EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

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Attenuation of Ground Motion

Since peak acceleration is the most commonly used ground motion parameter, many peak acceleration attenuation relations have been developed.

Cambell relationship

$\ln PGA(g) = -4.141 + 0.868\,M - 1.09 \ln [R + 0.0606 \times e^{0.7M}]$

M Local magnitude in Richter scale

R Epicentral distance in km

GROUND MOTION PARAMETERS

GROUND MOTION PARAMETERS

Several earthquake parameters are used to quantitatively describe the various characteristics of ground motion.

1. Amplitude – PGA, PGV, PGD
2. Frequency content - Ground motion Spectra
   - Spectral Parameters
3. Duration

GROUND MOTION PARAMETERS

I. Amplitude Parameters

a. Peak Ground Acceleration –PGA

PGA is a measure of maximum amplitude of motion and is defined as the largest absolute value of acceleration time history. PGA is extensively used in engineering. Vertical PGA is 2/3 of horizontal PGA. Response of stiff structure is related to PGA

b. Peak Velocity –PGV

PGV is the largest absolute value of Velocity time history. It is more sensitive to Intermediate frequency content of motion.

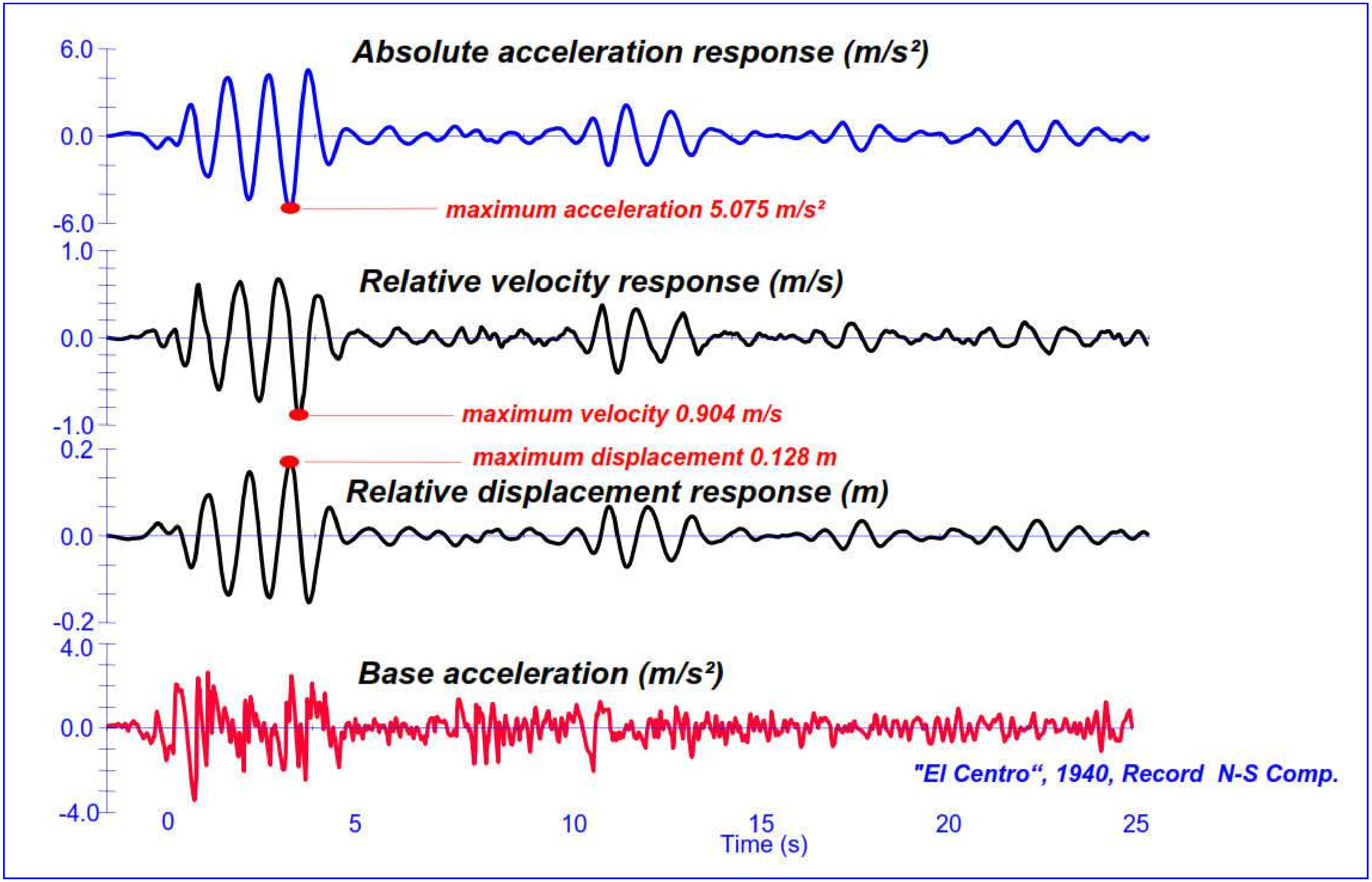
c. Peak Displacement – PGD

PGD reflects the amplitude of lower frequency components in ground motion.

Estimation of these is difficult as the errors in signal processing and numerical integration affects.

GROUND MOTION PARAMETERS

PGA, PGV, PGD



GROUND MOTION PARAMETERS

2. **Frequency Content of Motion.**

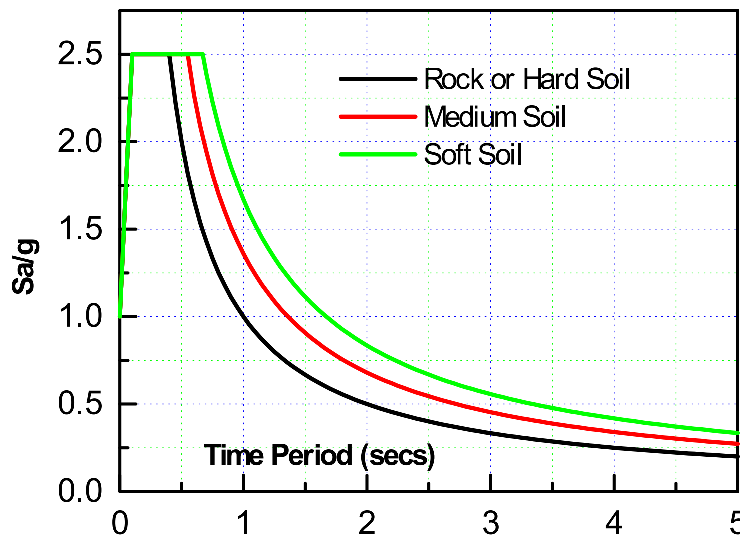
Earthquake ground motion is an amalgamation of harmonic motion with a range of frequency components and amplitude.

a. Response Spectra
b. Fourier Spectra
c. Power Spectra

2. **Frequency Content of Motion**

A. Response Spectrum

A response spectrum is simply a plot of the peak response (displacement, velocity or acceleration) of a number of SDOF systems of varying Natural period or Frequency, that are subjected to same base vibration. The resulting plot can then be used to find the response of any structure, knowing its Natural Period.



Response Spectrum IS : 1893 :2002

Advantages of Response Spectrum

- Response spectrum has found vital importance in structural engineering since its inception (Housner, 1941; Hudson, 1956; Newmark and Hall, 1982). Response spectrum method of analysis finds advantage due to following reasons.
- Unlike pseudo-static analysis it considers the frequency effects.
- Unlike thorough dynamic analysis, it provides a single suitable horizontal force for the design of structure.
- The idealization of treating the system as a single degree freedom system is acceptable in structural engineering problems where the complexities involved in terms of geometry, material property and boundary condition are relatively less.

Response Spectrum

- The response may be expressed in terms of acceleration, velocity or displacement.
- The maximum values of each of these parameters depend only on the natural period or frequency and damping ratio of the single degree of freedom system (SDOF).
- The maximum magnitudes of acceleration, velocity and displacement at different natural periods are referred to as the

  spectral acceleration (S_a),

  spectral velocity (S_v) and

  spectral displacement (S_d) respectively.
- A single degree of freedom system of zero natural period (infinite natural frequency) would be rigid, and its spectral acceleration would be equal to the peak ground acceleration.

Response Spectrum

The maximum response motions and the spectral acceleration, velocity, and displacement can be approximately related to each other by the following simple expressions:

Response Spectrum Nomenclature

$$\textbf{Spectral Displacement} = S_d = |x|_{\max}$$

$$\textbf{Spectral Velocity} = S_v = |\dot{x}|_{\max}$$

$$\textbf{Spectral Acceleration} = S_a = |\ddot{x} + \ddot{x}_g|_{\max} = \left|2\xi w_n \dot{x} + w_n^2 x\right|_{\max}$$

$$\textbf{\textit{Pseudo}-spectral velocity} = PS_v = \omega_n \cdot S_d$$

$$\textbf{\textit{Pseudo}-spectral acceleration} = PS_a = \omega_n^2 \cdot S_d$$

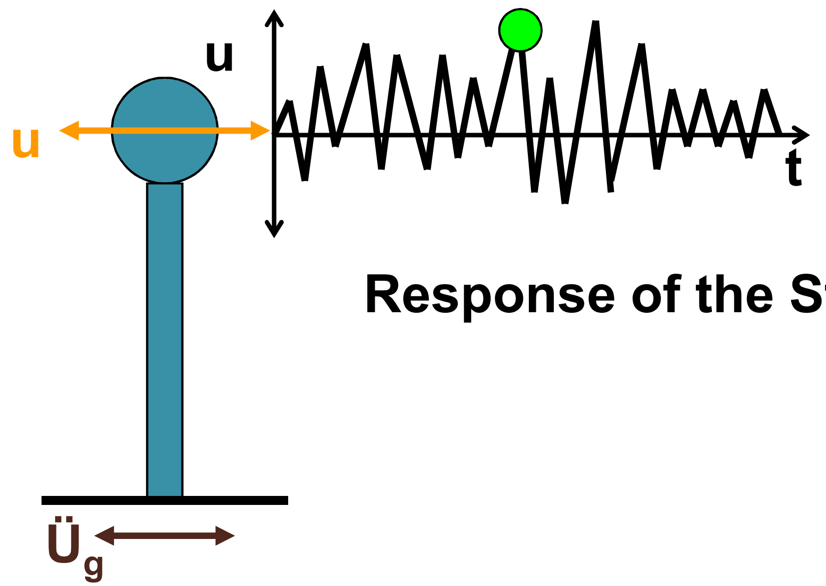
Although PSV and PSA are not the true maximum values of velocity and acceleration, they are usually very close to maxima for the recorded ground motions.

