International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August 2019

Design and Analysis of Multistory Building by using Shearwall Technology

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***Abstract**: In early 20th century there is a revolutionary change in software development and programing that change also helped the field of civil and structural engineering to make the analysis made easy by developing easy user interface software's. By the development of those sophisticated structural design software's even the G+10 building can analyze and design within 48 hours of time. But if the same building, if we design by manual calculations it takes lot of time and the design report is like a book with thousands of pages. In this particular thesis the G+5 residential building is designed by adopting structural wall systems without any columns. The analysis and design of super structure done in Etabs software for dead load, live load, earthquake, wind load. The uncracked model is prepared and checked against the lateral deflections due to lateral forces and vertical deflections of elements due to self-weight and modal analysis is carried out. The modal analysis is carried based on tall story code and earth quake codes, the translation modes and rotation modes are observed Cleary and designed the structure against the torsional buckling also. The same structure is also analyzed and designed for serviceability criteria's and strength criteria's by adopting the modification factors to achieve the accurate values about the long term deflection in both vertical and horizontal direction. The auto construction sequence method adopted for the finding the long term creep deflection values of the flexure members. All the members are designed against all kind of static and dynamic loads. By adopting the geotechnical report of the soil, the foundation system is adopted based on the S.B.C value and the allowable settlement value and the shear stress and settlement and soil pressure values are checked. The design of the entire footing system along with soil structure interaction is done in SAFE software and the detailing and design of the elements are done by taking one element in each type in drafting software.*

Keywords : long term deflection, serviceability criteria, lateral deflection, uncracked model, auto construction sequence, soil bearing capacity, creep, soil pressure, soil structure interaction

I. INTRODUCTION

In the early 20th century there is the revolutionary movement in globalization, it involves in rapid urbanization. This urbanization leads to increase population concentration in those areas it causes heavy usage of natural resources like land , water ,air.

Revised Manuscript Received on August 30, 2019.
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In the above natural resources land is the standard one no can increase or made by any means. So this increase in population leads to land scarcity in urban area for increased population and increase of cost was observed. So engineers and architects proposed the multi storey building to face that problem of land scarcity. By this way in urban areas and in tier-1 and tier-2 cities thousands of multistory buildings are built.

But for design of multi storey buildings and high rise buildings by manual calculation takes lot of time and here may be chance of miscalculation of forces and moments due to involvement of hundreds of structural elements like beams and columns, shear walls, slabs and footing systems.

In early 20th century there is a revolutionary change in software development and programing that change also helped the field of civil and structural engineering to make the analysis made easy by developing easy user interface software's. By the development of those sophisticated structural design software's even the G+10 building can analyze and design within 48 hours of time. But if the same building, if we design by manual calculations it takes lot of time and the design report is like a book with thousands of pages.

Now a days there are so many sophisticated software's which are very good at analysis of advanced analysis like push over, nonlinear dynamic analysis also. Some those software's are STAAD Pro (super structure design), STAAD FOUNDATION (sub structure design), ETABS (super structure design), SAFE (sub structure design), SAP2000 (both super structure and sub structure design), PROKON(sub structure design),ABAQUS,ANYSIS (advance non liner dynamic analysis including blast loading analysis and pushover , heat transfer analysis), Auto Desk RSA (advance non liner dynamic analysis including blast loading analysis and pushover , heat transfer analysis), MIDAS (both super structure and sub structure design).

A. Structural frame types:

In this particular thesis the analysis and design of RCC building is incorporated completely. While designing the R.C.C structure one can adopt different type of structure based on vertical loads and forces acting horizontal those are

Structural wall system: The structural wall system consist of rcc walls which are connected with floor diaphragms and resists the axial forces and shear, flexure forces as a result of axial and horizontal loadings.

Moment frame system: the moment frame system is the simple beam and column frame structure.

Moment frame along with structural wall system: in this particular system both the column beam frame type and structural walls are present. These two types of structural elements share the loads based on their relative stiffness of the element. The stiffness depends upon size and shape of the structure.

