Earthquakes Resistant Design

EARTHQUAKE RESISTANT DESIGN

- Severity of ground shaking at a given location during an earthquake can be *minor, moderate and strong.*

a. Minor *(and frequent) shaking with no damage to structural and non-structural elements.*

b. Moderate *shaking with minor damage to structural elements, and some damage to non-structural* elements.

c. Severe *(and infrequent) shaking with damage to structural elements, but with NO collapse (to save* life and property inside/adjoining the building).

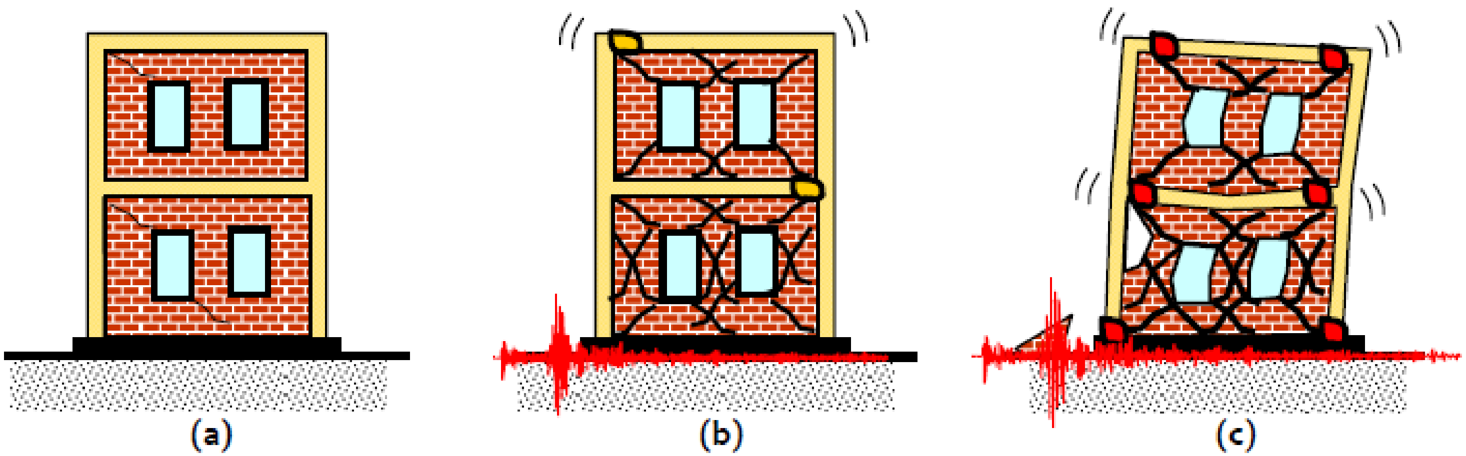


Figure: *Earthquake-Resistant Design Philosophy for buildings*: (a) *Minor (Frequent) Shaking* – No/Hardly any damage, (b) *Moderate Shaking – Minor structural damage, and some non-structural damage,* and (c) *Severe (Infrequent) Shaking* – Structural damage, but NO collapse

EARTHQUAKE RESISTANT DESIGN

- The principal cause of earthquake-induced damage is ground shaking.
- Seismic design loads are extremely difficult to determine due to the random nature of earthquake motions. However, experiences from past strong earthquakes have shown that *reasonable and prudent practices can keep a building safe during an earthquake*.
- Experience in past earthquakes has demonstrated that many common buildings and typical methods of construction lack basic resistance to earthquake forces.
- In most cases this resistance can be achieved by following simple inexpensive principles of good building construction practices .
- These simple rules will not prevent all damage in moderate or large earthquakes, but *life threatening collapses will be prevented, and damage limited to repairable proportions.*

EARTHQUAKE RESISTANT DESIGN

- Severity of ground shaking at a given location during an earthquake can be *minor, moderate and strong.*

- It costs money to provide additional earthquake safety in buildings, a conflict arises:

  Should we do away with the design of buildings for earthquake effects? Or should we design the buildings to be "earthquake proof" wherein there is no damage during the strong but rare earthquake shaking?

- Clearly, the former approach can lead to a major disaster, and the second approach is too expensive. Hence, the ***design philosophy should lie somewhere in between these two extremes***

EARTHQUAKE RESISTANT DESIGN

- Buildings are designed only for a fraction of the force but, sufficient initial stiffness is required to be ensured to avoid structural damage under minor shaking.

- The seismic design balances reduced cost and acceptable damage, to make the project viable.

- This careful balance is arrived based on extensive research and detailed post-earthquake damage assessment studies.

- A wealth of this information is translated into precise seismic design provisions.

- For this reason, design against earthquake effects is called as ***earthquake-resistant design and not earthquake-proof design.***

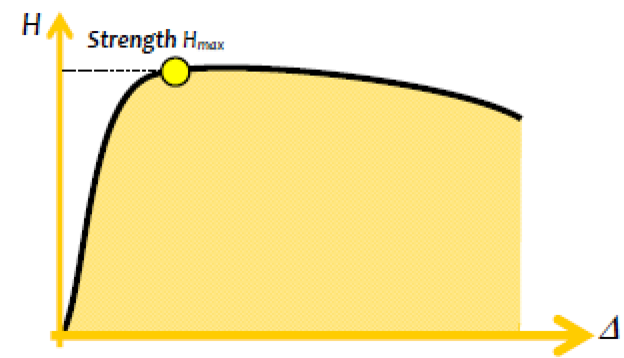
EARTHQUAKE RESISTANT DESIGN

Structural Stiffness, Strength and Ductility

Lateral stiffness refers to the initial stiffness of the building, even though stiffness of the building reduces with increasing damage.

(a)

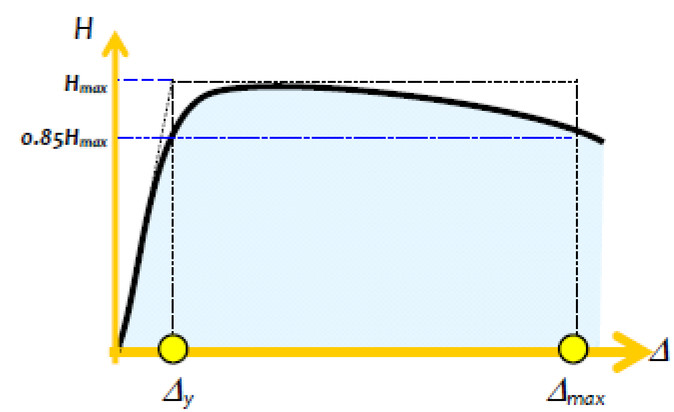
***Lateral strength** refers to the maximum resistance that the* building offers during its entire history of resistance to relative deformation.



(b)

***Ductility** towards* lateral deformation refers the ratio of the maximum deformation and the idealised yield deformation..

$$Ductility = \frac{\Delta_{max}}{\Delta_y}$$

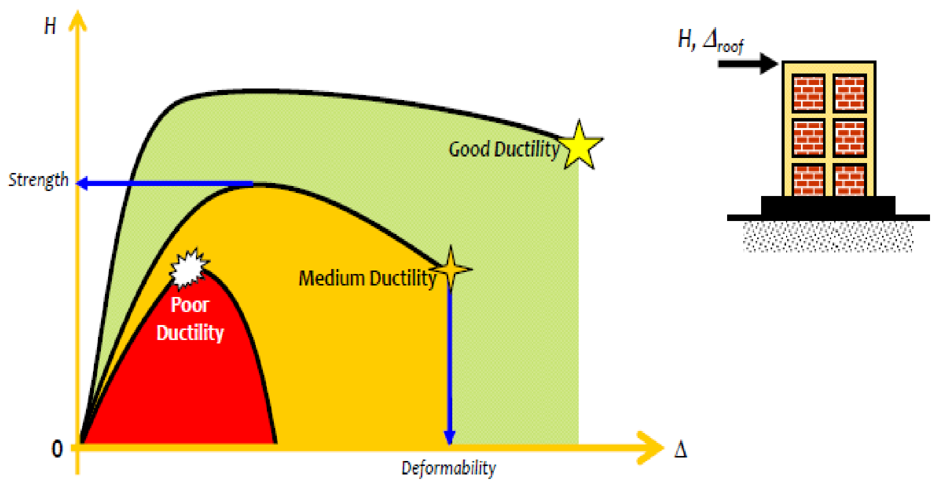


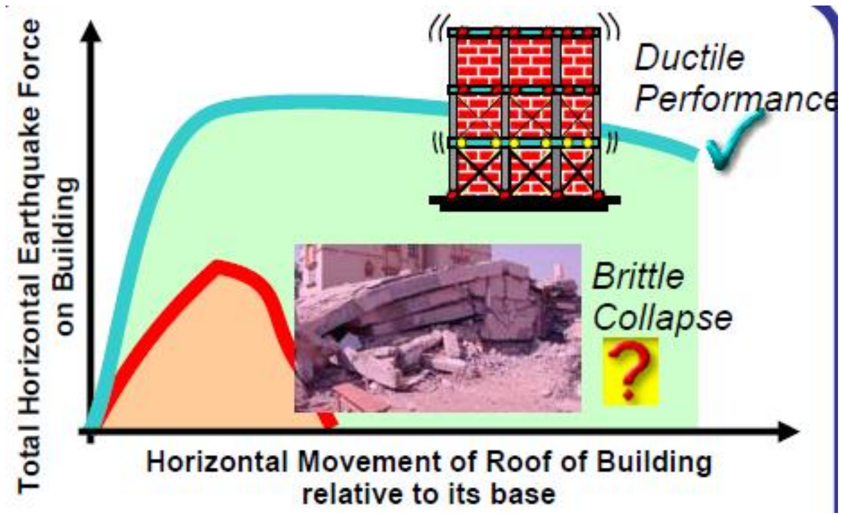
(c)

