DEPARTMENT OF CIVIL ENGINEERING

IIT DELHI

Dr. Suresh Bhalla

Associate Professor

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

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

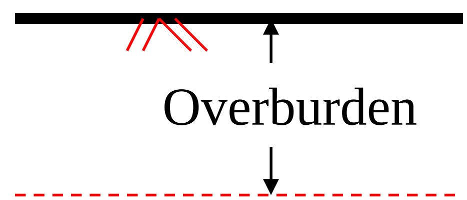
TERMINOLOGIES

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, $q_{safe, net}$

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

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

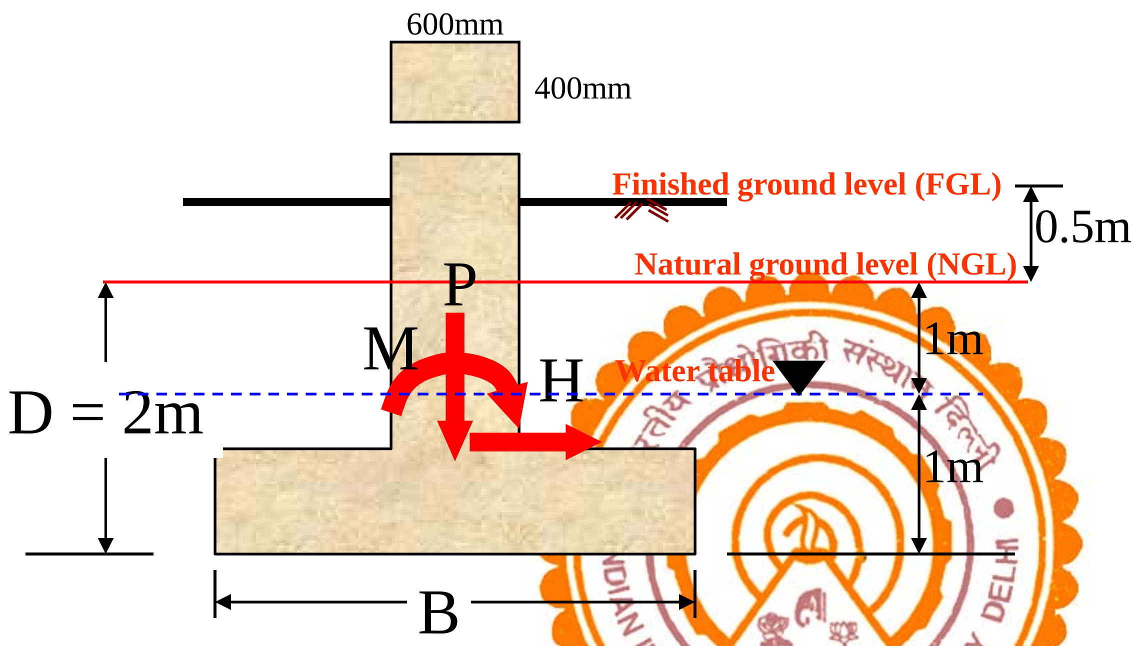
Maximum net pressure that foundation can transmit without the settlement exceeding the permissible value.

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

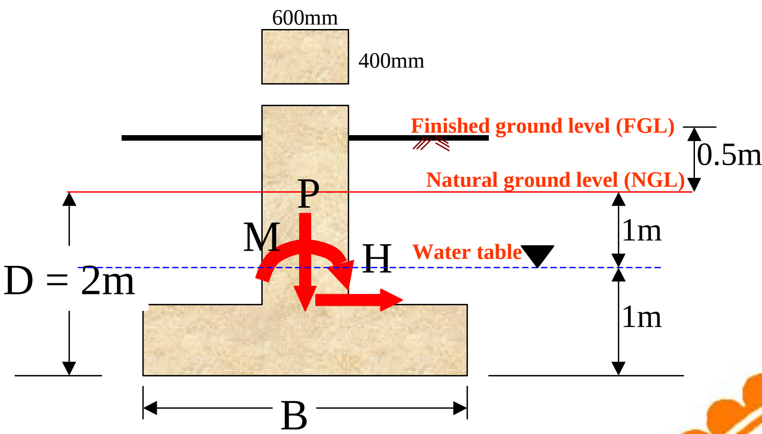
(2) Design of base for bending

(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

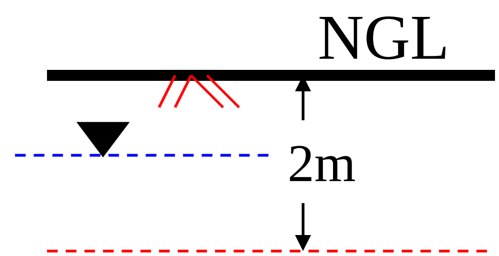
M = 125 kN-m

H = 20 kN

γ_{soil} = 18 kNm^{-3}

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

Try 2.5x2.5x0.4m thick footing



Under normal conditions

$q_{all,\,gross} = q_{all,\,net}$ + q = 180 + 18 x1 + (18-10)x1= 207 kNm^{-2}

Submerged density

Under wind/ earthquake

Submerged density

$q_{all,\,gross}$ = 1.25 $q_{all,\,net}$ + q = 1.25 x 180 + 18 x1 + (18-10)x1= 251 kNm^{-2}

