



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 10: Footings under Dynamic Loads: Design Procedure and Example on a New Method

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ERD of Foundations - Modules

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Module - 2

Shallow Foundations



Module -2: Chapters

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Chapter 5: Footings Subjected to Dynamic Loads

- Dynamic Loads and Methods of Analysis
- Pseudo-Static Analysis
- Earthquake Load: Horizontal Load and Moment
- Eccentric Load on Footings
- A new Method for Design of Eccentrically Loaded Footings
 - (a) Bearing Capacity (b) Settlement
- New Method: (a) Design Procedure (b) Design Example
- Inclined Load on a Footing

New Method: Design Procedure

Data Requirement:

1. Vertical load and moment and its eccentricity
2. Soil Properties: c , ϕ and/or SPT N value
3. Plate load test data: Load-settlement curve
4. Permissible values of settlement (S_m) and tilt (t)
5. Factor of safety against shear considerations

New Method: Design Procedure (Continued...)

Steps:

1. Trial dimension of the footing: Assume width B (and depth D_f)
2. Compute eccentricity ($e=M/Q$) and then ratio e/B
3. Compute the settlement
 - a) Find the ratio $\frac{S_e}{S_o}$ and $\frac{S_m}{S_o}$ using equations (6a) and (6b)
 - b) Compute the value of S_o from permissible value of S_m
 - c) Using equation (7), calculate the value of S_p for ($S_f = S_o$)

New Method: Design Procedure (Continued...)

4. Plate Load test data:

- a) Find the value of bearing pressure q_b that corresponds to settlement S_p
- b) Find the value of ultimate bearing capacity q_b using the tangent intersection method

Out of these two, the smaller value of q_b is further used

5. Failure Criteria of plate: check for general or local shear failure

6. Factor of safety of the footing:

- a) Compute ultimate bearing capacity q_{do} for $e/B = 0$
- b) The factor of Safety $FS = q_{do}/q_b$
- c) If FS is greater than required, then use this in design else revise the dimension

New Method: Design Procedure (Continued...)

7. Allowable Load

- a) Compute the ultimate bearing capacity q_d of actual footing for the computed value of e/B and use the failure criterion established in step 5
- b) Obtain the allowable bearing capacity $q_a = q_d/FS$
- c) Compute allowable load = $q_a \times \text{area}$
- d) If this Allowable load > Given load, Ok, else revise the design

