Analysis and Design of steel framed buildings with and without Steel Plate Shear Walls

Ms Deepika C. Hiwrale [1], Prof. P.S. Pajgade [2]

ABSTRACT

The present paper describes the analysis and design of high-rise steel building frame with and without Steel plate shear wall (SPSW). For present work equivalent static analysis is carried out for steel moment resisting building frame having (G+6) storey situated in zone III. Modelling will be done by using strip modelling. The analysis of steel plate shear wall and the building are carried out using Software STAAD PRO V8i SELECT series II. The main parameters consider in this paper to compare the seismic performance of buildings are bending moment, shear force, deflection and axial force. The models are analyze by equivalent static analysis as per IS 1893:2002 and design will be carried out by using IS 800-2007.

Keywords⎯⎯

Steel plate shear wall (SPSW) , steel building, strip model, IS 800-2007 , IS 1893-2002, seismic coefficient method, tension field action, seismic design, boundary element.

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1. 1 INTRODUCTION

As compare to the Reinforced cement concrete (RCC) the steel has got some important physical properties like the high strength per unit weight and ductility [3]. 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.

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[1] Final Year Student (M.E. Structure) , [2] Professor
Department Of Civil Engineering
Prof. Ram Meghe Institute of Technology & Research
Badnera, Amravati-444701, Maharashtra, India

Email ID: deepikahiwrale@gmail.com

Email ID: ppajgade@gmail.com

The web plates can be sufficiently stiffened to preclude buckling and allow the full shear strength of the web to be reached. The steel plate shear walls are mainly used in multistoried building in the foreign countries such America, Japan, Canada etc.

1.2 PURPOSE OF SPSW

Shear walls are not only designed to resist gravity / vertical loads (due to its self-weight and other living / moving loads), but they are also designed for lateral loads of earthquakes / wind. the walls are structurally integrated with roofs / floors (diaphragms) and other lateral walls running across at right angles, thereby giving the three dimensional stability for the building structures. Shear wall structural systems are more stable. Because, their supporting area (total cross-sectional area of all shear walls) with reference to total plans area of building, is comparatively more, unlike in the case of RCC framed structures.

- Walls have to resist the uplift forces caused by the pull of the wind.
- Walls have to resist the shear forces that try to push the walls over.
- Walls have to resist the lateral force of the wind that tries to push the walls in and pull them away from the building.

2. MODELING OF STEEL PLATE SHEAR WALLS

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. 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 figures.

The two models of the SPSWs are as shown in the following figures. The first one was proposed by Thorborn. The second, Multi-angle strip model was proposed by Rezaii.[9]
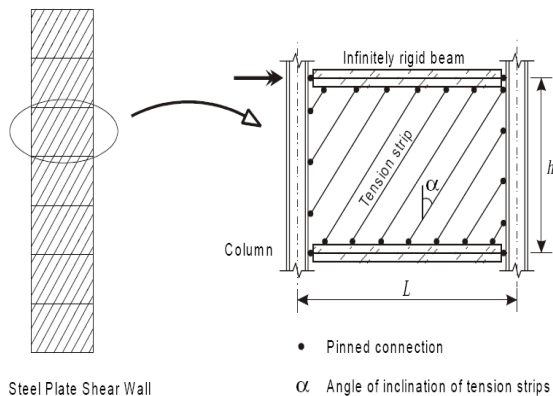

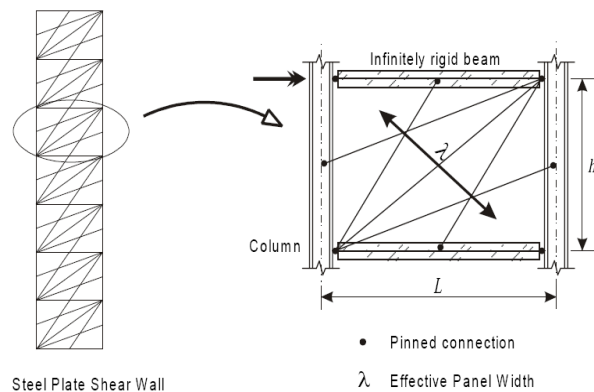**Figure 2.1.1 Strip Model Representation of a SPSW**

Figure 2.1.2 Multi-angle strip model of a SPSW

2.2 Modeling guide lines 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 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 figures. In the first 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.