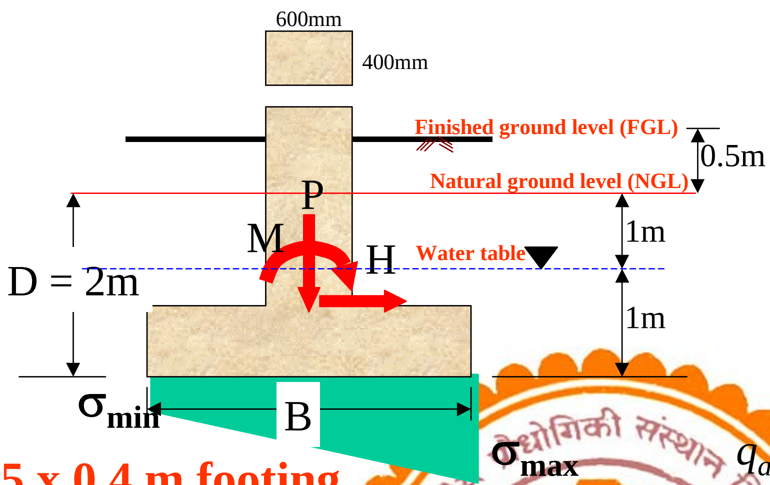
P (total) = P_t = P + Overburden = 1200 +2.5x2.5x0.4x (25-10) **Footing base**

+ (2.5x2.5-0.4x0.6) (0.6 x8 + 1.5 x 18) **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}

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

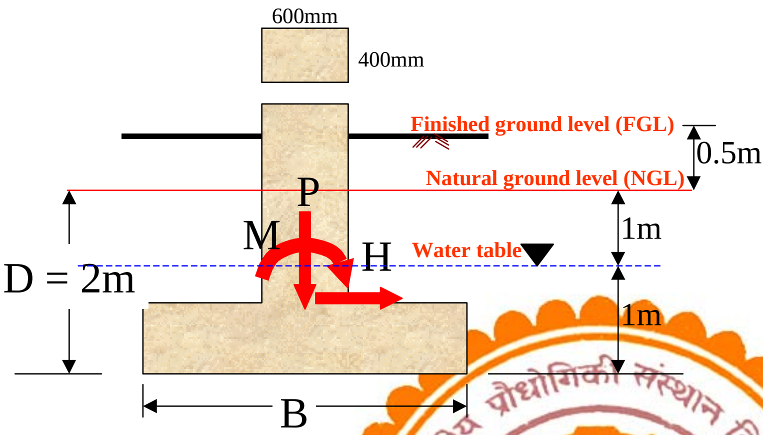
Try 2.7 x 2.7 x 0.4 m footing A = 7.29 m^2 **Z = 3.28 m^3** **P_t = 1461.7 kN**

