PROCEEDINGS OF THE
NINTH ASIAN REGIONAL CONFERENCE
ON SOIL MECHANICS
AND FOUNDATION ENGINEERING

VOLUME 1

9TH - 13TH DECEMBER 1991

BANGKOK, THAILAND

APPLICATION OF ZERO EXTENSION LINE IN BEARING CAPACITY

L. Behpoor Faculty Member, Department of Civil Engineering, Shiraz University, Shiraz, Iran
A. Ghahramani Faculty Member, Department of Civil Engineering, Shiraz University, Shiraz, Iran

SYNOPSIS The method of simple zero extension line field is used to calculate the bearing capacity coefficients for smooth strip footing on sandy soils. The relative settlement of the footing is correlated with shear strain enabling evaluation of load-displacement behavior by using the shear characteristics of sand. The predicted values compare favorably with those in literature. Charts and formulas are presented for bearing capacity coefficients as function of angle of internal friction and as function of relative settlement for given sand.

INTRODUCTION

The zero extension line concept (line with linear strain equal to zero) was first introduced by Roscoe (1970) for interpretation of the strain field in a sand media. The simple zero extension line field was proposed by James and Bransby (1970). The concept has been used by several investigators to predict earth pressure and bearing capacity of sandy soils (see references).

In the present work the bearing capacity of shallow, smooth, strip foundation on sandy soil is evaluated by using the simple zero extension line theory. In addition, the relative settlement of foundation is related to the bearing capacity factors. The results are presented in formulas and charts, and compared with existing results in literature.

THEORY

Because of the extensive coverage of the theory in the cited literature only elements relevant to the present work are briefly presented. Consider the strip footing rested on sand in Fig. 1.

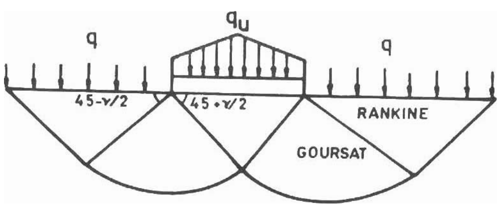

Fig. 1. Smooth Strip Foundation on Sand

The zero extension line field consisting of Rankine, Goursat, and mixed zones are shown. ν is the angle of dilation of soil. The Terzaghi bearing capacity equation is:

$$q_u = qN_q + \tfrac{1}{2}\gamma B N_\gamma \qquad (1)$$

where q is the applied surcharge, γ the soil unit weight, B the width of the foundation, and N_q and N_γ are the bearing capacity factors.

The zero extension line theory predicts a linear pressure distribution at the foundation contact surface.

Considering the equilibrium of the above zones and using the zero extension line theory, based on previous works, N_q and N_γ are evaluated.

$$N_q = K_{pq} \qquad (2)$$

$$N_\gamma = \frac{K_{p\gamma}}{\cos(\frac{\pi}{4} + \frac{\nu}{2})} - \tan(\frac{\pi}{4} + \frac{\nu}{2}) \qquad (3)$$

where K_{pq} and $K_{p\gamma}$ are the passive pressure coefficients on the boundaries of the Goursat zone and have been evaluated by Jahanandish, Behpoor and Ghahramani (1989) are as follows:

$$K_{pq} = \cos(\delta + \nu) D e^{K\cdot\frac{\pi}{2}} \qquad (4)$$

$$K_{p\gamma} = \cos(\delta + \nu)[B e^{-K(\frac{\pi}{4} - \frac{\nu}{2})} + A e^{K\cdot\frac{\pi}{2}}] \qquad (5)$$

$$A = \cos\nu \frac{\sin(\delta + \frac{\pi}{4} + \frac{\nu}{2})}{\cos(2\delta + \nu)} e^{\frac{\pi}{2}\tan\nu} \qquad (6)$$

$$B = \frac{\cos\lambda}{\cos(2\delta + \nu)} B' e^{-(\frac{\pi}{4} - \frac{\nu}{2})\tan\nu} \quad (7)$$

$$B' = \cos(\frac{\pi}{4} - \frac{\nu}{2} + \delta + \lambda) e^{\tan\lambda.(\frac{\pi}{4} - \frac{\nu}{2})}$$

$$-\cos(\frac{\pi}{4} + \frac{\nu}{2} + \delta + \lambda) e^{\tan\lambda.(\frac{\pi}{4} + \frac{\nu}{2})} \quad (8)$$

$$D = \frac{\cos\nu \sin(\frac{\pi}{4} + \frac{\nu}{2} + \delta)}{\sin(\frac{\pi}{4} - \frac{\nu}{2})\cos(2\delta + \nu)} \quad (9)$$

$$\tan\lambda = \tan(2\delta + \nu) + 2\tan\nu \quad (10)$$

$$K = \tan(2\delta + \nu) + \tan\nu \quad (11)$$

$$\tan\delta = \frac{\sin\phi - \sin\nu}{\cos\nu} \quad (12)$$

where ϕ is the angle of internal friction and ν the angle of dilation of sand. It is seen that once the ϕ and ν are known the bearing capacity factors N_q and N_γ can be evaluated. Normally ϕ and ν are obtained from shear test. However if only ϕ is known, ν can be evaluated by using formulas relating ϕ and ν. The authors prefer to use the relationship

$$\nu = \phi - 30 \quad (13)$$

The usefulness of zero extension line field is that in addition to predicting the stresses, displacements can also be evaluated. Fig. 2

