Evaluation of Bearing Capacity of ground in Transition Zone

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Abstract: The determination of ultimate bearing capacity in transition zone by classical theory is not clearly explained (Murthy (2011), Punmia (2005), IS-6403). Most of them including IS: 6403 - 1981 suggest a linear interpolation between general and local shear failure in transition zone with no further explanation. Practicing engineers do not have consistency in calculation of bearing capacity in the transition zone. More often, they are likely to encounter the situation of the angle of internal friction lying between 28^o and 36^o. Many a times, it is felt that the baring capacity is over estimated. Therefore an attempt is made in this paper to determine the ultimate bearing capacity by different methods in the transition zone and to give more precise calculation procedure for the determination of bearing capacity in the transition zone. For this purpose, Terzaghi's bearing capacity factors are used in the analysis. An attempt is made to present bearing capacity factors as a function of angle of internal friction of soil considering local shear zone, transition zone and general shear zone. Three methods to determine the ultimate bearing capacity of soil in transition zone are discussed and their relative conveniences are brought out.

Keywords: Bearing Capacity, Transition Zone, Local shear; general shear, Bearing Capacity Factors.

1. Introduction

The determination of bearing capacity of soil is the most important requirement of foundation design. Depending on strength and stiffness of soil, bearing capacity failures can be broadly divided in to three modes, namely general shear failure when the angle of internal friction of soil, $\phi > 36°$, mixed or transition zone when $28° < \phi < 36°$, and local shear failure when $\phi < 28°$. Local shear failure generally occurs in loose sand while general shear failure occurs in dense sand (Terzaghi (1967), Punmia (2008), IS: 6403-1981). For general shear failure conditions bearing capacity equations are available and for local shear failure conditions, same equations are reduced by considering reduced shear parameters. However, for intermediate values of ϕ, in mixed or transition state between local and general shear failure, no separate equations are available. As ϕ increases above 28°, there is a need for gradual transition from local to general shear failure. IS: 6403-1981suggests interpolation between local and general shear failure for determination of bearing capacity in transition zone with no further explanation. The curve obtained by plotting ultimate bearing capacity versus friction angle (ϕ) is not smooth. Terzaghi (1967) suggested that linear interpolation be made to evaluate ultimate bearing capacity for soil with ϕ lying between 28° and 36°. Punmia (2005) indicates that no separate equation is available for intermediate values of ϕ in mixed zone and that there should be gradual transfer from local to general shear failure.

2. Methods for Determination of Bearing Capacity in Transition Zone

Ultimate bearing capacity of soil according to Terzaghi's method of analysis is as follows.

For general shear failure ($\phi > 36°$),

$$Qf = c\ Nc + \gamma\ D\ Nq + 0.5\gamma\ B\ N\gamma \qquad (1)$$

For local shear failure ($\phi < 28°$),

$$Qf = c_m\ Nc' + \gamma\ D\ Nq' + 0.5\gamma\ B\ N\gamma' \qquad (2)$$

Here, c is cohesion of soil, γ is unit weight of soil, D is depth of footing, B is width of footing Nc, Nq and Nr are Terzaghi's bearing capacity factors that depend on soil friction angle, ϕ. Bearing capacity factors corresponding to the local shear failure Nc′, Nq′, Nγ′ are reduced in Eq 2. ($\tan \phi_m = 2/3 \tan \phi$, $c_m = 2/3$ c). Let us consider a strip footing of width 1.2m and depth 0.9m, in a homogenous soil having cohesion c=10 kN/m^2, and unit weight γ = 18kN/m^3. Let Q_f be the ultimate bearing capacity of a given soil mass in kN/m^2. Let us consider a smooth curve to connect from ultimate bearing capacity at 28^o to ultimate bearing capacity at 36^o for which a best fit curve is drawn by taking a 5^{th} order polynomial as shown in Fig. 1.

