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Study of Seismic Behavior of Reinforced Concrete Buildings under varying frequency contents

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ABSTRACT

Earthquake is the result of sudden release of energy in the earth's crust that generates seismic waves. Ground shaking and rupture are the major effects generated by earthquakes. It has social as well as economic consequences such as causing death and injury of living things especially human beings and damages the built and natural environment. In order to take precaution for the loss of life and damage of structures due to the ground motion, it is important to understand the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. These characteristics play predominant rule in studying the behavior of structures under seismic loads. The strength of ground motion is measured based on the PGA, frequency content and how long the shaking continues. Ground motion has different frequency contents such as low, intermediate, and high.

1. Introduction

An earthquake is the result of a rapid release of strain energy stored in the earth's crust that generates seismic waves. Structures are vulnerable to earthquake ground motion and damage the structures. In order to take precaution for the damage of structures due to the ground motion, it is important to know the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. These characteristics play predominant rule in studying the behavior of structures under the earthquake ground motion.

Severe earthquakes happen rarely. Even though it is technically conceivable to design and build structures for these earthquake events, it is for the most part considered uneconomical and redundant to do so. The seismic design is performed with the expectation that the severe earthquake would result in some destruction, and a seismic design philosophy on this premise has been created through the years. The objective of the seismic design is to constraint the damage in a structure to a worthy sum. The structures designed in such a way that should have the capacity to resist minor levels of earthquake without damage, withstand moderate levels of earthquake without structural damage, yet probability of some nonstructural damage, and withstand significant levels of ground motion without breakdown, yet with some structural and in addition nonstructural damage. [2]

In present work, two, six, and twenty-story regular as well as irregular RC buildings are subjected to six ground motions of low, intermediate, and high-frequency content. The buildings are modeled as three dimension and linear time history analysis is performed using structural analysis and design (STAAD Pro) software [1].

Origin of Project

A few research is carried out to study the frequency content of the ground motion. Cakir [3] studied the evaluation of the effect of earthquake frequency content on seismic behavior of cantilever retaining wall including soil-structure interaction. Also, Nayak & Biswal [4] studied seismic behavior of partially filled rigid rectangular tank with bottom-mounted submerged block under low, intermediate, and high-frequency content ground motions.

No work is carried out on seismic behavior of RC buildings under varying frequency content ground motions. The present study deals with seismic behavior of reinforced concrete buildings under low, intermediate, and high-frequency content ground motions.

Research Significance

The earth shakes with the passing of earthquake waves, which discharge energy that had been confined in stressed rocks, and were radiated when a slip broke and the rocks slid to release the repressed stress. The strength of ground quaking is determined in the acceleration, duration, and frequency content of the ground motion.

The responses of RC buildings are strongly dependent on the frequency content of the ground motions. Ground motions have different frequency contents such as low, intermediate, and high. Low, mid, and high-rise reinforced concrete buildings show different response under low, intermediate, and high-frequency content ground motions.

The present work shows that how low, mid, and high-rise reinforced concrete buildings behave under low, intermediate, and high-frequency content ground motions.

Objective and Scope

The purpose of this project is to study the response of low, mid, and high-rise regular as well as irregular three-dimension RC buildings under low, intermediate, and high-frequency content ground motions in terms of story displacement, story velocity, story acceleration and base shear preforming linear time-history analysis using STAAD Pro [1] software.

From the three dynamic characteristics of ground motion, which are PGA, duration, and frequency content, keeping PGA and duration constant and changing only the frequency content to see how low, mid, and high-rise reinforced concrete buildings behave under low, intermediate, and high-frequency content ground motions.

2. Literature review

In the literature review, characteristics of ground motion, that play vital rule in the seismic analysis of structures, explained. Then behavior of RC buildings under seismic loads are represented. There are few researches concerning to the seismic behavior of structures under frequency content.

Cakir [3] studied the evaluation of the effect of earthquake frequency content on seismic behavior of cantilever retaining wall involving soil-structure interaction. Also, seismic behavior of partially filled rigid rectangular tank with bottom-mounted submerged block are studied under low, intermediate, and high-frequency content ground motions. Nayak & Biswal [4].

