Seismic Behavior of Symmetric and Asymmetric Building for Static and Dynamic Analysis using STAAD.Pro

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Abstract - *The main objective of this research is the comparative study on the seismic behavior of two sets of commercial office buildings (G+9) using both static and dynamic response analysis method in STAAD.Pro. SET-A is regular and symmetric building while SET-B is irregular and asymmetric building. Revit Architecture is used for 3D modelling of buildings and STAAD. Pro is used for analysis of 3D framed structure. This project is done to analyze the two set of multi-story buildings for response spectrum and finding out the base shear, horizontal forces (i.e. lateral load on structure due to earthquake), mode shape of buildings due to response spectrum, displacement of joints, maximum shear forces, bending moments, axial forces on beams & columns, maximum absolute stresses & displacement in slabs and reinforcement details for the structural components of building (such as beams, columns and slabs) to develop the economic design.*

Key Words: Base shear, displacement, dynamic loading, reinforcement, response spectrum, seismic, structure, STAAD.Pro.

1. INTRODUCTION

Structural analysis is the analysis of behavior of the structure subjected to self-weight of the structural members (such as beams, columns, slabs, ceilings), dead load (such as weight of furniture's, doors, windows, tiles), imposed load (such as load due to movement of people), dynamic load (due to wind, earthquake loads) etc..

Base shear (V_B) is the maximum horizontal force on the base of the structure due to wind and seismic activity. To calculate base shear, dynamic analysis is done. In STAAD.Pro base shear is calculated using following formula:

$$V_B = A \times B \times C \times D$$

Here; A = Mass participation factor for that node,
B= Total mass specified for that direction,
C= Spectral acceleration for that node ($\frac{S_a}{g}$)
D= Direction factor for particular load.
In STAAD.Pro there are two methods of dynamic analysis:

a) Response spectrum analysis, and
b) Time history analysis.

In this research two set of (G+9) commercial office RCC buildings are designed and analyzed by using response spectrum analysis method in STAAD.Pro.

SET A: **Regular and symmetrical (G+9) RCC building with 72x24m in plan.** (Fig.-1)
SET B: **Irregular and asymmetrical (G+9) RCC building with 69x36m in plan.** (Fig.-4)

1.1 Salient features of SET-A & SET-B buildings:

Building type: Commercial office building
Type of construction: RCC framed structure
No. of stories: 10 (G+9)
No. of floors: 10(+1 roof)
Thickness of floors: 0.150m
Thickness of roof slab: 0.125m
Floor to floor height: 3.5m
Size of all beams = 400 x 450mm
Size of columns (base to 5th story) = 850 x 850mm
Size of columns (6th to 10th story) = 600 x 600mm
Type of walls: Brick wall
Thickness of walls: 0.230m

2. RESEARCH METHODOLOGY

STAAD.Pro is a Structural Analysis and Design Program used to analyze input data, verify results and using these results steel or concrete designing is done. STAAD.Pro v8i is used in this project.

2.1 Formation of SET-A building:

Shape of building= Regular and symmetric
X-coordinate of structure= 0 to 72m
Y-coordinate of structure= -3.5 to 35m
(-3.5 to 0 m for substructure & 0 to 35 m for super structure)
Z-coordinate of structure= 0 to 24m
Total no. of nodes/ joints=1500
Total no. of beams (both horizontal & vertical) =3795
Total no. of plates = 968
Total no. of supports = 125
Total degree of freedom = 8250
Total primary load cases = 6
No. of mode requested = 15

