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Investigation of Load Transfer Mechanism in Building Structure with Analysis and Design of Biaxially Loaded Column & its Isolated Slope Footing - A Case Study at Silchar Airport

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Abstract: *The mechanism in a construction work of building where the building floor system consists of reinforced concrete slab which is supported on a rectangular grid of beams. The grid of beams takes load from slab and transfer it towards column. Hence, slab thickness can reduce by a structural designer, depending upon on the geometric configuration of grid forming beams. The structural elements of a building such as slab, beam, column and footing bearing their own loads and imposed load i.e. dead load and live load and transfers from roof to floor beam, floor beam to column and finally from footing to soil. So, all the structural elements are interrelated to each other for providing the structural stability in a building. Without geotechnical survey of soil condition, footing can not be design, because without proper bearing capacity of soil, the whole structure may fail at any condition due to earthquake load, wind load, snow load, hydrostatic pressure, low soil bearing capacity, etc. There are several restriction must follows while designing any structural element.*

The purpose of the study is to aid structural designers while designing the structural elements of building. This study investigates how the structural elements transfer loads from top level to bottom of the building. In this research work, a small portion of building frame has considered which is constructed in modification of terminal building (G+3) storey at Silchar Airport. As well, the various aspects and manually designing procedure for Biaxially Loaded Column with Isolated Slope Square Footing as per IS code provisions where as few datas are taken from S.T. Enterprise consultant's report.

Keyword: *Soil-structure interaction, load transfer mechanism, Beam-column joint, structural elements, failure mechanism, structural design, building systems, biological design in Structural Engineering, structural optimization.*

I. INTRODUCTION

Structural Engineering started from ancient Egyptians & "Imhotep" (2700 BC) constructed step pyramid for Pharaoh Djoser known the first Structural Engineer. In the structural engineering field, the main aspect to investigate, design & develop low budget economical structure with more functional facilities, durabilities and shear & moments and strengthening of structural elements in a proper manner. While designing of buildings, bridges, offshore and industrial structures- a set of planning and controlling of various elements design is necessary for performing the imagination into real world. Proper load transformation and functions of each elements are necessary to form a building structure, otherwise building many collapse with heavily self loaded, external forces, and other unwanted aspects. So, structural optimization, soil-structure interaction studies is necessary while analysis of structural elements for design. External loads like seismic forces, wind load, etc. are to be considered in each and every structural elements with maintaining proper safety factors, as per code provisions.

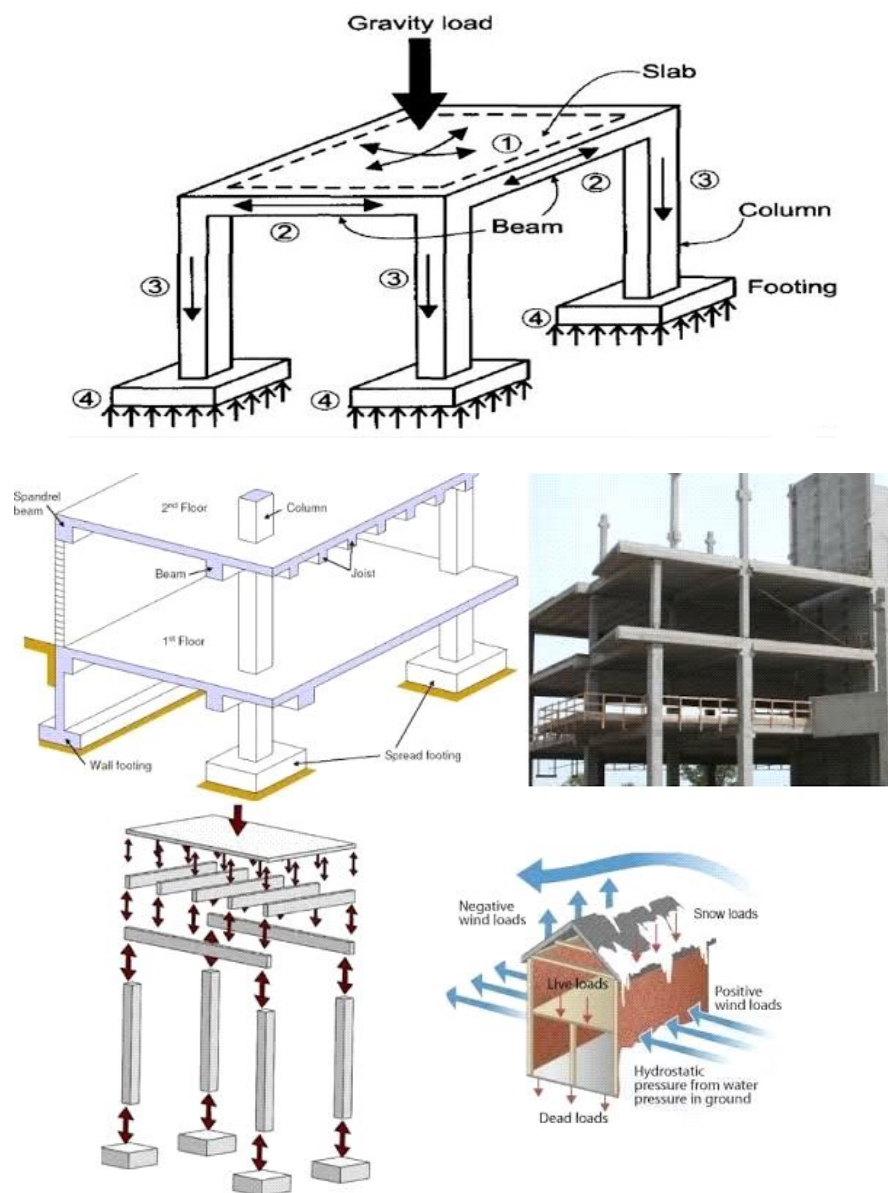
The load-transfer mechanism of building tells us about load configuration exerted by each element through its geometrical as well as structural aspects. In case of slab, depending upon the ratio of longer span and shorter span-designer has consider to follow one-way or two-way load carrying slab. In case of beam, it has consider to check natural axis's position for balancing the load with proper reinforcement as well for proper maintaining of development length for smooth transferring of load towards column at beam-column junction. While in footing case- depending upon on load capacity and column positioning as well as soil conditions, it could design in several type like- Isolated footing, eccentrically loaded footing, pile foundation, etc. majorly in rectangular, square or circular form. So, soil-structure interaction occurs and is required to investigate all data for performing a better structural health of a building. Shear calculation is required to check the amount of shear exerted by particular element from external and internal

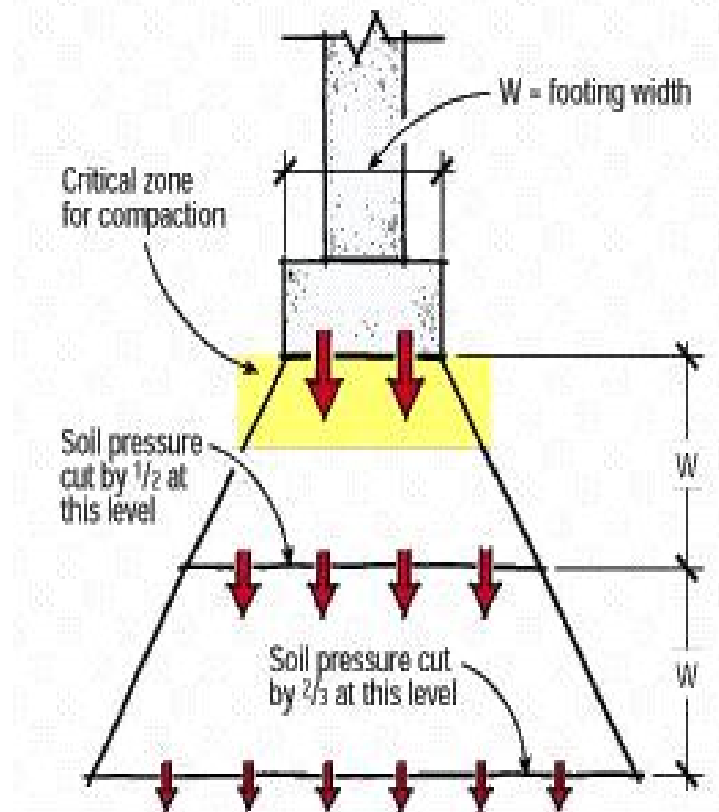
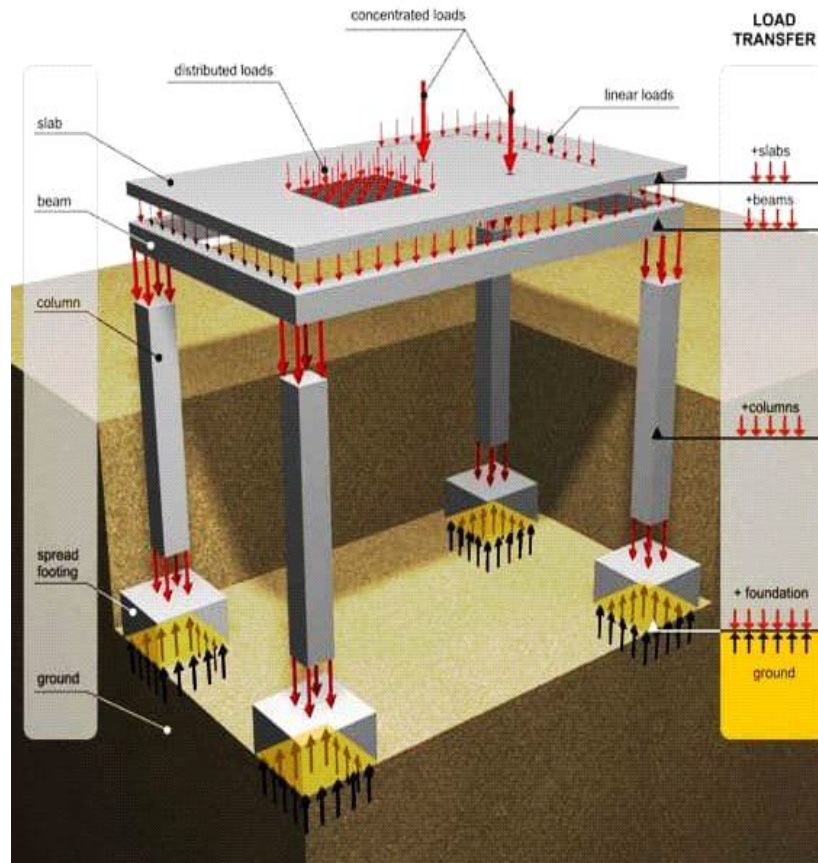
loads while resulting shear failure at its own position or shears small away and to balance the shear force through shear reinforcement. Moment calculation is necessary to design the element which could bear its own & overburden load. Otherwise elements could fail due to compression or tension resulting flexural failure or modulus of rupture, and overburden failure or buckling from compression or brittle failure.