No research work is done on seismic behavior of RC buildings under low, intermediate, and high-frequency content ground motions.

Characteristics of Ground Motion

Ground motion at a specific site because of earthquakes is influenced by source, local site conditions, and travel path. The first relates to the size and source mechanism of the earthquake. The second defines the path effect of the earth as waves travel at some depth from the source to the spot. The third describes the effects of the upper hundreds of meters of rock and soil and the surface topography at the location. Powerful ground motions cause serious damages to made-up amenities and unluckily, From time to time, induce losses of human lives. Factors that affect strong ground shaking are magnitude, distance, site, fault type, depth, repeat time, and directivity and energy pattern. [11]

Rathje, et al. [12] studied three simplified frequency content, which are mean period (Tm), predominant period (Tp), and smoothed spectral predominant period (Tp). They computed the frequency parameters for 306 motion records from twenty earthquakes. They used the data for developing a model to describe the site reliance, magnitude, and distance of the frequency content parameters. Model coefficients and standard error terms are evaluated by means of nonlinear regression analyses. Their results show that the conventional Tp parameter has the highest uncertainty in its prediction and the earlier correlation suggested predicting Tp are unreliable with their current data set. Moreover, the best frequency content characterization parameter is Tm.

The stochastic method is a basic and powerful method for simulation of ground motions. It is specified as adjustment of combination of parametric or functional description of the amplitude spectrum of ground motion with a random phase spectrum such that the motion is distributed over a time span related to the earthquake magnitude and to the distance from the source. This method is useful for simulation of higher-frequency ground motions (e.g. 0-1 Hz) and when the recordings of the potentially damaging earthquakes are not accessible, it is used to predict them. [13]

Rathje, et al. [14] established empirical relationships for frequency content parameters of earthquake ground motions. The frequency content of an earthquake ground motion is significant because the dynamic response of soil and structure is influenced by it. Mean period (Tm), Average spectral period (Tavg), Smoothed spectral predominant period (To), and predominant spectral period (Tp) are the four parameters that describe the frequency content of strong ground motions. Low-frequency content of ground motions are differentiated by Tm and Tavg., while high-frequency content is influenced by To. The frequency content of astrong ground motion may not be defined by Tp .

They developed empirical relationships that predict three parameters (Tm, Tavg, and To) as a function of earthquake magnitude, rupture directivity, site to source distance, and site conditions. They claim that new relationships update those early ones. Their results show that three site classes, which classify between rock, deep soil, and shallow soil present better prediction of the frequency content parameters and minor standard error terms than traditional “rock” and “soil” site classes. The frequency content parameters, particularly Tm and To are increased noticeably due to forward directivity, at distances less than 20 km. Among the frequency-content parameters, Tm is the preferred one because the frequency content of strong ground motions is best distinguished by means of it.

Chin-Hsun [10] proposed a new stochastic model of ground excitation in which both frequency content intensity are time dependent. The proposed ground motion model can be effectively employed in simulations as well as random vibration and reliability studies of nonlinear structures. Responses of single-mass nonlinear systems and three-story space frames, with or without deterioration under the no stationary biaxial ground motion are found through the equivalent linearization method and Monte Carlo simulations. His results indicate that the time- varying frequency content and the dominant frequencies of ground motion are close to the structural natural frequency. In addition, biaxial and torsional response may become noteworthy in an unsymmetrical structure.

Şafak & Frankel [11] studied the effects of ground motion characteristics on the response of base-isolated structures. They presented response of base-isolated structures in two models to show the effects of ground motion characteristics. They considered one and three-dimension velocity models for a six and seven-story base-isolated buildings, which are subjected to ground motions. Their results indicate that efficiency of base isolators is greatly dependent on the frequency characteristics as well as amplitudes of ground motion.

Early standards had been mainly focused on to protect buildings against collapse; the new and further improved rules are allotted to minimize the damage costs, by preserving the non- structural elements and the structures within an acceptable damage level. Thus, the fundamentals of Performance Based Seismic Design were set up. [12]

Behavior of RC Buildings under Seismic Load

A seismic design method taking into account performance principles for two discrete limit states is presented by Kappos & Manafpour [13], including analysis of a feasible partial inelastic model of the structure using time-history analysis for properly scaled input motions, and nonlinear static analysis (pushover analysis).