EARTHQUAKE RESISTANT DESIGN

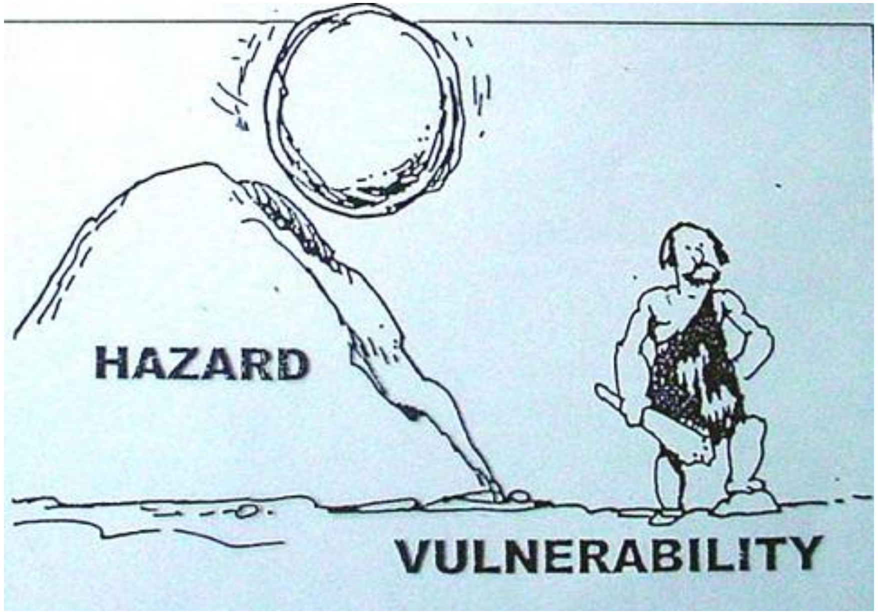
Ductility

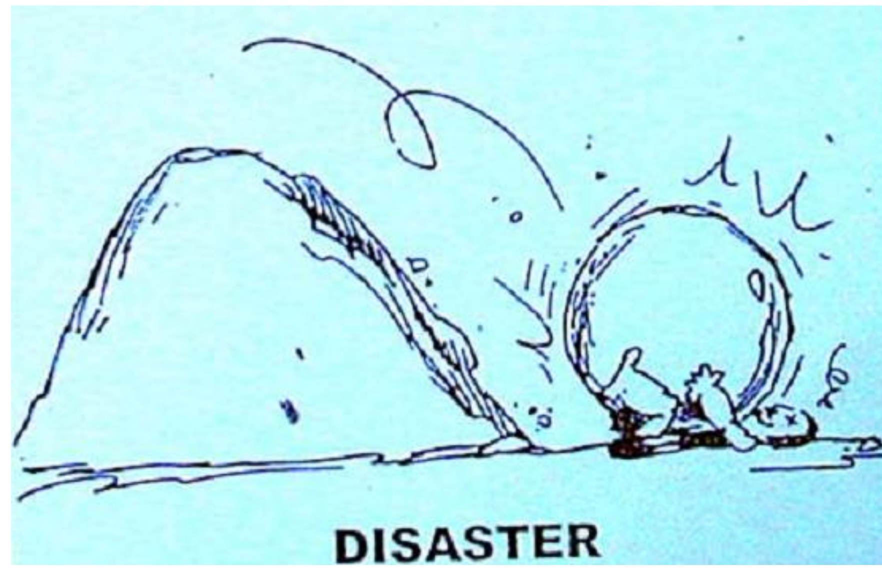
The design for a fraction of the elastic level of seismic forces is possible, only if the building can stably withstand large displacement demand through structural damage without collapse and undue loss of strength. This property is called ductility.





Hazard, vulnerability & disaster





Disaster = F (Hazard, Vulnerability)

Ingredients of Risk

H x V - C = R

Hazard x vulnerability – capacity = risk

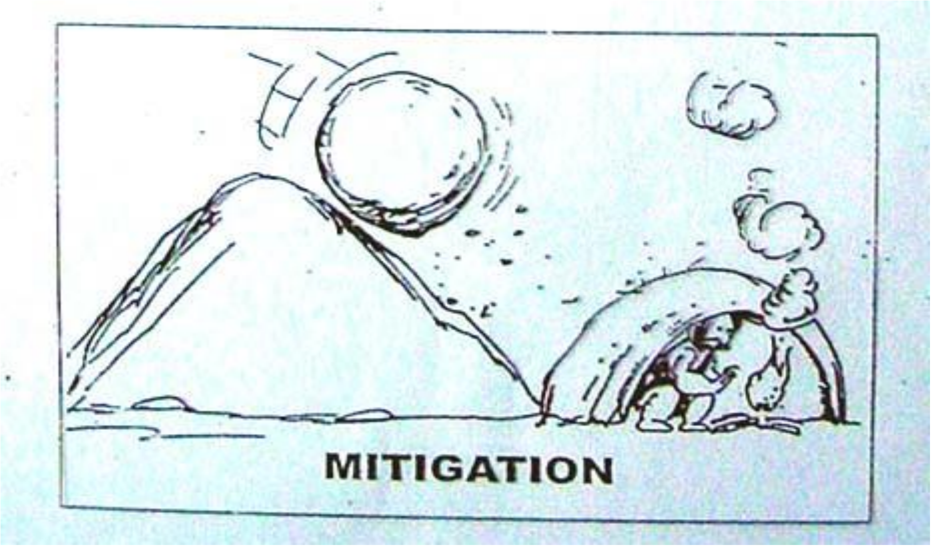
H - potential threat to humans and their welfare
V - exposure and susceptibility to loss of life or dignity
C - available and potential resources
R - probability of disaster occurrence

Capacity - *"resources, means and strengths which exist in households and communities and which enable them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster"*

Disaster Prevention, Mitigation & preparedness

- Prevention requires the elimination of risk while mitigation is the reduction of risk..

- Disaster Preparedness : Forecast and take precautionary measures in advance of an imminent threat.

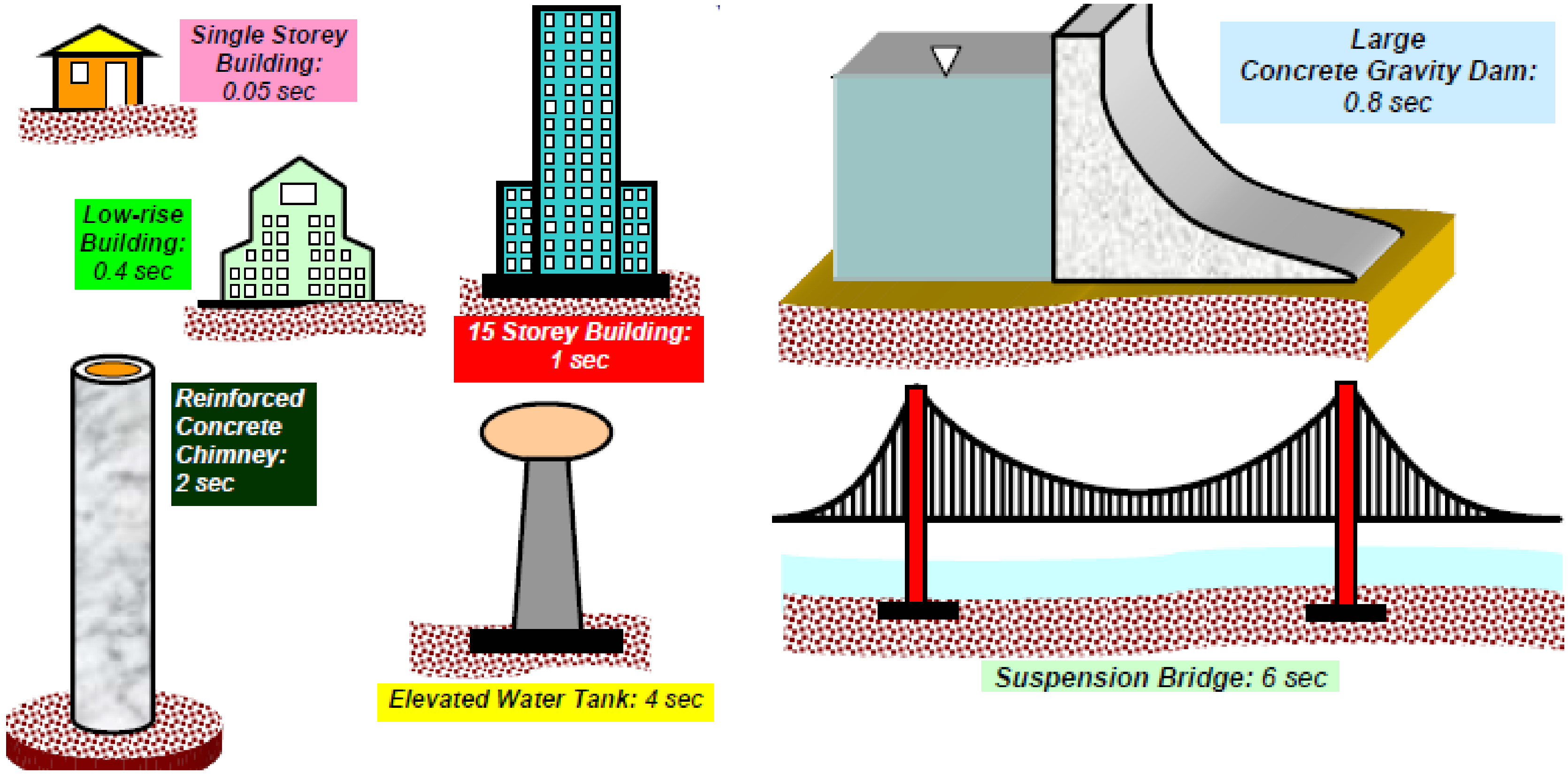


Disaster Preparedness, Mitigation and Response

Earthquake Do Not Kill People

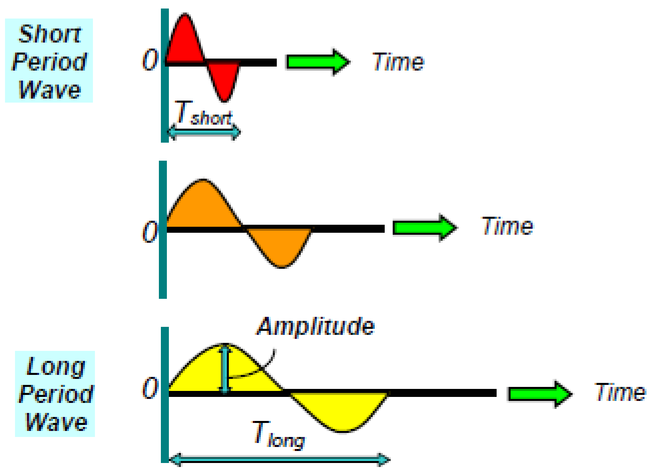
Improperly Designed Structures Do!

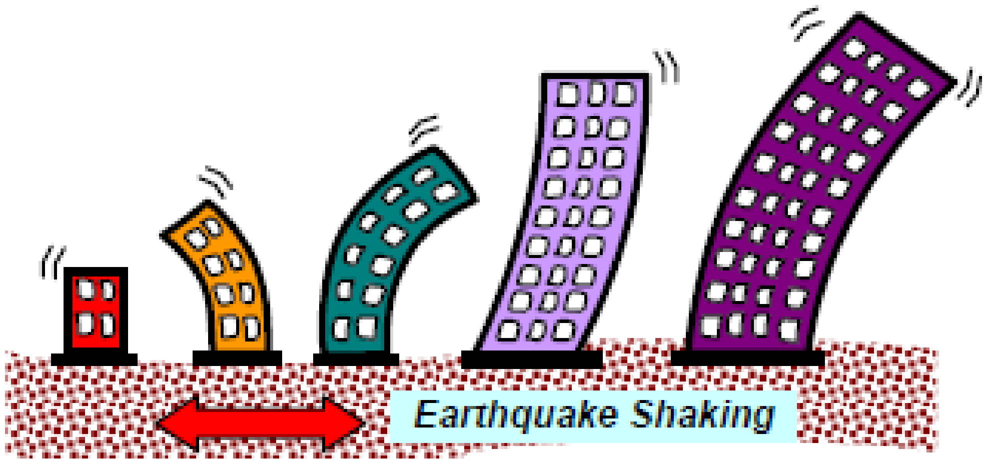
Response of the Different Time period Building to Earthquakes



Fundamental natural period *T is an inherent* property of a building. Any alterations made to the building will change its *T. Fundamental natural* periods *T of normal single storey to 20 storey* buildings are usually in the range *0.05-2.00 sec. Some* examples of natural periods of different structures are shown in Figure.

Response of the Different Time period Building to Earthquakes





- In general, earthquake shaking of the ground has waves whose periods vary in the range *0.03-33sec. Even within this range, some earthquake* waves are stronger than the others.

- Depending on the value of *T of* the buildings and on the characteristics of earthquake ground motion (*i.e., the periods and amplitude of the* earthquake waves), some buildings will be shaken more than the others.

Basic principles of Earthquake Resistant Design

Principle 1: The architect and the engineer collaborate from the outset!

