Pundkar R. S, Alandkar P. M / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp.1940-1945

Influence of Steel Plate Shear Wall on Multistorey Steel Building

Pundkar R. S[1], Alandkar P. M[2]
[1, 2] Civil / Structure Department, SCOE Pune-41, Pune University, INDIA.

Abstract

The present paper describes the analysis and design of high-rise steel building with and without Steel Plate Shear Wall (SPSW). For present work four models with different SPSW locations ware analyzed for same geometry and loading. Four models of building frame having (G+19) storey situated in zone III are then compared with moment resisting frame (MRF) and X-braced frame. Modelling is done by using strip modelling. The analysis of steel plate shear wall building is carried out using Software SAP2000 V15. The main parameter considers in this paper to compare the seismic performance of buildings for deflection. The models are analyzed by Response Spectrum analysis as per IS 1893:2002 and design has been carried out by using IS 800-2007.

***Keywords*–** Steel plate shear wall (SPSW), steel building, strip model, IS 800-2007, IS 1893-2002, Response spectrum method, tension field action, seismic design.

I. INTRODUCTION

For the past few decades global attention and interest has grown in the application of Steel Plate Shear Walls (SPSW) for building lateral load resisting systems. Advantages of using SPSWs in a building is lateral force resisting system compromise stable hysteretic characteristics, high plastic energy absorption capacity and enhanced stiffness, strength and ductility. A significant number of experimental and analytical studies have been carried out to establish analysis and design methods for such lateral resisting systems; however, there is still a need for a general analysis and design methodology. As compared to the Reinforced cement concrete (RCC) the steel has got some important physical properties like the high strength per unit weight and ductility [1]. The high yield and ultimate strength result in slender sections. Being ductile the steel structures give sufficient advance warning before failure by way of excessive deformations. These properties of steel are of very much vital in case of the seismic resistant design. Steel shear wall is a lateral load resisting system consisting of vertical steel plate infills connected to the surrounding beams and columns and installed in one or more bays along the full height of the structure to form a cantilever wall. Shear walls are vertical elements of the horizontal force resisting system. The main role of steel shear wall is to collect lateral forces of earthquake in a building and transfer those forces to the foundation. The web plates in steel shear walls are categorized according to their ability to resist buckling.

I.1. Purpose of erecting steel plate shear walls.

Shear wall systems are 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 loads and support gravity loads. Shear walls designed for resisting lateral loads of earthquakes and wind. Steel plate shear wall system has emerged as an efficient alternative to other lateral load resisting systems, such as reinforced concrete shear walls, various types of braced frames, etc. SPSWs are preferred because of the various advantages they have over other systems, primarily, substantial ductility, and high initial stiffness, fast pace of construction, light weight, provides more space inside due to minimum thickness which is another advantage for architect and the reduction in seismic mass.

I.2. Modeling of steel plate shear walls.

I.2.1. **Strip Modeling:** This is the most popular way of modeling thin, non-compact shear walls. It is purely based on the diagonal tension field action developed immediately after the buckling of the plate [2]. This type of modeling is recommended by the code of Canada, the CAN/CSA-S16-01 in the analysis and design procedure of the SPSWs. In the analysis software the steel plate in the wall panel is to be replaced by a series of truss members (struts) or the strips along the tension field. There are two ways of modeling by this method. The first one is the strips inclined at uniform angle with the horizontal and the other is the multi-strip model as shown in the following fig. I.2.1.1 and fig. I.2.1.2. respectively.

