International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 09 | Sep -2016 www.irjet.net p-ISSN: 2395-0072

LINEAR STATIC ANALYSIS OF MASONRY INFILLED SOFT STOREY RC BUILDINGS WITH AND WITHOUT OPENING FOR EARTHQUAKE RESISTANT DESIGN

Nusfa Karuvattil[1], Priyanka Dilip P[2]

[1] *Student, Department of Civil Engineering, AWH engineering College, Calicut, Kerala, India*
[2] *Assistant Professor, Department of Civil Engineering, AWH engineering College, Calicut, Kerala, India*

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Abstract - *Masonry infill walls are mainly used to increase initial stiffness and strength of reinforced concrete (RC) frame buildings .It is mainly considered as a non-structural element. In many cities of India, it is very common to leave the first storey of masonry infilled reinforcement concrete (RC) frame building open preliminary to generate parking space or any other purposes (Ex-Reception lobbies) .This Open First storey is also termed as "Soft Storey". The upper storeys have brick infilled wall panels with various opening percentage in it. These types of buildings are highly undesirable in seismically active areas because various vertical irregularities are created in such buildings which have consistently performed very poor behaviour during past earthquake. Therefore it is important to take immediate measures to prevent the indiscriminate use of soft first storeys in buildings, which are designed without regard to the increased displacement and force demands in the first storey columns. The current study investigates the seismic response of reinforced concrete moment resisting-frame multi-story buildings with soft storey or open storey located at different levels with and without opening and designed according to the IS code. Building models are bare frame, infilled frame with soft storey at GL, FF and TF and infilled frame with soft storey at three different levels along with 10% and 30% centre and corner openings. Infill panel effect is induced in the structure by using Equivalent Diagonal strut method. This research made an attempt to strengthen the soft storey by different methods. Thus linear static analysis is to be carried out on the models by using computer software ETABS from which different parameters are computed.*

Key Words: **Masonry infill, SS (Soft storey), Moment Resisting frame, linear static analysis, Equivalent Diagonal strut**

1. INTRODUCTION

Many urban multistorey buildings in India today have open first storey as an unavoidable feature. This leave the open first storey of masonry infilled reinforced concrete frame building primarily to generate parking or reception lobbies in the first storey. It has been known for long time that masonry infill walls affect the strength and stiffness of infilled frame structures. There are plenty of researches done so far for infilled frames, however partially infill frames are still the topic of interest. Though it has been understood that the infill's play significant role in enhancing the lateral stiffness of complete structures, infills have been generally considered as non-structural elements and their influence was neglected during the modelling phase of the structure. A SS building is a multi-storey building with one or more floors, which are "soft" due to structural design. These floors can be especially dangerous in earthquakes. As a result, the SS may fail, causing what is known as a SS collapse. If a building has a floor that is 70% less stiff than the floor above it, it is considered a SS building. As per IS 1893(part 1): 2002 code [1] some design criteria are to be adopted after carrying out the earthquake analysis, in which the columns and beams of the soft stories are the designed for 2.5 times the storey shears and moments calculated under seismic loads.

SS building shows comparatively a higher tendency to collapse during earthquake because of the SS effect. Large lateral displacements are induced at the first floor level of such buildings yielding large curvatures in the ground storey columns. The bending moments and shear forces in these columns are also magnified accordingly as compared to a bare frame building (without a SS). The energy developed during earthquake loading is dissipated by the vertical resisting elements of the ground storey resulting the occurrence of plastic deformations which transforms the ground storey into a mechanism, in which the collapse. The construction of open ground storey is very dangerous if not designed suitably and with proper care. Modern seismic codes just neglect the effects of non-structural infill walls during

1.1 Typical Masonry Infilled Buildings

As early 1960s, studies have been carried out to study the influence of infill on the moment resisting frames under lateral loads induced by earthquakes, wind and the blast. Numerous experimental and analytical investigations have been carried out; nevertheless, a comprehensive conclusion has never been reached due to the complex nature of material properties, geometrical configuration and high cost of computation. Though the effect of infill is widely recognized, there is no explicit consideration in the modern codes, thus the design engineer's end up designing the building based on judgment.

