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Evolution of shallow foundation load test from static to cyclic loading

Évolution de l'essai de chargement de fondations superficielles, de la charge statique à la charge cyclique

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ABSTRACT: The conventional bearing capacity of a shallow foundation under vertical centered loading measured under static and cyclic loading differs. This observation is of crucial importance to anticipate behaviour of structure under cyclic loads with or without eccentricity. The most important factor appears to be the ratio of the cyclic load amplitude to the maximum static bearing capacity. This paper presents an experimental study during which a 0.1m square steel footing was statically and cyclically loaded. A parametric study was carried out by performing tests on a physical model based on a sand mass reconstituted at a fixed density index. Complementary tests were performed on an intact silty soil on an experimental test site. The loading frequency was kept below 1Hz, which is lower than the natural frequency of the foundation. Prior to testing, cone penetration test and laboratory tests were performed to determine engineering properties of the soil. An analysis of the results and a comparison with previous tests available in the literature are presented. Predictions of the footing settlement were made by traditional methods, which were then modified to take into account of the effect of cyclic loading.

RÉSUMÉ: Les capacités portantes conventionnelles d'une fondation superficielle sous une charge verticale centrée mesurées sous une charge statique et cyclique diffèrent. Cette observation est d'une importance cruciale pour anticiper le comportement de la structure sous des charges cycliques avec ou sans excentricité. Le facteur le plus important semble être le rapport entre l'amplitude de la charge cyclique et la capacité portante statique maximale. Cette communication présente une étude expérimentale au cours de laquelle une semelle carrée en acier de 0,1 m de coté a été soumise à des essais de chargement statiques et cycliques. Une étude paramétrique a été réalisée en effectuant des essais sur un modèle physique basé sur une masse de sable reconstituée à un indice de densité fixe. Des essais complémentaires ont été réalisés sur un sol limoneux intact sur un site d'essai expérimental. La fréquence de chargement a été maintenue en dessous de 1 Hz, ce qui est inférieur à la fréquence naturelle de la fondation. Avant les essais, des essais de pénétration au cône et des essais en laboratoire ont été réalisés pour déterminer les propriétés techniques du sol. Une analyse des résultats et une comparaison avec les essais précédents disponibles dans la littérature sont présentées. Les prévisions du tassement de la semelle ont été faites par des méthodes traditionnelles, qui ont ensuite été modifiées pour prendre en compte l'effet de la charge cyclique.

Keywords: Shallow foundation; load test; static; cyclic.

1 INTRODUCTION

The appearance of load eccentricity can have a major impact on the behaviour of the foundation systems of certain statically or cyclically loaded structures. In this paper we consider the case of shallow foundations on granular soil.

Current methods of calculating bearing capacity, either indirect methods based on soil mechanical parameters deduced from laboratory tests or correlation tests (Terzaghi and Peck, 1948) or direct methods based on correlation with the results of in-situ tests (Briaud, 1992; AFNOR, 2013; Lehane, 2019), only consider the static case. For low frequencies where inertial and kinematic effects are not predominant, fatigue induced by the action of cycles can lead to failure of the soil beneath the foundation (Andersen, 2009). With this in mind, we carried out cyclic loading tests on foundations with different eccentricity and loading amplitude conditions.

2 TESTS PRESENTATION

The tests were carried out at the RTRI facilities using a hydraulic loading frame enhanced by a speedcontrolled loading system developed by the University of Tokyo.

2.1 Sand

The sand N°6 used in this study is a clean sand with a narrow grain size similar to Toyoura sand. Figure 1 shows its particle size distribution.

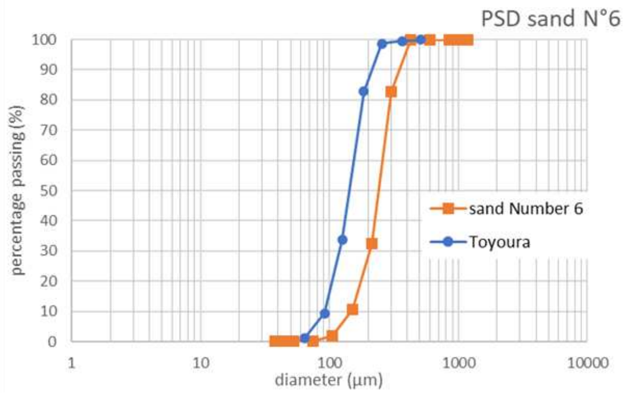

Figure 1. Particle size distribution.

The dry sand mass was reconstituted by tamping to a relative density of 80%. The peak friction angle at this relative density is 42°.

2.2 Foundation and equipment

The foundations are square stainless-steel plates, 100 mm wide and 25 mm thick. A simple spherical connection was used for the initial tests, but this was replaced as the tests began to introduce eccentricity to limit slippage. A spherical washer resting on a conical seat was used afterwards as the ball joint.

