking decreases and the underlying liquefied soil becomes more dense.

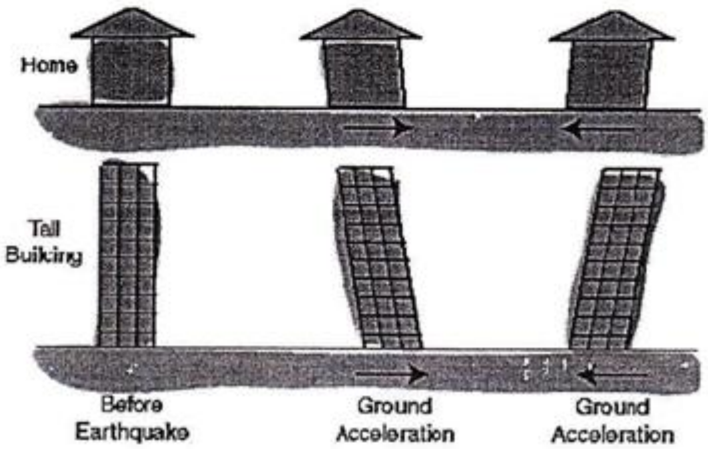
5. Explain the methods to reduce liquefaction in structure with sketches? Briefly describe any five methods to reduce liquefaction of soil? Nov / Dec 2012

There are basically three possibilities to reduce liquefaction hazards when designing and constructing new buildings or other structures as bridges, tunnels, and roads.

1. **A void liquefaction-susceptible soils:**
   - The first possibility is to avoid construction on liquefaction-susceptible soils. There are various criteria to determine the liquefaction- susceptibility of a soil.

   - By characterizing the soil at a particular building site according to these criteria, one can decide if the site is susceptible to liquefaction and therefore unsuitable for the desired structure.

2. **Build liquefaction-resistant structures:**
   - If it is necessary to construct on liquefaction susceptible soil due to reasons such as space restrictions, favorable location, or other reasons, it may be possible to make the structure liquefaction resistant by designing the foundation elements to resist the effects of liquefaction.



- Structure that possesses ductility has the ability to accommodate large deformations, adjustable supports for correction of differential settlements.

3. **Shallow foundation aspects:**

✓ It is important that all foundation elements in a shallow foundation are tied together to make the foundation move or settle uniformly, thus decreasing the amount of shear forces induced in the structural elements resting upon the foundation.

✓ The well-reinforced perimeter and interior wall footings are tied together to enable them to bridge over areas of local settlement and provide better resistance against soil movements.

✓ A stiff foundation mat (Figure 4) is a good type of shallow foundation, which can transfer loads from locally liquefied zones to adjacent stronger ground.

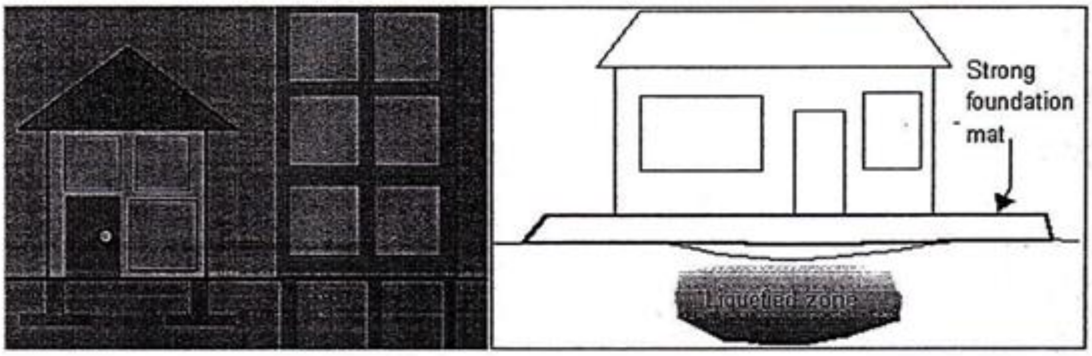


Fig. Mat foundation

Buried utilities, such as sewage and water pipes, should have ductile connections to the structure to accommodate the large movements and settlements that can occur due to liquefaction.

4. **Deep foundation aspect:**

- Liquefaction can cause large lateral loads on pile foundations.
- Piles driven through a weak, potentially liquefiable, soil layer to a stronger layer not only have to carry vertical loads from the superstructure, but must also be able to resist horizontal loads and bending moments induced by lateral movements if the weak layer liquefies.
- Piles of larger dimensions and or more reinforcement can achieve sufficient resistance. It is important that the piles are connected to the cap in a ductile manner that allows some rotation to occur without a failure of the connections.

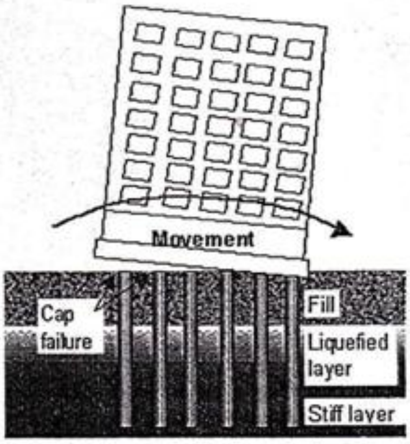


Fig. Failure of pile foundation

5. **Improve the soil:**

- The next option involves mitigation of the liquefaction hazards by improving the strength, density, and/or drainage characteristics of the soil. This can be done using a variety of soil improvement techniques.

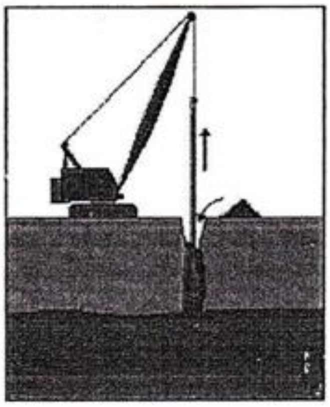
- The main aim of most soil improvement techniques used for reducing liquefaction hazards is to avoid large increases in pore water pressure during earthquake shaking.