Besides on all failure configuration of structural elements, Structural Engineers design all the elements with special care. There are several software package has developed to design the structural components easily with consideration of safety factors, like- Staad Pro, ANSYS, SAFE, RISA, Autodesk Revit, SAP2000, 3D Max, Navisworks, etc. The present study was carried out while construction of Modification of Terminal Building (G+3) storey at Silchar Airport where as we will see how structural elements transfers loads from one stage to another and later on in this paper- a structural element-Footing (Isolated sloped square) for rectangular column will design manually.

II. STRUCTURAL ELEMENTS

Major elements of building structure are Slab, Beam, Column, Foundation, Stair etc. where they carry loads and transfer to downgrade to surve support, enclose and protect the building structure.





III. BENDING BEHAVIOUR ON SLAB

Depending upon of load bearing capacity on each span of a slab, it may design mainly in One-directional or two directional slab. In here, the load bears by each span are discuss elaborately.

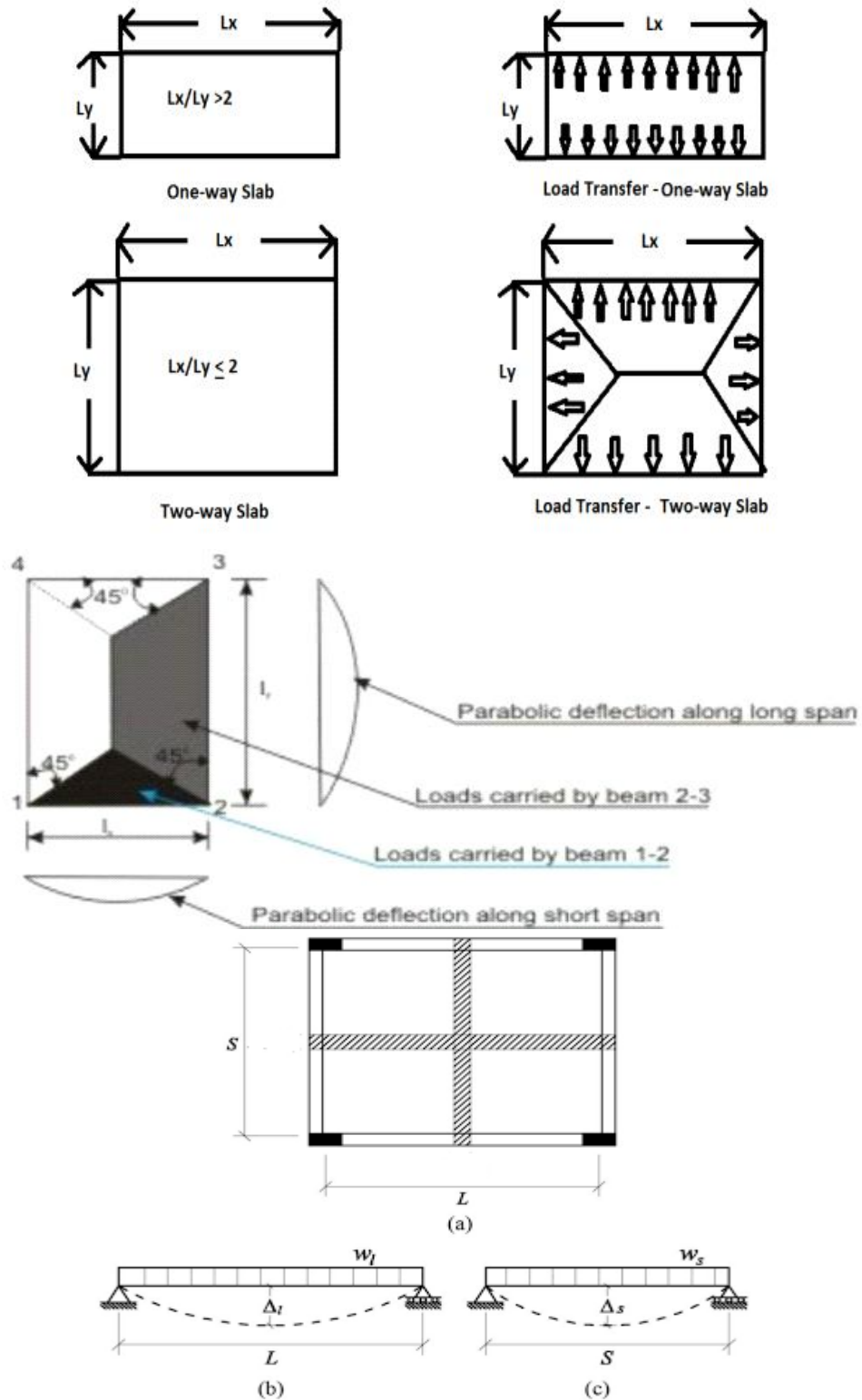


Figure : (a) Strips in the short and long directions; (b) deflection in the long direction; (c) deflection in the short direction

Consider, W = Udl on slab, L_y = Longer span & L_x = Shorter span

W_x = Load carried by strip AC along X direction,

W_y = Load carried by strip BD along Y direction,

Therefore, Total Load, $W = W_x + W_y$ eq.1.

$$d_c = (5/384) \times (WL^4/EI) \text{eq.2}$$

d_c = deflection at centre, W = UDL, L = length of Area/Beam/Strip.

$$(d_p)_x \text{ along X direction} = (5/384) \times (W_x L_x^4/EI) \text{eq.3}$$

$$(d_p)_y \text{ along X direction} = (5/384) \times (W_y L_y^4/EI) \text{eq.4}$$

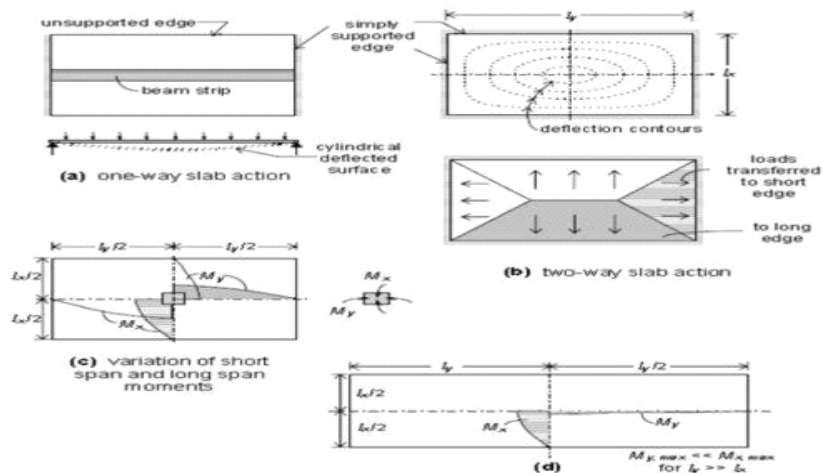
when $(d_p)_x = (d_p)_y$

$$\& W_x = L_y \times (L_y/L_x)^4$$

Putting the value of W_x in eq.1, we get $W_y = W / \{1 + (L_y/L_x)^4\}$,

$$\text{and } W_x = \{W \times (L_y/L_x)^4\} / \{1 + (L_y/L_x)^4\}$$

$$\text{Finally, } W = W_x + W_y = \{W \times (L_y/L_x)^4\} / \{1 + (L_y/L_x)^4\} + W / \{1 + (L_y/L_x)^4\} \text{eq.5}$$



1) For CASE-1 - One way slab

When $L_y/L_x >= 2$, say $L_y/L_x = 2$, Then $W_y = W / (1 + 2^4) = 0.05 W$

$$\text{and } W_x = W \times (2^4) / (1 + 2^4) = 0.95 W$$

i.e., Load carried by strip BD along Y direction is only 5% of total udl & by strip AC along X direction is 95% of total load i.e. almost all loads. That's why, Bending will happen only in one direction i.e. along Shorter direction- called One way slab. Also, Main Reinforcement provided along Shorter span of slab.

Here from Case-1 figure, Each of B1 & B2 carries = Half of the rectangular load = $(WL_x)/2$

2) For CASE-2 - Two way slab

When $L_y/L_x < 2$, say $L_y/L_x = 1.2$, Then $W_y = W / (1 + 1.2^4) = 0.33 W$

$$\text{and } W_x = W \times (1.2^4) / (1 + 1.2^4) = 0.67 W.$$

i.e., Load carried by strip BD along Y direction by 33% of total udl & strip AC along X direction is 67% of total load. So, bending will happen only in both directions - called Two way slab. Also, Main Reinforcement provided along both direction of slab.

