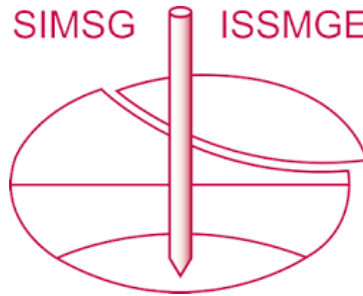


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# Comparison between the Calculated and Experimental Values of the Ultimate Bearing Capacity

Comparaison entre les valeurs calculées et expérimentales de la capacité portante

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## SUMMARY

This paper presents field test results carried out by the author on cohesive soils and by Muhs (1959, 1961) on poorly cohesive materials. The dimensions of the rectangular foundations were  $A$  by  $B = 2.0$  by  $0.5$  m and of square foundations  $A = 1.0$  m and  $A = 0.71$  m. The results of the ultimate bearing capacity, obtained by the field tests, are compared with the calculated values of several authors. For non-cohesive materials the results obtained by Balla's theory agree well with the experimental values. However, for cohesive materials the most reliable results are given by the Brinch Hansen theory.

## SOMMAIRE

Cet article donne les résultats des essais en chantier effectués par l'auteur sur des sols cohérents et par Muhs (1959, 1961) sur des sols faiblement cohérents. Les dimensions des fondations rectangulaires étaient  $A$  par  $B = 2,0$  par  $0,5$  m et de celles carrées  $A = 1,0$  m et  $A = 0,71$  m. Les résultats de la capacité portante sont comparés avec les valeurs calculées de plusieurs auteurs. Pour les sols non-cohérents, les résultats obtenus selon la théorie de Balla sont conformes aux valeurs expérimentales. Cependant pour les sols cohérents, la méthode de Brinch Hansen donne des solutions plus exactes.

MOST THEORIES dealing with the problem of the ultimate bearing capacity assume approximate sliding surfaces which usually are kinematically impossible. Because of different assumptions, the values obtained differ considerably from one another. The foundation depth and the bearing capacity factor,  $N_\gamma$ , are of particular importance.

The loading tests in the field were made on foundations of relatively large dimensions. The ultimate bearing capacity values obtained in this way were compared with those obtained theoretically.

## THE GENERAL BEARING CAPACITY EQUATIONS

K. Terzaghi (1943) proposed the following formula for the bearing capacity of a centrally and vertically loaded strip foundation:

$$q_t = cN_c + \gamma D_f N_q + 0.5\gamma B N_\gamma \quad (1)$$

where  $c$  = cohesion,  $D_f$  = depth of the foundation,  $B$  = width of the foundation,  $\gamma$  = unit weight of the soil, and  $N_c$ ,  $N_q$ ,  $N_\gamma$  = bearing capacity factors. Brinch Hansen (Brinch Hansen, 1952; Brinch Hansen and Lundgren, 1960) has extended this equation by introducing shape factor,  $s$ , depth factor,  $d$ , and inclination factor,  $i$ :

$$q_t = cN_c s d i + \gamma D_f N_q s d i + 0.5\gamma B N_\gamma s_\gamma d_\gamma i_\gamma \quad (2)$$

According to Prandtl (1920)  $N_c$  and  $N_q$  factors may be calculated by considering the theoretical case of weightless earth ( $\gamma = 0$ ):

$$N_q = e^{\bar{u} \tan \varphi} \tan^2(\bar{u}/4 + \varphi/2) \quad (3)$$

$$N_c = (N_q - 1) \cot \varphi. \quad (4)$$

Since the shape of the rupture surface, which is both kinematically and statically possible, is not yet known, Brinch Hansen recommends the following expression for the coefficient  $N_\gamma$ :

$$N_\gamma \simeq 1.80(N_q - 1) \tan \varphi. \quad (5)$$

According to Brinch Hansen, the following formulae for the depth and shape factors are:

$$d_c \simeq 1 + 0.35/[B/D_f + 0.60/(1 + 7 \tan^4 \varphi)] \quad (6)$$

$$d_q = d_c - (d_c - 1)/N_q, \quad (7)$$

$$s_c = 1 + (0.20 + \tan^6 \varphi)B/A \quad (8)$$

where  $A$  is the length of the rectangular foundation.

