DOWNLOAD PDF EARTHQUAKE RESISTANT DESIGN

Chapter 1 : Earthquake-resistant construction | racedaydvl.com

Earthquake-Resistant Design Concepts. An Introduction to the NEHRP Recommended Seismic Provisions for New Buildings and Other Structures. FEMA P / December

WhatsApp Earthquake resistant design are such designed structures which can withstand earthquake. This earthquake resistant design techniques are helpful in reducing the loss of life and property by preventing the building to collapse during earthquake. However there is no building which will be completely immune during the earthquake. Although earthquake produces more than one type of shocks such as vertical, horizontal and circular. So according to the building codes , such earthquake resistant design on structure are implemented in such a way that the structures should be erect during the seismic activity and should be less liable to the damages. However this also depends on the building materials and building techniques which used in the construction on earthquake vulnerable areas. Such techniques are not used for strengthening the building but it reduces the frequency and pulses of the seismic activity. Earthquake resistance design techniques used in construction: Such technique introduces flexibility to the structure and the structures are supported by the bearing pads. This bearing pads are flexible pads. Different types of base isolator used in the earthquake resistant design are: Also in this earthquake resistant design the building is free to slide both horizontally and vertically. When the seismic waves stops, it back to its original place. Lead rubber bearing employs a high damping. This lead rubber bearing is very much flexible in horizontal direction and very stiff in vertical direction. It was invented by William Robinson. In this method, the dampers absorbs the shock and damp the motion of the building. Building uses to dissipate energy because of its large movement due to shock and due to the increase of internal strain in the building units such as column and beam. This dissipation devices are also called as damping devices So we can decrease the seismic energy by using the energy dissipated devices in the building to absorb the seismic energy upto some extent. Types of seismic dampers are: Energy is utilizes by the silicone based fluids passing between piston cylinder. Energy is utilizes by the distortion of metal compounds within the limit Friction Dampers: Energy is utilizes by frictional forces to dissipate energy Viscoelastic Dampers: Energy is utilizes by the controlled shearing of solids IS Codes for earthquake resistant design:

Chapter 2 : Sustainable earthquake-resistant skyscraper crowned world's best high-rise

Chosen from over 1, towers built in the past two years, the office building was hailed for its innovative earthquake-resistant design. Following an international architecture competition, LBR&A.

So a building resting on it will experience motion at its base. But since the walls and columns are connected to it, they drag the roof along with them. 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 the roof is different from that of the ground Figure 1. Buildings experience motion due to earthquake. Effect of Deformations in Structures The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns. During earthquake shaking, the columns undergo relative movement between their ends. In Figure 2, this movement is shown as quantity u between the roof and the ground. The larger is the relative 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. For this reason, these internal forces in the columns are called stiffness forces. In fact, the stiffness force in a column is the column stiffness times the relative displacement between its ends. Horizontal and Vertical Shaking Earthquake causes shaking of the ground in all three directions - along the two horizontal directions X and Y, say , and the vertical direction Z, say Figure 3. All structures are primarily designed to carry the gravity loads, The downward force Mg is called the gravity load. The vertical acceleration during ground shaking either adds to or subtracts from the acceleration due to gravity. Since factors of safety are used in the design of structures to resist the gravity loads, usually most structures tend to be adequate against vertical shaking. Structures designed for gravity loads, in general, may not be able to safely sustain the effects of horizontal earthquake shaking. Hence, it is necessary to ensure adequacy of the structures against horizontal earthquake effects. Flow of Inertia Forces to Foundations Under horizontal shaking of the ground, horizontal inertia forces are generated at 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 columns, to the foundations, and finally to the soil system underneath Figure 4. So, each of these 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. Similarly, poorly designed and constructed reinforced concrete columns can be disastrous. Importance of Architectural Features The behavior 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. Other undesirable scenarios Gravity vs Earthquake Loading in a Reinforced Concrete Building Reversal of stresses takes place during earthquake shaking Gravity loads Self weight causes RC frames to bend, resulting in stretching and shortening at various locations. Tension is generated at surfaces ACI special provisions for seismic design General The principal goal of the Special Provisions is to ensure adequate toughness under inelastic displacement reversals brought on by earthquake loading. The provisions accomplish this goal by requiring the designer to provide for concrete confinement and inelastic rotation capacity. No special requirements are placed on structures subjected to low or no seismic risk. Structural systems designed for high and moderate seismic risk are referred to as Special and Intermediate respectively. For lightweight aggregate concrete, an upper limit of psi is placed on concrete strength; this limit is based on a lack of experimental evidence for higher-strength lightweight concretes. The ACI Code Hoops, ties and cross ties Confinement for concrete is provided by transverse reinforcement consisting of stirrups. Hoops are closed ties that can be made up of several reinforcing elements, each having seismic hooks at both ends, or continuously wound ties with seismic hooks at both ends. The hooks on crossties must engage peripheral longitudinal reinforcing bars. Hoops, ties and crossties: Advantages Closely spaced horizontal closed ties in Column help in three ways, namely they carry the horizontal shear forces induced by earthquakes, and thereby resist diagonal shear cracks, they hold together the vertical bar and prevent them from excessively bending outwards in technical terms, this bending phenomenon is called buckling , and they contain the concrete in the column. Such hook ends prevent opening of hoops and consequently buckling of concrete and buckling of vertical bars. The positive moment capacity at the face of columns must be at least one-half of the negative moment strength at the same location. Neither positive nor negative moment strength at any section in a member may be less than one-fourth of the maximum moment strength at either end of the member. Lap splices Not within the joints Not within twice the member depth; 2h, from the face of a joint or at other locations where flexural yielding is expected. Lap splices must be enclosed by hoops or spirals with a maximum spacing of one-fourth of the effective depth or 4 in. Transverse reinforcement in the form of hoops must be used over a length equal to twice the member depth measured from the face of the supporting member toward midspan at both ends, as per calculation, but fulfilling following conditions. The first hoops must be located not more than 2 in from the face of the supporting member. Max spacing of the hoops over the length must not exceed: Elsewhere spacing of ties is least of 6 db or 6 inch. Weak beam-Strong Column design: For a frame the flexural capacity of the members at a joint should be such that the columns are stronger than the beams. To provide adequate confinement within a joint, the transverse reinforcement used in columns must be continued through the joint. To provide adequate development of beam reinforcement passing through a joint, ACI Code Beam longitudinal reinforcement that is terminated within a column. Min two reinforcing bars top and bottom, throughout the member. The positive moment capacity at the face of columns must be at least one-third of the negative moment strength at the same location. Neither positive nor negative moment strength at any section in a member may be less than one-fifth of the maximum moment strength at either end of the member. Transverse Steel Lap Provision for Columns 1. No special requirement Just as ordinary Col requirement 2. No special requirement Just as ordinary Col requirement 3. Less Stringent requirement as given next 4. No special requirement Just as ordinary Col requirement For columns, within length L0 from the joint face, the tie spacing so may not exceed 8 times the diameter of the smallest longitudinal bar, 24 times the diameter of the tie bar, one-half of the smallest cross-sectional dimension of the column, or 12 in. Unlike regions of high seismic risk, two way slab system without beams are allowed in regions of moderate seismic risk. 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Chapter 3 : Earthquake engineering - Wikipedia

