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Seismic Evaluation of RC Building with Shear Walls of Different Materials

[1] Dilshad Akthar, [2] Sanjay B Borghate, [3] R.K. Ingle
[1] M.Tech Student [2] Assistant Professor, [3] Professor,
[1][2][3]Department of Applied Mechanics, Visvesvaraya National Institute of Technology, Nagpur

***Abstract:*— Shear wall systems are commonly used lateral- load resisting systems in buildings. Implementing Shear walls to resist the lateral forces produced during earthquake requires knowledge of its behaviour and its effect on the total building response. Shear walls can be constructed either using reinforced concrete (RC), steel plates or combination of concrete and steel plates called as composite material. Behaviour of these types of shear walls are different and hence the overall behaviour of the same building with different shear walls will be different. This paper presents a comparative study on building responses of a six storey RC bare frame building with RC shear wall, with steel plate shear wall(SPSW) and with composite steel plate shear wal(CSPW) for gravity and seismic forces. A better understanding on the influence of shear wall material on the building behaviour can be helpful in new constructions and retrofitting of existing buildings.**

***Index Terms* - composite steel plate shear wall(CSPW),RC building,RC shear wall, steel plate shear wall(SPSW).**

I. INTRODUCTION

Shear wall systems are one of the most commonly used lateral- load resisting systems in buildings and have been found to be useful in avoiding total collapse of buildings under seismic forces. Shear walls have very high in plane stiffness and strength making them advantageous in resisting large horizontal loads and supporting gravity loads, minimizing lateral sway of the building and hence reducing EQ damage. Implementing Shear walls to resist the lateral forces requires knowledge of its behaviour. Shear walls behaviour depends upon the material used, wall thickness, wall length, wall positioning in frame, etc. This paper focusses on the effect of shear wall material used on the building behaviour.

Shear walls can be classified on the basis of material used as RC, steel plate, composite shear wall etc. R.C shear Walls varies from 150 mm to 400 mm in thickness basedon the number of storyes, building age, and thermal Insulation requirements. The wall reinforcement generally consists of two layers of distributed reinforcement (horizontal and vertical) throughout the wall length and can be single layered also. Disadvantages include development of tension cracks and localized crushing during large cyclic displacements. Steel plate shear wall system consists of a steel plate wall (web element), boundary elements (columns and beams). Stiffened SPSW with relatively closely spaced horizontal and vertical stiffeners used earlier were later replaced by unstiffened SPSW as its post-buckling ductile behaviour is much more effective in resisting seismic forces. They exhibit substantial strength, stiffness, ductility and pronounced energy dissipation behaviour Disadvantages of SPSW due to buckling of the steel plates are reduction in: shear strength, stiffness and energy dissipation capacity, also large cyclic rotations of connections of boundary element and high interstory drifts. Composite plate shear walls are SPSWs connected with reinforced concrete panels on one or both sides of the steel infill plates (with bolts or lateral ties) thatmitigate the above mentioned issues. CSPW combine the advantages of steel (strength, ductility.etc) and concrete shear walls (higher stiffness, good fire protection, buckling prevention, etc.).They can be either traditional or innovative type. The difference is that there is a gap between the RC panels and boundary elements in innovative type (concrete act as a pure buckling restrainer till the gap closes) but not in traditional type.

.**Kubin et al.**[1] proposed techniques to stabilize the resultsforshell elementmodel (introduction of top chord) and frame elementmodel (full storey depth for rigid beam) of RC shear walls. Nonlinear dynamic analysis of RC building by**Sahu et al.** [2] proved the consistency oflayered shell element model of RC shear wallover frame element model with lumped plastic hinges.**Driver et al.**[3] modelled steel infill plate as a series of diagonal tension strips which gave a good prediction of the behavior shear wall specimenconsidered.**Londhe** and **Chavan** [4]foundthat use of steel shearwalls in buildings reduced the bending moments in the frame elements.**Zhao** and **Astaneh.**[5] conducted

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experimental studies of composite shear wall specimens. One with a traditional and other with an innovative wall system(32mm gap between the RC wall panel and boundary memebers).Both showed highly ductile behavior(more in innovative type)and stable cyclic post yielding performance.**Sun et al.**[6]proposed a Cross-Strip Model as shown in Figure below (Figure 7) for the innovative type of CSPWin which concrete panels which only act as a buckling restrainer for the steel plate. Detailed literartre about both SPSW and CPSW are given in **steel design guide-20**(AISC)[7].

