EARTHQUAKE-RESISTANT BUILDING CONSTRUCTION

S. Otani
Department of Architecture, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan

Keywords: Earthquake resistant buildings, earthquake ground motion, limit states, performance-based design, strength, ductility, capacity design, seismic isolation, vibration control, retrofit of existing buildings

Contents

Summary

The development of earthquake resistant design of buildings is briefly reviewed. The state-of-the-art of seismic design is discussed from the viewpoint of the performance criteria of buildings. These are (a) serviceability from frequent minor-intensity earthquake motions, (b) reparability from an infrequent but major-intensity earthquake motion, and (c) life safety from the maximum possible earthquake motion. The relation between the strength and ductility is discussed at length. With the introduction of performance-based engineering, the importance of reparability and serviceability criteria is emphasized. The state-of-the-art technology such as capacity design, base isolation and vibration control is briefly introduced. The importance to retrofit the existing building is emphasized.

1. Introduction

Building is a shelter which people occupy for their living or pursue their living functions. The shelter should have a structure to protect its occupants from natural phenomena such as rain, snow, heat and cold, and hazards such as strong winds and earthquakes. The intensity of natural hazards varies from region to region on the earth. A building should also provide its occupants with comfort for living and working space for their activities by controlling light, temperature and humidity in severe climate and environment. The degree of desired amenities varies from society to society according to economic conditions and personal priority in the life of the members.

Earthquakes are caused by rupture of rock zones called faults. The earth's surface consists of tectonic plates which move relative to one another building strain energy along the plate boundaries. When this energy exceeds the capacity of the rock materials along the fault surface, the fault ruptures with seismic waves transmitted through hard bedrock layers. Most of major earthquakes occur along the plate boundaries. The relative movement of tectonic plates also builds up stresses within a tectonic plate. When the stress level exceeds the capacity, the fault ruptures within the tectonic plate.

The state-of-the-art in earthquake engineering has reached a stage where earthquake resistant building construction can reduce the casualties from earthquake disasters. However, the application of such state-of-the-art is prohibitive in most seismically active regions due to the economic and technical reasons.

2. Historical Development

The earthquake engineering and technology have been developed with the lessons learned from earthquake disasters. The history of earthquake disaster on human life is long especially when the building construction used natural materials such as adobe, masonry and timber. The damage of buildings is caused by the inertia forces associated with the vibration of buildings exceeding the resistance of the structure. Heavy construction materials such as masonry and adobe attract large inertia forces whereas the resistance is low.

The importance of constructing buildings against lateral forces was recognized towards the end of the 19th century. For example, John Milne, a British instructor at The University of Tokyo, studied the damage of the 1891 Nohbi Earthquake, Japan, and recommended that "… we must construct, not simply to resist vertically applied stresses, but carefully consider effects due to movements applied more or less in horizontal directions."

The first quantitative seismic design recommendations were made by M. Panetti, Professor of Applied Mechanics in Turin after the 1908 Messina Earthquake, Italy. He recommended that the first story be designed for a horizontal force equal to 1/12 the weight above and the second and third stories to be designed for 1/8 of the building weight above.

The design seismic forces were introduced in the Enforcement Order of Urban Building Law (Japan) in 1924 after the 1923 Kanto Earthquake Disaster. Seismic coefficient (the ratio of design lateral force to weight at each floor level) of 0.10 was used in an allowable stress design framework. The 1927 Uniform Building Code (U.S.A.) adopted the same seismic coefficient in 1926 after the 1925 Santa Barbara Earthquake. Although design seismic forces were introduced in the building codes, no simple and practical methods of structural analysis were available to estimate the distribution of internal forces under design lateral forces until the introduction of the moment distribution method in 1930 and other structural analysis methods.

At this stage, researchers and engineers discussed the earthquake resistant building design without knowing the characteristics of earthquake motions. The U.S. Seismological Field Survey was established in 1932 and installed the first strong motion seismographs in California. The response of highly idealized simple systems was calculated when subjected to observed ground motions using a simple mechanical analyzer in 1941. The calculation revealed that the response of buildings to earthquake motions was sensitive to the period of a system. The 1943 City of Los Angeles Building Code introduced design seismic coefficients as a function of the number of stories, which influenced the period of oscillation of a building.

The risk of earthquake hazards varies from one region to another. A probability map of maximum ground accelerations expected in a certain year was formulated on the basis of historical data of earthquake occurrences. This was an important step to define an earthquake-zoning map for design.

With the development of digital computers, nonlinear earthquake response calculation for a structure became feasible. The relation between the maximum response of linearly elastic and elasto-plastic systems was reported in 1960. Linearly elastic response spectra have been used in the seismic design to determine the required resistance of a structure for an estimated ductility capacity. The importance of deformation capability of a structure was emphasized.