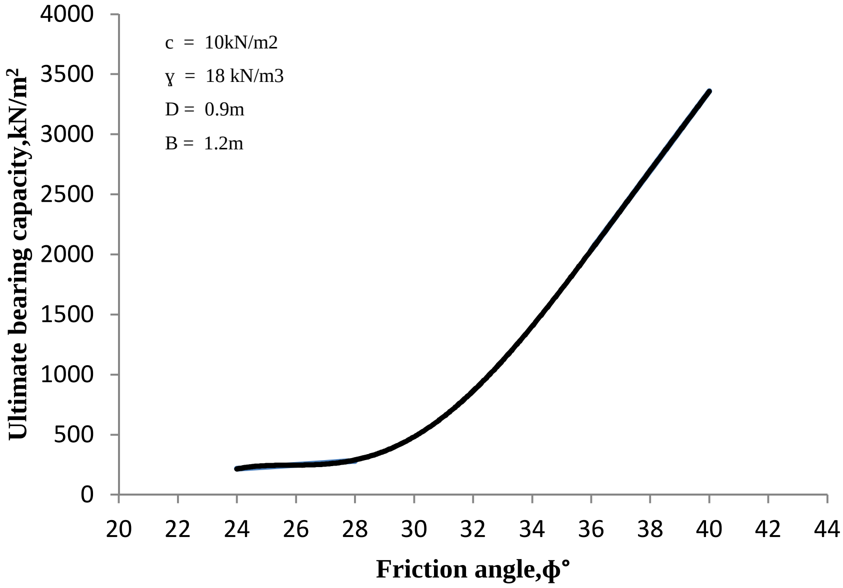

Fig. 1. Variation of ultimate bearing capacity with friction angle considering Best Fit Curve in transition zone.

2.1 Method – 1 (As suggested by IS: 6403-1981 by interpolation method.)

2.1.1 Procedure:

a. For various values of ϕ, ultimate bearing capacity for local and general shear failures are determined by Eq.1 and Eq.2.
b. In transition zone, ultimate bearing capacity is calculated by linear interpolation between local and general shear failure.
c. A graph is plotted, taking ultimate bearing capacity along y-axis and friction angle (ϕ) along x-axis.
d. It is compared with the best fit curve as shown in Fig. 2.

2.1.2 Example:

Table.1. Ultimate Bearing Capacity in Local and General Shear Failure zones

Failure zone	ϕ°	Reduced ϕ°	Reduced c (kN/m^2)	Q_f (kN/m^2)
Local shear failure	28°	19.52°	6.67	281.51
General shear failure	36°	36°	10.00	2036.95

For ϕ = 32°, Ultimate bearing capacity is determined by linearly interpolating between the ultimate bearing capacities of ϕ = 28°and 36° respectively as $(Q_f)_{32°}$ = 1159.23 kN/m^2.

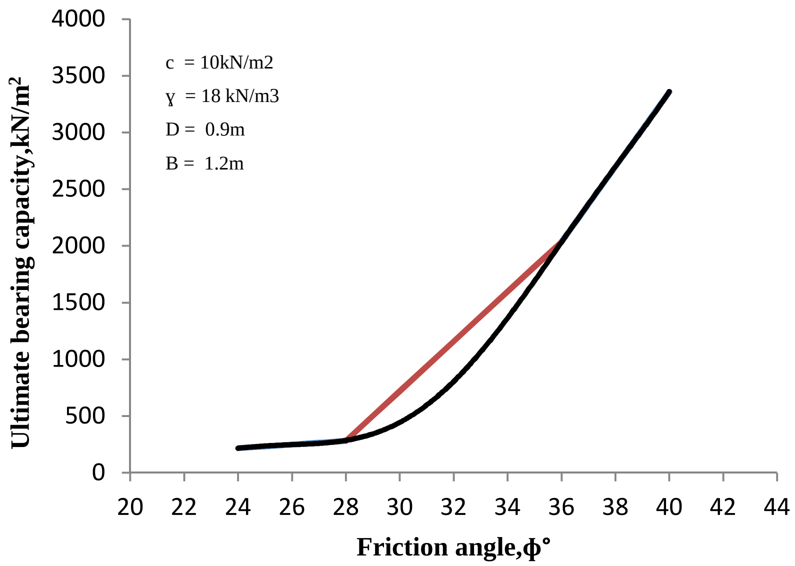

Fig. 2. Variation of ultimate bearing capacity with friction angle considering linear interpolation of Method -1 in transition zone.