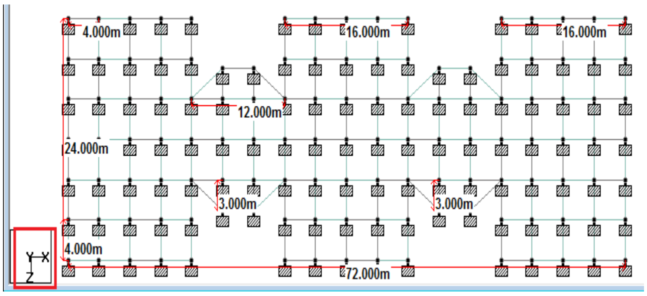

Fig -1: Top view of SET-A symmetric building

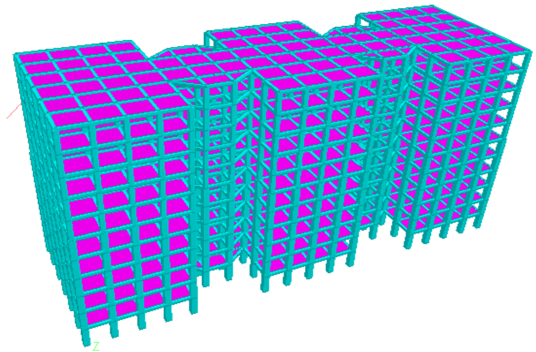

Fig -2: Rendered view of SET-A building in STAAD.Pro

Fig -3: Expected 3D view of SET-A building in Revit

2.2 Formation of SET-B building:

Shape of building= Regular and symmetric
X-coordinate of structure= 0 to 69m
Y-coordinate of structure= -3.5 to 35m
(-3.5 to 0 m for substructure & 0 to 35 m for super structure)
Z-coordinate of structure= 0 to 36m
Total no. of nodes/ joints=1440
Total no. of beams (both horizontal & vertical) =3641
Total no. of plates = 990
Total no. of supports = 120
Total degree of freedom = 7920
Total primary load cases = 6
No. of mode requested = 15

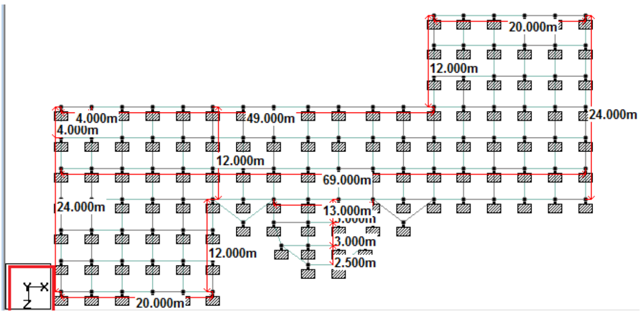

Fig -4: Top view of SET-B asymmetric building

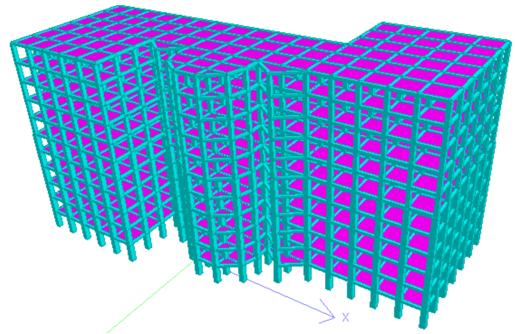

Fig -5: Rendered view of SET-B building in STAAD.Pro

Fig -6: Expected 3D view of SET-B building in Revit Architecture

3. LOAD CALCULATION

3.1 Dead load:

It is due to self-weight of all the members like beams, columns, slab loads and wall loads etc.

Beam & column=width x depth x unit wt. of RCC (25 KN/m^3)

For all beams; 0.40 x 0.45 x 25 = -4.5 KN/m^2

For lower columns (from base to 5^{th} story);
0.85 x 0.85 x 25 = -18.07 KN/m^2

For above columns (from 6^{th} story to 10^{th} story);
0.6 x 0.6 x 25 = -9 KN/m^2

Wall load = thickness x height x unit weight of brick mortar
For main wall; 0.23 x 3.5 x 20 = -16.1 KN/m
(Beam, column and wall loads are applied as uniform force in STAAD.Pro and negative sign indicate downward direction of load)

Slab load = thickness of slab x unit wt. of RCC (25 KN/m^3)

For 0.15m thick floor; 0.15 x 25 = -3.75 KN/m^2

Load of floor finishing tiles = -1 KN/m^2

Total dead load of floor slab = -4.75 KN/m^2
For 0.125m thick roof; 0.125 x 25 = -3.125 KN/m^2

