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Analysis & Design of Multistoreyed Building with Light Weight Concrete

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ABSTRACT: Our main project title is “Analysis and Designing of Commercial Building with Light Weight Concrete”. Multi-storied buildings are indispensable in urban areas due to high cost of land, shortage of open space and scarcity of lands. Many times these multi storey buildings are built with regular concrete, steel and other materials where the loads are high and require heavy structures and cost may not be effective. The use of light weight concrete and light weight materials will reduce the dead load of a structure, which then allows the structural designer to reduce the size of the columns, footings, and other load bearing elements. Structural light weight concrete mixtures can be designed to achieve similar strengths as normal weight concrete.

First of all we took up a regular six floor commercial building that is being constructed in Hyderabad and collected data such as land area of proposed building, number of flats per floor and floors height as part of the projects. Then we developed the building frame model and analyzed and designed the structural elements such as columns, beams, slab and staircases by considering vertical loads.

I. INTRODUCTION

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailibility and lessened the dead weight.

Lightweight concrete maintains its large voids and not forming laitance layers or cement films when placed on the wall. This research was based on the performance of aerated lightweight concrete. However, sufficient water cement ratio is vital to produce adequate cohesion between cement and water. Insufficient water can cause lack of cohesion between particles, thus loss in strength of concrete. Likewise too much water can cause cement to run off aggregate to form laitance layers, subsequently weakens in strength.

This report is prepared to show the activities and progress of the lightweight concrete use. The performance of aerated lightweight concrete such as compressive strength tests, water absorption and density and supplementary tests and comparisons were made with other types of lightweight concrete.

Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as nailibility and lessened the dead weight. It is lighter than the conventional concrete with a dry density of 300 kg/m³ up to 1840 kg/m³; 87 to 23% lighter. It was first introduced by the Romans in the second century where ‘The Pantheon’ has been constructed using pumice, the most common type of aggregate used in that particular year. From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom and Sweden.

The main specialties of lightweight concrete are its low density and thermal conductivity. Its advantages are that there is a reduction of dead load, faster building rates in construction and lower haulage and handling costs. The building of ‘The Pantheon’ of lightweight concrete material is still standing eminently in Rome until now for about 18 centuries as shown in Figure 1. It shows that the lighter materials can be used in concrete construction and has an economical advantage.

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Fig 1: The Pantheon

LIGHTWEIGHT AGGREGATE CONCRETE

Porous lightweight aggregate of low specific gravity is used in this lightweight concrete instead of ordinary concrete. The lightweight aggregate can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate. The main characteristic of this lightweight aggregate is its high porosity which results in a low specific gravity. The lightweight aggregate concrete can be divided into two types according to its application. One is partially compacted lightweight aggregate concrete and the other is the structural lightweight aggregate concrete. The partially compacted lightweight aggregate concrete is mainly used for two purposes that is for precast concrete blocks or panels and cast in-situ roofs and walls. The main requirement for this type of concrete is that it should have adequate strength and a low density to obtain the best thermal insulation and a low drying shrinkage to avoid cracking. Structurally lightweight aggregate concrete is fully compacted similar to that of the normal reinforced concrete of dense aggregate. It can be used with steel reinforcement as to have a good bond between the steel and the concrete. The concrete should provide adequate protection against the corrosion of the steel. The shape and the texture of the aggregate particles and the coarse nature of the fine aggregate tend to produce harsh concrete mixes. Only the denser varieties of lightweight aggregate are suitable for use in structural concrete. Figure 2 shows the feature of lightweight aggregate concrete.



Figure 2: Lightweight Aggregate Concrete

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AERATED CONCRETE

Aerated concrete does not contain coarse aggregate, and can be regarded as an aerated mortar. Typically, aerated concrete is made by introducing air or other gas into a cement slurry and fine sand. In commercial practice, the sand is replaced by pulverized- fuel ash or other siliceous material, and lime maybe used instead of cement.

