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Behaviour of Multi-storeyed Steel Building with Steel Plate Shear Wall

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***Abstract:** The present study describes the analysis and design of high-rise steel building frame with and without Steel plate shear wall (SPSW). Further it is compared with moment resisting steel framed building and X-Braced steel framed building. For present work Response Spectrum Analysis is carried out for steel moment resisting frame building having G+19 storey situated in zone III. Modeling is done by using strip modeling. The analysis of steel plate shear wall and the building are carried out using software SAP2000 V15. The main parameter considered in this project is to compare the seismic performance of buildings i.e. lateral 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

A significant number of experimental and analytical studies have been carried out to establish analysis and design methods for such lateral load 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. 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.

The ductility of steel is a unique property of the steel that no other building material exhibits in quite the same way. Through ductility steel is able to undergo a large deformation beyond the elastic limit without danger of fracture. These desirable properties of steel are made use in the high rise structures for using steel as the structural elements. In low, medium and high-rise structures the loads acting on the structures mainly consist of the gravity loads and the lateral loads. The gravity loads which include the self weight of the structure and the part of the live load that remains constant.

The lateral loads are due to wind, blast and earthquake etc. and are very severe due to earthquake. So the structures should have sufficient stiffness and strength laterally to perform satisfactorarily to these occasional loads. The structural system consists of horizontal framing system (beams and slab) and the other is the vertical framing system made of walls and column. Horizontal system transfers the vertical loads and the torsional loads to the vertical framing system, which is responsible for the transfer of vertical loads to the footing.

II. MODELLING

A. *Modelling of compact SPSWs*

The steel plate in the compact type is expected to yield in shear before buckling starts. Therefore in the analysis, it can be modelled using full shell element and isotropic material. It is suggested that the wall panel be modelled using at least 16 shell elements (4 □4 mesh) per panel. The shear force acting on the cross section of the wall can be worked out by adding up the shear in the elements

B. *Modelling of Non-compact SPSWs*

In non-compact or slender shear walls, the steel plate buckles along compressive diagonals under relatively small shear force. After buckling, the tension field action along tension diagonal becomes the primary mechanism to resist the shear force in the wall. These can be modelled using shell elements or the Strip Models.

C. Shell Element Modelling

This behaviour should be considered in the analysis by modelling the shear wall using shell elements that can buckle along the compression diagonal. For this the shear wall shall be modelled using the full shell element and anisotropic material. Different values of modulus of elasticity and shear modulus has to be assigned to three principle directions of the wall such that the compression diagonal will have much less stiffness and will attract much less shear in proportion to its buckling capacity than the tension diagonal. The wall panel shall have at least 16 shell elements (4 □4 mesh) per panel. Fig. 3.1 gives a brief idea of the quadrilateral and triangular shell elements.

D. Strip Modelling

This is the most popular way of modelling thin, non-compact shear walls. It is purely based on the diagonal tension field action developed immediately after the buckling of the plate. This type of modelling is recommended by the code of Canada, the CAN/CSA-S16-01 in the analysis and design procedure of the SPSWs [1]. 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 modelling 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 fig below The two models of the SPSWs are as shown in the following figures, the first one was proposed by Thorborn [1]. The second, Multi-angle strip model was proposed by Rezaii[23].

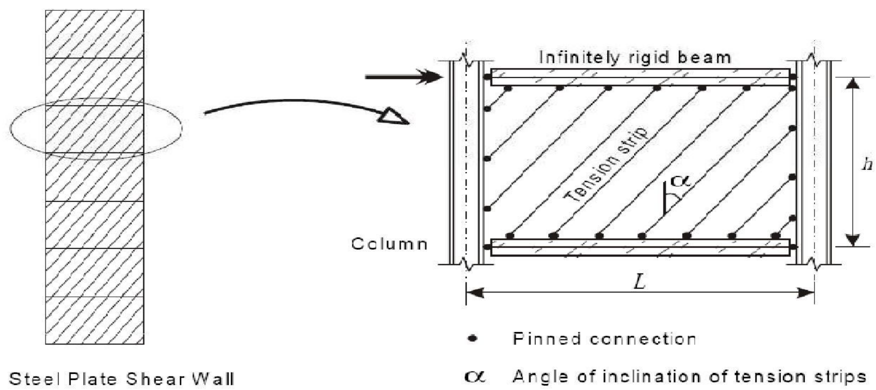

Fig. 1 Strip Model Representation of a SPSW (as suggested by code of Canada CAN/CSA-S16 -01)

III. ANALYTICAL WORK

In this section, a 20- storey structure in plan is shown. In this structure, the shown plan is upto 16^{th} storey is maintained symmetrically, 17^{th} to 19^{th} stories are extended with left part of symmetrical portion. 20^{th} storey is extended for stairs and lift room point of view. In this structure various positions of shear walls are considered. The loads acting on the structure are contributed from slabs, beams, columns, walls and finishes. They are calculated by conventional methods according to IS: 800 – 2007 an d are applied as gravity loads along with live loads as per IS: 875 (Part II)-1987 in the structural model. The lateral loads and their vertical distribution on each floor level are determined as per IS: 1893 – 2002. These loads are then applied in response spectrum method.

