Comparative Study of Super-Structure Stability Systems for Economic Considerations

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Abstract - *The scope of the study includes analysis and design and comparison of waffle slab, flat slab and conventional slab system. Design of the slab systems are done for different spacing/ grid size of column to find out which grid size of the column spacing or plan area, which slab type is economical. The plan includes 36x36m in which variation of column spacing 6x6m, 9x9m, 12x12m and vertical variations are 10 story with each storey height being 3.5m for each system. Code referral basis are IS 456:2000 and IS 875, 1893:2000. Material overuse could be usually done if the sections and rebar quantity provided is in excess, that is either by over reinforcing or excess cross sectional area of elements. Hence to optimize the same, a comparative study of structural analysis for the above mentioned grid spacing is carried out (Limit State), and ultimately the best economical system is found out leading to less consumption of construction materials (10 percent wastage included).*

***Key Words*: Structural systems, Flat slab, Waffle slab, Comparision, Costing**

1. INTRODUCTION

Civil engineering has various branches among which structural engineering is a branch related to buildings whose elements are subjected to a bending moment, shear force, vertical, horizontal displacements, axial and shear forces. Analysis of such parameters can be done manually as well but since its a complex task, we rely on software such as ETABS, STAAD PRO, SAFE and many more. Among various softwares used for analysis we have used ETABS and SAFE. ETABS is used for the frame analysis for various cross sections of columns and beams and to find out the resulting shear, torsion, bending moment, deflection of the frame and slab and for the design of the same. In real life commercial construction, client with a property consults the architectural consultancy which further recommends or uses its in-house experts for the respective nature of jobs. Our scope comes under structural part, the available property area is 36x36m, hypothetically, for the purpose of this project.

2. Literature Review:

K.N. MATE (June 2015) studied about the benefits of flat slab construction, its ease of getting constructed, placing of formwork and workmanship. This comprehensive study helps us understand the selection of drop panel, sectional sizes, width of panel and detailing of reinforcement. His analysis was done in accordance to IS 456:2000.

D.RAMYA (October 2015) studied the differences in analysis and design of softwares such as STAAD PRO and ETABS. It was found that the reinforcement quantity provided by ETABS was 9.25% less than STAAD PRO hence leading to cheaper construction costs. She had analyzed a G+10 story building for the same.

3. METHODOLOGY

Manual calculations for selection of sections:-

Manual calculations for approximation of sections of members of all three structural systems such as calculations for beam design, column design, membrane slab design, column width drop, stiff slab and punching shear check for the systems were performed.

Modelling, Analysis and Design using ETABS AND SAFE:-

Definition of materials, frame sections, assigning load cases and combinations for the define d load patterns of live load = 3 KN/m

And super imposed load of 2.5 KN/m

Modelling of the sectional members is done and loads are assigned to the structure.

In our case the earthquake zone is taken as in Bangalore's which is zone II and winds speed of Bangalore as 33 m/s is considered according to IS19893 :Part 3and 4. Structure is analyzed after assigning of base restraints as fixed and deformations are checked. Limitations of deformations are checked for span/350 or 20mm whichever is less. Exceeding of limitation of any of the deformation demands to iterate the definition of sections design checks of sections is performed and results are checked for failures. Columns are sometimes subjected to over stress due to PMM ratio and reinforcement required exceeds the reinforcements provided. Beams can be subjected to shear or torsional failure. In all such cases member sections are redefined. The sections are checked for rebar percentages and preferences of bar diameters are given.

Slab modelling, design and analysis is done in SAFE. Slab sections are checked for excessive deformations and failures due to excessive moments. In flat slab and waffle slab design moments along column and middle strip and along the drop are checked and accordingly required rebar area are provided.

4. Comparison:

After the modelling and analysis is done, the models are checked and comparison of intra-system for centre to centre column spacing of 6x6 m, 9x9 m and 12x12 m is done.
The best economical intra-system is nominated for inter system comparison to find most economical system, taking into consideration all three systems.

