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BEHAVIOUR OF SHALLOW RING FOUNDATIONS WITH GEOTEXTILES

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SUMMARY This paper describes an application of a geotextile to shallow ring foundations. In this method, a geotextile is spread over the open space of a ring foundation and is fastened to its circular beam. Scale models on saturated cohesive soil were tested in a laboratory on the behavior of three types of foundations with the same outside diameter. These foundations are a reinforced ring foundation with geotextile, a circular plate foundation and a ring foundation. The model foundations were loaded vertically for various soil strength and embedded depth. Lead shots were placed in the model ground to observe the failure patterns of soil mass. X-ray photographs were taken at intervals during the loading. The test results show that the ultimate bearing capacity of the reinforced ring foundation is equal to that of the circular plate foundation. The settlement of the reinforced ring foundation is, however, larger than that of the circular plate foundation. The X-ray photographs show that the displacement patterns of the lead shots are similar between the two types of foundations.

INTRODUCTION

Methods of geotextile reinforcement have gained widespread use in geotechnical engineering. In particular, the applications to earth structures are actively investigated. One of the applications is to shallow foundations to improve the bearing capacity of soil under footings. There are two ways of increasing bearing capacity of a shallow foundation on a given soil. One of them is to increase the bearing capacity of the ground under the shallow foundation without enlarging the size of the foundation, and the other is to enlarge the loaded area on the soil surface. The work by GUIDO, BIESIADECKI & SULLIVAN (1985) shows that geotextiles can be used effectively as a horizontal reinforcing material in soil below shallow foundations. However, the greatest disadvantage of the horizontal reinforcement is that it can not be used in situ conditions without moving the soil. The subgrade under the footing has to be re-laid and the compaction of the layer becomes essential after placing the reinforcing elements (VERMA & CHAR, 1986).

A new type of reinforcement for shallow foundations, which

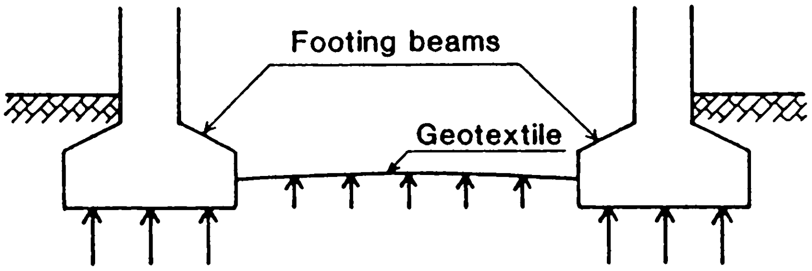


Fig.1 Foundation reinforced with geotextile

enlarges the loaded area with a geotextile, is introduced in this paper. In this method, a geotextile is used as a supporting member of shallow foundations. The geotextile is spread over the open space of footing foundations and is fastened to the footing beams (Fig.1). The weight of a structure is carried on the footing beams and the geotextile. The geotextile in this method can be replaced by other materials such as a plastic net, a polymer grid or a composite geotextile.

The new foundation is equivalent to a mat foundation of the same foundation area, although the settlement of the new foundation may be larger than that of the mat foundation because of flexibility of the geotextile. Allowable settlement of a structure, however, depends on the size, type and use of the structure and other surrounding conditions. In most cases, the allowable settlement is not governed by the total settlement but by the differential settlement. Where soil conditions are very bad, the design of shallow foundations allowing large uniform settlements may be adopted to avoid the increase of the construction costs by the use of soil improvements or deep foundations. This foundation aims to obtain the larger bearing capacity with inexpensive and simple construction method.

This paper presents the results of model tests on saturated cohesive soil to compare the behavior of three types of foundations of the same outside diameter: (a)reinforced ring foundation with geotextile; (b)circular plate foundation; and (c)ring foundation.

MODEL TESTS

Soil used for model ground was Kawasaki clay from Tokyo Bay. Dredged Kawasaki marine clay was thoroughly remoulded by adding water and was put through a sieve of 2mm openings. The clay slurry was mixed with a small amount of Toyoura sand and used for the model tests. To obtain a smooth grading, crushed particles of Toyoura sand were also added to the mixing. The properties of the soil are summarized in Table I.

Fig.2 shows the general arrangement of a model test. The length, depth and width of the soil box were 500mm, 450mm and 300mm respectively. Both sides of the soil box were made of steel covered with a teflon plate. Front and rear faces were made of acrylic resin with thickness of 20mm. Silicone grease was smeared on the walls of the soil box to reduce the side friction during consolidation.