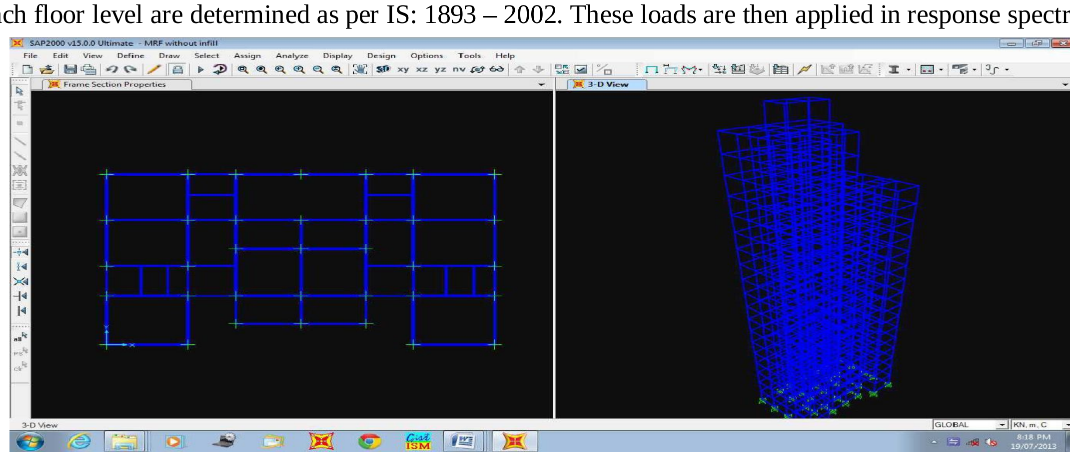

Fig 2 Window of SAP2000 V15 showing plan and 3D view of structure

With the availability of high-speed digital computers, a rigorous three-dimensional analysis of a multi storey building is performed. Three dimensional analysis is relatively more realistic. It gives significantly more exact results than those by two-dimensional analysis. Three-dimensional analysis is the only solution in case of an unsymmetrical geometry of the structure.

A. Models Considered for Analysis

In this study six different models are considered to analyze 20-storey structure. First model is moment resisting steel frame building model, 4 models with different locations of SPSWs and last one is steel frame building with X-Bracing.

1) Moment Resisting Steel Frame Building model (MRF).
2) Model 1: Steel frame building with Steel Plate Shear Wall 1 (SPSW1)
3) Model 2: Steel frame building with Steel Plate Shear Wall 2 (SPSW2)
4) Model 3: Steel frame building with Steel Plate Shear Wall 3 (SPSW3)
5) Model 4: Steel frame building with Steel Plate Shear Wall 4 (SPSW4)
6) Steel Frame Building model with X-Bracing

B. Structural Data

Building consists of 12.45 m in short direction and 19.47 m in long direction, so from preliminary design the sizes of various structural members were estimated as follows. Many trials have been taken to select proper structural members which can satisfy the requirements of IS 800-2007.

1) *Column Size*

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 Steel building SPSW models

TUBE 330 X 330 X 16
TUBE 300 X 300 X 10
TUBE 270 X 270 X 8

For X-braced Steel building models

TUBE 330 X 330 X 20
TUBE 330 X 330 X 16
TUBE 330 X 330 X 10
TUBE 270 X 270 X 8

2) *Beam Size*

For all models

B1 = ISMB 300
B2 = ISMB 200

Slab Thickness: Slab Thickness for all the span is 100 mm

Shear Wall Thickness: 6 mm thick steel shear wall for all storey are provided in Model no. 1, 2, 3 & 4. Storey height is kept as 3.3 m for all the floors. Grade Fe-250 hot rolled steel is recommended to be used. Concrete having M-20 strength for slabs is to be employed.

X-Braced frame: Tube 270 X 270 X 8 mm is used for 1st to 4th storey. Indian standard Tube 172 X 92 X 5.4 mm is used for 5th to 19th storey. Grade Fe-250 hot rolled steel is recommended to be used. Concrete having M-20 strength for slabs is to be employed.

C. Loading

1) *Gravity loading*

Gravity loading consists of dead and live loading. Dead loading can be predicted reasonably accurately from the designed member sizes and material densities. Dead load due to structural self weights and superimposed dead loads are as follows:

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Dead Load (DL):
Intensity of wall (External & Internal wall) = 8.85 KN /m (for 3.3 m height)
Intensity of parapet wall = 3.60 KN /m (for 1.2 m height)
Intensity of slab load = 2.5 KN /m^2
Intensity of floor finish load = 1 KN /m^2
Live load (LL):
Intensity of live load = 2 KN /m^2

2) Lateral loading

Lateral loading consists of earthquake loading. Earthquake loading has been calculated by the program and it has been applied to the mass center of the building. Since the building under consideration was in Zone -III with standard occupancy.
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)

Period Calculation: Program Calculated
Top Storey: Storey- 20
Bottom Storey: Base
Response reduction factor (R) = 5
Importance factor (I) = 1
Building Height (H) = 66 m
Soil Type = II
Z = 0.16
Base shear is converted into lateral forces over the top of each storey.