5. Calculations:

Weight of concrete of all the elements segregated according to concrete grade of M30 and M40.
Where, M40 is used for columns .
M30 is used for beam and slab.
Total volume of concrete = Mass of concrete in Kg/2400 Kg/m^3 .
Weights are obtained in KN to convert it into Kg,
1KN = 101.9 Kg.
Permissible deflection for Flexural members = Span/ 350 or 20 mm (whichever is less).
In our case deflection only for 6x6 m c/c column spacing goes less than 20mm i.e 17.14mm.

For Earthquake load: Calculated as per IS-1893 (part 1): 2002

Seismic Definition

Earthquake zone – III (Z=0.36)
Response reduction factor – 5
Importance Factor – 1 (Very Important Building)
Rock and Soil Site Factor- 2 (Medium Soil)
Type of Structure- 1
Damping - 5% (0.05)
Soil Type: Medium soil
Natural Time Period (T_a) - $0.075h_{0.75}$ (T_a = 0.73199 sec)

Sl.no	Item description	Rate
1.	**CONCRETE**	
1.1	M30	Rs. 4,200/- PER CUM
1.2	M40	Rs. 4,800/- PER CUM
2.	**STEEL FE - 415**	Rs. 55,000/- PER TONNE

5.1 Design calculations

(for selection of trial cross sections):

1. Design of flat slab(w/drop):

Depth= l/d = 26 x MF (ref IS456 Pg 38)

Consider pt %=4%

*Depth d= 177.51 mm.

Over all depth= 200 mm.

d= 200- 1/2 -30

D=165 mm.

W=15.75.

Load Calculations :-

Self wt. Of Slab = t x 25 =0.2 x 25 = 5.

Floor finish =2.5

Dead load = 7.5 KN/m.

Live Load = 3 KN/m.

Total Dead Load = 10.5 x 1.4 =15.75 KN/m.

Stiffness for slab:-

Longer span

For slab = Ks = 4EI/L = 4 x E x ((6000 x200^3)/(6000x12)) = 2.6x10^6.

For column = Kl = 4EI/L = 4 x E x ((400 x 400^3)/(6000x12)) = 2.4380x10^6.

α_c=1.066

Shorter Span

Ks = 4EI/L = same

Kc = Same

LL/DL = 3/7.5 = 0.1 <= 0.5

No need of pattern load check

Total design Moment

M_0 = wln^2 =(w x l x ln^2)/l = 425.160

REBAR AREA:

	-ve (depth= 162mm) (MS)	+ve(d= 162mm) (CS)	-ve(d= 162mm) (MS)	+ve(d=1 62mm)(CS)
moment	0.75 x 0.65 x M_0 = 231.64	0.35 x 0.60 x M_0 = 99.78	0.65 x M_0 = 77.217	0.35 x M_0 = 66.528
Pt(%)	0.556	0.57	0.433	0.37
Area(mm)	2780	1846.8	1402.92	1199.26

CHECK FOR 2 WAY SHEAR:

d/2 = 250/2 = 125

B_0 = 550 x 4 = 2200mm

Vu = $(6^2 - 0.55^2)$x 19.5.5

Vu = 696.10 KN

Ʈv = Vu/b_0 d = 1.2656 N/mm

FLAT SLAB DESIGN: **(6 x 6 m)**

Drop = 250mm thick

Falt slab = 200 mm thick

Column = 300 x 300

Loads Calculations: DL = 0.2 x 25 = 5 kN/m

LL = 3kN/M

SDL = 2.5 kN/M

TDL = 7.5 kN/M

Depth of slab = 200 mm = D

d = 162 mm

Stiffness(LS = SS)

K_s = 4EI/L

K_S = $(4 \times E \times 6000 \times 200^3)/ 6000 \times 12 = 9 \times 10^6$

K_c = 4EI/L =$(4 \times E \times 400 \times 400^3)/ 12 \times 6000$

K_c = 4EI/L = 1.42×10^6

αc = 0.157

LL/DC = 3/7.5 = 0.4 <= 0.5

Therefore there is no need for pattern load check.