Mwafy & Elnashai [14], studied static pushover vs. dynamic collapse analysis of RC buildings. They studied natural and artificial ground motion data imposed on twelve RC buildings of distinct characteristics. The responses of over one hundred nonlinear dynamic analyses using a detailed 2D modeling approach for each of the 12 RC buildings are used to create the dynamic pushover envelopes and compare them with the pushover results with various load patterns. They established good relationship between the calculated ideal envelopes of the dynamic analyses and static pushover results for a definite class of structure.

Pankaj & Lin [15] carried out material modeling in the seismic response analysis for the design of RC framed structures. They used two alike continuum plasticity material models to inspect the impact of material modeling on the seismic response of RC frame structures. In model one, reinforced concrete is modeled as a homogenized material using an isotropic Drucker-Prager yield condition. In model two, also based on the Drucker-Prager criterion, concrete and reinforcement are included independently; the later considers strain softening in tension. Their results indicate that the design response from response history analyses (RHA) is considerably different for the two models. They compared the design nonlinear static analysis (NSA) and RHA responses for the two material models. Their works show that there can be important difference in local design response though the target deformation values at the control node are near. Likewise, the difference between the mean peak RHA response and the pushover response is dependent on the material model.

Sarno [16] studied the effects of numerous earthquakes on inelastic structural response. Five stations are chosen to signify a set of sites exposed to several earthquakes of varying magnitudes and source-to-site distances. From the tens of records picked up at these five sites, three are chosen for each site to denote states of leading and lagging powerful ground motion. RC frame analysis subjected to the same set of ground motions used for the response of the RC frame, not only verify that multiple earthquakes deserve broad and urgent studies, but also give signs of the levels of lack of conservatism in the safety of traditionally designed structures when subjected to various earthquakes.

3. Structural Modeling

Concrete is the most widely used material for construction. It is strong in compression, but weak in tension, hence steel, which is strong in tension as well as compression, is used to increase the tensile capacity of concrete forming a composite construction named reinforced cement concrete. RC buildings are made from structural members, which are constructed from reinforced concrete, which is formed from concrete and steel. Tension forces are resisted by steel and compression forces are resisted by concrete. The word structural concrete illustrates all types of concrete used in structural applications. [17]

Gravity loads, dead as well as live loads, are given. A brief description is provided for concrete and steel. Also, the concrete and steel bar properties which are used for modeling of the buildings are shown. At the end of this section, in section 3.6 the size of structural elements are presented.

Regular RC Buildings

Two, six, and twenty-story regular reinforced concrete buildings, which are low, mid, and high- rise, are considered. The beam length in (x) transverse direction is 4m and in (z) longitudinal direction 5m. Figure 1 shows the plan of the three buildings having three bays in x-direction and five bays in z-direction. Story height of each building is assumed 3.5m. Figure 2-3. shows the frame (A-A) and (01-01) of the twenty, six, and two-story RC building respectively. For simplicity, both the beam and column cross sections are assumed 300 mm x 400 mm.