2.2 Method – 2

2.2.1 Procedure:

a. For various values of ϕ in local and general shear zones, ultimate bearing capacities of soil are determined by Eq.1 and Eq.2.
b. Ultimate bearing capacity of a soil in mixed zone is determined by assuming the linear interpolation at the given ϕ in between local and general shear failure for same value of ϕ.
c. Hence, for given values of ϕ (28°<ϕ<36°), Ultimate bearing capacity is calculated for both local and general shear failure and interpolated between them by Eq.3.
d. The graph of ultimate bearing capacity along y-axis and friction angle (ϕ) along x-axis plotted in this condition is compared with best fit curve as shown in Fig. 3.

$$Q_f'' = Q_f' + (Q_f - Q_f')/(36 - 28) * (\phi - 28) \qquad (3)$$

Here, Q_f'' - Ultimate bearing capacity for a given value of ϕ in transition zone.

Q_f - Ultimate bearing capacity for a same value of ϕ, considering soil to undergo general shear failure.

Q_f' - Ultimate bearing capacity for a same value of ϕ, considering soil to undergo local shear failure.

2.2.2 Example: For ϕ =32°, assuming that the soil in transition zone may undergo mixed shear failure i.e.it may undergo both local and general shear failure for same value of ϕ. Value of ultimate bearing capacity, considering local shear failure $(Q_f)_{32°}$ = 389.156 kN/m2 and general shear failure $(Q_f)_{32°}$ = 1252.196 kN/m^2 Therefore ultimate bearing capacity at ϕ = 32° from Eq.3, is $(Q_f)_{32°}$ = 820.676 kN/m^2.

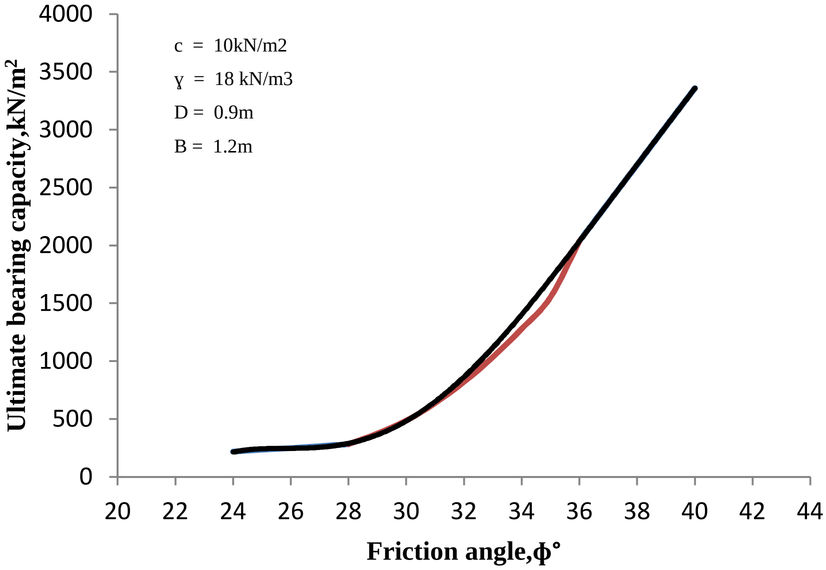

Fig. 3. Variation of ultimate bearing capacity with l friction angle considering interpolation at the given ϕ of Method -2 in transition zone.

2.3 Method – 3.

2.3.1 Procedure:

a. For various values of ϕ, ultimate bearing capacity for local and general shear failures is determined by Eq.1 and Eq.2.
b. In transition zone, ultimate bearing capacity of a soil is determined by gradually varying the reduction factor for Cohesion and friction angle from 2/3 to 1 (i.e. from 28° to 36°).
c. A graph is plotted, taking ultimate bearing capacity along y-axis and friction angle (ϕ) along x-axis and the results are compared with best fit curve as shown in Fig. 4.

