ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 5, Issue 5, May 2016

Dynamic Behavior of High-Rise RC Building with a Vertical Irregularity

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***Abstract*— An earthquake is a natural phenomenon where there is a dislocation of the earth's segment takes places. This results in failure of the structure. The main reason for these failures are insufficient lateral stiffness and also irregularities. In this paper, an attempt is made to study the dynamic behavior of structure with a vertical irregularity i.e., soft storey effect. To eliminate soft storey nature of the building, masonry infill walls are used and also been tried to investigate the behavior of this system by considering the wall openings in the infill masonry unit. The modeling of the building is done using the software ETABS V15.2 and dynamic analysis is carried out. The parameters analysed were storey displacement, drift, storey stiffness.**

***Index Terms*— Masonry infill, Multi-storey RCC building, Response Spectrum, Soft Storey**

I. INTRODUCTION

An Earthquake, is the most natural disaster in which shaking of the earth's surface takes place. This results in huge loss of properties and kills many life. Though many studies and experiments are done about earthquake, it is difficult to avoid the structure undergoing damage or failure during this distinctive shaking. Earthquake causes more damage to buildings having irregularities than a regular structure. Modern buildings which comprises of irregular structures (such as open base parking, plan irregularity etc.,) has been trend in these days. Hence to construct these kinds of structure, high level designers and engineers are required. This paper deals with an analytical study of a Stiffness irregularity i.e., soft storey behavior of an simple high-rise building under the dynamic loads. Tall building is considered having stiffness irregularity, i.e. making different floors as a soft storey and masonry wall is used for stiffening the other floors. G+34 Storey building is considered for the analysis purpose. Response Spectrum (RSX and RSY) method is followed for analyzing the model.

Manuscript received May, 2016.

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A. *Irregular Buildings:*

There are numerous examples in report of the past earthquakes, that the failure of the structures is due to these irregularities in configuration

❖ **Vertical Irregularities**

It is the sudden change of stiffness, strength, mass or geometry which leads to the distribution of forces irregularly over the height of the building.

❖ **Horizontal Irregularities**

Discontinuity in the horizontal elements like, cutouts, re-entrant corners, torsion effect, large openings. It may results in stress concentrations, diaphragm deformations and tensions due to this abrupt changes.

B. *soft storey*

A soft storey is characterized by the vertical discontinuity in stiffness. When an individual storey is made taller in the building or more open in construction, then the storey is designated as soft storey or flexible storey. Though it is seen more in ground level between a rigid foundation system, sometimes does occur in upper floors too with a relatively stiffer in that floor. These kind of construction is in residential and commercial buildings. Stiff buildings are those which has a soft storey at a ground level with open spaces left for parking. According to IS 1893:2002 (part 1), Soft storey is the one in which the lateral stiffness is less than 70% of the lateral stiffness in the above storey or it is less than 80% of the average lateral stiffness of the above 3 storeys

Fig 1. Soft Storey Building (Left side) and Collapsing of open ground floor (Right side)

II. BUILDING PARAMETRIC DETAILS

A. *Structural Data:*

An RC building having a plan dimension of 50mX30m is considered which is of special moment resisting frame (G+34). The typical storey height is taken as 3m and basement is 4.5m for all the models. Loads are applied as per IS 875 Part 1-Part 5.

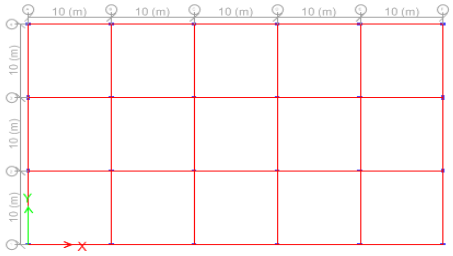


Fig 2. Typical Plan Dimensions

Table I. Members Sizes

Elements	Floor	Dimensions(mm)
Columns	Base to 10th floors	300X600
	10th to 20th floors	300X500
	20th to 30th floors	300X450
	30th to 35th floors	300X400
Beams	Base	200X600
	1st to 15th floors	200X450
	15th to 30th floor	200X400
	30th to 35th floor	200X300
Slab thickness	1st floor	150
	Remaining floors	125