D. Figures Showing Different Models For Study

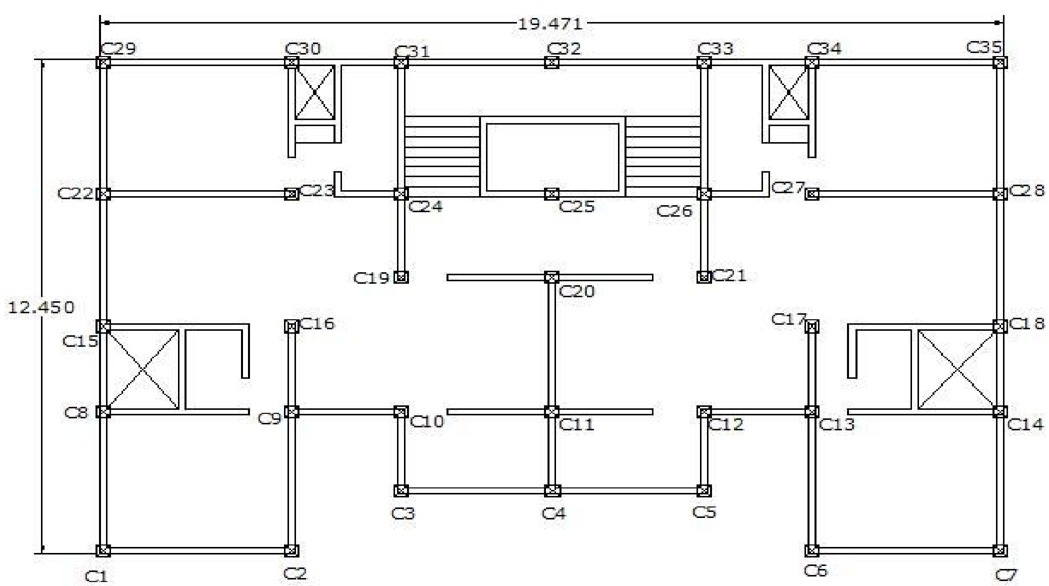

Fig 3 Plan of MRF building

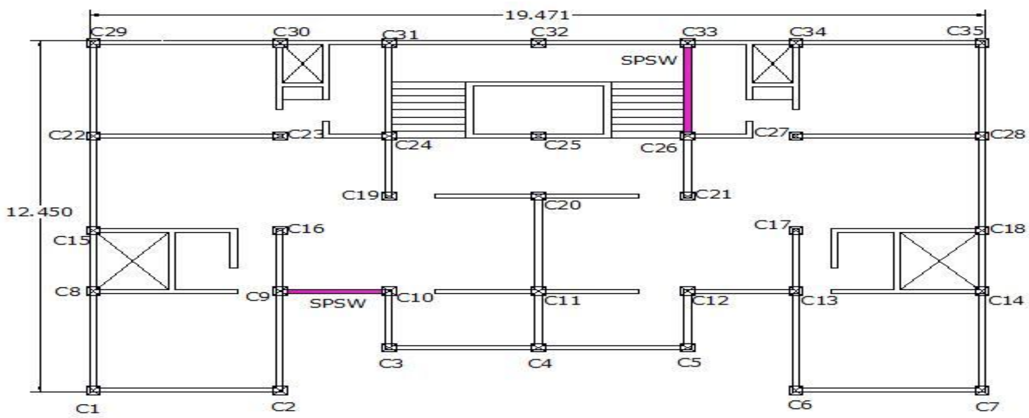

Fig 4 Plan showing Steel frame building with SPSW1 (Model 1)

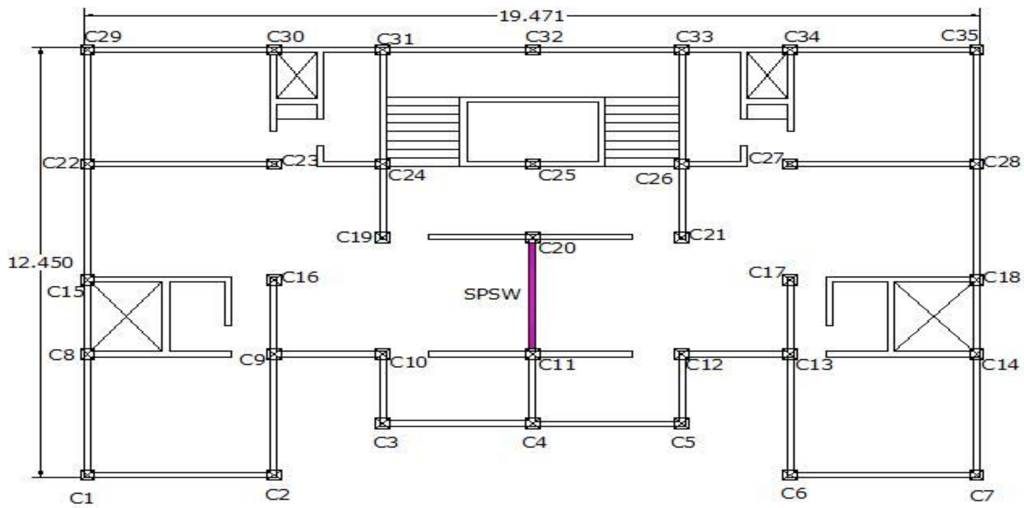

Fig 5 Plan showing Steel frame building with SPSW2 (Model 2)

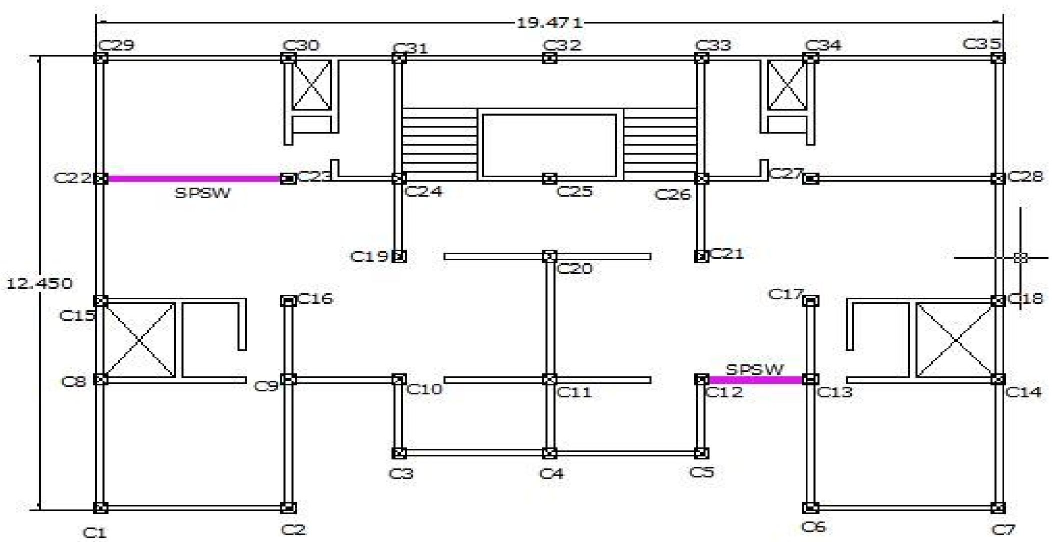

Fig 6 Plan showing Steel frame building with SPSW3 (Model 3)

