MODEL INVESTIGATION ON THE BEARING CAPACITY OF MICROPILE FOUNDATION WITH PRESTRESS

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Abstract

To clarify the mechanism of load bearing by micropile foundation, a series of model loading tests were carried out. From the investigation, the remarkable interaction between the subsoil, footing and micropile group was recognized. And notable effect of pre-stressed micropile on bearing capacity was observed.

Keywords: Micropile, Footing, Reinforcement, Model Loading Test, Sand Ground, Bearing Capacity, Interaction, Relative Density, Prestress.

1. Introduction

In this study, the model micropiles were installed beneath the footing in the artificial sand ground, and the behavior was observed under some series of vertical loading tests. To examine the mechanism of the interaction between footing and a group of micropiles and improve the bearing capacity effectively, prestress was introduced into the micropile group. The soil material enclosed by the micropile group and the footing was confined due to the prestress, as a result the stiffness of the soil material and base pressure of the footing were increased.

2. Method for model loading tests

The method of the model loading tests has been reported by Tsukada et al. [1,2] and Tsubokawa [3], but in this study a newly developed apparatus for the model micropile foundation test has been introduced as shown in Fig. 1, which made it possible to measure the load born by the micropile group and the base pressure on the footing separately. So the mechanism of interaction with the footing is examined. The other main characteristics of the tests are summarized below.

The model footing is made of stainless steel with a diameter of 40 mm, which is reinforced with a group of micropiles; five types of model footings are available to fit the need of variation of the pile number and pile inclination angle in the micropile group.

The model micropiles used were made of stainless steel with high bending stiffness of EI=1.28x10^{-1}Nm^2 (E=2.1x10^{5}MPa). And they were coated with thin sand layer so as to mobilize sufficient skin friction with ground; sand particles were glued to the micropile surface. The model micropile foundation was set up on the surface of the model sand ground formed in a mold. Oven dried silica sand was deposited through air with a nozzle, and tapped with a rubber hummer so as to obtain prescribed three different relative densities: dense, medium, and loose grounds. The physical and mechanical properties of the model sand ground are shown in Table 1.

The loading apparatus is a computer-aided monitoring and controlling system. Vertical load is applied in a displacement-controlled manner.

3. Test results and discussion

The loading tests conducted in this study consist of three test series, as illustrated in Fig. 2. First, the behavior of surface footing without any reinforcement is observed in FT-Test series. Then, the behavior of micropiles was observed in MP-Test, where the footing was freestanding, clear from the ground surface. The bearing capacity mechanism of micropile foundation was investigated in MP-FD-Test. The applying point of load is maintained at the center of footing on ground surface, throughout the entire test series, as shown in Fig. 2. In MP-FD test, the prestress was introduced.

3.1 FT-Test

The results of FT-Test under vertical load are shown in Fig. 3 in the form of base pressure q_v vs. displacement S_v relationship. Typical shear failure patterns appeared on the ground surface are shown in Photo. 1. In the case of dense ground, the load-displacement behavior is typical general shear type; the base pressure q_v has a peak and the shear failure plane appeared on the surface. On the other hand, the behavior observed on the medium ground and loose ground is local shear type; the shear failure plane was not observed clearly on the surface.

This difference in the load bearing behavior and the failure pattern is attributed to the relative density dependent dilatancy properties of the sand ground, as illustrated in Fig. 4. The dilative behavior of dense sand beneath the footing enhances the shear failure plane to extend toward the ground surface; on the other hand, the contractive behavior of loose sand restrains the extension of the shear failure plane towards the ground surface.

