DEPARTMENT OF CIVIL ENGINEERING

IIT DELHI

FOOTING DESIGN

Dr. Suresh Bhalla

Professor

Tel: 2659-1040 Email: Sbhalla@civil.iitd.ac.in

FOUNDATIONS

- SHALLOW
  - FOOTINGS
    - ISOLATED
    - COMBINED
  - MAT
  - RAFT
- DEEP
  - PILES
  - CAISSONS

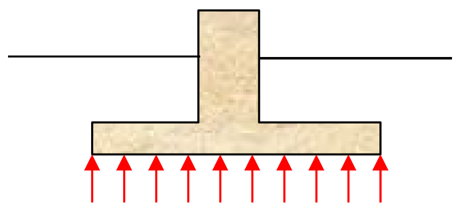
There is no glory in foundations (Terzaghi)

Foundations can bring glory to structure (Kaniraj)

FOUNDATIONS

SHALLOW

Depth to width ratio, D/B <= **1**



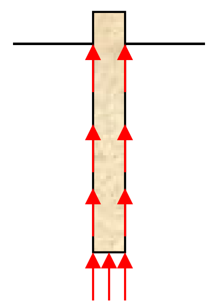
Load transfer through direct soil pressure

Construction: Excavate, construct, cover, compact (small disturbance)

DEEP

Moderately deep: 1 < D/B <= **15**

Deep: D/B > **15**



Load transfer through skin friction and end reaction

Driving or boring + casting (Large disturbance)

FOUNDATIONS

Geotechnical Engineer

Location and depth criteria

Bearing capacity criteria- safety against shear failure of soil

Settlement criteria- should not settle excessively.

Structural Engineer

Structural drawings follow location and depth criteria

Soil pressure does not exceed allowable pressure as per soil report

Structurally safe

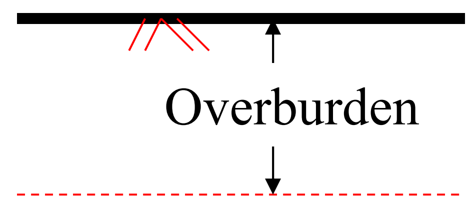
TERMINOLOGIES

Ultimate bearing capacity, q_{ult}

Total gross pressure at base of foundation which causes shear failure.

Ultimate net bearing capacity, $q_{ult, net}$

$q_{ult, net} = q_{ult} - q$ **(q = Effective soil pressure at foundation base)**



Safe net bearing capacity, $q_{safe, net}$

$q_{safe, net} = (q_{ult, net})/$ **Factor of safety**

Safe bearing pressure, $q_{safe, pr}$

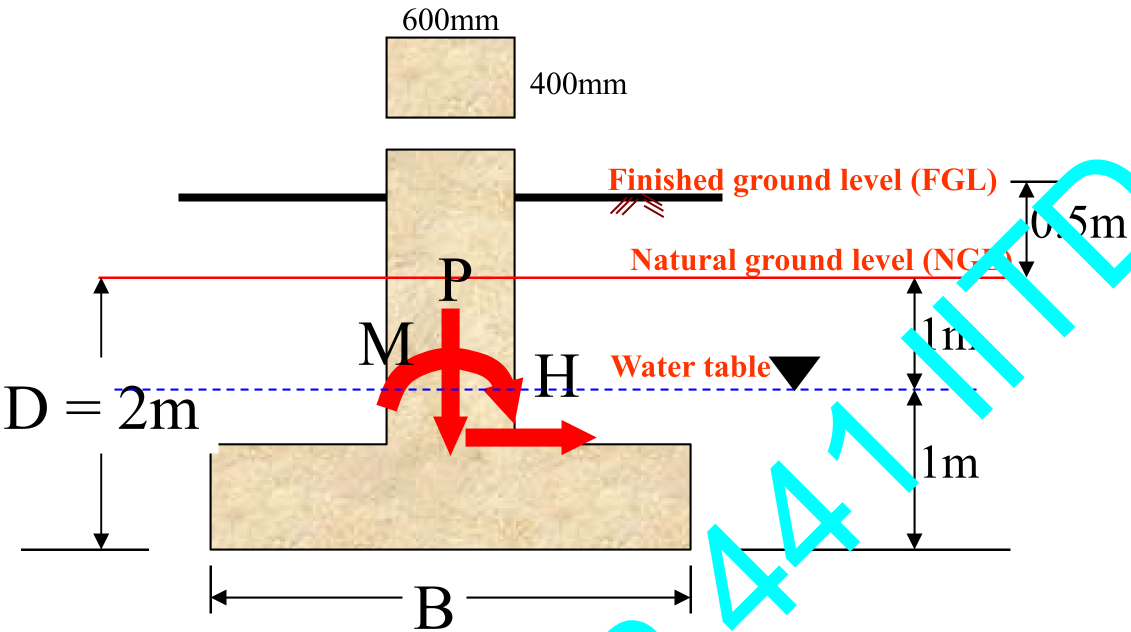
Maximum net pressure that foundation can transmit without the settlement exceeding the permissible value.

Allowable net bearing pressue, $q_{all, net}$

Lower of ($q_{safe, net}$ and $q_{safe, pr}$)

WORKING STRESS APPROACH

ISOLATED FOOTING



Dead + Earthquake

$P = 1200$ kN

$M = 125$ kN-m

$H = 20$ kN

$\gamma_{soil} = 18$ kNm^{-3}

$q_{all,\ net} = 180$ kNm^{-2}

Design Steps:

(1) Size of footing to satisfy base pressure requirements

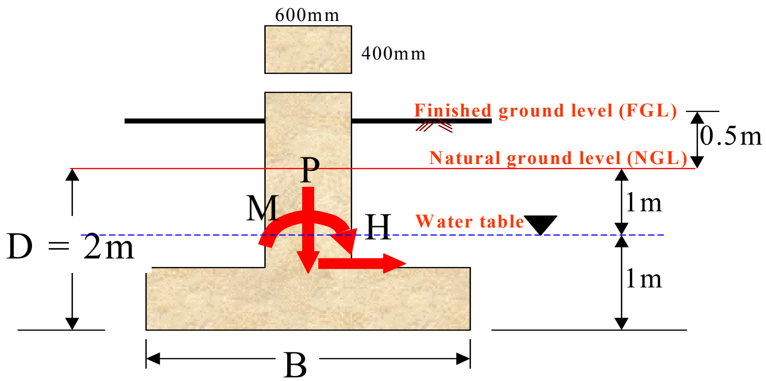
(2) Design of base for bending

(3) Check for one-way shear

(4) Check for two-way shear

(5) stability against sliding and overturning

(1) SIZE OF FOOTING TO SATISFY BASE PRESSURE REQUIREMENTS



Dead + Earthquake

P = 1200 kN

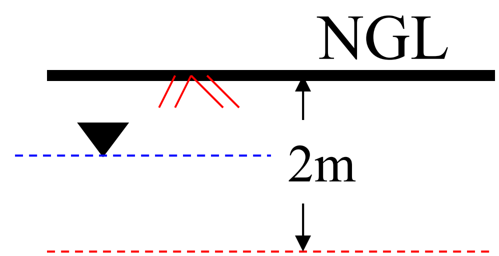
M = 125 kN-m

H = 20 kN

$\gamma_{soil} = 18$ kNm^{-3}

$q_{all,\ net} =$ 180 kNm^{-2}

Try 2.5x2.5x0.4m thick footing



Design Steps:

Under normal conditions

Submerged density

$q_{all,\ gross} = q_{all,\ net} + q = 180 + 18 \times 1 + (18-10) \times 1 = 207$ kNm^{-2}

Under wind/ earthquake

Submerged density

$q_{all,\ gross} = 1.25\ q_{all,\ net} + q = 1.25 \times 180 + 18 \times 1 + (18-10) \times 1 = 251$ kNm^{-2}

P (total) = P_t = P + Overburden = 1200 +2.5x2.5x0.4x (25-10) + (2.5x2.5-0.4x0.6) (0.6 x8 + 1.5 x 18)

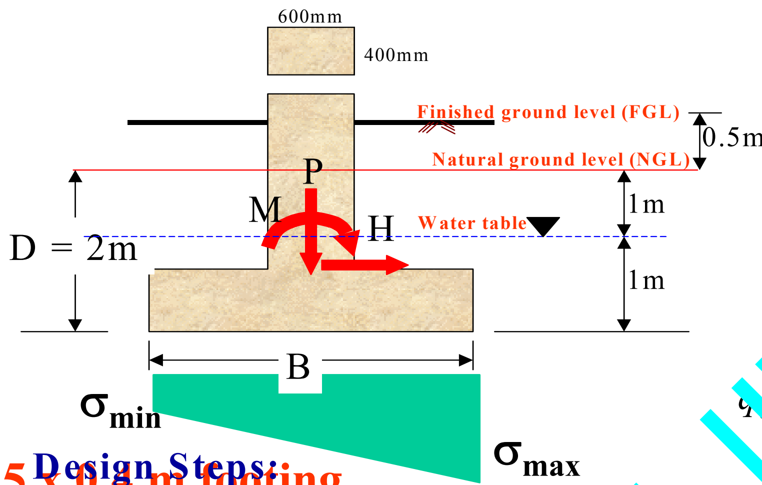
Footing base

Soil

= 1428.61 kN

M (total) = M_t = M + H*(Footing thickness) = 125 + 20 x 0.4 = 133 kN-m

(1) SIZE OF FOOTING TO SATISFY BASE PRESSURE REQUIREMENTS



Dead + Earthquake

$P = 1200$ kN

$M = 125$ kN-m

$H = 20$ kN

$\gamma_{soil} = 18$ kNm^{-3}

$q_{all,\ net} = 180$ kNm^{-2}

Design Steps:

For 2.5 x 2.5 x 0.4 m footing

Area A = B^2 = 6.25 m^2 **Section modulus Z = ($B^3/6$) = 6.25 m^3**

$$\sigma_{max} = \frac{P_t}{A} + \frac{M_t}{Z}$$

$$\sigma_{min} = \frac{P_t}{A} - \frac{M_t}{Z}$$

279.65 kN/m^2 > $q_{all,\ gross}$ = 251 kN/m^2

177.51 kN/m^2

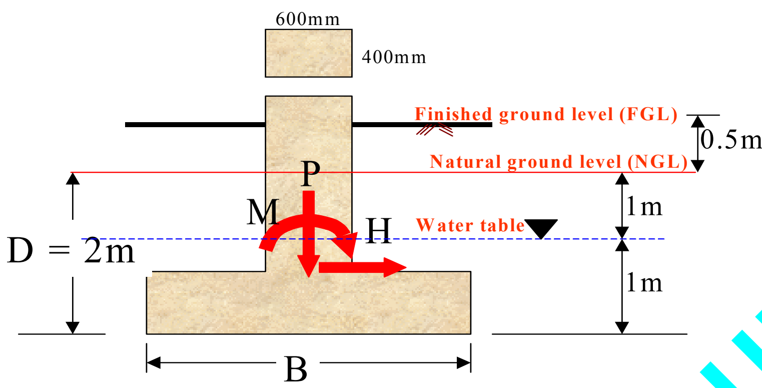
Try 2.7 x 2.7 x 0.4 m footing A = 7.29 m^2 **Z = 3.28 m^3** **P_t = 1461.7 kN**

σ_{max} = 241.05 kN/m^2

< $q_{all,\ gross}$ = 251 kN/m^2

σ_{min} = 159.96 kN/m^2

(1) SIZE OF FOOTING TO SATISFY BASE PRESSURE REQUIREMENTS



Dead + Earthquake

$P = 1200$ kN

$M = 125$ kN-m

$H = 20$ kN

$\gamma_{soil} = 18$ kNm^{-3}

$q_{all,\,net} = 180$ kNm^{-2}

Design Steps:

P (total) = P_t = P + Overburden

$$\sigma_{1,2} = \frac{P_t}{A} \pm \frac{M_t}{Z} = \frac{P}{A} \pm \frac{M_t}{Z} + \frac{P_{overburden}}{A}$$

