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Nonlinear Seismic Behaviour of Torsional Reinforced-Concrete Structure Subjected to Earthquake Ground Motion

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Abstract: The present paper aims to prove importance of torsional effect when subjected to seismic ground motion load. As per IS1893:2016 irregularity considered in analysis of existing building in Mahad Mumbai. The seismic performance of conventional RC building frame, with fundamental mode in torsional compared with frame with shear wall and bracing is estimated through nonlinear time history analysis. The analysis is carried out in finite element software. The modal analysis is performed to investigate fundamental time period and mode shape direction. Finally it is proved that with the inclusion of shear wall, bracing and change in orientation of column positions reduces fundamental period of the building. The seismic performance of buildings is increased in terms of strength, displacements, drift and ductility compared to building with fundamental mode in torsion.

Keywords: ground motions, seismic analysis, shear wall, Story drift, time history, torsion,

I. INTRODUCTION

In construction industry the critical importance of considering seismic forces, including torsional effects, when designing civil structures in earthquake-prone regions. Earthquake ground motion refers to the shaking of the ground caused by the propagation of seismic waves through the Earth. It is the primary source of earthquake-induced forces on structures. Ground motion can vary significantly in amplitude, frequency, and direction depending on the earthquake's magnitude, depth, and distance from the epicenter. Seismic analysis is a crucial step in the design and evaluation of structures in earthquake-prone areas. Engineers use various methods to assess how a building will respond to ground motion. This analysis helps ensure that structures can withstand the forces generated by earthquakes and protect human life.

Torsion, or twisting, can occur in a building during an earthquake due to eccentricities between the center of stiffness and the center of mass. This torsional behavior can lead to unequal demands on structural elements, potentially causing damage or failure. Torsional effects are especially significant in irregular structures or those with asymmetrical mass and stiffness distributions. Irregularities in building shape, mass distribution, or stiffness can amplify torsional effects during earthquakes. Irregular structures may include setbacks, asymmetrical floor layouts, or changes in building height. These irregularities can result in uneven seismic forces and require special attention in the design process.

Engineers assess a structure's response to seismic forces using parameters like maximum story displacement and story drift. Maximum story displacement measures how much each floor moves during an earthquake, while story drift quantifies the relative displacement between adjacent floors. Both parameters are critical for evaluating structural performance and safety. Ductile structures are designed to undergo significant deformation during an earthquake while maintaining their integrity. This ductility allows them to absorb and dissipate seismic energy, reducing the risk of collapse. However, even in ductile structures, excessive torsional effects can lead to non-uniform deformation and potential damage. In summary, your study aims to investigate how torsion affects irregular structures during seismic events. Understanding the behavior of buildings under different ground motion scenarios is essential for improving the seismic resilience of structures and minimizing the risk to people's lives and property in earthquake-prone areas. Proper engineering practices and seismic design considerations are critical for achieving these goals.

