EARTH QUAKE

The earthquake intensity measurement and Earthquake study

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The Earthquake Measurement Intensity

The Modified Mercalli Intensity Scale (MM)

The Modified Mercalli Scale measures the intensity of an earthquake. The intensity of an earthquake is its destructiveness due to the amount of ground movement, at a particular place. The table below gives Modified Mercalli Scale intensities that are typically observed at locations near the epicenter of an earthquake.

I. Instrumental	Generally not felt by people unless in favourable conditions.
II. Weak	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Stationary motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV. Moderate	Felt indoors by many people, outdoors by few people during the day. At night, some awaken. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Stationary motor cars rock noticeably. Dishes and windows rattle alarmingly.
V. Rather Strong	Felt outside by most, may not be felt by some outside in non-favourable conditions. Dishes and windows may break and large bells will ring. Vibrations like large train passing close to house.
VI. Strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.
VIII. Destructive	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved.
IX. Violent	General panic; damage considerable in specially designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Intense	Some well built wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent.
XI. Extreme	Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII. Cataclysmic	Total destruction - Everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or levelled by several meters. In some cases, even the routes of rivers are changed.

(References)

The Richter Scale

The Richter Scale, also known as the Richter Magnitude Scale, is an alternative measurement of the magnitude of earthquakes. This scale was developed by Charles F. Richter of the California Institute of Technology in 1935. It is a logarithmic scale that ranges from 0 to over 10. Each unit of increase on the Richter Scale corresponds to an increase by a factor of 10. Magnitude on the Richter Scale is expressed in the form of whole numbers and decimal fractions.

The magnitude of an earthquake is measured using the instrument known as a seismograph. The magnitude is determined by the Richter Scale from the logarithm of the amplitude of the waves, that are recorded by the seismograph. For example, a moderate earthquake shows a magnitude of 5.4 on the scale, whereas a strong one shows the magnitude of just 6.2. This is because each whole number on the Richter Scale corresponds to a tenfold increase in the measured amplitude. Based on the values expressed by the Richter Scale, earthquakes with a magnitude of about 2.0 or less are generally referred to as micro earthquakes and are not commonly felt by people. Moderate earthquakes are the ones with a magnitude of about 4.5. Several such shocks are experienced in a year. Earthquakes with magnitude of 8.0 or higher are termed as great earthquakes and generally occur once in a year, in some part of the world.

Richter Magnitude (at the epicentre)	Description	Effects	Frequency of Occurrence Worldwide
0 - 2.0	Micro	Not felt	About 8 000 per day
2.0 - 2.9	Minor	Not felt but recorded on seismographs	About 1 000 per day
3.0 - 3.9	Minor	Often felt, but causes no damage	49 000 per year
4.0 - 4.9	Light	Often felt with shaking and rattling noises, but causes no significant damage	6 200 per year
5.0 - 5.9	Moderate	Can cause major damage, especially to poorly constructed buildings	800 per year
6.0 - 6.9	Strong	Can be destructive in areas up to about 160 km from the epicentre	120 per year
7.0 - 7.9	Major	Can cause serious damage	18 per year
8.0 - 8.9	Great	Causes serious damage over large areas	1 per year
9.0 - 9.9	Great	Can be very destructive in areas several kilometres across	1 per year
10.0 and more	Epic	Has never been recorded	Extremely Rare

(Reference)

Comparison between the Richter and Mercalli scales

The effects of any one earthquake can vary greatly from place to place, so there may be many Mercalli intensity values measured for the same earthquake. These values can be best displayed using a contoured map. Each earthquake, on the other hand, has only one magnitude. The table below is a rough guide to the degrees of the Modified Mercalli Intensity Scale in comparison to the Richter Earthquake Magnitude Scale.

Richter Magnitude	Typical Maximum Modified Mercalli Intensity
1.0 - 3.0	I
3.0 - 3.9	II - III
4.0 - 4.9	IV - V
5.0 - 5.9	VI - VII
6.0 - 6.9	VII - IX
7.0+	VIII or higher

Magnitude	Description	Mercalli intensity	Average earthquake effects	Average frequency of occurrence (estimated)
Less than 2.0	Micro	I	Microearthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs.[15]	Continual/several million per year
2.0–2.9	Minor	I to II	Felt slightly by few to many people. No damage to buildings.	Over one million per year
3.0–3.9		II to IV	Often felt by at least some people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Many people to everyone feel the earthquake. Slightly felt outside. Generally causes none to slight damage. Moderate to significant damage very unlikely. Some falling of objects.	10,000 to 15,000 per year
5.0–5.9	Moderate	VI to VIII	Can cause moderate to major damage to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. Deaths can depend on the effects.	1,000 to 1,500 per year

6.0–6.9	Strong	VII to X	Can be damaging/destructive in populated areas in regions of any size. Damage to many to all buildings. Earthquake-resistant structures survive with slight to moderate damage. Poorly-designed structures receive moderate to severe damage. Felt in wider areas; likely to be hundreds of miles/kilometers from the epicenter. Can be damaging of any level further from the epicenter. Strong to violent shaking in epicentral area. Death toll between none and 25,000.	100 to 150 per year
7.0–7.9	Major	VIII to XII[16]	Causes damage to many to all buildings over areas. Some buildings partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt in enormous areas. Death toll is usually between none and 250,000.	10 to 20 per year
8.0–8.9	Great		Major damage to poorly-designed buildings and most structures, likely to be destroyed. Will cause moderate to heavy damage to normal and earthquake-resistant buildings. Damaging in big areas. Possible total destruction. Definitely felt in unusually large regions. Death toll is usually between 100 and one million; however some earthquakes this magnitude have killed none.	One per year (rarely none, two, or over two per year)
9.0–9.9			Severe damage to all or most buildings with massive destruction. Damage and shaking extends to distant locations. Ground changes. Death toll usually between 1,000 and several million.	One per 5 to 50 years
10.0 or over	Massive	X to XII	Colossal damage/devastation across enormous areas. Destroys all buildings fairly easily and quickly. Will be felt at extremely distant from the epicenter (thousands of miles away, worldwide). Death toll can easily exceed over 25,000 people. Large ground changes. Effects will last for an extremely long time. An earthquake of this magnitude has never been recorded.	None per year (unknown, extremely rare, or impossible/may not be possible)

studies have shown that the two most important geologic characteristics that affect levels of ground shaking during an earthquake are:

- *the softness of the ground at a site, and*
- *the total thickness of sediments above hard bedrock.*

the softer and thicker the soil, the greater the shaking or amplification of waves produced by an earthquake.

seismic waves travel faster through hard rock than through softer rock and sediments. As the waves pass from harder to softer rocks, the waves slow down and their amplitude increases. Thus shaking tends to be stronger at sites with softer surface layers, where seismic waves move more slowly. Ground motion above an unconsolidated landfill or soft soils can be more than 10 times stronger than at neighboring sites on rock for small ground motions.
the effect of the underlying soil on the local amplification is called the site effect.

