Settlement of reinforced subgrades under dynamic loading

Règlement des sous-grades renforcés sous le chargement dynamique

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ABSTRACT

Model tests were conducted in the laboratory to study the settlement behavior of small size footing resting on geogrid reinforced sand layer and subjected to dynamic loads. Tests were conducted by first subjecting the footing to an initial sustained static load and then superimposing additional predetermined dynamic loads. The frequency of dynamic load was kept at 1 Hz which was well below the resonant frequency of the system. Based on the observed test results, the nature of variation of the permanent settlement of the foundation with intensity of static loading and the amplitude of cyclic load are presented in this paper.

RÉSUMÉ

Des essais modèles ont été effectués dans le laboratoire pour étudier le comportement de règlement de la pose modèle se reposant sur le sable renforcé pargrille et soumis aux charges dynamiques. Des essais ont été effectués en soumettant d'abord la pose à une première charge statique soutenue et en superposant ensuite les charges dynamiques prédéterminées additionnelles. La fréquence de la charge dynamique a été maintenue à 1 hertz qui était bien au-dessous de la fréquence de résonance du système. Basé sur les résultats d'essai observés, la nature de la variation du règlement permanent de la base avec l'intensité du chargement statique et l'amplitude d'intensité cyclique de charge sont présentées en cet article.

Keywords: sand, geogrid, foundation, settlement, load, dynamic

1 INTRODUCTION

Model tests for determination of permanent settlement of shallow footing subjected to various types of dynamic loads were reported by Cunny and Sloan (1961), Shenkman and McKee (1961), Jackson and Hadala (1964) and Carroll (1963). Raymond and Komos (1978) presented the results of dynamic load versus settlement for strip footings resting on dense sand. Brumund and Leonards (1972) presented results of laboratory model on permanent settlement of circular footing on granular soil subjected to vertical vibrations.

Several studies have been conducted in recent years to evaluate the effectiveness of geogrids in improving the bearing capacity of soils, for example Guido et al., (1986), Khing et al., (1992, a and b), and Das et al.,(1995) . This paper presents the results of laboratory model tests dealing with the settlement of rigid square footing resting on surface of geogrid reinforced sand and subjected to combined static and dynamic load.

2 TEST PARAMETERS

A square foundation of width B, resting on sand reinforced with N layers of geogrids is shown in Fig. 1. The top most geogrid layer is at a depth u below the bottom of the foundation. The vertical spacing of consecutive geogrid layers is h. The plan dimensions of each geogrid layer are ‘b’ x ‘b’. The geogrid layers are provided within a depth ‘d’ below the bottom of the foundation. Several investigators have shown that, for case of static loading with b/B, u/B and h/B remaining constant, there is a critical reinforcement depth ratio, $d/B = (d/B)_{cr}$ beyond which the increase in ultimate bearing capacity due to reinforcement is negligible.

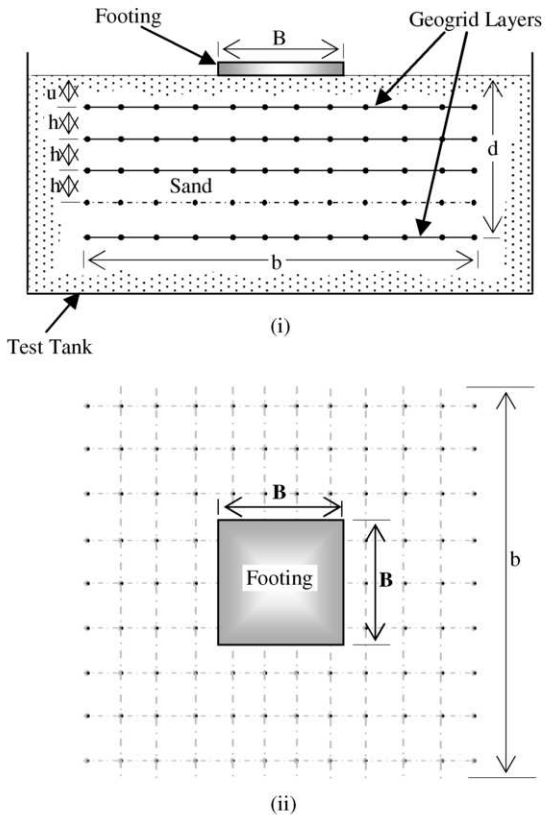

Fig. 1. Test set-up (i) Section and (ii) Plan

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-925

Also, if the u/B, h/B and d/B are kept constant, there is a critical width ratio, b/B = $(b/B)_{cr}$ beyond which the increase in the bearing capacity is marginal. It has been determined (Binquet and Lee, 1975; Guido et al., 1986; and Khing et. al., 1992a and b) that the maximum benefits of reinforcement result when the u/B ratio is less than about 0.67 to 0.75. Therefore, in this study, the ratio of u/B and h/B were both adopted as 1/3. This investigation had two phases. In phase I static bearing capacity tests were conducted to determine $(b/B)_{cr}$ and $(d/B)_{cr}$ In phase II, the model footing was tested with optimum reinforcement combinations, i.e (b/B)=$(b/B)_{cr}$, (d/B) =$(d/B)_{cr}$ and u/B=1/3. An initial sustained static load was first applied followed by dynamic load of rectangular waveform.