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

γ_{soil} = 18 kNm^{-3}

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

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

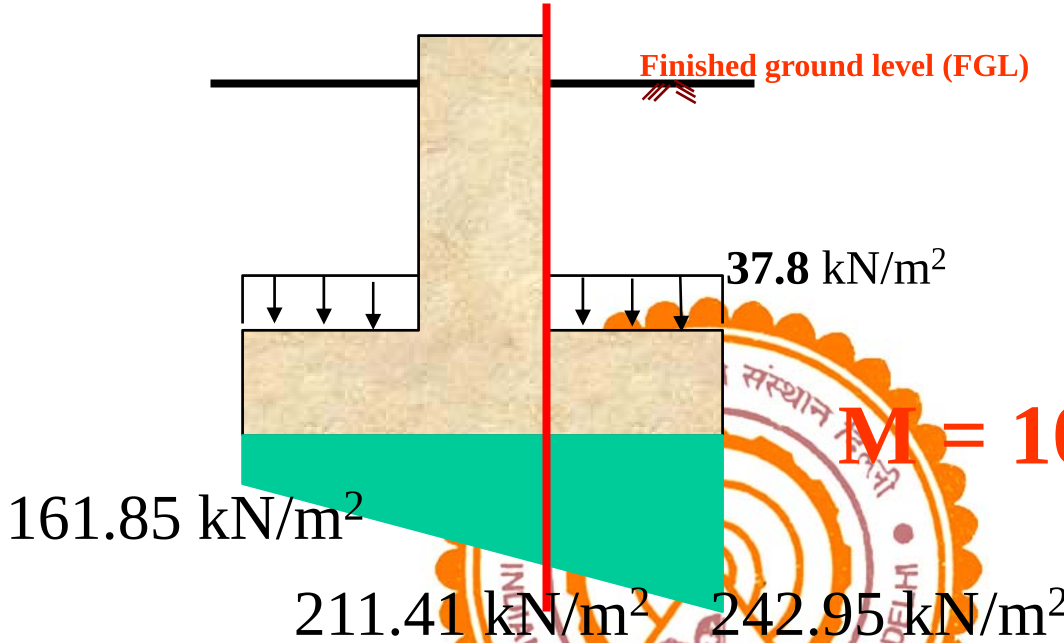
σ_{max} = 242.95 kN/m^2

σ_{min} = 161.85 kN/m^2

Slightly higher since additional soil considered at col. location

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

(2) DESIGN OF BASE FOR BENDING



M25 concrete
Fe415 steel

d = 400-50-10 = 340mm

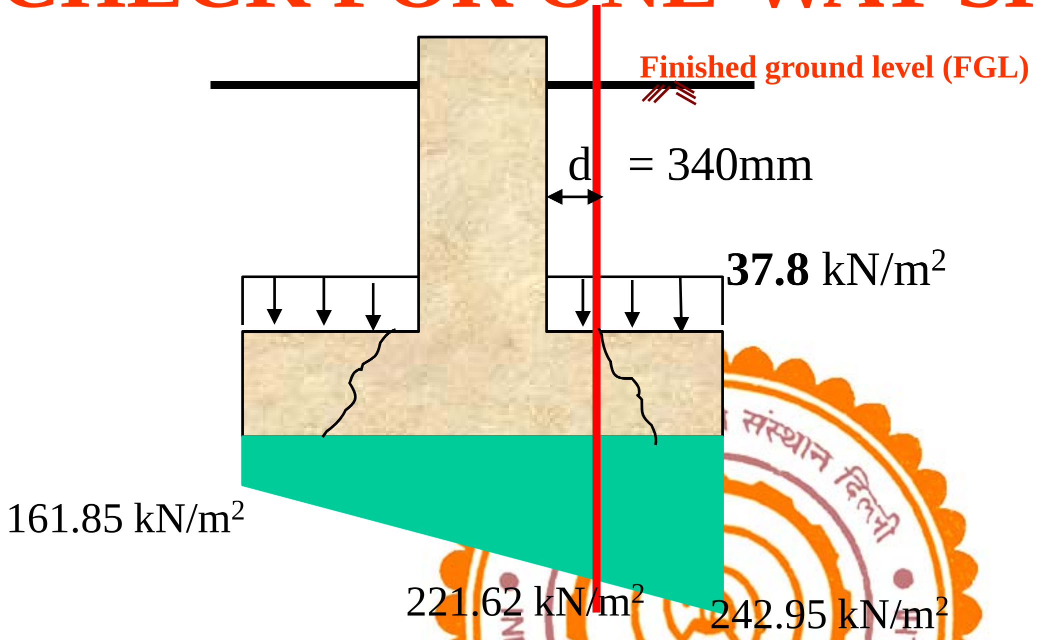
M = 107.29 kNm/m

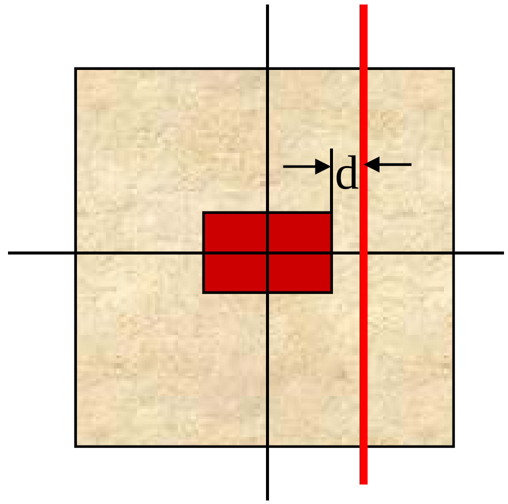
$$M_u = 1.5 \times 107.29 = 160.94 \text{ kNm/m}$$

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

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 = 107.29 kNm/m **V_u = 1.5 x 138.1 = 207.13 kN/m**

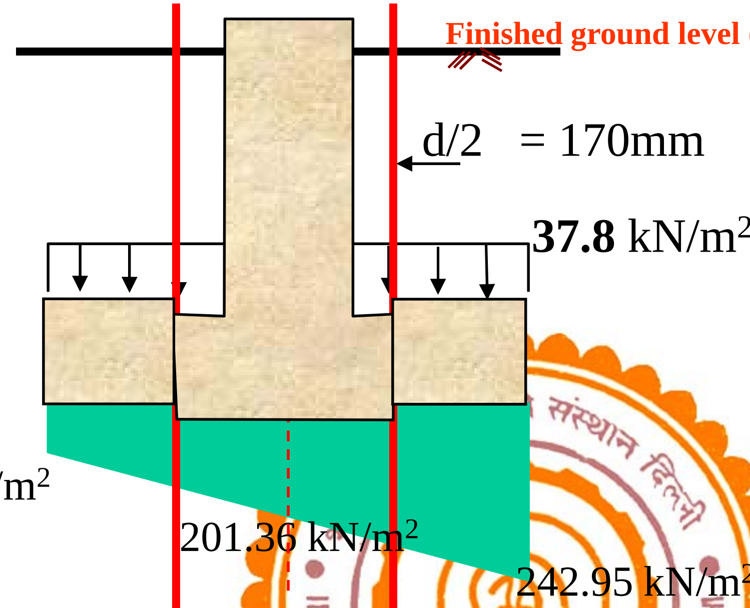
Nominal shear stress $\tau_v = \dfrac{207.13 \times 10^3\ N}{1000mm \times (340)\ mm} = 0.609\ Nmm^{-2}$

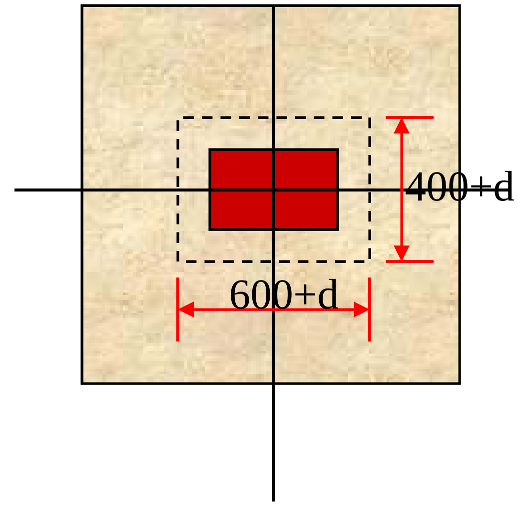
Shear strength of concrete (for 0.42% steel) $\tau_c = 0.448\ Nmm^{-2} < \tau_v$