8. Find tilt using equation (5) and it shall be less than permissible tilt, else, revise the design

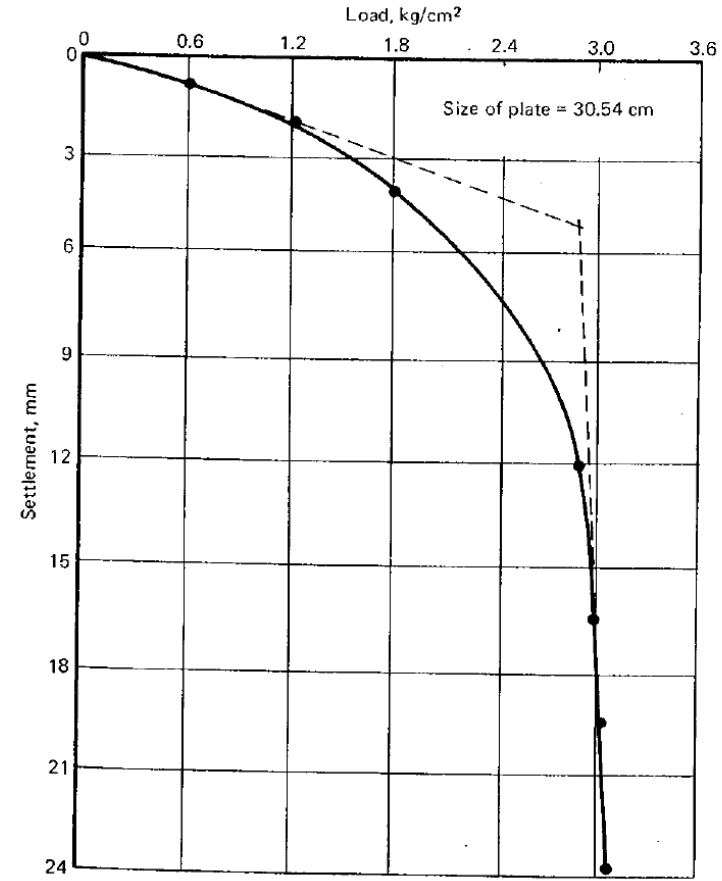
New Method: Design Example

Example 1: Design the footing that is subjected to a vertical load 70 t and moment of 23.8 t-m. The soil characteristics are as follows:

$$c = 0.025 \text{ kg/cm}^2, \phi = 35^\circ, \gamma = 1.75 \text{ g/cm}^3$$

A unit load versus settlement curve was (shown in next slide) obtained by conducting standard plate load test. Permissible value of settlement, S_m and tilt, t of the footing are given as 20 mm and 1° respectively.

Load Settlement Curve of a plate 30.54 cm square



New Method: Design Example (Continue)

Solution:

1. Assume the trial dimension of the footing as 2m*2m square at a depth of 1m below the ground level.
2. Eccentricity $e = M/Q = 23.8/70 = 0.34\text{m}$
Hence $e/B = 0.34/2 = 0.17$
3. Computation of settlement using equation (6a) and (6b)

(a)
$$\frac{s_e}{s_o} = 1.0 - 1.63 \left(\frac{e}{B}\right) - 2.63 \left(\frac{e}{B}\right)^2 + 5.83 \left(\frac{e}{B}\right)^3$$

$$\frac{s_e}{s_o} = 1.0 - 1.63(0.17) - 2.63(0.17)^2 + 5.83(0.17)^3 = 0.676$$

New Method: Design Example (Continue)

$$\frac{S_m}{S_o} = 1.0 + 2.31 \left(\frac{e}{B}\right) - 22.61 \left(\frac{e}{B}\right)^2 + 31.54 \left(\frac{e}{B}\right)^3$$
$$\frac{S_m}{S_o} = 1.0 + 2.31(0.17) - 22.61(0.17)^2 + 31.54(0.17)^3 = 0.894$$
$$S_o = S_m/0.894 = 20/0.894 = 22.37 \text{ mm}$$

(b)

$$S_o = S_P \left[\frac{B_f(B_P+30)}{B_P(B_f+30)} \right]^2$$
$$\frac{S_o}{S_P} = \left[\frac{200(30.54+30)}{30.54(200+30)} \right]^2 = 2.97$$
$$S_P = 22.37/2.97 = 7.53 \text{ mm}$$

New Method: Design Example (Continue)

4. Plate load test data

- (a) From the plate-load test data, the bearing pressure q_b corresponding to the settlement, 7.53mm, is 2.4 kg/cm^2
- (b) When the intersection tangent method is used, the ultimate bearing capacity of the plate is 2.9 kg/cm^2 .

Thus smaller of these two i.e. $q_b = 2.4 \text{ kg/cm}^2$ is used further

5. Shape of the load settlement curve indicates the general shear failure criteria.

6. Factor of Safety

- (a) For $e/B = 0$ and $\phi = 35^\circ$ (using chart given in next slide)
 $N_c = 53$, $N_q = 39$ and $N_\gamma = 40$