Here from Case-2 figure, Each of B1 & B3 carries = Trapezoidal Load

$$= (WL_x)/2 [1 - (1/3b^2)], \text{ b} = L_y/L_x$$

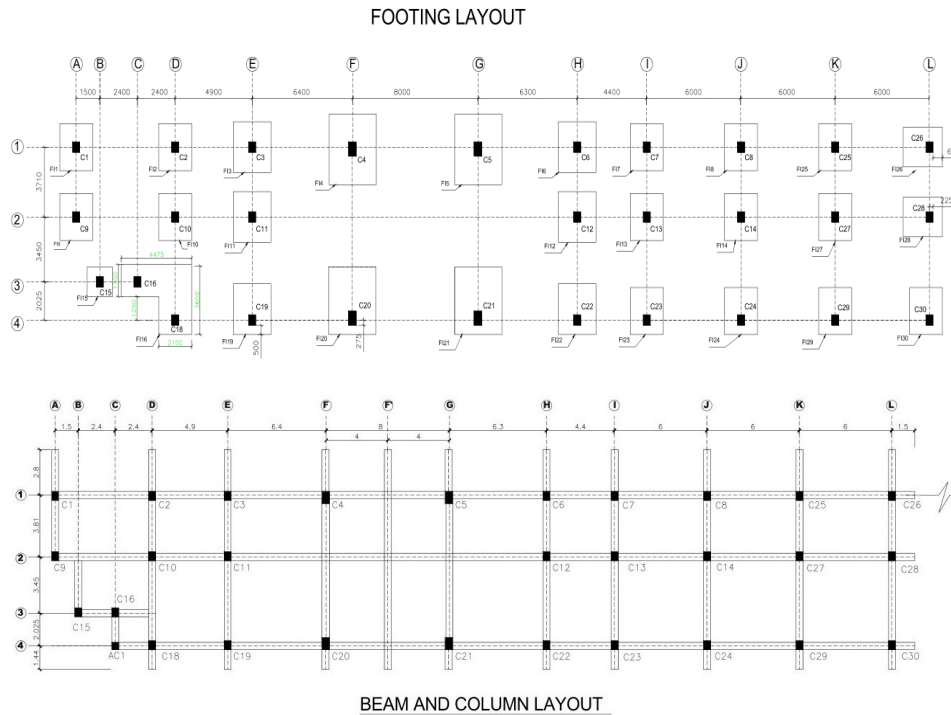
& Each of B1 & B3 carries = $(WL_x)/3$

3) When $L_y/L_x = 1$, Then $W_y = W / (1 + 1^4) = 0.5 W$

$$\text{and } W_x = W \times 1^4 / (1 + 1^4) = 0.5 W.$$

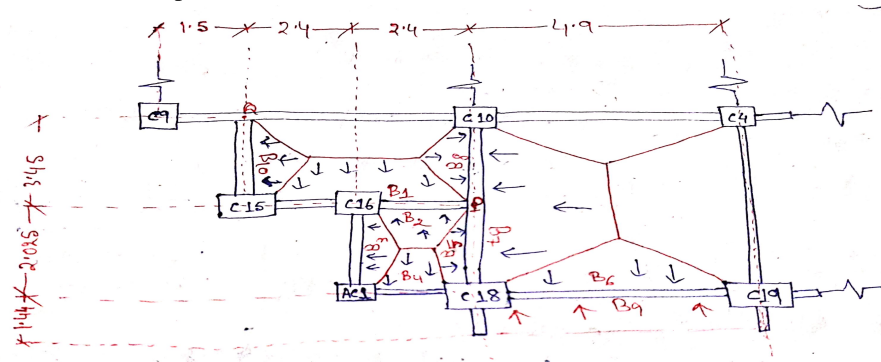
i.e., Load carried by both strip BD along Y direction & strip AC along X direction by 50% of total udl on each span as shown in Case-3. So, bending will happen only in both directions - also called Two way slab. Also, Main Reinforcement provided along both the span.

IV. AN APPROACH FOR LOAD-DISTRIBUTION SYSTEM (METHOD-1)



A. Nomenclature of Beam and Column

Considering a small portion of the above plan,



Distribution of loads from slab to footing:

From above plan,

slab thickness= 130 mm, Beam size= 450 mm X 600 mm

Size-1 type column= 450 mm X 550 mm (Columns are C9, C10, C11, C15, C16, C18, C19)

Size-2 type column= 300 mm X 450 mm (Column AC1)

Column Height= 4.1 m

width of wall (including plastering)=250 mm and neglecting parapet wall.

Factor of safety = 1.5

M25 grade of concrete & Fe 500 grade of steel.

From I.S 875-1987 Code, considering-

Density of concrete= 25 KN/m³

Unit weight of Brick masonry= 20 KN/m³

Live load on Roof= 1.5 KN/m²

Live load on Floor= 5.75 KN/m²

Floor Finish= 2 KN/m² (Including other finishes)

1) *Load of Roof Slab*

Self weight of Roof = $0.13 \text{ m} \times 25 \text{ KN/m}^3 = 3.25 \text{ KN/m}^2$

Live Load on Roof = 1.5 KN/m^2

Floor Finishing (Including Water proofing) = 2 KN/m^2

Total Load = 6.75 KN/m^2

Total Factored Load on Roof slab = $1.5 \times 6.75 = 10.125 \text{ KN/m}^2$

2) *Load of Floor Slab*

Dead Load of slab = $0.13 \text{ m} \times 25 \text{ KN/m}^3 = 3.25 \text{ KN/m}^2$

Live Load on Floor = 5.75 KN/m^2

Floor Finishing (Including other finishes) = 2 KN/m^2

Total load = 11 KN/m^2

and Factored Load of slab = $1.5 \times 11 = 16.5 \text{ KN/m}^2$

3) *Load of Beam per meter length (Each Floor)*

Self weight of Beam per meter length = $B \times H \times \text{Density of concrete}$

= $0.45 \times 0.60 \times 25 = 6.75 \text{ KN/m}$.

Factored Load on Beam per meter length = $1.5 \times 6.75 = 10.125 \text{ KN/m}$

4) *Load of Column (floor to Floor)*

Load on each size-1 type column = $L \times B \times H \times \text{Density of concrete}$

= $0.45 \times 0.55 \times 4.1 \times 25 = 25.37 \text{ KN}$.

Factored load on each size-1 type column = $1.5 \times 25.37 = 38.05 \text{ KN}$

Similarly, factored load on size-2 type column = $1.5 \times (0.3 \times 0.45 \times 4.1 \times 1.5)$

= 20.76 KN .

5) *Load of Wall in Each Floor*

Height of wall = centre to centre at Floor to Floor Height - depth of Beam.

= $4.1 - 0.6 = 3.5 \text{ m}$

Weight of brickwork per meter length = $B \times H \times \text{Unit weight of brick masonry}$

= $0.25 \times 3.5 \times 20 = 17.5 \text{ KN/m}$.

Factored wall load = $1.5 \times 17.5 = 26.25 \text{ KN/m}$.

Factored wall load on C18 Column = $(\text{WL}/2) + (\text{WL})$

= $(26.25 \times 12.125/2) + (26.25 \times 1.165) = 190.51 \text{ KN}$

Factored wall load on C16 Column = $(\text{WL}/2) = (26.25 \times 5.425) = 71.2 \text{ KN}$

Factored wall load on AC1 Column = $(\text{WL}/2) = (26.25 \times 3.55) = 46.60 \text{ KN}$

Factored wall load on C15 Column = $(\text{WL}/2) = (26.25 \times 4.9) = 64.31 \text{ KN}$

B. *Distribution of Load from Slab to Beam*

Grouping B2 & B4 in ---- Group-1, because of similar load condition.

Similarly, Grouping B5 & B5 in ---- Group-2 and Grouping B8 & B10 in ---- Group-3.

At B1- From drawing (column C15 towards C16 to P)->

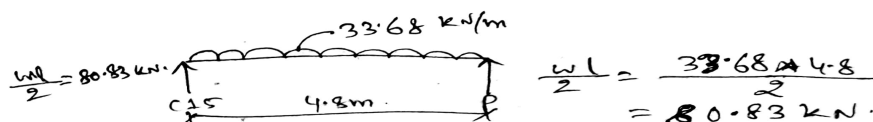
One trapezoidal load + self wt. of Beam

= $\{(W L_x^2)/2\} \times [1 - \{1/(3 \times b^2)\}] + \text{Self weight of Beam}$

= $\{(16.5 \times 3.45)/2\} \times [1 - \{1/(3 \times 1.39^2)\}] + 10.125 \dots\dots\dots$

$b = L_y/L_x = (2.4+2.4) / 3.45 = 1.3913$, $L_x = \text{Shorter span}$ and $L_y = \text{Longer span}$

= 33.68 KN/m .



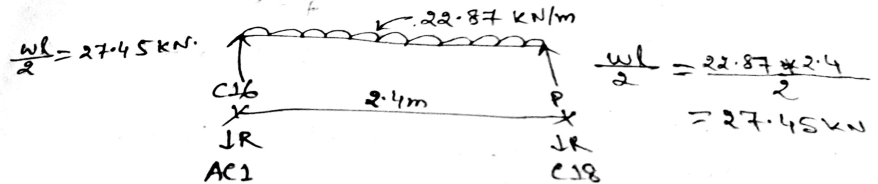
Since, C16 is at mid-length of C15 & P. So here, C16 will take = $(WL/2)$ load = 80.83 KN alone.

and, C15 and P will take a load of = $1/2 \times (WL/2) = 40.42$ KN separately.