Pg 73, IS 456

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

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





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

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

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

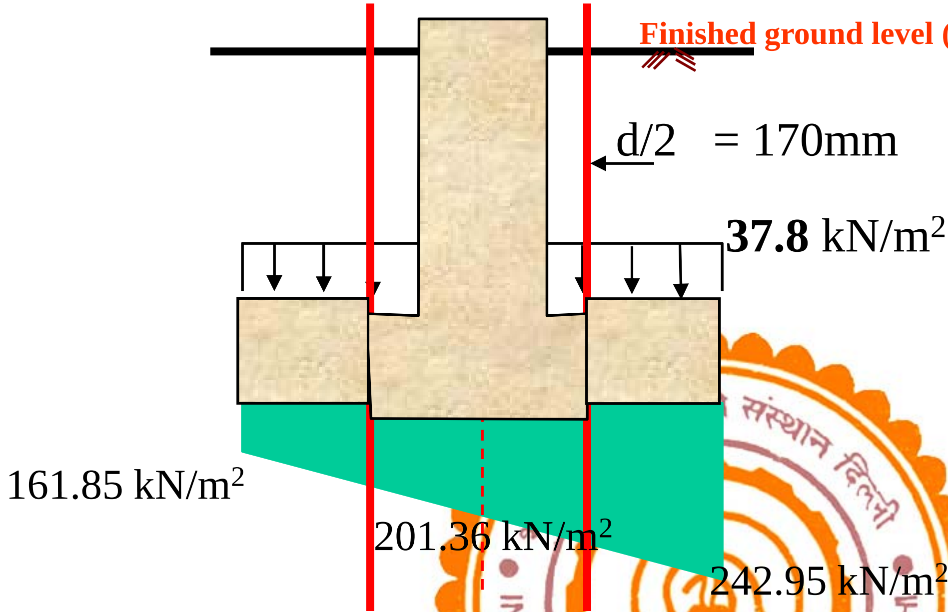
β_c = (0.4/0.6)

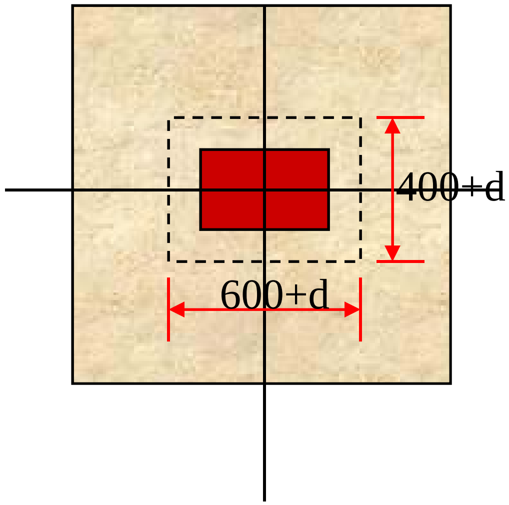
(Pg. 59, IS 456)

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

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

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





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

Increase thickness to 500mm => d = 440mm

$V = 1200 - (1.04 \times 0.84)(201.36 - 37.8) = 1057.1 \text{ kN}$

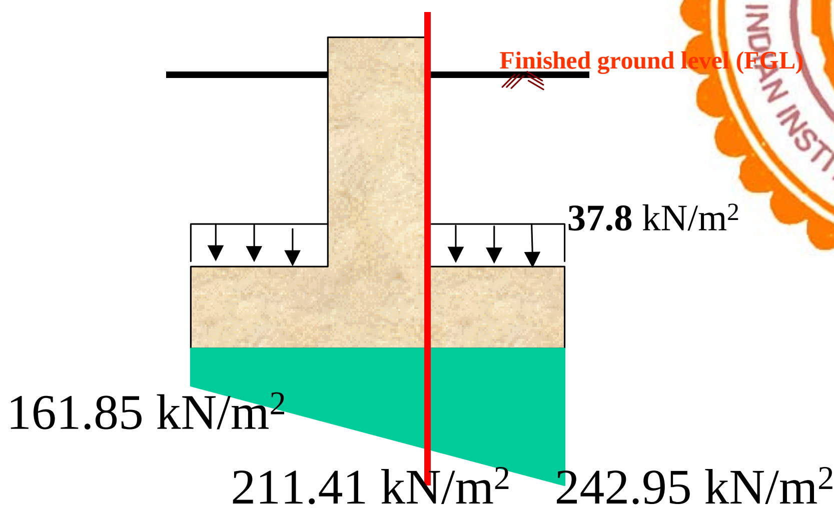
$V_u = 1.5 \times 1057.1 = 1585.65 \text{ kN}$