Ʈc' = k_s x Ʈc

K_s = o.5 + 300/300

K_s = 1.5 > 1.0

If $k_s > 1$

Consider $k_s = 1$

Ʈc =0.25$\sqrt{f_ck}$ = 0.25$\sqrt{30}$ = 7.5 N/mm^2

Ʈv < Ʈc

No shear reinforcement required.

BEAM DESIGN OF 9x9m CONVENTIONAL SLAB:

Mu = Mulim + M_2

M_2 = Mu - Mulim

Mulim = 0.36fck x Xumax x b x (d - 0.42Xu) …………… tension steel

M_2 = 0.87fy x Ast_2 x $(d - d^1)$ ………………… tension steel

M_2 = (fsc - fcc) x Asc x (d - d') …………… Compaction steel

Xu/d = 0.48

Xumax = 0.48 x d

Xumax = 0.48 x 600 = 288 mm

1) Mu = 196 KN

Mulim = 0.36fck x Xumax x b x (d - 0.42Xu)

= 0.36 x 30 x 288 x 300 x (600 - 0.42 x 288)

Mulim = 447 KNm

Mu = Mulim + M_2

M_2 = 447 - 196

= 251 KNm

M_2 = 0.87fy x Ast_2 x $(d - d^1)$

251 = 0.87 x 415 x Ast_2 x (600 - 30)

Ast_2 = 1219.639 mm^2

M_2 = (fsc - fcc) x Asc x (d - d^1)

251 = (355 - 13.5) x Asc x (600 - 30)

Asc = 1289.46 mm^2

C =T

0.36 fck Xub =0.87 fyAst

Ast1= (0.36 x 30 x 288 x300)/(0.87 x 415)

Ast1 = 2584.46. mm^2

Tension steel = Ast1+ Ast2 = 2584.46 +1219.639

Tension stell = 3804.10 mm^2

Compression steel =1289.46 mm^2

Shear Reinforcement :-

W = Self wt. Of slab acting on beam =45 +45. (two tributaries)

LL = 3 KN/m

SDL =2.5 KN/m

Self wt. Of beam =4.5 KN/m

Total wt =102.5 KN/m x 1.5 =153.75 KN/m

Vu = wl/2 =(153.75 x 6)/2= 461.25 KN.

Critical section occurs at 'd' from support:-

* 461.25 /3 = Vuc/(3 - 0.6)

Vuc =369 KN

Pt % =(Ast x 100)/bd =2011% for M30,

Ast 100/ bdτc

By interpolation,

2.0 0.84

2.110.8576

2.25 0.88

sDesign Shear Strength = Ʈc =0.8576 N/mm^2

Design Shear force = Vus =Vuc -Ʈc bd

=369 -(0.85 x300 x600x10^3)

Vus = 216 KN.

Vu =0.87fy Asv sinα

Vus = 0.87 x415 x628.31 x sin 45°

Vus =329 KN.

Shear force resisted by bent up bars = 329/ 2

Shear force resisted by stirrups = 329 - 164 = 164 KN.

*Shear force resisted by stirrups=

Vus =σ sv x (Asv/Sv)x d

=0.87 fy Asv d/Sv

164 x 10^3 = 0.87 x 415 x 2 x π/4 x 8^2 x 600 /Sv

Sv= 132 mm.

Minimum spacing =126.515

1) 0.7 d= 450

2) 300

3) Sv =132mm (considered)

Provide 132 mm 2 legged c/c 18mm ϕ bars.

