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Mattress foundation by geogrid on soft clay under repeated loading

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ABSTRACT: The small-scaled model tests were carried out at the laboratory to find a design method of unpaved roads on soft foundations reinforced with the geotextiles. The tests were mainly aimed at providing a basis for the selection of a compatible embankment geometry and reinforcement layout. According to the results from model tests for adaptation of the geomesh and geogrid, it was proved that application of a geogrid with cellular layout is most preferable for reducing the settlement of the fill on soft grounds under traffic-induced cyclic loading because of the high rigidity of geocell with the gravels contained inside and the eminent interlocking effect exerted between geogrid and gravels.

1 INTRODUCTION

Soft clay subgrades under traffic-induced cyclic loading sometimes exhibit the predominant deflection which may lead to the harmful settlements of pavements for motorways, railways and runway. Behaviour of clay subgrades subjected to cyclic loading is so complex that its mechanism has not been clarified yet. Adaptation of geotextiles is counted as one of the promising countermeasures against settlements of clay under cyclic loading (Yamanouchi et al., 1967: Yasuhara et al., 1986). However, reinforcement by the geomesh has not been successful for preventing it (Yamanouchi, 1967: Yasuhara et al., 1986).

Based on the laboratory small-scaled model footing tests, the present paper explores the best way how to use the geotextiles for controlling the settlements of unpaved roads founded on soft clay grounds. Three kinds of geotextiles so called geomesh, geomesh-pipe and geogrid were selected to investigate the behaviour of soft clay under cyclic loading with an inclusion of the geotextile as well as to determine the most suitable material on this subject. It is aimed in this study that laboratory model tests will provide a basis for selection of a compatible geometry and reinforcement layout.

2 EXPERIMENTAL PROGRAMME

To detect the selection of compatible geometry and reinforcement layout for reducing the settlements of soft clay under cyclic loading, several families of small-scaled model tests were carried out. Those were:

1) Without geotextiles,
2) With planar layout of geotextiles and
3) With cellular layout of geotextiles.

All the test series involved in the present paper are summarized in Table 1. The modeled ground with planar layout of geotextiles is reinforced by laying the geogrid between the upper soft clay layer and the lower sand layer. As shown in Table 1, in addition to this, the cellular layouts by the mattress-type of geogrid with gravels contained inside (Test no. G-6) and by the folding mattress-type geogrid (Test no. G-3) were also used for reinforcing the layered ground. The difference of those two layouts is schematically illustrated in Fig. 1.

The outline of the apparatus for model tests was shown in Fig. 2. The plane strain model test was carried out on the footing apparatus made of the steel frames with 2.0 m in width, 1.0 m in depth and 0.5 m in length. The clay layer with 20 cm and 40 cm in depth was covered by the sand layer with 17 cm in depth. The width of the loading plate was 15 cm for most of

Table 1 Details of model footing tests

Test no.	Material	Layout	Clay layer (cm)	Width of apparatus (cm)	Cyclic pressure (kPa)	Loading plate (cm)	No.of cycles
N-1	Non.	—	20	100	40	15	(static)
-2		—	〃	〃	10	30	18000
-3		—	〃	〃	〃	〃	130000
-4		—	〃	〃	40	15	〃
-5		—	40	〃	〃	〃	〃
-6		—	20	〃	〃	〃	〃
-7		—	40	200	〃	〃	15
M-1	Mesh	Planar	20	100	10	30	18000
-2	(Z-31)	〃	〃	〃	40	15	130000
MP-1	Mesh-	Hori.	〃	〃	10	30	〃
-2	pipe	〃	〃	〃	〃	15	〃
-3	(PDS-50)	〃	〃	〃	40	〃	〃
-4		Ver.	〃	〃	〃	〃	〃
G-1	Geogrid	Planar	〃	〃	10	30	〃
-2	(SS-2)	〃	〃	〃	40	15	〃
-3		Cellular	〃	〃	〃	〃	95000
-4		Planar	〃	〃	〃	〃	130000
-5		〃	〃	〃	〃	〃	10540
-6		Cellular	40	200	〃	〃	100000
Q-1			20	〃	10	30	130000

