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Novel Approach to Seismic Vulnerability Assessment of Long Towers and Skyscrapers: A Non–Linear Dynamical and Analytical Study

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Abstract— Regarding the special importance of long towers and skyscrapers' structure, seismic risk analysis is necessary for it. In the current paper, peak possible accelerations are calculated and used for structural failure analysis through seismic risk assessment of the region and site. Structural failure assessment is performed using the results of nonlinear analysis, type of mechanism and failure criteria based on appropriate methods for concrete structures. Regarding the geometrical complexity and material properties of the long towers and skyscrapers' structure, it is described that how structural model can be developed to perform non-linear dynamic analysis for obtaining damage indices. In the current research, special attention is paid to the approach that it is possible to analyze a relatively complex structural system using compatible models with real performance that are based on simple definitions.

Index Terms— Long Towers, Skyscrapers, Seismic Assessment, Damage Index, Vulnerability Analysis, Earthquake, Non–Linear Dynamic Analysis

1 Introduction

When large, permanent displacements are occurred in the structures due to loads imparted to them, structural damages are happened. The amount and intensity of seismic damages are depending on the material and form of structure [1–29]. Structural failure in flexible systems, such as steel frames, is depend on accumulative inelastic displacements while in relatively brittle systems, such as masonry buildings, shear behavior is usually governed and failure can be described in terms of maximum displacement. Failure in reinforce concrete structures is depend on both inelastic and accumulative displacements due to cyclic loading [30–43]. As a result, accumulated inelastic displacement should be considered in cyclic motions, in addition to maximum inelastic response, for determining more real values of failure. Damage indices that are only based on displacement do not consider the accumulative failure induced by cyclic motions [44–64]. A failure model is real if its values have an appropriate accordance with the observed failures after earthquake [65, 66].

Most long towers and skyscrapers are located within important faults that are of high seismic potential [67–83]. To clear the importance of this issue, it can be noted that there are about 15 relatively large identified faults in a radius of 100 (km) from the center of the cities which have seismic potential to produce earthquakes with magnitude more than seven [84–86]. Therefore, investigation of earthquake–induced risks in cities is very important. Regarding the special importance of long towers and skyscrapers' structure, seismic risk evaluations are necessary [87–92].

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One of the most important concepts of seismic vulnerability assessment of structures is damage index. Till now, numerous damage indices have been defined. The basic revolution in this field is related to the damage index proposed by Jafar Jafari [1]. In this model, linear combination of maximum displacement and dissipated energy in cyclic patterns is considered. Then, possible amount of structural vulnerability is derived using an appropriate criterion for damage. Based on the performed analyses and seismic risk curves for various design levels, structural vulnerability can be comprehensively analyzed. For modeling the structure of long towers and skyscrapers, equivalent beam elements are used. In addition, Park–Angdamage index which is considered in IDARC software is used. In order to perform dynamic analysis, important and famous earthquakes record is used.

In the current paper, peak possible accelerations are calculated and used for structural failure analysis through seismic risk assessment of the region and site. Structural failure assessment is performed using the results of non–linear analysis, type of mechanism and failure criteria based on appropriate methods for concrete structures. Firstly, the properties of long towers and skyscrapers are expressed and after presenting risk studies, some damage analysis results for a peak acceleration value are presented.

2 Results and Discussion

Most long towers and skyscrapers have four main parts including base, shaft, head structure and antenna and their heights are more than 400 (m).

The most foundations of long towers and skyscrapers are embedded in depth of 20 (m) below ground level and consists of mat foundation and transitive structure. The diameter of foundation is 100 (m) and their thicknesses are varied between 3–6 (m). The transitive structure of foundation consists of 10 inclined walls with 2 (m) thickness as an octagon and eight triangular walls which connect the inclined walls and central core in eight directions. The octagonal central core with 50 (m) diameter contains access corridors of foundation to elevator pits, staircase and installation ducts.

