SEISMIC BEHAVIOR OF REINFORCED CONCRETE BUILDINGS UNDER VARYING FREQUENCY CONTENTS

A Thesis

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CERTIFICATE

This is to certify that the thesis entitled "**SEISMIC BEHAVIOR OF REINFORCED CONCRETE BUILDINGS UNDER VARYING FREQUENCY CONTENTS**" submitted by **Sohrab Youldash** bearing Roll No. 212CE2515 in partial fulfilment of the requirements for the award of **Master of Technology** Degree in **Civil Engineering** with specialization in **Structural Engineering** during 2012-2014 session to the National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any Degree or Diploma.

Project Guide

Place: NIT Rourkela

Prof. **K. C. BISWAL**

Date:

Department of Civil Engineering

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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

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NOTATION AND SYMBOLS

Abbreviation

GM1	=	Ground motion 1, 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component
GM2	=	Ground motion 2, IS 1893 (Part1) : 2002
GM3	=	Ground motion 3, 1957 San Francisco (Golden Gate Park) GGP010 component
GM4	=	Ground motion 4, 1940 Imperial Valley (El Centro) elcentro_EW component
GM5	=	Ground motion 5, 1992 Landers (Fort Irwin) FTI000 component
GM6	=	Ground motion 6, 1983 Coalinga-06 (CDMG46617) E-CHP000 component
IS	=	Indian Standard
MDOF	=	Multi-degree-of-freedom
NSA	=	Nonlinear static analysis
PGA	=	Peak ground acceleration
PGD	=	Peak ground displacement
PGV	=	Peak ground velocity
RC	=	Reinforced concrete
RCMRFs	=	Reinforced concrete moment resisting frames
RHA	=	Response history analysis
SDF	=	Single-degree-of-freedom
STAAD Pro	=	Structural analysis and design for professional
URM	=	Unreinforced masonry
2D	=	Two-dimension
3D	=	Three-dimension

Roman upper case symbols

E_c = Modulus of elasticity of concrete (MPa)

E_s = Modulus of elasticity of steel (MPa)

F_c = Compressive strength of concrete (MPa)

F_y = Yield strength of steel (MPa)

F_u = Tensile strength of steel (MPa)

G_c = Shear modulus of concrete (MPa)

G_s = Shear modulus of steel (MPa)

Roman lower case symbols

f = Natural frequency (Hz)

g = Acceleration of gravity (m/s^2)

x = Transverse direction

z = Longitudinal direction

Greek symbols

α_c = Thermal coefficient of concrete

α_s = Thermal coefficient of steel

γ_c = Unit weight of concrete (kN/m^3)

γ_s = Unit weight of steel (kN/m^3)

ν_c = Poisson ratio of concrete

ν_s = Poisson ratio of steel

ς_c = Damping ratio of concrete (%)

CHAPTER 1

INTRODUCTION

1.1 Overview

In this chapter, a brief definition is given for earthquake and then the most three important dynamic characteristics of ground motion, which are peak ground acceleration (PGA), frequency content, and duration are presented in section 1.2. Furthermore, the seismic design philosophy is shortly explained.

Two, six, and twenty-story regular as well as irregular reinforced concrete (RC) buildings which are modeled as three-dimension and six ground motions of low, intermediate, and high-frequency content are subjected to the corresponding models and linear time-history analysis is performed using structural analysis and design (STAAD Pro) [1] software.

In section 1.3, origin of the project is shortly represented. Section 1.4 gives a brief description about the significance of the research work. The objective and scope of the current work is explained in precise in section 1.5. At last, the procedures, which are used to accomplish the work, is presented in section 1.6.

1.2 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].

1.3 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.

1.4 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.

1.5 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.

1.6 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.

CHAPTER 2

2 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].

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

2.2 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 (T_m), predominant period (T_p), and smoothed spectral predominant period (T_p). 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 T_p parameter has the highest uncertainty in its prediction and the earlier correlation suggested predicting T_p are unreliable with their current data set. Moreover, the best frequency content characterization parameter is T_m.

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 (T_m), Average spectral period (T_{avg}), Smoothed spectral predominant period (T_o), and predominant spectral period (T_p) are the four parameters that describe the frequency content of strong ground motions. Low-frequency content of ground motions are differentiated by T_m and $T_{avg.}$, while high-frequency content is influenced by T_o. The frequency content of a strong ground motion may not be defined by T_p . They developed empirical relationships that predict three parameters (T_m, T_{avg}, and T_o) 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 T_m and T_o are increased noticeably due to forward directivity, at distances less than 20 km. Among the frequency-content parameters, T_m is the preferred one because the frequency content of strong ground motions is best distinguished by means of it.

Chin-Hsun [15] 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 [16] 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. [17]

2.3 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 [18], 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 [19], 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 [20] 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 [21] 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.

Cakir [3] studied the evaluation of the effect of earthquake frequency content on seismic behavior of cantilever retaining wall involving soil-structure interaction. He carried out a 3D backfill-structure-soil/foundation interaction phenomenon via finite element method in order to analyze the dynamic behavior of cantilever retaining wall subjected to various ground motions. He evaluated influences of earthquake frequency content as well as soil-structure interaction utilizing five different ground motions and six different soil types. He also carried out analytical formulations by using modal analysis technique to check the finite element model verification, and he obtained good enough agreement between numerical and analytical results. Finally, he broadened the method to examine parametrically the influences of not only earthquake frequency content but also soil/foundation interaction, and nonlinear time history analyses carried out. His results indicate that with change of soil properties, some comparisons are made on lateral displacements and stress responses under different ground motions. He summarized that the dynamic response of cantilever wall is highly susceptible to frequency characteristics of the earthquake record and soil structure interaction.

Stefano & Pintucchi [22] carried out research on seismic behavior of irregular buildings. They reviewed three areas of research. First, The effects of plan-irregularity using single-story and multi-story building models. Second contains passive control as an approach to diminish torsional effects, using base isolation and other types of devices. Third, one concerns vertically irregular structures and setback buildings. Even though, less number of papers are published in the last one, this state-of-the art reports extensively on research efforts and progress into the seismic behavior of irregular buildings in elevation to show the growing interest within specialists in the field.

Hao & Zhou [23] worked on rigid structure response analysis to seismic and blast caused ground motions. Comparing to an earthquake ground motion, ground shock produced by underground or surface blast has very high amplitude, high-level frequency and short time. Furthermore, vertical component of a ground shock may be noticeably higher than the acceleration of gravity. This will result in the unfastened inflexible structure hop or fly into air. Subsequently, the responses and stability regions of a rigid structure to blast actuated ground shock will be largely different from those under seismic ground motions. In their study, theoretical derivation and numerical prediction of rigid structure response to ground shock are done. They derived numerical results of stability locales of rigid structures to ground shock. Specific considerations are paid to the situation when the vertical ground shock is greater than

1.0 g and the rigid structure takes off to the air. They compared the results with those found with earthquake ground motions.

They found that when vertical ground motion amplitude is more than gravity acceleration, split of the rigid block from ground occurs and the block enters into a flying mode. They also established that as a result of its short duration and higher-frequency contents, the demanded ground shock amplitude to tumble a rigid block is considerably bigger than that of an earthquake ground motion.

Habibi & Asadi, 2013 [24], have studied seismic performance of RC frames irregular in elevation designed based on Iranian seismic code. They designed several multistory Reinforced Concrete Moment Resisting Frames (RCMRFs) with different types of setbacks, as well as the regular frames in elevation, corresponding to the requirements of the Iranian national building code and Iranian seismic code for the high ductility class. They carried out inelastic dynamic time-history analysis on all frames subjected to ten ground motions. Their outcomes show that when setback occurs in elevation, the provision of the life safety level are not fulfilled. They have also indicated that the parts close to the setback undergo the highest damage. Therefore, it is necessary to reinforce these elements by proper technique to comply with the life safety level of the frames.

Traditionally buildings are considered to have fixed base. However, flexibility of the supporting soil makes the foundation to move. Dutta, et al. [25] studied the response of low-rise buildings under earthquake ground motion including soil-structure interaction. They studied low-rise building frames lying on shallow foundations, namely, isolated and grid base. They used artificial earthquake to analyze the response. Their study shows such response may be increased considering the effect of soil-structure interaction, especially for low-rise rigid structure.

The weight of the building manages seismic design besides to the building stiffness, because earthquake generates inertia forces that are proportionate to the building weight. Earthquake load is displacement-type and wind and other loads are force-type. Buildings are capable of resisting certain relative displacement within it due to seismic load, while they resist certain amount of force applied on it due to wind load. Wind design requires elastic behavior is required in the entire range of displacement in wind design. However, in earthquake design the building remains elastic or experiences inelastic behavior. Normal buildings are designed using elastic analysis, and special buildings, such as nuclear power plants are designed using inelastic approach. Murty, et al. [26]

Murty, et al. [26], studied influence of Unreinforced Masonry (URM) infill walls. Infill walls are considered as nonstructural elements in most of the countries. They are not included in the analysis due to vertical or lateral load. In fact, URM infill walls intervene with lateral deformation of beams and columns of building frames during earthquake and has major influence on seismic behavior of buildings during earthquake shaking. Moreover, mode shape of a building is dependent on the distribution of lateral story stiffness along the height of the building. Improvement of lateral story stiffness is reliant on the distribution of URM in each story. Open ground story has less lateral story stiffness from the above stories. Accordingly, open ground story influences the mode shape of the building. Thus, the mode shape attained with lateral stiffness contribution of URM infill walls is considerably different from that without it.

Nayak & Biswal [4], studied seismic behavior of partially filled rigid rectangular tank with bottom-installed submerged block. They utilized six different ground motions of low, intermediate and high-frequency content to examine the dynamic behavior of tank liquid-submerged block system. They established a velocity potential based Galerkin finite element model for the analysis and showed the effect of submerged block on impulsive and convective response components of hydrodynamic behavior in terms of base overturning moment, base shear, and enumerated pressure distribution along both the tank and block wall.

The magnitudes of the corresponding convective responses are lower than the peak impulsive response components of dynamic physical parameters, in all the ground motions studied for the exploration, regardless of their frequency content. Nayak & Biswal [4]

In addition, the impulsive response is almost not dependent on the frequency content of the ground motions and is reliant on the PGA, which is a measure of intensity of earthquake. However, convective response is noticeably influenced by the frequency content of the ground excitation. The effect of the bottom- mounted submerged blocks has a substantial influence on the overall dynamics of the tank-liquid system and such effect vary largely under seismic motions of different frequency content. [4]

CHAPTER 3

3 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.

3.2 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 3.1 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 3.2-3.4 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.

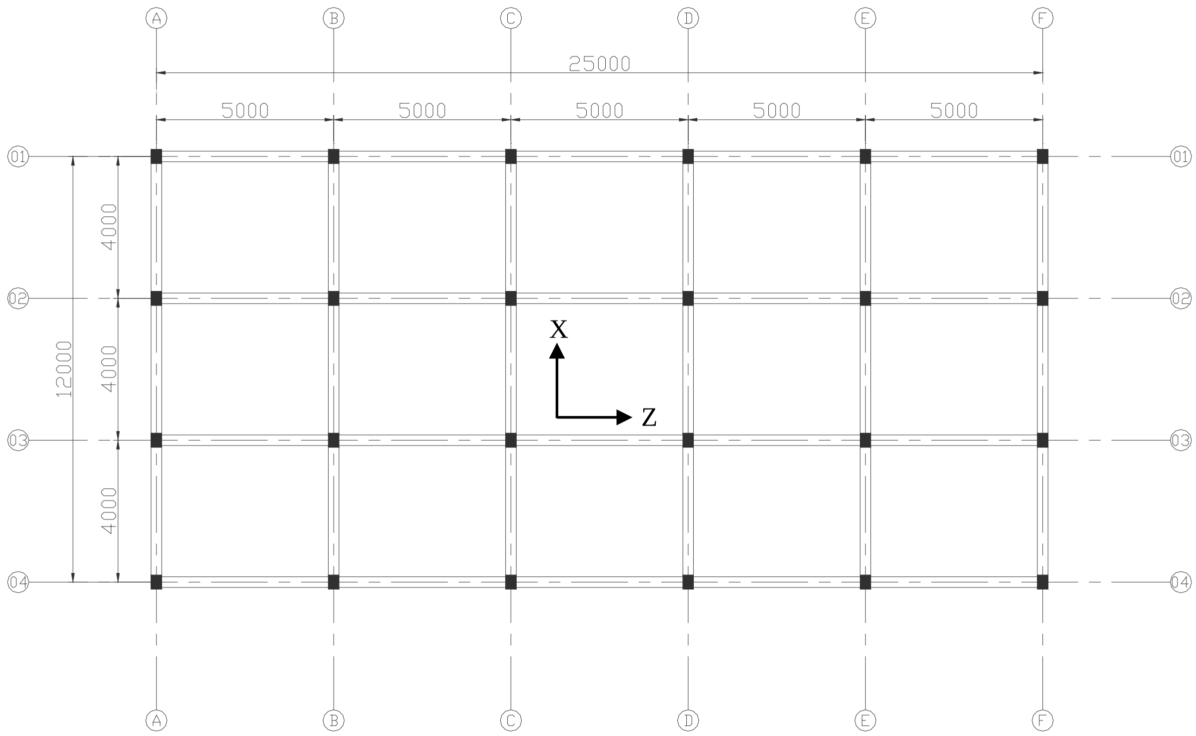
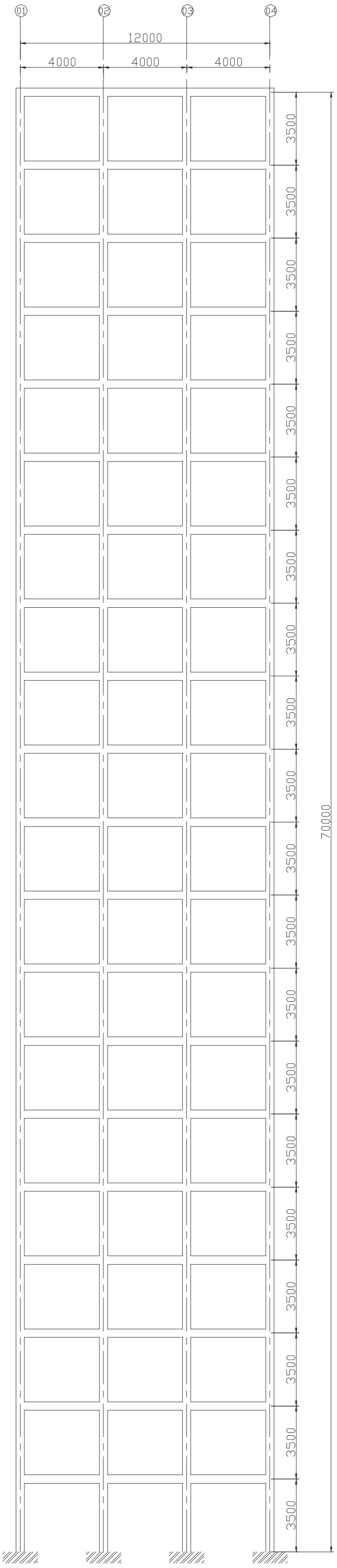
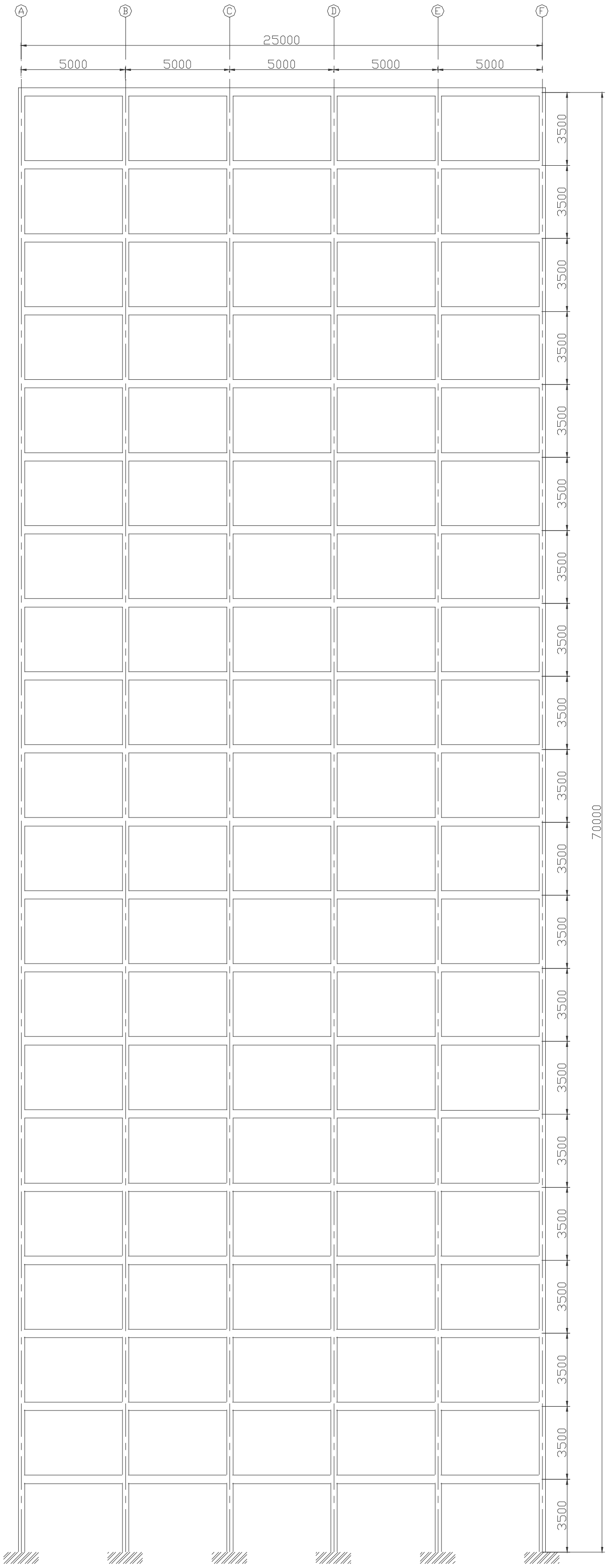


Figure 3.1: Plan of two, six, and twenty-story regular RC buildings (all dimensions are in mm)

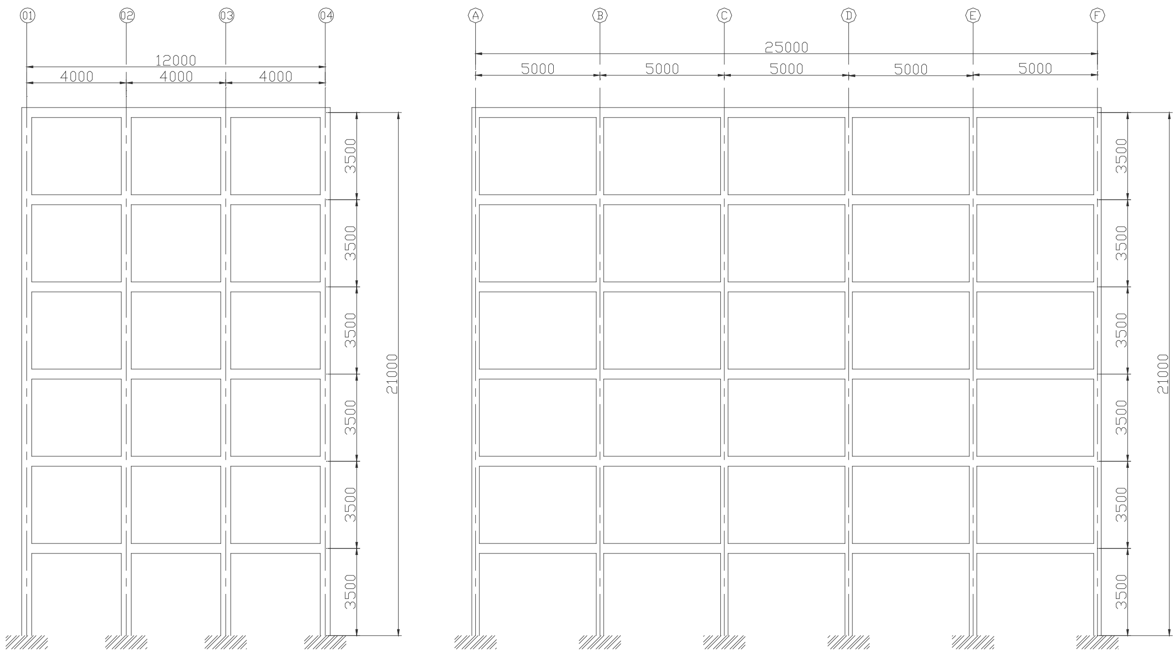


Frame (A-A)



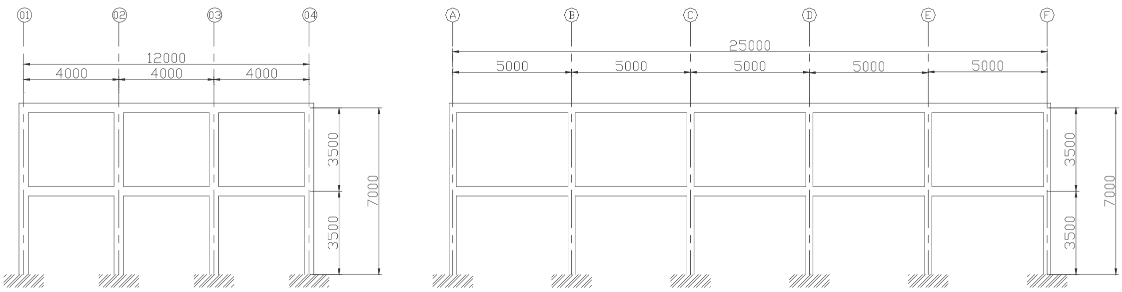
Frame (01-01)

Figure 3.2: Frame (A-A) and (01-01) of twenty-story regular RC building (all dimension are in mm)



Frame (A-A)　　　　Frame (01-01)

Figure 3.3: Frame (A-A) and (01-01) of six-story regular RC building (all dimension are in mm)



Frame (A-A)　　　　Frame (01-01)

Figure 3.4: Frame (A-A) and (01-01) of two-story regular RC building (all dimension are in mm)

3.3 Irregular RC Buildings

Two, six, and twenty-story irregular 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 3.5 shows the plan of the three buildings having five bays in x-direction and five bays in z-direction. Story height of each building is assumed 3.5m. Figure 3.6, 3.8, and 3.10 shows frame (01-01) and (06-06) of the twenty, six, and two-story irregular RC buildings respectively. Figure 3.7, 3.9, and 3.11 shows frame (A-A) and (F-F) of the twenty, six, and two-story irregular reinforced concrete building respectively. For simplicity, both the beam and column cross sections are assumed 300 mm x 400 mm.

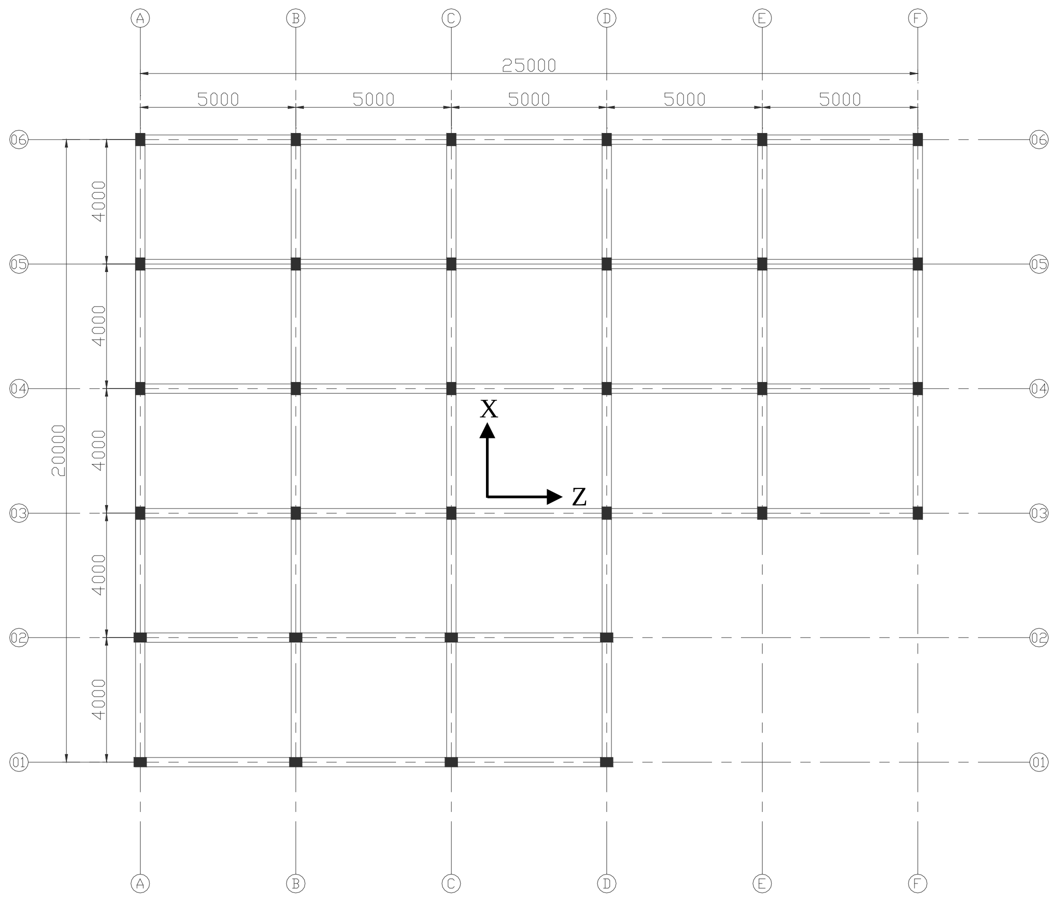


Figure 3.5: Plan of two, six, and twenty-story irregular RC buildings (all dimensions are in mm)

Here the plan configurations of the two, six, and twenty-story RC buildings and their lateral force resisting systems contain re-entrant corners, where both projections of the buildings beyond the re-entrant corner are 40 percent, which is more than 15 percent of their plan dimension with respect to their direction. Therefore, the corresponding RC buildings are considered as irregular structures. [6]

$$\frac{A_1}{L_1} > 0.15 \ \left(\frac{10}{25} = 0.4 > 0.15 \right)$$
$$\frac{A_2}{L_2} > 0.15 \ \left(\frac{8}{20} = 0.4 > 0.15 \right)$$

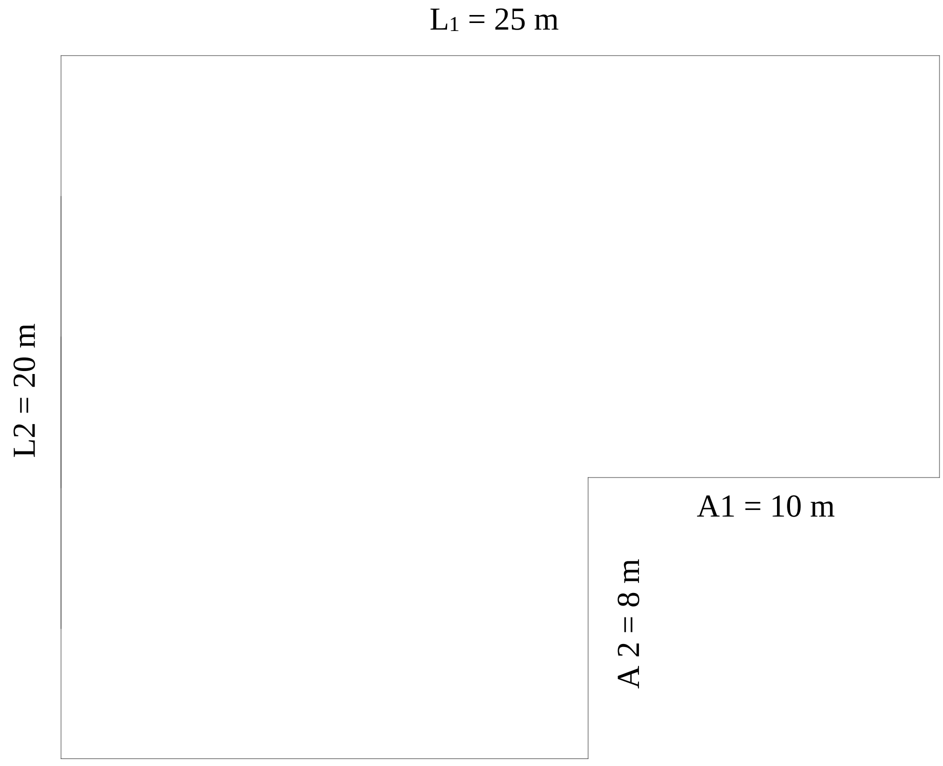
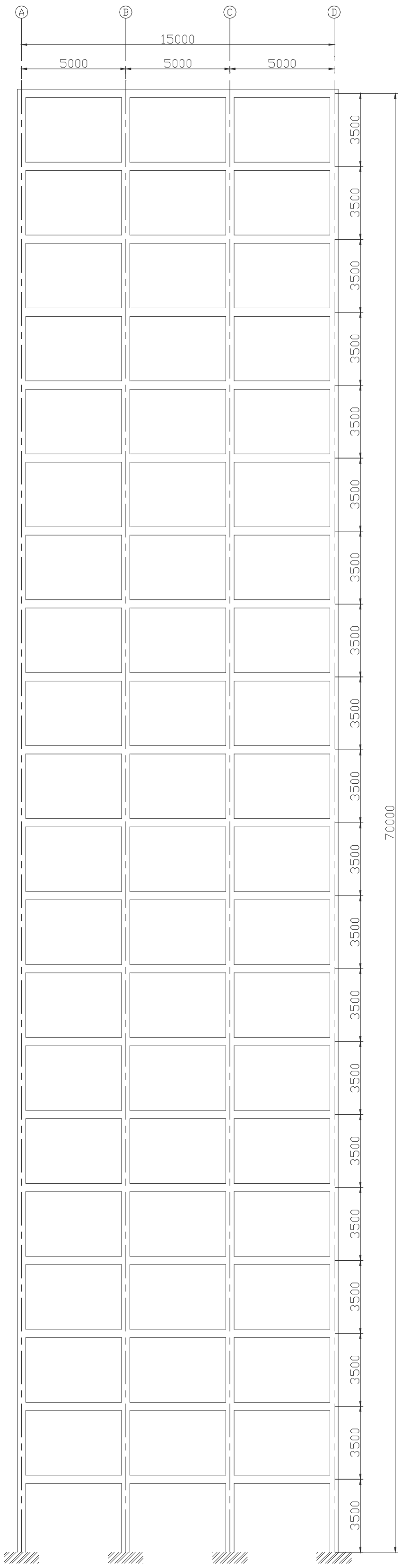
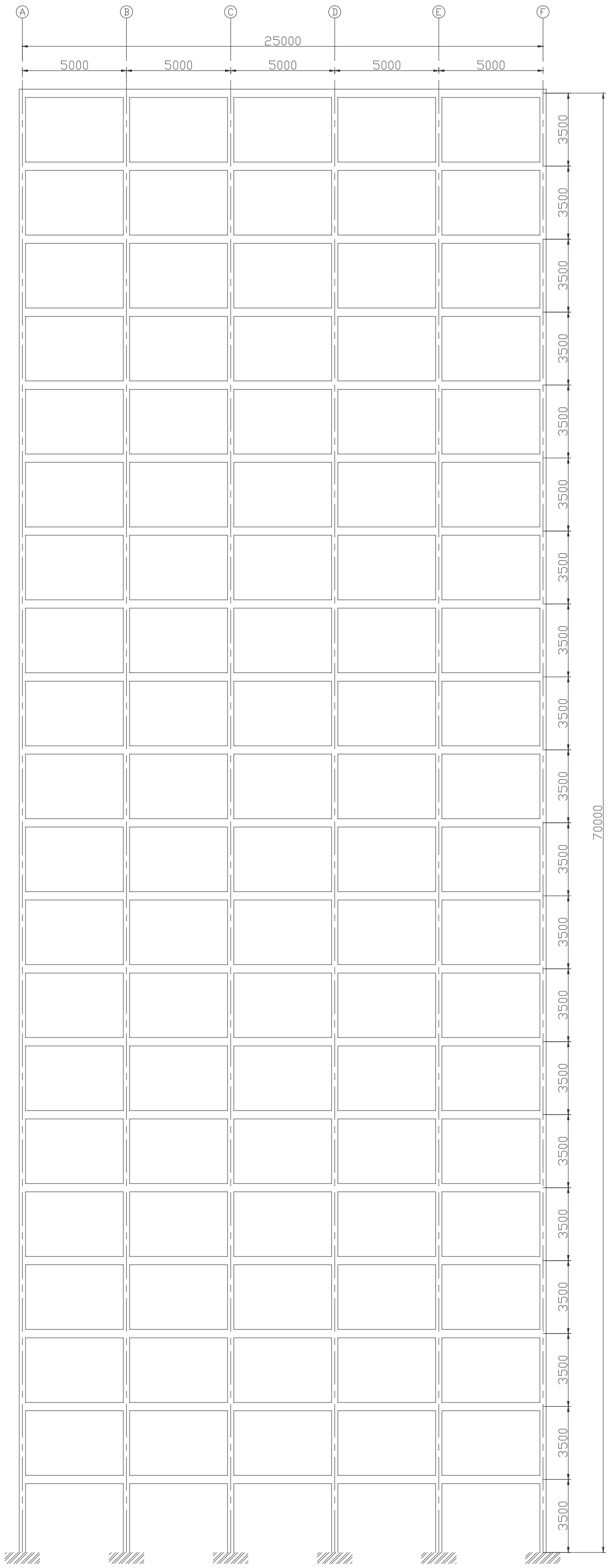


Figure 3.6: Re-entrant corners as per Table 4 of IS 1893 (Part1) : 2002

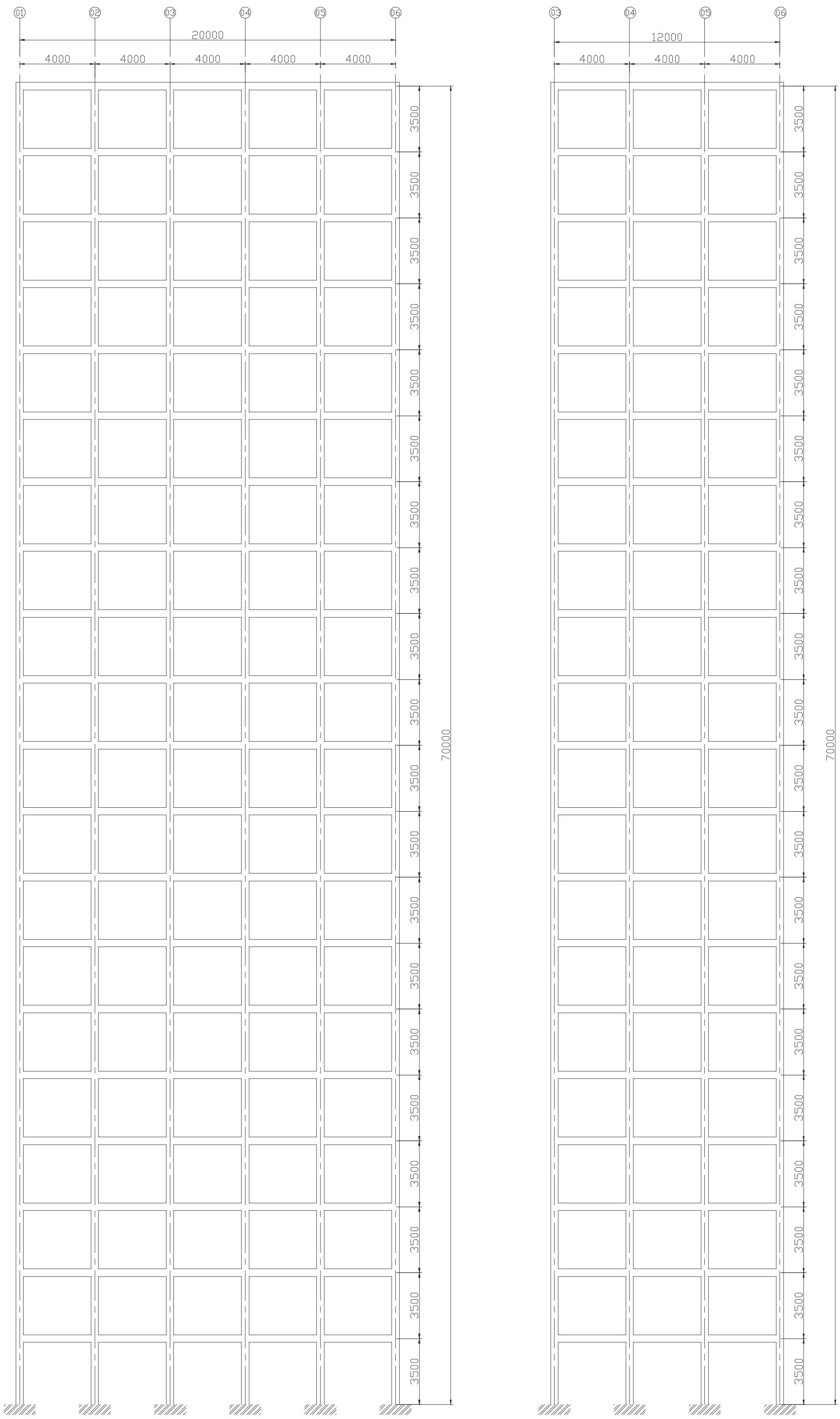


Frame (01-01)