3. METHODS 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, one has to use the equivalent static method also called as Seismic coefficient method only. This is because of the fact that the tension struts in the strut model are effective only when they are oriented in such a way that they carry axial tension. As the SPSWs are modeled here by using the popular tension-strip model also called as strip model,the method of analysis used is the seismic coefficient method as specified by the IS 1893 (Part I) : 2002.

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

3.1.1 Static Analysis
Load factors

In the design of steel structure, following load combinations as given in the   IS 1893 (Part1): 2002 and IS 800-2007 are:

1.5 DL+1.5 LL+ 1.5RLL
1.2 DL+0.6 LL+1.2 EL
1.2 DL+0.6 LL-1.2 EL
1.5 DL+1.5 EL
1.5 DL-1.5 EL
0.9 DL+1.5 EL
0.9 DL-1.5 EL

4. DESIGN OF STEEL BUILDING WITH AND WITHOUT

STEEL PLATE SHEAR WALL

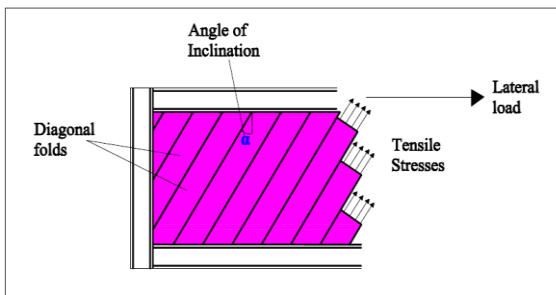### 4.1 DESIGN OF STEEL BUILDING WITH STEEL PLATE SHEAR WALL

Fig. 4.1 Idealized tension- field action in a typical SPW

4.1.1 Thickness of steel panel

$$t_{wi} = \frac{2\,V_i}{0.95\,F_{yL}}$$

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

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

4.1.3 DESIGN OF VERTICAL BOUNDARY ELEMENT

For vertical boundary elements (VBE), it has been recommende that the moment of inertia Ic should be such that [9] :

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

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

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]

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

where,
f_y =   yield stress of material
A_g =   gross area of cross – secti
Υ_{mo} =   partial safety factor for failure in tension By yielding

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 Staad pro V8i SELECT SERIES 2. [20]

5.1 ANALYSIS PROBLEM

1	Type of structure	M.R.S.F
2	Zone	III
3	Layout	As shown Fig 6.1
4	No. of Stories	G+6
5	Lateral load resisting system	Steel plate shear walls
6	Height of each storey	3m
7	Depth of foundation	3m
8	Thickness of slab	150mm
9	External wall thickness	230mm
10	Internal wall thickness	150mm
11	Shear wall Thickness	6mm
12	width of strips	350mm
13	angle of inclination of strips with vertical (α)	45°
14	Unit weight of masonry	20 kN/m3
15	Floor Finish	2 kN/m2
16	Live load	4 kN/m2 at terrace
4 kN/m2 at intermediate floor
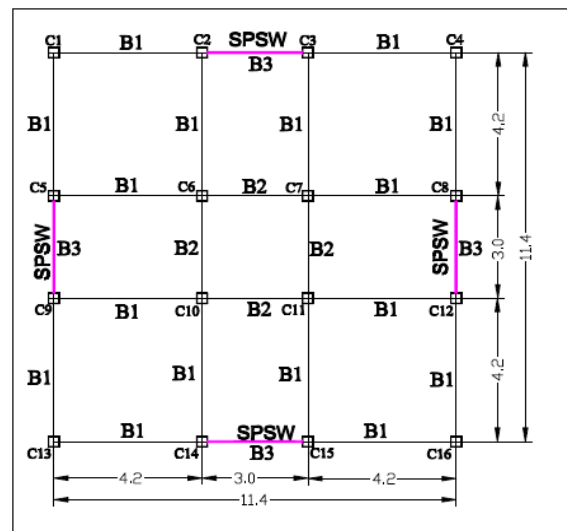| 17	Type of soil	Medium
18	Seismic Analysis	Seismic coefficient Method (IS 1893-2002)
19	Design of philosophy	Limit state method conforming to IS 800-2007