Load of roof finishing tiles = -1 KN/m^2

Total dead load of roof slab = -4.125 KN/m^2

(Slab load is applied as floor load in STAAD.Pro and negative sign indicate downward direction of load)

3.2 Live load:

It is assumed as floor load of,

-4 KN/m^2; (for commercial office buildings)

-1.5 KN/m^2; (at roof 14m)

3.3 Seismic load:

Using the IS code 1893-2002/2005 of seismic load for both the set of the buildings;
Location of buildings = Dehradun, Uttarakhand, India
Seismic Zone- IV (Z=0.24)
Response reduction factor (RF) = 5 (for Special Moment Resisting Frame)
Importance factor (I) = 1.5 (for commercial office buildings)
Soil site factor = 2 (assumed medium soil condition)
Damping ratio = 5% (from IS 1893(Part 1):2002)
Approximate fundamental natural period of vibration in seconds; $[T = \frac{0.09\,h}{\sqrt{d}}]$ ......Eq^n- 1

Here; h = Height of building in m = 35m
d = Base dimension of building along the considered direction of the lateral force in meter.

For SET-A building:

Time period in X- dir^n = $\frac{0.09 \times 35}{\sqrt{72}}$ = 0.371 s

Time period in Z- dir^n = $\frac{0.09 \times 35}{\sqrt{24}}$ = 0.643 s

For SET-B building:

Time period in X- dir^n = $\frac{0.09 \times 35}{\sqrt{69}}$ = 0.379 s

Time period in Z- dir^n = $\frac{0.09 \times 35}{\sqrt{36}}$ = 0.525 s

For medium soil sites

$$\frac{S_a}{g} = \begin{cases} 1 + 15\,T; & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.55 \\ 1.36/T & 0.55 \le T \le 4.00 \end{cases}$$

Fig -7: Value of $\frac{S_a}{g}$ for different fundamental natural period

3.4 Temperature load:

For both the set of buildings:
The maximum temperature of Dehradun in summer = 38°C
The minimum temperature of Dehradun in winter = 3°C
Assume ambient temperature = 20°C
Hence change in temperature for axial elongation of beams, columns & slabs, Δt_1 = 38 – 20 = 18°C

Δt_2 = 3 – 20 = -17°C

3.5 Response Spectrum load:

For dynamic response spectrum analysis all the dead loads and live loads are applied in all the three directions i.e. global x, y & z with positive values of loads.
Following are the parameters used for both the set of buildings;
Code used = IS 1893
Combination method=Complete Quadratic Combination (CQC)
(There are total 7 combination method in response spectrum analysis).
Subsoil class = Medium soil (assumed)
Damping ratio = 5%
Design horizontal seismic coefficient;

$[A_h = \frac{Z \times I}{2 \times R} \times \frac{S_a}{g}]$ ......Eq^n- 2

Here; Z = Zone factor = 0.24
I = Importance factor = 1.5
R = Response reduction factor = 5
$\frac{S_a}{g}$ = Average response acceleration coefficient (from fig. 7)

For SET-A building:

A_h in x- dir^n = $\frac{0.24 \times 1.5}{2 \times 5}$x2.5 = 0.09

A_h in Z- dir^n = $\frac{0.24 \times 1.5}{2 \times 5}$x2.115 = 0.076

For SET-B building:

A_h in X & Z- dir^n = $\frac{0.24 \times 1.5}{2 \times 5}$x2.5 = 0.09

3.6 Load Combination:

There are total 15 no. of load combinations are used in static analysis. Major combinations are;

1. 1.5 [DL + LL]
2. 1.2 [DL + LL]
3. 1.2 [DL + LL ± EQ]
4. 1.5 [DL ± EQ]
5. 0.9 DL ± 1.5 EQ

Earthquake load is provided in both X (i.e. EQ-X) and Z (i.e. EQ-Z) directions.