RESPONSE SPECTRUM CONSTRUCTION

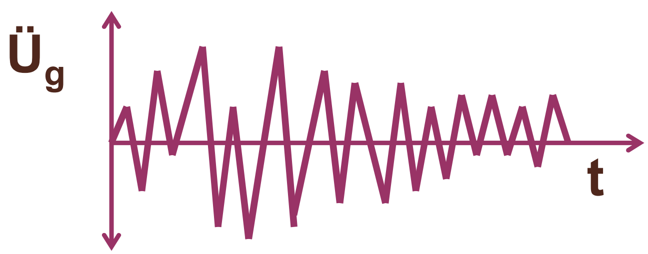
Find u_{max}

$$f_i = 1/(2\pi)\sqrt{k_i / m}$$

$$T_i = 1 / f_1$$



Response of the Structure



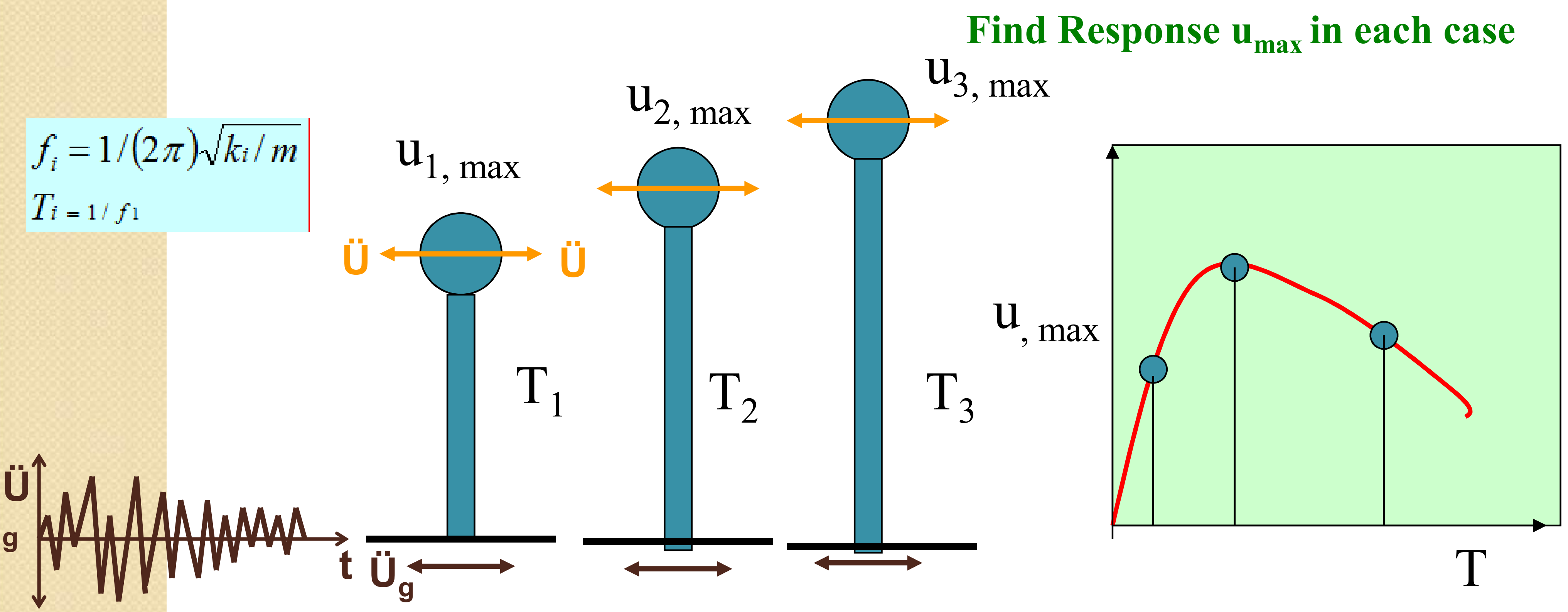
Earthquake Accelerogram

It is a plot of the peak response (Velocity, Displacement or Acceleration) with respect to Period of SDOF system for a given base motion (Accelerogram.)

Concept of Response Spectrum

$f_i = 1/(2\pi)\sqrt{k_i/m}$

$T_i = 1/f_1$



Earthquake Accelerogram

For various values of Period of SDOF structures, Find Peak Displacement for the given input earthquake acceleration and plot Response v/s Period

GROUND MOTION PARAMETERS

b. Fourier Spectra

The plot of Fourier amplitude or phase angle of input time history vs. Time period or Frequency is known as Fourier Spectra. The Fourier amplitude spectrum provides inputs on the frequency content of the motion and helps to identify the predominent frequency of motion.

c. Power Spectra

Frequency contents of ground motion can also be represented by a power spectrum or power spectral density function.

3. Duration of strong Motion

Several definition have been proposed for the strong motion duration of an accelerogram. Duration of strong motion as the interval in which 90% of the total contribution to the energy of the accelerogram.

BUILDING CHARACTERISTICS

Building Characteristics

- **The seismic forces exerted on a building are not externally developed forces like wind instead they are the response of cyclic motions at the base of a building causing accelerations and hence inertia force**
- **The response is therefore essentially dynamic in nature**
- **The dynamic properties of the structure such as natural period, damping and mode shape play a crucial role in determining the response of building**
- **Besides, other characteristics of the building system also affect the seismic response such as ductility, building foundation, response of non-structural elements etc.**

Building Characteristics

1. Mode Shapes and Fundamental Period

- ***Fundamental modes of the building may be determined by any one of several methods developed for the dynamic analysis of structures***

- **On the basis of time period, building may be classified as rigid (T< 0.3 sec), semi – rigid (0.3 sec < T < 1.0 sec) and flexible structure (T > 1.0 sec)**

- **Buildings with higher natural frequencies, and a short natural period, tend to suffer higher accelerations but smaller displacement**

- **In the case of buildings with lower natural frequencies, and a long natural period, this is reversed: the buildings will experience lower accelerations but larger displacements**

Behavior of Flexible and Rigid System

In case of structural system very flexible, it has low natural frequency, The motion practically is not transmitted to the mass and the mass Remains more or less stationery in space. Thus the relative displacement of the mass w.r.t. ground will tend to be equal to the ground displacement.

In case structural system very stiff or rigid having a very high natural frequency, the motion of the mass is approximately the same as that of the ground and the absolute acceleration of the mass will tend to be equal to the found acceleration

Building Characteristics

2. Building Frequency and Ground Period

- Inertial forces generated in the building depend upon the frequencies of the ground on which the building is standing and the building's natural frequency
- When these are near or equal to one another, the building's response reaches a peak level
- Past studies show that the
  - predominant period at a firm ground site 0.2 – 0.4 sec

    rigid structure (0-0.3)will have more unfavorable seismic response than flexible structures,
  - while period on soft ground can reach 2.0 sec or more.

    seismic response of flexible structures (t>1.0) on soft foundation sites will have more unfavorable seismic response than Rigid structures

Building fundamental periods of approximately 0.1N (where, N is the number of storey),

On the basis of time period, building may be classified as rigid (T< 0.3 sec), semi – rigid (0.3 sec < T < 1.0 sec) and flexible structure (T > 1.0 sec)

Building Characteristics

3. Damping

- The degree of structural amplification of the ground motion at the base of the building is limited by structural damping
- Damping is the ability of the structural system to dissipate the energy of the earthquake ground shaking
- Since the building response in inversely proportional to damping, the more damping in a building possesses, the sooner it will stop vibrating--which of course is highly desirable from the standpoint of earthquake performance
- In a structure, damping is due to internal friction and the absorption of energy by the building's structural and nonstructural elements
- There is no numerical method available for determining the damping. It is only obtained by experiments

Building Characteristics

4. Ductility

- **Ductility is defined as the capacity of the building materials, systems, or structures to absorb energy by deforming in the inelastic range**

- **The safety of building from collapse is on the basis of energy, which must be imparted to the structure in order to make it fail**

- **In such instance, consideration must be given to structure's capacity to absorb energy rather than to its resistance**

- **Therefore ductility of a structure in fact is one of the most important factors affecting its earthquake performance**

Building Characteristics

5. Seismic weight

- Seismic forces are proportional to the building weight and increases along the height of building.
- Weight reduction can be obtained by using lighter materials or by reducing the filling and other heavy equipments not essential for building construction.

Building Characteristics

6. Redundancy

- Hyper static system yields or fails, the lateral force can be redistributed to secondary elements or system to prevent progressive failure (alternate load path)
- Hyperstaticity of the structure causes the formation of plastic hinges that can absorb considerable energy without depriving the structure of its stability.

Building Characteristics

7. Quality of Construction and Materials

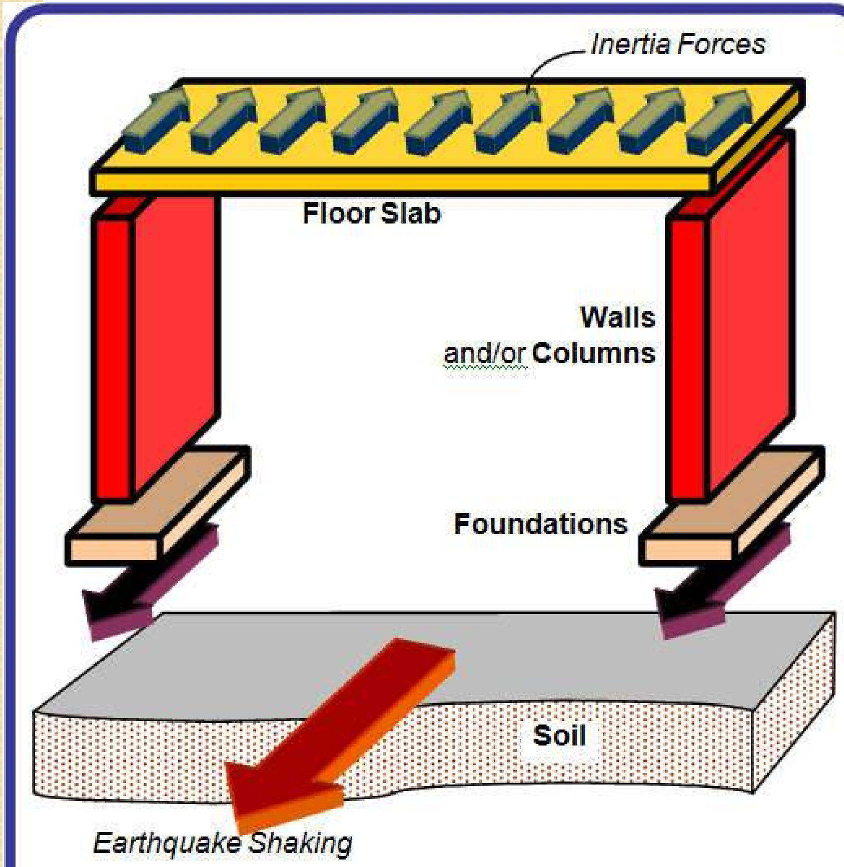
- Grade of concrete not achieved in site
- Poor execution of the concrete joint/ discontinuity- quality of concrete
- Reinforcement detailing not taken care of appropriately.
- Accumulation of sawdust, dust and loose materials at the surface of joint.

