Behavior of geonet in Sand replacement method on very soft clay

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ABSTRACT: The sand replacement method reinforced by geonet is used for improving the trafficability in the temporary road construction on very soft clay. However, the replacement technique is based on the field experiences so that the theoretical consideration has been required to adapt the geonet. In this study, we have considered the mechanical behavior of the geonet on the very soft clay for proposing the design method and the execution management. And also, we show applied examples in several sites.

1 INTRODUCTION

Sand replacement is one of the road construction methods on the very soft clay. Its idea is very simple. Dumping the sand into the soft clay by force, it has an advantage to make a bearing stratum during a short time economically. Therefore it has been used for some time. However, there is a very strange phenomenon in the site. In spite of the road by this method was in existence on the soft clay yesterday, the road goes out of sight today. Workers in the site call it "ghost road" and are afraid of this phenomenon.

This method is based on the old technology, which is made up of senses and experiences. Therefore the sand shape does not uniform. It has been gradually decreasing because of the unreliable sand shape. In recent years, this method is new employed using the resinous mesh (Yasuhara & Tsukamoto, 1982). Hereafter, there is no ghost road phenomenon. After Yasuhara's study, we have improved this method with theoretical consideration. Then, we call it Geonet Replacement Method (GRM).

In this study, we show you the theoretical consideration of GRM and applied examples in the field.

2 GEONET REPLACEMENT METHOD

The outline of GRM is shown in Figure 1. Procedure to construct the road on the very soft clay ground is as follows:

(1) Put the geonets on the very soft ground with human power.
(2) Connect the geonets each other.
(3) Push out the sand on the geonet to one direction as smooth as possible by a little bulldozer.
(4) The sand's own weight forces the reclaimed clay to the both sides of the sand mass with plastic flow.
(5) Replace clay with sand.
(6) The sand passageway exists on the soft ground.

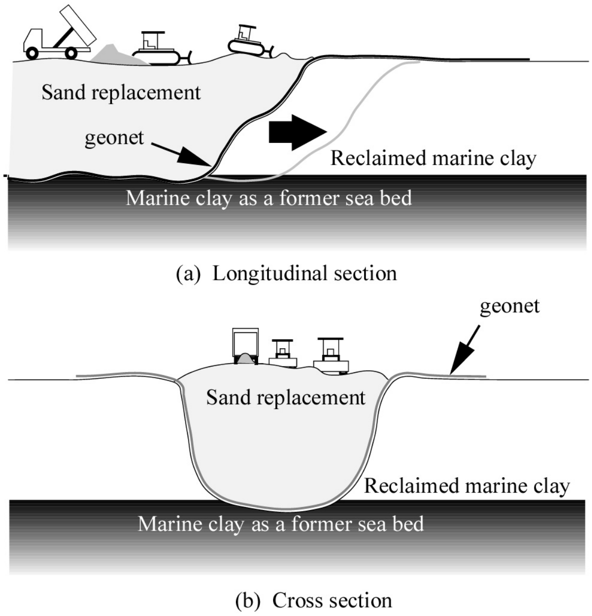

Figure 1. Geonet Replacement Method

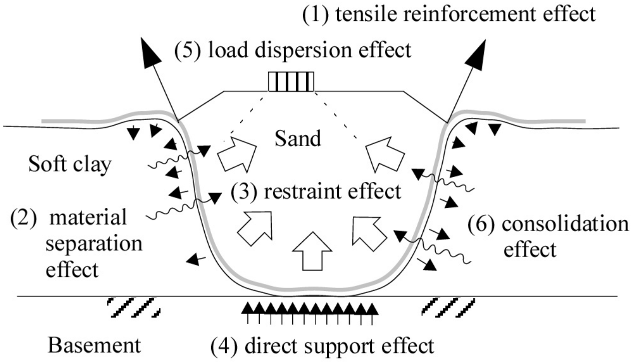

Figure 2. Effects of the geonet reinforcement

(7) Continue the dumping, the subsidence speed of the sand mass is gradually slower than before and finally steadies on the stiff ground and then quit the dumping.

Sheet-Net Method (SNM) needs to dump the sand with thin layer. Otherwise, GRM is better to dump the sand on a spot. SNM takes notice of the small deformation. GRM allows the large deformation and aims to slip into the soft ground with good shape.