Slab design (membrane):-

ly/ lx = 6/6 = 1<2

*Two way slab

1) Depth of slab = l/d =26

d= l/(26 x MF)

*d = 9000/ 26 x 1.5 =153.85/230

Taken 200mm thick

l = 25 mm

d =200 + 25 =225 mm

2) Eff. Span

l_{ff}= lx + depth =9200 mm

3) Load calculation

DL=0.225 x 25

DL = 5.625 KN / m^2

LL = 3 KN/m^2

SDL =2.5 KN/m^2

Total load =11.125 KN/m x 1.5 =16.6875 KN/n

$Mx = \alpha_x wlx^2$

$My = \alpha_y wlx^2$

For l_y / l_x, $\alpha_x = 0.062$

$\alpha_y = 0.062$

$M_x = 0.062 \times 16.7 \times 9000^2 = 83.86$ KNm

$M_y = 0.062 \times 16.7 \times 9000^2 = 83.86$ KNm

Check for depth :-

$M_d = 83.86$ KNm

$M_d = 0.36fck \times Xumax \times b \times (d - 0.42Xumax)$

$83.86 \times 10^6 = 0.36 \times 30 \times 0.48d \times 1000 \times (d - 0.42 \times 0.48 \times d)$

$= 5104d - 1045.0944d$

$= 4138.9d$

d = 202.613 < 225mm

Calculation of steel :-

$Ast_x - 0.5fck/fy\ [\ 1 - \sqrt{(1 - 4.6)/(fck \times b \times d^2)}\ ] \times b \times d$

$Ast_y = 1274.216\ mm^2$

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Spacing = (Area of 1 bar x 1000)/ Ast req.

$= [(\pi/4) \times 16^2 \times 1000]/1274.216$

$= 157 \approx 150$ mm

Provide 16mm dia bars @ 150mm c/c

COLUMN DESIGN:

Pu = 0.45 fck Ac + 0.67 fy Asc

Axial load Pu = 13427 KN

Axial load includes self weight of all the corner beams and slabs, Live load pof 3 KN and SDL of 2.5KN,on each floor.

Ag = Asc + Ac

Assume pt % = 5%

Therefore Asc = 0.05 Ac

$13427 \times 10^3 = 0.45 \times 40 \times Ac + 0.67 \times 415 \times 0.05 \times Ac$

Therefore Ac= 421220.814 mm^2

Size of a square column comes up to 650mm,

Since we are adopting minimum reinforcement and increasing the colum,n area for compensation, size of column to be adopted is 900x900mm.

Hence, Asc = 0.05 Ac

= 0.05 x 421220.814

Asc = 21229.52903 mm^2

Table -1:Cost considerations of concrete

Section (Info arrangement according to below mentioned sequence) Row 1.Flat slab 6x6m Row 2.Conventional Slab 9x9m Row 3.Waffle slab 6x6m	Pieces	Total weight	?
Perimeter Beam 250x500 M30 Column 600x600 m40 Column 800x800mm Column 1200x1200mm M40 Column 1000x1000mm Column 1500x1500mm Flat Slab Drop Total	292 240 98 48 4 48	6385.6144 5983.2332 2143.1172 671.8016 55.9835 671.8016 59742.3588 5623.3395 81277.2498	3.66E+08
Floor 2,3, 4 revised columns Beam 300x600 M30 Column 500x500 M40 Floor 800x800 mm middle columns Slab Membrane 200mm thk Total	21 400 149	3428.9875 15126.3334 3258.4128 1175.6528 64780.871 87770.2575	3.95E+08
Column 300x300 M40 Modified colums 400x400 story 1 Waffle Drop Total	480 10	34009.9573 314.907 30028.6329 10796.8118 75150.309	3.38E+08

Table -2 :Cost considerations of steel

BAR DIAMETER 1.Conventional Slab9x9m 2.Flatslab 6x6m 3.Waffle slab 6x6m	LENGHT(M)	WEIGHT (MTON)	?
10	108.82	0.07	3850
12	8325.96	7.39	406450
14	1495.64	.81	99550
16	4494.74	7.09	389950
18	2281.12	4.56	250800
TOTAL		20.92	1150600
20	7243.26	17.86	982300
22	56.2	0.17	9350
25	1918	7.93	436150
TOTAL		25.42	1398100
10	4705.14	2.9	159500
12	362.26	0.32	17600
14	378.84	0.46	25300
16	12145.56	19.17	1054350
18	351.08	0.7	38500
22	74.66	0.22	12100
TOTAL		23.77	1307350

Table -3:Total cost (Steel+Concrete)

Structural Systems	Concrete cost for 10 Storey (?)	Steel cost for 1 Storey (?)	Total cost (?)
Conventional Slab (9x9m)	36,57,44,044	11,50,600	36,68,94,644
Flat Slab (6x6m)	39,49,66,098	13,98,100	39,63,64,198
Waffle Slab (6x6m)	33,81,76,389	13,07,350	33,94,83,739

The one marked in grey is the cheapest.