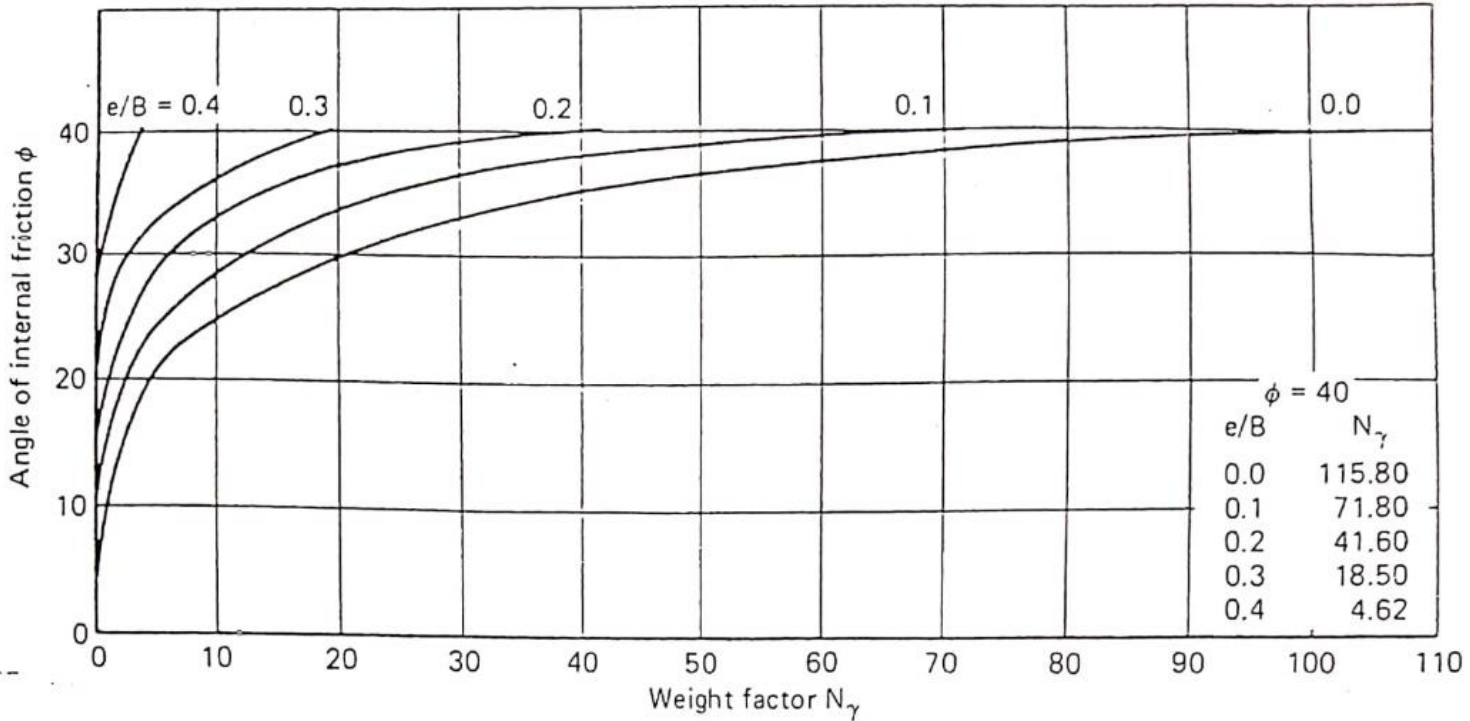


Figure 6.8 Bearing capacity factor N_γ vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

