EARTHQUAKES-Siesmic Design Limit States

- It is customary to consider various levels of protection, each of which emphasizes a different aspect to be considered by the designer.
- Broadly these relate to preservation of functionality, different degrees of efforts to minimize damage that may be caused by a significant seismic event, and the prevention of loss of life.
- The degree to which levels of protection can be afforded depends upon economic constraints.
- While regions of seismicity are now reasonably well defined, the prediction of a seismic event within the projected lifespan of a building is extremely crude.

EARTHQUAKES-Siesmic Design Limit States

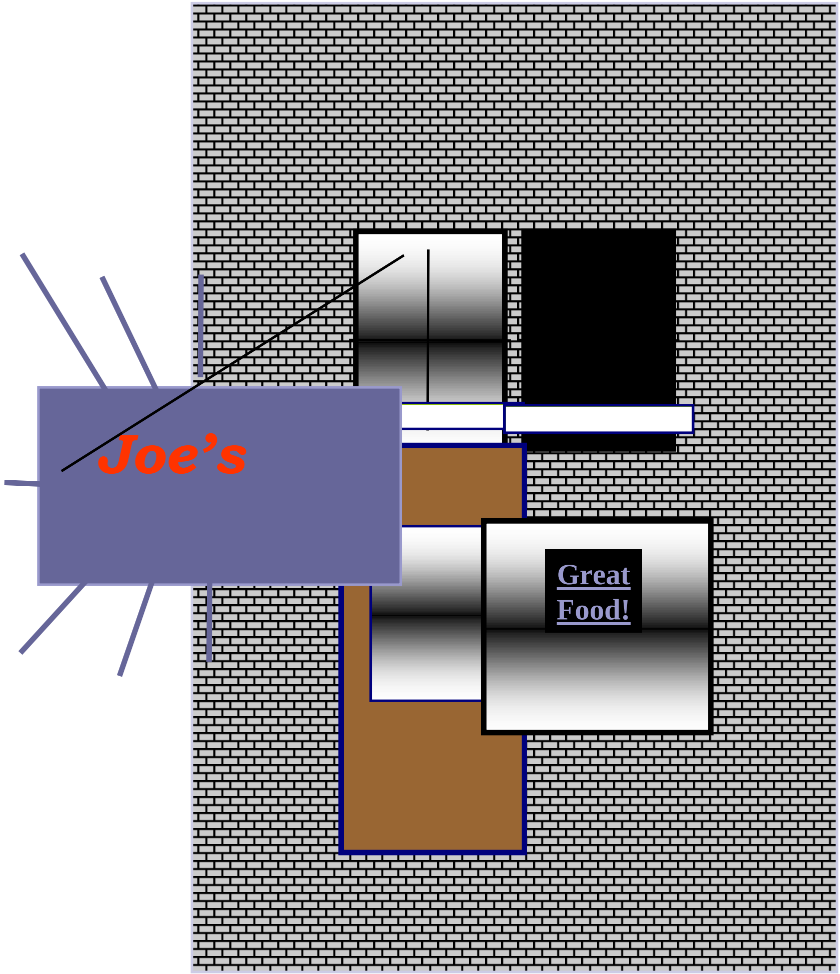
- **Serviceability Limit State** relatively frequent earthquakes inducing comparatively minor intensity of ground shaking should not interfere with functionality, such as the normal operation of a building or the plant it contains.
- This means that no damage needing repair should occur to the structure or to non structural components, including contents.
- The appropriate design effort will need to concentrate on the control and limitation of displacements that could occur during the anticipated earthquake.
- Reinforced concrete and masonry structures may develop considerable cracking at the serviceability limit state, but no significant yielding of reinforcement, resulting in large cracks, nor crushing of concrete or masonry should result.

EARTHQUAKES-Siesmic Design Limit States

- The frequency with which the occurrence of an earthquake corresponding to the serviceability limit state may be anticipated will depend on the importance of preserving functionality of the building.
- Thus, for office buildings, the service- ability limit state may be chosen to correspond to a level of shaking likely to occur, on average, once every 50 years (i.e., a 50-year-return-period earth- quake).
- For a hospital, fire station, or telecommunications center, which require a high degree of protection to preserve functionality during an emergency, an earthquake with a much longer return period will be appropriate.

