



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS:

Lecture 5: Shallow Foundations – Numericals

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Module - 2

Shallow Foundations



Module -2: Chapters

1. General Requirements
2. Bearing Capacity and Settlement
3. Combined Footings
4. Raft Foundations
5. Dynamic Bearing Capacity



Chapter 2

Bearing Capacity and Settlement



Chapter 2c: Numerical Examples

- **For bearing capacity**
- **For settlement**

Bearing Capacity of shallow foundation

Example 1: Determine the ultimate bearing capacity (q_u) of a strip footing, **1.5m wide** with its base at a **depth of 1m**, resting on a dry sand saturation with $\gamma_d = 17 \text{ kN/m}^3$, $\phi' = 38^\circ$ and $c' = 0$ (use Terzaghi's theory)

Also determine q_u when ground water table is located at

- (a) At a depth of 0.5m below the base of footing
- (b) At a depth of 0.5m below the ground surface

Assume $\gamma_{\text{sat}} = 20 \text{ kN/m}^3$ and $\gamma_w = 10 \text{ kN/m}^3$. Also given that according to Terzaghi's theory for $\phi' = 38^\circ$, $N_q = 60$ and $N_\gamma = 75$

Example: 1 (Continued...)

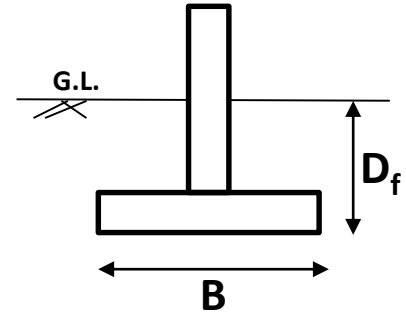
Solution:

Since $\phi' > 36^\circ$, hence general shear failure will occur

Therefore, $q_u = cN_c + qN_q + 0.5\gamma BN_\gamma$

Here $c = 0$ & $q = \gamma_d * D_f = 17 * 1 = 17 \text{ kN/m}^2$

$$\begin{aligned} \text{➤ } q_u &= \gamma_d D_f N_q + 0.5\gamma BN_\gamma \\ &= 17 * 1 * 60 + 0.5 * 17 * 1.5 * 75 \\ &= 1020 + 956.25 \\ &= 1976.25 \text{ kN/m}^2 \end{aligned}$$



Example: 1 (Continued...)

Exact Method

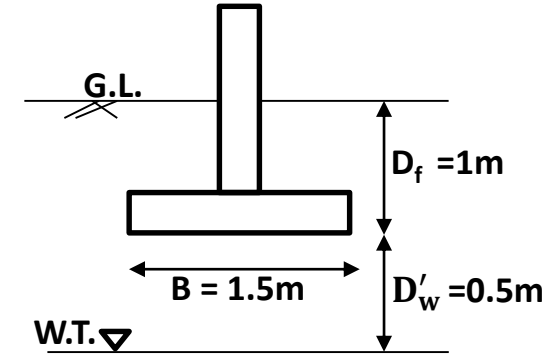
(a) When the water table at a depth of 0.5m below the base of footing

$$q_u = \gamma D_f N_q + 0.5\gamma B N_\gamma$$

No change in γ in first term

$$\begin{aligned}\text{In second term } \gamma &= \gamma' + \frac{D'_w}{B} (\gamma_t - \gamma') \\ &= 10 + \frac{0.5}{1.5} (17 - 10) = 12.33 \text{ kN/m}^3\end{aligned}$$

$$\begin{aligned}\Rightarrow q_u &= \gamma D_f N_q + 0.5\gamma B N_\gamma \\ &= 17 * 1.0 * 60 + 0.5 * 12.33 * 1.5 * 75 \\ &= 1020 + 694 = 1714 \text{ kN/m}^2\end{aligned}$$



$$\begin{aligned}\gamma' &= \gamma_{\text{sat}} - \gamma_w \\ &= 20 - 10 \\ &= 10 \text{ kN/m}^3\end{aligned}$$

Example: 1 (Continued...)