Table II. Seismic and Wind parameters

PARAMETERS	
Seismic	Wind
Zone factor -V	Terrain category - 4
Response reduction - 5	Structural classes - C

B. *Model Analysis:*

Case 1: Bare Frame Model (BFM)

Case 2: Building with Infill walls and soft storey effect at different floors

Model 1: Soft storey at 1st or Ground Floor and other floors having infill walls. (M1)

Model 2: 10th floor having soft storey effect with others as infill walls. (M2)

Model 3: Building with soft storey effect at 20th floor and remaining floor are infill walls. (M3)

Model 4: 30th storey is without infill walls and rest are having infill walls (M4)

Model 5: 35th or Terrace floor are soft storey and all others with infill walls.(M5)

Case 3: Buildings having infill walls with the **openings** for above all the 5 models. (OM1, OM2, OM3, OM4, OM5). Wall openings are given in two types, 25% and 50% of the area (AOM and BOM)

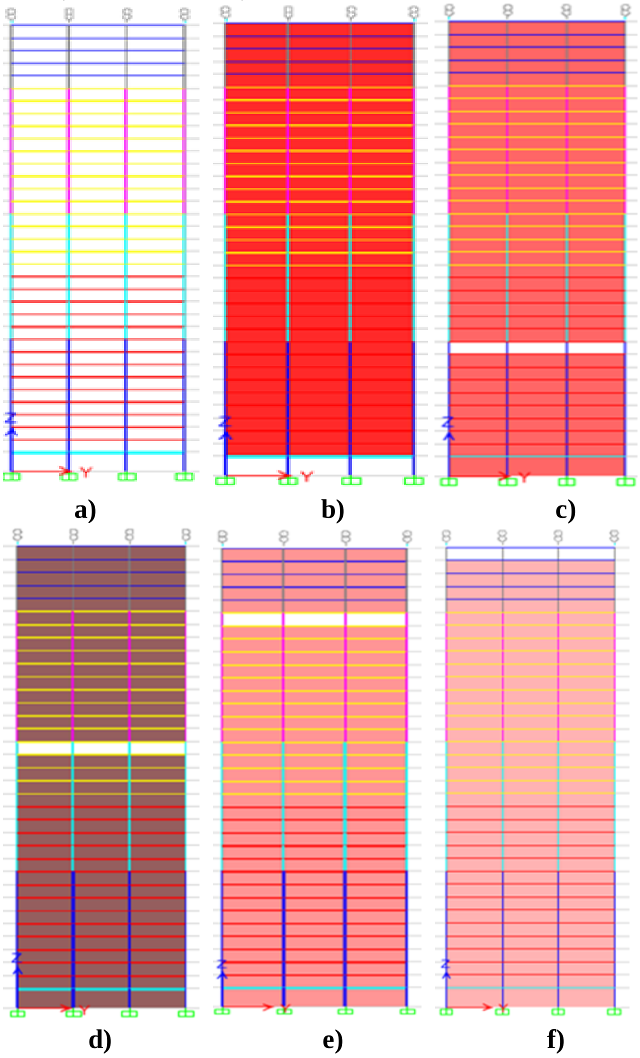


Fig 3. a) Elevation of BFM, b) Elevation of M1 model, c) Elevation of M2 model, d) M3 Elevation, e) M4 Elevation, f) M5 model Elevation.

