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FIELD STUDIES OF THE BEHAVIOR OF GEOGRIDS AND VERY SOFT GROUND

ETUDES DE CHANTIER SUR LE COMPORTEMENT DE GEOGRILLES SUR UN SOL TRES MOU

FELDSTUDIEN ÜBER DAS VERHALTEN VON GEONETS UND SEHR WEICHEN BÖDEN

Polymernets are used to stabilize very soft ground. They are especially widely used to compensate for shortages in the bearing capacity of ground when filling earth is spreaded on it. However, the bearing capacity of soft ground including the effect of polymernets has not been clearly defined and estimation of bearing capacity factors (such as Nc) has been a problem for construction engineers. In an attempt to investigate the behavior of soft ground and the effect of polymernets, a field test was conducted at the test site. Measurements were made of the settlement of the banking fill, heave and lateral movements in the clay stratum, the strain and tensile stress on the polymernets during and after spreading the earth fill. Based on the analysis of these field measurements the behaviors of polymernets and very soft ground have been made clearer.

Polymernetz werden zur Stabilisierung eines sehr weichen Bodens verwendet. Sie werden besonders zur Ausgleichung von Mängel in der Tragfähigkeit des Erdbodens gebraucht, wenn darauf Füllerde gestreut wird. Die Tragfähigkeit von weichen Böden, darunter die Wirkung der Polymernetz wurde jedoch bisher nicht genau definiert und die Bewertung der Tragfähigkeits-Faktoren (wie z.B. Nc) ist für Bauingenieure ein Problem gewesen. Ein Baustellenversuch wurde am Bauort vorgenommen, um das Verhalten eines weichen Bodens und die Wirkung der Polymernetz zu untersuchen. Messungen wurden in der Setzung der Bankungsaufschüttung, in der horizontalen Sprungweite und Seitenbewegung der Tonschicht, und in der Belastung und Zugspannung der Polymernetz nach Streuung der Füllerde vorgenommen. Aufgrund der Auswertung dieser Feldmessungen wurde das Verhalten der Polymernetz und des sehr weichen Bodens verständlicher gemacht.

INTRODUCTION

Polymernets are being increasingly used in ground reinforcement, wherein they are installed on soft clay ground with covering earth spread or banked on them. In Japan, marine clay obtained by pump dredgers, is often used as land reclaiming material, and subsequently, the reclaimed land is almost immediately liquid after the reclamation work, possessing almost no load bearing capacity. To provide trafficability to such soft grounds, sandy soil is laid on them, but before the soft clay layer hardens sufficiently to be able to support the covering earth, they must be left several years, if no special treatment is given.

Polymernets are also finding increasing use as reinforcing material for installation on soft grounds with banking soil laid on them. Polymernets with sufficient tensile strength, prevent the banking soil from sinking into the soft clay layer and compensate for the lack of bearing capacity of the clay layer.

To select proper polymernets materials and to calculate bearing capacity in this application, Yamanouchi (1) proposed a practical formula for bearing strength, based on Terzaghi's continuous footing bearing capacity formula. This practical formula was obtained as a combination of the bearing capacity formula and model test results, but no generally agreed method for giving values to the various parameters used in the formula has been available so far. The authors considered the cause for the lack of such a method to be the following; 1) The difference between the actual behaviors of soft clay ground and polymernets at sites and their behavior under theoretical conditions assumed for analysis and model experiments, and 2) the scarcity of actual measured examples of the parameters involved in the formula obtained at actual work sites.

This report describes the behavior of the soft clay ground and the polymernets observed through field tests conducted under conditions that were made very close to the theoretical conditions and the model experiment conditions. Then, the values of the various parameters contained in the practical formula were obtained from the observed results, and the influence of changes in these parameters on the bearing capacity were examined.

GENERAL DESCRIPTION OF FIELD TEST

Site Characteristics

The field test was conducted on the reclaimed land in Fushiki-toyama harbor in Hokuriku, Japan, where silty clay pumped from the bottom of the neighboring sea by pump dredgers, was used as the land reclaiming material.

The experiment was conducted 3 month after completion of the reclamation work, and that time, the reclaimed land was so soft that it could not be walked upon.

Soil Profile

From the surface, the 8 m layer was clay with a 110 to 125 % moisture content. The original sand sea bed extended beneath. The ground water table was nearly at the same level with the surface of the reclaimed land.

Fig. 1 shows the result of the soil investigation made immediately before the site experiment.