1.2 Review of Literatures

Jaswant n. Arlekar, et al [2] argues to adopt immediate measures to prevent the indiscriminate use of SS in a building. This paper brought out the errors involving in modelling the building as complete bare frame and neglecting infill panel in the upper storeys. Static and dynamic analysis is carried out on different models to study the effects of SS and presence of infill wall in the model. This study concludes that building with first SS exhibits poor performance during earthquake. It is necessary to increase the stiffness of first storey by at least 50%. Adequate stiffness and lateral strength can be adopted by providing stiffer columns. Soil flexibility is the main criteria to finalize the analytical model of the building

Haroon Rasheed tamboli et al [3] investigated the behaviour of different reinforced concrete (RC) frame building models using equivalent lateral force method and the software ETABS is used for the analysis of all the frame models. The comparative study made for different models in terms of base shear, time period, natural frequency, storey drift. Concluded, the presence of infill wall can affect the seismic behaviour of frame structure to large extend and the infill wall increases the strength and stiffness of the structure for G+4 building

Md Rihan Maaze and S. S. Dyavanal [4] performs equivalent static and response spectrum analysis on infill frame and solid concrete block and compared to bare frame. In addition, non-linear pushover analysis is carried out for hinge properties. He concluded that SMRF building models are found more resistant to earthquake loads as compared to OMRF in terms of performance level point and hinge variation. Hence, ductile detailing is must for building under high seismic zone.

Dhadde santosh [5] carried out the performance evaluation on non-retrofitted buildings. SS is located at ground, intermediate and top and compared to retrofitted model. The performance evaluation was based on lateral deformation, storey shear, and hinge formation from the study, he had concluded that storey drift is maximum at SS and it decreases gradually upto the top. Plastic hinge formation, base reaction and roof displacement is more in existing SS building but less in retrofitted models.

1.3 Modelling of Infill Frame

Model development of any structure is crucial to achieve accurate output results. However, it is difficult to model the as-built structures due to numerous constraints with as it is difficult to incorporate all physical parameters associated with the behaviour of an infilled frame structure. Even if all the physical parameters, such as contact coefficient between the frame and infill, separation and slipping between the two components and the orthotropic of material properties are considered, then there is no guarantee that the real structures behaves similar to the model as their structural could also depend on the quality of material and construction techniques.

However, researchers later found that this model overestimates the actual stiffness of infilled frames and give upper bound values. Another model for masonry Infill panels was proposed by Mainstone in 1971 where the cross sectional area of strut was calculated by considering the sectional properties of the adjoining columns. The details of model are as shown in Fig. 4.1. The strut area A_e was given by the following equation.

However, to stimulate the structural behaviour of infilled frames. Two methods have been developed such as micro model and macro model. The micro model method is a finite element method where the frame elements, masonry work, contact surface, slipping and separation are modelled to achieve the results. This method generate better results but it is not gained popularity due to its cumbersome nature of analysis and computational cost.

The macro models which is also called simplified model or equivalent strut method was developed to study the global response of the infilled frames. This method uses one or more struts to represent the infill wall. The drawback of it is due to the lack of its capability to consider the opening precisely as found in the infill wall.

a) Micro model

It is a process of discretizing the structural components into a smaller sizes, maintaining the constitutive laws of material, in ordered to improve the accuracy of results. However, this method is mostly limited to small structures as it requires high computation equipment besides taking comparatively longer time.

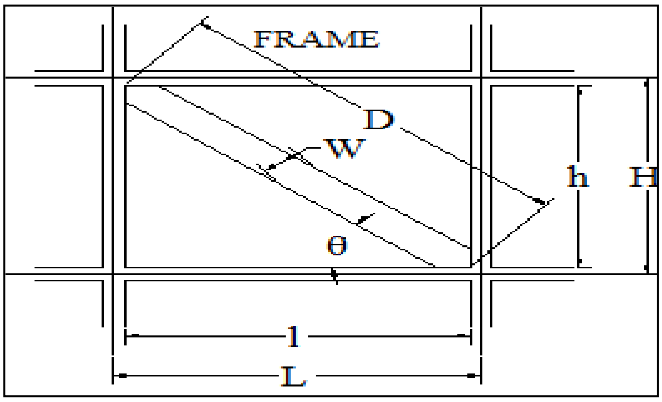

Fig 1- Equivalent Diagonal Strut

b) Macro Model

Equivalent Diagonal Strut Method

The simplest equivalent strut model includes a single pin-jointed strut. Holmes who replaced the infill by an equivalent pin-jointed diagonal strut made of the same material and having the same thickness as the infill panel suggest a width defined by,