A defective concrete joint, which contributed significantly to causing of failure of

many building in past earthquakes.

Lateral Load/Force Resisting Systems

Flow of Inertia Forces to Foundation



Flow of seismic inertia forces through all structural components.

- The lateral inertia forces are transferred by the floor slab to the walls or columns, to the foundations, and finally to the soil system underneath.

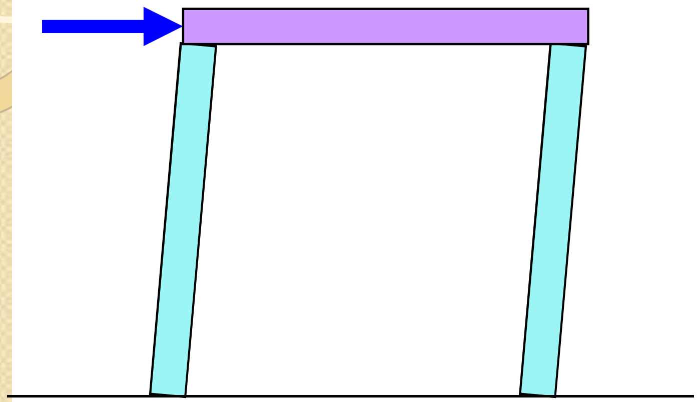
Lateral Load/Force Resisting Systems

The LFRS is used to resist forces resulting from wind or seismic activity

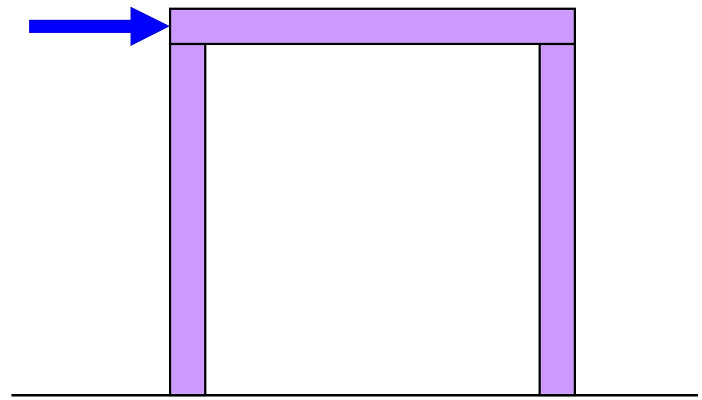
- **The load resisting system must be of closed loops, enable to transfer all the forces acting either vertically or horizontally to the ground**
- **Bureau of Indian Standards (BIS) has approved three major types of lateral force resisting system in the code IS 1893 (Part 1): 2002**

1. **Moment resisting building frame system,**
2. **Bearing wall system and**
3. **Dual system.**

