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MITIGATION TECHNIQUES FOR SEISMIC PROTECTION OF RC BUILDINGS WITH OPEN GROUND STOREY

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Abstract - *Construction of buildings with open ground storey is being practiced on a large scale in many countries around the world and also in developing countries such as India to facilitate the increasing need to provide parking space due to increasing population and unavailability and high costs of land in urban areas. Open Ground Storey (OGS) buildings are those type of buildings in which the ground storey is left open without the provision of infill walls in between the columns of the ground storey and infilled in all the upper stories thus introducing stiffness irregularity in the building making them vulnerable to earthquakes especially when located in higher seismic zones. It was observed that most of the buildings damaged during the past earthquakes like the Bhuj earthquake of 2001, were due to presence of open ground storey. Hence strengthening of buildings with such irregularity is the need of the hour inorder to avoid their poor performance during earthquakes in future and thus saving human lives.*

In this study, seismic analysis of G+15 RC building with open ground storey, located in seismic zone IV is carried out using response spectrum analysis in ETABS software. The infill walls are modeled as equivalent diagonal struts. Various mitigation techniques such as provision of stiffer columns in the open ground store, providing shear walls throughout the building height and shifting of soft storey to higher levels are studied by analyzing four different models in ETABS software. Various seismic responses such as storey stiffness, lateral displacement, storey drifts and column forces of the open ground storey are evaluated and a comparative study is done on all four models to understand the most feasible mitigation technique.

Key Words: Open ground storey, ETABS software, equivalent diagonal strut, response spectrum analysis, shear walls, mitigation techniques, infills etc.

1. INTRODUCTION

Open ground storey building commonly known as soft storey building is an unavoidable feature in the modern multistorey building as they provide the needed space for parking of vehicles, reception lobbies etc. Also most of the malls built nowadays are of open ground storey type. There is significant advantage of these category of buildings functionally but from seismic performance point of view such buildings are considered to have increased vulnerability. It was observed from the past earthquakes such as during 1999 Taiwan, 1999 Turkey, 2001 Bhuj and 2003 Algeria earthquakes that most of the damage was to the open ground storey buildings. Damages included snapping of lateral ties, crushing of core concrete, buckling of longitudinal bars etc. The Indian Seismic Code IS: 1893 (Part-1)-2002 defines soft storey as the one in which lateral stiffness is less than 70% of that in the storey above or less 80% of the average lateral stiffness of the three stories above. Presence of infill walls in the entire upper storey except for the ground storey makes the upper stories much stiffer than the open ground storey introducing stiffness irregularity (vertical irregularity) in the building. Thus, the upper stories move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself as a result of which the buildings sway back and forth like the inverted pendulum during earthquake shaking, and hence columns and the beams in the ground storey are severely stressed. Due to presence of infill walls in the upper stories, the lateral stiffness of the frame increases by three to four times.

Fig -1: Damage to OGS building during Bhuj earthquake

2. DESCRIPTION OF MODELS

The different models which are analyzed are as described below:

Model 1 (M1) – Building with open ground storey
Model 2 (M2) – Building with provision of stiffer columns (850x850 mm) in the open ground storey
Model 3 (M3) - Open ground storey building with shear wall throughout

Model 4 (M4) – Building with soft storey shifted to higher level (second storey in this case)

The plan of the G+15 RC building considered is assumed to be symmetric and are regular in elevation. The building is assumed to be located on medium soil (Type –II) in severe seismic zone IV. The seismic loads are applied as per IS:1893 (Part-I)-2002 and the live and dead loads are applied as per IS: 875 (1987)-Part I & Part-II. The building is assumed to be of special moment resisting type. The infill walls are modeled as equivalent diagonal strut and their width is calculated as per formula given by Mainstone in 1971. Columns C1 and C2 represent the external and internal column of the building. The other details are as given below:

- Frame type- Special moment resisting frame (SMRF)
- Type of building - Residential building
- Floor to floor height – 3.2m
- Diaphragm – Rigid diaphragm
- Unit weight of RCC – 25kN/m^3
- Unit weight of masonry – 18kN/m^3
- Live load on floor – 3kN/m^2
- Live load on roof - 2kN/m^2
- Water proofing load on roof - 2kN/m^2
- Floor finish - 1kN/m^2
- Depth of foundation – 2.5m
- Thickness of slab & shear wall – 150mm
- Plan Dimensions - 22.074m x17.16m
- Columns- G to 4th storey= 300x600 mm
  -5th to 8th storey = 300x500 mm
  -9th to 15th storey = 300x300 mm
- Beams – 300x450 mm
- Thickness of external wall (Full brick) -230mm
- Thickness of internal wall (Half brick) -115mm
- Materials- M30 concrete and Fe500 steel
- Importance factor – 1
- Response reduction factor – 5
- Zone factor – 0.24
- Type of foundation – Raft foundation
- SBC of soil - 150kN/m^2
- Compressive strength of masonry –f'm=8.5 N/mm^2
- Damping – 5%

