Seismic Performance and Assessment of RC Framed Structure with Geometric Irregularities

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Research Article

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Abstract

Over the few decades, irregularly shaped structures are famous in modern times because of their architectural significance. Symmetrical plan structures often exist, although irregular plan structure is practiced in developing nations. This study investigates the effect of geometric irregularity in reinforced concrete (RC) frame structures under seismic zone IV by using the software STAAD Pro. Moreover, the time displacement on the nodes from where the geometric irregularity starts has been analyzed. Three types of 8-Storey's frame models were considered for the dynamic behaviors, i.e., models M1, M2, and M3. Model M3 is geometrically regular in the x-y-plane, and geometric regularity is interrupted in models M1(less disturbed) and M2 (more disturbed) in the identical plane. The results showed that the time displacement is more geometrically more irregular structures. The time-frequency increases in each mode, which means the higher method has a higher frequency and more in a more geometrically rare form. The irregularity of the structures' geometricity is reflected in the irregularity shape factor (ISF). According to the finding, the rough geometrical shape significantly impacts the dynamic response of the building, and ISF of 0.26 (M2) and 0.24 (M1) greatly varies with frequency, period, velocity, acceleration, and displacements.

1. Introduction

Past earthquake destruction data have indicated that many building collapses occur due to the structure's vertical irregularities [1]. In later eras, regular advancements were accomplished in earthquake-resistant facilities [2]. RC structures with vertical geometric asymmetry are progressively considered for innovation of multi-story designs predominantly because of their serviceability and aesthetic purposes [3,4,5]. However, each structure's performance varies, corresponding to the assembly of the structural elements that appear in the system. The orientation depends on the various aspects, i.e., geometry, dimension, and shape of the structure [6]. The traditional buildings have no considerable discontinuities in the plan. However, the Irregular has substantial discontinuities in the program. In engineering practice, geometric asymmetries significantly contribute to the dynamic response in the light of time displacement, frequency, and velocity, including acceleration [7]. So far, several investigators have examined the influence of earthquake response on buildings having vertical and horizontal asymmetries [21,22]. Although, the loading and force are established and intended at the center of the structure's mass [8]. However, the careful variation of these considerations in the design of buildings enhances the system's effectiveness [8,9]. Asymmetries in structures are proposed for their aesthetic purposes and efficiency. The magnitude of variation in behavior varies on the type, intensity, and place of asymmetries appearing in the structure. The earthquake performance of multi-story or high-rise structures with vertical irregularities declines the stiffness by up to 30% and raises the story drift by 20-40% [9]. Furthermore, static, and dynamic assessments of the structures having mass irregularity are ineffective in predicting the response of the buildings [12]. However, some researchers emphasize the impact of floor plans on the seismic behaviors and dynamic evaluation of H and L-type structures [10]. Although, the 9-story steel structures response, along with setback asymmetries, explored more excellent torsion at higher segments of setbacks [11]. The impact of torsional irregularity on structures has been measured and revealed that torsion is irregularity among the mass and stiffness [13]. Similarly, parametric analyses on the six-story with variable shear wall positions, surface rotations, and torsional irregularity coefficient were suggested [14,23] and concluded that the torsional irregularity coefficient increases with the floor decrease. However, L-shaped structures defined that L-shaped structures have a higher response than the regular frame [15]. Correspondingly, from time history analysis for traditional multi-story buildings, it has been determined story drift slightly declines with an increase in the story height [16]. The irregular shape of the structure plan provides a severe high responsibility towards the ground motion and suitability of dynamic analysis compared to the static analysis [17]. However, the structure's static and dynamic evaluations are ineffective in evaluating the response under the dynamic behavior having mass irregularity [18,20]. Various analyses have been accomplished to analyze the performance of structures having variation in stiffness, mass, vertical geometry, etc. not many studies have been done on the effect of the irregularity shape factor (ISF), which has a more profound relationship to the behavior of a structure. Such structures sometimes are being constructed in a haphazard manner causing geometrical irregularity. Sometimes these geometrical irregularities are also responsible for mass and stiffness irregularities. Consequently, the response of such geometrical irregular structures has (model M1, model M2, and model M3) been generated over three model M1 correspondence to the less periodic system, and M2 Corresponds to more irregular structures than model M3, which is a standard model with geometrically stable structure. This research aims to evaluate the structure's response, especially displacement on the nodes from where the cut out (geometric irregularity) starts, along with analyzing the structure's response such as frequency, acceleration, and velocity due to geometric changes.

2. Methods

In the present work, seismic analyses of multi-story RC frame structures were carried out using the software STAAD Pro. as of its pros, such as its easy interface and its capability to analyze design(s) conforming to the Indian Standard Codes. In horizontal load applications such as earthquake and wind loads, geometric irregularity plays a significant role in the response behavior of buildings in terms of displacement, natural frequency, time, stiffness, velocity, and acceleration of the structure [1]. The time history analysis has been selected to check the dynamic response for the models under the earthquake conditions in seismic Zone IV [25,16]. The time displacement is higher in a geometrically more irregular structure (M2) than in one less irregular (M3). The time-frequency increases in each mode, which means the higher method has a higher frequency. The effect of the geometric irregularity of the structures has been reflected in terms of the irregularity shape factor (ISF). A comparison has been made concerning the regular geometrical shaped model M3. Structural models behaving differently have been attributed to the irregularity in geometry created in the structures. The Irregularity Shape Factor reflects the effect of the geometrical shape of the design. In xx, Iggy is the geometrical moment of inertia about XX and YY axes. The Regularity Ratio has been specified as the ratio of Igxy (M1 or M2)/ Igxy for (M3) as per the model studies in consideration. The flow chart is presented in Figure 1. Consequently, lateral stiffness in such stories should be increased suitably considering the irregularity shape factor. The outcomes are structural responses among the three models in time history displacement, velocity, frequency, and acceleration.

3. Modeling And Materials

3.1. Modeling

First, choose the space frame, and provide length units in Meters and force units in Kilo Newton in Staad Pro. Then select the prototype model like Bay Frame, Grid Frame, Floor Grid, etc. the Bay Frame model has been taken as per the dimensions of the structure. Then assign the support condition to the restrained joint, i.e., fixed support. Then define the general properties of the beams and columns. The size of the beam and columns of the whole structure has been taken at 450mm x 300mm. After that, select the seismic definition from the load and definition column properties. Select the seismic parameters from the seismic definition and select the zone and soil type. Additionally, add Weight to the structure. The 8-Storey (G+7) three RC frames models have been selected as Model M1, M2, and M3 dimensions are shown in Table 2. Model M3 is a geometrically regular one in the XY plane, and geometric regularity has been disturbed in models M1 and M2 in the same plane. The floor-to-floor height (length, height, width ratio) for (M1), (M2), (M3) models are represented in Table 3. The most disturbed or irregular model is M2, followed by model M1, which is geometrically less troubled than model M3 (considered a standard model due to geometrical symmetry). The geometrical shape of the structure for M1, M2, M3 models are presented in Figures 2-3(a-d).

Design codes used in the studies

IS:456-2000	Design Code for RCC Structure
IS:875(Part 1)-1987	Design Load (Imposed Load) For Building and Structure
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IS:875(Part 1)-1987	Design Load (Imposed Load) For Building and Structure
IS:875(Part 2)-1987	Design Load (Dead Load) Building and Structure
IS:875(Part 3)-1987	Design Load (Live Load) For Building and Structure
IS:875(Part 4)-1987	Design Load (Other than Earthquake) Building and Structure
IS:1893 (Part 1):2002	Criteria for Earthquake Resistant Design of Structure

3.2 Design Parameter

Various types of loads act on the building under different circumstances, and these loads are as per standard provision presented in Table 1

Table 1. Design parameters for (M1), (M2), (M3) models

Material	Grade
concrete grade	M25
Steel grade	Fe-415
Bearing Capacity	180 kN/m^2
Codes Used	As per IS 875(PART 1) (1987) and IS 875(PART 2)
Seismic loads (SL)	As per IS 1893(PART 1) (2000)
Dead Load (DL)	Self-weight of the structure, Floor load (5 kN/m^2)
Live Load (LL)	Live load 5 kN/m^2 is considered for floor weight
Earthquake Seismic zone	Zone IV
Rock/soil type	Medium
Rock and soil factor	1
Damping ratio	5%
Ductility design	IS:13920-1993
Shape of building	Rectangular
Type of construction	RCC framed structure

Table 2. Design Models (M1), (M2), (M3) Characteristics

S. No.	Dimension	Model (M1)	Model (M2)	Model (M3)
1	Dimension of beam	450×300 mm	450×300 mm	450×300 mm
2	Dimension of column	450×300mm	450×300mm	450×300mm
3	No. of column	176	106	200
4	No. of beam	155	224	320
5	Total height	24m	24m	24m
6	Supports	25	25	25
7	Support condition	Fixed	Fixed	Fixed
8	Clearspan	3m	3m	3m
9	No. of joints	225	225	225
10	No. of members	520	520	520

Table 3. Floor to floor height for (M1), (M2), (M3) models

	Model (M1)			Model (M2)			Model (M3)		
Floor	Height (m)	Length (m)	Width (m)	Height (m)	Length (m)	Width (m)	Height (m)	Length (m)	Width (m)
1	3	12	12	3	12	12	3	12	12
2	3	12	12	3	12	12	3	12	12
3	3	12	12	3	12	6	3	12	12
4	3	12	9	3	12	6	3	12	12
5	3	12	9	3	12	6	3	12	12
6	3	12	9	3	12	6	3	12	12
7	3	12	9	3	12	6	3	12	12
8	3	12	9	3	12	6	3	12	12

4. Results And Discussion

The Staad Pro carries out the outcomes and describes the assessment of the M1, M2, and M3 models. To analyze the three modeled RC frames, M1, M2, and M3, by the time-history method, the following results have been obtained for the dynamic response of the structures modeled.

