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Seismic Response of Rc Framed Masonry Infilled Buildings With Soft First Storey

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Abstract

RC frames buildings with open first stores (soft storey) are known to perform poorly during strong earthquake shaking, the presence of masonry infill wall influences the overall behaviour of the structure when subjected to lateral forces, when masonry infill are considered to interact with their surrounding frames the lateral stiffness and lateral load carrying capacity of structure largely increase. In this paper the seismic vulnerability of building with soft storey is shown with an Example of G+9 RC building. The infill wall is modelled using theory given by STAFFORD-SMITH and CARTER.

Keywords: soft storey, effect of infill wall, modelling of infill wall, STAFFORD-SMITH and CARTER theory.

1.0 INTRODUCTION

Reinforced concrete frames with Masonry infills are a popular form of construction of high-rise buildings in urban and semi urban areas around the world . The term infilled frame is used to denote a composite structure formed by the combination of a moment resisting plane frame and infill walls. The masonry can be of brick, concrete units, or stones .Usually the RC frame is filled with bricks as non-structural wall for partition of rooms. Social and functional needs for vehicle parking, shops, reception etc. are compelling to provide an open first storey in high rise building. Parking floor has become an unavoidable feature for the most of urban multistoried buildings. Though multistoried buildings with parking floor (soft storey) are vulnerable to collapse due to earthquake loads, their construction is still widespread. These buildings are generally designed as framed structures without regard to structural action of masonry infill walls. They are considered as non-structural elements. Due to this in seismic action, RC frames purely acts as moment resisting frames leading to variation in expected structural response. The effect of infill panels on the response of R/C frames subjected to seismic action is widely recognized and has been subject of numerous experimental and analytical investigations over last five decades. In the current practice of structural design in India masonry infill panels are treated as non-structural element and their strength and stiffness contributions are neglected. In reality the presence of infill wall changes the behaviour of frame action into truss action thus changing the lateral load transfer mechanism.

In this paper, stiffness balancing is proposed between the first and second storey of a reinforced concrete moment-resisting frame building with open first storey and brick infills in the upper storeys. A simple example building is analyzed with different models. The stiffness effect on the first storey is demonstrated through the lateral displacement profile of the building, and through the bending moment and shear force in the columns in the first storey

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2.0 DESCRIPTION OF STRUCTURAL MODEL

Significant experimental and analytical research is reported in the literature since five decades, which attempts to understand the behaviour of infilled frames. Different types of analytical models based on the physical understanding of the overall behavior of an infill panels were developed over the years to mimic the behavior of infilled frames. The available infill analytical models can be broadly categorized as i) Macro Model and ii)Micro models. The single strut model is the most widely used as it is simple and evidently most suitable for large structures (Das and Murthy, 2004). Thus RC frames with unreinforced masonry walls can be modeled as equivalent braced frames with infill walls replaced by equivalent diagonal strut which can be used in rigorous nonlinear pushover analysis. Using the theory of beams on elastic foundations (Stafford Smith and Carter, 1969) suggested a non-dimensional parameter to determine the width and relative stiffness of diagonal strut. Mainstone suggested another model representing the brick infill panel by equivalent diagonal strut. The strut area, Ae, was given by following expression:

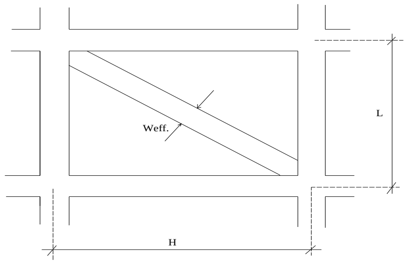


Figure 1 Compression Diagonal Model

$$A_e = w_e t$$

$$W_{eff} = 0.175\ \lambda_h h_{col}^{\ -0.4}\ r_m$$

Where,

$$\lambda_h = \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_c I_c h_m}}$$

$$\theta = \tan^{-1}\frac{h_m}{L}$$

The plan layout of the reinforced concrete moment resisting frame building with open first storey and Un-reinforced brick infill walls in the upper storeys, chosen for this study is shown in Fig. 3. The building is deliberately kept symmetric in both orthogonal directions in plan to avoid torsional response under pure lateral forces. Further, the columns are taken to be square to keep the discussion focused only on the soft first storey effect, without being distracted by the issues like orientation of columns. The building is considered to be located in seismic zone III and intended for residential use. Elastic moduli of concrete and masonry are 22361.68 MPa and 5,500 MPa, respectively, and their Poison's ratio is 0.2. Performance factor (K) has been taken as 1.0 (assuming ductile detailing). The unit weights of concrete and masonry are taken as 25 kN/m3 and 20 kN/m3. The floor finish on the floors is 1 kN/m2. The live load on floor is taken as 3 kN/m2 and that on roof as 1.5 kN/m2. In the seismic weight calculations, only 25% of the floor live load is considered.