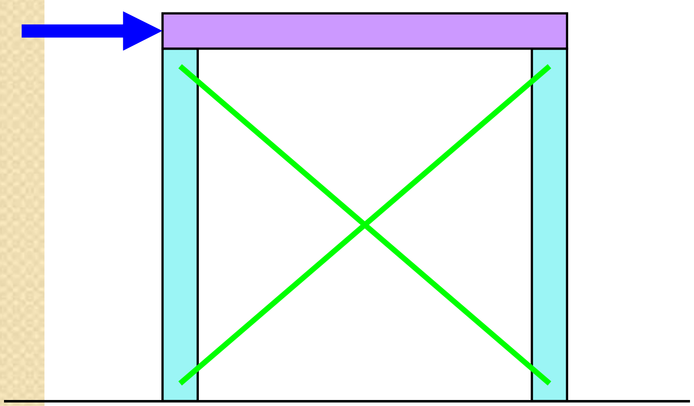
Load Resisting Systems



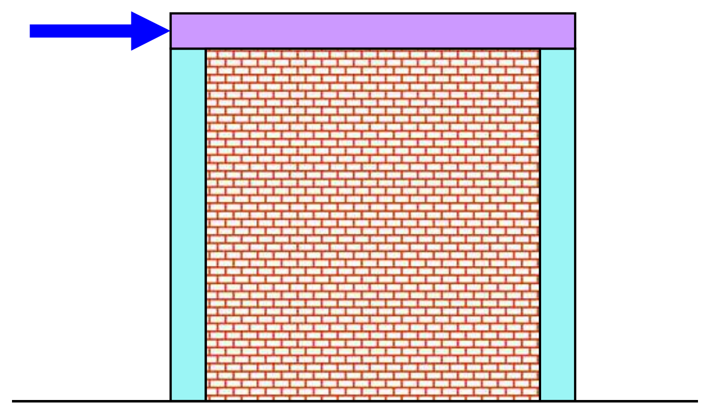
Simply supported System



Rigid Frame

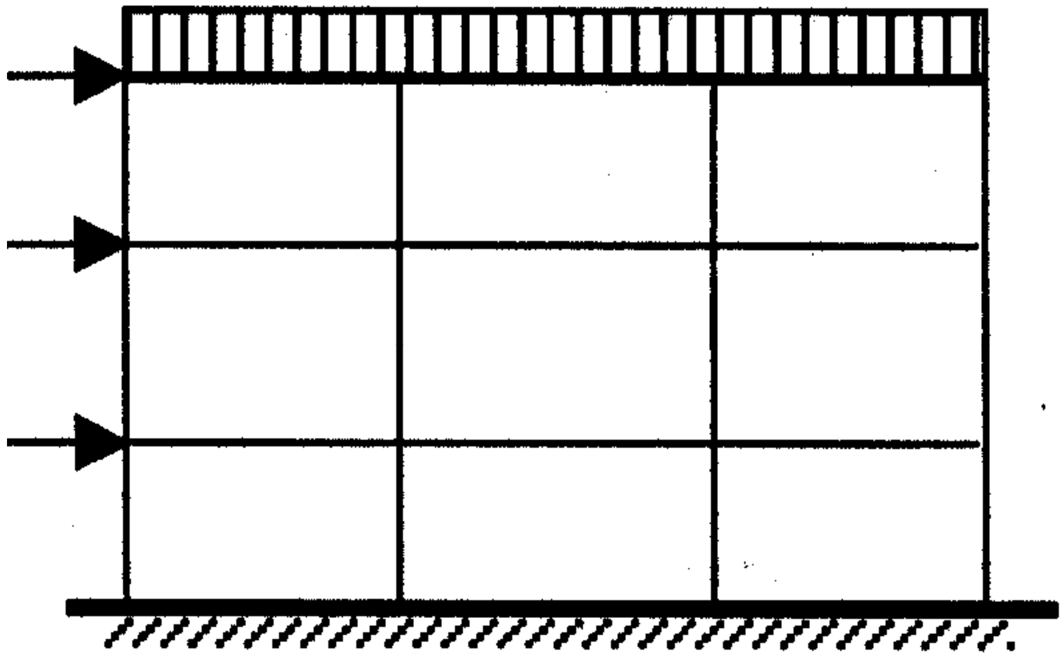


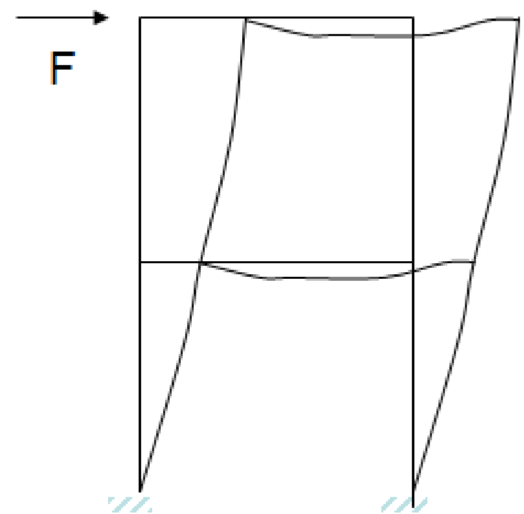
Bracing system



Shear wall System

Lateral Load Resisting Systems





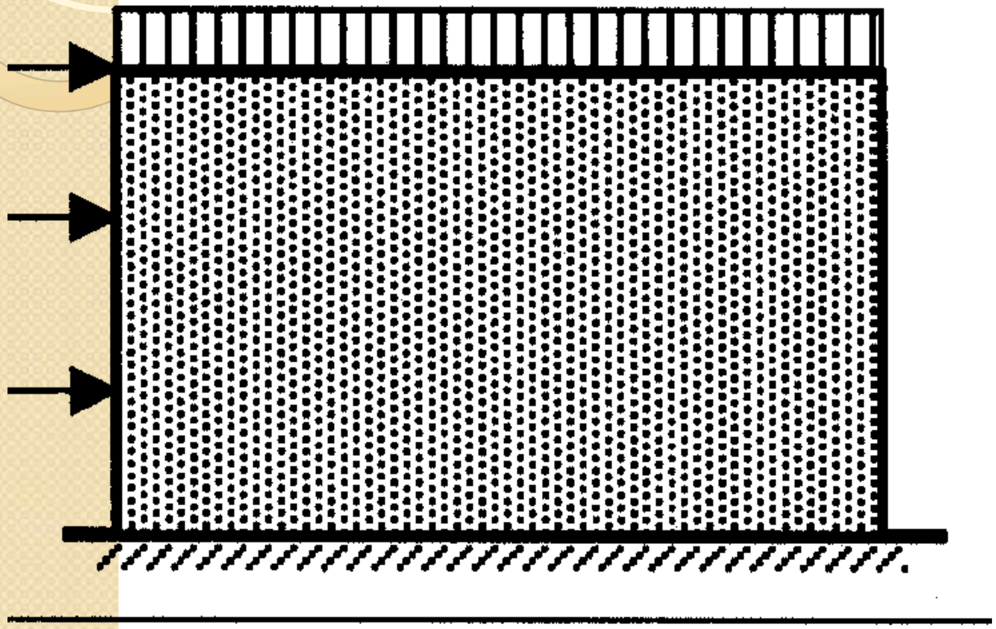
1. Moment Resisting Frames

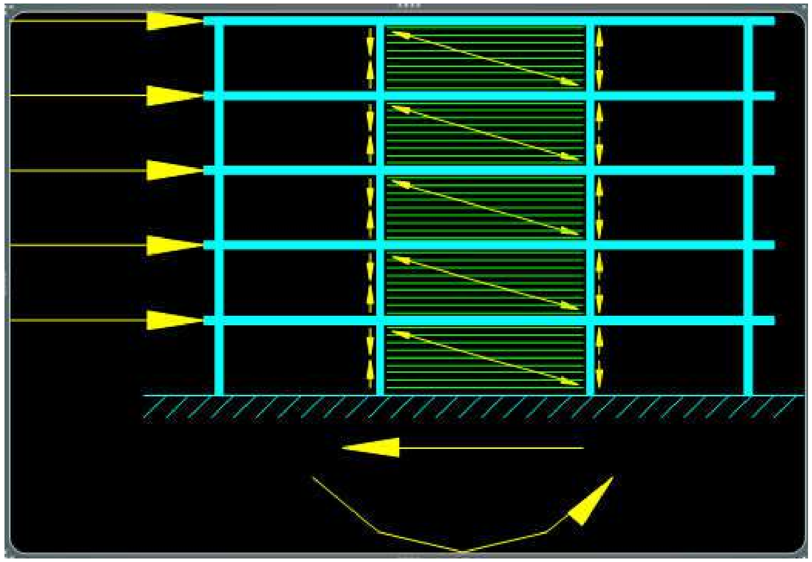
Lateral Load Resisting Systems

Moment Resisting Frames

- Columns and Girders joined by moment resisting connections
- Lateral stiffness of the frame depends on the flexural stiffness of the beams, columns, and connections.
- Economical for buildings up to about 10-15 stories.
- Well suited for reinforced concrete construction due to the inherent continuity in the joints.
- Gravity loads also resisted by frame action.
- This system is generally preferred by architects because they are relatively un-obtrusive compared with shear walls or braced frame

Lateral Load Resisting Systems





2. Bearing Wall System

Lateral Load Resisting Systems

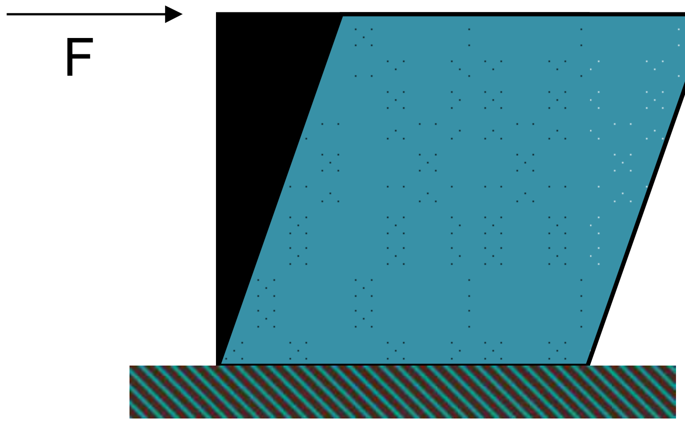
Bearing Wall System

- Steel or concrete frame infilled with concrete or masonry.
- Infill behaves as a strut in compression.
- Tension contribution is ignored.
- Due to random nature of masonry infill, it is difficult to predict the stiffness and strength of this system.
- No method of analyzing infilled frames has gained general acceptance.

Lateral Load Resisting Systems

3. Shear Walls

- wall elements designed to take vertical as well as in-plane horizontal (lateral) forces
  - Concrete buildings
  - Wood buildings
  - Masonry buildings
- resist lateral forces by shear deformation
- stiffer buildings



Shear Deformation

Lateral Load Resisting Systems

Shear Walls

- Generally constructed with concrete,
- Shear walls have high in-plane stiffness and strength.
- Well suited for tall buildings up to about 35 stories.
- Can be used around elevator and/or stair cores.

Lateral Load Resisting Systems

Reinforced concrete shear walls

– an excellent structural system

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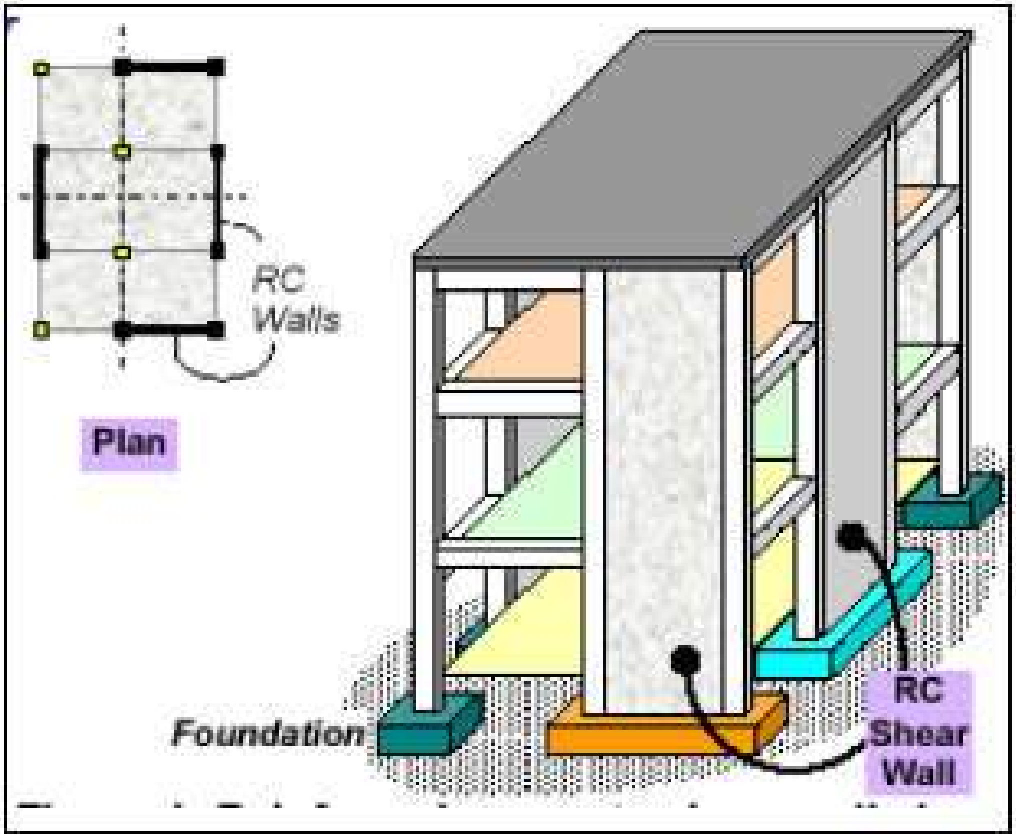
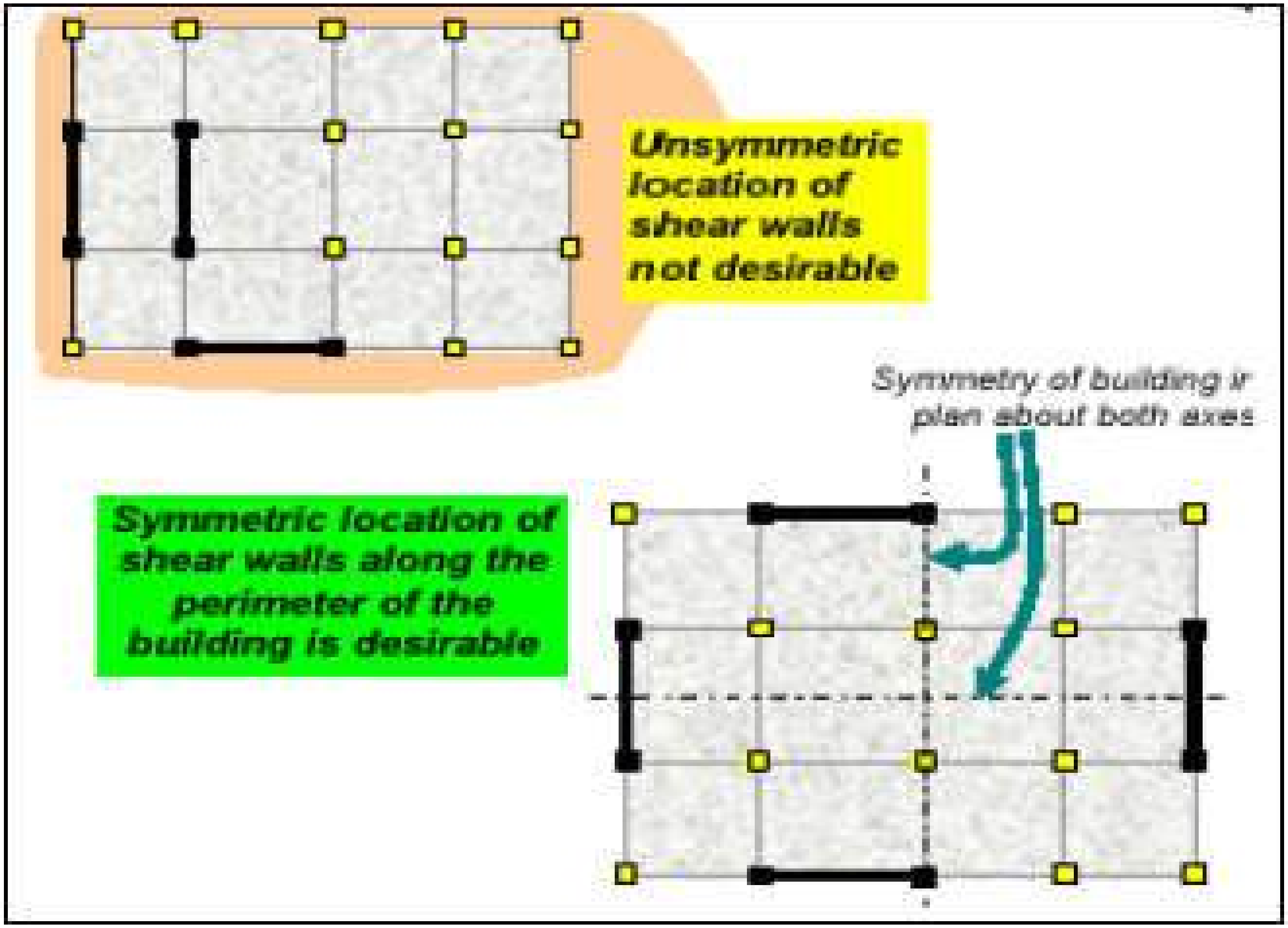