The soil mixture was puddled in a soil mixer under a high vacuum for about two hours. A layer of 50mm thick sand was placed

Table I Properties of soil used in experiments

Specific gravity of particles	G_s	:	2.68
Liquid limit	w_L	:	36.7%
Plastic limit	w_p	:	16.0%
Plasticity index	I_p	:	20.7%
Fraction of soil component (%)	(Sand)	:	42.9%
	(Silt)	:	20.6%
	(Clay)	:	26.5%
Ratio of undrained strength to consolidation pressure	c_u/p	:	0.42

at the bottom of the soil box shown in Fig.2. This sand layer was the drainage for consolidation of the clay. A sheet of filter paper was laid on the surface of the sand. The soil slurry was then poured into the soil box carefully avoiding air bubbles. The slurry was poured in eleven layers. Each layer was put under the preliminary consolidation by vertical pressure of 9.8kPa for a few hours. After the preliminary consolidation of each layer, the consolidation pressure was removed and lead shots with 2mm in diameter were placed on the surface of the layer to form grids of 20mm by 20mm as shown in Fig.2.

Having completed pouring slurry and the preliminary consolidation, the final consolidation pressure, either 23.5 or 47.0kPa, was applied. The settlement during the final consolidation was recorded by a displacement gauge. It took about 10 days to attain the degree of consolidation of 90%.

Three types of acrylic model foundations of the same outside diameter were prepared. Fig.3 shows schematic diagrams of the model foundations. These are (a) reinforced ring foundation with geotextile, (b) circular plate foundation and (c) ring foundation. During the tests of embedded foundations ((d),(e),(f)), a circular wall was installed in advance in a trench excavated in the consolidated clay. The embedded depth of the circular wall was 80mm. The pressure was applied once again and the clay was reconsolidated to eliminate various disturbance. The upper part of the model foundation was rigidly attached to the circular wall in the clay before testing. A sheet of geotextile was bonded to the circular beam of the ring foundation without stretch. Table II shows the properties of the geotextile used as a reinforcing material.

On completion of the clay consolidation, the model foundation was placed at the center on the clay surface. The general arrangement of the model is shown in Fig.2. A load cell was attached to the top of a screw jack. Displacement transducers were placed at the four corners of a loading plate. Load was applied to the model foundation at a displacement rate of 1mm/min by the screw jack. During the loading tests, X-ray photographs of the lead shots were taken at 0,5,10,20 and 30mm in the settlement of the model foundation.

Parameters considered in this research were the depth of model foundation and the soil strength. The soil strength is dependent on consolidation pressure. The depths of the model foundation (D_f) were 0 and 80mm. The consolidation pressures (p) were 23.5 and 47.0kPa. Table III shows the list of the tests.

