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Seismic performance of RC plane frame building Irregular in Mass

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Abstract

With increase in urban infrastructure, irregularities in buildings are increasing. These irregularities are results of aesthetic and functional needs. Past research works give clear difference between seismic response of regular and irregular building configurations. Seismic analysis and design of 10 storey Reinforced Concrete (RC) Moment Resisting Frame building is given in this paper. Vertical irregularity in terms of mass variation is present. Indian codes of practices are used for the modelling and analysis of building such as IS 1893(Part-1):2016 and IS 456. Linear static, linear dynamic and nonlinear time history analysis are used to get seismic response. Twenty-three earthquake ground motions have been used. Evaluated results such as displacement, storey drift, inter storey drift and storey shear are compared with regular building having similar configuration.

Keywords: Mass irregularity, Seismic response, Vertical irregularity; Plane frame, Seismic analysis.

1. Introduction

Vertically irregular structure is one which contains irregular distribution of mass, strength and stiffness along the building height. Architectural, functional, and economical constraints bring irregularities in building structures. As per IS 1893:2016, a story in a building is said to contain mass irregularity if its mass exceeds 150% than that of the adjacent story. Many existing buildings contain irregularity and sometimes buildings are designed to be irregular to fulfil different functional needs. Different usage of a specific floor with respect to the adjacent floors results in irregular distributions of mass, stiffness and strength along the building height. Buildings with simple regular geometry and uniformly distributed mass and stiffness in plan and in elevation suffer much less damage, than buildings with irregular configurations.

Eggert [1] has considered 2D plane frame. Ductility demand of many floors changes with variation of the mass ratio. Author has considered 5, 10 and 20 storey frame structures for seismic response evaluation considering stiffness, mass & strength of the structure. The structural response is calculated using time-history analysis using UBC procedure. Author considered heavy mass at 1st, 5th and 10th storey.

Al-Ali &Krawinkler [2]considered 10 storey vertically irregular structurewith height(H) wise variation of the seismic demands. Authors have used concept of strong beam & weak column (Column hinge model) philosophy. 15 strong ground motions(GMs) recorded on rock or firm soil are used. Elastic and Inelastic Dynamic analyses are carried out for a vertically irregular building withstiffness,mass & combination stiffness and mass irregularity. Elastic seismic response is assessing by considering elastic dynamic properties like fundamental period ratio, mode shape, modal participation factor & effective modal masses, drift,shear, overturning moments. It is found that the with increase in total mass ofthe structure there is a increment in the fundamental period and decrement in thespectral strength demand.

Das & Nau [3] have considered different vertical irregularities like mass, strength and stiffness due to presence of non-structural masonry infill. Linear analyses and Nonlinear Dynamic Time History are performed on the total 78 buildings of 5,10 and 20storey.All 78 buildings which are subjected to GMs have SMRF design as per ELF process andstrong-column and weak-beam (SCWB) criteria of ACT 318-99 and UBC-1997. It is observed that ELF rocess given in code is unnecessarily conservative for some types of vertical irregularities. From the analytical study, it is found out that the combination of irregularities has more impact on the seismic response. In addition, an unexpected variation in the seismic response is examined near the location of irregularities. It is also determined that the mass irregularity has the minimum on the structural damage index and, for all building models analysed, it is found to be less than 0.40.

Choi [4] has determined the seismic response of building frame with vertical mass irregularities. 3 cases are

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Table 1. Mass limits and empirical equations for estimating fundamental period as per different codes of

Sr. No	Name of Code	Year	Mass irregularity limit	Time Period equation
1	UBC	1997	$M_r < 150\%$	$C_t h^{0.75}$
2	EC 8	2004	-	$C_t h^{0.75}$
3	KBCS	2005	$M_r < 150\%$	$C_t h_n^{0.75}$
4	NBCC	2015	$M_r < 150\%$	0.01N
5	IS 1893	2016	$M_r < 150\%$	$\frac{0.09h}{\sqrt{d}}$
6	NBC	2016	$M_r < 150\%$	$\frac{0.09h}{\sqrt{d}}$
7	ASCE 7	2016	$M_r < 150\%$	$C_t h_n^x$
8	IBC	2018	-	$C_t h_n^x$

M_r - mass irregularity limit, C_t - constant which varies for different codes,
T - fundamental period, h - total height of the building, N – number of stories.

studied: (i) mass irregularities at the bottom position, (ii) at the middle storey , and (iii) at the top storey position It is found that seismic demands are higher in the third case. When mass irregularity was present in the top position hysteric energy demands was observed to be greater than that drift demand [4].