Figure 2 shows the reinforcement effects of geonet in GRM.
There are six effects. These are tensile reinforcement effect, material separation effect, sand restraint effect, direct support effect on the stiff ground, load dispersion effect, and consolidation effect around the replaced sand.

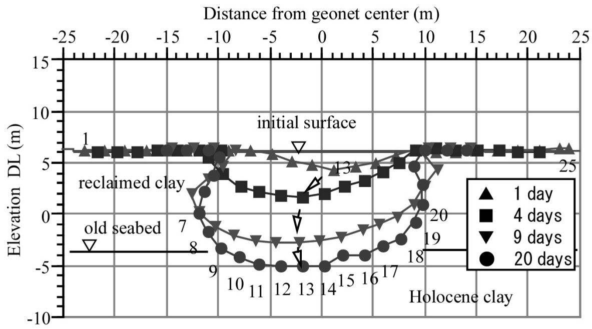

Figure 3. Monitored geonet deformation in the field test

3 PROPOSAL OF DESIGN METHOD

3.1 *View point of design*

GRM keeps the stable shape in the very soft clay to restrain the replaced sand mechanically. Required points to design GRM are as follows:
(1) Estimation of replaced sand volume
(2) Selection of geonet material
(3) Stability of sand mass on the stiff ground
Considering the GRM mechanism, important points are the replaced sand shape and geonet stress. Therefore, GRM can be designed by the deformation and tensile stress of geonet.

3.2 *Field test*

Field test was carried out on the dredged marine clay ground in man-made island of Hakata bay, Fukuoka City. Geotechnical properties are as follows. The undersea ground of these site consisted of Holocene deposit marine clay in 7 meters thick and Pleistocene deposit coarse sand in 10 meters thick, on the Tertiary sand stone and shale. The dredged clay has been reclaimed in 10 meters thick on these strata.
Figure 3 shows the subsidence locus of geonet in the dredged marine clay ground. The monitoring of the geonet was carried by Two Dimensional Deformation Meter (2DDM), which consists of piezometer and metal detector. 2DDM can measure the strainacting the geonet and its deformation (Imanishi et al, 1996). According to this figure, The geonet formed a hummock shape in the first stage and the sand mass subsides into the soft ground leaning toward the left side. In proportion to the sand load increasing, the bottom of the geonet subsides with a small extending vertically. However, the geonet deformation changes a hammock shape to an U-shape ditch form. Sand mass subsides into the soft ground keeping an U-shape ditch form. Finally, the replaced sand bottom stopped on 1.5 meters getting into Holocene deposit marine clay.

Tensile stress distribution during the execution of works is shown in Figure 4. When the subsidence is shallow, tensile stress occurred on all over the geonet, its magnitude is about 40 to 50 percentages of designed value. On the subsidence is deep, the tensile stress is not increasing more over. Finally, the tensile stress distributes like an isosceles triangle taking apex for the geonet center.

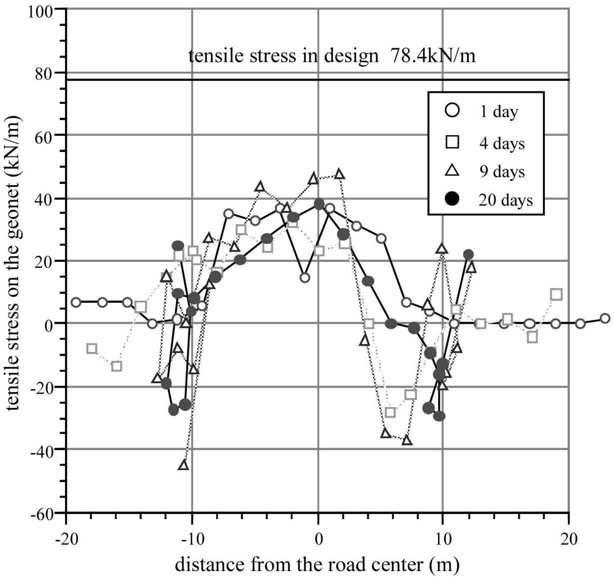

Figure 4. Tensile stress distribution on the geonet in the field test

3.3 *Equation of geonet deformation and stress distribution*

Based on field test that shows in former paragraph, we construct the model by using the mechanical balance on the geonet. Then, we have a fundamental equation to apply the design and the execution (Imanishi et al, 1998).