4.1 Time history Displacement Calculation

In all the models, the front frame has been considered an authentic replica of all the structures in its back, with bottom coordinates as x=0, y =0; x=12, y=0. The acceleration generated under zone-IV, which is responsible for displacement in the structure, has been tabulated in Table 4.

Table 4. Time history acceleration data for zone-IV

Sr. No.	Time (sec)	Acceleration(m/s^2)
1	0	0.0063
2	0.02	0.00364
3	0.04	0.00099
4	0.06	0.00428
5	0.08	0.00758
6	0.1	0.01087
7	0.12	0.00682
8	0.14	0.00277
9	0.16	-0.00128
10	0.18	0.00368

Table 5.Time history displacement of Model M1(Geometrically less irregular structure)

Floors	X-Displacement (E-3 mm)					
1	**Node no.**	**6**	**7**	**8**	**9**	**10**
	Upper	11.6	11.6	11.6	11.6	11.6
	lower	-12.6	-12.6	-12.6	-12.6	-12.6
2	**Node no.**	**11**	**12**	**13**	**14**	**15**
	Upper	27.4	27.4	27.4	27.4	27.5
	lower	-29.2	-29.3	-29.3	-29.3	-29.3
3	**Node no.**	**16**	**17**	**18**	**19**	**20**
	upper	42.3	42.3	42.3	42.1	42
	lower	-44.9	-44.9	-44.8	-44.7	-44.6
4	**Node no.**	**21**	**22**	**23**	**24**	
	upper	57.8	57.7	57.7	57.7	
	lower	-62.8	-62.8	-62.8	-62.7	
5	**Node no.**	**26**	**27**	**28**	**29**	
	upper	72.4	72.4	72.4	72.4	
	lower	-81.8	-81.8	-81.8	-81.8	
6	**Node no.**	**31**	**32**	**33**	**34**	
	upper	85.4	85.4	85.4	85.4	
	lower	-100	-100	-100	-100	
7	Node no.	36	37	38	39	
	upper	96.2	96.2	96.2	96.2	
	lower	-116	-116	-116	-116	
8	**Node no.**	**41**	**42**	**43**	**44**	
	upper	103	103	103	103	
	lower	-127	-127	-127	-127	

The data generated from the model M1 have been tabulated in Table 5, which shows the upper values exhibit the displacement along the X-axis in the (+) direction. However, the lower displacement along the nodes indicates displacement in the (–) X-direction. Figure 4(a) shows that on the 1st floor, the displacement is 11.6 E-3 mm which further increases up to the 8th floor with the displacement of 103 E-3 mm in the upper direction. However, Figure 4(b) exhibits the displacement along the lower path, which is

12.6 E-3 mm at the 1st-floor level and increases up to 8th-floor displacement is 127 E-3 mm. The displacement increases with the order of increment up floors. This exhibits that the lateral force increases floor-wise in an upward direction. It has been observed that there is a change in displacement one story up and one level down on floor 3. Therefore floors 2 and 3 are affected by the geometric irregularity created on floor 3.

Table 6. Time history displacement for model M2 (Geometrically more irregular structure)

Floors	X-Displacement (E-3 mm)					
1	**Node no.**	**6**	**7**	**8**	**9**	**10**
	Upper	17.5	17.5	17.5	17.5	17.5
	lower	-20.7	-20.7	-20.8	-20.8	-20.8
2	**Node no.**	**11**	**12**	**13**	**14**	**15**
	Upper	41.8	41.8	41.7	41.4	41.2
	lower	-47.9	-47.9	-47.8	-47.6	-47.4
3	**Node no.**	**16**	**17**	**18**	**19**	
	upper	70.7	70.7	70.7	70.6	
	lower	-79.8	-79.8	-79.8	-79.8	
4	**Node no.**	**21**	**22**	**23**	**24**	
	upper	101	101	101	101	
	lower	-114	-114	-114	-114	
5	**Node no.**	**26**	**27**	**28**	**29**	
	upper	131	131	131	131	
	lower	-150	-150	-150	-150	
6	**Node no.**	**31**	**32**	**33**	**34**	
	upper	158	158	158	158	
	lower	-185	-185	-185	-185	
7	**Node no.**	**36**	**37**	**38**	**39**	
	upper	180	180	180	180	
	lower	-214	-214	-214	-214	
8	**Node no.**	**41**	**42**	**43**	**44**	
	upper	195	195	195	195	
	lower	-233	-233	-233	-233	

The displacement increases with the increase of floors. The dynamic response of the lateral force increases floor-wise in the upward direction of the structure. Figure 5(a) shows that the displacement in the upper path on the 1st floor is 17.5 E-3 mm, which further increases up to the 8th story to the extent of 195 E-3 mm, and Figure 5(b) exhibits the displacement in the lower direction on the 1st floor is 20.7 E-3 mm which increases up to 8th story to the extent 233 E-3 mm. The displacement increases with the increase in the height of the frame's structure. It has been observed that the change in displacement is one story up and one level down on floor 2. Therefore floors 1 and 3 are affected by the geometrical irregularity created on floor 2.

Table 7. Time history displacement for model M3 (Geometrically regular structure)

Floor	**X-Displacement (E-3 mm)**					
1	**Node no.**	**6**	**7**	**8**	**9**	**10**
	Upper	16.8	16.8	16.8	16.9	16.8
	lower	-19.6	-19.6	-19.6	-19.6	-19.6
2	**Node no.**	**11**	**12**	**13**	**14**	**15**
	Upper	41	41	41	41	41
	lower	-46.7	-46.8	-46.8	-46.8	-46.8
3	**Node no.**	**16**	**17**	**18**	**19**	**20**
	upper	66.1	66.1	66.1	66.1	66.1
	lower	-75.5	-75.5	-75.5	-75.5	-75.5
4	**Node no.**	**21**	**22**	**23**	**24**	**25**
	upper	91	91	91	91	91
	lower	-105	-105	-105	-105	-105
5	**Node no.**	**26**	**27**	**28**	**29**	**30**
	upper	115	115	115	115	115
	lower	-133	-133	-133	-133	-133
6	**Node no.**	**31**	**32**	**33**	**34**	**35**
	upper	136	136	136	136	136
	lower	-159	-159	-159	-159	-159
7	**Node no.**	**36**	**37**	**38**	**39**	**40**
	upper	153	153	153	153	153
	lower	-181	-181	-181	-181	-181
8	**Node no.**	**41**	**42**	**43**	**44**	**45**
	upper	164	164	164	164	164
	lower	-195	-195	-195	-195	-195

Figure 6(a) shows the ground surface floor-0 displacement is 0, which further increases up to the 8th story to the extent of 164 E-3 mm, and Figure 6(b) exhibits the displacement in the upper direction at 1st floor to the size of 19.6 E-3 mm which increases up to 8th Floor to the magnitude 195 E-3 mm. The displacement increases with the increase of subsequent base upwards, where each floor attains the height of 3.00 m.

4.2 Time-frequency calculation

Figure 7(a) shows the time frequencies mode shape for model M1. However, in Figure 7 (b), there are variations in the frequencies in each mode. In the first Mode, the time frequency is 1.024 Hz, and it is 4.941 Hz in the 8th mode. The frequency increases with the extent to standard mode M3 subsequently. The increase in the frequency concerning the first to the last mode is 382.51% which means the modal frequency in the previous mode is 4.83 times that first mode. The functional relationship of increment in frequency ratio w.r.t 1st-floor for model 1 is shown in Figure 8 (a). However, in Figure 7 (c), there is a variation in the frequencies from the first node to 8 nodes. The frequency varies from 1.013 H_Z to 4.921 H_Z. The frequency increases with every mode, which means the higher mode has a higher frequency than its lower one. The increase in the frequency from the first to the highest is 385.78 percent. That means the highest modal frequency is 4.86 times the first mode frequency. The functional relationship of increment in frequency ratio w.r.t 1st-floor in model 2 is shown in Figure 8(b). However, In Figure 7(d), there is variation in the frequencies on each floor, which varies from 0.969 H_Z to 4.909 H_Z from the 1st floor to the top floor. The frequency increases with the increase in the modes. That means the higher method has a higher frequency than its lower one. The increase in the frequency from the first to the highest is 406.60 percent. That means the highest modal frequency is 5.07 times the first mode frequency. The functional relationship of increment in frequency ratio w.r.t 1st-floor in model 3 is shown in Figure 8(c).

4.3 Relationship of frequency ratio

Figure 8 shows the relationship of frequencies ratio concerning the fundamental frequency for models M1, M2, and M3 w.r.t the ground floor.

4.4 Time acceleration calculation

Figure 9(a) describes that time acceleration on the 1st floor is 3.9 E-3 m/s^2, further increasing on the up bases and reaching 13.4 E-3 m/s^2 on the 8th floor in the upper direction. Figure 9(b) observed acceleration in the lower order of 2.6 E-3 m/s^2 to the magnitude of (1st floor), which further increases upto10.8 E-3 m/s^2 on the 8th floor. The time acceleration increases with the increase in height, which means that the higher floor will have higher acceleration than the lower ones.

Figure 9 (c) exhibits the time acceleration at a 1st-floor level to the magnitude of 5.84 E-3 $m/s^{2,}$ which further increases on the up floors and reaches 23 E-3 m/s^2 on the 8th floor in the upper direction, and

Figure 9 (d) exhibits time acceleration to the extent of 4.84 E-3 m/s^2 at (1-floor), which increase to 17.5 E-3 m/s^2 at 8th floor in the lower direction. The time acceleration increases with the increase in height, which means that the higher floor will have higher acceleration than the lower ones. Figure 9(e) displays the acceleration at the first-floor level (1st floor) to the extent of 5.58 E-3 m/s^{2,} which further increases on the up bases and reaches 17.9 E-3 m/s^2 on the 8th floor in the upper direction, and Figure 9(f) show lower direction time acceleration, i.e., 3.94 E-3 m/s^2 at (1st floor), which increase 16.2 E-3 m/s^2 at 8th floor in the more downward direction. The time acceleration increases with the increase in height, which means that the higher floor will have higher acceleration than the lower ones.