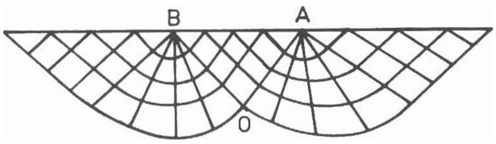

Fig. 2. Zero Extension Line Net

shows the zero extension line net under footing AB. This net theoretically behaves like rigid links connected at nodes. The settlement of the footing AB causes an expansion of the wedge BOA such that OA and OB rotate by an amount θ about O. θ is related to the settlement S by the following formula:

$$\theta = 2 \frac{S}{B} \quad (14)$$

where B is the width of the footing. If S/B is called the relative settlement, then the rotation is twice the relative settlement. From previous work (Jahanandish, Behpoor, Ghahramani, 1989), the shear strain in each quadrilateral in Goursat and Rankine zones is constant in this case. The shear strain in each quadrilateral is simply the change of angle and is equal to θ. Therefore once the relative settlement is given the shear strain can be evaluated and from the results of the shear tests relating Sinϕ with shear strain such as Fig. 3a, the angle of internal friction can be evaluated as function of relative settlement, (Fig. 3b). It is to be noted that the Fig's 3a and 3b

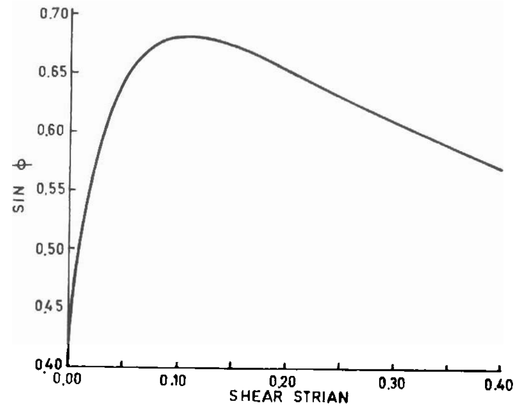

Fig. 3a. Sinϕ versus Shear Strain

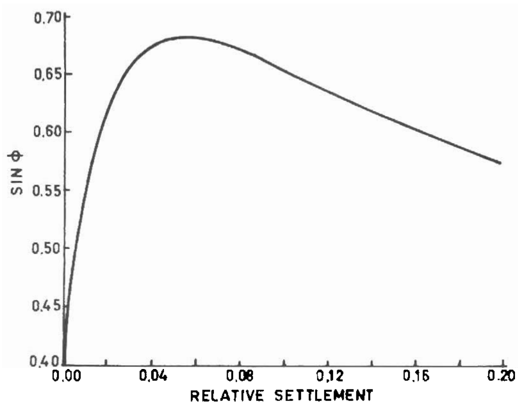

Fig. 3b. Sinϕ versus Relative Settlement

have the same ordinate but the abscissa of Fig. 3b is half of that of Fig. 3a. This signifies that once a shear test is run or is chosen to present the behavior of sand under the footing, the relative settlement can be evaluated as a function of ϕ. Therefore, the settlement and bearing capacity can be related to each other.

RESULTS

The bearing capacity factors, based on Eq. (13), predicted by the zero extension line theory are presented in Fig. 4 as the function of ϕ.

For the dense sand of Fig's 3a and 3b the bearing capacity factors are related to relative settlement and are shown in Fig. 5.