1) At Group-1,-- B2 and B4

One trapezoidal load + self wt. of Beam

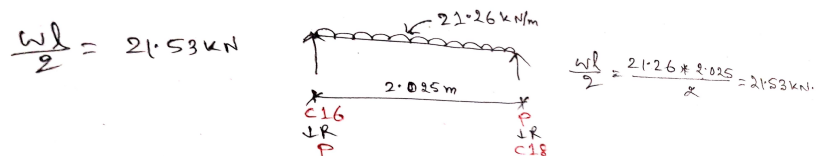
$$= \{(16.5 \times 2.025)/2\} \times [1 - \{1/(3 \times 1.185^2)\}] + 10.125 = 22.87 \text{ KN/m.}$$



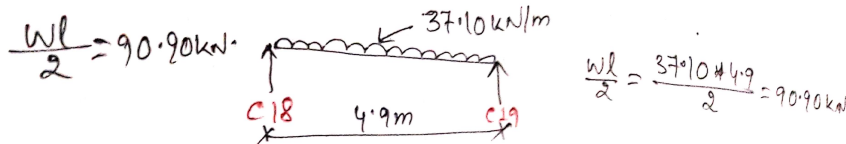
2) At Group-2,-- B3 and B5

One triangular load + self wt. of Beam

$$= (WL_x)/3 + 10.125 = (16.5 \times 2.025)/3 + 10.125 = 21.26 \text{ KN/m}$$



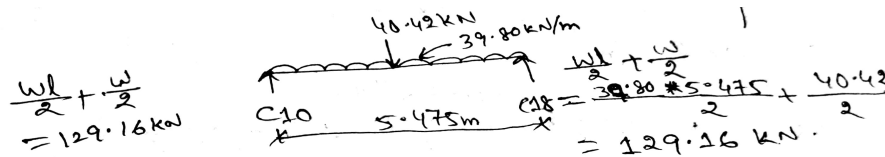
a) At B6 : one triangular load + self weight of Beam = $(16.5 \times 4.9)/3 + 10.125 = 37.10 \text{ KN/m}$



b) At B7: One trapezoidal load + Point load + Self weight of Beam

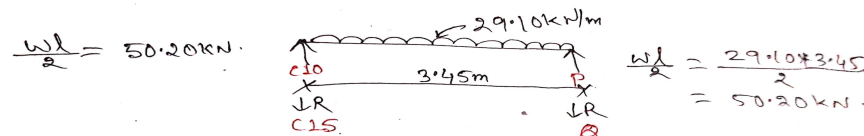
$$= \{(16.5 \times 4.90)/2\} \times [1 - \{1/(3 \times 1.12^2)\}] \text{ KN/m} + 40.42 \text{ KN} + 10.125$$

$$39.80 \text{ KN/m} + 40.42 \text{ KN.}$$



3) At Group-3,-- B8 and B10 : One triangular load + self weight of Beam

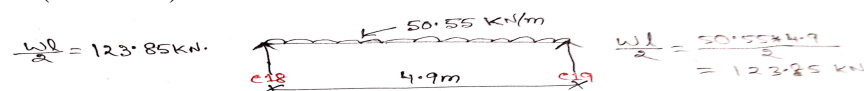
$$= (16.5 \times 3.45)/3 + 10.125 = 29.10 \text{ KN/m}$$



a) At B9 : Cantilever Portion of C18 & C19 :

Half rectangular load + self weight of Beam = $(WL/2) + 10.125$

$$= (16.5 \times 4.90)/2 + 10.125 = 50.55 \text{ KN/m.}$$



C. Distribution of Load from Floor slab to Beam

At B1- From drawing (column C15 towards C16 to P)->

One trapezoidal load + self wt. of Beam

$$= \{(W L_x^2)/2\} \times [1 - \{1/(3 \times b^2)\}] + \text{Self weight of Beam}$$

$$= \{(10.125 \times 3.45^2)/2\} \times [1 - \{1/(3 \times 1.39^2)\}] + 10.125 = 24.58 \text{ KN/m.}$$

Reaction at each end = $(24.5 \times 4.8)/2 = 59 \text{ KN}$

at column C16 = 59 KN

at C15 & P. Each one take load = $(WL/2) = 29.5 \text{ KN}$ alone.

At Group-1,-- B2 and B4 : Each of C16, P, AC1 & C18 takes load = 21.53 KN

At Group-2,-- B3 and B5 : Each of C16, P & C18 takes load = 17.17 KN

At B6 : Each of C10 & C19 takes load = 65.32 KN

At B7: Each of C10 & C18 takes load = $77.48 + 14.75 = 92.23 \text{ KN}$.

At Group-3,-- B8 and B10 : Each of C10, P, Q & C15 takes load = 37.55 KN

At B9 : Cantilever Portion of C18 & C19 : Each of C18 & C19 takes load = 85.58 KN

D. Total Factored Load on Each Column

For Column C16, C18, AC1 & C15 at Plinth Beam level.

No of Floor slab = 3 Floor slab + 1 Roof slab.

Total load on Each column = (No. of floor x total factored load on each column) + Roof Floor + Total self weight of column + Total load from wall on each column.

1) Load at C16 at plinth Beam level = $\{3 \times \text{floor load from (B1 + B2 + B3)}\} + \{1 \times \text{Roof load from (B1 + B2 + B3)}\} + (4 \times \text{self weight of C16 column from floor to floor}) + (4 \times \text{wall load from floor wall to floor wall at C16 column})$.

$$= \{3 \times (80.83 + 27.45 + 21.53)\} + \{1 \times (59 + 21.53 + 17.17)\} + (4 \times 38.05) + (4 \times 71.2)$$

$$= 924.16 \text{ KN.}$$

2) Load at C18 at plinth Beam level = $\{3 \times \text{floor load from (B4 + B5 + B6 + B7 + B8 + B9)}\} + \{1 \times \text{Roof load from (B4 + B5 + B6 + B7 + B8 + B9)}\} + (4 \times \text{self weight of C18 column from floor to floor}) + (4 \times \text{wall load from floor wall to floor wall at C18 column})$.

$$= \{3 \times (27.45 + 21.53 + 90.90 + 129.16 + 50.20 + 123.85)\} + \{1 \times (21.53 + 17.17 + 65.32 + 92.23 + 37.55 + 85.58)\} + (4 \times 38.05) + (4 \times 175.22) = 2501.76 \text{ KN}$$

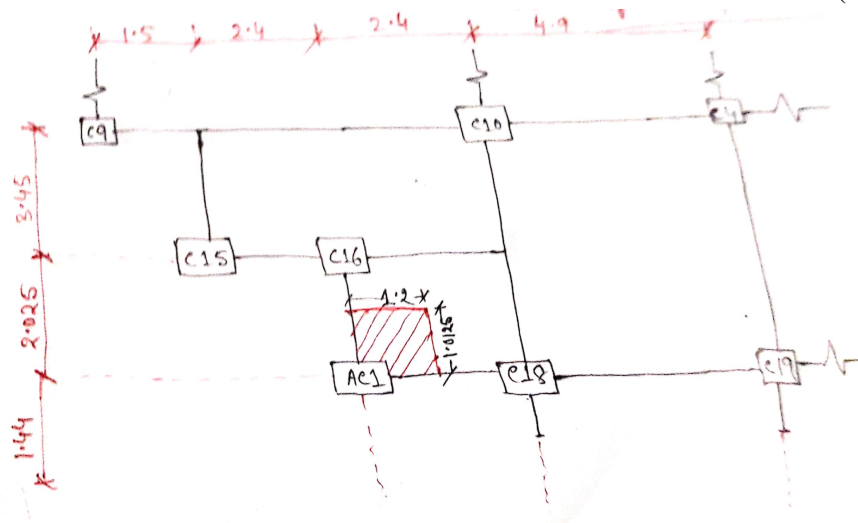
3) Load at AC1 at plinth Beam level = $\{3 \times \text{floor load from (B3 + B4)}\} + \{1 \times \text{Roof load from (B3 + B4)}\} + (4 \times \text{self weight of AC1 column from floor to floor}) + (4 \times \text{wall load from floor wall to floor wall at AC1 column})$.

$$= \{3 \times (21.53 + 27.45)\} + \{1 \times (17.17 + 21.53)\} + (4 \times 20.76) + (4 \times 46.60) = 455.08 \text{ KN.}$$

4) Load at C15 at plinth Beam level = $\{3 \times \text{floor load from (B1 + B10)}\} + \{1 \times \text{Roof load from (B1 + B10)}\} + (4 \times \text{self weight of C15 column from floor to floor}) + (4 \times \text{wall load from floor wall to floor wall at C15 column})$.

$$= \{3 \times (40.42 + 50.20)\} + \{1 \times (29.5 + 37.55)\} + (4 \times 38.05) + (4 \times 64.31) = 748.35 \text{ KN.}$$

V. AN APPROACH FOR APPROXIMATE METHOD OR LUMPSUM PROCEDURE (METHOD-2)



The highlighted area or the elements surrounded by this column AC1 in all side are considered at a distance of 'half' portion from column in X & Y direction.

We have already calculated the following details-

Factored load of Roof slab = 10.125 KN/m^2

Factored load of Floor slab = 16.5 KN/m^2

Factored load of walls = 26.25 KN/m

Factored load of Beam = 10.125 KN/m

Factored load of Column AC1 = 5.06 KN/m

From the highlighted portion of column AC1-

Floor Area = $1.2 \text{ m} \times 1.0125 \text{ m} = 1.215 \text{ m}^2$

Length of Beam = $1.2 + 1.0125 = 2.2125 \text{ m}$

Length of wall = wall length - deduction of column portion = $(1.0125 + 1.2) - 0.2 = 2.0125 \text{ m}$

Total Height = $4 \times 4.1 = 16.4 \text{ m}$.

A. Load on Column AC1

1) Load from Roof to Third Floor

Total Roof Load = $10.125 \text{ KN/m}^2 \times$ Highlighted area surrounded by Column AC1.

$$= 10.125 \times 1.215 = 12.30 \text{ KN}$$

Load on Beam = $10.125 \text{ KN/m} \times$ length of Beam = $10.125 \times 2.2125 = 22.40 \text{ KN}$.

Load on wall = $26.25 \text{ KN/m} \times$ length of wall = $26.25 \times 2.0125 = 52.83 \text{ KN}$

$$\text{Total load} = 87.53 \text{ KN.}$$

2) Load from third Floor to Second Floor

Floor load = $16.5 \times 1.215 = 20.05 \text{ KN}$

Load on Beam = $10.125 \times 2.2125 = 22.40 \text{ KN}$

Load on wall = $26.25 \times 2.0125 = 52.83 \text{ KN}$.

Total Load = 95.28 KN .

Similarly, Load from second floor to first floor = 95.28 KN

& Load from First floor to Ground floor = 95.28 KN .

Therefore, Total load on Column AC1 at Plinth Beam Level

$$= \text{Total Floor Load from Roof to G.F} + \text{Self weight of column in total floor.}$$

$$= 87.53 + 95.28 + 95.28 + 95.28 + (5.06 \times 16.4) = 456.4 \text{ KN.}$$

Thus, it conclude that from the above both methods, Loads on each column are approximately same in each case. So, the mechanism of load transformation & its behaviour in each and every structural element has done on such manner from top level to ground.

VI. DESIGN OF BIAXIALLY LOADED COLUMN C15

From the plan, the rectangular column C15 carrying biaxially load subjected to biaxial bending properties. Bending moment coming from both axes may be transfered from attached beam or caused by axial load being applied eccentrically to one axis or both axes rather than through the centre of the column.