4. RESULTS AND DISCUSSIONS

Following are the results obtained by analyzing the structure for the applied load cases:

4.1 Lateral load on buildings (using static analysis):

Lateral loads are live loads due to horizontal forces like-seismic load. From static analysis following lateral loads are obtained for both the set of buildings in x & z dir^n (table-1).

Table -1: Lateral load at different levels of structures

Height of floor in (m)	Lateral load in (KN)			
	For SET-A Building		For SET-B Building	
	In X- dir^n	In Z- dir^n	In X- dir^n	In Z- dir^n
0.0	94.868	80.262	90.863	90.863
3.5	379.474	321.048	363.450	363.450
7.0	853.817	722.358	817.764	817.764
10.5	1517.896	1284.191	1453.800	1453.800
14.0	2371.711	2006.549	2271.566	2271.566
17.5	3102.779	2625.062	2971.599	2971.599
21.0	3797.910	3213.163	3637.097	3637.097
24.5	4960.538	4196.787	4750.494	4750.494
28.0	6278.178	5311.555	6012.339	6012.339

31.5	7750.834	6557.476	7422.637	7422.637
35.0	6504.240	5502.805	6327.296	6327.296
Total	**37612.244**	**31821.248**	**36118.896**	**36118.896**

From IS 1893(Part 1):2002- base shear calculated using fundamental period T; $\mathbf{V_b = A_h \times W}$
Here; A_h = Horizontal seismic coefficient (from Eq^n -2)
W = Seismic weight of building
(It is equal to total dead load plus 50% of live load).
= 417913.824 KN (for SET-A building)
= 401321.056 KN (for SET-B building)
For SET-A building (using static analysis method):
V_b in X-dir^n = 0.09 x 417913.824 = 37612.244 KN
V_b in Z-dir^n = 0.076 x 417913.824 = 31821.248 KN
For SET-B building (using static analysis method):
V_b in X & Z-dir^n = 0.09 x 401321.056 = 36118.896 KN

4.2 Base shear on buildings (using dynamic analysis):

Following are the values of peak story shear obtained by dynamic response spectrum analysis for both the set of buildings in x & z dir^n (table-2).

Table -2: Peak shear on different floors of structures

Height of floor in (m)	Peak Story Shear in (KN)			
	For SET-A Building		For SET-B Building	
	In X- dir^n	In Z- dir^n	In X- dir^n	In Z- dir^n
35.0	6271.67	5033.25	5760.54	6033.31
31.5	13514.65	11305.32	13343.80	13404.81
28.0	18406.97	15567.90	18674.53	18476.44
24.5	21944.92	18373.47	22235.27	22090.67
21.0	24427.80	20500.56	24808.96	24563.40
17.5	26664.34	22416.86	27131.70	26784.45
14.0	29362.36	24549.47	29820.50	29561.35
10.5	32168.67	26964.69	32836.88	32521.68
7.0	35041.23	29520.36	35965.32	35521.68
3.5	37460.23	31498.31	38376.58	37988.10
0.0	**38500.28**	**32278.22**	**39331.18**	**39033.47**

Base shear calculated using dynamic response spectrum analysis method *(CQC method):*
For SET-A building (multiply factor $\frac{V_b}{V_B}$ *= 1.469)*
V_B in X-dir^n = 38500.28 KN (Mass participation= 93.892%)
V_B in Z-dir^n = 32278.22 KN (Mass participation= 91.266%)
For SET-B building (multiply factor $\frac{V_b}{V_B}$ *= 1.6567):*
V_B in X-dir^n = 39331.18 KN (Mass participation= 92.133%)
V_B in Z-dir^n = 39033.47 KN (Mass participation= 93.873%)
[*Check*- a. Now V_B is greater than V_b
b. Sum total of modal masses of all modes (i.e. 50) is more than 90% of the total seismic mass.]