4.5 Time velocity calculation

Figure 10(a) displays the velocity in the upper direction on the 1st floor to the extent of 162 E-3 mm/s and on the 8th floor is 895 E-3 mm/s velocity, and Figure 10(b) shows the velocity in the lower direction on the 1st floor to the extent of 140 E-3 mm/s. On the 8th floor, it is 811 E-3 mm/s. In Figure 10(c), the velocity (upper) on the 1st-floor magnitude of 282 E-3 mm/s, and at the last base (8th), it is 1480 E-3 mm/s, and Figure 10(d) shows the lower direction velocity at 1st floor, i.e., 208 E-3 mm/s and at 8th floor, velocity is 1450 E-3 mm/s. The time velocity has different behavior on floors 2 to 4. As discussed, the geometric irregularity has affected a change in velocity one foot up, and one is floor down.

Figure 10(e) shows the velocity in the upper direction on the 1st floor to 255 E-3 mm/s. At the last base (8th), it is 1130 E-3 mm/s, and Figure 10(f) shows the lower direction the velocity on the 1st floor is 213 E-3 mm/s, and on the 8th floor, velocity is 1160 E-3 mm/s in the more downward movement. There is variation in time acceleration at floors/stories. This is probably due to a change in acceleration from ground to first floor/story. The results reveal a lot of variation in the dynamic response of the structure due to changes in geometrical shape in RC frame models M1, M2, and M3. Each frame has eight floors (8 stories). Each frame has four outputs for each bed in terms of displacement, frequency, acceleration, and velocity. The fundamental frequency contributes to mass participation of 71.26% in M1, 78.15% in M2, and 83.17% in M3. Consequently, results focus more on floor level one for M1, M2, and M3 RC frames models. A comparison has been described between standard model M3 and the other two models, M1 and M2. The input data has created 3-D models in STAAD Pro. Software along with the formation of the nodes and elements. The effect of the geometrical shape of the structures has been reflected in the irregularity shape factor ISF. The geometrical moment of inertia has been correlated by the square root of the sum of square (SRSS) method taking into consideration the effect of both geometrical moments of inertia about xx and yy axes in the analysis. The geometrical moment of inactivity has been assigned because this is not the actual moment of inertia of the structure. Instead, it is related to the structure's geometry, so is the name geometry assigned.

4.6 Time history displacement

It has been observed from the results that the displacement increases with the increment in the height of the structural frame, and the removal of the floor situated at a higher level has higher displacements, as can be seen in the models M1, M2, and M3. The highest floor (8th floor) has the highest displacement. However, the ground level has zero displacements.

Time history displacement has been considered zero on the ground floor as the base is fixed concerning other floors. In model M1, the displacement increases in an upper direction from 11.6 E-3 mm on the first floor to 103 E-3 mm on the 8th floor. It varies from 17.5 E-3 mm to 195 E-3 mm in model M2 and 16.8 E-3 mm to 164 E-3 mm in the case of model M3. In general, it has been observed that the displacement in model M1 is higher than in model M2. Model M2 has a higher displacement in comparison to model M3. The increase in displacement in model M1 is 30.95% (11.6 E-3mm) and 4.1 % (17.5 E-3mm) in M2 concerning M3 (16.8 E-3 mm) at the first-floor level, and the model M2 has the higher displacement in comparison to model M3. The increase in displacement in model M1 is 37.19% (103 E-3mm) and 18.90% (195 E-3 mm) in M2 concerning M3 (164 E-3 mm) on the 8th floor. There is an increase in the horizontal displacement concerning the rise in height, i.e., as the height of the structure increases, removal at a higher level also increases. The displacement at the level of geometric irregularity, there is a change in the displacement in the node where abnormality (cut) has been generated. It also has been observed that there is a change in displacement one story down and one story up in the adjacent stories (M1). This can be observed that the geometric irregularity starts at level 3 in M1, and floor disturbance in displacement has been observed on floors 2 and 4. That indicates one floor up and one down adjoining the affected floor needs to be paid attention to special structural treatment. This disturbance is due to geometric irregularity. The displacement has also affected the entire length of 5 modes on floor three. Therefore, a complete story/floor must be paid attention to. It can be restricted that floors 2, 3, 4 need special attention for structural treatment. Similarly, in the case of M2, the variation in the upper displacement in the outer node varied from 41.2 E-3 mm to 41.8 E-3 mm in story second, where irregularity is present in M2. However, the changes in one floor up and one floor down displacement has been noticed. It also has been observed that the geometric irregularity changes the displacement behavior affecting the entire floor as in the case of M1 on floors 2, 3, 4 in the case of M2 and, affected feet are 1, 2, 3. The displacement in the adjoining floor up and down needs special attention under such circumstances. Appropriate reinforcement treatment may have to be required to treat the concentration of stresses. Figure 10(a-f) exhibit that the behavior of the function of displacement is almost similar except from floor 2 to 4, which is the area where irregularity in the geometry has been created in M1; however, the function of displacement does change from floor 1 to 3 in case of M2. That means irregularity plays a vital role in the response behavior of the structures.

4.6 Time history frequency

It has been observed that the frequency increases with the irregularity generated in the frame structure, which means the models M1 and M2, which have disturbed regularity, have a higher frequency than the regular model M1. The comparison has been drawn in Table 8.

Table 8. Time history Frequency for models M1, M2, and M3

Mode	Frequency of model M1 m sec	Frequency of model M2 m sec	Frequency of model M3 m sec	Percentage change in frequency of M1 concerning M3 (%)	Percentage change in frequency of M2 concerning M3 (%)
1	1.024	1.013	0.969	-5.67	-4.54
2	1.295	1.264	1.204	-7.55	-4.983
3	1.433	1.388	1.253	-14.3655	-10.77
4	2.91	2.99	2.911	0.03	-2.71
5	3.574	3.692	3.662	2.40	-0.81
6	3.659	3.922	3.705	1.241	-5.85
7	4.758	4.835	4.205	-13.151	-14.98
8	4.941	4.921	4.909	-0.132	-0.04

Time-frequency increases from 1.024 Hz to 4.941Hz in model M1, from 1.013 Hz to 4.921Hz in model M2, and from 9.69 Hz to 4.909 Hz in the case of model M3. In general, it has been observed that the frequency in models M1 and M2 is higher than in model M3 except at floor levels 4,5,6, where the frequency is lower in M1 than M2. Model M2 has a higher frequency in comparison to model M3. The increase in frequency in model M1 is 5.67% (1.024H_Z) and 4.54% (1.013H_Z) in M2 concerning M3 (0.969H_Z) at the first-floor level, and the decrease in frequency in model M1 is 0.132 % (4.941H_Z) and -0.04% (4.941H_Z) in M2 concerning M3 (4.909H_Z) at 8th floor. Percentage increase in frequency M1 concerning M3 from mode -1to mode-3 is 5.67% to 14.36%, and then it decreases from mode 4 to 6, and again, it increases in mode-7 to mode-8. The percentage change in frequency M2 concerning M3 from mode-1 to mode-8 is 4.54% to 0.04%. Since mode-3 has shown significant change, it may have some relationship in 3-floor level geometrically M1 and M2 at floor-2. Table 8 exhibits the function's behavior of frequency changes at level 3 and level 7 in M1. Therefore, there appears to be some relation between the point of geometric irregularity and frequency modes as on floor 3; mode 3 has a significant change in its frequency increased to M3. Frequency has another considerable change at mode seven which means a band formation in frequency has happened. Therefore, irregularity plays a vital role in the response behavior of the structures. The model M2, which is more irregular, shows more frequency than M1 and has a higher frequency than M3 (regular).

4.7 Time history acceleration

Table 9. Time acceleration in seismic zone IV for models M1, M2, and M3

Mode	X-Acceleration of model M1 (E-3 m/s^2)	X-Acceleration of model M2 (E-3 m/s^2)	X-Acceleration of model M3 (E-3 m/s^2)	% Change in the acceleration of M1 concerning M3 (%)	% Change in the acceleration of M2 concerning M3 (%)
1	3.904	5.84	5.58	30.03	-4.65
2	7.994	11.8	11.3	29.25	-4.42
3	9.68	14.5	13.3	27.21	-9.022
4	8.59	14.5	11.7	26.58	-23.93
5	7.28	13	9.68	24.79	-34.29
6	7.49	12.7	10.1	25.841	-25.74
7	10.3	18.3	13.9	25.899	-31.65
8	13.4	23.2	17.9	25.1396	-29.60

Table 10. Time acceleration ratio of models M1, M2, and M3

Time acceleration (M1) (E-3 m/s^2)	Time acceleration (M2) (E-3 m/s^2)	Time acceleration (M3) (E-3 m/s^2)	Time acceleration ratio concerning the lower floor (M1)	Time acceleration ratio concerning the lower floor (M2)	Time acceleration ratio concerning the lower floor (M3)
3.904	5.84	5.58	1	1	1
7.994	11.8	11.3	1.047643	1.020548	1.02509
9.68	14.5	13.3	0.210908	0.228814	0.176991
8.59	14.5	11.7	-0.1126	0	-0.1203
7.28	13	9.68	-0.1525	-0.10345	-0.17265
7.49	12.7	10.1	0.028846	-0.02308	0.043388
10.3	18.3	13.9	0.375167	0.440945	0.376238
13.4	23.2	17.9	0.300971	0.26776	0.28777

The acceleration increases along with the floors. It varies from 3.90% to 13.40% in case of M1; 5.84 % to 23.2% in M2 and 5.58% to 17.9% in M3 from floor -1 to floor 8. The acceleration change is almost the same in M1 and M2 concerning M3 after floor -3, an area of geometric irregularity interference. However, From Figure 11(a-b), acceleration in model M1 is less s in all floors than in model M2 and model M3. Last floor which is 8th floor in each models has the highest time acceleration i.e., 13.4 E-3 m/s^2, 23.2 E-3 m/s^2, and 17.9 E-3 m/s^2 for M1, M2, M3 respectively. The decrease in Time Acceleration in frame model M1 is 30.03 % (3.904 E- m/s^2), and an increase of 4.65 % (5.84 E-3 m/s2) in M2 concerning M3 (5.58 E-3) m/s^2 at the first-floor level is the most critical level for such studies as most of the mass participation comes from this floor. The decrease in Time Acceleration in frame model M1 is 25.13% (13.4 E -3 m/s^2) and increase of 29.60 % (23.2 E-3 m/s^2) in model M2 with reference to model M3 (17.9 E-3 m/s^2) at 8-floor level. Figure 11(c-d) exhibits that time acceleration has tangible effects at level 2, the area of geometric irregularity for M2. Due to geometric irregularity, the time acceleration behavior differs from floors 2 to 4.