Structural wall systems with flat slab:this type of system mostly used for commercial building with large area. In this system the flats are adopted as area element and this flat slab directly rests on structural walls without beams. As we already know that structural wall is capable of flexure resistance, hence there is no need of beams.

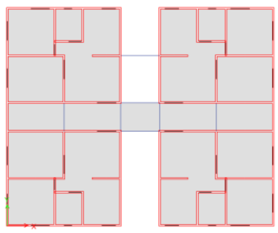
Core and out rigger structural wall system: in this particular system the central part consist of core structural wall and outer perimeter does not have walls and instead of walls the columns are adopted to carry gravity loads. These columns and core wall system are connected by beams called out triggers and the perimeter columns are called as outrigger columns. This type of system is mostly adopted for high rise buildings to get more stiffness against the lateral loads.

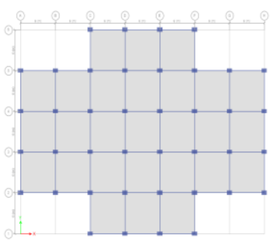
Core out trigger belt wall systems: This system is almost same as core out trigger structural wall system expect about the perimeter column connections. In this system the perimeter columns should not connect directly to core system it connects to adjacent column through deep beams and those adjacent columns will connect to core system. Those deep beams are also called as belt truss elements

Framed tube system: in this system the compression members (columns) are closely space by deep beams to get the tube like action in the inner area and the outer area also. This tube action increase the stiffness of the tall story building.

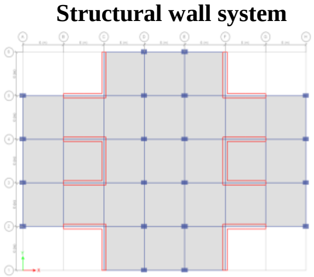
Tube in tube system:tube in tube structure is asme as the framed tube section but in inner area of building instead of closely space columns with deep beams there is a core wall system and the our areas is same as the framed tube system. This system is highly efficient to resist the lateral forces by providing the sifness in all the global direcions.

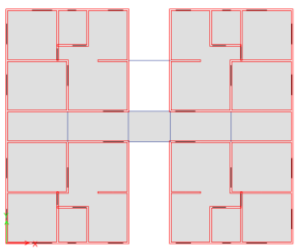
Out of these systems the structural wall system was adopted for this residential project because there is no much complexity in plan it is just like butterfly shaped architectural plan.



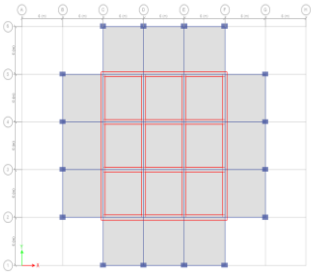


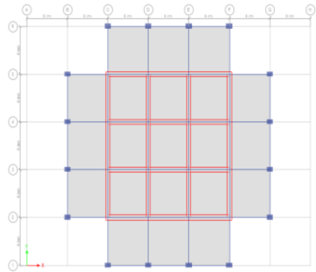
Structural wall system **Moment frame system**



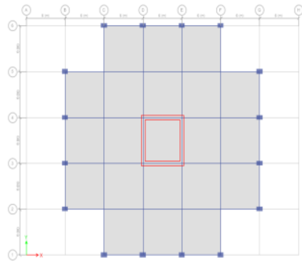


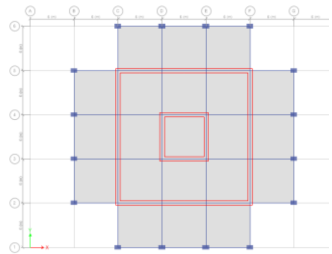
Moment frame along withStructural wall system
Structural wall systems with flat slab





Core and out rigger structural wall system Core out trigger belt wall systems





Framed tube system **Tube in tube system**

Now days the structural engineering are facing issues with the design and analysis of the multi-story and tall story building. In tall story building there is a lot of calculations involved in it due to the involvement of earth quake analysis and wind analysis apart from that now a days the clients want to build the high-rise building even in small area due to land crises and economy. This leads to building acts as a slender building which causes the torsion on the building due to horizontal forces.