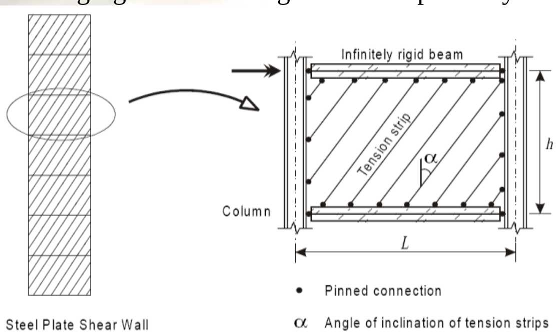

Fig. I.2.1.1: Strip Model Representation of a SPSW

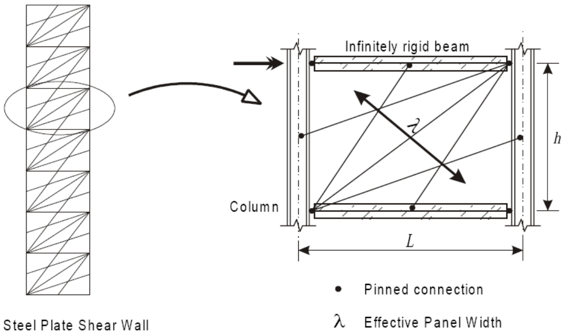

Fig. I.2.1.2: Multi-angle strip model of a SPSW

I.2.2 Modeling guidelines for Strip Model

- A minimum of ten strips are to be provided per wall panel.
- Each strip is pinned at both of its ends to the surrounding beams and/or columns as per its location in the wall panel.
- Each strip has the width equal to the centre to centre spacing of the consecutive strips.
- Thickness of the strips is kept same as that of the plate.
- The strips are normally inclined at 45 degree with the horizontal. The angle of inclination shall be in the range of 38 to 45 degrees with the horizontal. Slight variation in the angle does not affect the behaviour of the model.
- The connection of the beams of that panel with the columns shall be kept pinned or hinged.
  The researchers who have worked in this area have thus suggested two strip models as shown in the fig. I.2.1.1 and fig. I.2.1.2. In the first figure the strips are inclined diagonally at an uniform angle, generally at 45^0 with the horizontal. The other is the multi-angle strip model in which the strips are inclined at different angles.

I.3. Method of Analysis.

There are a number of methods by which the buildings with the steel shear walls can be analysed. The thin steel shear walls modeled using the strip model. As the SPSWs are modeled here by using the popular tension-strip model also called as strip model for multistorey high rise steel building, the method of analysis used is the Response Spectrum method as specified by the IS 1893 (Part I) : 2002 [12].

I.3.1. Seismic Analysis Using IS 1893 (Part 1): 2002

I.3.1.1 Load Factor: In the design of steel structure, following load combinations as given in the IS 1893 (Part1): 2002 are.

1.7 (DL+LL)
1.7 (DL+EL)
1.7 (DL-EL)
1.3 (DL+LL+EL)
1.3 (DL+LL-EL)

I.4. Design of steel building with and without steel plate shear wall

In present paper, 20 storied steel frame building (Fig. II.2.1) has been taken. Four models of steel frame building with different SPSW locations have been taken. All four models compared with each other and find the ideal location of SPSW. After finding the ideal location, that model is to be compared with other lateral load resisting systems such as steel Moment Resisting Frame (MRF) & X-braced framed steel building for the same geometry and loading.

I.4.1. Design of steel building with steel plate shear wall

Four models have been analysed using SPSW. Strip modelling (Fig. I.4.1) is carried out based on the diagonal tension field action developed immediately after the buckling of the plate recommended by the code of Canada, the CAN/CSA-S16-01 in the analysis and design procedure of the SPSWs. Model 1 represents plan with SPSW 1 only, similarly Model 2 ~ SPSW 2, Model 3 ~ SPSW 3, Model 4 ~ SPSW 4.

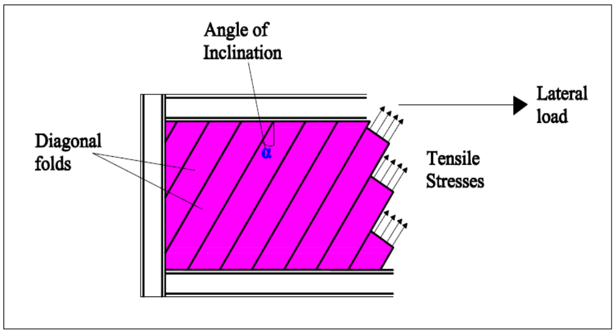

Fig. I.4.1 Idealized tension- field action in a typical SPSW

I.4.1.1 Thickness of steel panel (t_{wi})

$$t_{wi} = \frac{2\,V_i}{0.95\,F_y\,L}$$

Where i - the i-th story, Vi- is the storey shear
L- is the bay width, Fy-the material yield stress