4.8 ComparisonTime history velocity

Table 11. Time velocity of models M1, M2, and M3

Mode	X-Velocity of model M1 (E-3 m/s^2)	X-Velocity of model M2 (E-3 m/s^2)	X-Velocity of model M3 (E-3 m/s^2)	Percentage change in velocity of M1 concerning M3 (%)	Percentage change in the rate of M2 concerning M3 (%)
1	165	282	255.5	35	-10.37
2	361	629	571	36	-10.15
3	507	931	807	37.17	-15.36
4	604	1140	951	36.48	99.47
5	676	1260	1030	34.36	-22.33
6	752	1330	1070	29.71	-24.29
7	825	1400	1100	25	-27.27
8	895	1480	1130	20.79	-30.97

Figure 12 of time history velocity is zero at the ground because the base is fixed. For the 2nd floor in the model, M1 velocity is 165 E-3 m/s on the 1st floor and 895 E-3 mm/s on the 8th floor. Model M2 velocity is 282 E-3 mm/s on the 1st floor and 1480 E-3 mm/s on the 8th floor. In model M3 velocity varies with height i.e., 255.5 E-3 m/s to 1130 E-3 m/s. The velocities in all the M1, M2, and M3 models are different. It can be observed that the M2 has the highest velocity, which is a most irregular model. The time velocity is lower in M1 than in M2, which has less geometric irregularity. Therefore, it can be concluded that geometric irregularity affects the time velocity in the structure, and it is different in some of the interference of geometric irregularity.

4.9 Irregularty shape factor

An attempt has been made to define an irregularity shape factor (ISF) for a rectangular geometrical structure. The use of the moment of inertia has been made a basis for such a factor. The effect of the geometry of the designs has been reflected in terms of irregularity shape factor ISF. A comparison has been made concerning the regular geometrical shaped model M3. The variation in the response behavior has been attributed to the irregularity in geometry created in the structure. The Regularity Ratio (RR) has been defined as the ratio of Igxy (M1 or M2) / Igxy for (M3) as per the model studies in consideration.

5. Conclusions

The seismic analysis of geometric irregularity in multistoried RC frames has been carried out. Three types of models, M1 (geometrically less irregular), M2 (geometrically more irregular), and M3 (geometrically regular), have been used under seismic zone IV conditions. It has been concluded from the study that geometric irregularity affects the displacement in the structure. There is more change in dynamic response in more geometrically disturbed models than in the regular ones less disturbed. It has also been found that there is a change in displacement, one story down and one level up from the floor where geometric irregularity has been created. It also has been observed that the cut out at a base affects the entire floor (horizontally), having changes in displacement at horizontal nodes. Consequently, special attention is required in such stories for structural treatment. One of the primary concerns in geometrical irregularities is the localization of seismic demand, which must be fulfilled per the analysis requirement. The structural geometric irregularity affects the time-frequency also. It is a more geometrically irregular structure than the regular ones—the time acceleration increases along with up- floors. The change in time acceleration is visible at the level of geometric irregularity. The time velocity increases along up bottoms of the structures. The shift in time velocity is visible at the level of geometric irregularity on floor 3 for (M1) and floor-2 (M2). The behavior of time velocity is nonuniform on floors 1 and 3 for M2, and on floors 2 and 4 remains the same for M1. A term defined as Irregularity Shape Factor corresponding to the geometry of the structures reflects the geometric irregularity of the design. The Irregularity Shape Factor (ISF) for model M1 is 0.24 and 0.26 for the M2 model; from such factor, the degree of irregularity of the structure can be assessed.

Declarations

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Data Availability Statement: The data used to support the findings of this study are included in the article.

Conflicts of Interest: The author declares that there is no conflict of interest

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Figures

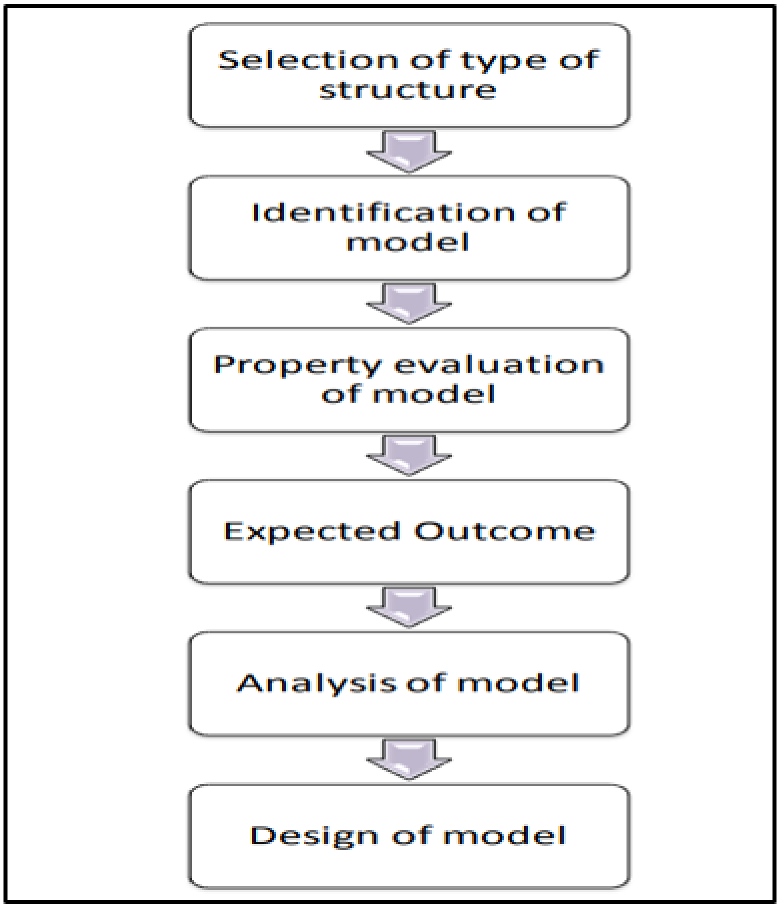


Figure 1

Flow Chart of the RC frames models for eight storeys

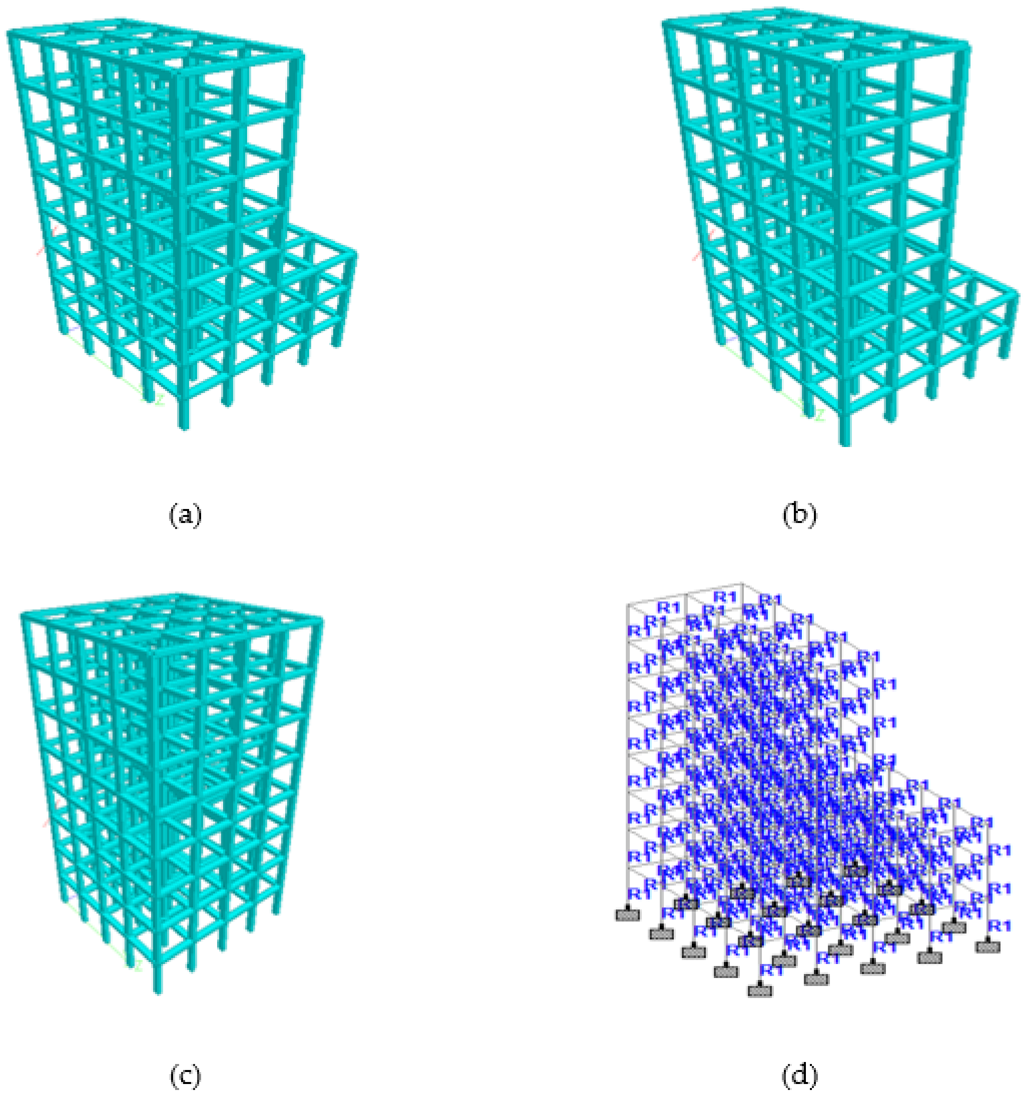


Figure 2

Geometrically Shape of the structure for models M1, M2, M3. (**a**) Model M1 Geometrically less irregular structure; (**b**) Model M2 Geometrically more irregular structure; (**c**) Model M1 Geometrically stable structure; (**d**) Properties on the whole structure.