$$s_q = s_c - (s_c - 1)/N_q \quad (9)$$

$$s_\gamma \simeq 1 - \frac{1}{2}(0.20 + \tan^6 \varphi)B/A. \quad (10)$$

Balla (1962) considered the figure of failure that would satisfy both the static and kinematic conditions. Applying Kötter's equation in considering the equilibrium of the infinitesimal part, Balla gives the following general equation for the ultimate bearing capacity:

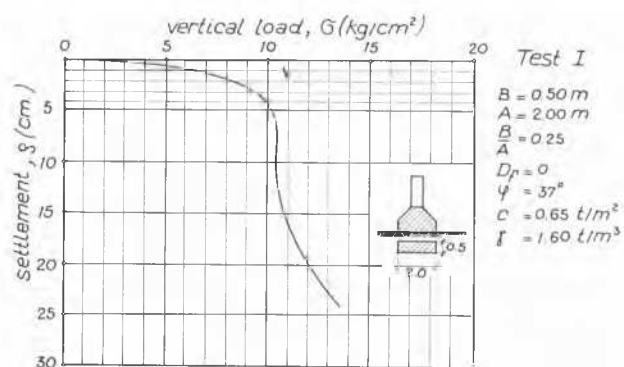
$$q_t = C(\tan \varphi + \rho F_6) + \gamma D_f(1 + \rho F_5) + 0.5\gamma B \rho(\rho F_4 + F_5 \tan \varphi) \quad (11)$$

where the coefficients  $F$  are only functions of the angle of internal friction  $\varphi$ , while the parameter  $\rho$  is the function of the angle  $\varphi$ , and of the dimensionless relationships  $D_f/(B/2)$  and  $C/(B/2 \times \gamma)$ . In other words, the bearing capacity factors do not depend only on the angle  $\varphi$  but also on the values  $D_f$ ,  $B$ ,  $C$ , and  $\gamma$ .

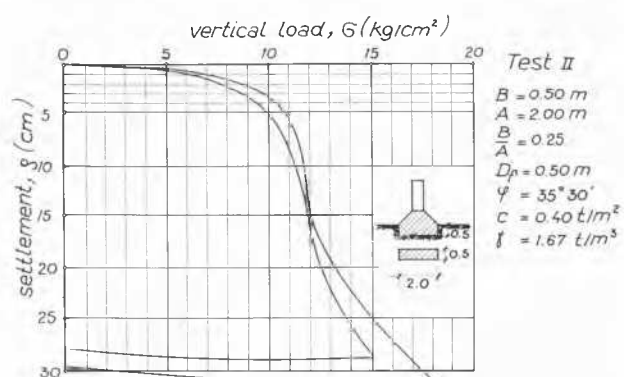
## LOADING TESTS RESULTS

Muhs (1959; 1961) carried out loading tests of poorly cohesive soils with a square foundation of the size of  $A = B = 1.0$  m and with rectangular foundations of the dimensions  $A$  by  $B = 2.0$  by  $0.5$  m. The results of these tests are given in Fig. 1.

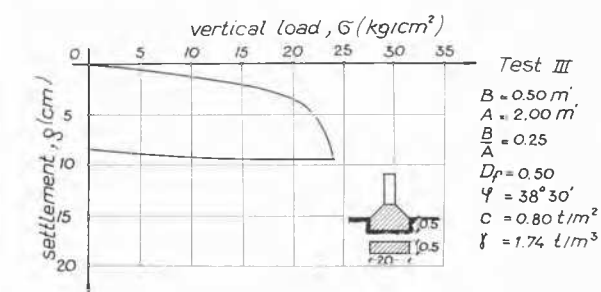
Applying the above-mentioned methods, the calculation of the ultimate bearing capacity has been made for all four