I.4.1.2 Equation for the inclination angle of the tension field, in a SPSW infill plate:

$$\alpha = \tan^{-1}\sqrt[4]{\frac{1+\frac{t\,.\,L}{2\,.\,A_c}}{1+t.h\,.\left(\frac{1}{A_b}+\frac{h^3}{360\,.\,I_c\,.\,L}\right)}}$$

Where, t = Thickness of web plate
L = distance between VBE centerline
Ac = cross- sectional area of a VBE
h = distance between HBE centerline
Ab = cross- sectional area of a HBE
Ic = moment of inertia of a VBE taken perpendicular to the direction of the web plate line

I.4.1.3 Design of vertical boundary element

For vertical boundary elements (VBE), it has been recommend that the moment of inertia *Ic* should be such that [3]

$$0.70\, h \left(\frac{t_w}{2\, L\, I_c}\right)^{0.25} \leq 2.5$$

$$I_c \geq \frac{0.00307\, t_w\, h^4}{L}$$

I.4.1.4 Shear strength of steel plate panel

The shear panels are represented as a series of inclined strip members, capable of transmitting tension forces only, and oriented in the same direction as the principal tensile stresses in the panel [10].
Design Strength of Tension member as per the IS 800-2007 cl. 6. 2. [12].

$$T_{dg} = \frac{A_g\, f_y}{\gamma_{mo}}$$

where, f_y = yield stress of material
A_g = gross area of cross section
γ_{mo} = partial safety factor for failure in tension by yielding.

I.4.2 Design of steel building without steel plate shear wall

Design of steel building without SPSWs carried out as per the specification given in IS 800-2007 by using design software SAP2000 V15.

II. ANALYTICAL WORK

II.1. Analysis problem

1	Type of structure	M.R.S.F.
2	Zone	III
3	Layout	Shown in Fig.II.2.1
4	No. of storey	G+19
5	Lateral load resisting system	Steel plate shear walls
6	Height of each storey	3.3 m
7	Thickness of slab	100 mm
8	Wall thickness	150 mm
9	Shear wall thickness	6 mm
10	Width of strip	295 to 360 mm
11	Angle of inclination (α)	40^0 to 45^0
12	Unit weight of masonry	20 KN/m^3
13	Floor finish	1KN/m^2
14	Live Load	2 KN/m^2
15	Type of soil	Medium (Type II)
16	Seismic Analysis	Response spectrum method (IS 1893-2002)
17	Design of philosophy	Limit State method confirming to IS 800-2007

II.2. Structural Planning. (Models)

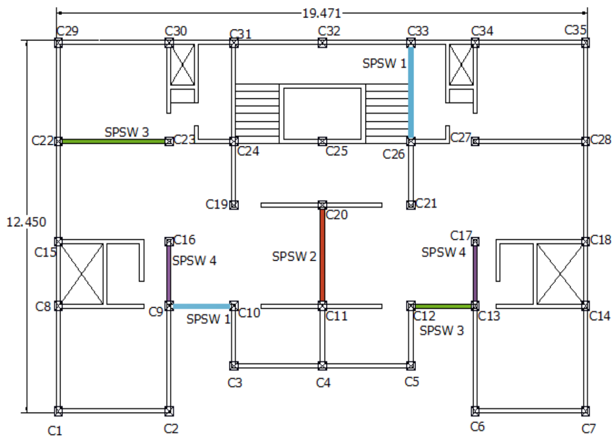

Fig. II.2.1 Plan of a G+19 story Steel building

II.5.3 Member Specification

In the present analysis it was observed that rolled steel sections for columns are not very much suitable to the adjoining beams, hence various built-up tubular sections are used for columns. Different column combinations are used as per requirement of models. Beam sections are common for all models discussed in this paper.