Soil Types and Shaking Amplification

One contributor to the site amplification is the velocity at which the rock or soil transmits shear waves (S-waves). Shaking is stronger where the shear wave velocity is lower. The National Earthquake Hazards Reduction Program (NEHRP) has defined 5 soil types based on their shear-wave velocity (Vs). We have modified these definitions slightly, based on studies of earthquake damage in the Bay Area. The modified definitions are as follows:

Soil type A	*Vs > 1500 m/sec*	Includes unweathered intrusive igneous rock. Occurs infrequently in the bay area. We consider it with type B (both A and B are represented by the color blue on the map). Soil types A and B do not contribute greatly to shaking amplification.
Soil type B	*1500 m/sec > Vs > 750 m/sec*	Includes volcanics, most Mesozoic bedrock, and some Franciscan bedrock. (Mesozoic rocks are between 245 and 64 million years old. The Franciscan Complex is a Mesozoic unit that is common in the Bay Area.)
Soil Type C	*750 m/sec > Vs > 350 m/sec*	Includes some Quaternary (less than 1.8 million years old) sands, sandstones and mudstones, some Upper Tertiary (1.8 to 24 million years old) sandstones, mudstones and limestone, some Lower Tertiary (24 to 64 million years old) mudstones and sandstones, and Franciscan melange and serpentinite.
Soil Type D	*350 m/sec > Vs > 200 m/sec*	Includes some Quaternary muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected.
Soil Type E	*200 m/sec > Vs*	Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.

Earthquakes cause massive vibrations in the Earth's crust. This can cause a number of problems in the ground, which in turn becomes a hazard to all life and property. The effect depends on the geology of soil and topography of the land.

1964 Niigata earthquake

Ground Motion

The most destructive of all earthquake hazards is caused by seismic waves reaching the ground surface at places where human-built structures, such as buildings and bridges, are located. When seismic waves reach the surface of the earth at such places, they give rise to what is known as strong ground motion. Strong ground motions cause's buildings and other structures to move and shake in a variety of complex ways. Many buildings cannot withstand this movement and suffer damages of various kinds and degrees.

Most deaths, injuries, damages and economic losses caused by earthquake result from ground motion acting on buildings and other manmade structures not capable of withstanding such movement.

Ground Failure

Strong ground motion is also the primary cause of damages to the ground and soil upon which, or in which, people must build. These damages to the soil and ground can take a variety of forms: cracking and fissuring and weakening, sinking, settlement and surface fault displacement.

One of the most important types of ground failure is known as liquefaction. Liquefaction takes place when loosely packed, water-logged sediments at or near the ground surface lose their strength in response to strong ground shaking. Liquefaction occurring beneath buildings and other structures can cause major damage during earthquakes.

Ground Sliding

Strong ground motion is also the primary cause of damages to the ground and soil upon which, or in which, people must build. These damages to the soil and ground can take a variety of forms: cracking and fissuring and weakening, sinking, settlement and surface fault displacement.

Ground Tilting

Sometimes, due to earthquake, there is tilting action in the ground. This causes plain land to tilt, causing excessive stresses on buildings, resulting in damage to buildings.

Differential Settlement

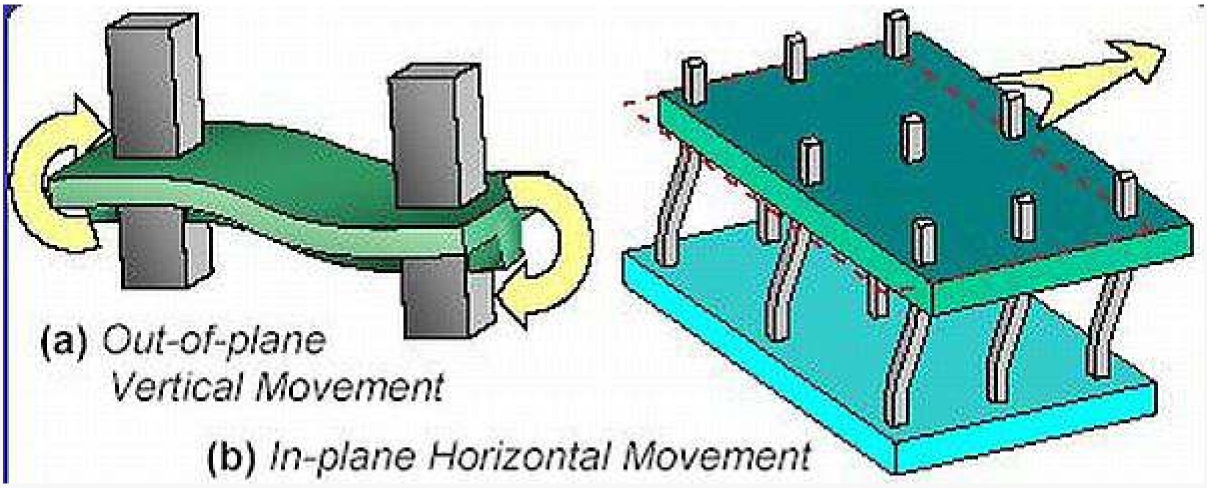
If a structure is built upon soil which is not homogeneous, then there is differential settlement, with some part of the structure sinking more than other. This induces excessive stresses and causes cracking.

Soil Liquefaction

During an earthquake, significant damage can result due to instability of the soil in the area affected by internal seismic waves. The soil response depends on the mechanical characteristics of the soil layers, the depth of the water table and the intensities and duration of the ground shaking. If the soil consists of deposits of loose granular materials it may be compacted by the ground vibrations induced by the earthquake, resulting in large settlement and differential settlements of the ground surface. This compaction of the soil may result in the development of excess hydrostatic pore water pressures of sufficient magnitude to cause liquefaction of the soil, resulting in settlement, tilting and rupture of structures

How Earthquakes affect Reinforced Concrete Buildings

A typical RC building is made of horizontal members (beams and slabs) and vertical members (columns and walls), and supported by foundations that rest on ground. The system comprising of RC frame. The RC frame participates in resting the earthquake forces. Earthquake shaking generates inertia forces in the building, which are proportional to the building mass. Since most of the building mass is present at floor levels, earthquake induced inertia forces primarily develop at the floor levels. These forces travel downwards - through slabs and beams to columns and walls, and then to foundations from where they are dispersed to ground. As inertia forces accumulate downwards from the top of the building, the columns and walls at lower storey experience higher earthquake- induced forces and are therefore designed to be stronger than those in storey above.