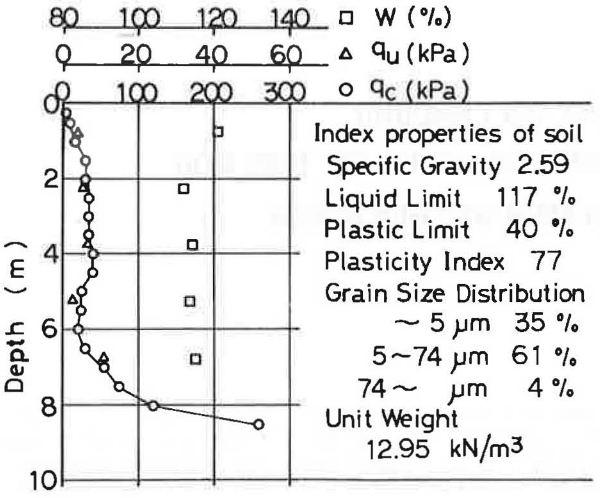

Fig. 1 Geotechnical profile at test site

Instrumentation and Earthwork

Fig. 2 shows the arrangement of the 14 settlement gauges, the 32 control stakes used to measure the lateral movement and the ground surface heave, the 21 strain gauges and 3 tension gauges for measuring the tensile stress of the polymernets.

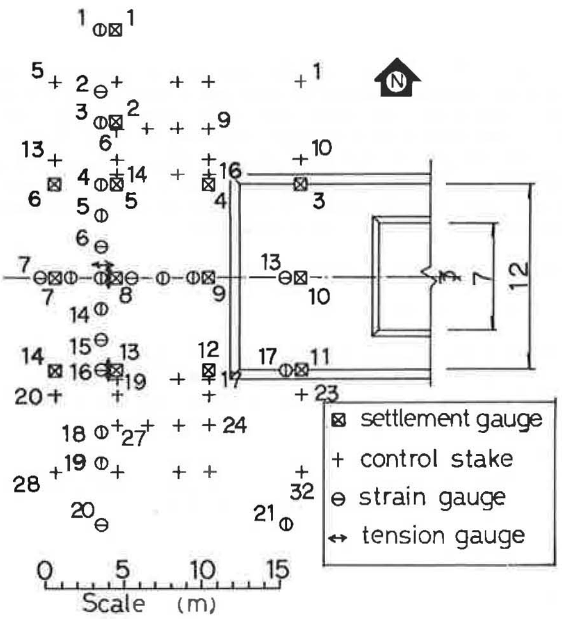

Fig. 2 Plan of test site

Polymernets with a 15 mm netting opening and a 6.9 kN/m yield strength were used for this experiment. The plan view of the polymernets is shown in Fig. 3.

The polymernets were laid on the reclaimed ground surface manually, and banking soil was spread over them in strips across the test site by 3.5 ton, low contact pressure type bulldozers.

The banking was in two layers, with the lower layer 12 m in the top width B_1 and 0.6 m in thickness H_1, and the second layer 7 m in the top width B_2 and 0.4 m in thickness H_2. The changes in the various values were measured in time series with the progress of the banking process.

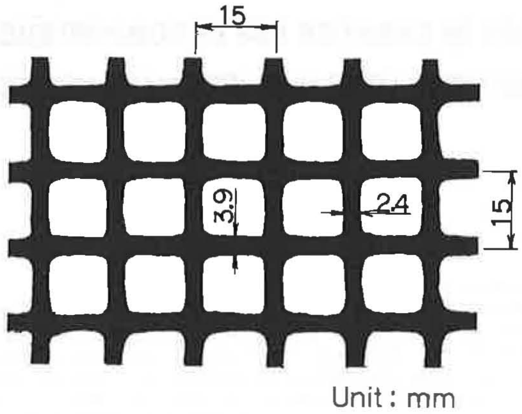

Fig. 3 Plan view of the polymernet

RESULT OF FIELD TEST

Settlement and Heave

Fig. 4 shows the readings of the settlement gauges (Nos. 7, 8, 9 and 10) installed on the center line of the banking. The distances of the settlement gauges from the end of the banking strip are taken along the abscissa to indicate the changes of the ground with the progress of the banking process. During the banking of the lower layer, the settlement gauge started to move as the banking front came within 15 m of it. As the banking front approached closer, the gauge showed high heaving until the maximum heaving was recorded immediately before or just as the advancing banking front moved past the gauge. The ground started to sink rapidly immediately after the banking soil was placed on it. The sinking depth stabilized when the advancing front of the banking went 4 m past the settlement gauge (Fig. 4a).