Devdas Menon [5] has suggested a new method for dynamic characteristic i.e, mass & stiffness to quantify irregularity in building frame. This weakness might be created either by discontinuities in stiffness or mass between adjacent storey and it is a reason of sudden variation in the geometry of the frame along the whole height of building.

Varadharajan [6] hasconsidered single parameter to quantify stiffness, mass and strength irregularity in terms of both location and magnitude. Author has proposed the dynamic characteristics of the building. Building model is analysed considering different type of irregularity with variation in magnitude and location of irregularity. 27 GMs are considered in analysis. With the help of the regression analysis the seismic response databank parameters like maximum roof displacement, maximum inter-story drift ratio and fundamental period are proposed for the irregular buildings in terms of the proposed irregularity index. Author has also validated proposed equation on 2D and 3D building models [6].

2. DESIGN CODE PERSPECTIVE REGARDING MASS IRREGULARITY

The limit of mass irregularity as per different codes of practice is shown in Table 1practice [7-14]. Codal approaches specify irregularity in terms of its magnitude only and the aspect of irregularity locationhas been ignored.However, in actual practice, both magnitude and location ofirregularity play acritical role in deciding the seismic performance.

3. BUILDING FRAMES USED IN THE STUDY

The present study is based on 10 storey plane RC frame with bay width and storey height equal to 6 m and 3 m, respectively as shown in Fig. 1 Fundamental time period is

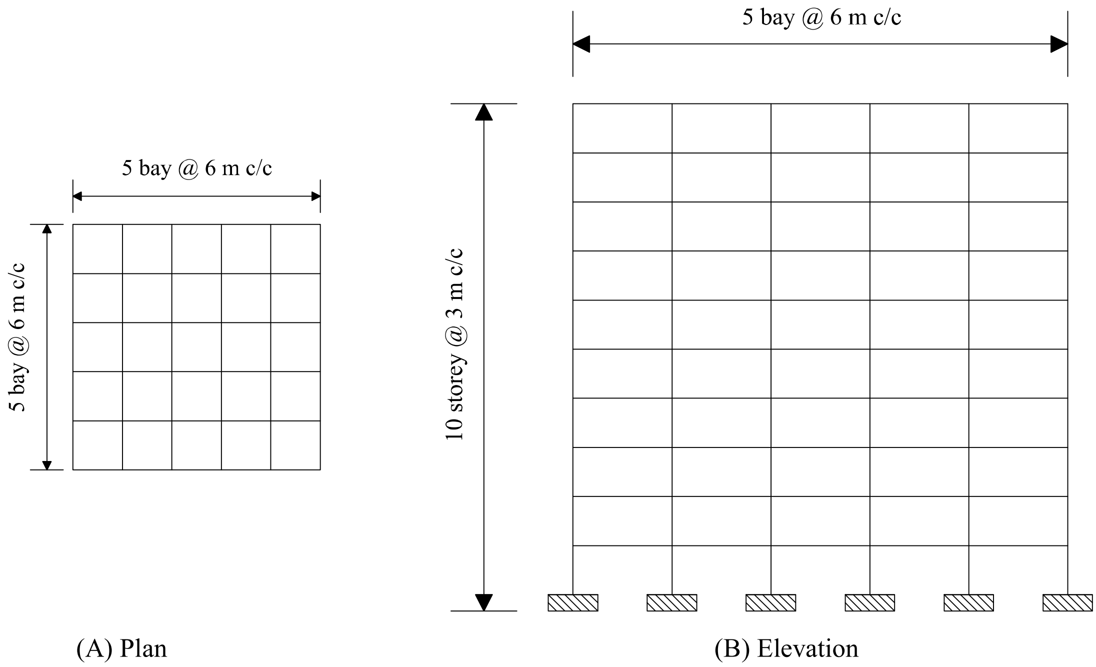

Fig 1. Basic layout of the building model.