3.2 MP-Test

Shown in Fig. 5 is the observed behavior of a group of 8 vertically installed micropiles of S-R-Type, which was subjected to vertical load. The observed load-length relationships are fitted with parabolas; Q_v is proportional to the square of L; this means that not point bearing but skin friction is the main factor and is proportional to depth z; see Fig.5. As shown in Fig. 5 the bearing capacity of micropiles is remarkably dependent on the relative density of the ground. The difference of the angle of internal friction listed in Table 1 is not enough to explain this difference in skin friction. Then the effect of dilatancy induced by the deformation of ground associated with penetration of the micropiles must be considered. Fig. 6 illustrates the effect of relative density on the bearing capacity of micropiles. In the case of dense ground, the horizontal stress, which confines the micropiles, increases due to the dilative deformation behavior of the ground. On the other hand, in loose ground, the horizontal stress around the micropile may be reduced. This change of horizontal confining stress is considered to be responsible for the remarkable dependence of bearing capacity of micropile on the relative density.

3.3 MP-FD-Test

The typical observed behaviors of micropile foundations are shown in Fig. 7. As shown in Fig. 8 the influence of the inclination angle is clearer in dense ground than in the medium and loose grounds. At the small subsidence of S_v/B=5%, the bearing capacity tends to become maximum at the inclination angle of micropiles of θ=30deg; at the large subsidence of S_v/B=20%, at a lower inclination angle of about θ=15 deg. Also the bearing capacity is much dependent on the relative density of ground especially with a small inclination angle of the micropiles. The bearing capacity in dense ground is notably high compared with those in medium and loose grounds. In the case of vertically installed micropile foundation (θ=0deg), the ground failed in local shear type as shown in Photo. 2. The contrast with the general shear failure type observed in the surface footing (Photo. 1(a)) suggests the confining effect with a group of micropiles on the ground material beneath the footing. As explained in Fig. 9, the confinement by the interaction between footing and a group of micropiles becomes effective with the dilatant behavior of the dense sand beneath the footing.

Shown in Figs. 10 is the effect of the number of micropile on the bearing capacity of the micropile foundation. In general, the bearing capacity increases with the increase of the number of the micropile.

3.4 Assessment of the Improvement of Bearing Capacity

To assess the degree of improvement of the bearing capacity with micropiles quantitatively, the improvement ratio R was newly introduced (Fig. 11). The R of unit means that the bearing capacity of the footing reinforced with micropiles is equal to the summation of the surface footing and the micropile group. If the confining effect by the interaction between of the subsoil, footing and the micropile group is positive, the interaction improves the bearing capacity, and the value of R becomes larger than unit. In Fig. 12, the improvement ratio of bearing capacity with the reinforcement of micropiles is presented.

3.5 Effect of Prestress on the Improvement of Bearing Capacity

As discussed in the previous sections, it was found that the confinement of the ground material with the interaction between the footing and the micropile group plays an important role in the improvement of the bearing capacity. The confinement increases the confining stress in the ground material beneath the footing and then the base pressure on the footing as shown in Fig.9. The confining effect is a function of the geometry and stiffness of the micropile group and the mechanical properties of ground material. The improvement of bearing capacity, that is positive effect of the confining effect, was not mobilized in loose and medium grounds and also in the early stage of loading with small displacement in dense ground as shown in Fig. 12. To induce the confining effect more effectively even under small displacement, the raise of confining stress on the ground material beneath the footing at initial stage is important. Then, in the series of model loading test on the micropile foundation, some amount of prestress was induced to the micropile group as shown in Fig.13; at the same time the initial base pressure as well as confining stress was increased as a reaction of the prestress.

The test series with prestress was conducted on the micropile foundation with vertical micropile group in the dense and medium model grounds. With the newly devised model micropile foundation shown in Fig.1, the load on the micropile group could be measured with the load cell inside the model micropile foundation; the base pressure was evaluated from the difference between the total load and the load on micropile group. The degree of prestress was indicated with the ratio $-Q_{mp0}/Q_{mpmax}$ of prestress on the micropile foundation to its ultimate value from Fig. 5.

