Earthquake Engineering – Past and Present Day Trends.

What you should be aware of and what you should demand?

By
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The two great quakes in Sumatra followed by one in Pakistan have once again put the challenge of effectively designing structures in front of the engineering community. It has also most certainly instilled a sense of fear and caution amongst the common masses and reminded the law makers of their duty to continuously update and upgrade the provisions of the building codes. The U.S. Geological Survey (USGS) predicts that there is a 67 percent chance of a quake with a magnitude of 7 or larger hitting San Francisco before 2020 which may kill thousands and cause economic losses running in many hundreds of billions.

People living in the seismic zones, are becoming increasingly savvy about the seismic components of the structures in which they live and work. The structural consultants are no longer designing only to meet the government building code requirements but are going by the performance criteria laid down by their clients in addition to the mandatory requirements of the building codes. Building codes are applicable to all buildings at large belonging to all strata of society and therefore the socio-economic conditions need to be carefully looked into before formulating them. For this reason it is not possible to lay down the stringent earthquake safeguards as many would not simply be able to afford the associated cost. Most building codes in the developing world are aiming only to prevent a total collapse of a building. The codes do not specify that there should be, no or minimal structural damage to the building. For the user this implies that even if the building codes are followed to the strictest, earthquake resistant design as advocated by most, there is no guarantee that their building will be habitable for living or doing business after an earthquake. The earthquake will structurally damage (further explanation will follow in succeeding paragraphs) the building and incase the damage is significant there would be no option but to demolish and re-construct the building. The Indian building codes also suffer from the same disadvantage. With the growing public awareness in the field many have decided against taking the associated risk and are laying down additional conditions and safeguards to their architects and structural engineers as to how their building should perform in a seismic event. This method of structural design is popularly known as “performance based design” because the client is spelling out a performance criteria which should be achieved for the structure he is paying. Some may contend with having their buildings designed to resist upto 6.5 magnitude earthquake on the Richter scale where as another person would demand a structural performance even in the case of a magnitude 8.0 earthquake simply because he is not willing to accept the associated risk that the earthquake damage may expose him to.

Another huge factor governing these trends is the risk assessment exercises by the major insurance companies. Businesses want to limit the threat to their employees as well as cover their business losses against earthquakes. For many businesses the cost of shutting down for a day runs into many thousands of dollars. The insurance companies are refusing to guarantee such losses unless the buildings which house these businesses adhere to standards specified by them. So they are laying down performance conditions that the structures must comply with before getting the insurance coverage. Many insurance companies in Japan had to suffer huge losses after the Kobe earthquake of 1995; today they do not insure businesses and buildings that do not employ the state-of-the-art earthquake protective measures.

These days established businesses are going in for expensive seismic systems which can be said to be perhaps a case of overkill; they are using combinations of base isolators paired with fluid viscous dampers that far exceed any building code requirement. But then the other argument is that what happens to a company whose sole existence is on sensitive equipment that will make them inoperable in case it fails, they say that the expenditure is well worth it. It is mandatory for the computer data centers mushrooming all over the United States to be designed to withstand the severest of the earthquakes as they house the sensitive data of not one but many hundreds of businesses. The repercussions of not designing buildings to withstand earthquakes are grave. Similarly the US government has laid down very strict compliance criteria for seismic performance of hospitals; they say “you cannot have deaths due to building collapse in a place that is meant to treat earthquake victims”. Various government departments are also paying a great deal of attention on keeping essential infrastructure like bridges and airports operational even in case of a major earthquake.

What is an earthquake? The simple explanation being that an earthquake is a series of forces that has specific time duration i.e. earthquake may last for 20 seconds or for that matter even a minute. In other words an earthquake is nothing but an event by which energy is supplied to a system in our case a building. The only way this energy can be absorbed by the building is by way of causing some damage, which may be the breaking of non-structural components like the window panes/ brick walls/ tiles or by cracking of concrete or by the elongation/yielding of steel in the beams/columns/slabs which are also the structural members. Effectively all energy absorbed is associated with some form of damage. When the damage in the structural members crosses a threshold level which can also be said to be the capacity of that building the building would collapse. Not so long back, in the developed countries exposed to seismic risk and even today in most countries, the designers aim at achieving a building performance against earthquakes by aiming to absorb all the energy through the yielding of steel so that the threshold danger level is not exceeded, thereby implying that they are aiming to use the full capacity of the structure for preventing a total collapse. This is known as “Life-Safety”, or “Minimum Code Design”. However, different earthquakes have different characteristics and it may well so happen that for a seismic event the threshold energy absorbing capacity is exceeded and the building collapses. Even if the building does not collapse, the yielding may cause the structure to be so badly damaged that the building could be unusable and subsequently condemned. Now the owner would face additional costs to have the building demolished, and still has lost their entire real estate investment. The Indian earthquake building code also follows the “Life-Safety” principal.

