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Semi-rigid piled-raft system for soft subsiding ground

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ABSTRACT : Laboratory scale model tests were conducted with (a) rigid piled-raft system (RPRS) in clay and (b) model footings resting on unreinforced and reinforced granular fill overlying reconstituted Ariake clay with or without floating piles.

A reinforced granular bed (RGB) over piles in clay (RGBPC) is suitable in subsiding environment. It can deform in accordance with that of the subsiding ground and behave as a semi-rigid piled-raft system (SRPRS) in clay. In the case of RGB on clay (RGBC) or RGBPC, the reinforcements in the fill improve its stiffness, by virtue of which the loads from the footing get spread through the fill onto a larger area on the surface of the clay, thereby reducing the settlements. The piles in the case of RGBPC help to further improve the load carrying capacity (or Bearing Capacity Ratio, BCR) and reduce the settlements.

1 INTRODUCTION

A rigid piled-raft system (RPRS) is commonly used as foundation for light and medium structures in clays. However, it is particularly well suited in non-subsiding grounds, for e.g. in stiff clays. In soft subsiding grounds, a gap could be left between the bottom of the raft (or the cap) and the subsiding ground, which will unduly load the piles excessively. For e.g., in the case of cross-drainage (CD) works such as sluiceways built on end-bearing piles across highway embankments on soft Ariake clay in the Saga Plain in Japan, cavities are found to be formed beneath sluiceways, as also cracking of embankment near the shoulders. The embankment load causes the soft soil to settle while the piled foundation prevents the downward movement of the sluiceway, thus creating a void. The cracking of the embankment near its shoulders arises from the large differential settlements. A reinforced granular bed (RGB) over piles in clay (RGBPC) which is particularly well suited for consolidating or subsiding grounds and soft clays is therefore recommended.

A RGBPC has the stiffness to transfer the loads to the piles and at the same time has the flexibility to deform in accordance with the subsiding ground unlike a RPRS, thereby not loading the piles unduly excessively. In addition, replacing the end bearing piles with floating piles makes the foundation consistent and compatible with the soft soil and the sluiceway deformations (Miura & Madhav 1994). Therefore in this study, a RGBPC, with a densely reinforced granular bed, is envisaged to behave as a semi-rigid piled-raft system (SRPRS).

Placing the polymer geogrid reinforcements in one or more layers in the granular fill is more effective than placing the reinforcements at the interface. The granular soils in the fill develop good shearing resistance with the reinforcement. Reinforcements in the fill improve its stiffness. With the soft clay underneath, the settlements will be considerably larger and hence the soil-reinforcement interaction in the RGB overlying clays will also be more intense.

2 LABORATORY MODEL TESTS AND TESTING PROGRAM

Two series of constant strain bearing capacity loading tests were performed in this study (Figure 1) in a thick-walled PVC soil tank measuring 500 mm in diameter and 600 mm height. The inner surface of the soil tank was coated with grease, and a plastic sheet was provided to reduce the effects of the side wall friction (Figure 2). Reconstituted Ariake clay sample was prepared in the soil tank. Loading during consolidation was done in small increments to prevent the squeezing out of the soft clay. Bearing capacity loading tests were generally continued upto a final settlement of 40 mm.

Series I (B-C Series, B1 to B4 and C1 to C7) included tests with (a) RPRS in clay and (b) model footings resting on unreinforced and reinforced granular fill overlying reconstituted Ariake clay with or without floating piles. The efficiency of RPRS in clay was compared with that of RGBPC (Table 1). Series II (A-D Series, A1 and D1 to D16) included tests only