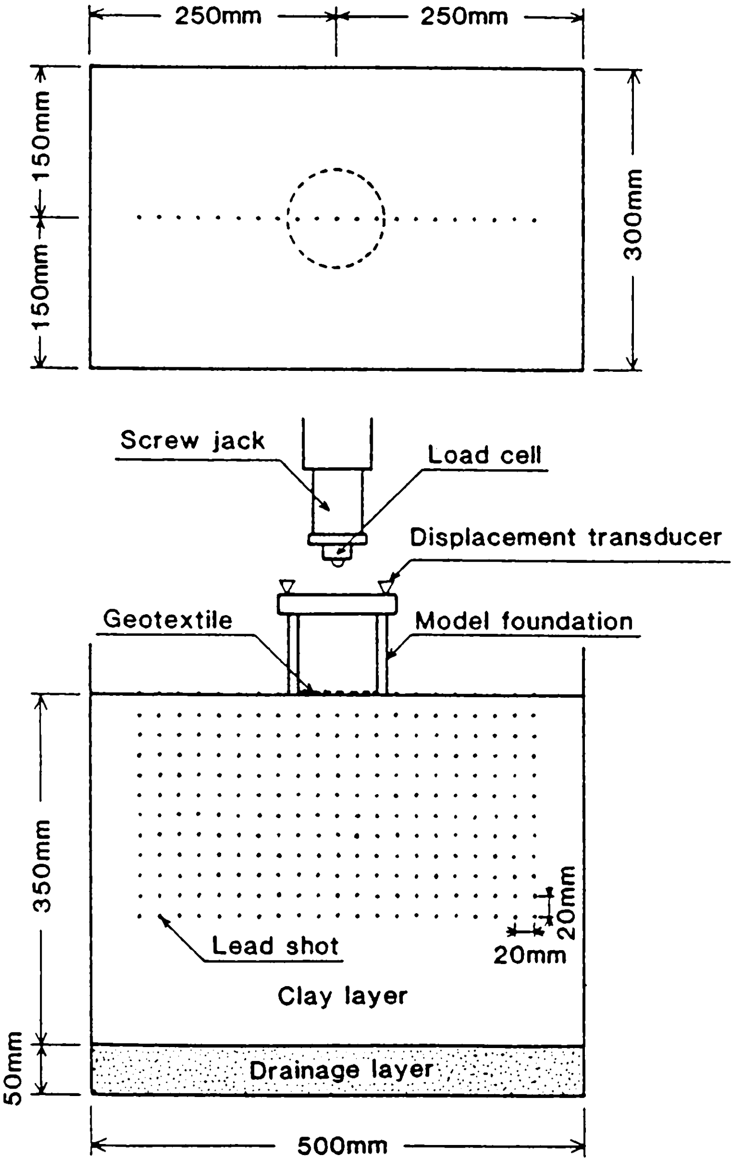


Fig.2 Arrangement of model test

Table II · Properties of geotextile

Structure		Woven
Thickness		0.25mm
Weight		$1.42N/m^2$
Tensile strength	(warp)	0.98kN/3cm
(wet)	(weft)	0.80kN/3cm
Extension	(warp)	23%
(wet)	(weft)	14%

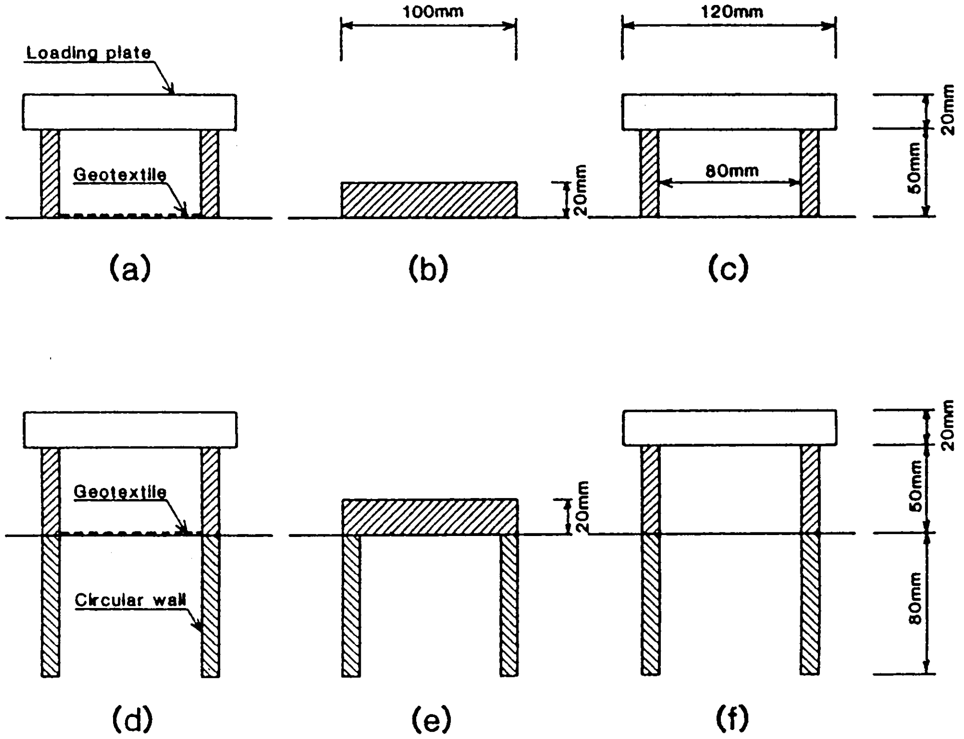


Fig.3 Schematic diagrams of model foundations

Table III List of tests

Type of foundation	Consolidation pressure (kPa)	Depth of foundation (mm)	Peak bearing stress (kPa)
Reinforced ring foundation	23.5	0	36.9
	23.5	80	51.4
	47.0	0	79.2
	47.0	80	106.9
Circular plate foundation	23.5	0	35.8
	23.5	80	48.8
	47.0	0	75.4
	47.0	80	100.4
Ring foundation	23.5	0	18.0
	23.5	80	26.4
	47.0	0	35.0
	47.0	80	82.5

TEST RESULTS AND DISCUSSION

Figures 4 and 5 show the relationships between the vertical load and the settlement of model foundations obtained for two