Fig. 4b shows the ground sinking conditions during the banking of the upper layer, with the final settlement height after the banking of the lower layer taken as the new "0" sink height. In this way, the sinking depths given in Fig. 4b may be taken as those solely caused by the weight of the upper layer. During the banking of the upper layer, almost no ground heaving occurred as the advancing banking front approached the settlement gauges. The reason for this may be that since the upper layer was lighter than the lower layer, the lower layer soil acted as an efficient counterbalance weight. After the banking front moved past the settlement gauges, the ground sank quite rapidly as with the lower layer. However, settlement stabilized when the banking front had advanced approximately 10 m past the gauges.

Fig. 5 summarizes the final ground contour along the north-south direction through the settlement gauges Nos. 7 through 10. The penetrating sink depth at the center line of the banking strip was 30 cm and 70 cm respectively after banking of the lower layer and the upper layer.

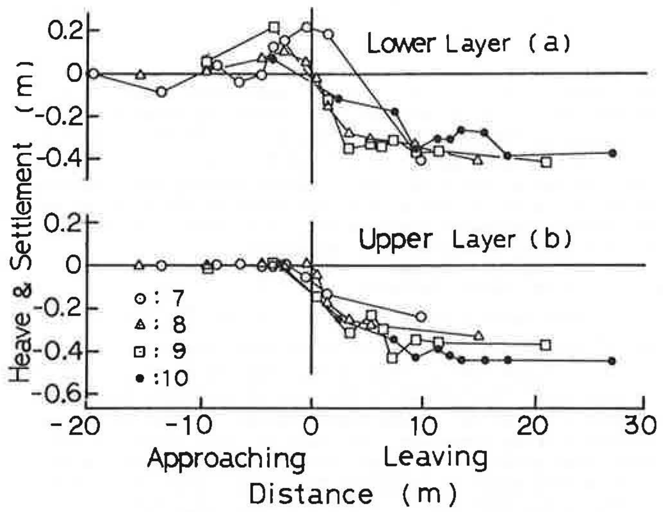

Fig. 4 Deformation of ground surface along E-W centerline

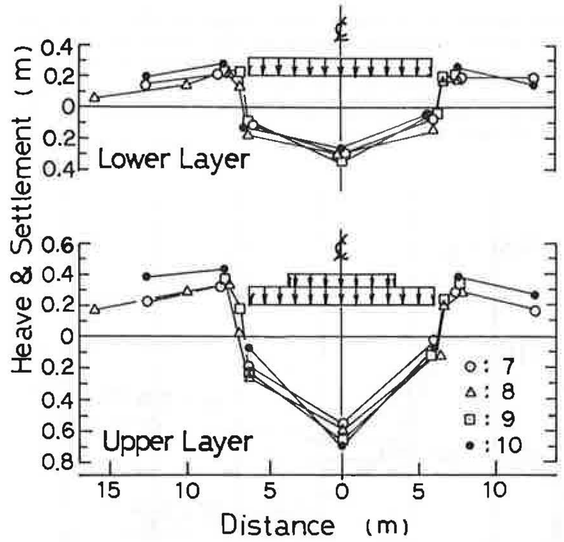

Fig. 5 Deformation of ground surface in N-S direction

Lateral Movement

Fig. 6 shows the horizontal displacement of the ground in the east-west direction during banking of the lower layer strip as measured at settlement gauges Nos. 3 through 14. The distances between the banking strip end and the respective measuring points are taken along the abscissa, as with Fig. 4.

Fig. 6 indicates that the clay in the surface layer of the reclaimed ground moves laterally, as if pushed out by the banking soil, with the displacement linearly increasing as the banking front approaches, until the peak was reached when the banking front came within 2 to 4 m.

Since both the lateral displacement and the sinking depth reached the maximum when the banking front came to points approximately 4 m from the measuring points, and doubtlessly, the settlement of the banking strip was caused by the lateral flow of the surface layer clay.