Lateral Load Resisting Systems

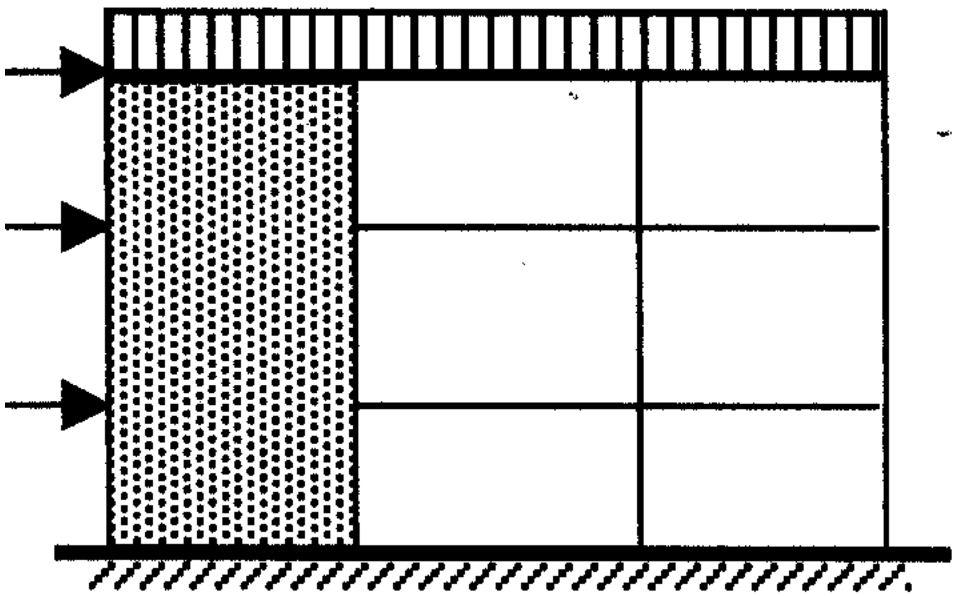
SHEAR WALLS



Layout and symmetry

Lateral Load Resisting Systems

4. Building with Dual System



- These systems are further subdivided according to the type of construction material used. Table 7 of IS 1893 (Part 1): 2002 lists the different framing system and response reduction factors

Response Reduction Factor- R

Sl No	Lateral Load Resisting System	R
	Building Frame Systems	
1	Ordinary RC moment Resisting frame (OMRF)[2]	3.0
2	Special RC moment Resisting Frame (SMRF)[3]	5.0
3	Steel Frames with a) Concentric Braces b) Eccentric Braces	 4.0 5.0
4	Steel Moment Resisting Frame Designed as per SP 6(6)	5.0
	Buildings with Shear Walls[4]	
5	Load Bearing Masonry Wall Buildings[5] a) Un-reinforced b) Reinforced with Horizontal RC Bands c) Reinforced with Horizontal RC Bands and Vertical bars At corners of rooms and jambs of openings	 1.5 2.5 3.0
6	Ordinary Reinforced Concrete Shear Walls[6]	3.0
7	Ductile shear Walls[7]	4.0
	Buildings with Dual Systems[8]	
8	Ordinary Shear wall with OMRF	3.0
9	Ordinary Shear wall with SMRF	4.0
10	Ductile Shear wall with OMRF	4.5
11	Ductile Shear wall with SMRF	5.0

$$V_B = A_h W$$

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

Lateral Load Resisting Systems

Building with Dual System

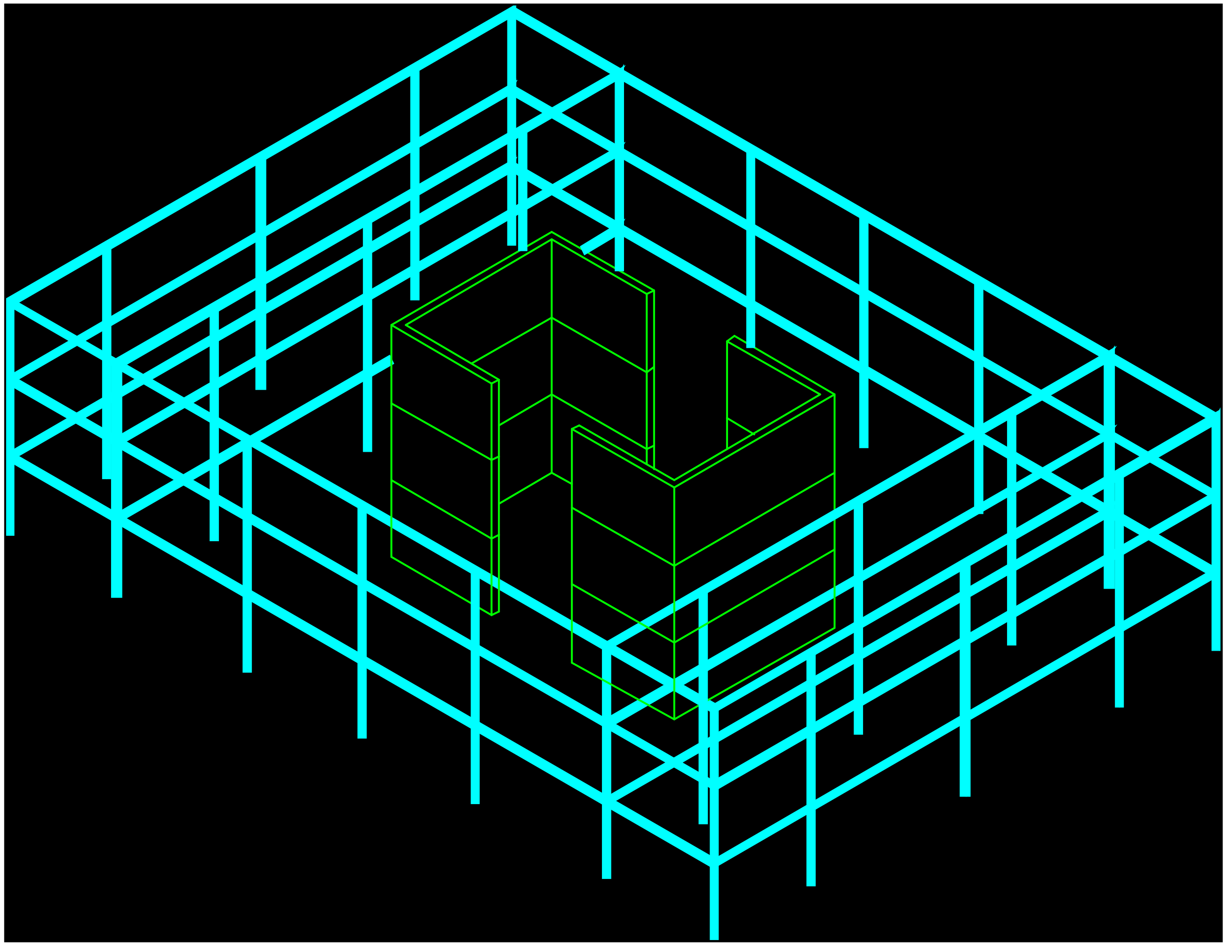
- **This system consists of shear wall (or braced frame) and moment resisting frame**

- **The two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of the dual system at all floor levels**

- **The moment resisting frames are designed to independently resist at least 25% of design seismic base shear**

In general, a dual system has comparably higher value of R since a secondary lateral support system is available to assist the primary nonbearing lateral support system

Lateral Load Resisting Systems



Lateral Load Resisting Systems

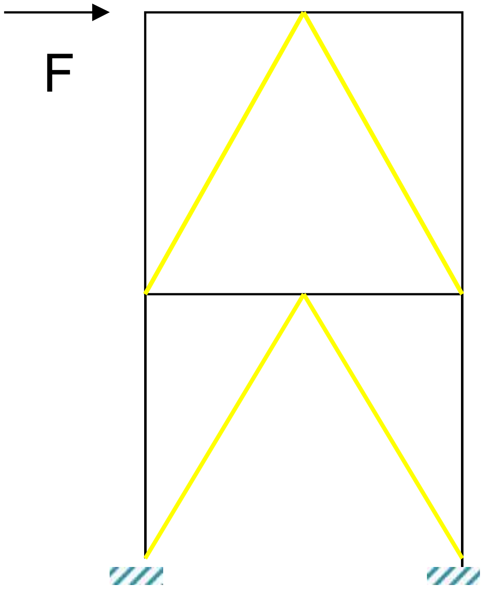
5. Braced Frames

- Braced Frames are basically vertical truss systems.
- Almost exclusively steel or timber.
- Highly efficient use of material since forces are primarily axial. Creates a laterally stiff building with relatively little additional material.
- Good for buildings of any height.
- May be internal or external.