1 GENERAL CONCEPTS OF EARTHQUAKE RESISTANT DESIGN Chapter 3 GENERAL CONCEPTS OF EARTHQUAKE RESISTANT DESIGN INTRODUCTION Experience in past earthquakes has dem-onstrated that many common buildings.

How can existing buildings be strengthened to resist earthquakes? There are a wide variety of earthquake effects â€" these might include a chasm opening up or a drop of many metres across a fault line. Therefore, it is not possible to design an earthquake proof building which is guaranteed to resist all possible earthquakes. However, it is possible during your design and construction process to build in a number of earthquake resistant features by applying earthquake engineering techniques, which would increase enormously the chances of survival of both buildings and their occupants. What is an earthquake? Both the seabed and the land that we inhabit are formed of a crusty skin of light rocks floating on the soft centre of the earth, which is made of heavier molten rock and molten iron. This crusty skin is not one solid piece but is made up of lumps, separated by faults and trenches, or pressed together into mountains. Some plates are moving apart, particularly in the Mid Ocean Trenches, where molten material pushes up and shoves the plates apart, whilst others are bumping into each other head on, these form mountains like the Himalayas the whole of the Indian Sub Continent is moving northwards and hitting Asia, for example. Some are sliding one over another, like the west coast of the Americas, where the land plates are sliding over the denser ocean bed plates, causing the Andes and the Rockies to be thrust upwards. All of these movements cause earthquakes and usually volcanoes as well. If the movement was steady, about a millimetre or so a year, no one would notice. But the plates tend to jam; the movement carries on, but the material where they touch is stretched, or compressed, or bent sideways. The material deforms like stretching or compressing or twisting a bit of plastic. At some stage it reaches the breaking point along all or part of the joint, then it breaks, and there is a sudden movement. The movement may be tiny or may be several feet; but enormous amounts of energy are released, far more than the biggest Nuclear Bombs. The shock waves from this release of energy shoot out in all directions, like the ripples when you throw a stone in a pond: They can be measured all around the whole world. This is an Earthquake. Prior to the Earthquake there are often little warning shakes, where highly stressed bits break and the plate joints readjust themselves a little, but allow the main join to become more stressed. After the primary Earthquake when the main join has failed and moved, there is another readjustment, and further bits around the fault become overstressed too, and they fail. These aftershocks can themselves be highly energetic Earthquakes. After the Earthquake, the area settles down again. But the movement carries on and the next Earthquake is already building up, remorselessly. People forget and build buildings and structures that are going to kill their children next time when they could ensure that during the design and construction phase some earthquake proof measures have been incorporated. Back to Top What makes a building or structure fail in earthquakes? An Earthquake moves the ground. It can be one sudden movement, but more often it is a series of shock waves at short intervals, like our ripples from the pebble in the pond analogy above. It can move the land up and down, and it can move it from side to side. All buildings can carry their own weight or they would fall down anyway by themselves. They can usually carry a bit of snow and a few other floor loads and suspended loads as well, vertically; so even badly built buildings and structures can resist some up-and-down loads. But buildings and structures are not necessarily resistant to side-to-side loads, unless this has been taken into account during the structural engineering design and construction phase with some earthquake proof measures taken into consideration. This weakness would only be found out when the Earthquake strikes, and this is a bad time to find out. It is this side-to-side load which causes the worst damage, often collapsing poor buildings on the first shake. The side-to-side load can be worse if the shocks come in waves, and some bigger buildings can vibrate like a huge tuning fork, each new sway bigger than the last, until failure. This series of waves is more likely to happen where the building is built on deep soft ground, like Mexico City. A taller or shorter building nearby may not oscillate much at the same frequency. Often more weight has been added to a building or structure at most frequently at greater heights; say another floor and another over that; walls built round open balconies and inside partitions to make more, smaller, rooms; rocks piled on roofs to stop them blowing away; storage inside. This extra weight produces great forces on the structure and helps it collapse. The more weight there is, and the higher this weight is in the building, the stronger the building and its foundations must be to be resistant to side earthquakes; many buildings have not been strengthened when the extra weight was added. Often, any resistance to the sway loading of the building is provided by walls and partitions; but these are sometimes damaged and weakened in the Main Earthquake. The building or structure is then more vulnerable, and even a weak aftershock, perhaps from a slightly different direction, or at a different frequency, can cause collapse. In a lot of multi storey buildings, the floors and roofs are just resting on the walls, held there by their own weight; and if there is any structural framing it is too often inadequate. This can result in a floor or roof falling off its support and crashing down, crushing anything below. Often more weight has been added to building or structure at a higher level, for example another floor, extra walls and partitions, extra storage or even rocks piled on roofs to stop them blowing away. Small cracks appear in