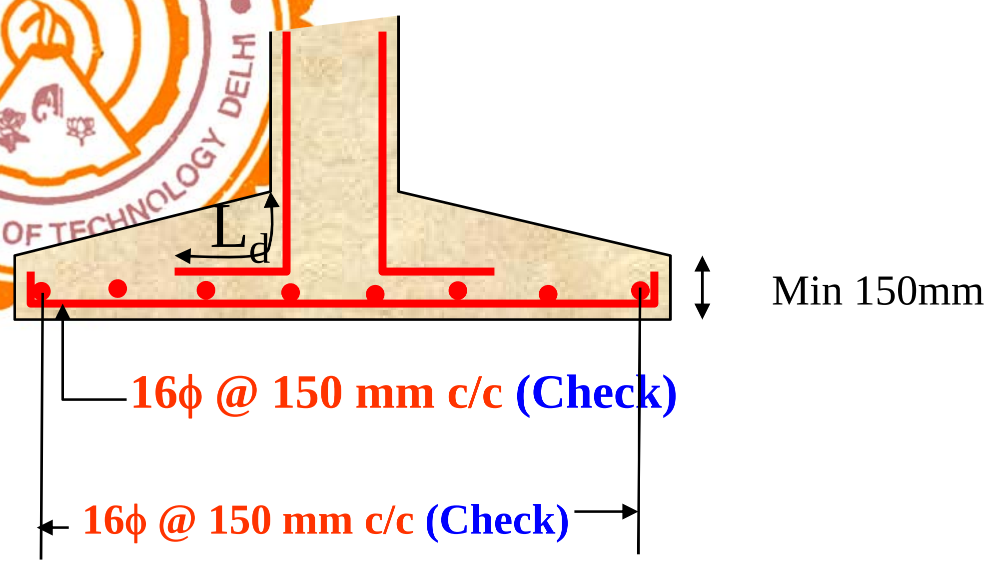
$$\tau_v = \frac{1585.65 \times 10^3 \text{ N}}{2(1040+840)\text{mm} \times (440) \text{ mm}} = 0.958 \text{ Nmm}^{-2} < k_s \tau_c$$

OK

*REDESIGN FOOTING FOR BENDING AND 1-WAY SHEAR

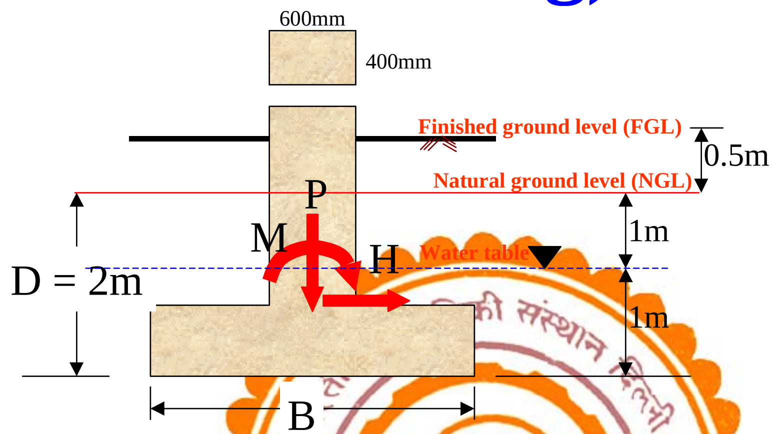
REINFORCEMENT DETAILING





(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

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

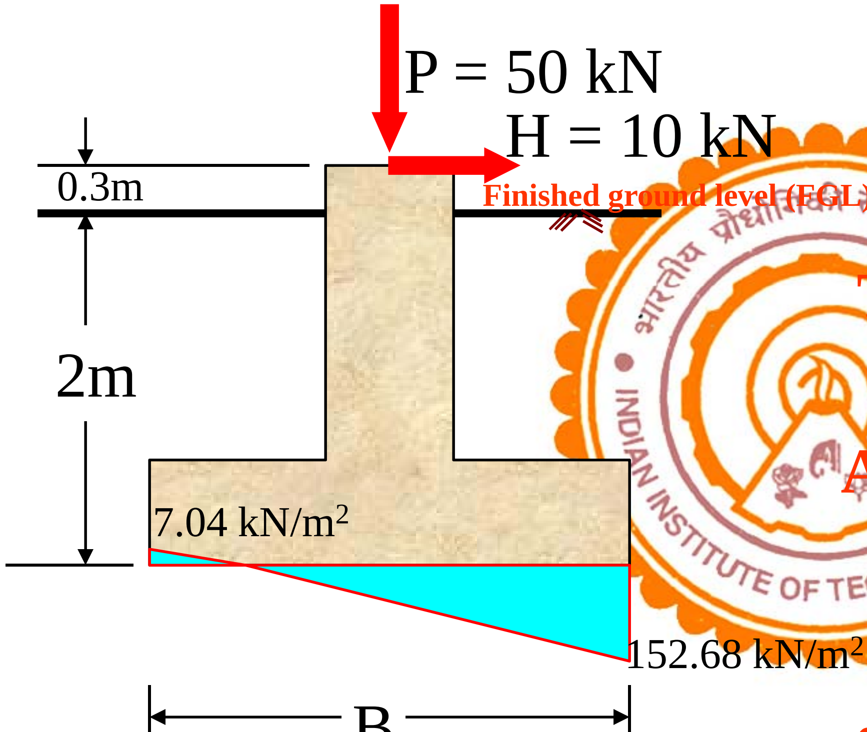
Restoring force > 1.4 H

Consider a DL = 90% IL = 0

DL = Dead load

IL = Imposed load

STAND ALONE FOOTING
(say for a pipe support)