Exact Method

(b) When the water table at a depth of 0.5m below the ground surface

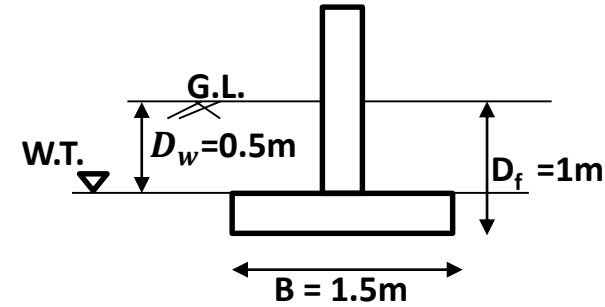
$$q_u = \gamma D_f N_q + 0.5\gamma B N_\gamma$$

$$\text{In first term, } \gamma = \gamma' + \frac{D_w}{D_f} (\gamma_t - \gamma')$$

$$= 10 + \frac{0.5}{1} (17 - 10) = 13.5 \text{ kN/m}^3$$

$$\text{In second term, } \gamma = \gamma' = 10 \text{ kN/m}^3$$

$$\begin{aligned} \Rightarrow q_u &= \gamma D_f N_q + 0.5\gamma B N_\gamma \\ &= 13.5 * 1.0 * 60 + 0.5 * 10 * 1.5 * 75 \\ &= 810 + 562.5 = 1372.5 \text{ kN/m}^2 \end{aligned}$$



$$\begin{aligned} \gamma' &= \gamma_{\text{sat}} - \gamma_w \\ &= 20 - 10 \\ &= 10 \text{ kN/m}^3 \end{aligned}$$

Example: 1 (Continued...)

Approximate Method

(a) When the water table at a depth of 0.5m below the base of footing

$$R_w' = 0.5 + 0.5 * \frac{D_w'}{B} = 0.5 + 0.5 * \frac{0.5}{1.5} = 0.67$$

$$q_u = \gamma D_f N_q + 0.5 \gamma B N_\gamma R_w'$$

γ in first term γ_d and in second term $\gamma = \frac{17*0.5+20*1.0}{1.5} = 19 \text{ kN/m}^3$

$$\begin{aligned} \blacktriangleright q_u &= \gamma D_f N_q + 0.5 \gamma B N_\gamma R_w' \\ &= 17*1.0*60 + 0.5*19*1.5*75*0.67 \\ &= 1020 + 716 = 1736 \text{ kN/m}^2 \end{aligned}$$

Example: 1 (Continued...)

Approximate Method

(b) When the water table at a depth of 0.5m below the ground surface

$$R_w' = 0.5$$

$$R_w = 0.5 + 0.5 * \frac{D_w}{D_f} = 0.5 + 0.5 * \frac{0.5}{1} = 0.75$$

$$q_u = \gamma D_f N_q R_w + 0.5 \gamma B N_\gamma R_w'$$

γ in second term γ_{sat} and in first term $\gamma = \frac{17*0.5+20*0.5}{1} = 18.5 \text{ kN/m}^3$

➤ $q_u = \gamma D_f N_q R_w + 0.5 \gamma B N_\gamma R_w'$
 $= 18.5 * 1.0 * 60 * 0.75 + 0.5 * 20 * 1.5 * 75 * 0.5$
 $= 832.5 + 562.5 = 1395 \text{ kN/m}^2$

Bearing Capacity of shallow foundation

Example 2: Determine the ultimate bearing capacity (q_u) of a strip footing, **2m wide** with its base at a **depth of 1.5m**, below ground surface and resting on a saturated clay soil with $\gamma_{\text{sat}} = 20 \text{ kN/m}^3$,

(a) $\phi_u = 0^\circ$ and $c_u = 40 \text{ kN/m}^2$ (for undrained condition)

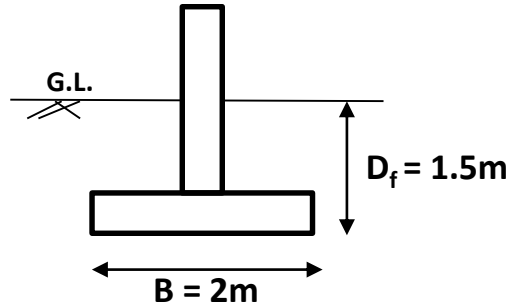
(b) $\phi' = 20^\circ$ and $c' = 10 \text{ kN/m}^2$ (for drained condition)

The natural water table is at 1m below the ground level

Ignore depth factor and use Terzaghi's theory

Example: 2 (Continued...)

Solution: The ultimate bearing capacity for the undrained and drained loading condition can be determined by using the total stress and effective stress shear strength parameter respectively for the clay.