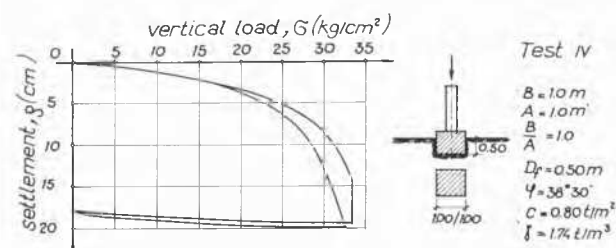
(a)



(b)



(c)



(d)

FIG. 1. Loading tests on poorly cohesive soils: (a) Test I, (b) Test II, (c) Test III, (d) Test IV.

cases. The results thus obtained are shown in Table I. Comparing the theoretical and experimental results one may conclude that the values calculated to Balla's theory are in good agreement with the experiments. In the cases where the foundation depth was greater than zero the values obtained by the Meyerhof method are considerably higher than the results of the loading tests.

The author has carried out loading tests on cohesive materials with square foundations of the size of  $A = B =$

TABLE I. CALCULATION OF ULTIMATE BEARING CAPACITY

Test number	Foundation depth $D_f$ (m)	Method	Ultimate bearing capacity $q_t$ (kg/sq.cm.)
I	0	Terzaghi	7.62
		Meyerhof	6.68
		Caquot and Kérisel	5.79
		Brinch Hansen	6.23
		Balla	10.34
		Muhs	10.80
II	0.50	Terzaghi	7.80
		Meyerhof	16.84
		Caquot and Kérisel	7.18
		Brinch Hansen	8.80
		Balla	14.11
		Muhs	12.0
III	0.50	Terzaghi	15.23
		Meyerhof	34.86
		Caquot and Kérisel	13.70
		Brinch Hansen	17.53
		Balla	25.18
		Muhs	24.20
IV	0.50	Terzaghi	18.55
		Meyerhof	46.96
		Caquot and Kérisel	14.47
		Brinch Hansen	22.52
		Balla	32.50
		Muhs	33.0

TABLE II. THEORETICAL AND EXPERIMENTAL VALUES OF ULTIMATE BEARING CAPACITY

Test number	Foundation depth $D_f$ (m)	Method	Ultimate bearing capacity $q_t$ (kg/sq.cm.)
V	0.40	Terzaghi	4.47
		Meyerhof	6.58
		Caquot and Kérisel	3.03
		Balla	6.74
		Brinch Hansen	3.98
		Milović	4.1
VI	0.50	Terzaghi	5.77
		Meyerhof	8.84
		Caquot and Kérisel	4.08
		Balla	10.18
		Brinch Hansen	5.74
		Milović	5.50
VII	0	Terzaghi	2.51
		Meyerhof	2.51
		Caquot and Kérisel	1.65
		Balla	2.93
		Brinch Hansen	1.98
		Milović	2.20
VIII	0.30	Terzaghi	2.90
		Meyerhof	4.10
		Caquot and Kérisel	2.00
		Balla	4.40
		Brinch Hansen	2.57
		Milović	2.70

0.71 m. The results of these tests are shown in Fig. 2. Table II shows the theoretical and experimental values of the ultimate bearing capacity.

Comparing the results of loading tests in cohesive materials with the calculated values, it can be seen that the most reliable results are obtained by Brinch Hansen's and Terzaghi's methods. Meyerhof's method gives values which are too high in cases where the foundation depth is greater than