1/2

Wrong:

«Serial-design»

1. Architect: Conceptual design of structure and non-structural elements
2. Engineer: Calculations…

1. Structure for gravity loads
2. Non-structural elements
3. Structure for seismic action

Much better and more economical:

«Parallell-design»

- The architect and engineer collaborate
- General purpose structure and non-structural elements

«Serial-design» is particularly *bad and inefficient.*

It is not at all efficient that the architect performs the conceptual design and selects the types and materials of the non-structural partition walls and façade elements before entrusting the engineer with the calculations and detailed design of the structure.

It is also wrong to consider seismic loading only after completing the gravity load design and selecting the non-structural elements. By then the structure can only be «fixed» for earthquakes. This will often result in an expensive and unsatisfactory design.

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- The architect and engineer collaborate
- General purpose structure and non-structural elements

A **«parallel-design»** is much better and usually substantially more economical. The architect and the engineer design together and, taking into account the relevant aesthetic and functional requirements, *develop a safe, efficient, and economical «general-purpose» structure for gravity loads and seismic action.*

This collaboration cannot wait for the calculation and detailed design stage, but must start at the earliest conceptual design stage when choices are made that are crucial for the seismic resistance and vulnerability of the building.

Basic principles of Earthquake Resistant Design

Principle 2: Follow the seismic provisions of the codes

Internationally harmonized standards:

ISO 3010
International Building Code (IBC)
Uniform Building Code (UBC)
Eurocode 8

National standards:

SIA 261 (Switzerland)
IS 1893 (India)
DIN 4149 (Germany)
PS 92 (France)
....

Follow the seismic provisions of the codes!

The ignorance or disregard of the seismic provisions of the building codes, even if only partial, can result in an inferior building.

The building owner, the architect, the engineer, and the authorities therefore have a vested interest in ensuring that the seismic provisions of the building codes are strictly enforced, and that appropriate structural calculations and verifications are kept with the construction documents.

Basic principles of Earthquake Resistant Design

Principle 3: Architectural Features Affect Buildings During Earthquakes

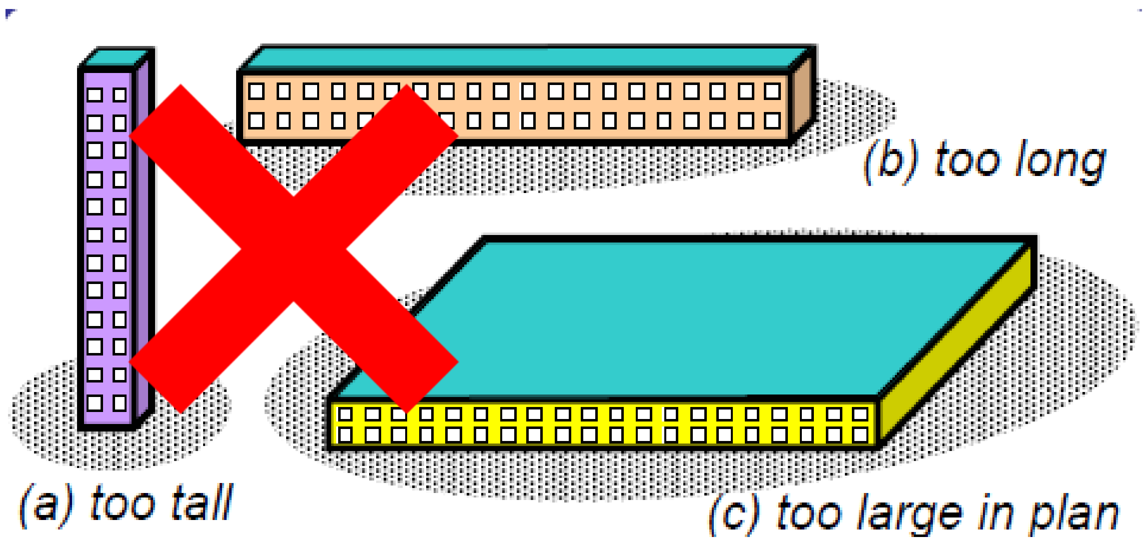
The behaviour of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavorable features are avoided and a ***good building configuration is chosen.***

The importance of the configuration of a building was aptly summarized by Late Henry, a noted Earthquake Engineer of USA, as:

"If we have a poor configuration to start with, all the engineer can do is to provide a band-aid - improve a basically poor solution as best as he can. Conversely, if we start-off with a good configuration and reasonable framing system, even a poor engineer cannot harm its ultimate performance too much."

Basic principles of Earthquake Resistant Design

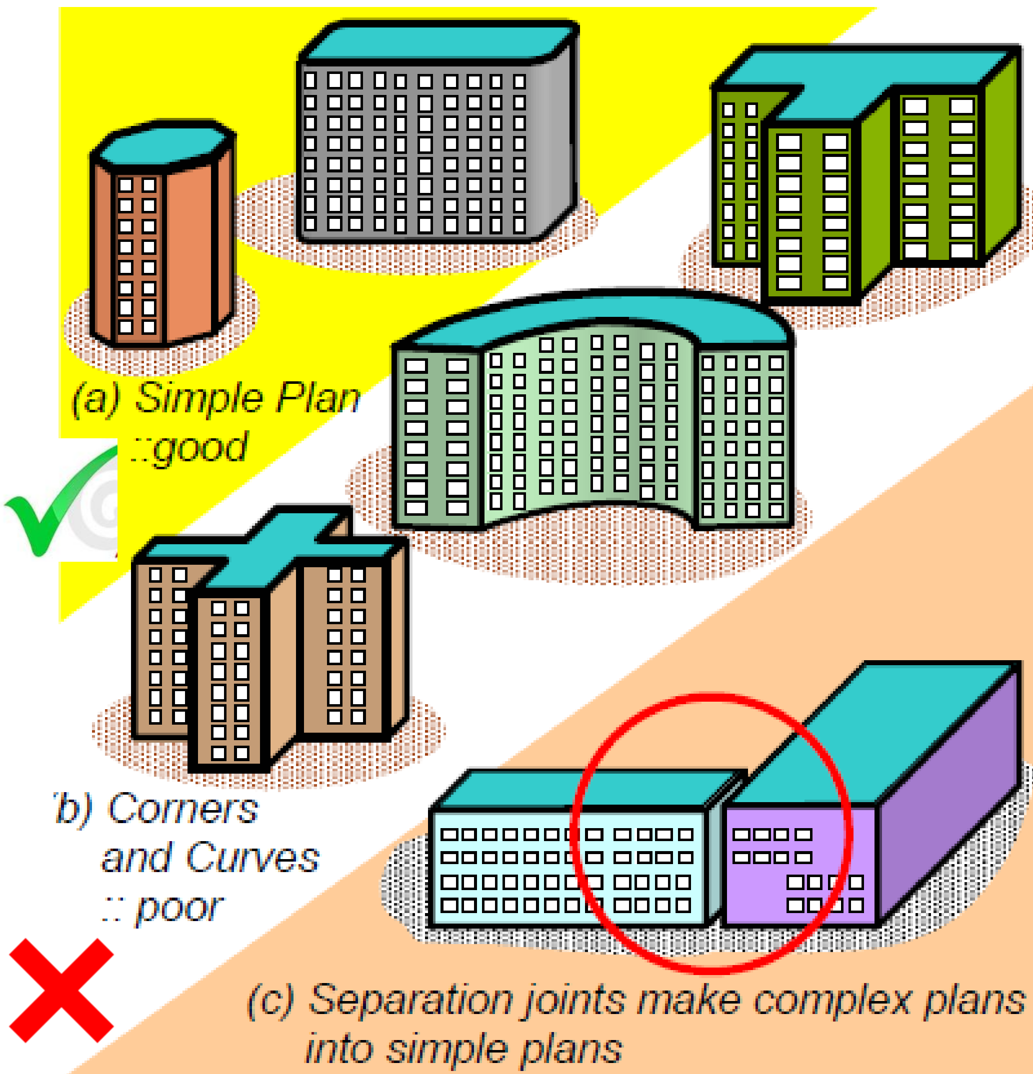
Principle 3: Architectural Features Affect Buildings During Earthquakes



- In tall buildings with large height-to-base size ratio (Fig. a), the horizontal movement of the floors during ground shaking is large.
- In short but very long buildings (Fig. b), the damaging effects during earthquake shaking are many.
- In buildings with large plan area like warehouses (Fig.c), the horizontal seismic forces can be excessive to be carried by columns and walls.

Basic principles of Earthquake Resistant Design

Principle 3: Architectural Features Affect Buildings During Earthquakes



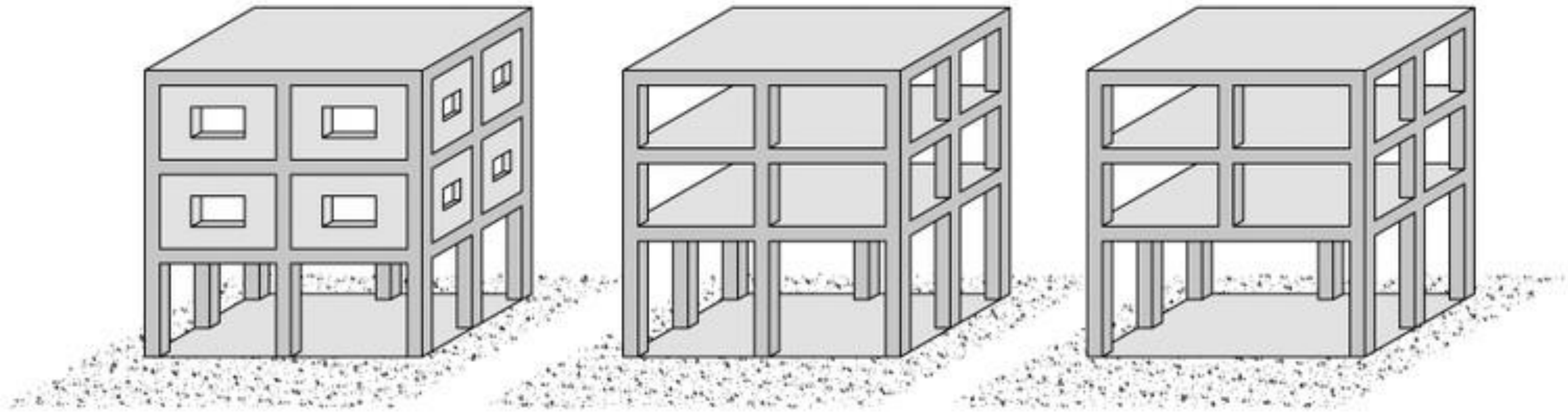
In general, buildings with simple geometry in plan performed well during strong earthquakes.

Buildings with re-entrant corners, like those U, V, H and + shaped in plan have sustained significant damage.

Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. For example, an L-shaped plan can be broken up into two rectangular plan shapes using a separation joint at the junction

Basic principles of Earthquake Resistant Design

Principle 4: Avoid soft-storey ground floors



(a) Stiff and strong upper floors due to masonry infills

(b) The columns in one storey longer than those above

(c) Soft storey caused by discontinuous column

One storey is higher than others, or one storey is weaker than others.

1. A soft or weak storey exists if the height of that storey is at least 15% greater than storeys above or below; or
2. if it has at least 30% fewer columns in the case of a frame system, or
3. at least 30% less full-height structural or infill wall length in the case of a wall or infill wall system, or
4. storey has 30% less lateral stiffness or strength.