Structural Properties-Stiffness

Serviceability



- *Negligible structural and nonstructural damage*
- *Utilities are available*
- *Facility is available for immediate re-use*
- *Repair costs are minimal to nil*

Structural Properties-Stiffness

Serviceability

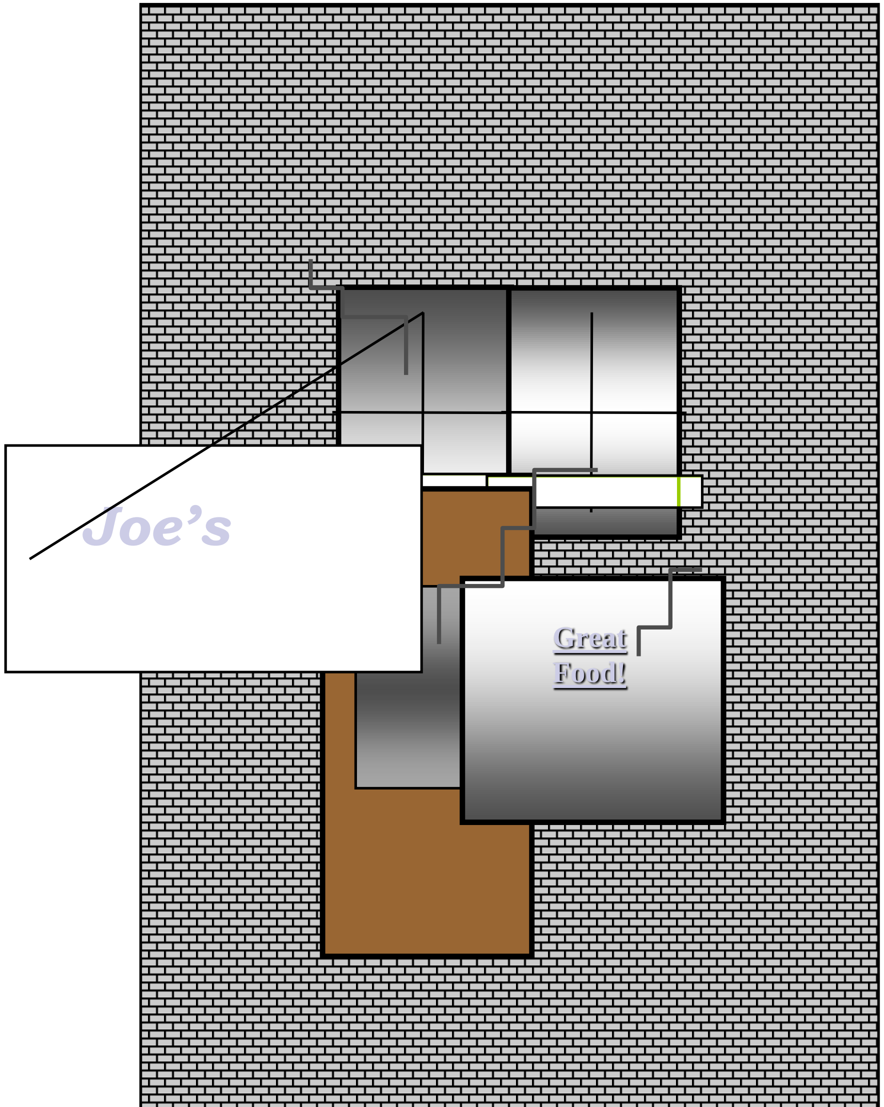
EARTHQUAKES-Siesmic Design Limit States

- **Damage Control Limit State** for ground shaking of intensity greater than that corresponding to the serviceability limit state, some damage may occur.
- Yielding of reinforcement may result in wide cracks that require repair measures such as injection grouting to avoid later corrosion problems.
- Also, crushing or spalling of concrete may occur, necessitating replacement of unsound concrete.

EARTHQUAKES-Siesmic Design Limit States

- A second limit state may be defined which marks the boundary between economically repairable damage and damage that is irreparable or which cannot be repaired economically.
- Ground shaking of intensity likely to induce response corresponding to the damage control limit state should have a low probability of occurrence during the expected life of the building.
- It is expected that after an earthquake causes this or lesser intensity of ground shaking, the building can be successfully repaired and reinstated to full service.

Structural Properties-Stiffness



Immediate Occupancy

- *Negligible structural damage*
- *Minor nonstructural damage*
- *Building is safe to occupy but may not function*
- *Limited interruption of operations*
- *Repair Cost < 15%*

Structural Properties-Stiffness

Immediate Occupancy

EARTHQUAKES-Siesmic Design Limit States

- **Survival Limit State** In the development of modem seismic design strategies, very strong emphasis is placed on the criterion that loss of life should be prevented even during strongest ground shaking feasible for the site.
- For this reason, particular attention must be given to those aspects of structural behavior that are relevant to this single most important design consideration: **survival**.
- For most buildings, extensive damage to both the structure and building contents, resulting from such severe but rare events, will have to be accepted.
- In some cases this damage will be irreparable, but collapse must not occur.