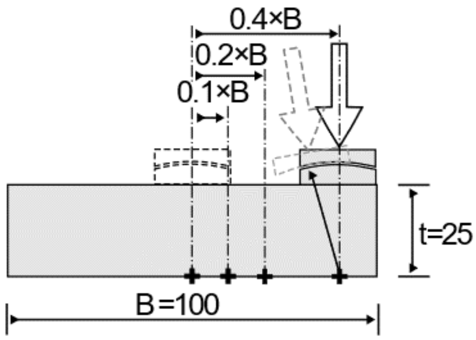

Figure 2. Foundation geometry.

The radius of the ball-joint was chosen to be very close to plate thickness t, in order to keep the point of load application at the base of the footing. A schematic drawing of the foundation is shown in Figure 2.

Foundations were placed diagonally in a soil container wide enough to avoid any interference from sides, regarding the failure zones

2.3 Testing program

As shown on Figure 3, two types of loading were studied. Loading by force step, as used during the on-site tests, was used to define the maximum vertical loads acceptable by the foundation. Each load step is maintained 5 minutes. Cyclic loading between two force values was applied , followed by a final loading to failure.

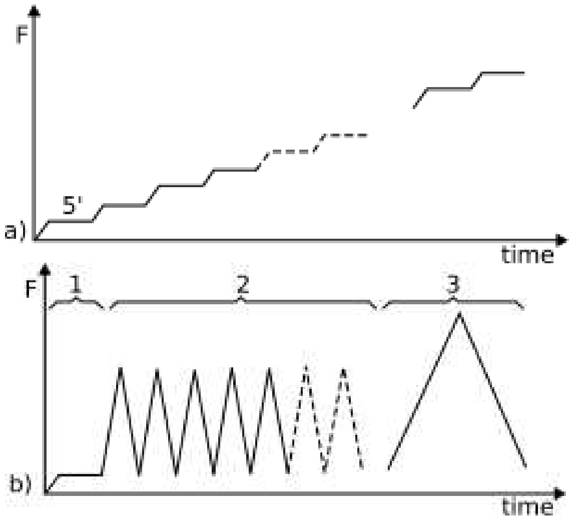

Figure 3. Loading program.

Ratios ranging from 40% to 80% of the maximal vertical load were considered and studied excentricity ranged from 0.1 to 0.4xB. All tests were performed at soil surface without embedment.

A load sensor and four displacement transducers placed at each corner were used to record force and settlement during the tests. At the end of the load test, i.e. when a settlement greater than B/10 was reached, the equipment was removed, the tank emptied and refilled for the next set of load tests.

3 TEST RESULTS

Table 1 summarize the main characteristics of the 21 tests performed in this test session. For the monotonic loading, the maximum vertical load V_0 is derived from the load-settlement curve using B/10 method (Briaud and Gibbens, 1999). Two types of loads may be defined for cyclic test, the load observed at end of phase 1 that may be obtained during monotonic test at the same settlement, and the maximal load reached during the final monotonic loading.

3.1 Monotonic loading - Influence of eccentricity

Figure 4 shows the load settlement curve of the monotonic loading of the shallow foundation according to the eccentricity.

Table 1. Main tests results.

Test	Tank	e/B	V/V_0	Load	V_{min}	V_{max}	V_0
01	1	0		S			1430
02	1	0		S			1150
03	1	0		S			1350
04	2	0.1		S			1100
05	2	0.2		S			788
06	2	0.2	0.4	C	50	370	1000
07	3	0.2	0.6	C	50	530	782
08	4	0.4		S			384
09	4	0.2	0.8	C	50	690	1221
10	4	0.1	0.4	C	50	490	2000
11	5	0.4	0.8	C	50	370	486
12	5	0.4	0.4	C	50	210	509
13	5	0.4	0.6	C	50	290	510
14	6	0.1	0.6	C	50	710	1913
15	6	0.1	0.8	C	50	930	2185
16	6	0	0.4	C	50	1170	2670
17	7	0.4		S			406
18	7	0	0.6	C	50	890	1765
19	7	0	0.4	C	50	610	1965
20	8	0		S			1084
21	8	0	0.4	C	420	980	1286

The mean settlement indicated in the following Figures has been computed at the rotation point for each test as illustrated on Figure 2.

