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Analytical method for geotextiles used for earth spreading work and applicability

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ABSTRACT: Experiment has confirmed that the geotextile used for any earth spreading work when a continuous load was applied on very soft clayey ground indicated a distribution of displacement that can be expressed by an ellipse. One experiment was done to clarify the upward pressure that was used to predict the geotextile displacement and the generating tension by numerical analysis using the pneumatic membrane theory. The result of numerical analysis for which measurements of the upward pressure in this experiment were used, agreed well with the result of the model test. Therefore, it is thought that the geotextile behavior analyzed by the pneumatic membrane theory has sufficient reliability for use.

1 INTRODUCTION

To clarify the interaction between the ground and the geotextile used for the earth spreading work on very soft clayey ground, an analytical method which regarded the geotextile as a membrane structure was proposed by the authors (Watari, et al, 1986) on the basis of results obtained from a model test. The following two assumptions were used for the analysis in this report:

(1) The displacement of the geotextile, when a continuous load is applied, can be approximated by an elliptic curve, and

(2) The upward load strength acting from the ground to the geotextile is proportional to the relative settlement from the maximum heaving point of the geotextile.

The assumptions were indicated by the model test and a back analysis of its results. Therefore, the validity had to be verified. This experimental model was first applied out in this research where the geotextile and ground materials were replaced by rubber-membrane and water models, respectively, to investigate the validity of the above assumptions. In this experiment, the deformed curve of the rubber membrane was measured three-dimensionally and, at the same time, the upward load acting on the rubber membrane was measured with open piezometers. Subsequently, the loading experiment was carried out by using cohesive materials instead of water and the influence of the cohesion and unit weight on the deformation of geotextile was investigated.

2 OUTLINE OF EXPERIMENT

2.1 Experimental Method

The soil vessel was 105 cm wide, 100 cm long, and 50 cm deep. The soil vessel was filled with water, then a 0.6-mm-thick rubber membrane was spread on the water surface with its four edges fixed to the side walls of the soil vessel. A continuous load was applied by sticking lead shot on a 10-cm-wide tape and adjusting the loading strength per unit area to 5 gf/cm^2. Three loads (5, 10, and 15 gf/cm^2) were applied by stacking these loads up to three steps.

The displacement of the rubber membrane due to load was determined by measuring the X, Y, and Z coordinates of lattice points prepared on the surface at 1.0-cm intervals.

Upward pressure acting on the rubber membrane was measured by five open piezometers mounted on the membrane. Measurement locations and loading locations are shown in Figure 1, and the experimental

scenes were as shown in Figure 2.
A watersoluble polymer (sodium carboxymethylcellulose, or CMC) and kaoline clay were used in place of water in the experiment using clay as the ground material. In this case, only the displacement of the rubber membrane was measured.

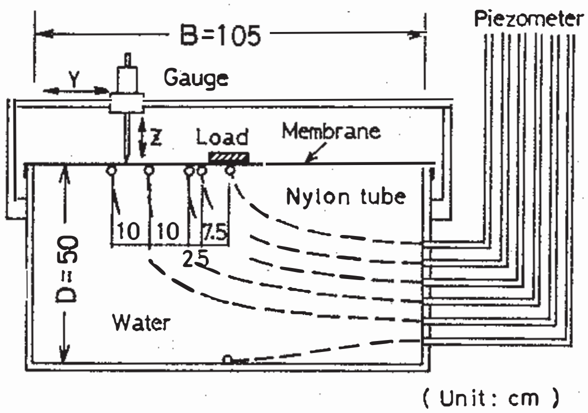

Fig. 1 Arrangements of model and measuring instruments

3 RESULTS AND DISCUSSION

3.1 Displacement of the Membrane

Figure 3 compares the measured displacement of the rubber membrane near the loading points with an elliptic curve approximating the measurements. The distance from the loading end to the point where the displacement of membrane surface became nearly constant was used as the major axis. The sum of respective maximum heaving and maximum settlement was used as the minor axis. As can be seen in Figure 3, the displacement measurements agreed well with the elliptic curve. So it can be assumed valid to approximate the displacement of a membrane surface by an elliptic curve.