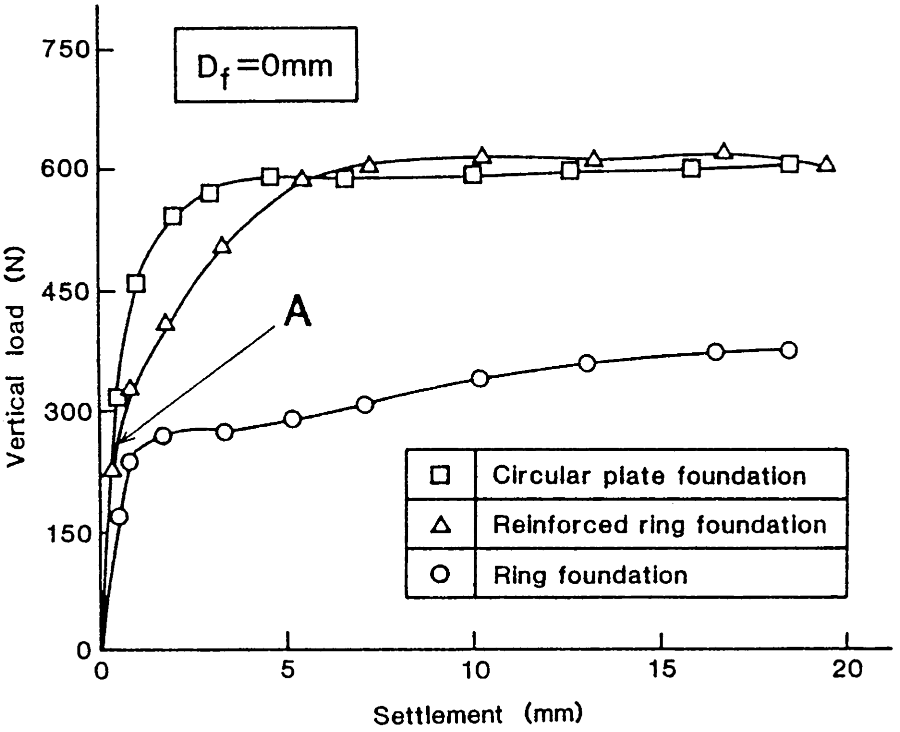


Fig.4 Load-settlement relationships of model foundations (Consolidation pressure p=47.0kPa)

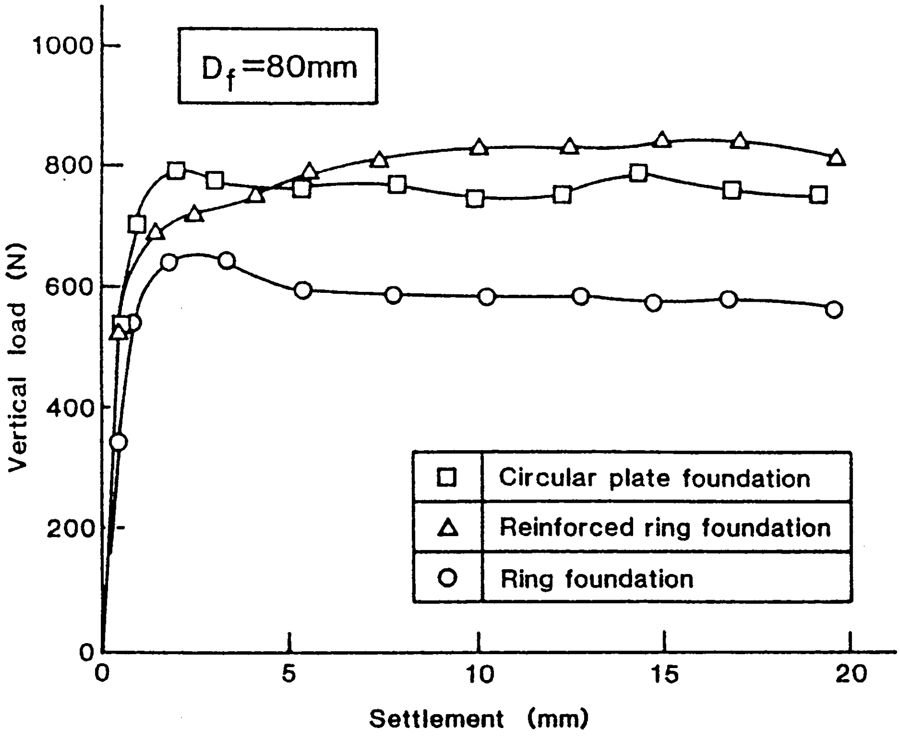


Fig.5 Load-settlement relationships of model foundations (Consolidation pressure p=47.0kPa)

embedded depths with consolidation pressure p=47.0kPa. Similar relations were obtained in the case of p=23.5kPa. The load-settlement curves for the reinforced ring foundations are located between the circular plate foundations and ring foundations. The ultimate bearing capacities of the reinforced ring foundations are equal to those of the circular plate foundations. The settlements of the reinforced ring foundations are, however, larger than those of the circular plate foundations.