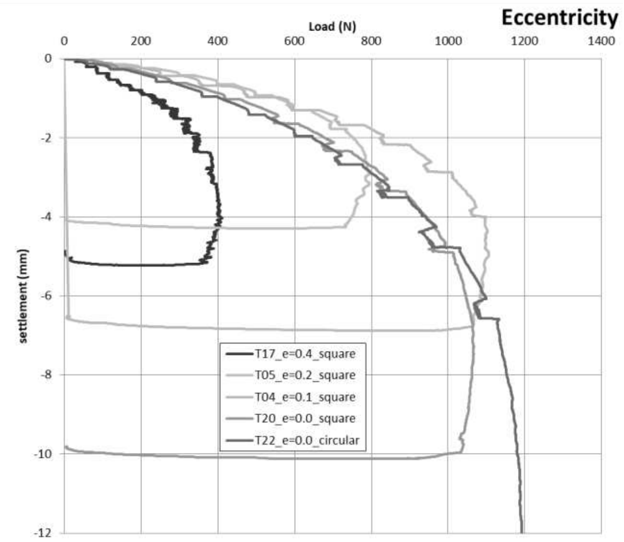

Figure 4. Load settlement curve of monotonic tests.

Figure 5 shows the evolution of the load reduction coefficient with respect to the relative eccentricity e/B. The relationships $i_e = 1 - 2 \cdot {}^{e}/_{B}$ and $i_e = \left(1 - 2 \cdot {}^{e}/_{B}\right)^2$ are also shown. This evolution had already been observed in the first studies on small foundation models by Meyerhof (1951), which enabled him to suggest the relationship mentioned above.

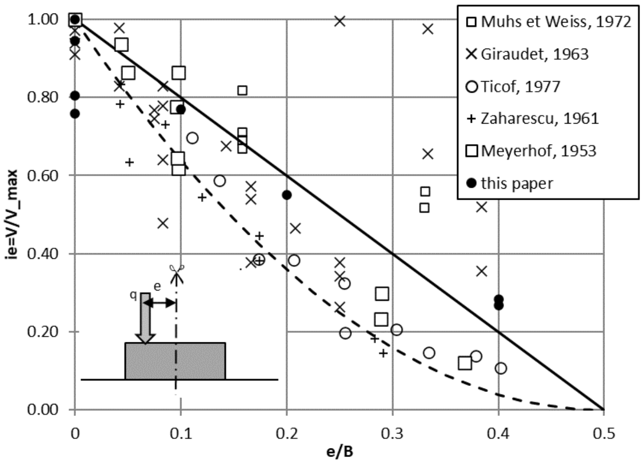

Figure 5. Evolution of normalized maximum load according to relative eccentricity.

Results of monotonic tests performed during this first phase of the research are in accordance with previous research.

3.2 Cyclic loading - Influence of eccentricity

Figure 5 shows test 18 performed in the second phase of the research program. The three loading phases may be identified clearly.

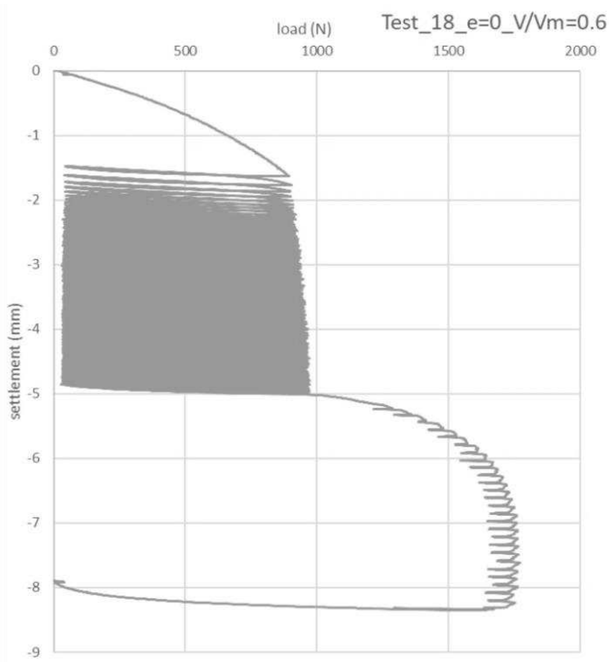

Figure 6. Load settlement curve of test 18.

Figure 7 illustrates the fact that cyclic loading has a positive influence on the maximum load achievable after a post-cyclic monotonic loading (phase 3). However for eccentricity higher thar 0.2 this effect disappears.

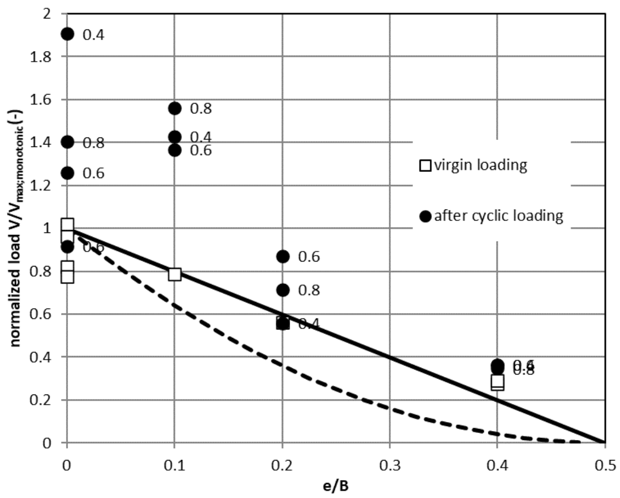

Figure 7. Influence of cyclic phase on final step loading.