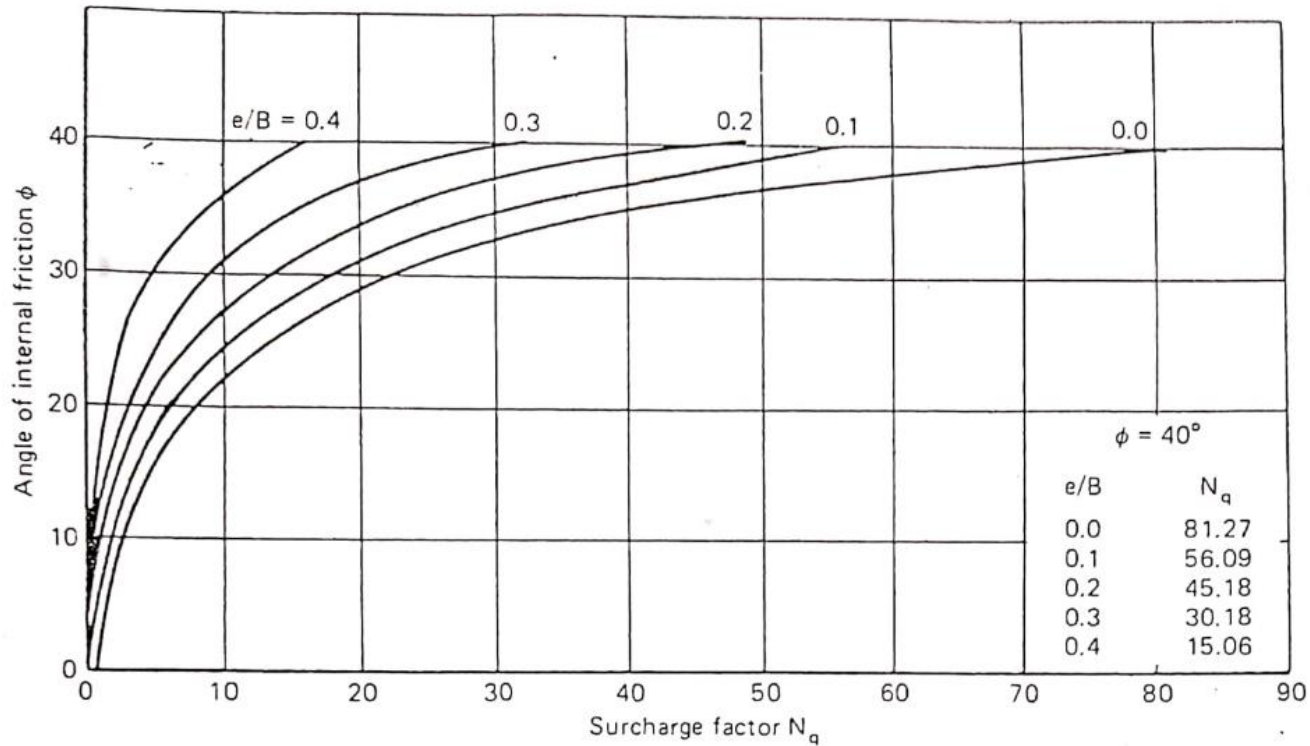


Figure 6.9 Bearing capacity factor N_q vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