III. RESULTS AND DISCUSSION

Type A. Comparison Between The Buildings Having Soft Storey Effect At Different Levels.

a) Displacement in X-Direction (RSX)

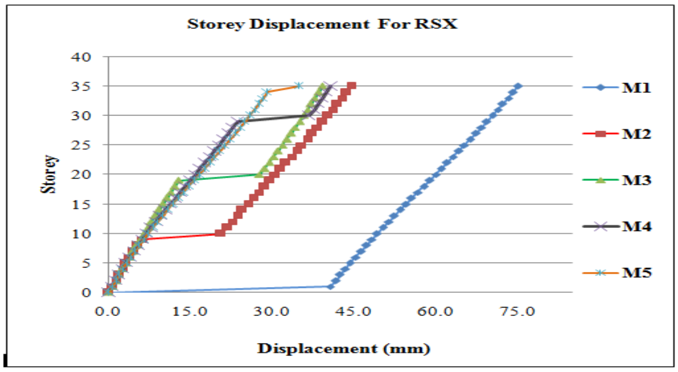


Fig 4. Storey Displacement for different soft storey location in X-direction

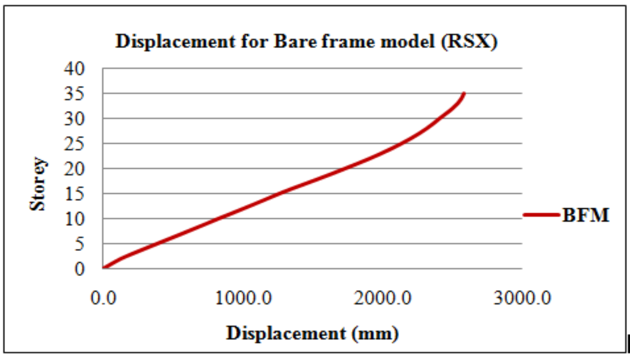


Fig 5. Storey Displacement for bare frame model in X-direction

b) Displacement in Y-Direction (RSY)

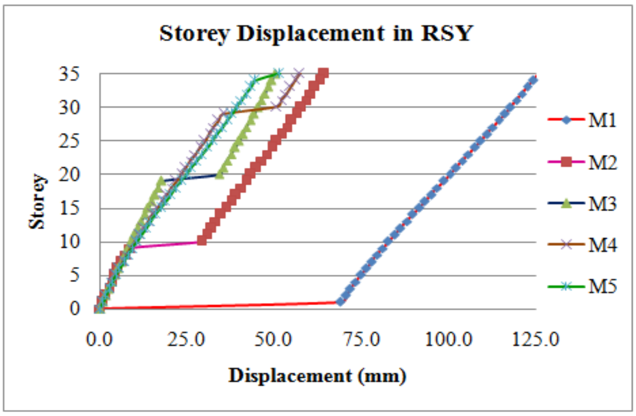


Fig 6. Storey Displacement for different soft storey location in Y-direction

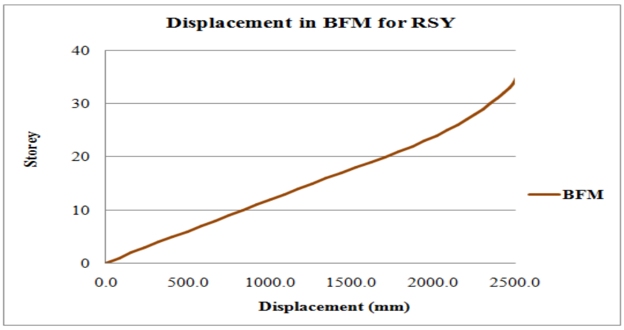


Fig 7. Storey Displacement for bare frame model in Y-direction

Discussion on Displacement Values

The displacement in X-direction and Y-direction for load case response spectrum is mentioned above graphs for all kind of models (BFM, M1, M2, M3, M4 and M5). Displacement is the main parameter which helps to know the deflection behavior caused due to the lateral loads acting on the structure. The maximum displacement is at the 35th floor in all the models. For open ground floor (M1) model, displacement is almost 41% more than other models having soft storey effect (M2 to M5) in different levels for X-Direction, whereas in RSY almost 48% more. Other than open ground floor, models M2 to M5, have same displacement values. in case of infill walls, there will be sudden change in the displacement at a floor where infill walls are absent and varies linearly. In case of bare frame model (BFM), displacement is too high in compare with models having masonry infill walls.