In the tests of embedded depth D_f=0mm, the load increases linearly with settlement both in the circular plate foundation and in the ring foundation. when the reinforced ring foundation approaches its failure, however, there is a pronounced increase in the settlement. The load-settlement curve changes its slope at A as shown in Fig.4. When the settlement is small, the difference is insignificant between the reinforced ring foundation and ring foundation without reinforcement. As the settlement increases, the effect of reinforcement becomes apparent. The reinforcement with geotextile becomes effective after the settlement reaches certain value. The rate of increase in load of the reinforced ring foundation, after the point A, is smaller than that of the circular plate foundation. The load carried by the reinforced ring foundation is composed of two factors. Up to the point A, the circular beam carries most load and the geotextile little. As the settlement increases further, the geotextile carries most of the increasing load. In this stage, the geotextile requires certain amount of deformation.

In the tests of embedded depth D_f=80mm, the load increases steadily with settlement and indicates an obvious peak point both in the circular plate foundation and in the ring foundation. The load of the reinforced ring foundation, on the other hand, increases gradually from the value between the peak loads of two other types of foundations. There is not large difference among the maximum bearing capacities of the three types of foundations with D_f=80mm. This is due to the friction acting on the circular wall, which carries the major part of applied load. Thus, the reinforcement of the ring foundation with geotextile shows larger contribution to the bearing capacity when D_f=0mm rather than D_f=80mm.

Fig.6 shows the deformation of the geotextiles obtained for the reinforced ring foundations. These were observed by X-ray photographs of a lead foil placed beneath the geotextile. X-ray photographs of the lead foil and lead shots were taken at the same time. Abscissa indicates the shape of the geotextile when settlement is 0mm. Ordinate indicates the vertical displacement of the geotextile from the lower edge of the circular beam where geotextile is fixed.

The geotextiles show large deformation when the foundations settle from 0mm to 10mm. Beyond this settlement, the geotextiles show little deformation even when the foundations settle from 10mm to as large as 30mm. After the settlement became larger than 10mm, there was no increase in load in the reinforced ring foundations as shown in Figs.4 and 5. No increase in load makes no deformation of the geotextile. The geotextile changes the shape of itself because of the increasing load. The geotextile does not transfer the load to the circular beam without deformation when it is loaded vertically, because the only mechanism for the geotextile to resist the load is the tensile resistance. Thus the geotextile requires enough deformation to mobilize its tensile stress of which the