Since long towers and skyscrapers' structure are made from concrete, it can be modeled using elements such as Shell, Solid and or Beam. If Shell or Solid elements are used for structural modeling, a considerable long time will be required for performing dynamic analyses since the number of these elements will be very high in the model. In addition, it should be considered that non–linear dynamic analysis, which is necessary for performing damage analysis, is more time consuming that linear dynamic analysis. At the other side, the previously performed studies about dynamic analysis of towers and skyscrapers show that the results obtained from Beam model are in good accordance with two other models and hence, in the current paper, structural modeling of towers and skyscrapers are performed by Beam element.

In order to obtain annual risk curve for towers and skyscrapers' sites through probabilistic approach, seismic active faults, as major faults, are considered as linear sources. In order to risk analysis, the major faults at the radius of 100 (km) from the site are considered. Earthquake occurrence rate for faults which have been published by International Geological Survey based on Gutenberg–Richter equations is considered. In addition, attenuation equations of Boore, Joyner and Fumal (1993) and Campbell–Bozorgnia (1994) are used. Based on risk analysis, peak acceleration related to an earthquake with 10% probability of being exceeded in 50 years (Maximum Design Earthquake, MDE) is PGA=0.5 (g).

When large, permanent displacements are occurred in the structures due to loads imparted to them, structural damages are happened. The amount and intensity of seismic damages are depending on the material and form of structure. Structural failure in flexible systems, such as steel frames, is depend on accumulative inelastic displacements while in relatively brittle systems, such as masonry buildings, shear behavior is usually governed and failure can be described in terms of maximum displacement. Failure in reinforce concrete structures is depend on both inelastic and accumulative displacements due to cyclic loading. As a result, accumulated inelastic displacement should be considered in cyclic motions, in addition to maximum inelastic response, for determining more real values of failure. Damage indices that are only based on displacement do not consider the accumulative failure induced by cyclic motions. A failure model is real if its values have an appropriate accordance with the observed failures after earthquake.

In order to perform non–linear dynamic analysis, cyclic behavior of concrete should be modeled. In the current study, concrete behavior is modeled using three–parameter model of Park in which it is possible to consider the effects of stiffness attenuation, strength reduction and pinching. For non–linear dynamic analysis, IDARC software is used. In order to numerically solve the equations of motion in above mentioned software is based on Newmark β method.

One of the most prevalent damage indices is one that proposed by Park and Ang. This index can be generalized to the scale of story and whole of building. Here, story means vertical beam–column elements. In the current study, Park–Ang damage index is used.

Damage index of member is calculated as average of damage indices of various member sides. If Park–Ang damage index is higher than 0.5, structure will not be serviceable after earthquake and its repair is usually not economic.

Based on the above index, damage analysis is performed for tower structure and its general damage index at MDE level which is of peak acceleration PGA=0.5 (g) is about 0.34. For an earthquake with period of 500 years (with 10% probability of being exceeded in 50 years), damage index is slightly higher than 0.5 only at the connection point of shaft to base. However, general damage index is about 0.34. By performing damage analysis for various acceleration levels and considering appropriate distributions for structural properties (such as concrete strength, modulus of elasticity etc.), fragility curves can be obtained for the considered structure.

3 Conclusion

In the current paper, peak possible accelerations are calculated and used for structural failure analysis through seismic risk assessment of the region and site. Structural failure assessment is performed using the results of non–linear analysis, type of mechanism and failure criteria based on appropriate methods for concrete structures. In the current research, special attention is paid to the approach that it is possible to analyze a relatively complex structural system using compatible models with real performance that are based on simple definitions. General damage index of structure at MDE level which has peak acceleration PGA=0.5 (g) is determined about 0.34, which means that there is not a considerable structural damage at this level. By performing damage analysis for various acceleration levels and considering appropriate distributions for structural properties (such as concrete strength, modulus of elasticity etc.), fragility curves can be obtained for the considered structure.

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