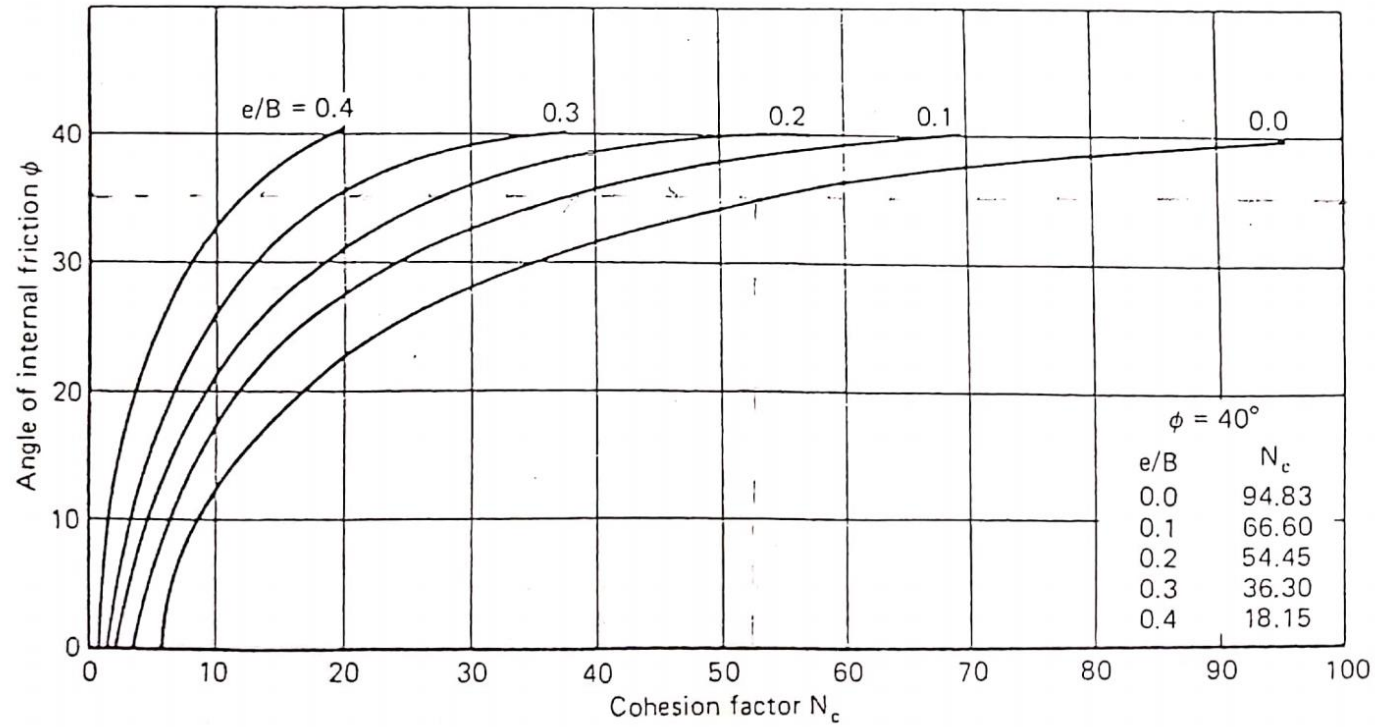


Figure 6.10 Bearing capacity factor N_c vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

New Method: Design Example (Continue)

using the equation (4a) and (4b),

$$\Delta_\gamma = 1.0 + \left(\frac{2e}{B} - 0.68 \right) \left(\frac{B}{L} \right) - \left(\frac{3e}{B} - 0.43 \right) \left(\frac{B}{L} \right)^2$$

$$\Delta_\gamma = 1.0 + (2 * 0 - 0.68)(1) - (3 * 0 - 0.43)(1)^2 = 0.75$$

$$\Delta_q = 1 \text{ and } \Delta_c = 1.2$$

$$q_u = cN_c\Delta_c + \gamma D_f N_q \Delta_q + 0.5\gamma B N_\gamma \Delta_\gamma$$

$$q_{do} = (25 * 53 * 1.2 + 1.75 * 100 * 39 * 1.0 + 0.5 * 1.75 * 200 * 40 * 0.75) / 1000$$

$$q_u = 13.67 \text{ kg/cm}^2$$

b) $FS = q_{do} / q_b = 13.67 / 2.4 = 5.69$

c) $FS > 3.0$ (O.K.)

New Method: Design Example (Continue)

7. Allowable load

a) For $e/B = 0.17$ and $\phi = 35^\circ$ (using chart)

$$N_c = 31, N_q = 31 \text{ and } N_\gamma = 20$$

using the equations (4a) and (4b),

$$\Delta_\gamma = 1.0 + \left(\frac{2e}{B} - 0.68 \right) \left(\frac{B}{L} \right) - \left(\frac{3e}{2B} - 0.43 \right) \left(\frac{B}{L} \right)^2$$

$$\Delta_\gamma = 1.0 + (2 * 0.17 - 0.68)(1) - \left(\frac{3}{2} * 0.17 - 0.43 \right) (1)^2 = 0.835$$

$$\Delta_q = 1 \text{ and } \Delta_c = 1.2$$

$$q_u = cN_c\Delta_c + \gamma D_f N_q \Delta_q + 0.5\gamma B N_\gamma \Delta_\gamma$$

$$q_d = (25*31*1.2 + 1.75*100*31*1.0 + 0.5*1.75*200*20*0.835)/1000$$

$$q_d = 9.28 \text{ kg/cm}^2$$

New Method: Design Example (Continue)

b) Allowable bearing pressure

$$q_a = q_d / FS = 9.28 / 5.69 = 1.63 \text{ kg/cm}^2$$

b) Allowable load $Q_a = 1.63 * 200 * 200 = 65.22 \text{ t}$ which may be accepted

c) Allowable load Q_a is close to the given vertical load on the footing 70t with $FS = 5.69$, hence the design is safe.