3 LABORTORY MODEL TESTS

Laboratory tests were conducted using a rigid model footing 76.2 mm x 76.2 mm. The sand used in the tests was SP and a relative density of 70% was used in all tests. A biaxial geogrid of PP/HDPE co-polymer with nominal rib thickness of 0.762mm and nominal junction thickness of 2.286 mm was used. Model tests were conducted in Plexiglas box measuring 760mm x 760mm x 760mm with sides adequately reinforced to prevent lateral yielding. The base of the footing was made rough by cementing sand grains to it. A layer of foam was glued to the bottom of the test tank to avoid the effect of reflected waves on the footing settlement.

The sand for the tests was deposited in 25.4 mm thick layers using rainfall technique. The accuracy of sand placement and consistency of placement density was checked in each case. Static Load Tests: Static tests were conducted in phase I to determine $d/B)_{cr}$ and $(b/B)_{cr}$ .These tests were conducted by applying load to the model foundation with a hydraulic jack. The applied load and the resulting settlement were recorded. Three series of tests (Table 1) were conducted.

Table 1. Static load tests – Phase 1

Test Series	Constant Parameters	Variable Parameters	Comments
1–A	D_r = 70%	--	Unreinforced Case
1–B	D_r = 70% u/b = h/B = 1/3 b/B = 6	N = 1, 2, 3, 4, 5, 6	To Determine $(d/B)_{cr}$
1–C	D_r = 70% u/b = h/B = 1/3 N = 4	b/B = 1, 2, 3, 4, 5, 6	To Determine $(b/B)_{cr}$

Dynamic Load Tests: Based on information obtained from the static tests (discussed later), all dynamic loading tests were conducted using u/B=h/B=0.333, b/B=$(b/B)_{cr}$ =4; and d/B ≈ $(d/B)_{cr}$=1.33 at relative of sand of 70 %. . In this series of tests, a universal testing machine was used to apply the loads on the foundation. The magnitude of the load and the settlement were recoded using a data acquisition system. A static pressure q_s =q_u/FS was first applied to the foundation, followed by application of the dynamic load. 'q_s' refers to the applied pressure and 'q_u' is the ultimate bearing capacity of the footing. The dynamic load frequency used in all tests was 1 Hz. The details of the dynamic load tests are summarized in Table 2.

4 TEST RESULTS

Static Tests (Phase 1): Figure 2 shows the results of pressure 'q' and settlement 's' obtained from test series 1-A and 1-B.

Table 2. Dynamic load tests – Phase 2

Test Series	q_s/q_u (%)	FS= q_u/q_s	q_d/q_u
2–A	13.2	7.6	4.36, 10.67, 14.49, and 22.33
2–B	25.0	4	As Above
2–C	33.3	3	As Above

Note: For all tests, d/B ≈ $(d/B)_{cr}$= 1.33;
b/B ≈ $(b/B)_{cr}$= 4; q_u = 175 kN/m^2 (Phase 1)

The tests in series 1-A are for unreinforced sand and in series 1-B the tests were conducted using u/B = h/B = 0.333, and b/B = 6. It may be observed from Fig.2, that the ultimate bearing capacity, q_u increased with the increase in number of reinforcement layers. This is also accompanied by an increase in settlement at the ultimate load. The magnitude of s/B at load is about 3.5 % for unreinforced case and it increased to about 6.5% for N=6. Figure 3 shows a plot of q_u versus d/B which is based on the data obtained from Fig. 2.The magnitude of q_u is seen to increase with the increase in d/B ratio. As d/B becomes more than about 1.33, the increase in value of q_u with increase in d/B becomes insignificant. Therefore $(d/B)_{cr}$ may be taken as 1.33. Figure 4 shows the effect of b/B on q_u (series 1-C) when u/B=h/B=0.33 and d/B=1.33. It may be observed from this figure that beyond b/B = 4, very little increase in q_u occurs. Thus $(b/B)_{cr}$ may be taken as 4.