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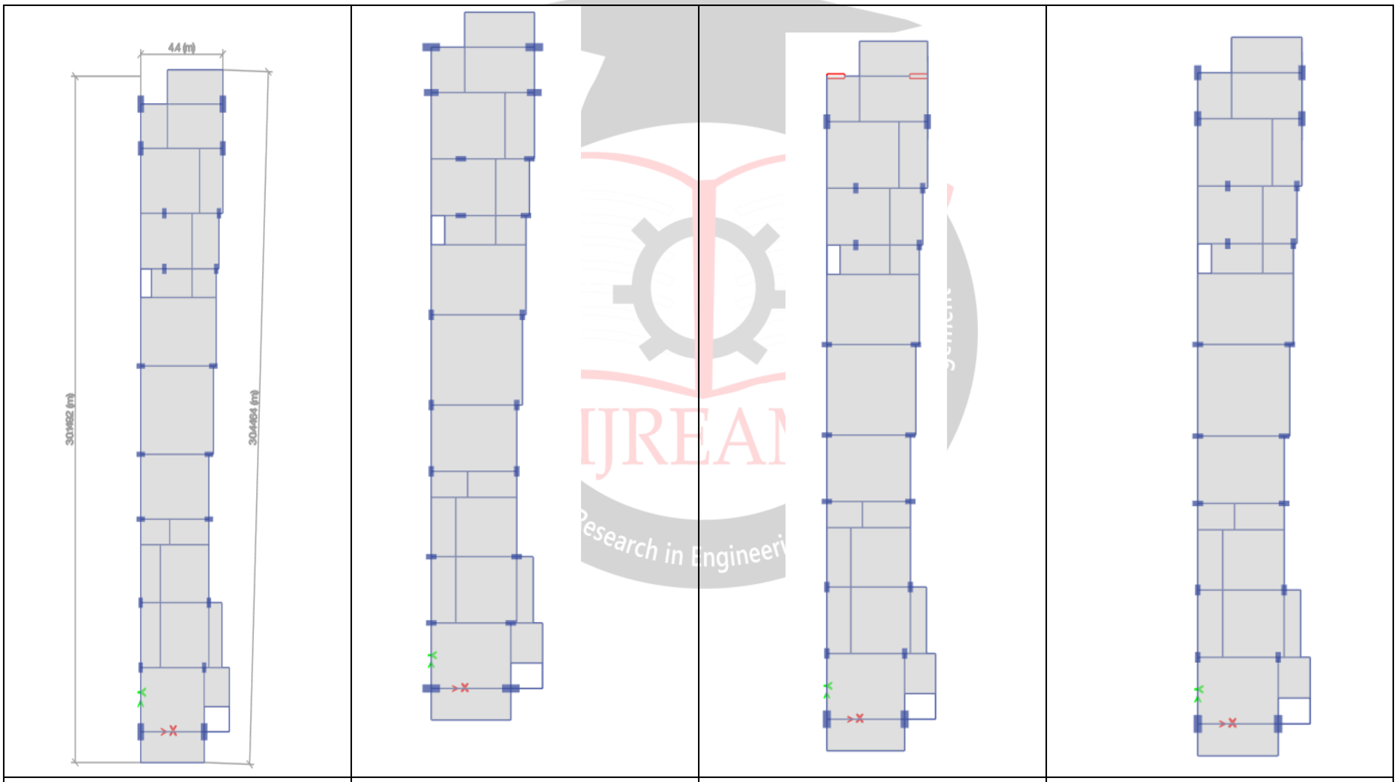
II. BUILDING MODEL CONSIDERED

The building taken for the study of torsional effect on the existing building has been constructed in Mahad in Mumbai. The building is slender shaped in plan. It has first floor as parking area with subsequent upper floor for use of residential purpose. At the building terrace has water tank. Plan and other building details are as follow.

1. Depth of footing = 1.5 m
2. Ground Floor Height = 3.1m
3. Typical Floor Height = 3.1m
4. Plan Dimensions = 4.40m × 30.15m
5. Column Dimensions = 300 mm×530 mm, 300 mm ×600 mm, and 300mm×650 mm as per design
6. Beam Dimensions = 230 mm X 450 mm, 230 mm X 530 mm
7. Slab Thickness = 125 mm
8. Live load = 2.0 kN/m^2
9. Floor Finish = 1.5 kN/m^2
10. External wall load = 11.28 kN/m
11. Internal wall load = 5.64 kN/m
12. Seismic zone = III
13. Soil type = Medium
14. Response reduction factor = 5
15. Type of frame = Special moment resisting frame

The building structure is modeled in ETABs 2018 finite element software for simulation of Gravity Loads and Lateral Load.



Model 1 **Model 2** **Model 3** **Model 4**

Fig.1 Plan of RC building frame

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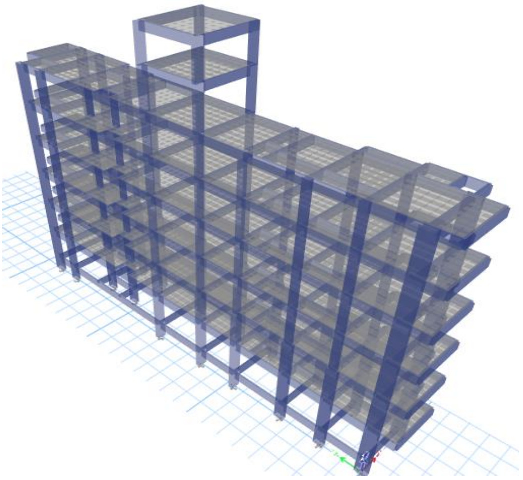