Table 2. Seismic coefficient IS 1893 (Part 1):2016

Z^1	I^2	R^3	*Type of soil*[4]	ξ^5
0.36	1.2	5	I	5 %
1. Seismic Zone Factor defined in Table 3				
2. Importance factor defined in Table 8				
3. Response reduction factor defined in Table 9				
4. Type of soil defined in Table 4				
5. Damping Ratio defined in Cl. 7.2.4				

1.08 sec, Grade of concrete is 25 N/mm^2 and Grade of steel is 415 N/mm^2. Beam and column dimensions are 350 mm × 350 mm and 450 mm × 450 mm, respectively. Slab thickness of 120 mm is considered in analysis. Triangular load Pattern is considered in analysis. Live load at Floor and Roof are 4 kN/m^2 and 2 kN/m^2, respectively.

4. QUANTIFICATION OF MASS IRREGULARITY

As per the seismic code irregularity can be effectively captured by the dynamic analysis response of the buildings, which can be effectively represented by dynamic analysis response parameters such as frequency of vibration and mass participation factors.

Modal Mass (M_k) for each mode can be given by as per IS 1893:2016 Part 1.

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \phi_{ik}\right]^2}{g \sum_{i=1}^{n} W_i (\phi_{ik})^2} \tag{1}$$

The modal participation factor (P_k) in Mode (k) can be obtained from the equation as suggested by Rayleigh as (reported in IS 1893:2016 Part 1)

$$P_k = \frac{\sum_{i=1}^{n} W_i \phi_{ik}}{\sum_{i=1}^{n} W_i (\phi_{ik})^2} \tag{2}$$

Where ϕ_{ik} = Mode shape coefficient at floor i in mode k, W_i = Seismic weight of floor i, g = Acceleration due to gravity, M_k = Modal mass of mode k, P_k = Mode participation factor of mode k.

Mass variations considered in an analysis are shown in Fig 2. In Base case model mass ratio considered as 1 and other mass variation is considered with respect to base case. MM(1)*2 represent MM is mass modification, (1) is storey, 2 mass ratio factor with respect to base case. MM(1-5) * 0.5 represent MM is mass modification, (1-5) is storey, 0.5 mass ratio factor with respect to base case.

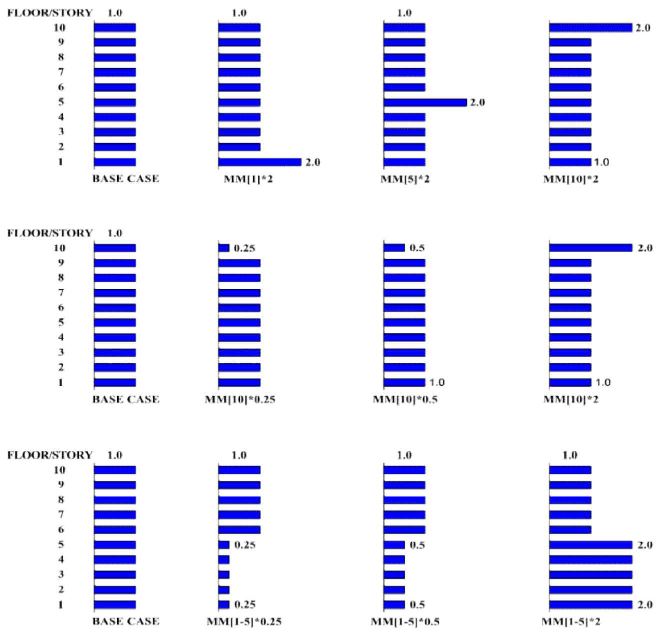

Fig 2.Ratios of Modified Masses of the Cases with Mass Irregularities to the Masses of the Base Case

4.1 Results linear static and linear dynamic of mass irregularity configurations based on codal approach

Results obtained through Linear Static analysis are shown in Fig.3a, 3b, 3c and 3d.Results from Linear Dynamic analyses are shown in Fig. 4a, 4b, 4c and 4d. Maximum displacement from the Linear Static analysis is 21.6 mm, maximum Drift is 2.85 mm, maximum inter-storey drift is 0.00098 and story shear is 92.1 kN. From Linear Dynamics analysis maximum displacement is obtained as 15.1mm, maximum Drift is 2.25 mm, maximum inter-storey drift is 0.00077 and story shear is 77.9 kN.