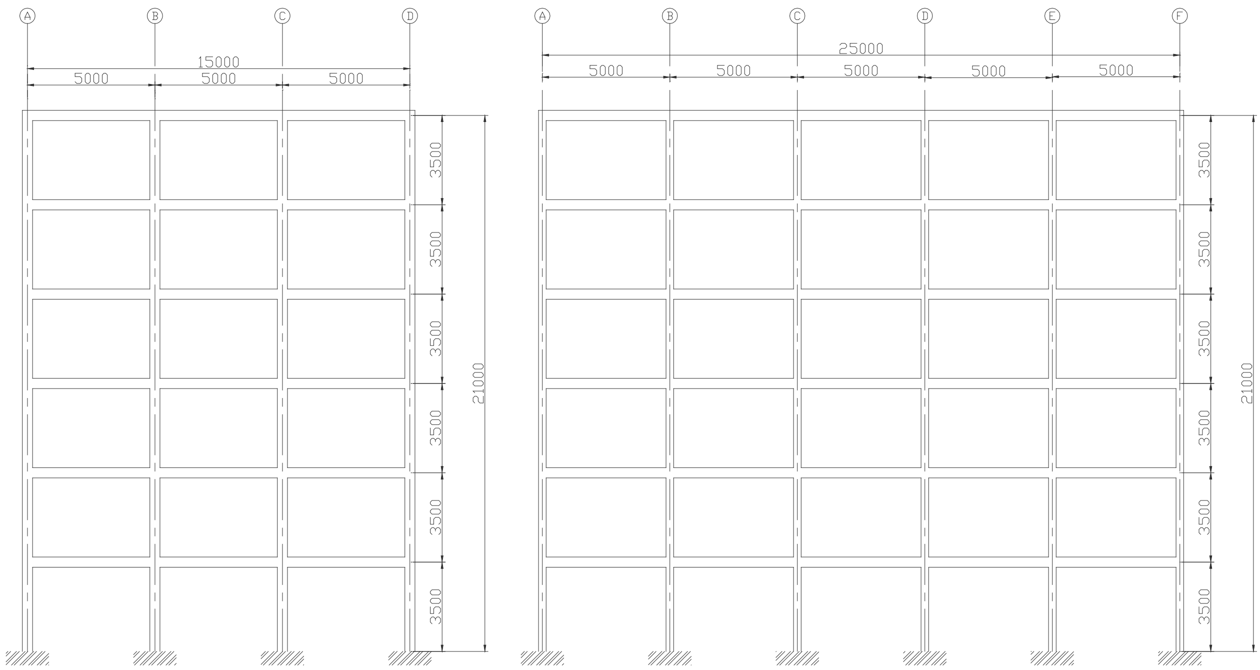
Frame (06-06)

Figure 3.7: Frame (01-01) and (06-06) of twenty-story irregular RC building in z-direction (all dimensions are in mm)



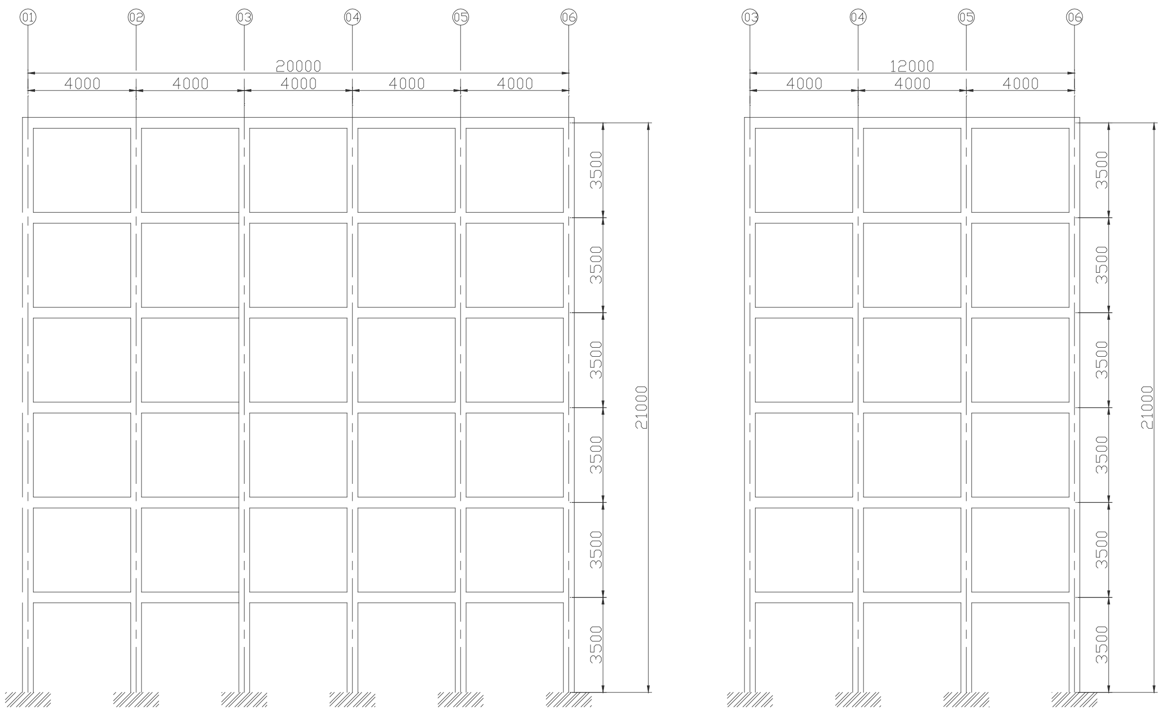
Frame (A-A) Frame (F-F)

Figure 3.8: Frame (A-A) and (F-F) of twenty-story irregular RC building in x-direction (all dimensions are in mm)



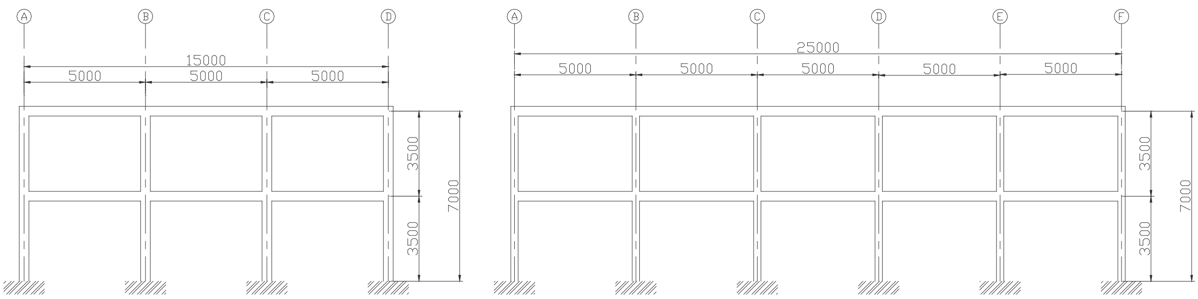
Frame (01-01) Frame (06-06)

Figure 3.9: Frame (01-01) and (06-06) of six-story irregular RC building in z-direction (all dimensions are in mm)



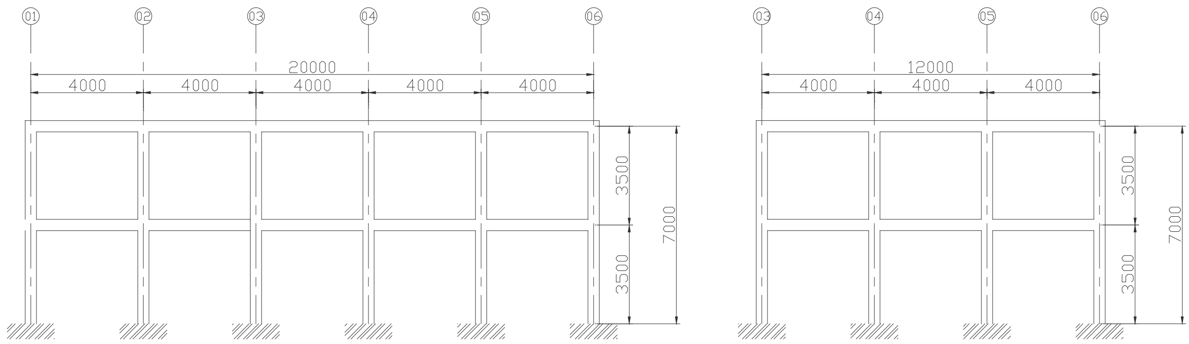
Frame (A-A) Frame (F-F)

Figure 3.10: Frame (A-A) and (F-F) of six-story irregular RC building in x-direction (all dimensions are in mm)



Frame (01-01) Frame (06-06)

Figure 3.11: Frame (01-01) and (06-06) of two-story irregular RC building in z-direction (all dimensions are in mm)



Frame (A-A) Frame (F-F)

Figure 3.12: Frame (A-A) and (F-F) of two-story irregular RC building in x-direction (all dimensions are in mm)

3.4 Gravity Loads

Slab load of 3 kN/m^2 is considered for the analysis and wall load of 17.5 kN/m is applied both on exterior and interior beams of the RC buildings as per IS 875 (Part1) [28]. Live load of 3.5 kN/m^2 is provided in accordance to IS 875 (Part2) [29]. Table 3.1 shows the gravity loads.

For seismic weight, total dead load and 50 percent of live load is considered as per Table 8 of IS 1893 (Part1) : 2002. For calculation of seismic weight, no roof live load is taken.

Table 3.1: Gravity loads which are assigned to the RC buildings

Gravity Load	Value
Slab load (dead load)	3 (kN/m^2)
Wall load (dead load)	17.5 (kN/m)
Live load	3.5 (kN/m^2)

3.5 Material Properties

Table 3.2 shows the concrete and steel bar properties, which are used for modeling of the reinforced concrete buildings in STAAD Pro [1].

Table 3.2: Concrete and steel bar properties as per IS 456 [30]

Concrete Properties		Steel Bar Properties	
Unit weight (γ_c)	25 (kN/m^3)	Unit weight (γ_s)	76.9729 (kN/m^3)
Modulus of elasticity (E_c)	22360.68 (MPa)	Modulus of elasticity (E_s)	2x10^5 (MPa)
Poisson ratio (ν_c)	0.2	Poisson ratio (ν_s)	0.3
Thermal coefficient (α_c)	5.5x10^{-6}	Thermal coefficient (α_s)	1.170x10^{-6}
Shear modulus (G_c)	9316.95 (MPa)	Shear modulus (G_s)	76923.08 (MPa)
Damping ratio (ς_c)	5 (%)	Yield strength (F_y)	415 (MPa)
Compressive strength (F_c)	30 (MPa)	Tensile strength (F_u)	485 (MPa)

3.6 Structural Elements

Linear time history analysis is performed on two, six, and twenty-story regular and irregular reinforced concrete buildings and six ground motions of low, intermediate, and high-frequency content are introduced to STAAD Pro [1]. In order to compare the results, for simplicity beam and column dimensions are assumed 300 mm x 400 mm. Height of the story is 3.5m and beam length in transverse direction is taken 4m and in longitudinal direction 5m. These dimensions are summarized in Table 3.3. The thickness of the wall is assumed 250 mm.

Table 3.3: Beam and column length and cross section dimension

Structural Element	Cross section (mm x mm)	Length (m)
Beam in (x) transverse direction	300 x 400	4
Beam in (z) longitudinal direction	300 x 400	5
Column	300 x 400	3.5

CHAPTER 4

4 GROUND MOTIONS AND LINEAR TIME HISTORY ANALYSIS

4.1 Overview

Ground motion is the movement of the earth's surface from blasts or earthquakes. It is generated by waves that are produced by sudden pressure at the explosive source or abrupt slip on a fault and go through the earth and along its surface. In this chapter, the characteristics of the six ground motions, which are used for the time-history analysis of the RC buildings, are explained. Then, a brief description is given for linear time-history analysis. Section 4.2 gives an introduction to the definition, sources, causes, characteristics, magnitude, intensity, instrument, and classification of earthquake.

Section 4.3 gives a detail explanation about the six ground motion records, which are considered for the current work. The acceleration, velocity, and displacement versus time for each ground motion record are shown. The ground motions are classified as low, intermediate, and high-frequency content.

A brief definition is given for the linear time-history analysis in section 4.4. The dynamic characteristics of the two, six, and twenty-story regular RC buildings as well as irregular RC buildings are also presented.

4.2 Introduction

An earthquake is a hysteria of ground quaking caused by a sudden discharge of energy in the earth’s lithosphere. This energy may come mainly from stresses formed during tectonic processes, which involves interaction between the crust and the inner side of the earth’s crust. Strain energy stored inside the earth will be released and maximum of it changes to heat, sound and remaining as seismic waves. The science of the earthquake is called seismology. The source and nature of earthquakes is the science of seismology.

Sources of earthquake are tectonic, volcanic, rock fall or collapse of cavity which are natural source and mining induced earthquake, reservoir induced earthquake, and controlled source (explosive) which are man-made source. In fact, 90 percent of the earthquakes are due to plate tectonics. There are six continental sized plates which are African, American, Antarctic, Australia-Indian, Euro-Asian, and pacific plate.

There are mainly four principle plate boundaries such as divergent boundary (inner side of the earth adds new plate material), subduction boundary (plates converge and the beneath thrust one is consumed), collision boundary (previous subduction zone where continents resting on plates are smashing), and transform boundary (two plates are sliding one another). [31]

Geologists are interested in the nature and properties of the earthquake; they use seismograph to record the seismic waves (seismogram), while engineers are interested in the nature and properties of ground motion; they use accelerograph to measure the ground acceleration record (accelerogram). Seismic waves are classified as P-waves, S-waves, Love wave, and Rayleigh wave.

The motion of sufficient strength that effects people and environment is called strong ground motion. It is described by three transitions and three rotations. The effect of the three rotations is very small which may be neglected. The maximum absolute value of the ground acceleration is peak ground acceleration (PGA). PGA, frequency content and duration are the most important characteristics of earthquake. The rock site experiences higher acceleration, soil site undergoes higher velocity, and higher displacement.

The smallest natural frequency of a structure is the fundamental frequency and the dominating frequency of earthquake is the excitation frequency. Resonance occurs when the dominating frequency of the earthquake ground motion matches with the fundamental frequency of the structure. Earthquake ground motion is dynamic load, which can be classified as deterministic non-periodic transient load as well as probabilistic load. Earthquake is classified based on location, focal depth, causes, magnitude, and epicentral distance.

Earthquake is specified regarding magnitude and intensity. The magnitude of earthquake is a measure of energy discharged. It is characterized as logarithm to the base 10 of the maximum trace amplitude, represented in microns, which the standard short-period torsion seismometer (with a time period of 0.8 s, magnification 2,800 and damping almost critical) would register because of the earthquake at an epicentral distance of 100 km. [6]

The intensity of an earthquake at a location is a measure of the strength of a shaking during an earthquake and is designated by roman numbers I to XII in accordance to the modified Mercalli Scale or M.S.K Scale of seismic intensities. For a particular earthquake magnitude is constant, however, intensity varies from place to place. Magnitude is quantitative measurement; intensity is qualitative measure of the severity of earthquake at a particular site. [32]

Quantitative instrumental measures of intensity include engineering parameters such as peak ground acceleration, peak ground velocity, the Housner spectral intensity, and response spectra in general. Magnitude is a quantitative measure of the size of an earthquake, which is the amount of energy released, which is independent of the place of inspection. It is measured by Richter Scale (Dr. Charles Richter, he observed that “at same distance magnitude is directly proportional to amplitude of earthquake”). Earthquake has social as well as economic consequences such as fatality and injury to human beings, and damage to the built and natural environment. [33] For every one unit increase in magnitude, there is 10 times increase in amplitude and 32 times increase in energy. [34]

Measurement of ground motion during an earthquake gives fundamental data for earthquake analysis. The records of the motions of structures give understanding how structures behave during earthquakes. The basic element of ground shaking measuring instruments is some form of transducer. A transducer is a mass-spring-damper system mounted inside a rigid frame that is attached to the surface whose motion is to be measured. [35] Three separate transducers are required to measure three components of ground motion. When subjected to motion of support point, the transducer mass moves relative to the frame, and this relative displacement is recorded after suitable magnification.

The basic instrument to record three components of ground shaking during earthquakes is the strong-motion accelerograph as shown in Figure 4.1, which does not record continuously but is triggered into motion by the first waves of the earthquake to arrive. [35] Table 4.1 shows the direct and indirect effects of earthquake [36].

Figure 4.1: Accelerograph, courtesy of Museum of Geoastrophysics National Observatory of Athens [37]

Table 4.1: Direct and indirect effects of earthquake [36]

Direct Effects	Indirect Effects
Ground shaking, ground cracking, ground lunching, differential ground settlement, Soil liquefaction, lateral spreading, landslide, rock falls, vibration of structures, falling objects, structural damage, and structural collapse	Landslides, tsunamis, seiches, avalanches, rock falls, floods, fires, and toxic contamination

Six ground motions are taken for the study purpose. The first ground motion is the 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, second ground motion is the IS 1893 (Part1) : 2002, the third ground motion is 1957 San Francisco (Golden Gate Park) GGP010 component, the fourth ground motion is 1940 Imperial Valley (El Centro) elcentro_EW component, the fifth ground motion is 1992 Landers (Fort Irwin) FTI000 component, and the last one is 1983 Coalinga-06 (CDMG46617) E-CHP000 component. Each ground motion is explained in section 4.3 and the corresponding velocity and displacement versus time are obtained.

4.3 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]:

- High-frequency content PGA/PGV > 1.2
- Intermediate-frequency content 0.8< PGA/PGV< 1.2
- Low-frequency content PGA/PGV < 0.8

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]

Figure 4.2 shows the variation of unscaled ground acceleration with time. The first curve shows the 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component with -0.253 g PGA. The second curve shows the IS 1893 (Part1) : 2002 with -1 g PGA. The third curve shows 1957 San Francisco (Golden Gate Park) GGP010 component with -0.0953 g PGA. The fourth curve shows 1940 Imperial Valley (El Centro) elcentro_EW component with 0.214 g. The fifth curve shows 1992 Landers (Fort Irwin) FTI000 component with -0.114 g and the last curve shows 1983 Coalinga-06 (CDMG46617) E-CHP000 component with -0.148 g PGA.

Figure 4.3 shows all the six ground accelerations versus time with 0.2 g PGA and 40 second duration. The ground motions are scaled to 0.2 g PGA and 40 second duration in order to see the effects of the frequency content on low, mid, and high-rise RC buildings.

Figure 4.4 (a) shows the variation of 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground acceleration versus time with -0.253 g PGA. The second curve is the ground velocity, obtained by integrating the acceleration-time function. The PGV is -0.488 m/s. Integration of ground velocity gives the ground displacement, displayed as the lowest trace. The peak ground displacement is 0.316 m. In the same manner, Figure 4.5-4.6 shows the variation of ground acceleration versus time with PGA, ground velocity versus time with PGV, and ground displacement versus time with PGD for corresponding ground motions. Then from the acceleration and velocity curves of the ground motion, frequency content, which is the ratio of PGA/PGV, can be obtained.

It is difficult to determine accurately the ground velocity and displacement because analog accelerographs do not record the initial part until the accelerograph is triggered of the acceleration-time function and thus the base line is not known. Digital accelerographs overcome this problem by providing a short memory so that the onset of ground motion is measured. There are several different versions of the ground motion. The variations among them arise from differences in (1) how the original analog trace of acceleration versus time was digitized into numerical data, and (2) the procedure chosen to introduce the missing baseline in the record. [35]

Table 4.2 shows six ground motion records with their characteristics and classified as low, intermediate and high-frequency content. Table 4.3 shows the six ground motions with 40 s duration. As shown in the Table 4.2 and 4.3, the 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component has 0.5182 < 0.8 PGA/PGV value, hence, it is defined as low-frequency content ground motion. Likewise, the IS 1893 (Part1) : 2002 as intermediate-frequency content, 1957 San Francisco (Golden Gate Park) GGP010 component as high-frequency content ground motions. The same manner, 1940 Imperial Valley (El Centro) elcentro_EW component, 1992 Landers (Fort Irwin) FTI000 component, and 1983 Coalinga-06 (CDMG46617) E-CHP000 component are classified as low, intermediate, and high-frequency content ground motions respectively.

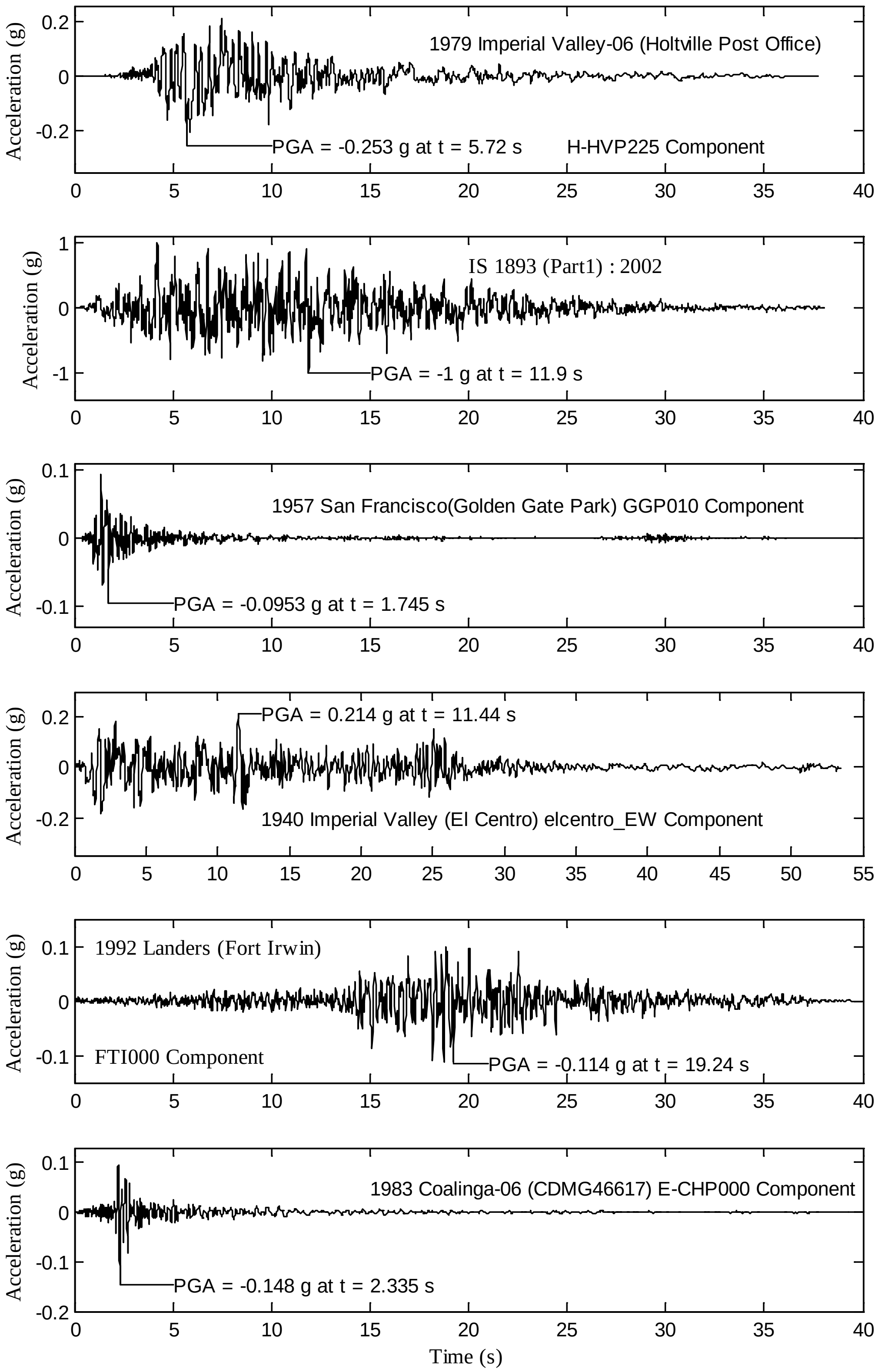


Figure 4.2: Ground motion acceleration versus time with PGA value of 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (El Centro) elcentro_EW component, 1992 Landers (Fort Irwin) FTI000 component, and 1983 Coalinga-06 (CDMG46617) E-CHP000 component

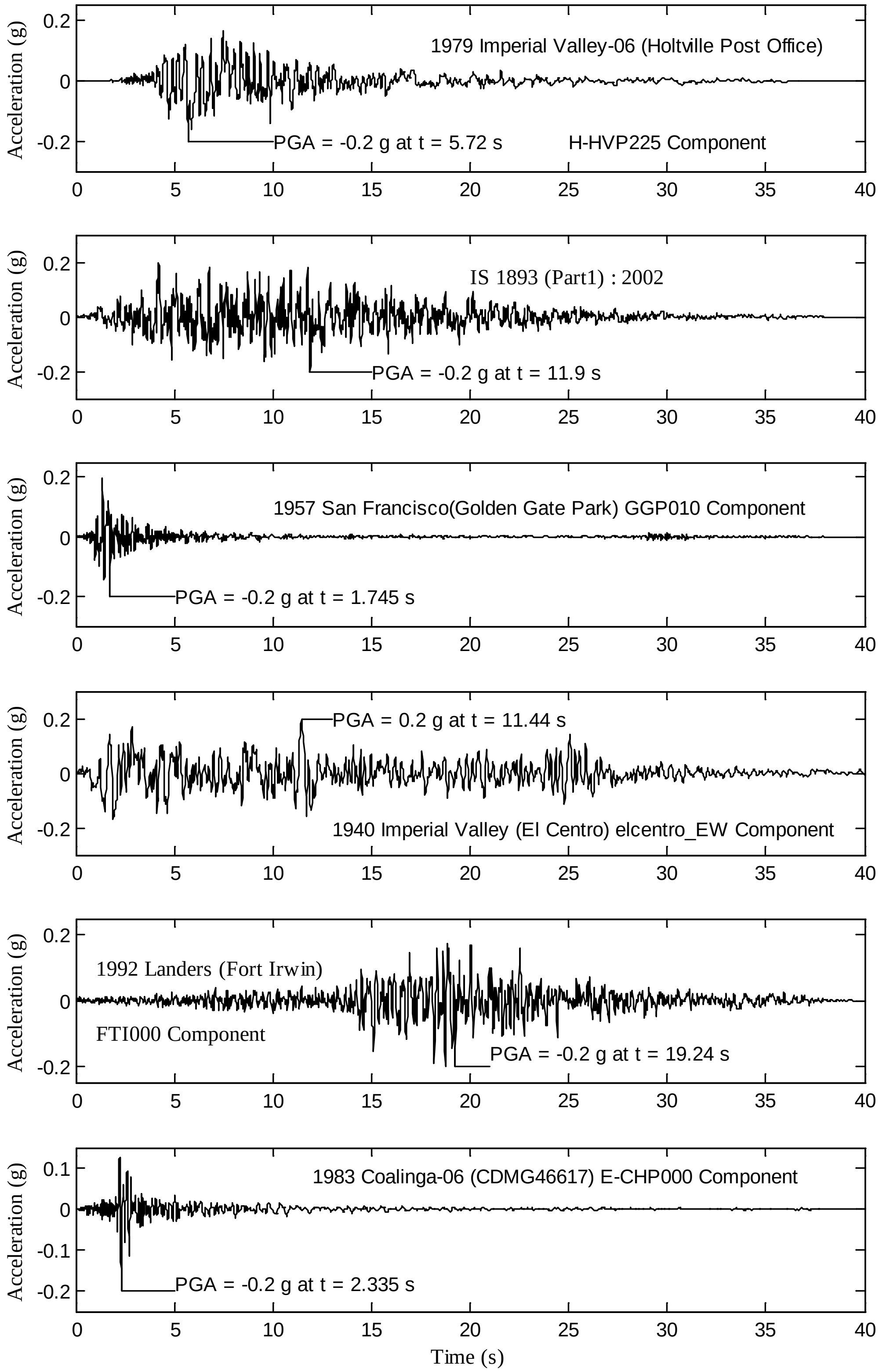
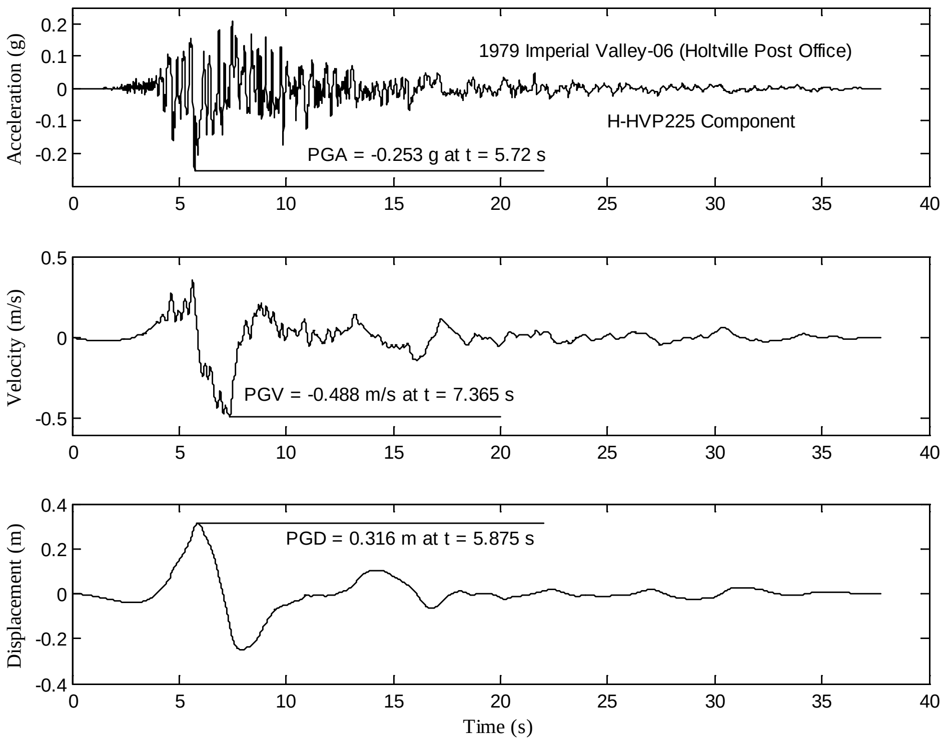
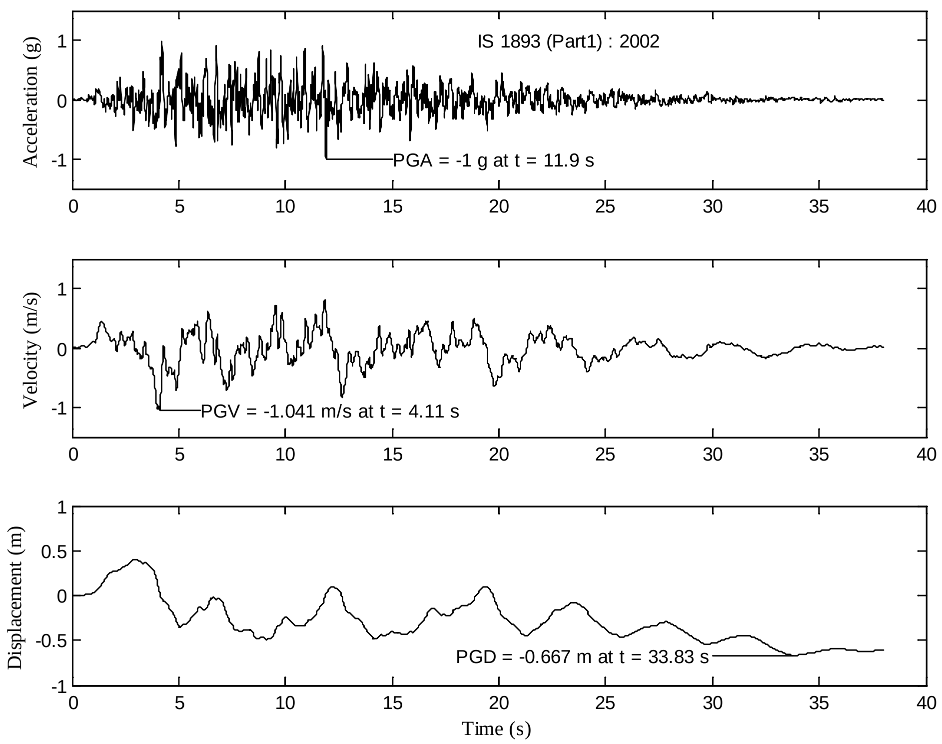


Figure 4.3: Ground motion acceleration versus time with PGA scaled to 0.2 g and 40 s duration of 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (El Centro) elcentro_EW component, 1992 Landers (Fort Irwin) FTI000 component, and 1983 Coalinga-06 (CDMG46617) E-CHP000 component

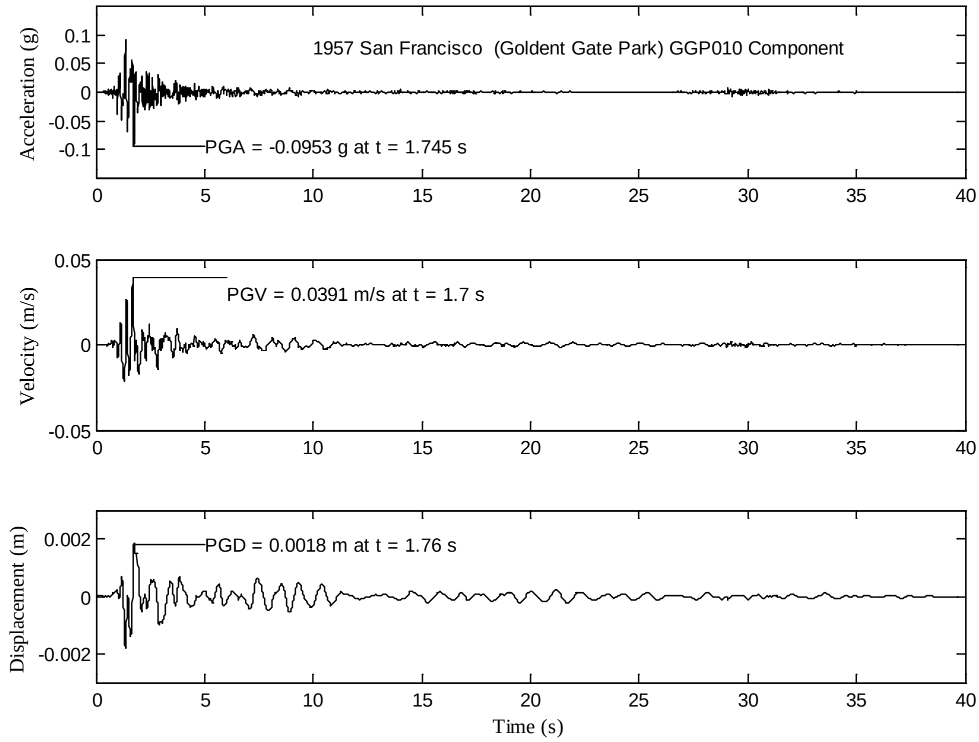


(a)

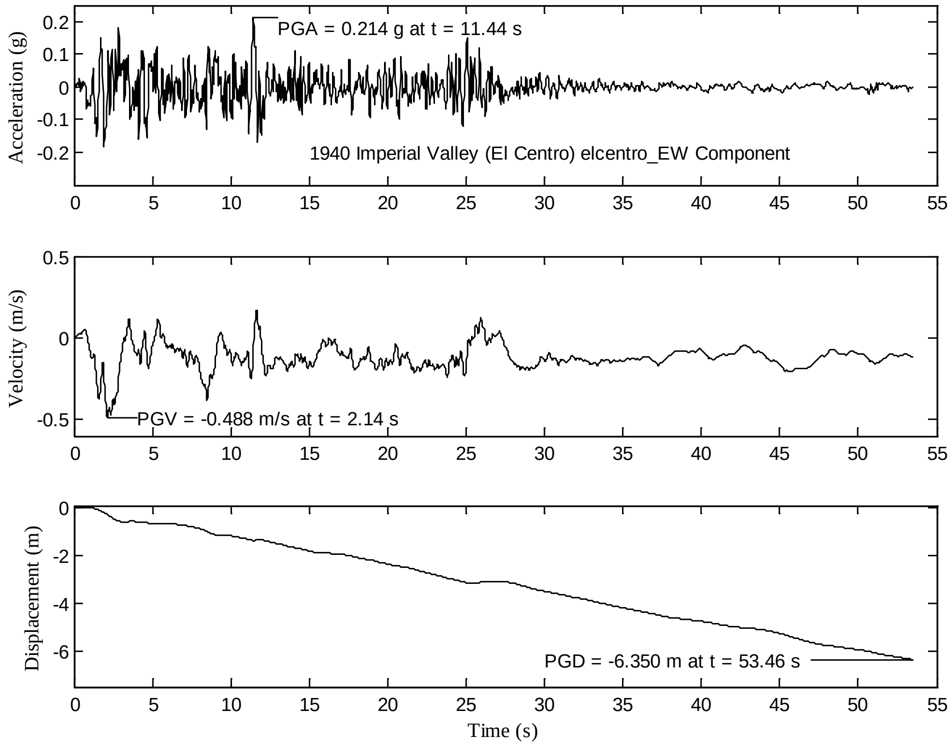


(b)