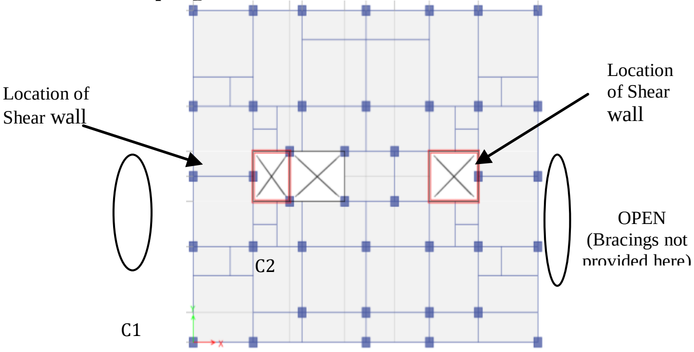
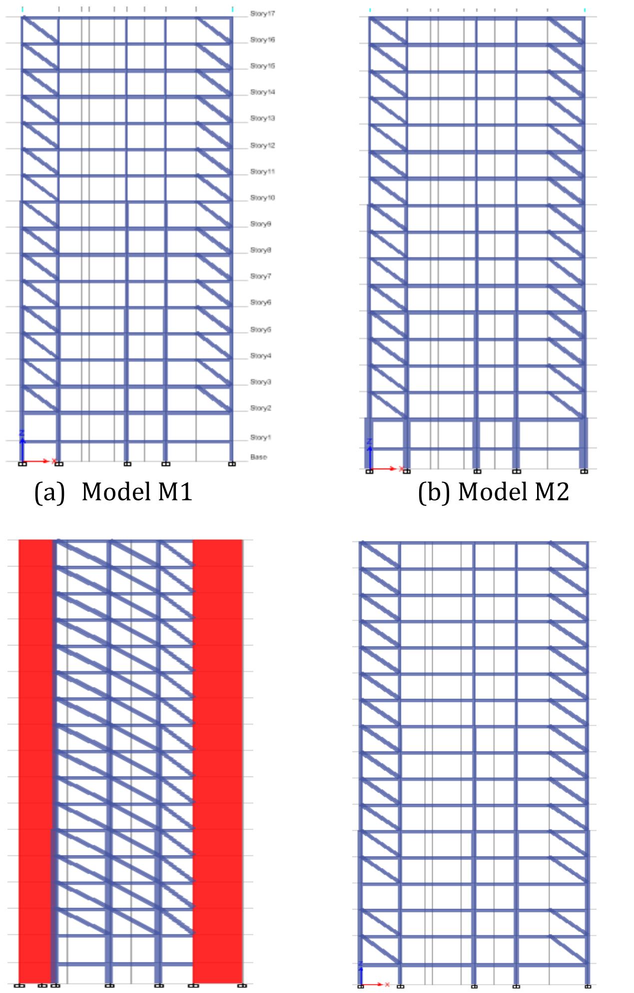


Fig -2: Plan of G+15 RC building (ETABS model)



(a) Model M1 (b) Model M2

(c) Model M3 (d) Model M4

Fig-3: Elevations of the different models studied

2.1 Modeling of Structural Elements

The beams are modeled as line element with six degrees of freedom at each node and slab as a four nodded membrane element with three degrees of freedom at each node. The infill walls are modeled as equivalent diagonal struts to incorporate the stiffness of infills. The end connections of strut are assumed to be pinned to the confining frame. Floor slabs are modeled as a rigid diaphragm to ensure integral action of all the vertical lateral load-resisting elements. The column to footing connection is considered as fixed.