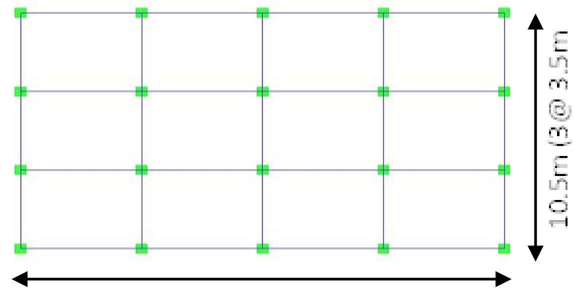
Following four models are investigated in the study.

Model I: Bare frame. However, masses of infill walls are included in the model.

Model II: Soft first storey.
Building has no walls in the first storey and external walls (230 mm thick), internal walls (110 mm thick) in the upper stories

Model III: Soft first storey with walls at specific locations in first storey.
Building has 230mm thick external walls and 110mm thick internal wall in the upper stories. Further, 230mm thick masonry infill is provided in the first storey at specific location.

Model IV: Soft first storey with stiffer columns.
Buildings has no walls in the first storey and external walls (230 mm thick), internal walls (110 mm thick) in the upper stories. However, the columns in the first storey are stiffer than those in the upper stories to reduce the stiffness irregularity between the first storey and the storey above.



18m (4@ 4.5m c/c)

Figure 2 plan X-Y plane

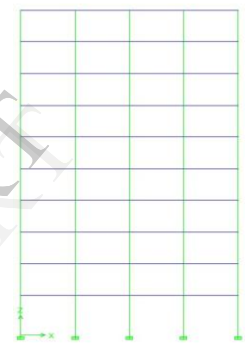


Figure 4 Bare frame X-Z plane

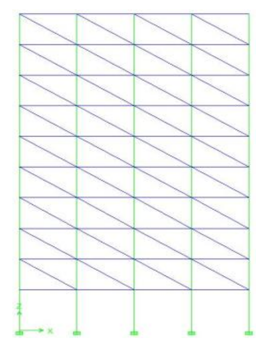


Figure 3 soft storey frame X-z plane

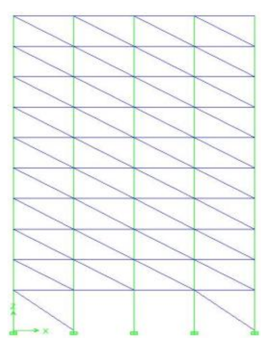


Figure 6 Soft first storey with MI walls at specific locations in first storey

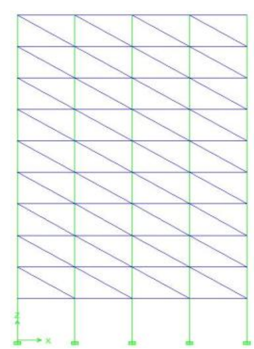


Figure 5 Soft first storey with stiffer columns

3.0 ANALYSIS OF THE BUILDING

Linear elastic analysis is performed for the four models of the building using ETABS analysis package. The frame members are modeled with rigid end zones, the walls are modeled as panel elements, and the floors are modeled as diaphragms rigid in-plane. Two different analysis are performed on the models of the building considered in this study, namely the equivalent static analysis and the response spectrum analysis. These are briefly described below.

Equivalent Static Analysis

The natural period of the building is calculated by the expression, $09H/\sqrt{D}$ given in IS:1893-1984, wherein H is the height and D is the base dimension of the building in the considered direction of vibration. Thus, the natural periods for all the models in this method, is the same. The lateral load calculation and its distribution along the height is done as per IS:1893-1984. The seismic weight is calculated using full dead load plus 25% of live load.