Shown in Fig. 14 and Fig. 15 are the observed load-displacement behaviors in dense and medium sand grounds, respectively; where the averaged base pressure q_v, the equivalent base pressure Q_{mp}/A_f to load on the micropile group and the base pressure evaluated as q_f (= q_v - Q_{mp}/A_f) are plotted against displacement s_v. In the case of no-prestress ($-Q_{mp0}/Q_{mpmax}$ = 0) the base pressure is rather low and does not increase clearly with displacement on both dense and medium grounds. Due to the induced prestress on micropile group the load on micropile group becomes negative and base pressure increases at initial condition. And during the loading the base pressure increases notably and total load at a certain displacement increases as a result. The load born by micropile group Q_{mp} decreases with the prestress and the micropile group gains the margin until the ultimate condition.

Shown in Fig. 16 and Fig. 17 are the improvement of bearing capacity with the prestress in dense and medium sand grounds, respectively. With the increase of prestress, the load on micropile group was reduced monotonically, on the other hand the base pressure on the footing increased; this trend is recognized at all the levels of displacement until s_v/B = 20%. As a result the total base pressure increases with the prestress as shown in Fig. 16 and Fig. 17, even under initial stage of loading (s_v/B = 5%). It can be seen that the bearing capacity was increased almost 100% with the prestress equivalent to a half of ultimate bearing load of micropile group.

4. Conclusions

To clarify the mechanism of the improvement of the bearing capacity of footing reinforced with a group of micropiles, a series of model loading tests were carried out. The circular footings were reinforced with a group of micropiles with variety of the arrangement of micropiles, and were subjected to vertical load. Based on the observed load-displacement behaviors from the comparative examinations, the following concluding remarks were drawn:

The significant effect of the relative density on the bearing capacity was recognized, in the tests of surface footing, a group of micropiles and foundation reinforced with micropiles. In dense ground, due to the dilatant behavior of ground material, bearing capacity was remarkably high compared with those in medium and loose grounds. In the case of surface footing, only in dense ground was the shear failure plane generated freely and observed on the surface. Because of the increase in confining pressure on the surface of micropiles due to the dilatant behavior of dense ground material, the skin friction of micropiles is remarkably increased.

An interaction was recognized between the footing and the micropile group, and this interaction was significantly effective on the confinement of ground material and on the improvement of the bearing capacity of footing in dense sand. Due to the confinement, the base pressure of the footing was increased and the confining pressure on the micropile surface was also increased. In the case of the footing reinforced with a group of vertically installed micropiles, the bearing capacity was more than twice the summation of bearing capacities of the surface footing and the micropile group. The skin friction and bending stiffness of micropiles are effective on the increase in bearing capacity. The bending stiffness was necessary to enhance the improvement of bearing capacity with the interaction between of the footing and the micropile group.

It was found that the prestress on the micropile group is effective for the improvement of bearing capacity of micropile foundation. The prestress which is introduced on the micropile group increases the initial base pressure on the footing and reduces the load on micropile group during the loading process. The prestress was effective even in initial loading stage with small displacement on both dense and medium sand ground. In the test condition of this study, the prestress equivalent to a half of the ultimate bearing load on the micropile group increased the total bearing capacity of micropile foundation by almost 100%.

References:

[1] Tsukada, Y., Miura, K., Tsubokawa, Y., Ishito, M., Nishimura, M., Otani, Y. and You, G. L..: "Experimental Investigation on the Improvement of Bearing Capacity of Surface Footing with Micropiles," Proc. of 2nd International Workshop on MicroPile, pp.1/8-10/8, 1999

[2] Tsukada, Y, Miura, K. and Tsubokawa, Y.: Model Loading Tests on Micropile Foundation on Sand Ground, Japanese Geotechnical Society, *Tsuchi-to-kiso*, Vol.47, No.1, pp. 35-38, 1999 (in Japanese).