4.2 Nonlinear Time History analysis of mass irregular configurations

Selection of Time History is based on Codal design spectra and scaled Time Histories are selected from PEER. Input parameters are Magnitude (Mw), Epicentral distance (R_{jb}), Shear velocity (V_s) which are selected as per ASCE 7-16 and period is matched between 0.2T to 1.5T where T is time period of structure. From Free Vibration analysis fundamental time period is obtained 1.08 sec. Set of 23 GMs is as shown in Table 3. All time history are processed in

Commercial software SeismoMatch 2020 and used as an inputto software ETABS. In analysis, P - Δ effect and material nonlinearity are included. Hilber Hughes Taylor isused for a direct integration. Mass and stiffness proportional damping is also used in the present analysis.

5.2.1 Results of Base Case

Results obtained from Time History analysis for a base case are shown in Fig. 5 (a-d)

5.2.2 Results of Bhuj and Uttarkashi Earthquake on different mass configurations

Fig 6(a-d) represent results obtained for mass irregular configuration for Bhuj Earthquake and Fig 7(a-d) represent results obtained for Uttarkashi Earthquake

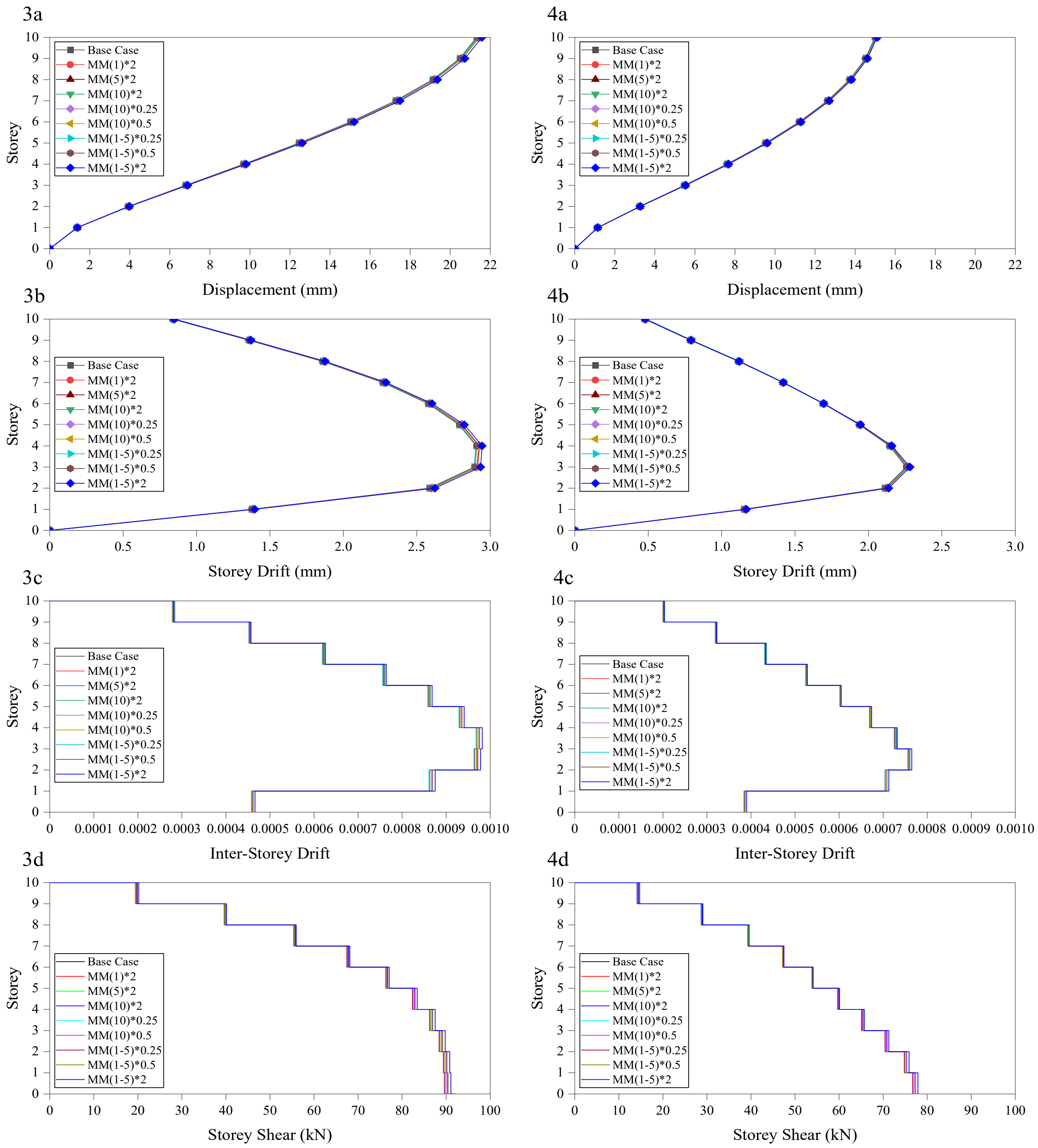

Fig 3 (a-d). Results of linear static analysis and Fig 4 (a-d). Results of linear dynamic analysis