There are two methods to prepare the aerated concrete. The first method is to inject the gas into the mixing during its plastic condition by means of a chemical reaction. The second method, air is introduced either by mixing-in stable foam or by whipping-in air, using an air-entraining agent. The first method is usually used in precast concrete factories where the precast units are subsequently autoclaved in order to produce concrete with a reasonable high strength and low drying shrinkage. The second method is mainly used for in-situ concrete, suitable for insulation roof screeds or pipe lagging. Figure 3 shows the aerated concrete.



Figure 3: Aerated Concrete

NO-FINES CONCRETE

No-fines concrete can be defined as a lightweight concrete composed of cement and fine aggregate. Uniformly distributed voids are formed throughout its mass. The main characteristics of this type of lightweight concrete is it maintains its large voids and not forming laitance layers or cement film when placed on the wall. Figure 4 shows one example of No-fines concrete.

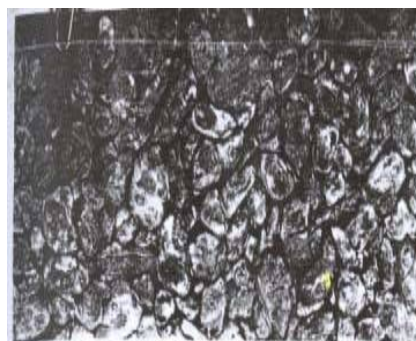


Figure 4: No-fines Concrete

APPLICATION OF LIGHTWEIGHT CONCRETE

Lightweight concrete has been used since the eighteen centuries by the Romans. The application on the 'The Pantheon' where it uses *pumice* aggregate in the construction of cast in-situ concrete is the proof of its usage. In USA and England in the late nineteenth century, *clinker* was used in their construction for example the 'British Museum' and other low cost housing. The lightweight concrete was also used in construction during the First World War. The United States used mainly for shipbuilding and concrete blocks. The *foamed blast furnace-slag* and *pumice*

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aggregate for block making were introduced in England and Sweden around 1930s.

Nowadays with the advancement of technology, lightweight concrete expands its uses. For example, in the form of *perlite* with its outstanding insulating characteristics. It is widely used as loose-fill insulation in masonry construction where it enhances fire ratings, reduces noise transmission, does not rot and termite resistant. It is also used for vessels, roof decks and other applications.

III. METHODOLOGY

Table 1: Density of Hardened Concrete and Compressive Strength at 28 days

Density (kg/m ³)	Compressive Strength (kn/m ²)
1470	2.52
1720	5.5
1770	10.34
1780	9.19
1810	13.12
1820	11.87
1840	13.21
1840	16.78
1920	16.73
1990	16.58
2040	17.27
2040	12.18
2050	9.35
2060	22.99

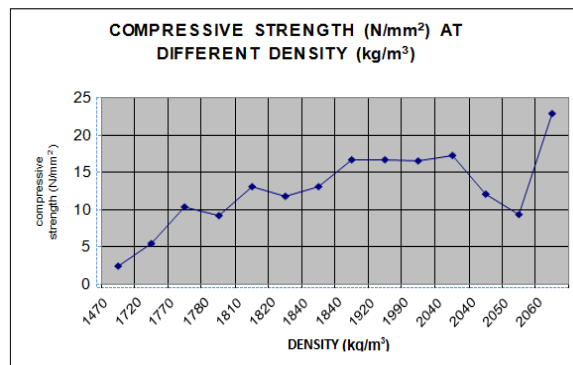


Figure 5: Compressive Strength at Different Density of Hardened Concrete

Table 2: Compressive Strength for Different Percentage of Foam

Days	Compressive Strength (kn/m ²)			
	25% Foam	50% Foam	75% Foam	100% Foam
7	13.2	9.45	8.12	1.43
14	14.68	8.88	11.02	2.44
21	16.41	14.42	11.96	2.23
28	17.27	11.87	13.12	2.52
32	19.53	14.14	12.89	2.62

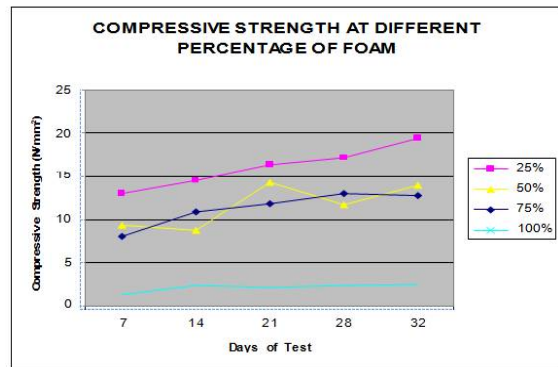


Figure 6: Compressive Strength at Different Percentage of Foam.