2.2 Modeling of Infill walls

Infills are considered as non – structural elements in conventional design practice but they do influence the overall behavior of the structure. Infills increase initial strength and stiffness of RC frame buildings. Research has proved that the infill system behave as a braced frame with the wall forming 'compression struts'. Hence the infills are being modeled as equivalent diagonal struts. This strut is modeled in such as way that it will not contribute for resisting any bending moment but will certainly contribute the stiffness of wall. The material properties and thickness of struts are same as that of masonry wall. To calculate the effective width of strut various empirical formulae are available. In this study, the formula proposed by Mainstone in 1971 is used to calculate the equivalent width of the strut. Fig. 3 depicts representation of infill as equivalent diagonal strut. 'dm' represents diagonal length of the infill, l' is clear span of the infill panel & 'h' the clear height of column. The equivalent strut width, 'Z' depends on a relative flexural stiffness of the infill to that of the column of the confining frame. The relative infill to frame stiffness shall be evaluated by using following equation:

$$\lambda = \left[\frac{Em\ tm \sin 2\theta}{4\ Ef\ Ic\ hm}\right]^{\left(\frac{1}{4}\right)} \qquad (2.1)$$

$$\theta = tan^{-1}\left(\frac{hm}{lm}\right) \qquad (2.2)$$

$$Em = 550 f'm \qquad (2.3)$$

$$Ef = 5000\sqrt{fck} \qquad (2.4)$$

Hence the equivalent width of the strut as per Mainstone is calculated as follows:

$$Z = 0.175 dm(\lambda * hm)^{-0.4} \qquad (2.5)$$

Where
Z = Equivalent width of strut
λ = Relative infill to frame stiffness
E_m = Young's modulus of elasticity for masonry (taken as per IS:1905-1987)
E_f = Young's modulus of elasticity of the frame (taken as per IS:456-2000)
I_c = Moment of inertia of column cross-section
θ = angle of inclination of diagonal strut with the horizontal
h_m = effective height of column
t_m = thickness of strut
l_m = effective length of the panel
d_m = diagonal length of infill

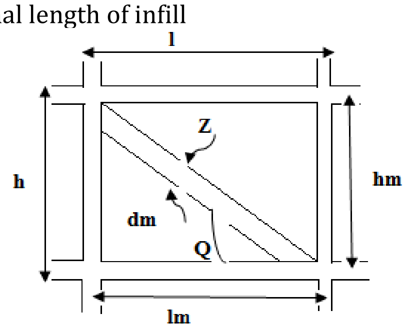


Fig - 4: Equivalent width of structure

3. METHODS OF ANALYSIS

The Response Spectrum Method of analysis is the most efficient and widely used method by the structural engineers for the purpose of design and analysis of RC framed structure. In this study, the response spectrum analysis is carried out using ETABS software.

In this method, the response of a structure during an earthquake is obtained directly from earthquake response spectrum. This procedure gives an approximate peak response, but this is quite accurate for structural design applications. This method takes into account the multiple modes of response of a building. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass. The responses of different modes are combined to provide an estimate of total response of the structure using modal combination methods such as complete quadratic combination (CQC), square root of sum of squares (SRSS), or absolute sum (ABS) method. Response spectrum method of analysis should be performed using the design spectrum specified or by a site – specific design spectrum, which is specifically prepared for a structure at a particular project site. The same may be used for the design at the discretion of the project authorities

3. RESULTS AND DISCUSSIONS

The various structural models are analysed and the following plots are plotted based on the results obtained

3.1 Storey stiffness

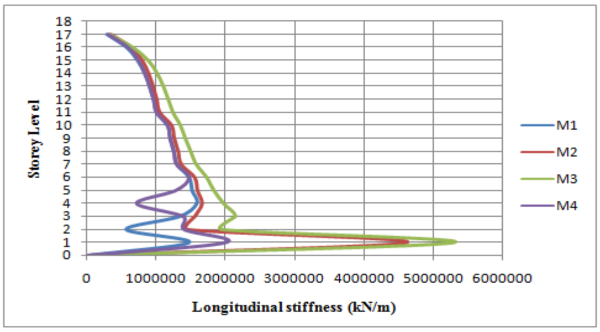


Fig-5: Longitudinal stiffness (kN/m)

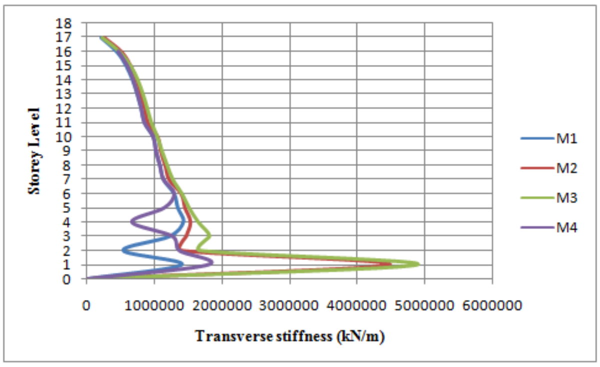


Fig-6: Transverse stiffness (kN/m)