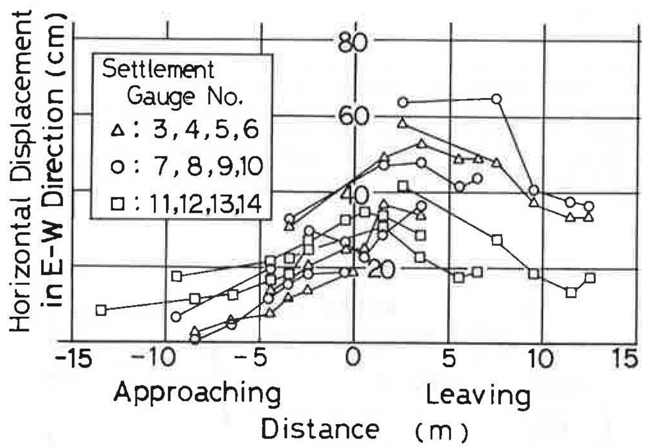

Fig. 6 Horizontal displacement in E-W direction

STUDY OF BEARING CAPACITY

Proposed Practical Formula

Yamanouchi, et al. proposed the following formula to calculate the ultimate bearing capacity of clay ground reinforced with polymernets (1), based on the Telzaghi bearing capacity theory;

$$q_D = \alpha \cdot c \cdot Nc + T\left(\frac{2\sin\theta}{B} + \frac{N_q}{R}\right) + \gamma' \cdot Df \cdot N_q \quad \cdots\cdots\cdots \quad (1)$$

where α : shape factor of footing
c : undrained shear strength of clay
Nc, N_q: bearing capacity factor
T : polymernet tensile stress
B : banking strip width
γ' : unit weight of clay
R, θ : coefficients given in Fig. 7

Fig. 7 schematically shows the banking load and the effect of polymernets as expressed by formula (1). The values of α, c, Nc, Nq, B and γ' can be determined on the basis of the shape of the banking strip and the soil properties of the clay ground, but the values of R, θ and T must be determined on the basis of the actual case history.

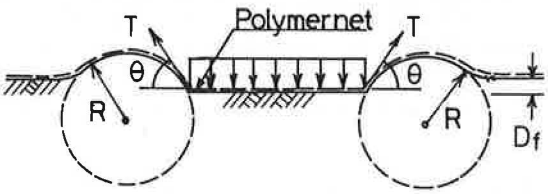

Fig. 7 Effect of polymernet

Measurement of R, θ and T

Fig. 8 shows the ground deformation in the north-south direction during the banking of the lower layer strip, as measured at settlement gauges Nos. 4, 5, 12 and 13. The values of R and θ as obtained from the deformation are entered in it. From these results, the mean values of R and θ for this site were obtained as R = 2.4 m and θ = 20°.

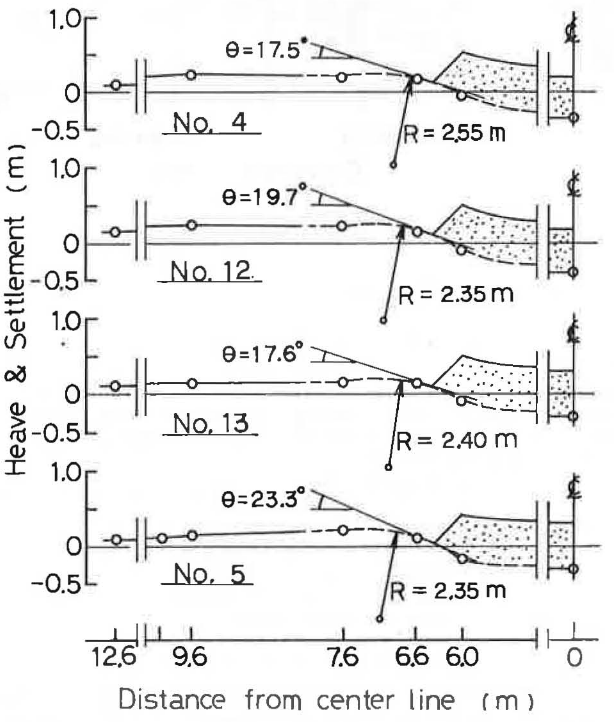

Fig. 8 Ground deformation and values of R and θ

Fig. 9 shows the tensile stress in the polymernets as calculated from their strain in the north-south direction. Although the readings of the strain gauges were also entered in the diagram, the readings of the tension gauges installed on the center line of the banking strip were not obtained because of the failure of the gauge. These readings indicate that the polymernet strain at the toes of the bank slope are in the order of 1.5 kN/m.