A comparative study on the seismic behaviour of the same RC building with these different material shear walls using SAP 2000[8]is donein this paper. A better understanding on the influence of shear wall material on the building behaviour can be helpful in new constructions and retrofitting of existingnbuildings.

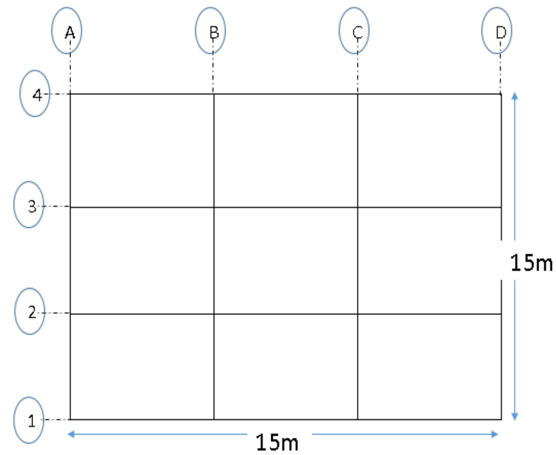
II. DESCRIPTION OF BUILDING

A six storey RC building frame with three bays of 5 m each in both direction and data given in Table 1 was considered for comparison.

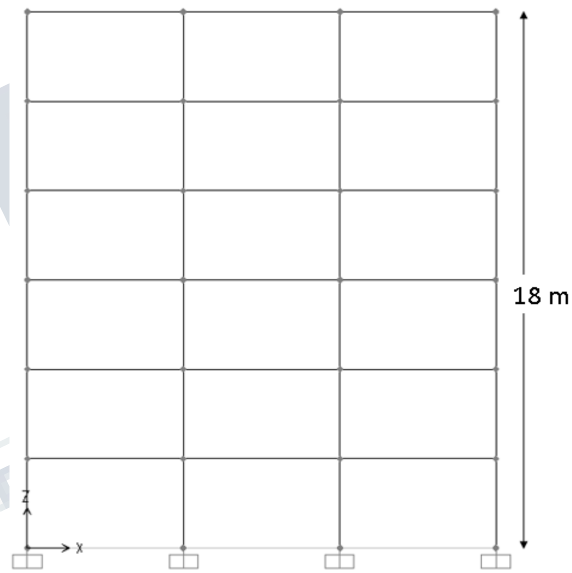
Table 1: Data for the building for comparison

PLAN SIZE	15 X 15 m
TOTAL HEIGHT	18m
STOREY HEIGHT	3m
BEAM	250 X 400 mm
COLUMN	400 X 450 mm
SLAB THICKNESS	150mm
FLOOR LIVE LOAD	3 KN/M2
ROOF LIVE LOAD	1.5 KN/M2
Z	0.24
I	1.5
R	3
SOIL TYPE	HARD ROCKY SOIL
RC SHEAR WALL	200 mm thick
STEEL PLATE SHEAR WALL	10 mm thick
STEEL PLATE IN COMPOSITE SHEAR WALL	10 mm thick
CONCRETE PANEL THICKNESS IN COMPOSITE SHEAR WALL	100 mm thick on both sides

The plan and elevation of the building is shown in Figure 1.



a) The typical floor plan of six storey RC building



b).The elevation of six storey RC buildingFigure 1: configuration of Analysed RC building of six storey

Thebare frame was designed for the max force and moment found from analysing it as per load combinations specified by IS 1893(part 2):2002[9]for gravity and seismic loads (Equivalent static method).Here we are comparing the same frame with and without shear walls and the bare frame have been already designed to carry full earthquake force along with gravity loads.So here we are incorporating different material shear walls of nominal sizes (as given in table 1) to the fully designed bare frame and noticing the effect of inclusion of them on the bare frame.

2.1. Shear wall Location:

The designed frame was then repeatedly analysed for four different cases i.e. bare frame, frame with RC shear wall,

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frame with steel plate shear wall and frame with composite shear wall. Modelling and analysis of all cases were carried out in SAP 2000[8].Shear walls are provided at middle bays of exterior frame of buildings as shown inFigure 2.