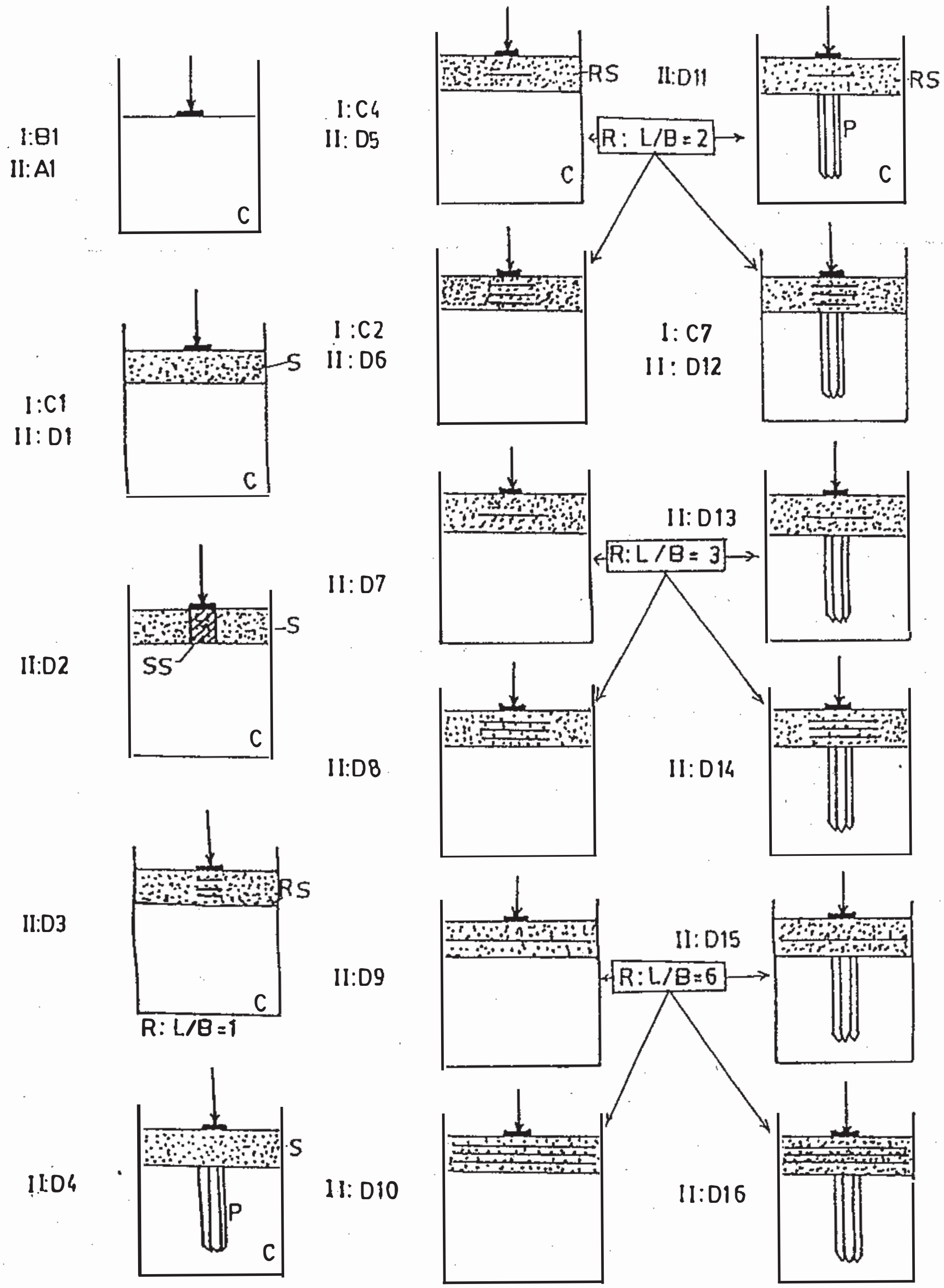


Figure 1. Various tests performed [Series I (B–C series)–C_u of clay = 5 kPa, D_r of sand = 50% (15 kN/m^3); Series II (A–D series)–C_u of clay = 2.75 kPa, D_r of sand = 60% (16 kN/m^3)].

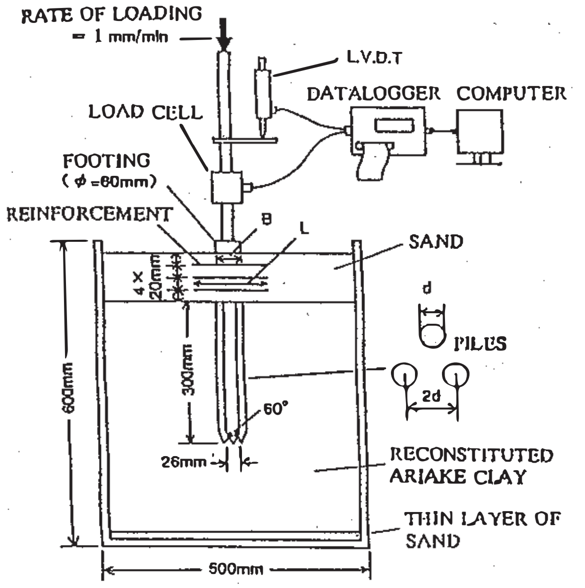


Figure 2. Typical experimental set-up in case of RGBPC.