The irregularities in the shape of the building also causes the torsion on the building, architects don't concern about type forces and stability about he the building they simply look about the pace and aesthetic view. Due to this type of mind set the building will face the torsion irregularity, and mass eccentricity and eccentricity in stiffness.

Due to these structural irregularities most of the designers adopts the structural wall systems and Core and out rigger structural wall system. In general in any concrete structures the basic structural elements are slabs, beams, column, foundation system but in structural wall systems the columns are replace by structural wall. Walls alone acts as compressing members and resist some amount of out of plane forces also not like column.

II. Complexities in Analysis

Even the structure is small the complexities present in the model or structure make the analysis vulnerable. Those complexities in analysis is listed below,

- Geometric complexity
- Code base complexity
- Structural fundamental complexity
- Complexity occur due to combination of all above

A.Geometric complexity: Now days the engineers and architectures and property owners want to make the structure as the iconic symbol for that are for that purpose ther want to design the building in any article shape or in any special shapes makes the structure geometry in complex, which causes the torsion in the entire structure. Some of them are slender buildings, oval shape structures, butterfly plan structures, wrench shape plan structures etc.

B.Code base complexity : in indianhighrise building code IS:16700-2017the modification factors that given may not practical, when we compare with the FEMA-461, and UBC-37. The modification factors from Indian code is mentioned below and modified modification factors also mentioned separately.

Modified values of modification factors:

[1] Sl.no	[2] elements	[3] Un-Factored loads		[4] Factored loads	
[5]	[6]	[7] AREA	[8] M.O.I	[9] AREA	[10] M.O.I
[11] 1	[12] slab	[13] 1.0	[14] 0.35	[15] 1.0	[16] 0.25
[17] 2	[18] beam	[19] 1.0	[20] 0.5	[21] 1.0	[22] 0.35
[23] 3	[24] column	[25] 1.0	[26] 1.0	[27] 1.0	[28] 0.7
[29] 4	[30] wall	[31] 1.0	[32] 1.0	[33] 1.0	[34] 0.7

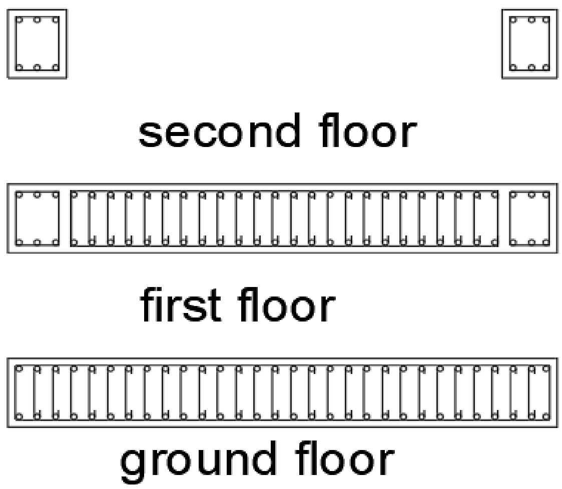
NOTE: Un-factored loads are used for serviceability criteria and Factored loads are used for strength design criteria.

2.1IDEALIZATION OF SHEAR WALL: Idealization of shear wall in the name itself it indicates the classification of the shear wall, the classification is about the reinforcement placing based on the different parameters like element idealisation, forces and moments.

Idealization is classified as below:

1. Object based
2. Flexure based
3. Shear based

2.1.1.Object Based Idealization: this condition arises when the bottom floors needs the structural wall and when the floors go up the loads gets decrease due to that the sizes of members get decrease along with loads. This will make that the structural wall is no more necessary at that time the columns are adopted in place of shear wall. But the thing about this is reinforcement placing plays a great role and for that up to bottom stories the reinforcement will arranged normally and when coming to upper floor the rebar's that are not necessary for column will be stooped at that particular floor and the rebar that require for column. This simply termed as object based idealization of shear wall.