Table 3. Details of earthquake record

No	RSN	Event	Station	Mw	R_{jb} (km)
1	–	Bhuj	Ahmedabad	7.00	239.00
2	–	Uttarkashi	IITR station bhat	7.00	21.70
3	80	San Fernando	Pasadena - Old Seismo Lab	6.61	21.50
4	293	Irpinia_ Italy-01	Torre Del Greco	6.90	59.63
5	748	Loma Prieta	Belmont - Envirotech	6.93	43.94
6	771	Loma Prieta	Golden Gate Bridge	6.93	79.71
7	782	Loma Prieta	Monterey City Hall	6.93	39.69
8	796	Loma Prieta	SF - Presidio	6.93	77.34
9	798	Loma Prieta	SF - Telegraph Hill	6.93	76.40
10	1011	Northridge-01	LA - Wonderland Ave	6.69	15.11
11	1041	Northridge-01	Mt Wilson - CIT Seis Sta	6.69	35.53
12	1109	Kobe_ Japan	MZH	6.90	69.04
13	1112	Kobe_ Japan	OKA	6.90	86.93
14	1219	Chi-Chi_ Taiwan	CHY062	7.62	56.93
15	1245	Chi-Chi_ Taiwan	CHY102	7.62	36.06
16	1248	Chi-Chi_ Taiwan	CHY109	7.62	40.37
17	1442	Chi-Chi_ Taiwan	TAP067	7.62	95.31
18	1613	Duzce_ Turkey	Lamont 1060	7.14	25.78
19	1786	Hector Mine	Heart Bar State Park	7.13	61.21
20	1787	Hector Mine	Hector	7.13	10.35
21	5646	Iwate_ Japan	IWTH14	6.90	99.04
22	5680	Iwate_ Japan	MYGH04	6.90	40.42
23	8167	San Simeon_ CA	Diablo Canyon Power Plant	6.52	37.92