Floor Bends with he Beam but moves all columns at that level together

Role of Floor Slabs and Masonry

Floor slabs are horizontal plate like elements, which facilitate functional use of buildings. Usually, beams and slabs at one storey level are cast together. In residential multi-story buildings, thickness of slabs is only about 110-150mm. when beams bend in the vertical direction during earthquakes, these thin slabs bend along with them (fig2a). And, when beams move with columns in the horizontal direction, the slab usually forces the beams to move together with it. In most buildings, the geometric distortion of slab is negligible in the horizontal plane; this behavior is known as the rigid diaphragm action .

After columns and floors in a RC building are cast and the concrete hardens, vertical spaces between columns and floors are usually filled-in with masonry walls to demarcate a floor into functional spaces (rooms). Normally, these masonry walls, also called infill walls, are not connected to surrounding RC columns and beams. When columns receive horizontal forces at floor levels, they try to move in horizontal direction, but masonry walls tend to resist this movement. Due to their heavy weight and thickness, these walls attract rather large horizontal forces. However, since masonry is a brittle material, these walls develop cracks once their ability to carry horizontal load is exceeded. Thus masonry walls is enhanced by mortars of good strength, making proper masonry courses, and proper packing of gaps between RC frame and masonry infill walls.

Effects of Horizontal Earthquake Vibrations

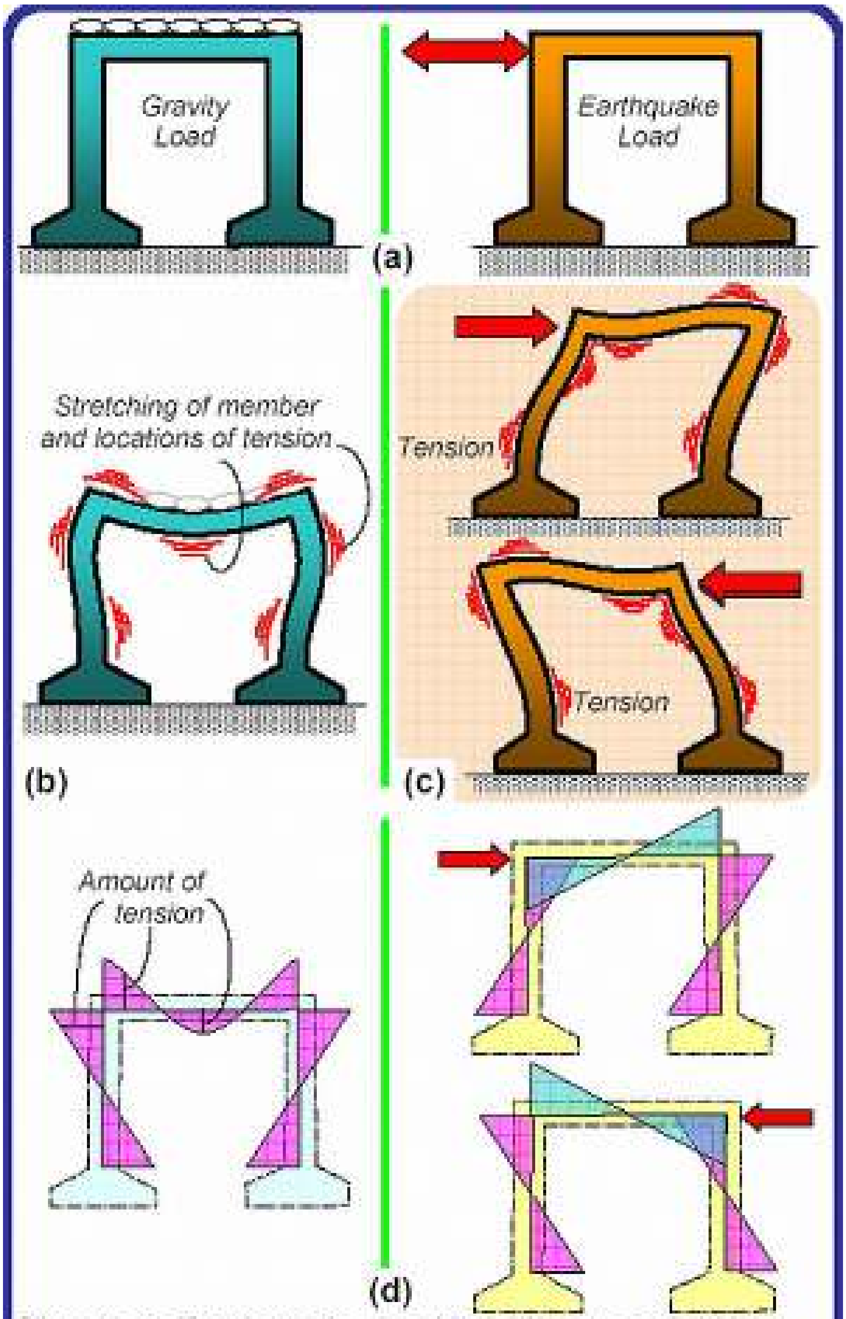


Figure 4: Earthquake shaking reverses tension and compression in members – *reinforcement is required on both faces of members.*

Under gravity loads, tension in the beams is at the bottom surface of the beam in the central location and is at the top surface at the ends. The level of bending moment due to earthquake loading depends on severity of shaking and can exceed that due to gravity loading. Thus, under strong earthquake shaking, the beam ends can develop tension on either of the top and bottom faces. Since concrete cannot carry this tension, steel bars are required on both faces of beams to resist reversals of bending moment.

Strength Hierarchy

For a building to remain safe during earthquake shaking, columns should be stronger than beams, and foundations should be stronger than columns. If columns are made weaker, they suffer severe local damage, at the top and bottom of a particular storey.

Seismic Base Isolation Technique for Building Earthquake Resistance

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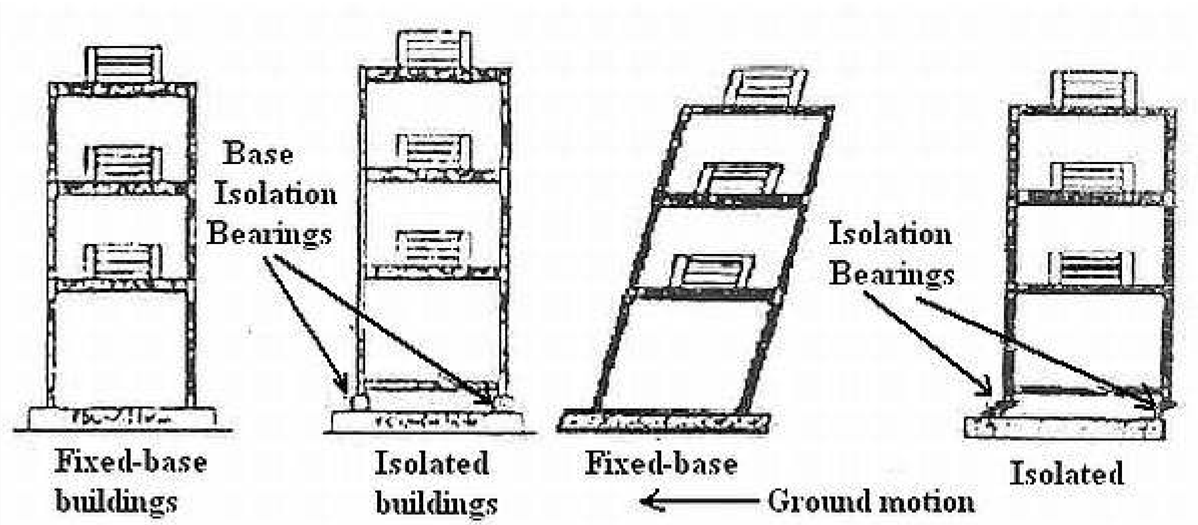
It is easiest to see the principle at work by referring directly to the most widely used of these advanced techniques, known as base isolation. A base isolated structure is supported by a series of bearing pads, which are placed between the buildings and building foundation.