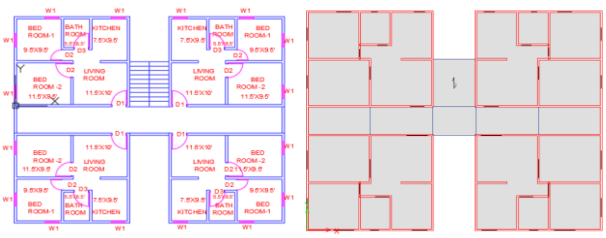


Object Based Idealizations

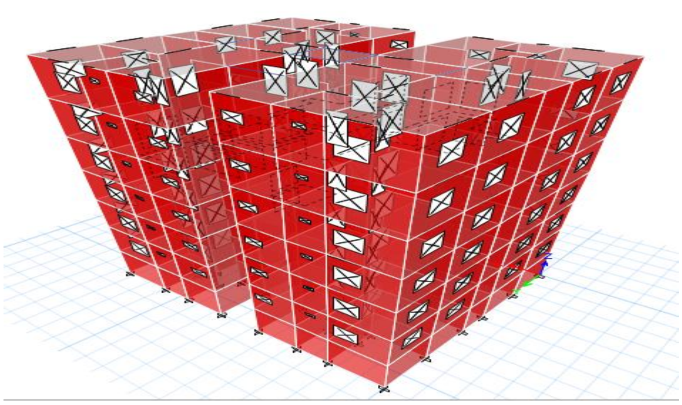
2.1.2.Flexure Based Idealization: when the shear wall is to resist the axial load along with the higher moment values. For that the bending places a major role in structural wall system design. This is helped by arranging the rebar's in the both the direction to prevent flexure. In general the out of plane shear may not primary force in structural wall, but in some cases it plays a major role.

2.1.3.Shear Based Idealization: when the shear wall is to resist the axial load along with the higher shear values. For that the shear in out of plane direction places a major role in structural wall system design. This is helped by arranging the rebar's in the both the direction to prevent flexure an shear. In general the out of plane shear is primary force in structural wall, but in some cases along with moment shear plays a major role.

III. Analysis and Design



ARCHITECTURAL PLAN STRUCTURAL PLAN



3D VIEW

PROJECT INFORMATION

Location -Rajahmundry
Type - Residential
Floors - G+6storeys
Structural floors - 7
Analysis Software – ETABS
Analysis Software - SAFE
Detailing Software – STAAD RCDC
Drafting Software – AUTO CAD

SOFTWARE INPUT DATA:
SLAB:

1. Slab 125 mm thick - For Habitual Floors
2. Slab 200 mm thick – For Staircase
3. Slab 200 mm thick – For Water Tank

SHEAR WALL:

Thickness:100mm

SECTIONS USED FOR FRAMING THE STRUCTURE

1. BEAM -230mmX400 mm
2. COLUMN - N/A
3. SHEAR WALL - 100 mm

MARETIALS USED:

1. CONCRETE – M35
2. STEEL- HYSD 500

3.3 LOADS:

[35] SL.NO	[36] SLAB TYPE	[37] DEAD LOAD(kN/ m^2)	[38] LIVE LOAD(kN/m^2)
[39] 1	[40] Habitual slab	[41] 1.5	[42] 2
[43] 2	[44] Stair case	[45] 3	[46] 3
[47] 4	[48] washroom	[49] 3	[50] 2
[51] 5	[52] Terrace	[53] 3	[54] 1.5
[55] 6	[56] Water tank	[57] 18.67	[58] 0.75
[59] 7	[60] Lift machine room	[61] 18	[62] 0.75
[63] 8	[64] parking	[65] 0.5	[66] 4
[67] 9	[68] Lobby	[69] 1.5	[70] 3

3.4 EARTHQUAKE ANALYSIS

Location = Rajahmundry

Earthquake load zone = III (IS 1893-2002 Part 1 Fig. 1 seismic zone of India)
&
(IS 1893-2002 part 1 annex E)

Zone Factor = 0.16(1893-2002 Part 1 Clause 6.4.2 Table 3)
Time Period = Ta (As per 1893-2002 part 1 clause 7.6.2)
Considering building with infilled wall,

At X direction $= 0.09h/\sqrt{d}$
$= 0.09 \times 21/ \sqrt{17.1663}$
= 0.456 Sec

At Y Direction $= 0.09h/\sqrt{d}$
$= 0.09 \times 21 / \sqrt{14.0208}$
= 0.504 Sec