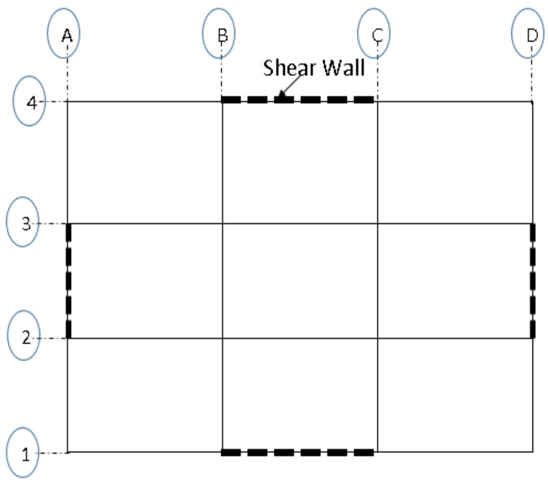


Figure2: plan of the six storey RC building showing shear wall position.

2.2Finite element modelling techniques of shear walls.

RC shear wall:

The RC shear wall (200 mm thick) was modelled using four noded thin shell element having six degree of freedom per node(Ux,Uy,Uz,θx,θy and θz)the shell element was divided into small meshes of size 50X50cm(Figure 3) having aspect ratio 1:1to achieve maximum accuracy.

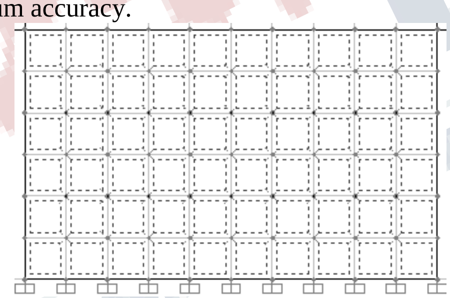


Figure 3: RC shear wall modelled with shell element discretised to small meshes.

Figure 3 shows the shell element model of RC shear wall with boundary members and shell element discretised to meshes of 50X50cm.The bottom supports are assigned as fixed supports.

Steel plate shear wall: The steel plate shear wall (10 mm thick) was modelled as diagonal tension strips as per the guidelines of steel design guide-20[7].Number of each strip group is suggested not less than 10.The section area and node locations of these strips rely heavily upon the angle, α, which is the angle between the diagonal strip and the vertical.Equations to find angleα (1) and area of the tension strip (2) as per steel design guide-20[7] is given below:

$$\propto = \tan^{-1} \sqrt[4]{\left(\frac{1+\frac{tL}{2Ac}}{1+th\left(\frac{1}{Ab}+\frac{h^3}{360\ Ic\ L}\right)}\right)} \quad \text{……….(1)}$$

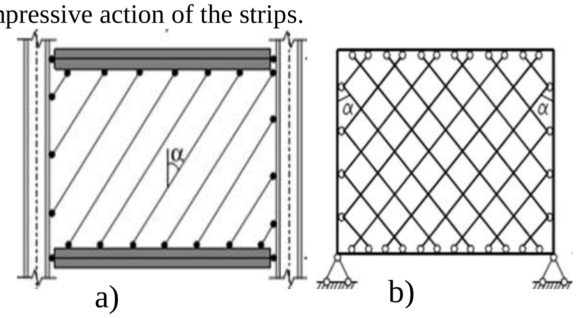
$$As = \frac{1}{n}(L\cos\propto + h\sin \quad \text{………(2)}$$

Where in equation (1)t is thickness of plate, L is center to center (c/c) distance between columns, h is c/c distance between beams,Ac is area of column, Ab is area of beam and Ic is moment of inertia of column.In equation (2) As is area of each tension strip,n is number of strips,tw is thickness of steel plate and rest notations are same as that of equation 1.Width of each strip can be found by dividing the area of strip(equation 2)by thickness of plate.

Figure4a shows image of a typical strip model for steel plate shear wall with pin jointed tension strips and boundary elements.

Composite Steel plate shear wall:

The composite shear wall (innovative) was modelled using cross strip model proposed by Sun et al.[6].Cross-strip model (Figure 4b) have two groups of diagonal parallel strips inclined at angle ∝ (similar strips and angle as in case of strip model) are defined to simulate the steel plate in a CSPW while the concrete panel will not appear in the model, as it does not resist lateral force, bearing in mind the fact that there are gaps between the concrete panel and the boundary members. The effect of the panel to restrain the out-of-plane deformation of the steel plate is modelled by allowing the compressive action of the strips.



a)Schematic representation of strip model for SPSW (Rezai et al.[10] and b) Cross-strip model for CSPW(Sun et al.)[6]. Figure 4: Modelling of steel plate shear walls.