$M = 10 \times 2.3 = 23$ kN-m

Try 1.2m x1.2m footing

$A = 1.44\ m^2 \quad Z = 0.288\ m^3$

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

$\sigma_{1,2} = 152.68, -7.04$ kN/m^2

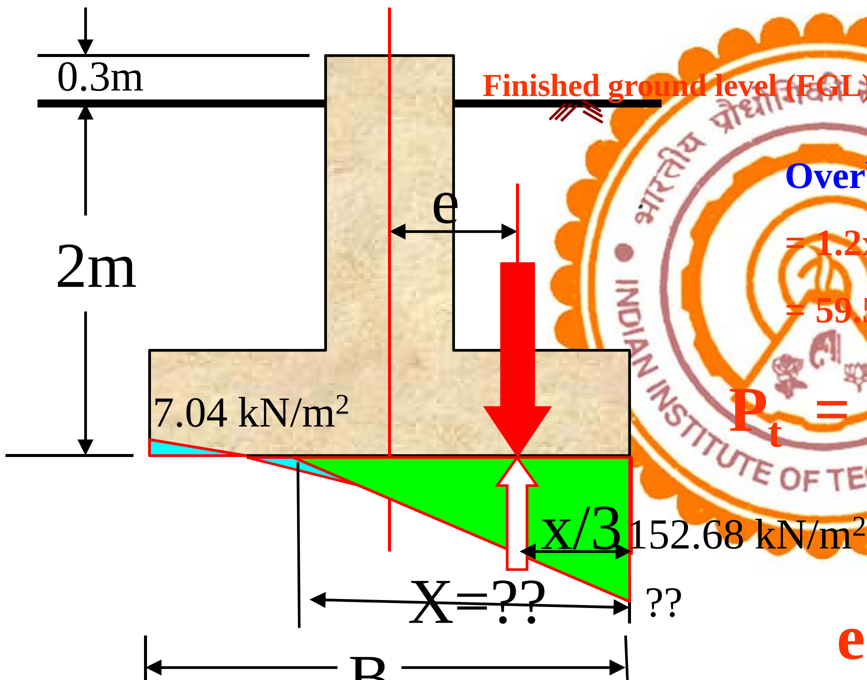
$q_{all,\,net} = 180\ kNm^{-2}$

Hence, redistribution of base pressure will take place

STAND ALONE FOOTING

(say for a pipe support)

$e = M/P_t$



Overburden :

= 1.2x1.2x0.3x25+ 0.4x0.6x 2.0x25+(1.2x1.2- 0.4x0.6)x1.7x18

= 59.52 kN

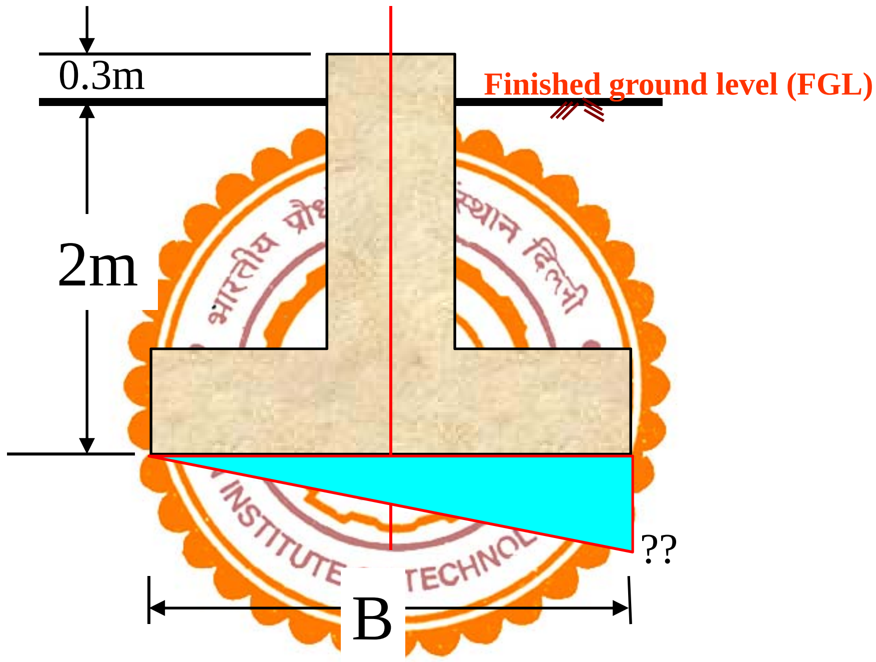
P_t = P + Overburden =109.52 kN

$e = M/P_t$ = 0.21m

$(x/3+e) = B/2$ => $x = 3(0.5B-e)$ => $x = 1.17$m

$0.5xB\ \sigma_1 = P_t$ => σ_1 = 156 kN/m²

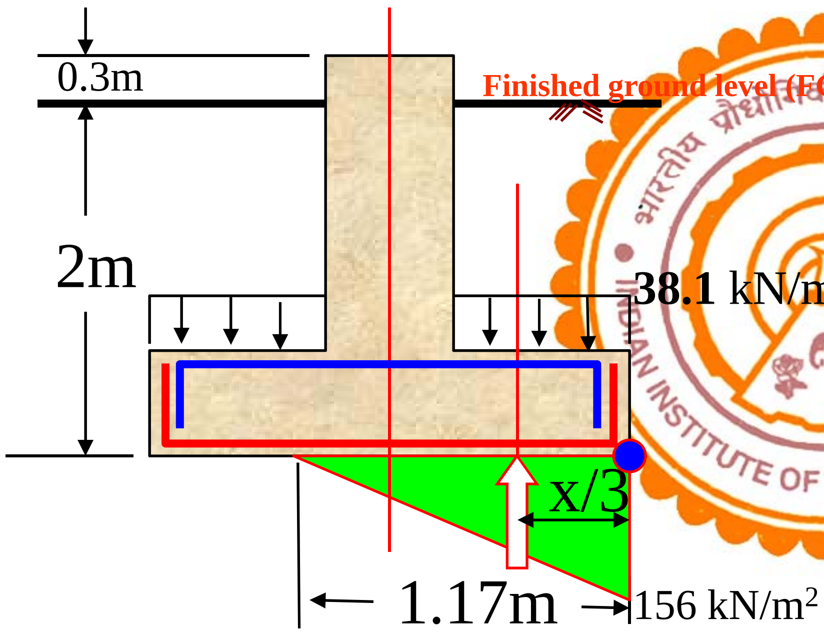
STAND ALONE FOOTING
(say for a pipe support)