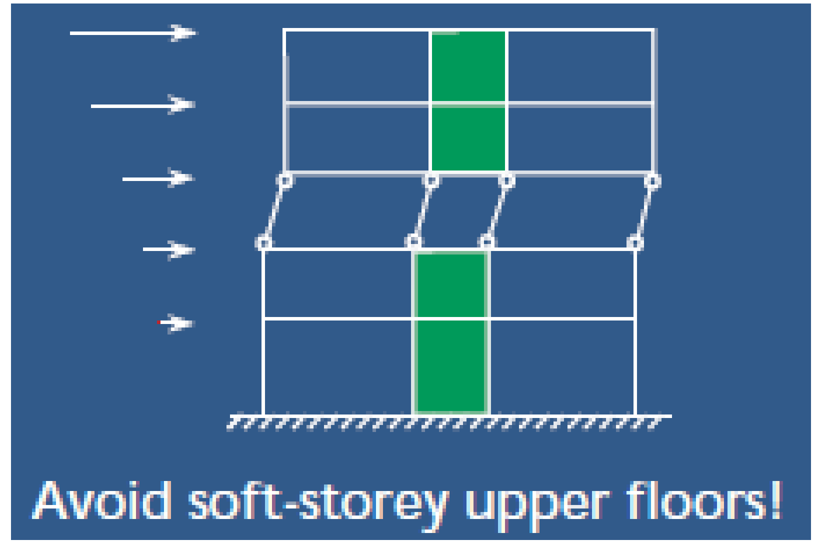
This irregularity is often found in buildings where open first (ground) storey is used to make space for parking, shops, or offices

Basic principles of Earthquake Resistant Design

Principle 4: **Avoid soft-storey ground floors**

Basic principles of Earthquake Resistant Design

Principle 5: Avoid soft-storey upper floors!



An upper storey can also be soft in comparison to the others if the lateral bracing is weakened or omitted, or if the horizontal resistance is strongly reduced above a certain floor. The consequence may again be a dangerous sway mechanism

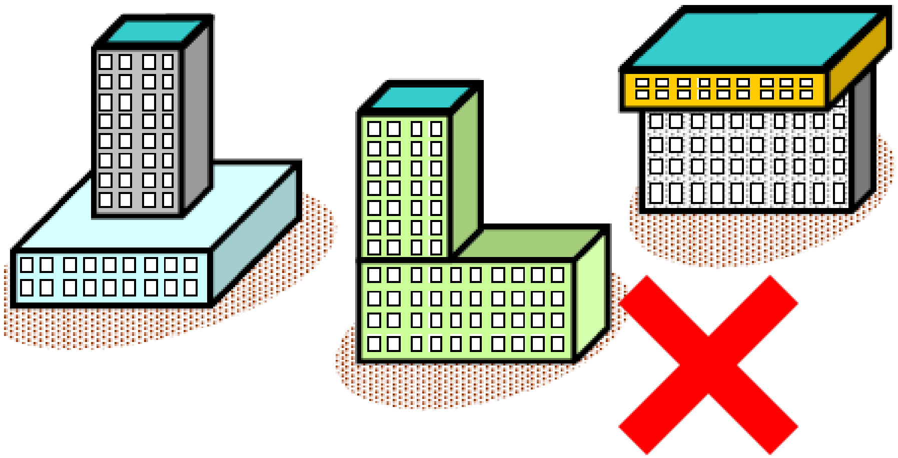
Basic principles of Earthquake Resistant Design

Principle 5: Avoid soft-storey upper floors!

Collapsed soft-storey at upper floor

Basic principles of Earthquake Resistant Design

Principle 6: Avoid vertical setbacks

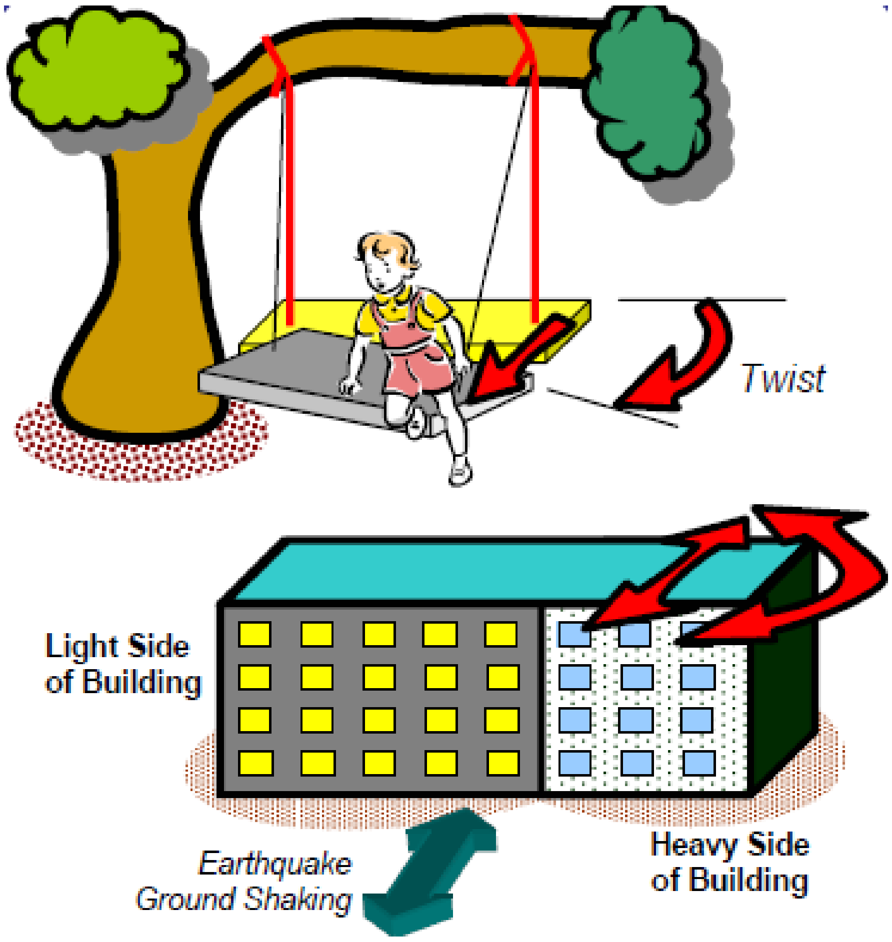


The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building.

Buildings with vertical setbacks (like the hotel buildings with a few storey wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity

Basic principles of Earthquake Resistant Design

Principle 7: Avoid Twisting of the Building During Earthquakes

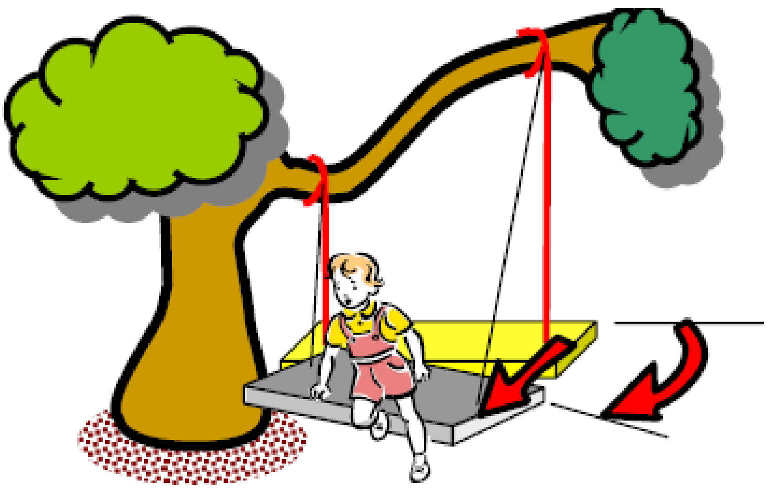


If the mass on the floor of a building is more on one side (for instance, one side of a building may have a storage or a library), then that side of the building moves more under ground movement. This building moves such that its floors displace horizontally as well as rotate.

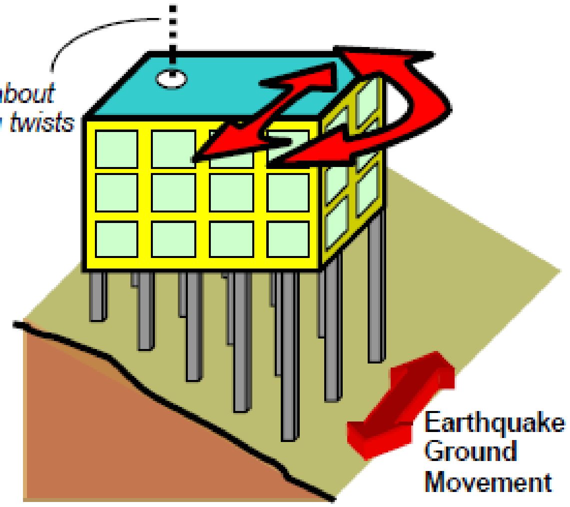
Even if vertical members are placed uniformly in plan of building, more mass on one side causes the floors to twist.

Basic principles of Earthquake Resistant Design

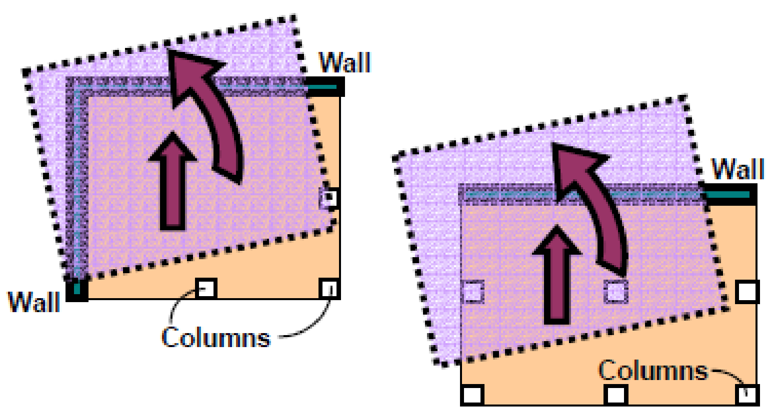
Principle 7: Avoid Twisting of the Building During Earthquakes



(a) Swing with unequal ropes



(b) Building on slopy ground

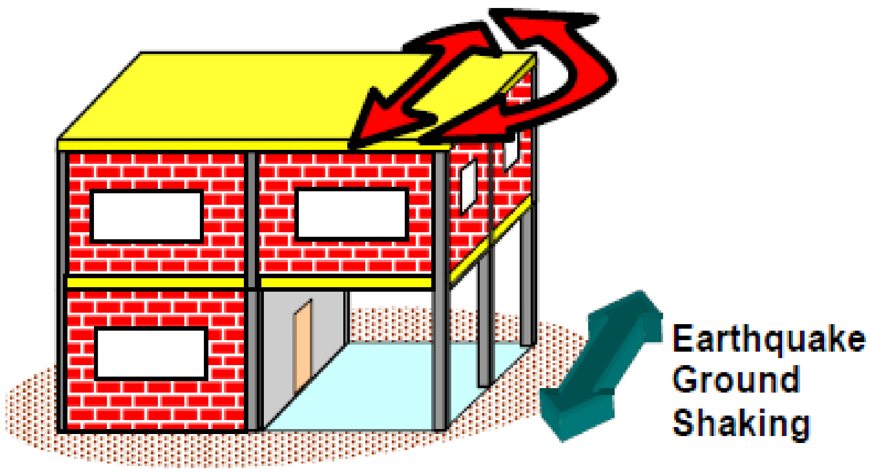


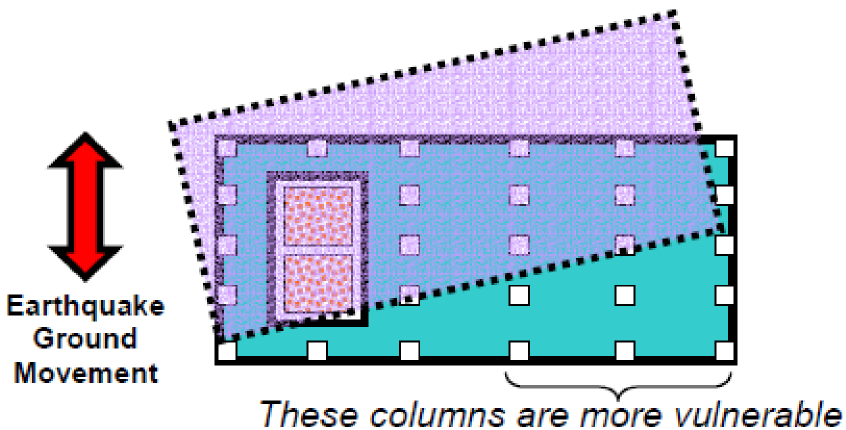
(c) Buildings with walls on two/one sides (in plan)

- In Buildings with unequal vertical members (i.e., columns and/or walls), the floors twist about a vertical axis (Fig. b) and displace horizontally.
- Likewise, buildings, which have walls only on two sides (or one side) and thin columns along the other, twist when shaken at the ground level (Fig. c).