Fig. 2 View of loading test

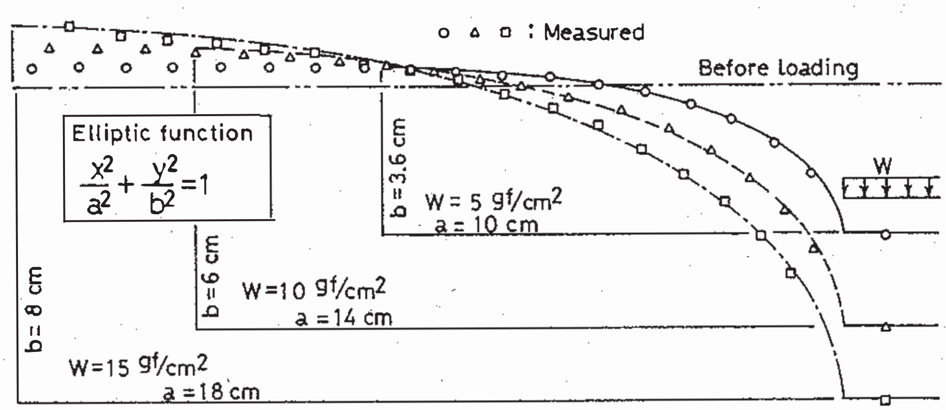

Fig. 3 Membrane displacement and elliptic curves under different load cases

3.2 Upward Pressure Acting on the Membrane

Figures 4 and 5 show changes in the displacement of the membrane surface and changes in the water level indicated on the open piezometers, when 5, 10 and 15 gf/cm^2 loads were applied. It can be verified from this figure that the water level indicated at each loading step agrees approximately with the maximum heaving height of the membrane. This result indicates that each location on the membrane surface is acted on by a pressure equal to the hydrostatic pressure where the relative displacement from the maximum heaving part of membrane surface is regarded as the water depth. Therefore, assumption (2) can be assumed to be valid.

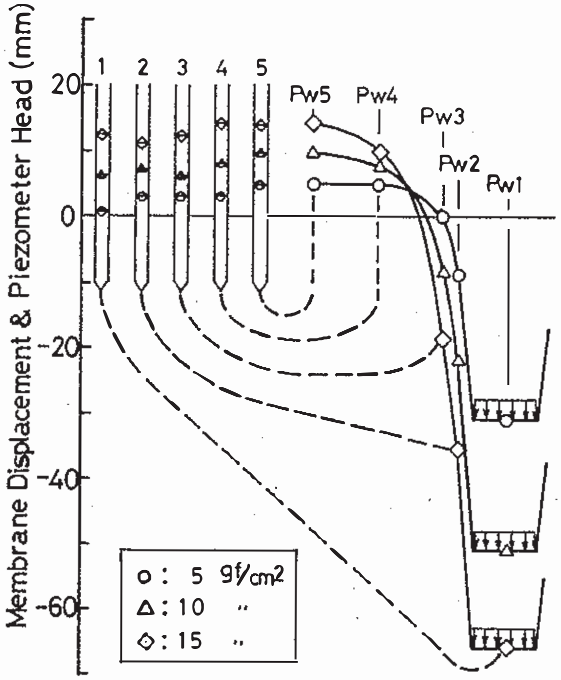

Fig. 4 Results of measurements

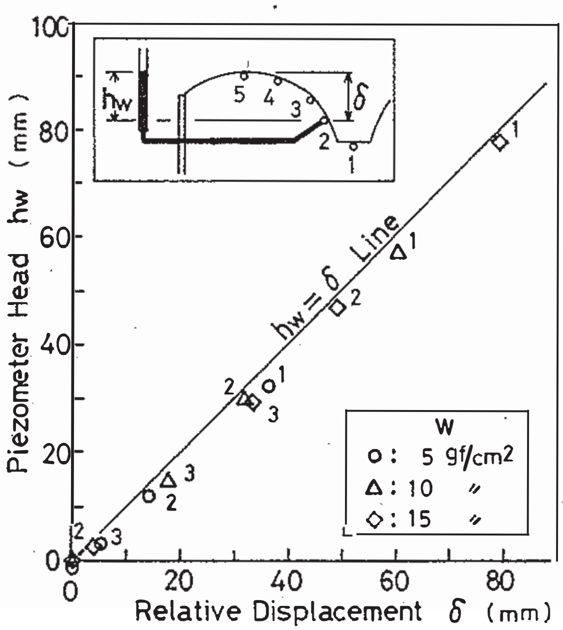

Fig. 5 Relation between relative displacement and piezometer head

4 NUMERICAL ANALYSIS BY COMPUTER

Numerical analysis of the deformation of the rubber membrane was done using measurements of hydrostatic pressure. The tensional rigidity of the membrane material (which was one of input constants used in the analysis) was determined by a tension test of the rubber membrane. The influence of the specimen's width on the tensional rigidity was investigated by changing the ratio of specimen's width to length (B/L) in the tension test. Figure 6 shows the results of the tension test. This figure shows that tensional rigidity is not influenced by the specimen's width. Further, a value of 1,000 gf/cm (corresponding to a measurement of 3% of tensile strain for the membrane material when 5 gf/cm^2 load was applied) was utilized from this figure as the value of tensional rigidity to be used for the analysis. Figure 7 compares the analyzed result with actual measurements: the values agreed very well over the entire membrane surface. This agreement shows that the pneumatic membrane theory can be applied to the deformation analysis of the geotextile.

