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EXPERIMENTAL INVESTIGATION ON R.C BUILDINGS OF SEISMIC BEHAVIOR UNDER SIGNIFICANCE OF FLUCTUATING FREQUENCY

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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.

Present work deals with study of frequency content of ground motion on reinforced concrete (RC) buildings. Linear time history analysis is performed in structural analysis and design (STAAD Pro) software. The proposed method is to study the response of low, mid, and high-rise reinforced concrete buildings under low, intermediate, and high- frequency content ground motions. Both regular and irregular three-dimension two, six, and twenty- story RC buildings with six ground motions of low, intermediate, and high-frequency contents having equal duration and peak ground acceleration (PGA) are studied herein.

The response of the buildings due to the ground motions in terms of story displacement, story velocity, story acceleration, and base shear are found. The responses of each ground motion for each type of building are studied and compared. The results show that low- frequency content ground motions have significant effect on both regular as well as irregular RC buildings. However, high-frequency content ground motions have very less effect on responses of the regular as well as irregular RC buildings.

Keywords: ***Reinforced concrete building, ground motion, peak ground acceleration, frequency content, time history analysis.***

I 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 damages 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].

1.1 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.

1.2 Methodology

The following six ground motion records, which have low, intermediate, and high-frequency content, have been considered for the analysis:

1. 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component [5]
2. IS 1893 (Part1) : 2002 (Artificial ground motion) [6]
3. 1957 San Francisco (Golden Gate Park) GGP010 component [7]

4. 1940 Imperial Valley (El Centro) elcentro_EW component [8]
5. 1992 Landers (Fort Irwin) FTI000 component [9]
6. 1983 Coalinga-06 (CDMG46617) E-CHP000 component [10]

Ground motion record (1), (3), (5), and (6) are selected from Pacific Earthquake Engineering Research Center (PEER) Next Generation Attenuation (NGA) database. The ground motion record (2) is the compatible time-history of acceleration as per spectra of IS 1893 (Part1) [6] for structural design in India. The ground motion (4) is the 1940 El Centro east west component.

All the above six ground motions duration is 40 s. In order to have same PGA, the above ground motions are scaled to magnitude of 0.2 g. Two, six, and twenty-story RC buildings, which are considered as low, mid, and high-rise reinforced building are modeled as three-dimension regular and irregular reinforced concrete buildings in STAAD Pro [1]. Then the ground motions are introduced to the software and linear time history analysis is performed.

The basis of the present work is to study the behavior of reinforced concrete buildings under varying frequency contents. This study shows how low, mid and high-rise reinforced concrete buildings behave in low, intermediate, and high-frequency content ground motions.

Here, the story displacement, story velocity, story acceleration, and base shear of low, mid, and high-rise regular and irregular reinforced concrete buildings due to the six ground motions of low, intermediate and high-frequency content are obtained. The methodology, which is conducted, is briefly described as below:

1. Ground motion records are collected and then normalized.
2. Linear time history analysis is performed in STAAD Pro [1].
3. Building response such as story displacement, story velocity, story acceleration, and base shear are found due to the ground motions.
4. The results of the three regular and irregular RC buildings are compared with respect to the six ground motions.

II LITERATURE REVIEW

2.1 Overview

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].

III STRUCTURAL MODELING

3.1 Overview

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. [27]

In this chapter, building description is presented. The plan, elevation of two, six, and twenty-story regular reinforced concrete buildings of low, mid, and high-rise are shown in section 3.2. In section 3.3 the plan and elevation of the two, six, and twenty-story irregular reinforced concrete buildings which are considered as low, mid, and high-rise buildings are shown.

Gravity loads, dead as well as live loads, are given in section 3.4. 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 in section 3.5. At the end of this chapter, in section 3.6 the size of structural elements are presented.