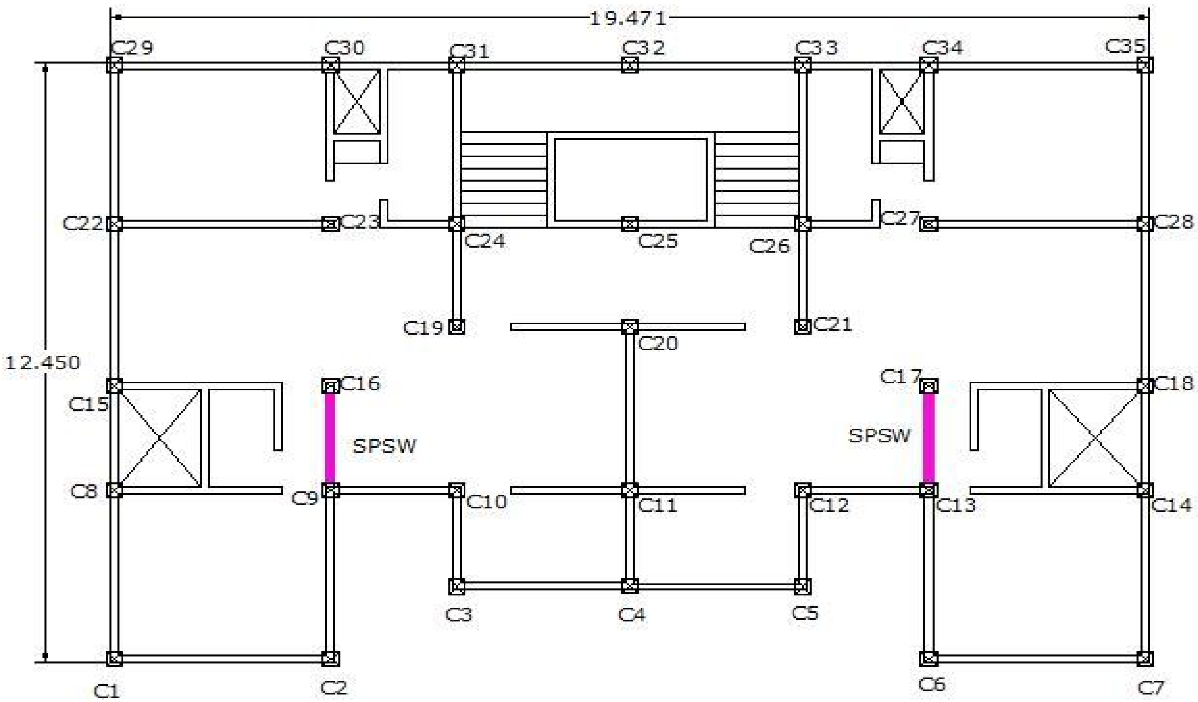

Fig 7 Plan showing Steel frame building with SPSW4 (Model 4)