Figure 5 shows the balance condition for the geonet between the soft clay and the replaced sand. Modeling is based on the following assumptions: i) Geonet rigidity is ignored. ii) Subgrade reaction comes into existence and its magnitude follows the Winkler's Equation. iii) Uniform shear strength occurs between the geonet and the soft clay. iv) Consolidation of the soft clay is not under consideration.

Considering the unit width Δx, the tensile stress T_x at a point *A* required from the balance condition on the x-axis equals to the resultant force that is sum of the undrained shear strength between the geonet and the soft clay, and the tensile stress T_x' at a point *B*. Equation (1) can be obtained. And also, the tensile stress T_y at a point *A* required from the balance condition on the y-axis equals to the resultant force which is the sum of the undrained shear strength between the geonet and the soft clay, the tensile stress T_y' at a point *B*, the overburden load *q* on the geonet *AB* and the subgrade reaction *p*. Equation (2) can be obtained.

$$T_x' - T_x + c \cdot \Delta s \cdot \cos\theta = 0 \qquad (1)$$

$$T_y' - T_y + c \cdot \Delta s \cdot \sin\theta - q + p = 0 \qquad (2)$$

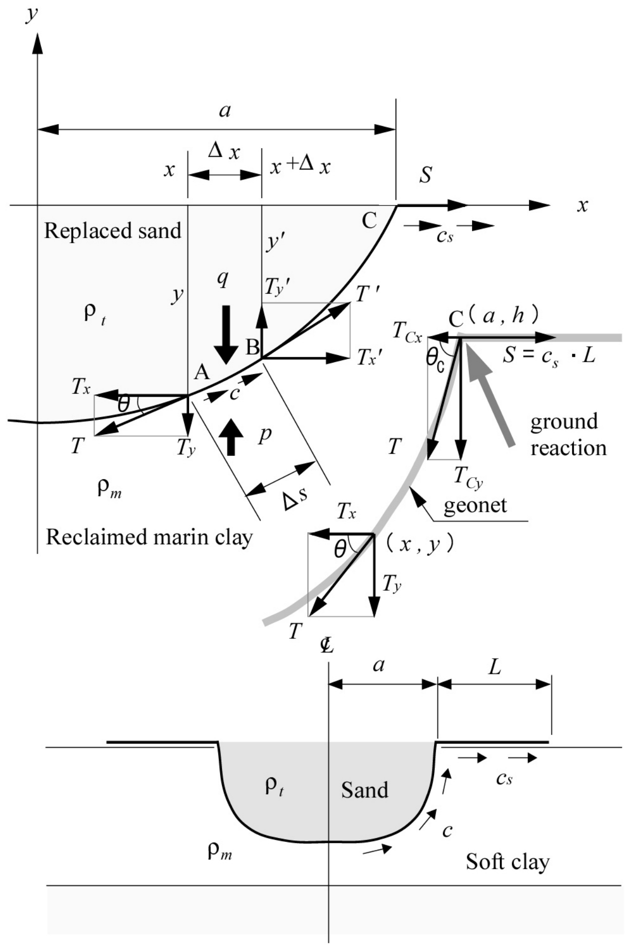

Figure 5. Balance condition of the geonet

Establishing a differential equation from Equation (1) and (2), finally, we obtain the basic differential equation of the geonet deformation.

$$\frac{d^2 y}{dx^2} - k^2 \cdot y = 0 \tag{3}$$

We define k as follows,

$$k = \sqrt{\frac{(\rho_t - \rho_w) \cdot g - K}{n_1 \cdot c_s \cdot L + n_2 \cdot c \cdot a}} \tag{4}$$

where $0 \leqq n_1 \leqq 1,\ 0 \leqq n_2 \leqq 1$

We call n_1, n_2 tensile coefficients, and define them as unrelated constant to *x*. We can solve Equation (3) as an approximation easily. The geonet deformation solution is indicated as follows,

$$y = \frac{h}{e^{k \cdot a} + e^{-k \cdot a}} \left(e^{k \cdot x} + e^{-k \cdot x} \right) \tag{5}$$

Hence, integrating Equation (5) from x = -a to +a, we obtain the replaced sand volume. Furthermore, the stability of sand mass can consider by the bearing theory. The geonet tensile stress can be obtained on the leading process of Equation (3). The equation of the tensile stress is as follows,

$$T = \frac{T_x}{\cos\theta} = \frac{c_s \cdot L \cdot \cos\theta_C + c \cdot (a - x)}{\cos\theta} \qquad \bullet(6)$$

The maximum tensile stress on the geonet is sum of the maximum value of the first member and that of the second member in Equation (6). Considering the balance condition in Figure 5, when $0 \leqq x \leqq a$, the maximum value of the first member becomes $c_s \cdot L$, and the second one becomes $c \cdot a$. Therefore, the maximum tensile stress is as follows,

$$T_{\max} = c_s \cdot L + c \cdot a \qquad (7)$$

The geonet must select the material that has the tensile strength exceeds Equation (7).