Response Spectrum Analysis

Dynamic analysis of the building models is performed on ETABS. The lateral loads generated by ETABS correspond to the seismic zone III and the 5% damped response spectrum given in IS:1893-1984. The natural period values are calculated by ETABS, by solving the eigen value problem of the model. Thus, the total earthquake load generated and its distribution along the height correspond to the mass and stiffness distribution as modeled by ETABS. Here, as in the equivalent static analysis, the seismic mass is calculated using full dead load plus 25% of live load.

4.0 RESULTS AND DISCUSSIONS

The displacements and forces from the equivalent static method are consistently larger than those from the multi-modal dynamic analysis method.

4.1 Storey Stiffness:

The storey stiffness is defined as the magnitude of force couple required at the floor levels adjoining the storey to produce a unit lateral translation within the storey, letting all the other floors to move freely.

Stiffness of one column is equal to

$$K_c = \frac{12E_cI}{L^3}$$

Stiffness of diagonal strut is equal to

$$K_i = \frac{AE_m}{L_d}\cos^2\theta$$

Therefore total stiffness of one storey is

$$K = \sum k_c + \sum k_i$$

Table 1 Storey Stiffness of first and second storey for each model

Model	Storey Stiffness (kN/mm)			
	Longitudinal		Transverse	
	First	Second	First	Second
Model I	178.8	424.0	178.8	424.0
Model II	178.8	1491.52	178.8	935.58
Model III	550.84	1491.52	360.28	935.58
Model IV	905.58	1491.52	905.58	935.58

From the above results, it is observed that the stiffness of first storey for model I is about 42.16% of second storey stiffness. The stiffness of first storey for model II is about 11.98% and 19.11% of second storey stiffness in longitudinal and transverse direction respectively. Model II represent the realistic situation for earthquake. It is seen that use of brick infill at specific locations (Model III) reduces the stiffness irregularity marginally. In case of model III stiffness of first storey is increased to 36.93% of second storey stiffness. The use of stiffer columns (Model IV) increases the stiffness up to 60.77% and 96% in longitudinal and transverse direction respectively.

4.2 Lateral Deformation

The lateral displacement profiles of the various models for the two different analysis performed in this study are shown in Fig. 4. In these figures, the abrupt changes in the slope of the profile indicate the stiffness irregularity. All displacement profiles corresponding to models having stiffness irregularity (I & II) have a sudden change of slope at first floor level. However, the other models i.e. III & VI, show smooth displacement profiles than other two. The displacements at first floor level are shown in Table 3. The inter-storey drift demand is largest in the first storey for all the models with soft ground storey. This implies that the ductility demand on the columns in the first storey, for these models, is the largest. Storey drift values of second storey for Model II, III and IV are 60.25 %, 35.63 % and 30 % less as compared to values of first storey drift respectively. Due to absence of masonry walls in the first storey of Model II, stiffness gets reduced and accordingly drift increases. Thus, the drift ductility demand in the first storey can be greatly reduced by ensuring that the storey stiffness at least equal to 50% of the 2nd storey.

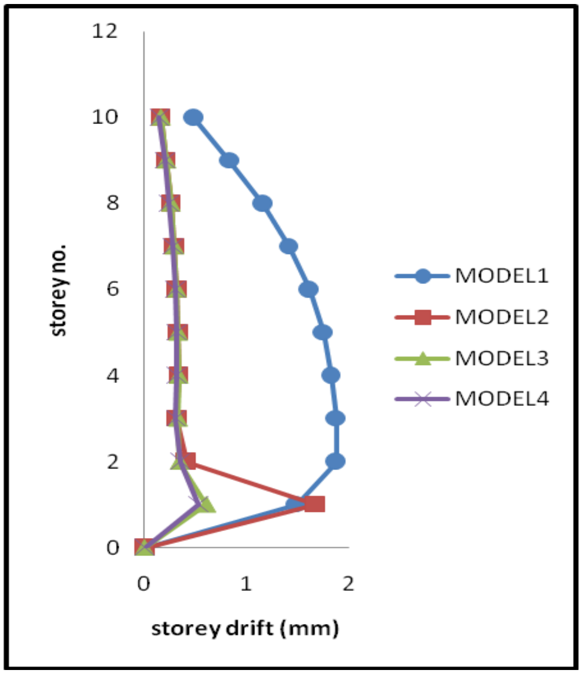


Figure 7 Lateral Displacement Profile by (a) Equivalent Static Analysis in longitudinal direction.