the concrete. This was beautifully demonstrated under the Oakland Freeway, where huge round concrete columns crumbled and crumpled. They have now been reinforced with massive belts around them as a result of an earthquake engineering review and to improve structural dynamics. So the ground-to-first floor columns, which carry the biggest loads from the weight and the biggest cumulative sideways loads from the earthquake, are the longest and the least restrained and have the least end fixity. They are often the first to fail. It only takes one to fail for the worst sort of disaster, the pancake collapse so familiar to any one who has seen the results in Armenia, Mexico, Turkey, Iran, Peru, and now Pakistan and Kashmir. Sometimes buildings are built on soft soil; this can turn into quicksand when shaken about, leading to complete slumping of buildings into the soil. Some tall buildings can stay almost intact but fall over in their entirety. The taller the building, the more likely this is to happen, particularly if the building can oscillate at the frequency of the shock waves, and particularly if some liquefaction of soft soil underneath has allowed the building to tilt. Back to Top How can we make buildings resistant to earthquakes with earthquake engineering? To be earthquake proof, buildings, structures and their foundations need to be built to be resistant to sideways loads. The lighter the building is, the less the loads. This is particularly so when the weight is higher up. Where possible the roof should be of light-weight material. If there are floors and walls and partitions, the lighter these are the better, too. If the sideways resistance is to be obtained from walls, these walls must go equally in both directions. They must be strong enough to take the loads. They must be tied in to any framing, and reinforced to take load in their weakest direction. They must not fall apart and must remain in place after the worst shock waves so as to retain strength for the after shocks. If the sideways resistance comes from diagonal bracing then it must also go equally all round in both directions. Where possible, it should be strong enough to accept load in tension as well as compression: And the loads have got to go down to ground in a robust way. If the sideways load is to be resisted with moment resisting framing then great care has to be taken to ensure that the joints are stronger than the beams, and that the beams will fail before the columns, and that the columns cannot fail by spalling if in concrete. Again the rigid framing should go all around, and in both directions. If the building earthquake resistance is to come from moment resisting frames, then special care should be taken with the foundation-to-first floor level. If the requirement is to have a taller clear height, and to have open holes in the walls, then the columns at this level may have to be much stronger than at higher levels; and the beams at the first floor, and the columns from ground to second floor, have to be able to resist the turning loads these columns deliver to the frame. Alternatively, and preferably, the columns can be given continuity at the feet. Such steel grillage can also keep the foundations in place. If the beams in the frame can bend and yield a little at their highest stressed points, without losing resistance, while the joints and the columns remain full strength, then a curious thing happens: If the building was vibrating in time with shock waves, this vibration will tend to be damped out. All floors have to be connected to the framing in a robust and resilient way. They should never be able to shake loose and fall. Again all floors should be as light as possible. They should go all round each column and fix to every supporting beam or wall, in a way that cannot be shaken off. One way of reducing the vulnerability of big buildings is to isolate them from the floor using bearings or dampers, but this is a difficult and expensive process not suitable for low and medium rise buildings and low cost buildings though it may be a good technique for Downtown Tokyo. Generally it is wise to build buildings that are not too high compared to their width in Earthquake areas, unless special precautions are taken. Back to Top When looking at design and construction, how do we earthquake proof buildings? When designing earthquake safe structures the first consideration is to make the highest bit, the roof, as light as possible. This is best done with profiled steel cladding on light gauge steel Zed purlins. This can also have double skin with spacers and insulation. It can have a roof slope between 3 and 15 degrees. Such a slab will be completely bonded to the frame and will not be able to slip off, or collapse. If the building or structure is a normal single storey, then any normal portal frame or other steel framed building, if the design and construction is competently done, will be resistant to Earthquake loads. If it is to have 2 or more stories, more needs to be done to ensure its survival in an earthquake. As with the roof, the floors should be made as light as possible. The first way to do this is to use traditional timber joists and timber or chipboard or plywood flooring. If this is done it is vital that the timber joists are firmly through bolted on the frames to avoid them slipping or being torn off. The frame needs them for stability and the floor must never fall down. A better alternative is to substitute light gauge steel Zeds for the timber joists. These can span further and are easier to bolt firmly to the framework. Then, floor-boards or tongue-and-groove chipboard can easily be screwed to the Zeds. However in Hotels, Apartment buildings, Offices and the like, concrete floors may be needed. In such cases we should reduce the spans to the spanning capacity of composite decking flooring, and pour reinforced concrete slabs onto our decking. The decking is fixed to the joists, the joists into the main beams, the main beams into the columns and the concrete is poured around all the columns. There is simply no way that such floors can fall off the frame.