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Table 3: Compressive Strength at Different Foam Agent and Water Ratio

Days	Compressive Strength (kn/m ²)		
	1:25	1:30	1:40
7	4.09	8.12	11.15
14	4.86	11.02	11.95
21	5.45	11.96	13.72
28	5.5	13.12	13.21
Density (kg/m³)	1720	1810	1840

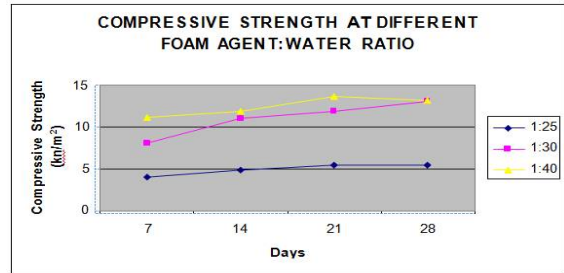


Figure 7: Compressive Strength at Different Foam Agent And Water Ratio.

Table 4: Compressive Strength at Different Cement and Sand Ratio

Days	Compressive Strength (kn/m ²)		
	1:2	1:3	1:4
7	19.44	8.12	7.57
14	17.58	11.02	7.16
21	21.28	11.96	7.44
28	22.99	13.12	10.34
Density (kg/m³)	2060	1810	1770

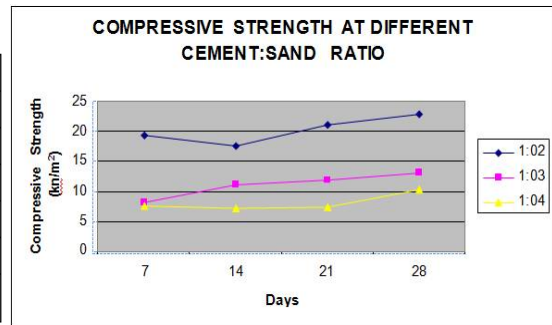


Figure 8: Compressive Strength at Different Cement And Sand Ratio.

Table 5: Compressive Strength at Different Cement and Water Ratio.

Days	Compressive Strength (kn/m ²)		
	1 : 0.25	1 : 0.30	1 : 0.45
7	10.29	13.91	8.12
14	10.12	13.45	11.02
21	11.34	16.14	11.96
28	12.18	16.73	13.12
Density (kg/m³)	2040	1920	1810

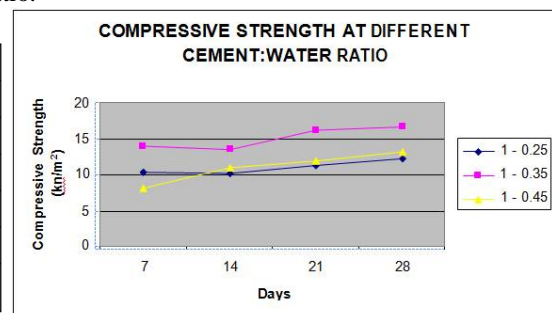


Figure 9: Compressive Strength at Different Cement And Water Ratio.

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Table 6: Water Absorption at Different Percentage of Foam.

% Of Foam	Water Absorption (%)
25	1.4
50	2.46
75	3.31
100	7.21

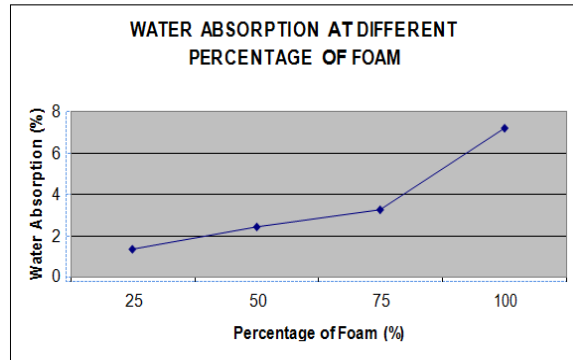


Figure 10: Water Absorption at Different Percentage of Foam.