ALTERNATE APPROACH:

Increase size such that no point on footing loses contact with soil

STAND ALONE FOOTING
(say for a pipe support)



OVERTURNING

Overturning moment =

$1.2\ M_o$(due to DL) + $1.4\ M_o$(due to IL)

= 0 + 1.4x23

= 32.2 kNm

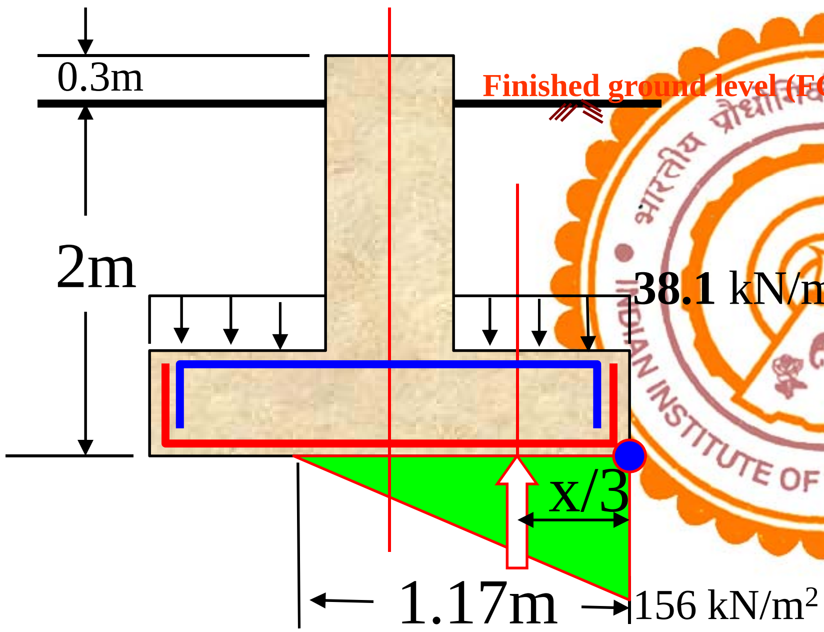
Restoring moment = 0.9x59.52x0.6

= 32.14 kNm

Marginally unsafe, increase dimension to 1.3m

STAND ALONE FOOTING

(say for a pipe support)



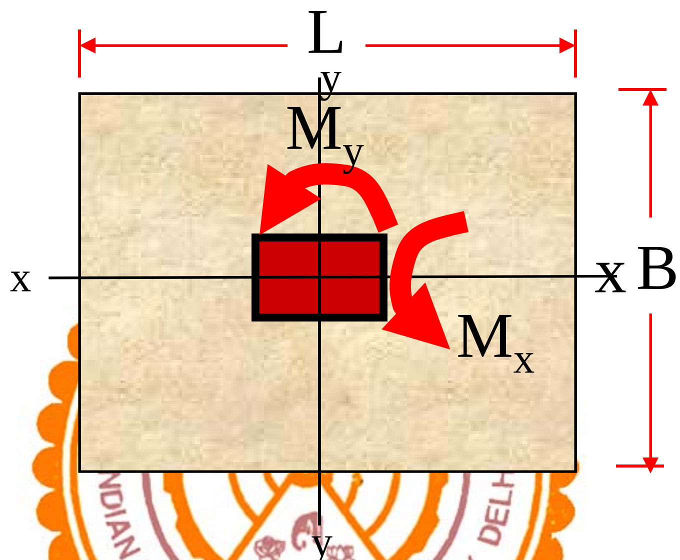
SLIDING

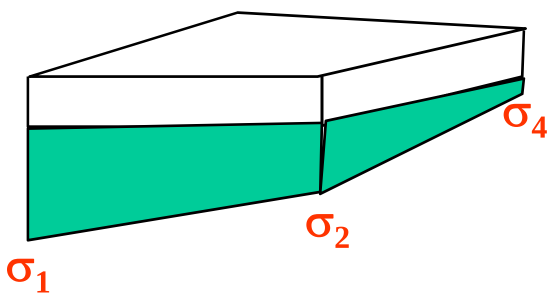
Coeff. of friction 0.4-0.5 (concrete-soil)

Restoring force	>	1.4 Sliding Force
0.9x59.52 x 0.45		1.4 x 10
24.1 kN	**>**	**14 kN**

(OK)

