REINFORCED CONCRETE BUILDINGS OF SEISMIC BEHAVIOR UNDER SIGNIFICANCE OF FLUCTUATING FREQUENCY

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ABSTRACT

Earthquake is the result of sudden release of energy in the earth's crust that generates seismic waves. Ground shaking and rupture are the major effects generated by earthquakes. It has social as well as economic consequences such as causing death and injury of living things especially human beings and damages the built and natural environment. In order to take precaution for the loss of life and damage of structures due to the ground motion, it is important to understand the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. These characteristics play predominant rule in studying the behavior of structures under seismic loads.The strength of ground motion is measured based on the PGA, frequency content and how long the shaking continues. Ground motion has different frequency contents such as low, intermediate, and high. Present work deals with study of frequency content of ground motion on reinforced concrete (RC) buildings. Linear time history analysis is performed in structural analysis and design (STAAD Pro) software. The proposed method is to study the response of low, mid, and high-rise reinforced concrete buildings under low, intermediate, and high- frequency content ground motions. Both regular and irregular three-dimension two, six, and twenty- story RC buildings with six ground motions of low, intermediate, and high-frequency contents having equal duration and peak ground acceleration (PGA) are studied herein. The response of the buildings due to the ground motions in terms of story displacement, story velocity, story acceleration, and base shear are found. The responses of each ground motion for each type of building are studied and compared. The results show that low- frequency content ground motions have significant effect on both regular as well as irregular RC buildings. However, high-frequency content ground motions have very less effect on responses of the regular as well as irregular RC buildings

Keywords: Reinforced Concrete Building, Ground Motion, Peak Ground Acceleration, Frequency Content, Time History Analysis

I. INTRODUCTION

An earthquake is the result of a rapid release of strain energy stored in the earth's crust that generates seismic waves. Structures are vulnerable to earthquake ground motion and damages the structures. In order to take precaution for the damage of structures due to the ground motion, it is important to know the characteristics of the ground motion. The most important dynamic characteristics of earthquake are peak ground acceleration (PGA), frequency content, and duration. These characteristics play predominant rule in studying the behavior of structures under the earthquake ground motion. Severe earthquakes happen rarely. Even though it is technically conceivable to design and build structures for these earthquake events, it is for the most part considered uneconomical and redundant to do so. The seismic design is performed with the expectation that the severe earthquake would result in some destruction, and a seismic design philosophy on this premise has been created through the years. The objective of the seismic design is to constraint the damage in a structure to a worthy sum. The structures designed in such a way that should have the capacity to resist minor levels of earthquake without damage, withstand moderate levels of earthquake without structural damage, yet probability of some nonstructural damage, and withstand significant levels of ground motion without breakdown, yet with some structural and in addition nonstructural damage. 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 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.

II. STRUCTURAL MODELING

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

2.1 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 Figure 1 shows the frame (A-A) and (01-01) of the twenty, six, and two-story RC building respectively. For simplicity, both the beam and column cross sections are assumed 300 mm x 400 mm.