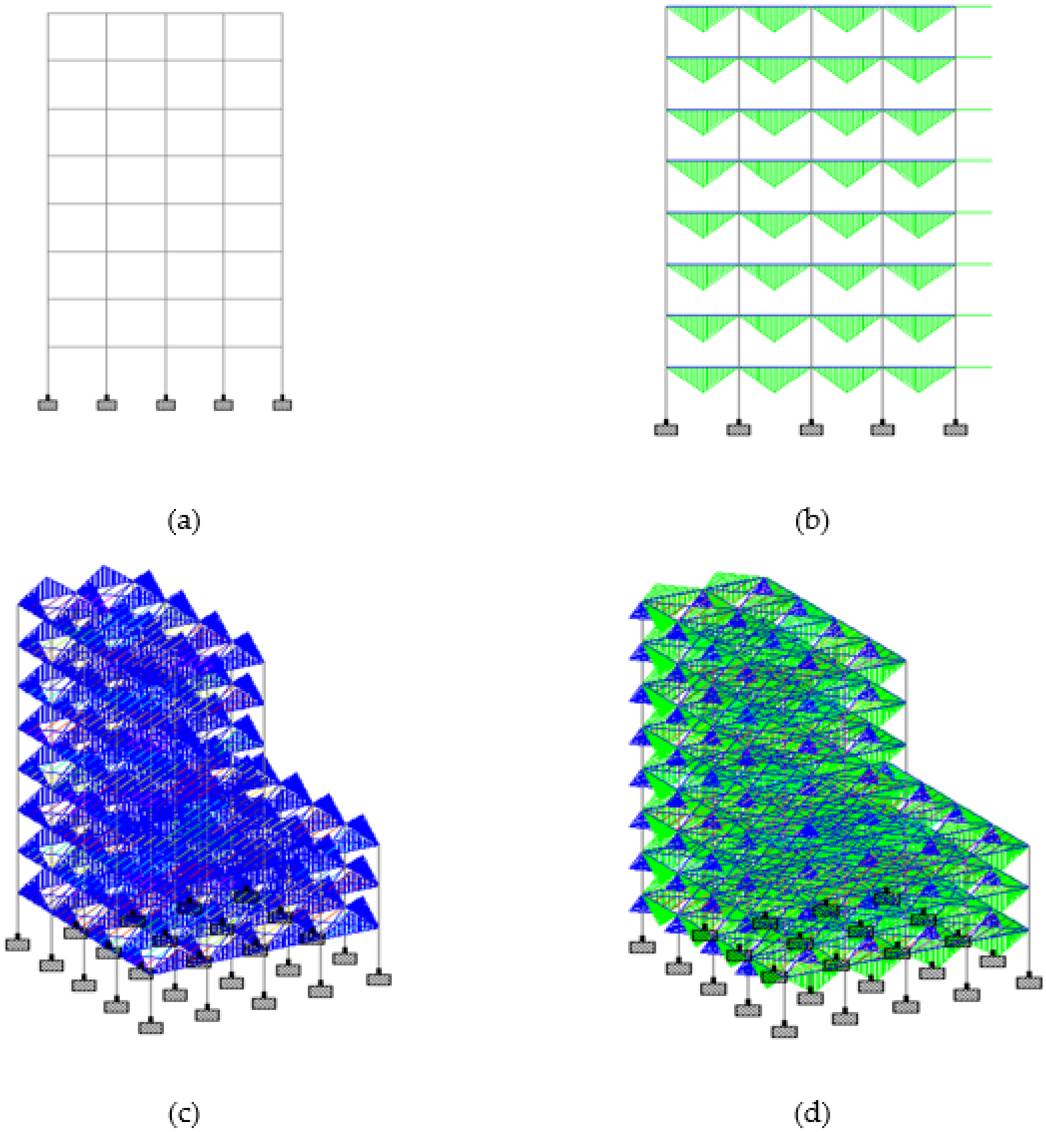
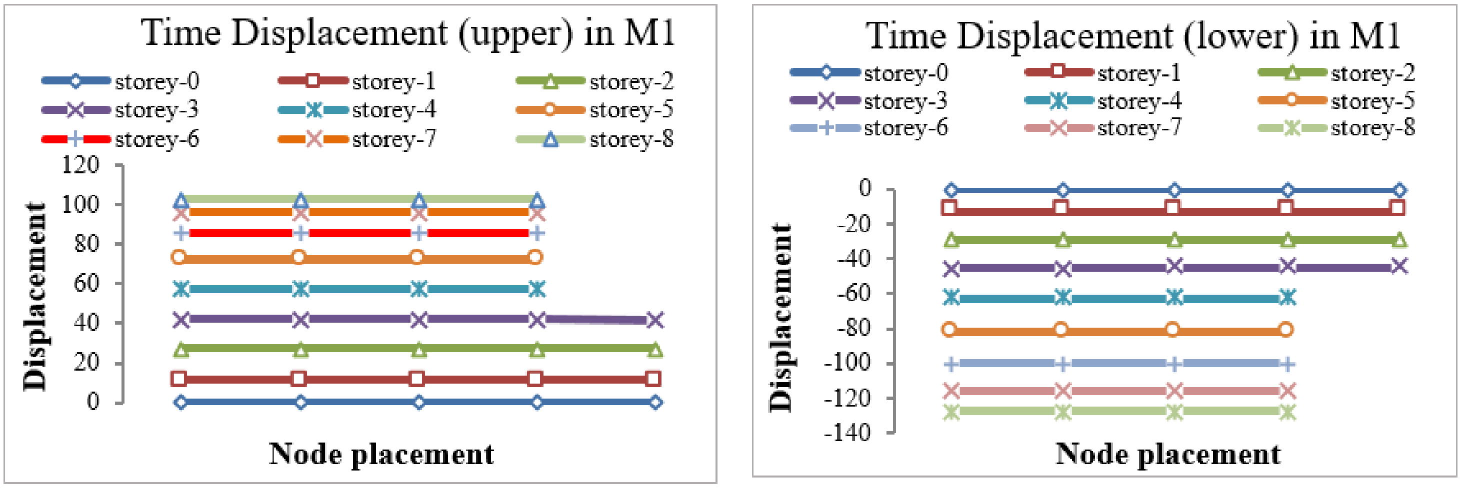


Figure 3

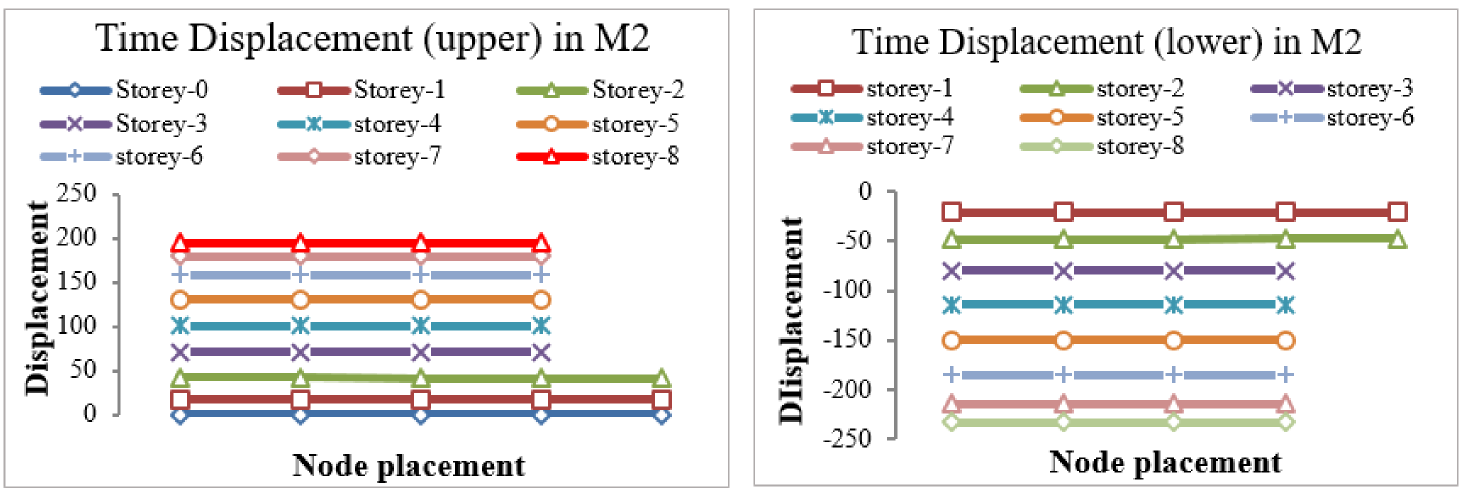
Shape and load on the structure for models M1, M2, M3. (**a**) 2D shape of Structure; (**b**) Floor load on the structure; (**c**) Static floor load on the structure; (**d**) Dynamic load on the structure.