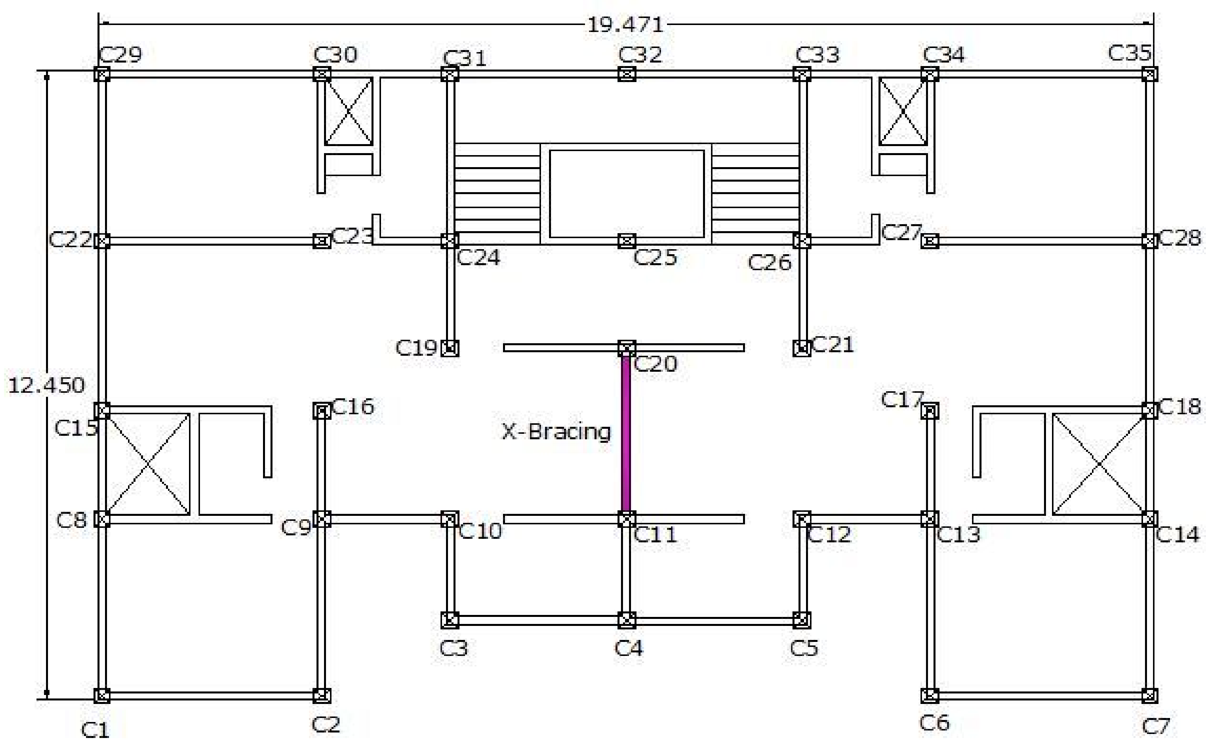

Fig 8 Plan showing Steel frame building with X-braced model

IV. RESULTS AND COMPARISONS

Table 1 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY) column no. 15

Storey	Joint	Height (m)	MRF	X- Braced	Model 2
0	988	0	0.00	0.00	0.00
1	939	3.3	8.76	6.01	5.01
2	890	6.6	21.65	14.56	13.91
3	841	9.9	34.76	25.08	23.81
4	792	13.2	47.82	35.14	34.00
5	743	16.5	61.01	45.67	44.13
6	694	19.8	74.16	56.08	54.12
7	645	23.1	86.99	65.89	63.97
8	596	26.4	99.38	76.09	73.59
9	547	29.7	111.28	86.11	82.96
10	498	33	122.67	95.93	92.09
11	449	36.3	134.17	104.39	101.93
12	400	39.6	145.03	114.07	111.34
13	351	42.9	155.17	124.89	120.24
14	302	46.2	164.51	132.94	128.58
15	253	49.5	172.97	139.11	136.32
16	204	52.8	180.46	146.89	143.39
17	155	56.1	186.81	155.13	149.76
18	106	59.4	191.78	161.14	154.78
19	57	62.7	195.54	168.26	158.62

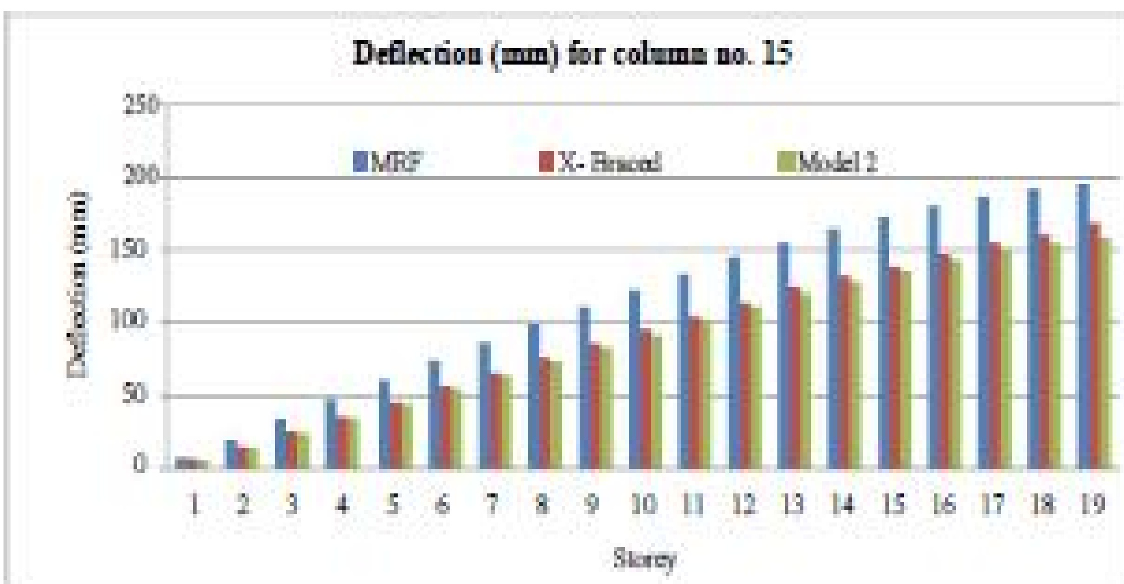

Fig 9 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY)

Table 2 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY) Column no. 20

Storey	Joint	Height (m)	MRF	X- Braced	Model 2
0	1025	0.0	0.00	0.00	0.00
1	976	3.3	5.05	4.76	3.68
2	927	6.6	14.49	12.11	10.01
3	878	9.9	25.01	20.13	17.15
4	829	13.2	35.57	33.98	24.66
5	780	16.5	45.76	43.97	32.26
6	731	19.8	55.63	49.53	39.86
7	682	23.1	65.32	61.29	47.48
8	633	26.4	74.71	72.54	55.03
9	584	29.7	83.73	79.68	62.46
10	535	33.0	92.37	85.82	69.75
11	486	36.3	101.04	92.41	77.51
12	437	39.6	109.21	98.86	84.94
13	388	42.9	116.81	105.49	92.01
14	339	46.2	123.78	111.26	98.67
15	290	49.5	130.03	117.67	104.92
16	241	52.8	135.59	122.59	110.69
17	192	56.1	141.26	128.46	116.92
18	143	59.4	146.41	133.21	122.86
19	94	62.7	150.64	137.84	128.28