Boundary elements in the strip model in Figure 4 have non-rigid connections, but in analysis rigid connections

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between boundary elements were considered as per steel design guide-20[7].

III.ANALYSIS AND COMPARISON OF RESULTS:

In this section comparison of analysis results for storey shear, storey displacement and drift, time period and forces in frame elements for the RC building in four different cases i.e. bare frame and three cases with different shear walls mentioned earlier. i) Storey shear v/s floor level: Figure5 shows graph comparing value of storey shear dueto applied earthquake force in X direction at each storey level for the RC building in four cases

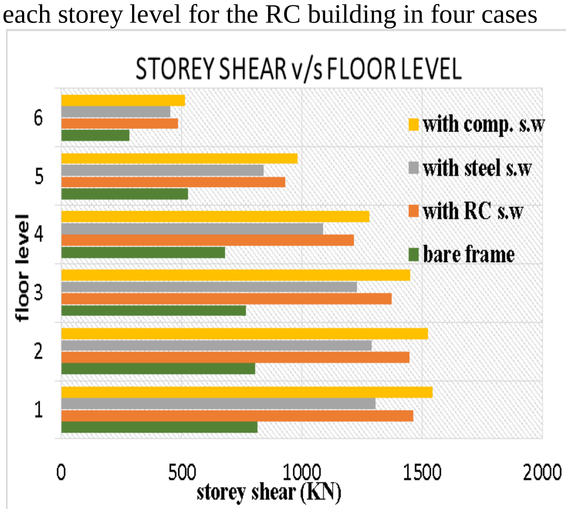

Figure. 5: storey shear

Figure5indicates that the frame with composite shear wall attracts more earthquake force since the storey shears at each level for this case is greater than that of other three cases. The bare frame attracts the least earthquake force and the base shear in this is almost half of that with composite shear wall. Frame with 200mm thick RC shear wall and Frame with 10mm thick steel plate shear wall attracts 5% and 15% less base shear respectively than that with composite shear wall.

ii) Storey displacement v/s floor level: Figure6 shows graph comparing value of floor displacement due to applied earthquake force in X direction at each storey level for the RC building in five cases i.e. the former four cases but composite shear wall. Case is divided into two; frame with composite shear wall considering the concrete cover panel (composite shear wall (1)) and composite shear wall neglecting the concrete cover panel (composite shear wall(2)). The case of composite shear wall neglecting concrete panel is considered so as to understand how well the unbuckled steel plate shear wall behaves or if the buckling of the plate is prevented by any other light weight means.

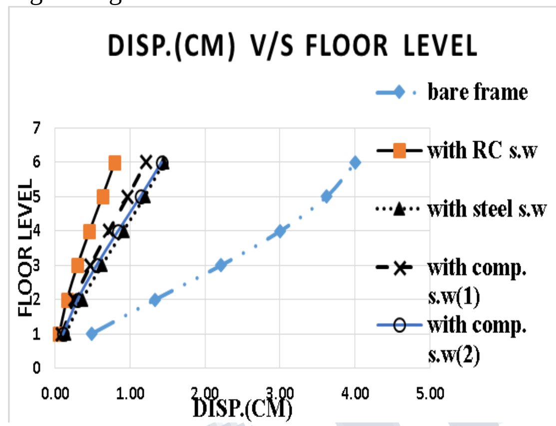

Figure 6: floor lateral displacement.

Figure6 indicates that RC shear wall reduced the displacement of the bare frame at each level considerably (almost 5 times reduction at top storey).inclusion of steel plate also decreased the displacement to a low value (almost 2.7 times at top storey). Inclusion of composite shear wall (1) shows it to be slightly more effective in controlling displacement. The effectiveness of composite shear wall (2) lies more or less halfway between RC and steel plate shear wall but a slight leaning towards steel plate shear wall behavior.

iii) Drift ratio v/s storey level: Figure7 shows graph comparing value of storey drift ratio due to applied earthquake force in X direction at each storey level for the RC building in five cases similar to the above comparison of displacement.