Overburden pressure = 0.4x(25-10) + 0.6 x (18-10) + 1.5 x 18 = 37.8 kN/m^2

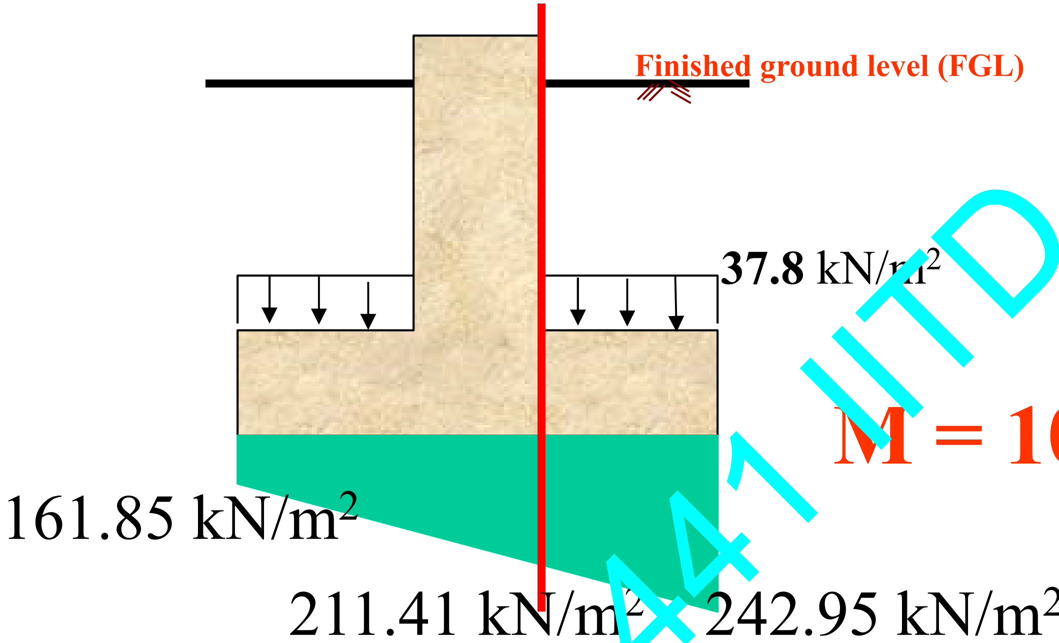
$\sigma_{max} = 242.95$ kN/m^2

$\sigma_{min} = 161.85$ kN/m^2

Slightly higher since additional soil considered at col. location

$\sigma_{max} = 241.05$ kN/m^2 ⟵ **Exact** ⟶ $\sigma_{min} = 159.96$ kN/m^2

(2) DESIGN OF BASE FOR BENDING



M25 concrete
Fe415 steel

d = 400-50-10 = 340mm

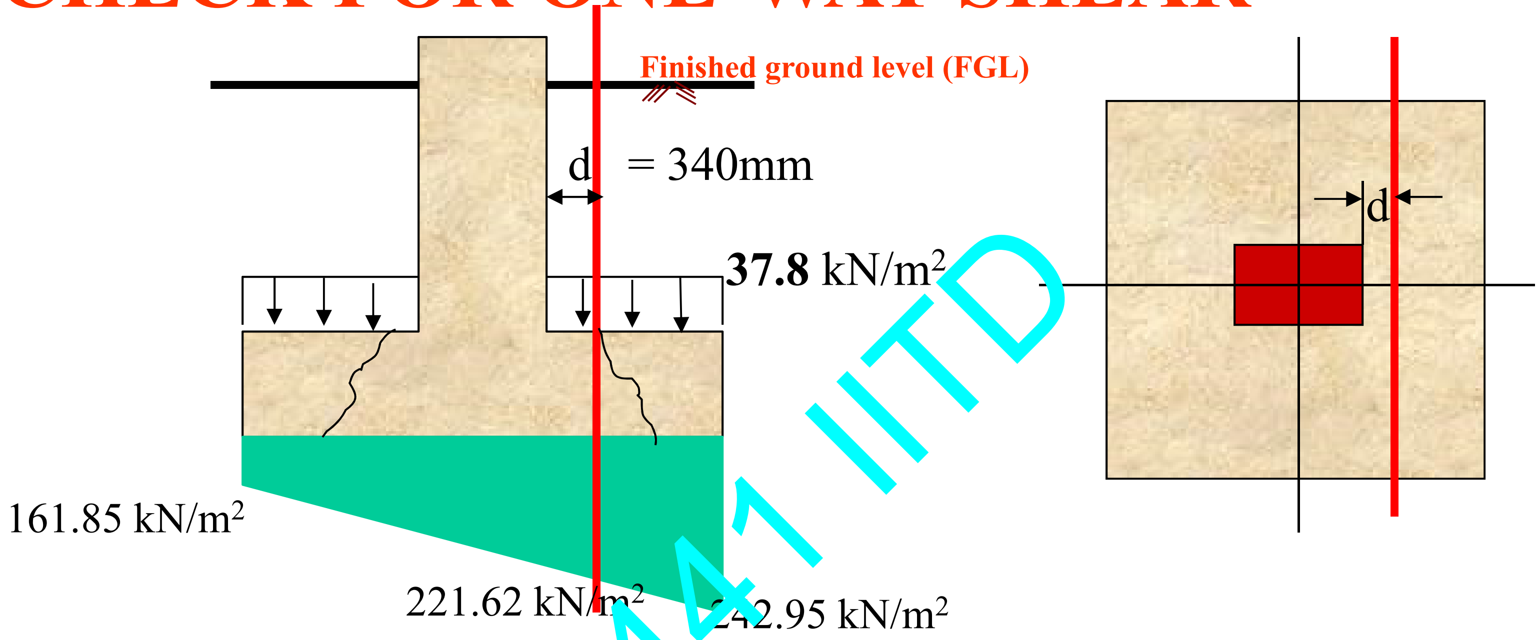
M = 107.29 kNm/m

$$M_u = 1.5 \times 107.29 = 160.94 \text{ kNm/m}$$

$$M_u / bd^2 = \frac{160.94 \times 10^6 \text{ Nmm}}{1000\text{mm} \times (340)^2 \text{ mm}^2} = 1.39 \text{ Nmm}^{-2}$$