$$\frac{W}{d} = \frac{1}{3}$$

Paulay and Priestley suggested the width of equivalent strut as,

$w = 0.25d$

Where,

d = Diagonal length of infill panel

w = Depth of diagonal strut

Fig 4.1: Equivalent diagonal strut model

$A_e = W t$

$W = 0.175 (\lambda H)^{-0.4} D$

$$\lambda = \sqrt[4]{\frac{E_i t \sin 2\theta}{4 E_f I_C h}}$$

Where,

E_i = the modules of elasticity of the infill material, N/mm²

E_f = the modules of elasticity of the frame material, N/mm²

I_c = the moment of inertia of column, mm⁴

t = the thickness of infill, mm

H = the Centre line height of frames

h = the height of infill

L = the centre line width of frames

l = the width of infill

D = the diagonal length of infill panel

θ = the slope of infill diagonal to the horizontal

2. OBJECTIVES

- To study ETABS software for linear static analysis
- To study Equivalent diagonal strut method for the design of infilled frames
- To study the performance of a structure with SS location either at ground fifth or TF.
- To study the effect of centre and corner opening in buildings with SS at ground or fifth or TF.
- To develop a method to strengthen the SS
- To check the validity of MF 2.5 used for the design of structures with SS
- To make a building earthquake resistant

3. METHODOLOGY

- Review of the existing literatures by different researchers and also by the Indian design code provision for designing the SS buildings.
- Study the equivalent diagonal method for representing the effect of infill frames using FEMA 273 [6] and ATC 40[7]
- Select the building models for the case study.
- A G+9 storey building is to be selected for the investigation
- Building with SS at GL, building with SS at FF and building with SS at TF are the three basic models meant for the research. Performance of these basic models need to be investigated.
- Basic models are to be provided with the 10 % and 30 % centre and corner openings
- Perform Linear static analysis on the selected building models and a comparative study is to be done on the results obtained from the analyses.
- Check which model has higher vulnerability towards seismic forces
- SS strengthening techniques such as providing stiff column, providing adjacent infill (brick) panel at corners of the SS, providing shear wall at different locations i.e. one wall on each side at middle and corner shear wall are to be tried to choose a best strengthening technique.
- SS is to be analysed by providing diagonal bracings, and lateral buttresses also.
- Column bending moments and shear forces of Bare frames and Infilled frame with SS are to be obtained to get the MF
- Interpretation of results and conclusions

4. OBJECTIVES

The typical building plan layout of 3D reinforced concrete moment resisting building frame is selected as shown in Figure 1 and figure 2. 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 rectangular to keep the discussion focused only on the SS effect, without being distracted by the issues like orientation of columns. G+9 storey model is modelled for the study. Unreinforced masonry infill was generated using equivalent strut model according to FEMA-273 (1997) [6] .SS was then provided at GL, FF and TF.

Properties of the structure is described below

Floor height is 4m.

Material properties are:-

Unit weight of the concrete	=	25 kN/m³
Unit weight of masonry	=	20 kN/m³
Elastic modulus of steel	=	2x10⁸ kN/m²
Elastic modulus of concrete	=	25000 kN/m²
Elastic modulus of masonry	=	3600000 kN/m²
Poisson's ratio of concrete	=	0.2
Poisson's ratio of masonry	=	0.15
Characteristic strength of Concrete	=	25 N/mm²
Yield strength of steel	=	415 N/mm²

Analytical Properties are:-

Number of Stories	=	G+9
Bottom storey Height	=	2.4m
Storey Height	=	4 m
Height of lift cab	=	2.3 m
Seismic Zone	=	Zone III
Building is resting on Hard Soil.		
Response Reduction Factor	=	5
Special Moment Resisting Frame		
Importance Factor	=	1.5

Column size	=	230 x 600 mm
Beam Size	=	230 x 450 mm
Plinth Beam	=	230 X 300 mm
Shear wall	=	250 mm