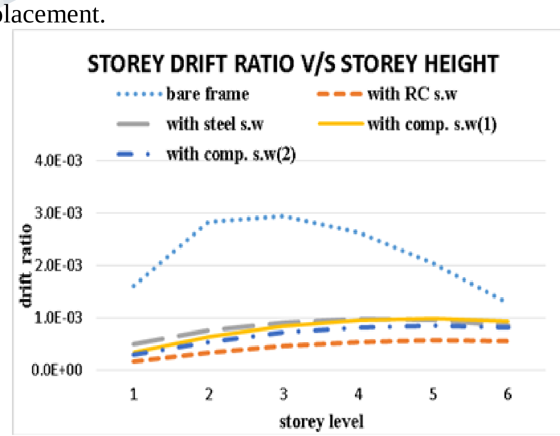

Figure 7:storey drift ratio.

from graph in Figure7 it can be seen that no cases exceeded the permissible drift ratio (0.004 as per IS 1893:2002)[9].200mm thick RC shear wall is more effective than composite shear wall(2),then composite shear wall(1)

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and then 10 mm steel plate shear wall. But the latter three cases are almost converging towards top storey.

iv): Time period v/s mode: Figure8 below shows graph comparing time period for different modes from modal analysis for the RC building in four cases.

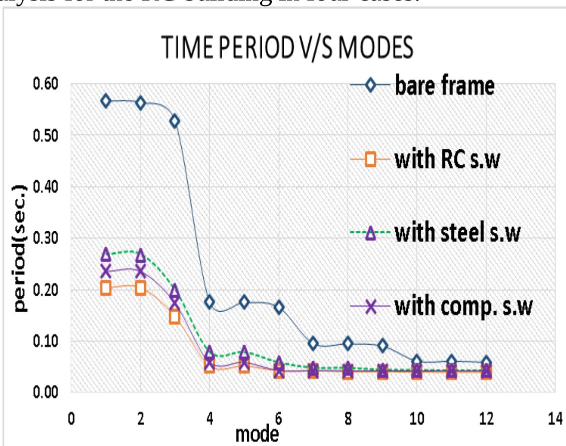

Figure8:Time period v/s modes

From Figure 8 it can be understood that inclusion of different shear walls made the bare frame rigid as the time periods for the three cases are almost 2-3 times less than that of bare frame for first three modes (major mass participating modes) The rigidity is more in frame with RC shear wall (200mm), then with composite shear wall and then with 10mm steel plate. The three cases differ by marginal value

v) Maximum Shear force and moment in frame elements: the maximum Shear and maximum moment occurred from applied load cases (1.5(D.L-EQ X)) was found for a corner column (A1), an interior column (B2), and an interior beam (A2-B2) at all level for the RC building in five cases i.e. bare frame, frame with RC shear wall, frame with steel shear wall, frame with composite shear wall considering the concrete cover panel (composite shear wall (1))and composite shear wall neglecting the concrete cover panel (composite shear wall (2)).The comparison graphs are shown below: Figure9&10respectively shows the plot of shear force and bending moment column in A1 at all storey levels in the RC building for the five cases.