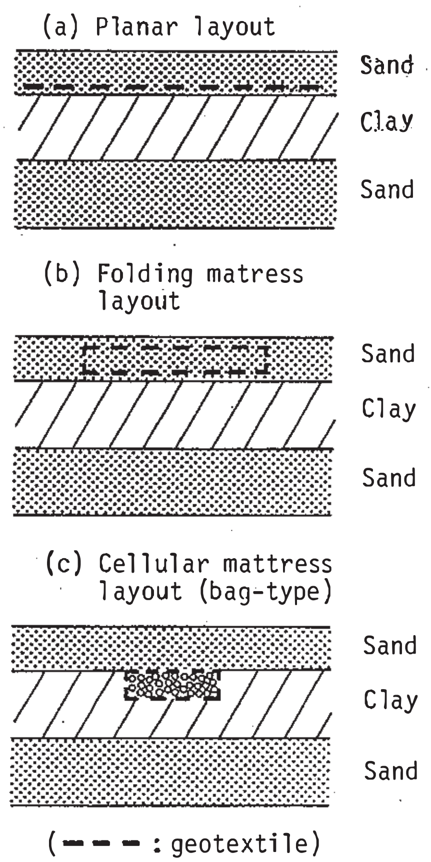


Fig. 1 Layout of geogrid

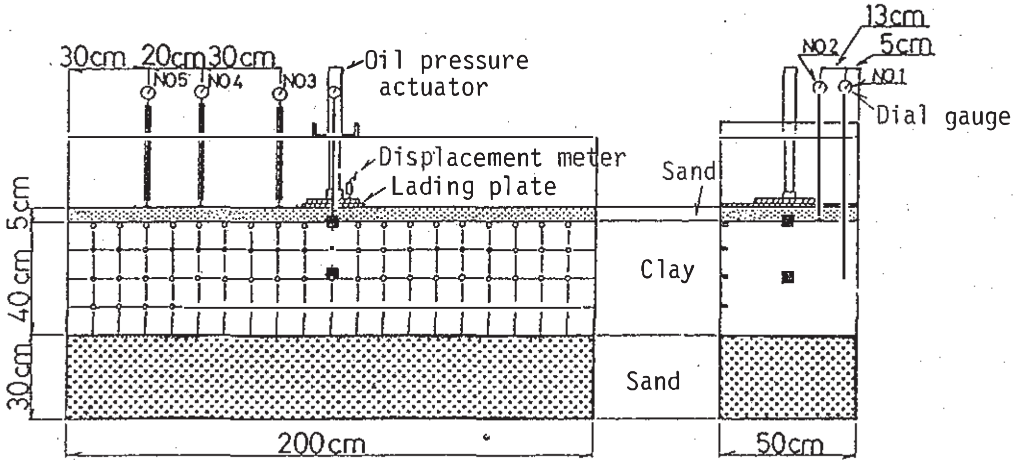
tests and 30 cm for some tests, respectively.

The loading procedure of each model test to simulate the soft ground whose surface was covered by the thin sand layer is shown in Fig. 3. The preconsolidation pressure with σ_{vo} = 0.1 kgf/cm^2 was applied to a model ground until 100% primary consolidation of clay was attained. Then, an incremental cyclic vertical pressure of $\Delta\sigma_v$ = 0.4 kgf/cm^2 or 0.1 kgf/cm^2 with the frequency of 0.1 Hz was applied to the surface of the ground through the oil-servo controlled bellofram cylinder. The number of load cycles was 130000 on the average. The strain gauge was attached to the geogrid and the earth pressure meters were instrumented among soil layers as was shown in Fig. 2.

The reconstituted Ariake clay with index properties of G_s = 2.49, W_L = 108%, I_P = 66 was used to produce the clay layer with 20 cm and 40 cm in height. The properties of sand in the upper and lower layers are listed in Table 2.

Table 2 Index properties of sand

	G_s	ρ_d (t/m^3)	D_r (%)
Upper sand	2.65	1.14	63
Lower sand	2.65	1.49	85



(■: pressure cell, o: marker)