Fig. 2 Three Dimensional View of RC Building frame

III.NONLINEAR MODELING OF FRAME ELEMENT

In the present study, nonlinearity to beams and columns has been assigned using lumped plasticity approach recommended in FEMA356 (2000). The flexural hinges have been assigned, probably at the location near the end of the element. Flexural hinge for column is coupled degree of freedom (P–M–M) and for beam uncoupled (M_3) degree of freedom has been defined. In this study auto hinges are defined for beam and column element.

Table 1 Fundamental time period

Sr. No.	Fundamental period in Second			
1	Model 1	Model 2	Model 3	Model 4
2	1.313	1.154	1.224	1.221
3	1.237	1.079	0.959	0.922
4	0.981	1.022	0.876	0.592

Discussion fundamental time period

From table 1, it is observed that, fundamental time period has reduced by 12.10%, 6.78% and 7.0% in model 2, model 3 and model 4 respectively as compared to model 1. Hence model 2 gives higher stiffness as compared to other building models.

IV NONLINEAR TIME HISTORY ANALYSIS

Nonlinear dynamic time history analysis is the most perfect method used to predict seismic responses of structures subjected to ground motions.

To perform nonlinear time history analysis, ground motions directly applied to the model. The analysis is carried out using finite element software, and response parameters, namely maximum story displacement, and story drift, are compared

Table 2: The selection of ground motions data as per criteria given in FEMA p695.

Sr. No.	Criteria	Values or Types
1	Magnitude	6.5 – 7.5
2	Site class	B, C, D
3	Source type	Strike-slip, thrust
4	Source distance	More than 10 km
5	PGA	More than 0.2g
6	PGV	More than 30 m/sec

Selected Ground Motion Data

The time history data is obtained from the strong motion database of the Pacific Earthquake Engineering Research (PEER). The six ground motions considered for the study as shown in Table 3.

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Table no 3: Ground motion data

GM ID	Earthquake Name	Year	Recording Station Name	M	PGA (g)	PGV (cm/s)
1	San Fernando	1971	San GM	6.6	0.71	47
2	Kobe Japan	1995	Shin osaka	6.9	0.24	38
3	Lander	1992	Lucern	7.3	0.72	54
4	Cape Mendocino	1992	Rio Dell	7.0	0.55	44
5	Duzce, Turkey	1999	Duzce	7.1	0.82	62
6	Northridge	1994	Beverly Hills	6.7	0.48	45

V. RESULT AND DISCUSSION

Story Displacement

The time history analysis has been conducted on above mentioned models and performance has been measured in terms of displacement for said ground motion data.