2.3.2 Example: For ϕ = 28°, c and tan ϕ are reduced to 2/3 (c) and 2/3 * (tan ϕ) respectively. Similarly for ϕ = 29°, c and tan ϕ is reduced to (2/3+ 1/24) times and so on. At 36° there is no reduction in c and ϕ.

For ϕ = 32°, c and ϕ becomes 8.33kN/m^2 and 27.51° respectively. Therefore, ultimate bearing capacity at ϕ = 32° is $(Q_f)_{32°}$ = 703.99 kN/m^2.

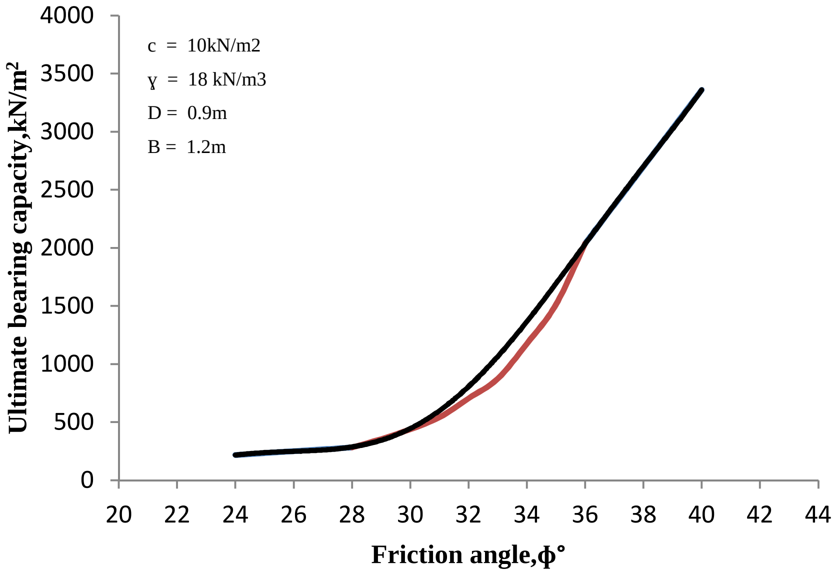

Fig. 4. Variation of ultimate bearing capacity with friction angle considering gradual transition of Method -3 in transition zone.

3. Comparison of ultimate bearing capacity by three methods

For various values of ϕ, ultimate bearing capacity determined by above three methods is plotted in the same graph as shown in Fig. 5.