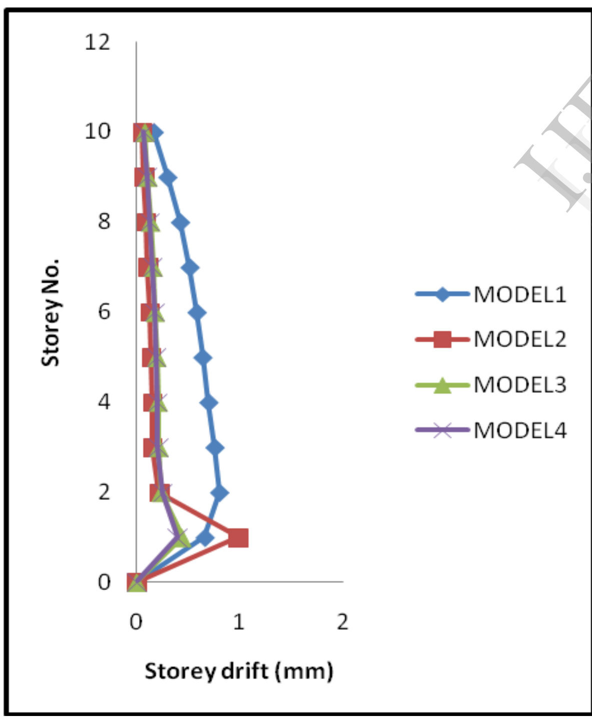


Figure 8 Lateral Displacement Profile by Response Spectrum Analysis in longitudinal direction

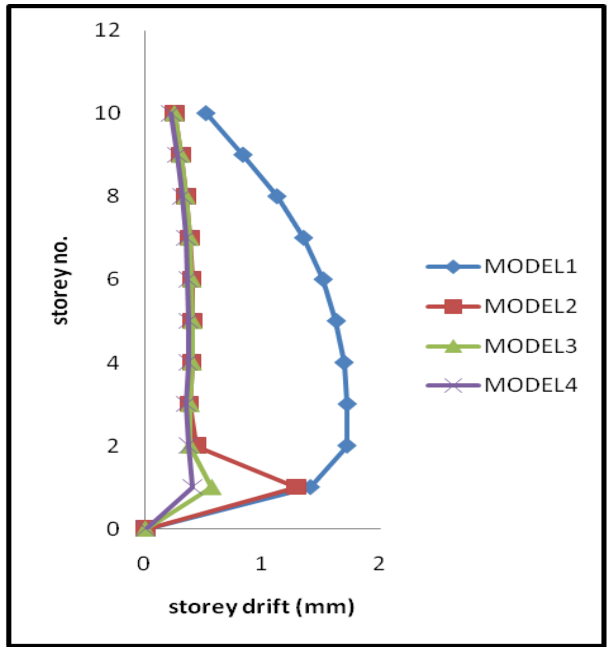


Figure 9 Lateral Displacement Profile by (a) Equivalent Static Analysis in transverse direction

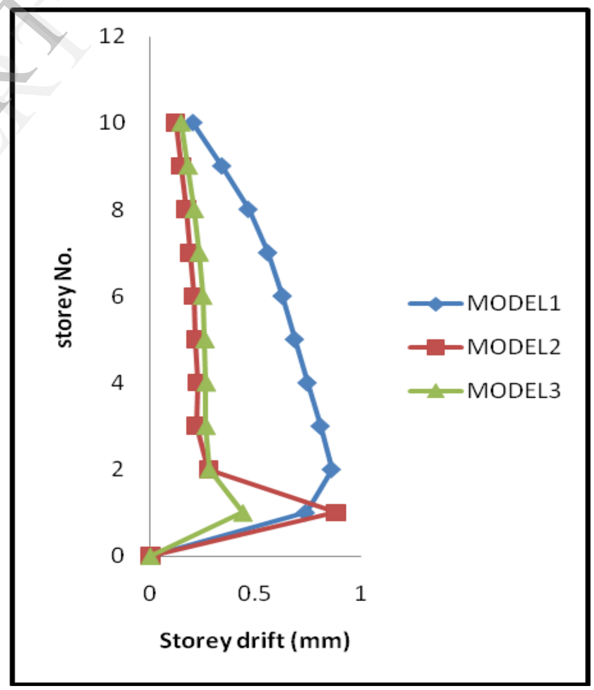


Figure 10 Lateral Displacement Profile by Response Spectrum Analysis Transverse direction