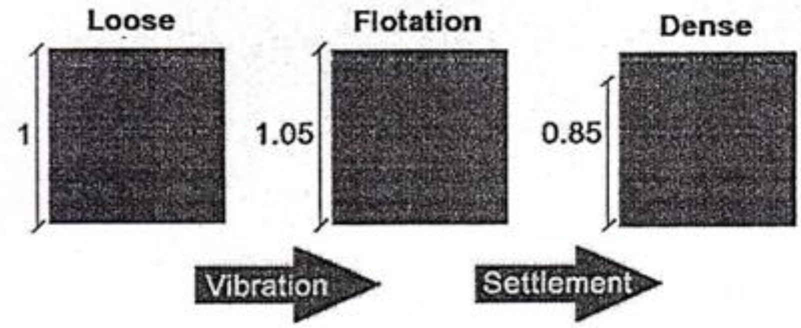
- This can be achieved by densification of the soil and or improvement of its drainage capacity with the help of the following methods:

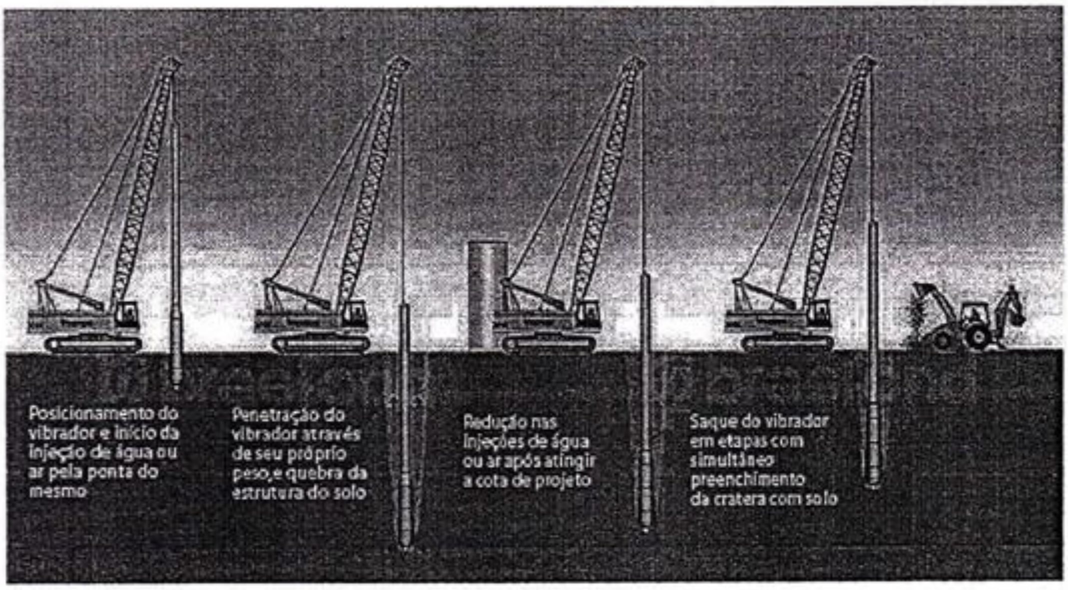
a) **Vibrofloatation:**

✓ Vibrofloatation involves the use of a vibrating probe that can penetrate granular soil to depths of over 100 feet (Figure 6).

✓ The vibrations of the probe cause the grain structure to collapse thereby densifying the soil surrounding the probe.





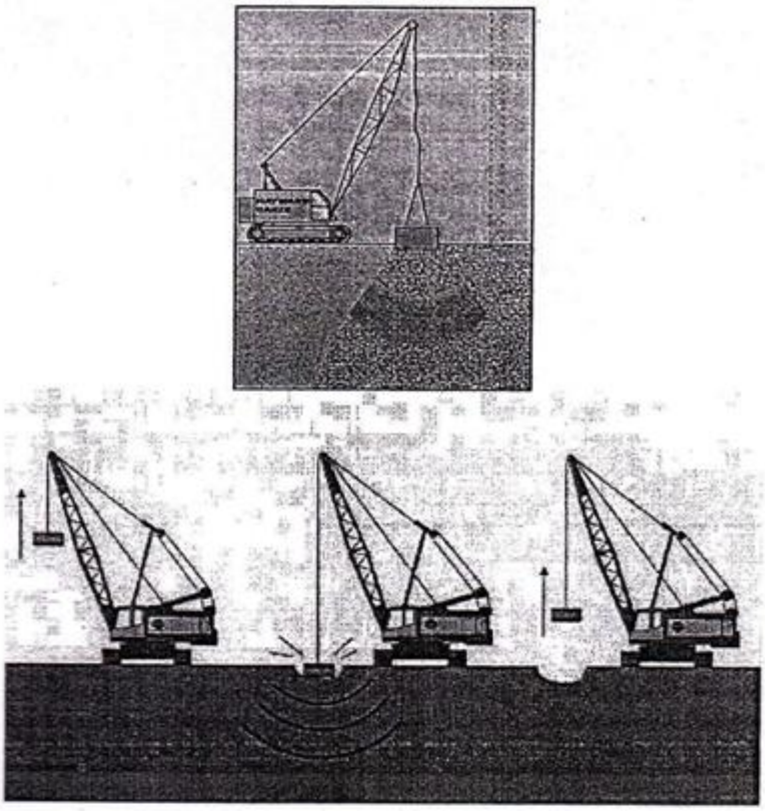


Vibrofloatation

- ✓ To treat an area of potentially liquefiable soil, the vibrofloatation is raised and lowered in a grid pattern. Vibro replacement is a combination of vibrofloatation with a gravel backfill resulting in stone columns, which not only increases the amount of densification, but provides a degree of reinforcement and a potentially effective means of drainage.

b) Dynamic Compaction:

- ✓ Densifiction by dynamic compaction is performed by dropping a heavy weight of steel or concrete in a grid pattern from heights of 30 to 100 ft as shown in Fig.
- ✓ It provides an economical way of improving soil for mitigation of liquefaction hazards. Local liquefaction can be initiated beneath the drop point making it easier for the sand grains to densify.

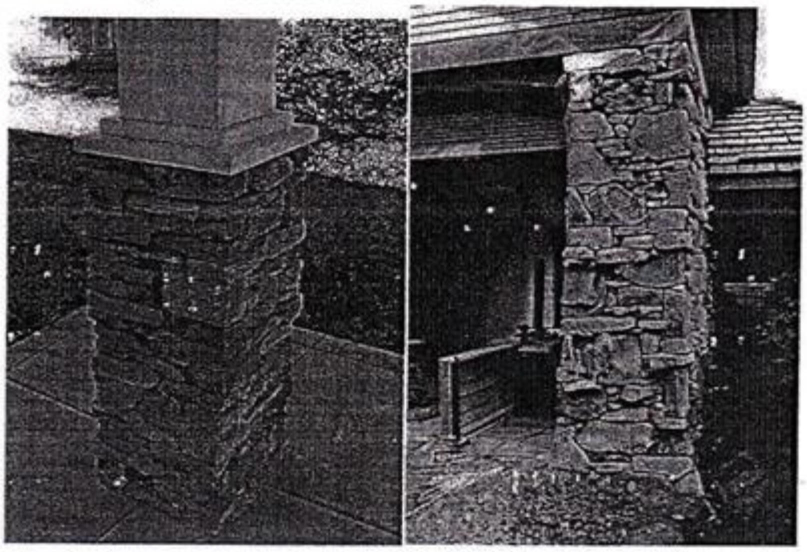


Dynamic Compaction

- ✓ When the excess pore water pressure from the dynamic loading dissipates, additional densification occurs. However, the process is somewhat invasive; the surface of the soil may require shallow compaction with possible addition of granular fill following dynamic compaction.