Importance Factor = 1(As per 1893-2002 part 1 clause 7.2.3 Table 8)

Response Reduction Factor= 4(As per 1893-2002 part 1 clause 7.2.6 table 9),

$\mathbf{Q_i = V_b \times W_i h_i^2 / \sum(Wihi)^2}$ (As per 1893-2002 part 1 clause 7.6.3)

Where,

Q_i = Design lateral force at floor
W_i = Seismic weight of floor
Hi = Height of floor i measured from baseFor Designing of structure considered Dynamic Analysis.

$\mathbf{Vb = A_h.W,}$

Where,

Ah = Design horizontal acceleration spectrum value as per using the fundamental Natural period Time period
W = Seismic weight of the building

Design Acceleration Spectrum$\mathbf{A_h = Z/2 \times I/R \times Sa/g}$, (As per 1893-2002 part 1 clause 6.4.2)
The spectral acceleration coefficient Sa/g for he site type II and particular time period from the graph of IS:1893-2002 can adopt directly or it can calculate by using

$$\frac{Sa}{g} = 1+15T$$

From the graph it is adopted as Sa/g=1 and the base shear Vb is calculated by using above formulas.

Direction	Period Used (sec)	W (kN)	V_b (kN)
X	0.456	17676.8261	883.8413
X + Ecc. Y	0.456	17676.8261	883.8413
X - Ecc. Y	0.456	17676.8261	883.8413

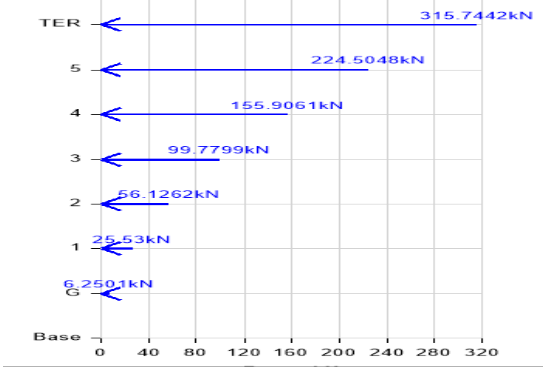
Direction	Period Used (sec)	W (kN)	V_b (kN)
Y	0.505	17676.8261	883.8413
Y + Ecc. X	0.505	17676.8261	883.8413
Y - Ecc. X	0.505	17676.8261	883.8413

In the calculation of the V_b the mass of the each stories required those are shown in below table

Table 1.11 - Mass Summary by Story

Story	UX kg	UY kg	UZ kg
TER	263851.7	263851.7	0
5	255354.67	255354.67	0
4	255354.67	255354.67	0
3	255354.67	255354.67	0
2	255354.67	255354.67	0
1	261342.99	261342.99	0
G	255921.19	255921.19	0
Base	11030.48	11030.48	0

In direction X the lateral loads are calculated and made a pictorial representation and also tabulated the same

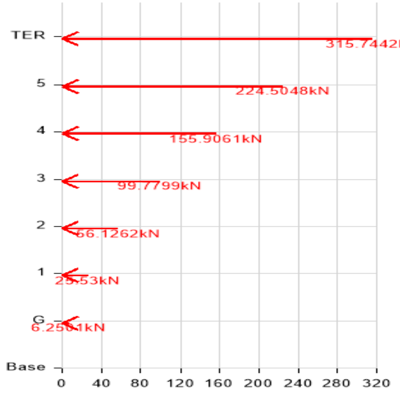


Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
TER	21	315.7442	0
5	18	224.5048	0
4	15	155.9061	0
3	12	99.7799	0
2	9	56.1262	0
1	6	25.53	0
G	3	6.2501	0
Base	0	0	0

Lateral load on the structure due to EQ-X

In direction Y the lateral loads are calculated and made a pictorial representation and also tabulated the same

Story vies wind forces values:



Story	Elevation	X-Dir	Y-Dir
	m	kN	kN
TER	21	0	315.7442
5	18	0	224.5048
4	15	0	155.9061
3	12	0	99.7799
2	9	0	56.1262
1	6	0	25.53
G	3	0	6.2501
Base	0	0	0

Lateral load on the structure due to EQ-Y

WIND LOAD CALCULATIONS:

Wind loads will be calculated in accordance with IS 875 2015 : Part 3.