Fig. 2 Model footing test apparatus

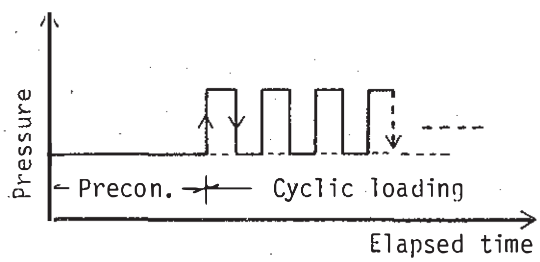


Fig. 3 Loading sequence

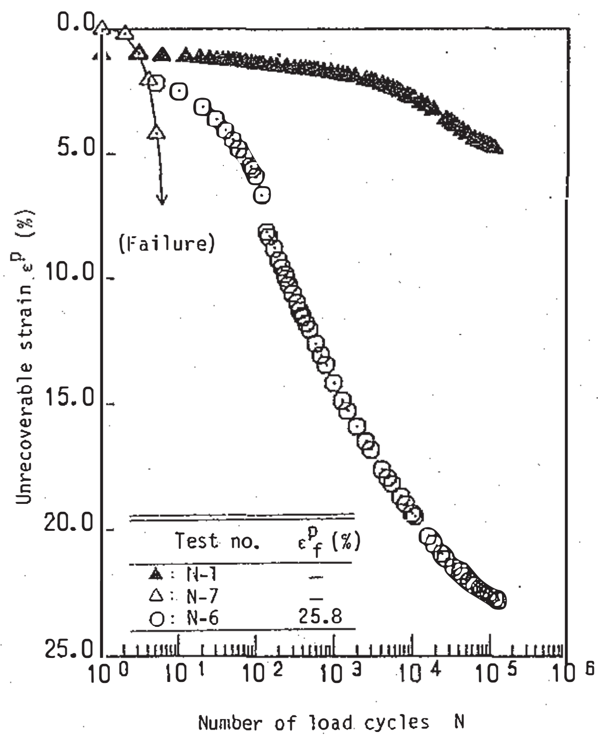


Fig. 4 Comparison of settlements under sustained and repeated loading

3 TEST RESULTS AND INTERPRETATION

Before starting discussion on the effects of geotextiles on stability and settlement of soft grounds, it is essential to illustrate the fundamental behaviour of clay grounds under cyclic loading without reinforcement and improvement. For this purpose, the first attempt was to run a model test on sand-clay ground without geotextiles.

Fig. 4 illustrates the settlement versus number of load cycles for this test. As can be seen from Fig. 4, the model ground (depth of clay layer is 40 cm) without reinforcement by geotextiles leaded to a complete failure at the number of load cycles of 15. Even in the case of a thin clay layer with 20 cm in depth, more eminent settlement was observed than in the case under static loading as also shown in Fig. 4 although this model ground was not completely failed. The settlement of the model ground under cyclic loading was approximately 5 times as the settlement under static loading as shown in Fig. 4. Those results from two tests without geotextile reinforcement indicate the necessity of reinforcement with geotextiles against settlement of soft grounds under cyclic loading, especially true is this on the ground whose clay layer is thicker compared with width of the loading plate in model tests.

3.1 Planar Layout of Geotextiles

It was indicated from the previous studies by Yamanouchi et al. (1967, 1970) and Yasuhara et al. (1986) that the use of geomesh was not effective to reduction of settlements of clay under cyclic loading though it was available for improvement of bearing capacity in soft grounds (Yamanouchi, 1967). This was made sure as well in the field test where the geomesh was placed by being combined with the quick-lime stabilisation (Yamanouchi et al., 1978).

To improve the defect of geomesh under this situation, the adaptation of geogrid has been attempted instead of geomesh by the laboratory model tests. Fig. 5

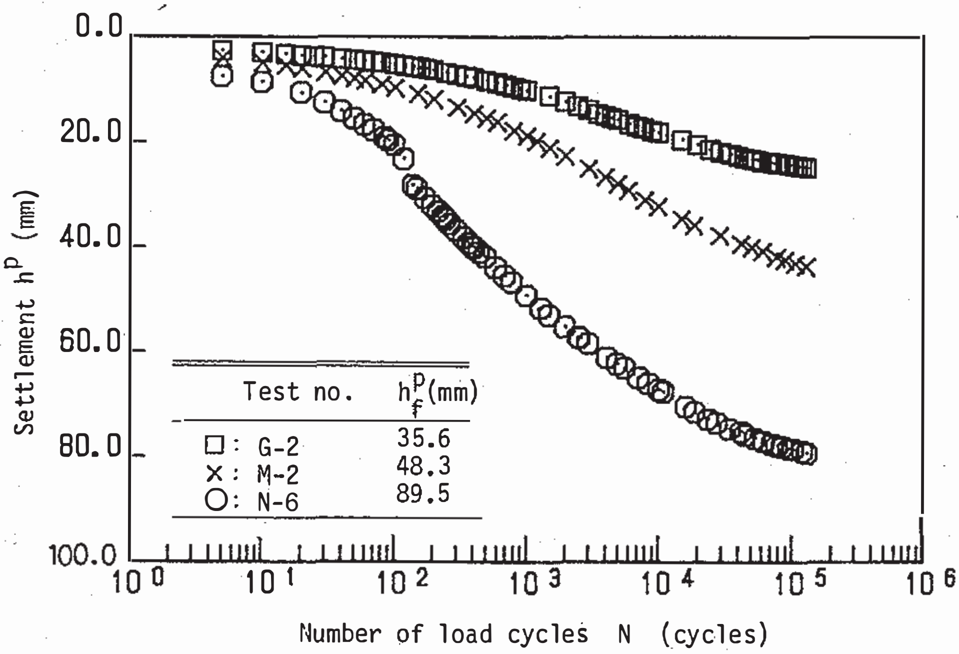


Fig. 5 Settlement versus number of load cycles relations with and without geotextiles