With accumulated experimental data, realistic hysteresis models for structural members and systems were developed to simulate the response under load reversals. Furthermore, with the development of digital computer technology, realistic nonlinear response of building structures was calculated under earthquake motions. The construction of high-rise buildings was made possible even in seismically active regions. Recent application of base isolation and vibration control can further reduce the damage of building construction during an intense earthquake.

3. Seismic Actions

Lateral forces excited in a building by an earthquake motion are influenced by the characteristics of ground motion, mass and stiffness distribution of the structure, and strength and deformation capacities of structural members.

3.1. Characteristics of Earthquake Motion

The earthquake risk is not uniform on the earth, but varies significantly from one region to another. Most major earthquakes occur along the boundaries of tectonic plates due to their relative movement. These plate boundary earthquakes occur at a relatively uniform interval (50 to a few hundred years) for a given region with accumulation of strain energy. Some earthquakes of lesser magnitudes occur by the fracture of active faults within a tectonic plate caused by stresses developed by the plate movement. Some active faults have been identified on the ground surface, but others are buried under the ground. An active fault in a tectonic plate may fracture once in a few thousand years.

Earthquake ground motion specific at a construction site is influenced by the geometry of active faults, dynamic rupture process of earthquake sources, and the transmission of earthquake motions from the earthquake source to the construction site. The global parameters such as fault length, width and magnitude of an earthquake must be estimated by the seismic history, geological investigation and source modeling of active faults. The transmission characteristics of earthquake motion may be estimated on the basis of observation of more frequent minor earthquakes. The intensity of earthquake wave decays with distance. These estimates involve a large uncertainty.

The earthquake wave is generally transmitted from the fracture fault through hard rock layers and then to the ground surface through relatively soft surface soil. The characteristics of ground motion are significantly modified by the properties of surface soil layers, such as the properties and geometry of the subsurface soil layers, surface topography, and depth and properties of the underlying bedrock. Soft soil layers consisting of river deposits tend to amplify long period components of an earthquake motion, causing serious damage to houses and buildings.

-
-
-

Bibliography

Biot M. A. (1941). A Mechanical Analyzer for the Prediction of Earthquake Stresses, Bulletin, *Seismological Society of America*, Vol. 31, No. 2, 151-171. [This paper presented the first response analysis of a simple system to observed earthquake motions].

Cross H. (1930). Analysis of Continuous Frames by Distributing Fixed End Moments, Proceedings, *American Society of Civil Engineers*. [This paper presented a simple and practical method of structural analysis].

Housner G. W. (1984). Historical View of Earthquake Engineering, Conference Lecture, Proceedings, *Eighth World Conference on Earthquake Engineering*, San Francisco, Post-Conference Volume, 25 - 39. [This outlines the development of earthquake engineering].

Kawasumi H. (1968). Measure of Earthquake Danger and Expectancy of Maximum Intensity throughout Japan as Inferred from the Seismic Activity in Historical Times, Bulletin, *Earthquake Research Institute*, University of Tokyo, Vol. 46, 663-666. [This paper is the first to evaluate seismic risk in various region].

Milne J. and Burton W. K. (1891). *The Great Earthquake of Japan 1891*, Lane, Crawford & Co., Yokohama, Japan. [This book reports the earthquake disaster from the 1981 Nohbi Earthquake, and discusses the importance of earthquake resistance design].

Paulay T. (1977). Capacity Design of Reinforced Concrete Ductile Frames, Proceedings, *Workshop on Earthquake-Resistant Reinforced Concrete Building Construction*, University of California at Berkeley, Vol. III, 1043-1075. [This paper introduces the capacity design procedure for the first time outside New

Zealand].

Veletsos A. S. and Newmark N. M. (1960). Effect of Inelastic Behavior on the Response of Simple Systems to Earthquake Motions, Proceedings, *Second World Conference on Earthquake Engineering*, Tokyo-Kyoto, Volume II, 895 - 912. [This paper presents the results of nonlinear response analysis of simple systems and proposes design criteria for survival].

Biographical Sketch

Dr. Shunsuke Otani graduated from Department of Architecture, University of Tokyo, and obtained M.Sc. and Ph.D. degrees from Department of Civil Engineering, University of Illinois at Urbana-Champaign. After teaching in the Department of Civil Engineering at the University of Illinois at Urbana-Champaign and also at the University of Toronto, he became an associate professor and subsequently professor in Department of Architecture, University of Tokyo. His areas of research are earthquake engineering, structural behavior of reinforced concrete members and nonlinear earthquake response of reinforced concrete buildings.