4 PROPOSAL OF THE EXECUTION MANAGEMENT

Execution management controls the quality along the specification for the design. However, many troubles occur in the construction site, control point must be expected not too many and easy. The most important point to control GRM is the figure management. The tensile stress is also an important point. But its measurement has much dispersion in the data. It is not appropriate as a control point. If the geonet shape can be controlled, the stability of sand mass can also be under control.

The most stable shape of sand mass is a rectangle in the cross section. This is the case that the tensile stress at a point *C* on the geonet in Figure 5 is zero, and the undrained shear strength in soft clay is zero. The soft clay ground has cohesion. The geonet shape becomes an U-shape ditch form. But for the heterogeneous and the uneven ground and the different shear strength along the depth, the sand mass is not necessarily symmetrical. Figure 3 shows this phenomenon. According to the observation at the site, it is found that the balance of the geonet length on the soft ground surface causes this phenomenon. The geonet of both sides are the same length, the sand mass is symmetrical. But, one side geonet length is longer than the other side. It is not symmetrical. The sand volume on both sides is not the same for the reason of losing the tensile stress balance of both sides. This phenomenon can be verified by Equation (6).

From the above mentioned, the execution process to make a symmetrical shape like a U-shape ditch form is as follows:

(1) When the dumping starts, both sides of geonet on the soft clay ground keep controlling the same length.

(2) If the one side does not slip into the soft ground against the other side, the geonet slipping side does not subside sufficiently, the extra dumping should be done in the slipping side.

(3) In that case, the extension of the geonet is needed to the slipping side.

(4) When the geonet bottom reaches on the stiff ground under the soft ground, both ends of the geonet role up toward the geonet center, and cutting the friction between the geonet and the soft clay ground.

(5) Finally, the subsidence of the sand mass comes to a stop.

The most important point is the understanding the under ground phenomenon through the observation at the site.

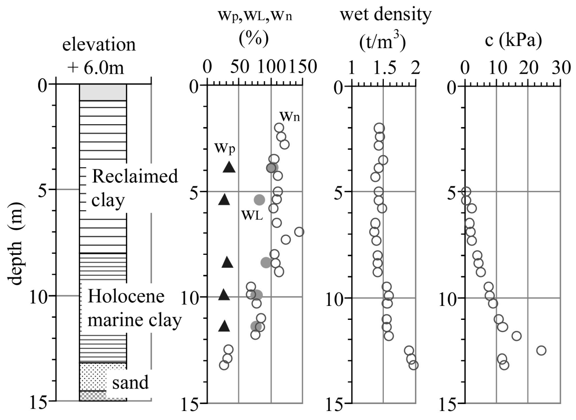

Figure 6. Geotechnical condition in the reclaimed land

5 APPLICATION TO THE FIELD

5.1 *Shape of the sand mass and tensile stress on the geonet*

We applied GRM to another reclaimed land. The geotechnical condition shows in Figure 6.

Figures 7 and 8 show the shape of the sand mass and the tensile stress on the geonet. In this site, the sand mass shape was confirmed by boring. The strain gages checked the tensile stress on the geonet.

In the Case-1, The sand mass is symmetrical and the calculation result fits to the measured result. The measured tensile stress distribution has a small dispersion. The magnitude of the maximum stress is approximately the same.

In the Case-2, The sand mass is inclined to the left hand. The subsidence stops at the 11th day after the dumping starts. For this instance, the slipping of the right side geonet is larger than the left side. The extension of the right side geonet was done on the halfway. The tensile stress in the right side is larger than the left side due to the extension.

Figure 9 shows the shape of the geonet from birds view in Case-3. It is found that the geonet seems to be an U-shape ditch form.