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Chapter 4 : Earthquake-resistant structures - Wikipedia

However, it is possible during your design and construction process to build in a number of earthquake resistant features by applying earthquake engineering techniques, which would increase enormously the chances of survival of both buildings and their occupants.

The answer is yes and no. There are of course, engineering techniques that can be used to create a very sound structure that will endure a modest or even strong quake. However, during a very strong earthquake, even the best engineered building may suffer severe damage. Engineers design buildings to withstand as much sideways motion as possible in order to minimize damage to the structure and give the occupants time to get out safely. Buildings are basically designed to support a vertical load in order to support the walls, roof and all the stuff inside to keep them standing. Earthquakes present a lateral, or sideways, load to the building structure that is a bit more complicated to account for. One way to to make a simple structure more resistant to these lateral forces is to tie the walls, floor, roof, and foundations into a rigid box that holds together when shaken by a quake. The most dangerous building construction, from an earthquake point of view, is unreinforced brick or concrete block. Generally, this type of construction has walls that are made of bricks stacked on top of each other and held together with mortar. The roof is laid across the top. The weight of the roof is carried straight down through the wall to the foundation. When this type of construction is subject to a lateral force from an earthquake the walls tip over or crumble and the roof falls in like a house of cards. Construction techniques can have a huge impact on the death toll from earthquakes. The difference in those death tolls comes from building construction and technology. In Haiti, the buildings were constructed quickly and cheaply. Chile, a richer and more industrialized nation, adheres to more stringent building codes. Acting like shock absorbers in a car, these systems allow the building to be decoupled from the shaking of the ground. Watch the video below to see these system in action. In the event of a major earthquake, they can sway up to a few feet. Another technique to dampen the swaying of a tall building is to build in a large several tons mass that can sway at the top of the building in opposition to the building sway. Weighing in at tons and capable of moving 5ft in any direction, it takes the prize as the worlds largest and heaviest building damper. In fact, it is so heavy that it had to be constructed on site since it is to heavy to be lifted by a crane. Can you build a better building? Here is a great video from WIRED that shows how a large shake platform can be used to test a full-scale structure in response to the motion of an earthquake. I love the crazy shot at 1:

Chapter 5 : Seismic Design Principles | WBDG Whole Building Design Guide

Earthquake causes shaking of the 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.