(C) Stone Columns:

- ✓ Stone columns are columns of gravel constructed in the ground. Stone columns can be constructed by the vibroflotation method.

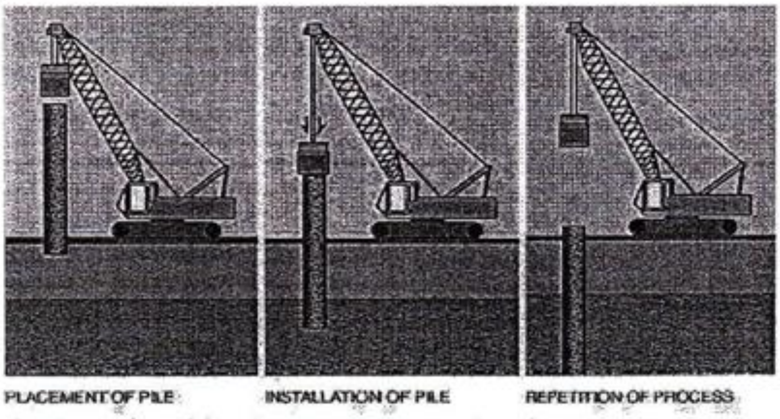


Stone Columns

- ✓ They can also be installed in other ways, for example, with the help of a steel casing and a drop hammer. In this approach, the steel casing is driven into the soil and gravel is filled in from the top and tamped with a drop hammer as the steel casing is successively withdrawn.

(d) Compaction Piles:

✓ Installing compaction piles is a very effective way of improving soil. Compaction piles are usually made of prestressed concrete or timber. Installation of compaction piles both densifies and reinforces the soil.



Compaction Piles

- ✓ The piles are generally installed in a grid pattern and are generally driven to a depth of up to 60 ft.

(e) Compaction Grouting:

✓ Compaction grouting is a technique whereby a slow-flowing water/sand/cement mix is injected under pressure into a granular soil. The grout forms a bulb that displaces and hence densifies the surrounding soil. Compaction grouting is a good option if the foundation of an existing building requires improvement, since it is possible to inject the grout from the side or at an inclined angle to reach beneath the building.

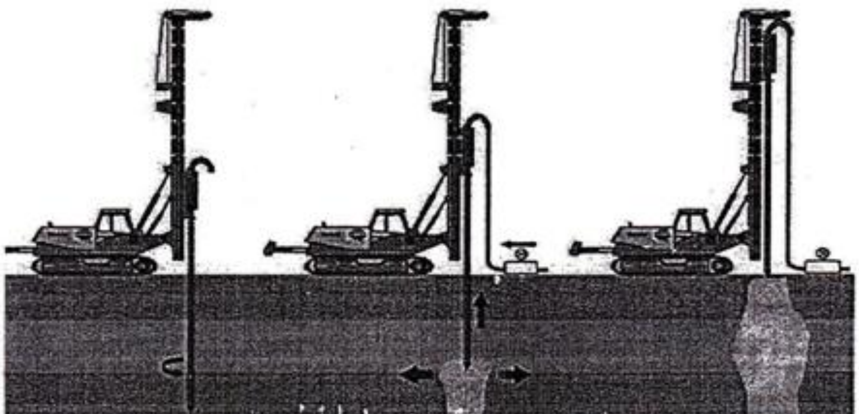
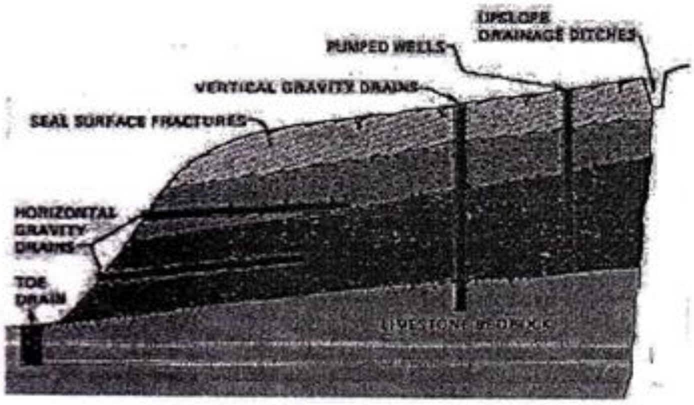


Figure 8 Compaction grouting technique.

6. Drainage techniques:

- ✓ Liquefaction hazards can be reduced by increasing the drainage ability of the soil. If the pore water within the soil can drain freely, the build-up of excess pore water pressure will be reduced.

- ✓ Drainage techniques include installation of drains of gravel, sand or synthetic materials. Synthetic wick drains can be installed at various angles, in contrast to gravel or sand drains that are usually installed vertically.



Drainage techniques

- ✓ Drainage techniques are often used in combination with other types of soil improvement techniques for more effective liquefaction hazard reduction.

7. Verification of improvement:

- ✓ A number of methods can be used to verify the effectiveness of soil improvement. In-situ techniques are popular because of the limitations of many laboratory techniques. Usually, in-situ tests are performed to evaluate the liquefaction potential of a soil deposit before the improvement was attempted.
- ✓ With the knowledge of the existing ground characteristics, one can then specify a necessary level of improvement in terms of in- situ test parameters. Performing in-situ tests, after improvement has been completed, allows us to decide if the degree of improvement was satisfactory.
- ✓ In some cases, the extent of the improvement is not reflected in in-situ test results until sometime after the improvement has been completed.

6. Effect of Soil Properties and Damping on Seismic Performance of Structures May / June 2011

- Seismic response of structures is influenced by the properties of soil on which the structure is founded.
- Strong and stiff soils transfer less of the ground motions while weak soils transmit larger portion of the ground motions. Hence, the response of the structure does not depend simply on the properties of the structure and its elements done, but on the type of soil stratum on which the structure is founded.
- The ground motions that are not influenced by the presence of structures are referred to as free-field motions. When a structure founded on solid rock is subjected to an earthquake, the rock mass, which is extremely stiff, constrains the rock motion to be very close to the free motion. Structures founded on rock are considered to be fixed base structures.
- Damping of structural systems plays a major role in determine the response of the structure for ground motions induced by the earthquake. The actual stiffness of foundation and damping coefficient are dependent on the frequency of vibration.