4.3 Mode shape of the structure:

A total 2 no. of mode shapes (out of 15) in response spectrum analysis for both the set of buildings is shown below; (Fig.-8 and fig.-9)

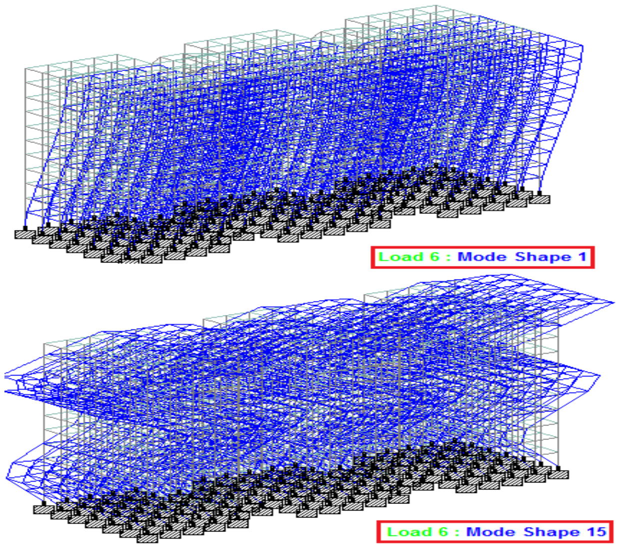

Fig -8: Mode shapes for SET-A building

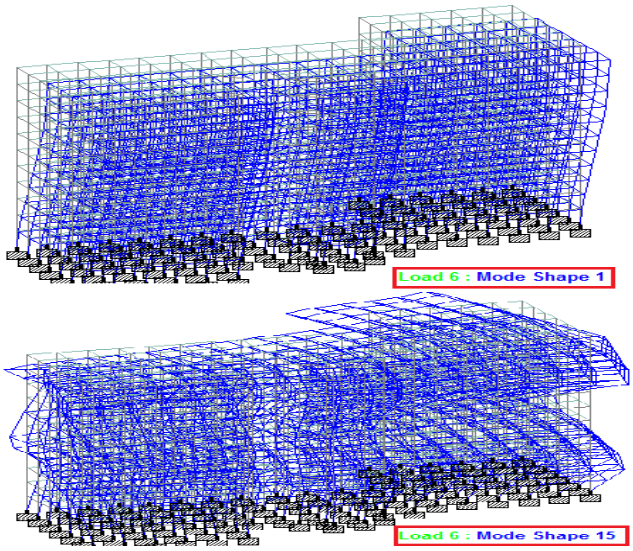

Fig -9: Mode shapes for SET-B building

4.4 Maximum bending moment for beams:

Table -3: Maximum bending moment

Maximum B.M. in (KN-m)				
Case	Type of building	Beam no.	Load case	Maximum B.M. (Mz)
Dynamic Analysis	SET-A	4610	Temperature load	1786.542

	SET-B	2382	Response spectrum	1354.181
Static Analysis	SET-A	3862	1.5(DL+EQX)	1949.085
	SET-B	2404	1.5(DL+EQX)	1885.856

4.5 Maximum shear force for beams:

Table -4: Maximum shear force

Maximum S.F. in (KN)				
Case	Type of building	Beam no.	Load case	Maximum S.F. (Fy)
Dynamic Analysis	SET-A	4610	Temperature load	718.991
	SET-B	3416	Temperature load	473.606
Static Analysis	SET-A	4610	Temperature load	718.991
	SET-B	438	1.5(DL+EQZ)	576.688

4.6 Maximum axial force for beams:

Table -5: Maximum axial force

Maximum Axial Force in (KN)				
Case	Type of building	Beam no.	Load case	Maximum Axial force (Fx)
Dynamic Analysis	SET-A	3840	Dead load	3763.135
	SET-B	2338	EQ-Z	4245.115
Static Analysis	SET-A	4742	1.5(DL+EQZ)	8661.391
	SET-B	2338	1.5(DL+EQZ)	10222.763

4.7 Maximum deflection of the beams:

Deflection diagram for the beam in Y direction for both set of building is shown below; (fig.-10 and fig.-11)