Size of Beam : B1 = ISMB 300
B2 = ISMB 200

Size of Column :

For MRF Steel building
TUBE 330 X 330 X 20
TUBE 330 X 330 X 16
TUBE 330 X 330 X 12
TUBE 330 X 330 X 10
TUBE 330 X 330 X 8

For building with SPSW models
TUBE 330 X 330 X 16
TUBE 300 X 300 X 10
TUBE 270 X 270 X 8

For building with X-braced frame model
TUBE 330 X 330 X 20
TUBE 330 X 330 X 16
TUBE 330 X 330 X 10
TUBE 270 X 270 X 8

The above mentioned steel MRF building & all models (Four Models) of SPSW steel building frames have been analysed and Designed using SAP2000 V15 software. For getting results some column has been selected and they are as column nos. 15, 20, 29 & 32. The results found to be are shown with the help of graph for deflection & steel consumption for columns.

III. RESULT & DISCUSSION

III.1. Lateral Displacement

Various load combinations are used in the design of building as per IS 1893-2002, it is found that the load combination 1.7(DL + EQ-Y) is responsible for maximum deflection for all models. The deflections for column nos. 15, 20, 29 and 32 are shown at each storey for 4 different models (Fig. III.1.1, III.1.2, III.1.3, and III.1.4).

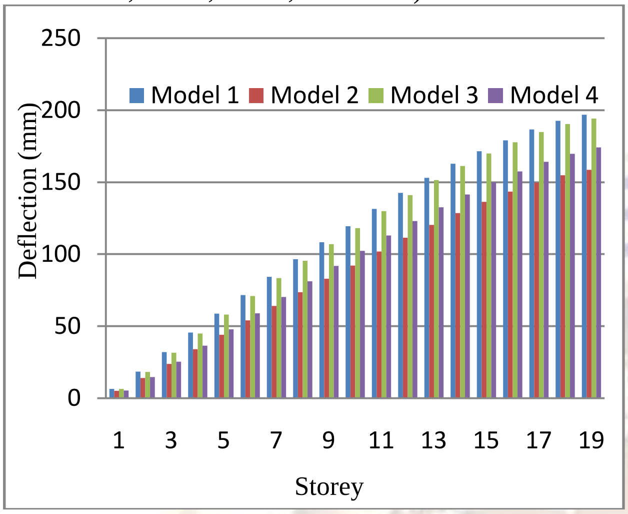

Fig.III.1.1: Deflection of Column no. 15, Models 1, 2, 3 & 4, for 1.7(DL + EQ-Y)

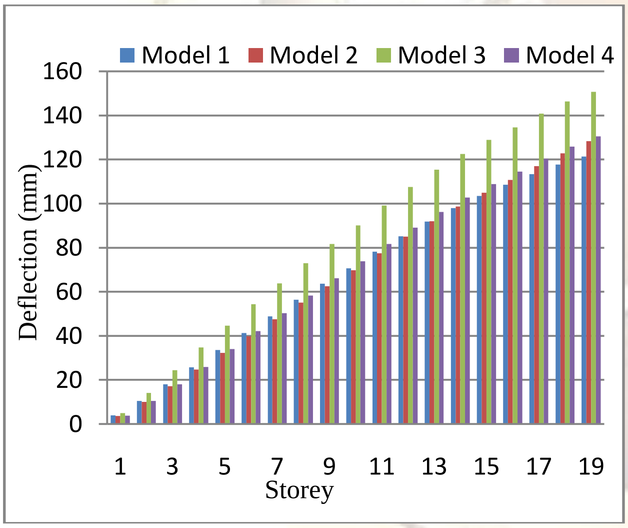

Fig.III.1.2: Deflection of Column no. 20, Models 1, 2, 3 & 4, for 1.7(DL + EQ-Y)

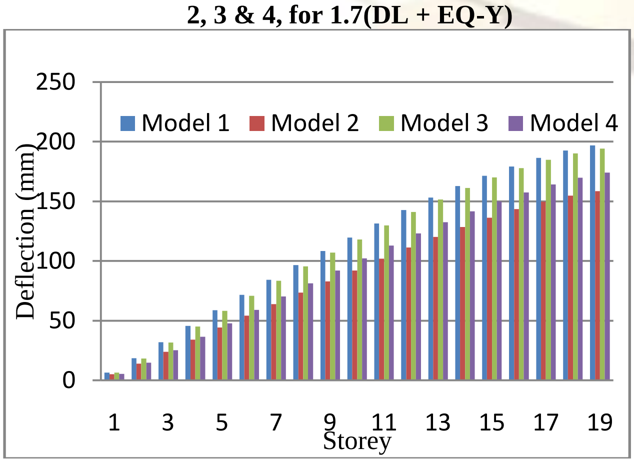

Fig.III.1.3: Deflection of Column no. 29, Models 1, 2, 3 & 4, for 1.7(DL + EQ-Y)