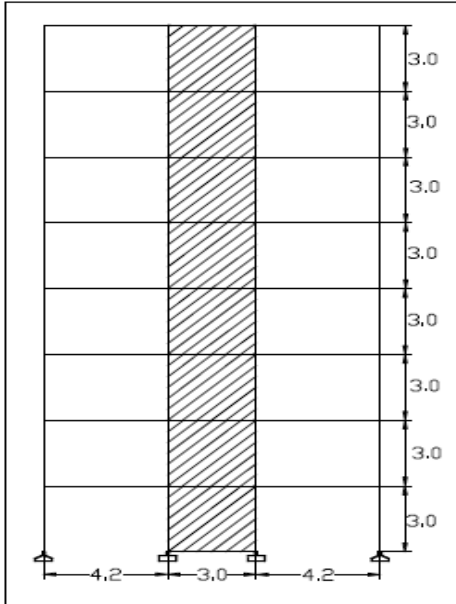### 5.2 STRUCTURAL DETAILS :-
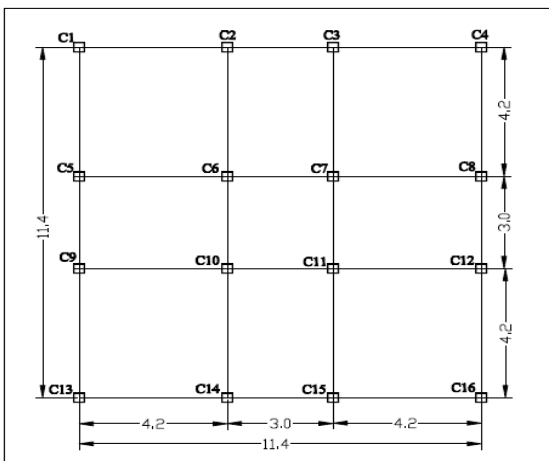
5.2 .1 Plan of a G+6 story Steel buildi
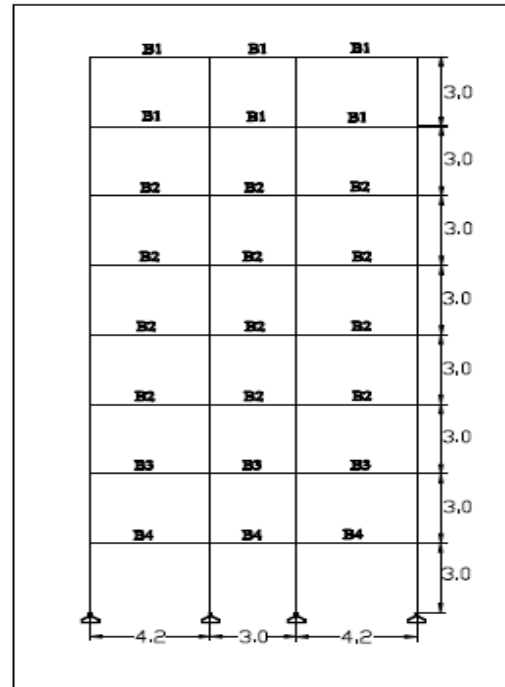
5.2 .2 Elevation of a G+6 story Steel building

5.2.3 Plan of a G+6 story Steel building with SPSW

5.2.4 Elevation of a G+6 story Steel building with SPSW

5.3 Member Specification:

For Steel building :

Size of Beam   :