IV GROUND MOTIONS AND LINEAR TIME HISTORY ANALYSIS

4.1 Ground Motion Records

Buildings are subjected to ground motions. The ground motion has dynamic characteristics, which are peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), frequency content, and duration. These dynamic characteristics play predominant rule in studying the behavior of RC buildings under seismic loads. The structure stability depends on the structure slenderness, as well as the ground motion amplitude, frequency and duration. [23] Based on the frequency content, which is the ratio of PGA/PGV the ground motion records are classified into three categories [38]:

The ratio of peak ground acceleration in terms of acceleration of gravity (g) to peak ground velocity in unit of (m/s) is defined as the frequency content of the ground motion. [38]

4.2 Linear Time History Analysis

Time history analysis is the study of the dynamic response of the structure at every addition of time, when its base is exposed to a particular ground motion. Static techniques are applicable when higher mode effects are not important. This is for the most part valid for short, regular structures. Thus, for tall structures, structures with torsional asymmetries, or no orthogonal frameworks, a dynamic method is needed.

In linear dynamic method, the structures is modeled as a multi degree of freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix. The seismic input is modeled utilizing time history analysis, the displacements and internal forces are found using linear elastic analysis. The playing point of linear dynamic procedure as for linear static procedure is that higher modes could be taken into account.

In linear dynamic analysis, the response of the building to the ground motion is computed in the time domain, and all phase information is thus preserved. Just linear properties are considered. Analytical result of the equation of motion for a one degree of freedom system is normally not conceivable if the external force or ground acceleration changes randomly with time, or if the system is not linear. [35]. Such issues could be handled by numerical time-stepping techniques to integrate differential equations.

In order to study the seismic behavior of structures subjected to low, intermediate, and high-frequency content ground motions, dynamic analysis is required. The STAAD Pro [1] software is used to perform linear time history analysis.

Two, six, and twenty-story regular as well as irregular RC buildings are modeled as three-dimension. Material properties, beam and column sections, gravity loads, and the six ground motions listed in Table 4.3 are assigned to the corresponding RC buildings and then linear time history analysis is performed. The linear time-history analysis results for regular and irregular RC buildings are shown in chapter 5 and 6 respectively.

In the analysis of structures, the number of modes to be considered should have at least 90 percent of the total seismic mass. [6].

V REGULAR RC BUILDINGS RESULTS AND DISCUSSION

5.1 Overview

In this chapter, the results of two, six, and twenty-story regular 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 found. In section 5.2, the two-story regular 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 5.3, the six-story regular RC building responses due to the above six ground motions are displayed. Finally, in section 5.4, the results of the twenty-story regular RC building due to the mentioned ground motions are presented.

5.2 Two-Story Regular RC Building

Figure 5.1 shows story displacement, velocity, and acceleration of two-story regular RC building due to ground motion GM1[1], GM2[2], GM3[3], GM4[4], GM5[5], and GM6[6]. 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 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 and GM6. It indicates that the building undergoes high story displacement due to low-frequency content ground motion and high story velocity and acceleration due to

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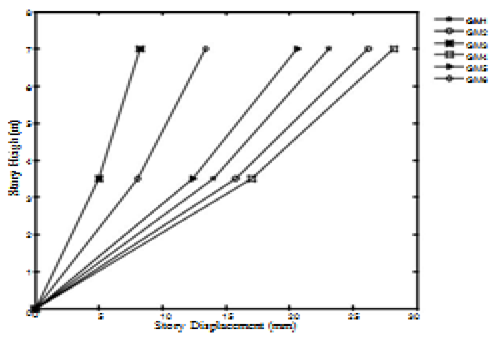
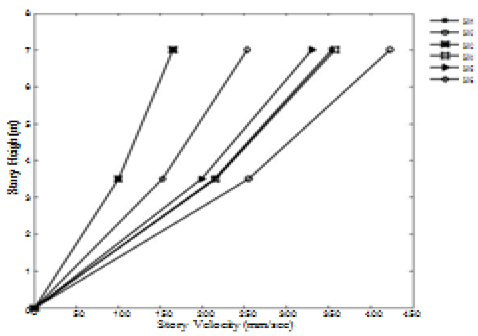
intermediate-frequency content ground motion. However, it experiences low story displacement, velocity, and acceleration due to high-frequency content ground motion in (x) transverse direction.

Figure 5.2 shows story displacement, velocity, and acceleration of two-story regular RC building 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 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, story velocity and story acceleration due to low-frequency content ground motion. However, it experiences low story displacement, velocity, and acceleration due to the high-frequency content ground motion in (z) longitudinal direction.