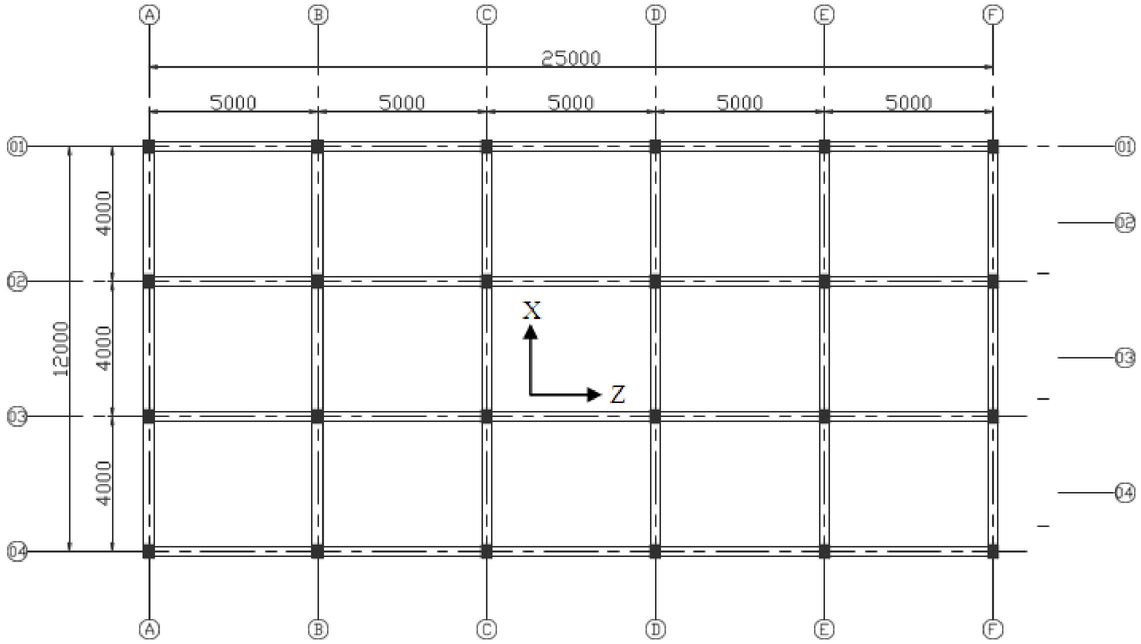
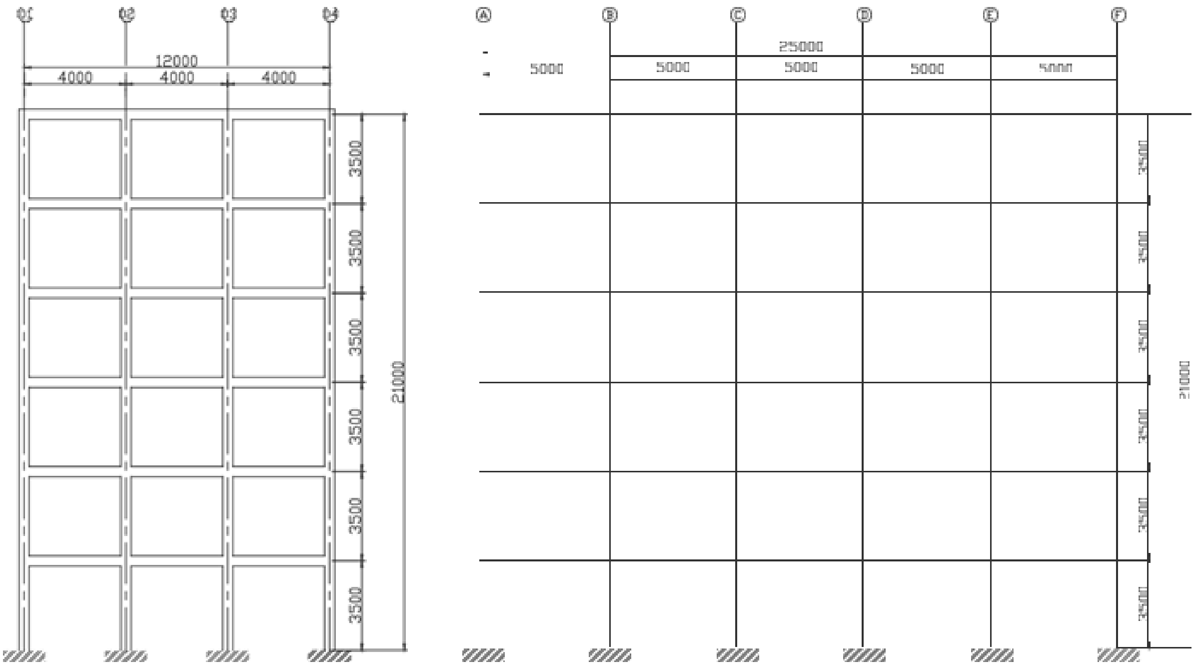