Design wind speed V_z = V_b x K_1 x K_2x K_3

V_b= Basic wind velocity for Rajahmundry

= 50 m/s (As per IS 875 2015 part 3 clause 6.2 anex A)

k1=Risk coefficient for a design life of 50 years= 1.00 (As per IS 875 2015 part 3 clause 6.3.1 table 1 (General building)

K2= 1.00 (As per 875 2015 part 3 clause 6.3.2 table 2)

k3= 1.0 (As per Is 875 2015part 1 per 3 clause 6.3.3)

Vz= 50 x 1.00 x 1.0 x 1

= 50 m/sec

Design wind pressure (P_z) = 0.6 x Vz^2

P_z= 0.6 x 50^2

=1500 N/m^2

= 1.50 kN/m^2

LEVEL	HEIGHT	VB	K1	K3	K2	VZ	0.6VZ^2	AX	FX	AY	FY
TER	18	50	1	1	0.964	48.2	1393.944	21.312	29.70773	25.74945	35.89329
5	15	50	1	1	0.94	47	1325.4	42.624	56.49385	51.4989	68.25664
4	12	50	1	1	0.904	45.2	1225.824	42.624	52.24952	51.4989	63.12859
3	9	50	1	1	0.88	44	1161.6	42.624	49.51204	51.4989	59.82112
2	6	50	1	1	0.88	44	1161.6	42.624	49.51204	51.4989	59.82112
1	3	50	1	1	0.88	44	1161.6	42.624	49.51204	51.4989	59.82112
G	0	50	1	1	0.88	44	1161.6	21.312	24.75602	25.74945	29.91056

Coefficients of winds are calculated on the basis of IS 875 recommendations, the values of Height and width and length. The H/L, L/W are calculated and the pressure coefficients are observed from the tables which is given below

Windward coefficient In x direction = 0.7
In y direction = 0.7

Leeward coefficientIn x direction= 0.25
In y direction = 0.25

IV. RESULT AND DISCUSSION

Stability checks:

1. Static base shear in x, y direction should equal to respective direction Dynamic base shear

Static base shear in x direction EX= 883.841
Static base shear in y direction EY= 883.841
Dynamic base shear in x direction SPECX= 883.84
Dynamic base shear in Y direction SPECY= 883.84

2. Inter story drift ratio should be less than 0.004 x height of floor(As per 1893 2016 part 1 clause 7.11.1.1)
SPEC X = 0.00003801<**0.012**
SPEC Y= 0.000025<**0.012**
The SPEC X,SPEC Y <**0.004 x 3=0.012 (Allowable)**……………Safe

3. Maximum deflection allowed against wind is H/500(As per IS 456 -2000 clause 20.5)
Wx = 0.22mm
Wy= 0.22 mm
W0, W90<H /500=(18X 1000) / 500 = 36 mm…………..Safe

4. Maximum allowed deflection against earthquake is H/250 (As per IS 1893 2016 part 1)
SPEC X = 0.65 mm,
SPEC Y = 0.44mm,
SPEC X,SPEC Y <**H/250= (21x1000) / 250 =84mm**…………… Safe

5. Maximum deflection against cantilever or any individual element allowed (As per IS 456-2000 clause 23.2)
span/350 or 20mm (After occupancy)
Span /350 **=3000/ 350 = 8.57mm (allowable)**
Deflection in slab – axial in column = 0.796-0.482= 0.314**8.57mm**……………..Safe

6. Guide line for fundamental time period = 0.1Xnumber of floors = 0.1X6 =0.6

Time period observed is 0.159 secs <0.6 ……..SAFE

7. First mode of vibration is performed to be translation mode As per 1893 2016 part 1

U_X = 69.93(TRASLATION), R_Z=0.0001, (0% ROTATION)
8. Sum of modal mass participation in 3RD mode should be more than 65 %
Sum Ux = 69.93 % , Sum Uy = 72.62 %, Sum Rz = 77.86 %

9. No. of modes given should be in such a way that around 85% to 98% modal participating mass ratio shall be achieved.

10. As the deflection of slab is 0.34 mm it should check against the long term deflection , creep deflection by changing the parameters to material nonlinearity for the span of the structure 100 years.