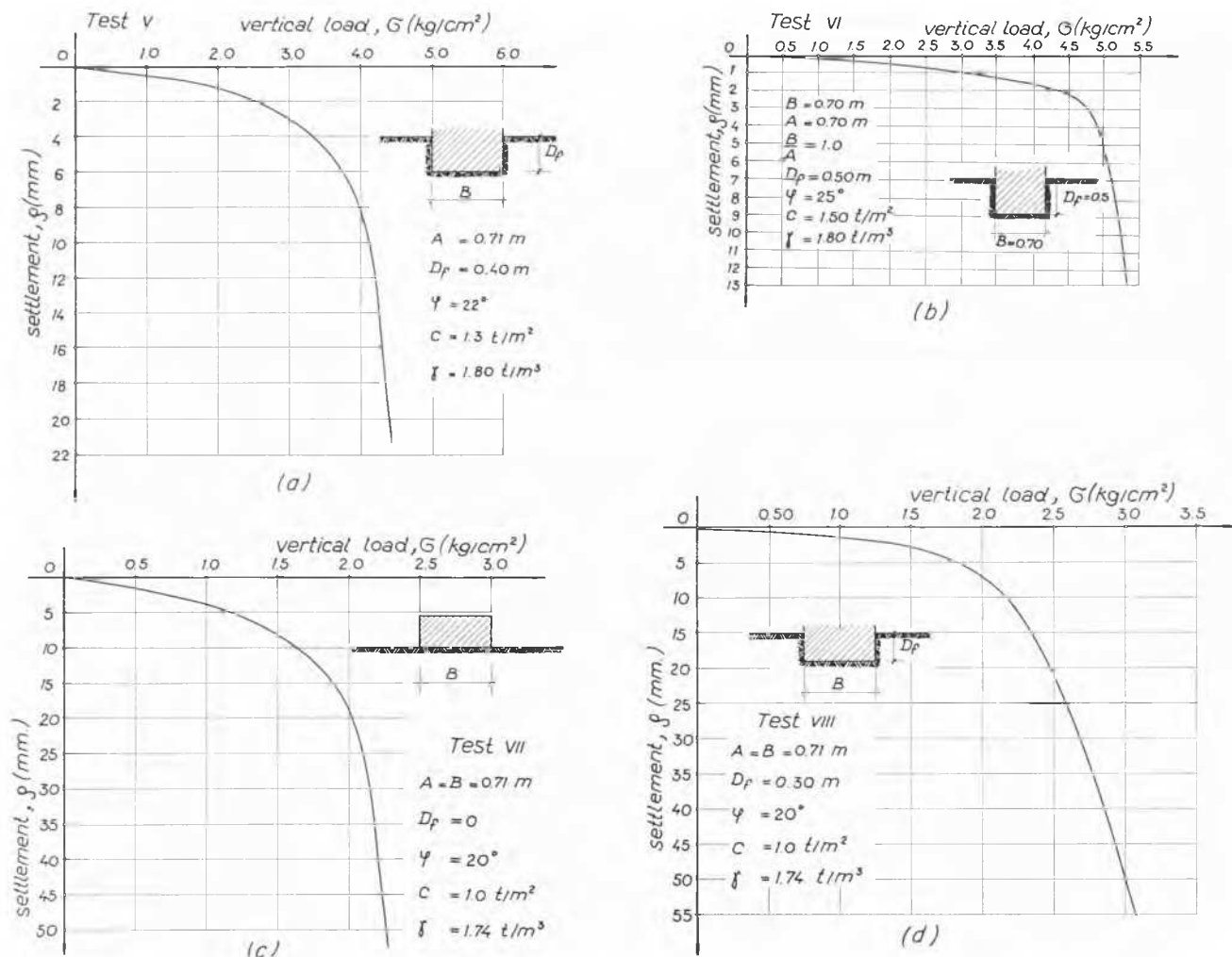


FIG. 2. Loading tests on cohesive soils: (a) Test V, (b) Test VI, (c) Test VII, (d) Test VIII.

zero. The results obtained by Balla's theory are also considerably higher than the experimental values.

#### CONCLUSIONS

In cases of non-cohesive and poorly cohesive materials the results of the ultimate bearing capacity obtained by Balla's theory are in good agreement with the experimental values. By Meyerhof's theory, considerably higher values were obtained in cases where the foundation depth was greater than zero.

For cohesive materials, Brinch Hansen's theory gives values that approach closely the results obtained by the loading tests. The values calculated by Meyerhof's method in cases where the foundation depth was greater than zero exceed the experimental values. The values obtained by Balla's method are also considerably higher than the results from loading tests.

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