    B1 = ISHB 225
    B2 = ISWB 350
    B3 = ISHB 300H
    B4 = ISHB 400

Size of Column :

    1)   FOR C1 , C4 , C13 , C16
           TUBE 330 X 330 X 8
           TUBE 330 X 330 X 10
           TUBE 330 X 330 X 16

    2)   FOR C2 , C3 , C5 , C9 , C8 ,
              C12 , C14 , 15
           TUBE 330 X 330 X 16
           TUBE 330 X 330 X 12
           TUBE 330 X 330 X 10
           TUBE 330 X 330 X 8

    3)   FOR C6 , C7 , C10 , C11
           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 SPSWs Building:

Size of Beam :

    B1 = ISWB 300
    B2 = ISHB 200
    B3 = ISWB 150

Size of Column :

    1)   FOR C1 , C4 , C13 , C16
           TUBE 270 X 270 X 6
           TUBE 270 X 270 X 8

    2)   FOR C2 , C3 , C5 , C9 , C8 ,
           C12 , C14 , 15
           TUBE 270 X 270 X 8
           TUBE 270 X 270 X 10
           TUBE 270 X 270 X 12

    3)   FOR C6 , C7 , C10 , C11
           TUBE 270 X 270 X 8
           TUBE 270 X 270 X 10

The above mentioned both the frame has been analysed and Design by using STAAD-PRO V8i SELECT SERIES 2 software. For getting results some column has been selected and they are as column nos. 1 ,7 & 9. The results found to be are shown with the help of graph for the parameters.

1. **Deflection**
2. **Shear force**
3. **Moment**
4. **Axial force**
5. **Ast**

6.1 COMPARISON OF RESULTS

6.1.1 DEFLECTION RESULT

6.1.2 SHEAR FORCE RESULT

Figure:1 Deflection in (mm) for Column No. 01

Figure: 4 Shear Force in (kN) for Column No. 01

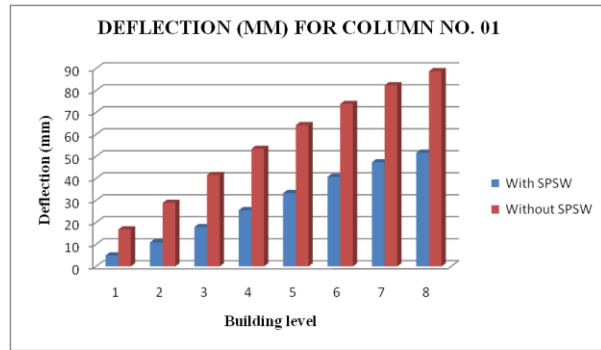

Figure: 2 Deflection in (mm) for Column No. 07
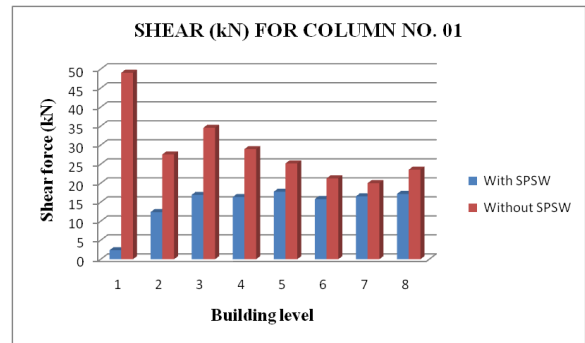

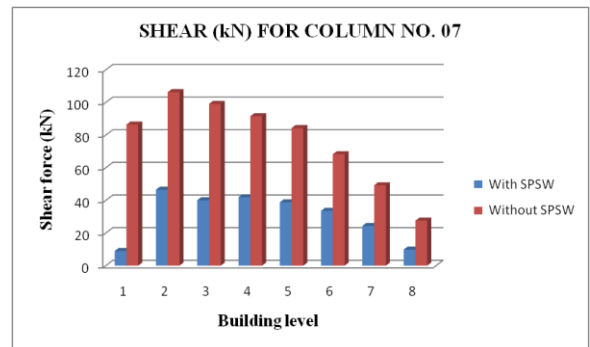Figure: 5 Shear Force in (kN) for Column No. 07