Structural response as a function of soil properties

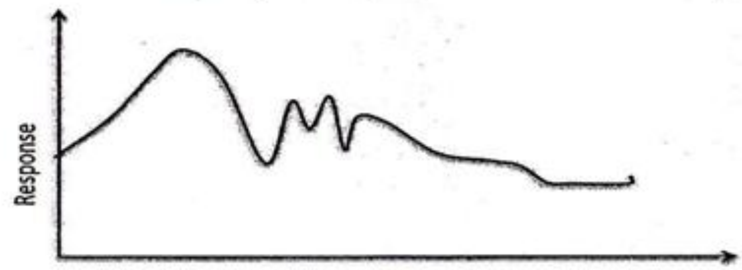
✓ The effect of soil properties on seismic response of structures is highly significant. A dense and solid mass soil transmits quite a large amount of ground motions and results in more destruction in resistance.

✓ The energy transmitted from the dense soil mass is almost equal to energy available from the earthquake, with little or no loss. In case of weak soils, the amount of seismic energy transmitted to the structure is significantly lower than the amount of seismic energy received by the stratum.

✓ A lot of seismic energy is wasted and hence, the structure receives less ground motion than that received by the soil mass. But a weak and loose soil stratum is vulnerable to liquefaction due to seismic energy which erodes most of the load bearing capacity, resulting in the failure of foundations.

7. Discuss about the response spectrum? (Nov/Dec 2007)

- ✓ The graph showing the variation of the maximum response (maximum displacement, velocity, acceleration, or any other quantity) with the natural frequency (or natural period) of a single degree of freedom system to a specified forcing function is known as the *response spectrum.*
- ✓ Using a computer one can calculate the response of SDOF system with time from to time history of response.
- ✓ Pick max. Response of this SDOF system of given't' and damping from this response time history.
- ✓ Repeat this exercise for different values of natural period or design we usually need only the max response.
- ✓ Hence for future use plot max. Response Vs natural period such a plot of max. Response Vs natural period for a given accelerograph is called "RESPONSE SPECTRUM"
- ✓ Since the maximum response is plotted against the natural frequency (or natural period), the response spectrum gives the maximum response of all possible single degree of freedom systems. The response spectrum is widely used in earthquake engineering.
- ✓ Once the response spectrum corresponding to a specified forcing function is available, we need to know just the natural frequency of the system to find its maximum response.

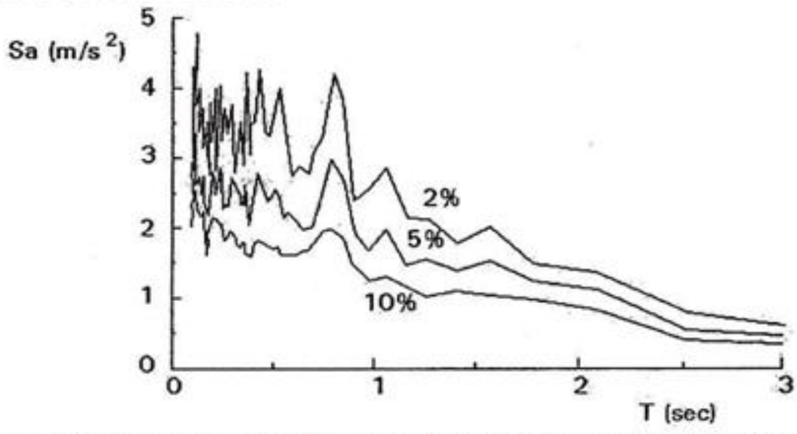


Response Spectrum

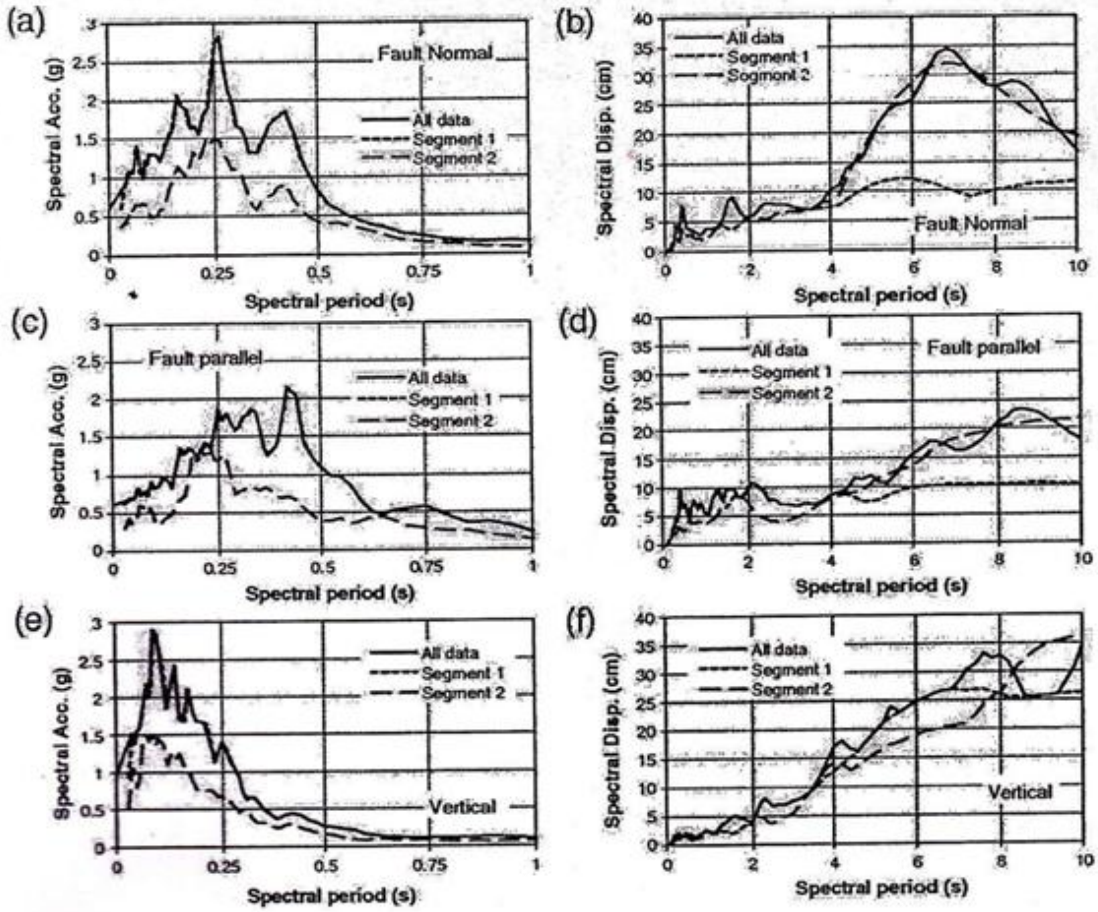
USES

- ➢ To obtain Max. Response of a SDOF system
- ➢ To obtain Max. Response in a particular mode of vibration of a MDOF system
- ➢ It tells about the characteristic of the ground motion