[3] Tsubokawa, Y.: *Experimental Study on the Bearing Capacity Characteristics of the Foundation Reinforced with Micropiles*, Hokkaido University, Master thesis, 1999. (in Japanese)

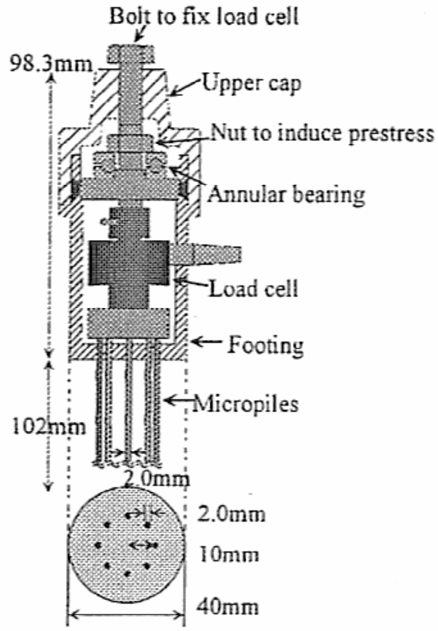


Fig. 1. Newly developed model micropile foundation for the inducement of prestress on micropile group

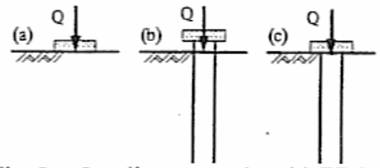


Fig. 2. Loading test series; (a) FT-Test, (b) MP-Test, (c) MP-FD-Test with vertical MPs

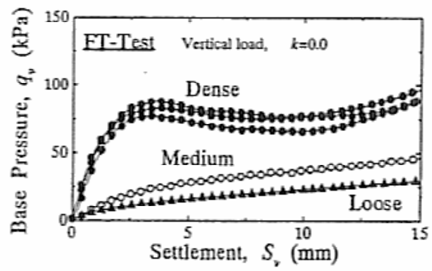
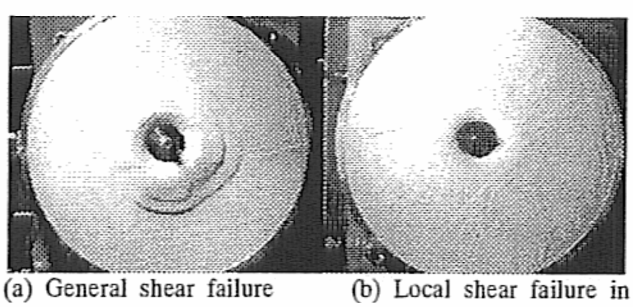


Fig. 3. Base pressure q_v vs. displacement S_v relationship under vertical loading in FT-Test series k=0.0.

Table 1. Physical and mechanical properties of sand ground

Grain density: ρ_s = 2.717 g/cm^3	The angle of internal friction, ϕ_d (deg.);
Max. and Min. dry densities; ρ_{dmax} = 1.610 , ρ_{dmin} = 1.255 g/cm^3	Dense ground, Dr = 95 ± 2%; 38.5 Medium ground, Dr = 65 ± 2%; 36.2 Loose ground, Dr = 50 ± 2%; 34.8
Mean grain size; D_{50} = 0.18mm, Uniformity coefficient; U_c = 1.82	



(a) General shear failure dense ground (b) Local shear failure in in medium sand

Photo. 1 Shear failure patterns observed on the surface at the relative displacement S/D = 0.20 in FT-Test series

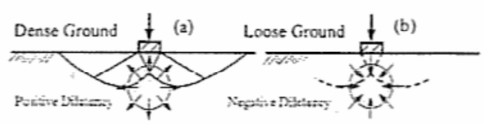


Fig. 4. Illustration of shear failure pattern of surface footing, (a) general shear failure in dense ground, (b) local shear failure in loose ground

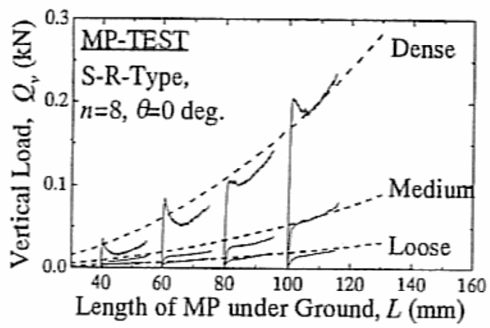


Fig. 5. Load Q_v vs. length of MP L relationship under vertical loading in MP-Test.