A_{st} = 0.417% = 14.2 cm²/m. Provide 16ϕ @ 140 mm c/c = 14.36 cm²/m = 0.42%

(3) CHECK FOR ONE-WAY SHEAR



$V = 138.1$ kNm/m $\quad V_u = 1.5 \times 138.1 = 207.13$ kN/m

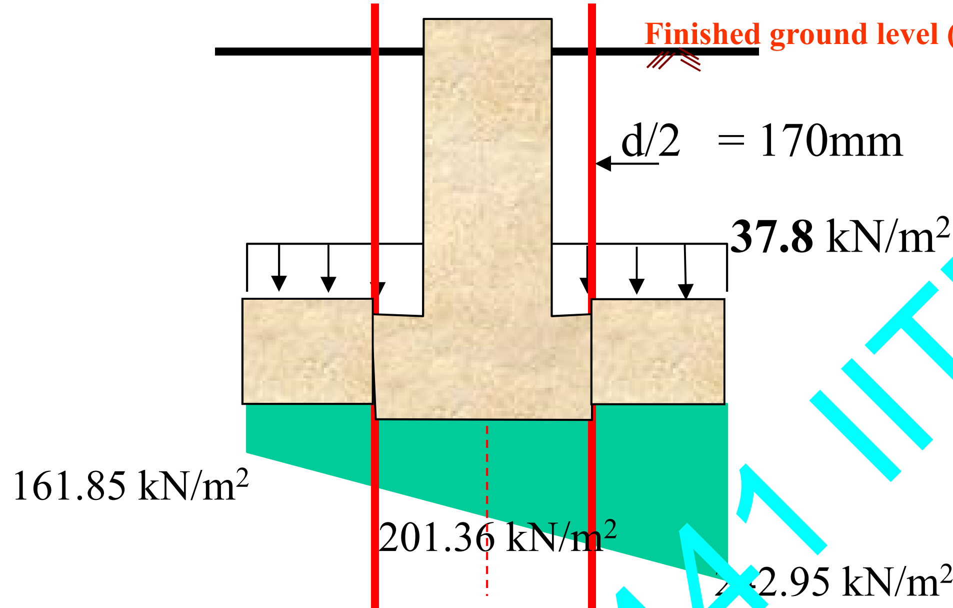
Nominal shear stress $\tau_v = \dfrac{207.13 \times 10^3 \text{ N}}{1000\text{mm} \times (340) \text{ mm}} = 0.609 \text{ Nmm}^{-2}$

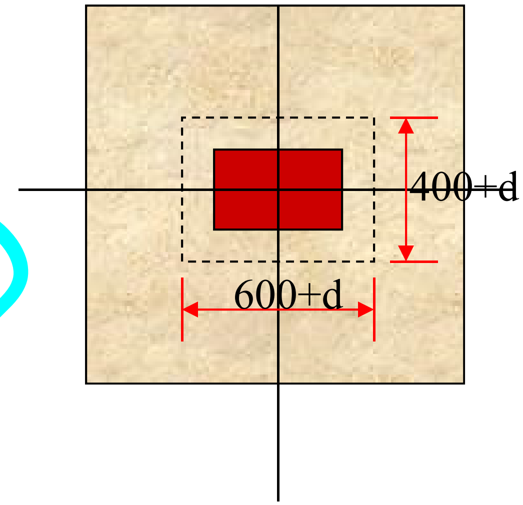
Shear strength of concrete (for 0.42% steel) $\tau_c = 0.448 \text{ Nmm}^{-2} < \tau_v$

Pg 73, IS 456

Either increase ‘d’ or increase reinforcement to 1% (let us increase reinforcement)

(4) CHECK FOR TWO-WAY (PUNCHING) SHEAR





$$V = 1200 - (0.9 \times 0.74)(201.36 - 37.8) = 1086.23 \text{ kN}$$

$$V_u = 1.5 \times 1086.23 = 1629.34 \text{ kN}$$

$$\tau_v = \frac{1629.34 \times 10^3 \text{ N}}{2(940+740) \text{ mm} \times (340) \text{ mm}} = 1.426 \text{ Nmm}^{-2}$$

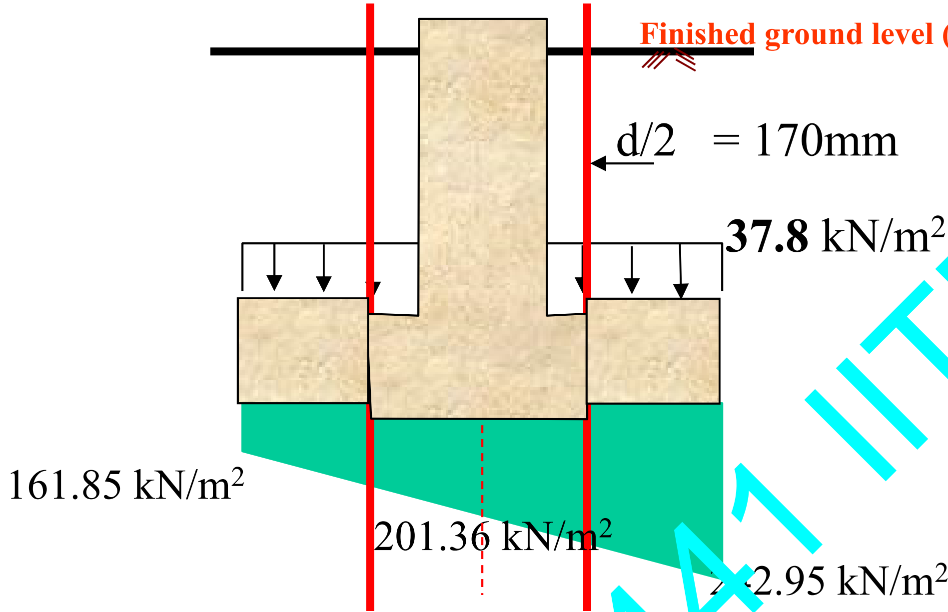
$\beta_c = (0.4/0.6)$

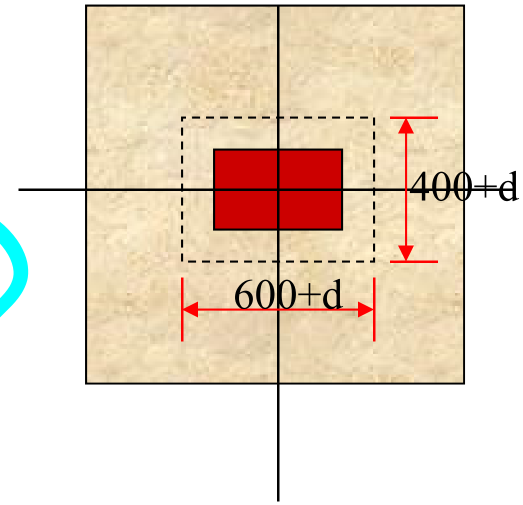
(Pg. 59, IS 456)