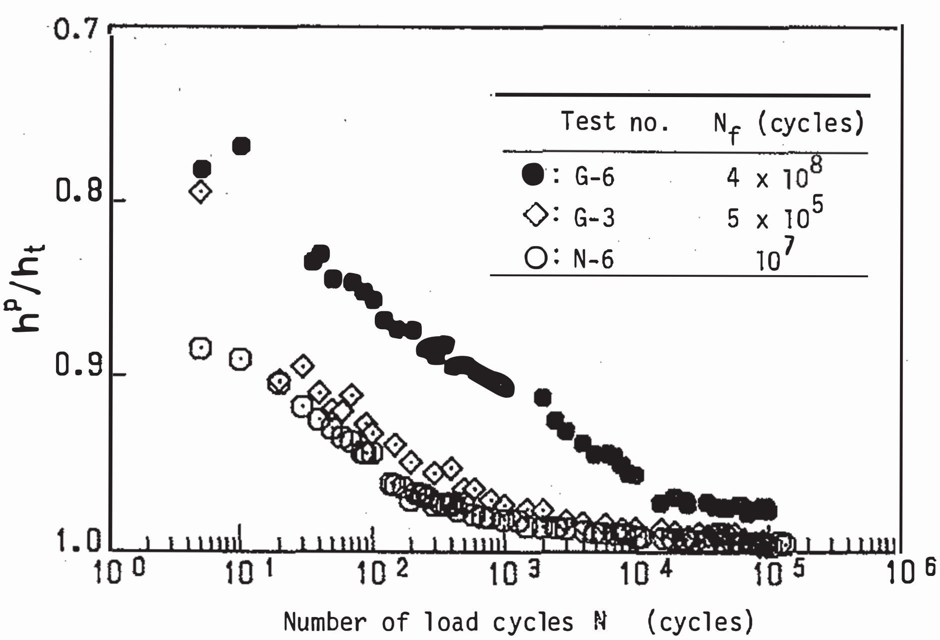


Fig. 6 Variations of settlement ratio with number of load cycles with and without geotextiles for extrapolation of final settlement under cyclic loading

illustrates the settlement versus time relations of model tests (20 cm clay layer and 17 cm sand layer) with non-geotextiles, geomesh and geogrid in order to compare the effect of geomesh and geogrid on reduction of clay settlement due to cyclic loading. Note that the converged displacement, h_f, under cyclic loading was determined by extrapolating the strain ratio, h^p/h_t (h^p, h_t: unrecoverable and total settlements, respectively) on each cycle versus number of load cycles relation as shown in Fig. 6. According to the final settlement determined by this procedure (Yasuhara, et al., 1983), it is pointed out from Fig. 5 that the geogrid is much useful for this purpose rather than the geomesh for settlement control.

As mentioned above, the difference of effectiveness between geomesh and geogrid may be derived from the fact that the larger pull-out resistance should be exerted between sand and geogrid than between sand and geomesh.

3.2 Cellular Layout of Geotextiles

The mattress foundation using the geogrid is expected to provide the effect of formation of the restraint layer among soils in addition to the effect of planar layout of geogrid for improvement of stability and compressibility of soft grounds. The reason for it is that the mattress foundation is possible to unify the reinforced area enclosed by the geogrid.

The characteristics of bearing capacity of modeled footing on sand reinforced by the cellular geogrid belonging to the mattress foundation were investigated by Fukuda et al. (1987). In the present study, in order to clarify the effect of mattress foundation on clay, the same type of test was carried out on the two layered model ground with folding mattress by geogrid which was placed among sand layer. This folding-mattress by geogrid was full of the sand inside. The results from the cyclic loading tests were illustrated in Fig. 7 to make sure of the difference in settlement versus time relations of model grounds reinforced with geogrid and folding geo-mattress. It is not obvious from Fig. 7 that the folding-mattress foundation should be the more desirable layout for controlling the settlement of clay-sand foundations under cyclic loading than the planar layout of a geogrid. A