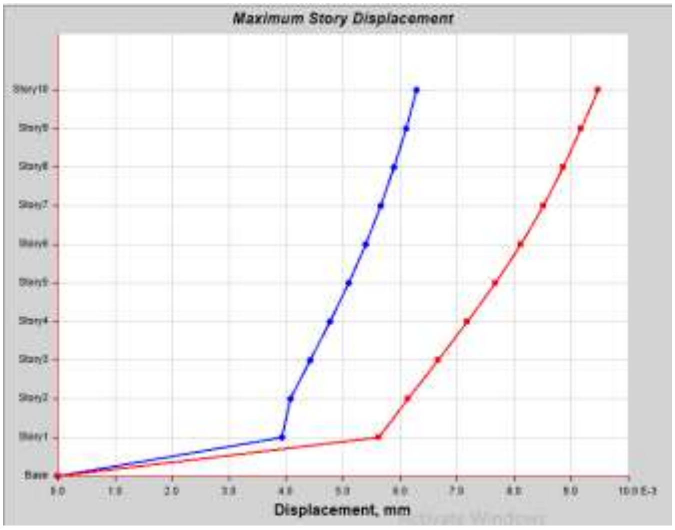

Chart -1: Storey displacement for Conventional Slab 9x9m..

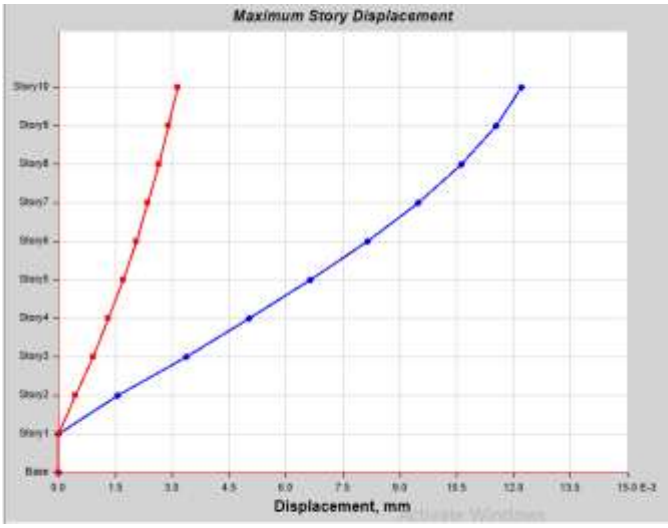

Chart -2: Storey displacement for Flat slab 6x6m.

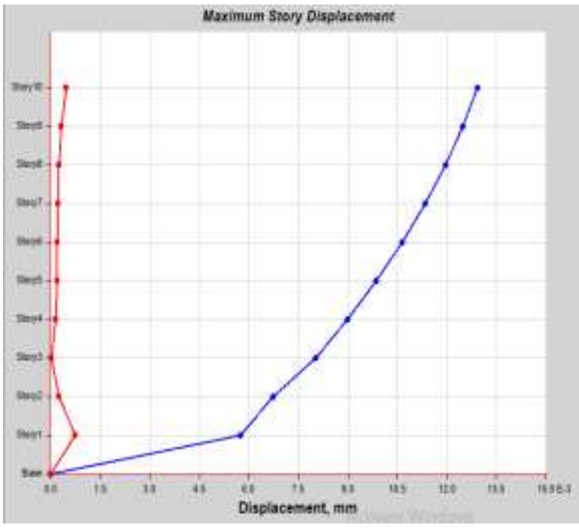

Chart -3: Storey displacement for Waffle slab 6x6m.