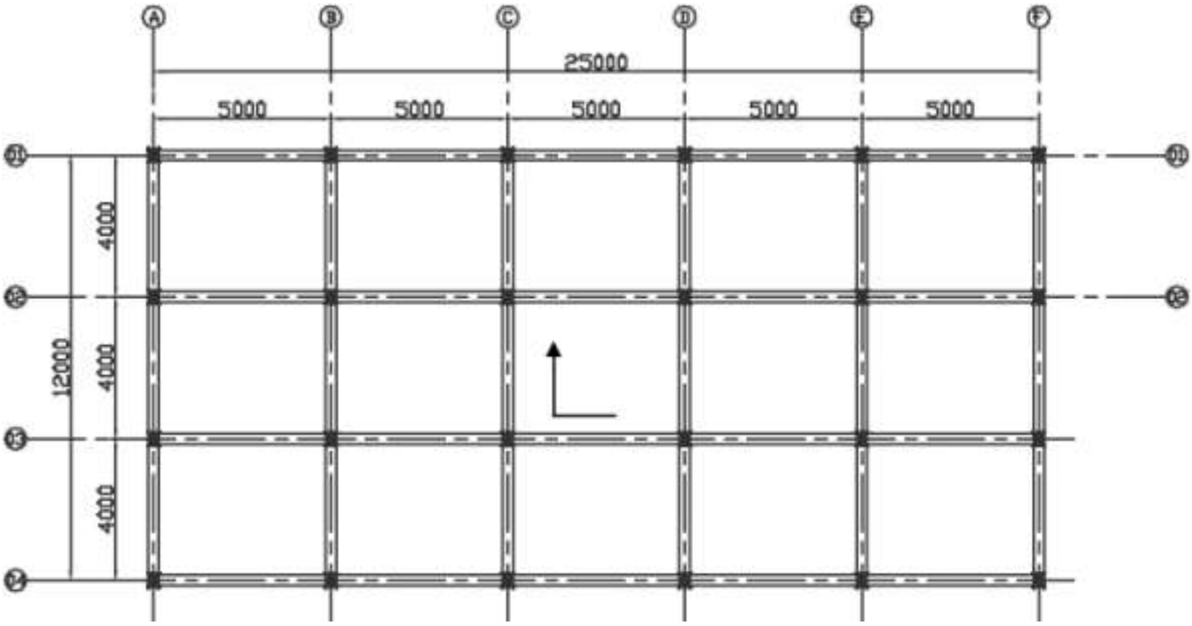

Figure 1: Plan of Two, Six, and Twenty-Story Regular RC Buildings
(All Dimensions Are In Mm)

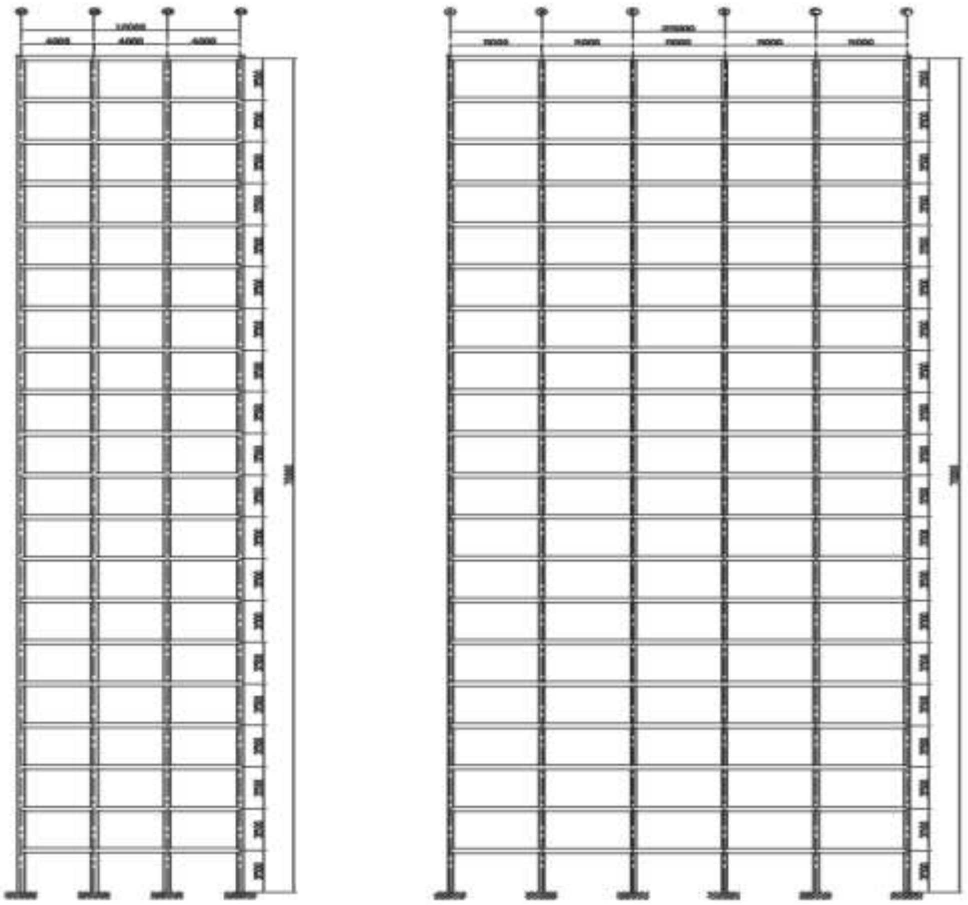

Figure : 2 : Frame (A-A) and (01-01) of Twenty-Story Regular RC Building
(All Dimension Are In Mm)

