UNIT-IV

RESPONSE OF STRUCTURES TO EARTHQUAKE

Effect of Earthquake on different type of structures

- Earthquakes are natural hazards under which disasters are mainly caused by damage or collapse of buildings and other man-made structures.
- Experience has shown that for new constructions, establishing earthquake resistant regulations and their implementation is the critical safeguard against earthquake-induced damage.
- For existing structures, it is necessary to evaluate and strengthen them based on evaluation criteria before an earthquake.
- Earthquake damage depends on many parameters including intensity, duration and frequency content of ground motion, geologic and soil condition, quality of construction, etc.
- Building design must be such as to ensure that the building has adequate strength, high ductility and will remain as one unit, even while subjected to very large deformation.
- Observation of structural performance of buildings during an earthquake can clearly identify the strong and weak aspects of the design, as well as desirable qualities of materials and techniques of construction and site selection.
- The principle cause of earthquake-induced damage is ground shaking.
- As the earth vibrates, all buildings on the ground surface will respond to that vibration in varying degrees.
- Earthquake induced accelerations, velocities and displacements can damage or destroy a building unless it has been designed and constructed or strengthened to be earthquake resistant.
- Therefore, the effect of ground shaking on buildings is a principal area of consideration in the design of earthquake resistant buildings.

- Seismic design loads are extremely difficult to determine due to random nature of earthquake motions.
- However, experiences from past strong earthquakes have been shown that reasonable and prudent practices can keep a building safe during the earthquake.

Inertial forces:

- When EQ shaking occurs, a building gets thrown from side to side and/or up and down.
- When the ground is violently moving from side to side, the building tends to stand at rest, similar to passenger standing on a bus that accelerates quickly.
- Once the bldg. starts moving, it tends to continue in the same direction, but by this time the ground is moving back in the opposite direction. (as if the bus driver first accelerated quickly, then suddenly braked)
- Internal forces in a building caused by vibration of the building's mass during earthquake shaking are called inertial forces.
- Inertial forces are equal to the product of mass and acceleration as per the Newton's second law $F = m \times a$. Where 'a' = acceleration is the change of velocity over time and is function of the nature of the earthquake, mass 'm' is an attribute of the bldg.
- Since the forces are inertial, an increase in the mass generally results in an increase in the force.
- Hence the immediate virtue of the use of light weight construction as a seismic design approach.
- The other detrimental aspect of mass, besides its role in increasing the lateral loads, is that failure of vertical elements such as columns and walls can occur by buckling when the mass pushing down due to gravity exerts its force on a member bent or moved out of plumb by the lateral forces.

  This phenomenon is known as the P-e, or P-Delta effect.

- Earthquakes shake the ground in a variety of directions - including up and down components.
- Historically, codes generally treated these vertical EQ forces lightly, although they may be two-thirds as great as the lateral EQ forces, and "seismic design" and "design for lateral forces".
- It is vertical loads that almost always cause buildings to collapse in EQ; however in EQ buildings generally fall down, not over.
- The lateral forces use up the strength of the structure by bending and shearing columns, beams and walls and then gravity pulls the weakened and distorted structure down.
- It is important to note that the main difference between the nature of earthquake by winds loading is due to the fact that the EQ ground motion induces internally generated inertial forces caused by vibration of the building's mass, whereas wind loading acts in the form of externally applied pressure.

Fundamental period of Vibration:

- If one shook a flag pole with a heavy weight on top in the attempt to break it, one would quickly learn to synchronize one's pushes & pulls with the pole's natural tendency to vibrate back and forth at a certain rate - its fundamental period.
- If it tends to swing back and forth one complete cycle once a second when plucked and allowed to vibrate, it has a fundamental period of one second.
- Fundamental periods ranges from 0.05 s + well anchored equipment
  - 0.1 s - one storey simple bent or frame
  - 0.5 s - Low structure upto about 4 stories
  - 1-2 s - Tall building from 10-20 stories
  - 2.5-6 s - Water tank on an offshore drilling rig
  - > 6 s - Large suspension bridge.

- Natural periods of soil are usually in the range of 0.5-1 sec so that it is possible for the building and ground to have the same fundamental period and therefore there is a high probability for the building to approach a state partial resonance.