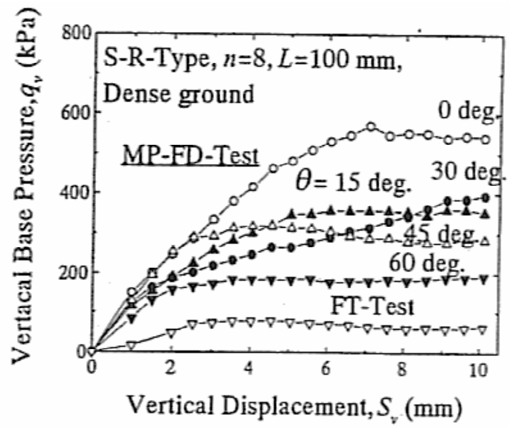


Fig. 7. Base pressure q_v vs. displacement S_v relationships for micropile foundations with inclined micropiles in dense ground

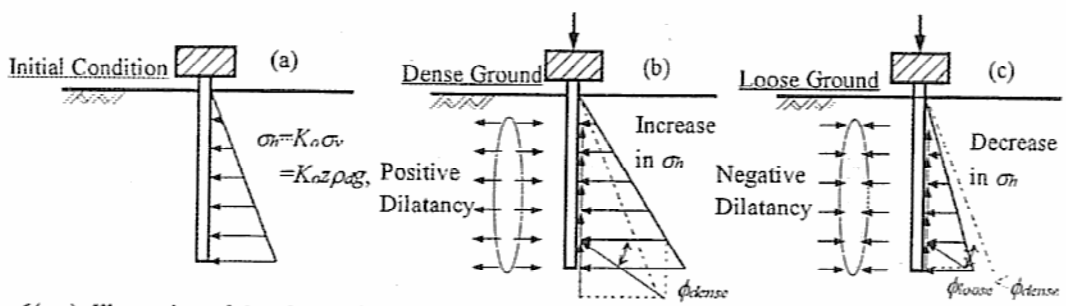


Fig. 6(a-c). Illustration of the change in underground stress condition due to dilatancy behavior; (a) Initial condition, (b) Positive dilatancy in dense ground, (c) Negative dilatancy in loose ground.

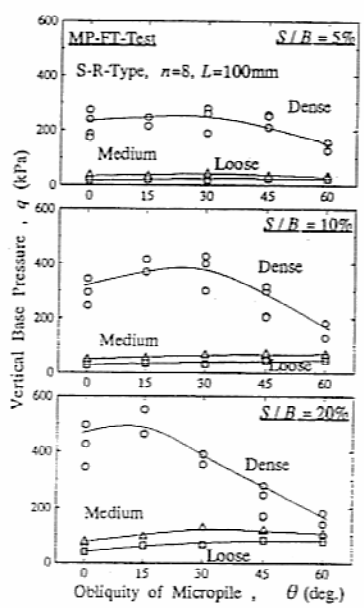


Fig. 8. Influence of relative density of ground on the improvement of bearing capacity of micropile

