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A Rapid Banking Method Using the Resinous Mesh on a Soft Reclaimed Land

Méthode de remblayage rapide utilisant le filet résineux sur le terrain mou remblayé

A case history of the rapid embankment for the highway on the extremely soft reclaimed land was successfully performed by spreading the resinous mesh over the ground. The mesh has been hitherto employed as a sort of the bamboo method. The broad embankment for the reclaimed land should have been slowly filled up without any remolding of the ground. Therefore, the mesh has played a role as the restrained layer exerted between the embankment and the ground to reinforce the earth. The main scope of the present case history is, in contrast with the conventional use, to carry out the rapid displacement of the extremely soft soil into the transported soil. Different from the forced displacement without any kind of geotextiles, in this case, the ultimate settling and spreading of embankment do not develope unlimitedly because of restrainment of the resinous mesh. Resultantly, the two layered ground forms the natural pattern of the foundation. Consequently, the current banking method is characterized by the possibility of the rapid and economical embankment using the ordinary construction machines.

Un cas de remblayage rapide pour la route sur le terrain extremement mou a été effectué, en posant le filet résineux sur le terrain. Jusqu'à présent, le filet résineux était utilisé comme une sorte de "méthod de bamboo". Dans la méthode habituelle, le remblai vaste pour le terrain de remblayage devait être entassé lentement sans aucun rebuttage de terrain. Par conséquent, le filet jouait un rôle comme couche restreinte entre remblai et terrain pour renfocer le sol. En contraste avec l'usage conventionnel, le présent cas de remblayage a pour but pricipal deffectuer le déplacement force rapide de sol extrêmement mou par le sol transporté, en plus de l'acquisition de la facilité de circulation des machines de construction. A la difference du déplacement forcé sans géotextile, dans le présent cas, l'affaissement illimité de remblai ne s'est pas developpe a cause de la restriction de la couche de borne par le filet résineux. Il en résulte que le terrain à deux couches a formé le type naturel de la foundation. En conséquence, la présente méthode de remblayage se caractérise par la possibilité d'un remblayage rapide et économique utilisant les machines ordinaires de construction.

1 INTRODUCTION

Recently in Japan, the reclaimed land has been very rapidly constructed near the shore because of the economical demand. The reclaimed lands for every use have been increased up to about 540 million m^2 since 1960. Most of them consist of the extremely soft clay soil which is transported from the off-shore by the dredger and is sedimented.

For requirement of the site of near-shore structures such as the factory, the storage facility and the electric power plant, there have been built the stable structures whose surface layer of the soft ground is improved into the rigid plate by means of cement or lime stabilization. Besides, the geotextiles such as the permeable cloth and the resinous mesh treated in the paper have been prevailed to fulfill its function as the restrained layer in the ground, while the design procedure for stabilzing the surface layer of soft grounds and the mechanism of the interaction between soil and geotextile have not completely been known.

The aim of this paper is to present a case history where the displacement method using the resinous mesh on the extremely soft reclaimed land is employed for the road embankment. Also, the reasonable and economical design procedure is proposed on the basis of the results of model footing tests and field earthworks.

2 CONCEPT OF EARTHWORK METHOD USING RESINOUS MESH

2.1 Conventional Use of Resinous Mesh

The effectiveness of a resinous mesh for earthworks on soft grounds has been continuously explained at laboratory and at field by Yamanouchi (1967, 1970, 1975, 1980). The principle of the earthwork method using the resinous mesh is almost the same as the fascine work which had been practiced from old times. Yamanouchi has proved that the resinous mesh is available for preventing from the penetration of subbase materials into the subgrades, the pumping up and the deflection of the pavement. At the present time, in addition to these uses, the mesh is used jointly with the other stabilizing method, for instance, sand drain, for the purpose of the improvement of not only the surface but also the depth in soft grounds. The conceptual description of the difference in these methods is illustrated in Fig. 1.