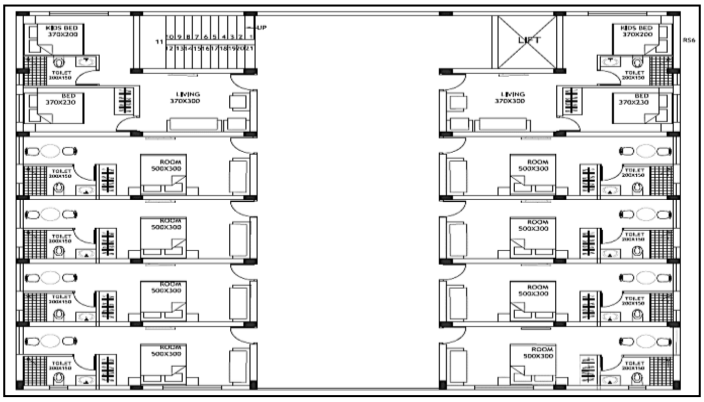

Fig-2 :GL Plan

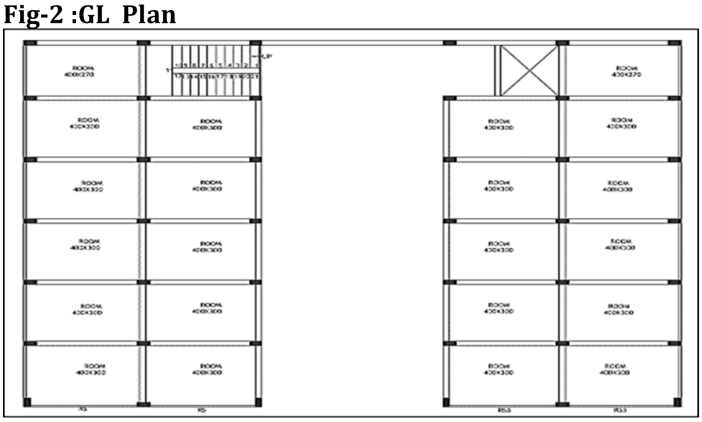

Fig -3: 1 -10 th Floor Plan

Plinth Beam	=	230 X 300 mm
Shear wall	=	250 mm
Thickness of slab	=	150 mm
Live load	=	4 kN/m^2
Floor finish	=	1 kN/m^2
Water proofing load	=	2.5 kN/m^2

5. STRENGTHENING TECHNIQUES

4.6.1 Shear Wall

Shear wall is one of the most commonly used lateral load resisting in high rise building. Shear wall has high in plane stiffness and strength which can be used to simultaneously resist large horizontal load and support gravity load.

4.6.2 Stiffer Column

The effects of stiffness is very important as if the setting of the stiffening elements at structure and their geometrical specifications are not opted accurately, the structure may undergo amplify against the earthquake waves and the structure may be subject to fracture and may even lose its practical aspects. If the stiffness of structure elements in multi-storey structures alters, it can precipitate the vibration of structural modes shape. Stiffness of a column means resistance to deformation- the larger is the stiffness, larger is the force required to deform it. This method is used to stiffen the structures with SS at GL. Size of column used for this research is 450x1000 mm .

4.6.3 Adjacent Infill

Masonry infill is normally considered as non-structural elements and their stiffness contributions are generally ignored in practice. Masonry infill has several advantages like good sound and heat insulation properties, high lateral strength and stiffness. These help to increase the strength and stiffness of RC frame and hence to decrease lateral drift, energy dissipation capacity due to cracking of infill and friction between infill and frame. This in turn increases redundancy in building and reduces bending moment in beams and columns. Masonry infill has disadvantages like very high initial stiffness and compressive strength. Hence at the SS location adjacent infill panels are provided on corners of the SS. Adjacent infill has same properties as that of the brick wall. It has thickness of 230 mm

4.6.4 Bracing

Bracings can be provided in different manners.

a) K-bracing

The full diagonal bracing is not used in areas where a passage is required. In such cases, K bracings are preferred over diagonal bracings because there is a room to provide opening for doors and windows etc. as shown in Figure 4.22.

b) Eccentric bracing

Besides K-bracing, there is another type in which door and window openings can be allowed known as eccentric bracing such type of bracing arrangement because the bending of the horizontal members of the web of braced bent. Generally these types of braced bents resist the lateral forces by bending action of beams and columns. These provide less lateral stiffness, hence less efficient as compared to diagonal bracing.