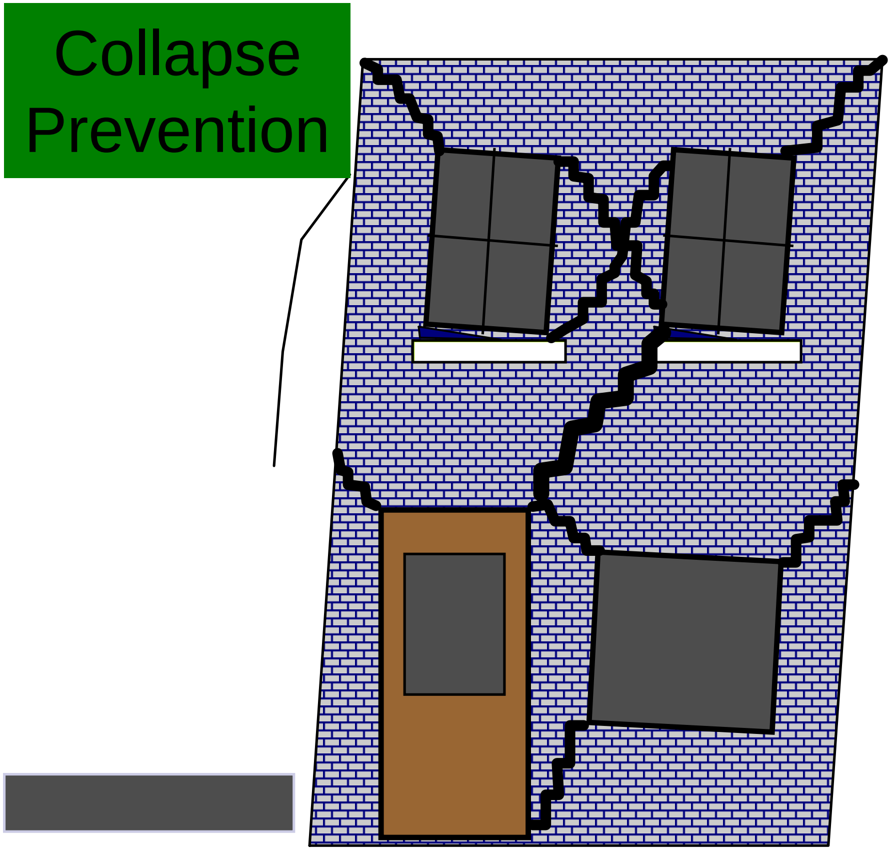
EARTHQUAKES- Siesmic Design Limit States

- Unless structures are proportioned to possess exceptionally large strength with respect to lateral forces, usually involving significant cost increase, inelastic deformations during large seismic events are to be expected.
- Therefore, the designer will need to concentrate on structural qualities which will ensure that for the expected duration of an earthquake, relatively large displacements can be accommodated without significant loss in lateral force resistance, and that integrity of the structure to support gravity loads is maintained.

EARTHQUAKES-Siesmic Design Limit States

- It must be appreciated that the boundaries between different intensities of ground shaking, requiring each of the foregoing three levels of protection to be provided cannot be defined precisely.
- A much larger degree of uncertainty is involved in the recommendations of building codes to determine the intensities of lateral seismic design forces than for any other kind of loading to which a building might be exposed.
- The capacity design process, aims to accommodate this uncertainty.
- To achieve this, structural systems must be conceived which are tolerant to the crudeness in seismological predictions.

Structural Properties-Stiffness



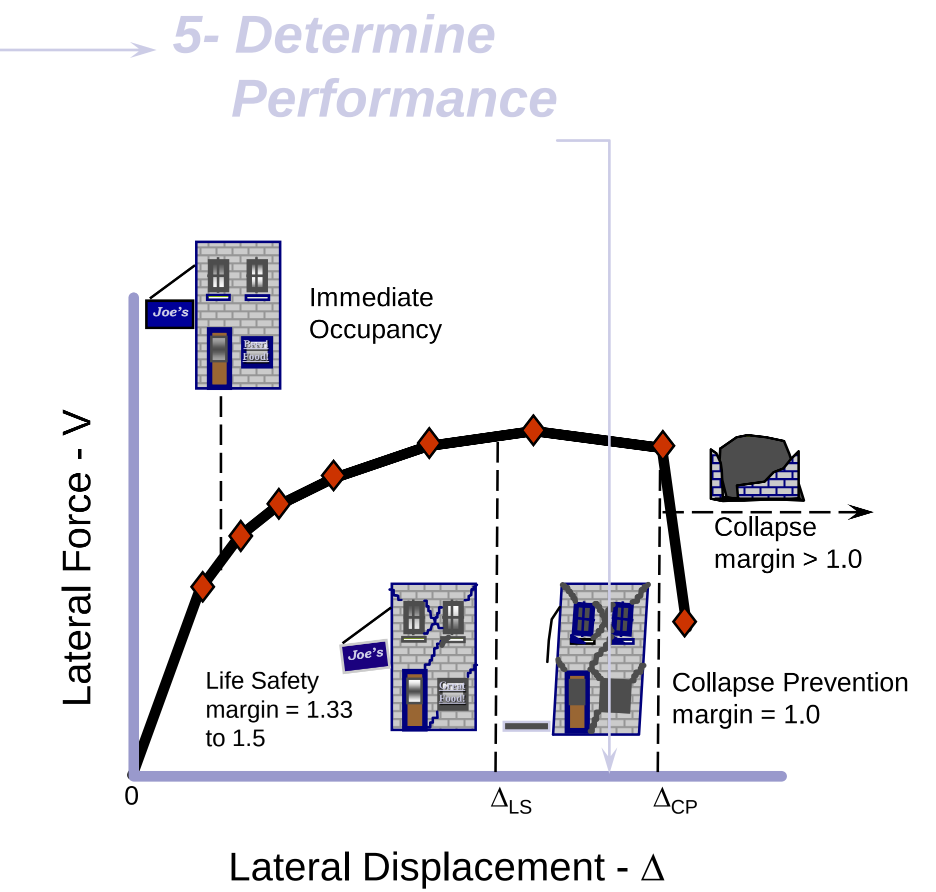
- *Extensive structural and non-structural damage*
- *Extended loss of use*
- *Repair may not be practical*
- *Repair costs >> 30%*