Figure 4.4: Acceleration, velocity, and displacement of (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion

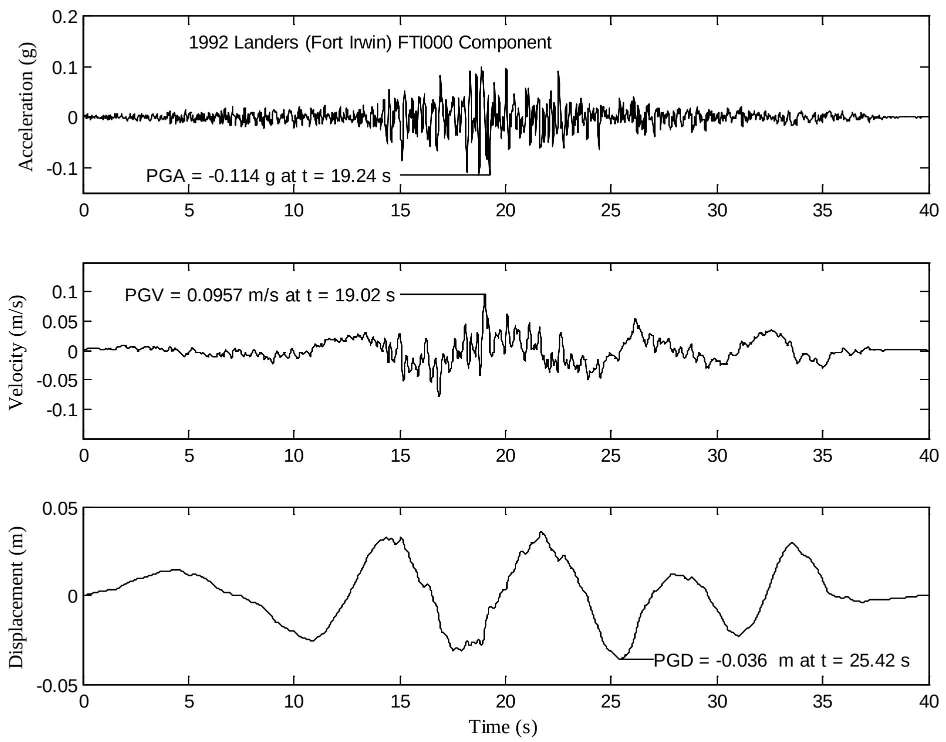


(a)

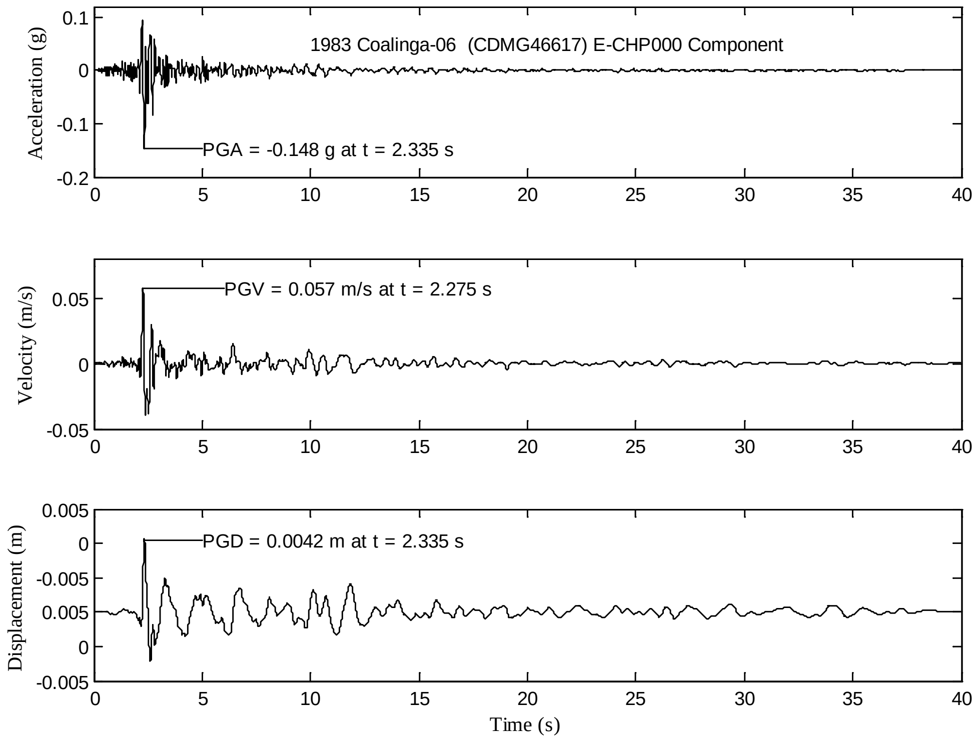


(b)

Figure 4.5: Acceleration, velocity, and displacement of (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion



(a)



(b)

Figure 4.6: Acceleration, velocity, and displacement of (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion

Table 4.2: Ground motion characteristics and classification of its frequency-content

Records (Station)	Component	Magnitude	Epicentral Distance (km)	Duration (s)	Time step for response computation (s)	PGA (g)	PGV (m/s)	PGA/PGV	Frequency Content Classification
1979 Imperial Valley-06 (Holtville Post Office)	H-HVP225	6.53	19.81	37.74	0.005	0.2526	0.4875	0.5182	Low
IS 1893 (Part1) : 2002*	-	-	-	38.01	0.01	1	1.0407	0.9609	Intermediate
1957 San Francisco (Golden Gate Park)	GGP010	5.28	11.13	39.72	0.005	0.0953	0.0391	2.4405	High
1940 Imperial Valley (El Centro)	elcentro_EW	7.1	-	53.46	0.02	0.2141	0.4879	0.4389	Low
1992 Landers (Fort Irwin)	FTI000	7.28	120.99	39.98	0.02	0.1136	0.0957	1.1868	Intermediate
1983 Coalinga-06 (CDMG46617)	E-CHP000	4.89	9.27	39.995	0.005	0.1479	0.0573	2.5810	High

Table 4.3: Ground motion characteristics and classification of its frequency-content for 40 s duration

Records (Station)	Component	Magnitude	Epicentral Distance (km)	Duration (s)	Time step for response computation (s)	PGA (g)	PGV (m/s)	PGA/PGV	Frequency Content Classification
1979 Imperial Valley-06 (Holtville Post Office)	H-HVP225	6.53	19.81	40	0.005	0.2526	0.4875	0.5182	Low
IS 1893 (Part1) : 2002	-	-	-	40	0.01	1	1.0407	0.9609	Intermediate
1957 San Francisco (Golden Gate Park)	GGP010	5.28	11.13	40	0.005	0.0953	0.0391	2.4405	High
1940 Imperial Valley (El Centro)	elcentro_EW	7.1	-	40	0.02	0.2141	0.4879	0.4389	Low
1992 Landers (Fort Irwin)	FTI000	7.28	120.99	40	0.02	0.1136	0.0957	1.1868	Intermediate
1983 Coalinga-06 (CDMG46617)	E-CHP000	4.89	9.27	40	0.005	0.1479	0.0573	2.5810	High

* Compatible time history of acceleration as per spectra of Indian Standard Code 1893 (Part1) : 2002

4.4 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]. Table 4.4-4.9 shows that the number of modes considered here are greater or close to the criteria.

Table 4.4 shows the dynamic characteristics of the two-story regular reinforced concrete building for mode 1 and 2. The fundamental frequency of the structure is 12.717 rad/s and fundamental period is 0.494 s. 94.6 percent and 96 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.4: Dynamic characteristics of the two-story regular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	12.717	0.494	0	0	95.994	95.994
2	15.771	0.398	94.564	94.564	0	95.994

Table 4.5 shows the dynamic characteristics of the six-story regular reinforced concrete building for mode 1 to 6. The fundamental frequency of the structure is 3.506 rad/s and fundamental period is 1.792 s. 93.7 and 94.4 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.5: Dynamic characteristics of the six-story regular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	3.506	1.792	0	0	84.616	84.616
2	4.128	1.522	83.427	83.427	0	84.616
3	4.423	1.421	0	83.427	0	84.616
4	10.681	0.588	0	83.427	9.793	94.409
5	12.786	0.491	10.283	93.71	0	94.409
6	13.641	0.461	0	93.71	0	94.409

Table 4.6 shows the dynamic characteristics of the twenty-story regular reinforced concrete building for mode 1 to 20. The fundamental frequency of the structure is 0.961 rad/s and fundamental period is 6.539 s. 97.6 and 98.8 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.6: Dynamic characteristics of the twenty-story regular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	0.961	6.539	0	0	81.008	81.008
2	1.043	6.03	78.359	78.359	0	81.008
3	1.181	5.324	0	78.359	0	81.008
4	2.903	2.166	0	78.359	10.001	91.009
5	3.217	1.955	12.046	90.405	0	91.009
6	3.581	1.754	0	90.405	0	91.009
7	4.951	1.27	0	90.405	3.388	94.397
8	5.737	1.096	3.569	93.974	0	94.397
9	6.183	1.017	0	93.974	0	94.397
10	6.981	0.9	0	93.974	1.737	96.134
11	8.168	0.769	1.827	95.801	0	96.134
12	8.765	0.717	0	95.801	0	96.134
13	9.054	0.694	0	95.801	1.052	97.186
14	10.713	0.587	1.098	96.899	0	97.186
15	11.159	0.563	0	96.899	0.711	97.897
16	11.435	0.549	0	96.899	0	97.897
17	13.295	0.473	0.751	97.65	0	97.897
18	13.302	0.472	0	97.65	0.51	98.407
19	14.169	0.443	0	97.65	0	98.407
20	15.463	0.406	0	97.65	0.382	98.789

Table 4.7 shows the dynamic characteristics of the two-story irregular reinforced concrete building for mode 1 and 2. The fundamental frequency of the structure is 13.069 rad/s and fundamental period is 0.481 s. 91.4 percent and 91.8 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.7: Dynamic characteristics of the two-story irregular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	13.069	0.481	0.086	0.086	91.41	91.41
2	15.036	0.418	91.315	91.401	0.446	91.856

Table 4.8 shows the dynamic characteristics of the six-story irregular reinforced concrete building for mode 1 to 6. The fundamental frequency of the structure is 3.550 rad/s and fundamental period is 1.77 s. 94 and 94.1 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.8: Dynamic characteristics of the six-story irregular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	3.550	1.77	0.006	0.006	82.393	82.393
2	4.040	1.555	82.816	82.822	0.053	82.446
3	4.317	1.456	1.131	83.953	1.72	84.166
4	10.870	0.578	0.002	83.955	9.643	93.809
5	12.416	0.506	9.821	93.776	0.015	93.824
6	13.308	0.472	0.232	94.008	0.264	94.088

Table 4.9 shows the dynamic characteristics of the twenty-story irregular reinforced concrete building for mode 1 to 20. The fundamental frequency of the structure is 0.961 rad/s and fundamental period is 6.527 s. 98.2 and 98.3 percent of the seismic mass is participated in x and z-direction respectively.

Table 4.9: Dynamic characteristics of the twenty-story irregular RC building

Mode	Natural Frequency (rad/s)	Period (s)	Mass Participation X (%)	Mass Participation Sum X (%)	Mass Participation Z (%)	Mass Participation Sum Z (%)
1	0.961	6.527	0.189	0.189	79.458	79.458
2	1.068	5.889	79.427	79.616	0.243	79.701
3	1.169	5.371	0.137	79.753	0.934	80.635
4	2.909	2.158	0.022	79.775	10.044	90.679
5	3.248	1.934	10.908	90.683	0.01	90.689
6	3.537	1.776	0	90.683	0.137	90.826
7	4.995	1.258	0	90.683	3.357	94.183
8	5.661	1.11	3.457	94.14	0	94.183
9	6.038	1.04	0.023	94.163	0.055	94.238
10	7.056	0.89	0	94.163	1.725	95.963
11	8.024	0.783	1.764	95.927	0.001	95.964
12	8.558	0.734	0.02	95.947	0.027	95.991
13	9.180	0.685	0	95.947	1.049	97.04
14	10.462	0.601	1.059	97.006	0.001	97.041
15	11.153	0.563	0.018	97.024	0.006	97.047
16	11.335	0.554	0	97.024	0.724	97.771
17	12.937	0.486	0.717	97.741	0	97.771
18	13.547	0.464	0	97.741	0.489	98.26
19	13.823	0.455	0.015	97.756	0.037	98.297
20	15.482	0.406	0.464	98.22	0	98.297

CHAPTER 5

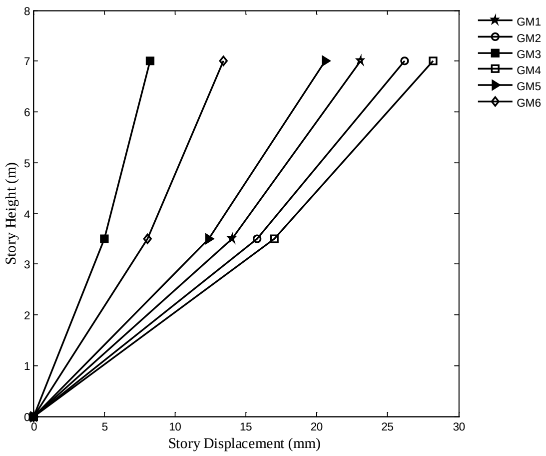
5 REGULAR RC BUILDINGS RESULTS AND DISCUSSION

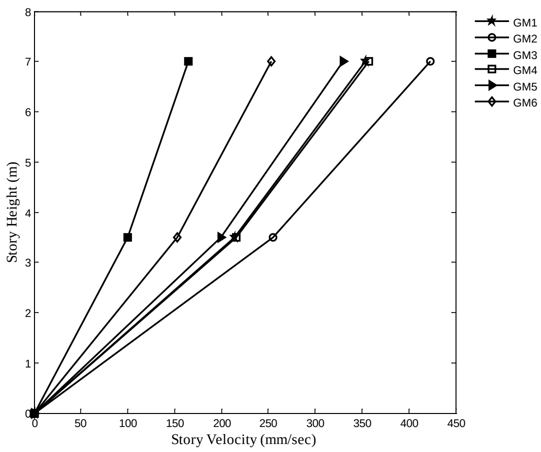
5.1 Overview

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





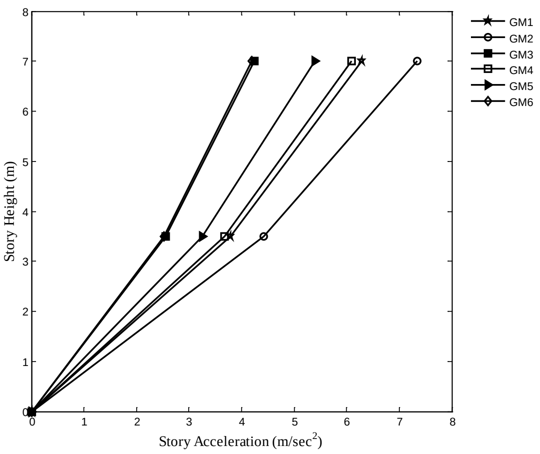
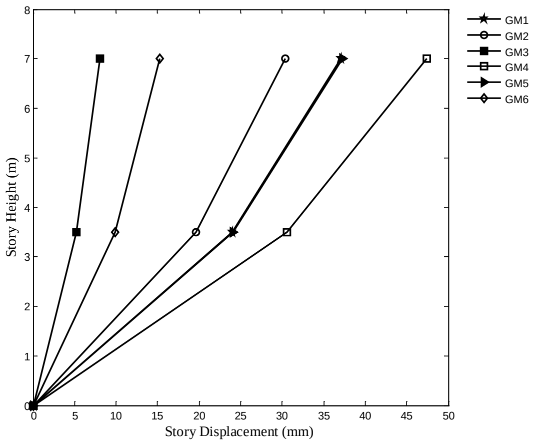


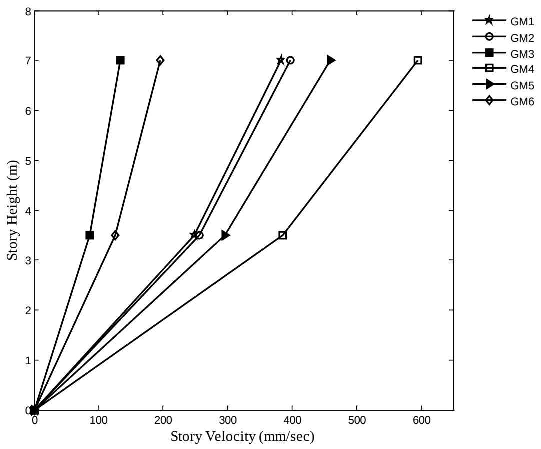
Figure 5.1: Story displacement, velocity, and acceleration of two-story regular reinforced concrete building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

[1] 1979 Imperial Valley-06 (Holtville Post Office) HVP225 component (low- frequency content)
[2] IS 1893 (Part1) : 2002 (intermediate-frequency content)
[3] 1957 San Francisco (Golden Gate Park) GGP010 component (high-frequency content)
[4] 1940 Imperial Valley (El Centro) elcentro_EW component (low- frequency content)
[5] 1992 Landers (Fort Irwin) FTI000 component (intermediate-frequency content)
[6] 1983 Coaling-06 (CDMG46617) E-CHP000 component (high-frequency content)

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 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.





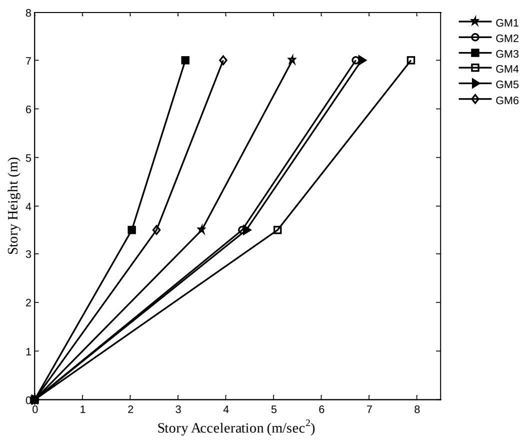
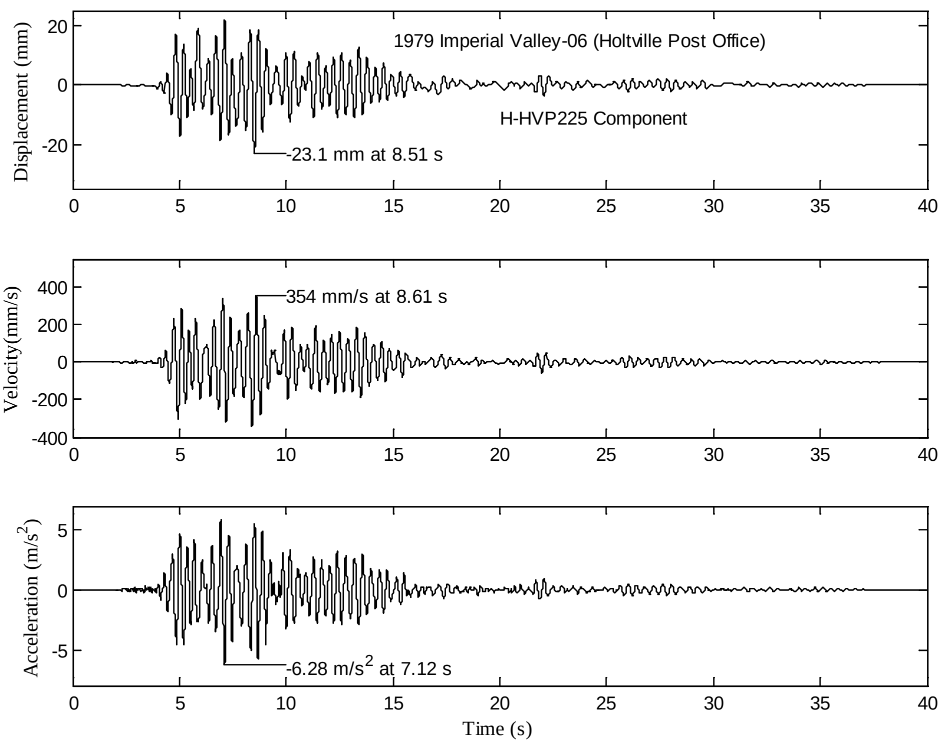


Figure 5.2: Story displacement, velocity, and acceleration of two-story regular reinforced concrete building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

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 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.



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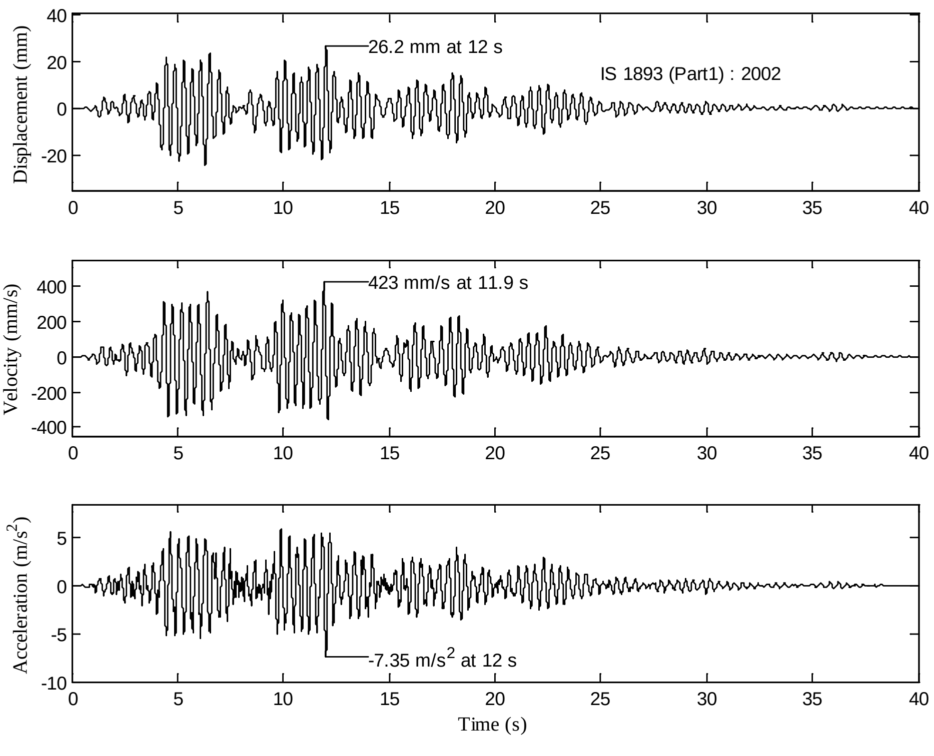
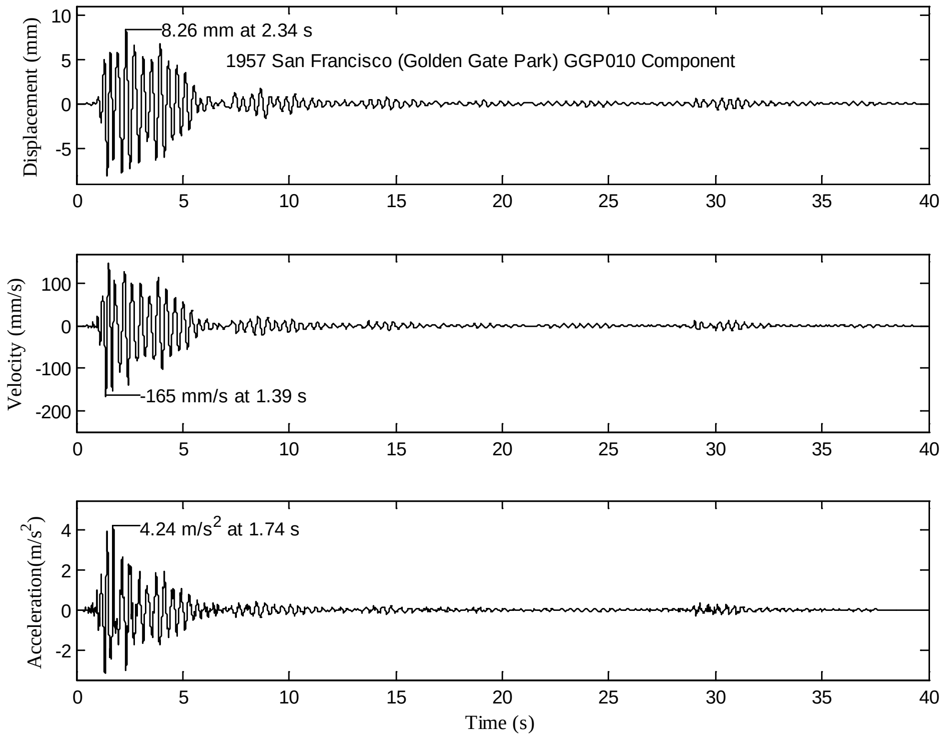


(b)

Figure 5.3: Roof displacement, velocity, and acceleration of two-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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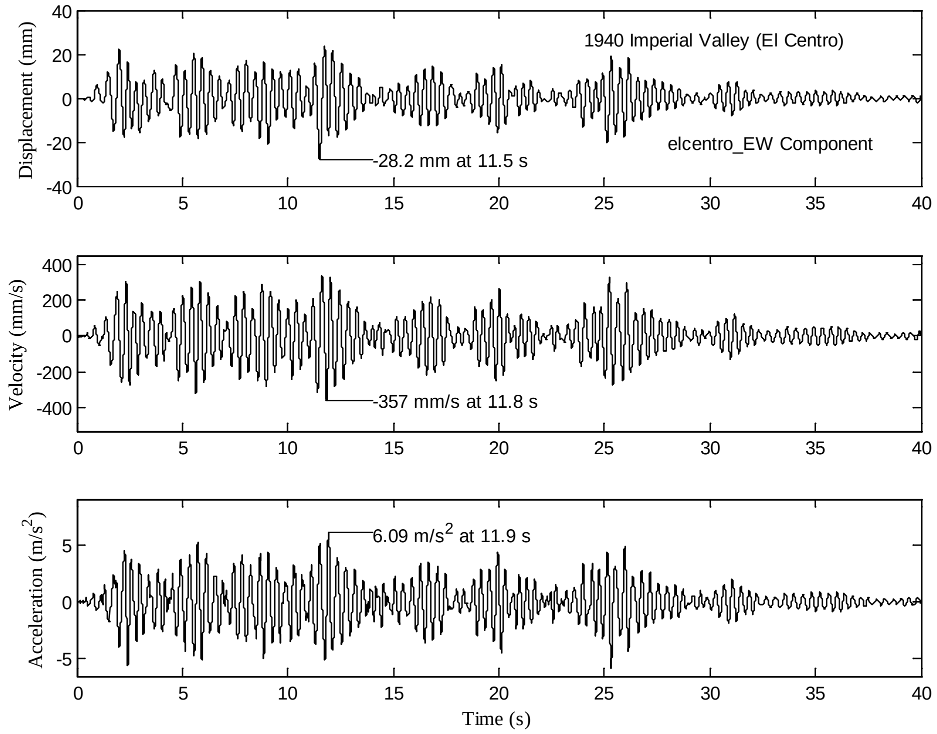
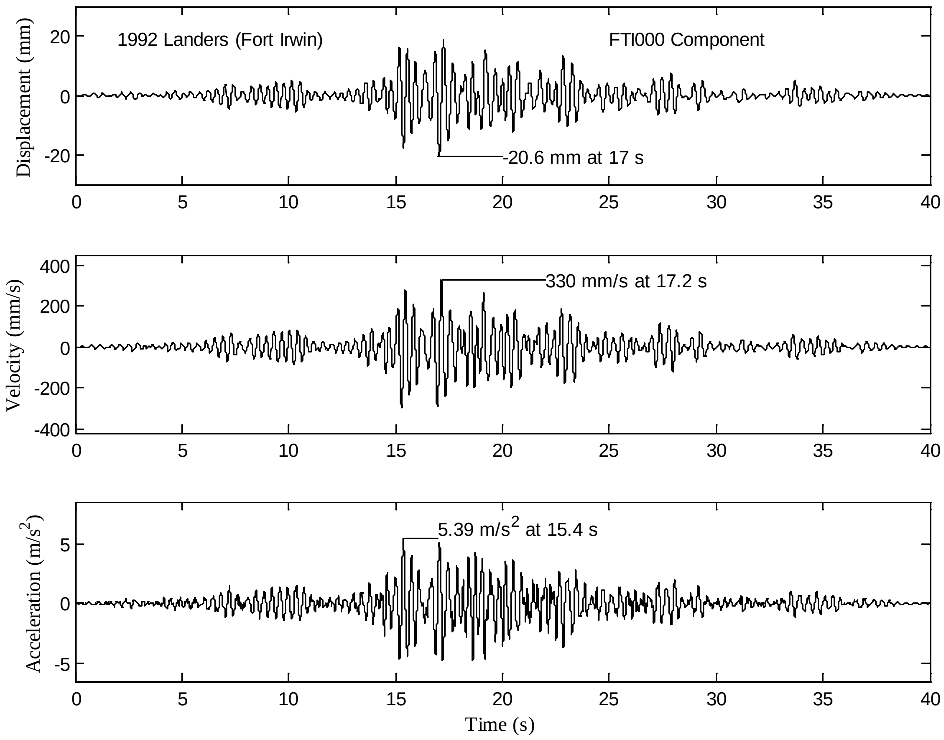


(b)

Figure 5.4: Roof displacement, velocity, and acceleration of two-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction



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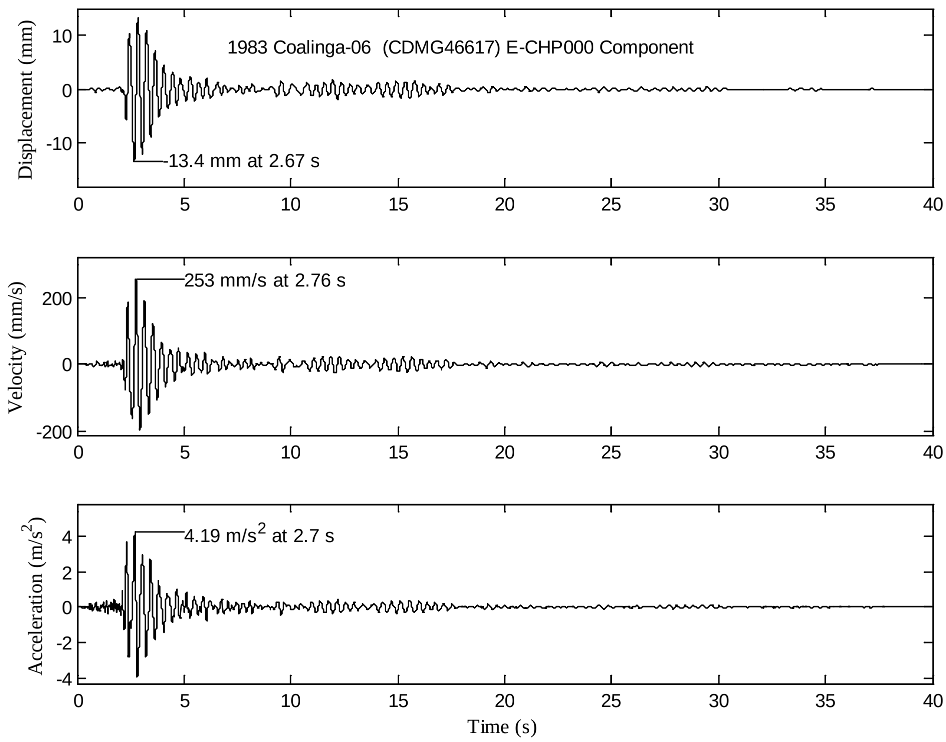
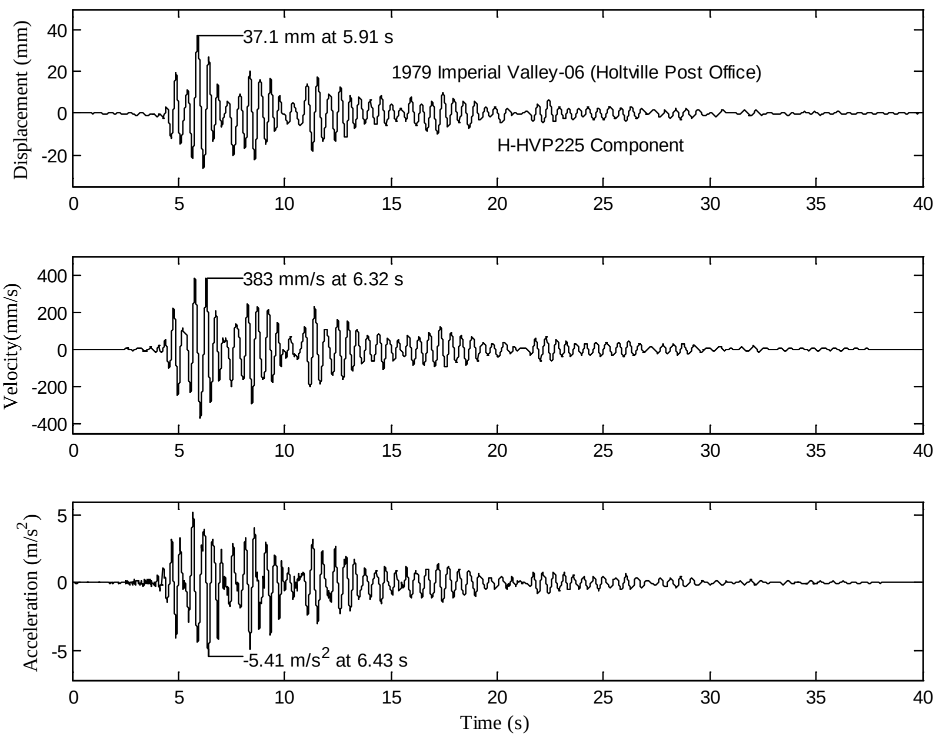
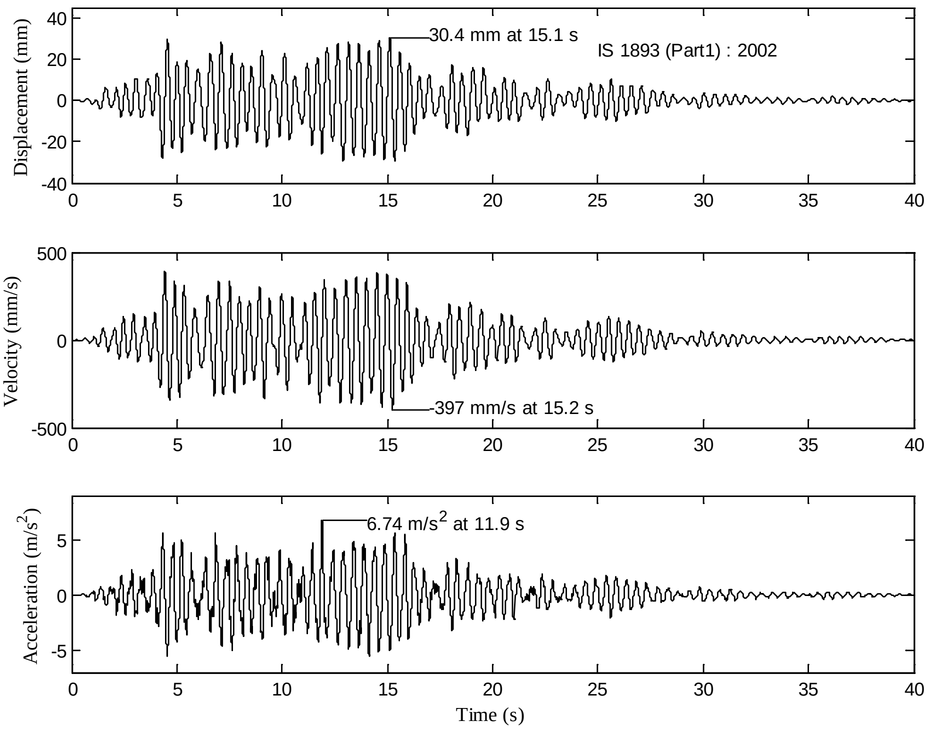


(b)

Figure 5.5: Roof displacement, velocity, and acceleration of two-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction

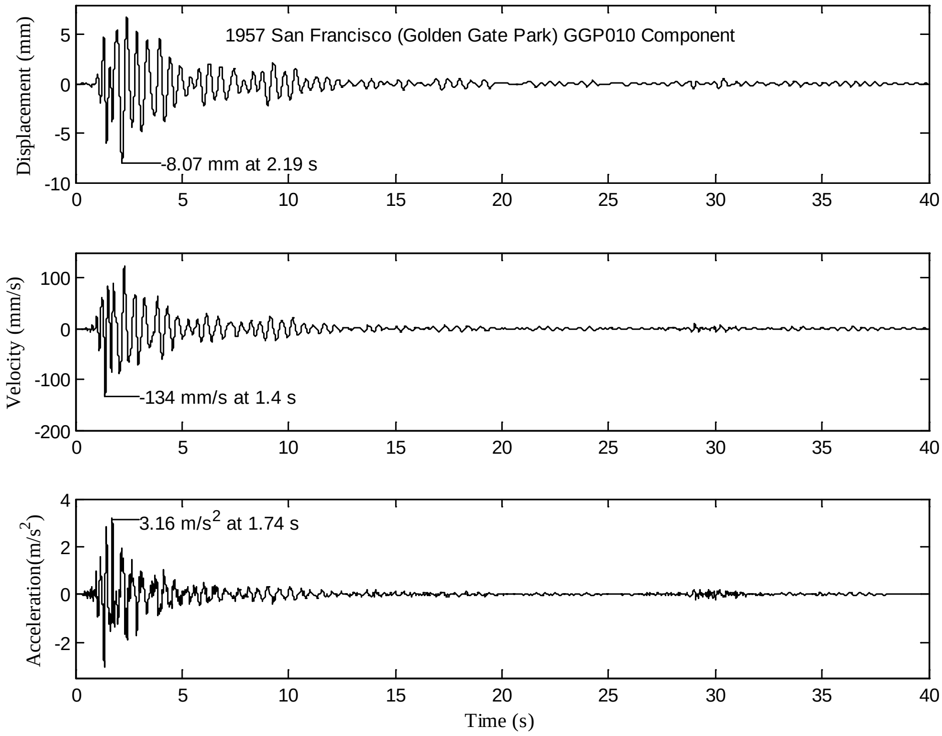


(a)



(b)

Figure 5.6: Roof displacement, velocity, and acceleration of two-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 z-direction



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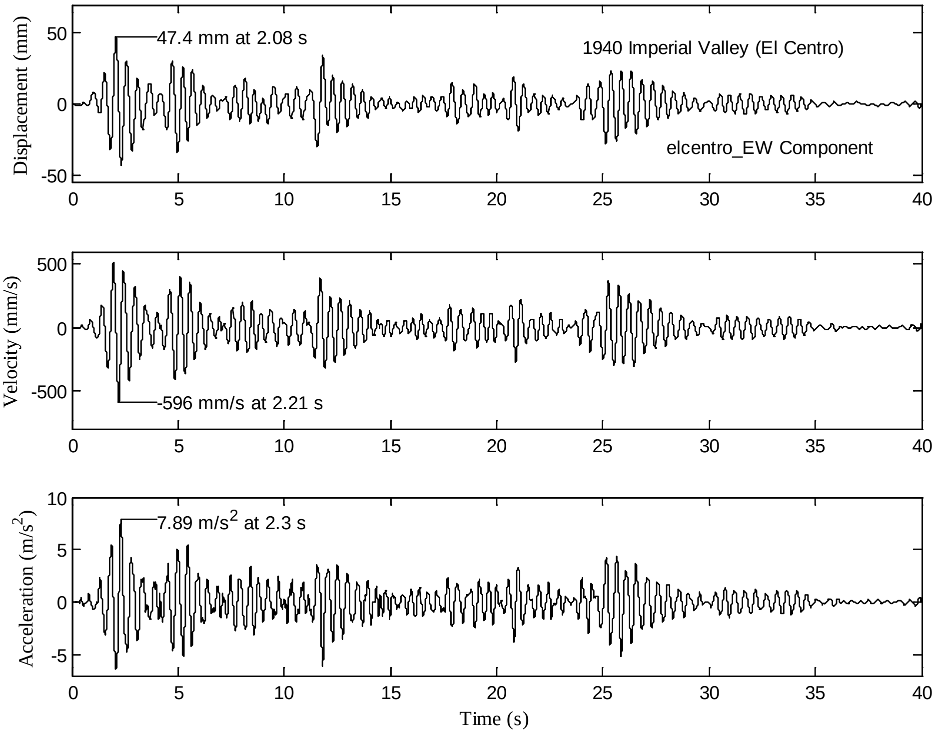
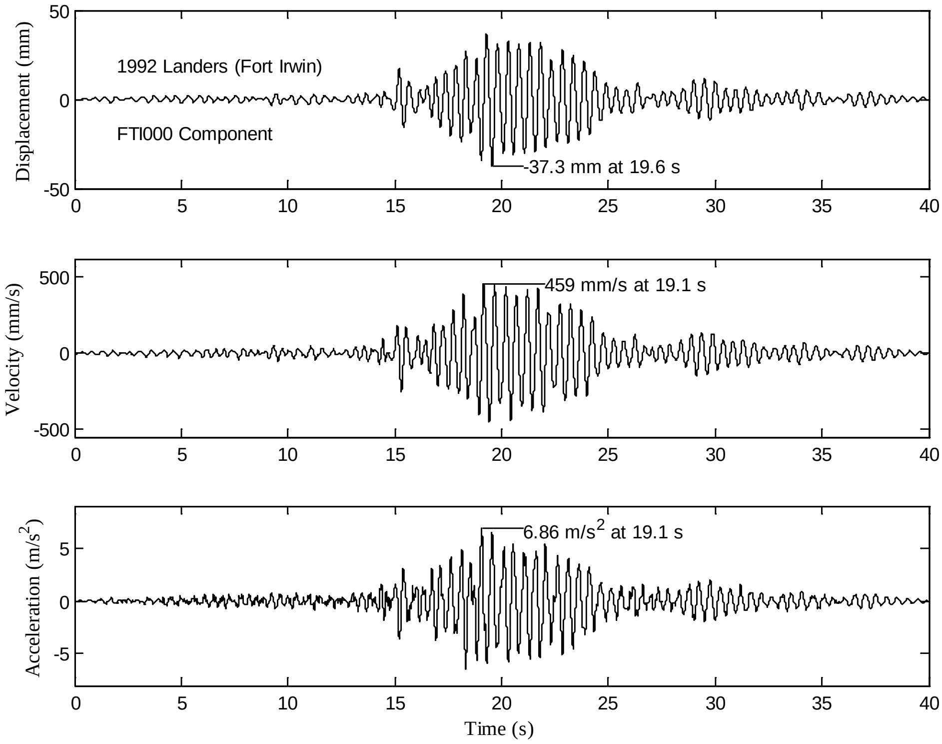
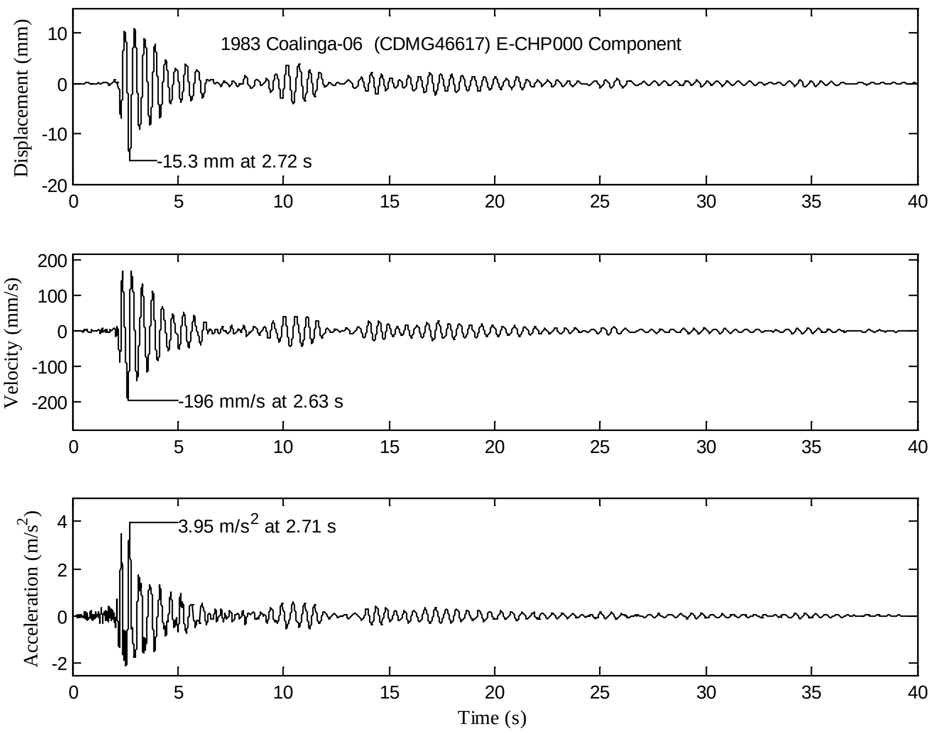


(b)

Figure 5.7: Roof displacement, velocity, and acceleration of two-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction



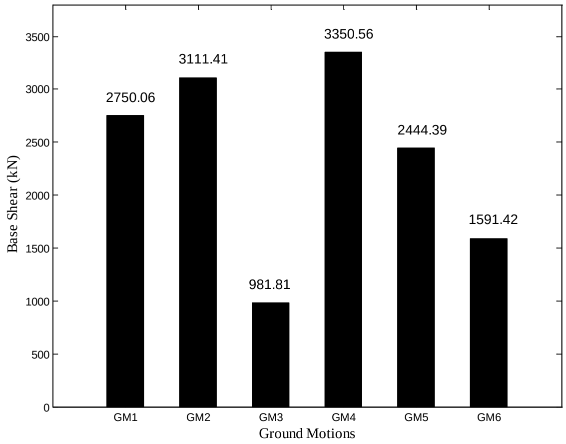
(a)



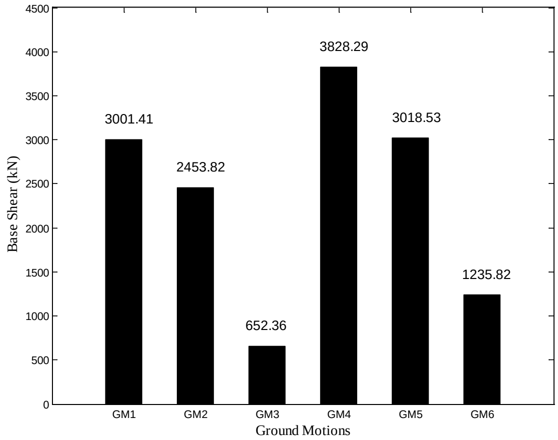
(b)

Figure 5.8: Roof displacement, velocity, and acceleration of two-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-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.



(a)

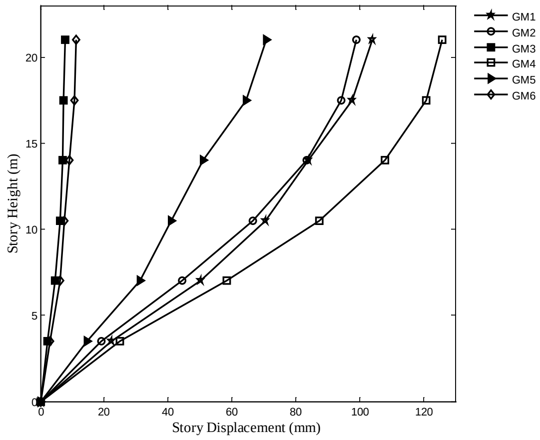


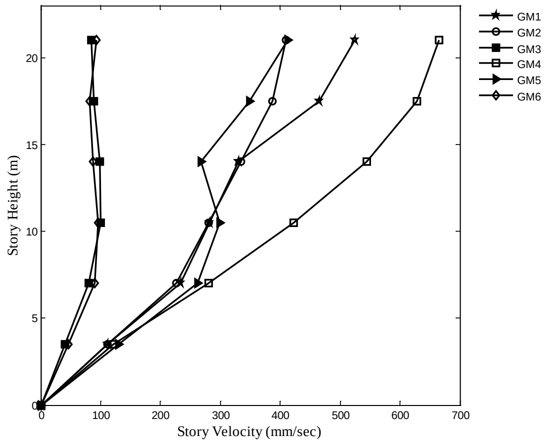
(b)

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 5.10 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 GM3 and GM6. The story acceleration is maximum due to ground motion GM5 and minimum due to ground motion GM6. It indicates that the building undergoes high story displacement and velocity due to low-frequency content ground motion and high story 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.





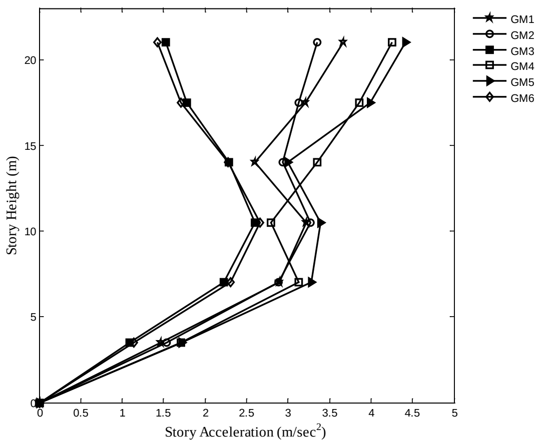
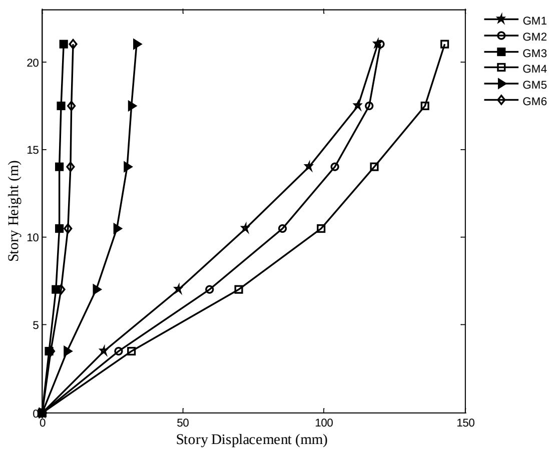
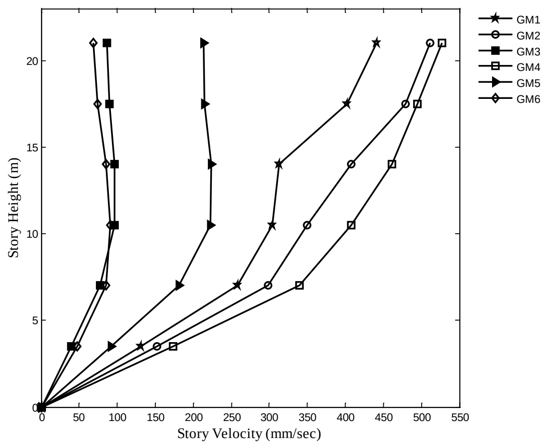


Figure 5.10: Story displacement, velocity, and acceleration of six-story regular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

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.





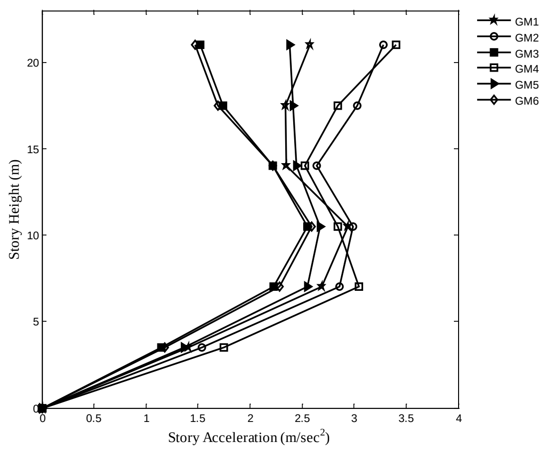
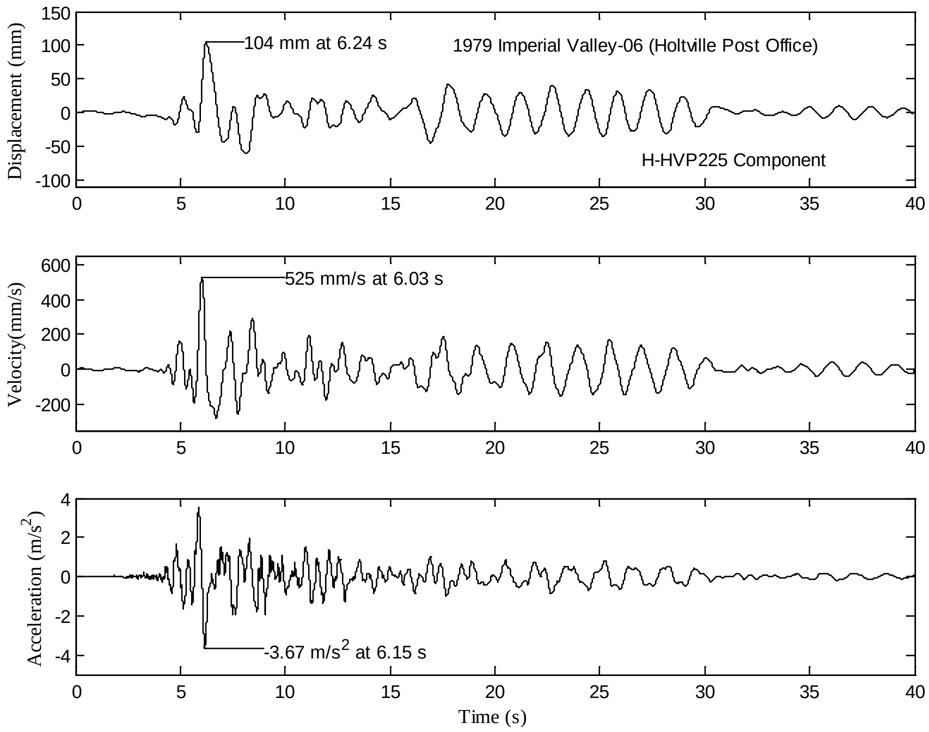


Figure 5.11: Story displacement, velocity, and acceleration of six-story regular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

Figure 5.12-5.17 shows roof displacement, velocity, and acceleration with respect to time for six-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 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.



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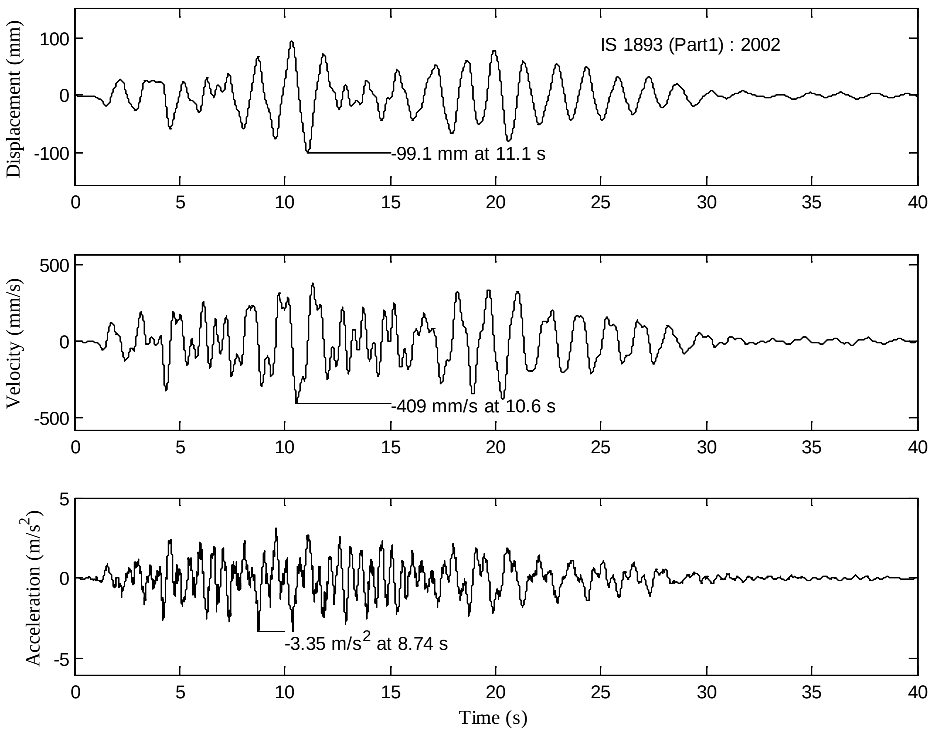
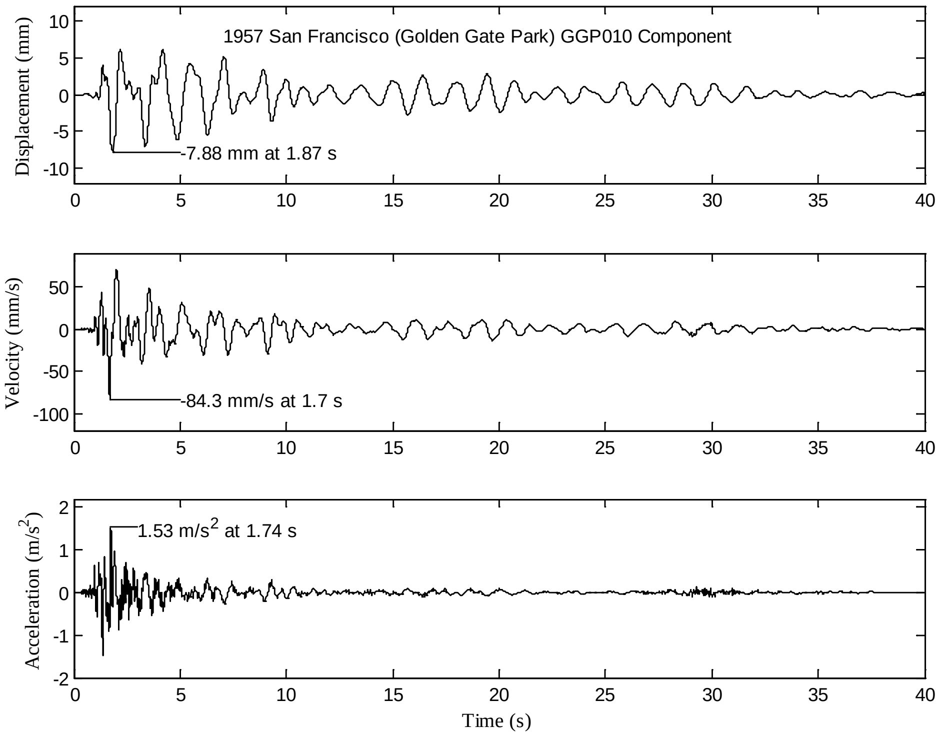
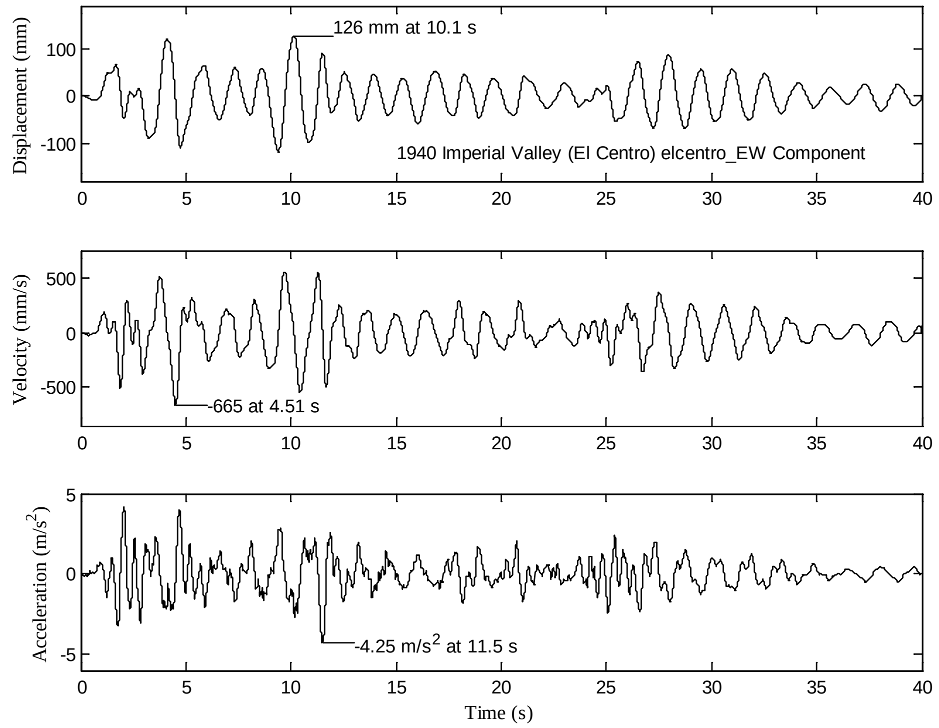


(b)

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

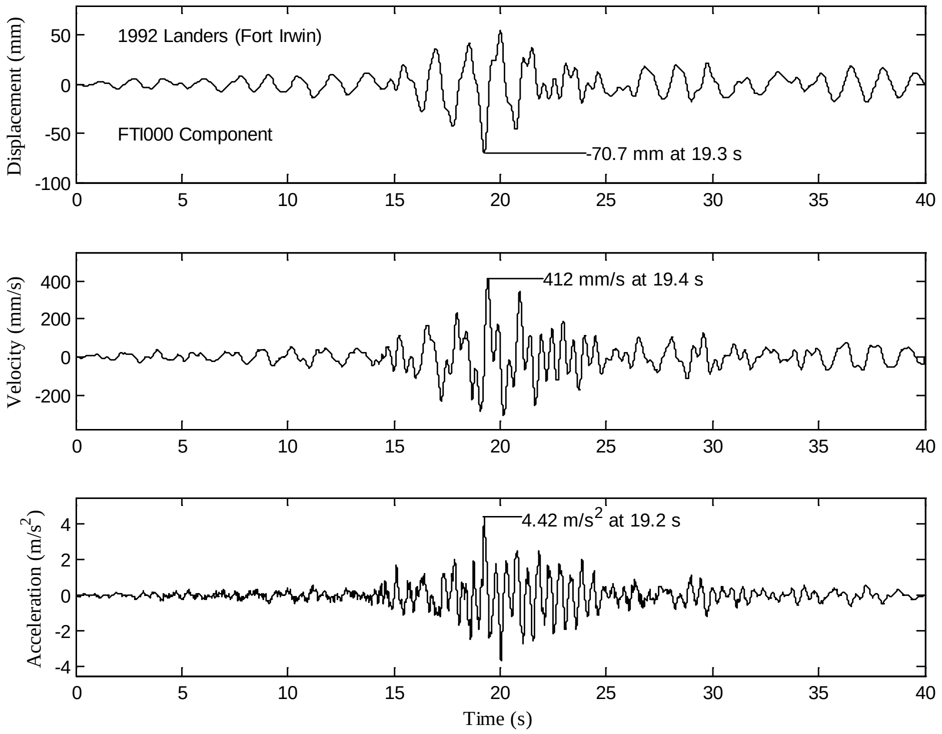


(a)

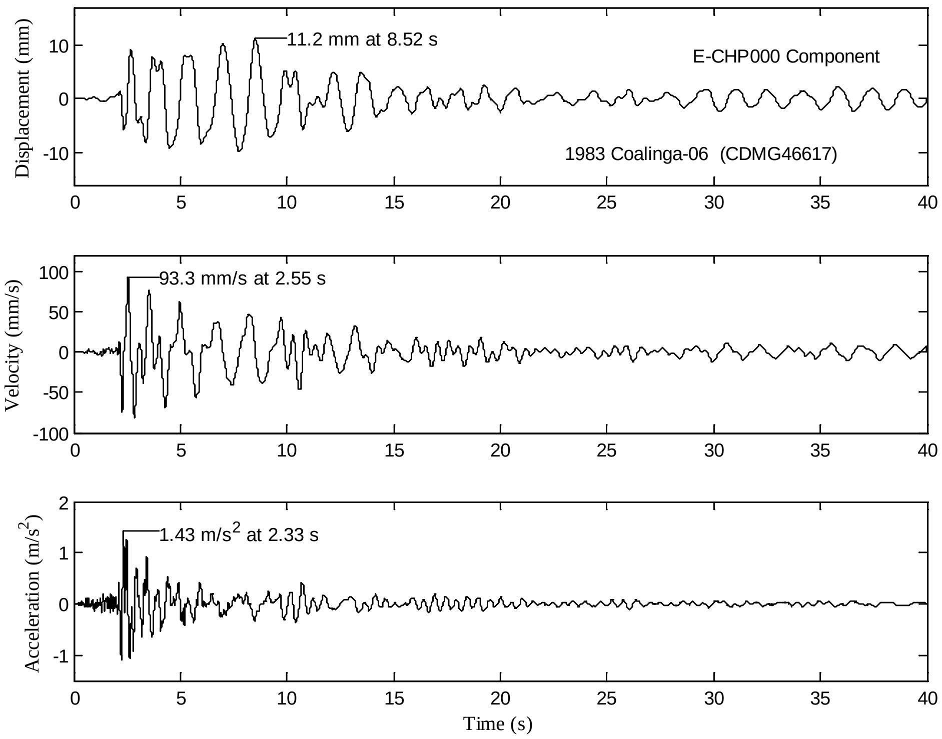


(b)

Figure 5.13: Roof displacement, velocity, and acceleration of six-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction

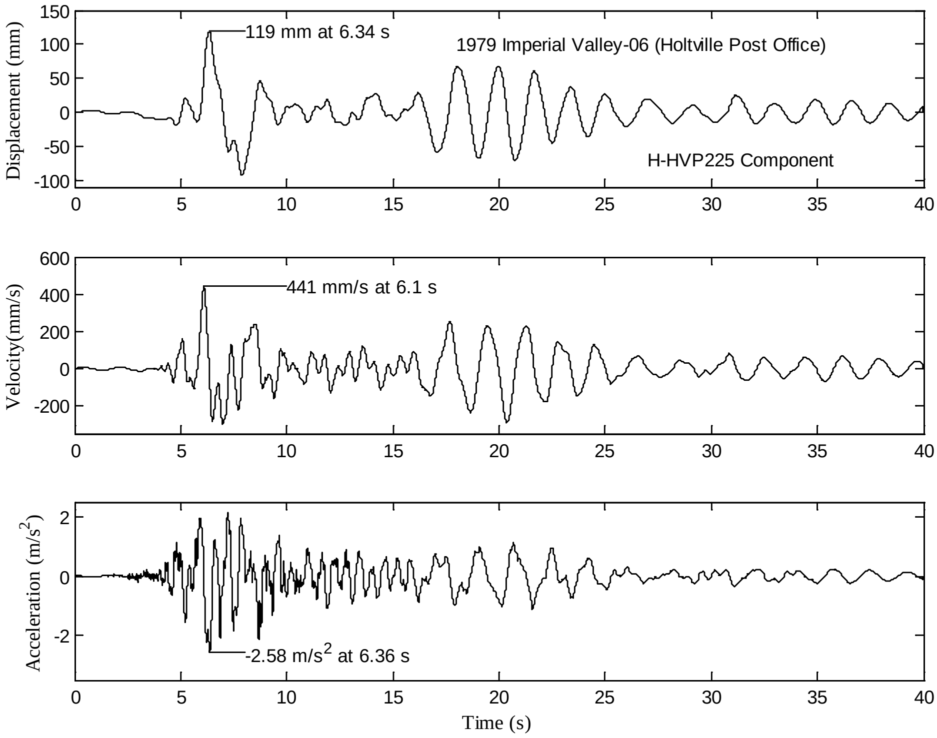


(a)



(b)

Figure 5.14: Roof displacement, velocity, and acceleration of six-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction



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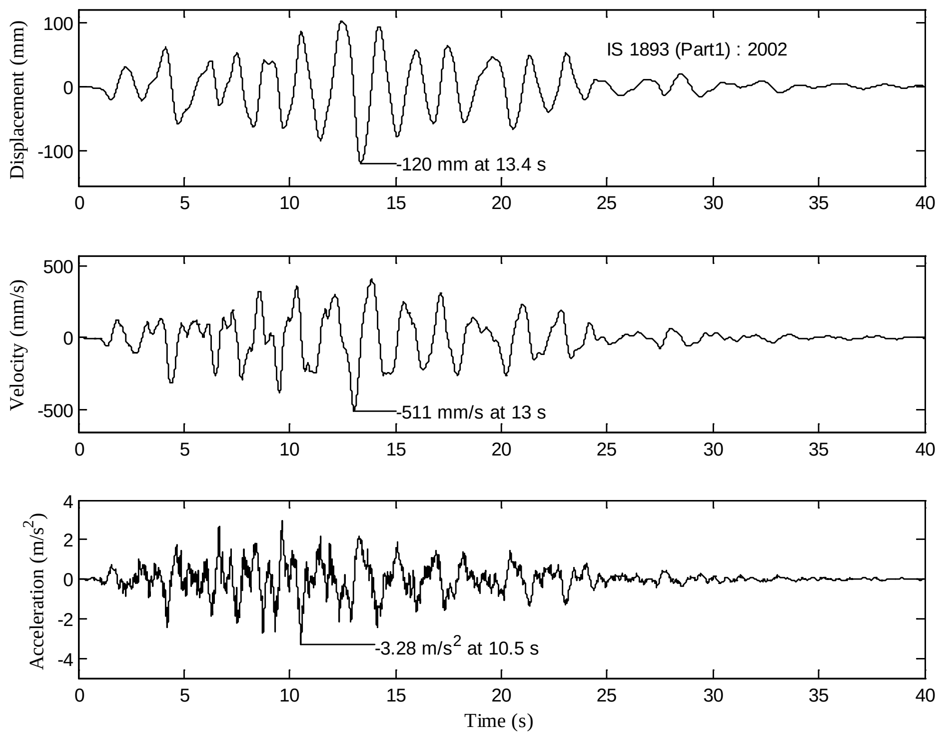
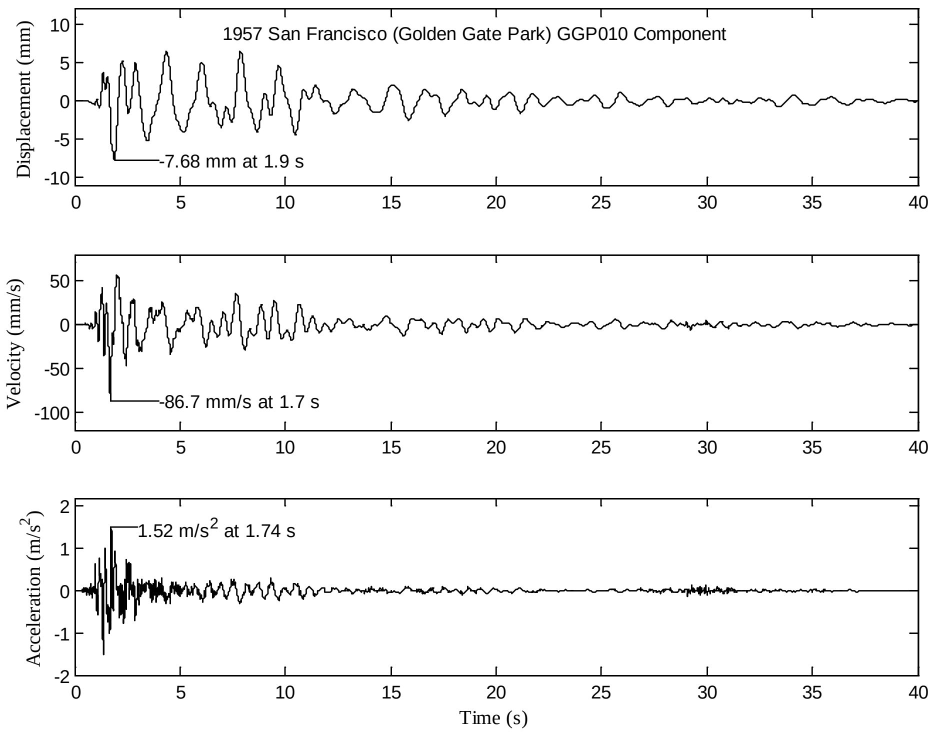
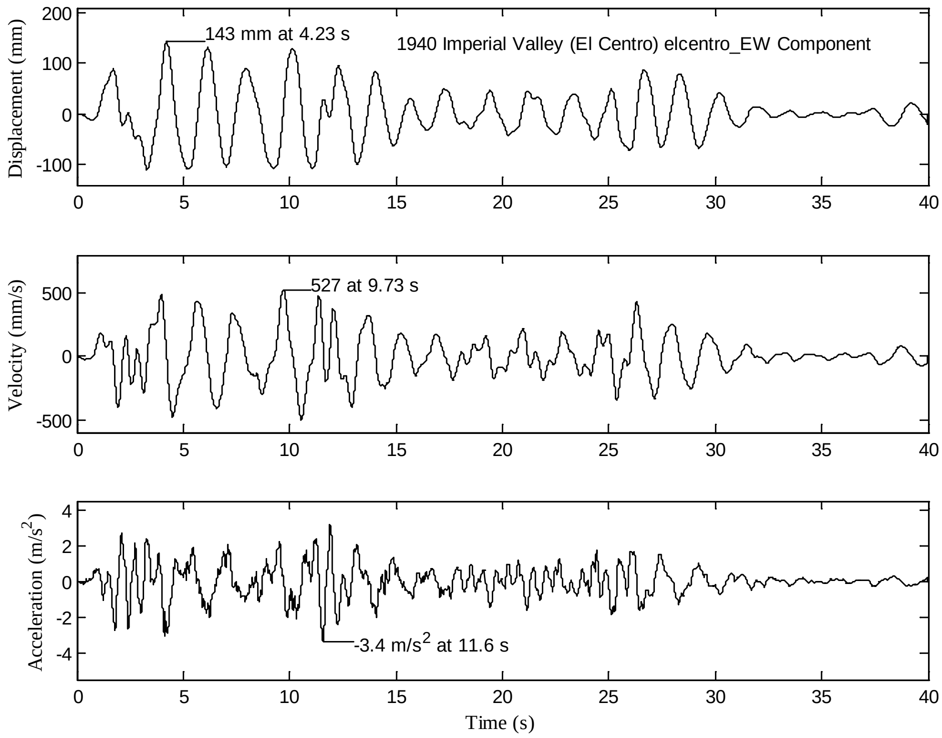