4.6.5 Buttress

A buttress is an architectural structure built against or projecting from a wall which serves to support or reinforce the wall. Buttresses are fairly common on more ancient buildings, as a means of providing support to act against the lateral (sideways) forces arising out of the roof structures that lack adequate bracing. In addition to flying and ordinary buttresses, brick and masonry buttresses that support wall corners can be classified according to their ground plan.

4.6 RESULTS AND DISCUSSIONS

Researches suggests to design the buildings by considering the effect of infill. Infill frame with SS at GL and its MF is obtained is shown in Table 1

Table 1 :MF when SS was provided at GL

Table 1: MF when SS was provided at GL

COLUMN	PROPERTY	BARE FRAME	SS AT GL	MF
Exterior Columns	M	78.44	144.78	1.84
	S	42.5196	68.96	1.621
Interior Columns	M	120.61	92.7716	0.76
	S	44.7159	37.26	0.83

Similarly, our second model is infill with SS at FF and its MF is obtained as shown in Table 2.

Table 2: MF when SS was provided at FF

COLUMN	PROPERTY	BARE FRAME	SS AT FF	MF
Exterior Columns	M	78.2186	121	1.54
	S	41.068	60.369	1.46
Interior Columns	M	120.61	120.4842	0.99
	S	44.7159	60.0861	1.34

Next model is infill with SS at TF shown in figure 5.3, MF is shown in Table 5.3.

Table 3: MF when SS was provided at GL

COLUMN	PROPERTY	BARE FRAME	SS AT TF	MF
Exterior Columns	M	173.49	232	1.3
	S	94.36	122.5499	1.29
Interior Columns	M	120.61	62.5812	0.51
	S	44.7159	6.2106	0.13

The graphical representation of Displacement with respect to height of structure of 10 % opening is represented in figure 4.

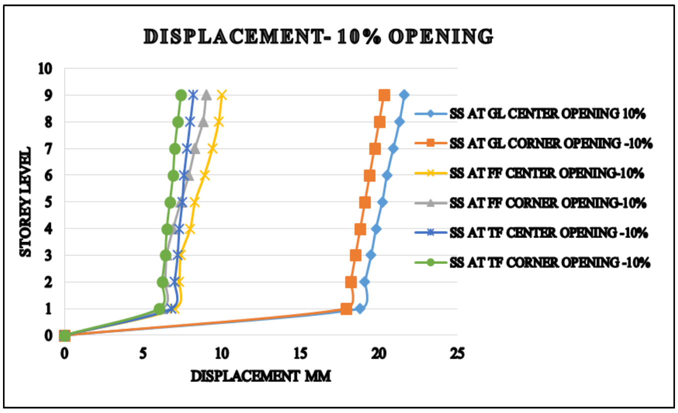

Fig 4 – Displacement of 10% opening

The graphical representation of time period with respect to mode number of 10% opening is represented in figure 5

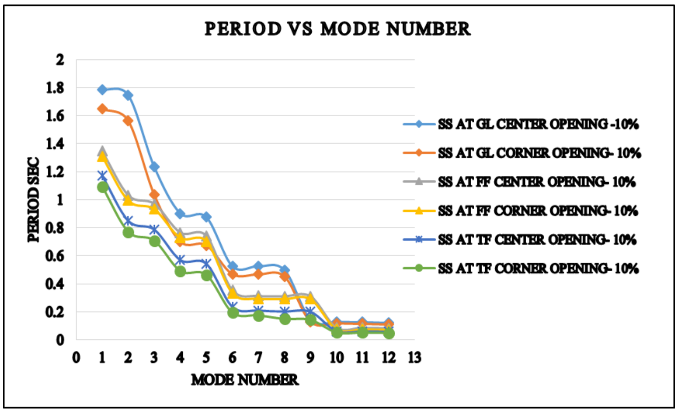

Fig 5 : Time period of 10% opening

The graphical representation of Displacement with respect to height of structure of 30 % opening is represented in figure 6