Additional Resources This resource page provides an introduction to the concepts and principles of seismic design, including strategies for designing earthquake-resistant buildings to ensure the health, safety , and security of building occupants and assets. The essence of successful seismic design is three-fold. First, the design team must take a multi-hazard approach towards design that accounts for the potential impacts of seismic forces as well as all the major hazards to which an area is vulnerable. Third, and as important as the others, because earthquake forces are dynamic and each building responds according to its own design complexity, it is essential that the design team work collaboratively and have a common understanding of the terms and methods used in the seismic design process. In addition, as a general rule, buildings designed to resist earthquakes should also resist blast terrorism or wind, suffering less damage. Description About half of the states and territories in the United Statesâ€”more than million people and 4. Seismicity of the United States A. Friction caused by plates colliding, extending, or subducting one plate slides under the other builds up stresses that, when released, causes an earthquake to radiate through the crust in a complex wave motion, producing ground failure in the form of surface faulting [a split in the ground], landslides, liquefaction, or subsidence , or tsunami. This, in turn, can cause anywhere from minor damage to total devastation of the built environment near where the earthquake occurred. Ground failure-landslideâ€”Alaska, Saada Hotel before â€”Agadir, Morocco, Saada Hotel after ground shaking damageâ€—Agadir, Morocco, Measuring Seismic Forces In order to characterize or measure the effect of an earthquake on the ground a. Displacement is the distance from the point of rest, measured in centimeters. Duration is the length of time the shock cycles persists. Magnitude is the "size" of the earthquake, measured by the Richter scale, which ranges from The Richter scale is based on the maximum amplitude of certain seismic waves, and seismologists estimate that each unit of the Richter scale is a 31 times increase of energy. Moment Magnitude Scale is a recent measure that is becoming more frequently used. If the level of acceleration is combined with duration, the power of destruction is defined. Usually, the longer the duration, the less acceleration the building can endure. A building can withstand very high acceleration for a very short duration in proportion with damping measures incorporated in the structure. Intensity is the amount of damage the earthquake causes locally, which can be characterized by the 12 level Modified Mercalli Scale MM where each level designates a certain amount of destruction correlated to ground acceleration. Earthquake damage will vary depending on distance from origin or epicenter , local soil conditions, and the type of construction. Ground shaking pushing back and forth, sideways, up and down generates internal forces within buildings called the Inertial Force FInertial , which in turn causes most seismic damage. The greater the mass weight of the building , the greater the internal inertial forces generated. Lightweight construction with less mass is typically an advantage in seismic design. Earthquakes generate waves that may be slow and long, or short and abrupt. The length of a full cycle in seconds is the Period of the wave and is the inverse of the Frequency. All objects, including buildings, have a natural or fundamental period at which they vibrate if jolted by a shock. The natural period is a primary consideration for seismic design, although other aspects of the building design may also contribute to a lesser degree to the mitigation measures. If the period of the shock wave and the natural period of the building coincide, then the building will "resonate" and its vibration will increase or "amplify" several times. Height is the main determinant of fundamental periodâ€”each object has its own fundamental period at which it will vibrate. The period is proportionate to the height of the building. The soil also has a period varying between 0. Soft soils generally have a tendency to increase shaking as much as 2 to 6 times as compared to rock. Also, the period of the soil coinciding with the natural period of the building can greatly amplify acceleration of the building and is therefore a design consideration. Tall buildings will undergo several modes of vibration, but for seismic purposes except for very tall buildings the fundamental period, or first mode is usually the most significant. Seismic Design Factors The following factors affect and are affected by the design of the building. It is important that the design team understands these factors and deal with them prudently in the design phase. Objects and buildings have a center of mass, a point by which the object building can be balanced without rotation occurring. If the mass is uniformly distributed then the geometric center of the floor and the center of mass may coincide. Uneven mass distribution will position the center of mass outside of the geometric center causing "torsion" generating stress concentrations. A certain amount of torsion is unavoidable in every building design. Symmetrical arrangement of masses, however, will result in balanced stiffness against either direction and keep torsion within a manageable range. Buildings in general are poor resonators to dynamic shock and dissipate vibration by absorbing it. Damping is a rate at which natural vibration is absorbed. Ductility is the characteristic of a material such as steel to bend, flex, or move, but fails only after considerable deformation has occurred. Non-ductile materials such as poorly reinforced concrete fail abruptly by crumbling. Good ductility can be achieved with carefully detailed joints. Strength is a property of a material to resist and bear applied forces within a safe limit. Stiffness of a material is a degree of resistance to deflection or drift drift being a horizontal story-to-story relative displacement. Building configuration determines the way seismic forces are distributed within the structure, their relative magnitude, and problematic design concerns.

Chapter 6 : The Science Behind Earthquake-Proof Buildings | VIATechnik

A fellow of the American Society of Civil Engineer (ASCE), and the Structural Engineering Institute (SEI), DesRoches' research focuses on the design of resilient infrastructure systems under extreme loads and the application of smart and adaptive materials.