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4.3 Bending Moment and Shear Force in Columns

The maximum bending and maximum shear forces in the columns in the first and the upper storeys are shown in Table 2; the bending moment and shear force (strength) demands are severely higher for first storey columns, in case of the soft first storey buildings. The introduction of walls in the first storey (model *III)* reduces the force in the first storey columns. As the force is distributed in proportion to the stiffness of the members, the force in the columns of the upper storeys, for all the models (except model *I*), are significantly reduced due to the presence of brick walls. When the bare frame model is subjected to earthquake load, mass of each floor acts independently resulting each floor to drift with respect to adjacent floors. Thus the building frame behaves in a flexible manner causing distribution of horizontal shear across floors.

Table 2 Displacement at first floor, maximum bending forces in first storey columns and avg. of maximum forces in the columns of storey above for differnt model

model	DISPLACEMENT AT FIRST FLOOR (mm) trans	long.	MAXIMUM BENDING MOMENT (kNm) transverse First	transverse 2nd	longitudinal first	longitudinal 2nd
Equivalent static load analysis						
1	5.6	5.9	109.15	81.48	110.7	82.37
2	5.1	6.7	111.17	41.17	145.98	66.71
3	1.6	2.1	41	27.5	49.65	38.7
4	1.52	1.9	142.7	27.76	188.25	34.37
Response spectrum analysis						
1	2.44	2.49	110.71	75.78	109.57	82.77
2	3.437	3.863	144.64	66.68	69.25	34.09
3	1.656	1.642	36.74	22.46	28.44	19.56
4	1.28	1.524	186.51	43.32	86.65	24.08

In presence of infill, the relative drift between adjacent floors is restricted causing mass of the upper floors to act together as a single mass. In such a case, the total inertia of the all upper floors causes a significant increase in the horizontal shear at base or in the ground floor columns. It is observed that for Model I base shear value is less and displacement is more as compared to other models. Other three models having nearly same base shear value but there is difference in displacement. Model IV *i.e.*, RC frame with stiffer columns at first storey having minimum displacement comparing to other models. Due to absence of masonry walls in Model I, there is increase in natural time period resulting in less base shear. Also stiffness get reduced because of absence of masonry walls, hence displacement increases

Table 3 maximum bending forces in first storey columns and avg. of maximum forces in the columns of storey above for differnt model

Model	MAXIMUM SHEAR FORCE (kN) transverse first	transverse rest	Longitudinal first	Longitudinal Rest
Equivalent static load analysis				
1	534.67	393.08	537.68	393.08
2	639.97	477.23	842.1	628.072
3	647.3	482.45	856.42	638.324
4	644.15	480.21	852.26	365.356
Response spectrum analysis				
1	237.62	149.25	229.47	144.28
2	433.34	257.66	490.09	277.682
3	493.46	308.28	604.14	368.03
4	522.17	329.95	618.9	377.883

4.4 TIME PERIOD

Table 4 Time period of various modes for each

TIME PERIOD				
Mode	model1	model2	model3	model4
1	2.13998	1.21392	1.01251	0.94494
2	2.06626	1.10362	0.83941	0.81372
3	1.88816	0.99243	0.69059	0.71887
4	0.69496	0.38127	0.33031	0.316
5	0.67143	0.31699	0.27428	0.2701
6	0.61554	0.26623	0.2288	0.23397