c) Drift in X-Direction (RSX)

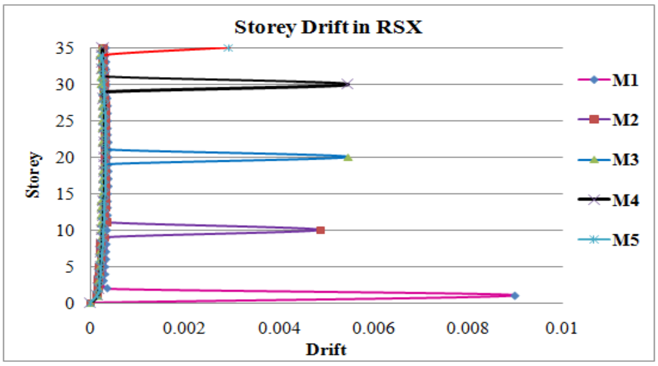


Fig 8. Storey Drift for different soft storey location in X-direction

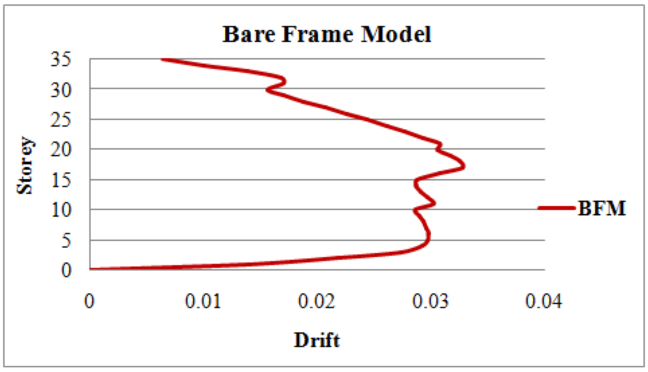


Fig 9. Storey Drift for bare frame model in X-direction

d) Drift in Y-Direction (RSY)

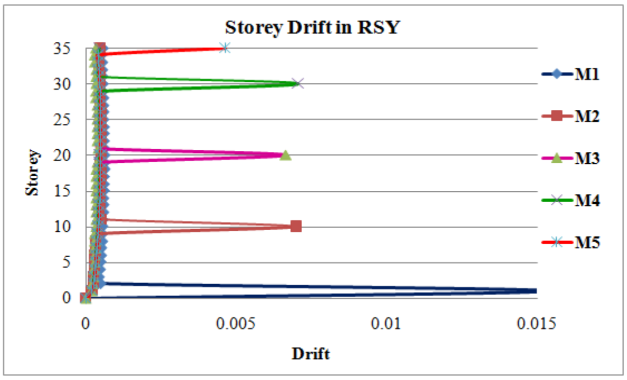


Fig 10. Storey Drift for different soft storey location in Y-direction

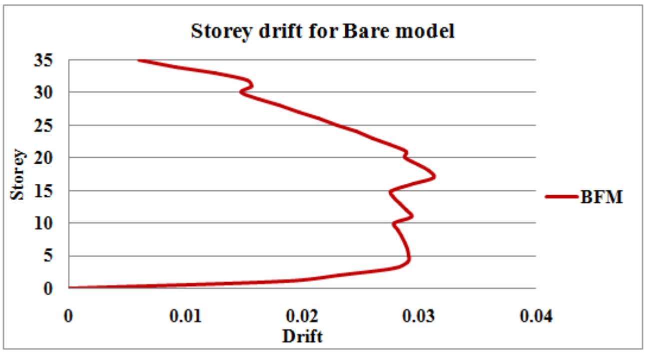


Fig 11. Storey Drift for bare frame model in Y-direction

Discussion on Drift Values

Drift is another important parameter for knowing the behavior of the structure. From IS 1893 (Part 1): 2002, storey drift can be defined as the relative displacement of one level to the above or below levels. The drift varies for different storeys in bare frame model and decreases at 35th floor. It reaches highest value in the middle of the building say at storey 17 for the bare frame in both the directions (RSX and RSY). For the model without infill walls at 1st floor has greater value of drift at the same level, when compared with other models (M2 to M5). It increases gradually at the floor where there is a soft storey and decreases again when it moves to other floors with the infill effect. Model M2, M3 andM4 has almost same values of storey drift and M5 has very low value. Drift is more in the Y-Direction that of in RSX because of its shorter span.