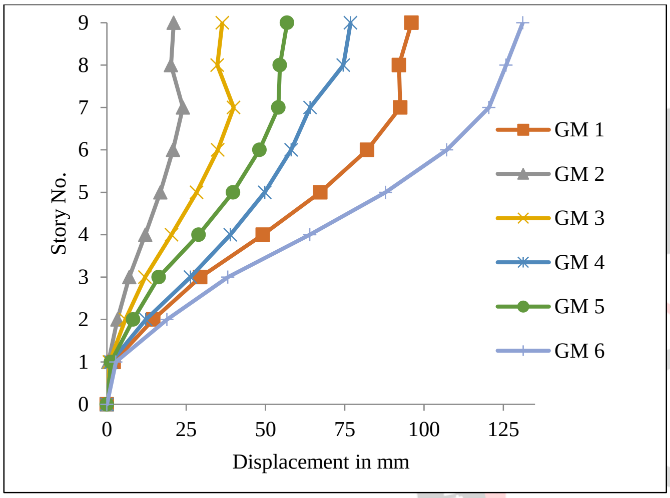

Fig.3 Story Displacement model 1 in X Direction

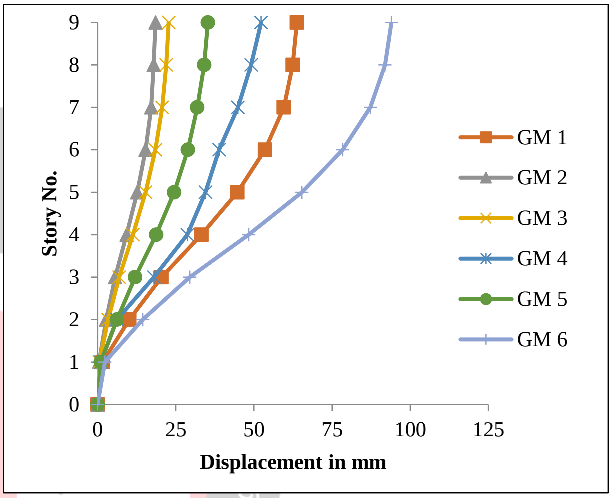

Fig.4 Story Displacement model 1 in Y Direction

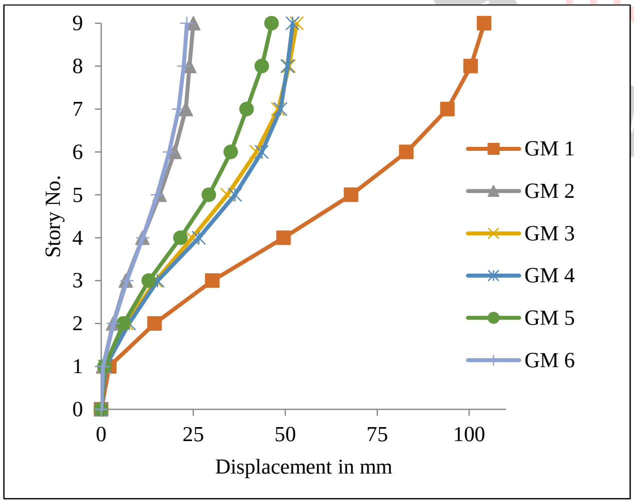

Fig.5 Story Displacement model 2 in X Direction

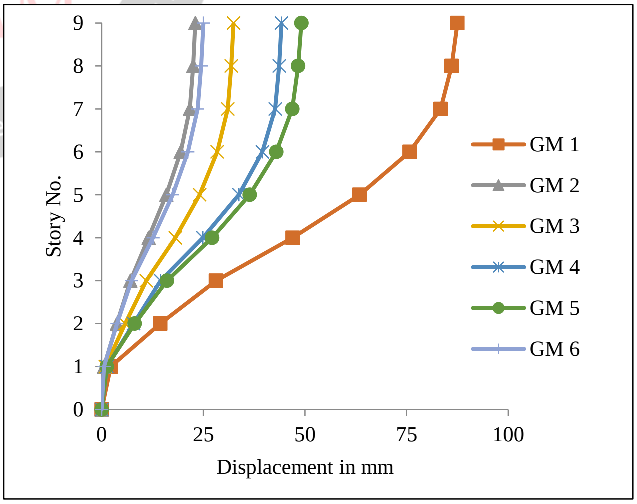

Fig.6 Story Displacement model 2 in Y Direction

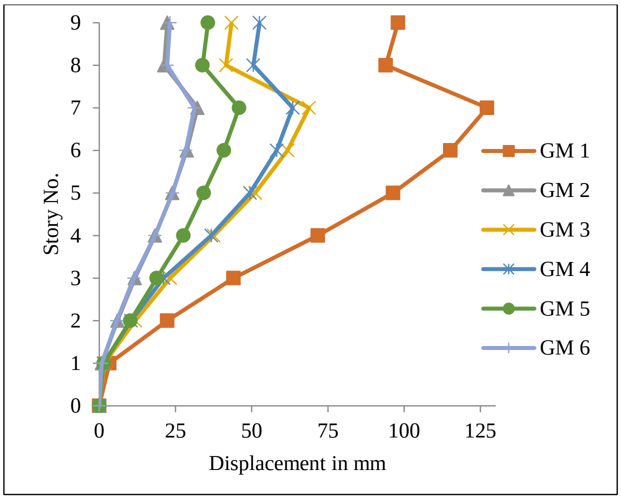

Fig.7 Story Displacement model 3 in X Direction

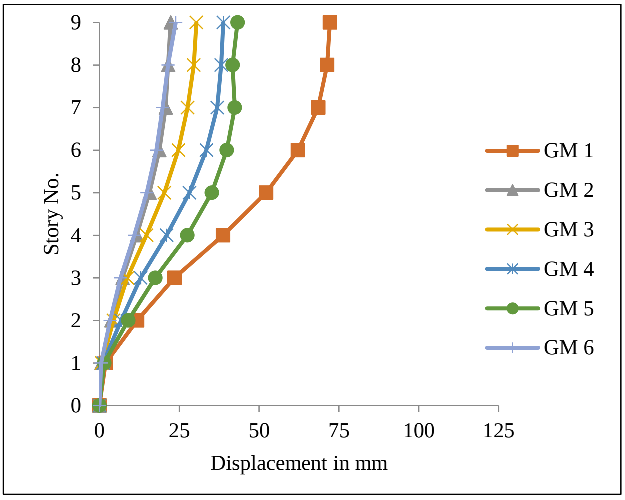

Fig.8 Story Displacement model 3 in Y Direction