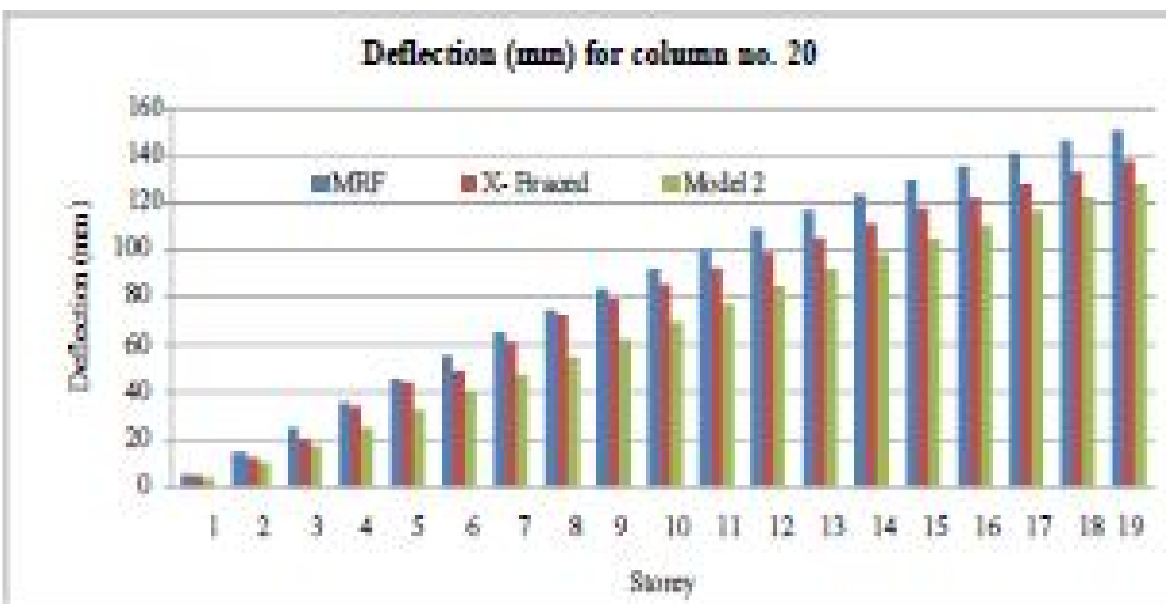

Fig 10 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY)

Table 3 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY) Column no. 29

Storey	Joint	Height (m)	MRF	X- Braced	Model 2
0	990	0	0.00	0.00	0.00
1	941	3.3	8.76	6.01	5.01
2	892	6.6	21.65	14.56	13.91
3	843	9.9	34.76	25.08	23.81
4	794	13.2	47.82	35.14	34.00
5	745	16.5	61.01	45.67	44.13
6	696	19.8	74.16	56.08	54.12
7	647	23.1	86.99	65.89	63.97
8	598	26.4	99.38	76.09	73.59
9	549	29.7	111.28	86.11	82.96
10	500	33	122.67	95.93	92.09
11	451	36.3	134.17	104.39	101.93
12	402	39.6	145.03	114.07	111.34
13	353	42.9	155.17	124.89	120.24
14	304	46.2	164.51	132.94	128.58
15	255	49.5	172.97	139.11	136.32
16	206	52.8	180.46	146.89	143.39
17	157	56.1	186.81	155.13	149.76
18	108	59.4	191.78	161.14	154.78
19	59	62.7	195.54	168.26	158.62

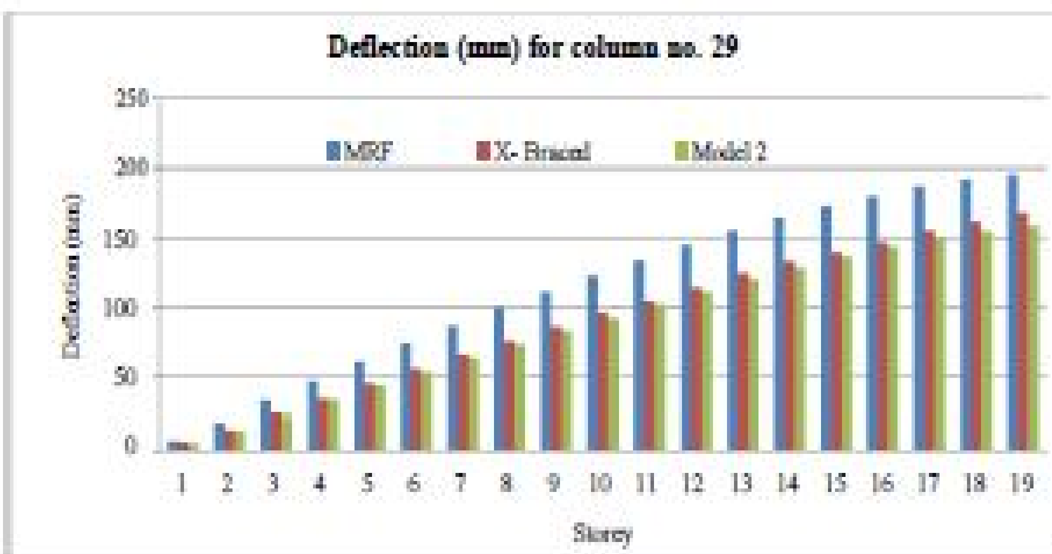

Fig 11 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY)

Table 4 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY) Column no. 32

Storey	Joint	Height (m)	MRF	X- Braced	Model 2
0	993	0	0.00	0.00	0.00
1	944	3.3	5.05	4.76	3.68
2	895	6.6	14.49	12.11	10.01
3	846	9.9	25.01	20.13	17.15
4	797	13.2	35.57	33.98	24.66
5	748	16.5	45.76	43.97	32.26
6	699	19.8	55.63	49.53	39.86
7	650	23.1	65.32	61.29	47.48
8	601	26.4	74.71	72.54	55.03
9	552	29.7	83.73	79.68	62.46
10	503	33	92.37	85.82	69.75
11	454	36.3	101.04	92.41	77.51
12	405	39.6	109.21	98.86	84.94
13	356	42.9	116.81	105.49	92.01
14	307	46.2	123.78	111.26	98.67
15	258	49.5	130.03	117.67	104.92
16	209	52.8	135.59	122.59	110.69
17	160	56.1	141.26	128.46	116.92
18	111	59.4	146.41	133.21	122.86
19	62	62.7	150.64	137.84	128.28