Figure: 3 Deflection in (mm) for Column No. 09
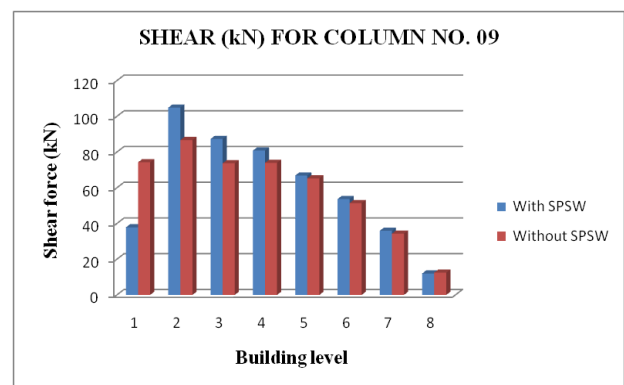
Figure: 6 Shear Force in (kN) for Column No. 09

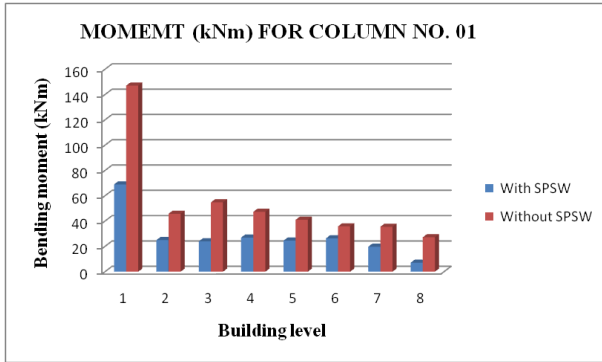### 6.1.3 BENDING MOMENT   RESULT

Figure: 7 Bending moment in (kNm) for Column No. 01

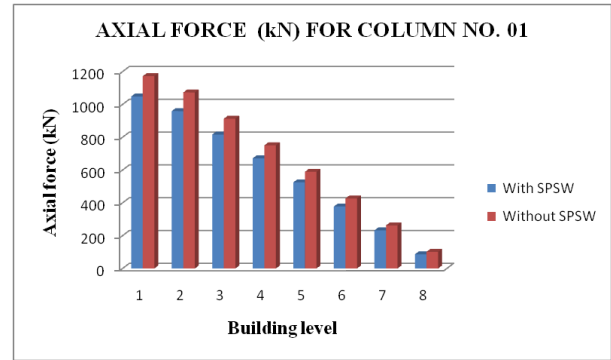### 4.1.4 AXIAL FORCE RESULT

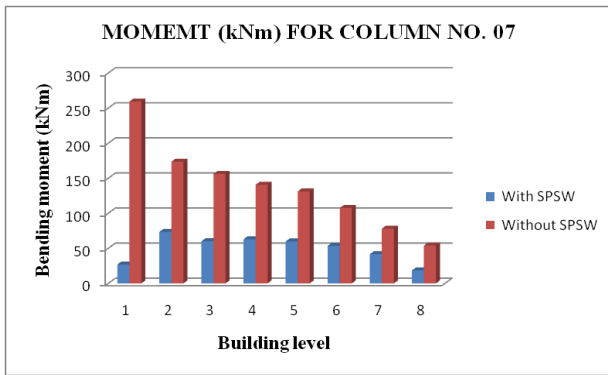Figure: 10 Axial Force in (kN) for Column No. 01