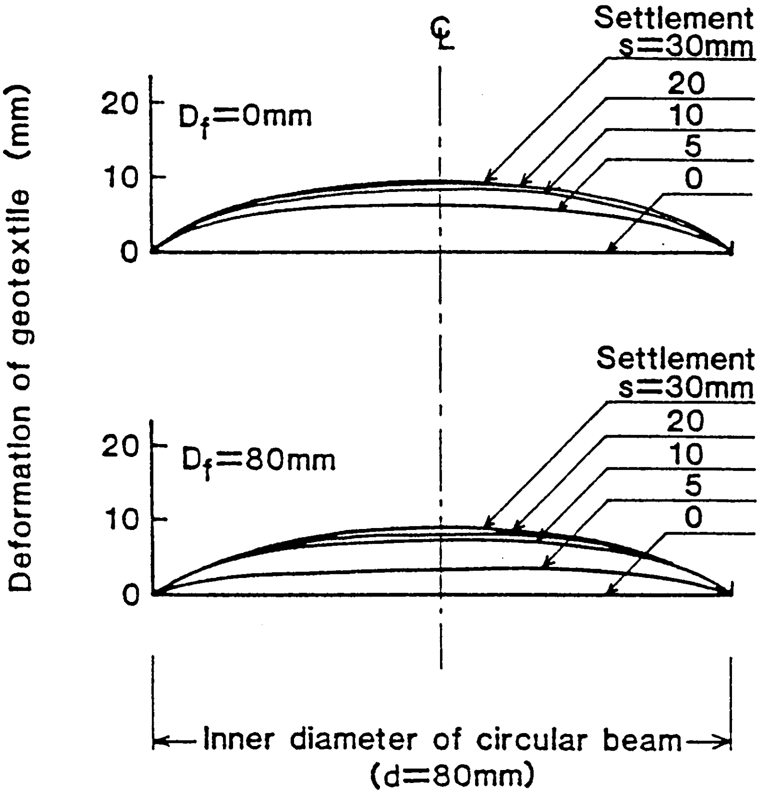
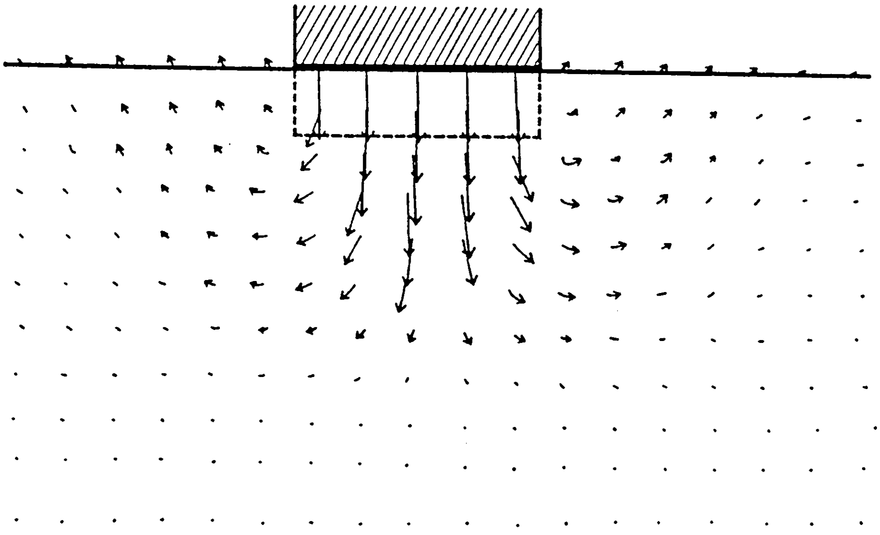


Fig.6 Deformation of geotextiles for reinforced ring foundations

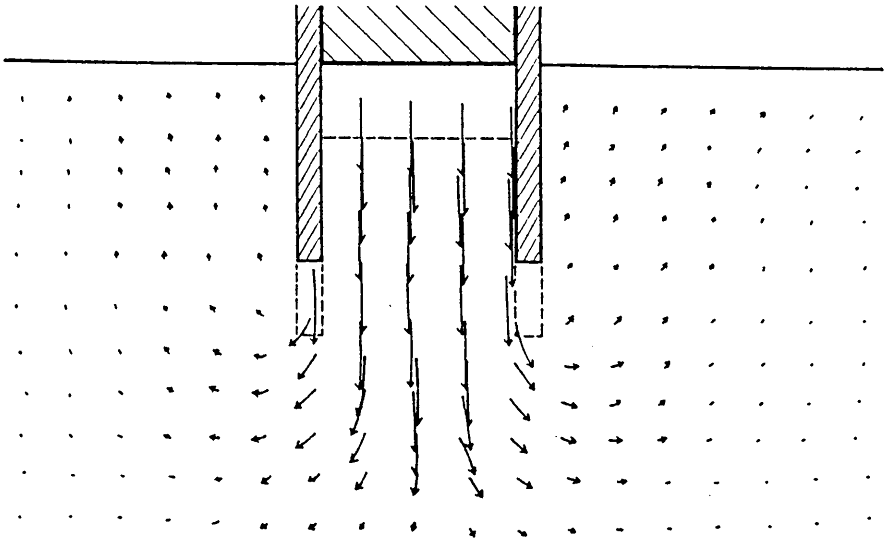
vertical component contributes to the bearing capacity of the foundation.

Figures 7, 8 and 9 show diagrams of displacement vectors of the clay under consolidation pressure p=47.0kPa. These figures correspond to the settlement of 30mm. Fig.7 shows the circular plate foundations, Fig.8 shows the reinforced ring foundations, and Fig.9 shows the ring foundations. The coordinates of lead shots in X-ray photographs were evaluated by an X-Y analyzer. The horizontal and vertical movements were converted into vectors. Arrows in these figures show the direction and magnitude of the motions of the lead shots in the clay. Shadowed foundations show the initial positions. The foundations settled down finally to the positions shown by the broken lines.