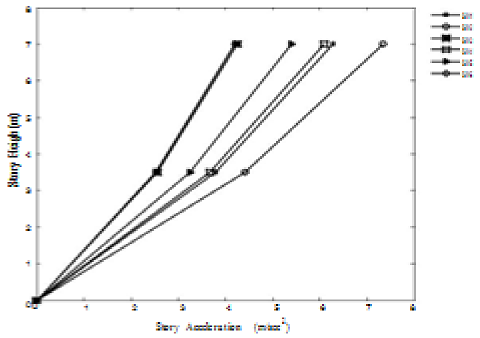


Figure 5.1: Story displacement, velocity, and acceleration of two-story regular reinforced concrete building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

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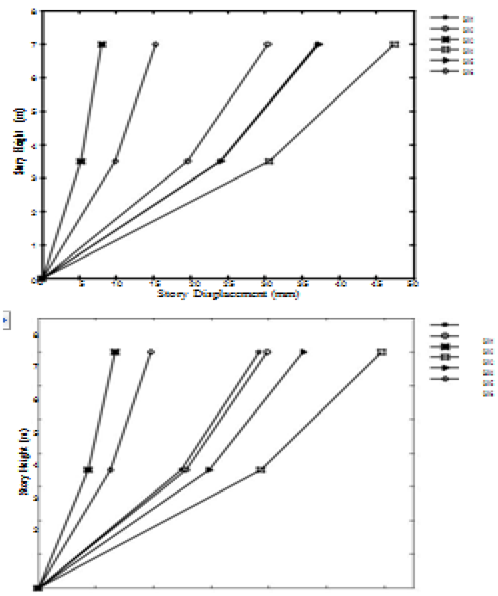

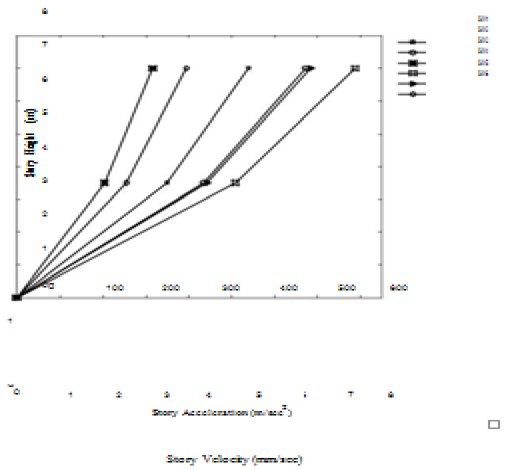

Figure 5.2: Story displacement, velocity, and acceleration of two-story regular reinforced concrete building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

Figure 5.3-5.8 shows roof displacement, velocity, and acceleration with respect to time for two-story regular RC building 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 motion in x and z-direction respectively.

The structure has maximum roof displacement of -28.2 mm at 11.5 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of 8.26 mm at 2.34 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 423 mm/s at 11.9 s due to IS 1893 (Part1) : 2002 ground motion and minimum velocity of -165 mm/s at 1.39 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof acceleration of -7.35 m/s^2 at 12 s due to IS 1893 (Part1) : 2002 ground motion and minimum 4.19 m/s^2 at 2.7 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction.

The structure has maximum roof displacement of 47.4 mm at 2.08 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -8.07 mm at 2.19 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -596 mm/s at 2.21 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 7.89 m/s^2 at 2.3 s due to 1940 Imperial Valley (El Centro) elcentro_EW ground