Structural Properties-Stiffness

Collapse Prevention

Structural Properties-Stiffness

- A typical nonlinear relationship between induced forces or loads and displacements, describing the response of a reinforced concrete component subjected to monotonically increasing displacements, is shown in figure.



EARTHQUAKES-Seismic Risk

- As has already been discussed, small earthquakes occur more frequently than large earthquakes.
- They can generate peak ground accelerations of similar magnitudes to those of much larger earthquakes, but over a much smaller area.
- The quantification of seismic risk at a site thus involves assessing the probability of occurrence of ground shaking of a given intensity as a result of the combined effects of frequent moderate earthquakes occurring close to the site, and infrequent larger earthquakes occurring at greater distances.

EARTHQUAKES-Seismic Risk

- Mathematical models based on the probability of occurrence of earthquakes of given magnitude per unit volume, and attenuation relationships can be used to generate site-specific seismic risk, and the relationship between risk, generally expressed in terms of annual probability of exceedance of a given level of peak ground acceleration and that level of peak ground acceleration.
- In general, only one of the three limit states will govern design at a given site, dependent on the seismicity of the region.

EARTHQUAKES-Design limit states

- If we consider a typical design of a ductile frame building,
  - the serviceability limit state might be taken as the onset of yield in beam members,
  - the damage control limit state as that corresponding to a displacement ductility of $\mu = 4$, and survival limit state as $\mu = 8$.
  - Table 2.2 compares risk and resistance for the three levels of seismicity of Fig. 2.16, using these levels of ductility and a relative risk on resistance of 1.0

EARTHQUAKES-Design limit states

- Table compares risk and resistance for the three levels of seismicity of above figure, using these levels of ductility and a relative risk on resistance of 1.0 at p=0.0002
- Resistance is based on the equal-displacement concept of equivalent elastic response.
- By dividing risk by resistance for the three limit states, the highest resulting number identifies the critical state.

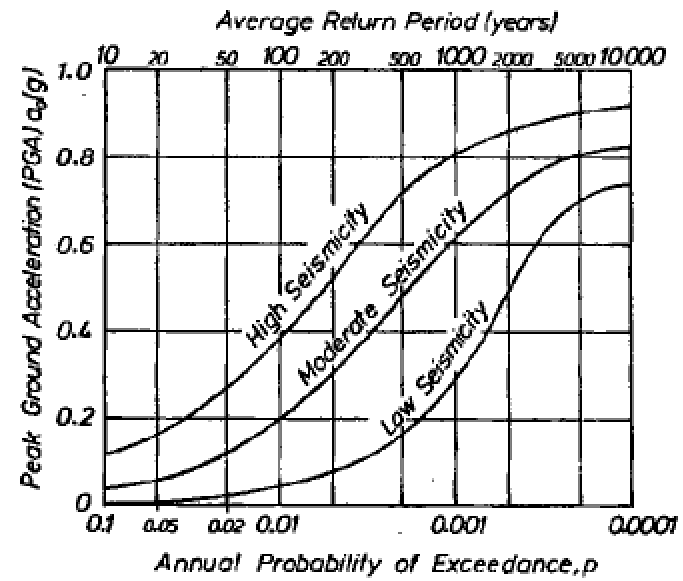


TABLE 2.2 Seismic Risk and Resistance Compared for Different Seismic Regions

Limit State	Annual Probability	Relative Resistance	Relative Risk[a]			Risk/Resistance[a]		
			Hi	Mod.	Low	Hi	Mod.	Low
Serviceability	0.0200	0.125	0.30	0.15	0.03	2.50	1.20	0.25
Damage control	0.0020	0.500	0.80	0.60	0.30	1.60	1.20	0.40
Survival	0.0002	1.000	1.00	1.00	1.00	1.00	1.00	1.00