e) Stiffness in X-Direction (RSX)

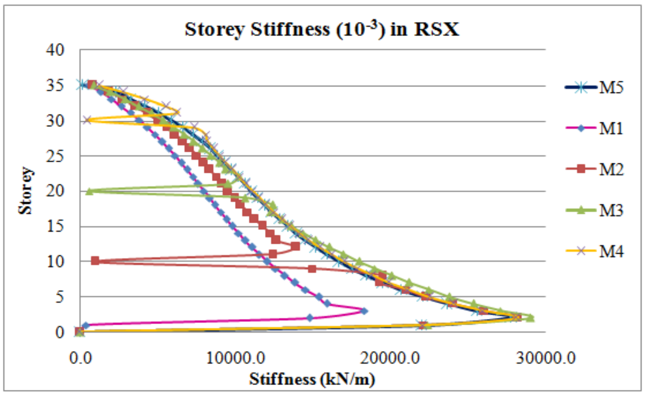


Fig 12. Storey Stiffness for different soft storey location in X-direction

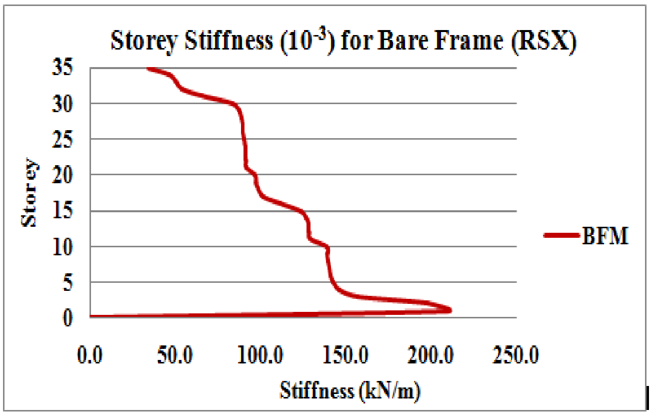


Fig 13. Storey Stiffness for bare frame model in X-direction

f) Stiffness in Y-Direction (RSY)