It can be suggested from past experiences that the method using the resinous mesh for improving the vast reclaimed land is classified as follows :

(1) Belt-like embankment for highway ($B/D < 2 \sim 3$)
(2) Over-spreading earth for construction of the extensive site ($B/D > 2 \sim 3$)

where B : the width of embankment, D : the depth in stabilized layer. Most of the case histories where the mesh has been utilized until the present time belong to the category of the case (2). Since even in the case (1) the placement of the resinous mesh is done on the basis of the same idea, the post-construction settlement due to consolidation of soft clay beneath the stabilized layer continues over the long term period. Hence, for embankment on soft grounds where the field condition fits in with the case (1), the forced displacement method using the resinous mesh which is described in the present

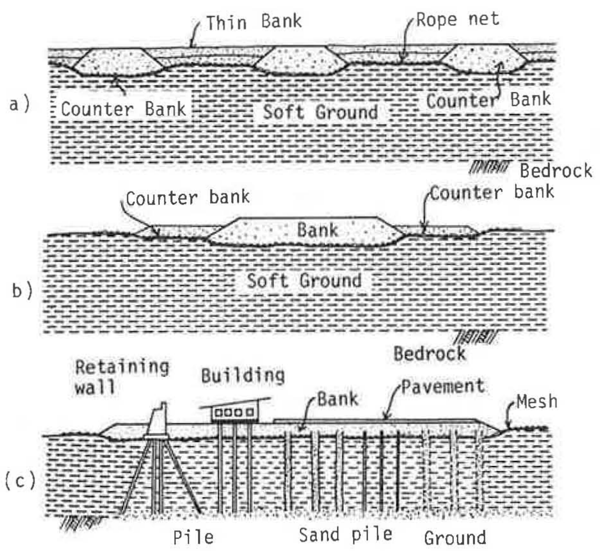


Fig. 1 Examples of earth reinforcement using resinous mesh

paper will be recommended in order to decrease the post-construction settlement of soft ground as little as possible.

2.2 New Banking Method using Resinous Mesh

There is shown in Fig. 2 the typical ground section where the resinous mesh is spreaded over the soft ground for the surface stabilization. In laying the mesh over the minimum area of the surface of ground, the subsoil is replaced by as much the banking soil as possible, by taking advantage of the temporary decrease of the bearing capacity of the ground due to remolding. Thus, the efficient displacement will be attained and the reasonable layered ground is formed as shown in Fig. 3 since the tensile force of the mesh itself and the restrained effect among the mesh, the banking soil and the soft soil is exerted sufficiently.

The above-mentioned method is characterized by the advantageous features as follows :

1) Since clay or silt layer is decreased by the displacement, we can minimize the post-construction settlement.

2) Stress developed by traffic loads is smoothly distributed because of the rigidity and the homogeneity of the fill material.

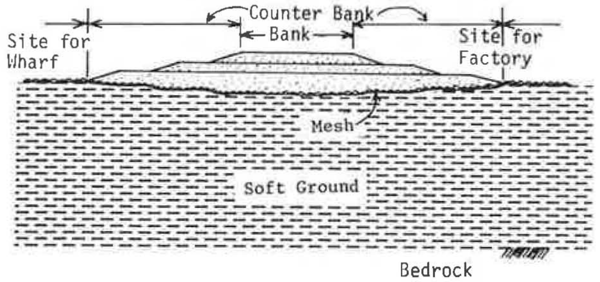


Fig. 2 Conventional earthwork method using resinous mesh

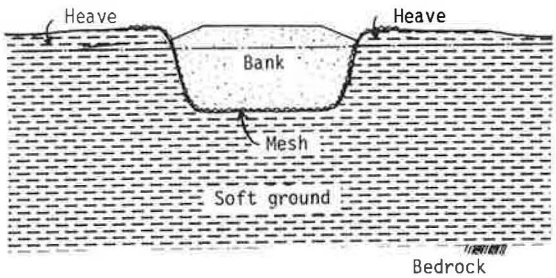


Fig. 3 Displacement method using resinous mesh

3) By displacement of the soft ground into the permeable fill material, it also works as a kind of the sub-drainage.

3 MODEL FOOTING TEST

3.1 Purpose of Model Test

As a simulation of the displacement method using the resinous mesh, the several series of model footing tests are carried out at laboratory to investigate deformation characteristics of the ground involving the mesh during earthworks. Also, test results are expected to provide information available for the design procedure and the methods how to connect the mesh each other and how to spread it over the soft ground.