(b)

Figure 5.15: 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 z-direction

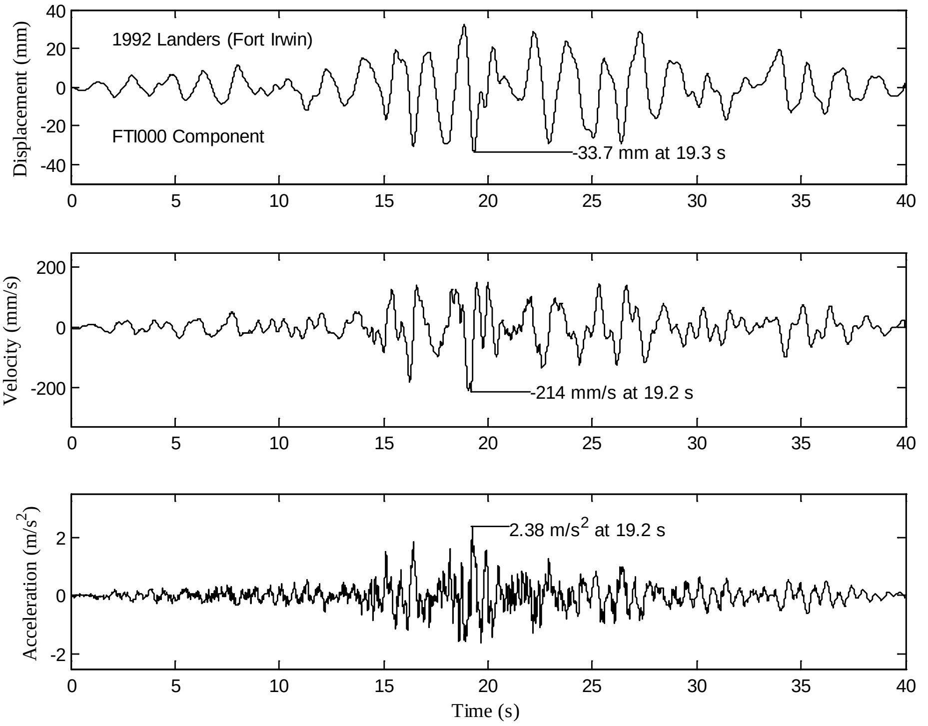


(a)

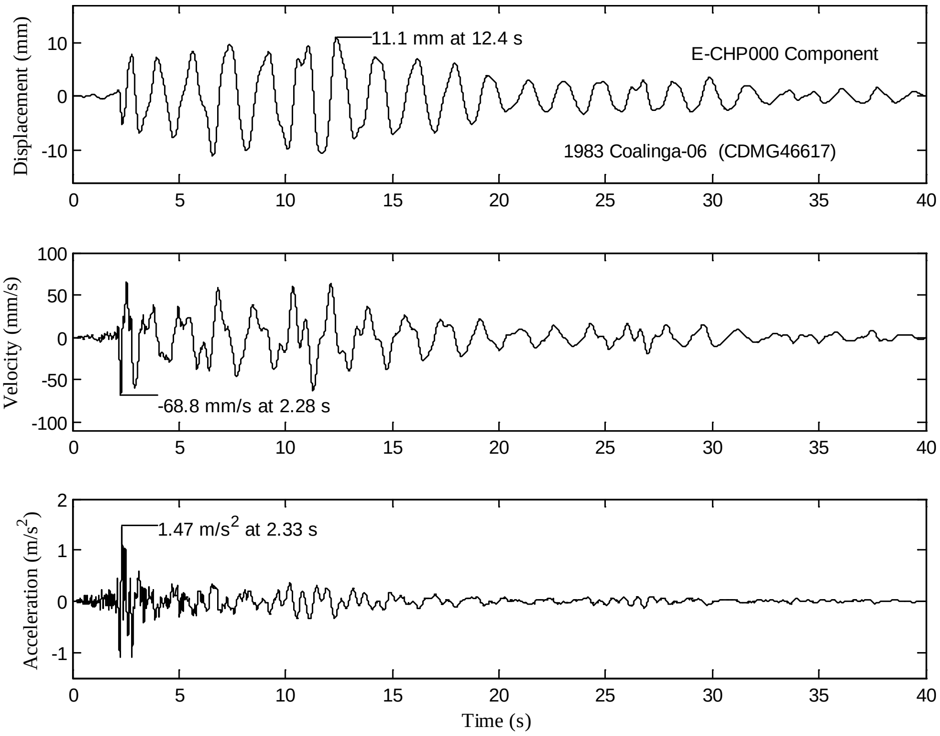


(b)

Figure 5.16: Roof displacement, velocity, and acceleration of six-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction



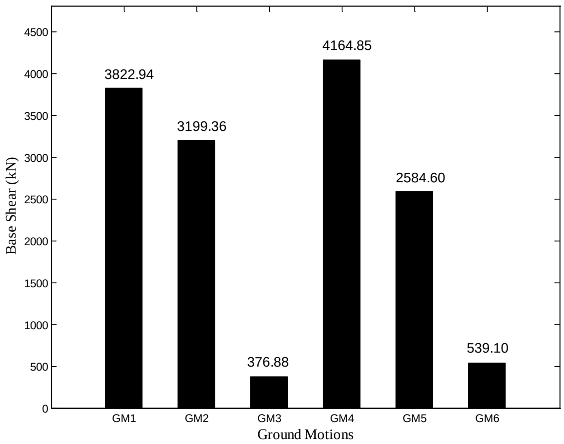
(a)



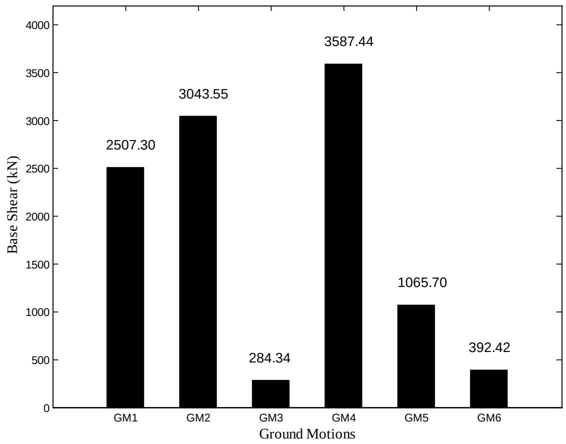
(b)

Figure 5.17: Roof displacement, velocity, and acceleration of six-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction

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)

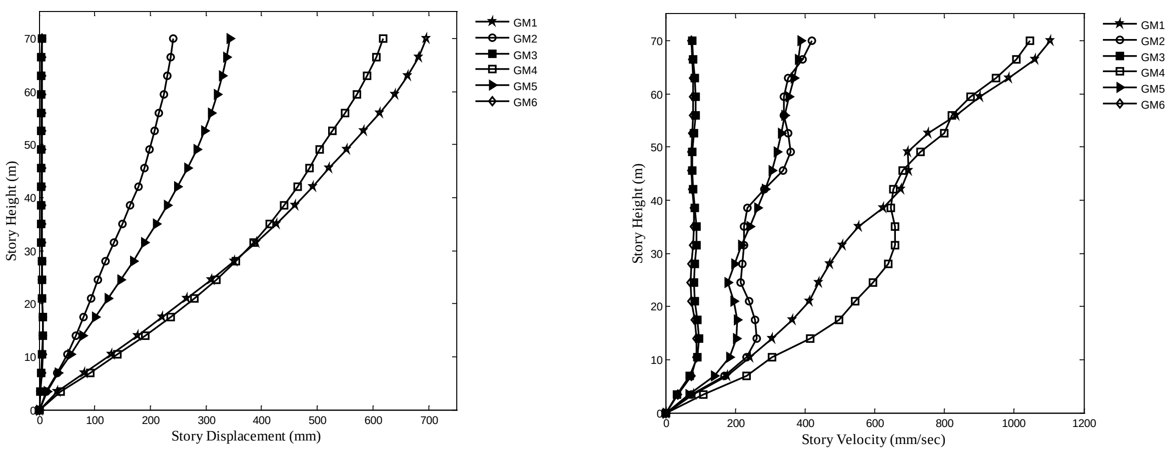


(b)

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

5.4 Twenty-Story Regular RC Building

Figure 5.19 shows story displacement, velocity, and acceleration of twenty-story regular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story velocity is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. 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 (x) transverse direction.



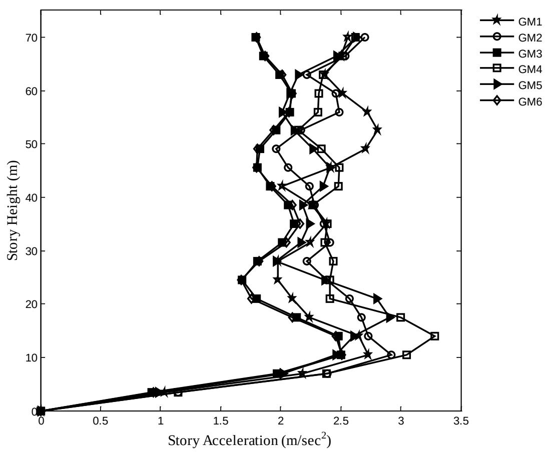
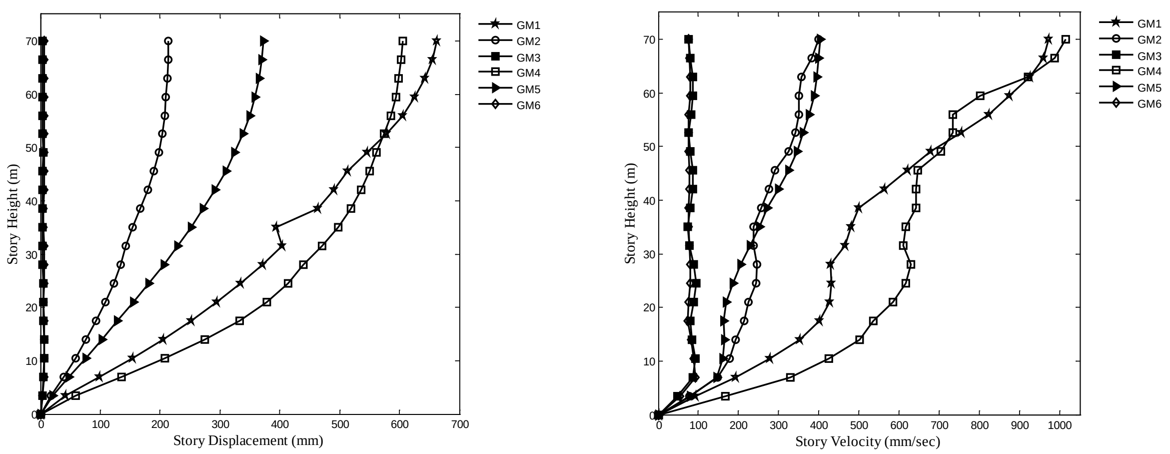


Figure 5.19: Story displacement, velocity, and acceleration of twenty-story regular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

Figure 5.20 shows story displacement, velocity, and acceleration of twenty-story regular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story velocity is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. 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.



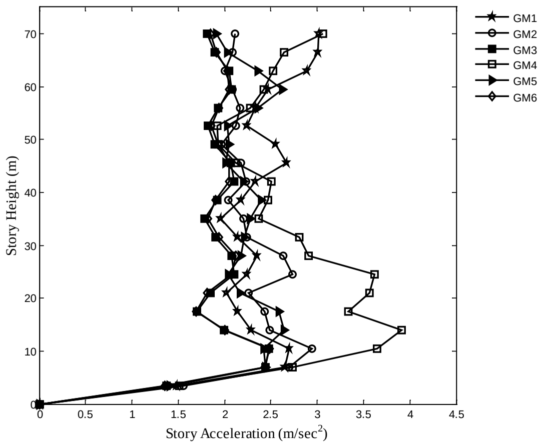
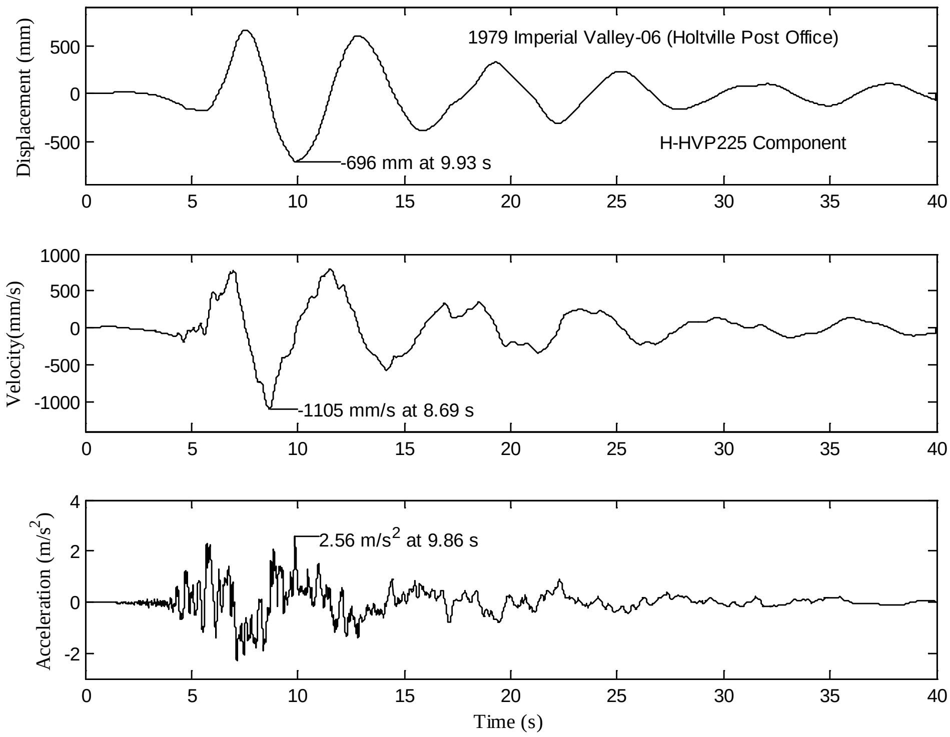


Figure 5.20: Story displacement, velocity, and acceleration of twenty-story regular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

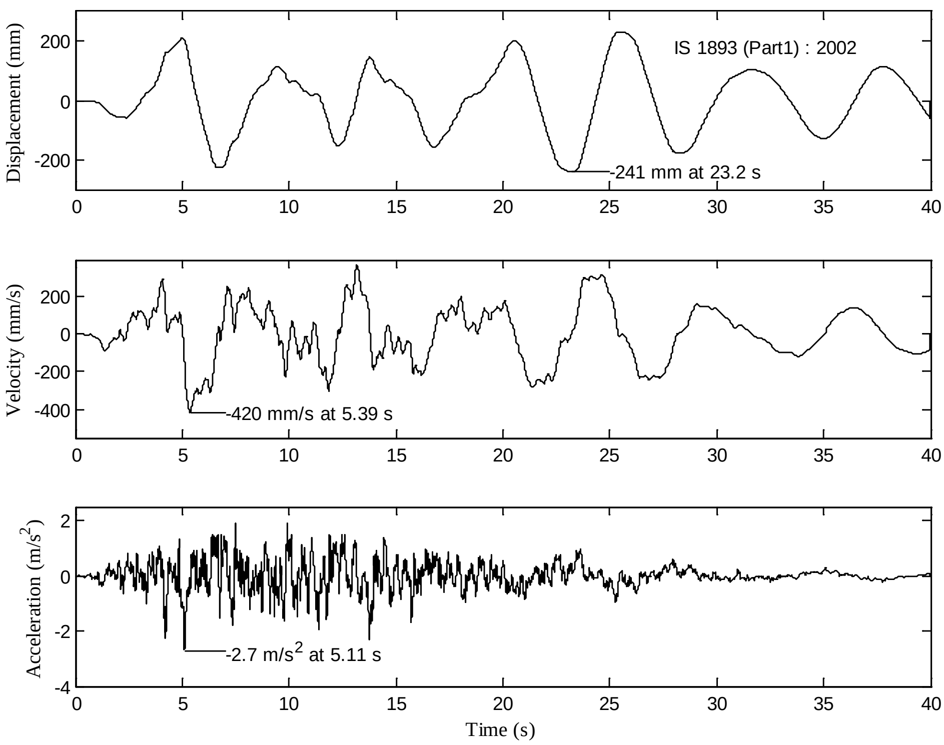
Figure 5.21-5.26 shows roof displacement, velocity, and acceleration with respect to time for twenty-story regular RC building due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (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 -696 mm at 9.93 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum roof displacement of 4.83 mm at 3.13 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -1,105 mm/s at 8.69 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum velocity of -74.7 mm/s at 2.27 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion. It has maximum roof acceleration of -2.62 m/s^2 at 2.68 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum acceleration of 1.79 m/s^2 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 662 mm at 7.6 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum roof displacement of 3.69 mm at 1.36 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 1,014 mm/s at 13.3 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum velocity of -75.9 mm/s at 1.7 s due to 1957 San Francisco (Golden Gate Park) GGP010 component motion. It has maximum roof acceleration of 3.06 m/s^2 at 13 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum -1.81 m/s^2 at 1.37 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

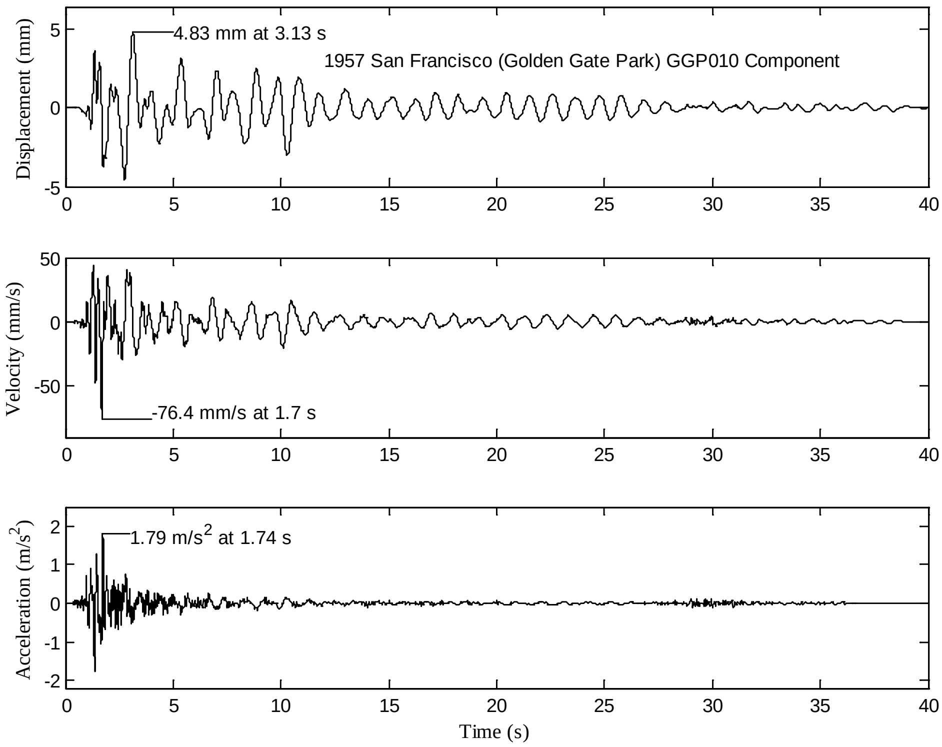


(a)

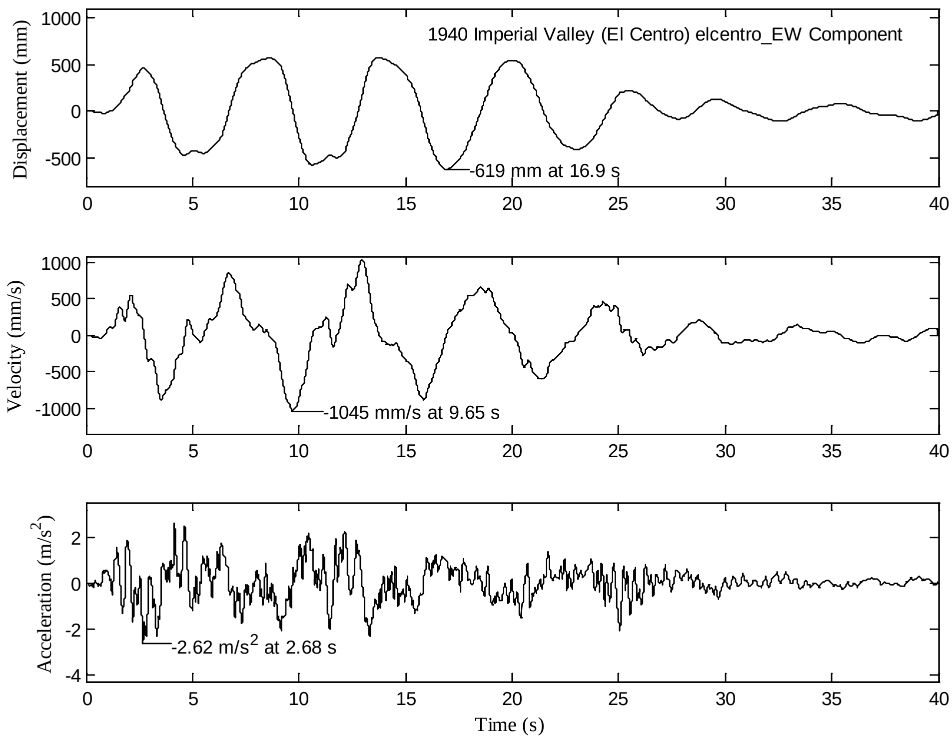


(b)

Figure 5.21: Roof displacement, velocity, and acceleration of twenty-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

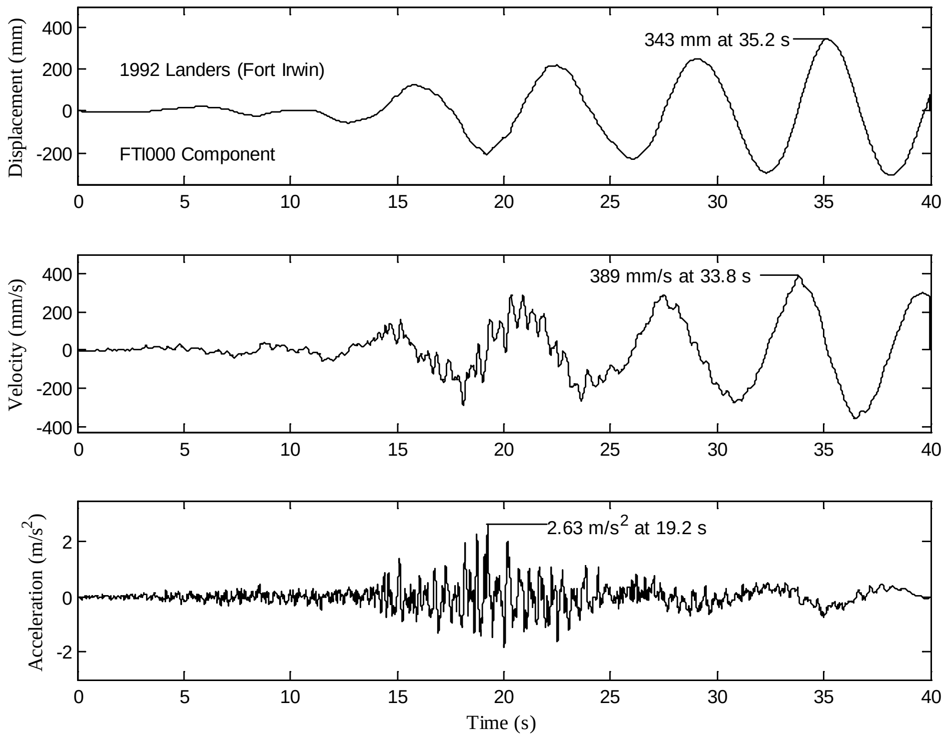


(a)

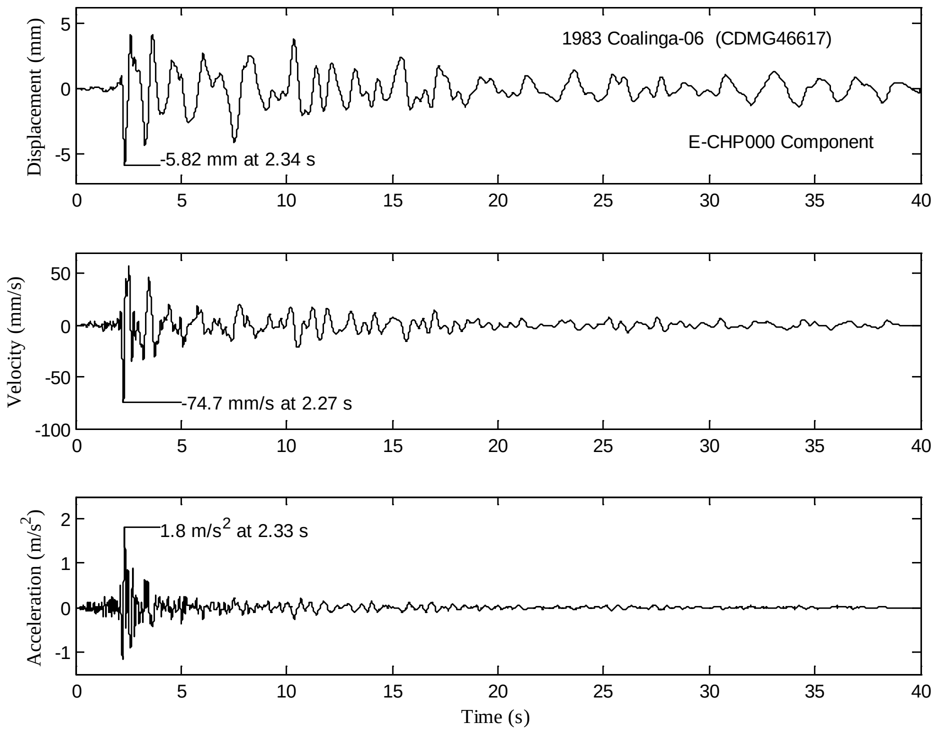


(b)

Figure 5.22: Roof displacement, velocity, and acceleration of twenty-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction

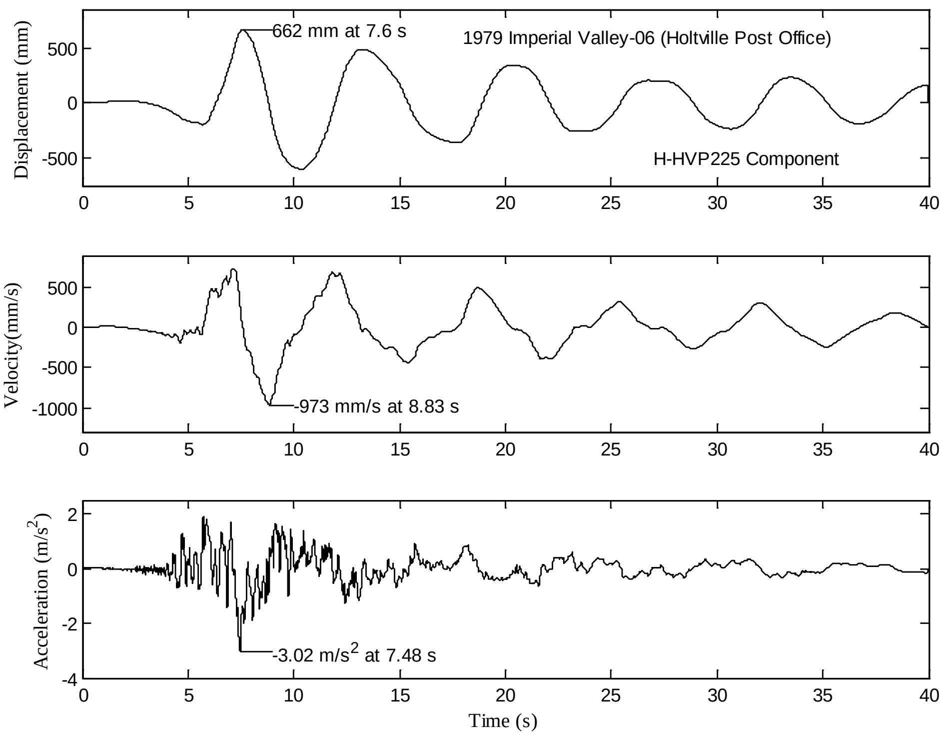


(a)

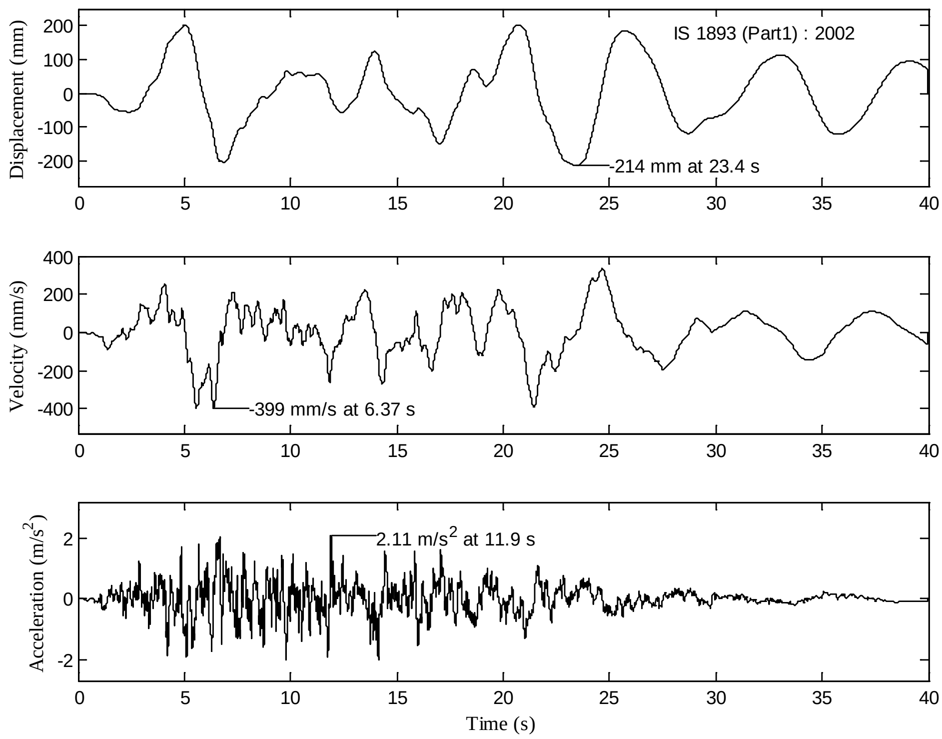


(b)

Figure 5.23: Roof displacement, velocity, and acceleration of twenty-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction

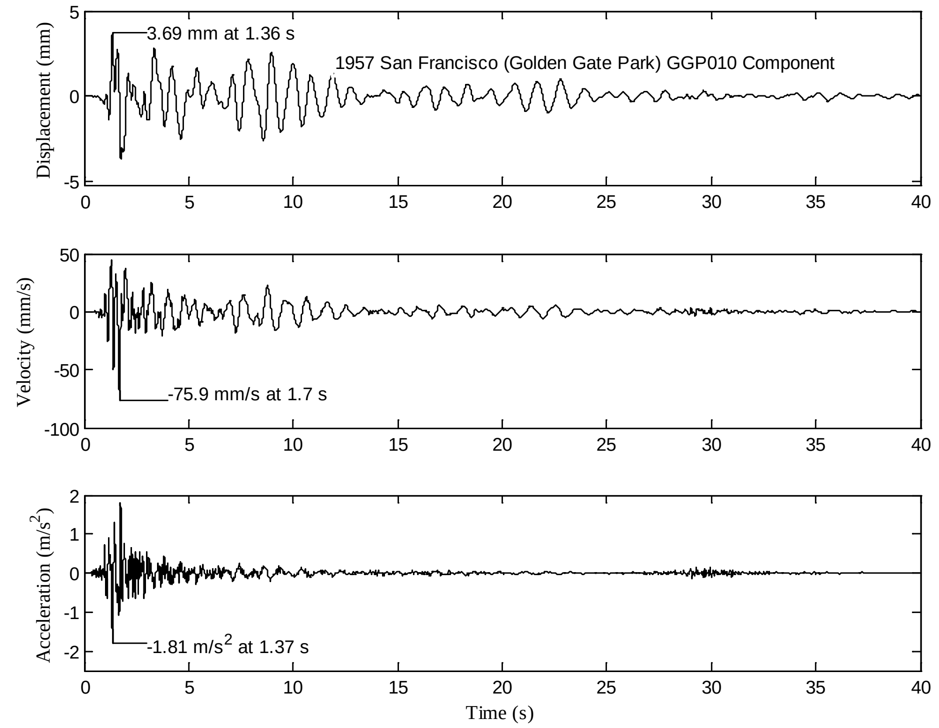


(a)

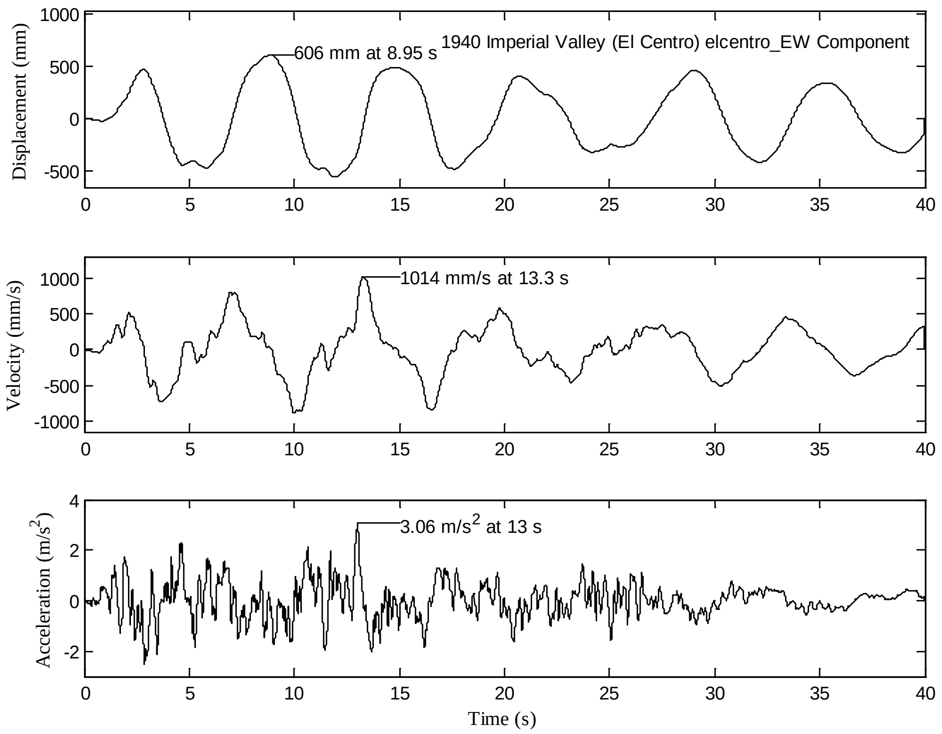


(b)

Figure 5.24: Roof displacement, velocity, and acceleration of twenty-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 z-direction

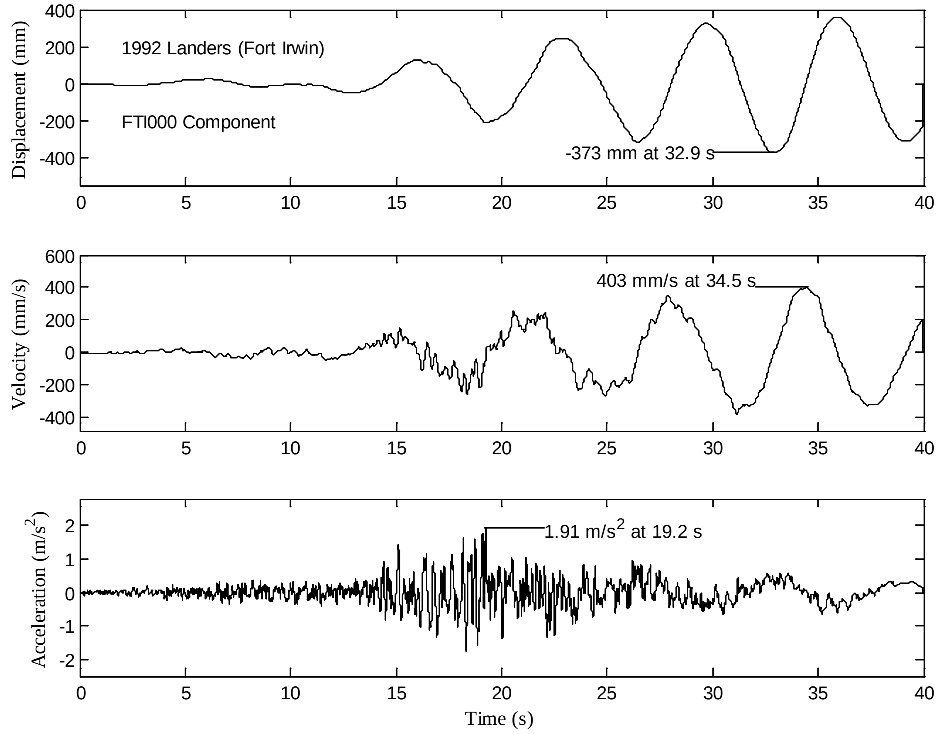


(a)

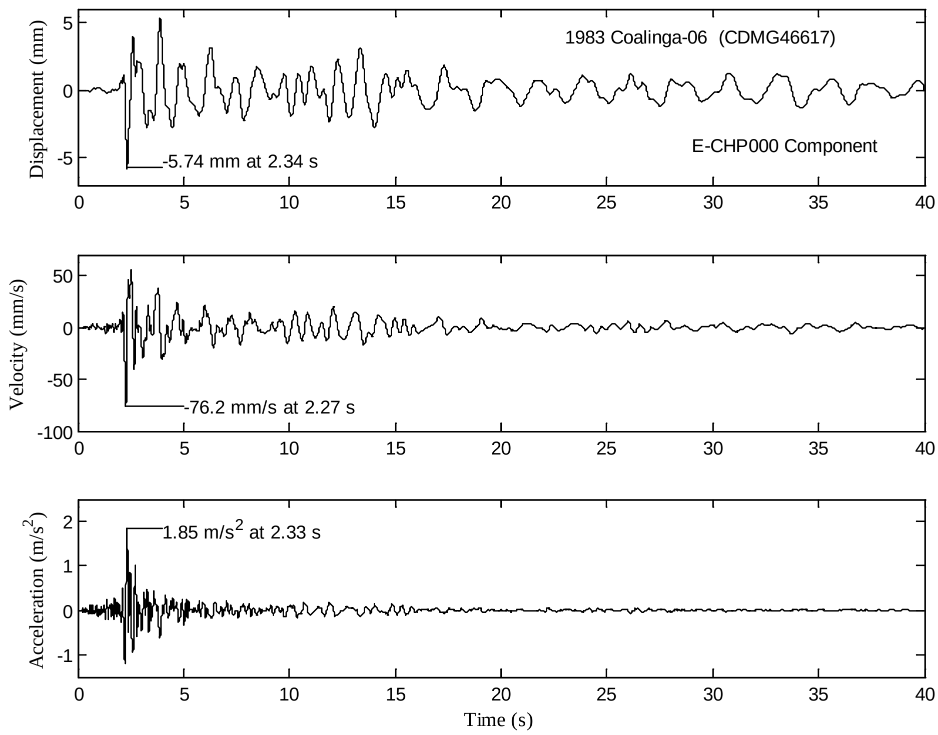


(b)

Figure 5.25: Roof displacement, velocity, and acceleration of twenty-story regular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction



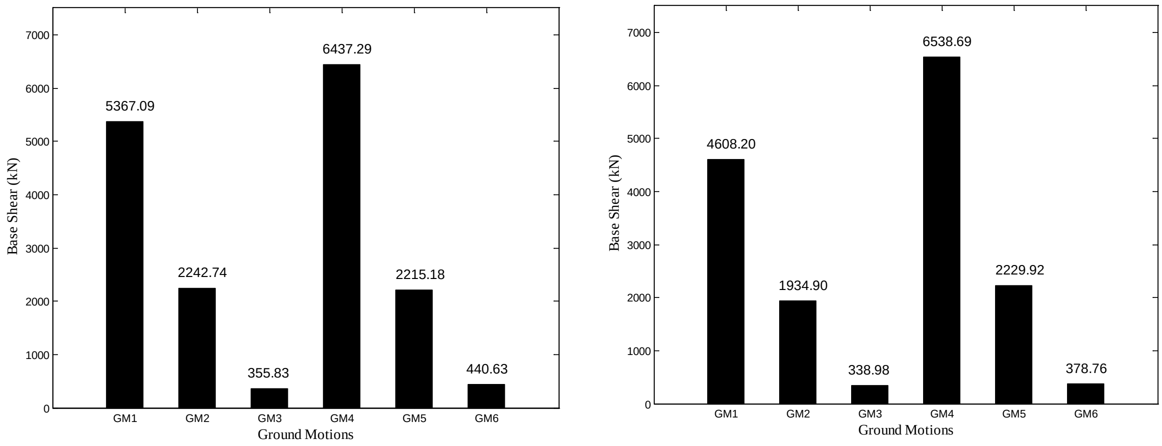
(a)



(b)

Figure 5.26: Roof displacement, velocity, and acceleration of twenty-story regular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction

The base shear of twenty-story regular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 5.27. Figure 5.27 (a) shows that the building has maximum base shear of 6,437.29 kN due to1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 355.83 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 5.27 (b) shows that the building has maximum base shear of 6,538.69 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 338.98 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.