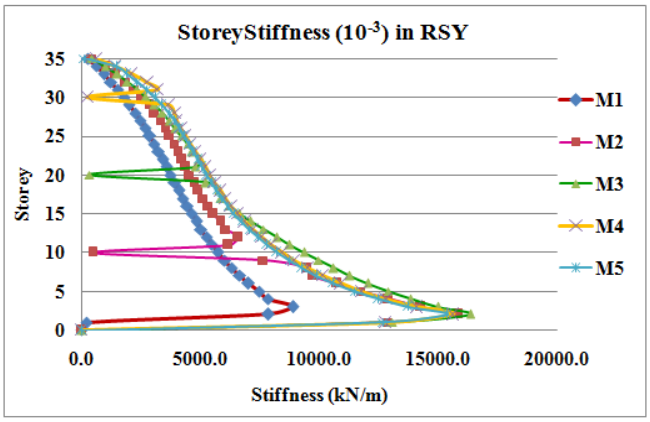


Fig 14. Storey Stiffness for different soft storey location in Y-direction

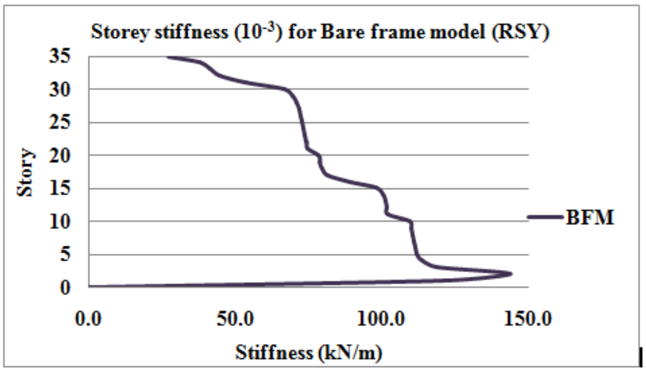


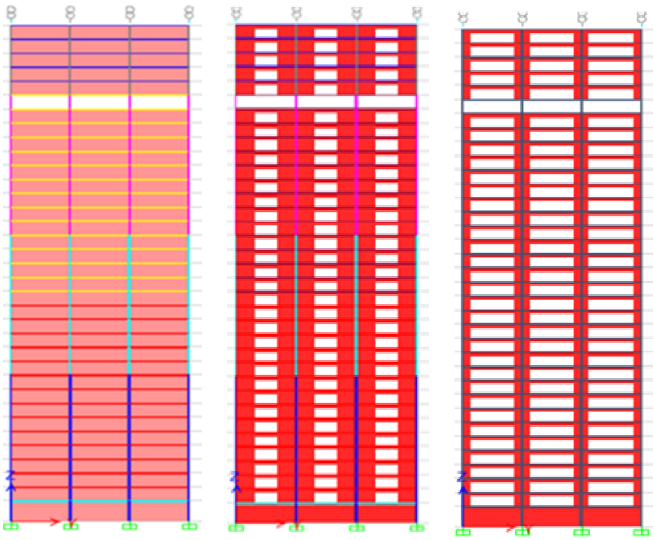
Fig 15. Storey Drift for bare frame model in Y-direction

Discussion on Stiffness Values

Stiffness is the most important parameter while analyzing the building for soft storey concept. More the stiffer the structure is, more can resist them from failure due to lateral loads. The building without any lateral resisting unit is less stiffer and failure will be more in that case. The bare frame model has very less values for stiffness due to absences of any infill walls. Stiffness is more in ground floor and reduces as it moves to upper floors. The model M1, Stiffness is less at ground floor in compare with all other models because of its soft storey effect at ground floor. Other models from M2 to M5, stiffness is too high at ground floor due to presences of masonry infill and there will be slight decreasing. At the floor, without masonry infill walls, stiffness suddenly drop down to low value and again regains its stiffness in remaining floors.

Type B. Comparison of the responses between the buildings having soft storey effect and soft storeys with openings. (M and OM)

Models of case 3 is done by providing openings for the infill walls. It is achieved in two types , (a) 25% (AOM) of area ($10X3=30m^2$), and (b) 50% (BOM)of the area. Here, only one type of model is illustrated with the results. Consider the model M4, which as soft storey effect at 30th storey and others having infill masonry walls also with the wall openings models AOM4 and BOM4. Wall openings are not assigned for the ground floor.



a) b) c)

Fig 16. a) Elevation of M4, b) elevation of AOM4, c) elevation of BOM4.

i) Displacement in X-Direction (RSX)