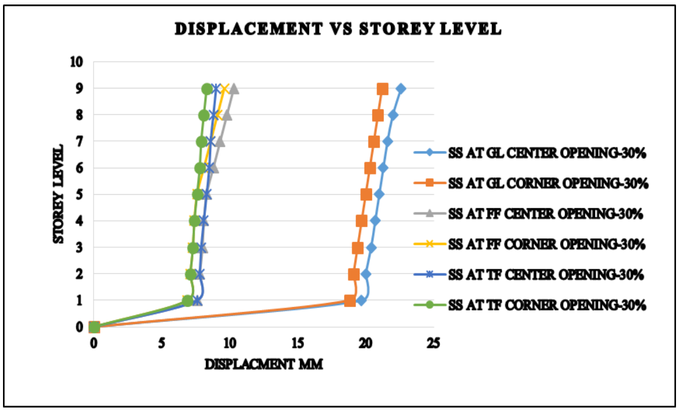

Fig 6– Displacement of 30% opening

The graphical representation of time period with respect to mode number of 30% opening is represented in figure 7

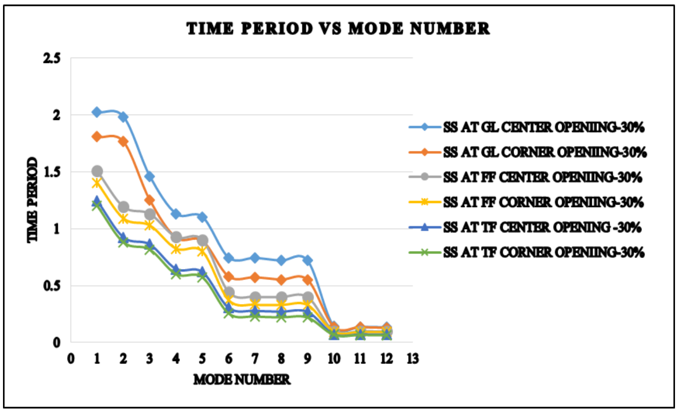

Fig 7 – Displacement of 30% opening

The graphical representation of Displacement with respect to height of structure of 10 % opening and 30% corner opening is represented in figure 8

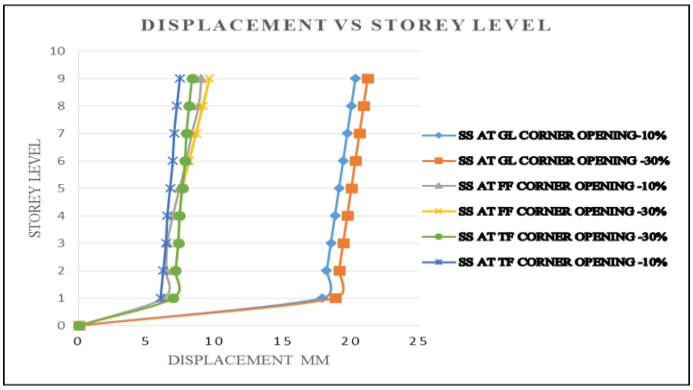

Fig 8 : Displacement of 10% and 30% corner opening

The graphical representation of Displacement with respect to height of structure of 10 % opening and 30% center opening is represented in figure 9

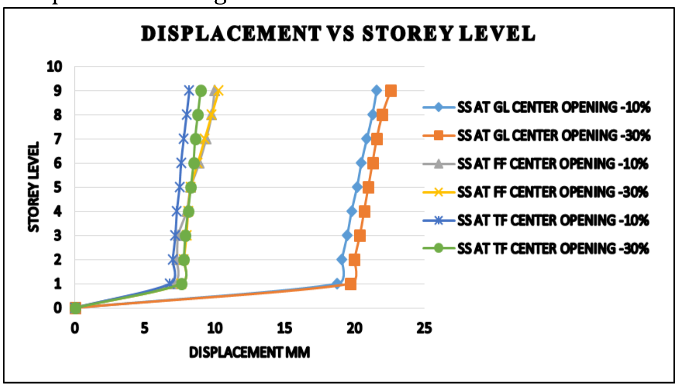

Fig 9: Displacement of 10% and 30% center opening

After strengthening following variations are observed in the roof displacement. When SS was provided at GL, roof displacement variation is shown in Figure 10. When SS was provided at FF, roof displacement variation is shown in Figure 11. When SS was provided at TF, roof displacement variation is shown in figure 12