(a) (b)

Figure 5.27: Base shear of twenty-story regular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

The maximum and minimum values of story displacement, story velocity, story acceleration, and base shear of two, six, and twenty-story regular RC building due to GM1-GM6 in x and z-direction are summarized in Table 5.1.

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

* GM (x): Ground motion in x-direction
** GM(z): Ground motion in z-direction
1, 2, 3, 4, 5, and 6 represents the ground motion serial number

CHAPTER 6

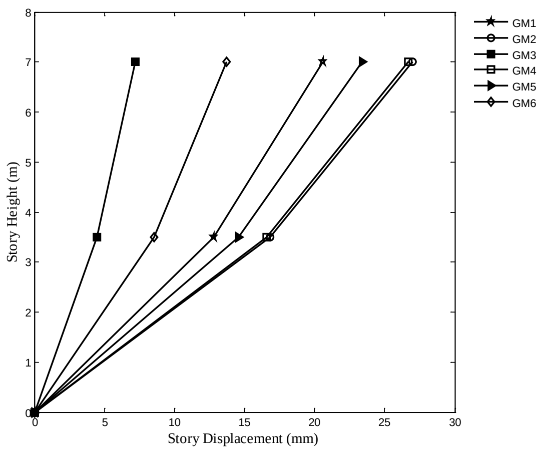
6 IRREGULAR RC BUILDINGS RESULTS AND DISCUSSION

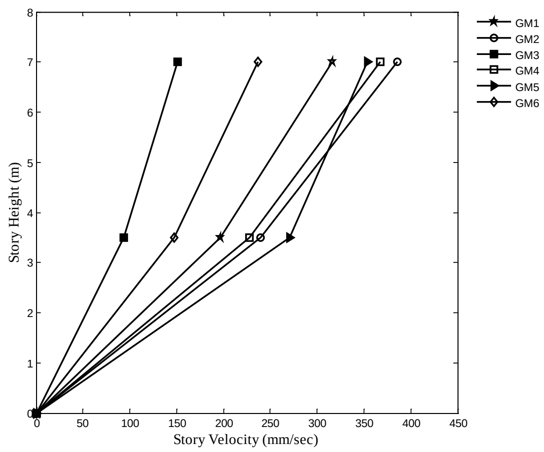
6.1 Overview

In this chapter, 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.

6.2 Two-Story Irregular RC Building

Figure 6.1 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.





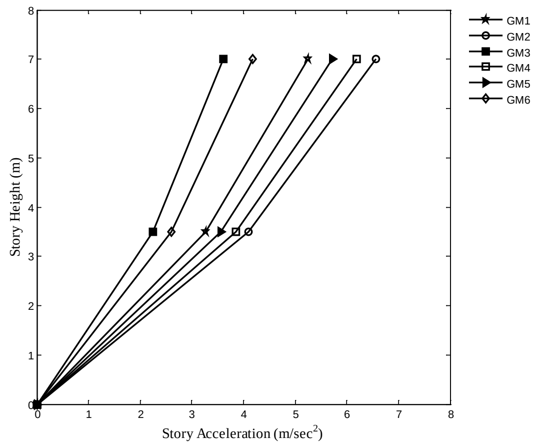
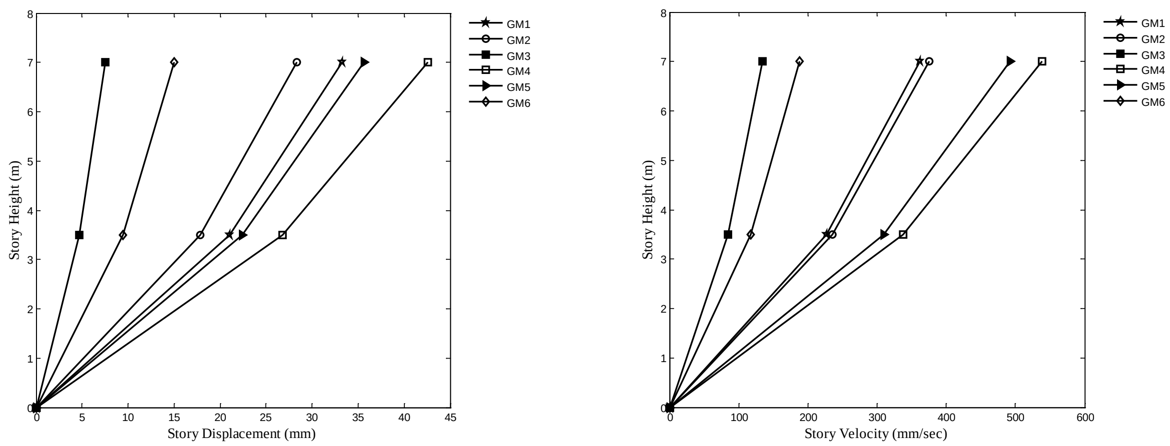


Figure 6.1: Story displacement, velocity, and acceleration of two-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

Figure 6.2 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.



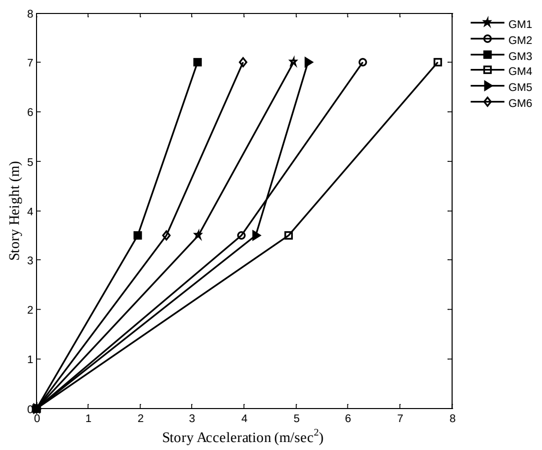
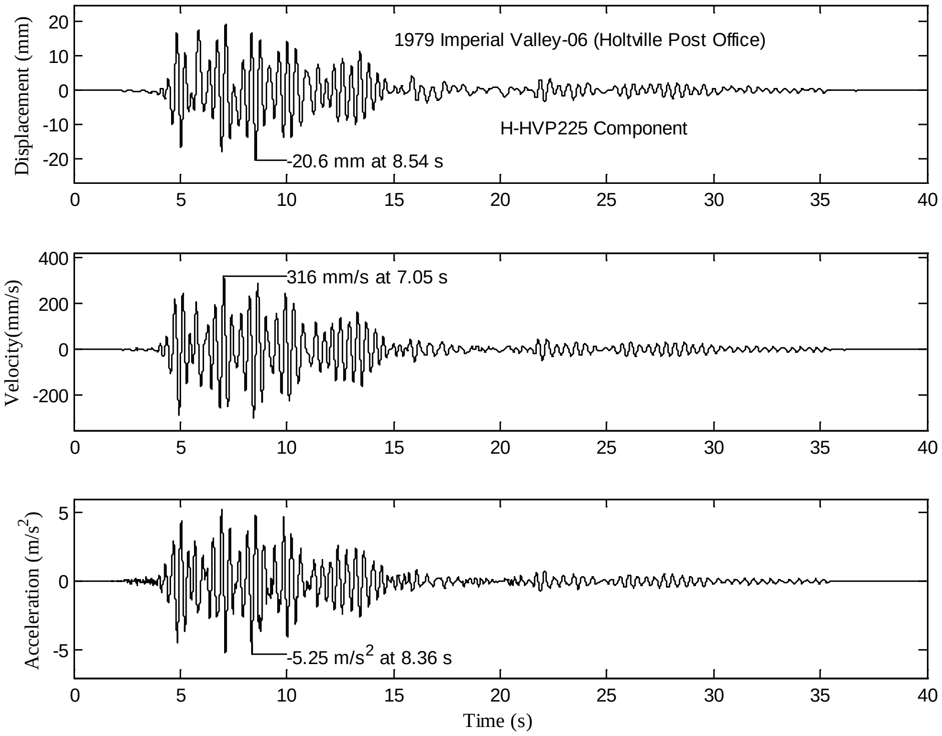


Figure 6.2: Story displacement, velocity, and acceleration of two-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

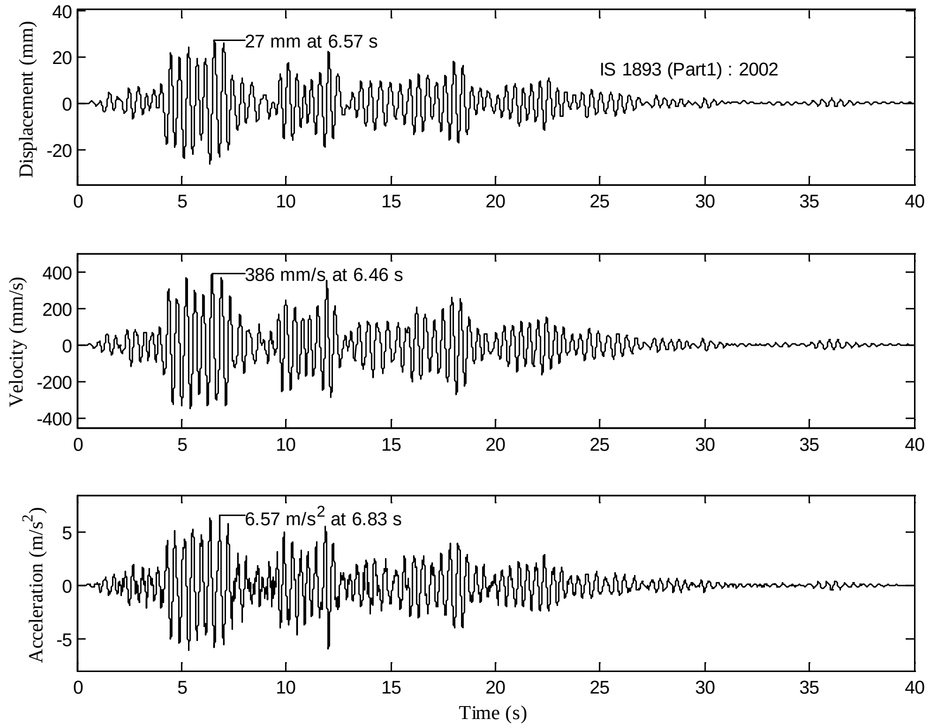
Figure 6.3-6.8 shows roof displacement, velocity, and acceleration with respect to time for two-story irregular RC building due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (El 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 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/s^2 at 6.83 s due to IS 1893 (Part1) : 2002 ground motion and minimum 3.61 m/s^2 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/s^2 at 2.3 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 3.11 m/s^2 at 1.74 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

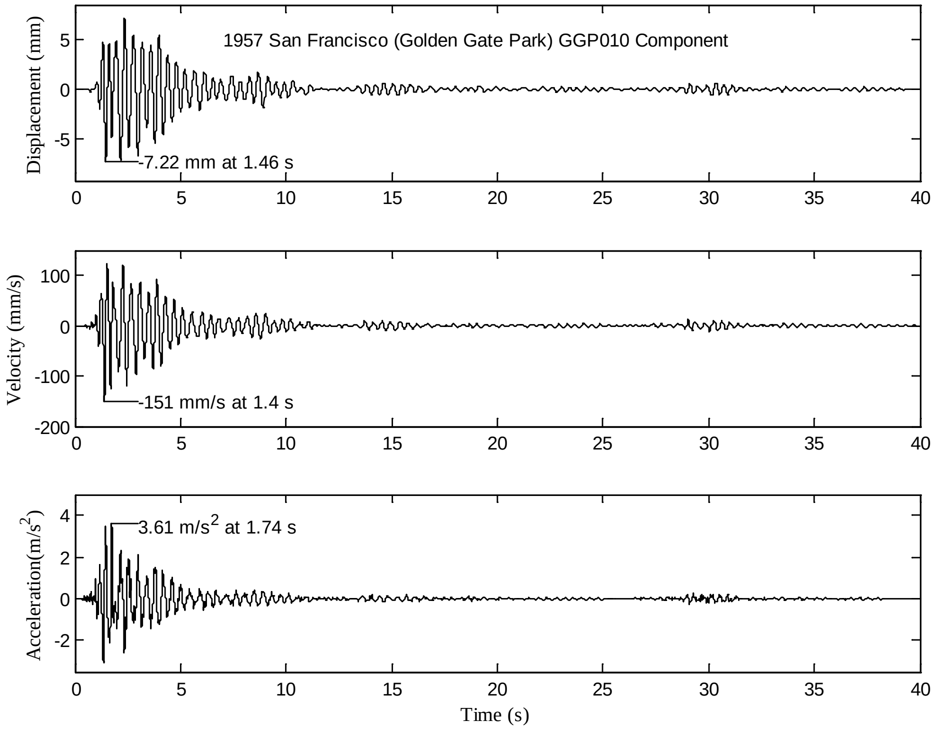


(a)

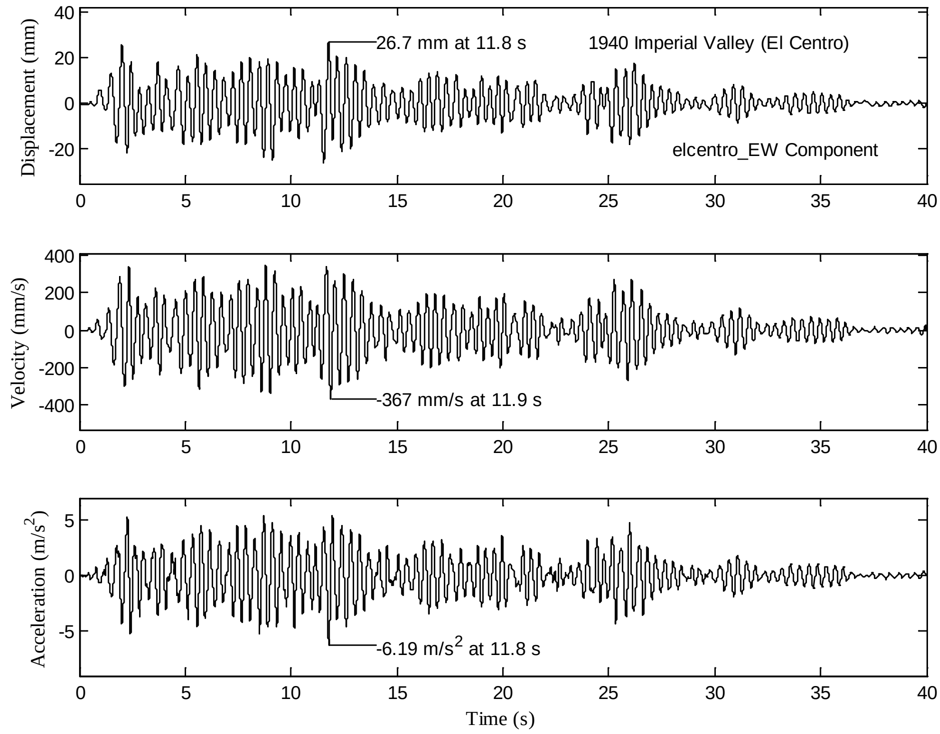


(b)

Figure 6.3: Roof displacement, velocity, and acceleration of two-story irregular 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

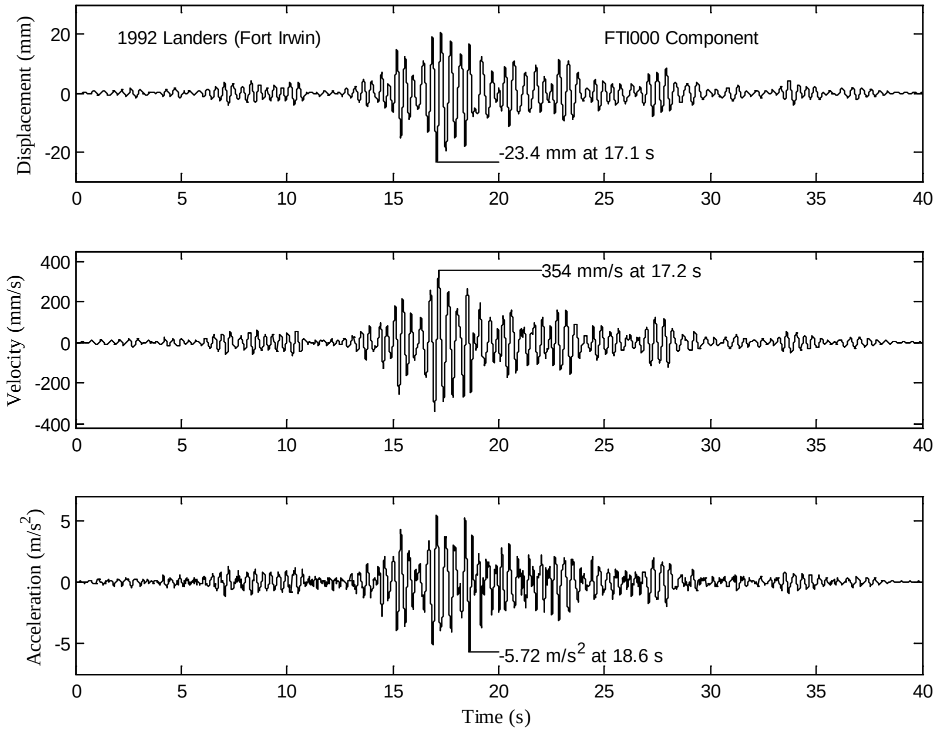


(a)

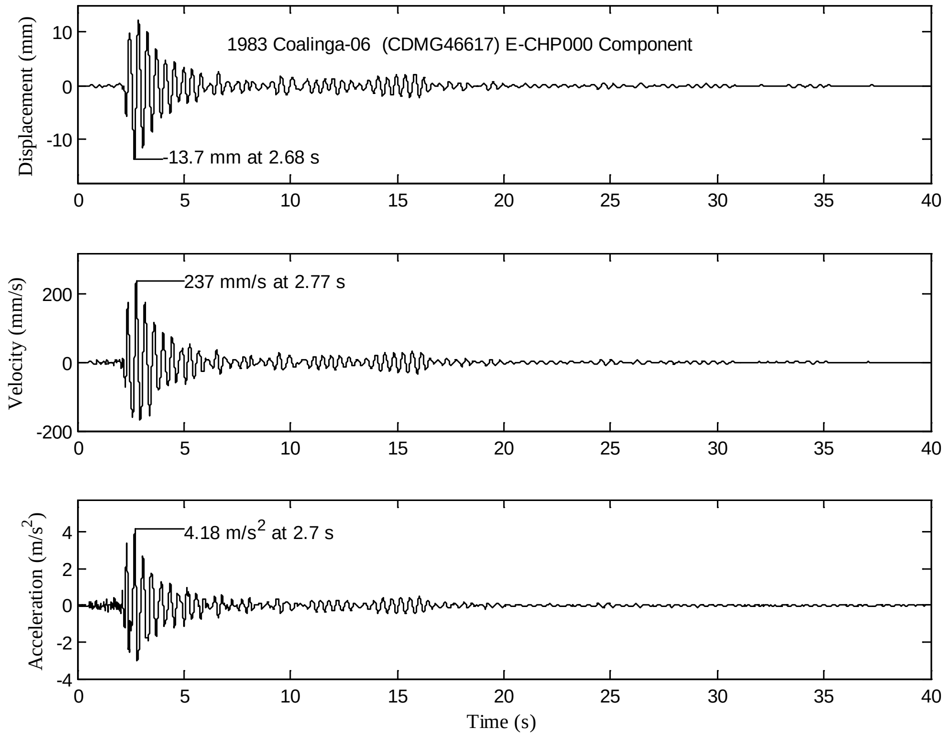


(b)

Figure 6.4: Roof displacement, velocity, and acceleration of two-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction

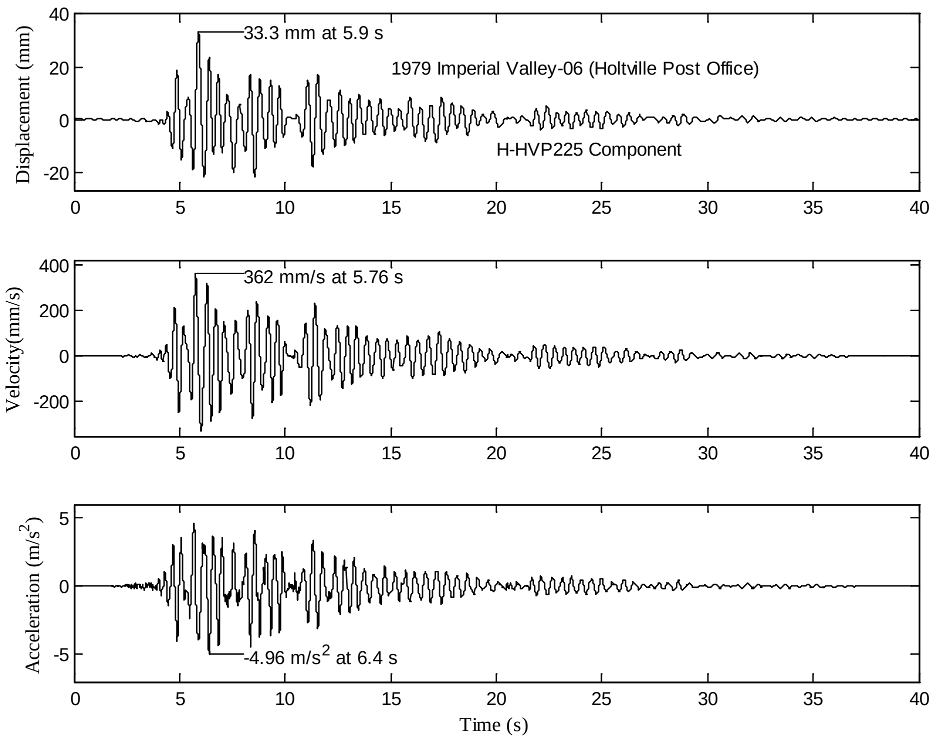


(a)

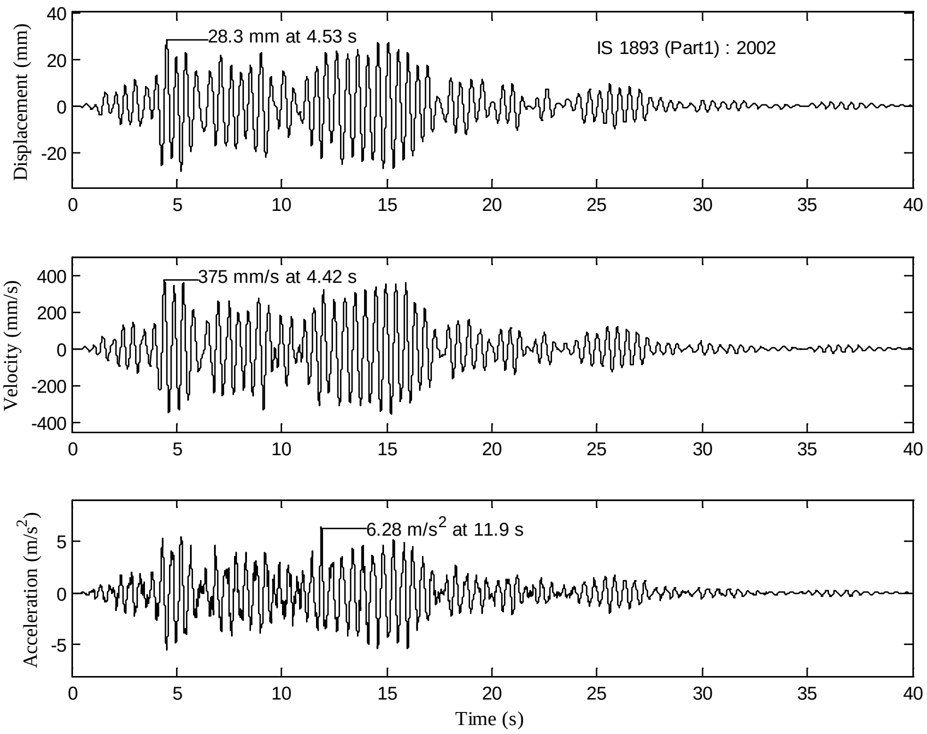


(b)

Figure 6.5: Roof displacement, velocity, and acceleration of two-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction

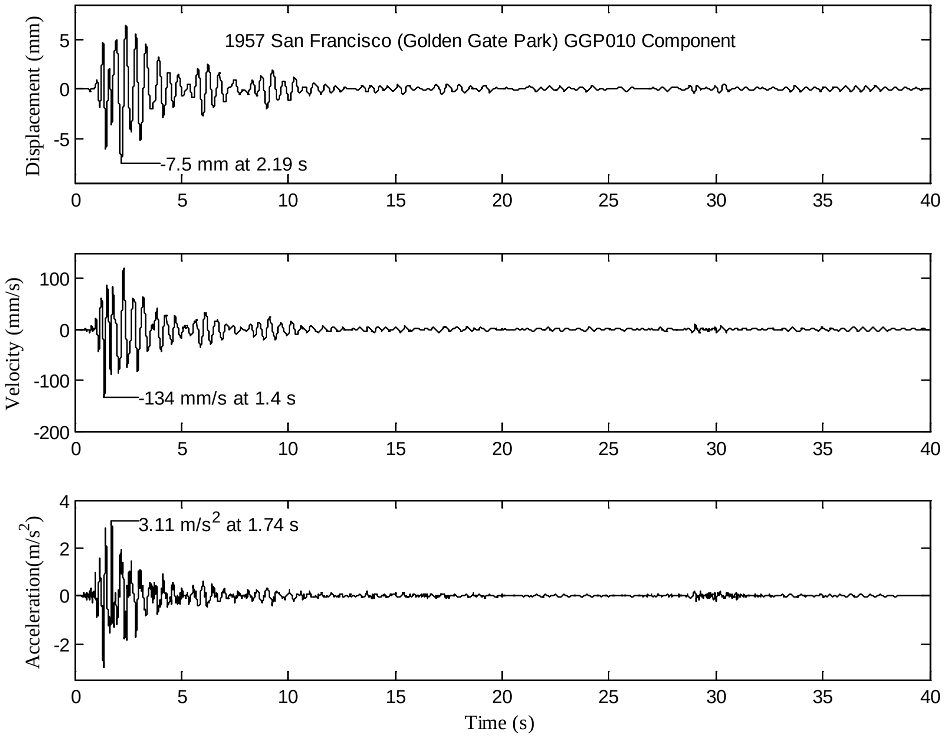


(a)

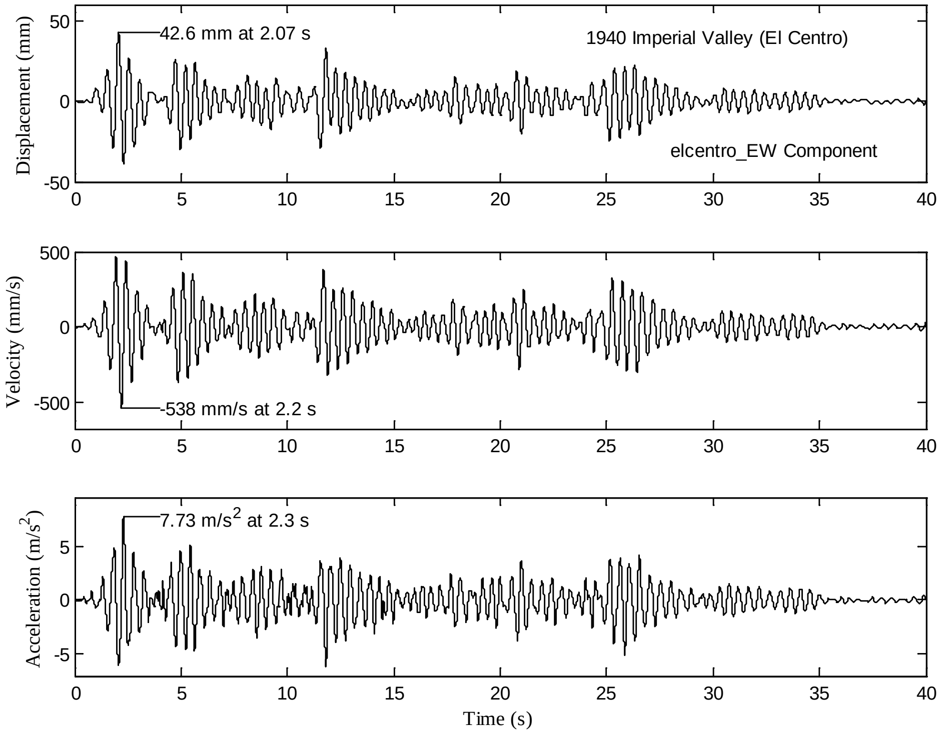


(b)

Figure 6.6: Roof displacement, velocity, and acceleration of two-story irregular RC building due to (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion in z-direction

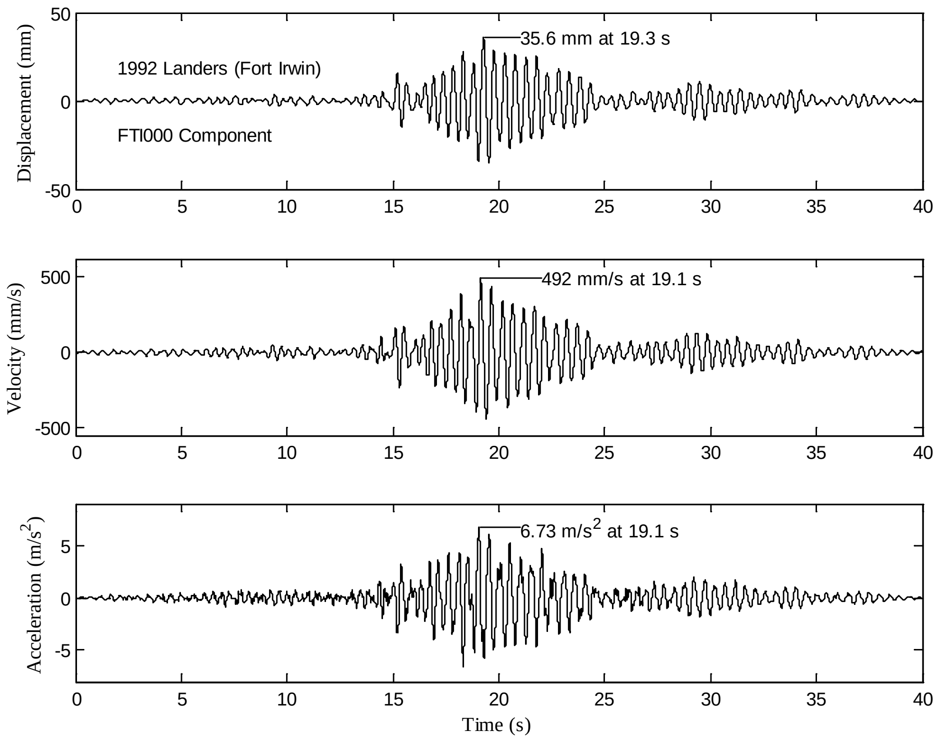


(a)



(b)

Figure 6.7: Roof displacement, velocity, and acceleration of two-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction



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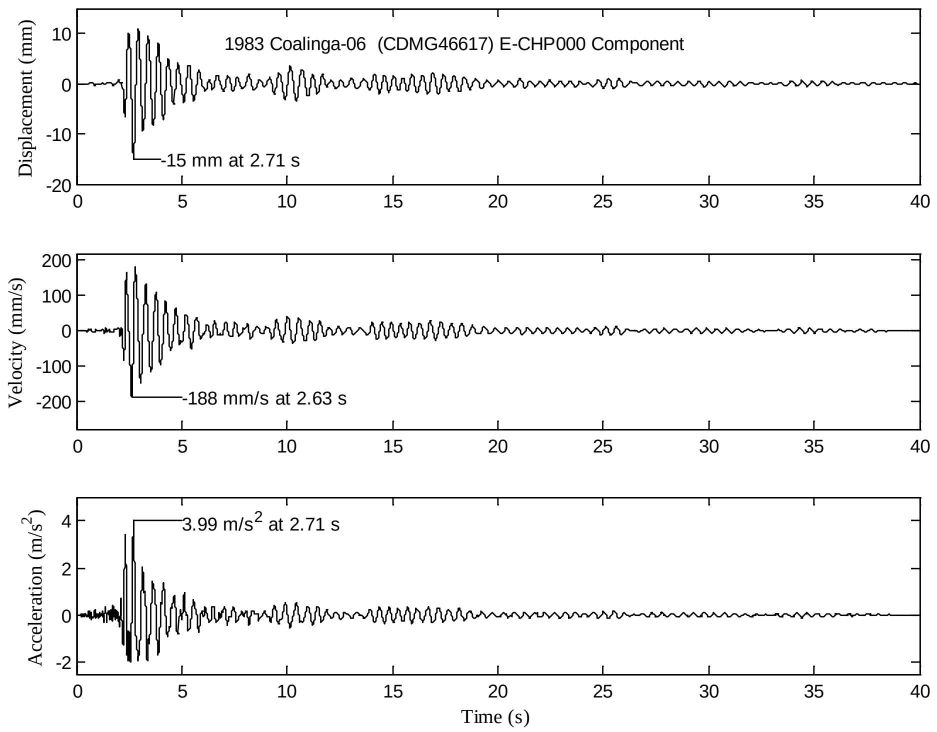
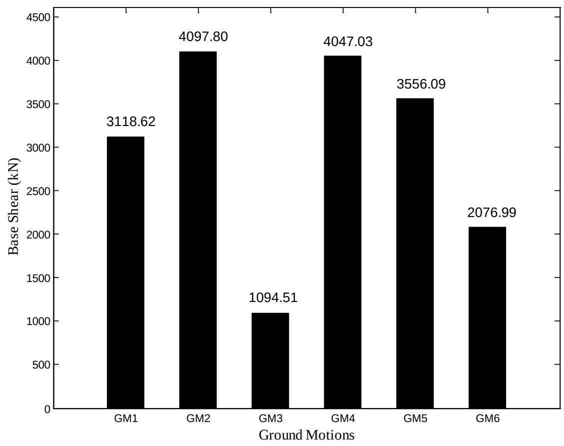


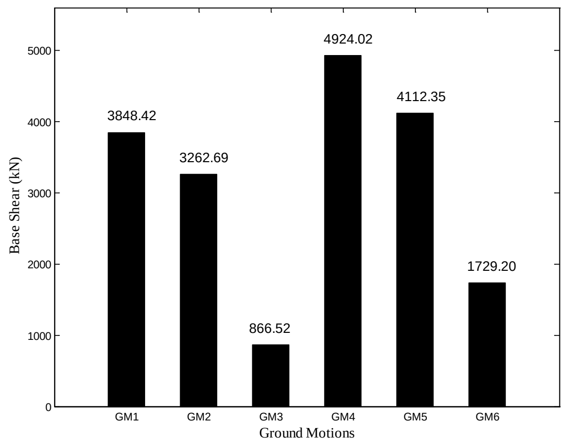
(b)

Figure 6.8: Roof displacement, velocity, and acceleration of two-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction

The base shear of two-story irregular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 6.9. Figure 6.9 (a) shows that the building has maximum base shear of 4,097.80 kN due to IS 1893 (Part1) : 2002 and minimum base shear of 1,094.51 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 6.9 (b) shows that the building has maximum base shear of 4,924.02 kN due to 1940 Imperial Valley (El Centro) elcentro_EW and minimum base shear of 866.52 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.