Figure 8 shows that settlements here extrapolated at 10000 cycles increase at higher stress amplitude $\Delta V/V_0$.

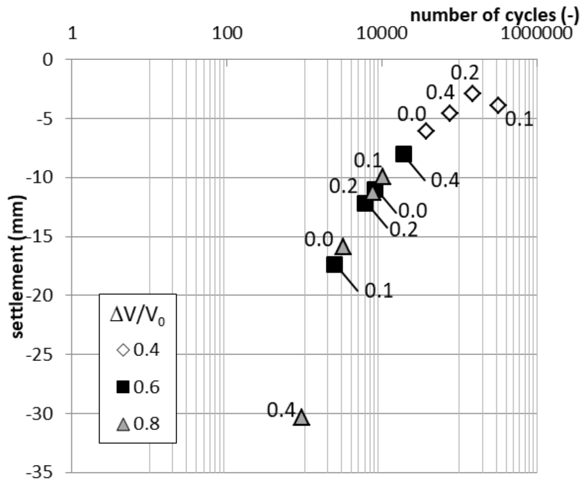

Figure 8. Influence of cyclic phase on settlement (eccentricity is attached to the symbols)

It may be noted that in these experiments, foundations were unloaded to a force of 40 N.

4 CONCLUSIONS

Experiments on shallow foundations submitted to cyclic loading under different eccentricity have been presented. Preliminary results have shown the effect of cycling on a further monotonic loading to failure, and the effect of eccentricity on the settlement reached after a given number of cycle for increasing amplitude.

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REFERENCES

AFNOR (2013) Justification of geotechnical work - National application standards for the implementation of Eurocode 7 - Shallow foundations, NF P94-261, p. 160.

Amar, S., Baguelin, F., and Canepa, Y. (1998). Shallow foundations – experimental study under cyclic loading. *Proceedings of Geotechnical Hazards*, Rotterdam, pp. 477-483.

Andersen, K. H. (2009) *Bearing capacity under cyclic loading — offshore, along the coast, and on land*. Can. Geotech. J., 46: 513–535 https://doi.org/10.1139/T09-003.

Briaud, J.-L., (1992), The pressuremeter, CRC, 340 pages

Briaud, J.L., Gibbens R. (1999) *Behaviour of Five Large Spread Footings in Sand*, ASCE, JGGE, 125(9): 787-796. https://doi.org/10.1061/ (ASCE)1090-0241(1999)125:9(787).

Das, B., Yen, S., Singh, G. (1995) Settlement of Shallow Foundation on Sand Due to Cyclic Loading, *3rd Int. conf. on recent advances in Geotech. Earthquake Eng. And Soil Dynamics*, Vol. 1, pp 385-388.

Giraudet, P (1965) Recherches expérimentale sur les fondations soumis à des efforts inclinés ou excentrés. Ann Ponts Chaussées 3: pp. 167–193.

Lehane, B.M. (2019). *CPT-based design of foundations*. E.H. Davis Memorial Lecture (2017),Australian Geomechanics, 54(4), pp. 23-48.

Meyerhof, G.G. (1953). The Bearing Capacity of Foundations under Eccentric and Inclined Loads. *Proc. 3rd ICSMFE*., vol. I, Zurich.

Muhs, H. and Weiß, K. (1973). Inclined load tests on shallow strip footings, *Proc. 8th ICSMFE*, Vol 2, pp. 173–179.

Raymond, G.P., Komos, F. El (1978), Repeated load testing of a model plane strain footing, *Canadian Geotechnical Journal*, 15, pp.190-201 https://doi.org/10.1139/t78-019.

Sawicki, A., Swidzinski W., Zadroga B. (1998) *Settlement of Shallow Foundation Due to Cyclic Vertical Force*, Soil and Foundation, 38(1), pp 35-43, DOI: 10.3208/sandf.38.35.

Terzaghi, K., Peck R. (1948) Soil Mechanics in Engineering Practice, 1rst edition, New York Wiley , 719 pages

Ticof, J., (1977) Surface footings on sand under general planar loads University of Southampton PhD Thesis

Zaharescu, E., (1961) Sur la stabilité des fondations rigides, 4ème Conf Int. Méca. des Sols, Paris, 3A/52, pp.867-871.