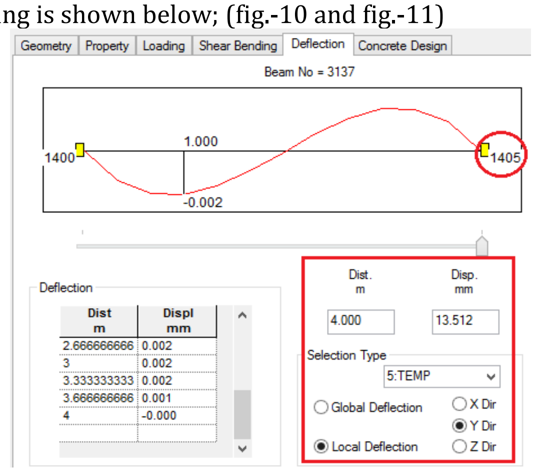

Fig -10: Maximum deflection diagram of beam in local Y dir^n (for node no. 1405) for SET-A building

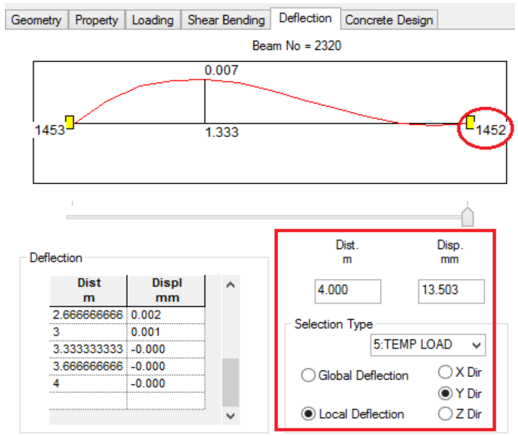

Fig -11: Maximum deflection diagram of beam in local Y dir^n (for node no. 1452) for SET-B building

4.8 Maximum stresses in plates:

The maximum absolute stresses (fig.-12 and fig.-13) and corner displacements of the plates/slabs (fig.-14 and fig.-15) for response spectrum load case in dynamic analysis for both the set of buildings are shown below;