Seismic loading Seismic loading means application of an earthquake-generated excitation on a structure or geo-structure. It happens at contact surfaces of a structure either with the ground, [4] with adjacent structures, [5] or with gravity waves from tsunami. It is related to the seismic hazard of the location. A structure is normally considered safe if it does not endanger the lives and well-being of those in or around it by partially or completely collapsing. A structure may be considered serviceable if it is able to fulfill its operational functions for which it was designed. Basic concepts of the earthquake engineering, implemented in the major building codes, assume that a building should survive a rare, very severe earthquake by sustaining significant damage but without globally collapsing. Seismic performance assessment[edit] Engineers need to know the quantified level of the actual or anticipated seismic performance associated with the direct damage to an individual building subject to a specified ground shaking. Such an assessment may be performed either experimentally or analytically. Experimental assessment[edit] Experimental evaluations are expensive tests that are typically done by placing a scaled model of the structure on a shake-table that simulates the earth shaking and observing its behavior. Due to the costly nature of such tests, they tend to be used mainly for understanding the seismic behavior of structures, validating models and verifying analysis methods. Thus, once properly validated, computational models and numerical procedures tend to carry the major burden for the seismic performance assessment of structures. Snapshot from shake-table video of a 6-story non-ductile concrete building destructive testing Seismic performance assessment or seismic structural analysis is a powerful tool of earthquake engineering which utilizes detailed modelling of the structure together with methods of structural analysis to gain a better understanding of seismic performance of building and non-building structures. The technique as a formal concept is a relatively recent development. In general, seismic structural analysis is based on the methods of structural dynamics. Numerical step-by-step integration proved to be a more effective method of analysis for multi-degree-of-freedom structural systems with significant non-linearity under a transient process of ground motion excitation. Performance evaluations are generally carried out by using nonlinear static pushover analysis or nonlinear time-history analysis. In such analyses, it is essential to achieve accurate non-linear modeling of structural components such as beams, columns, beam-column joints, shear walls etc. Thus, experimental results play an important role in determining the modeling parameters of individual components, especially those that are subject to significant non-linear deformations. The individual components are then assembled to create a full non-linear model of the structure. Thus created models are analyzed to evaluate the performance of buildings. The capabilities of the structural analysis software are a major consideration in the above process as they restrict the possible component models, the analysis methods available and, most importantly, the numerical robustness. The latter becomes a major consideration for structures that venture into the non-linear range and approach global or local collapse as the numerical solution becomes increasingly unstable and thus difficult to reach. Research for earthquake engineering[edit] Shake-table testing of Friction Pendulum Bearings at EERC Research for earthquake engineering means both field and analytical investigation or experimentation intended for discovery and scientific explanation of earthquake engineering related facts, revision of conventional concepts in the light of new findings, and practical application of the developed theories. The National Science Foundation NSF is the main United States government agency that supports fundamental research and education in all fields of earthquake engineering. In particular, it focuses on experimental, analytical and computational research on design and performance enhancement of structural systems. A definitive list of earthquake engineering research related shaking tables around the world may be found in Experimental Facilities for Earthquake Engineering Simulation Worldwide. Network for Earthquake Engineering Simulation The NSF Hazard Mitigation and Structural Engineering program HMSE supports research on new technologies for improving the behavior and response of structural systems subject to earthquake hazards; fundamental research on safety and reliability of constructed systems; innovative developments in analysis and model based simulation of structural behavior and response including soil-structure interaction; design concepts that improve structure performance and flexibility; and application of new control techniques for structural systems. The cyberinfrastructure, connected via Internet2 , provides interactive simulation tools, a simulation tool development area, a curated central data repository, animated presentations, user support, telepresence, mechanism for uploading and sharing resources, and statistics about users and usage patterns. This cyberinfrastructure allows researchers to: These resources jointly provide the means for collaboration and discovery to improve the seismic design and performance of civil and mechanical infrastructure systems. Earthquake simulation[edit] The very first earthquake simulations were performed by statically applying some horizontal inertia forces based on scaled peak ground accelerations to a mathematical model of a building. Dynamic experiments on building and non-building structures may be physical, like shake-table testing , or virtual ones. Therefore, there is a strong incentive to engage an earthquake simulation which is the seismic input that possesses only essential features of a real event. Sometimes earthquake simulation is understood as a re-creation of local effects of a strong earth shaking. Structure simulation[edit] Concurrent experiments with two building models which are kinematically equivalent to a real prototype. Similarity is some degree of analogy or resemblance between two or more objects. The notion of similarity rests either on exact or approximate repetitions of patterns in the compared items. In general, a building model is said to have similarity with the real object if the two share geometric similarity, kinematic similarity and dynamic similarity. The most vivid and effective type of similarity is the kinematic one. Kinematic similarity exists when the paths and velocities of moving particles of a model and its prototype are similar. The ultimate level of kinematic similarity is kinematic equivalence when, in the case of earthquake engineering, time-histories of each story lateral displacements of the model and its prototype would be the same. Seismic vibration control[edit] Seismic vibration control is a set of technical means aimed to mitigate seismic impacts in building and non-building structures. All seismic vibration control devices may be classified as passive, active or hybrid [20] where: However, the remaining portions of the incident waves during a major earthquake still bear a huge devastating potential. For this, some pads are inserted into or under all major load-carrying elements in the base of the building which should substantially decouple a superstructure from its substructure resting on a shaking ground. The first evidence of earthquake protection by using the principle of base isolation was discovered in Pasargadae , a city in ancient Persia, now Iran, and dates back to the 6th century BCE. Below, there are some samples of seismic vibration control technologies of today. The Incas were among the best