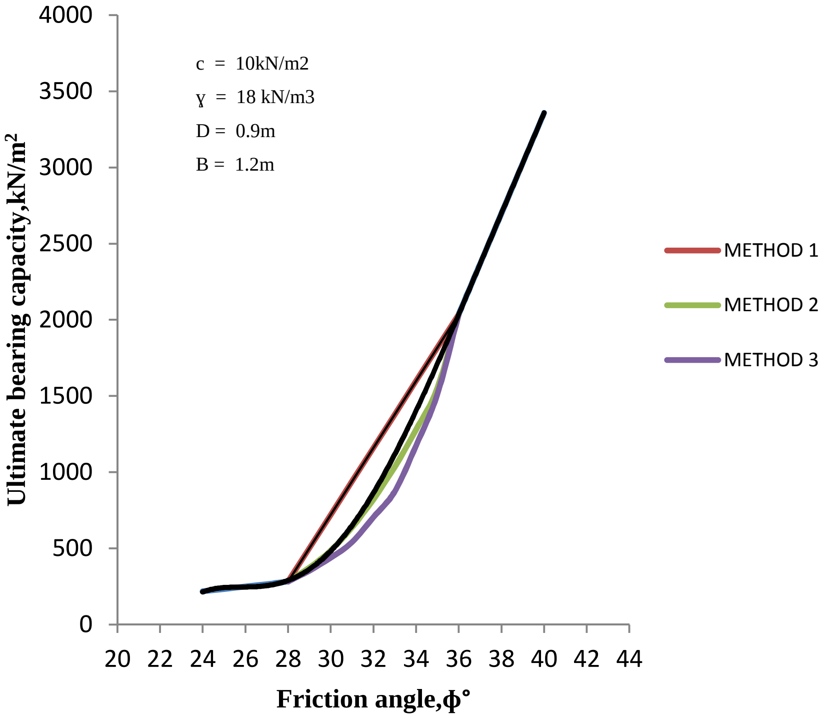

Fig. 5. Variation of ultimate bearing capacity with friction angle considering all three methods in transition zone.

Table.2. Percentage difference in area between best fit curve and the values obtained by different methods.

Problem No.	Problem Description	Percentage Error (%)		
		Method-1	Method-2	Method-3
1	Strip Footing c = 0 kN/m^2, ϕ = 16 kN/m^3, B = 1.5 m, D = 0.8 m	-21.58	+04.73	+11.66
2	Strip Footing c = 10 kN/m^2, ϕ = 18 kN/m^3, B = 1.2 m, D = 0.9 m	-18.30	+03.89	+10.64
3	Strip Footing c = 20 kN/m^2, ϕ = 17 kN/m^3, B = 1.7 m, D = 1 m	-17.86	+03.43	+10.27

4	Square Footing c = 0 kN/m^2, ϕ = 16 kN/m^3, B = 1.5 m, D = 0.8 m	-21.66	+04.24	+11.08
5	Square Footing c = 10 kN/m^2, ϕ = 18 kN/m^3, B = 1.2 m, D = 0.9 m	-16.18	+04.72	+11.33
6	Square Footing c = 20 kN/m^2, ϕ = 17 kN/m^3, B = 1.7 m, D = 1 m	-14.83	+04.97	+11.61
7	Circular Footing c = 0 kN/m^2, ϕ = 16 kN/m^3, B = 1.5 m, D = 0.8 m	-21.89	+03.52	+10.24
8	Circular Footing c = 10 kN/m^2, ϕ = 18 kN/m^3, B = 1.2 m, D = 0.9 m	-17.29	+03.36	+09.98
9	Square Footing Ground water table at 0.6 m from GL. c = 10 kN/m^2, ϕ = 18 kN/m^3, B = 1.2 m, D = 0.9 m, Rw1 = 0.833, Rw2 = 0	-14.96	-14.96	+11.20
10	Circular Footing Ground water table at 1.5m from GL. c = 10 kN/m^2, ϕ = 18 kN/m^3 B = 1.2 m, D = 0.9 m, Rw1 = 1, Rw2 = 0.75	-15.46	+04.51	+10.98

NOTE:-

- Positive sign is considered for under-estimated value and negative sign for overestimated value.
- Percentage error = (A_B - A) / A_B * 100, where, A_B = Area under the best fit curve in transition zone and A = Area under the curve by method 1, 2 or 3 in transition zone. Area is found out by integration of piecewise linear curves.

4. Conclusion

A number of problems are solved and the results are presented in Table 2 corresponding to the determination of ultimate bearing capacity in transition zone. From the above analysis, the inference is made as follows. From Fig. 2, it is evident that the ultimate bearing capacity obtained under transition zone using Method – 1 is over estimated compared to the capacity according to that of best fit curve. From Fig. 3, it is evident that the ultimate bearing capacity obtained under transition zone using Method – 2 is under estimated compared to the capacity according to that of best fit curve. From Fig. 4, it is evident that the ultimate bearing capacity obtained under transition zone using Method – 2 is under estimated compared to the capacity according to that of best fit curve. From Table 2, it is evident that the error is minimum in Method – 2. Further, the method underestimates the ultimate bearing capacity which is on the safer side. Hence, it is concluded that Method – 2, which is easy to compute also in addition to being most accurate is the best suited to determine the ultimate bearing capacity of soil in the transition zone.

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