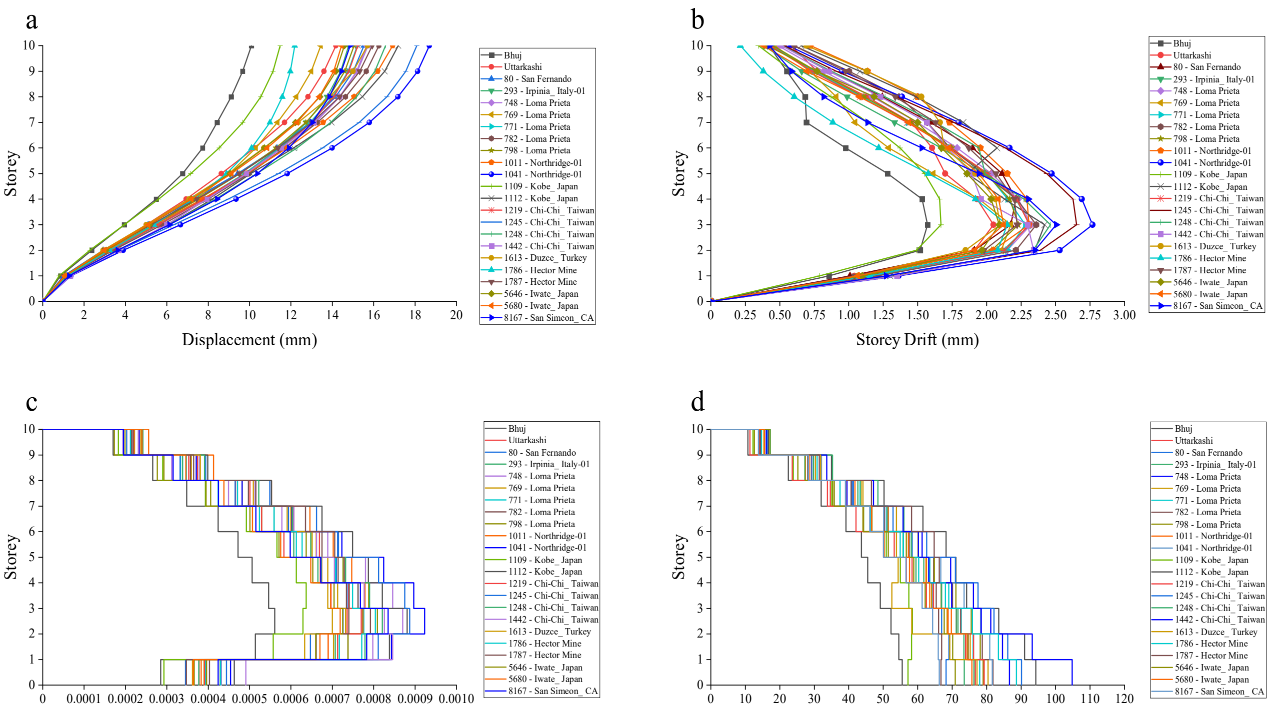

Fig 5.Base Case Results: (a) Displacement, (b) Drift, (c) Inter-Storey Drift, (d) Storey Shear