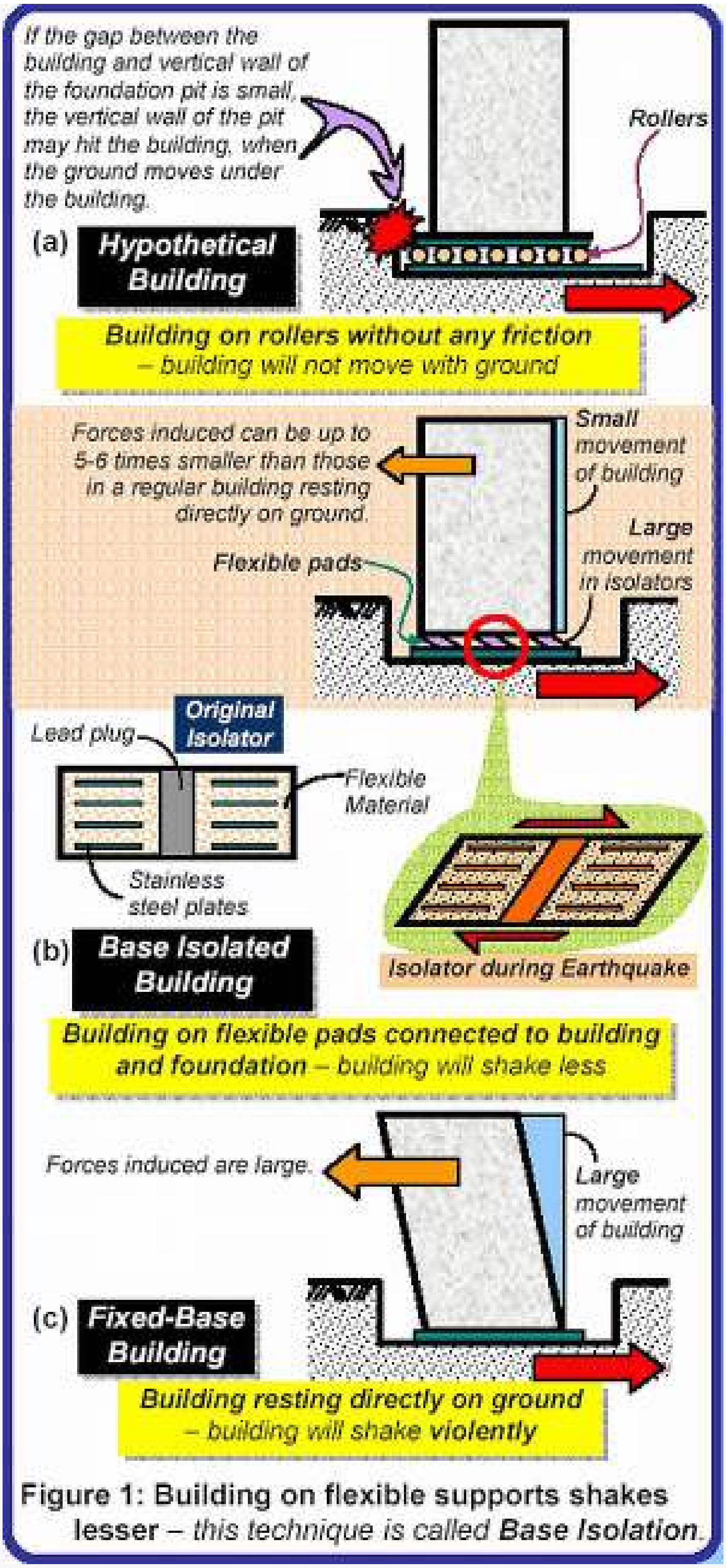


Base Isolation Technique

The concept of base isolation is explained through an example building resting on frictionless rollers. When the ground shakes, the rollers freely roll, but the building above does not move. Thus, no force is transferred to the building due to the shaking of the ground; simply, the building does not experience the earthquake.

Now, if the same building is rested on the flexible pads that offer resistance against lateral movements (fig 1b), then some effect of the ground shaking will be transferred to the building above. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building (fig 1c). The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. The main feature of the base isolation technology is that it introduces flexibility in the structure.

As a result, a robust medium-rise masonry or reinforced concrete building becomes extremely flexible. The isolators are often designed, to absorb energy and thus add damping to the system. This helps in further reducing the seismic response of the building. Many of the base isolators look like large rubber pads, although there are other types that are based on sliding of one part of the building relative to other. Also, base isolation is not suitable for all buildings. Mostly low to medium rise buildings rested on hard soil underneath; high-rise buildings or buildings rested on soft soil are not suitable for base isolation.



Concept of Base Isolation

Lead-rubber bearings are the frequently-used types of base isolation bearings. A lead rubber bearing is made from layers of rubber sandwiched together with layers of steel. In the middle of the solid lead “plug”. On top and bottom, the bearing is fitted with steel plates which are used to attach the bearing to the building and foundation. The bearing is very stiff and strong in the vertical direction, but flexible in the horizontal direction.

How it Works

To get a basic idea of how base isolation works, first examine the above diagram. This shows an earthquake acting on base isolated building and a conventional, fixed-base, building. As a result of an earthquake, the ground beneath each building begins to move. . Each building responds with movement which tends towards the right. The buildings displacement in the direction opposite the ground motion is actually due to inertia. The inertia forces acting on a building are the most important of all those generated during an earthquake.