Shear strength of concrete $= k_s \tau_c = 1.11 \text{ Nmm}^{-2} < \tau_v$

$\tau_c = 0.25\sqrt{f_{ck}} = 1.11 \text{ Nmm}^{-2}$ $k_s = 0.5 + \beta_c = 1.0 \ (<=1.0)$

(4) CHECK FOR TWO-WAY (PUNCHING) SHEAR





τ_v = 1.426 Nmm^{-2} > 1.11 Nmm^{-2} ($k_s \tau_c$)

Increase thickness to 500mm => d = 440mm

V = 1200 -(1.04 x 0.84)(201.36-37.8) = 1057.1 kN

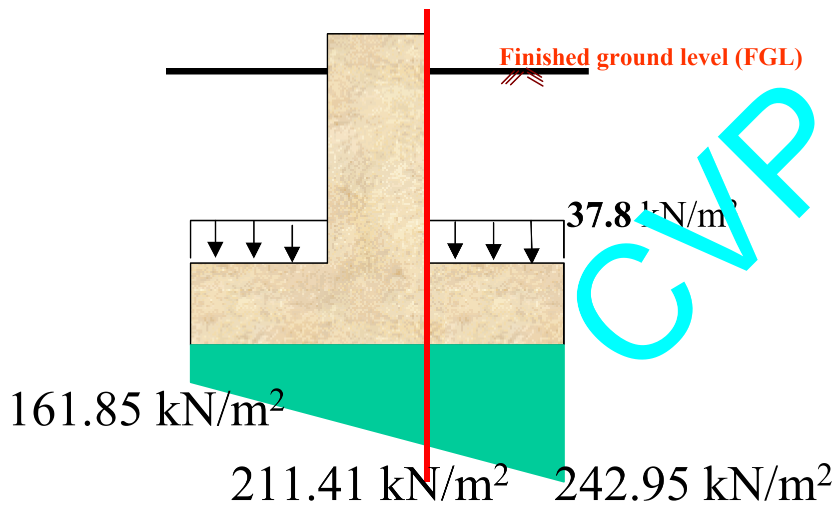
V_u = 1.5 x 1057.1 = 1585.65 kN

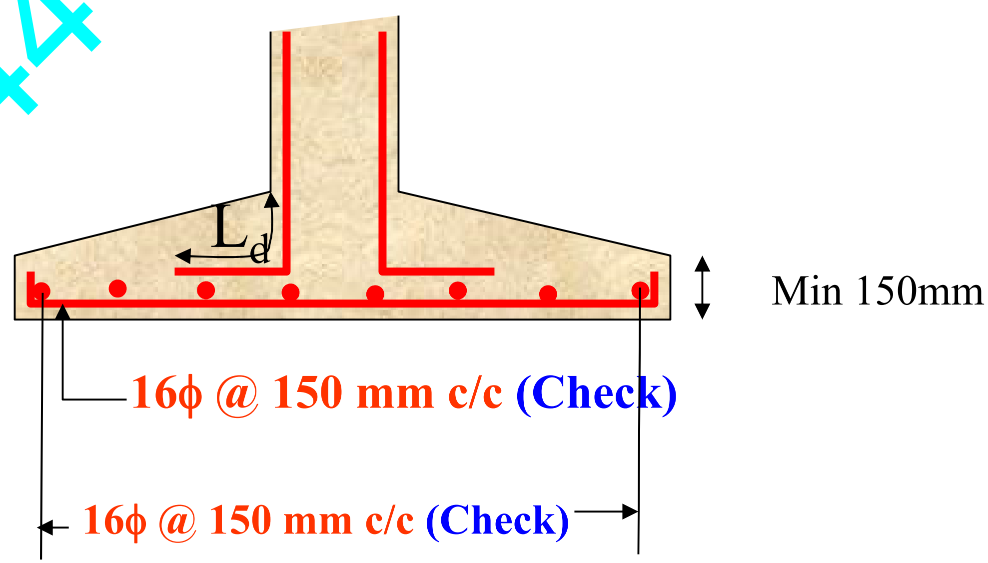
$$\tau_v = \frac{1585.65 \times 10^3 \text{ N}}{2(1040+840)\text{mm} \times (440)\text{ mm}} = 0.958 \text{ Nmm}^{-2} < k_s \tau_c$$

OK

*REDESIGN FOOTING FOR BENDING AND 1-WAY SHEAR

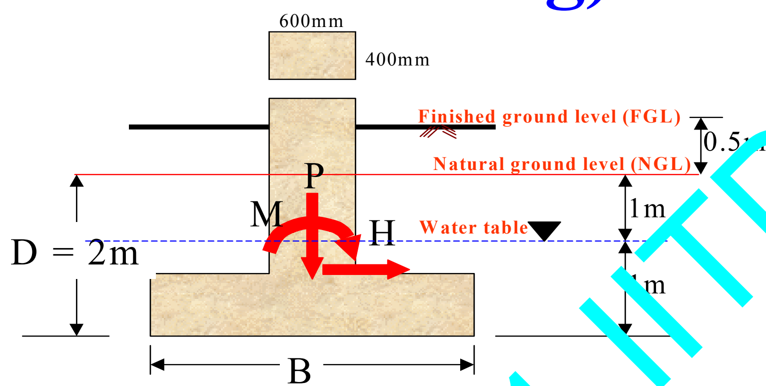
REINFORCEMENT DETAILING





(5) SAFETY AGAINST SLIDING AND OVERTURNING

(for a stand alone footing) Sec 20 (p33): IS 456:2000



Dead + Earthquake

P = 1200 kN

M = 125 kN-m

H = 20 kN

γ_{soil} = 18 kNm^{-3}

$q_{all,\ net}$ = 180 kNm^{-2}

OVERTURNING

Design Steps:

Restoring moment > 1.2 M_o(due to DL) + 1.4 M_o(due to IL)

Consider a DL = 90% IL = 0 for restoring moment calculation

Pg. 33, IS 456

SLIDING

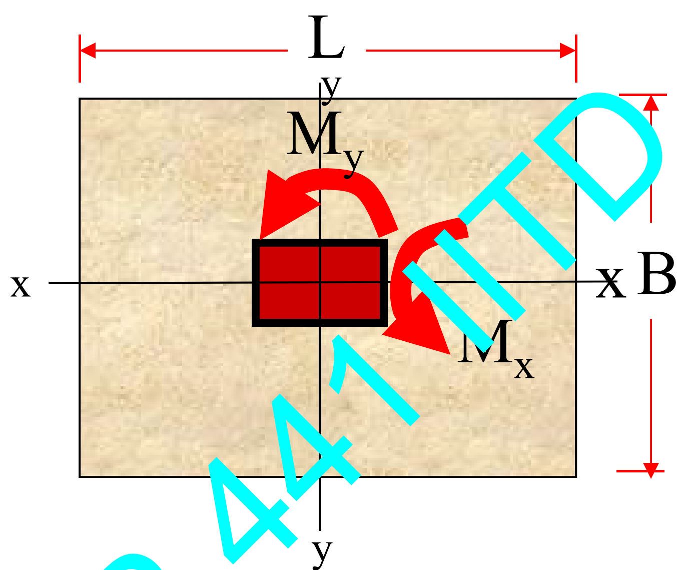
Restoring force > 1.4 H

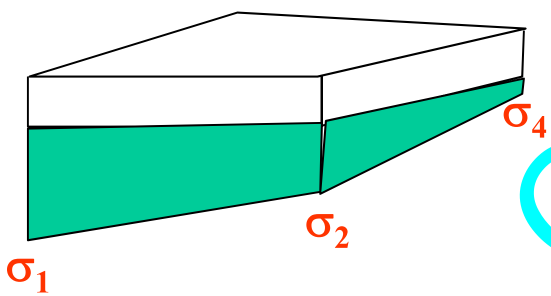
Consider a DL = 90% IL = 0

DL = Dead load

IL = Imposed load

ISOLATED FOOTING UNDER BIAXIAL BENDING





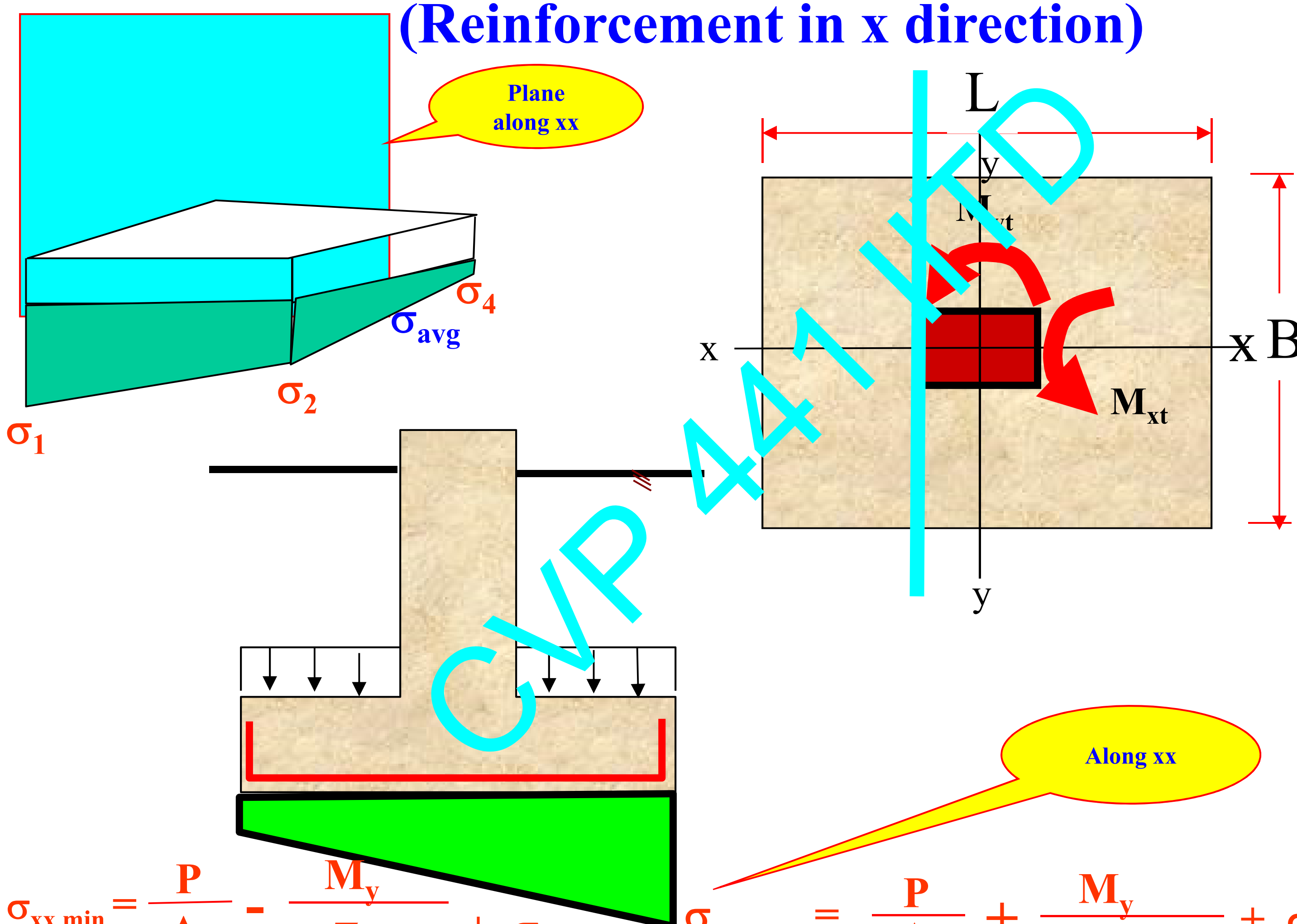
$$\sigma_{1,2,3,4(gross)} = \frac{P}{A} \pm \frac{M_x}{Z_x} \pm \frac{M_y}{Z_y} + \sigma_{overburden}$$