Here, Size of column, (bxd) = $450 \text{ mm} \times 550 \text{ mm}$

Ultimate load, $P_u = 455.08 \text{ KN}$.

Floor to floor height = 4.1 m

Moment of Resistance along X direction, $M_{ux} = 27 \text{ KN.m}$

and M.O.R along Y direction, $M_{uy} = 30 \text{ KN.m}$

So, Effective Length, $L_{eff} = 0.65L$ (take both side restrained)

$$= 0.65 \times 4.1 = 2.67 \text{ m.}$$

A. Slenderness Ratio of Column (l)

$$l = (L_{eff} / \text{Least Lateral Dimension}) = (2.67 / 0.45) = 5.93 < 12.$$

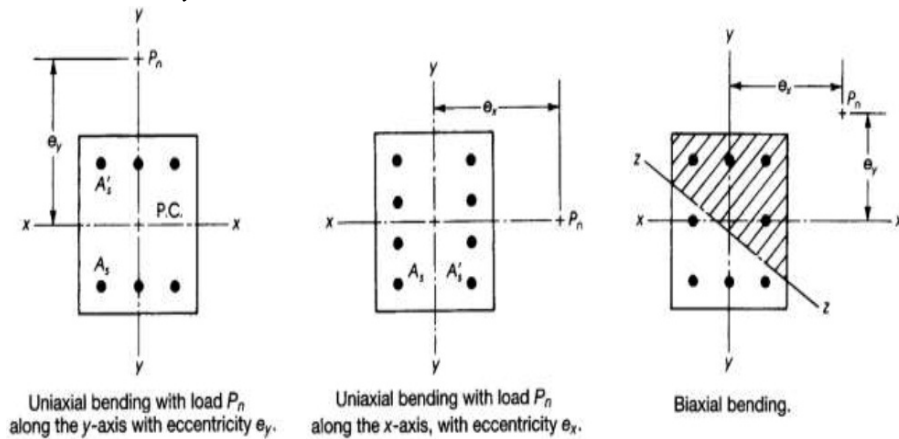
Therefore, It is a short column.

In other words, Depth,

$D =$ maximum of { not less than 400 mm , (or) not less than $0.12 L = 0.12 \times 4100 = 492 \text{ mm}$

Since, Depth, $D = 550 \text{ mm} > 492 \text{ mm}$. **OK.**

B. For Loading Condition, Eccentricity on Both Direction



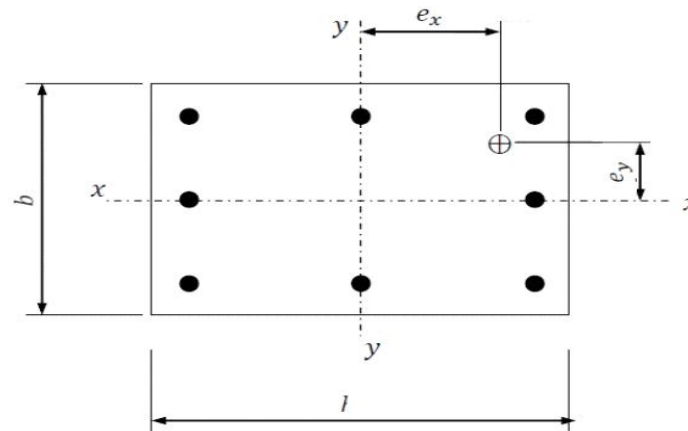
$$e = \{(L/500) + (D/30), \text{ (or) } 20 \text{ mm.}\}$$

$$\text{For X direction, } e_x = \{(4100/500) + (55 \times 0/30), \text{ (or) } 0.05D\}$$

$$= \{ 26.53 \text{ mm (or) } 27.5 \text{ mm}\}$$

$$\text{For Y direction, } e_y = \{(4100/500) + (450/30), \text{ (or) } 0.05b\}$$

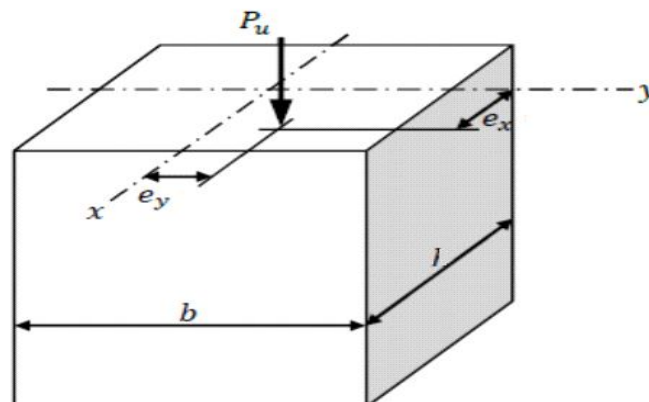
$$= \{ 23.20 \text{ mm (or) } 22.5 \text{ mm}\}$$

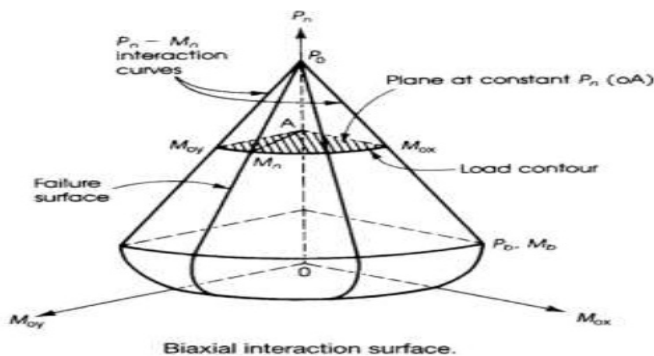


Since, $e_x > 0.05D$ & $e_y > 0.05b$

Therefore, It is designed as Short Biaxially loaded Column.

C. Calculation of Moment due to Eccentricity along X & Y Direction





Moment along X direction, $(M_u)_x = P_u \times e_y = 455.08 \times 0.0232 = 10.56 \text{ KN.m}$

Moment along Y direction, $(M_u)_y = P_u \times e_x = 455.08 \times 0.02653 = 12.07 \text{ KN.m}$

Consider 40 mm of effective cover.

From SP-16, I.S:456:1980, Chart-48,

$$(d' / D) = (40/550) = 0.07 \quad \& \quad (d' / b) = (40/450) = 0.089$$

$$\text{Therefore, } (P_u / f_{ck} \times b \times D) = \{(455.08 \times 10^3) / (25 \times 450 \times 550)\} = 0.074$$

Assume, percentage of steel, $P_t = 1 \%$, & $P_t / f_{ck} = (1/25) = 0.04$

$$(M_{ux} / f_{ck} \times b^2 \times D) = 0.03, \quad \text{So, } M_{ux} = 25 \times (450)^2 \times 550 \times 0.03 = 83.53 \text{ KN.m}$$

$$\& \quad (M_{uy} / f_{ck} \times b \times D^2) = 0.03, \quad \text{So, } M_{uy} = 25 \times 450 \times (550)^2 \times 0.03 = 102.10 \text{ KN.m}$$

From IS:456-2000, Cl. 39.6,

$$(M_{ux} / M_{ux,1})^a_n + (M_{uy} / M_{uy,1})^a_n \leq 1$$

$$\text{So, } (27 / 83.53)^a_n + (30 / 102.10)^a_n \leq 1, \dots\dots\dots \text{eq.1}$$

For $a_n = (\text{Axial Force} / \text{Pure Compressive Force}) = (P_u / P_{uz})$

$$\text{and, } P_{uz} = 0.45 f_{ck} A_c + 0.75 f_y A_{sc} = 0.45 \times 25 \times (A_g - A_{sc}) + 0.75 \times 500 \times A_{sc},$$

$$\begin{aligned} \text{Where } A_c &= \text{Area of concrete} = \text{Gross area} - \text{Area of steel} = A_g - A_{sc} = (b \times D) - (1\% \text{ of } bD) \\ &= (450 \times 550) - (0.01 \times 450 \times 550) = 247500 - 2475 = 245025 \text{ mm}^2 \end{aligned}$$

$$\text{Therefore, } P_{uz} = (0.45 \times 25 \times 245025) + (0.75 \times 500 \times 2475) = 3684.66 \text{ KN.}$$

$$\text{So, } (P_u / P_{uz}) = (455.08 / 3684.66) = 0.124$$

For value of $(P_u / P_{uz}) = 0.2$ to 0.8 , the values of (a_n) vary linearly from 1 to 2.

Interpolating, $a_n = 0.873$

So, From eq. (1),

$$(0.323)^{0.873} + (0.294)^{0.873} \leq 1, \quad \text{Finally, } 0.72 < 1, \quad \text{OK.}$$

closer to 1 is more economical.

D. Reinforcement Detailing

$$A_{st} = 1\% \text{ } bD = 2475 \text{ mm}^2$$

$$\text{Considering } 20 \text{ mm } f \text{ bars, } a_{st} = (p / 4) \times 20^2 = 314 \text{ mm}^2$$

$$\text{No. of bar} = (A_{st} / a_{st}) = (2475 / 314) = 7.88, \text{ say } 8 \text{ No.}$$

$$(A_{st})_{\text{provided}} = 8 \times 314 = 2512 \text{ mm}^2$$

For transverse reinforcement,

$$\begin{aligned} \text{Diameter of lateral ties or link, } f_t &= \text{maximum} \{ (1/4) f_L \text{ or, } 6 \text{ mm} \\ &= \text{maximum} \{ (1/4) \times 20 = 5 \text{ mm, or, } 6 \text{ mm} \\ &= 6 \text{ mm.} \end{aligned}$$

Consider, 10 mm f of transverse reinforcement & Pitch

$$= \text{minimum of } \{ \text{least lateral dimension, (or) } 16 f_L, \text{ (or) } 300 \text{ mm} \}$$

$$= \text{minimum of } \{ 450 \text{ mm, or } (16 \times 20) = 320 \text{ mm, or } 300 \text{ mm} \}$$

$$= 300 \text{ mm.}$$

Take Pitch upto 0.25L of column at support @ 100 mm $c/c < 300 \text{ mm}$, **OK.**

& at mid section @ 200 mm $c/c < 300 \text{ mm}$, **OK.**

E. Check for Extra Stirrups Requirement

Along X direction, spacing of bar = $\{(B - \text{Cover on both side})/3\} = (450 - 40 - 40)/3$
 $= 123.33 \text{ mm} > 75 \text{ mm}$

So, extra stirrup is required.