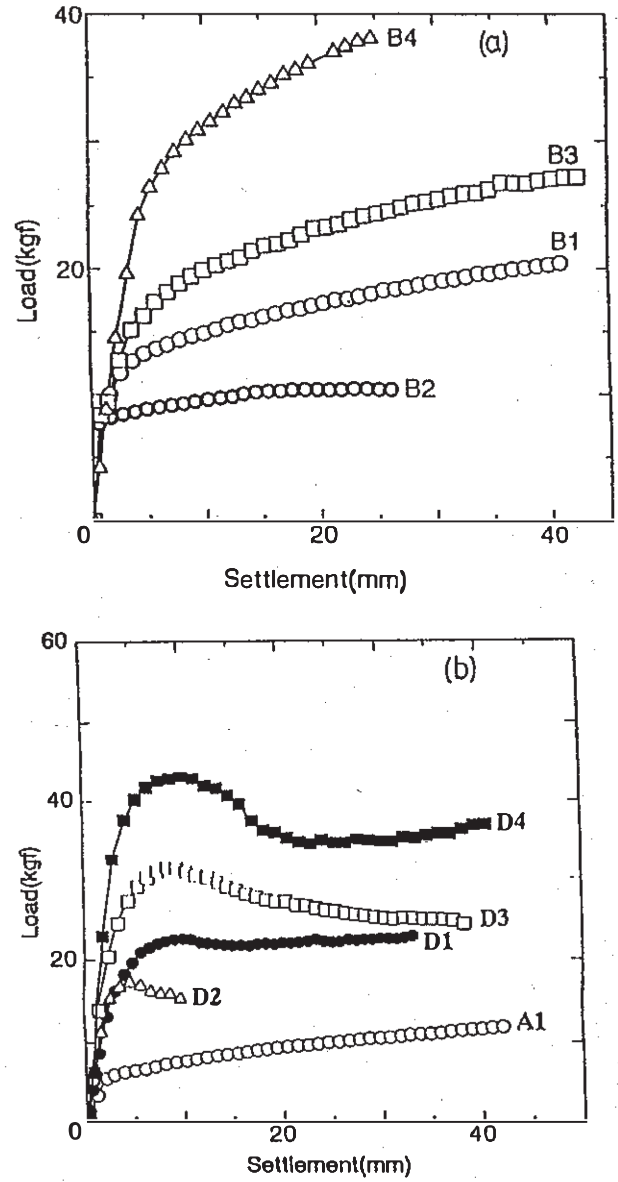
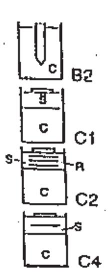


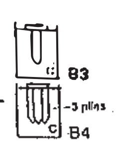
Figure 3. Load-displacement curves from some of the tests.

with model footings resting on unreinforced and reinforced granular fill overlying reconstituted Ariake clay with or without floating piles. In this case, the improvement in the stiffness of the system due to the presence of the piles and reinforcements was studied. Improvement in bearing capacity due to number of layers of reinforcement (N) and number of piles was studied in both the cases.

Table 1. Efficiencies of RPRS in clay and RGBPC (Series I tests).

Efficiency of	Defined as	Value
C3	[C3/(C1+B2)]	0.94
C5	[C5/(C4+B2)]	0.87
C6	[C6/(C2+B2)]	1.02
C7	[C7/(C2+3B2)]	0.89
	AVERAGE	0.93
AVERAGE EFFICIENCY VALUE OF RIGID PILED-RAFT SYSTEM		0.83





The reinforcement used was a polymer geogrid (Tensar SS35) having mesh sizes of about 28 mm x 33 mm. Model piles (in case of RGBPC and RPRS), 300 mm long and 26 mm diameter, having a conical tip with an apex angle of 60, were made of PVC and had their surfaces roughened with sand paper. The pile/s were pushed together into the consolidated clay at the rate of 10 mm/min. One week was allowed after that to let the porewater pressures in the clay dissipate. In case of tests where three piles were used, they were arranged in a triangular pattern with centre to centre spacing of twice the diameter of the pile (See Fig. 2).

In test D2, a cylindrical sand stone block of the same material as that of the surrounding sand, having the same diameter as that of the footing (80 mm) and its thickness equal to that of the granular fill (80 mm) was provided beneath the footing resting on the surface of clay. When the footing was loaded, the sand stone block was found to punch through the clay.

3 RESULTS AND DISCUSSIONS

3.1 Load transfer mechanism

Figures 3a and 3b show some of the load-settlement curves. The efficiencies of RPRS in clay and RGBPC are shown in Table 1. The results of tests D1 and D2 are compared. Test D2 peaked sooner than D1. This indicates that in the case of test D1, a load spread mechanism is more likely. The ultimate bearing capacity in the case of test D2, whose BCR w.r.t. A1 is about 1.45, was observed to be less than in case of test D1, whose BCR w.r.t. A1 is about 1.9. Huang & Tatsuoka (1988) conducted tests similar to D3 with L/B=1 on sands and attributed the improvement in the bearing capacity to a "deep footing effect". However, observations and results of this study again indicate that in case of test D3, a load spread through the fill is more likely. The reinforcement, with L/B=1, in the fill increases the stiffness of the fill to some extent.