EARTHQUAKES-Design limit states

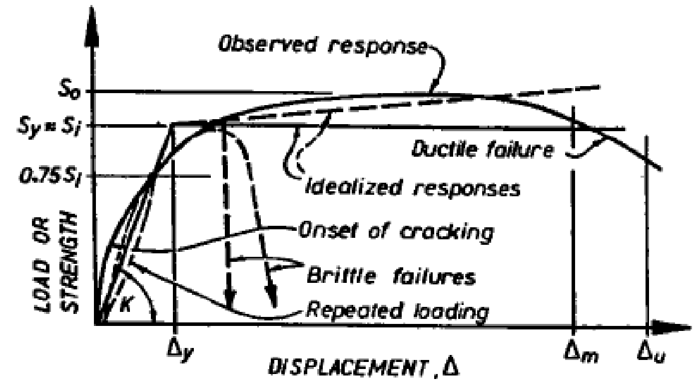
- For moderate seismicity, the risk/resistance ratio is seen to be reasonably uniform, but the damage control limit state appears somewhat more critical.
- For high-seismicity regions, it is clear that the serviceability state is significantly more critical. while for regions of low seismicity, the survival limit state dominates.
- It should be emphasized that the numeric values of previous figure and Table are intended only to indicate trends and are subject to considerable uncertainty. Caution should therefore be exercised in adopting them in practice.

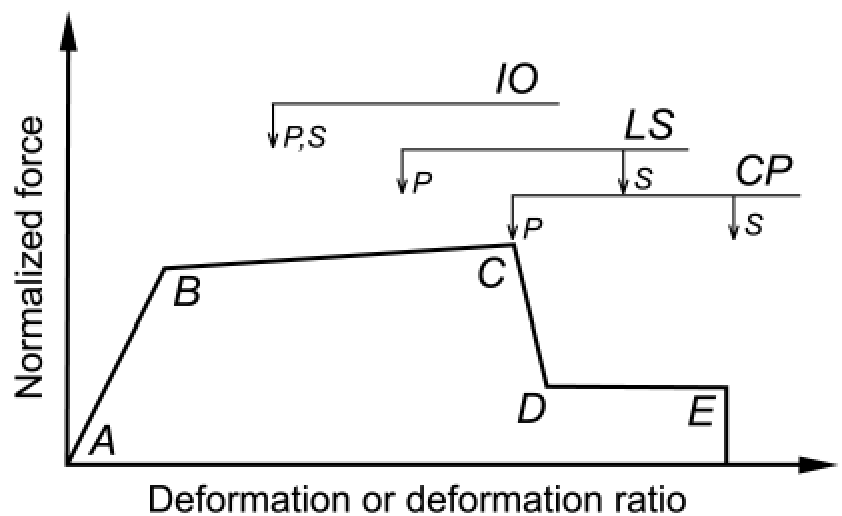
EARTHQUAKES-Economic considerations

- Economic considerations are, of course, another factor influencing the choice of design intensity.
- The extent to which economics become the overriding consideration depends on a number of factors: some quantifiable, other apparently not.
- The main factor that can readily be quantified is the cost of providing a given level of seismic protection, since this is objective.
- The key unquantifiable factor is the value of human life.

Structural Properties-Stiffness

- For purposes of routine design computations, one of the two bilinear approxima- tions may be used, where S_y defines the yield or ideal strength S, of the member. The slope of the idealized linear elastic response, $K = S_y/\Delta_y$, is used to quantify stiffness.