stonemasons the world has ever seen [24] and many junctions in their masonry were so perfect that even blades of grass could not fit between the stones. Peru is a highly seismic land and for centuries the mortar-free construction proved to be apparently more earthquake-resistant than using mortar. The stones of the dry-stone walls built by the Incas could move slightly and resettle without the walls collapsing, a passive structural control technique employing both the principle of energy dissipation coulomb damping and that of suppressing resonant amplifications. For this purpose, a steel pendulum weighing metric tonnes that serves as a tuned mass damper was designed and installed atop the structure. Suspended from the 92nd to the 88th floor, the pendulum sways to decrease resonant amplifications of lateral displacements in the building caused by earthquakes and strong gusts. Hysteretic dampers[edit] A hysteretic damper is intended to provide better and more reliable seismic performance than that of a conventional structure by increasing the dissipation of seismic input energy. They have an oval hysteretic loop and the damping is velocity dependent. While some minor maintenance is potentially required, viscous dampers generally do not need to be replaced after an earthquake. While more expensive than other damping technologies they can be used for both seismic and wind loads and are the most commonly used hysteretic damper. Friction dampers FDs Friction dampers tend to be available in two major types, linear and rotational and dissipate energy by heat. The damper operates on the principle of a coulomb damper. Depending on the design, friction dampers can experience stick-slip phenomenon and Cold welding. The main disadvantage being that friction surfaces can wear over time and for this reason they are not recommended for dissipating wind loads. When used in seismic applications wear is not a problem and there is no required maintenance. They have a rectangular hysteretic loop and as long as the building is sufficiently elastic they tend to settle back to their original positions after an earthquake. This type of damper absorbs a large amount of energy however they must be replaced after an earthquake and may prevent the building from settling back to its original position. Viscoelastic dampers VEDs Viscoelastic dampers are useful in that they can be used for both wind and seismic applications, they are usually limited to small displacements. There is some concern as to the reliability of the technology as some brands have been banned from use in buildings in the United States. Straddling pendulum dampers swing Base isolation[edit] Base isolation seeks to prevent the kinetic energy of the earthquake from being transferred into elastic energy in the building. These technologies do so by isolating the structure from the ground, thus enabling them to move somewhat independently. The degree to which the energy is transferred into the structure and how the energy is dissipated will vary depending on the technology used. It was invented by Bill Robinson , a New Zealander. However, for the rather pliant systems such as base isolated structures, with a relatively low bearing stiffness but with a high damping, the so-called "damping force" may turn out the main pushing force at a strong earthquake. The bearing is made of rubber with a lead core. It was a uniaxial test in which the bearing was also under a full structure load. Many buildings and bridges, both in New Zealand and elsewhere, are protected with lead dampers and lead and rubber bearings. Both are in Wellington which sits on an active fault. It is a base isolation device conceptually similar to Lead Rubber Bearing. One of two three-story town-houses like this, which was well instrumented for recording of both vertical and horizontal accelerations on its floors and the ground, has survived a severe shaking during the Northridge earthquake and left valuable recorded information for further study. Simple roller bearing Simple roller bearing is a base isolation device which is intended for protection of various building and non-building structures against potentially damaging lateral impacts of strong earthquakes. This metallic bearing support may be adapted, with certain precautions, as a seismic isolator to skyscrapers and buildings on soft ground. Recently, it has been employed under the name of metallic roller bearing for a housing complex 17 stories in Tokyo, Japan. It is based on three pillars: Snapshot with the link to video clip of a shake-table testing of FPB system supporting a rigid building model is presented at the right. Seismic design[edit] Seismic design is based on authorized engineering procedures, principles and criteria meant to design or retrofit structures subject to earthquake exposure. Nevertheless, seismic design has always been a trial and error process whether it was based on physical laws or on empirical knowledge of the structural performance of different shapes and materials. San Francisco after the earthquake and fire To practice seismic design , seismic analysis or seismic evaluation of new and existing civil engineering projects, an engineer should, normally, pass examination on Seismic Principles [34] which, in the State of California, include: Seismic Data and Seismic Design Criteria Seismic Characteristics of Engineered Systems Seismic Forces Seismic Analysis Procedures Seismic Detailing and Construction Quality Control To build up complex structural systems, [35] seismic design largely uses the same relatively small number of basic structural elements to say nothing of vibration control devices as any non-seismic design project. Normally, according to building codes, structures are designed to "withstand" the largest earthquake of a certain probability that is likely to occur at their location. This means the loss of life should be minimized by preventing collapse of the buildings. Seismic design is carried out by understanding the possible failure modes of a structure and providing the structure with appropriate strength , stiffness , ductility , and configuration [36] to ensure those modes cannot occur. Seismic design requirements[edit] Seismic design requirements depend on the type of the structure, locality of the project and its authorities which stipulate applicable seismic design codes and criteria. The Metsamor Nuclear Power Plant was closed after the Armenian earthquake [38] The most significant feature in the SDC design philosophy is a shift from a force-based assessment of seismic demand to a displacement-based assessment of demand and capacity. Thus, the newly adopted displacement approach is based on comparing the elastic displacement demand to the inelastic displacement capacity of the primary structural components while ensuring a minimum level of inelastic capacity at all potential plastic hinge locations. In addition to the designed structure itself, seismic design requirements may include a ground stabilization underneath the structure: Therefore, their seismic design is based on criteria far more stringent than those applying to non-nuclear facilities. Doubt has also been expressed over the seismic evaluation and design of certain other plants, including the Fessenheim Nuclear Power Plant in France. Failure modes[edit] Failure mode is the manner by which an earthquake induced failure is observed. It, generally, describes the way the failure occurs. Though costly and time consuming, learning from each real earthquake failure remains a routine recipe for advancement in seismic design methods. Below, some typical modes of earthquake-generated failures are presented. Typical damage to unreinforced masonry buildings at earthquakes The lack of reinforcement coupled with poor mortar and inadequate roof-to-wall ties can result in substantial damage to an unreinforced masonry building.