(a) (b)

Figure 4

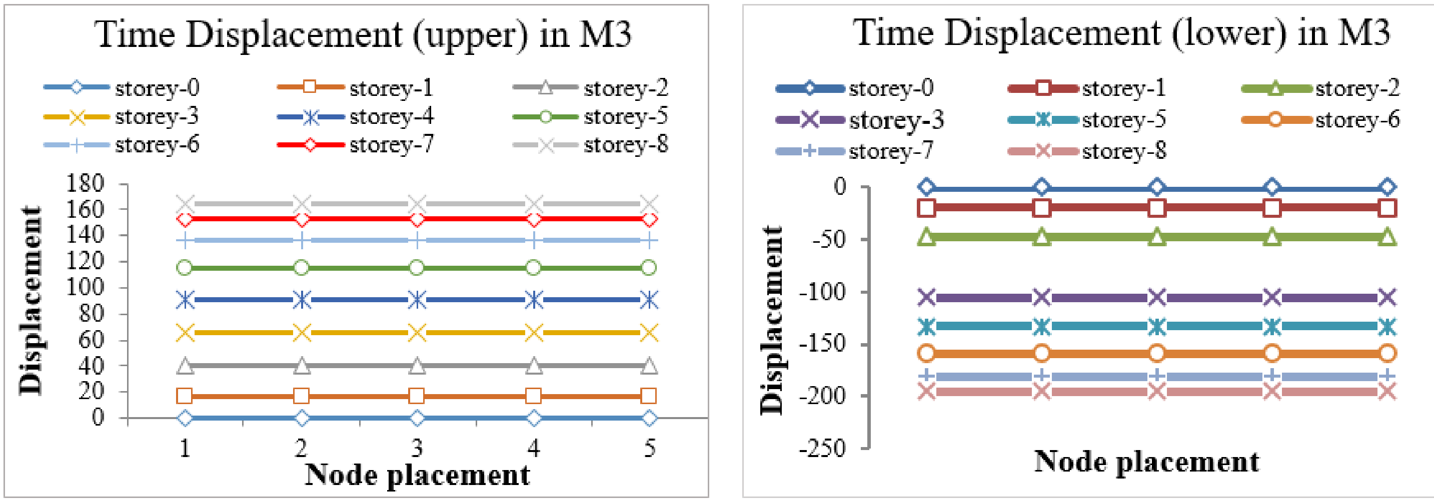
Time history displacement in model M1 (**a**) Geometrically less irregular structure(upper); (**b**) Geometrically less irregular structure(lower).



(a) (b)

Figure 5

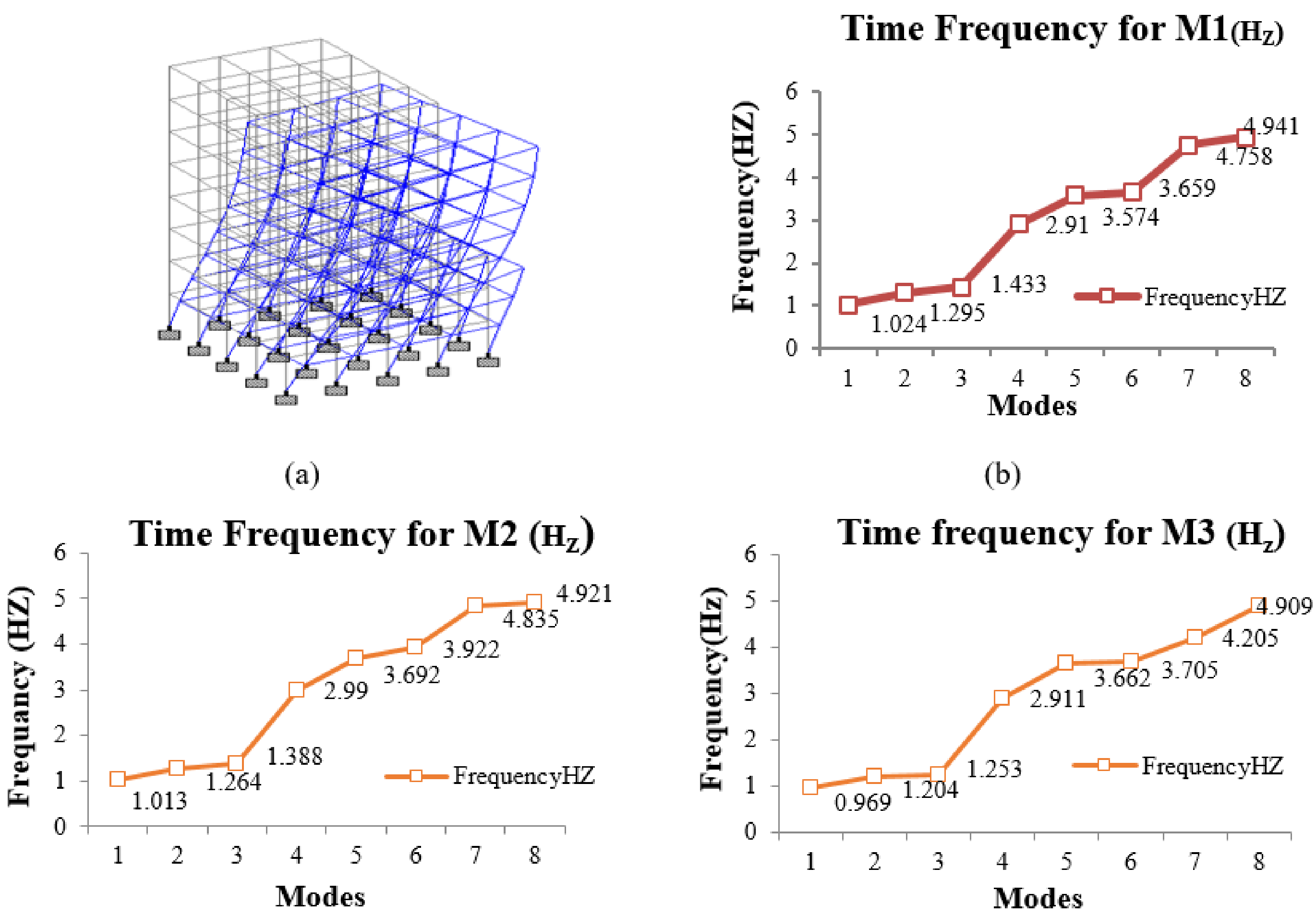
Time history displacement in model M2 (**a**) Geometrically more irregular structure(upper); (**b**) Geometrically more irregular structure(lower).



(a) (b)

Figure 6

Time history displacement in model M3 (a) Geometrically regular structure(upper); (b) Geometrically regular structure(lower).



(a) (b)

(c) (d)

Figure 7

Time-frequency relationship for models M1, M2, M3 (**a**) Time Frequencies mode shape model; (**b**) Time-frequency for model M1; (**c**) Time-frequency for model M2; (**d**) Time-frequency for model M3.

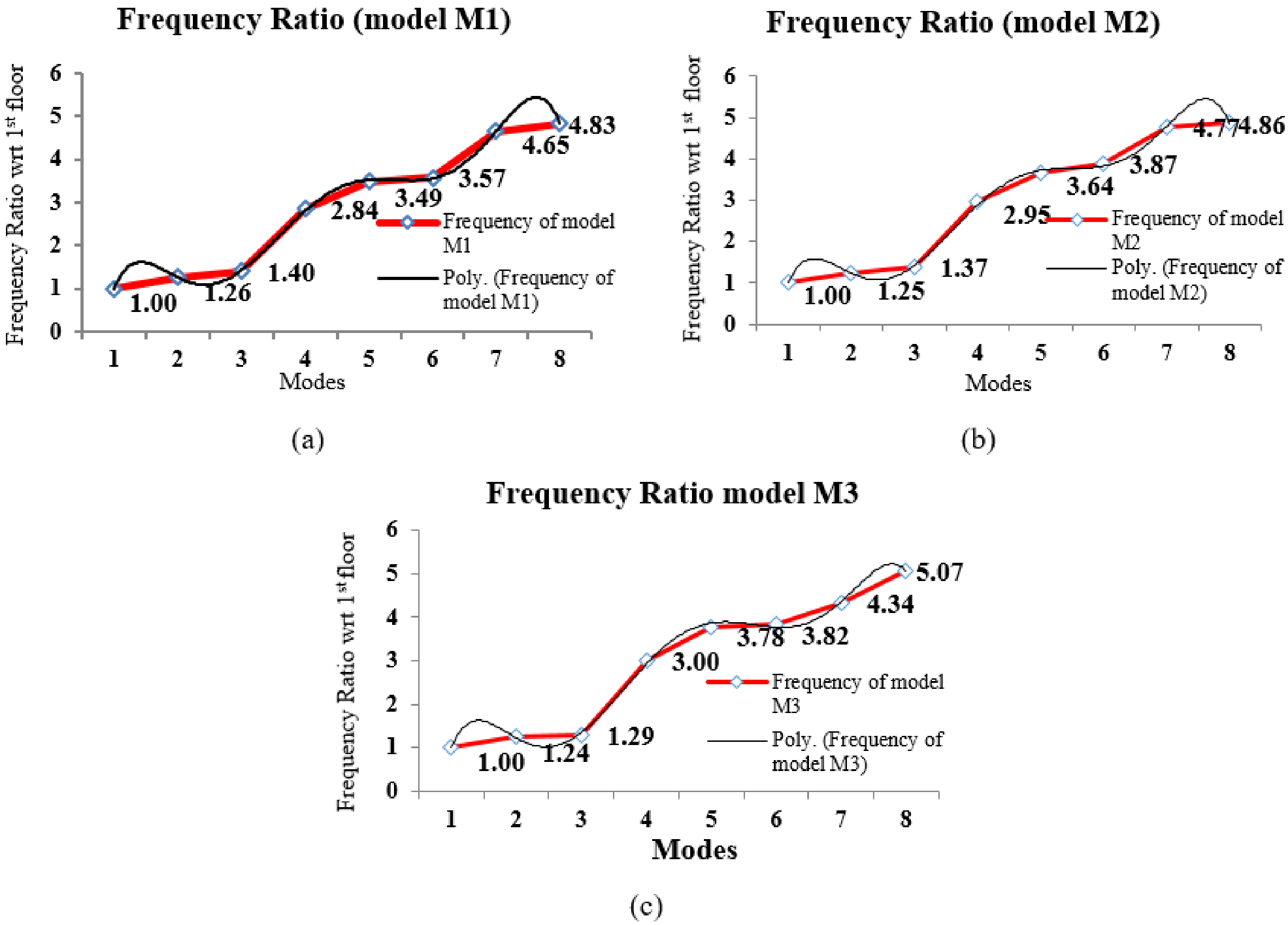


Figure 8

Relationship of frequency ratio concerning the first one (fundamental frequency) for models M1, M2, M3 (**a**) frequency ratio for model M1; (**b**) frequency ratio for model M2; (**c**) frequency ratio for model M3.

