



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS

Lecture 9: Footings under Dynamic Loads: Eccentric and Inclined Loads, A New Method

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ERD of Foundations - Modules

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- 2. Shallow Foundations**
3. Pile Foundations
4. Well Foundations
5. SSI for Deep Foundations



Module - 2

Shallow Foundations



Module -2: Chapters

1. General Requirements
2. Bearing Capacity and Settlement
3. Combined Footings
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5. Footings Subjected to Dynamic Loads

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

Dynamic Loads and Methods of Analysis

- Foundation are subjected to dynamic loads due to
 - a. Earthquake (Predominantly Horizontal)
 - b. Blasting (Predominantly Vertical)
 - c. Operation of Machine (Coupled)
- Methods of Analysis
 - a. Pseudo-Static Analysis
 - b. Dynamic Analysis

Pseudo-Static Analysis

- $k_h = \frac{a_h}{g}, k_v = \frac{a_v}{g}$
- $F_h = k_h W, F_v = k_v W$
- Most commonly used for the designing of foundation subjected to earthquake forces Adopting appropriate values of horizontal and vertical seismic coefficients, equivalent seismic force can be conveniently evaluated. These forces in combination of static force make the foundation subjected to eccentric inclined load.

Earthquake Loads on Footings

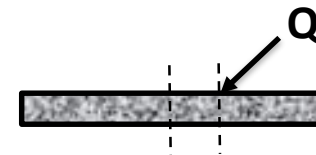
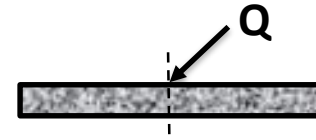
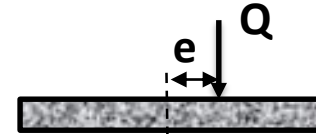
- Vertical Alternating Load – Failure follow a static pattern
- Horizontal Alternating Load – Sliding may occur
- Alternating Moment about one or more axis – slip surface forms on each side of the foundation

Effect of Horizontal Load and Moment

One of the three cases may arise, depending on whether the effect of moment are predominant as compared with horizontal thrust or reverse is the case or effect of both types of load are predominant.

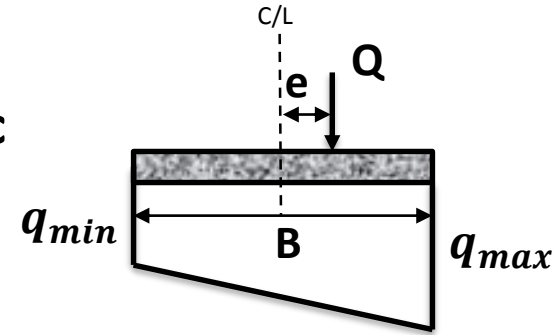
1. The effect of **moment** only is predominant, the footing is then an eccentric load footing.
2. The effect of **thrust** only is predominant, the footing is then under the action of inclined central load.
3. The effect of both **moment** and **thrust** are important, the footing is then subjected to eccentric inclined load.

$$e = M/Q$$



Eccentric Load on Footing

- The moment M on the footing is replaced by an eccentric vertical load so that eccentricity $e = M/Q$
- Where Q is the central vertical load due to static and live loads.
- Fig. shows the footing under the action of load Q acting with eccentricity e .
- For $e < B/6$, the footing is in compression throughout. As $e > B/6$, there is loss of contact of footing with the soil for $3(e - B/6)$ portion of width.



Eccentric Load on Footing (Continued...)

- For $e < B/6$ $q_{max} = \frac{Q}{A} \left(1 + \frac{6e}{B} \right)$ (1a)

- For $e > B/6$ $q_{max} = \frac{Q}{A} \left(\frac{4B}{3B-6e} \right)$ (1b)

- $q_{min} = 0$ at a distance of $3 \left(\frac{B}{2} - e \right)$ from the (right) edge of footing

The concept of effective width B' was introduced by Meyerhof (1953) and the ultimate bearing capacity of footing shall be computed

$$B' = B - 2e \quad (2)$$

Above method of reducing effective width suffers from the fact that only the ultimate bearing capacity is analyzed.