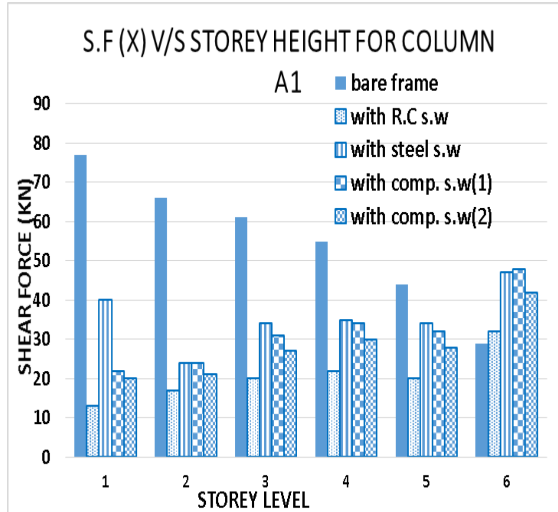

Figure 9:S.F v/s storey level for column A1tures

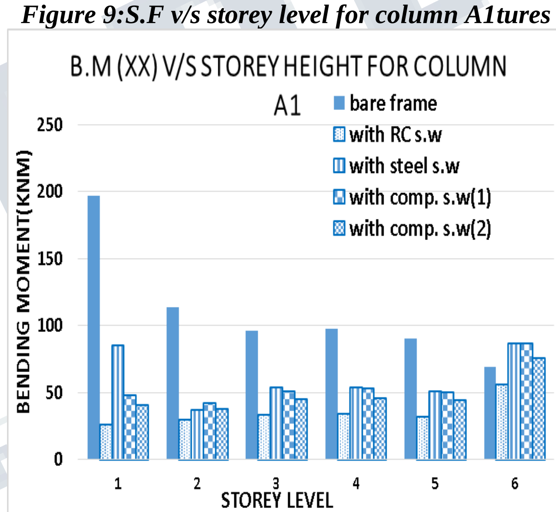

Figure.10:B.M v/s storey level for column A1

From Figures 9&10 it can be seen that inclusion of shear walls considerably reduced the max. Shear and moment in the column A1 even though there is a small increase in the forces in case of top storey column of shear wall building compared to bare frame. More or less their inclusion reduced the variation in force values from top to bottom columns. Overall RC shear wall was the most effective in reducing forces in the column but size of steel plate used should be considered. Effectiveness of other three shear walls were more or less the same except in 1st storey where composite shear wall was far better than steel plate shear wall. And in all other storeys too composite shear wall was marginally better than steel plate shear wall. Performance of composite shear wall neglecting concrete panel shows that buckling prevention of steel plate can still perform better. Comparison for the interior column B2 also showed the same trend and

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variation except the difference in magnitudes hence the graphs are not shown here.

Figure11&12respectively shows the plot of shear force and bending moment in Beam A2- B2 at all storey levels in the RC building for the above mentioned five cases.

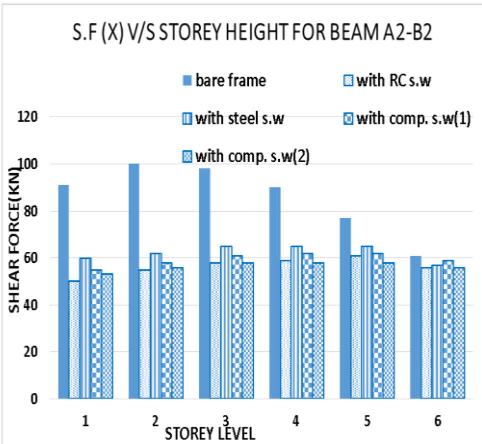

Figure 11:S.F v/s storey level for beam A2-B2

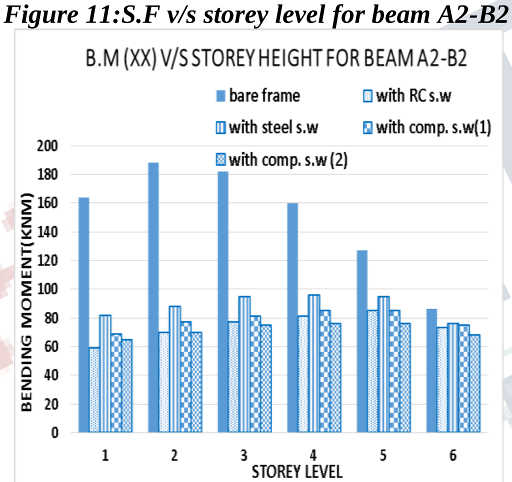

Figure12:B.M v/s storey level for beam A2-B2

From Figures 11&12 it can be seen that the trend of reduction of forces in the beam is similar to that of column but the magnitude of reduction and difference between the effectiveness of various shear walls have reduced.

IV. CONCLUSIONS

Even though base shear calculations show the frames with shear wall attract more earthquake forces than bare frame, the displacement analysis and storey drift ratio shows that they considerably reduce the storey displacement Inspite of being subjected to higher horizontal force. The inclusion of shear walls made the structure rigid andalsoreduced the S.F and B.M of both the columns and beams. Even though the 200mm thick RC shear frame performed alittile better, but considering the sizes of RC shear wall, steel shear wall and composite shear wall (keeping in mind that concrete panel was neglected in cross strip model) and the other advantages of steel plate like ductility, energy dissipation capacity along with weakness of concrete like crack formation and brittle failure etc. composite steel plate can be a good alternative to RC shear wall. And steel plate shear wall can be used wherever saving of space is required and where deformation of the plate don't cause much problems both in terms of structural and architectural aspects.

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