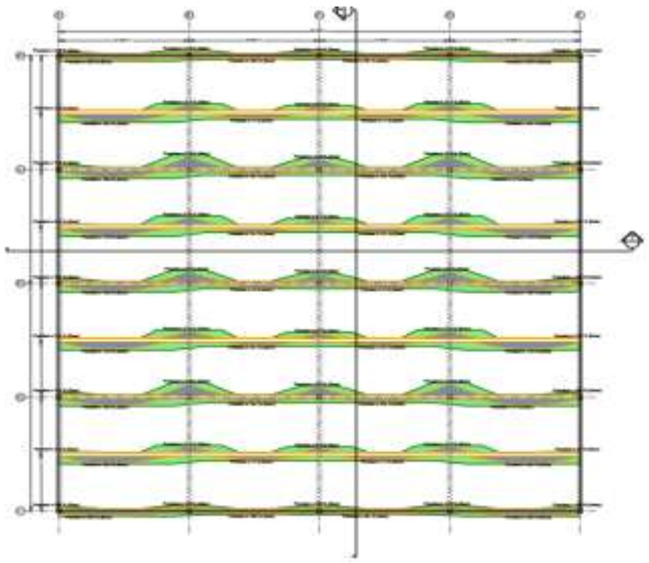

Fig -1: Reinforcement profile A for Conventional Slab 9x9m.

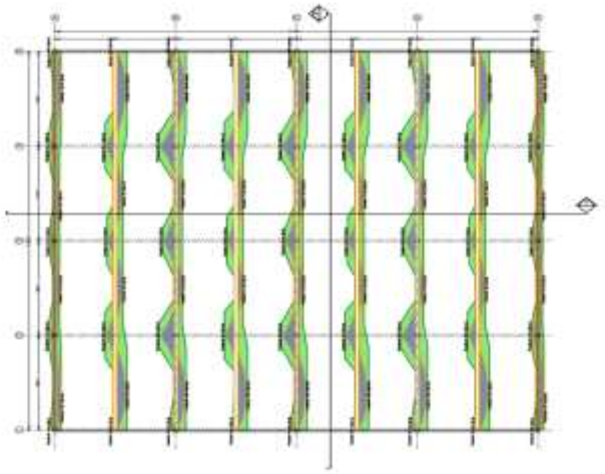

Fig -2: Reinforcement profile B for Conventional Slab 9x9m.

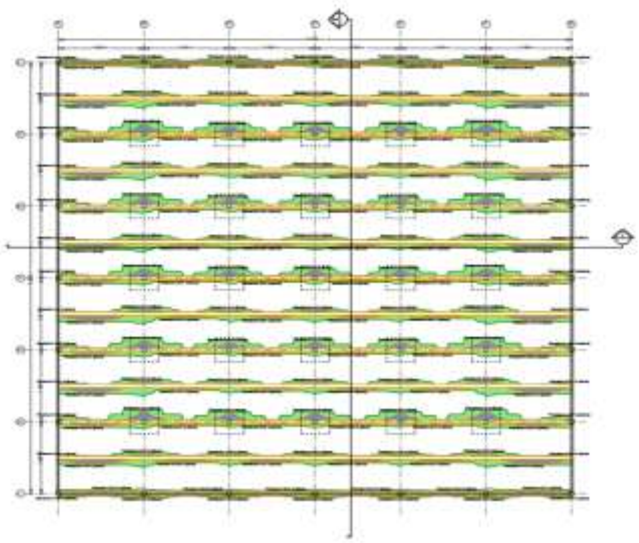

Fig -3: Reinforcement profile A for Flat Slab 6x6m.