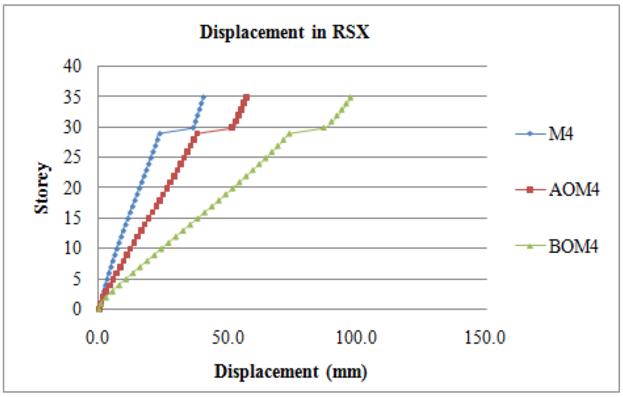


Fig 17. Storey Displacement in X-Direction for M4, AOM4, BOM4 Cases

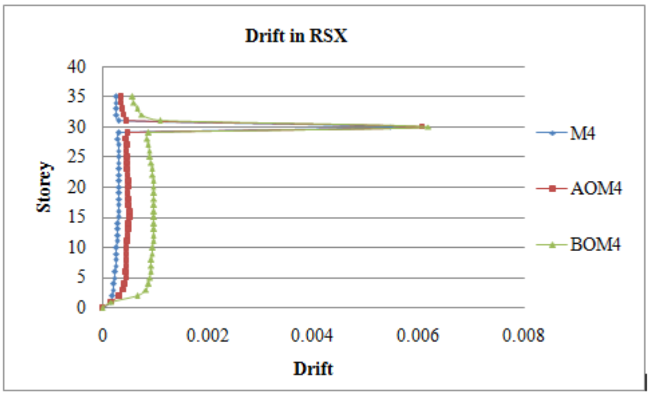


Fig 18. Storey Drift in X-Direction for M4, AOM4, BOM4 Cases

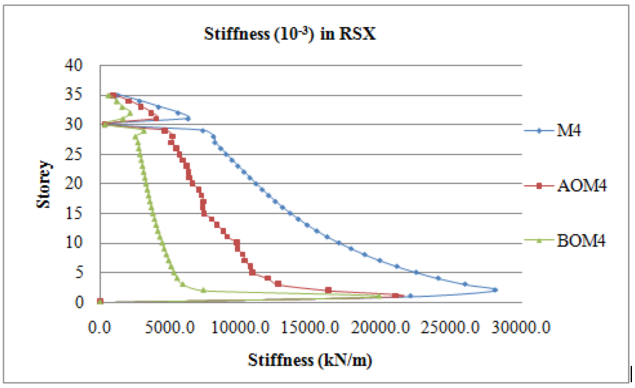


Fig 19. Storey Stiffness in X-Direction for M4, AOM4, BOM4 Cases

ii) Displacement in Y-Direction (RSY

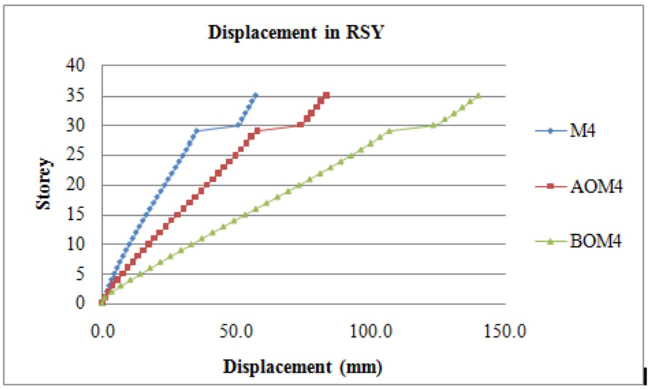


Fig 20. Storey Displacement in Y-Direction for M4, AOM4, BOM4 Cases

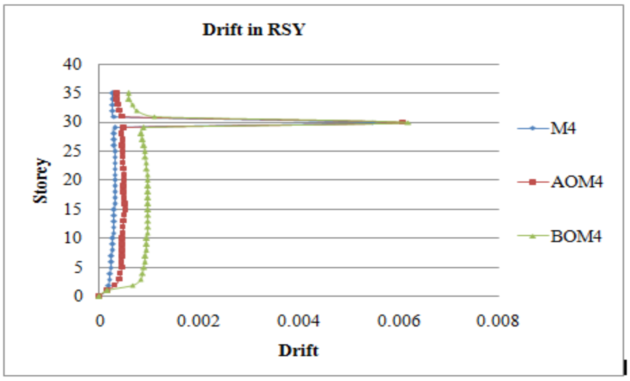


Fig 21. Storey Drift in Y-Direction for M4, AOM4, BOM4 Cases

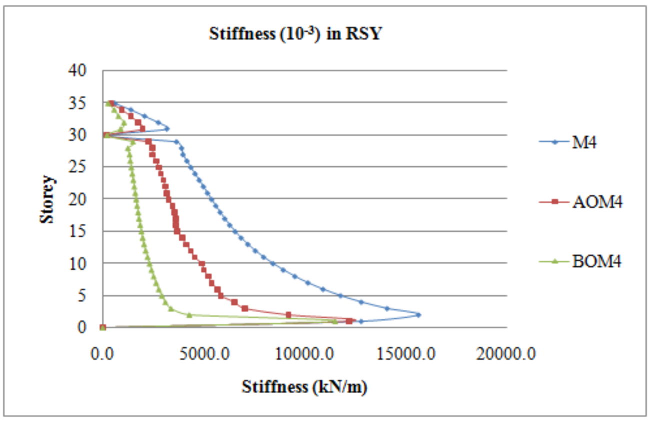


Fig 22. Storey Stiffness in Y-Direction for M4, AOM4, BOM4 Cases

Discussion on the Type 2 comparison. (M4, AOM4 and BOM4)

From fig 17 to fig 22, shows the variation of the responses under the load case RSX and RSY. The comparison is done between the 3 types of models, namely
(a)the model having a soft storey at 30th level and infill wall in rest of the floors (M4),
(b) Model with soft storey effect at 30th level having infilled walls at other floors and these infill walls is associated with wall openings of 25% of the area. (AOM4)
(c)30th floor is a soft storey and other floors are having infilled walls with 50% of the area is made as wall opening (BOM4).

It is seen that, The displacement is more at 35th floor in all the model cases. Under RSX load case, storey displacement is too more in case of model BOM4, i.e., 58% more than the model without wall openings(M4) and AOM4 is 29% more than model M4. For the displacement under RSY, at 35th level, BOM4 is 59% more than model M4 and 31% more in case of AOM4. Hence the presence of the wall openings for soft storey building will lead to increase in the displacement value.

The storey drift increases for the model having 50% wall openings, at the level which posses soft storey effect (30th floor) as shown in the fig 18 and fig 21. In compare with M4 and AOM4, there is no much changes in drift value, a slight increases in the model AOM4 can be observed in both RSX and RSY cases.