As can been seen from Fig.5 and Fig.6, the lateral stiffness increases gradually from level 0 to level 1 and decreases at level 2 (due to presence of soft storey level) for all the models. The stiffness of the ground storey (i.e. level 2) was found to be 42%, 93%, 91% and 100% along longitudinal direction and 44%, 95%, 92% and 107% along the transverse direction w.r.t. upper storey level for models M1, M2, M3 and M4 respectively. Hence it can been seen observed that the soft storey effect gets nullified for models M2, M3 and M4. However, of all the models analysed, maximum increase in stiffness at the ground storey is for model M3 (shear wall-frame system) with an increase of about 71% as compared to M1 (open ground storey building) along both the directions, followed by models M2 and M4 with an increase of about 58 to 60% respectively. Hence in terms of storey stiffness, model M3 is the most suitable of all models. The stiffness profile remains the same at all other storey levels except at the ground storey.

3.2 Lateral displacement

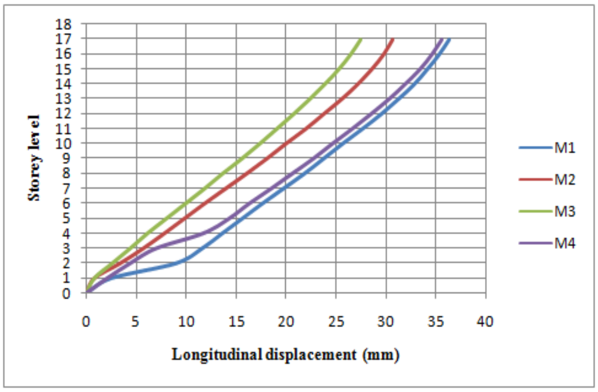


Fig-7: Longitudinal displacement (mm)

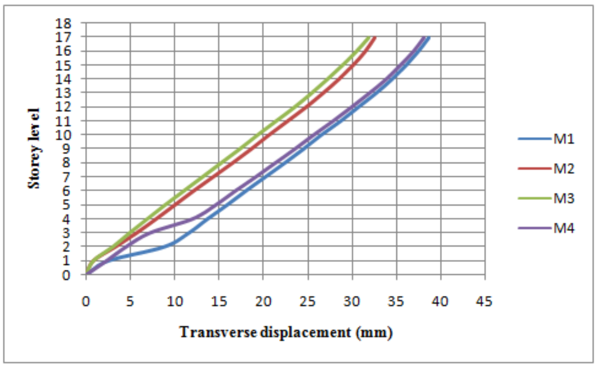


Fig-8: Transverse displacement (mm)

The above figures (i.e. Fig. 7 and Fig.8) show sudden change of slope at the ground storey (between level 1 and level 2) especially for models M1, M4 and M2 indicating the presence of soft storey at this level. However the slope becomes linear at this level for model M3, thus nullifying the soft storey effect. The top floor displacement was found to be 36.3mm, 30.6mm, 27.4mm and 35.6mm respectively for M1, M2, M3 and M4 along the longitudinal direction. Hence the minimum displacement occurs in M3 followed by M2 and M4. At the soft storey level, maximum reduction of 71.1% was observed in M3 whereas for M2 and M4 it was 62% and 51% as compared to M1 along the longitudinal direction. Hence models with shear wall (M3) and stiffer columns in ground storey (M2) would be ideal to nullify the soft storey effect in the building.

3.3 Storey drift

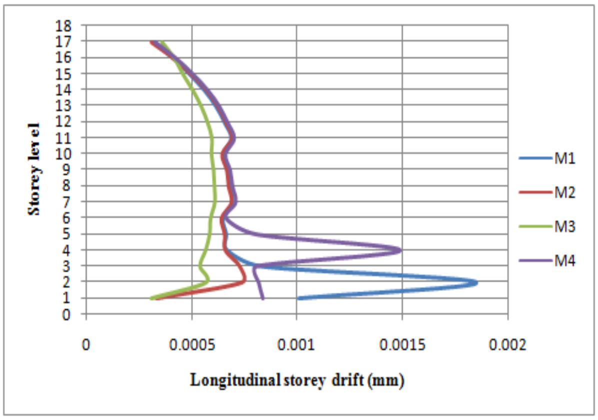


Fig-9: Longitudinal storey drift (mm)