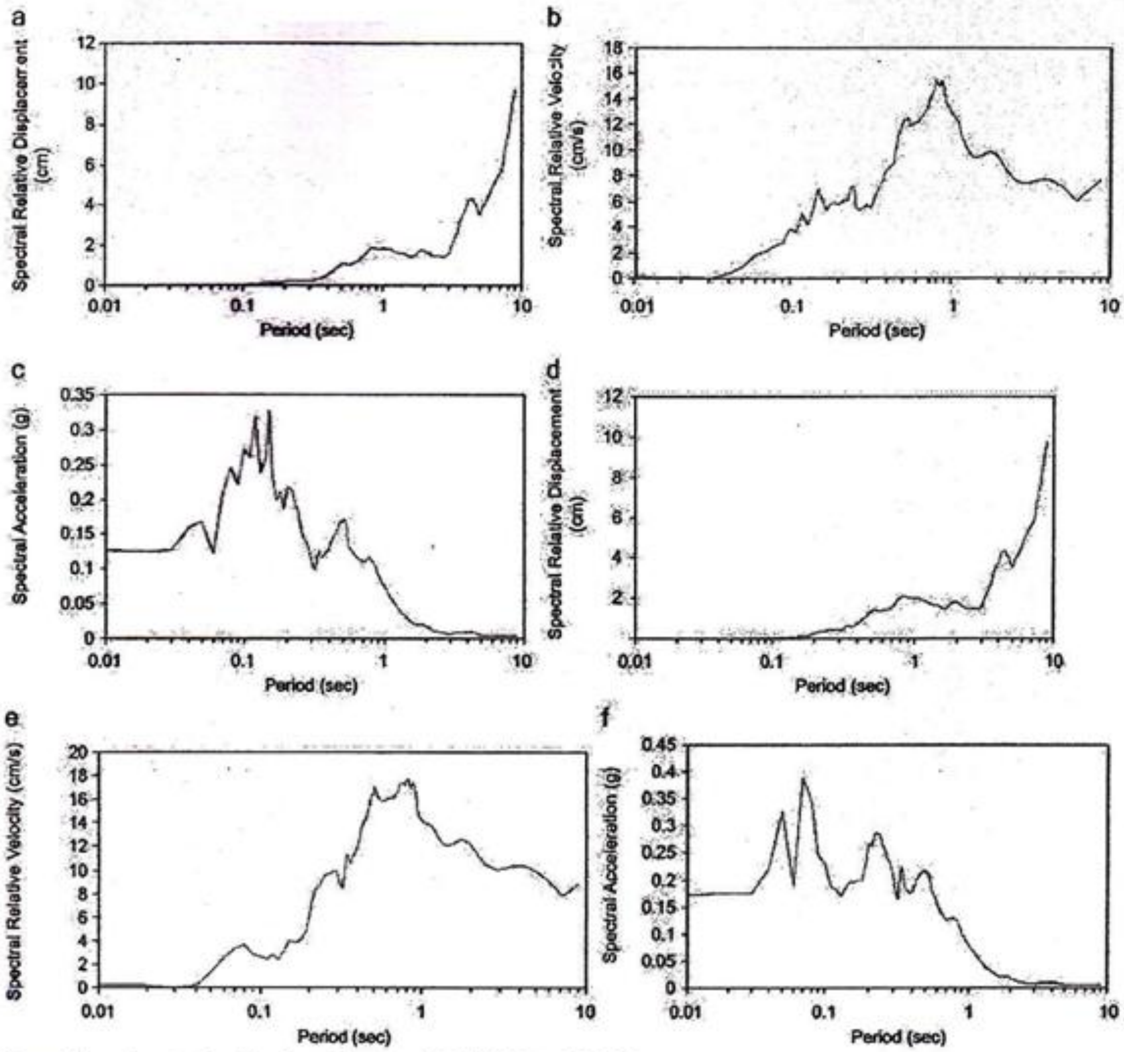
SMOOTH RESPONSE SPECTRUM



A typical acceleration response spectrum for three damping ratio values is shown in Fig.



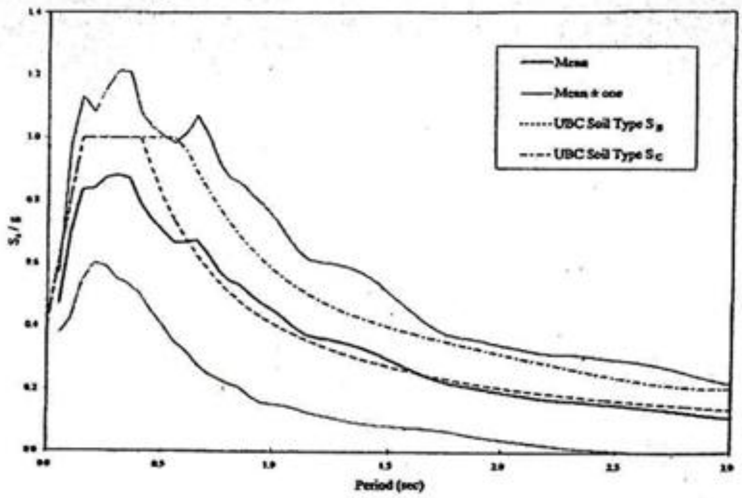
(a)
Spectral Acc. (g)
Spectral period (s)
Fault Normal
All data
Segment 1
Segment 2
(b)
Spectral Disp. (cm)
Spectral period (s)
Fault Normal
(c)
Fault parallel
(d)
(e)
Vertical
(f)