The clay is pushed out from beneath the loaded area and the surface of the surrounding soil heaves to maintain the constant volume condition because of the undrained loading. The soil movements are symmetrical in all the cases. In the circular plate foundation of D_f=80mm (Fig.7-(b)), the soil inside the circular wall moves downward vertically according with settlement of the foundation. The displacement vectors, developed under the base, of D_f=80mm are similar to those of D_f=0mm (Fig.7-(a)), although the foundation depths are unequal. These trends are also seen in the reinforced ring foundations (Fig.8). The soil movements under the geotextiles, however, not only are vertical but also have horizontal components owing to the deformation of the geotextiles. The failure



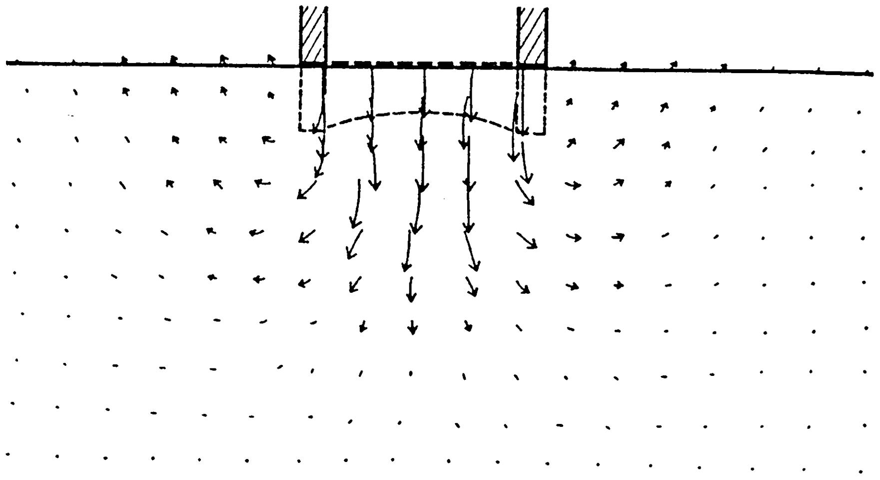
(a) D_f=0mm



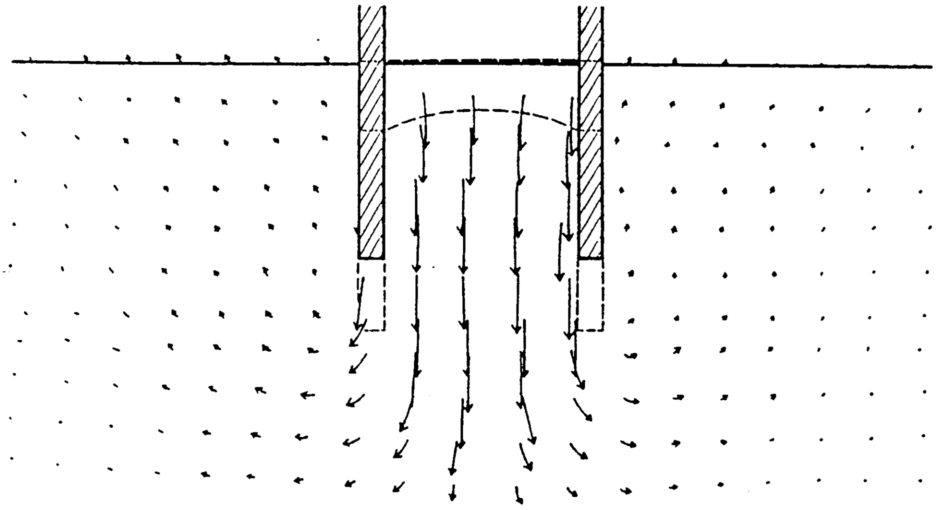
(b) D_f=80mm

Fig.7 Displacement vectors for model ground by circular plate foundations from 0 to 30mm settlement

pattern of the reinforced ring foundation is similar to that of the circular plate foundation for each embedded depth. This similarity justifies the equal ultimate bearing capacity between the reinforced ring foundation and the circular plate foundation. Since the both