Spacing between cover bar = $450 - 40 - 40 > 48f_t$
 $= 370 \text{ mm} < (48 \times 10 = 480 \text{ mm})$.

So, there is no requirement of Close type stirrup.

Provide open type of extra stirrup along X direction.

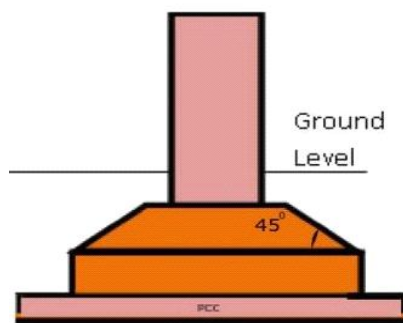
Similarly, Along Y direction, spacing of bar = $\{(L - \text{Cover on both side})/3\} = (550 - 40 - 40)/3$
 $= 156.67 \text{ mm} > 75 \text{ mm}$

& $550 - 40 - 40 > 48f_t$
 $= 470 \text{ mm} < 480 \text{ mm}$.

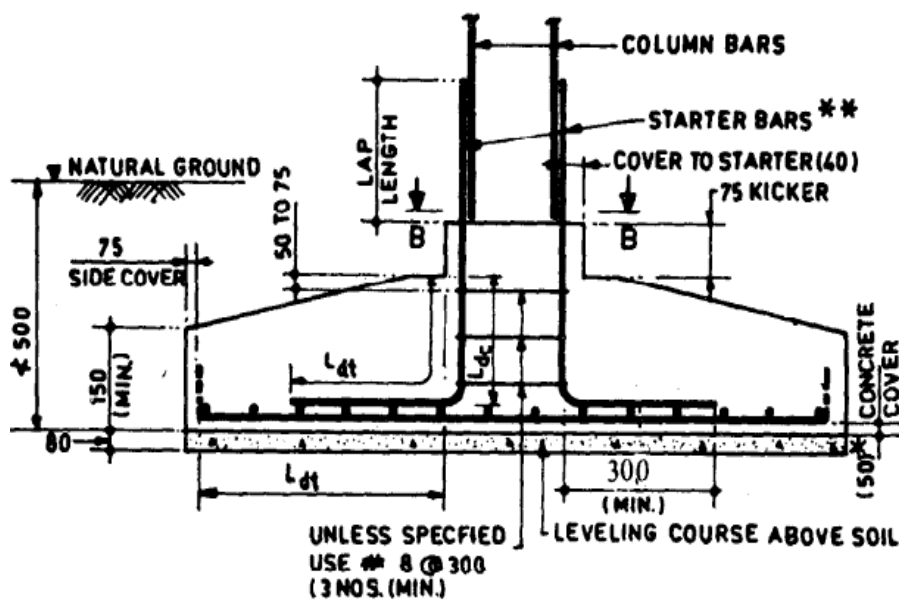
Provide open type of extra stirrup along Y direction.

VII. DESIGN OF ISOLATED SLOPE SQUARE FOOTING FOR C15 COLUMN

Footings which provides under a column independently called Isolated footing. With high bearing capacity of soil in general cases, Isolated footing introduce which comprise of thick slab in flat or sloped or stepped form. It is most economical when compare with other footings. Isolated slope footings are trapezoidal footings with top slope at 45 degree is maintained from all sides.



SLOPED FOOTING



In here, the designing aspect for isolated slope square footing of column C15 has discussed below.

From soil investigation report at Silchar Airport from S.T. Enterprise Consultant-

Unit weight of soil = 16.5 KN/m^3

Bearing Capacity of soil, S.B.C = 225 KN/m^2

Cohesion, $C = 8 \text{ KN/m}^2$

Factor of safety against Sliding = 1.5

F.O.S against overturning = 1.5

Coefficient of friction = 0.15

From Plan, Size of C15 column = $450 \text{ mm} \times 550 \text{ mm}$

Factored load on Column at Plinth level = 455.08 KN .

Working load on column at plinth load = $455.08/1.5 = 303.4 \text{ KN}$.

Since, C15 column is subjected to biaxial bending (and for biaxial bending or corner column, increment of load for bending due to effect of fixity can done 16% to 33%).

Adding @ 30% of self weight of footing = 91.02 KN .

So, Total Load = $303.4 + 91.02 = 394.42 \text{ KN}$.

A. Area of Footing

= Total working load/ S.B.C = $(394.42/225) = 1.753 \text{ m}^2$

Since, it is a rectangular column, difference in column dimension, $d = L - B = 0.55 - 0.45 = 0.1 \text{ m}$

So, $L = B + 0.1 \text{ m}$ and Area, $A = (B + 0.1) \times B = 1.753 \text{ m}^2$ So, $B = 1.28 \text{ m}$ and $L = 1.28 + 0.1 = 1.38 \text{ m}$

Therefore, minimum size of rectangular footing = $1.38 \text{ m} \times 1.28 \text{ m}$

Considering a square footing for rectangular column,

Area, $A = 1.753 \text{ m}^2 = B \times B \Rightarrow B = 1.33 \text{ m}$

So, minimum size of square footing required = $1.33 \text{ m} \times 1.33 \text{ m}$

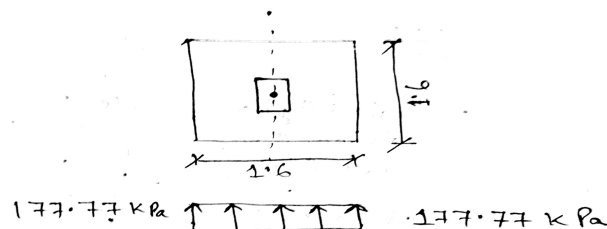
Introducing a square footing with size = $1.6 \text{ m} \times 1.6 \text{ m} > (1.38 \text{ m} \times 1.28 \text{ m})$ or $(1.33 \text{ m} \times 1.33 \text{ m})$

Satisfy.

B. Net Upward Soil Pressure (s_u)

$s_u = (\text{Total Factored Load} / \text{Area of Footing})$

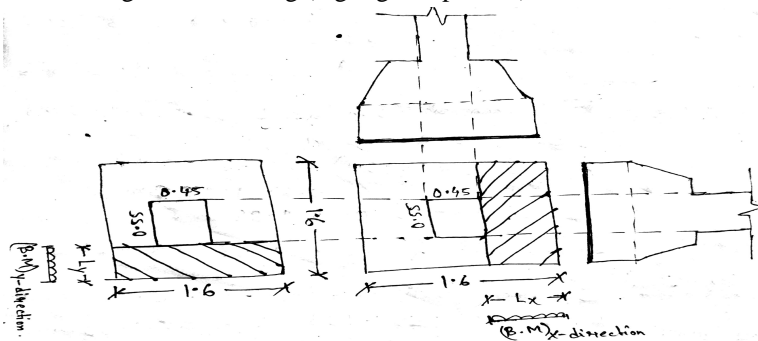
= $\{455.08 / (1.6 \times 1.6)\} = 177.77 \text{ KN/m}^2$



C. Calculation of Bending Moment at Critical Section of the Footing

Udl along both direction, $W = s_u \times B = 177.77 \times 1.6 = 284.43 \text{ KN/m}$.

Critical section @ face of column from edge of the footing (highlighted portion)



B.M about any direction, $M = (WL^2 / 2)$

Maximum B.M. about X direction, $M_x = (WL_y^2 / 2)$

$$L_y = \{(B-b)/2\} = (1.6 - 0.55)/2 = 0.525 \text{ m}$$

$$M_x = (284.43 \times 0.525^2 / 2) = 39.20 \text{ KN.m}$$

Maximum B.M. about Y direction, $M_y = (WL_x^2 / 2)$

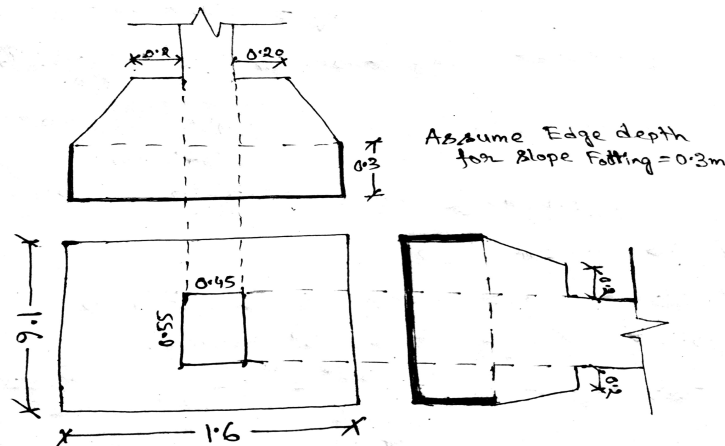
$$L_x = \{(L-a)/2\} = (1.6 - 0.45)/2 = 0.575 \text{ m}$$

$$M_y = (284.43 \times 0.575^2 / 2) = 47.02 \text{ KN.m}$$

D. Calculate Depth of Footing

Minimum offset with the column to be 50 mm.

Consider 200 mm of offset at all sides.



For M25 grade of concrete and Fe 500 steel,

Moment of Resistance, M.O.R, $M_u = 0.136 f_{ck} b d^2$

$$\text{M.O.R along X direction, } (M_u)_x = 39.20 \times 10^6 = 0.136 \times 25 \times 850 \times d^2,$$

b= width of resisting section along X direction = 450 + 200 + 200 = 850 mm

Calculating, $d = 116.46 \text{ mm}$

$$\text{Similarly, M.O.R along Y direction, } (M_u)_y = 47.02 \times 10^6 = 0.136 \times 25 \times 950 \times d^2,$$

b= width of resisting section along X direction = 550 + 200 + 200 = 950 mm

Calculating, $d = 120.65 \text{ mm}$

Consider overall depth, $D = 450 \text{ mm}$, 50 mm of effective cover, 16mm f bars use in both direction.