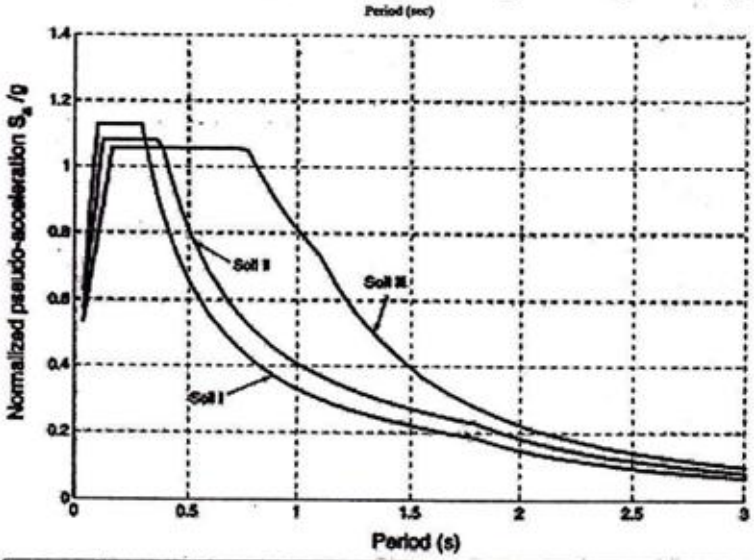


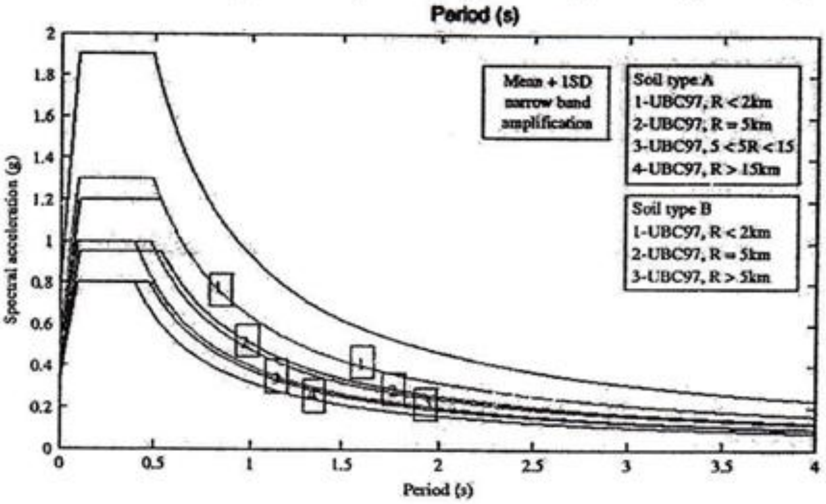
8. Describe about the Design Spectra? (Nov/Dec 2007)

- ✓ Response spectra developed for displacement, pseudo-velocity and pseudo acceleration in a combined manner for Elcentro earthquake' (1940) for various damping ratios as shown in Fig.
- ✓ This type of spectrum is called as *'tripartite response spectrum'*. Generally a real spectrum has irregular shape with local peaks and valleys.
- ✓ For design purpose, local peaks and valleys should be ignored, since natural period cannot be calculated with that much accuracy.
- ✓ Hence a smooth curve is plotted by considering the average of a number of elastic response spectrums corresponding to various possible earthquakes at a particular site.
- ✓ It is known as the smoothed elastic design response spectrum (SEDRS) as shown in Fig.
- ✓ Therefore design response spectrum incorporates the spectra for several earthquakes and represents the 'average' response spectrum for design.
- ✓ Generally, it is assumed that the shapes of the design spectra are the same for both the design and maximum probable earthquakes but that they differ in intensity as measured by peak ground acceleration.

- ✓ Hence, it is necessary to normalize the intensity of these design spectra to the peak ground acceleration
- ✓ Later scale them down to the appropriate peak acceleration levels which represent the design and maximum probable earthquakes.







Since some damage is expected and accepted in the structure during strong shaking, design spectrum is developed considering the over strength, redundancy and ductility in the structure.

Design spectrum must be accompanied by the following:

1. Load factors or permissible stresses that must be used (different choice of load factors will lead to different seismic, safeties to the structure.)
2. Damping to be used in design (variation in the value of damping used will affect the design force).
3. Method of calculating of natural period (depending on the modeling assumptions, one can get different values of natural period).
4. Type of detailing for ductility.

EARTHQUAKE RESPONSE SPECTRA

- ✓ The most direct description of an earthquake motion in time domain is provided by accelerograms that are recorded by instruments called *strong motion accelerographs.*
- ✓ The accelerograph records three orthogonal components of ground acceleration at a certain location. A typical accelerogram is shown in Figure 10.3.
- ✓ The accelerograms are generally recorded on photographic paper of film and are digitized for engineering applications.
- ✓ The peak ground acceleration, duration, and frequency content of the earthquake can be obtained from an accelerogram.
- ✓ An accelerogram can be integrated to obtain the time variations of the ground velocity and ground displacement.

9. What are the concepts of peak ground acceleration? (PGA) May) June 2013

- ✓ PGA stands for Peak Ground Acceleration.
- ✓ It is a measure of earthquake acceleration.
- ✓ Unlike Richter scale, it is not a measure of the total size of the earthquake, but rather how hard the earth shakes in a given geographic area.
- ✓ PGA is what is experienced by a particle on the ground.

The following procedure has been mostly used to establish the peak ground acceleration values for the maximum probable and design earthquakes:

1. Establish the locations of known active faults in the nearby region of the site. If the active fault is not known, it is required to carry out extensive investigation at the site.

2. To establish the maximum Richter magnitude possible for future earthquakes occurring along each fault, all historical seismic data available from past earthquakes occurring on this active fault are carefully studied.

3. By using empirical relations, mean PGA in expressed as a function of source-to-site distance R and maximum Richter magnitude.

Campbell gives the following expression to calculate mean PGA

$$a=b_1[R+b_4e^{b5m}]^{-b3}e^{b2m}$$

Where, a is mean PGA, b_1,b_2,b_3,b_4 and b_5 are constants determined through nonlinear regression analysis using to the extent possible, strong motion data recorded in the local region of the site.

R- source-to-site distance

M - max Richter magnitude

4. Using the largest value of mean PGA 'a' obtained for all active fault under consideration, the design PGA is then used to scale down the normalized *(lg)* response spectra to the appropriate level representing the maximum probable earthquake.

10. Zero period acceleration (ZPA) Nov | Dec 2013

- ✓ Zero period acceleration implies maximum acceleration experienced by a structure having zero natural period (T = 0). An infinitely rigid structure has zero natural period (T = 0). It does not deform; Thus relative motion between its mass and its base.
- ✓ Mass has same acceleration as of the ground. Hence ZPA is the same as peak ground acceleration. The spectra for different earthquake accelerograms are normalized by the PGA value so that they all have the same ordinate at T = O.
- ✓ A response spectrum is used to provide the most descriptive representation of the influence of a given earthquake on a structure or machine.
- ✓ It is possible to plot the maximum response of a single degree of freedom system in terms of the acceleration, relative pseudo-velocity, and relative displacement using logarithmic scales.