Example: 2 (Continued...)

(a) Undrained loading condition,

For $\phi_u = 0^\circ$, $N_c = 5.7$, $N_q = 1$ and $N_\gamma = 0$

Hence,

$$q_u = c_u N_c + q$$

$$\text{Here, } q = 20 \times 1 + 10 \times 0.5 = 25 \text{ kN/m}^2$$

Therefore,

$$\begin{aligned} \Rightarrow q_u &= 40 \times 5.7 + 25 \\ &= 228 + 25 = 253 \text{ kN/m}^2 \end{aligned}$$

Example: 2 (Continued...)

(b) Drained loading condition, For $\phi_u = 20^\circ$, $N_c = 17.7$, $N_q = 7.4$ and $N_\gamma = 5$

$$q_u = c'N_c + qN_q + 0.5\gamma BN_\gamma$$

$$\text{Here, } q = 20 \times 1 + 10 \times 0.5 = 25 \text{ kN/m}^2$$

Therefore,

$$\begin{aligned} \text{➤ } q_u &= 10 \times 17.7 + 25 \times 7.4 + 0.5 \times 10 \times 2 \times 5 \\ &= 177 + 185 + 50 = 412 \text{ kN/m}^2 \end{aligned}$$

It can be observed that q_u for under drained loading condition is higher than under undrained loading condition. Therefore, the bearing capacity analysis for a clay soil is carried out invariably under undrained loading condition.

Settlement of Shallow Foundation

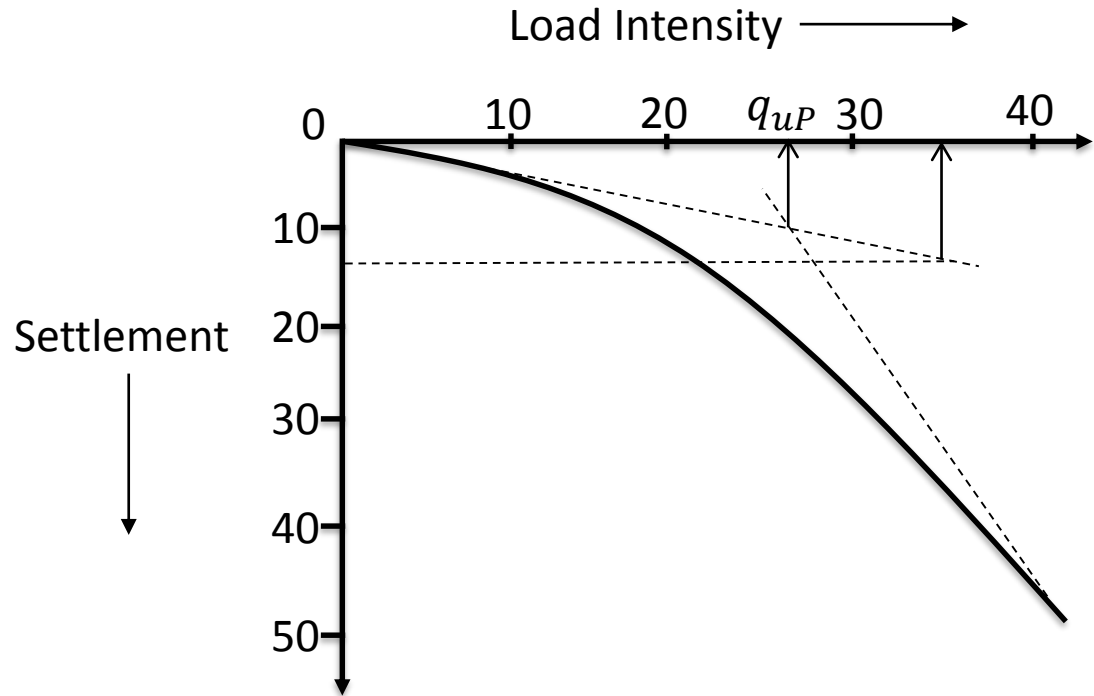
Example 3: The following data was observed from a plate load test carried out on a 60 cm square test plate at a depth of 3m below the ground surface on a sandy soil which extend upto a large depth. Determine the settlement of a foundation 3m*3m carrying a load of 110 tone and located at a depth of 3m below the ground surface. Water Table is located at a large depth from the ground surface.