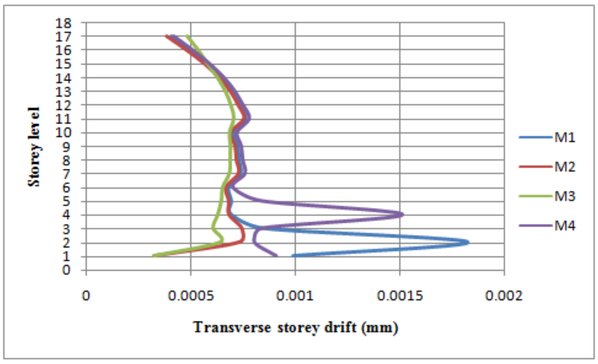


Fig-10: Transverse storey drift (mm)

The storey drift profile as shown in Fig.9 and Fig.10 is just the opposite to the storey stiffness profile i.e. the storey drift increases at level 2 due to presence of soft storey at this level. A very sharp curve is observed in model M1 indicating the largest storey drift due to presence of open ground storey in this building. However, it is minimum for model M3. Drastic reduction in storey drift of about 70% was observed for model M3 in comparison to model M1. It was found to be 60% and 55% for M2 and M4 respectively. Higher storey drifts at soft storey level of M1 indicate that the ductility demands on the columns of this storey are very high. All the storey drifts were found to be within permissible limits as per clause 7.11.1 of IS:1893 (Part I)-2002. The storey drift values at soft storey level were found to be more in the longitudinal direction as compared to that in transverse direction.

3.4 Soft storey column forces

3.4.1 Shear Force

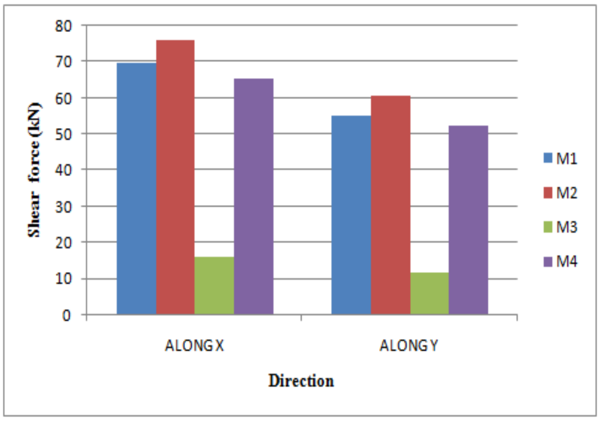


Fig-11: Shear force for external column, C1 (kN)

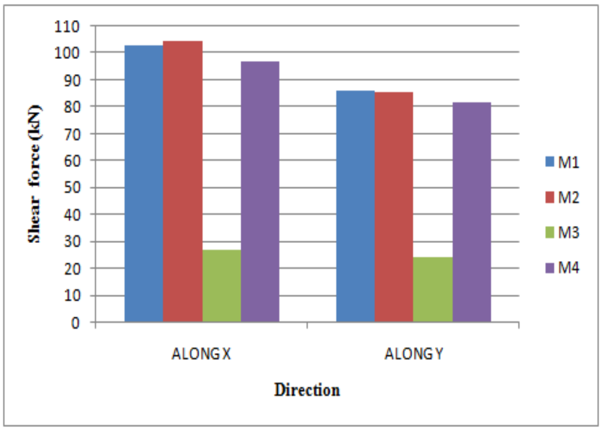


Fig-12: Shear force for internal column, C2 (kN)

The shear force for internal column, C2 is found to be more than that for external column C1. As can be observed from the results depicted in figures above (Fig.11 and Fig.12), the shear forces were found to increase considerably for model M2 (i.e. provisions of stiffer columns in soft storey) as compared to all other models. This is due to the fact that the stiffer columns attract larger forces. However, the shear forces are minimum for model M3 (with shear wall). This is due to the provision of shear wall throughout the building which has helped in resisting most of the lateral forces (almost 80% of the lateral forces). Almost 77% reduction occurred in shear forces for model M3 in comparison to M1 along the longitudinal and transverse directions. The reductions caused in shear forces when the soft storey is shifted to second floor level (model M4) was only 6% which is very less. Hence model M3 would be ideal as far as shear forces in the soft storey are concerned.