As per is code the max creep coefficient for 1 year is 2.2 for higher serviceability it is adopted as 3.

The creep deflection =3x deflection of slab
=3x0.34
=1.02mm
Therefore the long term deflection value is 1.02mm < allowable value 8.57mm. so the long term deflection also lesser than allowable value so there is no need for creep analysis separately.

Substructure results:
11.Settlement: (load combo-D+L)

- allowable settlement as per geotechnical report=25mm
- Observed value is=20.94 mm <25 mm ……safe against settlement.

12.Soil pressure: (load combo-D+L)
Allowable soil pressure as per geotechnical report=200KN/M^2
observed value =84KN/M^2< 200KN/M^2 ….safe
13.Shear stress: (load combo-SERVICE ENVELOPE)
In the direction of S13:
Allowable shear stress= $K_s\,\tau_c$
$K_s\,\tau_c$=0.9465 X 0.549212= **0.519828**N/mm^2
Ks=0.5+β=0.5+0.049212=0.549212
β=SHORTER DIMENION /LONGER DIMENSION= 150/3048=0.049212
$\tau_c=0.1\sqrt{fck}6=0.16\sqrt{35}$ =0.16 X5.916 =0.9465 N/mm^2
Observed value=0.42N/mm^2<**0.519828**N/mm^2 …..SAFE

In the direction of S23: (load combo-SERVICE ENVELOPE)
Allowable shear stress= $K_s \tau_c$
$K_s \tau_c$=0.9465 X 0.66149 = **0.62610 N/mm^2**
Ks=0.5+0.5+0.16149=0.66149
β=SHORTER DIMENION /LONGER DIMENSION= 150/928.8=0.16149
$\tau_c=0.16\sqrt{fck}=0.16\sqrt{35}$ =0.16 X5.916 =0.9465N/mm^2
observed value=0.281N/mm^2<**0.62610 N/mm^2**
……SAFE
14.FLOATATION CHECK: (load combo-0.9D+1.4W)
MAX VALUE= -2.77
MIN VALUE=-5.91 …Hence no uplift
15.CRACK WIDTH OBSERVED =0.2mm

V. CONCLUSION

After designing the structure with the structural wall (shear wall technology), the observations are made that the structure is more reliable and more strong to the self-weight and imposed load along with the lateral loads. It clearly observed that structure with moment frames are having less stiffness than compared to structural wall systems and those moment frame structures are more prone to collapse at the time of earthquake event.

- Inter story drift ratio is much lesser than allowable value due to usage of structural wall system.
- Due to structural wall system the lateral stiffness of the structure got increased and the deflections due to wind forces are observed below 1mm.
- Due to structural wall system the lateral stiffness of the structure got increased and the deflections due to earth quake forces are observed below 1mm.
- The deflection of the slab and beam elements is observed below 1mm.
- Natural frequency and time period of the structure is within the range.
- The translation and rotation requirements for different odes as per IS:1893-2016 code recommendations are achieved
- The deflection of the slab and beam elements for long term creep is observed as1mm.
- The deflection of the slab and beam elements for serviceability criteria is observed below 1mm.
- In serviceability design the Inter story drift ratio is much lesser than allowable value due to usage of structural wall system.
- Due to structural wall system the lateral stiffness of the structure got increased and the deflections due to earth quake forces are observed below 1mm even in serviceabilty checks.
- The settlement of raft foundation adopted is 20mm which is below than the allowable limit 25mm.
- The soil pressure is below 80 KN/M^2, Where allowable is 100 KN/M^2.
- No uplift is observed.
- Shear stress at the shear wall faces are wit in the limits and are less than **$K_s\tau_c$.**
- All members are designed as per limit state of collapse and limit state of serviceability and designed based on the ductilr detailing with the response reduction factor 4.

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