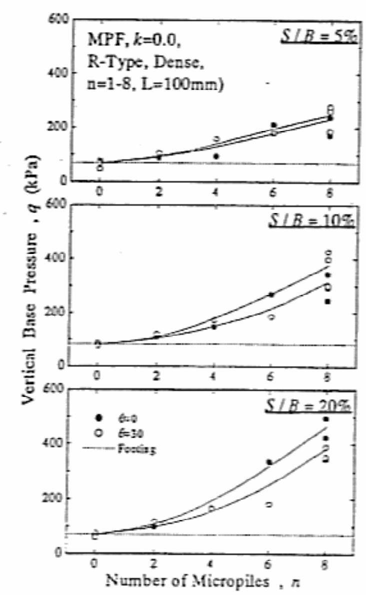


Fig. 10 Effect of number of micropiles on the bearing capacity

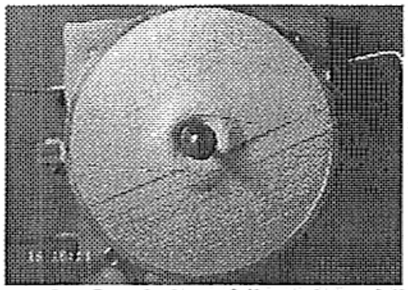


Photo. 2. Local shear failure shear failure observed in MP-FD Test at S_v/B=20%; S-R-Type, n=8, θ=0^0, dense ground

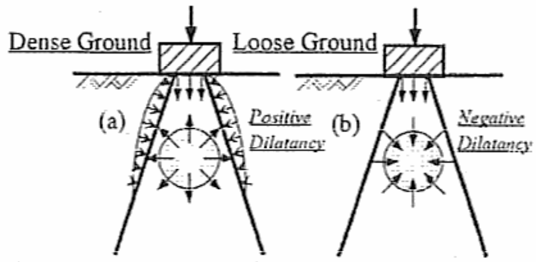


Fig. 9. Improvement of bearing capacity due to the confining effect on ground material beneath footing; (a) in dense ground, (b) in loose ground

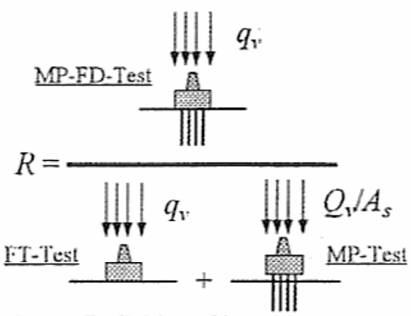


Fig. 11. Definition of improvement coefficient for the bearing capacity

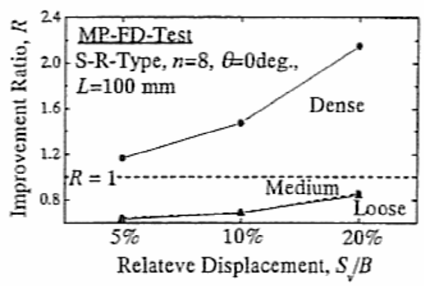


Fig. 12 Effect of relative density on the improvement ratio of bearing capacity

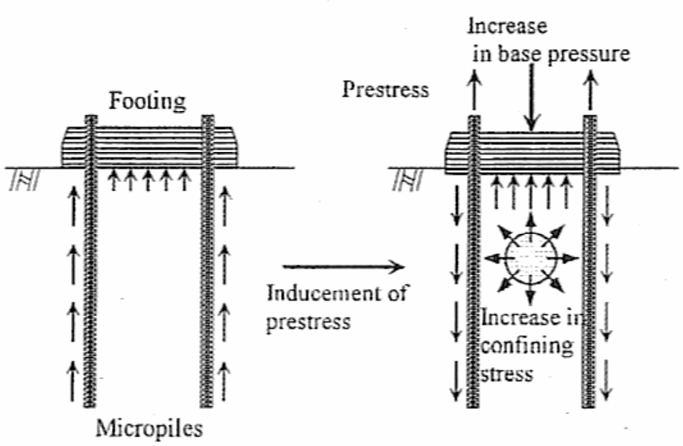


Fig. 13. Concept of prestress on micropile group and induced base pressure and confining pressure.