Load intensity (t/m ²)	5	10	15	20	25	30	35	40
Settlement (mm)	2.0	4.0	7.5	11.0	16.3	23.5	34.0	45

Example: 3 (Continued...)

Solution:

- The load-settlement curve is drawn using the given table in previous slide.
- Load intensity is in t/m^2 and Settlement is mm.



Example: 3 (Continued...)

Load intensity on the foundation = $110/(3*3) = 12.2 \text{ t/m}^2$

Settlement of test plate corresponding to this load intensity is $S_p = 5\text{mm}$

Now settlement of Foundation,

$$S_f = S_p * \left[\frac{B_f(B_P + 30)}{B_P(B_f + 30)} \right]^2 = 5.0 * \left[\frac{300(60 + 30)}{60(300 + 30)} \right]^2$$

$$S_f = 5 * 1.86 = 9.3\text{mm}$$

Settlement of Shallow Foundation

Example 4: Using the load test data in Example 3, determine the allowable load on a $1.5\text{m} \times 1.5\text{m}$ column footing with its base at a depth of 2m. The permissible settlement for the foundation is 20mm and a minimum **F.S. = 3** is determined against shear failure. The weight of soil is determined at the base of the test pit by the core cutter method was 2 t/m^3 .

Example: 4 (Continued...)

Solution: The angle of shearing resistance of the soil wrecked back with the help of ultimate bearing capacity of the test plate q_{up} .

$q_{up} = 24 \text{ t/m}^2$ (from the double tangent method) using chart

$q_{up} = 0.4\gamma B_p N_\gamma$, $N_\gamma = 24/(0.4*2*0.6) = 50$ (there is no surcharge)

For the For $N_\gamma = 50$, $\phi = 36.5^\circ$ and $N_q = 40$ using Peck, Hansun & Thornburn (1974) as shown in next slide

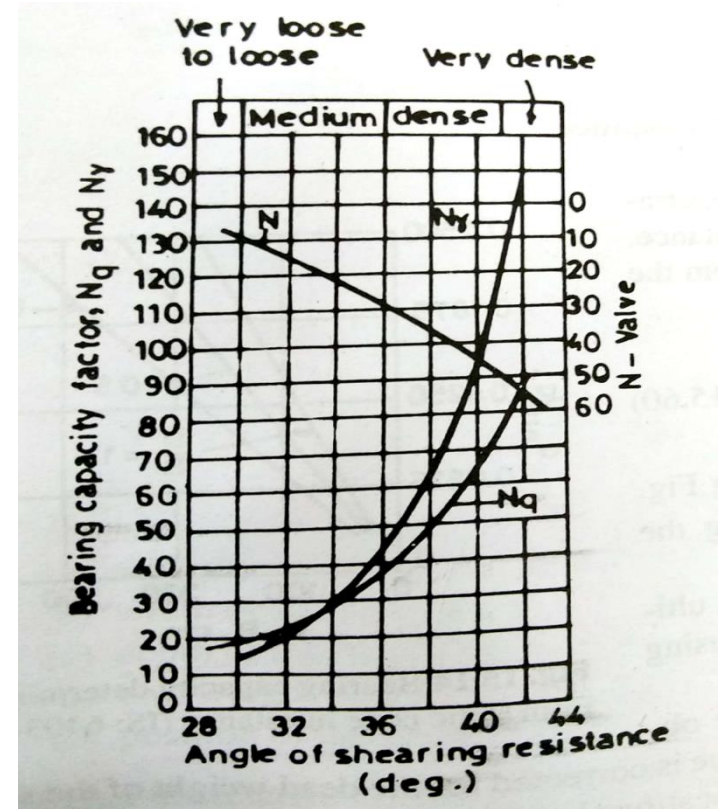
For foundation,

$$q_{nu} = \gamma D_f (N_q - 1) + 0.4\gamma B_f N_\gamma = 2 * 2(40 - 1) + 0.4 * 2 * 1.5 * 50 = 216 \text{ t/m}^2$$

$$q_{ns} = 216/3 = 72 \text{ t/m}^2$$

Example: 4 (Continued...)