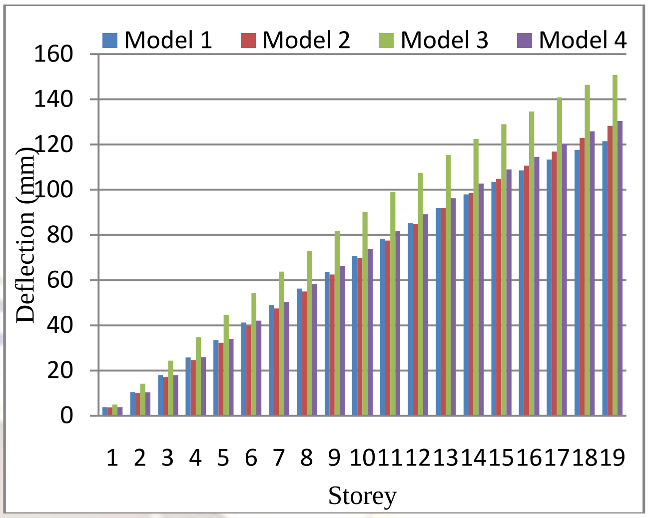

Fig.III.1.4: Deflection of Column no. 32, Models 1, 2, 3 & 4, for 1.7(DL + EQ-Y)

Deflections of column nos. 15, 20, 29, and 32 are compared for 4 models for 1.7(DL + EQ-Y), it is found that, model 2 is having maximum deflection of 158 mm as model 1 is having maximum deflection of 196 mm. From above results, it is clear that Model 2 is the ideal model between the 4 models having different locations of SPSWs (Fig. III.1.1, III.1.2, III.1.3, and III.1.4).

III.2 Comparison Lateral Displacement of MRF, X-braced frame & SPSW steel frame model 2.

Model 2 is compared with other two lateral load resisting systems such as MRF & X-braced frame. Position of X-braced frame is kept same as that of position of SPSWs in model 2. MRF is having the deflection of 196 mm; as that of X-braced frame deflection of 162 mm. Results shows that Model 2 is having minimum deflection of 158 mm from the above discussed models. Results for column nos. 15, 20, 29 and 32 for MRF, X-braced and Model 2 are shown below (Fig. III.2.1, III.2.2, III.2.3, and III.2.4).

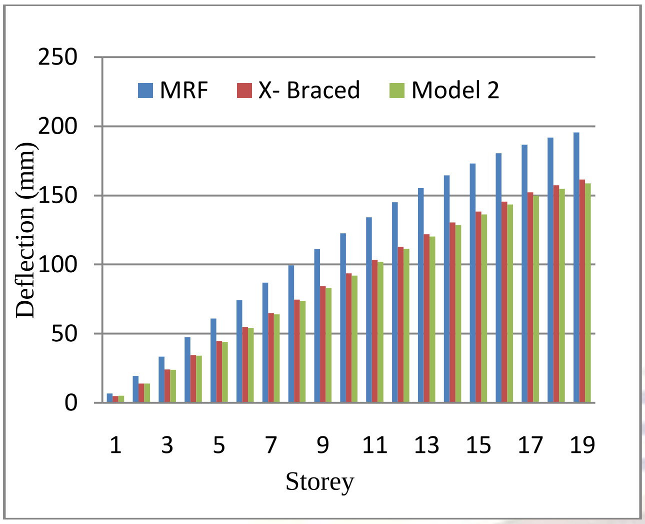

Fig.III.2.1: Deflection of Column no. 15, MRF, X-braced & Model 2, for 1.7(DL + EQ-Y)