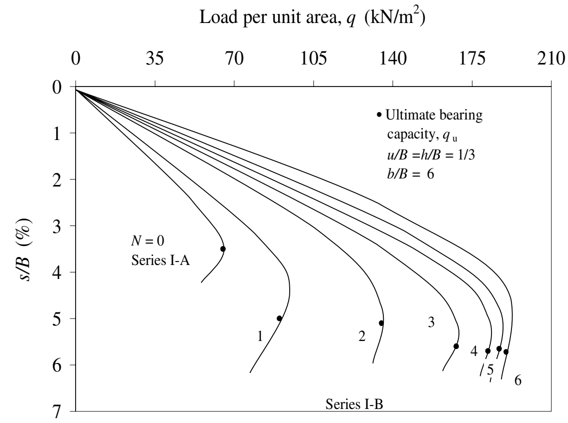

Fig. 2. Variation of load per unit area 'q' versus *s/B* (Series I-A and I-B)

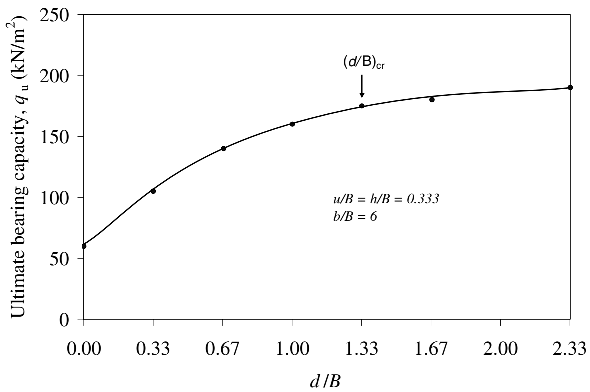

Fig. 3. Variation of q_u versus *d/B* (Series I-A and I-B)

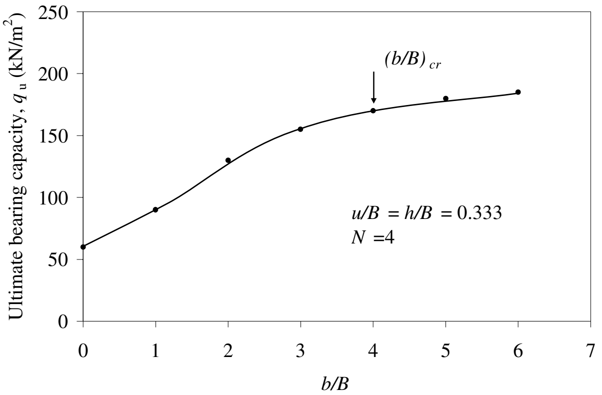

Fig. 4. Variation of q_u versus *d/B* (Series I-A and I-C)

Dynamic Load Tests (Phase-2): All dynamic load tests were conducted by using optimum reinforcement parameters based on the results of static load tests in phase -1. In these tests a sustained static stress q_s was first applied to the model foundation after which a dynamic stress q_d was imposed. The settlement s_d due to dynamic loading was monitored. The nature of variation of s_d with number of load cycles n for all tests is shown in Figure 5. The dynamic settlement s_d is seen to increase with n to a maximum value $s_{d(u)}$ at n = n_{cr}. For n > n_{cr}, the increase in settlement was small. The plots of s_d versus n for test series 2-A, 2-B and 2-C are shown in Figures 6, 7 and 8 respectively. The critical value of n ie n_{cr} is also shown on these figures. The following general conclusions may be drawn based on the results of these experimental results.

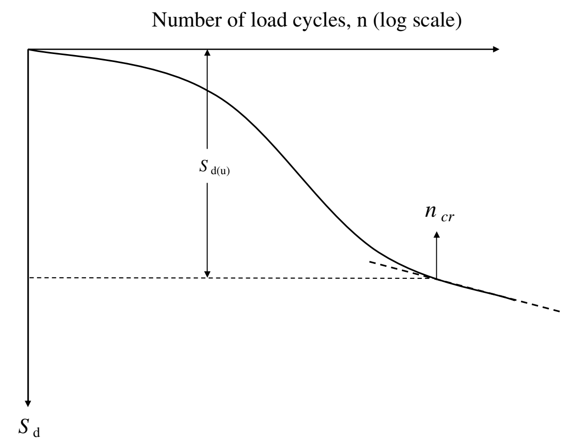

Fig. 5. Genral trend of variation of foundation settlement due to cyclic load

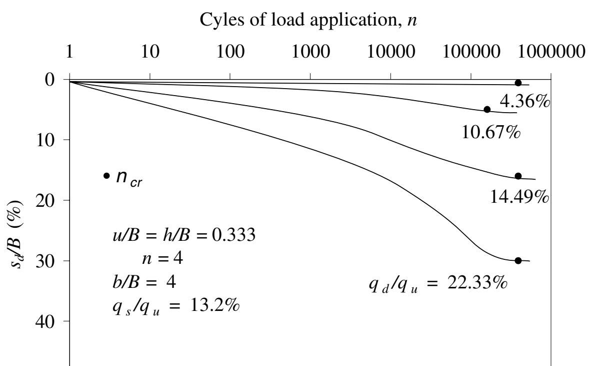

Fig. 6. Variation of s_d/B with *n* (Series II-A)