$Z_x = LB^2/6$ $\qquad$ $Z_y = BL^2/6$

M_x, M_y : TOTAL MOMENTS ABOUT THE BASE OF FOOTING

ISOLATED FOOTING UNDER BIAXIAL BENDING

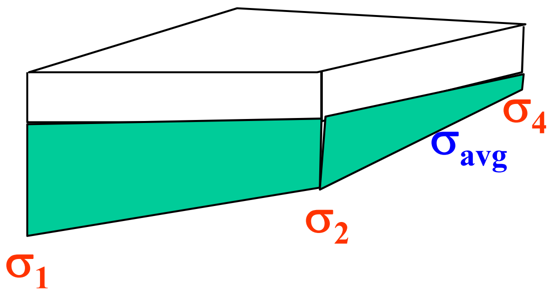
(Reinforcement in x direction)

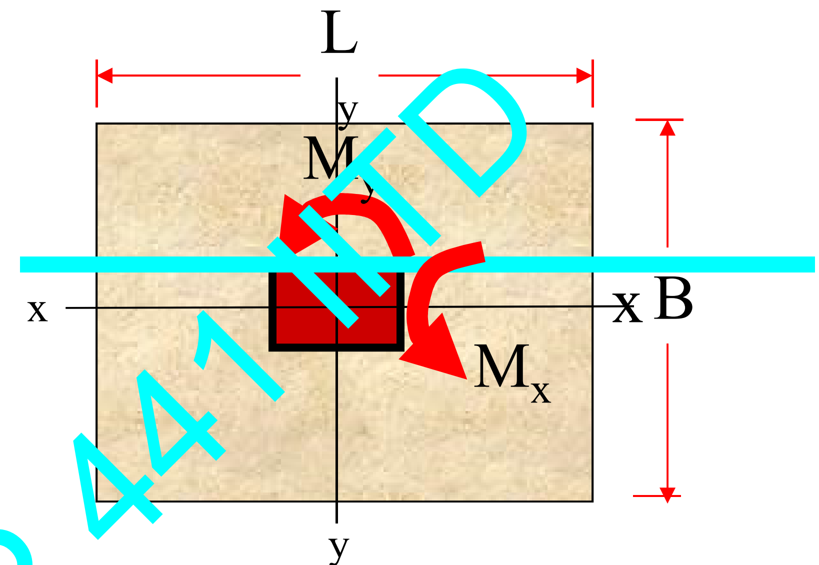


$$\sigma_{xx,min} = \frac{P}{A} - \frac{M_y}{Z_y} + \sigma_{overburden}$$

$$\sigma_{xx,\,max} = \frac{P}{A} + \frac{M_y}{Z_y} + \sigma_{overburden}$$

ISOLATED FOOTING UNDER BIAXIAL BENDING





Similarly, Reinforcement in y direction can be determined

Design Steps:

(1) Size of footing to satisfy base pressure requirements

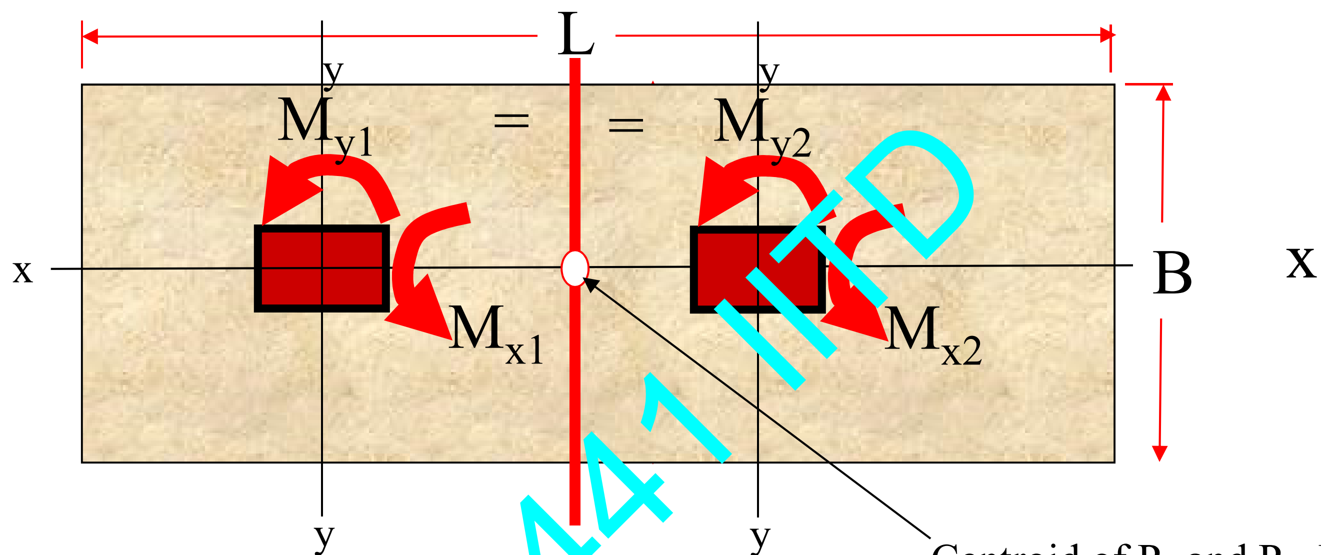
(2) Design of base for bending

(3) Check for one-way shear

(4) Check for two-way shear

(5) stability against sliding and overturning

COMBINED FOOTING



Centroid of P_1 and P_2. If not able to do this, additional moment should be added to M_{yt}