model

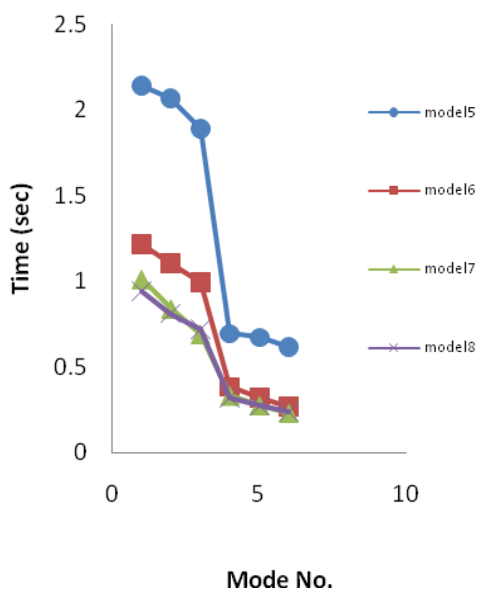

Figure 11 Comparison of Time period Vs Modes for each model

A graph is plotted taking Modes on the X axis and Time period in second on Y axis for all the building models. It is observed that the time period of vibration is more for model I, while it is considerably reduced for models II. Period of vibration is found to be minimum for models III and IV. From graph it is clear that after first three modes there is sudden change in time period of each model

4.4 Axial Force

Table 5 Maximum axial force in first and second storey columns for each model

Model	Axial Force (kN)	
	I Storey	II Storey
Model V	2722.51	2428.22
Model VI	2545.64	2235.97
Model VII	2544.18	2236.56
Model VIII	2622.37	2280.63

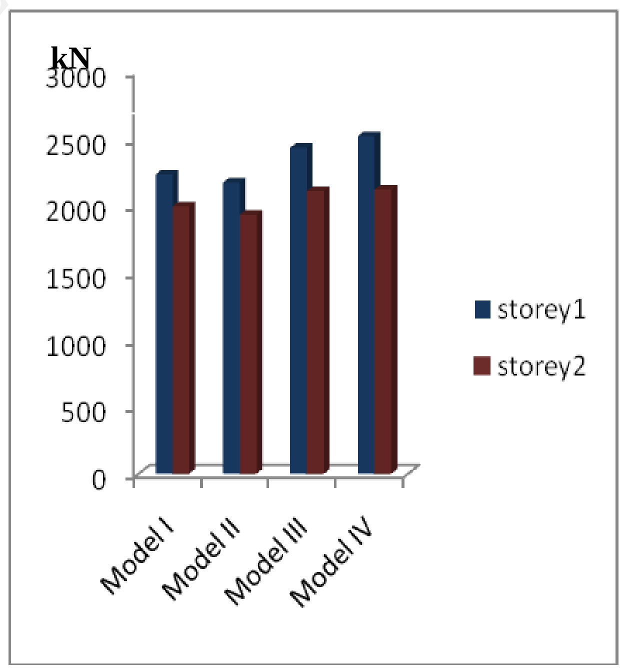

Figure 12 Maximum axial force in first and second storey columns for each model

Comparison of maximum Axial force in columns

A graph is plotted taking different Models on X axis and Axial force (kN) on Y axis. The axial force in model V, VI, VII and VIII is fairly same. In case of model VIII the axial force is increased as compared to model VI because of their large sizes.

Conclusion:

RC frame buildings with open first storeys are known to perform poorly during in strong earthquake shaking. In this paper, the seismic vulnerability of buildings with soft first storey is shown through an example building. The drift and the strength demands in the first storey columns are very large for buildings with soft ground storeys. It is not very easy to provide such capacities in the columns of the first storey. Thus, it is clear that such buildings will exhibit poor performance during a strong shaking. This hazardous feature of Indian RC frame buildings needs to be recognized immediately and necessary measures taken to improve the performance of the buildings.
The open first storey is an important functional requirement of almost all the urban multi-storey buildings, and hence, cannot be eliminated. Alternative measures need to be adopted for this specific situation. The under-lying principle of any solution to this problem is in (a) increasing the stiffness's of the first storey such that the first storey stiffness is at least 50% as stiff as the second storey, i.e., soft first storeys are to be avoided, and (b) providing adequate lateral strength in the first storey. The possible schemes to achieve the above are (i) provision of stiffer columns in the first storey, and (ii)provision infill wall at specified location at ground floor in the building. The former is effective only in reducing the lateral drift demand on the first storey columns. However the latter is effective in reducing the drift as well as the strength demands on the first storey columns. reducing the drift as well as the strength demands on the first storey columns.

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