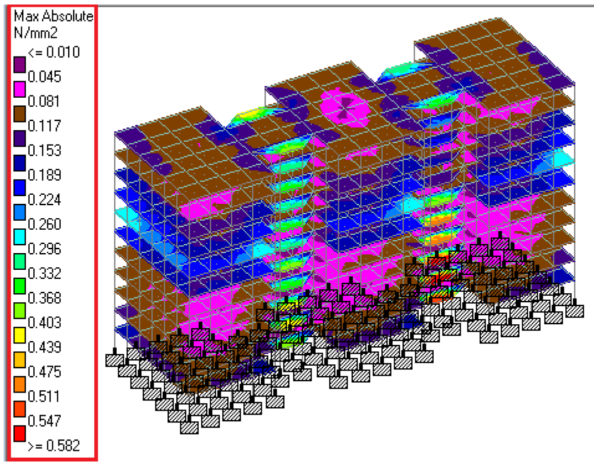

Fig -12: Maximum absolute stresses in plates for SET-A building

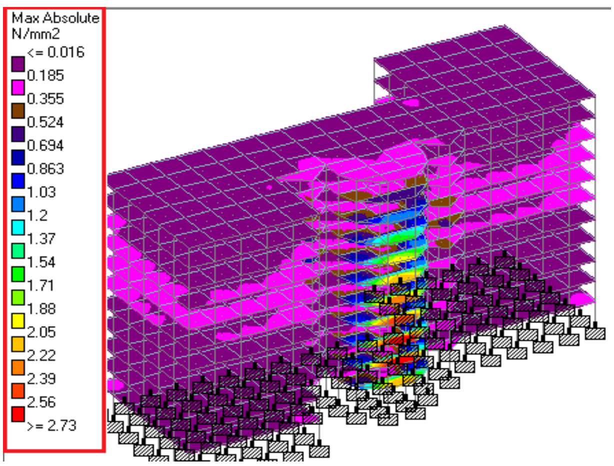

Fig -13: Maximum absolute stresses in plates for SET-B building

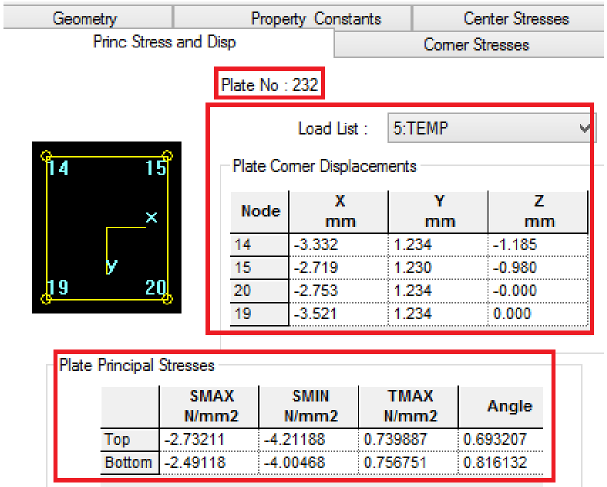

Fig -14: Corner displacement for plate (no. 232) of max^{m} principal stress in SET-A building

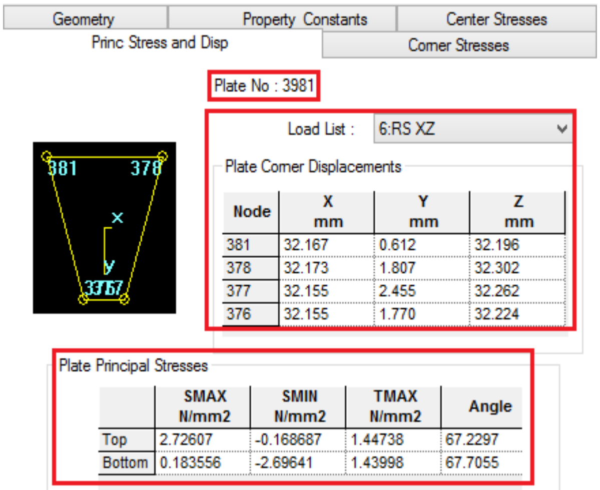

Fig -15: Corner displacement for plate (no. 3981) of max^{m} principal stress in SET-B building

5. CONCRETE DESIGN

5.1 Design parameter for beams and columns:

Following are the design parameters used in both the set of buildings: (Here designing is done as per dynamic analysis);
Code used= IS 456
Clear cover= 25mm (for beams)
= 40mm (for columns)

Grade of concrete = M30

Compressive strength of concrete for (M30); fc = 30 N/mm^2

Grade of steel = fe500

Yield strength of main reinforcement; F_Y = 500 N/mm^2

Yield strength of shear reinforcement; F_Y = 500 N/mm^2

Maximum size of main reinforcement = 25mm

Maximum size of secondary reinforcement = 20mm

Minimum size of main reinforcement = 16mm
Minimum size of secondary reinforcement = 12mm
Maximum % of longitudinal reinforcement allowed = 4%

5.2 Concrete design of beams:

Reinforcement schedule and cross section for randomly selected beams for the two set of buildings: (table-6)

Table -6: Reinforcement detailing of beams

Design Results of Beam M30(concrete) Fe500 (Main bar) Fe500 (Secondary bar) Length: 4000mm Size: 400x450mm Cover: 25mm		
Schedule of provided reinforced bars		
Type of building	SET-A	SET-B
Beam no. & position	2 (Leftmost corner ground floor beam)	195 (Leftmost corner ground floor beam)
Top reinforcement	7@16mm ϕ 1 layers	9@16mm ϕ 1 layer
Bottom reinforcement	7@16mm ϕ 1 layer	4@20mm ϕ 1 layer
Shear reinforcement	2 legged 12mm ϕ @190mm c/c	2 legged 12mm ϕ @190mm c/c