A new Method of designing eccentrically loaded Footing

A new method is proposed by Prakash and Saran (1971, 1973). An analytical solution of determining the ultimate bearing capacity of strip footing under the eccentric vertical load has been developed, assuming a one sided failure (Saran 1969). The results of bearing capacity computation have been expressed in the form of bearing capacity factors N_c , N_q and N_γ with the difference that these factors are function of angle of internal friction of soil ϕ and eccentricity of footing, expressed in terms of ratio of eccentricity e to width B of footing.

New Method: Bearing Capacity

The loss of contact of the footing width, with increase in eccentricity was accounted for while evaluating the bearing capacity factors. Thus, ultimate bearing capacity is expressed by:

$$q_u = cN_c + \gamma D_f N_q + 0.5\gamma B N_\gamma \quad (3a)$$

The bearing capacity factors N_c , N_q and N_γ have been plotted in next slides.

For designing footings under the eccentric loading, the following items were examined:

1. Bearing capacity
2. Settlement of footing under the load
3. Tilt of the footing

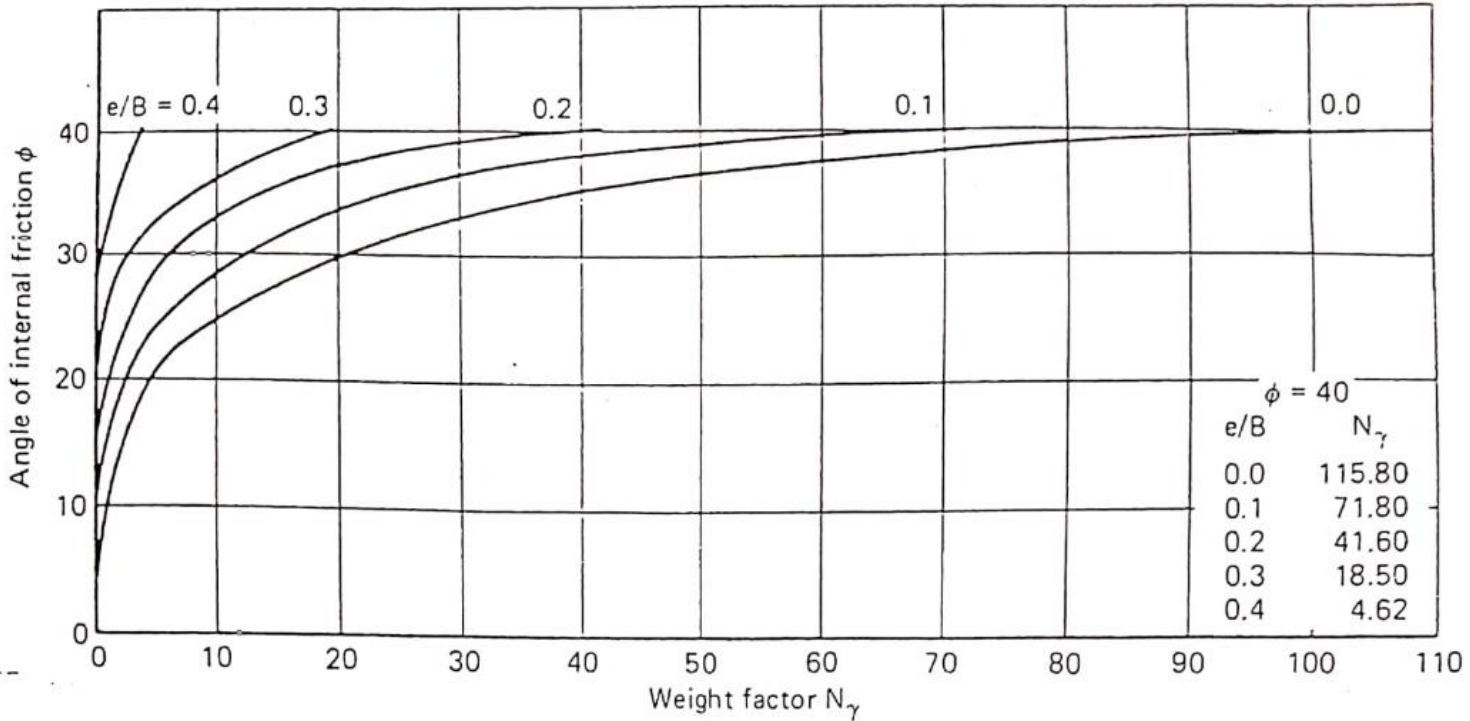


Figure 6.8 Bearing capacity factor N_γ vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