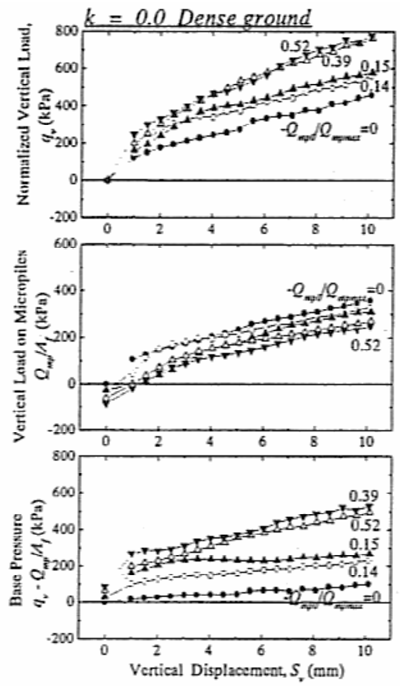


Fig. 14. Effect of prestress on the behavior of micro pile foundations on dense ground; (a) total load, (b) load on micropile group, (c) base pressure

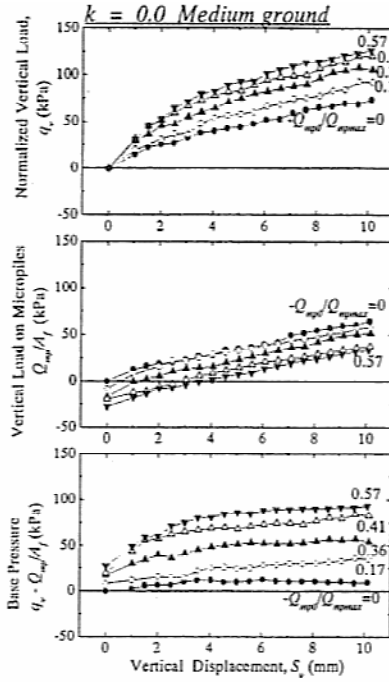


Fig. 15. Effect of prestress on the behavior of micro pile foundations on medium ground; (a) total load, (b) load on micropile group, (c) base pressure

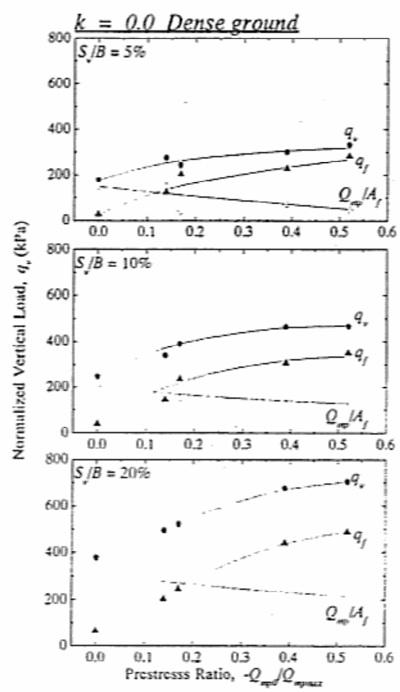


Fig. 16 Improvement of bearing capacity with inducement of prestress on micropile group in dense ground

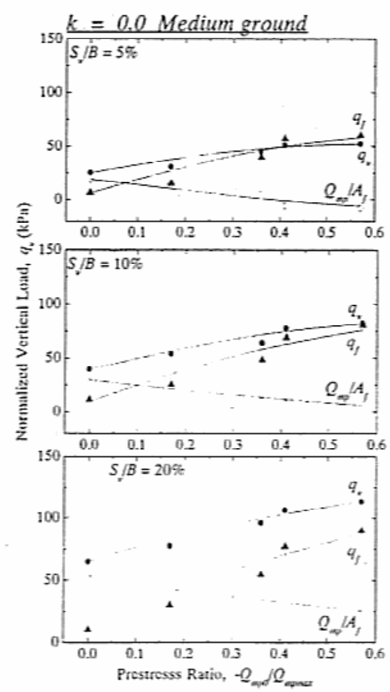


Fig. 17 Improvement of bearing capacity with inducement of prestress on micropile group in medium dense ground