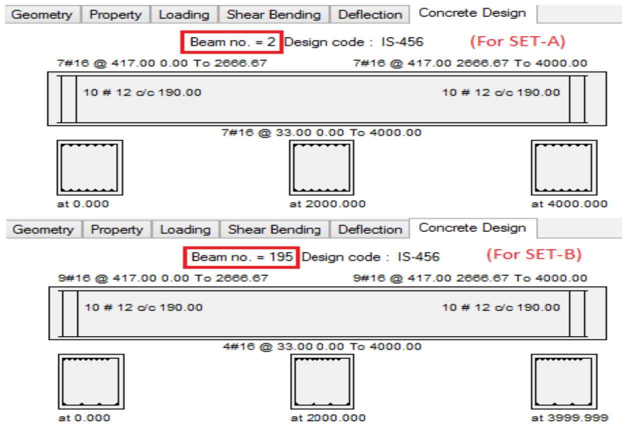

Fig -16: L-section and cross-section of beams

5.3 Concrete design of columns:

Concrete design results for the columns of maximum axial forces for both the set of buildings: (table-7)

Table -7: Reinforcement detailing of lower columns

Design Results of Column M30(concrete) Fe500 (Main bar) Fe500 (Secondary bar) Length: 3500mm Size: 850x850mm Cover: 40mm		
Type of building	SET-A	SET-B
Column no.	3840	2338
Type of column	Tension column	Tension column
Required steel area	17918.01 mm^2	25896.69 mm^2
Required concrete area	704582.12 mm^2	696603.44 mm^2
Main reinforcement provided	60@20mm ϕ =18849.55mm^2 (i.e. 2.61%, between 0.8% to 6% of cross section area)	56@25mm ϕ =27488.94mm^2 (i.e. 3.80%, between 0.8% to 6% of cross section area)
Tie reinforcement	12mm ϕ rectangular ties @300mm c/c	12mm ϕ rectangular ties @300mm c/c
Axial force	P_{UZ}= 16567.87 KN	P_{UZ}= 19691.01 KN

Worst load case	6 (i.e. response spectrum load)	6 (i.e. response spectrum load)
Interaction ratio	0.85	0.62

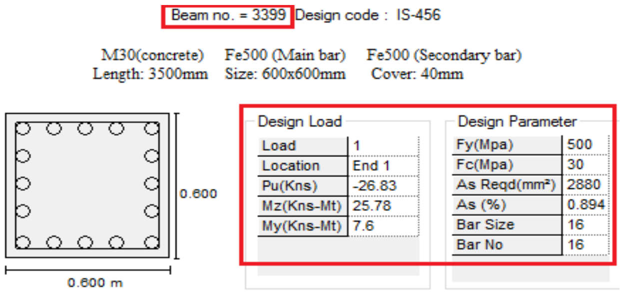

Fig -17: Cross section of upper 600x600mm column

5.4 Required quantity of concrete & reinforced steel:

Quantity of concrete & reinforced bar required for beams and columns for both the sets of buildings:
Total volume of concrete for SET-A building = 4347.4 m^3
Total volume of concrete for SET-B building = 4174.6 m^3

Table -8: Quantity of reinforcing steel

Bar Dia. (in mm)	Weight (in N)	
	For SET-A building	For SET-B building
12	1027864	988739
16	2182065	2243732
20	1971911	1896420
25	508201	887083
Total	5690040	6015974

6. CONCLUSIONS

I) Base shear for SET-B building is more than SET-A in dynamic analysis and for both the set of buildings base shear in X-dir^n is more than in Z-dir^n.
II) For SET-A building lateral loads in X-dir^n are more than SET-B and at a height of 31.5m, load is max^m for both the set of buildings in both X & Z dir^n.
III) Maximum shear force & bending moment occur on beam of SET-A building and max^m axial forces occur on SET-B building.
IV) For SET-A building temperature load is responsible for max^m bending moment, shear force of beams and max^m principal stresses at top and bottom of plates.
V) For SET-B building response spectrum load is responsible for max^m bending moment of beam and max^m principal stresses at top and temperature load is for max^m shear force.
VI) Maximum absolute stress for slabs occur in SET-B building due to response spectrum load case.
VII) Maximum shear stress and moment occur on slabs of SET-B building due to response spectrum load case.
VIII) SET-A symmetric building required more volume of concrete and less reinforcement as compared to SET-B asymmetric building.

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