5.2 *Consolidation effect around the sand mass*

Figure 10 shows the test points of CPT beside the sand mass and core sampling under the sand mass in Case-3.

(1) *Side part of the sand mass*
Figure 11 shows the result of the CPT to check the consolidation effect beside the sand mass. CPT was done at 3.5 meters and 8.5 meters from the sand mass side. It is found that the 3.5 meters clay can be improved twice as large as the original clay strength. But, the 8.5 meters clay cannot be improved so much.

(2) *Lower part of the sand mass*
Figure 12 shows the result of the laboratory test to check the consolidation effect under the sand mass. The 1.2 meters clay in thickness under the sand mass is influenced by the consolidation effect. Furthermore, in the 0.8 meters clay in thickness, the consolidation seems to finish. Its cohesion is twice as large as the original clay strength as well.

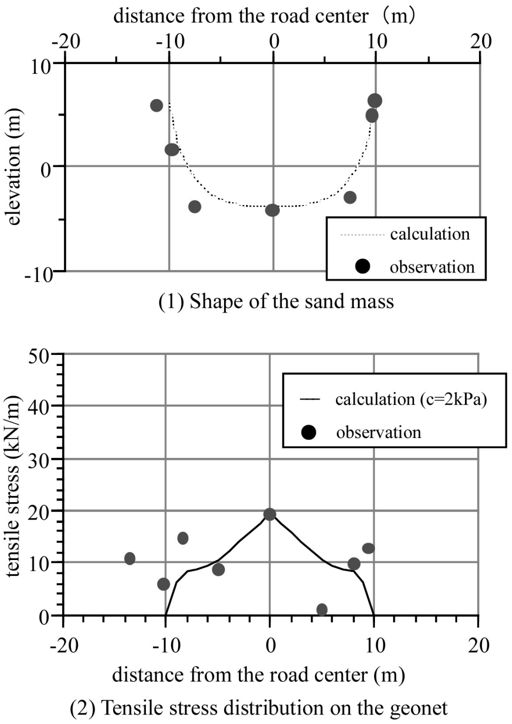

Figure 7. Geonet behavior in Case-1

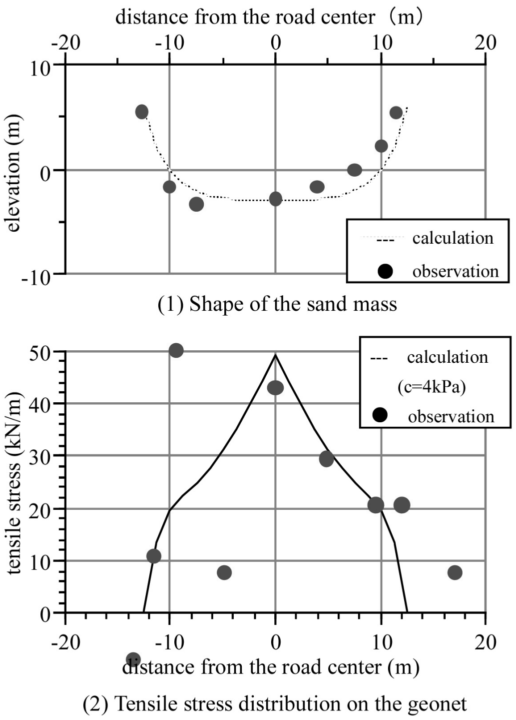

Figure 8. Geonet behavior in Case-2

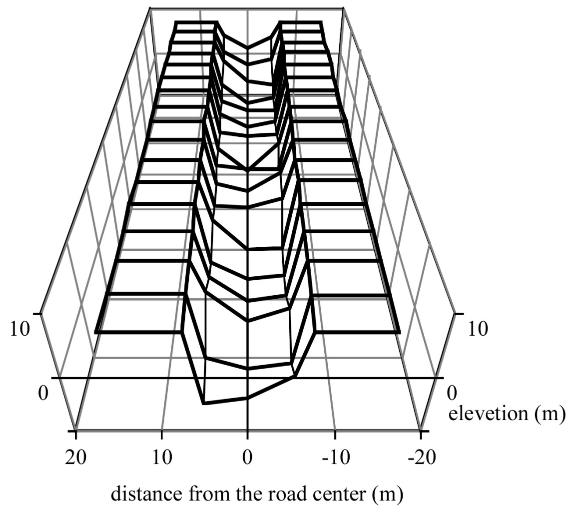

Figure 9. The U-shape ditch form in Case-3

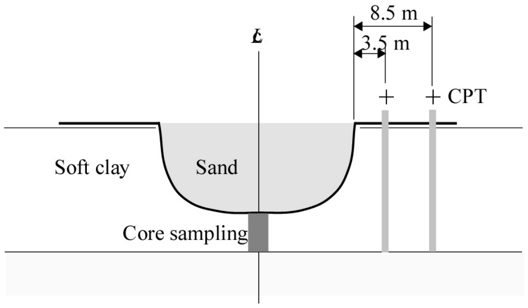

Figure 10. Test points in the field in Case-3

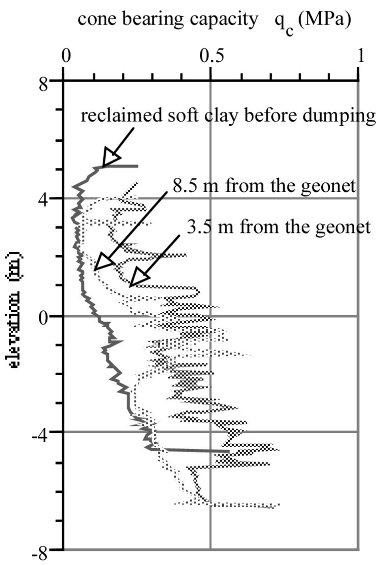

Figure 11. Consolidation effect beside the sand mass

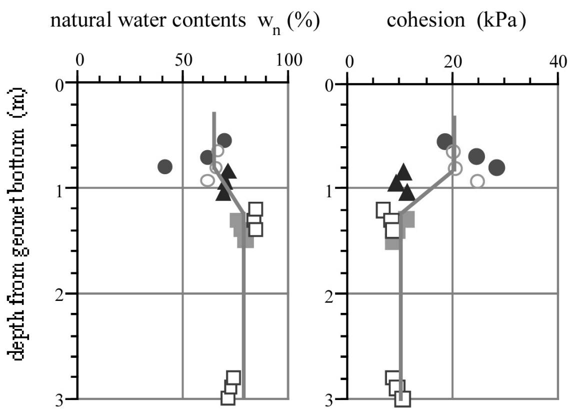

Figure 12. Consolidation effect under the sand mass

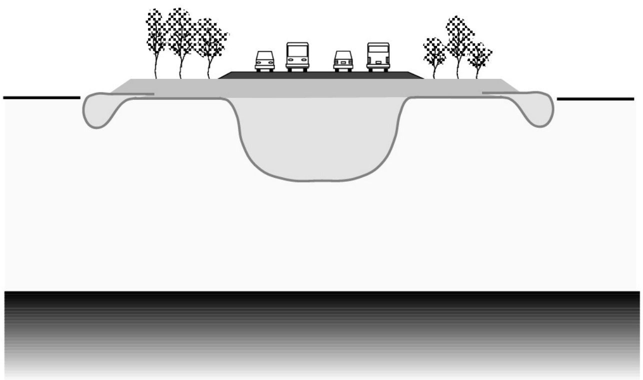

Figure 13. Floating artificial ground on the very soft clay

6 CONCLUSIONS

From above considerations, the following conclusions can be drawn:

(1) According to the field test, sand mass subsides into the soft ground keeping an U-shape ditch form. The tensile stress distributes like an isosceles triangle taking apex for the geonet center.
(2) GRM can be designed by the deformation and the tensile stress of the geonet.
(3) The geonet equation forms the homogeneous second-order linear differential equation simply.
(4) The deformation of the geonet is indicated by the exponential function according to the tensile coefficients n_1, n_2. The maximum tensile stress is also obtained.
(5) The most important point to control GRM is the figure management.
(6) We applied GRM to the several sites. The calculation results fit to the measured results.
(7) We verified the consolidation effect.

7 PROSPECT OF GRM

The strong point of GRM is constructing the soil structure such as the road easily and economically with short period on the very soft ground, which has the water content exceeded the liquid limit. Furthermore, we have an idea in Figure 13. Resistance of the geonet both ends keep constant.

Making use of the consolidation effect and lightweight material, we think the floating artificial ground can be constructed on the very thick soft clay ground. This is the new use of the geonet to revive the old technology.

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