11. Explain the Site Specific Response Spectra? May | June 2012

1. A site specific response spectrum is plotted by taking the average of each record of site specific ground motions.
2. This results in smooth mean spectrum. The recorded earthquake motions clearly show that response spectrum shape differs for different types of soil profile at the site. Seed, Ugas and Lysmer (1985) plotted the average shape of response spectra recorded on three different soil conditions as shown in Figure 10.7.
3. It may be observed that, softer soils exhibit wider plate ace indicating that longer period Structures will be affected more. This is reflected in the spectra specified in several codes.
4. Software can be used to establish a spectrum with a desired probability of evidence.

]

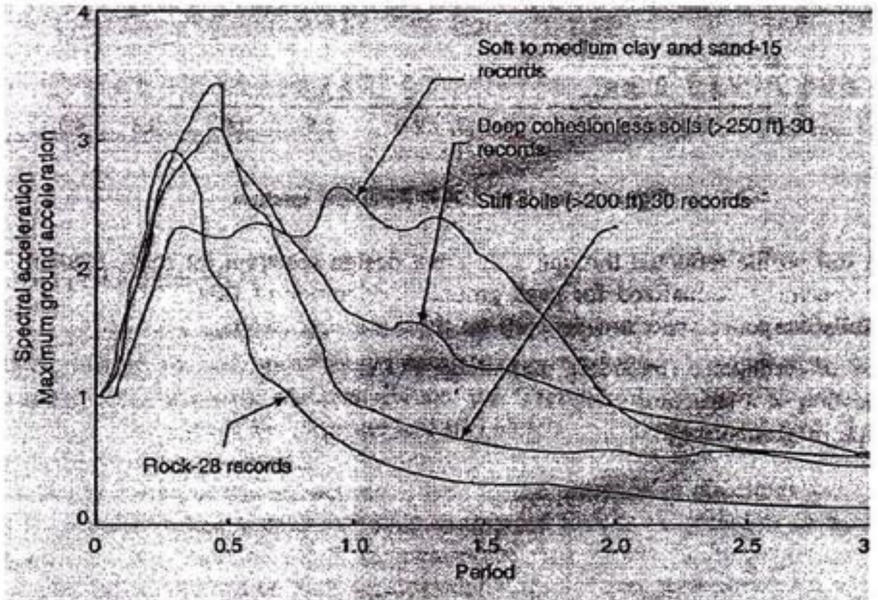
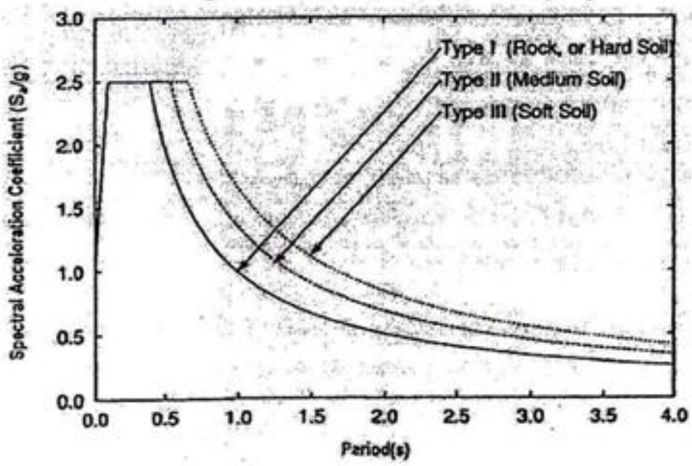


Figure 10.7 Response spectra for different soil conditions.

12. Explain the Response Spectrum (1S 1893:2002) part-1with neat sketch. May/ June 2013

The response spectra specified in IS 1893:2002 for a damping ratio of 5% is as shown in Figure 10.8. Modification factors are also given for other values of damping ratios.



Local soil profile reflected through a different design spectrum for rock, medium and soft soils. The spectra are normalized for peak ground acceleration of *l.*

Generally, response spectrum depends on the following factors:

1. Size of earthquake (including magnitude, PGA)
2. Location of a structure
3. Type of ground/soil.

13. Explain the importance of ductility in earthquake resistant design of R.C buildings

Concept of earthquake design philosophy is achieved by introducing ductility at the predetermined positions in the structure. This will enable the structure to absorb energy during earthquakes to avoid sudden collapse of the structure. The term ductility is defined as the ability of a structure to undergo inelastic deformations beyond the initial yield deformations without

Increase in load resistance. The magnitude of the earthquake forces induced in a structure will mainly depend on ductility of the structure. By introducing the ductility in earthquake resistant buildings, they have the ability to reverse large lateral deformations before failure during an earthquake and to withstand earthquake effects with some damage but without collapse. This is beneficial to the users of the structure as in case of earthquake if the structure is to collapse, it will undergo large deformation before failure. This gives a warning to the occupants and provides sufficient time for taking preventive measures. Hence it is important for the structure to behave as a ductile structure.

Buildings with lateral load resisting system consisting of (i) a ductile moment resisting frame as given by Fig(a), and (ii) a dual system consisting of ductile moment resisting frame and ductile flexural wall as shown in Fig(b).

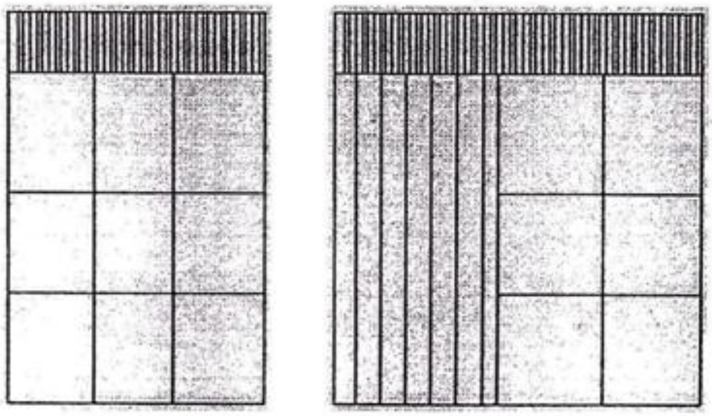


Figure 13.5(a) Moment resisting frame, and (b) Building with dual system.

A frame of continuous construction, comprising flexural members and columns designee and detailed to accommodate reversible large lateral displacements after the formation of plastic hinges without decrease in strength is known as ductile moment resisting frame. Shear walls *art* reinforced concrete structural walls cantilevering vertically from the foundation, and designee and also detailed to be ductile and to resist seismic forces. They are used to dissipate energy through flexural yielding at one or more plastic hinges during earthquake.

Measures of Ductility

A quantitative measure of ductility is arrived from load-deformation curve as shown Figure 13. (This is nearly horizontal that is the deformation increasing at nearly constant load.

The ratio of the ultimate deformation to the deformation at the initial yielding can give the measure of ductility and it is also called as ductility ratio or displacement ductility may be in the strain rotation, curvature or deflection.

Each may give a different value for the ductility ratio.