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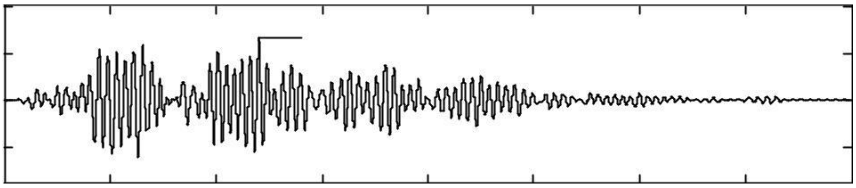
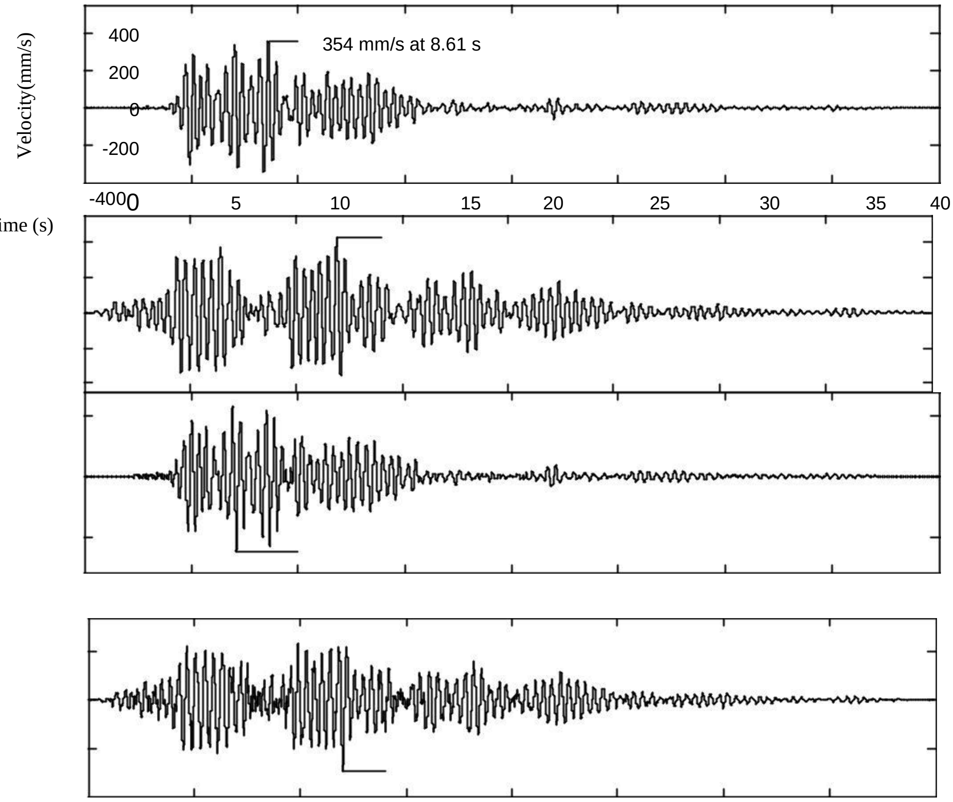


motion and minimum 3.16 m/s^2 at 1.74 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.



Time (s)

Time (s)

Figure 5.3: Roof displacement, velocity, and acceleration of two-story regularRC building due to (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion in x-direction

The base shear of two-story regular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 5.9. Figure 5.9 (a) shows that the building has maximum base shear of 3,350.56 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 981.81 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 5.9 (b) shows that the building has maximum base shear of 3,828.29 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 652.36 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

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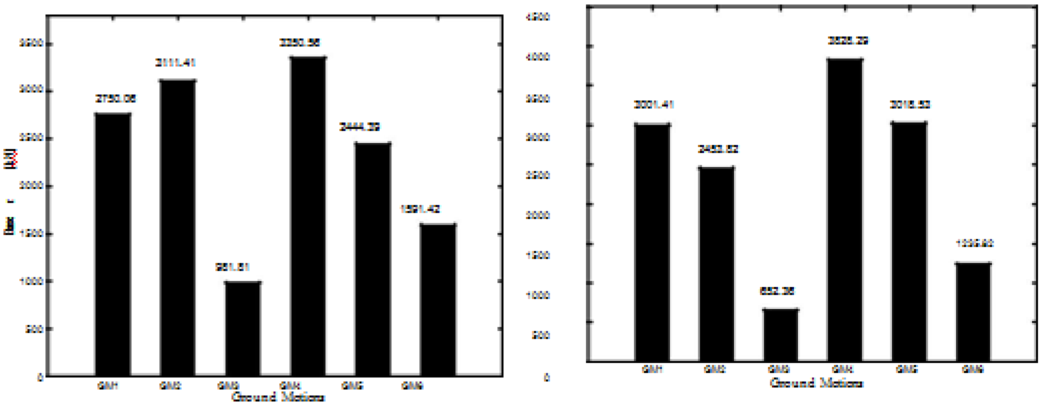
Ground Motions



(a) (b)

Figure 5.9: Base shear of two-story regular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

5.3 Six-Story Regular RC Building

Figure 5.11 shows story displacement, velocity, and acceleration of six-story regular RC building 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 GM6. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM6. It indicates that the building undergoes high story displacement, story velocity and story 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.