Lateral Load Resisting Systems

Braced Frame

- Braces used to resist lateral loads
  - steel or concrete
- Damage can occur when braces buckle
- Stiffer than pure frame



Earthquake Design Philosophy

OBJECTIVES OF EQ RESISTANT ESIGN

- **Should the structure be designed to withstand strong shaking without sustaining any damage**

  Such a construction will be too expensive

- **It may be more logical to accept some damage in case of strong shaking**
- **However, loss of life must be protected even in case of strong shaking.**

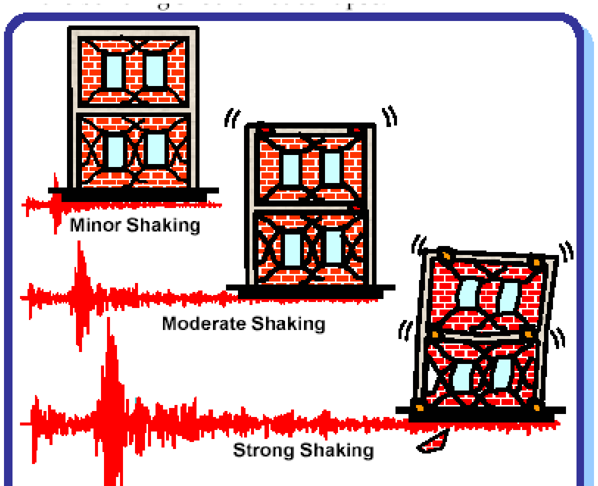
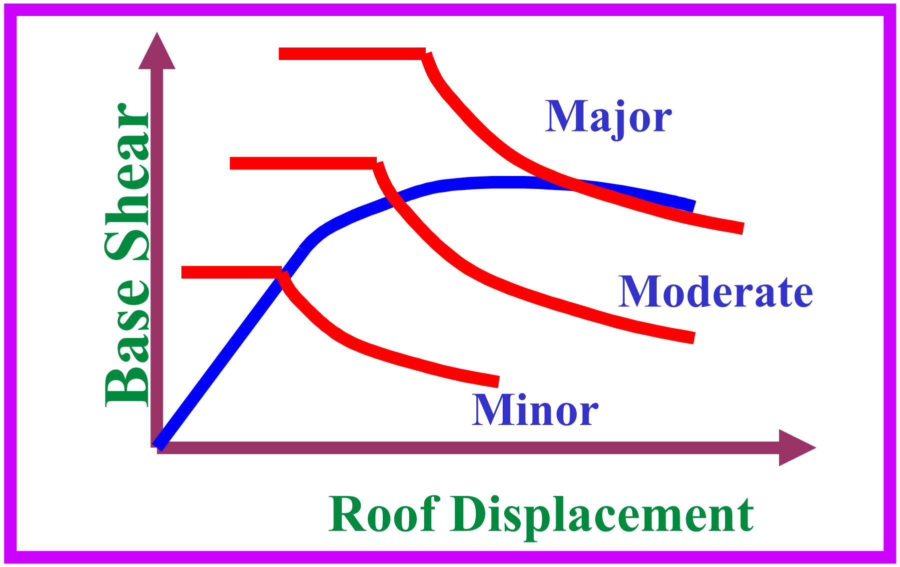


Figure 2: Performance objectives under different intensities of earthquake shaking – *seeking low repairable damage under minor shaking and collapse-prevention under strong shaking.*

Earthquake Design Philosophy



Minor shaking	**No structural damage**
Moderate shaking	**Repairable structural damage**
Major shaking	**Even irreparable structural damage, but ductile failure !**

Earthquake Resistant Design Philosophy

DBE – Max. EQ that can be expected to experience at the site Once during life time of the structure. (DBE generally half of MCE

- **Building**
  - **should resist minor earthquakes (<DBE) with some non-structural damage**
  - **should resist moderate earthquake (DBE) with some structural damage, but without failure**
  - **can fail at most severe earthquake (MCE), but with sufficient warning.**

Earthquake Resistant Design Philosophy

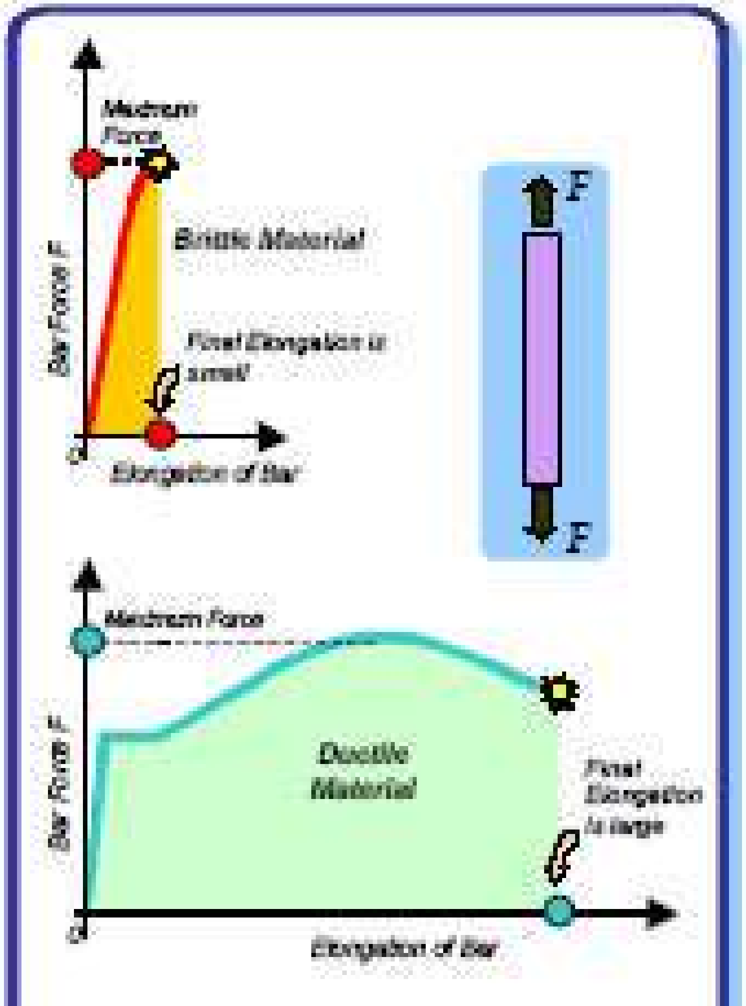


Figure 2: Tension Test on Materials – ductile versus brittle materials.

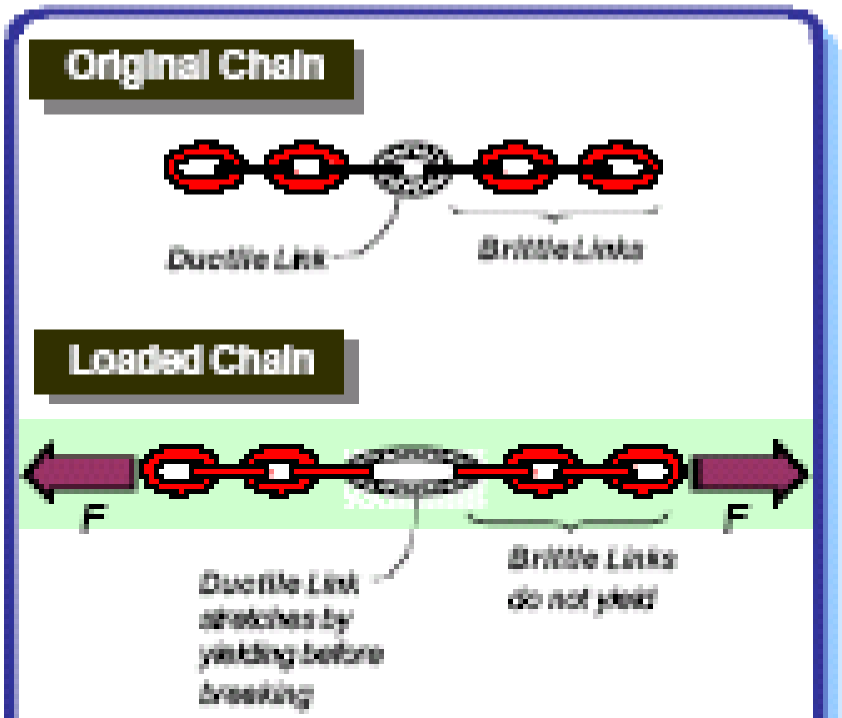
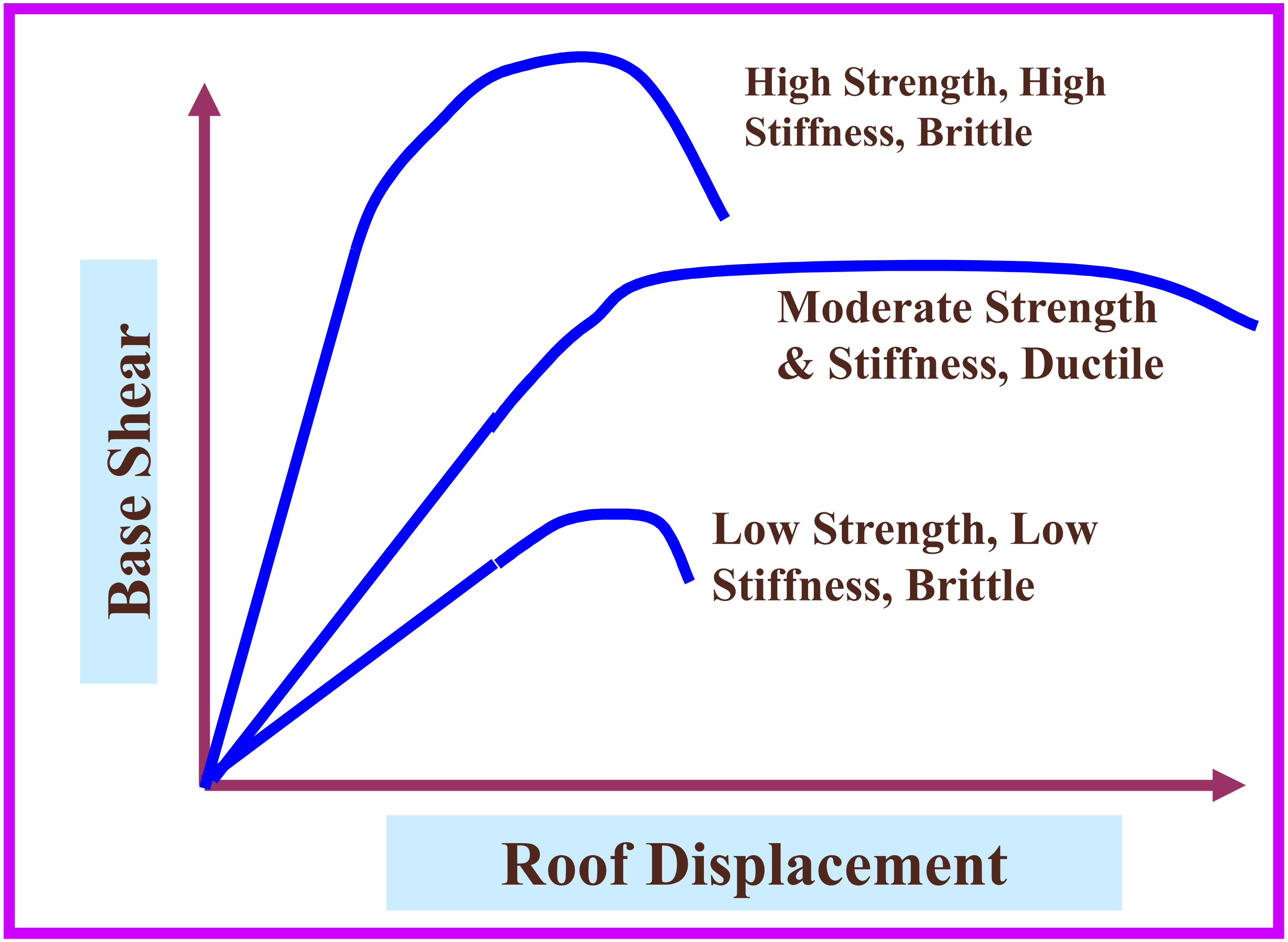