Basic principles of Earthquake Resistant Design

Principle 7: Avoid Twisting of the Building During Earthquakes



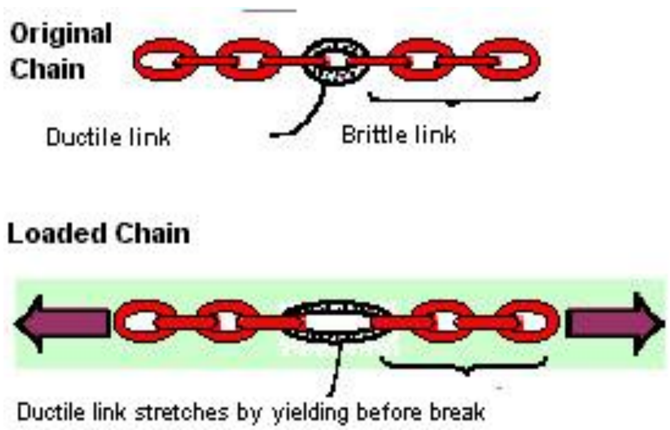


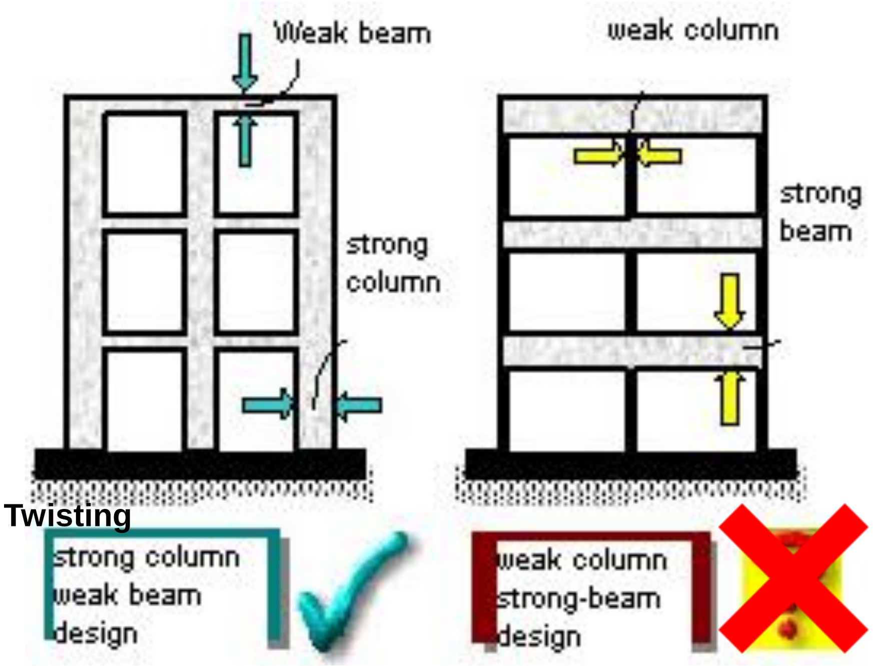
- **Buildings that are irregular shapes in plan tend to twist under earthquake shaking. For example, in a propped overhanging building, the overhanging portion swings on the relatively slender columns under it. The floors twist and displace horizontally.**

- **Twist in buildings, called *torsion by engineers,* makes different portions at the same floor level to move horizontally by different amounts. This induces more damage in the columns and walls on the side that moves more. Many buildings have been severely affected by this excessive torsional behaviour during past earthquakes. <u>It is best to minimize (if not completely avoid) this twist by ensuring that buildings have symmetry in plan (*i.e., uniformly distributed* mass and uniformly placed vertical members).</u>**

Basic principles of Earthquake Resistant Design

Principle 8: Use Strong Column weak beam concept

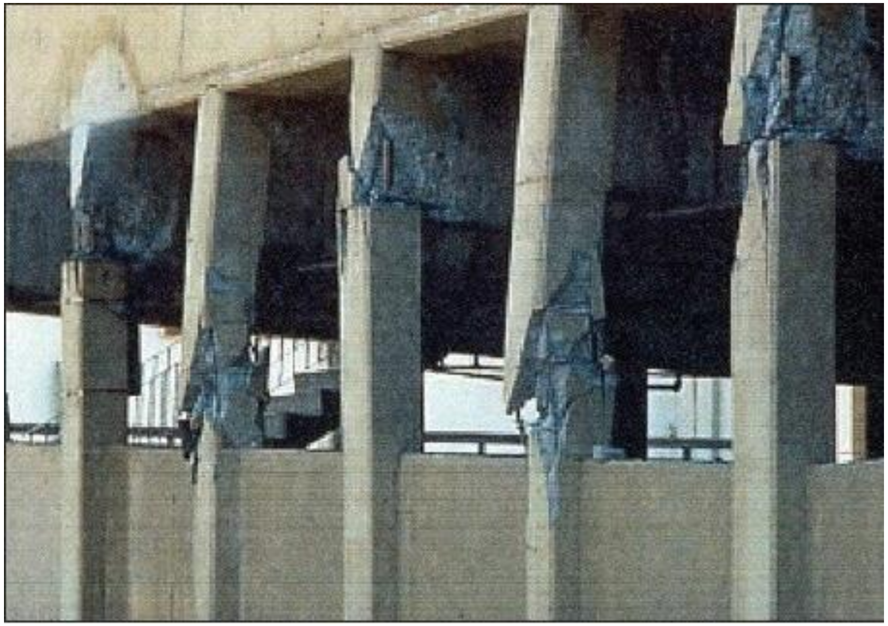




- Buildings should be designed like the ductile chain. For example, consider the common urban residential apartment construction - the multi-storey building made of reinforced concrete. It consists of horizontal and vertical members, namely *beams* and *columns*. The seismic inertia forces generated at its floor levels are transferred through the various *beams* and *columns* to the ground.

Basic principles of Earthquake Resistant Design

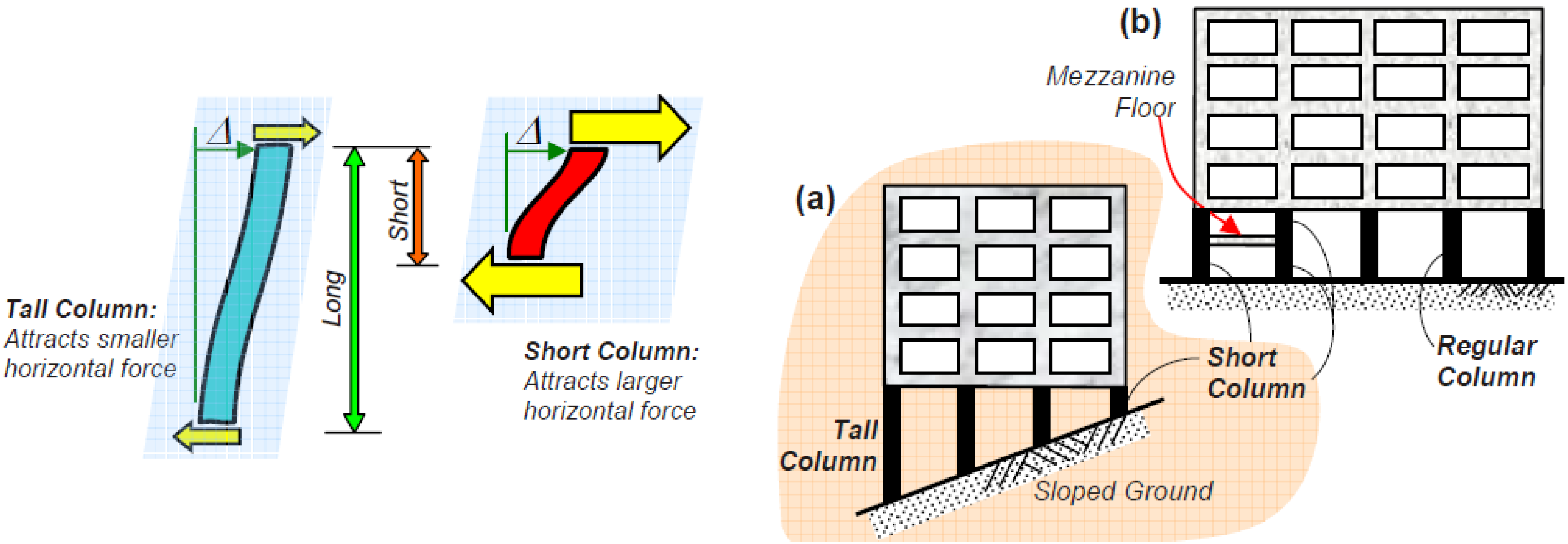
Principle 8: Use Strong Column weak beam concept



- The correct building components need to be made ductile. **The failure of a column can affect the stability of the whole building,** but the failure of a beam causes localized effect. **Therefore, it is better to make *beams* to be the ductile weak links than *columns*.**

Basic principles of Earthquake Resistant Design

Principle 8: Avoid short columns!