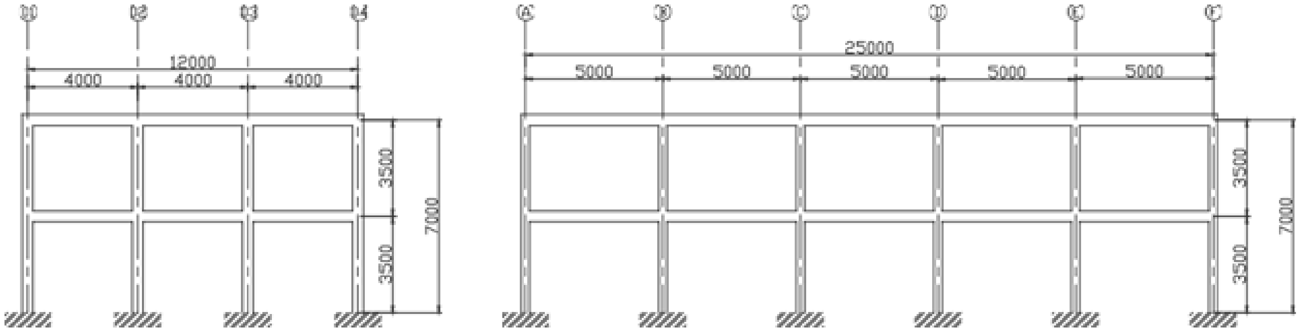
Figure 1: Plan of two, six, and twenty-story regular RC buildings (all dimensions are in mm)



Frame (A-A)

Frame (01-01)

Figure 2: Frame (A-A) and (01-01) of six-story regular RC building (all dimension are in mm)



Frame (A-A)

Frame (01-01)

Figure 3: Frame (A-A) and (01-01) of two-story regular RC building (all dimension are in mm)

4. Results and discussion

In this section, the results of two, six, and twenty-story irregular reinforced concrete buildings in terms of story displacement, story velocity, story acceleration, and base shear are presented in (x) transverse and (z) longitudinal direction. Also the roof displacement, roof velocity, and roof acceleration for each building due to each ground motion is illustrated in (x) transverse and (z) longitudinal direction .The responses of the structures due to the ground motions are shown. In section 6.2, the two-story irregular RC building responses due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (El Centro) elcentro_EW component, 1992 Landers (Fort Irwin) FTI000 component, and 1983 Coaling-06 (CDMG46617) E-CHP000 component ground motions are shown. In section 6.3, the six-story irregular RC building responses due to the above six ground motions are displayed. Lastly, in section 6.4, results of the twenty-story irregular RC building due to the mentioned ground motions are presented.

Two-Story Irregular RC Building

Figure 4. shows the story displacement, velocity, and acceleration of two-story irregular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM2 and minimum due to ground motion GM3. The story velocity is maximum due to ground motion GM2 and minimum due to ground motion GM3. The story acceleration is maximum due to ground motion GM2 and minimum due to ground motion GM3. It indicates that the building undergoes high story displacement, velocity and acceleration due to intermediate-frequency content ground motion. However, it experiences low story displacement, velocity, and acceleration due to high-frequency content ground motion in (x) transverse direction.

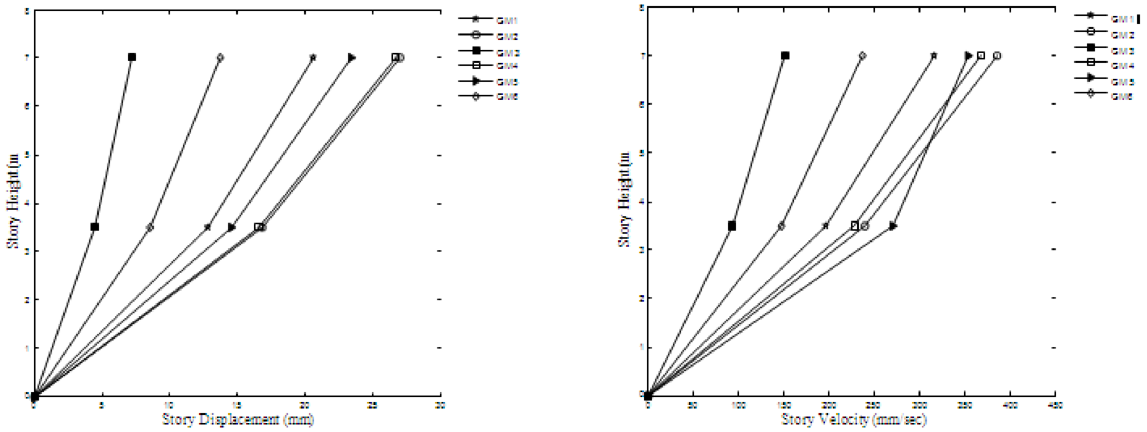


Figure 4: Story displacement, velocity, and acceleration of two-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