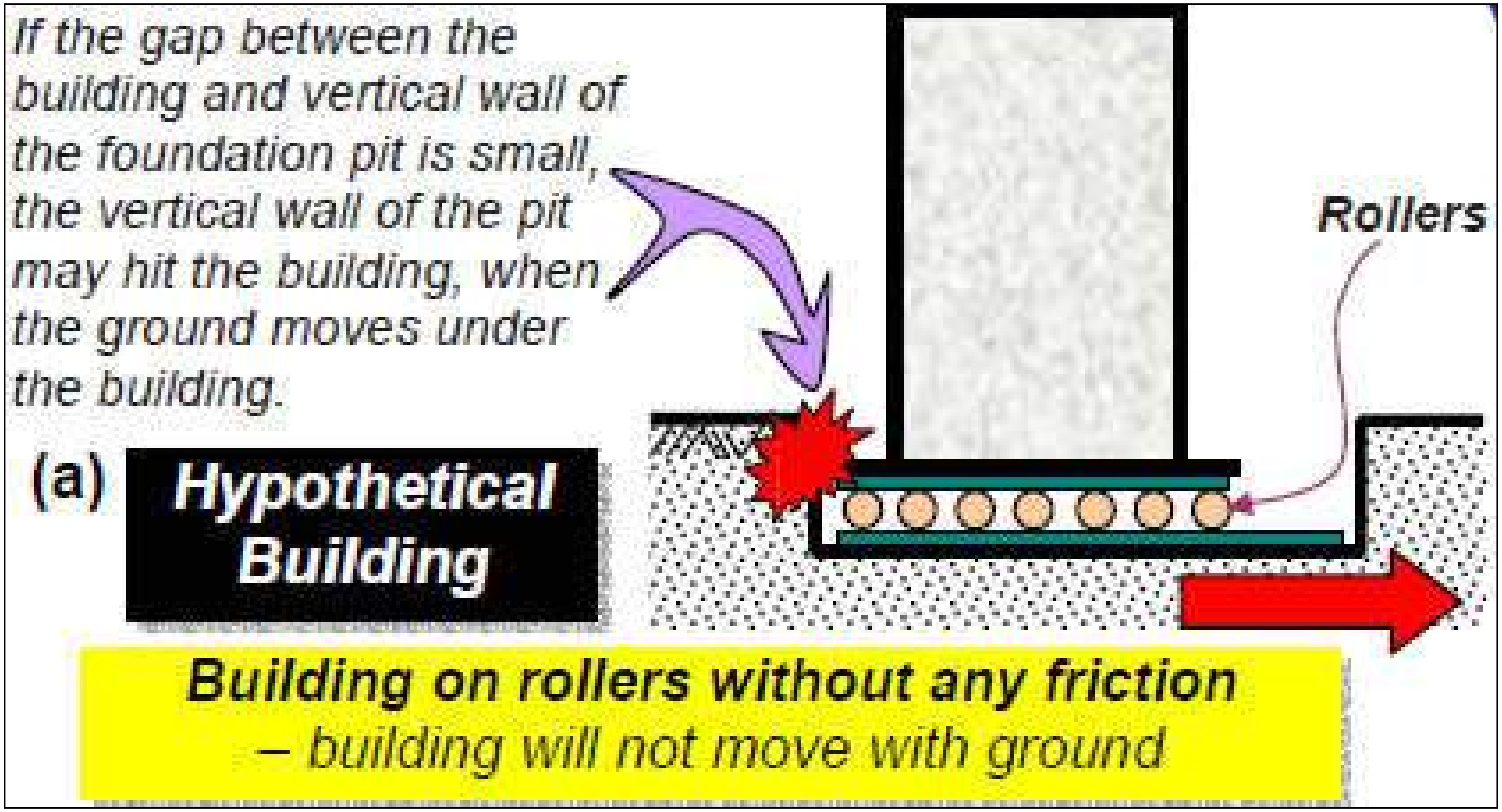
Figure 3: Ductile chain design.