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Chapter 7 : Can you build an Earthquake proof building

Earthquake Resistant Design For Engineers and Architects Second Edition David J. Dowrick This is the second edition of a book which has proved useful to large numbers of engineers and architects since it was first published.

See Article History Earthquake-resistant construction, the fabrication of a building or structure that is able to withstand the sudden ground shaking that is characteristic of earthquakes , thereby minimizing structural damage and human deaths and injuries. Suitable construction methods are required to ensure that proper design objectives for earthquake-resistance are met. Construction methods can vary dramatically throughout the world, so one must be aware of local construction methods and resource availability before concluding whether a particular earthquake-resistant design will be practical and realistic for the region. There is a fundamental distinction between the design of a building and the construction methods used to fabricate that building. Advanced designs intended to withstand earthquakes are effective only if proper construction methods are used in the site selection, foundation, structural members, and connection joints. Earthquake-resistant designs typically incorporate ductility the ability of a building to bend, sway, and deform without collapsing within the structure and its structural members. A ductile building is able to bend and flex when exposed to the horizontal or vertical shear forces of an earthquake. Concrete buildings, which are normally brittle relatively easy to break , can be made ductile by adding steel reinforcement. In buildings constructed with steel-reinforced concrete, both the steel and the concrete must be precisely manufactured to achieve the desired ductile behaviour. Building failures during earthquakes often are due to poor construction methods or inadequate materials. In less-developed countries, concrete often is not properly mixed, consolidated, or cured to achieve its intended compressive strength, so buildings are thus extremely susceptible to failure under seismic loading. This problem is often made worse by a lack of local building codes or an absence of inspection and quality control. Building failures are also frequently attributed to a shortage of suitable and locally available materials. For instance, when a building is designed with steel-reinforced concrete, it is critical that the amount of steel used is not reduced to lower the building cost. However, during an earthquake, lateral and shear loading occurs, which results in tensile and torsional forces on structural elements. Strong construction joints are critical in building a structure that will withstand the shear loading of an earthquake. Since stress is concentrated at the joints between the walls, it is important that all the joints be properly prepared and reinforced. Concrete joints must also be properly compacted and anchored in order to achieve optimum strength. In the case of unreinforced masonry joints mortar joints, such as those found in brick buildings , the anchoring between adjacent walls is especially important. When all the joints are tied together well, the building will act as a single integrated unit, enabling the forces of an earthquake to be transferred from one section to the next without catastrophic failure. Earthquake-resistant construction requires that the building be properly grounded and connected through its foundation to the earth. Building on loose sands or clays is to be avoided, since those surfaces can cause excessive movement and nonuniform stresses to develop during an earthquake. Furthermore, if the foundation is too shallow, it will deteriorate, and the structure will be less able to withstand shaking. The foundation should therefore be constructed on firm soil to maintain a structure that settles uniformly under vertical loading.

Chapter 8 : Earthquake Proof and Resistant Building Structures | REIDsteel

Earthquakes present a lateral, or sideways, load to the building structure that is a bit more complicated to account for. One way to to make a simple structure more resistant to these lateral forces is to tie the walls, floor, roof, and foundations into a rigid box that holds together when shaken by a quake.

Chapter 9 : STEM-Works - Earthquakes Activities - Build an Earthquake-Proof Structure

Earthquake-resistant construction: Earthquake-resistant construction, the fabrication of a building or structure that is *able to withstand the sudden ground shaking that is characteristic of earthquakes, thereby minimizing structural damage and human deaths and injuries.*