- Hence in a developing design strategy for a building, it is desirable to estimate the fundamental periods both of the building and of the site so that a comparison can be made to see if the probability of quasi-resonance exists.

Behaviour of Reinforced cement concrete, steel and Prestressing concrete structure under EQ loading:

- Different types of buildings suffer different degrees of damage during EQ and the same has been studied here.

* Mud and adobe houses
* Masonry buildings
* Brick - RC frame buildings
* Wooden buildings
* Reinforced concrete buildings
* steel skeleton buildings
* steel and reinforced concrete composite structure
* Prestressed concrete structures
* Shear Wall buildings

Mud and adobe houses:

- Unburnt sun dried bricks laid in mud mortar are called adobe construction.
- Mud houses are traditional construction, for poor and most suitable in view of their initial cost, easy availability, low level skill for construction and excellent insulation against heat and cold.
- More than 100 million people in India live in these type of houses.
- It is very weak in shear, tension and compression.
- Separation of walls at corner and junctions takes place easily under ground shaking.
- The cracks pass through the poor joints.
- After the walls fail either due to bending or shearing in combination with the compressive loads, the whole house crashes down.

Measures:

- Better performance is obtained by mixing the mud with clay to provide the cohesive strength.
- The mixing of straw improves the tensile strength.
- Coating the outerwall with waterproof substance such as bitumen improves against weathering.
- The strength of mud walls can be improved significantly by split bamboo or timber reinforcement.
- Timber frame or horizontal timber runners at lintel level with vertical members at corners further improves its resistance to lateral forces which has been observed during the earthquakes.

Masonry Buildings:

- Masonry bldgs. of brick & stone are superior with respect to durability, fire resistance, heat resistance and formative effects.
- Masonry bldgs. consist of various material & sizes
  (i) Large block [Block size > 50 cm] - concrete, rock or lime
  (ii) Concrete Brick - solid & hollow
  (iii) Natural stone masonry
- Because of its easy availability, economic reasons and the natural merits mentioned above this type of construction are widely used.

Causes of failure:

(i) These bldgs. are very heavy & attract large inertia forces.
(ii) Unreinforced masonry walls are weak against tension (Horizontal forces) and shear, therefore perform rather poor during EQ.
(iii) These bldgs. have large in plane rigidity & therefore have low time periods of vibration, which results in large seismic force.
(iv) It fall apart & collapsed because of lack of integrity.
(v) lack of structural integrity could be due to lack of 'through' stones, absence of bonding between cross walls, absence of diaphragm action of roofs and lack of box light action.

Damages:

- Severe damage resulting in complete collapse and pileup in a heap of stones.
- Inertia forces due to roof or floor is transmitted to the top of the walls and if the roofing material is improperly tied to the wall, it will be dislodged.

- Weak roof support connection is the cause of separation of roof from the support and leads to complete collapse.
- Failure of bottom chord of roof truss may also cause complete collapse of truss as well as the whole building.
- If the roof / floor material is properly tied to the top walls causing it to shear of diagonally in the direction motion through the bedding joints.
- The cracks usually initiate at the corners of the openings.
- Failure of pier occurs due to combined action of flexure and shear.
- Vertical cracks near corner wall joint occur indicating separation of walls.
- For motion perpendicular to the walls, the bending moment at the ends result in cracking and separation of the walls due to poor bonding.
- Generally gable end wall collapses.
- Due to large inertia forces acting on the walls, the wythe of masonry is either bulge outward or inward.
- The falling away of half the wall thickness on the bulged side is common feature.
- Unreinforced dressed rubble masonry (DRM) has shown slightly better performance than random rubble masonry.
- Unreinforced masonry should be avoided as construction material.

Reinforced masonry buildings:

- Reinforced masonry bldgs. have withstood EQ well, without appreciable damage.
- For horizontal bending, a tough member capable of taking bending if found to perform better during EQ.
- If the corner sections or opening are reinforced with steel bars even greater strength is attained.
- Even dry packed stone masonry wall with continuous lintel band over openings and cross walls did not undergo any damage.

Brick RC frame Buildings:

- This type of building consists of RC frame structures and brick lay in cement mortar as infill.
- It is suitable for seismic areas.

Causes of failure:

(i) Lack of good design of beams/columns frame action and foundation.

(ii) Poor quality of construction inadequate detailing or laying of reinforcement in all components particularly at joints and in columns/beams for ductility.