Peck, Hansun & Thornburn (1974) chart for bearing capacity factor



Example: 4 (Continued...)

$$S_p = S_f * \left[\frac{B_p(B_f+30)}{B_f(B_p+30)} \right]^2 = 20 * \left[\frac{60(150+30)}{150(60+30)} \right]^2 = 20*0.64 = 12.8 \text{ mm}$$

Now the load intensity corresponding to a settlement of 12.8mm is determined by the method suggested by Rao and Ramasamy

Net safe bearing pressure = 32 t/m²

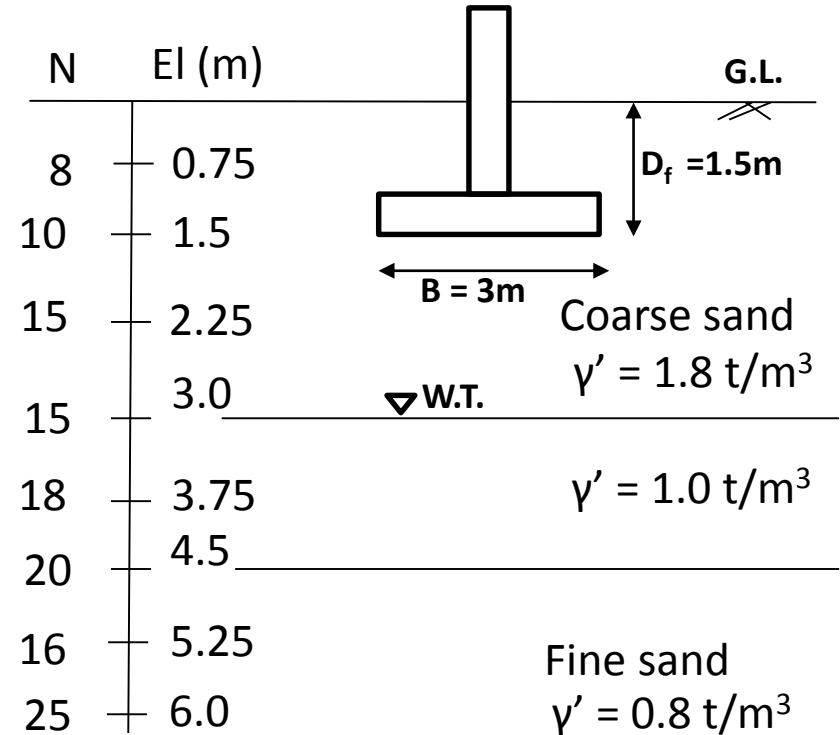
Hence the settlement criteria govern the design and net allowable bearing pressure = 32 t/m²

Allowable load on the footing = 32*1.5² = 72 tone

Settlement of Shallow Foundation

Example 5: Determine the allowable bearing pressure for the rectangular footing shown in Figure using the IS code recommendation. Allowable settlement is 40mm

$$C_N = 0.77 \log_{10} \frac{20}{\sigma_o}$$



Example: 5 (Continued...)

Solution: The average value of N_{cq} between El. – 1.5 and El. – 6m is considered for the calculation. This is upto a depth $4.5\text{m} = 1.5B$ below the base, if data available for values upto a depth equal to $2B$ below the base shall be included. The N values are corrected for overburden pressure and thus for dilatancy (only for saturated fine sand or silts)

El (m)	$\bar{\sigma}$ (t/m ²)	$\bar{\sigma}$ (kg/cm ²)	C_N	N_f	$N = C_N * N_f$	N' (Corrected Dilatancy)
1.5	2.7	0.270	1.44	10	14.4	14.4
2.25	4.05	0.405	1.30	15	19.5	19.5
3.0	5.4	0.540	1.21	15	18.1	18.1
3.75	6.15	0.615	1.16	18	20.9	20.9
4.50	6.90	0.690	1.13	20	22.6	18.8
5.25	7.30	0.750	1.10	16	17.6	16.3
6.00	8.10	0.810	1.07	25	26.8	20.9

Example: 5 (Continued...)

$$\text{Average } N = \frac{14.4+19.5+18.1+20.9+18.8+16.3+20.9}{7} = 18$$

Now, For $N = 18$, $\phi = 33^\circ$, from the chart given Peck, Hansun & Thornburn (1974) (next slide)

and For $\phi = 33^\circ$, $N_q = 22$ and $N_y = 28$, the chart given in IS:6403-1981 (next slide)