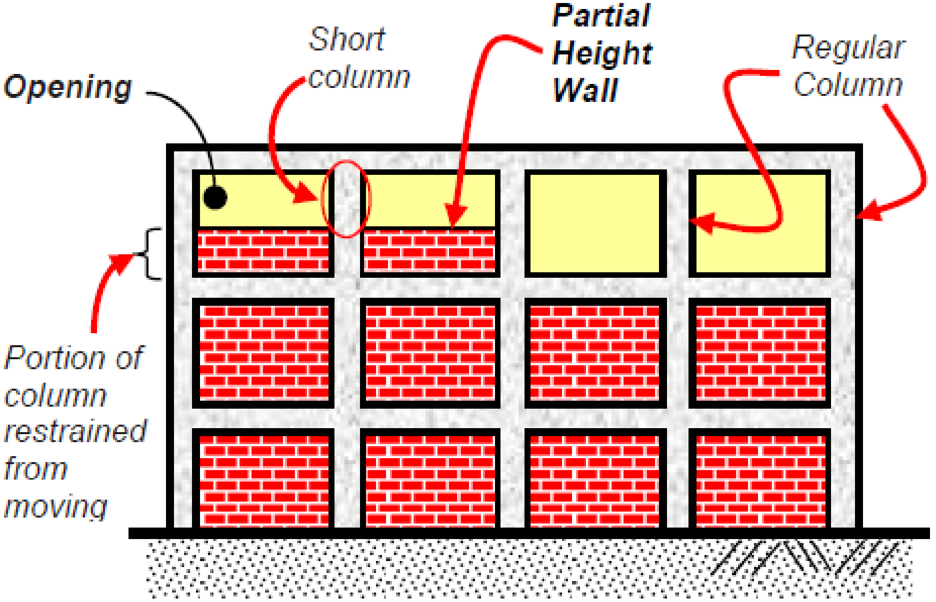


- **Poor behaviour of short columns is due to the fact that in an earthquake, a tall column and a short column of same cross-section move horizontally by same amount Δ. However, the short column is stiffer as compared to the tall column, and it attracts larger earthquake force.**

- **If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behaviour is called *Short Column Effect.***

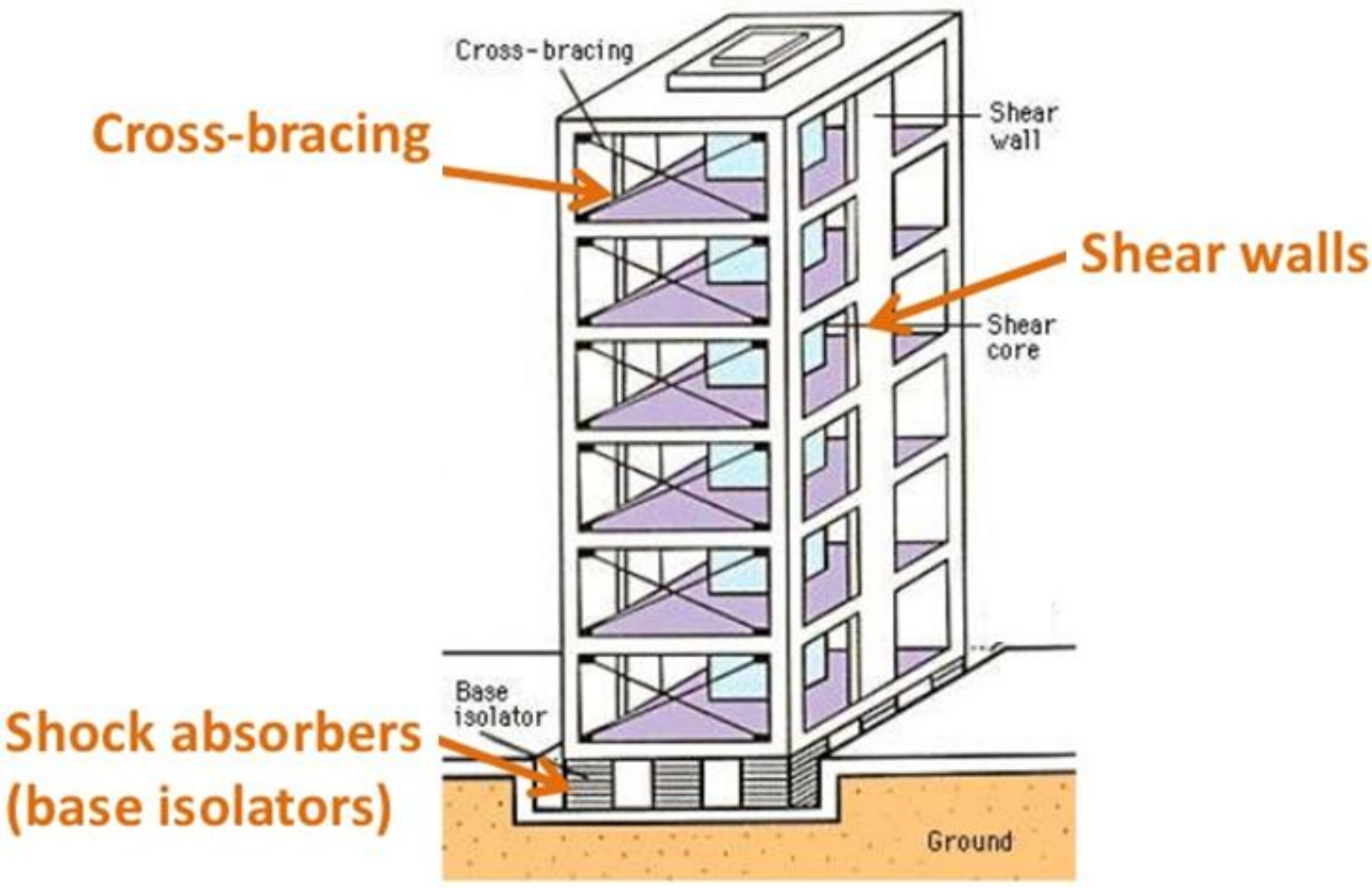
Basic principles of Earthquake Resistant Design

Principle 8: Avoid short columns!

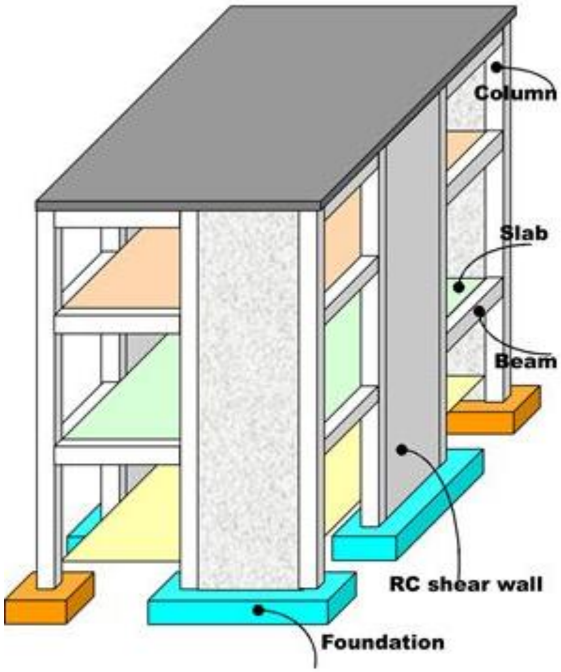


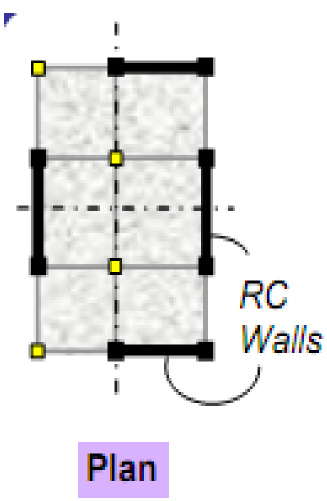
Unsupported height

Techniques to Resist Earthquake



Shear Walls



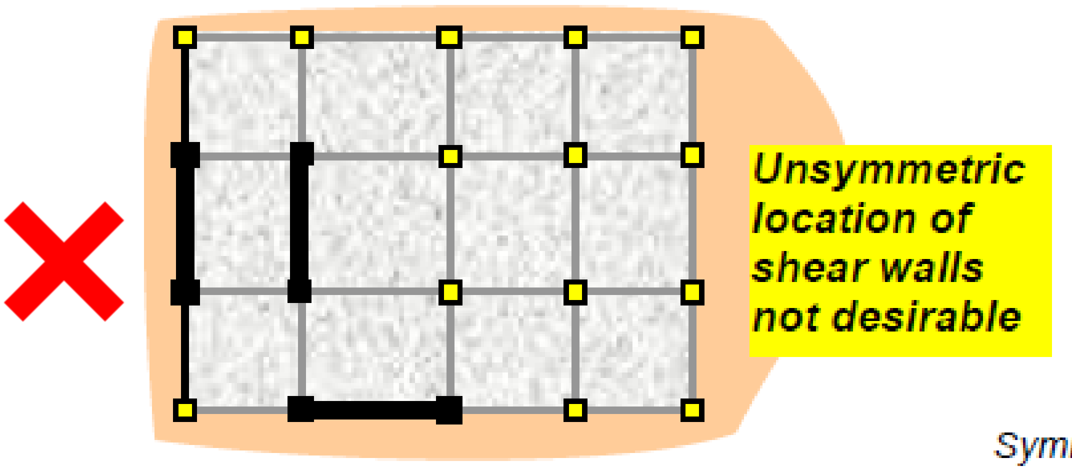


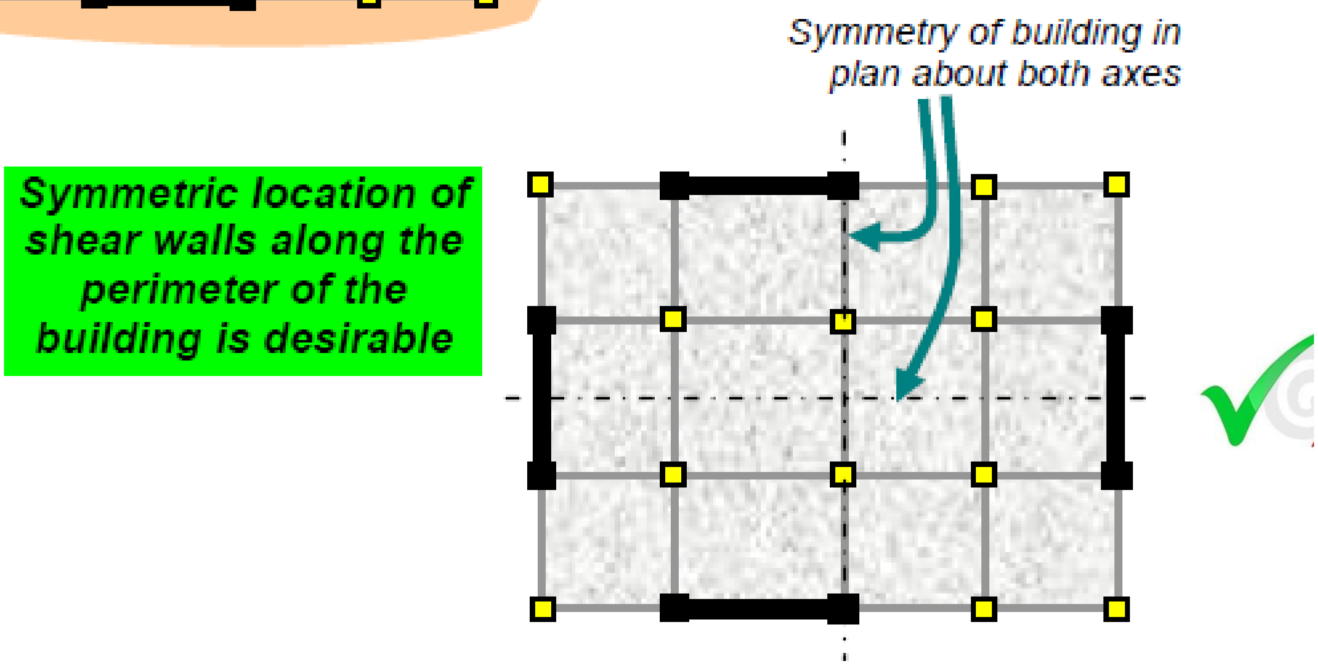
Reinforced concrete (RC) buildings often have *vertical plate-like RC walls called Shear Walls* in addition to slabs, beams and columns. Shear walls are like *vertically-oriented wide beams that carry* earthquake loads downwards to the foundation.