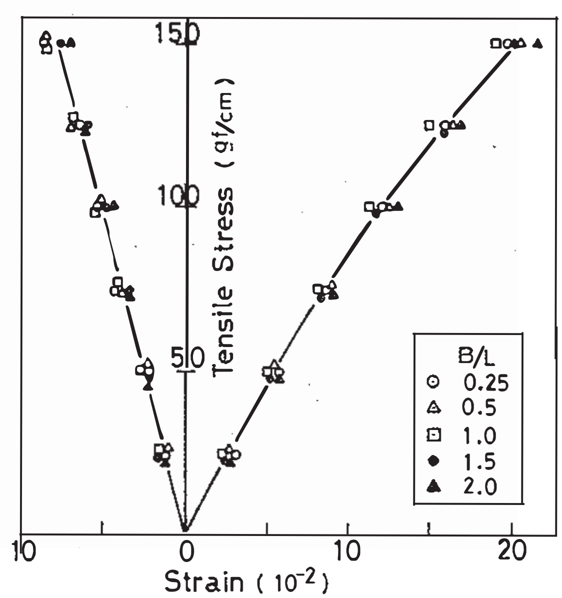

Fig. 6 Stress-strain curves of membrane

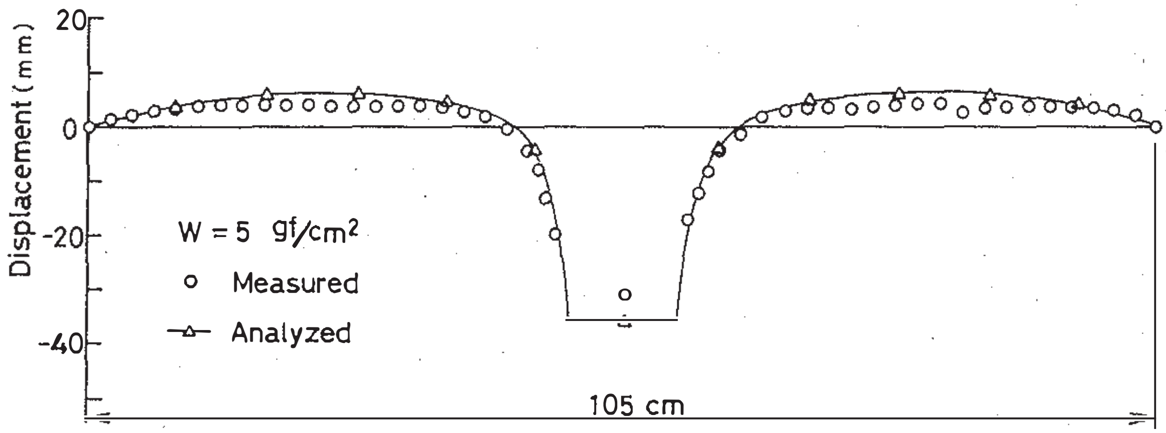

Fig. 7 Comparison of displacement between analysis result and measured values

5 LOADING EXPERIMENT ON COHESIVE GROUND

When water is used as the ground material, the ground cohesion, Cu, is zero. The geotextile behavior when the ground has some cohesion was investigated in the loading experiment using the materials shown in Table 1.

Table 1. Material properties

Material	Unit weight (gf/cm^3)	Cohesion (gf/cm^2)
Kaolin*	1.56	0.59
C.M.C.**	0.98	1.33

* Moisture content 75%
** Concentration 2%

Features of the ground materials used in the model are as follows:
1) The CMC water solution has a unit weight nearly equal to water but has a larger cohesion than water, and
2) The kaoline clay has a higher unit weight and larger cohesion than water.

In this connection, these cohesions were determined by measurements with the vane shear test.

Figure 8 shows the loading test results, including also the results using water. These indicate that both settlement of the loaded part and maximum heaving at the membrane surface decreased with the cohesion of the kaoline clay (and with increasing unit weight). This phenomenon is found in all experiments of loading strength. It is clear that the soil unit weight greatly influences the displacement of