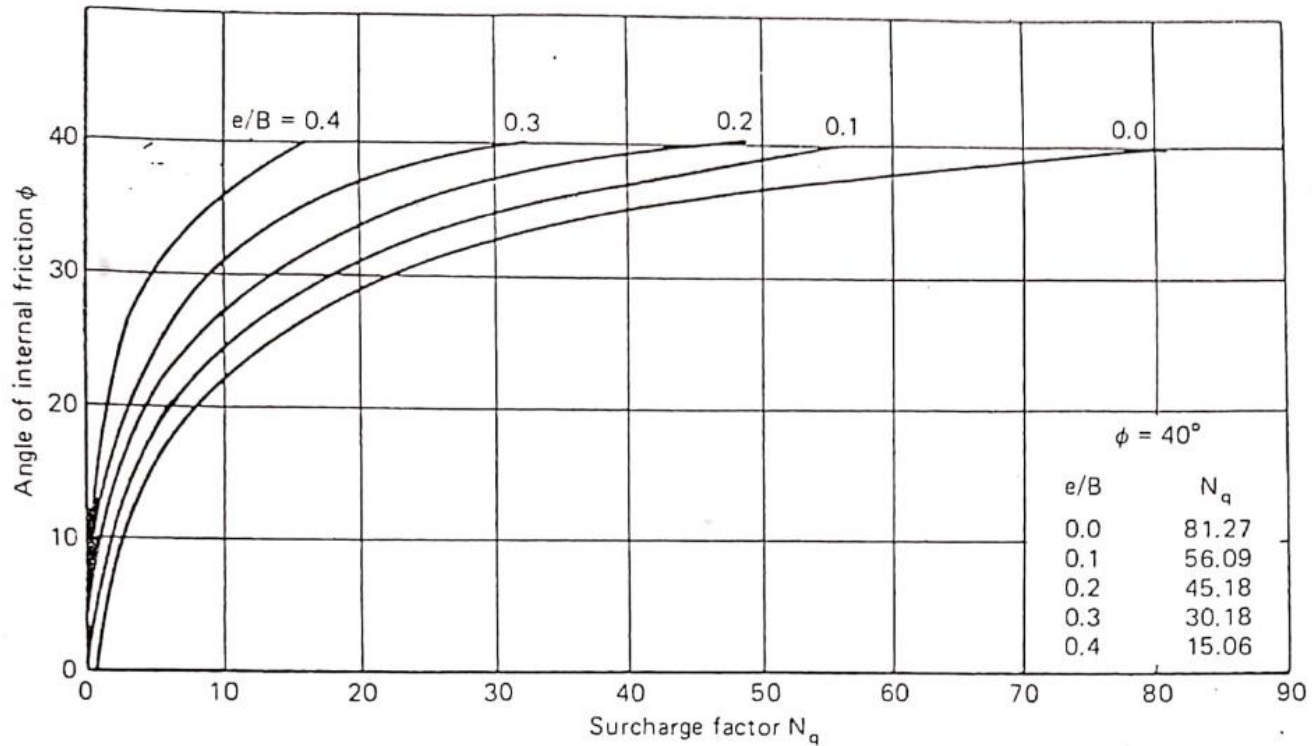


Figure 6.9 Bearing capacity factor N_q vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