Table 7: Water Absorption at Different Foam Agent and Water Ratio

Foam Agent : Water	Water Absorption (%)
1:25	2.60
1:30	3.31
1:40	4.46

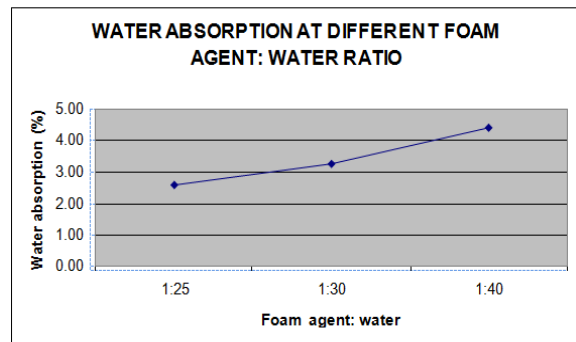


Figure 11: Water Absorption at Different Foam Agent And Water Ratio.

Table 8: Moisture Content at Different Percentage of Foam

% Of Foam	Moisture Content (%)
25	8.93
50	9.82
75	10.36
100	15.3

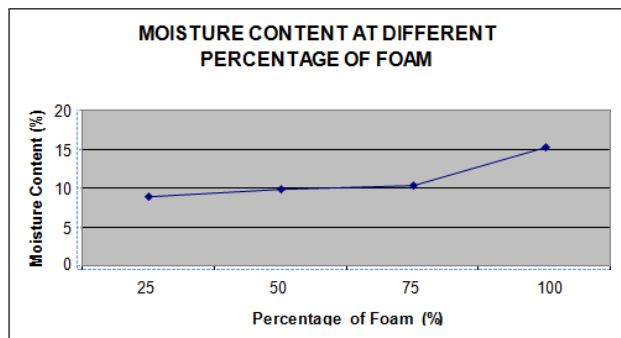


Figure 12: Moisture Content at Different Percentage of Foam.

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Table 9: Density of Hardened and Wet Concrete at Different Percentage of Foam.

Percentage of Foam (%)	Density (kg/m ³)	
	Hardened Concrete	Wet Concrete
25	2040	2000
50	1820	1770
75	1810	1790
100	1470	1460

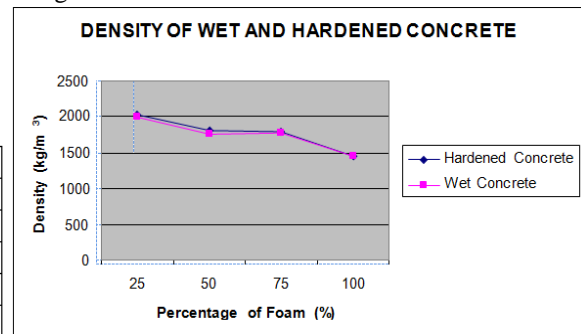


Figure 13: Density of Wet and Hardened Concrete

IV. BASIC DESIGN

Design of slab

i) Data:-

Clear span = 4.83 m

Wall thickness = 0.23 m

Live load = 2 kn/m²

Floor finish = 1 kn/m²

F_{ck} = 20 kn/m²

F_y = 415 kn/m²

dx = 4.83 m, dy = 6.02 m

dy/dx = 6.02/4.83 = 1.246 < 2

hence the slab is to be designed as a two way slab.

ii) Thickness of slab :-

Assume effective depth = span/28

$$= 4830/28$$

$$d = 172.5 \text{ say } 175 \text{ mm}$$

Adopting clear cover 20 mm & using 10 mm bars

Overall depth ; D = 175 + 20 + 10/2

D = 200 mm

iii) Effective span:-

Least of the following,

$$L_x = 4.83 + 0.175 = 5.005 \text{ m}$$

$$L_y = 6.02 + 0.175 = 6.195 \text{ m}$$

$$L_y/L_x = 6.195/5.005 = 1.238$$

iv) Loads :-

Self wt of slab = 0.200 × 1 × 25

= 5 kn/m²

Live load = 2 kn/m²

Floor finish = 1 kn/m²

Total load = 8 kn/m²

Factored load (W_u) = 1.5 × 8 = 12 kn/m²

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v) Design moments & shear forces :-