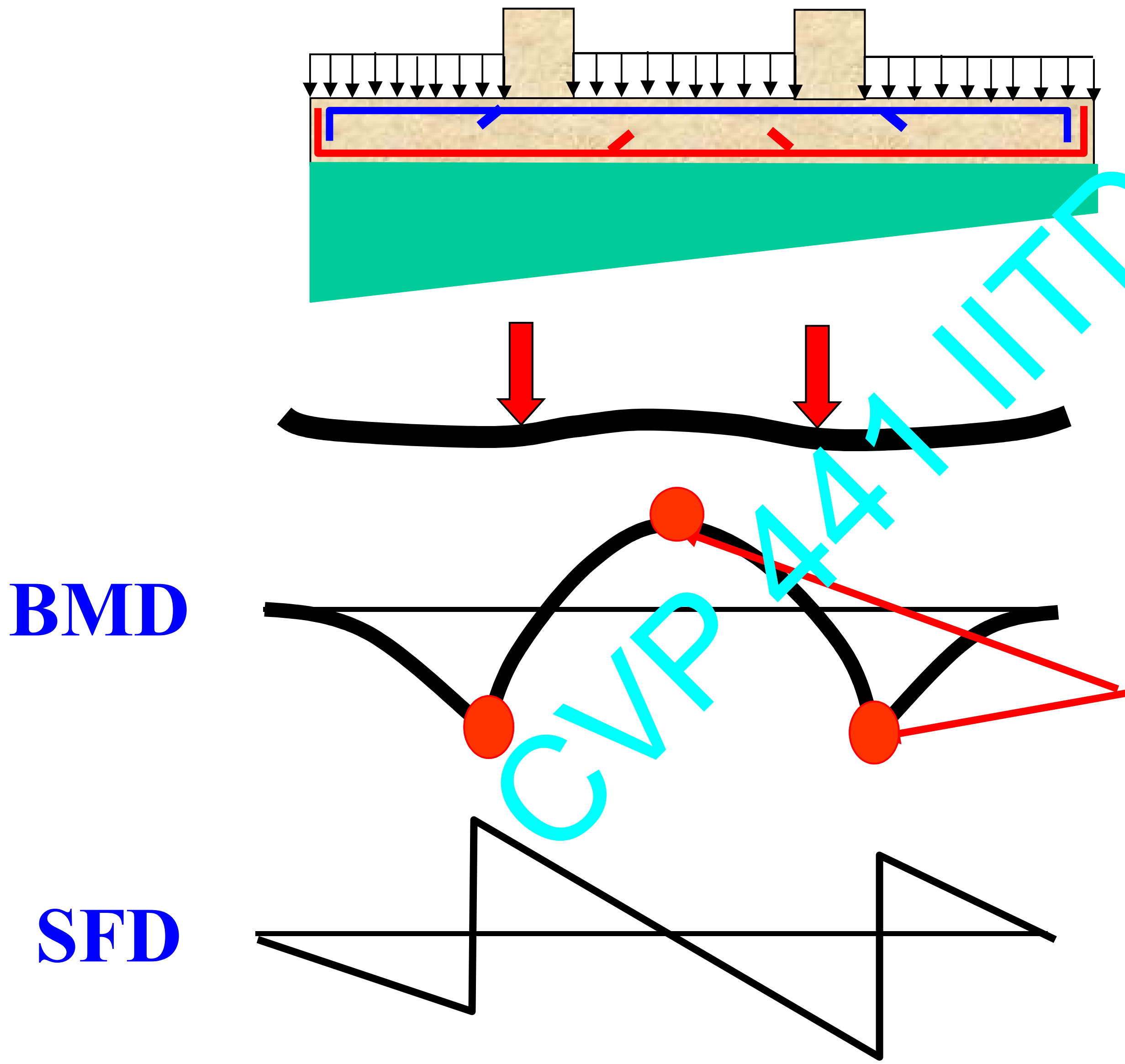
$P_t = P_1 + P_2$ + Overburden

$M_{xt} = M_{x1} + M_{x2}$ + Moment due to shears

$M_{yt} = M_{y1} + M_{y2}$ + Moment due to shears & eccentricity

$\sigma_{1,2,3,4}$ = To be determined as in the case of isolated footing
(assumption: Combined footing behaves as a rigid base)

COMBINED FOOTING



If very high, a beam may be provided in x direction (slab-one way)

DISTRIBUTION OF TENSILE REINFORCEMENT

(Section 34, pg. 65, IS 456:2000)

One way footing:

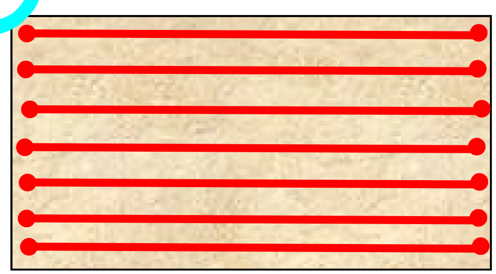
Should be uniformly distributed across entire width

Two way square footing:

Should be uniformly distributed across entire width in each direction

Two way rectangular footing:

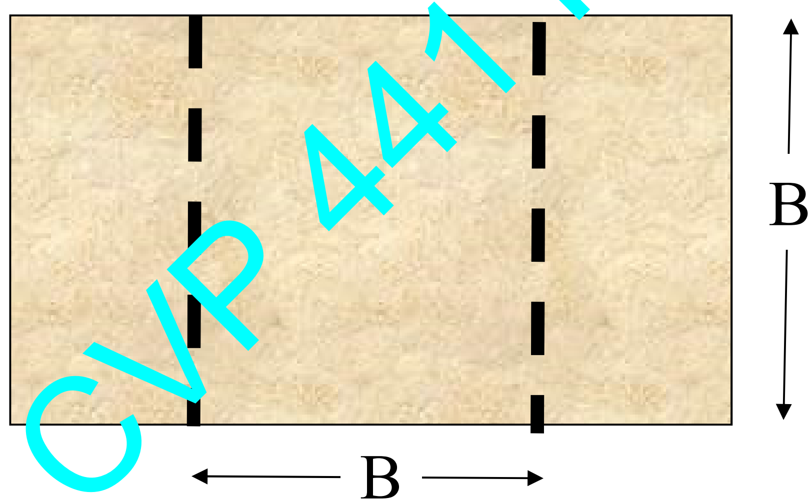
Reinforcement in longer direction should be uniformly distributed across entire width



DISTRIBUTION OF TENSILE REINFORCEMENT

Two way rectangular footing:

Reinforcement in shorter direction should be distributed in three strips



$$A_{centre} = \frac{A_{total}}{1+(L/B)}$$

Balance steel to be uniformly distributed in exterior strips