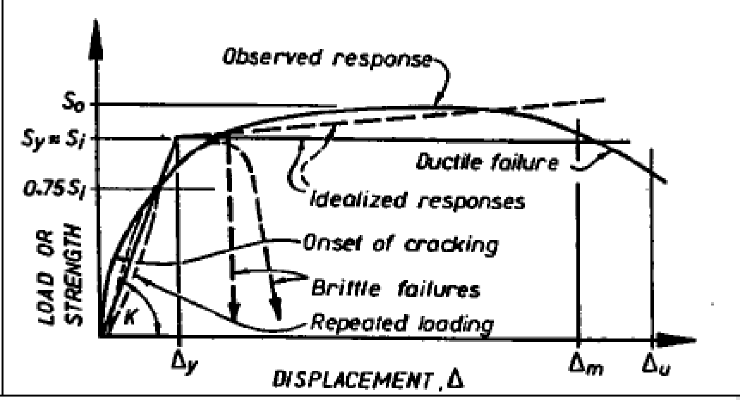


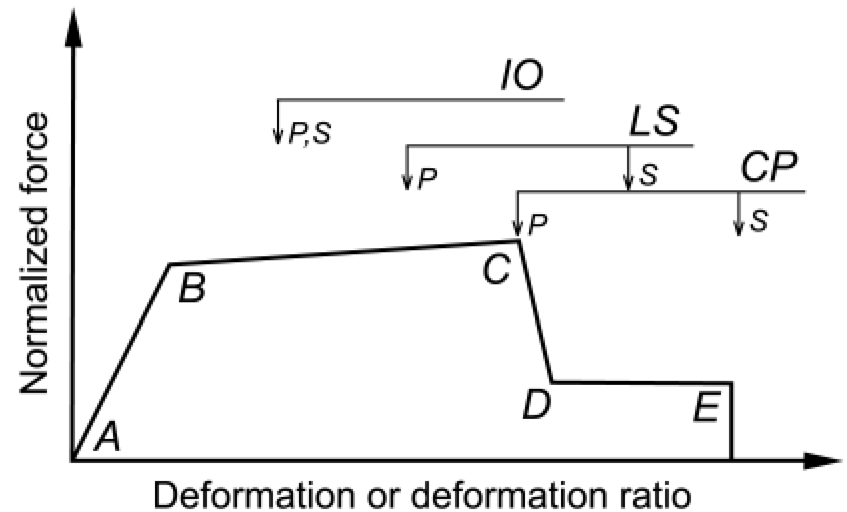


(c) Component or element deformation acceptance criteria

Structural Properties-Stiffness

- This should be based on the effective secant stiffness to the real load-displacement curve at a load of about 0.75S,, as shown in figure, as it is effective stiffness at close to yield strength that will be of concern when estimating response for the serviceability limit state.

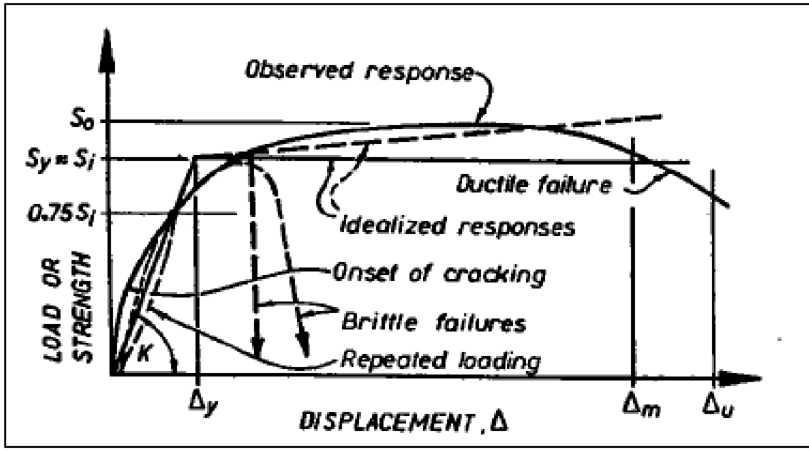




(c) Component or element deformation acceptance criteria

Structural Properties-Stiffness

- Under cyclic loading at high "elastic" response levels, the initial curved load-displacement characteristic will modify to close to the linear relation- ship of the idealized response.
- An early task within the design process will be the checking of typical inter-story deflections (drift), using realistic stiffness values to satisfy local requirements for serviceability.



Structural Properties-Ductility

- **Ductility** To minimize major damage and to ensure the survival of buildings with moderate resistance with respect to lateral forces, structures must be capable of sustaining a high proportion of their initial strength when a major earthquake imposes large deformations.
- These deformations may be well beyond the elastic limit.
- This ability of the structure or its components or of the materials used to offer resistance in the inelastic domain of response, is described by the general term ductility.
- Hence a ductile failure must be contrasted with a brittle failure , represented in figure by dashed curves.

Structural Properties-Ductility

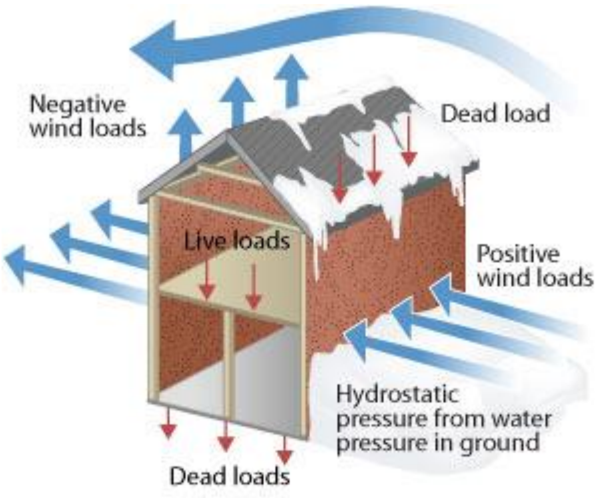
- It includes the ability to sustain large deformations, and a capacity to absorb energy by hysteric.
- For this reason it is the single most important property sought by the designer of buildings located in regions of significant seismicity.
- The limit to ductility, as shown for example in figure by the displacement of Δ_u, typically; corresponds to a specified limit to strength degradation.
- Although attaining this limit is sometimes referred to as failure, significant additional in-elastic deformations still may be possible without structural collapse.

Structural Properties-Brief

- Stiffness and ductility plays important role.
- Ductility of the structure is provided by the detailing of the reinforcement.
- For concrete and Steel structures ductility is defined by “R” value (3.5,5.5 and 8.5)
- Our structures are designed for serviceable limit state but they can perform up to collapse prevention stage provided detailing and construction quality is ensured.
- In spite of detailing and construction quality, the various architectural features also play important role during the performance of building during EQ. which will be discussed in the subsequent slides.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- A review design philosophy is a somewhat excellent term that we use for the fundamental basis of design.
- It covers reasons underlying our choice of design loads, and forces, our analytical techniques and design procedures, our preferences for particular structural configuration and materials, and our aims for economic optimization.
- The importance of a rational design philosophy becomes paramount when seismic considerations dominate design.