The slab is simply supported on all the four sides. The corners are not held down. Hence moment coefficients are obtained from table 27 of IS 456.

$$\alpha_x = 0.074$$

$$\alpha_y = 0.056$$

$$\begin{aligned} M_{ux} &= \alpha_x \omega l_x^2 \\ &= 0.074 \times 12 \times 5.005^2 \\ &= 22.24 \text{ kn-m} \end{aligned}$$

$$\begin{aligned} M_{uy} &= \alpha_y \omega l_x^2 \\ &= 0.056 \times 12 \times 5.005^2 \\ &= 16.83 \text{ kn-m} \end{aligned}$$

$$\begin{aligned} \text{Factored shear force (Vu)} &= W_u.l/2 \\ &= 12 \times 5.005/2 \\ &= 30.03 \text{ KN} \end{aligned}$$

vi) Min depth required :-

The minimum depth required to resist the bending moment

$$M_u = 0.138 f_{ck} b d^2$$

$$22.24 \times 10^6 = 0.138 \times 20 \times 1000 \times d^2$$

$$d = \sqrt{(22.24 \times 10^6 / 0.138 \times 20 \times 1000)}$$

$$d = 89.76 \text{ mm} < 175 \text{ mm}$$

vii) Reinforcement :-

Along x- direction

$$M_{ux} = 0.87 f_y A_{st} d (1 - f_y A_{st} / f_{ck} b d)$$

$$22.24 \times 10^6 = 0.87 \times 415 \times A_{st} \times 175 (1 - 415 \times A_{st} / 20 \times 1000 \times 175)$$

$$A_{st} = 368.05 \text{ mm}^2$$

Using 8 mm dia bars , spacing of bars

$$S = a_{st} / A_{st} \times 1000$$

$$= (\pi/4 \times 8^2) / 368.05 \times 1000$$

$$= 136.57 \text{ mm say } 130 \text{ mm}$$

$$\text{Maximum spacing is (1) } 3d = 3 \times 175 = 525 \text{ mm}$$

(2) 300 mm which ever is less

Hence, provide 8 mm bars at 130 mm c/c

Along y-direction

These bars will be placed above the bars in x-direction

$$\text{Hence, } d = 175 - 8 = 167 \text{ mm}$$

$$M_{uy} = 0.87 f_y A_{st} d (1 - f_y A_{st} / f_{ck} b d)$$

$$16.83 \times 10^6 = 0.87 \times 415 \times A_{st} \times 167 (1 - 415 A_{st} / 20 \times 1000 \times 167)$$

$$A_{st} = 289.54 \text{ mm}^2$$

Using 8 mm dia bars, spacing of bars

$$S = a_{st} / A_{st} \times 1000$$

$$= (\pi/4 \times 8^2) / 289.54 \times 1000$$

$$= 173.6 \text{ mm say } 170 \text{ mm}$$

$$\text{Max. spacing is (1) } 3d = 3 \times 167 = 501 \text{ mm}$$

(2) 300 mm which ever is less

Hence, provide 8 mm bars at 170 mm c/c

viii) Reinforcement in Edge strip :-

$$A_{st} = 0.12\% \text{ of gross area}$$

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$$= 0.12/100 \times 1000 \times 200$$