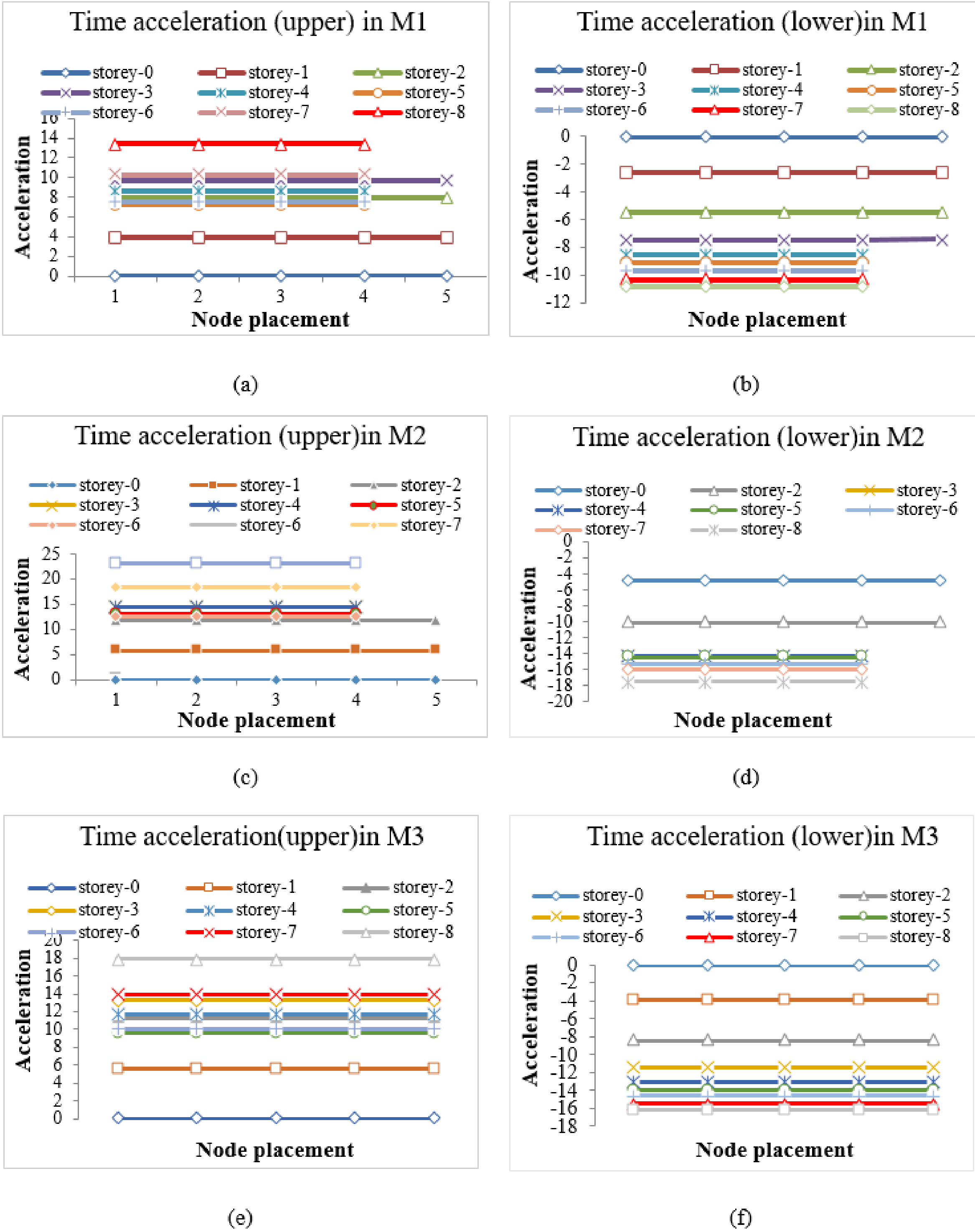


Figure 9

Time acceleration in models M1, M2, M3 for upper and lower direction (**a**) Geometrically less irregular structure (Upper) for M1 model; (**b**) Geometrically less irregular structure (Lower) for M1 model; (**c**) Geometrically more irregular structure (Upper) for model M2; (**d**) Geometrically more irregular structure (Lower) for model M2; (**e**) Geometrically stable structure (Upper) for model M3; (**f**) Geometrically stable structure (Lower) for model M3.

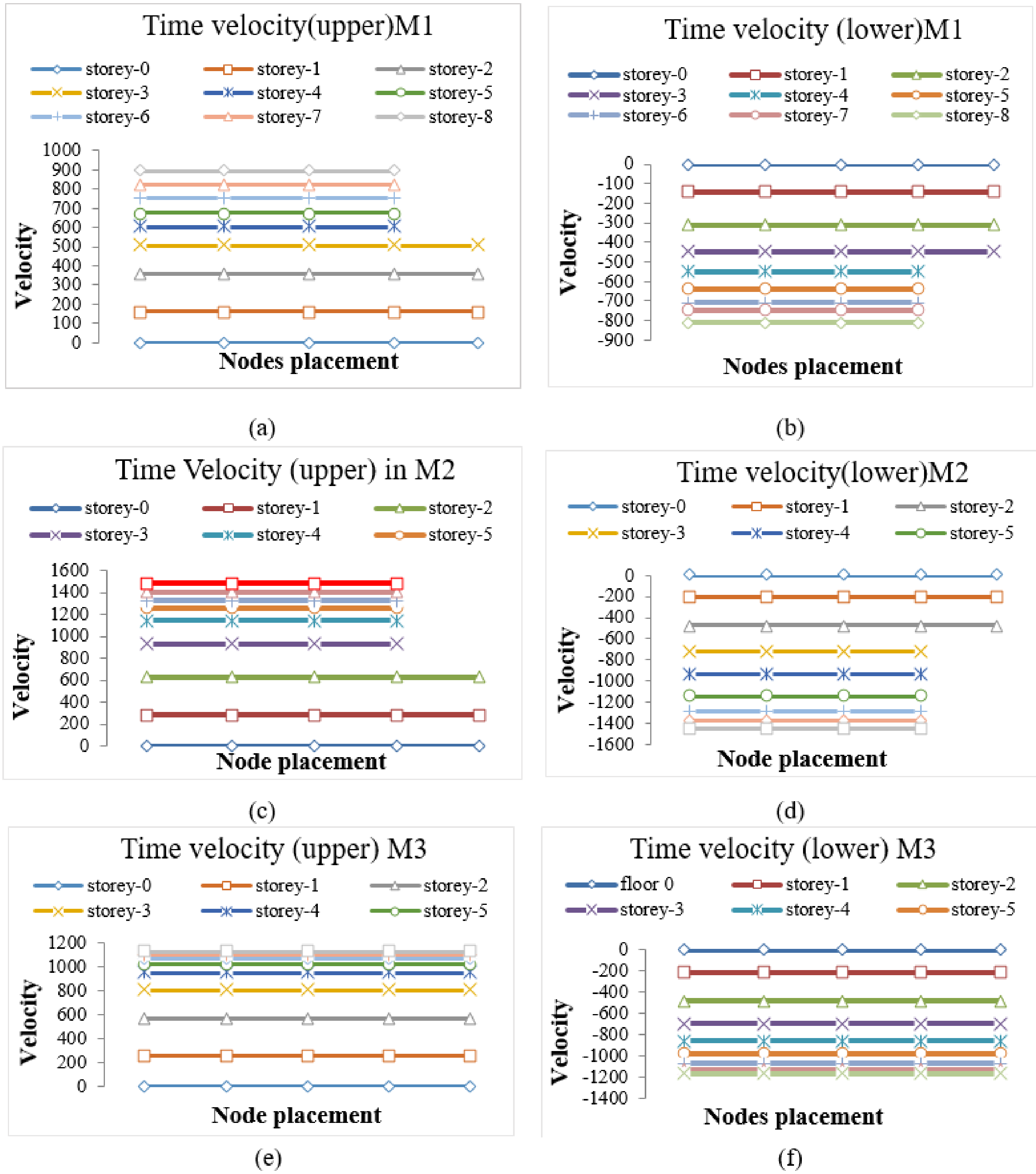


Figure 10

Time velocity in models M1, M2, M3 for upper and lower direction (**a**) Geometrically less irregular structure (Upper) for M1 model; (**b**) Geometrically less irregular structure (Lower) for M1 model; (**c**) Geometrically more irregular structure (Upper) for model M2; (**d**) Geometrically more irregular structure (Lower) for model M2; (**e**) Geometrically stable structure (Upper) for model M3; (**f**) Geometrically stable structure (Lower) for model M3.