Figure 5 shows story displacement, velocity, and acceleration due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM4 and minimum due to ground motion GM3. The story velocity is maximum due to ground motion GM4 and minimum due to ground motion GM3. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3. It indicates that the building undergoes high story displacement, velocity and acceleration due to low-frequency content ground motion. However, it experiences low story displacement, velocity, and acceleration due to high-frequency content ground motion in (z) longitudinal direction.

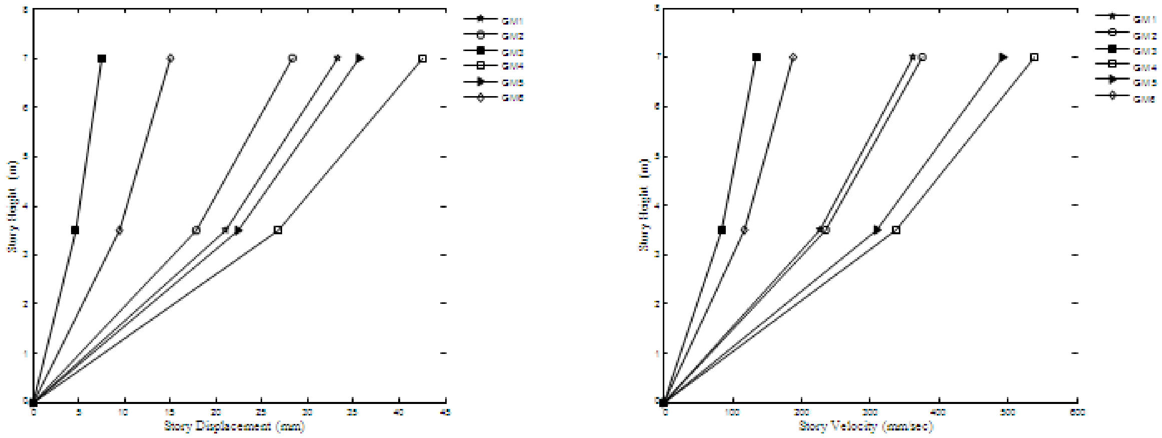


Figure 5: Story displacement, velocity, and acceleration of two-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

The structure has maximum roof displacement of 27 mm at 6.57 s due to IS 1893 (Part1) : 2002 ground motion and minimum roof displacement of -7.22 mm at 1.46 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 386 mm/s at 6.46 s due to IS 1893 (Part1) : 2002 ground motion and minimum velocity of -151 mm/s at 1.4 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof acceleration of 6.57 m/s2 at 6.83 s due to IS 1893 (Part1) : 2002 ground motion and minimum 3.61 m/s2 at 1.74 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction.

The structure has maximum roof displacement of 42.6 mm at 2.07 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -7.5 mm at 2.19 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -538 mm/s at 2.2 s due to 1940 Imperial Valley (El Centro) elcentro_EW ground motion and minimum velocity of 134 mm/s at 1.4 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof acceleration of 7.73 m/s2 at 2.3 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 3.11 m/s2 at 1.74 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

5. Conclusions

Following conclusions can be drawn for the two, six, and twenty-story regular RC buildings from the results obtained in Paper:

- Two-story regular RC building experiences maximum story displacement due to low-frequency content ground motion in x and z-direction
- Two-story regular RC building experiences minimum story displacement due to high- frequency content ground motion in x and z-direction
- Two-story regular RC building experiences maximum story velocity due to intermediate- frequency content ground motion in x-direction and low-frequency content ground motion in z-direction
- Two-story regular RC building experiences minimum story velocity due to high-frequency content ground motion in x and z-direction
- Two-story regular RC building experiences maximum story acceleration due to intermediate- frequency content ground motion in x-direction and low-frequency content ground motion in z-direction
- Two-story regular RC building experiences minimum story acceleration due to high-frequency content ground motion in x and z-direction
- Two-story regular RC building experiences maximum base shear due to low-frequency content ground motion in x and z-direction
- Two-story regular RC building experiences minimum base shear due to high-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes maximum story displacement due to low-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes minimum story displacement due to high-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes maximum story velocity due to low-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes minimum story velocity due to high-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes maximum story acceleration due to intermediate- frequency content ground motion in x-direction and low-frequency content ground motion in z-direction
- Six-story regular RC building undergoes minimum story acceleration due to high-frequency content ground motion in x and z-direction
- Six-story regular RC building undergoes maximum base shear due to low-frequency content ground motion in x and z-direction

References

[1] "Structural Analysis And Design (STAAD Pro) software," Bentley Systems, Inc.

[2] A. Baghchi, Evaluation of the Seismic Performance of Reinforced Concrete Buildings, Ottawa: Department of Civil and Environmental Engineering, Carleton University, 2001.

[3] Mandeep Sindhu, Paramjeet Malik, “Research Paper on Risk Analysis of BOT Scheme”, International Journal of All Research Education and Scientific Methods (IJARESM), ISSN: 2455-6211, Volume 4, Issue 7, July- 2016.

[4] T. Cakir, "Evaluation of the effect of earthquake frequency content on seismic behaviour of cantiliver retaining wall including soil-structure interaction," Soil Dynamics and Earthquake Engineering, vol. 45, pp. 96-111, 2013.

[5] S. K. Nayak and K. C. Biswal, "Quantification of Seismic Response of Partially Filled Rectangular Liquid Tank with Submerged Block," Journal of Earthquake Engineering, 2013.

[6] "Pacific Earthquake Engineering Research Center: NGA Database," 2005. [Online]. Available: http://peer.berkeley.edu/nga/data?doi=NGA0185. [Accessed 2013].

[7] Mandeep Sindhu, “Effects of Road Accidents and Safety Concerning Adolescent”, IJRAR- International Journal of Research and Analytical Reviews, E ISSN 2348-1269, Volume 5 , Issue 2, April – June 2018.

[8] IS 1893 (Part1), Indian Standard CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES PART 1, 6.1 ed., New Delhi 110002: Bureau of Indian Standards, 2002.

[9] "Pacific Earthquake Engineering Research Center: NGA Database," 2005. [Online]. Available:

http://peer.berkeley.edu/nga/data?doi=NGA0023. [Accessed 2013].

[10] "Vibration Data El Centro Earthquake," [Online]. Available: http://www.vibrationdata.com/elcentro.htm. [Accessed 2013].

[11] Mandeep Sindhu, “Design and study of motor sports and racing car setups”, International Journal of Advanced Science and Research, ISSN: 2455-4227, Volume 2; Issue 4; July 2017; Page No. 145-148.

[12] C. Chhuan and P. Tsai, International Training Program for Seismic Design of Building Structures.

[13] E. M. Rathje, N. A. Abrahamson and J. D. Bray, "Simplified Frequency Content Estimates of Earthquake Ground Motions," Journal of Geotechnical & Geoenvironmental Engineering, no. 124, pp. 150-159, 1998.

[14] D. M. BOORE, "Simulation of Ground Motion Using the Stochastic Method," Pure and Applied Geophysics, no. 160, pp. 635-676, 2003.

[15] E. M. Rathje, F. Faraj , S. Russell and J. D. Bray, "Empirical Relationships for Frequency Content Parameters of Earthquake Ground Motions," Earthquake Spectra, vol. 20, no. 1, pp. 119-144, February 2004.

[16] Mandeep Sindhu, “Effect of Efficient and Productive Transport in Economic Development of a Country”, 3rd International Conference on Emerging Trends in Engineering, Technology, Science and Management ICETETSM-2017, IETE Lodhi Road, Delhi, India, 11th June 2017, ISBN: 978-93-86171-48-1.

[17] Y. Chin-Hsun, "Modeling of nonstationary ground motion and analysis of inelastic structural response," Structural Safety, vol. 8, no. 1-4, pp. 281-298, July 1990.