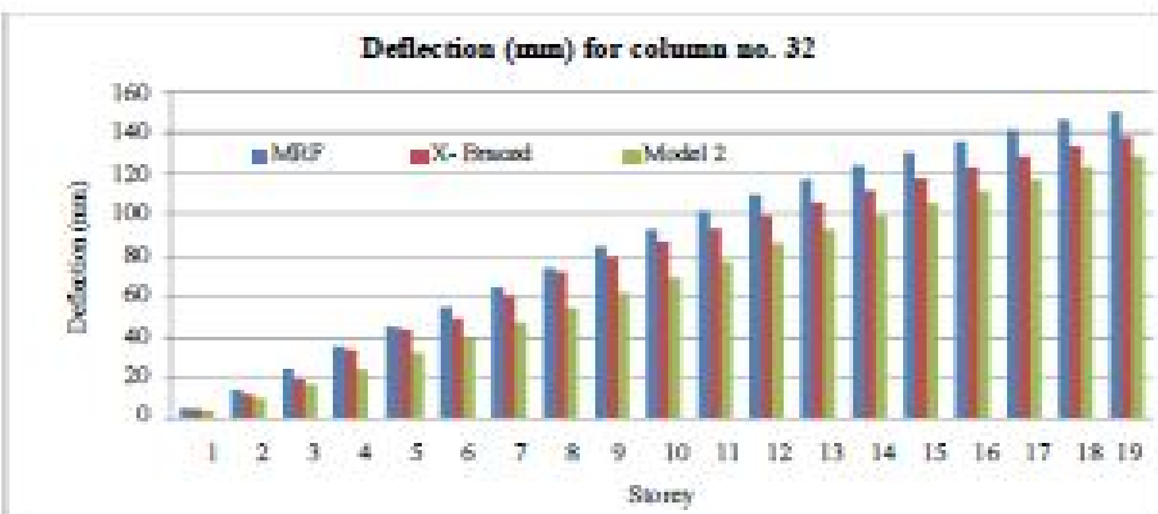

Fig 12 lateral deflection for MRF, X-Braced frame and Model2 for load combination 1.7(DL +/- EQY)

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Table 5 Steel Consumption for MRF model

Sr. No.	Section	Length	No of Column	No. Of Stories	Weight (Kg/m)	Total
01	Tube 330 X 330 X 20	3.3	35	4	194.43	89827.58
02	Tube 330 X 330 X 16	3.3	35	4	157.55	72789.32
03	Tube 330 X 330 X 12	3.3	35	4	119.67	55287.43
04	Tube 330 X 330 X 10	3.3	35	4	100.35	46362.62
05	Tube 330 X 330 X 08	3.3	35	3	80.78	27991.43
06	Tube 330 X 330 X 08	3.3	6	1	80.78	1599.51
				Total wt in Kg		293857.90

Table 6 Steel Consumption for X-bracing model

Sr. No.	Section	Length	No of Column	No. Of Stories	Weight (Kg/m)	Total
1	Tube 330 X 330 X 20	3.3	35	4	194.43	89827.58
2	Tube 330 X 330 X 16	3.3	35	6	157.55	109183.98
3	Tube 330 X 330 X 10	3.3	35	6	100.35	69543.94
4	Tube 270 X 270 X 8	3.3	35	3	65.73	22775.64
5	Tube 270 X 270 X 8	3.3	6	1	65.73	1301.47
				Total wt in Kg		292632.60

Table 7 Steel Consumption for Model 2

Sr. No.	Section	Length	No of Column	No. Of Stories	Weight (Kg/m)	Total
1	Tube 330 X 330 X 16	3.3	35	10	157.55	181973.30
2	Tube 330 X 330 X 10	3.3	35	6	90.94	63024.19
3	Tube 270 X 270X 8	3.3	35	3	65.73	22775.64
4	Tube 270 X 270 X 8	3.3	6	1	65.73	1301.47
				Total wt in Kg		269074.60