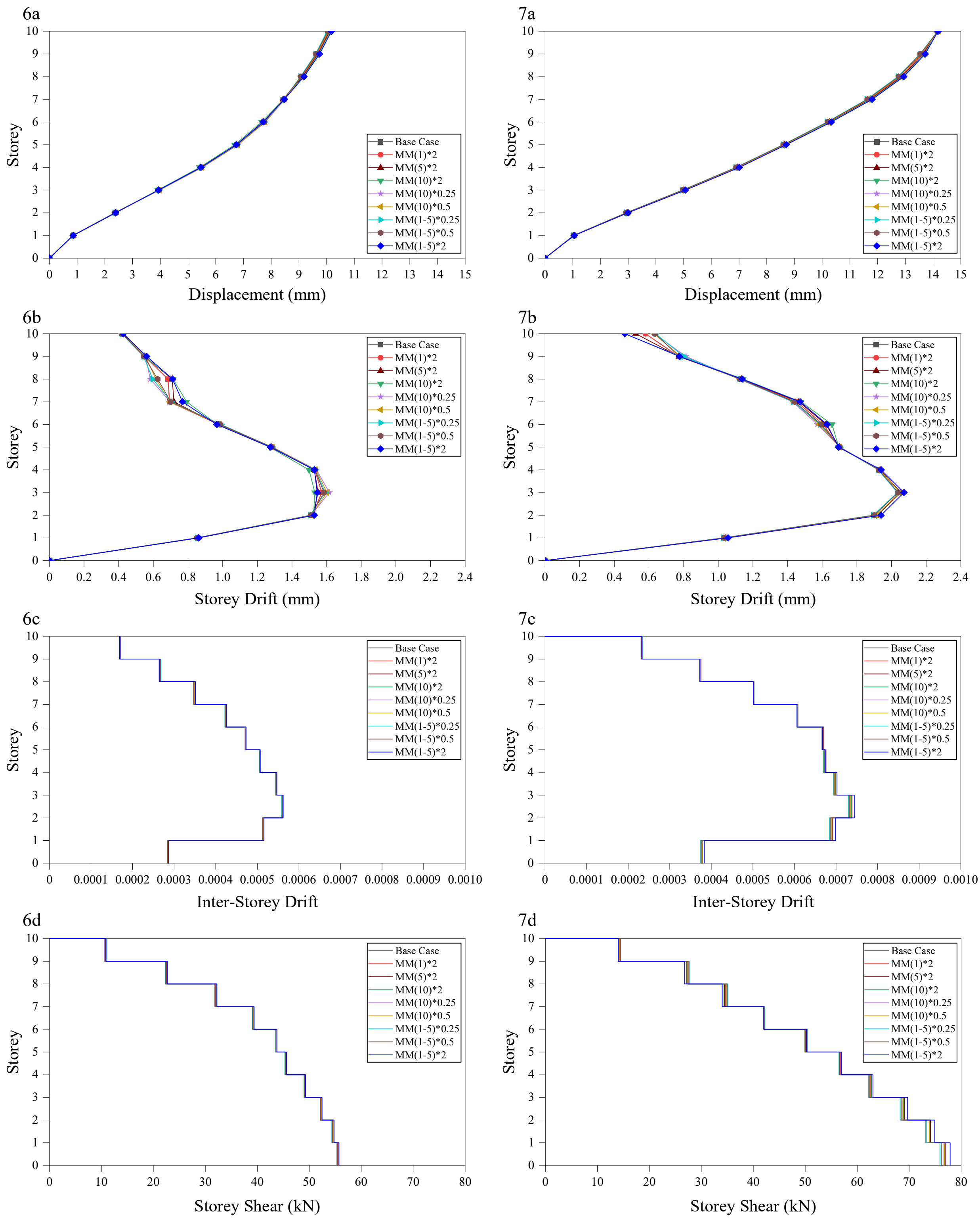

Fig. 6 (a-d). Results of Bhuj earthquake and Fig. 7 (a-d). Results of Uttarkashi earthquake

Table 4. Summary of seismic response

Seismic quantities	Case	Linear Static (%)	Linear Dynamics (%)	Nonlinear Time History (%)
Storey Displacement (mm)	MM(1-5)*2	100	56.76	55.56
Storey Drift (mm)	MM(1-5)*2	100	78.95	72.7
Inter-Storey Drift	MM(1-5)*2	100	78.57	75.51
Storey Shear (kN)	MM(1-5)*2	100	84.58	84.57

5. SUMMARY AND CONCLUSIONS

Results of summary presented in Table 4. For governing case MM(1-5)*2.

It is observed that the Equivalent Static method recommended by the IS code for low-rise structures given higher response characteristics like displacement, storey drift, inter-storey drift, storey shear as compared to Linear Dynamic and Nonlinear Time History Analysis. The governing case obtained through this study is MM(1-5)*2. Minimum seismic response is found in MM(1-5)*0.25 case. From Inelastic analysis maximum storey drift is found within codal prescribed limits. From Inelastic analysis maximum storey shear is found similar to linear dynamic analysis. It is noted that different mass ratios considered in the present study, give almost same result as compared to base case model. It is also observed that displacement, storey drift,

inter-storey drift, storey shear have mirror affect on mass irregularity.

Disclosures

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6. REFERENCES

1. Valmundsson, Eggert V., and James M. Nau. "Seismic Response of Building Frames with Vertical Structural Irregularities." *Journal of Structural Engineering* 123.1 (1997): 30-41.
2. Al-Ali, Ali AK, and Helmut Krawinkler. *Effects of vertical irregularities on seismic behavior of building structures.* John A. Blume Earthquake Engineering Center, (1999): 1-221.
3. Das, Satrajit, and James M. Nau. "Seismic Design Aspects of Vertically Irregular Reinforced Concrete Buildings." *Earthquake Spectra* 19.3 (2003): 455-477.
4. Choi, Byong J. "Hysteretic energy response of steel moment-resisting frames with vertical mass irregularities." *The Structural Design of Tall and Special Buildings* 13.2 (2004): 123-144.
5. Sarkar, Pradip, A. M. Prasad, and Devdas Menon. "Vertical geometric irregularity in stepped building frames." *Engineering Structures* 32.8 (2010): 2175-2182.
6. Varadharajan, S., V. K. Sehgal, and Babita Saini. "Seismic response of multistory reinforced concrete frame with vertical mass and stiffness irregularities." *The Structural Design of Tall and Special Buildings* 23.5 (2012): 362-389.
7. UBC. "Uniform building code." *International Conference of Building Officials, Whittier, CA*. (1997): 1-486.
8. EC 8 Part 1. "Eurocode 8: Design of Structures for Earthquake Resistance – Part 1: General Rules, Seismic Actions and Rules for Buildings." (2004): 1–231.
9. KBCS. "Korean Building Code." (2005): 1–37.
10. NBCC. "National Building Code of Canada" (2015): 1–1404.
11. IS 1893. "'Criteria for Earthquake Resistant Design of Structures, Part 1:General Provisions and Buildings.'" *Bureau of Indian Standards, New Delhi* 1893 (2016): 1–44.
12. NBC. "National Building Code Of India Volume 1." (2016): 1–1226.
13. ASCE 7. "Minimum Design Loads and Associated Criteria for Buildings and Other Structures." (2016): 1–889.
14. IBC. "International Building Code." (2018): 1–757.