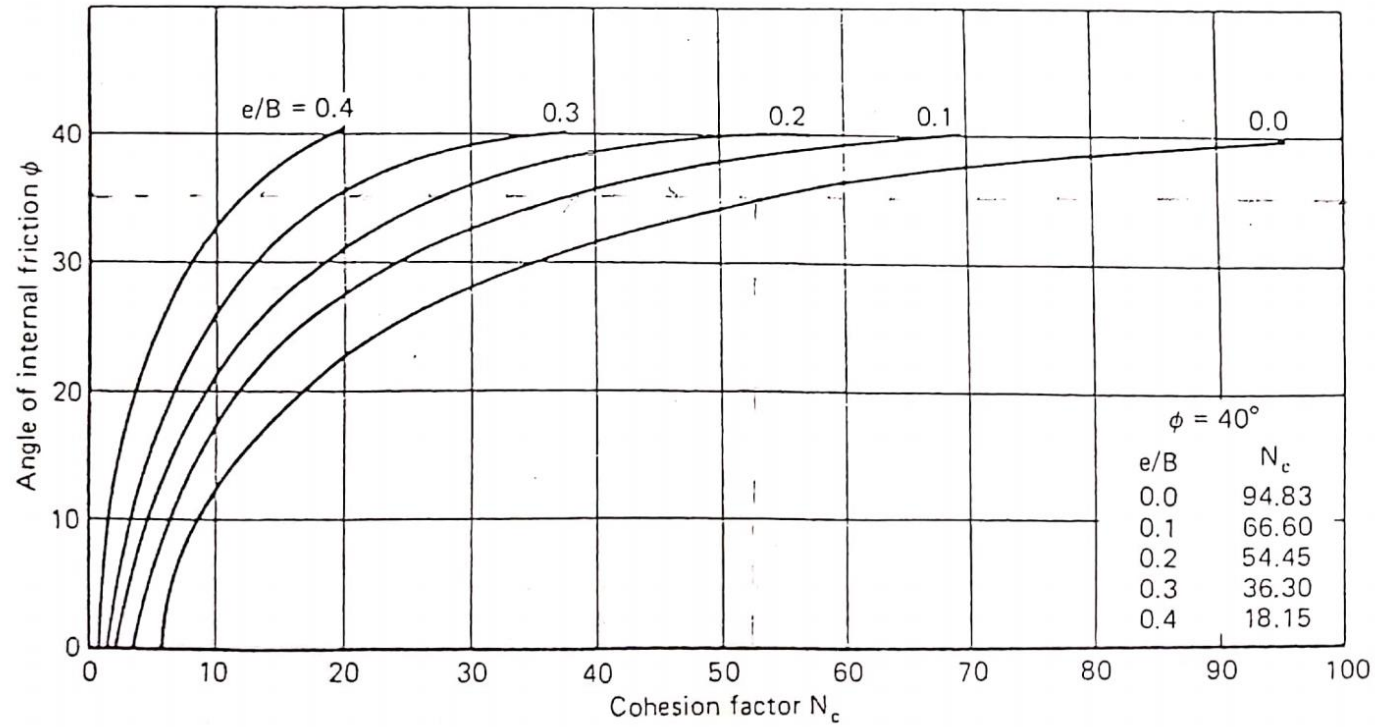


Figure 6.10 Bearing capacity factor N_c vs. ϕ and e/B of 0.1, 0.2, 0.3, 0.4. (After Prakash and Saran 1971.)

New Method: Bearing Capacity (Continued...)

Applying the correction factors, the bearing capacity is expressed by:

$$q_u = cN_c S_c d_c i_c + \gamma D_f N_q S_q d_q i_q + 0.5\gamma B N_\gamma S_\gamma d_\gamma i_\gamma \quad (3b)$$

Symbol S , d & i are shape factor, depth factor and inclination factor respectively. The shape factors with effect of eccentricity is denoted by Δ .

Shape factors Δ_γ and Δ_q for bearing capacity factors N_γ & N_q , respectively are given by

$$\Delta_\gamma = 1.0 + \left(\frac{2e}{B} - 0.68\right) \left(\frac{B}{L}\right) - \left(\frac{3e}{2B} - 0.43\right) \left(\frac{B}{L}\right)^2 \quad (4a)$$

Where, L = length of footing and

$$\Delta_q = 1.0 \text{ for all shapes of footing} \quad (4b)$$

New Method: Bearing Capacity (Continued...)