The only solution to this problem lay in developing a seismic system which could be incorporated into the building and which could somehow absorb the earthquake energy supplied by the seismic event. This would inadvertently mean decreasing the energy dissipation demand on the structural components i.e. beams/columns/slabs thereby increasing the survivability of the building structure. There exist several methods by employing which a building can withstand an earthquake with minimal structural damage. This field of seismic engineering is fast growing and the engineering community is endeavoring to find ways so as to make the technology more and more affordable. It would be prudent to mention that though many of the systems have existed for over a decade or two, the giant leaps in the computational powers of the home computers have made these technologies even more popular and affordable, since configuring each of the energy absorbing systems requires a series of complex structural analyses. Today the price that the clients are paying for sophisticated and state-of-the-art earthquake protection technologies is a fraction of what the clients paid, say 15 years back. Some of the popular methods that existed a few years back, their drawbacks and the present day trends in the field are listed in paragraphs below.

Past Trends:

Shear walls: Not so long back, shear walls were one of the most popular and economical methods to achieve seismic protection. Their purpose was to give additional strength and stiffness to the building and could be added to existing and new buildings alike. Shear walls are made of reinforced cement concrete (RCC) for both RCC and steel buildings. They are positioned after careful thought by the structural engineer as to how they would affect the seismic forces in a particular building. In multistory buildings, these would be the heaviest at the bottom where the base shear is the maximum. Their thickness would seldom be less than 12 to 18 inches as they have to provide sufficient rigidity. However with the recent advances in seismic engineering and the numerous tests undertaken on shake-tables, it is now a well proven fact that the stiffer a structure is built, the higher seismic forces it is going to attract. In simpler words stronger and stiffer buildings will have to dissipate or absorb more earthquake energy. Physically how this effects the buildings is that in case of a short duration earthquake say 15 second duration the building structure can well handle the stresses developed, however in case the duration of an earthquake is longer say 40 seconds the stresses developed in the shear walls are so high that they fail and become the cause of building collapse. Another major factor that has made this method not so attractive is the cost implication, adding RCC shear walls in a structure can raise the structural costs by 7-10 % whereas these days state of art fluid viscous dampers with guaranteed performance cost just 5-10% of the structural cost. These would be discussed later in the latest trends.

Braced frames: In this method diagonal braces are provided in the bays of the building. Diagonals stretch across the bay to form triangulated vertical frame and as triangles are able to handle stresses better than a rectangular frame the structure is also supposed to perform better. Braces can be configured as diagonals, X or even V shaped. Braces are of two types, concentric and eccentric. Concentric braces connect at the intersection of beams and columns whereas eccentric braces connect to the beam at some distance away from the beam-column intersection. Eccentric braces have the advantage that in case of buckling the buckled brace does not damage the beam-to-column or brace-to-beam joint. Bracing also suffers from the same disadvantages that the shear walls do and are losing ground to the damping systems or energy dissipation devices as they are commonly referred. The 1994 Northridge Earthquake, which took place northwest of Los Angeles, proved that steel-moment-resistive frames do not hold up, the Northridge earthquake resulted in steel structures cracking along the web of the columns and buckling throughout the assembly.

Present Trends:

Dampers or Energy Dissipators: As has been brought out earlier whenever there is some damage in the structure it is associated with some energy absorption which is also called damping. It is extremely difficult to evaluate the actual value of damping in a structure but it is generally in the range of 3-5% of the critical damping value, for RCC structures and 1-2% for steel structures. With the advances in the seismic technology it is possible to add physical dampers to the structure which can increase the structural damping to 40-50% of critical. Dampers literally soak up the energy of earthquake-induced motion and instead of the building swinging back and forth repeatedly as earthquake vibrations are transmitted; the building remains stationary as the motion of the dampers absorbs the energy. There are mainly four basic types of dampers:-

(a) Traditional Viscoelastic dampers are stacked plates separated by inert polymer materials. They have proved to be problematic over a varying temperature range and have not achieved much success in practical applications due to the somewhat undesirable added spring effect of these devices. There are no manufacturers that manufacture purely viscoelastic damper.