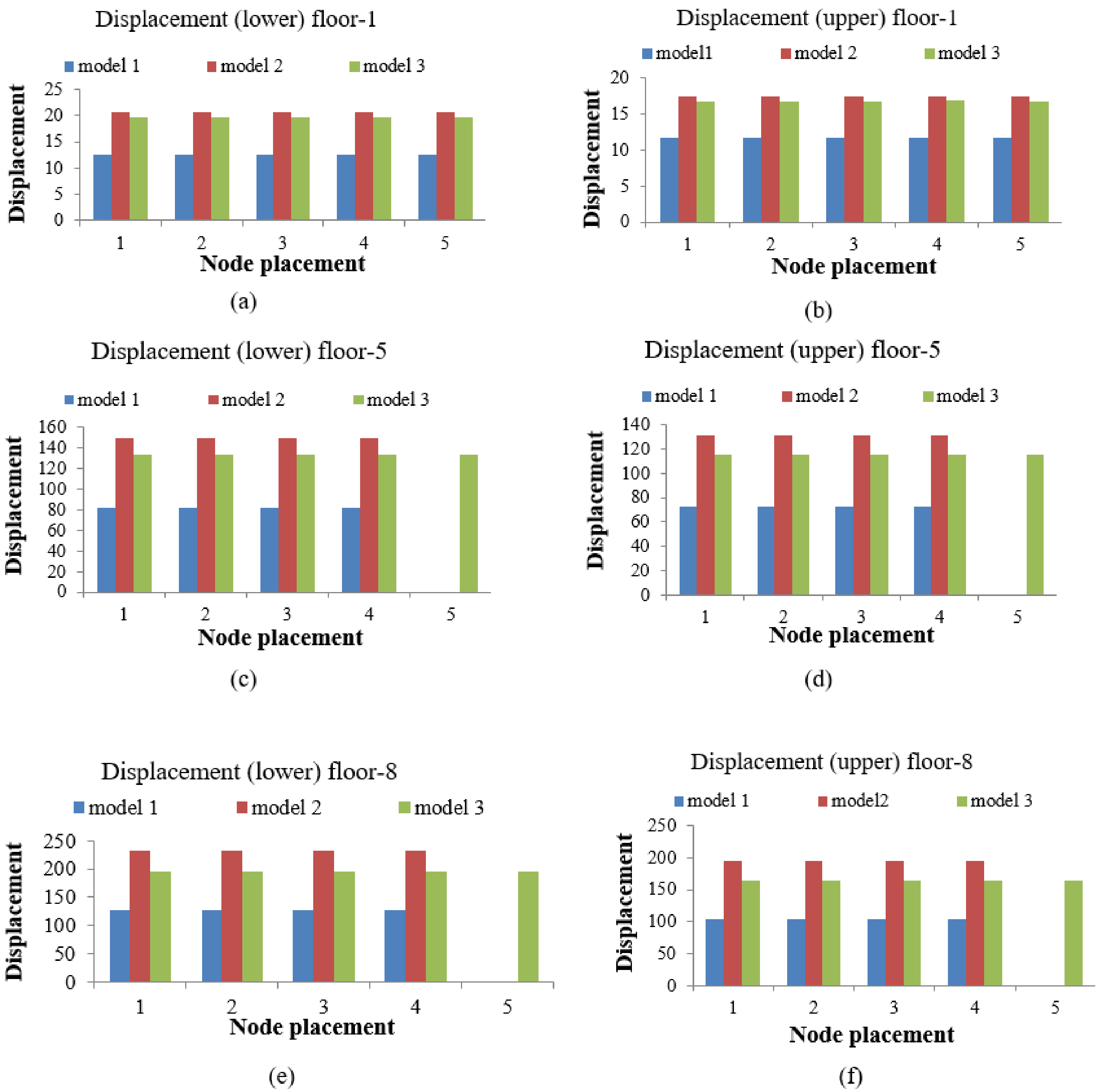


Figure 11

Time history displacement for Models M1, M2, and M3 (**a**) Time history displacement (lower) at 1st floor; (**b**) Time history displacement (upper) at 1st floor; (**c**) Time history displacement (lower) at 5th floor; (**d**) Time history displacement (Upper) at 5th floor; **(e**) Time history displacement (Lower) at 8th floor; (**f**) Time history displacement (Upper) at 8th floor.

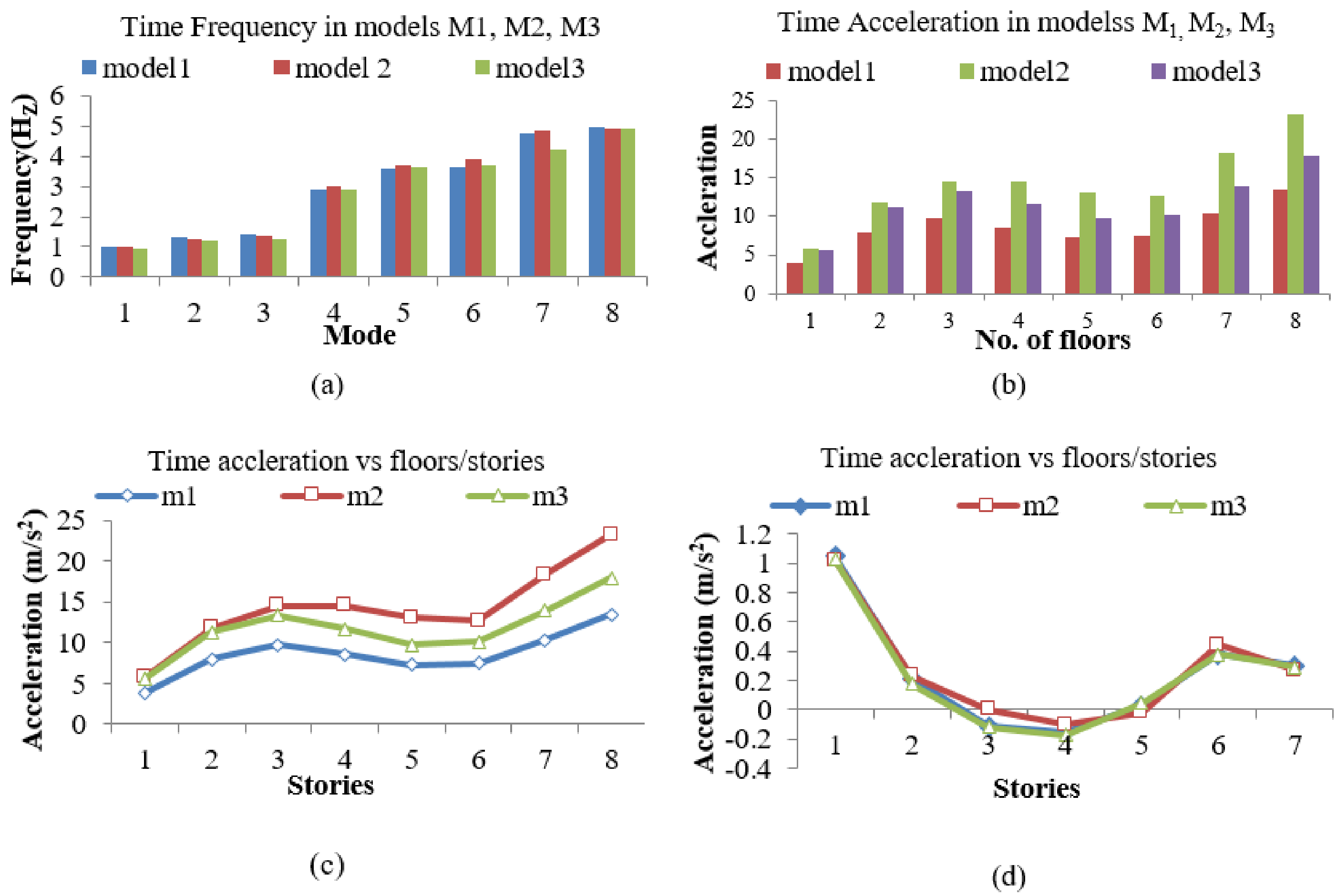


Figure 12

Time frequencies and acceleration of models M1, M2, and M3 in seismic zone IV

(a) Time frequencies in seismic zone IV; (b) Time acceleration in seismic zone IV; (c) Time acceleration ratio (lower); (d) Time acceleration ratio (Upper).

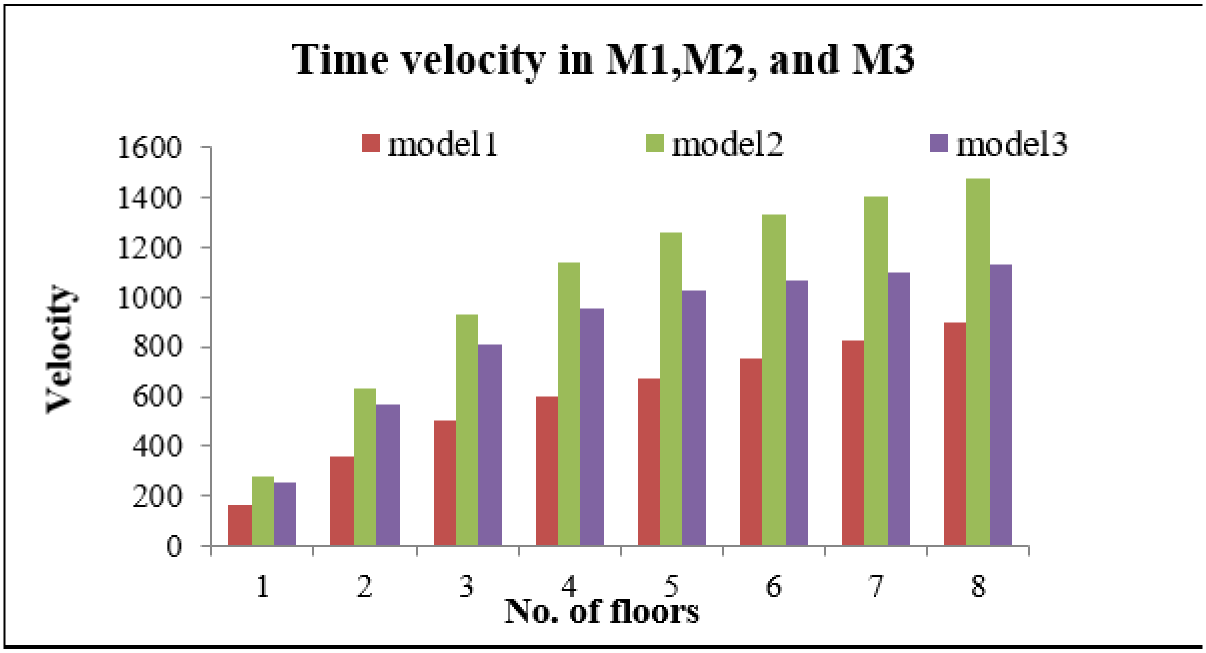


Figure 13

Time velocity of the model M1, model M2 and model M3 in the seismic zone