(a) D_f=0mm

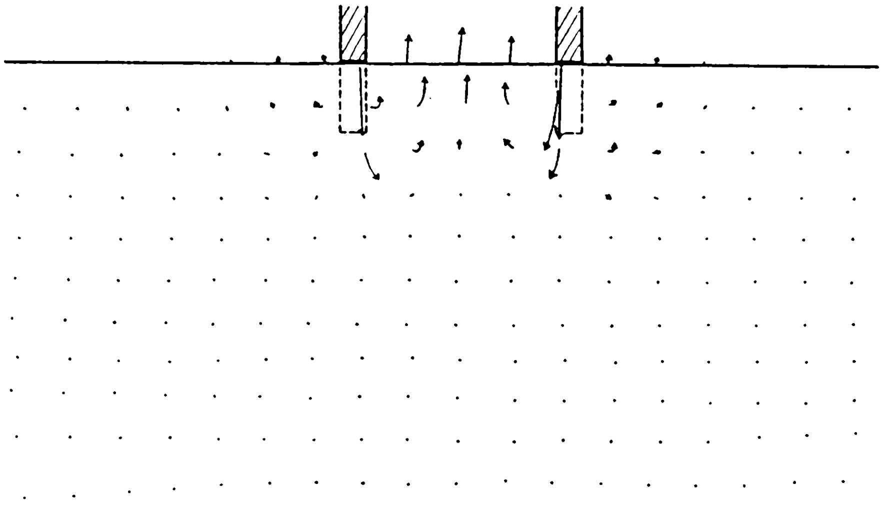


(b) D_f=80mm

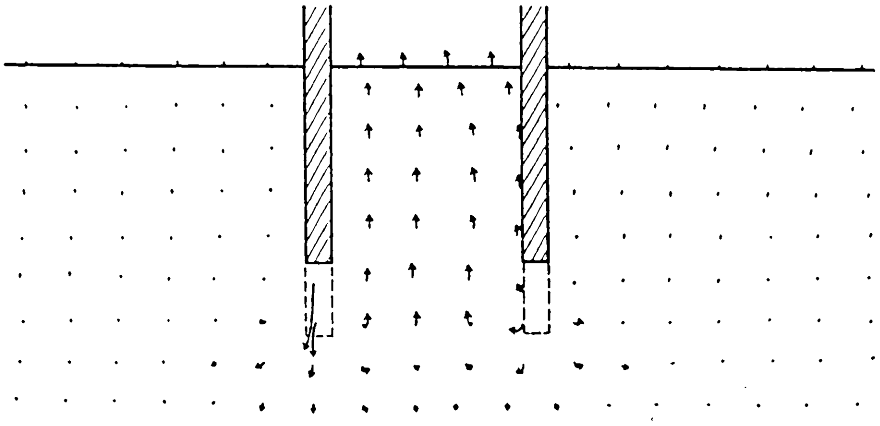
Fig.8 Displacement vectors for model ground by reinforced ring foundations from 0 to 30mm settlement

types of foundations have a wide distribution of the soil displacements, the large zone of soil mass contributes to the developments of the bearing capacities.

In contrast with the above mentioned foundations, the failure



(a) D_f=0mm



(b) D_f=80mm

Fig.9 Displacement vectors for model ground by ring foundations from 0 to 30mm settlement

zones by the ring foundations are poorly developed (Fig.9). Moreover, the soil inside the circular beam or circular wall of the ring foundation moves upward and heaves. The amount of soil heave inside the ring is larger than outside. The soil under the circular beam moved toward the center of the foundation. The soil inside the ring is forced to move upward. Geotextile reinforcement of the ring foundation, thus, plays an important role in confining the heaving of the soil inside the foundation. The inside heaving of D_f=80mm is smaller than that of D_f=0mm owing to the friction between the soil and inner surface of the circular wall. Since the frictional resistance acting on the inner wall, together with the geotextile, prevents the upward movement of the inside soil, geotextile reinforcement for D_f=80mm is ineffective compared with that for D_f=0mm.

A geotextile acting as a supporting member in a shallow ring foundation prevents the soil under it from heaving and makes the large zone of soil mass contributive to the development of the bearing capacity of the foundation.

CONCLUSIONS

A shallow ring foundation with geotextile reinforcement has been presented. The behaviour of the new foundation models were tested in comparison with those of the circular plate foundations and of the ring foundations having the same outside diameter. Experimental results are concluded as follows.

(1) Reinforcement of the shallow ring foundation with geotextile increases the bearing capacity of the foundation.
(2) The ultimate bearing capacity of the reinforced ring foundation with geotextile is equal to that of the circular plate foundation with the same loaded area. The settlement of the reinforced ring foundation is larger than that of the circular plate foundation.
(3) The geotextile used for reinforcing the shallow ring foundation changes the shape of itself with increasing load. Deformation of the geotextile increases the settlement of the foundation.
(4) The geotextile acting as a supporting member of the shallow ring foundation prevents the soil under it from heaving. The geotextile reinforcement makes the large zone of soil mass contributive to the development of the bearing capacity of the foundation.

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