Storey stiffness drops down in case of BOM4 model because of its larger wall opening effect. Stiffness decreases 18% in case of BOM4 model and 13% for AOM4 at 30th floor in compare with the model without masonry infilled walls (M4) under RSX load case. For RSY, stiffness of 16% decrease can be seen for model BOM4 and 10% drop down for model AOM4 in compare with M4 at 30th level.

Similarly, this kind of comparison is done for all other models (M1, AOM1, BOM1 to M5, AOM5, BOM5) in the main thesis, which gives same values and results at different soft storey floors.

IV. CONCLUSIONS

The bare frame posses high displacement and the risk of deflection during earthquake is high. Hence providing the lateral load resisting unit is important to minimize the risk of failure. Among all, masonry infill walls are the most commonly used as lateral load resisting element and also applicable to eliminate the soft storey effect. Masonry is frequently used for all kinds of walls such as infilled walls or partition walls. The designer should take care to check the interaction between the frame and the masonry because it will be subjected to lateral forces.

Open ground floor (M1) is having more displacement value compared to other models with different soft storey levels. Hence, the failure of open ground floor buildings are more during earth's shaking. Due to soft storey, sudden increase in the drift can be seen in that floor. Stiffness increases for the storey having infill walls and bare frame is weak in stiffness.

Infill walls with openings has weak performance compared to the walls without openings. Anyhow, some portion of openings(say 25%) can be provided which will be less effective to earthquake forces.

Instead of infill walls, shear walls can be used to check the behavior of the building under lateral loads for further studies.

ACKNOWLEDGMENT

I would like to thank my guide, the Head of the Department, management, faculty and friends of the Oxford College of Engineering, Bangalore, Karnataka for their support and guidance.

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