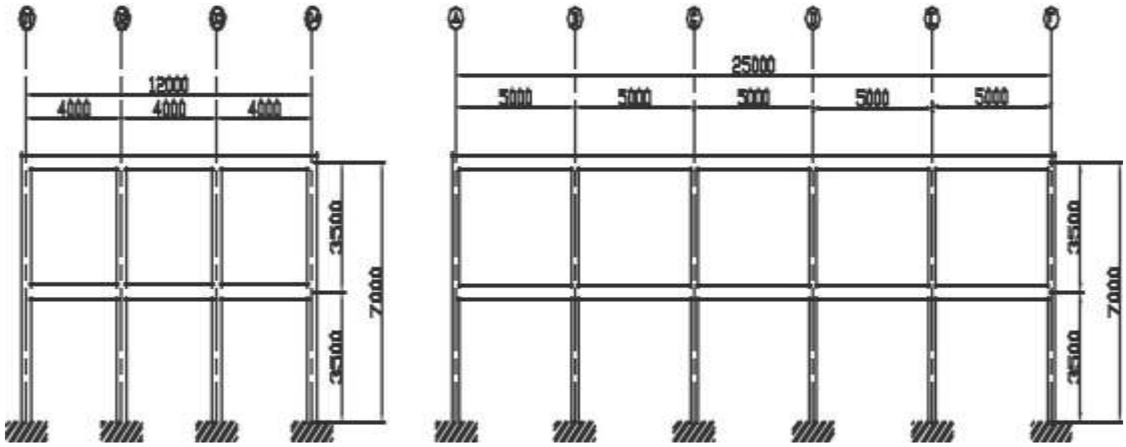

Figure 3. Frame (A-A) And (01-01) of Two-Story Regular RC Building

(All Dimension are in Mm)

2.2 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.

2.3 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 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.

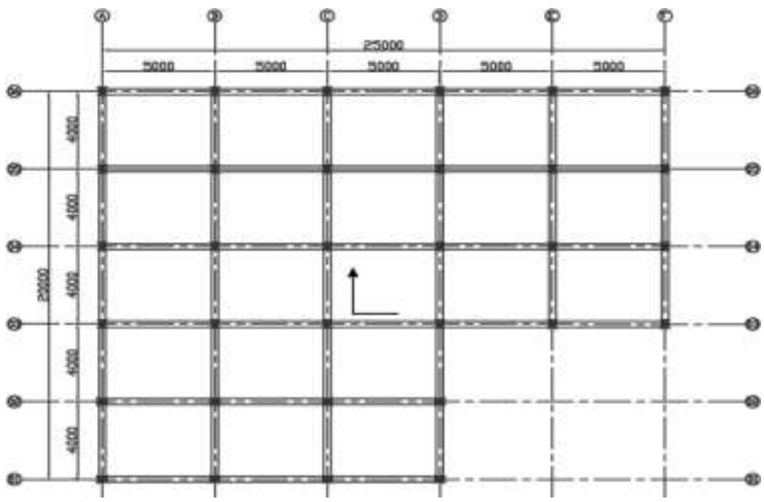

Figure 4: Plan of Two, Six, and Twenty-Story Irregular RC Buildings (All Dimensions Are In Mm)

Table 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)

2.4 Material Properties

Table 2 shows the concrete and steel bar properties, which are used for modeling of the reinforced concrete buildings in STAAD Pro [1].

Table 2: Concrete and Steel Bar Properties as Per IS 456 [30]

Concrete Properties		Steel Bar Properties	
Unit weight ( )	25 (kN/m^3)	Unit weight ( )	76.9729 (kN/m^3)
Modulus of elasticity ( )	22360.68 (MPa)	Modulus of elasticity ( )	2x10 (MPa)
Poisson ratio ( )	0.2	Poisson ratio ( )	0.3
Thermal coefficient ( )	5.5x10	Thermal coefficient ( )	1.170x10
Shear modulus ( )	9316.95 (MPa)	Shear modulus ( )	76923.08 (MPa)
Damping ratio (	5 (%)	Yield strength (	415 (MPa)
Compressive strength (	30 (MPa)	Tensile strength (	485 (MPa)

2.5 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.: 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

2.6 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 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.

III. REGULAR RC BUILDINGS RESULTS AND DISCUSSION

3.1 Two-Story Regular RC Building

Figure 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 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.

3.2 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.

3.3 Twenty-Story Regular RC Building

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 5.20 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. 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.

Table 5.1: Two, Six, and Twenty-Story Regular RC Building Responses Due to GM1-GM6 In X and Z-Direction

C 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

IV. 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.

V. 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 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.

VI. SCOPE OF FUTURE STUDY

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. 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.

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