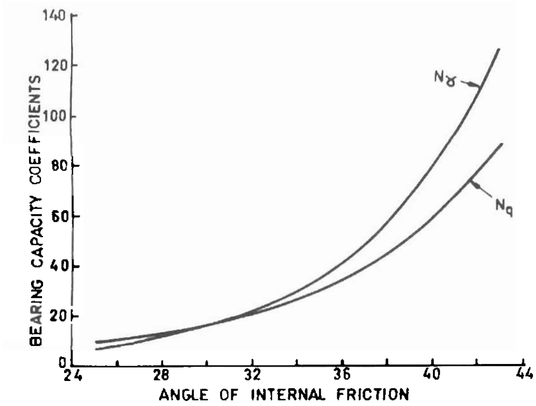

Fig. 4. Bearing Capacity Factors versus ϕ

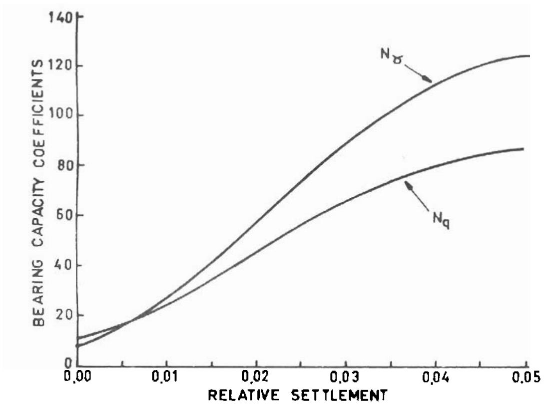

Fig. 5. Bearing Capacity Factors versus Relative Settlement

It should be emphasized that the user is not restricted to apply the bearing capacity factors predicted by the zero extension line theory and he can choose bearing capacity factors as proposed by other sources.

Then by using the results of soil shear test, the user can relate the chosen friction angle with the soil shear strain and consequently with the relative settlement which is half of the soil shear strain.

DISCUSSION OF THE RESULTS

The bearing capacity factors presented in Fig. 4 are comparable with the values cited in the literature. A partial comparison is seen in Table I.

TABLE I

Partial comparison between bearing capacity factors from literature* and from zero extension line theory

	N_q		N_γ	
	Literature	ZEL	Literature	ZEL
30	17.0	18	15.6	18
35	33.0	30	37.0	34
40	64.0	65	93.0	85

*Ref: Lee, White, Ingles; Geotechnical Engineering, P. 341. 1983, Pitman.

The relative settlement predicted by Fig. 5 for dense sand can best be compared with allowable bearing capacity for one inch settlement predicted by Standard Penetration Test results. For a relative settlement at small range of S/B, it is seen from Fig. 5 that N_γ varies almost linearly with relative settlement. This indicates a constant allowable bearing capacity for a given ϕ, which is in accordance with the N(SPT number) versus allowable pressure curves.

CONCLUSIONS

The following conclusions can be made regarding the application of zero extension line theory to the bearing capacity and settlement of smoothe strip footings on sand.

(1) The bearing capacity factors N_q and N_γ predicted by the method are comparable with the values cited in the literature.

(2) The settlement of the strip footing produces a constant shear strain in the elements of soil in the Goursat and Rankine zones, the magnitude of this shear strain is twice the relative settlement of the foundation which is defined as the settlement over the width of strip footing.

(3) The results of shear test on sand relating the angle of internal friction to shear strain can be used to predict the bearing pressure at a given settlement or vice versa. Thus the zero extension line method is capable of predicting the load-settlement curve for the strip footing.

REFERENCES

Behpoor, L., and Ghahramani, A. (1987). Zero extension line theory of static and dynamic bearing capacity. Proc. 8th Asian Regional conference on Soil Mechanics and Foundation Engineering, pp. 341-346. Kyoto, Japan.

Bhandari, R.K. (1987). Theme lecture on "Deep and Shallow Foundation". 8th Asian Regional Conference on Soil Mechanics and Foundation Engineering, 25pp. Kyoto, Japan.

Bransby, P.L., and Milligan, G.W.E (1975). Soil deformations near cantilever sheet piled walls. Gotechnique, vol. 25, No. 2, June pp. 175-195, London.

Ghahramani, A., and Clemence, S.P. (1980). Zero extension line theory of dynamic passive pressure. Journal of the Geotechnic Engineering Division, ASCE, vol. 106, No. GT6, June, pp. 631-644.

Ghahramani, A., and Clemence, S.P. (1990). Zero extension line displacement theory of earth pressure. Proc. First International Seminar of Soil Mechanics and Foundation Engineering of Iran. Vol. 3, Tehran, Iran.

Habibagahi, K., and Ghahramani, A. (1979). Zero extension line theory of earth pressure. Journal of the Geotechnical Engineering Division, ASCE, vol. 105, No. GT7, July pp. 881-896.

Jahanandish, M., Behpoor, L., and Ghahramani, A. (1989). Load-displacement characteristics of retaining walls. Proc. 12th International Conference on Soil Mechanics and Foundation Engineering, pp. 243-246. Rio De Janeiro, Brazil.

James, R.G. and Bransby, P.L. (1970). Experimental and theoretical investigation of a passive earth pressure problem. Geotechnique, vol. 20, No. 1, pp. 17-37, England.

James, R.G. and Bransby, P.L. (1971). A velocity field for some passive earth pressure problem. Geotechnique, vol. 21, pp. 61-83, England.

Roscoe, K.H. (1970). The influence of strains in soil mechanics. Geotechnique, vol. 20, No. 2, England.

Wroth, C.P., (1967). Review of earth pressure theory and earth behavior, Geotechnical Lecture series, ASCE Boston Society of Civil Engineers, pp. 1-51, Boston, Mass.

ACKNOWLEDGEMENTS

The writers wish to thank Miss. Z.Sarmadi for her fine effort in typing the manuscript and Mr. Bodnam for drawing the figures.