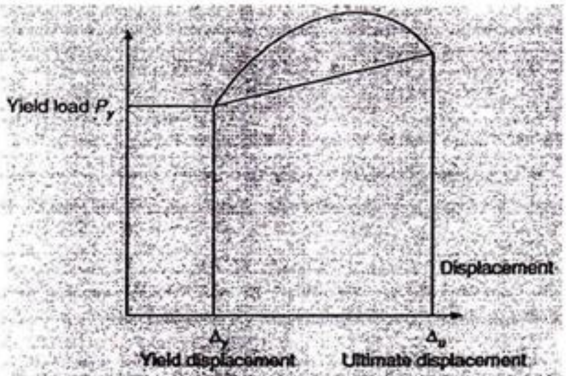


Figure 13.6 Load-Displacement curve.

$$\text{Ductility ratio } \mu = \frac{\text{Ultimate deformation}}{\text{Initial yielding deformation}} = \frac{\Delta_u}{\Delta_y}$$

Curvature ductility:

Curvature ductility is the ratio of curvature at the ultimate strength of the section to the curvature at the first yield at the section. This is obtained from Moment- Curvature relationship.

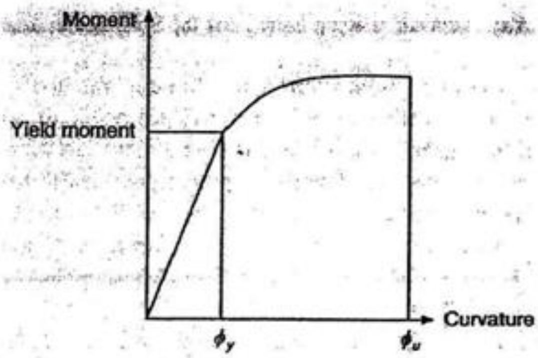


Figure 13.7 Moment-Curvature diagram.

$$\text{Curvature ductility } \mu_c = \frac{\phi_\mu}{\phi_y}$$

Element, global or structure ductility:

- ✓ In general, a structure is formed by assembling various elements such as beams and columns. Introducing ductility in individual element is called**local ductility.**
- ✓ This is generally with reference to the displacement and moment curvature relationship of a section. If the ductility is referred with respect to the whole building or entire structure, it is called **global ductility** or structure ductility.
- ✓ Structure ductility in a global sense depends on the displacement ductility of its element because response displacement of each element will contribute to the global ductility.

Global ductility $\mu_g$can be determined as

$$\mu_g = \frac{\sum_{i=1}^{n} F_i \mu_i}{\sum F_i}$$

Where, Fi is the lateral force at floor I and $\mu_g$its lateral displacement.

Methods to improve element level local ductility:

Element ductility can be generally improved by

(i) Reducing the area, yield stress and strain of the tension steel

(ii) Increasing the area of compression steel

(iii) Reduction in the axial compression on the section

(iv) Provisions of effective confinement stirse up hoops or ties such that compression steel does not buckle and the concrete is led into a three dimensional state of stress such that its ultimate compressive strain increases.

Methods to improve global level **ductility:**

Global level ductility can be generally improved by

(i) Increasing the redundancy of the structure

(ii) Adopting strong column and weak beam design

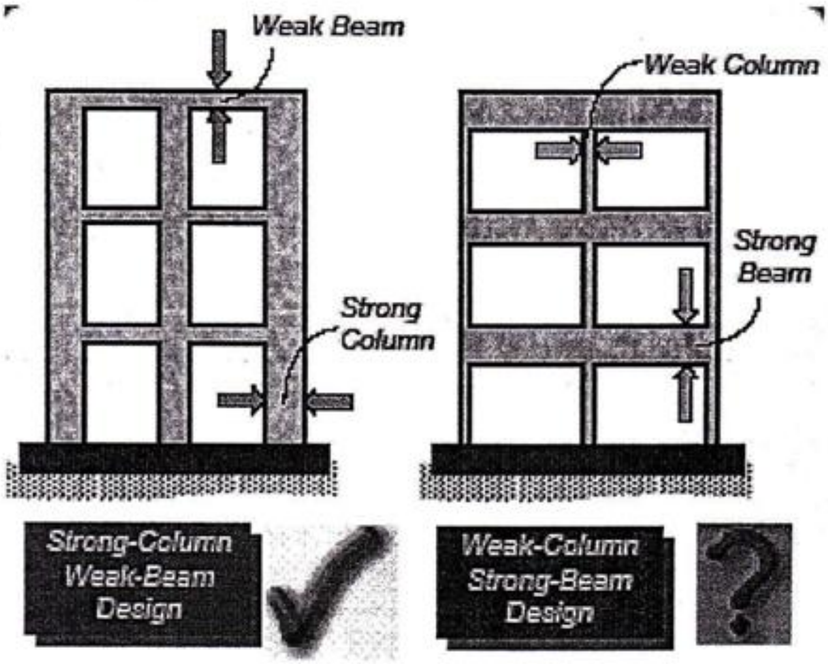
(iii) A voiding soft first storey effects

(iii) Avoiding non-ductile failure modes like shear, bond and axial compression at the element level.

14. Provisions for ductile detailing in the members of reinforced concrete buildings are given in IS 13920: 1993. These provisions will be discussed in the forthcoming chapter.

CAPACITY DESIGN May / June 2009

1. In case of framed structures, it has been noticed that some collapse mechanism ensures larger energy dissipation capacities in comparison with source collapse mechanism. Capacity design is the technique of ensuring a predetermined collapse mechanism by suitably adjusting the capacities of the members.



2. The basic concept of capacity design of structures is to distribute the inelastic deformation throughout the structures in such a way that the formation of plastic hinges at predetermined positions in the members.
3. During earthquake, the seismic inertia forces generated at the floor levels are transferred through beams and columns to the foundation.
4. In case of ductile frames, this can be achieved by formation of plastic hinges purposely at both ends of all the beams in all floors of the building while the column remains essentially elastic in all stories, excluding bottom storey as shown in Fig.
5. It is desired to allow the formation of plastic hinges in the beams rather than columns, because:
   a) Plastic hinges in beam have higher rotation capacities than in columns which are used to increase the ductile behaviour of the frame.
   b) Failure of a beam generally results in a localized failure, whereas failure of a column can affect the stability of the entire structure.

c) Failure in beam can be easily repaired and strengthened. But the entire structure may collapse due to the failure of column.

6. Thus, purposely we are designing the beam as a weaker member than the column. This concept of designing reinforced concrete frame is called the **Strong Column-Weak Beam Design.**

7. **In** capacity design, the strength developed in weaker member is related to the capacity of the stronger member while yielding.