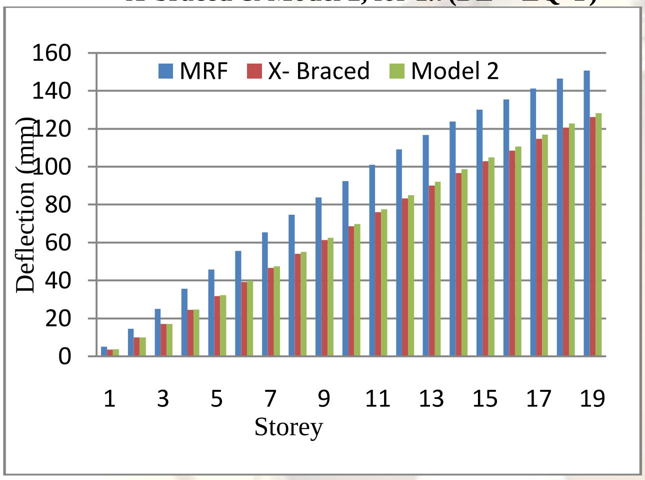

Fig.III.2.2: Deflection of Column no. 20, MRF, X-braced & Model 2, for 1.7(DL + EQ-Y)

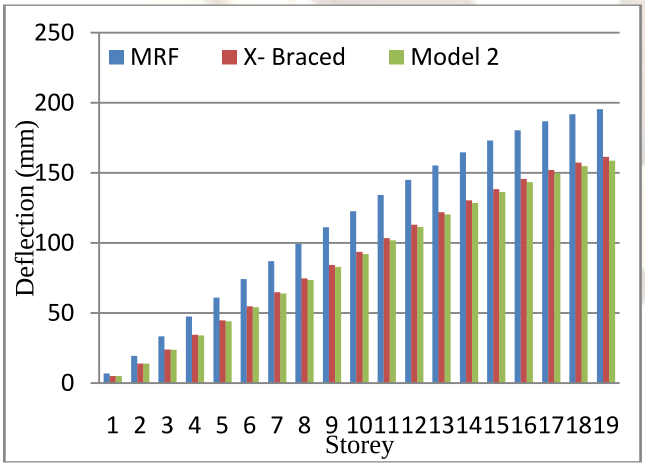

Fig.III.2.3: Deflection of Column no. 29, MRF, X-braced & Model 2, for 1.7(DL + EQ-Y)

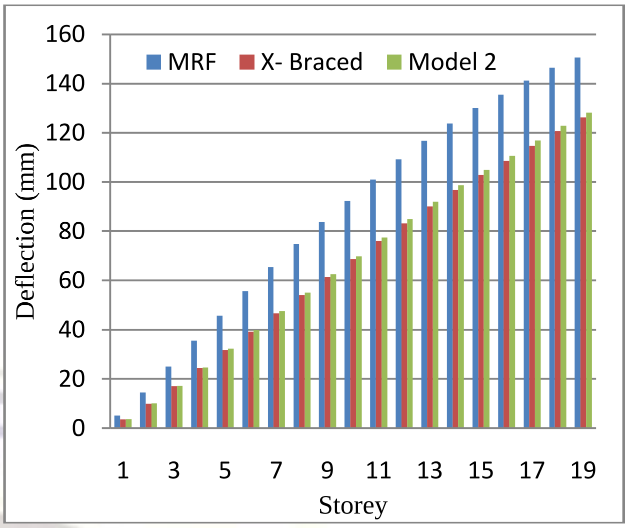

Fig.III.2.4: Deflection of Column no. 32, MRF, X-braced & Model 2, for 1.7(DL + EQ-Y)

III.3 Steel consumption of columns in MRF, X-braced frame & SPSW steel frame model 2.

Steel consumption for MRF, X-braced and Model 2 is calculated, it is found that Model 2 consumes less steel as compared to the other two, as results are shown below (Fig. III.3.1).