(b) Friction dampers consist of sliding steel plates and work on the principal that when two metal surfaces slide, friction heat is produced and energy gets dissipated. These types of dampers are susceptible to corrosion and cold welding which has a direct effect on the yielding threshold. There are also some associated maintenance problems.

(c) Metallic dampers consist of multiple steel plates which yield when a threshold force is reached. In other words these dampers become active only after a trigger force is crossed. As the metal yields, it dissipates energy. These dampers are required to be replaced after every seismic event. Over a period of time they have also not been able to catch the momentum as the technology in the other damper field has fast progressed.

(d) Fluid viscous dampers have existed for a long time and were developed and used in the aerospace industry. After the end of the cold war era the US government decided to make this technology available for civilian applications and the seismic dampers are as a direct result of that. Fluid viscous dampers are fluid filled metal cylinders with pistons and work like shock absorbers. They have proved to be the most superior of the lot both for seismic and wind applications. One of there biggest advantage is that they can be modelled to great accuracy and therefore the response of structures using them can be accurately studied. They absorb energy at all frequency ranges of the earthquake and also do not need to be replaced after an earthquake. Generally the life of the fluid viscous damper will be as long as the life of the structure it is protecting. They also have a great flexibility in design and can be configured to protect against an earthquake of any magnitude. They can be installed both on new and existing structures. Over the years they have become the most cost effective option and can guarantee seismic protection for as little as US$ 5-10 a sq ft. Today Taylor fluid viscous dampers guarantee seismic performance for 35 years.

Base Isolation: is a technique wherein the structure is separated from the foundation by inserting base isolators under the building. These isolators allow the structure to move independently of the shifting ground below, thereby effectively isolating it from the ground motion. Base isolators can be of the following type's i.e. high-damping rubber, lead-core rubber and friction pendulum. The effect that they have on the structure is the same. Base isolators made of rubber stretch with the building as the building is pushed to one side by the earthquake, then as the rubber seeks its natural form it pulls the building back into place. Pure rubber isolators are softer thereby allowing greater movement, however the lead core isolators absorb some of the seismic energy by yielding and also force the isolator back into place quicker. Friction pendulums isolators permit a lower displacement profile than the rubber counterparts. They function like a ball on a curved plate; the curved slider is attached either to the footing or the building above and slips around on a concave steel plate. The weight of the building re-centers the slider on the plate after an earthquake event, however many a times the problems associated with the slider sticking at the edges of the plate do crop up. Also, in case the quakes is of a magnitude higher that what the building has been designed for the edges can actually lift and pull the slider off the edge of the plate. Also the rubber bearing have a definite life which is directly dependent on the environmental conditions, such as excess moisture which can greatly reduce their life. It is for these reasons that the base isolators need continuous and periodic monitoring/maintenance.

Base isolators are not appropriate for all buildings and are found to be more suitable for squat buildings that have a much larger spread than its height. The full project costs of base isolation are very high. As commonly misunderstood the cost of a base isolation system is not only the cost of isolators themselves, the extra costs for the foundation work, a huge additional cost to make the first level above the isolation system into a rigid floor mat, all utilities connections must be detailed to be flexible in any direction (for +/-1 meter, or so), stairways, walkways and lifts must be detailed for moveability, a complete moat around the structure must be constructed upto the displacement limits that the isolation system has been designed for and finally the cost of the moveable (architectural) moat covers. This increases the project costs prohibitively and thus can be used only on structures of paramount importance, whereas fluid viscous dampers can provide the same safety levels in case of earthquakes for a fraction of the cost. Today even the projects of paramount importance that are budgeted at very high levels are using fluid viscous dampers along with base isolators as they greatly reduce the designed base isolation capacity and hence reduce costs. The average base isolation system may well cost up to a US$ 100 per sq ft. However base isolators can be suitable for renovation since most of the work is done at the foundation level.

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