(a)

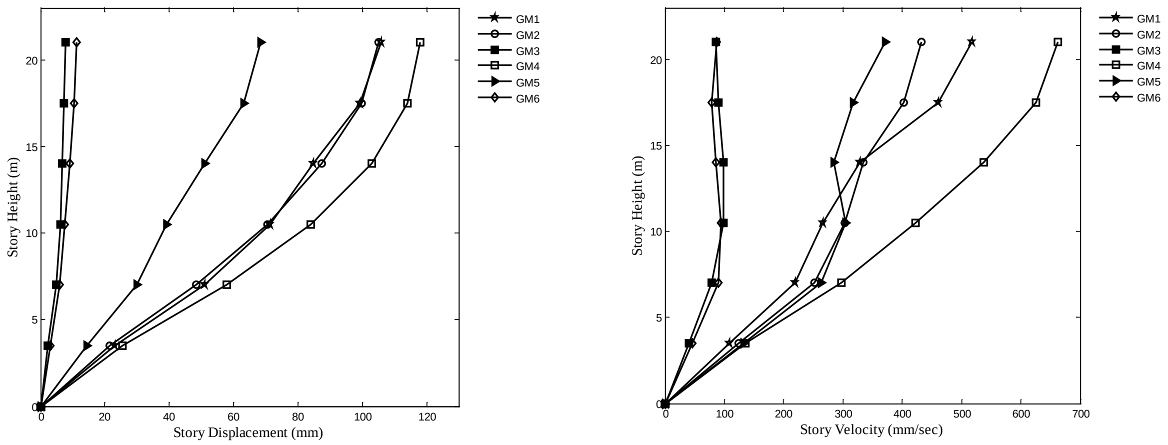


(b)

Figure 6.9: Base shear of two-story irregular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

6.3 Six-Story Irregular RC Building

Figure 6.10 shows story displacement, velocity, and acceleration of six-story irregular 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 GM3. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3 and 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 (x) transverse direction.



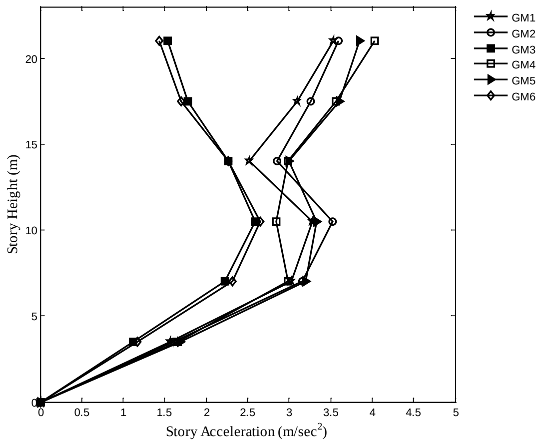
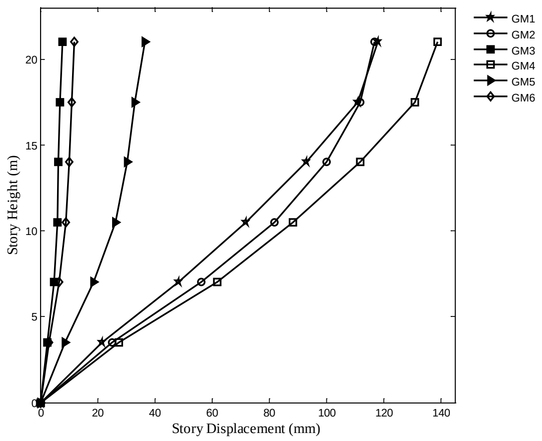
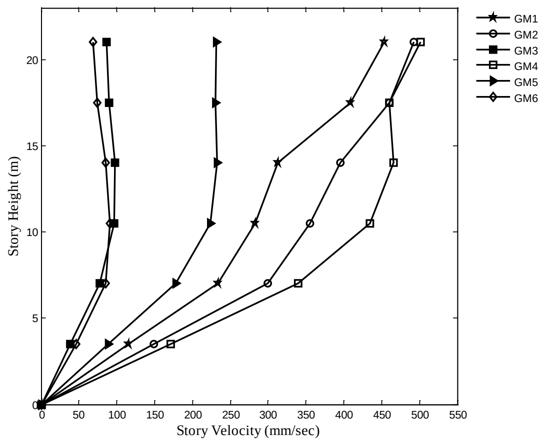


Figure 6.10: Story displacement, velocity, and acceleration of six-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

Figure 6.11 shows story displacement, velocity, and acceleration of six-story irregular 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, 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.





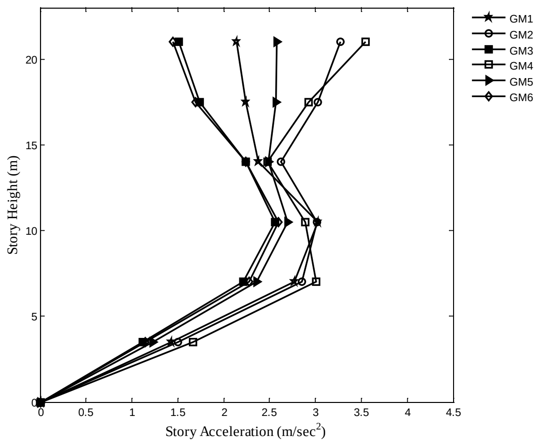
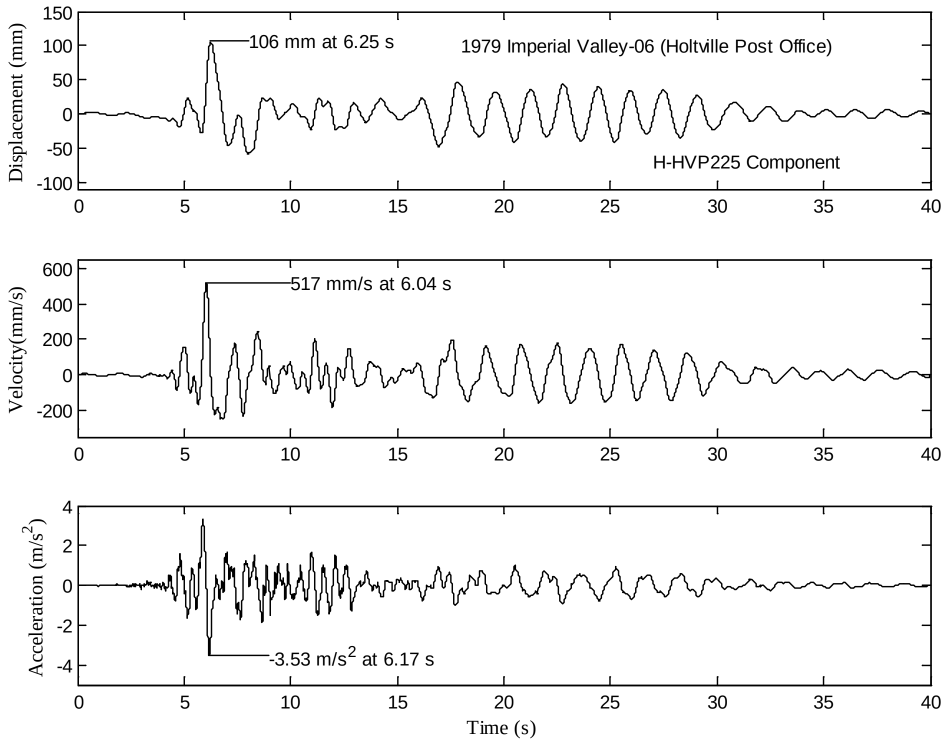


Figure 6.11: Story displacement, velocity, and acceleration of six-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

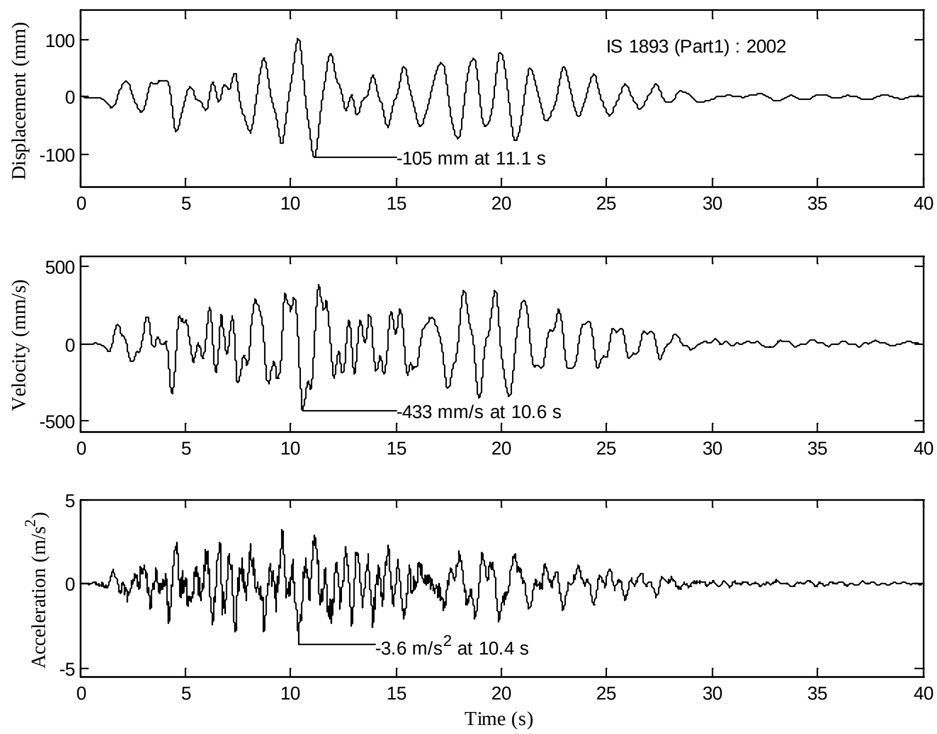
Figure 6.12-6.17 shows roof displacement, velocity, and acceleration with respect to time for six-story irregular RC building due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (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 118 mm at 4.1 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -7.85 mm at 1.87 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -662 mm/s at 4.52 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum velocity of -85.5 mm/s at 1.7 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof acceleration of 4.03 m/s^2 at 2.07 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 1.44 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 139 mm at 4.2 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum roof displacement of -7.76 mm at 1.89 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 502 mm/s at 3.97 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum velocity of -69.1 mm/s at 2.28 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion. It has maximum roof acceleration of -3.55 m/s^2 at 11.6 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 1.45 m/s^2 at 2.33 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction.

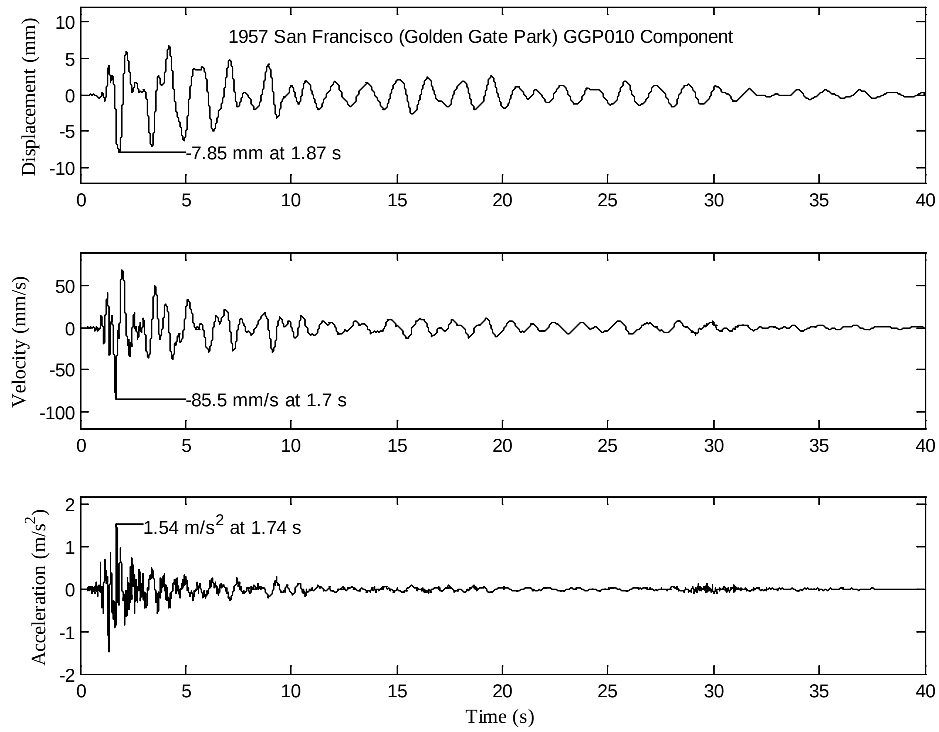


(a)

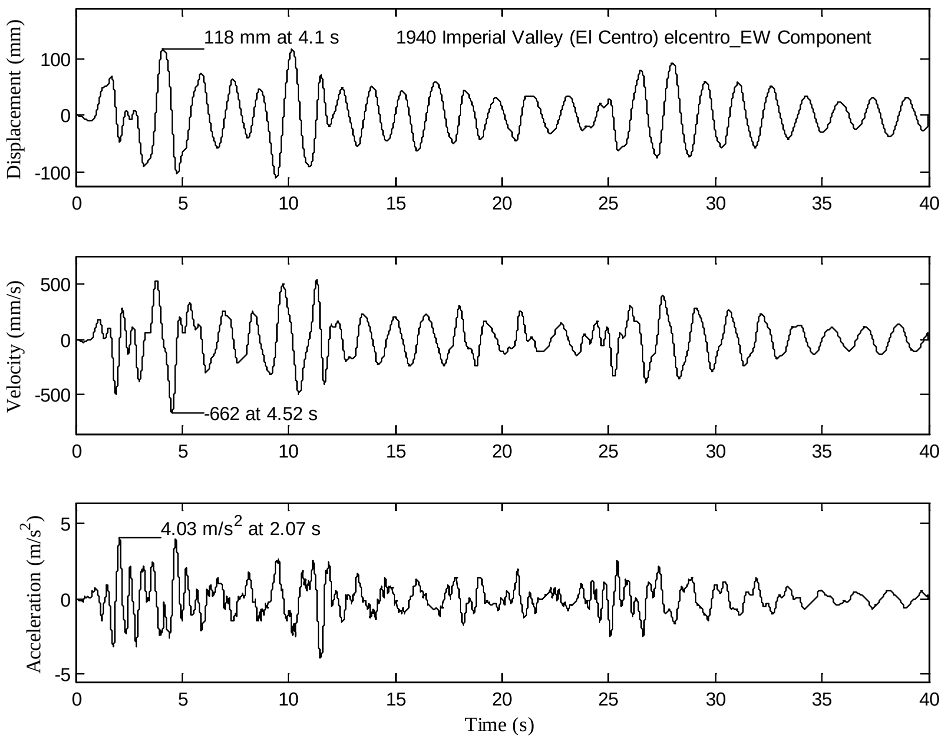


(b)

Figure 6.12: Roof displacement, velocity, and acceleration of six-story irregular 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

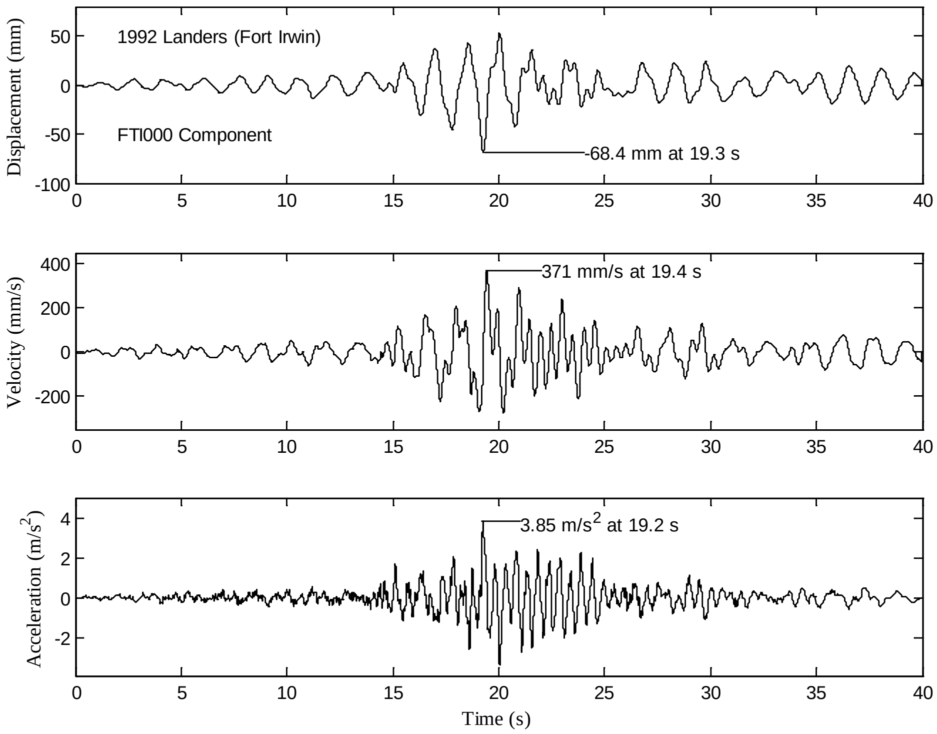


(a)

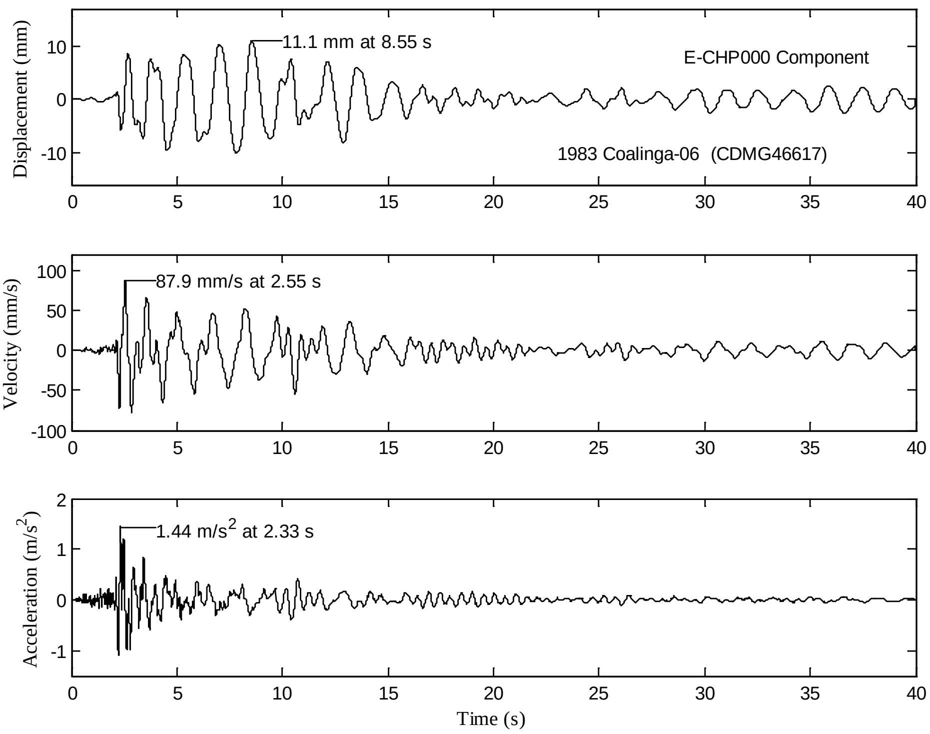


(b)

Figure 6.13: Roof displacement, velocity, and acceleration of six-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction

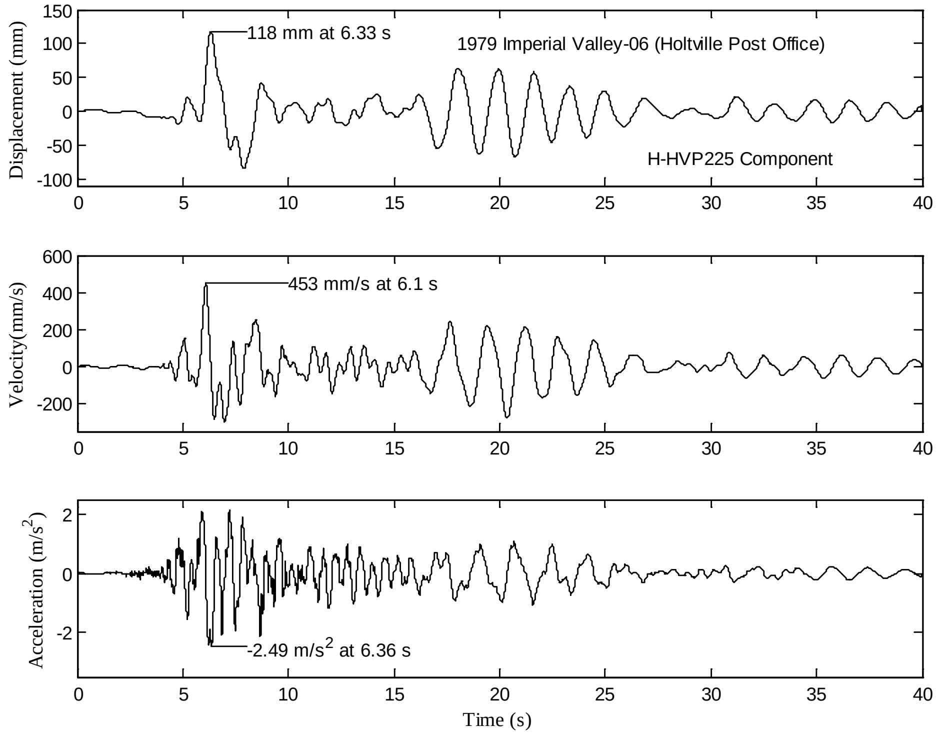


(a)

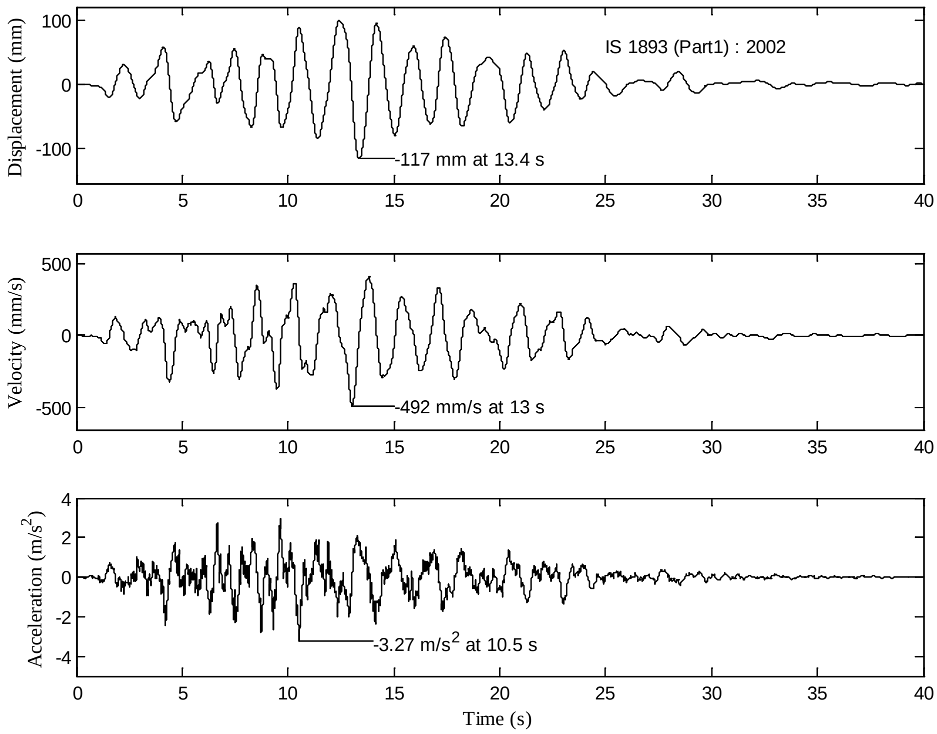


(b)

Figure 6.14: Roof displacement, velocity, and acceleration of six-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction



(a)



(b)

Figure 6.15: Roof displacement, velocity, and acceleration of six-story irregular RC building due to (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion in z-direction

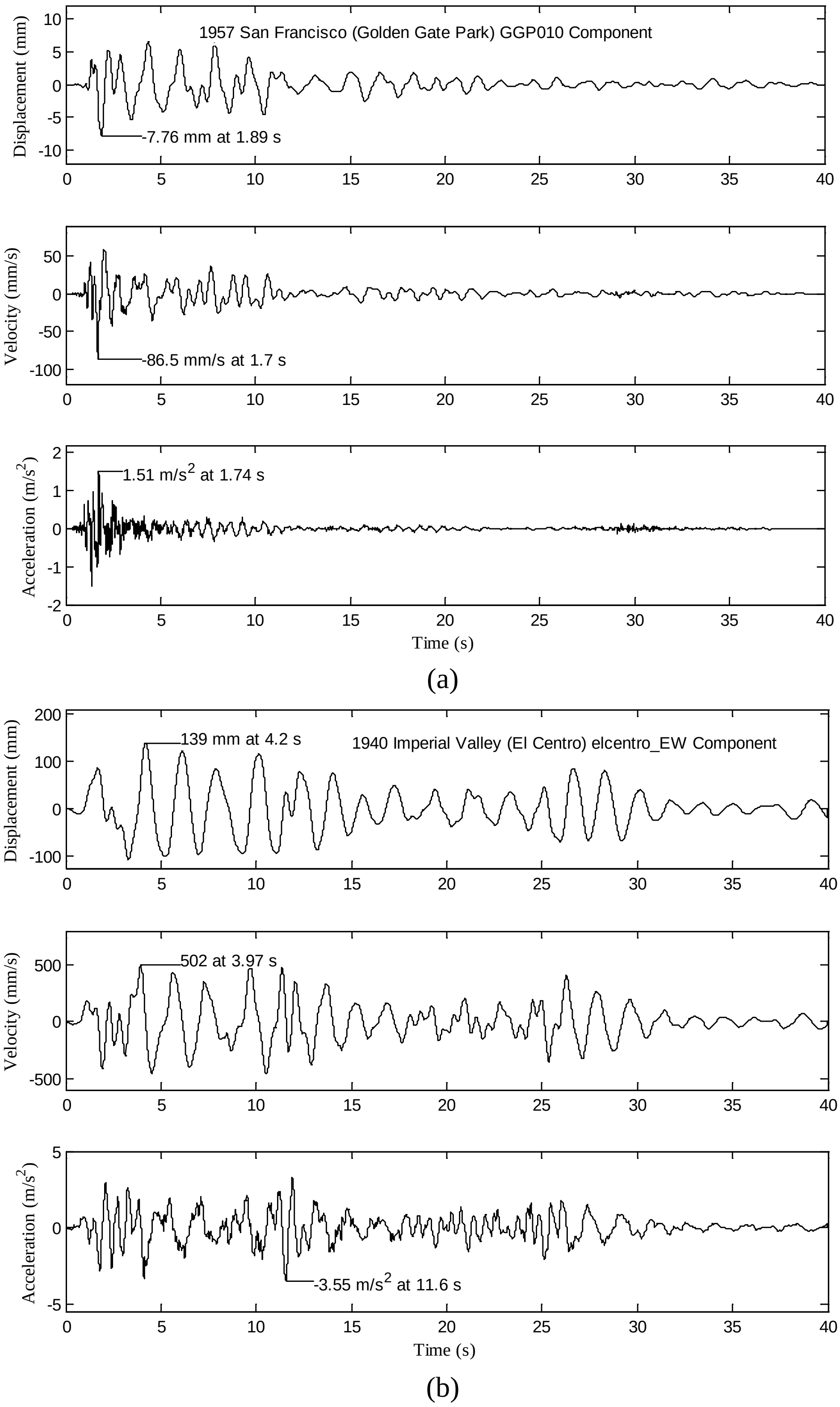
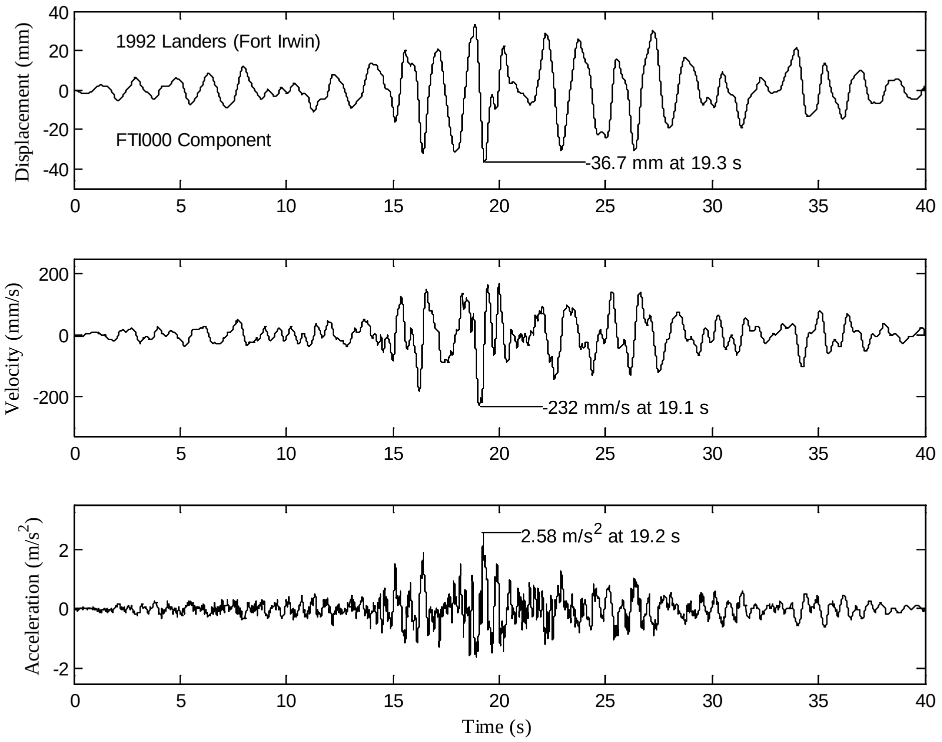
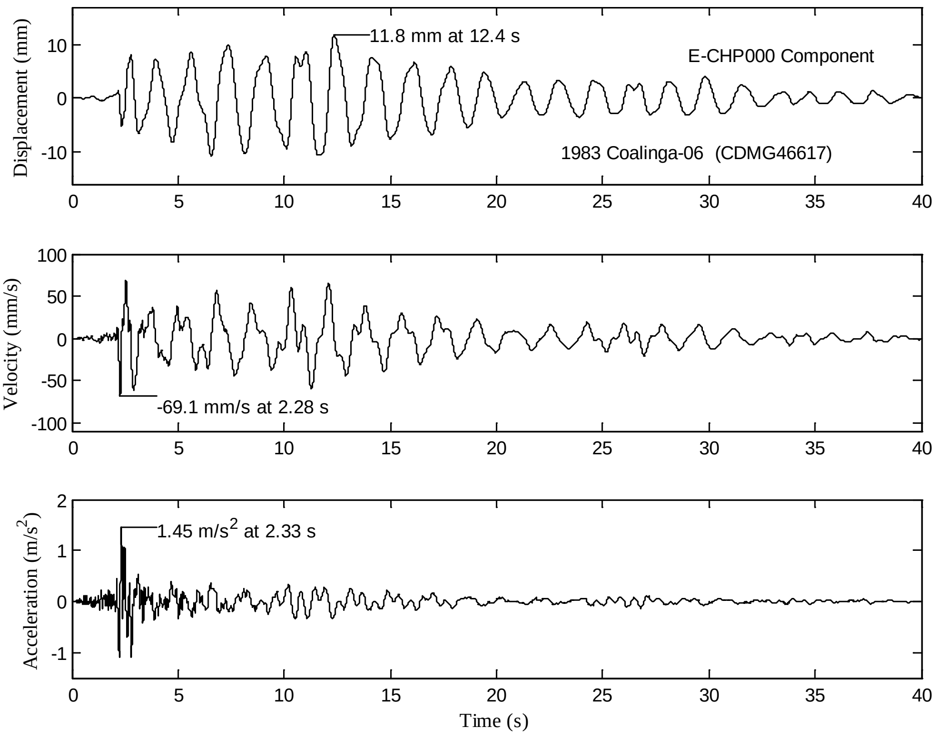


Figure 6.16: Roof displacement, velocity, and acceleration of six-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction



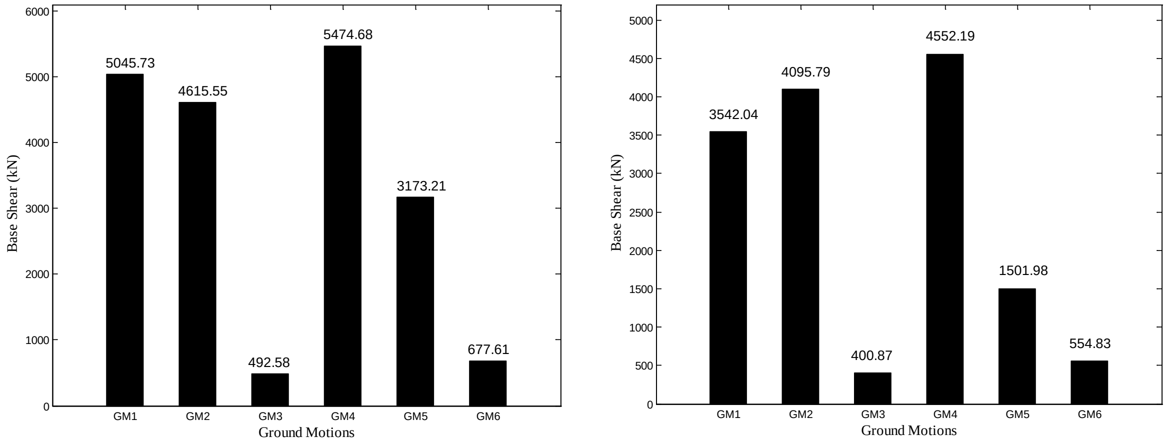
(a)



(b)

Figure 6.17: Roof displacement, velocity, and acceleration of six-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction

The base shear of six-story irregular RC building due to GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 6.18. Figure 6.18 (a) shows that the building has maximum base shear of 5,474.68 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 492.58 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 6.18 (b) shows that the building has maximum base shear of 4,552.19 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 400.87 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

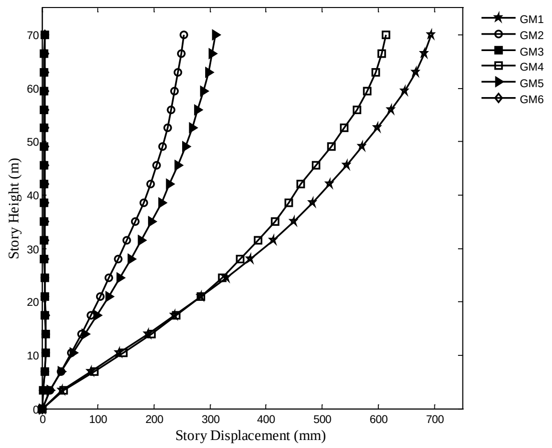


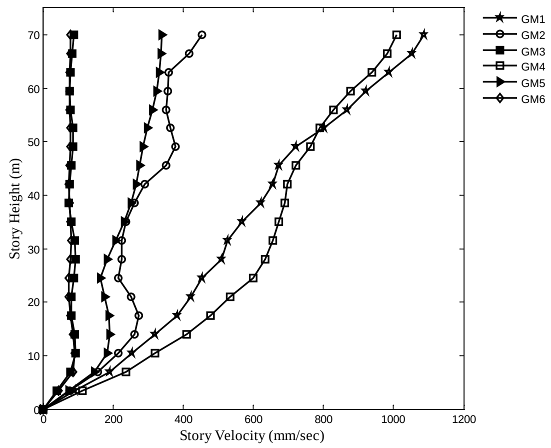
(a) (b)

Figure 6.18: Base shear of six-story irregular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

6.4 Twenty-Story Irregular RC Building

Figure 6.19 shows story displacement, velocity, and acceleration of twenty-story irregular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story velocity is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. 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 (x) transverse direction.