(iii) Inadequate diaphragm action of roof and floors.

(iv) Inadequate treatment of masonry walls.

Damages:

(i) Mostly due to failure of infill, columns or beams.

(ii) spalling of concrete in columns.

(iii) cracking or buckling due to excessive bending combined with D.L may damage the column.

(iv) Buckling of columns are significant when the columns are slender and the spacing of stirrup in the column is large.

(v) Severe crack occurs near rigid joints of frame due to shearing action, which may lead to complete collapse.

(vi) Differential settlement also causes excessive moments in the frame and may lead to failure.

Wooden Buildings:

- Common type of construction in areas of high seismicity.
- Failure is also due to deterioration of wood with passage of time.
- Wood frames without walls have almost no resistants against horizontal forces.
- Resistant is highest for diagonal braced wall.
- Buildings with diagonal bracing in both vertical and horizontal plane perform much better.
- It is suitable for two storeys

RC Buildings:

- Consists of shear walls and frame of concrete.
- Damage types
  - (i) Vibratory failure
  - (ii) Tilting (or) uneven settlement.

- When a RC bldg. is constructed on comparitively hard ground vibratory failure is seen, while on soft ground tilting, uneven settlement or sinking is observed.
- Shear walls are found to be effective to provide adequate strength to the buildings.
- Hollow concrete block bldgs. with steel R/F in selected grout filled cells have shown good performance.

Steel skeleton Buildings:

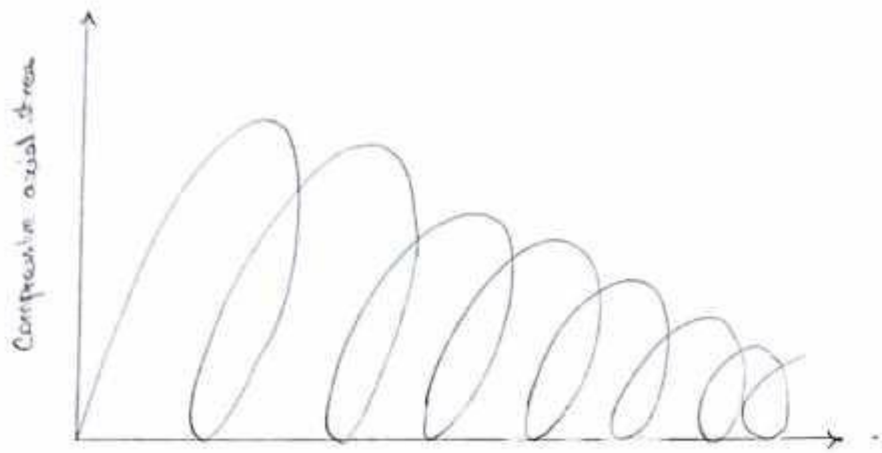
- It differ according to shapes of c/s & method of connection.
- This construction, particularly the structural type in which frames are comprised of beams and columns consisting of single member H-beams, is often used in high-rise bldgs.

Steel & RC composite structures:

- It is composed of steel skeleton and reinforced concrete and have the dynamic characteristics of both.
- It is better with respect to fire resistance and safety against buckling as compared to steel skeleton.
- Compared to RC, it has better ductility after yielding.
- Better performance during EQ.

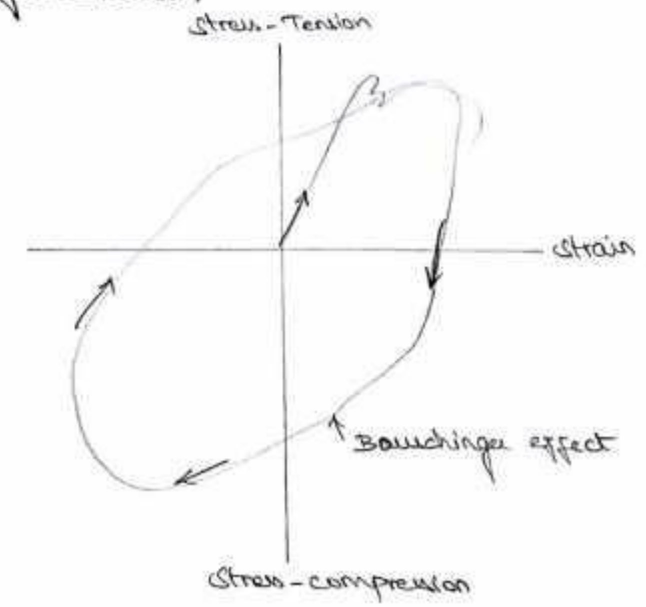
Cyclic Behaviour of concrete and R/F - Bauschinger and Pinching Effects:

Plain Concrete:



- It is a brittle material.
- If a specimen is loaded & unloaded & reloaded in compression, stress strain curves is similar as shown in fig.
- It can be seen that slope of the stress strain curves as well as the max. attainable stress decreases with no. of cycles.
- Thus, the stress strain relationship for plain concrete subjected to repeated compressive loads is cycle dependent.
- Decrease in stiffness and strength of plain concrete is due to the formation of cracks.
- compressive strength of concrete depends on rate of loading.
- As the rate of loading increases, the compressive strength of concrete increases but the strain at the max. stress decreases. It cannot be subjected to repeated tensile loads since its tensile strength is practically zero.

Reinforcements ;



- More ductility than plain concrete.
- ultimate strain in mild steel is of the order of 25%, whereas in concrete it is of the order of 0.3%..
- In the first cycle, the reinforcing steel shows stress strain curve similar to that obtained in the static test.
- After the specimen has reached its yield level and direction of load is reversed, that is unloading begins, it can be seen in fig. that the unloading curve is not straight but curvilinear.
- This curvature in the unloading segment of stress-strain curve is referred to as the Bouschinger effect after the discoverer of the phenomenon.
- Fig. shows one complete cycle of loading and unloading which is referred to as a hysteresis loop. The area within a loop exhibits energy absorbed by specimen in a cycle.

Evaluation of EQ Forces as per IS 1893-2002:

Recommendations provided by seismic codes help the designer to improve the behaviour of structures so that they may withstand the EQ effects without significant loss.

Seismic codes takes into account the
(i) Local seismology
(ii) Accepted level of seismic risk
(iii) Properties of available materials
(iv) Methods used in construction & bldg. Typologies

Most of the recommendations of IS codes are based on Earthquake engineering and property, also on observation during past EQ as well as experimental and analytical studies made by
- Scientists
- Engineers
- seismologists

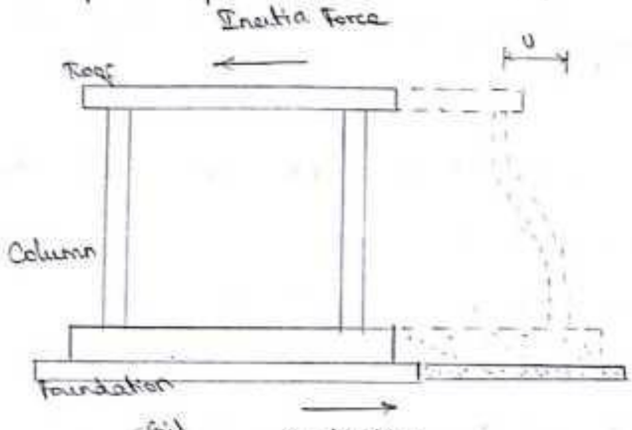
First seismic code in India:

IS: 1893 - criteria for EQ resistant design of structures published in 1962.

Inertia forces in structures:
- EQ causes shaking of the ground, so a bldg. resting on it will experience motion at its base.
- From Newton's I law of motion, even though the base of the bldg. moves with the ground, the roof

has a tendency to stay in its original position.

- But since the walls and columns are connected to it, they drag the roof along with them.



When the ground moves, even the bldg. is thrown backwards, and the roof experiences a force called inertia force.

If a roof has a mass 'm' and experiences an acceleration 'a', then from Newton's Second Law of motion, the inertia force 'F_I' is given by;

$$F_I = ma$$

its direction is opposite to that of the acceleration.

- clearly, more mass means higher inertia force.
- Therefore, lighter buildings sustain the EQ shaking better.

Response Spectra:

- Response spectra are curves plotted between max. response of SDF system subjected to specified EQ ground motion and its time period.
- It can be interpreted as the locus of max. response of a SDF system for given damping ratio.
- Response spectra thus helps in obtaining the peak structural responses under linear range, which can be used for obtaining lateral forces developed in structures due to EQ, thus facilitate in EQRS.