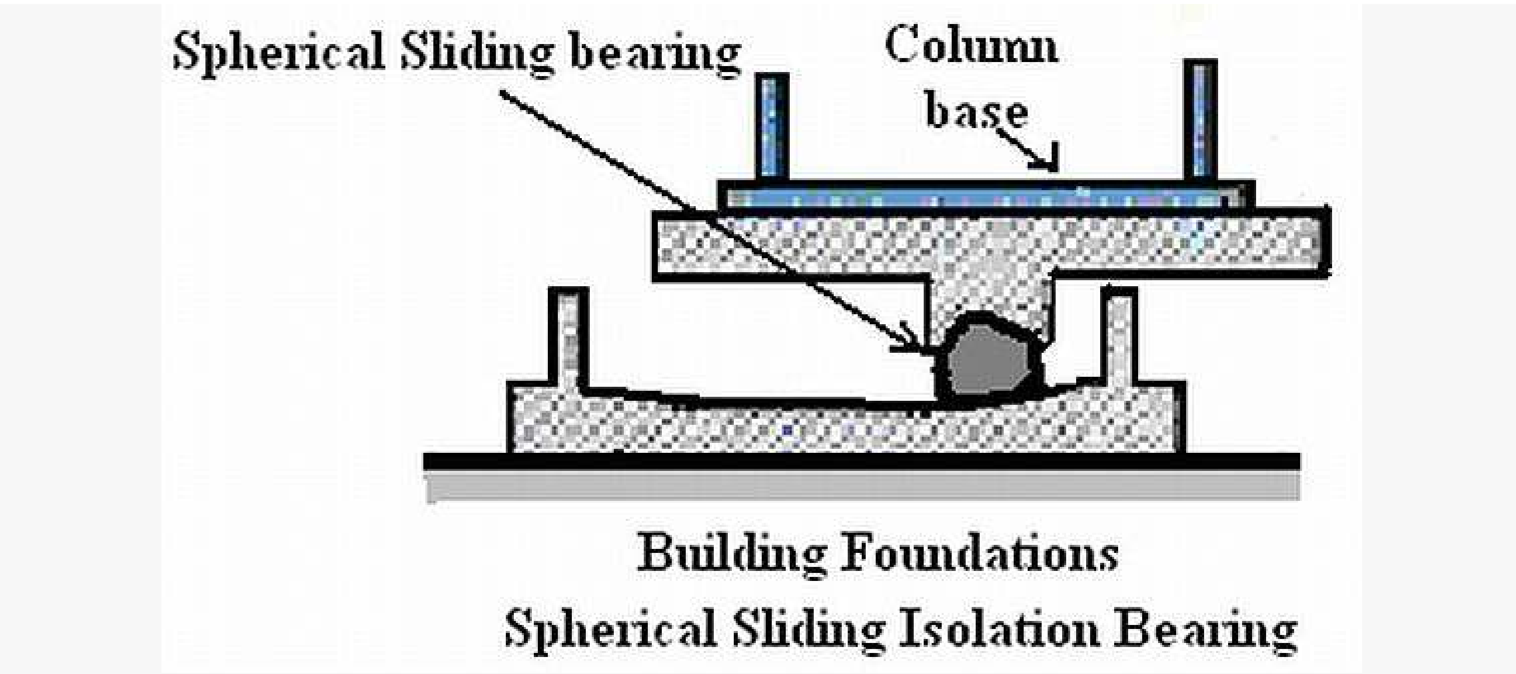
In addition to displacing towards right, the un-isolated building is also shown to be changing its shape from a rectangle to a parallelogram. We say that the building is deforming. The primary cause of earthquake damage to buildings is the deformation which the building undergoes as a result of the inertial forces upon it.

Response of Base Isolated Buildings

The base-isolated building retains its original, rectangular shape. The base isolated building itself escapes the deformation and damage-which implies that the inertial forces acting on the base isolated building have been reduced. Experiments and observations of base-isolated buildings in earthquakes to as little as ¼ of the acceleration of comparable fixed-base buildings.

Acceleration is decreased because the base isolation system lengthens a buildings period of vibration, the time it takes for a building to rock back and forth and then back again. And in general, structures with longer periods of vibration tend to reduce acceleration, while those with shorter periods tend to increase or amplify acceleration.

Spherical Sliding Base Isolation

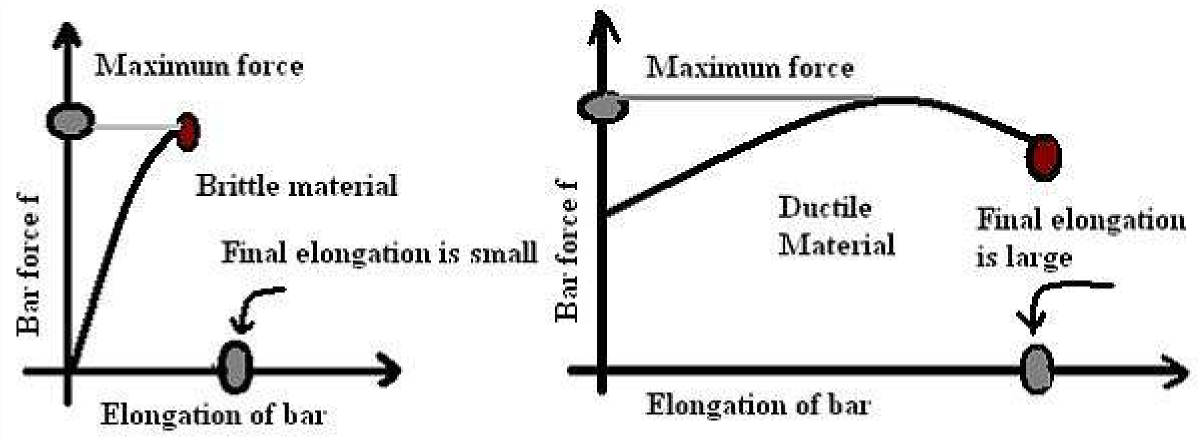


Spherical Sliding Base Isolation

Spherical sliding isolation systems are another type of base isolation. The building is supported by bearing pads that have a curved surface and low friction. During an earthquake the building is free to slide on the bearings. Since the bearings have a curved surface, the building slides both horizontally and vertically. The forces needed to move the building upwards limits the horizontal or lateral forces which would otherwise cause building deformations. Also by adjusting the radius of the bearings curved surface, this property can be used to design bearings that also lengthen the buildings period of vibration

Concept of Earthquake Resistant Engineering

If two bars of same length and same cross-sectional area - one made of ductile material and another of a brittle material. And a pull is applied on both bars until they break, then we notice that the ductile bar elongates by a large amount before it breaks, while the brittle bar breaks suddenly on reaching its maximum strength at a relative small elongation. Amongst the materials used in building construction, steel is ductile, while masonry and concrete are brittle.



Comparison of Brittle and Ductile Building materials

The correct building components need to be made ductile. The failure of columns can affect the stability of building, but failure of a beam causes localized effect. Therefore, it is better to make beams to be ductile weak links then columns. This method of designing RC buildings is called the strong-column weak-beam design method. Special design provisions from IS: 13920-1993 for RC structures ensures that adequate ductility is provided in the members where damage is expected.