8. Tilt using the equation (5)

$$\sin(t) = \frac{S_m - S_e}{\frac{B}{2} - e} = \frac{(0.894 - 0.676) * 22.37}{\frac{2000}{2} - 340} = 7.39 * 10^{-3}$$

$$t = 0.424^\circ < 1^\circ \text{ (O.K.)}$$

Inclined Load on a Footing

Footing is subjected to inclined loading R . This load is resolved into a vertical component Q_v and Horizontal component Q_H . The total horizontal resistance consists of passive soil resistance P_p and frictional resistance F at the base footing

Total passive resistance $P_p = \frac{1}{2} k_p \gamma H^2$

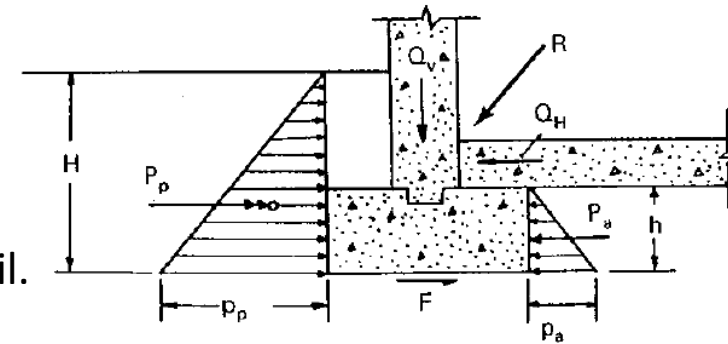
Total active pressure $P_a = \frac{1}{2} k_a \gamma h^2$

Total resistance at the base $F = c \times \text{area} + \mu Q_v$

μ is the coefficient of friction between footing and soil.

Factor of safety against sliding $= \frac{P_p + F - P_a}{Q_H}$

Considerable movement of the foundation is required to fully mobilize the passive resistance. Thus, only one third to one half of the passive resistance is used in above equation



Forces acting on a footing subjected to inclined loads

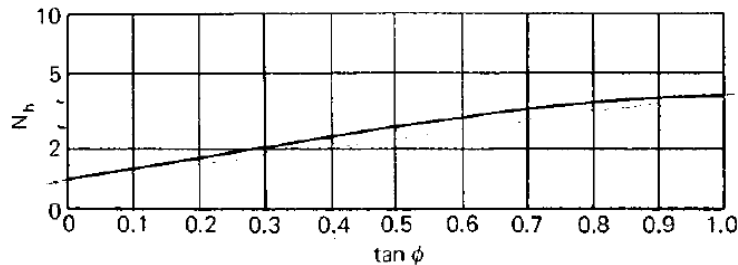
Inclined Load on Footing (Continued...)

Meyerhof (1953) and Janbu (1957) have extended the analysis of bearing capacities for inclined loads. According to Janbu,

$$\frac{Q_v + N_h Q_h}{A} = cN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

N_h can be read from the graph

Meyerhof (1953) derived the reduction factor for N_γ and N_c (Table). The vertical load is computed by multiplying the appropriate bearing capacity factor by the reduction factor.



Bearing capacity factor	D_f/B	Inclination of load with vertical				
		0°	10°	20°	30°	45°
N_γ	0	1.0	0.5	0.2	0	—
	1	1.0	0.6	0.4	0.25	0.15
N_c	0–1	1.0	0.8	0.6	0.4	0.25

Eccentric Inclined Load on a Footing: When the load is both eccentric and inclined, the reduction factor is combined with the reduced width (Prakash et al. 1979)

References

1. **Prakash S. (1981), "Soil Dynamics", McGraw-Hill Company, New York**
2. **Saran S. (2006), "Soil Dynamics & Machine Foundation", Galgotia Pub. Pvt. Ltd, New Delhi.**

Thank You