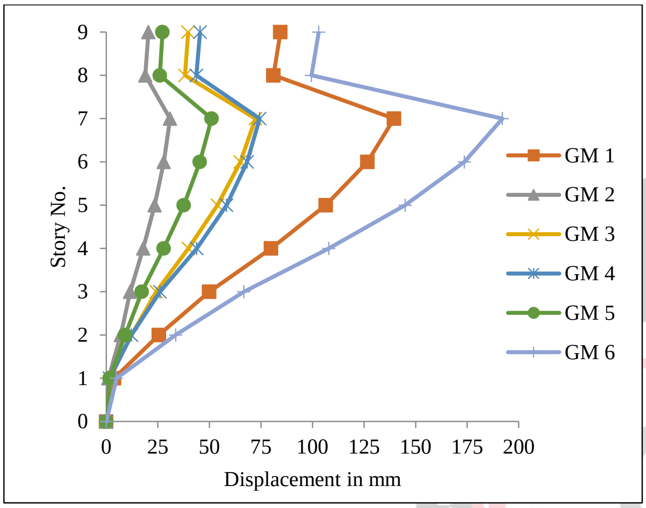

Fig.9 Story Displacement model 4 in X Direction

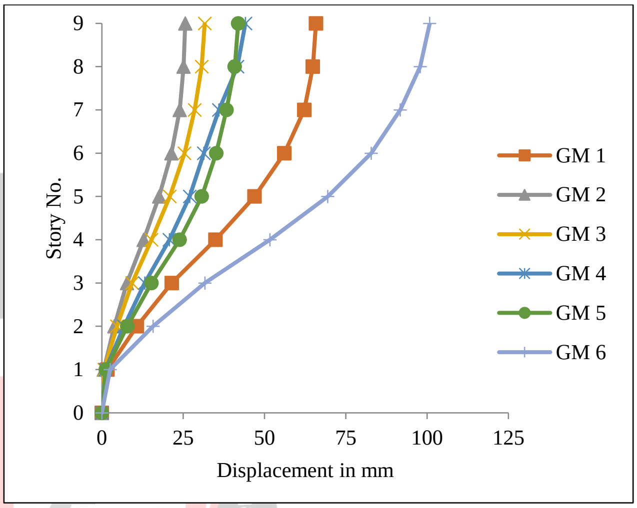

Fig.10 Story Displacement model 4 in Y Direction

Maximum story drift:

The inter-storey drift ratio is a significant engineering parameter and an indicator of structural performance. As per IS 1893 (Part 1), the storey drift in any storey due to the minimum specified design lateral force, with a partial load of 1.0, shall not exceed 0.004 times the storey height.