$$A_{st} = 240 \text{ mm}^2$$

Using 8 mm dia bars, spacing of bars

$$S = a_{st}/A_{st} \times 1000$$

$$= (\pi/4 \times 8^2) / 240 \times 1000$$

$$= 209.44 \text{ mm say } 200 \text{ mm}$$

$$\text{Max. Spacing is (1) } 5d = 5 \times 175 = 875 \text{ mm}$$

(2) 450 mm which ever is less

Hence provide 8 mm bars at 200 mm c/c in edge strips in both directions

ix) Torsion Reinforcement :-

Area of reinforcement in each layer

$$A_t = \frac{3}{4} A_{stx} = \frac{3}{4} \times 368.05 = 276.04 \text{ mm}^2$$

Distance over which Torsion reinforcement is to be provided = 1/5 short span

$$= 1/5 l_x$$

$$= 5005/5$$

$$= 1001 \text{ mm}$$

Using 6 mm bars, spacing

$$S = a_{st}/A_{st} \times 1000$$

$$= (\pi/4 \times 6^2) / 276.04 \times 1000$$

$$= 102.43 \text{ mm say } 100 \text{ mm}$$

Hence provide 6 mm bars at 100mm c/c at all the four corners in four layers

x) Check for deflection :-

For simply supported slabs basic value of l/d ratio = 20

Modification factor tension steel F1

% of steel,

$$= A_{st}/bd \times 100$$

$$= (368.05/1000 \times 175) \times 100$$

$$= 0.21 \%$$

$$F_s = 0.58 \times f_y = 0.58 \times 415 = 240 \text{ N/mm}^2$$

From fig 4 of IS 456, modification factor = 1.5

$$\text{Maximum permitted l/d ratio} = 1.5 \times 20 = 30$$

$$L/d \text{ provided} = 5005/175 = 28.6 < 30$$

Hence deflection control is safe

b) DESIGN OF BEAM:

1) Data:

$$f_{ck} = 20 \text{ N/mm}^2$$

$$f_y = 415 \text{ N/mm}^2$$

$$l = 6.02 \text{ N/mm}^2$$

2) Depth of beam :

Selecting the depth in range of 1/12 to 1/15 based on stiffness

$$d = 6020/15$$

$$= 401.33 \text{ mm}$$

Adopt $d = 410 \text{ mm}$

$$D = 450 \text{ mm}$$

3) Effective span:

$$\text{C/c distance between the supports} = 6.02 + 0.23$$

$$= 6.25 \text{ m}$$

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Clear span + d = 6.02+0.41
= 6.43m
Hence effective span = 6.25m

4) loads :-

Self weight of the beam = $0.23 \times 0.45 \times 1 \times 25$
= 2.58kn/m²
Load from slab = 8kn/m²
Total load = 10.58kn/m²
Factored load = $1.5 \times 10.58 = 15.87$ kn/m

5) factored B.M (Mu) & S.F:-

Factored B.M (Mu) = $Wul^2/8$
= 15.62×6.25^2
= 77.548kn-m
Factored s.f (Vu) = $Wul/2$
= 15.882×6.25
= 49.63kn

6) Depth required:-

The min depth req to resist b.m
 $Mu = 0.138Fckbd^2$
 $77.548 \times 10^6 = 0.138 \times 20 \times 250 \times d^2$
 $D = 349.5 < 410$ mm
Hence ok

7) Tension reinforcement:-

$Mu = 0.87 FyAst(1 - FyAst)$
 $Fckbd$
 $Ast = 0.87 \times 415 \times Ast \times 410 (1 - 415 \times Ast)$
 $20 \times 230 \times 410$
 $Ast = 604.19$ mm²

Provide 4 bars of 16φ bars
 Ast provided = 804.248mm²

8) design shear stress :-

Nominal shear stress (Tv) = Vu/bd
= $49.63 \times 10^3 / 230 \times 410$

DESIGN OF COLUMN

Load from beam = 76.765 KN
Self wt of column = $0.23 \times 1 \times 25$
= 5.75 Kn/m
Total load = 82.515 Kn/m
Factored load (wu) = 1.5×82.515
= 123.77 Kn/m
Length of column = 3.0 m
 $L_{eff} = 0.65 l$
= 0.65×3000
= 1950 mm
Check type of the column,
 $1950/230 = 8.478 < 12$
Hence designed as a short column.
Side of the column on one side = 230 mm

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Net gross area of column is — A_g