Concepts of Seismic Design-Siesmic Design and Seismic Performance

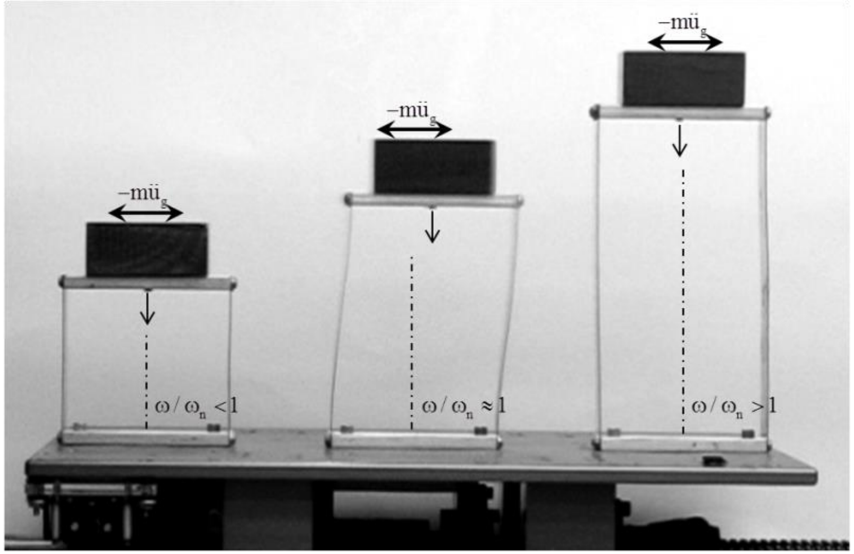
- This is because we typically accept higher risks of damage under seismic design forces than under other comparable extreme loads, such as maximum live load or wind forces.
- For example, modern building codes typically specify an intensity of design earthquakes corresponding to a return period of 100 to 500 years for ordinary structures, such as office buildings.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

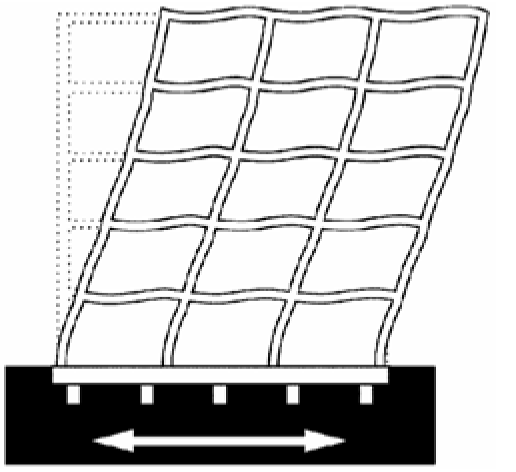
- The annual probability of developing the full strength of the building in seismic response can thus be as high as 1 to 3% .
- It follows that the consequences resulting from the lack of a rational seismic design philosophy are likely to be severe.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- The advent of strength design philosophies, and development of sophisticated computer-based analytical procedures, facilitated a much closer examination of the seismic response of multi-degree-of-freedom structures.
- It was found that previous practices have some serious flaws regarding the response of structure. Like time period , weight of building etc plays important role.



- However, when inelastic deformation resulted in severe reduction in strength, as, for example, often occurs in conjunction with shear failure of concrete or masonry elements, severe damage or collapse was common.
- With increased awareness that excessive strength is not essential or even necessarily desirable, the emphasis in design has shifted from the resistance of large seismic forces to the **"evasion" of these forces**.



Concepts of Seismic Design-Siesmic Design and Seismic Performance

- More recently, then, it has become accepted that seismic design should encourage structural forms that are more likely to possess ductility than those that do not.
- Generally, this relates to aspects of structural regularity and careful choice of the locations, often termed plastic hinges, where inelastic deformations may occur.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- These simple concepts, namely
- (1) **selection of a suitable structural configuration for inelastic response.**
- (2) **selection of suitable and appropriately detailed locations (plastic hinges) for inelastic deformations to be concentrated, and**
- (3) **Assurance, through suitable strength differentials that inelastic deformation does not occur at undesirable locations or by undesirable structural modes.**

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- Despite the increased awareness and understanding of factors influencing the seismic behavior of structures, significant disparity between earthquake engineering theory are reported in various conferences world wide.
- The damage in, and even collapse of, many relatively modern buildings in seismically active regions, shown in next slides.

- Figure illustrates one of the most common causes of failure in earthquakes, the "**soft story**."
- Where one level, typically the lowest, is weaker than upper levels, a column sway mechanism can develop with high local ductility demand.