ISOLATED FOOTING UNDER BIAXIAL BENDING





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

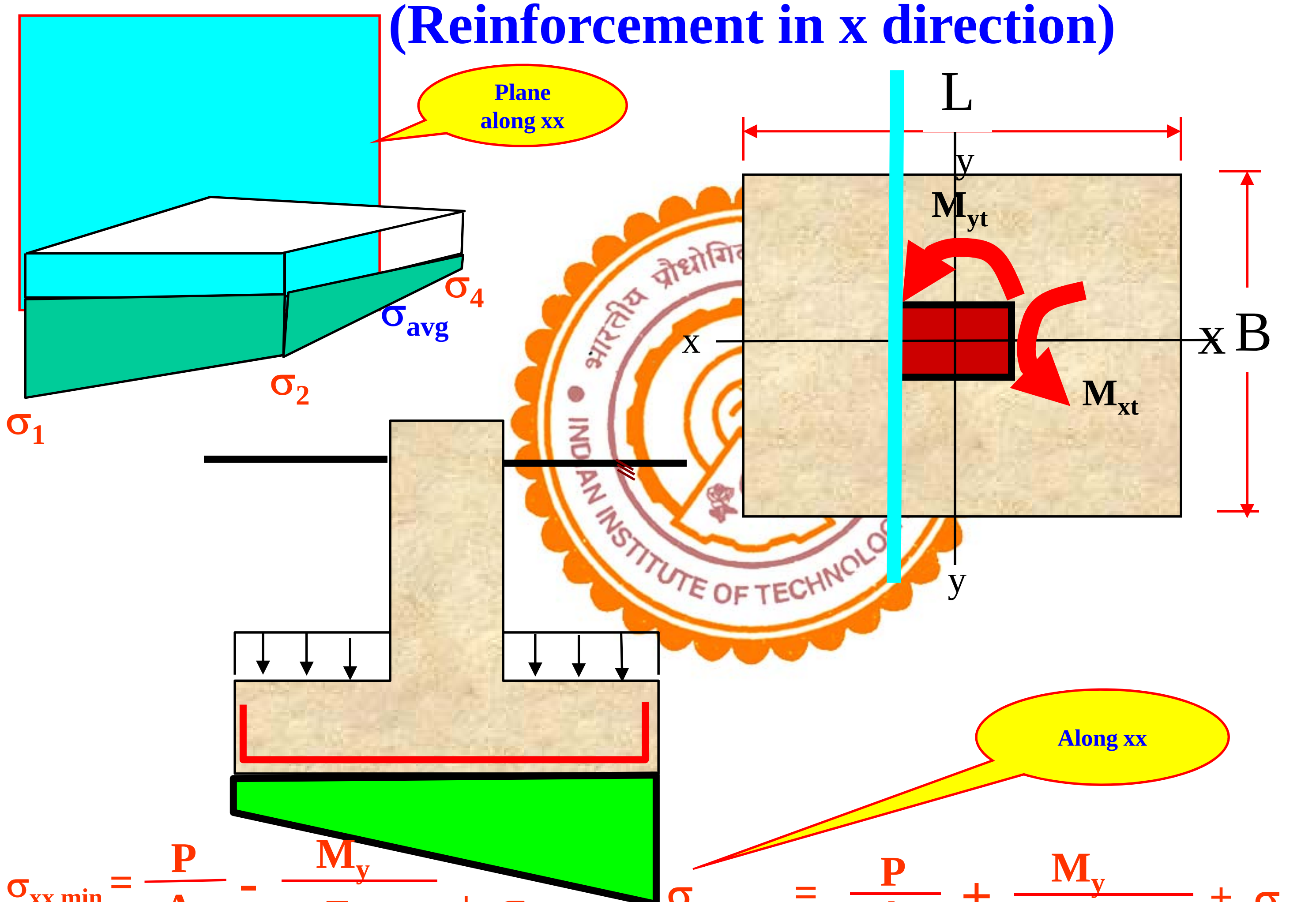
$Z_x = LB^2/6$

$Z_y = BL^2/6$

M_x, M_y : TOTAL MOMENTS ABOUT THE BASE OF FOOTING

ISOLATED FOOTING UNDER BIAXIAL BENDING

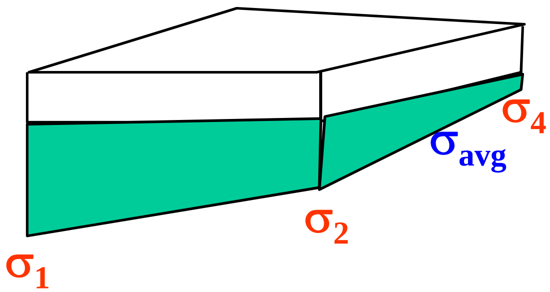
(Reinforcement in x direction)

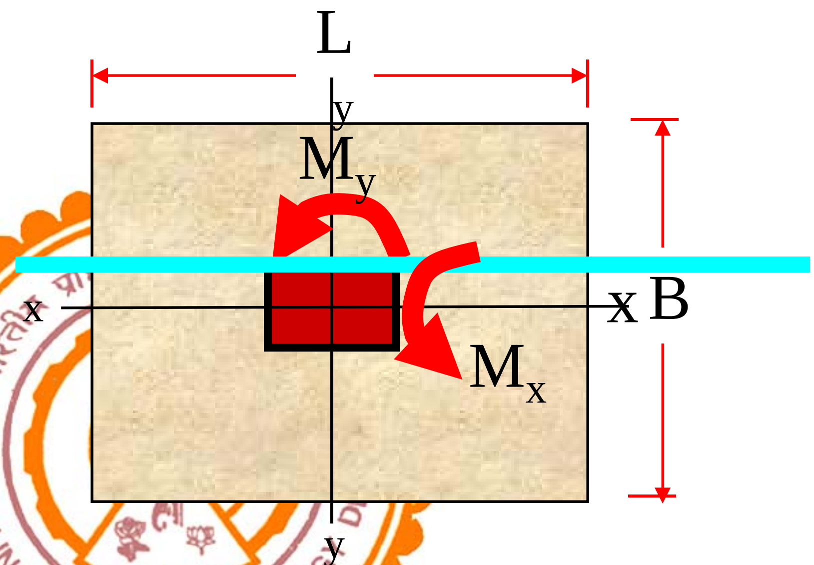


$$\sigma_{xx,min} = \frac{P}{A} - \frac{M_y}{Z_y} + \sigma_{overburden}$$

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

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

THANK YOU