For shape factor Δ_c to be applied to N_c , the following values are proposed based upon the analysis of test data by Meyerhof (1953) for eccentric loaded footings.

$$\begin{aligned} \Delta_c &= 1.2 \text{ for square footing } (L/B = 1) \\ &= 1.0 \text{ for strip footing } (L/B \geq 8) \end{aligned} \quad \left. \vphantom{\begin{aligned} \Delta_c &= 1.2 \text{ for square footing } (L/B = 1) \\ &= 1.0 \text{ for strip footing } (L/B \geq 8) \end{aligned}} \right\} \quad (4c)$$

For rectangular footing, a linear interpolation may be made.

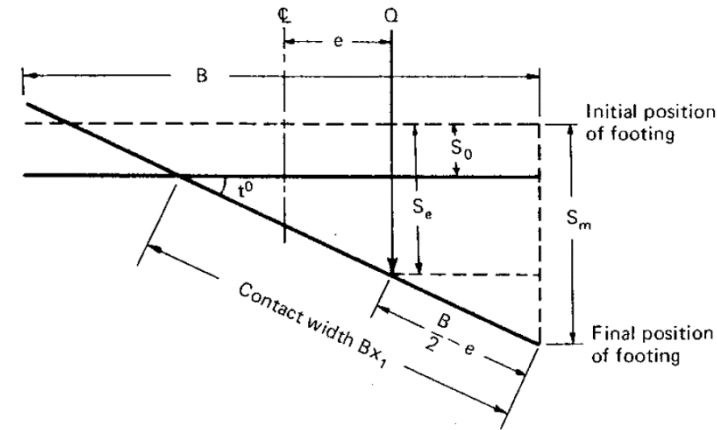
New Method: Settlement

Settlement of centrally loaded footing is estimated on the basis of a load test (IS 1888 - 1982). A design method for determining the settlement and tilt of an eccentrically loaded footing for a standard load test has been proposed.

An eccentrically loaded footing settles as shown in Fig.

S_e and S_m represent the settlement of the point under the load and settlement of the edge of the footing, respectively. Maximum settlement occurs at the edge of footing. If t is the tilt of the footing, then S_m can be given by:

$$S_m = S_e + (B/2 - e) \sin(t) \quad (5)$$



New Method: Settlement (Continued...)

In the model test conducted by Prakash and Saran (1971), S_e and t were measured. S_m was then computed using equation (5). The settlement (S_o) of such footing under the central vertical load were also determined. Plot of S_e/S_o and e/B ; and of S_m/S_o and e/B for equal factor of safety indicate that the average relationship can be represented by the following simple expressions:

$$\frac{S_e}{S_o} = 1.0 - 1.63 \left(\frac{e}{B}\right) - 2.63 \left(\frac{e}{B}\right)^2 + 5.83 \left(\frac{e}{B}\right)^3 \quad (6a)$$

$$\frac{S_m}{S_o} = 1.0 + 2.31 \left(\frac{e}{B}\right) - 22.61 \left(\frac{e}{B}\right)^2 + 31.54 \left(\frac{e}{B}\right)^3 \quad (6b)$$

Equation (6a) and (6b) is applicable only when $\left(\frac{e}{B}\right) \leq 0.4$

New Method: Settlement (Continued...)

Settlement of footing ($S_o = S_f$) is calculated using the plate load test

For Sand,
$$\frac{S_f}{S_p} = \left[\frac{B_f(B_p+30)}{B_p(B_f+30)} \right]^2 \quad (7a)$$

For Clay,
$$\frac{S_f}{S_p} = \frac{B_f}{B_p} \quad (7b)$$

Substituting the value of S_e and S_m in equation (5), the value of tilt can be obtained.

The settlement and tilts of the footings subjected to moments can be predicted from the plate load test under the central load. The ultimate bearing capacity can be determined by using bearing capacity factors.

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