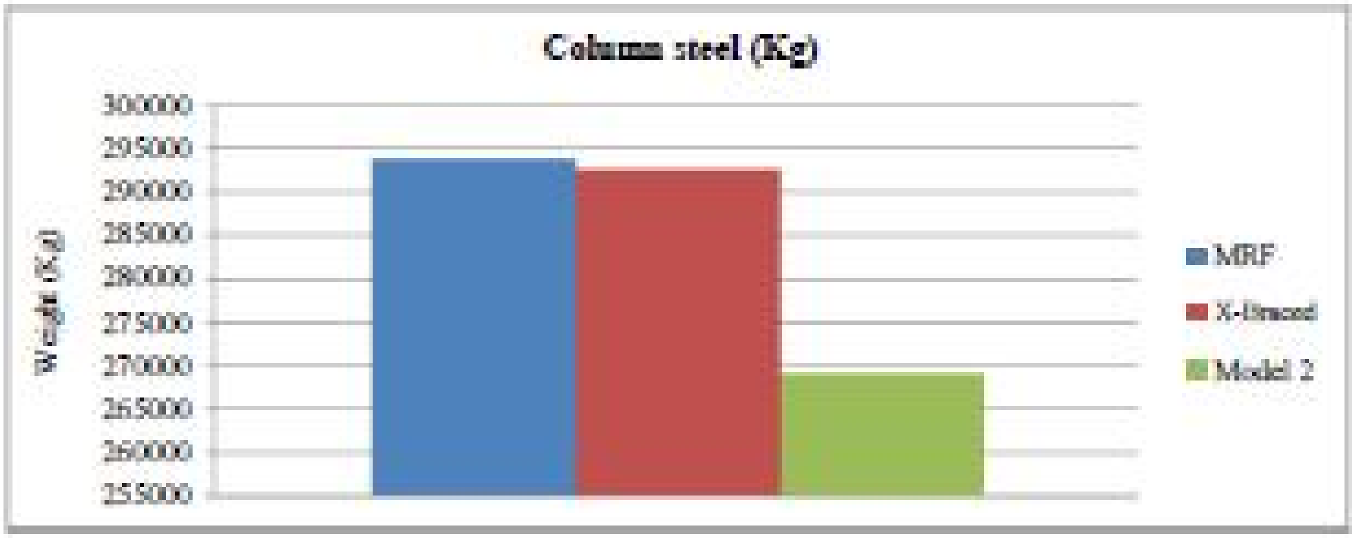

Fig 13 Steel Consumptions for column of MRF, X-bracing, and Model 2

V. CONCLUSIONS

A. From preliminary investigation it reveals that there is significant effect on deflection in orthogonal direction by shifting of shear wall location. Placing Shear wall away from centre of gravity resulted in increase in lateral deflection.
B. Orientation of shear wall in Y direction reduces deflection as compared to its orientation in X direction.
C. Results indicate that steel plate shear walls have a large effect on the behaviour of frames under earthquake excitation.
D. Results shows that the deflection in column which placed at the edge of the building is large as compared to the columns placed towards centre of building due to seismic forces.
E. Location of shear wall effects on static and dynamic axial load on the column.
F. In general, infill steel plate increases stiffness of the structure. Deflection in case of without SPSW is large as compared with SPSW.
G. SPSW location for Model 2 is found most suitable from deflection point of view.

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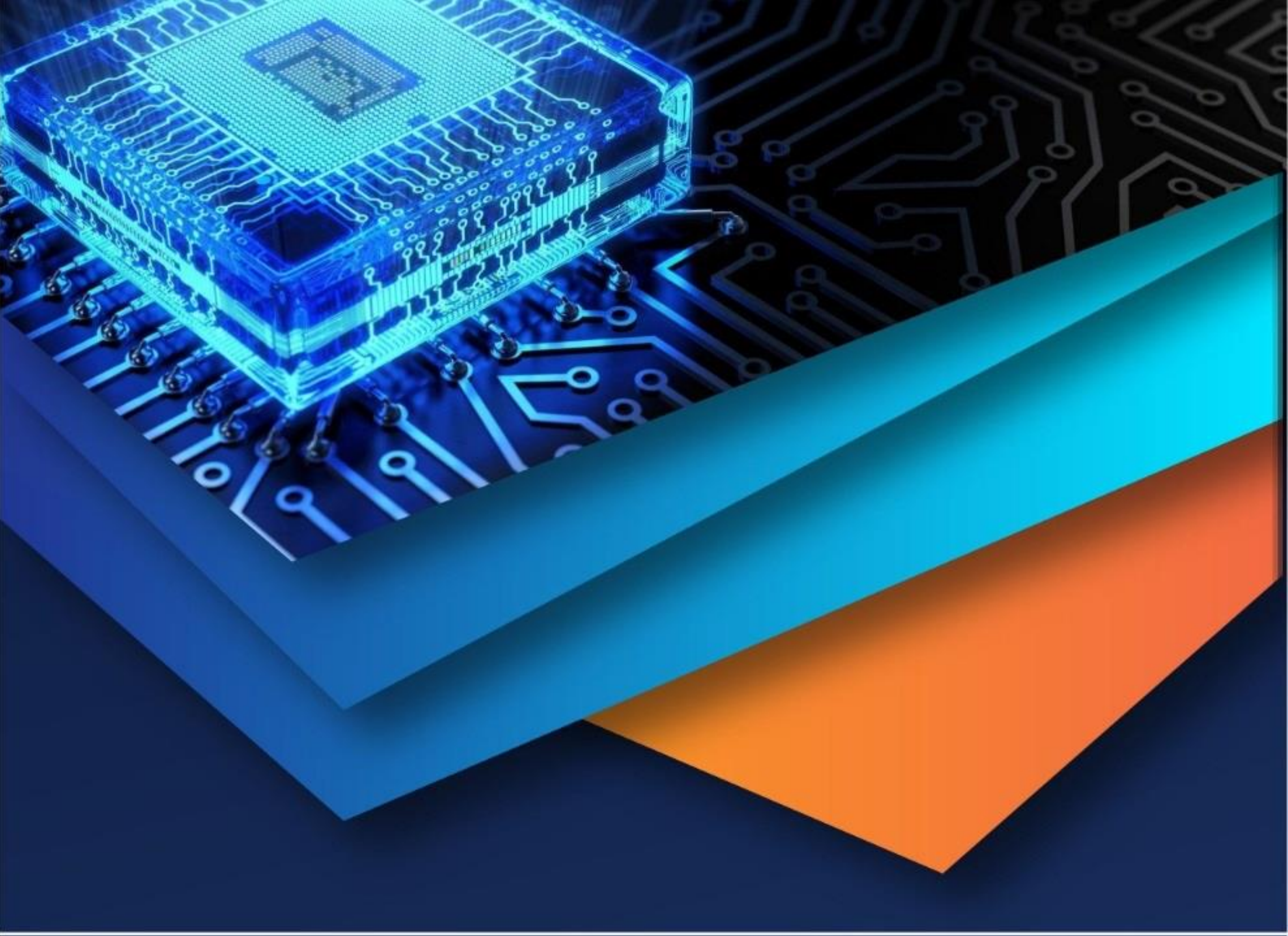

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