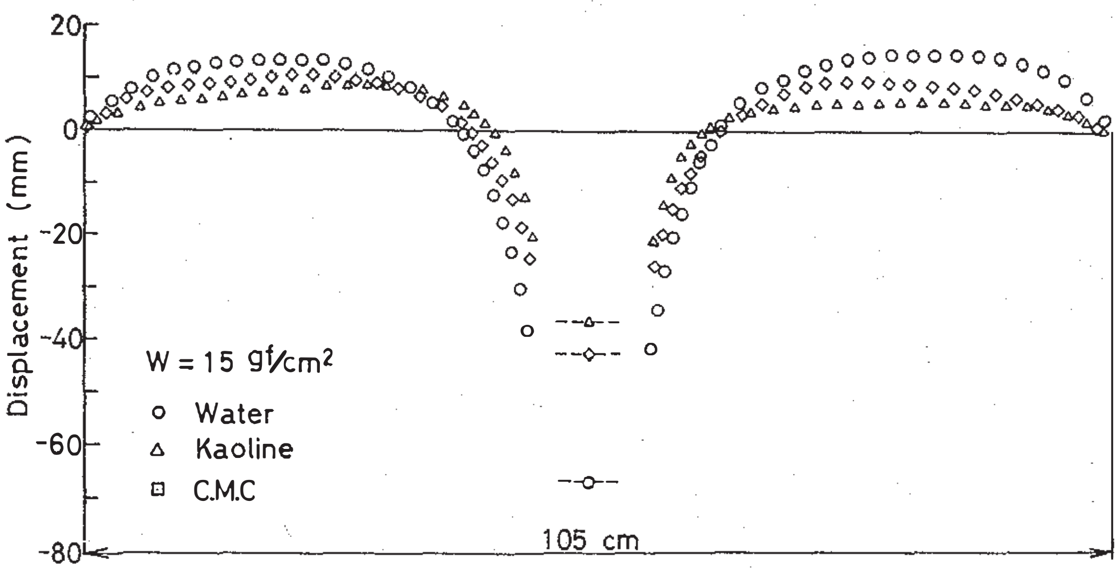

Fig. 8 Membrane displacement in the case of cohesive ground materials

geotextiles when the soil cohesion is small.

6 CONCLUSION

To analyze the behavior of a geotextile used for earth spreading work on very soft ground using the pneumatic membrane theory and to clarify the load acting on the geotextile, a series of experiments were carried out using a model. The conclusions derived from these results are as follows:

(1) The geotextile displacement near loading points agrees with an elliptic curve when a continuous load is applied.

(2) The upward pressure acting on the geotextile is proportional to the relative ground settlement from the maximum heaving part of the geotextile.

(3) The displacement of the geotextile is inversely proportional to the clay unit weight when the clay cohesion is small.

7 ACKNOWLEDGEMENT

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APPENDIX

ANALYTICAL METHOD FOR MEMBRANES

A deformation theory for a membrane surface can be systematized as a form of shell structures or suspension structures, with the basic formulas for a flat membrane surface being as follows.
The geometrical shape of an unstressed curved surface is defined by the following formula, for example an elliptical paraboloid shell, as shown in Figure 1:

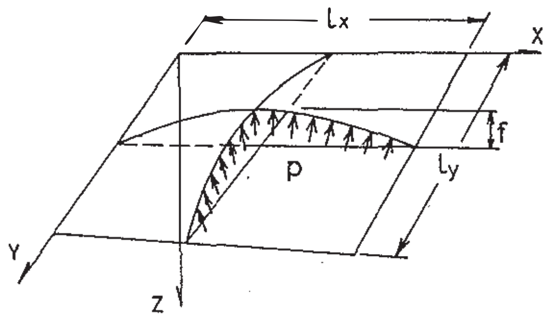

Fig. 1 Membrane surface expression

$$z = -16f(\xi - \xi^2)(\eta - \eta^2)$$

where

$$\xi = x/l_x, \eta = y/l_y$$

Expressing vertical displacement from the unstressed curved surface as when upward pressure is applied to the membrane surface, the following equations hold:

Equilibrium equation

$$H_x \frac{\partial^2}{\partial x^2}(z+w) + H_y \frac{\partial^2}{\partial y^2}(z+w) - p = 0$$

Elasticity law

$$H_x = \frac{E_x t_x}{2S_x - l_x}\left[-\int_0^{l_x} \frac{\partial^2 z}{\partial x^2} w\,dx + \frac{1}{2}\int_0^{l_x}\left(\frac{\partial w}{\partial x}\right)^2 dx\right]$$

$$H_y = \frac{E_y t_y}{2S_y - l_y}\left[-\int_0^{l_y} \frac{\partial^2 z}{\partial y^2} w\,dy + \frac{1}{2}\int_0^{l_y}\left(\frac{\partial w}{\partial y}\right)^2 dy\right]$$

By solving the above simultaneous equations, the displacement and the horizontal components H_x and H_y of membrane tension can be obtained. The symbols E , t and S represent Young's modulus of the membrane material, the membrane thickness and the initial length of the membrane, respectively. In addition, the analysis is based on the following conditions:

(1) As to the membrane material, the membrane surface has a large resistance against the tension in the fabric direction, with a linear relation between the tension and the strain, but a slight resistance against shearing force.

(2) Being nonlinear differential-integral of third degree, the fundamental equations necessitate numerical solution of nonlinear equations. However, judging from the slight influence due to neglecting the nonlinear terms in the case where the load is distributed on the overall membrane, the behavior may be taken as linear.

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