Effective depth,

$$\text{along Y direction, } d_y = \text{Overall depth} - \text{Cover} - j/2 = 450 - 50 - (16/2) = 392 \text{ mm}$$

$$\text{along X direction, } d_x = \text{Overall depth} - \text{Cover} - j - j/2 = 450 - 50 - 16 - (16/2) = 376 \text{ mm}$$

$$\text{Avg. depth} = (392 + 376)/2 = 384 \text{ mm.}$$

E. Reinforcement

Reinforcement along X direction->

$$\text{M.O.R, } (M_u)_y = 47.02 \times 10^6 \text{ N.m}$$

$$\text{Percentage of steel, Pt\%} = (50 f_{ck}/f_y) [1 - [1 - \{4.6 (M_u)_y / f_{ck} \times b \times d^2\}]^{1/2}]$$

$$= (50 \times 25/500) \times [1 - [1 - \{(4.6 \times 47.02 \times 10^6) / (25 \times 1600 \times 384^2)\}]^{1/2}] = 0.05 \%$$

Reinforcement along Y direction,

$$\text{M.O.R} = (M_u)_x = 39.20 \times 10^6 \text{ KN.m, and Pt\%} = 0.04 \%$$

But, as per I.S: 456: 2000, minimum reinforcement should be = 0.12 %

$$\text{taking 0.12\% of Pt, } A_{st} = (Pt/100) \times b d = (0.12/100) \times 1600 \times 384 = 737.28 \text{ mm}^2$$

$$\text{Take 16mm j bars, } a_{st} = 200.96 \text{ mm}^2$$

$$\text{No of bars} = A_{st}/a_{st} = (737.28/200.96) = 3.67, \text{ say 4 nos.}$$

F. Check for Clear Spacing

As per I.S:456-2000, Table-15,

For Fe500 steel, clear distance between bars should not be greater than 150 mm

$$c/c \text{ spacing} = (L\text{-cover on both sides} - j/2 - j/2) / (\text{No. of bar} - 1)$$

$$= (1600 - 50 - 50 - 16/2 - 16/2) / (4 - 1) = 494.67 \text{ mm}$$

and clear spacing between bars = $494.67 - j/2 - j/2 = 478.67 \text{ mm} > 150 \text{ mm}$

Not Satisfy.

Considering , c/c spacing between bar = 110 mm

so, clear spacing between bar = $110 - j/2 - j/2 = 94 \text{ mm} < 150 \text{ mm}$, Satisfy.

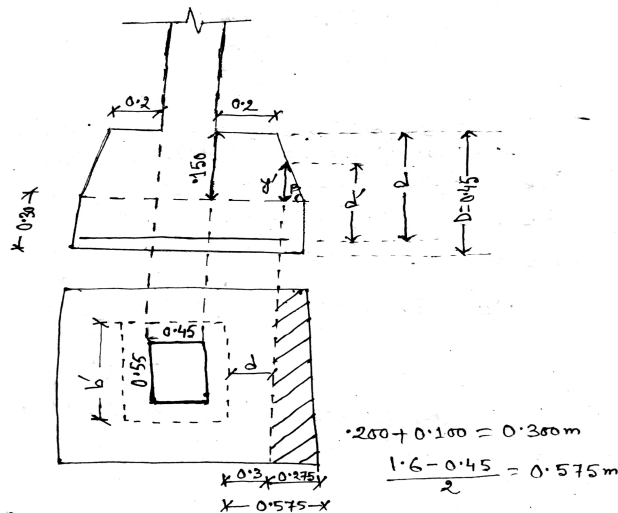
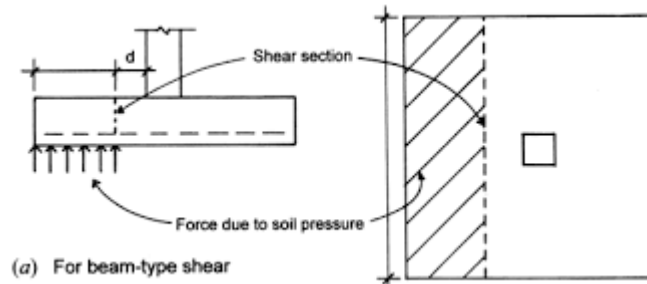
& No of bars = $\{(1600 - 50 - 50 - 8 - 8) / 110\} + 1 = 14.49$, say 15 Nos.

Therefore, Provide 15 Nos. of 16mm j bars @ 110 mm c/c in both direction.

$(A_{st})_{\text{provide}} = \text{no. of bar} \times \text{area of one bar} = 15 \times 200.96 = 3014.4 \text{ mm}^2 > 737.28 \text{ mm}^2$, OK.

$$Pt\% = 100 A_{st} / bd = (100 \times 3014.4) / (1600 \times 384) = 0.49 \%$$

G. Check for One-way Shear



$$\text{Depth @ face of column} = (450 - 300) = 150 \text{ mm}$$

For calculating y' ,

at depth 575 mm -> get depth = 150 mm

so at depth 275 mm -> get depth upto = $(150 / 575) \times 275 = 71.74 \text{ mm}$

Therefore, $Y' = 71.74 \text{ mm}$

$$d' = \text{depth of } y' + \text{edge depth} - \text{effective cover} - j/2 = 71.74 + 300 - 50 - (16/2) = 313.74 \text{ mm}$$

$$\text{Resisting width along Y direction, } b' = 450 + 2d = 450 + (2 \times 384) = 1218 \text{ mm.}$$

Critical section at 'd' distance from the face of column.

Max. shear stree, $u_u = \text{shear stress at critical section} \times \text{Area of Highlighted portion}$

$$= 177.77 \times (0.275 \times 1.6) = 78.22 \text{ KN}$$

& Nominal shear stress, I.S :456-2000, Page-72,

$$z_v = [u_u - \{ (M_u/d') \times \tan b \}] / b'd'$$

From diagram, $\tan b = (150/575) = 0.26$

$$\begin{aligned} \text{Moment @ critical section at distance 275 mm from the edge of footing, } M_u &= WL^2 / 2 \\ &= 284.43 \times 0.275^2 / 2 = 10.76 \text{ KN.m} \end{aligned}$$

$$\begin{aligned} \text{Therefore, Nominal shear stress, } z_v &= [78.22 - \{ (10.76/0.31374) \times 0.26 \}] / (1218 \times 313.74) \\ z_v &= 0.18 \text{ N/mm}^2 \end{aligned}$$

$$\text{\& Pt\%} = 100 A_{st} / bd = (100 \times 3014.4) / (1218 \times 313.74) = 0.79 \%$$

From Table-19, I.S:456-2000,

For M25 grade of concrete, $K = 1.32$

& If Pt% is 0.25% , then $z_c = 0.36$

$$\text{When Pt\% is 0.795, then } z_c = (0.36/0.25) \times 0.79 = 1.14 \text{ N/mm}^2$$

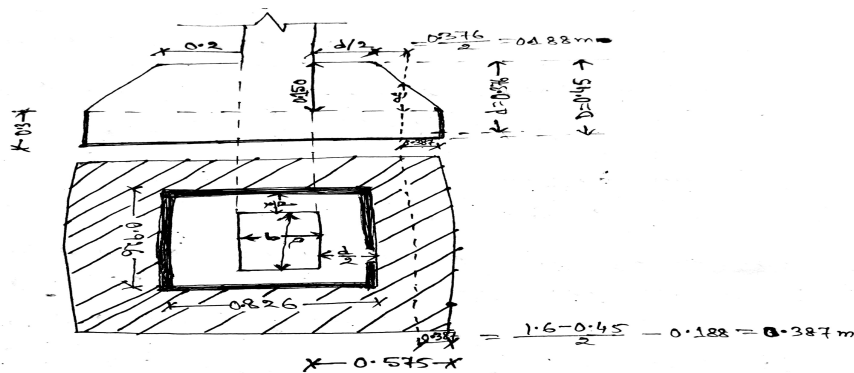
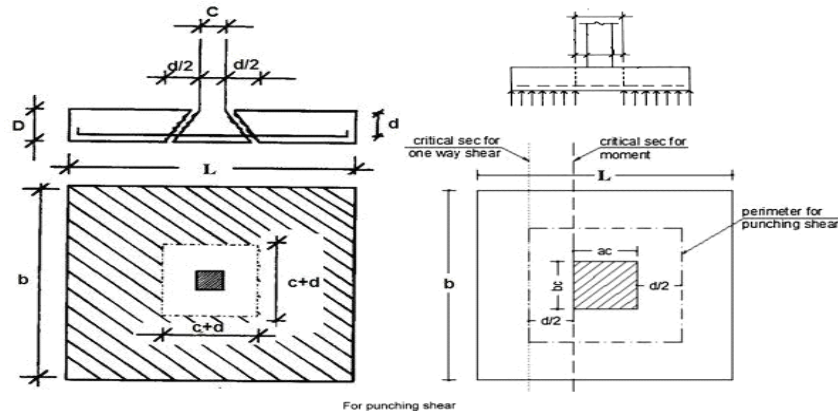
Finally, $z_c > z_v$ and One-way shear check is satisfied.

$$\begin{aligned} \text{For depth check, } u_u / Bd &= K z_c \Rightarrow d = u_u / (B \times K \times z_c) = (78.22 \times 10^3) / (1600 \times 1.32 \times 1.14) \\ &= 32.49 \text{ mm} < 384 \text{ mm on the basis of moment.} \end{aligned}$$

Hence, depth check is satisfied.