Quality Control in Construction

The capacity design concept in earthquake resistant design of buildings will fail if the strengths of the brittle links fall below their minimum assured values. The strength of brittle construction materials, like masonry and concrete is highly sensitive to the quality of construction materials. Workmanship, supervision, and construction methods. Similarly, special care is needed in construction to ensure that the elements meant to be ductile are indeed provided with features that give adequate ductility. Thus, strict adherence to prescribed standards, of construction materials and processes is essential in assuring an earthquake resistant building. Regular testing of materials to laboratories, periodic training of workmen at professional training houses, and on-site evaluation of the technical work are elements of good quality control.

Popular Earthquake Resistant Techniques

Conventional seismic design attempts to make buildings that do not collapse under strong earthquake shaking, but may sustain damage to non-structural elements (like glass facades) and to some structural members in the building. This may render the building non-functional after the earthquake, which may be problematic in some structures, like hospitals, which need to remain functional in the aftermath of earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Buildings with such improved seismic performance usually cost more than the normal buildings do.

Two basic technologies are used to protect buildings from damaging earthquake effects. These are **Base Isolation Devices** and **Seismic Dampers.** The idea behind base isolation is to detach (isolate) the building from the ground in such a way that earthquake motions are not transmitted up through the building or at least greatly reduced. Seismic dampers are special devices introduced in the buildings to absorb the energy provided by the ground motion to the building (much like the way shock absorbers in motor vehicles absorb due to undulations of the road)

Earthquake Resistant Structures by Planning and Design Approach

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Earthquakes have plagued man for millennia. It is a destructive force, which was once upon a time declared to be wrath of God for infidelity of human beings. But today, we understand what causes earthquakes, and can design effective mechanisms to mitigate the effects of earthquakes.

Haiti Earthquake 2010

Basically, there is the Conventional approach to achieving earthquake resistance, then there is the basic approach, and nowadays, there are Active Control Devices which can counteract the effects of earthquakes on buildings.

Conventional Approach

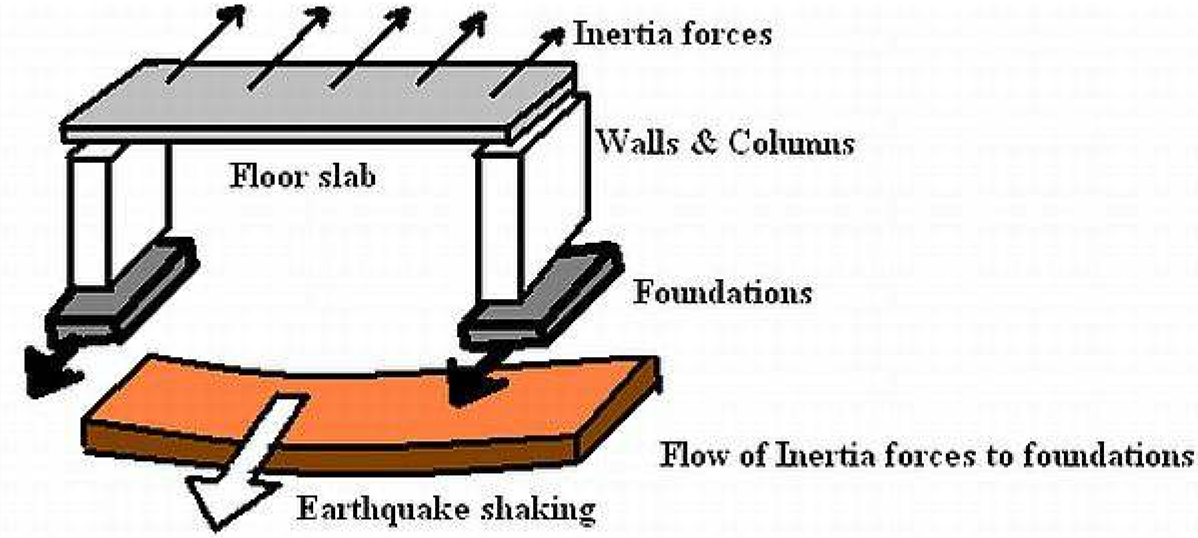
Design depends upon providing the building with strength, stiffness and inelastic deformation capacity which are great enough to withstand a given level of earthquake-generated force. This can be accomplished by selection of an appropriate structural configuration and careful detailing of structural members, such as beams and columns, and the connections between them.

Basic Approach

Design depends upon underlying more advanced techniques for earthquake resistance is not to strengthen the building, but to reduce the earthquake generated forces acting upon it. This can be accomplished by de-coupling the structure from seismic ground motion it is possible to reduce the earthquake induced forces in it by three ways.

1. Increase natural period of structures by Base Isolation.
2. Increase damping of system by Energy Dissipation Devices.
3. Mitigate earthquake effects completely by using Active Control Devices.

Flow of Inertia Forces to Foundations



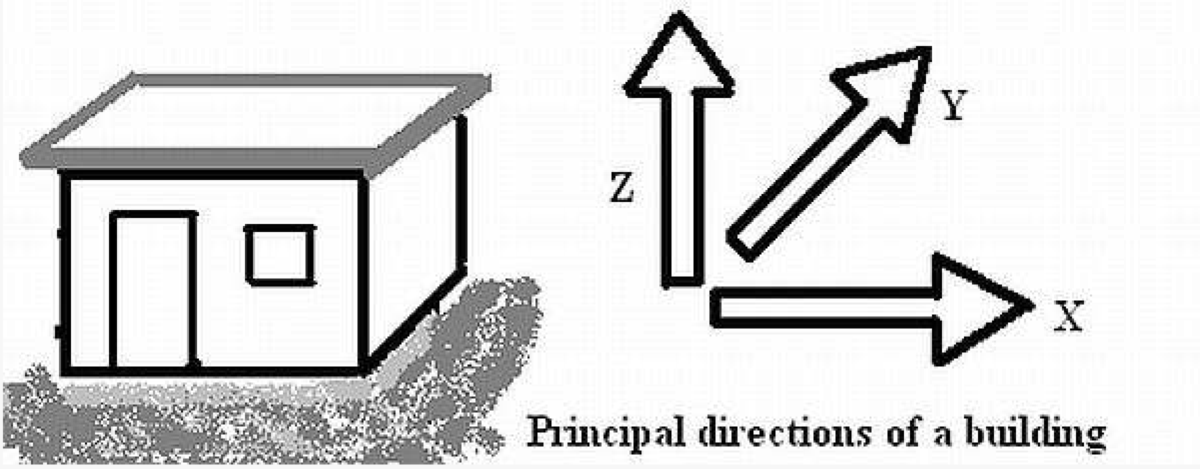
Flow of Inertia Forces to Foundation

Under horizontal shaking of ground, horizontal inertia forces are generated at a level of the mass of the structure (usually situated at the floor levels). These lateral inertia forces are transferred by the floor slab to the walls or the columns, to the foundations, and finally to the soil system underneath. So, each of this structural elements (floor slabs, walls, columns, and foundations) and the connections between them must be designed to safely transfer these inertia forces through them.