Figure: 8 Bending moment in (kNm) for Column No. 07
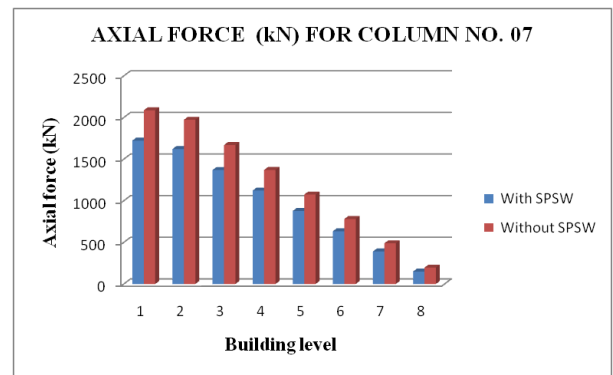

Figure: 11 Axial Force in (kN) for Column No. 07
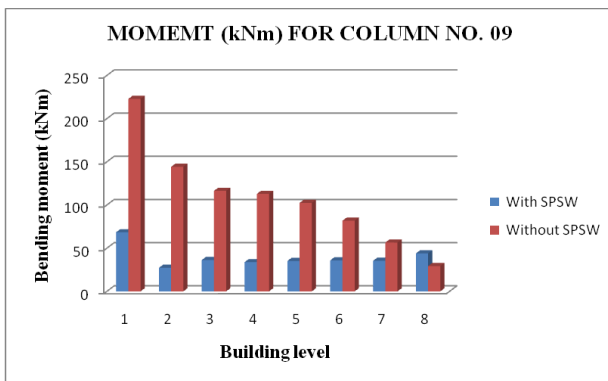

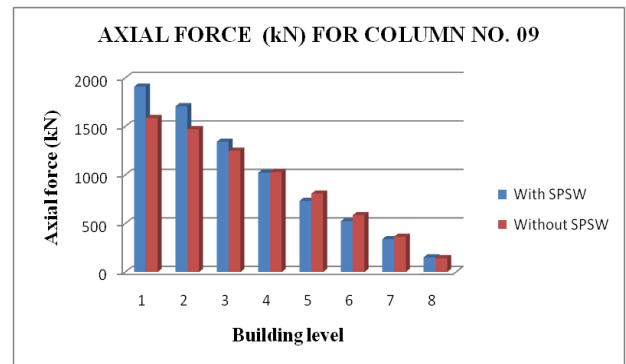Figure: 9 Bending moment in(kNm) for Column No. 09

Figure: 12 Axial Force in (kN) for Column No. 09
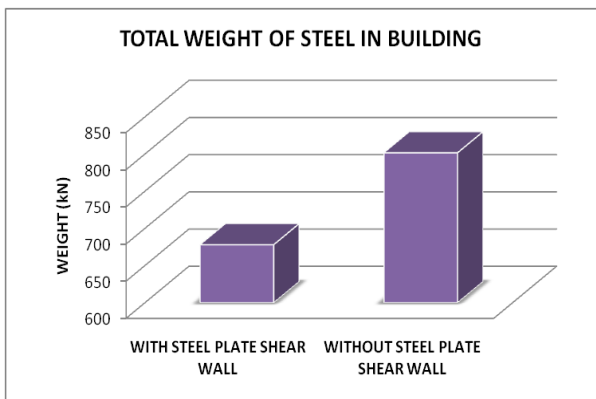
6.1.4 WEIGHT OF STEEL   RESULT

Figure: 13 Total weight of steel in (kN)

CONCLUSIONS:-

1)Results indicate that steel plate shear walls have a large effect on the behavior of   frames under earthquake excitation. In general, infill steel plate increase stiffness of the structure.

2) Deflection in case of without SPSW is very large & in case of with SPSW deflection is very less.

3) With the use of steel shear walls in the buildings, the bending moments in the column are reduce.

4) From fig. 13, due to presence of SPSW total weight of steel in building is reduced than building without SPSWs.

5) From above result it is observed that, due to use of SPSW in building there is considerable decrease in value of bending moment, shear force, deflection and axial force for some columns and also quantity of steel is reduced. Hence steel building with SPSWs is economical compare to without SPSWs.

6) Due to relatively small thickness of SPSW compared to reinforced concrete shear walls, from architectural point of view, steel shear wall occupy much less space than equivalent reinforced concrete shear wall .

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