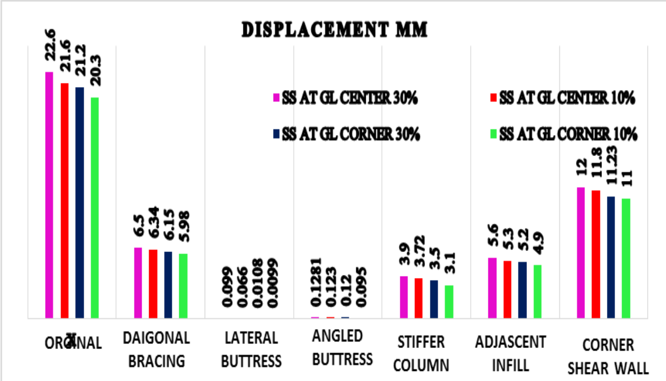

Fig 10 : SS at GL after strengthening

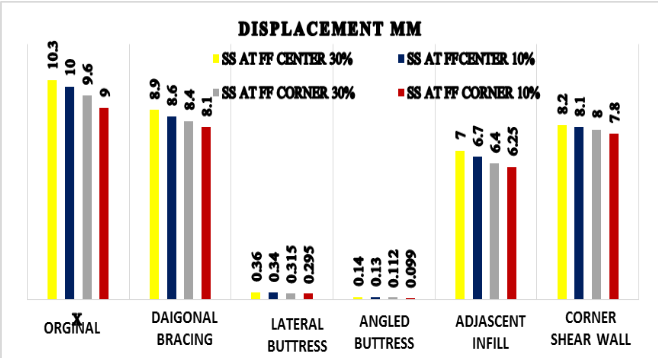

Fig 11 : SS at FF after strengthening

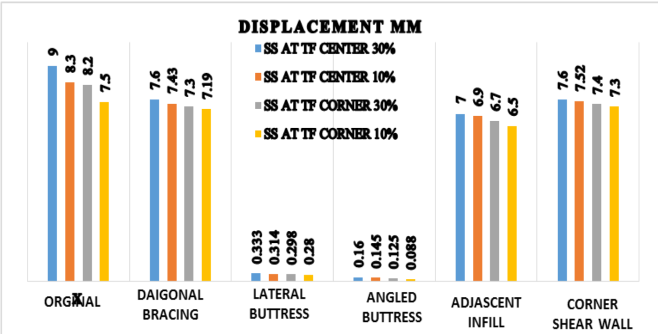

Fig 12 : SS at TF after strengthening

3. CONCLUSIONS

- MF obtained is less than the code specified value and hence the result recommends a modification in the code IS 1893(part 1):2002[1].
- Similarly structures with central opening is more vulnerable towards earthquake than structures with corner opening
- As the percentage of opening increases the deflection also increases
- SS location at TF with 10% corner opening is found to be the most stable structure among the 16 models studied.
- Stiffness decreases as the height of the structure increases. Stiffness is very low at SS location.
- Time Period is higher when SS was provided at GL with 30% central opening. It says that structure

with SS at ground level ad 30% central opening is the worst model towards earthquake.

- Frequency is high when SS was provided at TF with 10% corner opening. It depicts that SS at TF with 10% corner opening is more resistant towards earthquake.
- Different strengthening techniques where analysed, and it was observed that providing lateral buttress is the most efficient way to strengthen a particular structure.
- The displacement and force demands (i.e. BM & SF) in the first storey columns are very large for building with soft ground storey. It is difficult to provide such capacities in the columns of the first Storey. When incorporated the infill wall (panel) at soft ground storey, these demand are significantly reduced.
- The presence of walls in upper storeys makes them much stiffer than open ground storey. Hence the upper storey move almost together as a single block and most of the horizontal displacement of the building occurs in the soft ground storey itself. Such building swing back and forth like inverted pendulums during earthquake shaking and columns in the open ground storey are severely stressed. It is clear that building with SS will exhibit poor performance during a strong shaking. But the open first storey is an important functional requirement of almost all the urban multi-storey buildings and hence cannot be eliminated.
- The possible schemes to achieve the above are stiff column provided at open ground storey model and adjacent infill wall provided at each corner of SS building model. The configuration of infill in the parking frame changes the behaviour of the frame therefore it is essential for the structural system selected to be thoroughly investigated and well understood for catering to soft GL. The former is effective only in reducing lateral displacement on the first SS columns.
- Shear walls are also used to strengthen the structure. But not effective as that of lateral buttress , stiff column and adjacent infill
- Diagonal bracings are also tried and found to be effective in reducing the displacement and increasing the stiffness.

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