The structure has maximum roof displacement of 126 mm at 10.1 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -7.88 mm at 1.87 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -665 mm/s at 4.51 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum velocity of -84.3 mm/s at 1.7 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof acceleration of 4.42 m/s^2 at 19.2 s due to 1992 Landers (Fort Irwin) FTI000 component ground motion and minimum 1.43 m/s^2 at 2.33 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction.

The structure has maximum roof displacement of 143 mm at 4.23 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -7.68 mm at 1.9 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 527 mm/s at 9.73 s due to 1940 Imperial Valley (El Centro) elcentro_EW ground motion and minimum velocity of -68.8 mm/s at 2.28 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion. It has maximum roof acceleration of -3.4 m/s^2 at 11.6 s due to 1940 Imperial Valley (El Centro) elcentro_EW ground motion and minimum 1.47 m/s^2 at 2.33 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction.

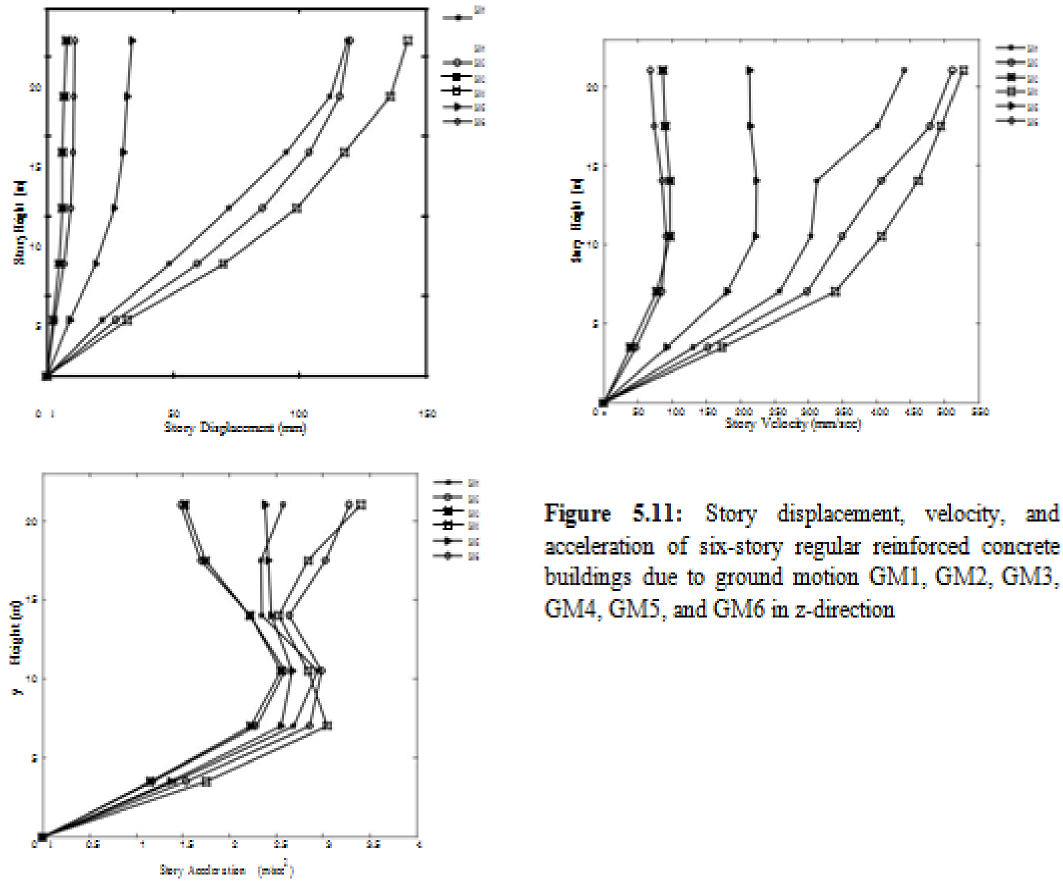


Figure 5.11: Story displacement, velocity, and acceleration of six-story regular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