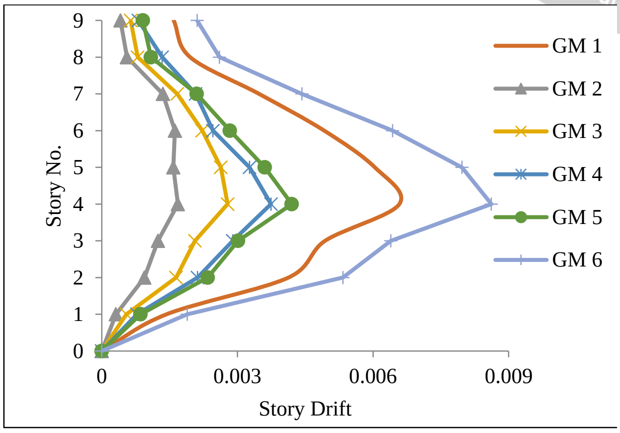

Fig.11 Story Drift model 1in X Direction

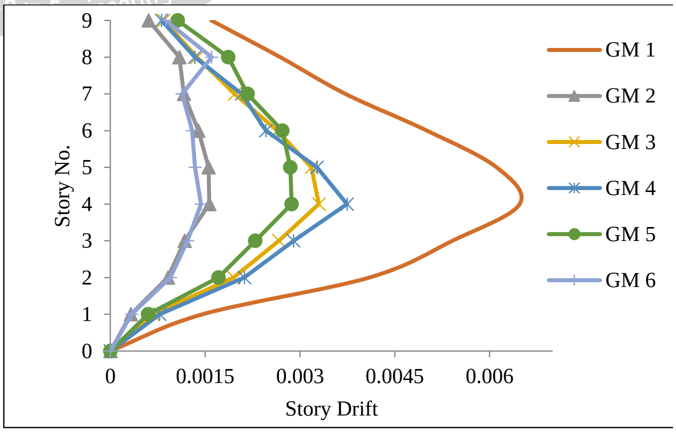

Fig.12 Story Drift model 2 in X Direction

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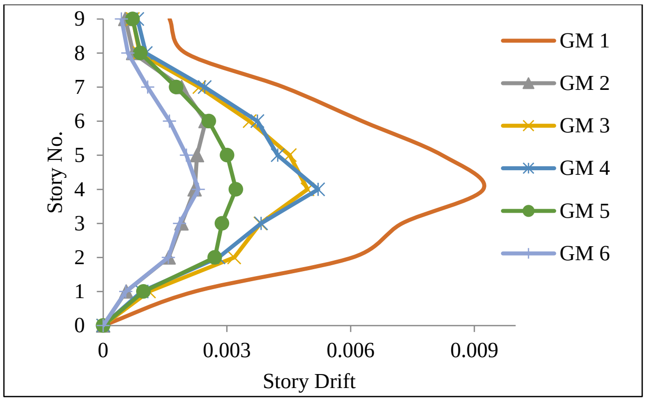