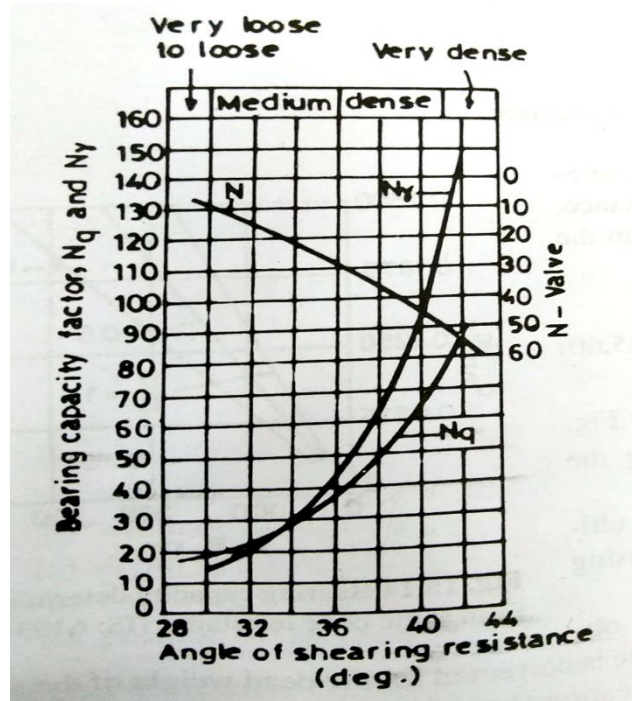
Thus for $c' = 0$ (from IS code), $q_{nu} = q (N_q - 1) S_q d_q + 0.5 \gamma B N_y S_y d_y w'$

The corrected value of factor,

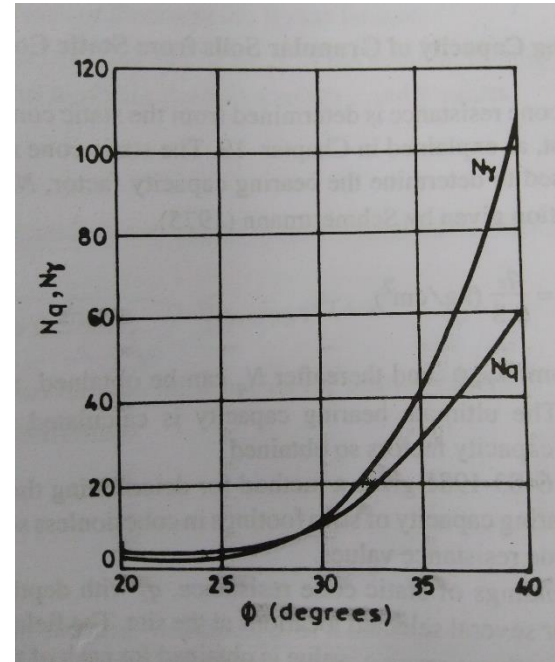
$$S_q = 1 + 0.2 \frac{B}{L} = 1 + 0.2 \frac{3}{5} = 1.12 \quad S_y = 1 - 0.4 \frac{B}{L} = 1 - 0.4 \frac{3}{5} = 0.76$$

$$d_q = d_y = 1 + 0.1 \frac{D_f}{B} (\tan(45^\circ + \phi/2)) = 1 + 0.1 \frac{1.5}{3} (\tan(45^\circ + 33/2)) = 1.09$$

Example: 5 (Continued...)



Peck, Hansun & Thornburn (1974)



IS:6403-1981

Example: 5 (Continued...)

$$q_{nu} = 2.7 (22-1) * 1.12 * 1.09 + 0.5 * 1.8 * 3 * 28 * 0.76 * 1.09 * 0.75 = 116 \text{ t/m}^2$$

$$q_{ns} = 116/3 = 38.7 \text{ t/m}^2$$

From chart for settlement for $N = 18$ and $B = 3\text{m}$

Settlement for 1 kgf/cm^2 (10t/m^2) = $0.015 \text{ m} = 15 \text{ mm}$

Taking into account the water table,

$$\text{C.F.} = 0.5 + 0.5 * D_w / B = 0.5 + 0.5 * 1.5 / 3 = 0.75$$

$$\text{Actual settlement} = 15 / (\text{C.F.}) = 15 / 0.75 = 20\text{mm}$$

$$\text{For } S_a = 40\text{mm}, q_{np} = \frac{10}{20} * 40 = 20 \text{ t/m}^2$$

$$\text{Hence } q_{net} = 20 \text{ t/m}^2$$

Thank You