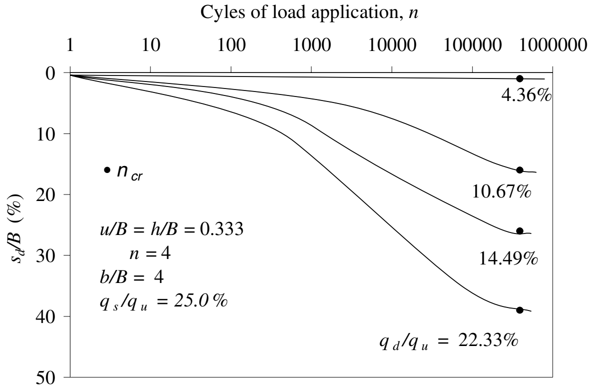

Fig. 7. Variation of s_d/B with *n* (Series II-B)

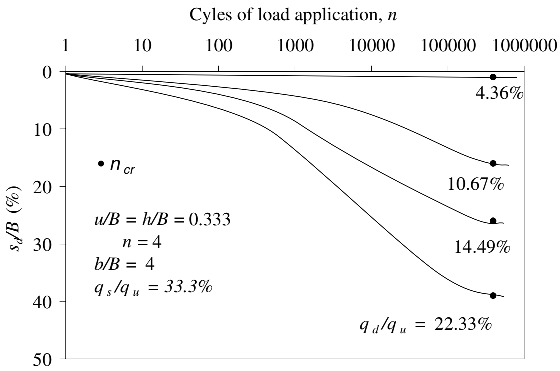

Fig. 8. Variation of s_d/B with n (Series II-C)

1. The magnitude of s_d/B increases with increase in q_d/q_u for any given values of q_s/q_u and n.
2. The magnitude of s_d/B increases with increase in value of q_s/q_u keeping q_d/q_u and n constant.
3. n_{cr} was approximately the same varying from 1.75 x10^5 to 2.5 x 10^5 cycles.

It may be observed from Figure 5, that the maximum settlement due to dynamic loading for a given value of q_s/q_u may be approximated as the settlement between n = 0 and n = n_{cr} loading cycles. Using this concept, the values of $s_{d(u)}$ were calculated for various values of q_s/q_u and q_d/q_u combinations.. These are shown in Figure 9. It may be observed from Figure 9, that for factor safety FS (=q_u/q_s) varying between 3 and 7 and $q_d/q_u \approx 10$ %, the magnitude of the maximum settlement due to dynamic loading may be between 5 % - 20 % the width of the foundation. If q_d/q_u increased to 20 %, the maximum settlement $s_{d(u)}$ ranges from 30 % to 40 %.

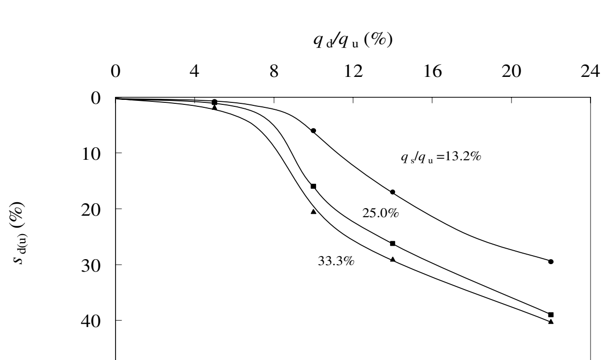

Fig. 9. Variation of $s_{d(u)}/B$ with q_d/q_u and q_s/q_u

5 CONCLUSIONS

1. It is observed from the test data that the maximum mobilization of bearing capacity for a given sand-geogrid system occurs when optimum values of depth of reinforcement and width of reinforcement are used.
2. For a given sustained stress and number of load cycles , the settlement due to dynamic loading increases with increase in magnitude of dynamic stress.
3. For given values of dynamic stress and number of load cycles, the dynamic settlement increases with increase in magnitude sustained static stress.

It may be mentioned that the effect of relative density of sand and geogrid stiffness was not studied in this investigation. It appears that the magnitude of maximum dynamic settlement of a foundation is a function magnitude of sustained static stress, magnitude of dynamic stress, number of load cycles, stiffness of geogrid, and relative density of sand.

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