Performance of Building

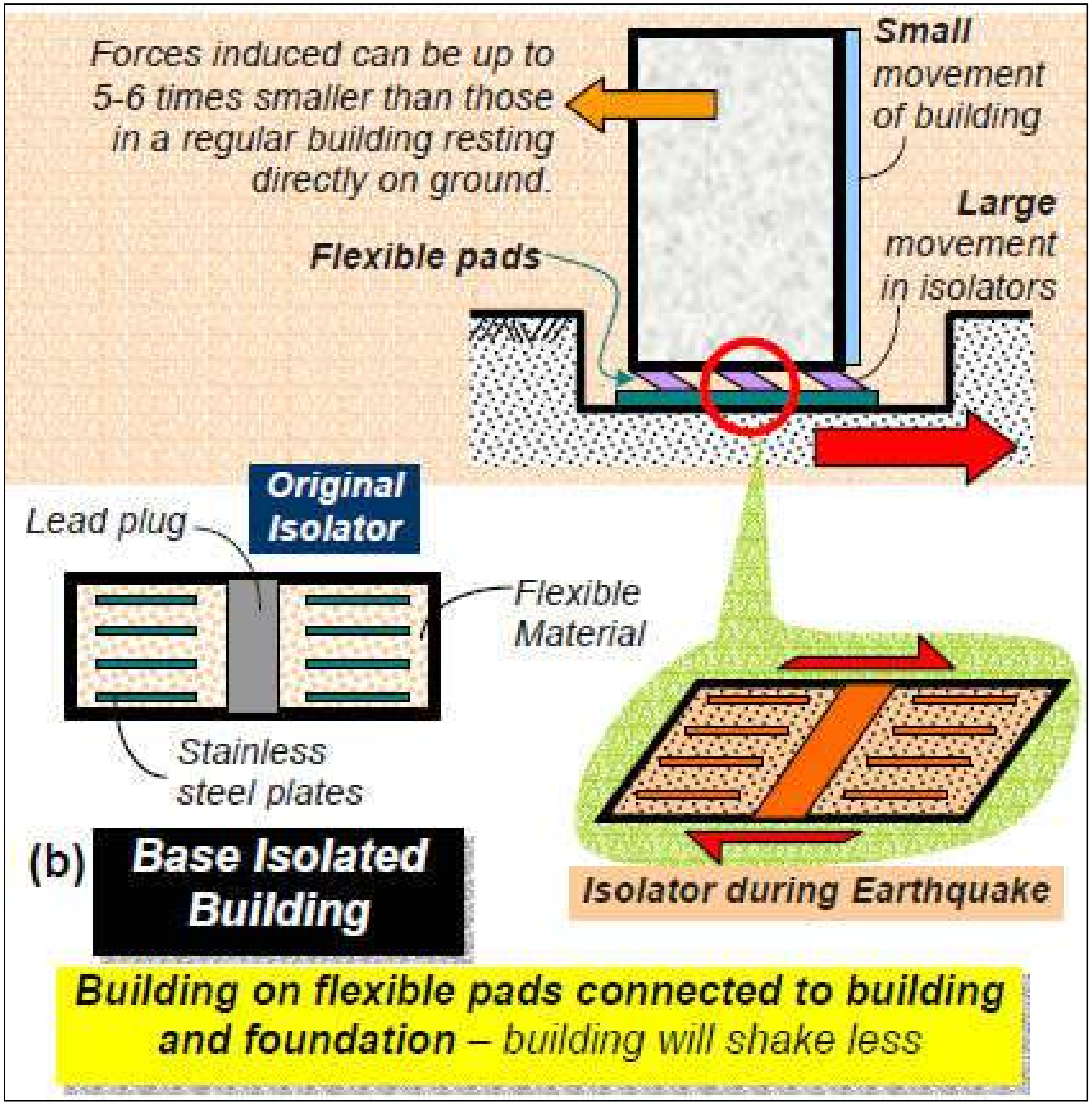


Base Isolation

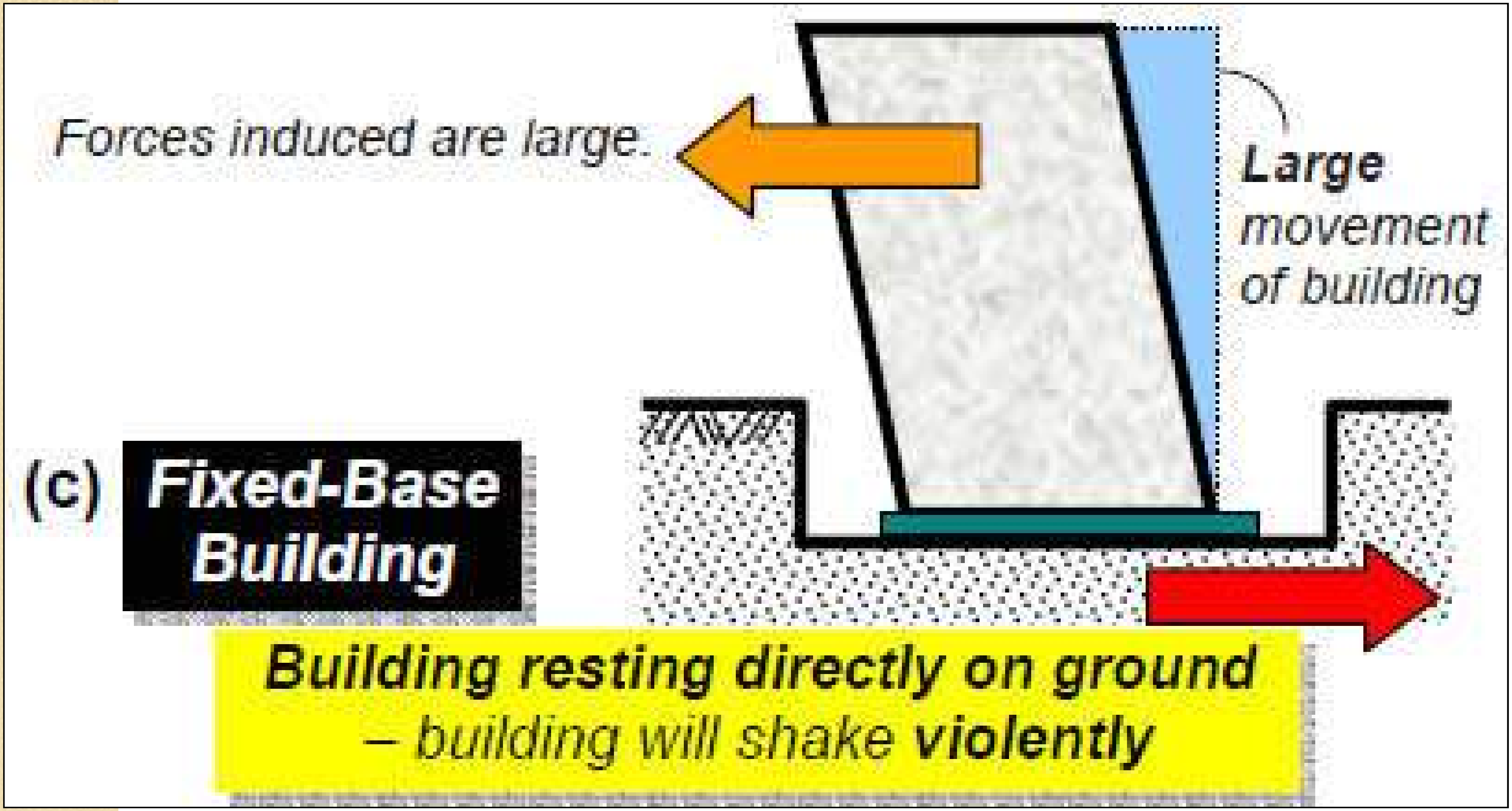
Base Isolation – Shock absorber between Structure & ground



Base Isolation



Base Isolation – Shock absorber between Structure & ground



Base Isolators under a building

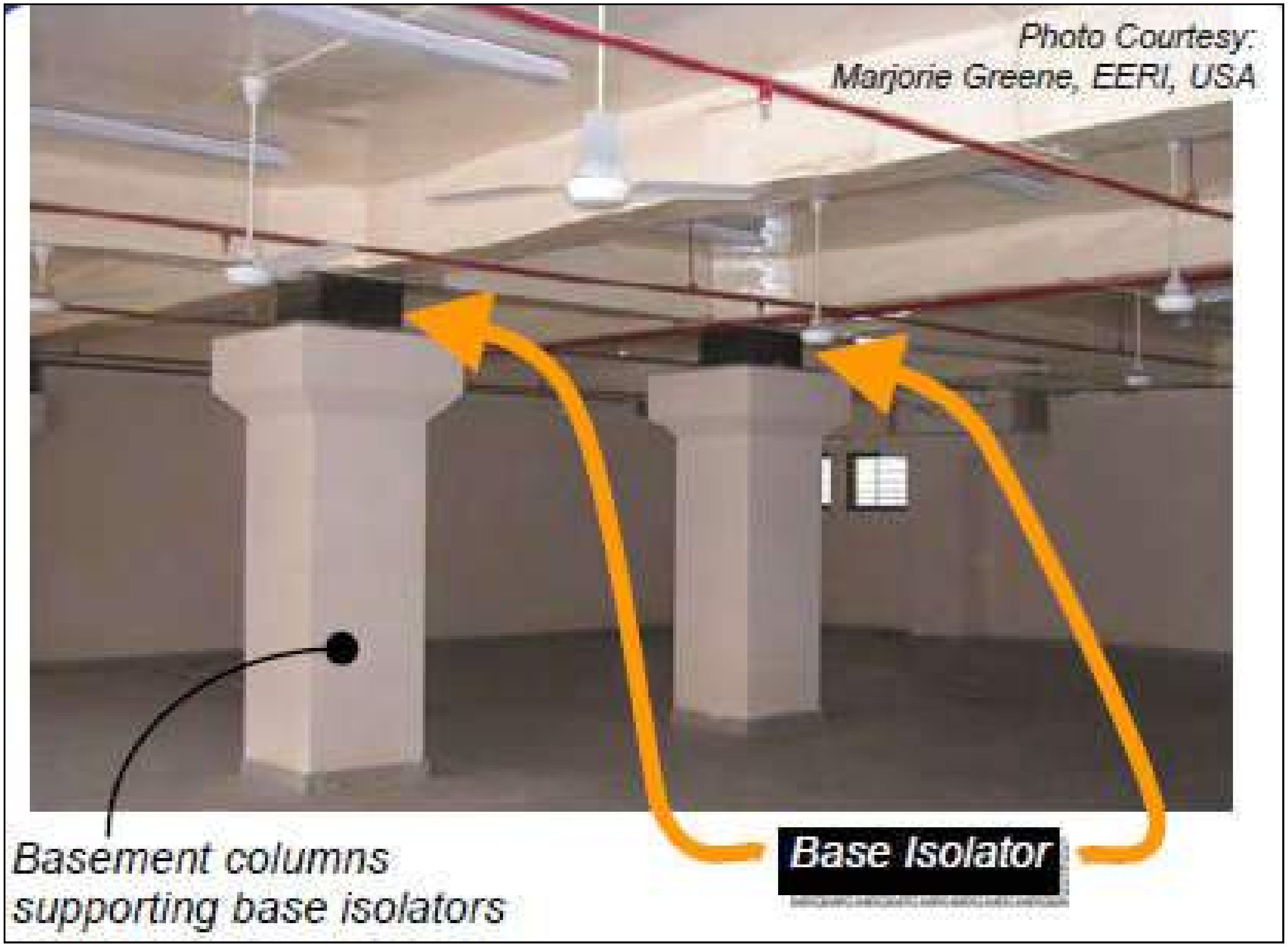
Computer Center for Tohoku Electric Power Company in Sendai, Miyako prefecture, Japan

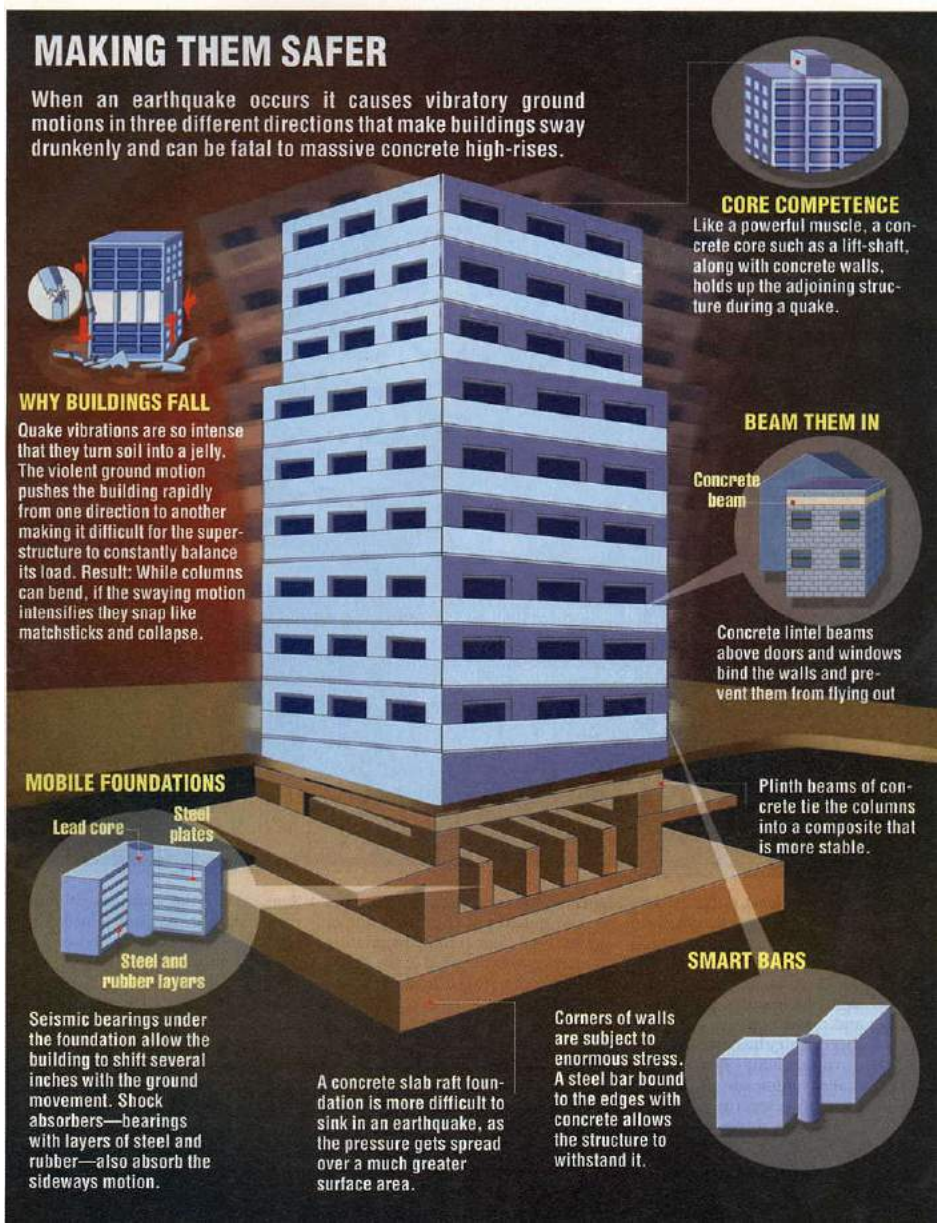
Six storey, 47000 sq.m, 120 elastomeric isolators, base acceleration during Kobe (1995) earthquake 0.41g, reduced to 0.13g at 6th floor

Foothill communities Law & Justice Center, Los Angeles, Built in 1985, Four Storey + basement, 98 base isolators of multilayered natural rubber bearings reinforced with steel plates

Fire Department Command & Control facility, Los Angeles County, 1990

Base Isolation above Basement floor in 4 storeyed Bhuj Hospital





Earthquake Resistant Construction

Thank You