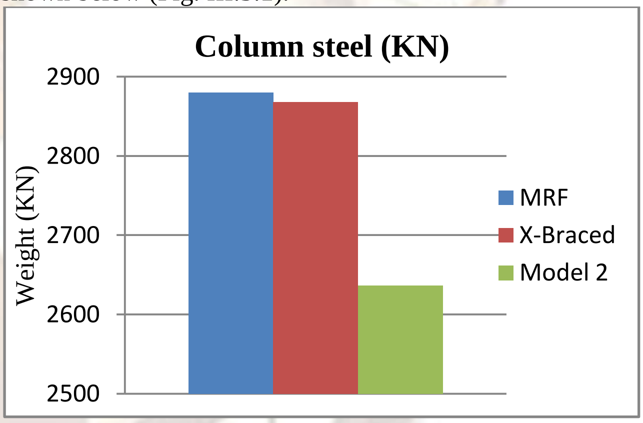

Fig.III.3.1 Steel consumption of columns in MRF, X-braced frame & SPSW steel frame model 2.

IV. CONCLUSION

From preliminary investigation reveals that the significant effects on deflection in orthogonal direction by the shifting the shear wall location. Placing Shear wall away from centre of gravity resulted in increase in lateral deflection. It may be observed from Fig. III.1.1, III.1.2, III.1.3, and III.1.4 that displacement of the building have been reduced due to presence of shear wall placed at centre. Placing of shear wall in y direction the displacement reduces but displacement not reduces in X direction. Results indicate that steel plate shear walls have a large effect on the behavior of frames under earthquake excitation. In general, infill steel plate increases stiffness of the structure. Deflection in case of without SPSW is large as compared with SPSW. Results show that the deflection of model 2 is found minimum as compared with MRF and X-braced framed building (Fig. III.2.1, III.2.3). It is observed from Fig.III.3.1, due to presence of SPSW total weight of steel in building is reduced than building without SPSWs. Hence steel building with SPSWs is economical compare to without SPSWs. Due to relatively small thickness of SPSW compared to reinforced concrete shear walls and X-braced moment resisting frame, from architectural point of view, steel shear wall occupy much less space.

REFERENCE

[1] Londhe R.S. and Chavan. A. P. (2010). "Behavior of building frames with steel plate shear wall". *Asian Journal of Civil Engineering (building and housing)* vol. 11, no. 1 pages 95-102.

[2] Thorburn J.L., Kulak G.L., and Montgomery C.J. (1983). "Analysis of steel plate shear walls", *Structural Engineering Report No.107*, Department of Civil Engineering, The University of Alberta Edmonton, Alberta, pp 1-167.

[3] Michel Bruneau, P. E., Jeff Berman, Diegolopez Garcia, and Darren Vian, " Steel plate shear building: Design requirements and research", Post-Doctoral research Associate, Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, NY 14260. Pp 1-3.

[4] Mayank K. Gupta1, Swapnil B. Kharmale2 and Siddhartha Ghosh3 . "Ductility-base seismic design of steel plate shear walls: Practical application using standard sections", Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, India , pp 93 – 98.

[5] Ghosh Siddhartha, Farooq Adam, Das Anirudha (2009). "Design of steel plate shear walls considering inelastic drift demand". *Journal of Constructional Steel Research 65. pp 1431_1437.*

[6] Berman Jeffrey and Bruneau Michel (November 2003). "Plastic Analysis and Design of Steel Plate Shear Walls." *Journal of Structural Engineering © ASCE.*

[7] Jeffrey Berman, "Plastic Analysis and Design of Steel Plate Shear Walls." Department of Civil, Structural & Environmental Engineering, University at Buffalo. Pp 36-39.

[8] A. Deylamia, J. Rowghani-Kashanib, "Analysis and Design of Steel Plate Shear Walls using orthotropic membrane model" *The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction. pp 3339 – 3345.*

[9] Mahmoud Rezai, Carlos E Ventura And Helmut, G. L., Prion," Numerical Investigation Of Thin Unstiffened Steel Plate Shear Walls", *12th World Conference on Earthquake Engineering 2000 pp 1-4*

[10] Sabelli, R. and Bruneau, M. (2007), "Design Guide 20: Steel Plate Shear Walls", *American Institute of Steel Construction*, Chicago, IL, USA.

[11] IS 1893 (Part 1):2002, Indian Standard, "Criteria For Earthquake Resistant Design of Structures", Part 1 General Provisions And Buildings. (Fifth Revision).

[12] IS 800:2007, Code of practice for general construction in steel, Bureau of Indian Standards, New Delhi.