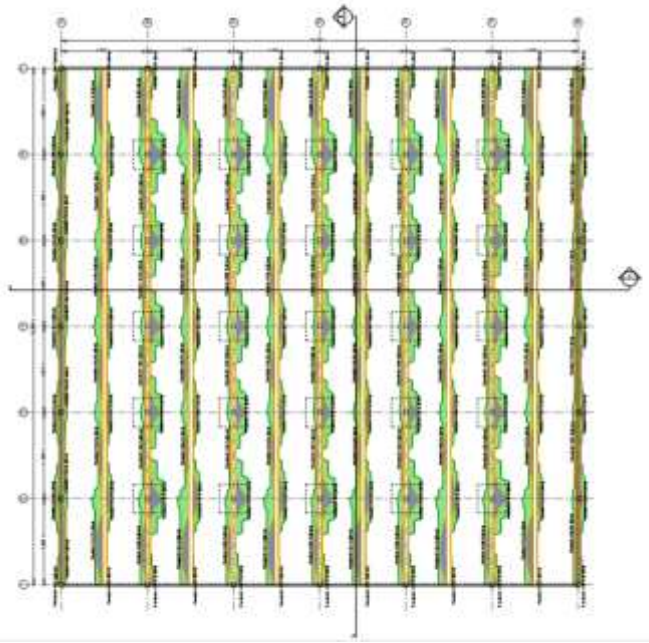

Fig -4: Reinforcement profile B for Flat Slab 6x6m.

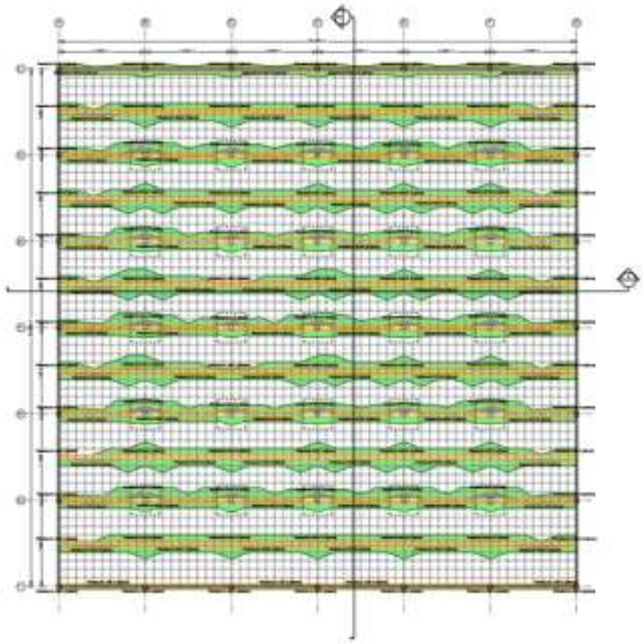

Fig -5: Reinforcement profile for Waffle Slab 6x6m.

As per clause 7.11.1 of IS 1893 (part-I):2002, the storey drift in any storey due to specified designed lateral force with partial load factor of 1.0, shall not exceed 0.004 times the storey height.Storey drifts are negligible for 10 storey as shown above for all three systems. The values so taken are from ETABS models. The reinforcement profiles are also mentioned below the storey drifts which mentioned the amount of reinforcements in positive and negative moment areas. The systems with 9x9m for spacing on conventional slab and 6x6m for flat and waffle slab are so selected based on comparison of least of concrete and steel quantity requirements.

6. CONCLUSIONS AND INFERENCES:

- Waffle slab method consumes the least amount of concrete since most of the concrete below the neutral axis is removed as it is found that concrete above the neutral axis takes considerable amount of compressive stress.
- The Waffle part which contains rebars act as equidistantly placed beams in a ribbed manner and the load bearing capacity of the slab increases prominently with the stiffness increasing over the entire span of slab.
- Cross sectional dimensions of the frame elements increase as the c/c spacing increases.
- Deflection is considerably reduced as the cross section of vertical frame elements are increased rather than horizontal.
- Beam and Slab system is more prone to deflection rather than the other two as the slab element comprises of membrane as opposed to shell thin in flat slab and waffle slab.
- The concrete pricing for 10 storey and steel pricing for 1 storey are mentioned below and an inference can be made that waffle slab 6 x 6 m comes out as the most economical structural system for a total span of 36 x 36 m plot.

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