Fig.13 Story Drift model 3 in X Direction

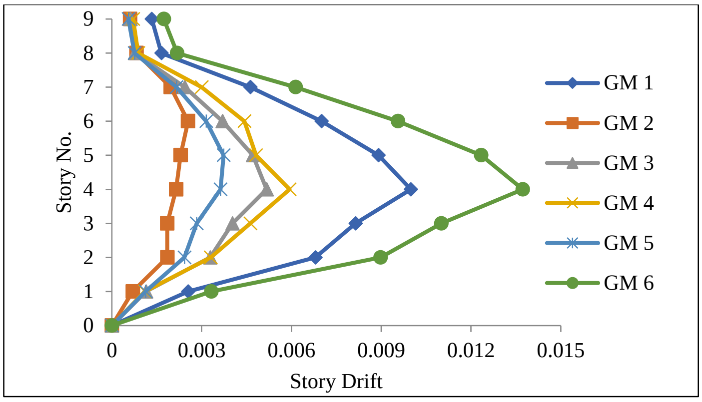

Fig.14 Story Drift model 4 in X Direction

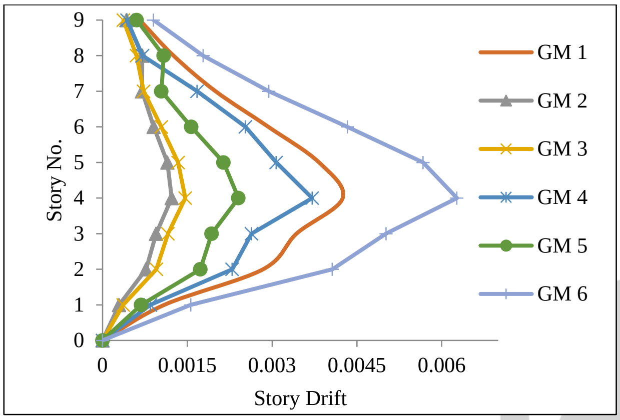

Fig.15 Story Drift model 1 in Y Direction

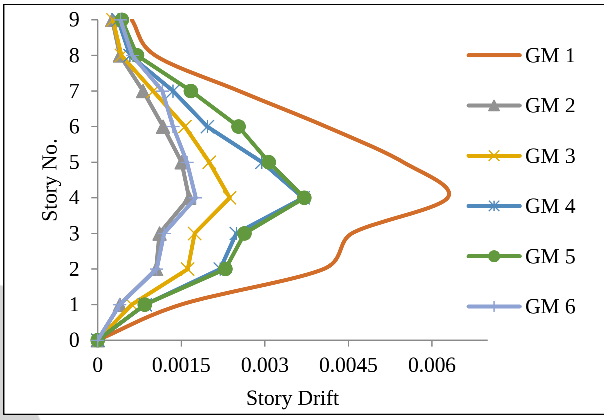

Fig.16 Story Drift model 2 in Y Direction

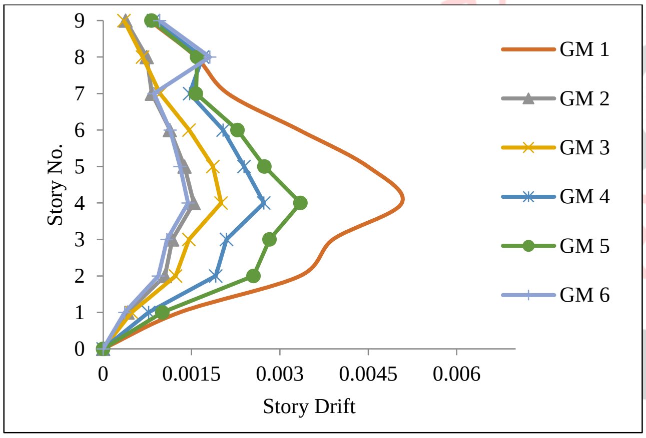

Fig.17 Story Drift model 3 in Y Direction

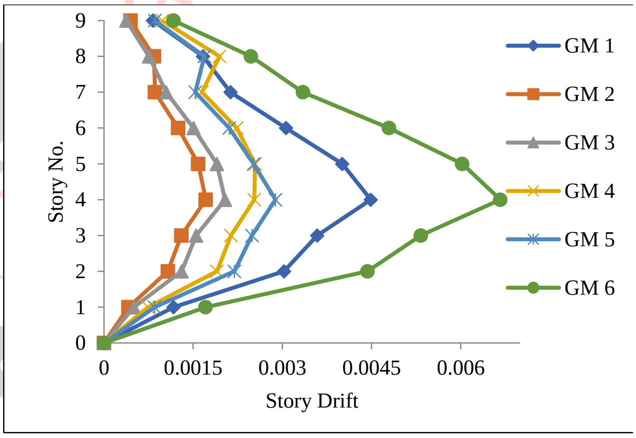

Fig.18 Story Drift model 4 in Y Direction

Table 4. Maximum drift and average drift in X direction

Model	GM 1	GM 2	GM 3	GM 4	GM 5	GM 6	Avg. Drift
Model 1	0.009475	0.003565	0.003298	0.007744	0.003867	0.001433	0.0049
Model 2	0.006581	0.001683	0.002783	0.003744	0.004203	0.008617	0.0046
Model 3	0.004215	0.002221	0.003956	0.004213	0.00322	0.002309	0.00336
Model 4	0.009991	0.002146	0.005173	0.005938	0.003629	0.013733	0.00677