Properly designed and detailed buildings with shear walls have shown *very good performance in past* earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarized in the quote:

“We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls.” :: Mark Fintel, a noted consulting engineer in USA

Shear Walls





Shear walls must be symmetric in plan layout – *twist in buildings can be avoided.*

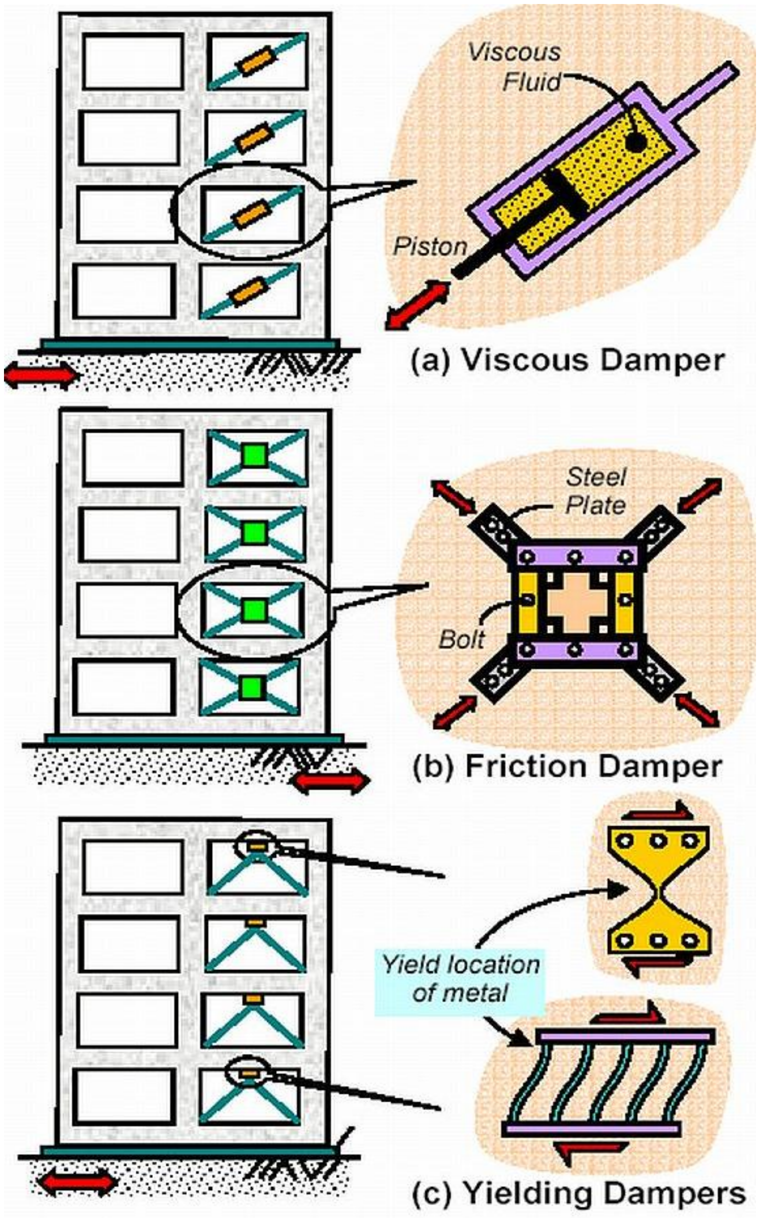
Bracing

Seismic Dampers

Dampers can be installed in the structural frame of a building to absorb some of the energy going into the building from the shaking ground during an earthquake. The dampers reduce the energy available for shaking the building. This means that the building deforms less, so the chance of damage is reduced.

The St. Francis Shangri-La Place
The first ever building to use
the STRUCTURAL DAMPERS

Seismic Dampers



For controlling seismic damage in buildings another approach is by installing seismic dampers in place of structural elements like diagonal braces. While seismic energy is transmitted through them, dampers absorb part of it, and therefore damp the motion of the building.

There are many types of dampers that can be installed in buildings. Here are some of them:-

a. Viscous Dampers

Energy is absorbed by silicone-based fluid passing between piston-cylinder arrangement.

b. **Friction Dampers**

Energy is absorbed by surfaces with friction between them rubbing against each other

c. Yielding Dampers

Energy is absorbed by yielding of metallic components.

viscous fluid damper

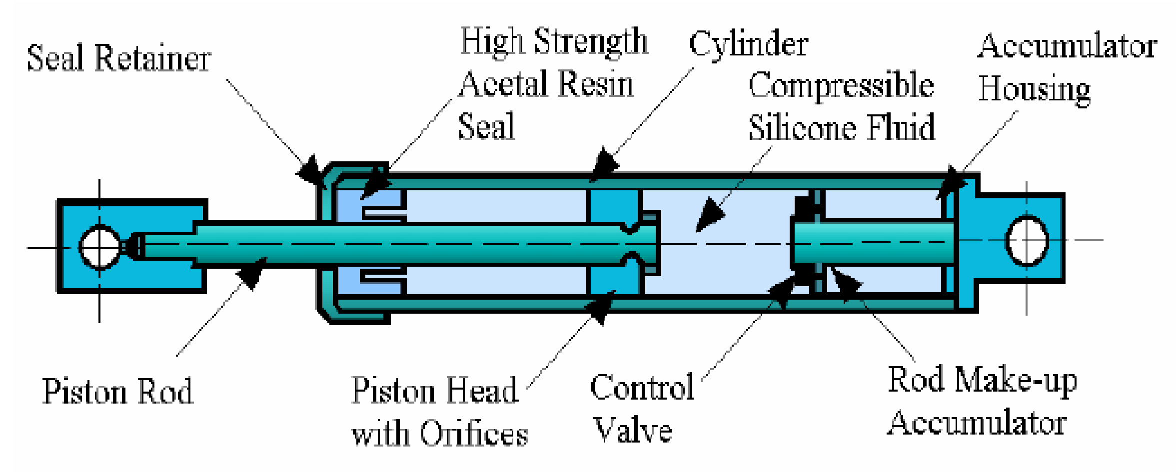
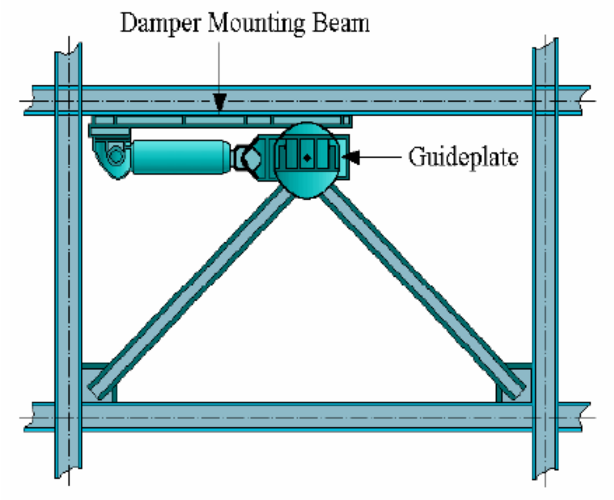


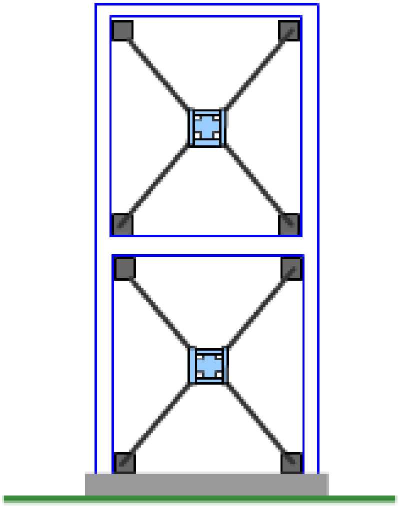
Fig: Cross-section of a Viscous Fluid Damper

Viscous spring dampers

FRICTION DAMPERS

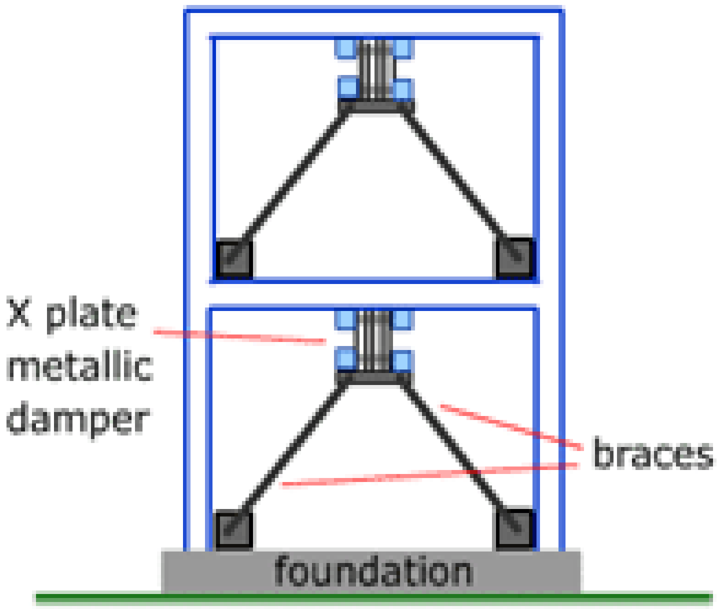


Installation of uniaxial friction damper in steel frame

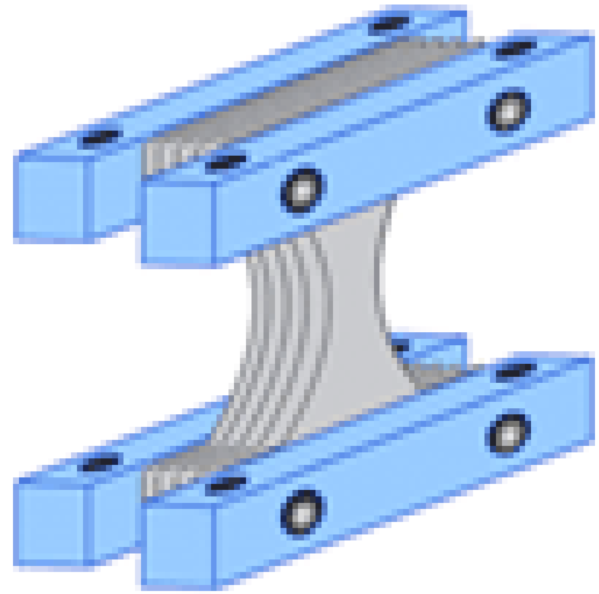


2 storey frame with
Pall friction dampers in position

Metallic Dampers



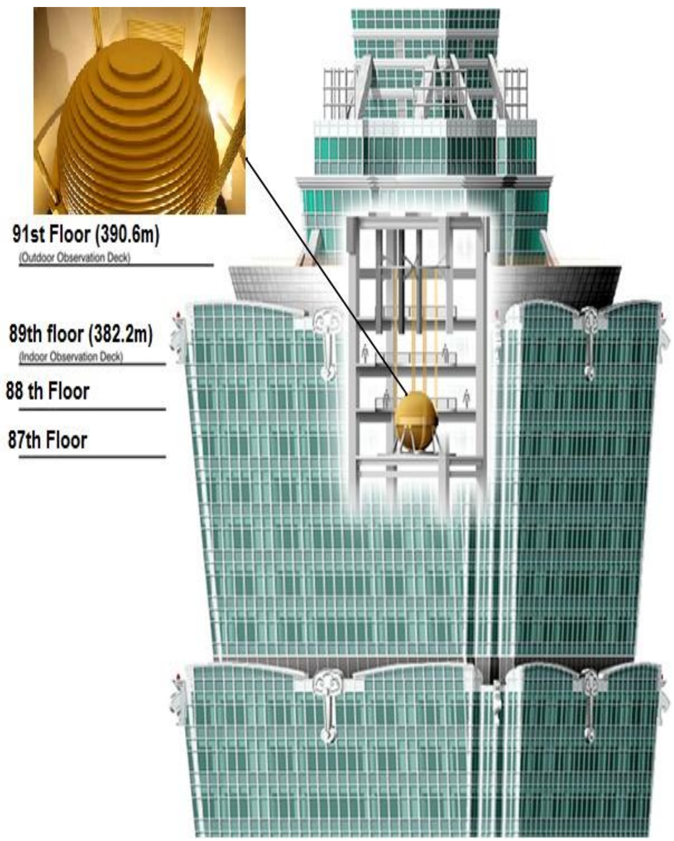
2 storey steel frame with metallic dampers in position

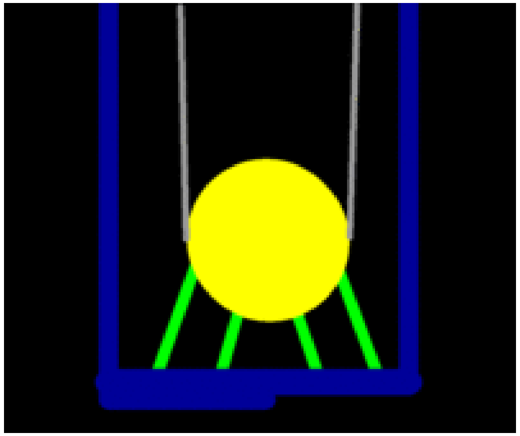


Metallic damper is a popular (and inexpensive) choice for an energy dissipation device because of its relatively high elastic stiffness, good ductility and its high possible for dissipating energy.