The following are the parameters in which response spectral value depends;

(i) Energy release mechanism
(ii) Epicentral distance
(iii) Focal depth
(iv) Soil condition
(v) Richter Magnitude
(vi) Damping in the system
(vii) Time period of the system

Concepts of Peak acceleration:

It is a measure of earthquake acceleration on the ground and known as design basis EQ Ground motion.

Unlike the Richter and moment magnitude scales, it is not a measure of the total energy of an EQ but rather how hard the earth shakes in a given geographic area.

PGA is measured by accelerographs and generally correlates with the Mercalli scale.

PHA is the most commonly used type of ground acceleration in engineering applications and is used to set building codes and design hazard risks.

PGA is easy to measure because the response of most instruments is proportional to ground acceleration.

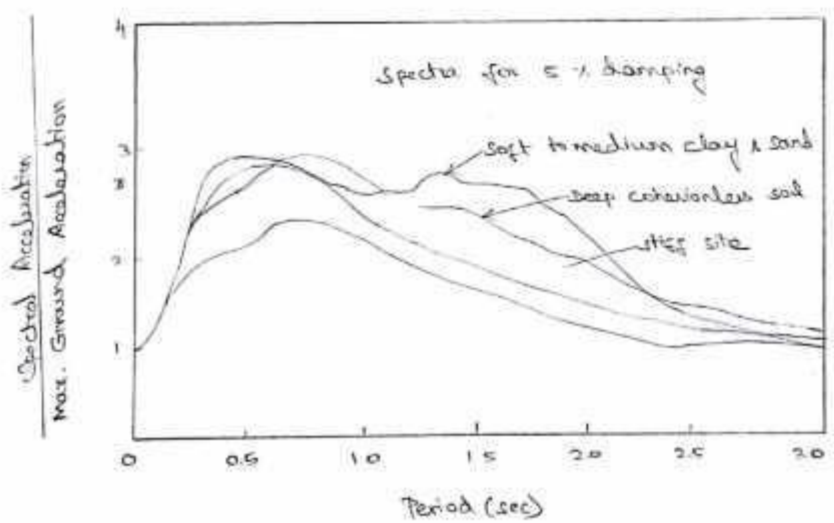
In terms of structural response, it corresponds to the peak value of the absolute acceleration of SDOF system with infinite stiffness that is natural period of vibration equal to zero.

Effective peak acceleration (EPGA) & Effective peak velocity (EPGV) have been proposed as alternatives to quantify the severity of Ground motion.

Site specific Response spectrum:

- To describe the design EQ, the type of spectrum required are std. design response spectra and site specific response spectrum.
- It is based on the seismic zone and the proximity of the seismic source.
- The site specific design response spectra should be developed based on EQ source condition, propagation path properties and local foundation characteristics associated with the specific site elastic design ~~p~~ response spectra can be predicted as ground motion parameter such as peak ground acceleration or velocity.

- A site specific response spectra is plotted by taking the average of each record of site specific ground motion.
- This type of spectra can be established by anchoring a selected response spectral shape for the site to the estimated peak ground acceleration.
- Effect of local soil conditions on response spectra is shown in fig.
- It may be observed from the curve that softer soil produce greater proportions of long period motion.



Lessons learnt from past EQ:

The buildings designed and constructed by taking proper EQ Resistant measures have helped by minimizing the damage.

The EQ resistant design & construction have been evolved as a result of lessons learnt from the damages due to past EQ and helped in evaluation and modification of provisions of the code of practice.

Most of multistorey buildings are either not designed for EQ forces at all or not designed & detailed adequately. In an event of an major EQ, most of the bldgs. are likely to damage, collapse and may lead to very severe disaster. It may be very difficult to cope up with such a disaster.

Recent Earthquake which causes more damages are as follows:

* Asian – Tibet – 1950
* KOYNA – 1967
* Bihar – Nepal – 1988
* uttarkashi – 1991
* KILLARI [Latur] – 1993
* Jabalpur – 1997
* Bhuj – 2001
* Sumatra – 2004
* EQ resulting Tsunami (India) – 2004
* Kashmir – 2005
* Sikkim – 2006