Table 5. Maximum drift and average drift in Y direction

Model	GM 1	GM 2	GM 3	GM 4	GM 5	GM 6	Avg. Drift
Model 1	0.006282	0.001641	0.00237	0.003688	0.003709	0.00176	0.00324
Model 2	0.004249	0.001225	0.001463	0.003709	0.002404	0.006268	0.00322
Model 3	0.00507	0.001538	0.002003	0.002728	0.003351	0.001441	0.00269
Model 4	0.004487	0.001712	0.002036	0.002529	0.002884	0.006667	0.00339

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Discussion on maximum story drift

a. The building frame with shear wall gives better performance in both X and Y direction.
b. From left figure it is observed that average drift in X direction developed in model 3, building frame with shear wall is 0.00336 which is less by 26.53%, 21.73% and 50.36% compared to model 1, model 2 and model 4 respectively.
c. From right figure it is observed that average drift in Y direction developed in model 3, building frame with shear wall is 0.00269 which is less by 16.97%, 16.45% and 20.64% compared to model 1, model 2 and model 4 respectively.

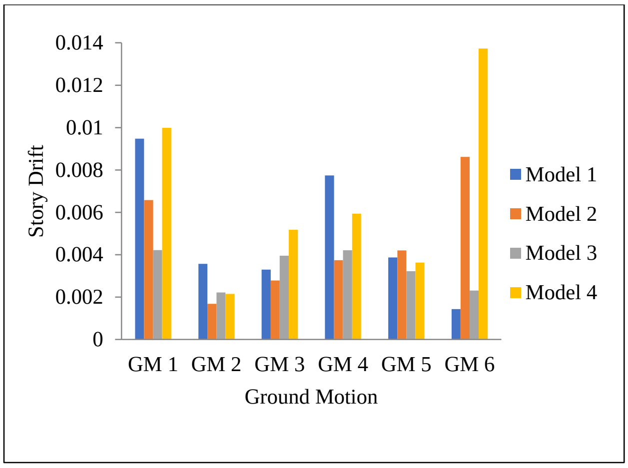

Fig.19 Maximum Story Drift in X Direction

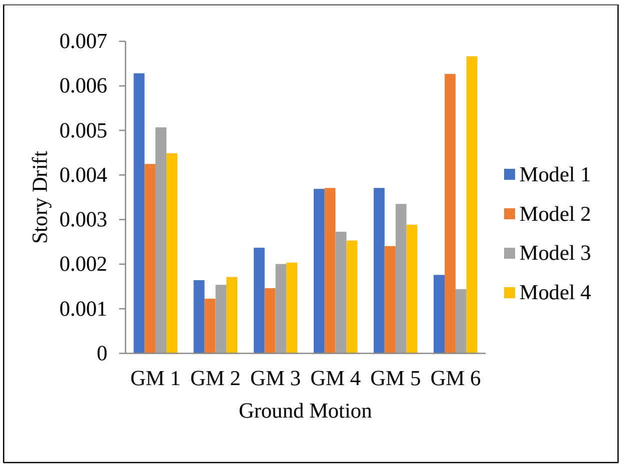

Fig.20 Maximum Story Drift in Y Direction

VI. CONCLUSIONS

A detailed study is obtained to investigate the nonlinear behaviour of concrete structures subjected to sequential earthquakes for real ground motion under mainshock, aftershock 1, and aftershock 2 in two sets. To obtain these objectives, three RC buildings are designed, analysed, and their seismic responses are compared with those of a mainshock earthquake and an aftershock earthquake.

1. Fundamental time reduced when effect of shear wall and bracing are considered. Also change in fundamental torsional mode translation mode reduces fundamental period.
2. Torsional building has significant impact on the seismic response of structure in terms of displacement, interstory drift etc.
3. In the X direction, the average drift for building frame with a shear wall is notably lower by 20% to 50%, when compared to the building frame with fundamental torsion mode, building frame with different column orientation, and building frame with bracing, respectively.
4. In the Y direction, the average drift for building frame with a shear wall is notably lower by 15% to 20%, when compared to the building frame with fundamental torsion mode, building frame with different column orientation, and building frame with bracing, respectively.
5. When a shear wall is incorporated into a building frame, it imparts greater flexibility in the Y-direction, ultimately leading to increased ultimate displacement compared to other models.
6. The nonlinear dynamic time history shows that average drift reduced in building frame with shear wall as compared to other models in X and Y direction.

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