Tuned Mass Damper (TMD)

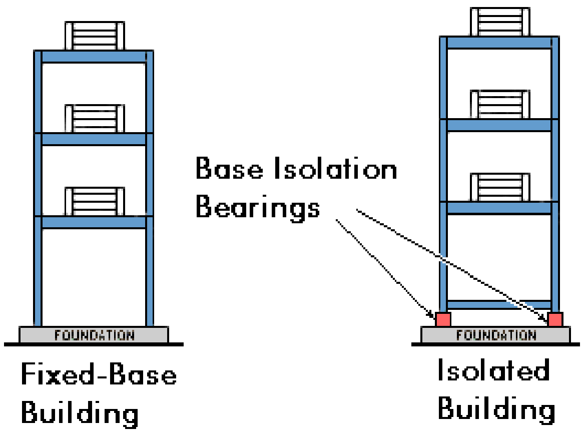
A **tuned mass damper**, also known is a device mounted in structures to reduce the amplitude of mechanical vibrations. Their application can prevent discomfort, damage, or outright structural failure. They are frequently used in power transmission, automobiles, and buildings.

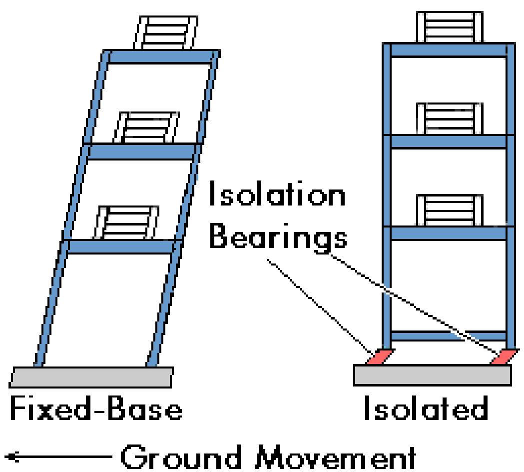




Taipei 101, the world's second tallest skyscraper is equipped with a tuned mass damper. This 18 feet dia.,730-ton TMD acts like a giant pendulum to counteract the building's movement--reducing sway due to wind by 30 to 40 %.

Base Isolation

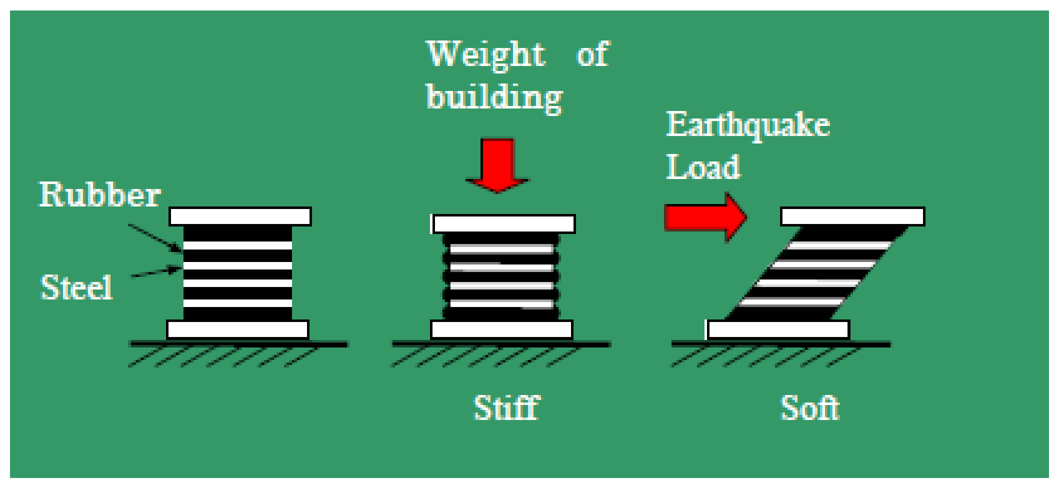




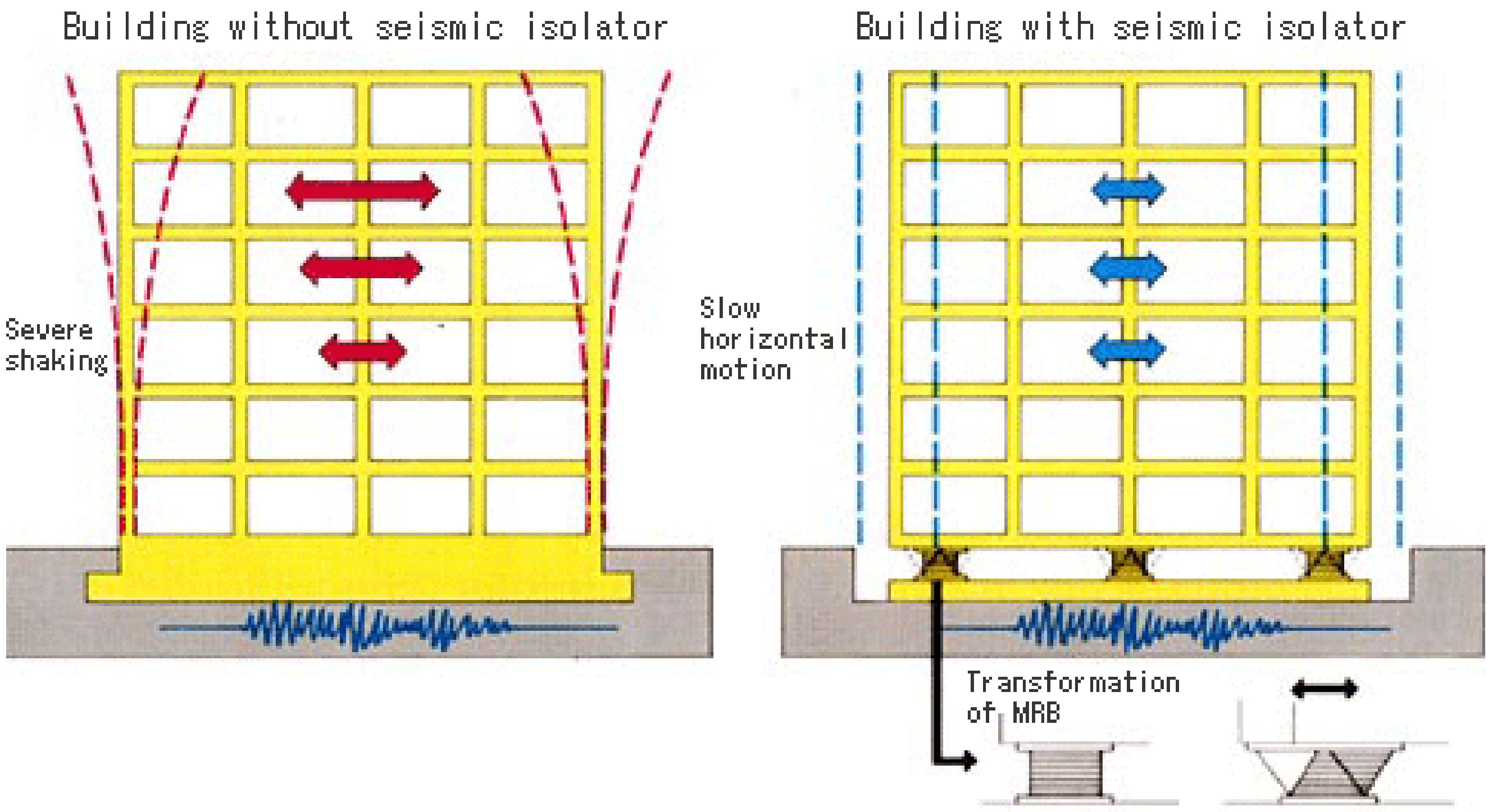
- Base isolation systems reduce building vibrations during earthquakes.

- The goal of base isolation is to reduce the energy that is transferred from the ground motion to the structure.

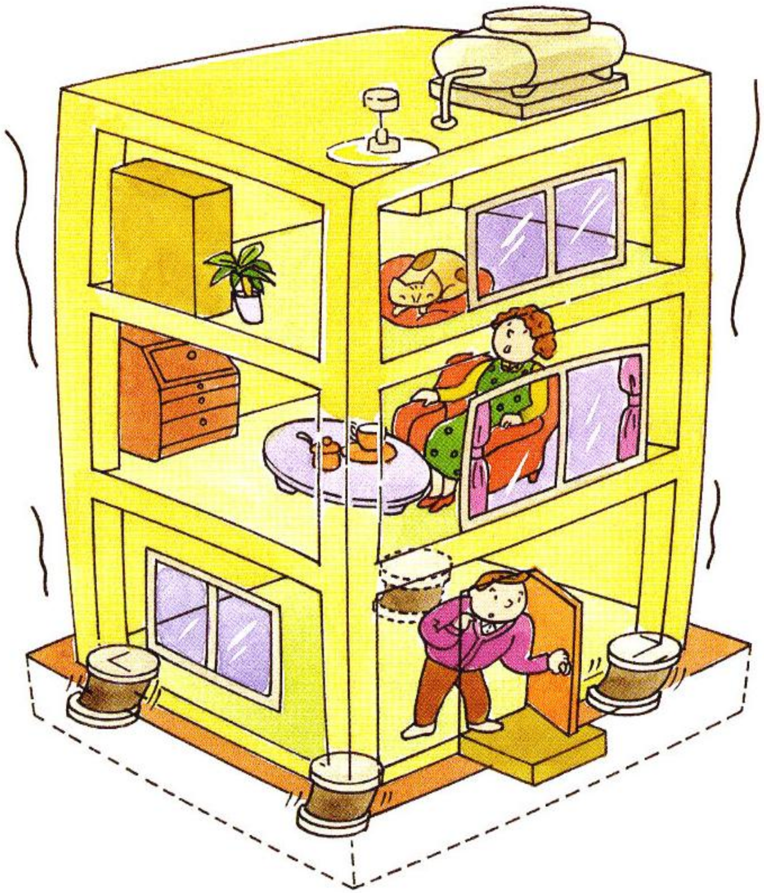
- These bearings are not very stiff in the horizontal direction, so they reduce the fundamental frequency of vibration of a building.



Base Isolation



Effects of Base Isolation System



Building with Seismic Isolation

Common Building