Walls or columns are the most critical elements in transferring the inertia forces. But, in traditional construction, floor slabs and beams receive more care and attention during design and construction, than walls and columns. Walls are relatively thin and often made of brittle material like masonry.

Horizontal and Vertical Shaking of a Structure

Earthquake cause shaking of ground in all three directions – along the two horizontal directions (X and Y, say), and the vertical direction (Z, say). Also during the earthquake, the ground shakes randomly back and forth (– and +) along each of this X, Y and Z directions.



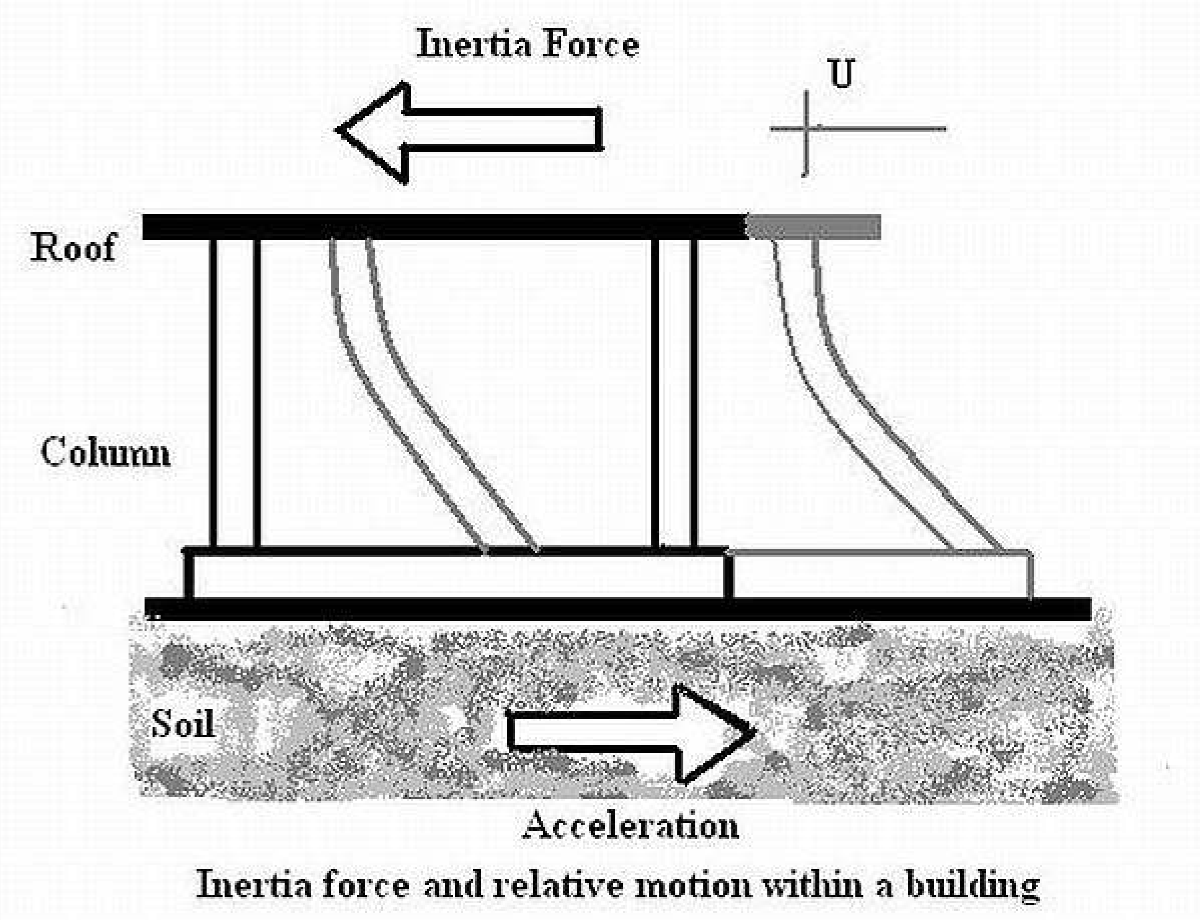
Horizontal and Vertical Shaking

All structures are primarily designed to carry the gravity loads, i.e. they are designed for a force equal to the mass M (this includes mass due to own weight and imposed loads) times the acceleration due to gravity g acting in vertical downward direction (– Z). The downward force Mg is called the gravity load. The vertical acceleration during ground shaking either adds or subtracts from the acceleration due to gravity. Since factors of safety are used in the design of structures to resist the gravity load, usually most structures tend to be adequate against vertical shaking.

However, horizontal shaking along X and Y directions (both + and – directions of each) remains a concern. Structures designed for gravity loads, in general, may not be able to safely sustain the effects of horizontal earthquake shaking.

Effects of Deformations in Structures

The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns. These forces generated in the columns can also be understood in another way. During earthquake shaking, the columns undergo relative movement between their ends.

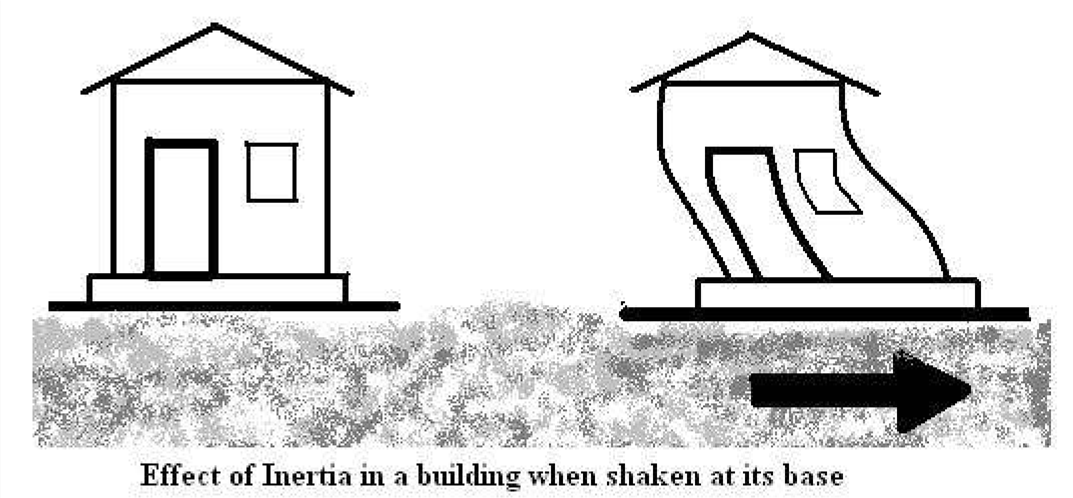


Deformation in a Structure

In the figure above, this movement is shown as quantity u between the roof and the ground. But, given a free option, columns would like to come back to the straight vertical position, i.e. columns resist deformations. In the straight vertical position, the columns carry no horizontal earthquake force through them. But, when forced to bend, they develop internal forces. The larger is the horizontal displacement u between the top and bottom of the column, the larger this internal force in columns. Also, the stiffer the columns are (i.e. bigger is the column size), larger is the force. For this reason, these internal forces in the columns are called stiffness forces. In fact, the stiffness force in the columns is the column stiffness times the relative displacement between its ends

Inertial Forces in a Structure

An earthquake causes shaking of ground. So a building resting on it will experience motion at its base. From Newton's first law of motion, even though the base of the building 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.