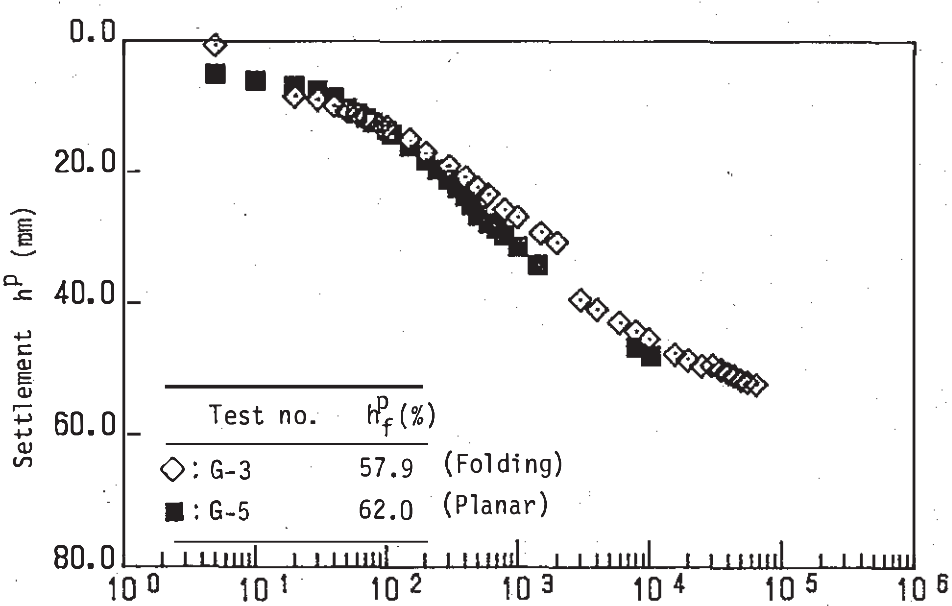


Fig. 7 Effect of planar and folding layout of geogrid on settlement versus number of load cycles relations

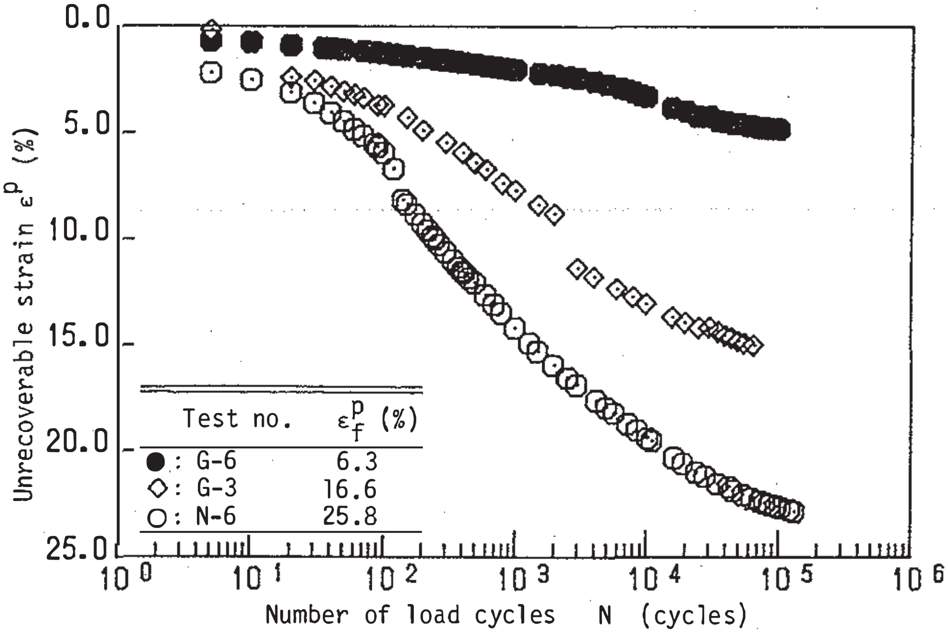


Fig. 8 Effect of mattress foundations on settlement versus number of load cycles relations

test was, therefore, added to simulate the another type of geo-mattress foundation which belongs to the cellular mattress, but is called the bag-type mattress in the current paper.

In comparison of the effect between folding geo-mattress and bag-type geo-mattress, the settlement versus time relations were shown in Fig. 8. The figure indicates that the bag-type or cellular mattress by geogrid takes advantage in reducing the settlements than the folding geo-mattress by polymer grid. This advantageous feature must be due to interlocking effect exerted between gravels and geogrid.

CONCLUSION

1) Geogrid is more useful to reduction of settlement of clay under cyclic loading than geomesh.
2) The cellular layout of geogrid takes more advantage in reducing the settlement of soft clay under cyclic loading than the planar layout.
3) The bag-type geo-mattress by polymer grid containing the gravels inside is most desirable for reducing the settlements of soft grounds. This effect must be due to the interlocking effect exerted between gravels and geogrid in the form of bag-type mattress.

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