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Chapter 1 : What is Earthquake Engineering? An Introduction to its Goals, Technologies, and Research

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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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Earthquake Engineering and Engineering Vibration was established in by the Institute of Engineering Mechanics (IEM), China Earthquake Administration, in cooperation with the Multidisciplinary Center for Earthquake Engineering Research (MCEER), University at Buffalo, State University of New York, to promote scientific exchange between.

Untitled[edit] Earthquake engineering is the study of the behavior of buildings and structures subject to seismic loading. It is a subset of both structural and civil engineering. Eminent authority on seismic risk mitigation, Caltech professor George W. The main objectives of earthquake engineering are: Understand the interaction between buildings or civil infrastructure and the ground. Foresee the potential consequences of strong earthquakes on urban areas and civil infrastructure. Design, construct and maintain structures to perform at earthquake exposure up to the expectations and in compliance with building codes [1]. A properly engineered structure does not necessarily have to be extremely strong or expensive. Seismic loading[edit] The worst-case loading scenario Seismic loading means application of an earthquake-generated agitation to a structure. It happens at contact surfaces of a structure either with the ground [6] , or with adjacent structures [7] , or with gravity waves from tsunami. Seismic loading depends, primarily, on: Sometimes, seismic load exceeds ability of a structure to resist it without being broken, partially or completely. Due to their mutual interaction, seismic loading and seismic performance of a structure are intimately related. A structure is, normally, considered safe if it does not endanger the lives and wellbeing 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. Parking structure at CSUN campus after Northridge earthquake Basic concepts of the earthquake engineering, implemented in the major building codes, assume that a building should survive The Big One the most powerful anticipated earthquake though with partial destruction. Drawing an analogy with a human body, it will have dislocated joints, fractured ribs, traumatized spine and knocked out teeth but be alive and, therefore, acceptable according to the prescriptive building codes [8]. This situation is a major barrier to implementation of any structural innovations in the earthquake engineering technologies employing vibration control and, particularly, the most effective brands of base isolation. However, alternative earthquake performance-based design approaches already exist. Some of them, for assessment or comparison of the anticipated earthquake performance, use the Story Performance Rating R as a major criterion [9] while the Seismic Performance Ratio SPR is used for a rather accurate prediction of earthquake performance of a building up to the point of its state of "severe damage" [10]. Seismic performance evaluation[edit] Performance evaluation of building structures at their earthquake exposure is one of the hottest topics of earthquake engineering [11]. Engineers need to know the quantified level of an actual or anticipated seismic performance associated with the direct damage to an individual building subject to a specified ground shaking. The best way to do it is to put the structure on a shake-table that simulates the earth shaking and watch what may happen next if you have no time to stand out in the field and wait for a real earthquake to strike, of course. Such kinds of experiments were performed still more than a century ago [2] Snapshot from shake-table video of a 6-story non-ductile concrete building destructive testing Another way is to evaluate the earthquake performance analytically. Thus, a publicly accessible research software called Earthquake Performance Evaluation Tool EPET enables concurrent virtual experiments on building models with and without vibration control using a kind of seismic base isolation called Earthquake Protector [12]. On demand, all virtual EPET experiments on two identical building models can be animated [13]. Any building or its model is treated here as an essentially nonlinear system. Major building seismic performance evaluation parameters in a performance evaluation procedure are, usually, the following: EPET animation of a concurrent testing of two building models Ground Acceleration Mitigation Factor, when only some maximum accelerations on a structure are available [14] , and Story Performance Rating, when the story drifts are also known [15]. EPET enabled concurrent testing of two story building models The parameter called Seismic Performance Ratio may be chosen as the primary parameter which would control anticipated losses due to a particular seismic exposure of the building. NEEScentral portal hosts valuable data on experimental validation of EPET, including some movie clips on the comparative shake-table testing of 6- and story building models [16]. EPET can use either real time-histories or earthquake simulations and predict seismic performance of a building up to the point of its virtual state of "severe damage" [17]. Seismic performance analysis[edit] Seismic performance analysis or, simply, seismic analysis is a major intellectual tool of earthquake engineering which breaks the complex topic into smaller parts 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. Chart of Seismic Performance In general, seismic analysis is based on the methods of structural dynamics [3]. However, those spectra are good, mostly, for single-degree-of-freedom systems. Numerical step-by-step integration [5] , applied with the charts of seismic performance [19] , proved to be a more effective method of analysis for multi-degree-of-freedom structural systems with severe non-linearity under a substantially transient process of kinematic excitation. Research for earthquake engineering[edit] Research for earthquake engineering incorporates both field and analytical investigation or experimentation aimed at discovery and interpretation of earthquake engineering related facts, revision of accepted theories in the light of new facts, or practical application of such new or revised 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. Research programs[edit] The NSF programs support 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 [20]. NEES Buffalo testing facility NEES comprises a network of 15 earthquake engineering experimental equipment sites available for experimentation on-site or in the field and through telepresence. NEES equipment sites include shake-tables , geotechnical centrifuges, a tsunami wave basin, unique large-scale testing laboratory facilities, and mobile and permanently installed field equipment [22]. NEES Cyberinfrastructure Center NEESit connects, via Internet2, the equipment sites as well as provides telepresence , a curated central data repository , simulation tools, and collaborative tools for facilitating on-line planning, execution, and post-processing of experiments. 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 [6]. With the further development of computational technologies, static approaches began to give way to dynamic ones. Earthquake simulation the "Cone" 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, like, e. Sometimes, earthquake simulation is understood as a re-creation of local effects of a strong earth shaking [25]. Structure simulation[edit] Theoretical or experimental evaluation of anticipated seismic performance mostly requires a structure simulation which is based on the concept of structural likeness or similarity. 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. Concurrent experiments with two kinematically equivalent to a real prototype building models [2] 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 is the similarity of time as well as geometry. It exists between a model and prototype when: 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 [26]. Seismic vibration control[edit] Seismic vibration control is a set of technical means aimed to mitigate seismic impacts in building and non-building structures [27]. All seismic vibration control devices may be classified as passive, active or hybrid [28] where: However, the remaining portions of the incident waves during a major earthquake still bear a huge devastating potential. Devices of the last kind, abbreviated correspondingly as TMD for the tuned passive , as AMD for the active, and as HMD for the hybrid mass dampers, have been studied and installed in high-rise buildings , predominantly in Japan, for a quarter of a century [33]. Mausoleum of Cyrus, the oldest base-isolated structure in the world However, there is quite another approach: 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: Below, there are some samples of seismic vibration control technologies of today. However, for the very 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 [35]. This finding created a theoretical ground for the new damping-disengaged base isolation technology called Earthquake Protector [36]. Taipei skyscraper needs to withstand typhoon winds and earthquake tremors common in its area of the Asia-Pacific. For this purpose, a steel pendulum weighing metric tons 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. It is based on three pillars [8]: 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. Elevated building foundation[edit] EBF abutment [4] upgrade Elevated building foundation EBF is an integral part of a building structure. This goal can be achieved by means of a proper choice of materials, dimensions, and configuration of EBF for the particular local soil conditions. As a result of multiple reflections , diffractions , and dissipations of the seismic waves in a process of their vertical propagation through horizontal strata of the EBF, any transmission of seismic wave energy into the superstructure furnished with elevated building foundation will be decreased considerably [37]. Seismic design[edit] Seismic design is based on authorized engineering procedures, principles and criteria meant to design or retrofit structures subject to earthquake exposure [6]. Those criteria are consistent just with the contemporary state of the knowledge about earthquakes and structures [9]. Therefore, the building design which blindly follows some seismic code regulations does not guarantee safety against collapse or serious damage [38]. The price of poor seismic design may be enormous. Nevertheless, seismic design has always been a trial and error process no matter it was based upon physical laws or empirical knowledge of the structural performance of different shapes and materials.

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Chapter 4 : Talk:Earthquake engineering/problems - Wikipedia

Viscoelastic (VE) dampers, with their stiffness and energy dissipation capabilities, have been widely used in civil engineering for mitigating wind-induced vibration and seismic responses of.

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Chapter 6 : Earthquake Engineering and Engineering Vibration

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Chapter 8 : Earthquake engineering - Wikipedia

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