Inertial Forces in a Structure

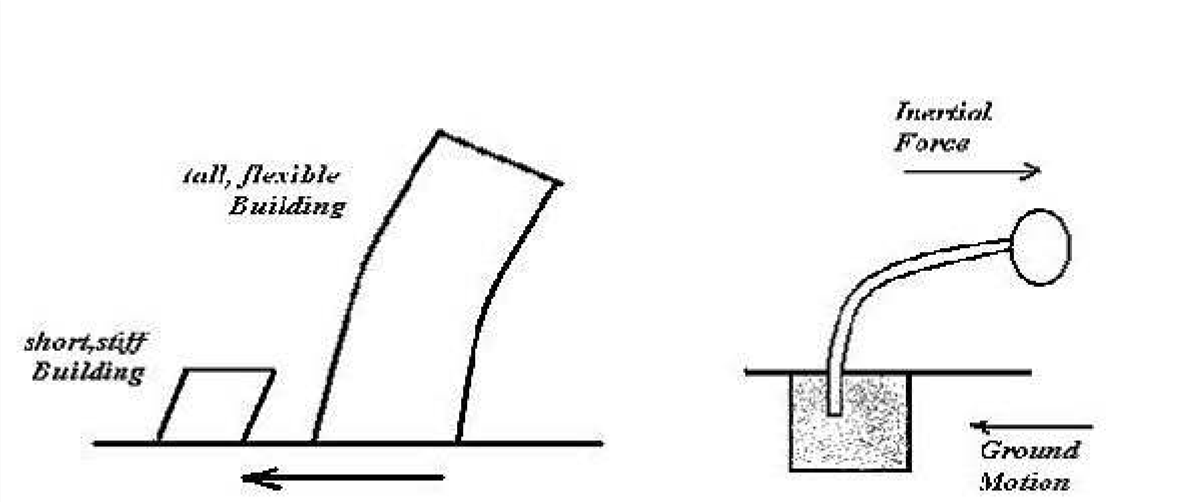
This is much like the situation that you are faced with when the bus you are standing in suddenly starts, your feet move with the bus, but your upper body tends to stay back making you fall backwards!

This tendency to continue to remain in the previous position is known as inertia. In the building since the walls or columns are flexible, the motion of roof is different from that of ground.

Consider a building, whose roof is supported on columns. Coming back to the analogy of yourself on the bus; when the bus suddenly starts, you are thrown backwards as if someone has applied a force on the upper body. Similarly, when the ground moves, even the building is thrown backwards, and the roof experiences a force, called inertia force. If the roof has the mass M and experiences an acceleration a, then from Newton's second law of motion, the inertia force F1 is mass M times acceleration a, and its direction is opposite to that of the acceleration.

Building Stiffness and Flexibility | Earthquake Engineering

The taller a building, the longer its natural period tends to be. But the height of a building is also related to another important structural characteristic: the building flexibility. Taller buildings tend to be more flexible than short buildings. (Only consider a thin metal rod. If it is very short, it is difficulty to bend it in your hand. If the rod is somewhat longer, and of the same diameter, it becomes much easier to bend. Buildings behave similarly) we say that a short building is stiff, while a taller building is flexible. (Obviously, flexibility and stiffness are really just the two sides of the same coin. If something is stiff, it isn't flexible and vice-versa).



Displacement of Building according to their Height & Stiffness

Ductility is the ability to undergo distortion or deformation without resulting in complete breakage or failure. To see how ductility can improve a building's performance during an earthquake, see the above figure. In response to the ground motion, the rod bends but does not break. (of course, metals in general are more ductile than materials such as stone, brick and concrete) The ductility of a structure is in fact one of the most important factors affecting its earthquake performance. One of the primary tasks of an engineer designing a building to be earthquake resistant is to ensure that the building will possess enough ductility to withstand the size and types of earthquakes it is likely to experience during its lifetime.

Effect of Earthquakes on Structures

Violent Ground Motion During Earthquakes

The seismic waves travel for great distances before finally losing most of their energy. At some time after their generation, these seismic waves will reach the earth's surface, and set it in motion, which we surprisingly refer to as earthquake ground motion. When this earthquake ground motion occurs beneath a building and when it is strong enough, it sets the building in motion, starting with the buildings foundation, and transfers the motion throughout the rest of building in a very complex way. These motions in turn induce forces which can produce damage.

Haiti Earthquake Damage 2010

Real earthquake ground motion at a particular building site is vastly more complicated than the simple wave form. Here it's useful to compare the surface of ground under an earthquake to the surface of a small body of water, like a pond. You can set the surface of a pond in motion – by throwing stones into it. The first few stones create a series of circular waves, which soon being to collide with one another. After a while, the collisions, which we term interference patterns, are being to predominate over the pattern of circular waves. Soon the entire surface of water is covered by ripples, and you can no longer make out the original wave forms. During an earthquake, the ground vibrates in a similar manner, as waves of different frequencies and amplitude interact with one another.

Building Frequency and Period

The characteristics of earthquake ground motions which have the greatest importance for buildings are the duration, amplitude (of displacement, velocity and acceleration) and frequency of ground motion.

Frequency

Frequency is defined as the number of complete cycles of vibration made by the wave per second.

Here we can consider a complete vibration to be the same as the distance between one crest of the wave and the next, in other words one full wavelength. Surface ground motion at the building site, then, is actually a complex superposition of vibration of different frequencies. We should also mention that at any given site some frequencies usually predominate.

The response of building to the ground motion is as complex as the ground motion itself, yet typically quite different. It also begins to vibrate in a complex manner, and because it is now a vibratory system, it also posses a frequency content. However, the buildings vibrations tend to center around one particular frequency, which is known as its natural or fundamental frequency. In general…

The shorter a building is, the higher its natural frequency. The taller the building is, the lower its natural frequency

Period

The natural period is the time it takes for the building to make one complete vibration.

The relationship between frequency F and period T is thus given as

$$T = 1 / F$$

This means that a short building with a high natural frequency also has a short natural period. Conversely, a very tall building with a low frequency has a long period.