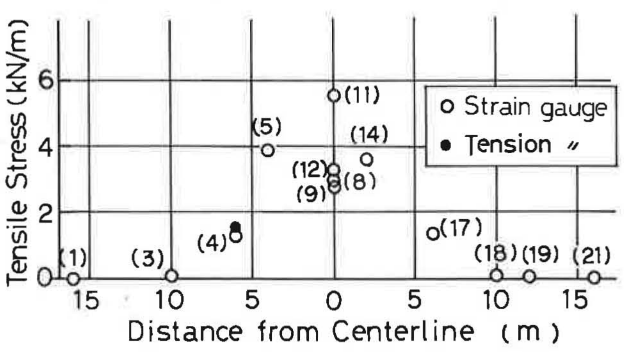

Fig. 9 Tensile stress in the polymernet in N-S direction

Value of Nc

Because the reclaimed ground consisted of clay (ϕ = 0°), the value of Nq = 1.0. On the other hand, Yamanouchi adopted Nc = 5.3 in Formula (1), which is between the two values proposed by Terzaghi (2), Nc = 5.14 (for continuous footing with smooth base) and Nc = 5.71 (for continuous fotting with rough base). Substituting the measured values of R, θ, T and Df for the lower banking strip and the undrained shear strength Cu = 1.67 kPa in Formula (1), the following Nc values are obtained:

General shear failure: Nc = 3

Local shear failure : Nc = 4.53 (Cu' = 2/3 Cu)

These values are substantially smaller than Nc = 5.3 proposed by Yamanouchi. This means that when the ground clay is very soft (Cu $\leq$ 2 kPa), the use of ordinary bearing capacity factor Nc values would result in overestimated ground bearing capacity. Therefore, when covering very soft clay ground with sandy soil, around 4.5 should be used as the bearing capacity factor Nc, also using 2/3·Cu as the undrained shear strength of the clay Cu'.

Evaluation of R and θ

The mean values of R and θ were respectively 2.4 m and 20°, and their measured values at the respective cross sections ranged between 2.35 and 2.55 m for R and 17.5 and 23.5° for θ. Therefore, the influence of the fluctuation of R and θ on the bearing capacity was studied and the results given in Fig. 10.

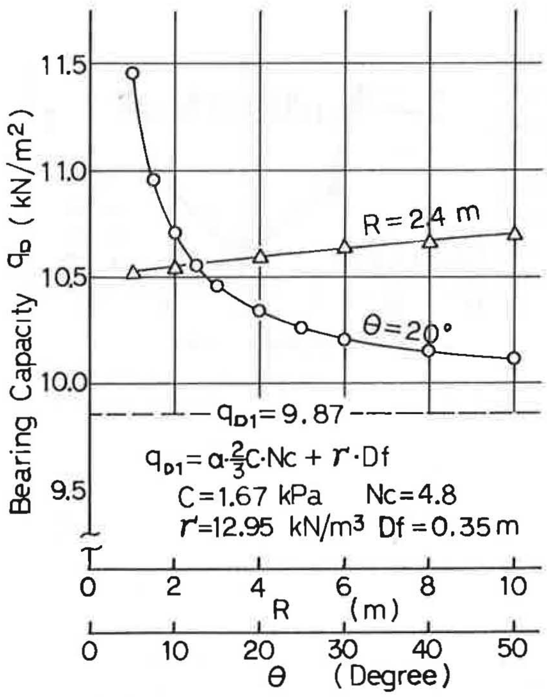

Fig. 10 Influence of fluctuation of R and θ on the bearing capacity

From the diagram, clearly, the bearing capacity reinforcing effect of polymernets in substantially influenced by fluctuations in R. Furthermore, bearing capacity fluctuation is notable where R is less than 3 m. From this, when calculating the bearing capacity of ground reinforced by polymernets with Formula (1), R = 3 m and $\theta = 20^{o}$ are considered to be appropriate values.

CONCLUSIONS

(1) During earth spreading, ground heave (40cm max.) was recorded within 20 meters of the spreading area.
(2) Ground heave in front of the fill during spreading of the second layer was negligible. This shows that the first layer fill with polymernets was effective in preventing ground heave caused by the second layer fill.
(3) Tensile stress produced within the polymernets was 2.9 kN/m at the center of the strip shaped bank and 1.5 kN/m at the toe of the slope of the bank.
(4) The bearing capacity factor (Nc) derived from this field test was 4.5, which is smaller than Terzaghi's value under local shear failure conditions.

REFERENCES

(1) Yamanouchi, T., e.a., "A Proposed Practical Formula of Bearing Capacity for Earthwork Method on Soft Clay Ground Using a Resinous Mesh", Technology Reports of the Kyushu University, Vol. 52, No. 3, 1979, pp.201-207. (in Japanese)
(2) Terzaghi, K., Theoretical Soil Mechanics, John Wiley & Sons, New York, 1943.