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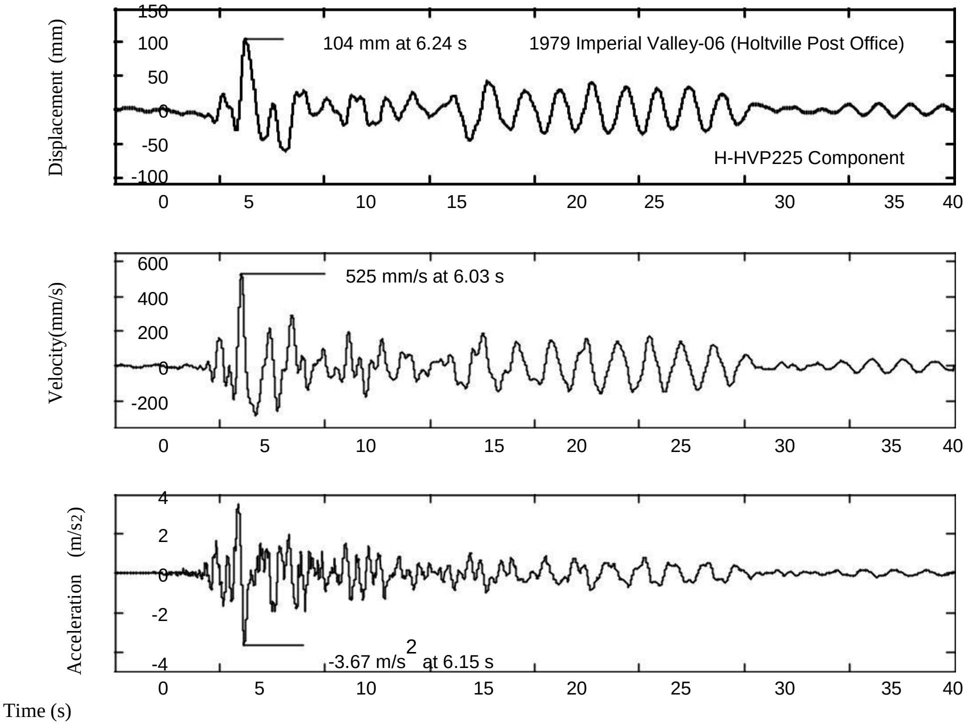
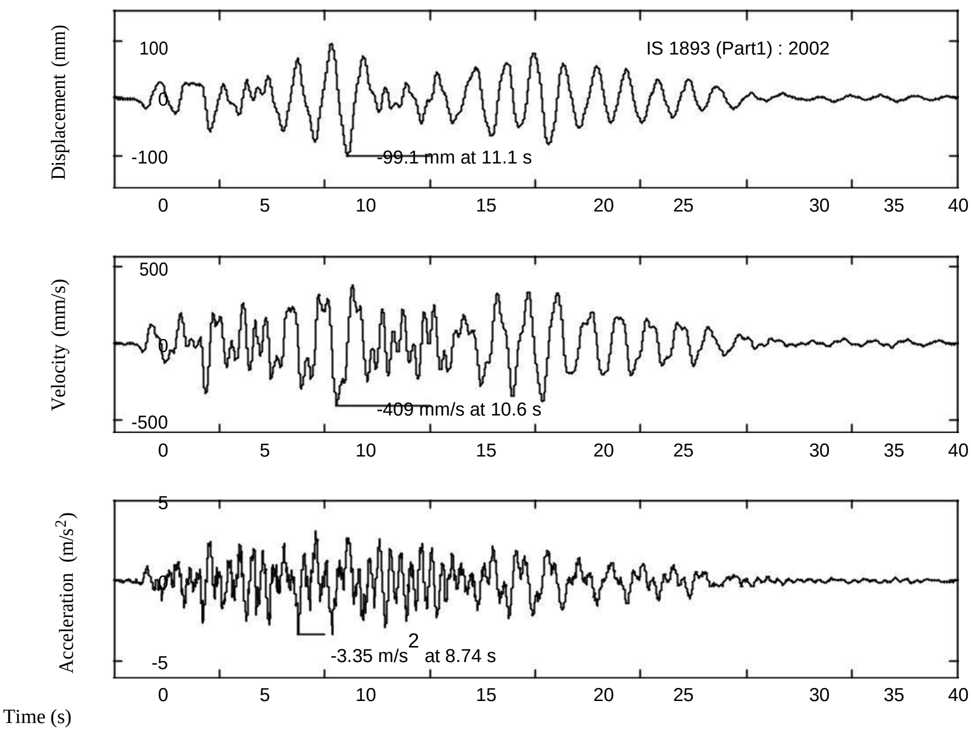