- In taller' buildings than that depicted in figure, this often results from a functional desire to open the lowest level to the maximum extent possible for retail shopping or parking requirements.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- The figure, also from the July 1990 Philippine's earthquake, shows a confinement ,failure at the base of a First-story column.
- Under ductile response to earthquakes, high compression strains are expected from the combined effects of axial force and bending moment.

- Unless adequate, closely spaced, well-detailed transverse reinforcement is placed in the potential plastic hinge region, spalling of concrete followed by instability of the compression reinforcement will follow.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

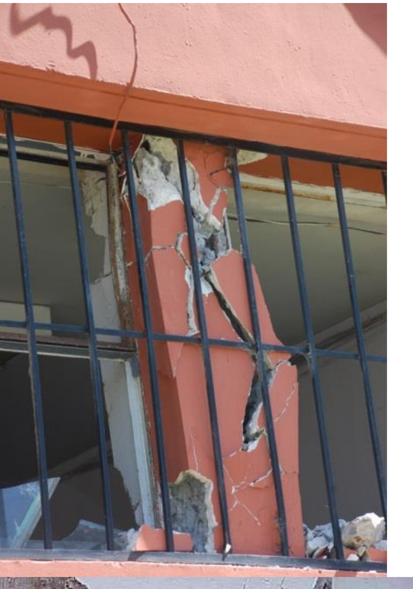
- In the example there is clearly inadequate transverse reinforcement to confine the core concrete and restrain the bundled flexural reinforcement against buckling.
- It must be recognized that even with a weak beam/strong column design philosophy which seeks to dissipate seismic energy primarily in well confined beam plastic hinges, a column plastic hinge must still form at the base of the column.
- Many structures have collapse as a result of inadequate confinement of this hinge.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- The shear failure of a column of a building in the 1985 Chilean earth- quake, shown in figure demonstrates the consequences of ignoring the stiffening effects of so-called nonstructural partial height masonry or concrete infill built hard up against the column.
- The column is stiffened in comparison with other columns at the same level, which may not have adjacent infill (e.g,, interior columns) attracting high shears to the shorter columns, often with disastrous effects.

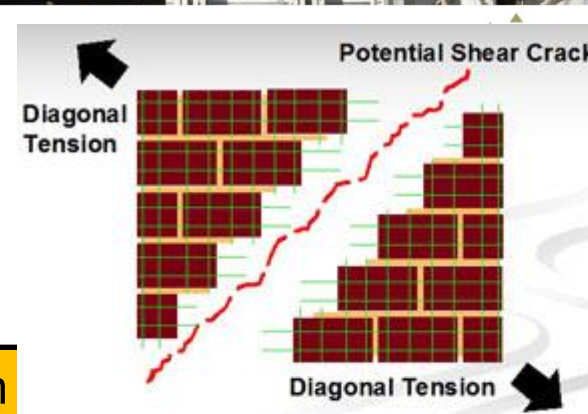
Concepts of Seismic Design-Siesmic Design and Seismic Performance

- This common structural defect can easily be avoided by providing adequate separation between the column and infill for the column to deform freely during seismic response without restraint from the infill.
- Unless adequately designed for the levels of flexural ductility, and shear force expected under strong ground shaking, flexural or shear failures may develop in structural walls forming the primary lateral force resistance of buildings.



Concepts of Seismic Design-Siesmic Design and Seismic Performance

- Spandrel beams coupling structural walls are often subjected to high ductility demands and high shear forces as a consequence of their short length.
- It is very difficult to avoid excessive strength degradation in such elements, as shown in the figure.



- The figure shows another common failure resulting from nonstructural masonry in fills in a R.C concrete frame.
- The stiffening effect of the wall attracts higher seismic forces to the in filled frame resulting in shear failure of followed by damage or failure to the columns.
- As with the partial height infill of shown in figure ,the effect of the nonstructural infill is to modify the lateral force resistance in a way not anticipated by the design.

- The final example shown in figure represents the failure of a beam-column connection in a reinforced concrete frame.
- The joint was not intended to become the weak link between the four components.
- Such elements are usually subjected to very high shear forces during seismic activity, and if inadequately reinforced, result in excessive loss in strength and stiffness of the frame, and even collapse.

- While there is something new to be learned from each earthquake, it may be said that the majority of structural lessons should have been learned.
- Patterns in observed earthquake damage have been identified and reported for some time.
- Yet many conceptual, design, and construction mistakes, that are responsible for structural damage in buildings are being repeated.
- Many of these originate from traditional building configurations and construction practices.
- There is still widespread lack of appreciation of the predictable and quantifiable effects of earthquakes on buildings and the impact of seismic phenomena on the philosophy of structural design.

Concepts of Seismic Design-Siesmic Design and Seismic Performance

- Although many designers prefer to assess earthquake-induced structural actions in terms of static equivalent loads or forces.
- It must be appreciated that actual seismic response is dynamic and related primarily to imposed deformation rather than forces.
- To accommodate large seismically induced deformations, most structures need to be ductile.
- Thus in the design of structures for earthquake resistance, it is preferable to consider forces generated by earthquake induced displacements rather than traditional loads.