H. Check for Two-way Shear

Punching shear check @ critical section at peripherical at 'd/2' distance from the face of column.



$$y' = (150/575) \times 387 = 100.96 \text{ mm}$$

$$d' = \text{depth of } y' + \text{edge depth} - \text{eff. cover} - j - j/2 = 100.96 + 300 - 50 - 16 - 16/2 = 326.96 \text{ mm}$$

$$\begin{aligned} \text{Length of Pheriphery, } b_o &= 2 \times [(a + d/2 + d/2) + (b + d/2 + d/2)] \\ &= 2 \times [(550 + 188 + 188) + (450 + 188 + 188)] = 3504 \text{ mm} \end{aligned}$$

Maximum shear stress @ critical section,

$$\begin{aligned} u_u &= \text{shear stress at critical section} \times \text{Area of Highlighted portion} \\ &= 177.77 \times [(1.6 \times 1.6) - (0.926 \times 0.826)] = 319.12 \text{ KN} \end{aligned}$$

Nominal shear stress, $z_v = u_u / b_o d' = (319.12 \times 10^3) / (3504 \times 326.96) = 0.28 \text{ N/mm}^2$

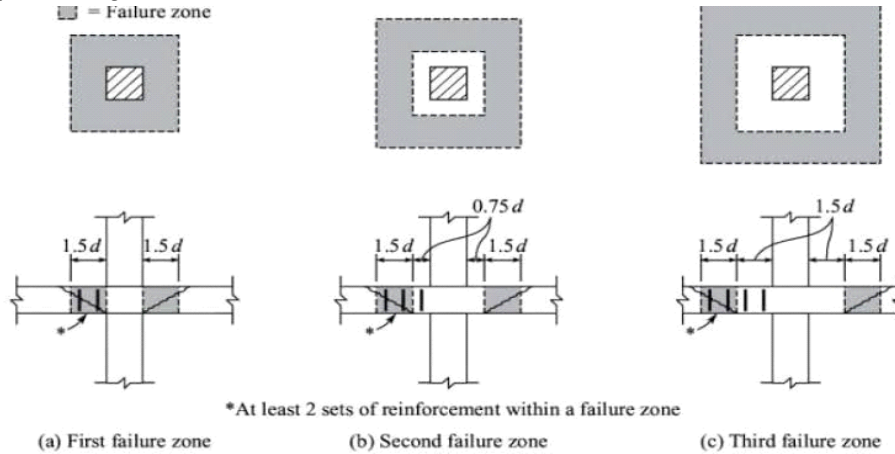
From IS: 456-2000, $z_c' = K_s \times z_c$, where $K_s = 0.5 + b_c = 0.5 + (B/D) = 0.5 + (450/550)$

So, $K_s = 1.32$ & $z_c = 0.25 (f_{ck})^{1/2} = 0.25 \times (25)^{1/2} = 1.25 \text{ N/mm}^2$

& $z_c' = K_s \times z_c = 1.32 \times 1.25 = 1.65 \text{ N/mm}^2$

Finally, $z_c' > z_c$, Two-way shear check is satisfied.

I. Check for Development Length (L_d)



According to IS: 456-2000,

$$L_d = (1/4) \times j \times (s_s / t_{bd})$$

For M25 grade of concrete & Fe 500 steel,

$$\text{Bond stress, } t_{bd} = 1.4 \text{ N/mm}^2$$

& Permissible stress for steel, $s_s = 0.55 f_y = 0.55 \times 500 = 275 \text{ N/mm}^2$

$$L_d = (1/4) \times 16 \times (275 / 1.4) = 785.71 \text{ mm}$$

(ix) Transfer of Load at Base of Column -

As per IS: 456-2000, Cl-76.4, Page-65,

$$\text{Allowable Bearing stress} = 0.45 f_{ck} = 0.45 \times 25 = 11.25 \text{ N/mm}^2$$

$$\text{Allowable Bearing Force} = \text{Allowable Bearing stress} \times \text{Area of column}$$

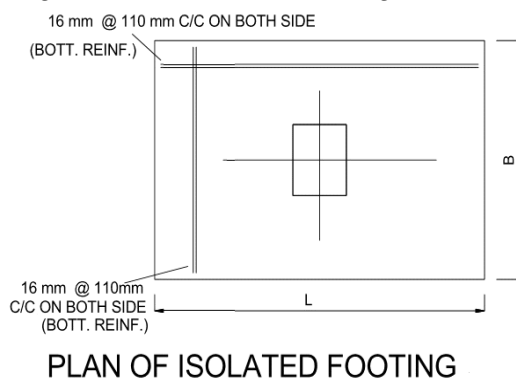
$$= 11.25 \times 450 \times 550 = 2784.4 \text{ KN}$$

Since, Actual load on column = 455.08 KN (Factored working load)

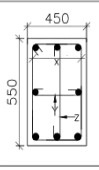
Therefore, Allowable Bearing Force > Actaul factored working load.

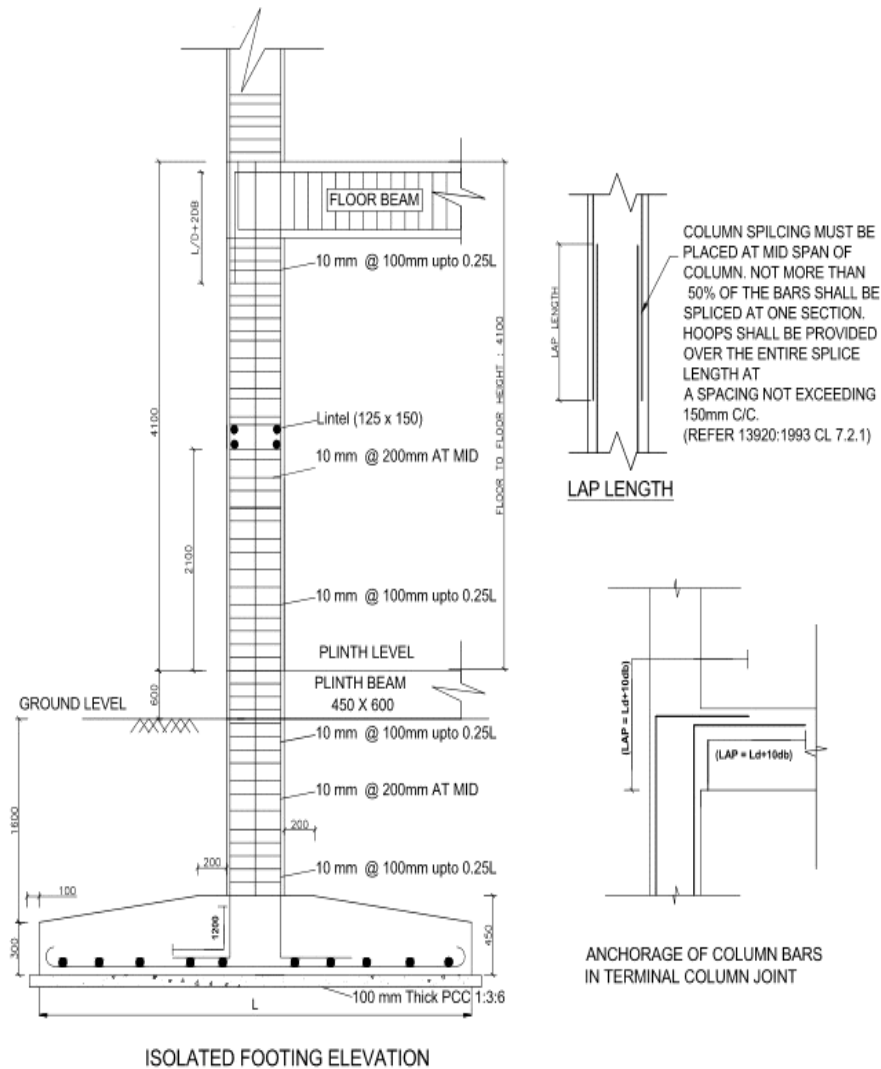
Hence, the structure s safe.

J. Detailing of Drawing (For both Column and Footing)



COLUMN SCHEDULE:

COLUMN SECTION FOOTING LVL. TO ROOF LVL.	
COLUMN SIZE	(450x550)
REINFORCEMENT	8-200
STIRRUPS	10 Q
SPACING SUPPORT UPTO 0.25L	@100 c/c(x,y,z)
SPACING MID	@200 c/c(x,y)
COLUMN MARKS	C15



Foundation Mark	Column No.	Column			Foundation		Cover (m)	Reinforcement
		b (m)	l (m)	h (m) above GL	L (m)	B (m)		16 mm @ 110 mm
F I15	C 15	0.550	0.450	4.100	1.600	1.600	0.050	16 mm @ 110 mm

ISOLATED FOOTING SCHEDULE

VIII. CONCLUSION

This study was undertaken for analysing the load transfer mechanism of structural elements and designing prospect of Biaxially Loaded Column with Isolated Slope Square Footing in building at construction of Modification of Terminal Building at Silchar Airport. The basic knowledge of structural elements design comes from its mechanism and analysis aspect which gives the better knowledge in this field. Structural footing plays a big rule in the construction industry. Few footing are easily design, few are in complex form depending on various demand comes from owner- in a small area with large prospect. While designing each and every structural elements in India, it is essential to follow up I.S codel provisions.

IX. ACKNOWLEDGMENT

Abdul Aziz was born at Nilambazar, Karimganj district of Assam. He pursued his bachelor degree in Civil Engineering from Holy Mary Institute of Technology under J.N.T. University, Hyderabad in 2017 and join continue in Master of Technology in Structural Engineering and Construction Management program from Golden Valley Integrated Campus, previously B.E.S Group of Institution, under J.N.T University, Ananapur, A.P. He has join at Airports Authority of India and Service one year of Professional Training as an Graduate Apprentice Trainee (GAT) at Silchar Airport. He is connected with many Civil and Structural Engineering societies and Associations such as Student Member of International Association for Bridge and Structural Engineering (IABSE)-Zurich, Switzerland, Graduate Member of The Institution of Engineers (IStructE)-UK, Associate Member in Indian Association of Structural Engineers (IAStructE), Professional Member of Institute for Engineering Research and Publication (IFERP), Member of Structural Engineering Forum of India. He has published research papers, paper¹ entitled 'Analysis on mix design of M25 grade of Concrete- A case study on modification of terminal building at Silchar Airport', paper² entitled 'Earthquake Resistant Design of Building-A case study on modification of terminal building at Silchar Airport'. His thesis entitled 'A case study on modification of terminal building at Silchar Airport'. His research interest on Earthquake Engineering, Analysis and Design of various structure, Concrete Technology, Construction Materials and Management. His thesis entitled 'A case study on modification of terminal building at Silchar Airport'.

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