(a)



(b)

Figure 5.12: Roof displacement, velocity, and acceleration of six-story regular RC building due to (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion in x-direction

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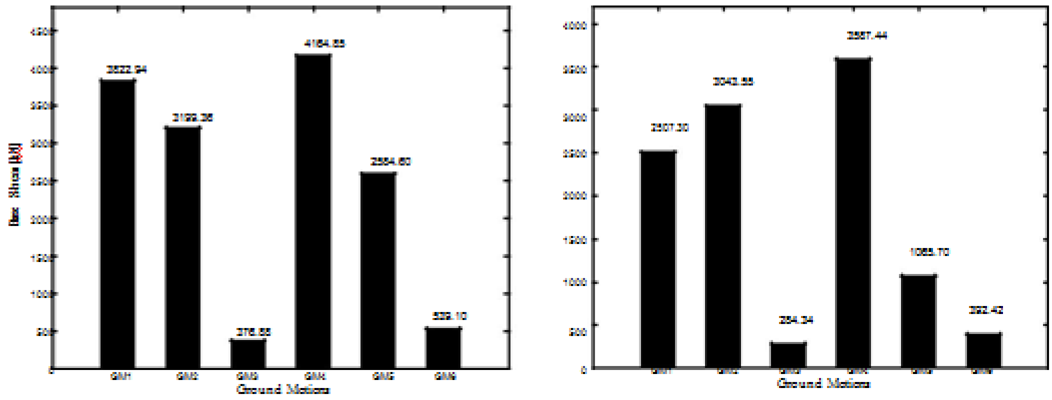
The base shear of six-story regular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 5.18. Figure 5.18 (a) shows that the building has maximum base shear of 4164.85 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 376.88 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 5.18 (b) shows that the building has maximum base shear of 3587.44 kN due to 1940 Imperial Valley (El Centro) elcentro_EW and minimum base shear of 284.34 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.



(a) (b)

Figure 5.18: Base shear of six-story regular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

RC Building	Two-Story				Six-Story				Twenty-Story			
GM (x, z)	GM (x)*		GM (z)**		GM (x)		GM (z)		GM (x)		GM (z)	
Maximum/ Minimum	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Story displacement	4	3	4	3	4	3	4	3	1	3, 6	1	3, 6
Story Velocity	2	3	4	3	4	3, 6	4	6	1	3, 6	4	3, 6
Story Acceleration	2	3, 6	4	3	5	6	4	6	4	3, 6	4	3, 6
Base Shear	4	3	4	3	4	3	4	3	4	3	4	3

Table 5.1: Two, six, and twenty-story regular RC building responses due to GM1-GM6 in x and z-direction

VI CONCLUSIONS

Following conclusions can be drawn for the two, six, and twenty-story regular RC buildings from the results obtained in chapter 5:

- 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

VII FURTHER WORK

The present work is carried out to study the behavior of two, six, and twenty-story regular as well as irregular three-dimension reinforced concrete buildings under low, intermediate, and high-frequency content ground motions. The structure responses such as story displacement, story velocity, story acceleration, and base shear are found and the results are compared. The study of frequency content of ground motion has wide range; one can study the behavior of structures such as steel building, bridge, reservoir etc. under low, intermediate, and high-frequency content ground motion.

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