3.4.2 Bending Moment

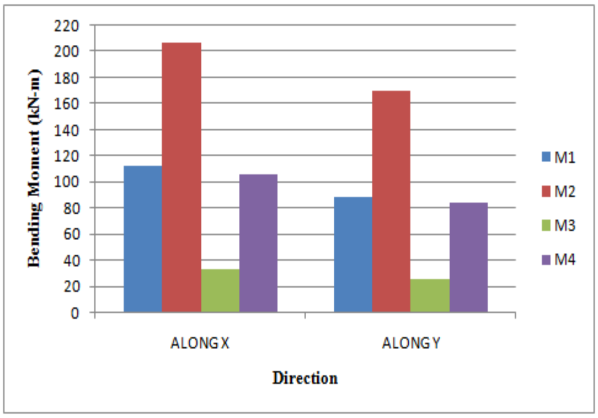


Fig-13: Bending moment for external column, C1 (kN-m)

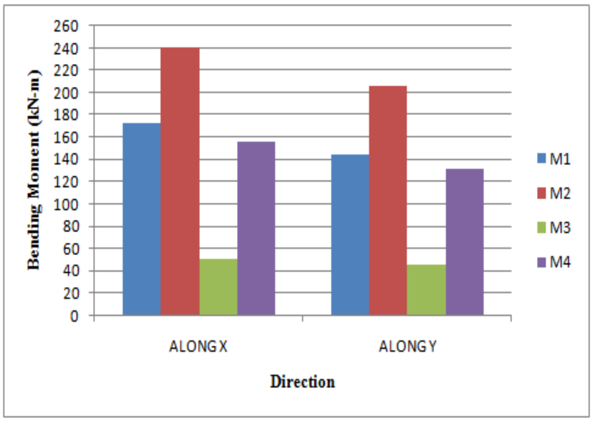


Fig-14: Bending moment for internal column, C2 (kN-m)

The above figures (Fig.13 and Fig.14) depict that there is drastic increase in bending moment of the soft storey columns for model M2 (with stiffer column) whereas it reduced for M3 (with shear wall). The increase in bending moments for ground storey columns of M2 is due to the same reason as for shear force. (i.e. since stiffer columns attract larger forces). The bending moments decreased by about 71% in the columns of soft storey for model M3, followed by model M4 in which it was reduced by 4 to 6% for external column and by 8 to 9% for internal column. Hence M3 will result in better seismic performance of the building.

4. CONCLUSIONS

This study was mainly carried out to study the different mitigation techniques that can be used to minimize the soft storey effect especially when the building is located in severe seismic zones. Linear dynamic analysis was carried out on G+15 RC building using response spectrum method in ETABS software. From the results obtained, it can be concluded that:

a) The provision of dual type structural system i.e. shear wall –frame interaction system (model M3) has proved to be the most efficient of all the mitigation techniques studied for nullifying the soft storey effect.

b) It was observed that the soft storey increased by 71% by the provision of shear wall (M3), followed by provision of stiffer column (M2) and shifting of location of soft storey to second storey (M4) with increase of 58% and 60% respectively in comparison the open ground storey (M1).
c) The top floor displacement was also found to be minimum for M3 as compared to all other models. The lateral displacement reduced by 71.1%, 62% and 51% in models M3, M2 and M4 as compared to M1. This clearly indicates that M3 is the best model.
d) Similar to the lateral displacements, the maximum reduction in storey drifts, also occurred in M3 followed by M2 and M4 with reductions of 70%, 60% and 55% respectively.
e) The soft storey column forces (including shear forces and bending moments) were found to increase drastically with the provisions of stiffer columns in the open ground storey (M2). However, these forces decreased considerably for the building with shear wall (M3). Both the forces i.e. shear force and bending moments were found to be reduced by about 71 to 77% for model M3 as compared to M1. However the reductions in model M4 are very negligible (about 5 to 6%)

Hence from the conclusions, the model M3 (shear wall-frame system) is with no doubt, the best configuration to nullify the effect of soft storey in a building followed by provisions of stiffer columns in the open ground storey (M2) and shifting the location of the soft storey to higher level (M4). However, with the provision of stiffer columns in the open ground storey, there was huge increase in the column forces of the open ground storey. At times, it becomes difficult to provide such high capacities in the column. Hence shifting of location of the soft storey to higher levels is found to be the second best option from this study.

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