3.2 Effect of piles and reinforcements

Tests D11 to D16 with RGBPC indicated that the effect of the piles remains more or less constant with settlement of footing once it has peaked (Figure 4). However, the effect of the reinforcements was found to increase with the settlement of the footing (Figures 5a & 5b), and peak at considerably larger values of settlements.

Improvement in stiffness of the system was studied from the initial slope of the load-displacement curves. In Figure 6, the vertical axis represents the stiffness ratio which is the ratio of the initial slope of any test with respect to that of test D1. It can be seen that the stiffness ratio is very significant with the presence of the piles. This suggests that the pile action takes place

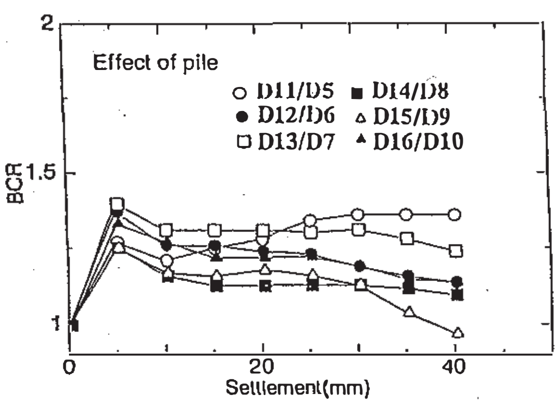


Figure 4. Effect of piles on BCR (Series II tests).

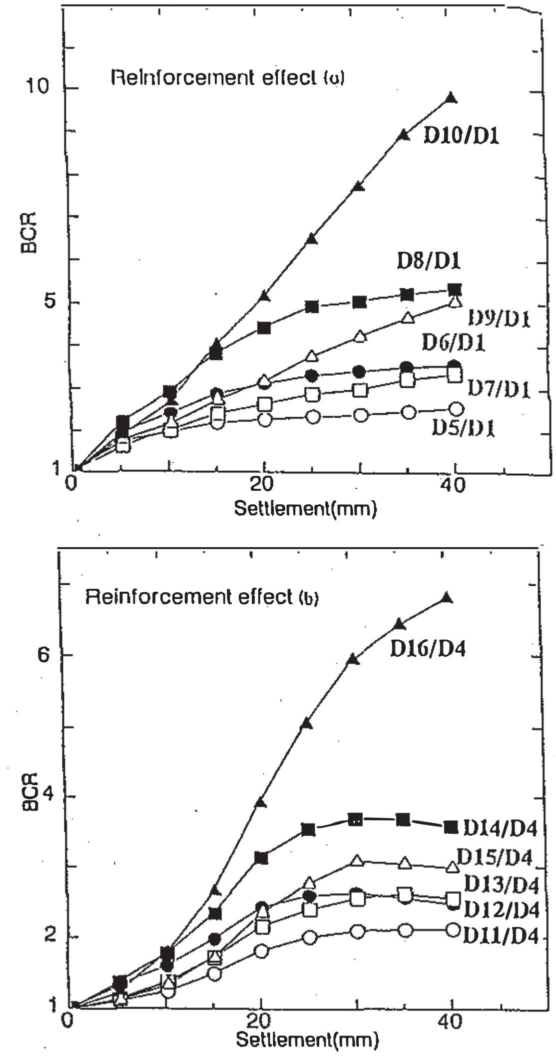


Figure 5. Effect of reinforcements on BCR (Series II tests) (a) without piles (b) with piles.

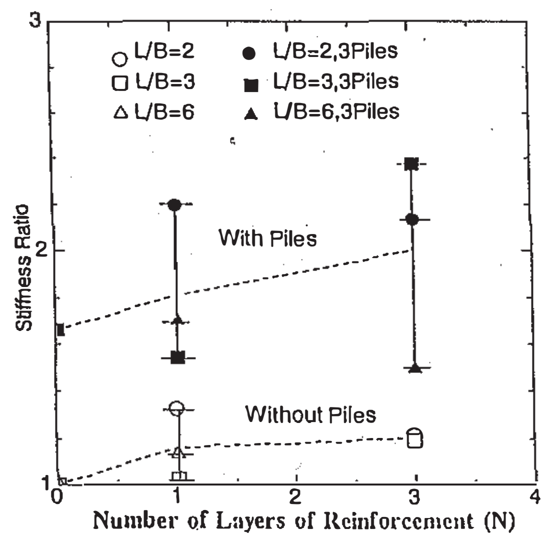


Figure 6. Improvement in stiffness, with and without piles (Series II tests).