Assuming 1% of steel,

$$A_{sc} = 1\% A_g = 0.01 A_g$$

$$\text{Area of concrete, } A_c = A_g - A_{sc} = A_g - 0.01 A_g = 0.99 A_g$$

For axially loaded short columns,

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}$$

$$123.77 \times 10^3 = 0.4 \times 20 \times 0.99 A_g + 0.67 \times 415 \times 0.01 A_g$$

$$A_g = 115667.5 \text{ mm}^2$$

Since the column is rectangular & one side of the column is 230 mm, dimension of the other side

$$A_g / 230 = 115667.5 / 230 = 502.9 \text{ mm say } 500 \text{ mm}$$

Adopt 230 mm × 500 mm rectangular column,

$$A_{sc} = 0.01 A_g = 0.01 \times 115667.5$$

$$= 1156.675 \text{ mm}^2$$

Provide 6 mm bars of 16 mm diameter,

$$A_{sc \text{ provided}} = 1206.4 \text{ mm}^2$$

Lateral ties :-

a) $\phi/4 = \frac{1}{4} \times 16 = 4 \text{ mm}$

b) 6 mm

Hence, adopt 6 mm diameter bars

Pitch of the ties shall be minimum of

a) least lateral dimension of column = 230 mm

b) 16 times of the dia of longitudinal bar = 16×16

$$= 256 \text{ mm}$$

c) 300 mm

DESIGN OF FOOTING :-

a) Data :-

Axial load = 307.068 KN

Size of the column = 280 × 500 mm

S.B.C of soil = 200 kN/m²

$f_{ck} = 20 \text{ kN/m}^2$

$f_y = 415 \text{ kN}$

1) Size of footing:

Load from the column = 307.068 kN

Self wt from of footing = 10% of column load = $307.068 / 10$

Total load on the soil = 337.775 kN

Area of footing = $337.775 / 200 = 1.689 \text{ m}^2$

Provide 1.2 × 1.5 m footing so that the cantilever projection of the footing from the column face is same equal to

$$\frac{1.2 - 0.23}{2} = \frac{1.5 - 0.5}{2}$$

$$(\text{-----}) = (\text{-----}) = 0.5 \text{ mm}$$

$$\frac{1.2 - 0.23}{2} = \frac{1.5 - 0.5}{2}$$

Area of footing provided = 1.2 × 1.5 m

2) Upward soil pressure:

Factored load $P_u = 1.5 \times 307.068$

$$= 460.602 \text{ kN}$$

Soil pressure at ultimate load =

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$Q_u = P_u / \text{area of footing}$
 $Q_u = P_u / \text{area of footing}$
 $Q_u = 460.602 / 1.2 \times 1.5$
 $= 255.89 \text{kn/m}^2$
 $= 0.26 \text{n/mm}$

3) Depth of footing from B.M consideration:

The c critical section for B.M will be at the face of the column as shown $M_u = q_u l (B-b/8)^2$
 $= 0.16 \times 1500 (1200-230/8)^2$
 $= 5.733 \times 10^6 \text{N-mm}$

4) Reinforcement:

$M_u = 0.87 F_y \times 415 \times A_{st} \times 450 (1 - 415 A_{st} / 20 \times 1500 \times 250)$
 $A_{st} = 557.25 \text{mm}^2$
Using 16mm diameter bars, spacing of bars
 $S = a_{st} \times B / A_{st}$
 $= 304.42 \text{mm}$

Hence provide 12mm bars at 300mm/c

5) Check for one way shear:

The critical section for one way shear is at a dist d from the face of the column

Fact S.F = V_u = soil pressure from the shaded area.

VI. CONCLUSION

Lightweight aggregate concrete has been shown by test and by performance to behave structurally in much the same manner as normal weight concrete. For properties which differ, the differences are largely those of degree. The designer must consider the benefits of lighter weight and better insulation in relation to the extra cost of the lightweight mix. The builder must recognize the few different requirements relative to transporting, placing, and finishing. Much helpful information is available from producers of lightweight aggregates through their field control and technical service.

We developed cost estimate of the commercial building by using the light weight concrete and other materials such as light weight wood and light weight metals. The goal is to reduce the load component without compromising on the strength to reduce the overall cost of the building and the time frame for construction. We conducted structural analysis by using moment distribution method and designed manually. The required drawings were developed in Auto-cad for this project.

Finally, the emphasis is on the benefits of light weight concrete and materials usage to reduce the load on the structure, cost and time of construction. The results, drawings and design and pertinent data is included in the report with conclusions and recommendations.

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