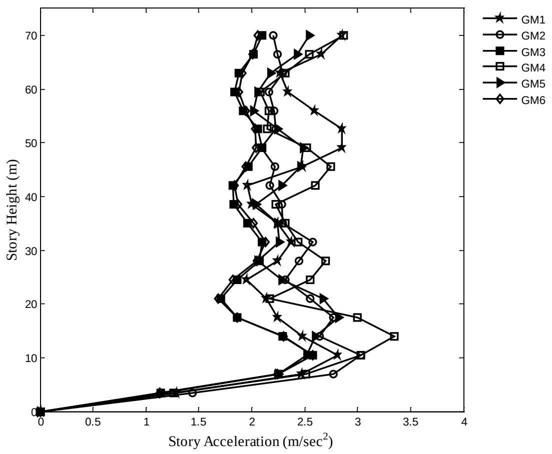
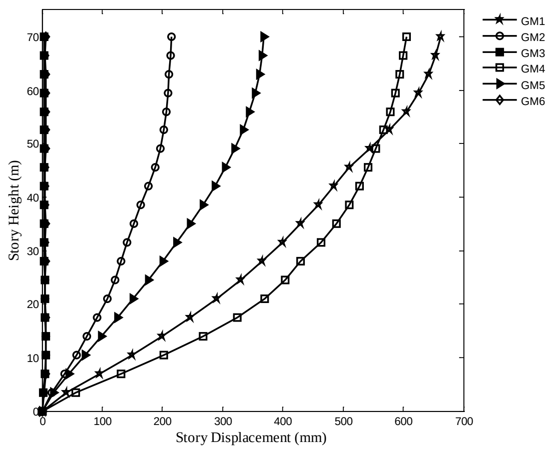
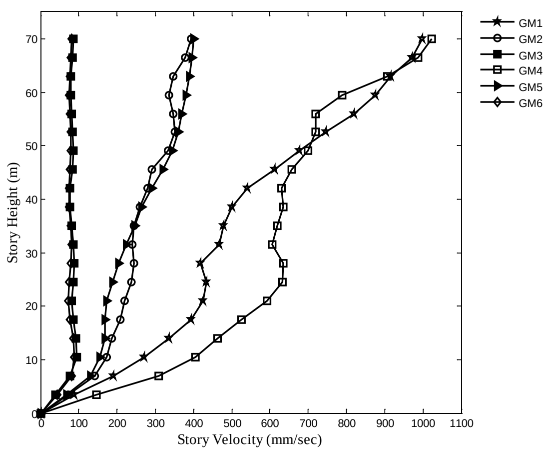


Figure 6.19: Story displacement, velocity, and acceleration of twenty-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in x-direction

Figure 6.20 shows story displacement, velocity, and acceleration of twenty-story irregular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6. The story displacement is maximum due to ground motion GM1 and minimum due to ground motion GM3 and GM6. The story velocity is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. The story acceleration is maximum due to ground motion GM4 and minimum due to ground motion GM3 and GM6. 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.





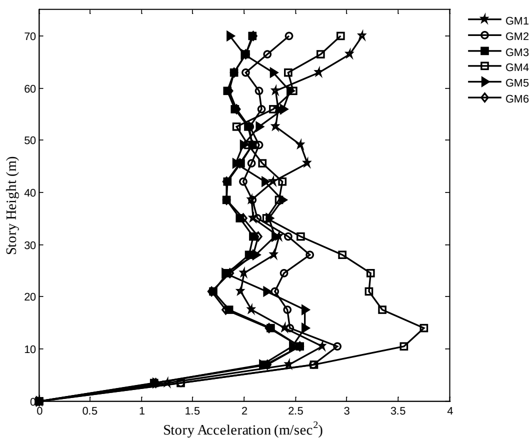
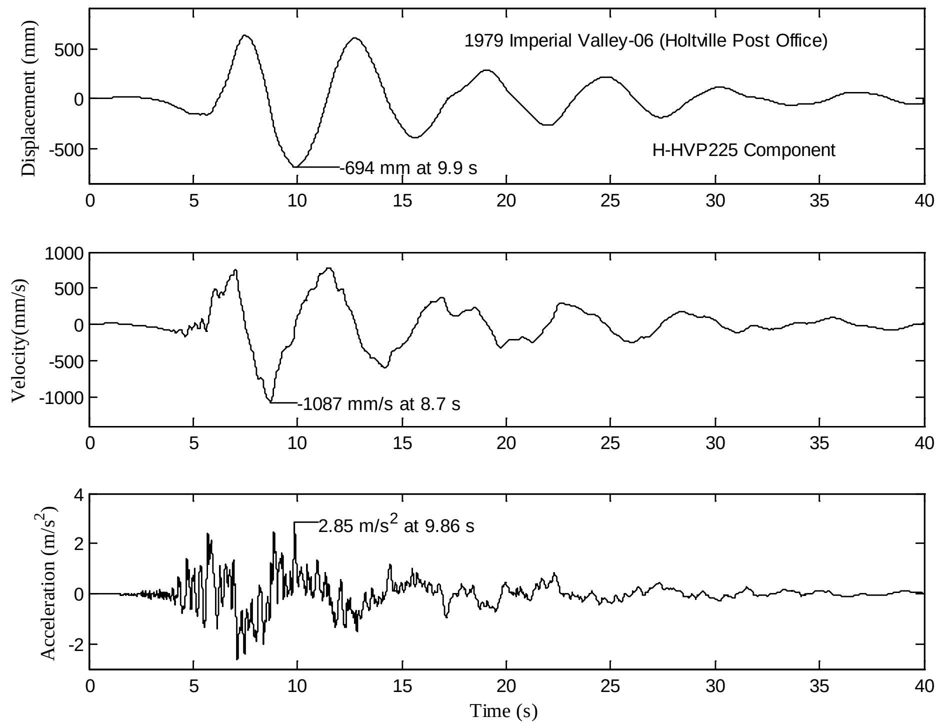


Figure 6.20: Story displacement, velocity, and acceleration of twenty-story irregular reinforced concrete buildings due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 in z-direction

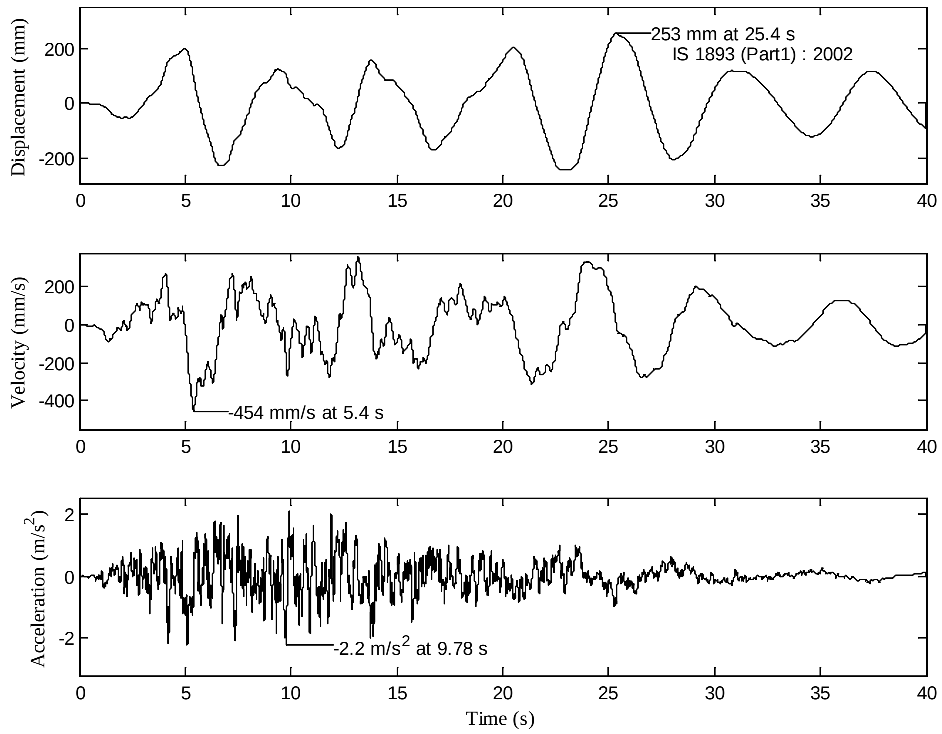
Figure 6.21-6.26 shows roof displacement, velocity, and acceleration with respect to time for twenty-story irregular RC building due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, IS 1893 (Part1) : 2002, 1957 San Francisco (Golden Gate Park) GGP010 component, 1940 Imperial Valley (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 -694 mm at 9.9 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum roof displacement of 5.03 mm at 3.15 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of -1,087 mm/s at 8.7 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum velocity of -79.7 mm/s at 2.27 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion. It has maximum roof acceleration of -2.87 m/s^2 at 2.84 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 2.06 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 662 mm at 7.59 s due to 1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component ground motion and minimum roof displacement of -4.08 mm at 1.76 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion. It has maximum roof velocity of 1,022 mm/s at 13.3 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum velocity of -80.9 mm/s at 2.27 s due to 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion. It has maximum roof acceleration of -2.94 m/s^2 at 2.86 s due to 1940 Imperial Valley (El Centro) elcentro_EW component ground motion and minimum 2.08 m/s^2 at 1.74 s due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.

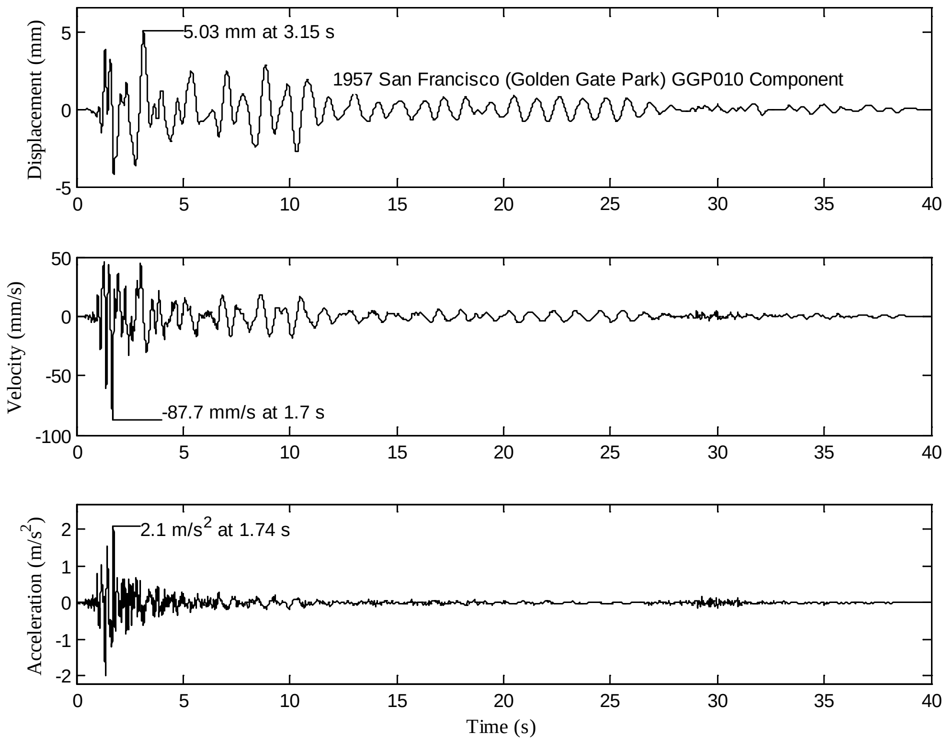


(a)

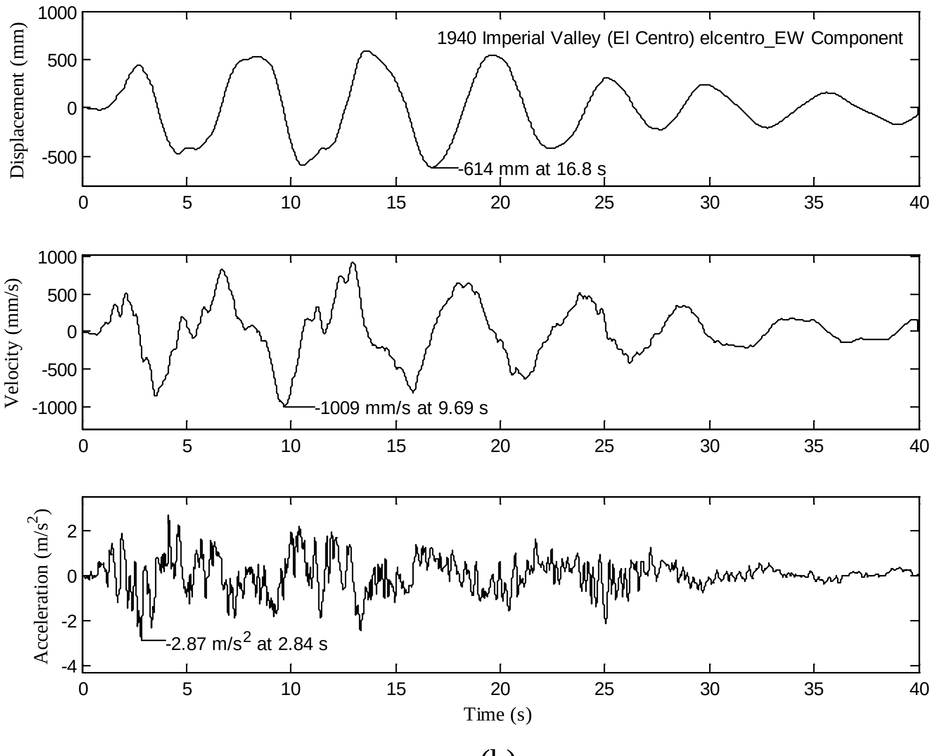


(b)

Figure 6.21: Roof displacement, velocity, and acceleration of twenty-story irregular 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

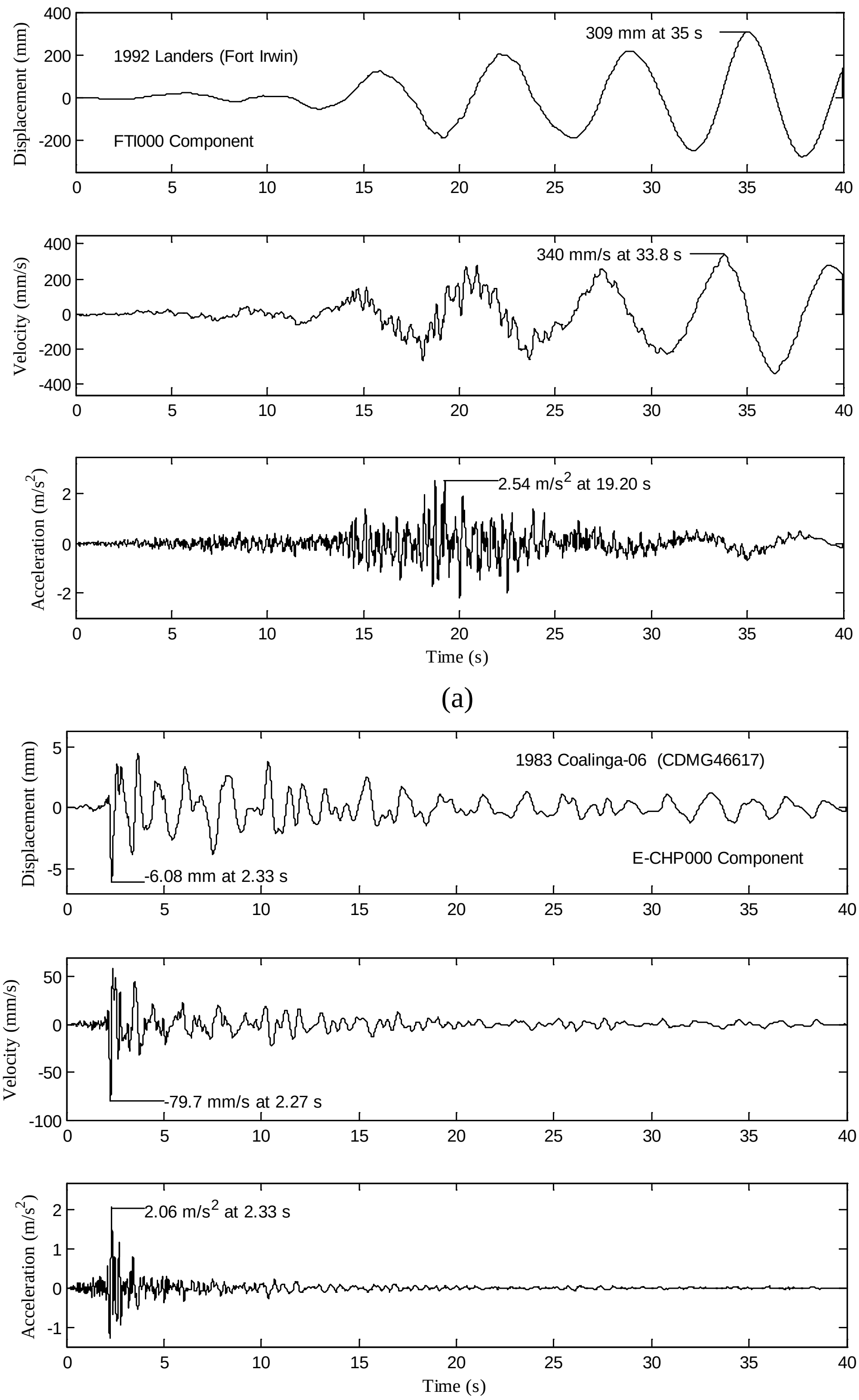


(a)



(b)

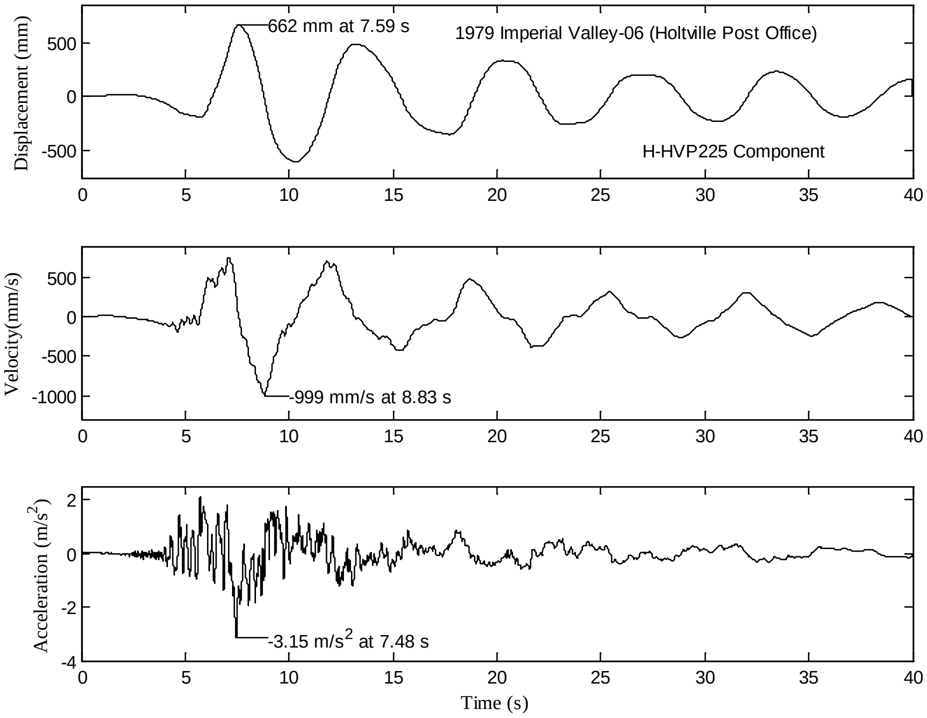
Figure 6.22: Roof displacement, velocity, and acceleration of twenty-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in x-direction



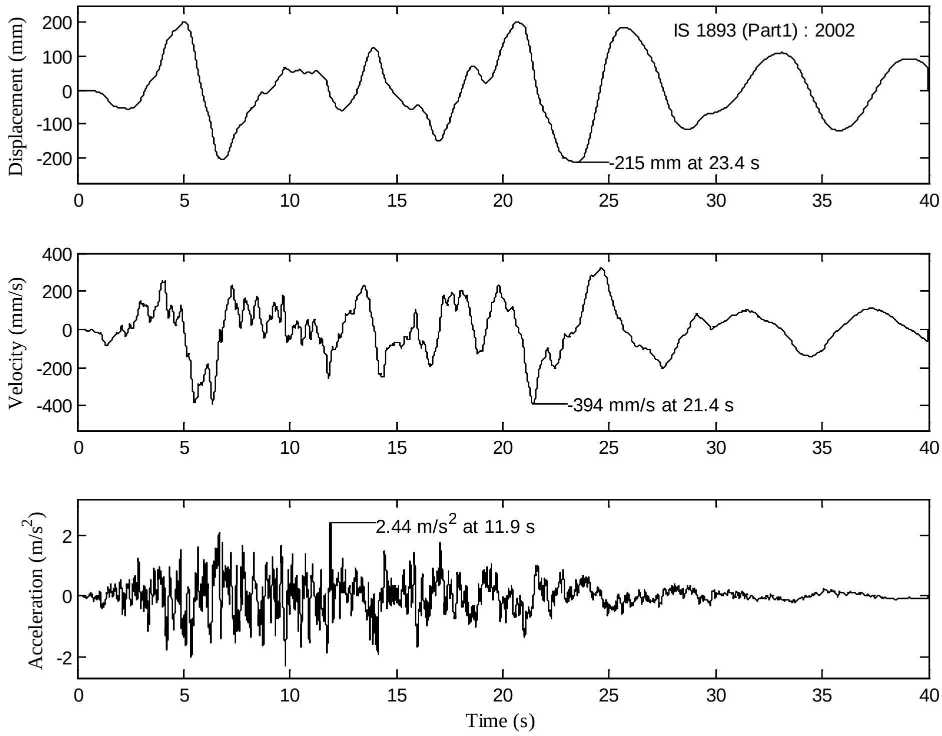
(a)

(b)

Figure 6.23: Roof displacement, velocity, and acceleration of twenty-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in x-direction

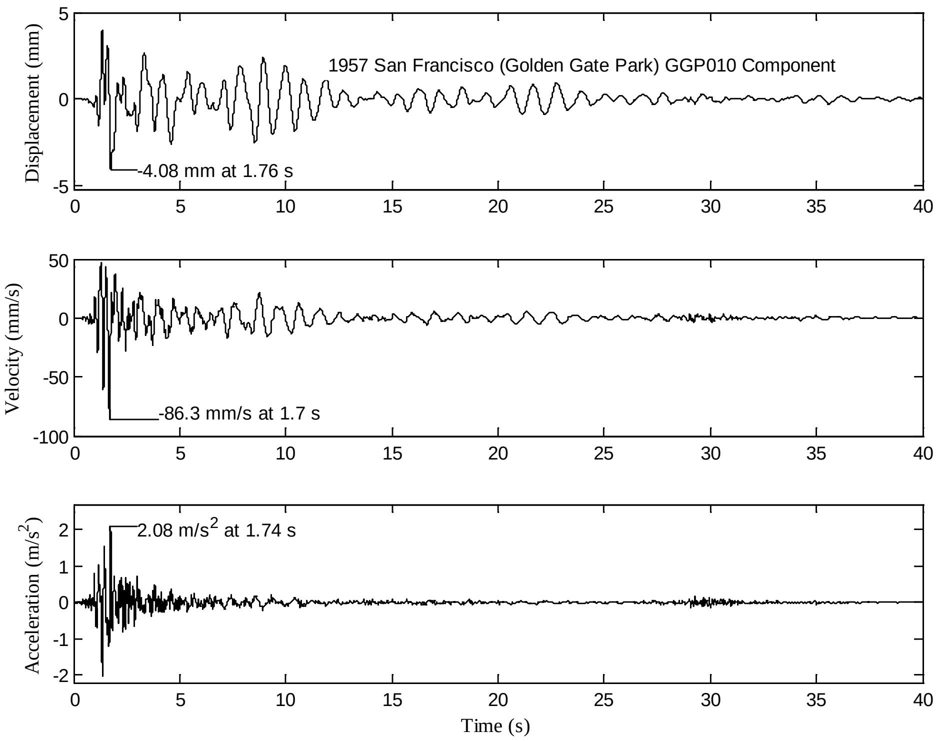


(a)

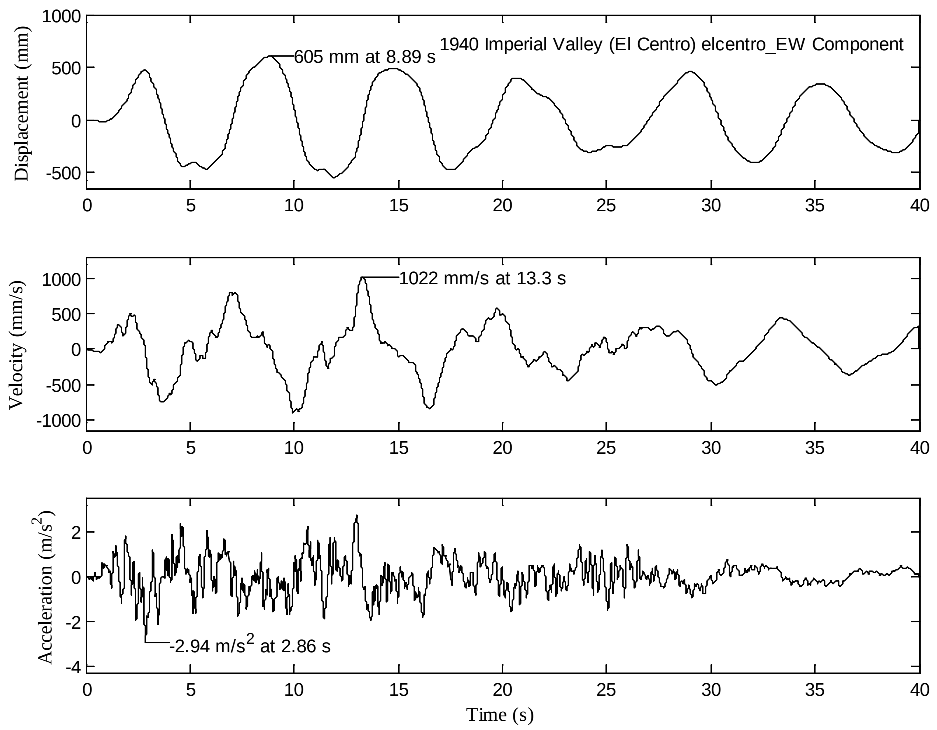


(b)

Figure 6.24: Roof displacement, velocity, and acceleration of twenty-story irregular RC building due to (a)1979 Imperial Valley-06 (Holtville Post Office) H-HVP225 component, and (b) IS 1893 (Part1) : 2002 ground motion in z-direction



(a)



(b)

Figure 6.25: Roof displacement, velocity, and acceleration of twenty-story irregular RC building due to (a) 1957 San Francisco (Golden Gate Park) GGP010 component, and (b) 1940 Imperial Valley (El Centro) elcentro_EW component ground motion in z-direction

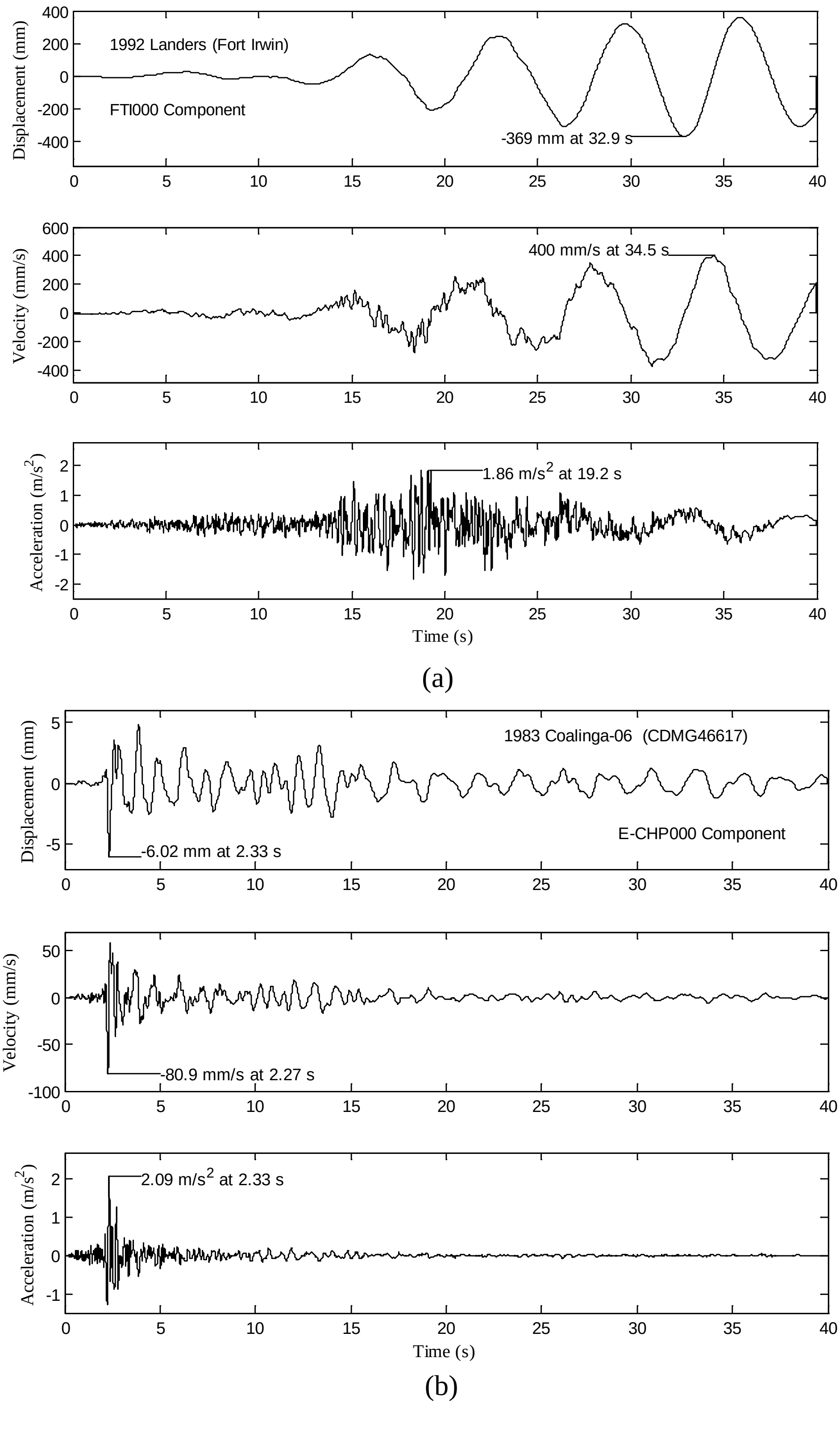
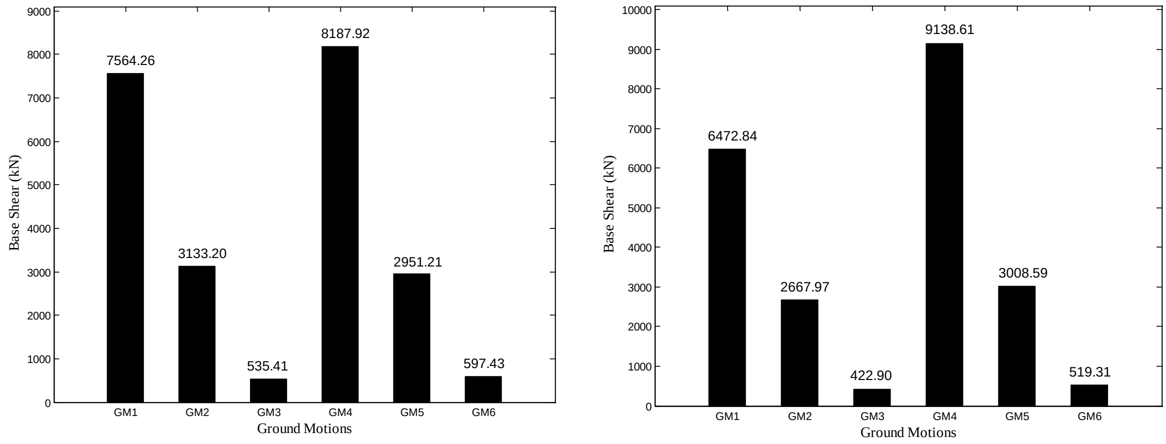


Figure 6.26: Roof displacement, velocity, and acceleration of twenty-story irregular RC building due to (a) 1992 Landers (Fort Irwin) FTI000 component, and (b) 1983 Coalinga-06 (CDMG46617) E-CHP000 component ground motion in z-direction

The base shear of twenty-story irregular RC building due to ground motion GM1, GM2, GM3, GM4, GM5, and GM6 is shown in Figure 6.27. Figure 6.27 (a) shows that the building has maximum base shear of 8,187.92 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 535.41 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in x-direction. Figure 6.27 (b) shows that the building has maximum base shear of 9,138.61 kN due to 1940 Imperial Valley (El Centro) elcentro_EW component and minimum base shear of 422.90 kN due to 1957 San Francisco (Golden Gate Park) GGP010 component ground motion in z-direction.



(a) (b)

Figure 6.27: Base shear of twenty-story irregular RC building due to ground motion GM1-GM6 in (a) x and (b) z-direction

The maximum and minimum values of story displacement, story velocity, story acceleration, and base shear of two, six, and twenty-story irregular RC building due to GM1-GM6 in x and z-direction are summarized in Table 6.1.

Table 6.1: Two, six, and twenty-story irregular RC building responses due to GM1-GM6 in x and 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	2	3	4	3	4	3	4	3	1	3, 6	1	3, 6
Story Velocity	2	3	4	3	4	3	4	6	1	3, 6	4	3, 6
Story Acceleration	2	3	4	3	4	3, 6	4	6	4	3, 6	4	3, 6
Base Shear	2	3	4	3	4	3	4	3	4	3	4	3

* GM (x): Ground motion in x-direction
** GM(z): Ground motion in z-direction
1, 2, 3, 4, 5, and 6 represents the ground motion serial number

CHAPTER 7

7 SUMMARY AND CONCLUSIONS

7.1 Summary

Ground motion causes earthquake. Structures are vulnerable to ground motion. It 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 characteristics of ground motion are peak ground acceleration, peak ground velocity, peak ground displacement, period, and frequency content etc.

Here, low, mid, and high-rise regular as well as irregular RC buildings are studied under low, intermediate, and high-frequency content ground motions. Six ground motions of low, intermediate, and high-frequency content are introduced to the corresponding buildings. Linear time history analysis is performed in STAAD Pro. [1] The outputs of the buildings are given in terms of story displacement, story velocity, story acceleration, and base shear. The responses of each ground motion for each type of building is studied and compared.

7.2 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
- 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

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

Following conclusions can be drawn for the two, six, and twenty-story irregular RC buildings from the results obtained in chapter 6:

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

- Twenty-story irregular RC building undergoes minimum base shear due to high-frequency content ground motion in x and z-direction

It can be summarized that low-frequency content ground motion has significant effect on both regular as well as irregular RC buildings responses. However, high-frequency content ground motion has very less effect on responses of both regular and irregular RC buildings. It is found that the intermediate-frequency content ground motion has less effect than low-frequency content ground motion and more effect than high-frequency content ground motion on the RC buildings.

7.3 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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