3.2 Outline of Test

As shown in Fig. 4, the two-dimensional plane strain type footing model (4m in width, 1.0 m in height and 0,5 m in length) is made of the lucite. The mixture of clay which was taken from the reclaimed land at the port of Kanda is poured into the apparatus. The average index characteristics are as follows : Specific gravity, G_s = 2.63, liquid limit, w_L = 113%, plasticity index, I_p = 76, initial water content, w_i = 130%, compression index, C_c = 0.58 and swelling index, C_s = 0.09. The sawdusts made of the lucite as the mark are attached at the corner of

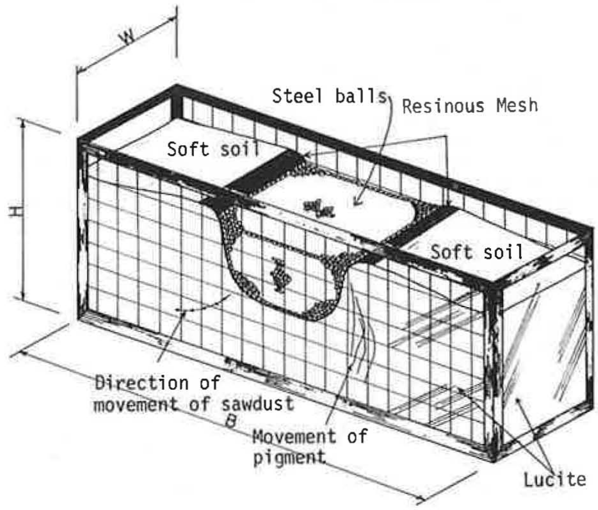


Fig. 4 Outline of apparatus of model footing test

the square comparted by 10 cm x 10 cm to observe the deformation behavior of soft ground. The so-called "mosquito net" is used instead of the resinous mesh with consideration of the similitude between field and laboratory. As the load, the steel balls with 38 kN/m^3 as the unit weight (2.5 cm in diameter) are spreaded over the ground surface to keep unity as B/D. The artificial clay ground has been cured for two days after pouring. Loading is done 5 times step by step. Each loading duration is about 2~3 hours. The total stress is accumulated up to 7.64 kPa on the average.

3.2 Kinds of Model Tests

Four kinds of model footing tests are run to simulate the following situations :

1) Fill with the mesh not laid

2) Fill with the mesh laid to observe the lateral flow

3) Fill with the mesh laid to observe the movement of soil particle and the lateral flow

4) Fill with the mesh laid over the ground interbedded by the sand seam

Change in index propoerties of the soft soil was examined before and after loading. The distinct difference of them was not recognized. This implies that the loading by means of the steel balls is done very rapidly as if in a manner of the undrained-unconsolidated test.

Representative observation is illustrated in Figs. 5 and 6. Behavior of the soil especially seen at the series (3) of the model test is pursued by the movement of the white pigments painted in the surface of the front lucite. The number in Fig. 6 shows the sequence of observation at the end of each loading. According to Fig.6, the following tendencies are appeared :

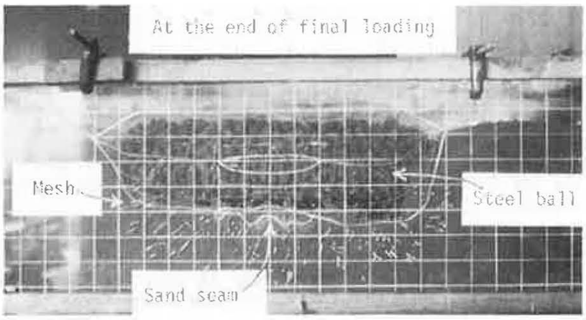


Fig. 5 Model footing test for the banking method using the resinous mesh (test series (4))

The ground at the vicinity of the center of the loading plate moves diagonally downwards, the ground beneath the fill shifts almost horizontally and the ground at the toe of fill moves diagonally upwards, then the heaving of the ground occurs. It is observed at the line outside the embankment that the soft soil is thrusted out at the same time of loading, then this movement reaches gradually at the depth from the surface. The lateral flow of the depth progresses in parallel with the longitudinal section. On the contrary, the surface movement is extremely complex. As a whole, the movement of the painting is in agreement with the movement of soil particles.

Thus, from the results of model tests, we can approximately grasp a behavior of the layered ground including the mesh. Besides, test results suggest that we should pay attention to the following items in filling embankment at field for displacement using the resinous mesh.

1) When the subsoil is replaced by the transported soil, the tensile strength of the mesh is required. Otherwise, the mesh is torn by the shearing force acting between soil and mesh with accompany by the embankment. Hence, the mesh must be reinforced by the rope or the cable.

2) Observation of the ground movement is essential in execution of the earthwork at field from the beginning of embankment especially for settlement prediction.

4 EMBANKMENT ON THE RECLAIMED LAND USING RESINOUS MESH

4.1 General View of the Port of Kanda

The port of Kanda (Fig. 7) which is located in the northern part of Kyushu in Japan had played an impotant role to export the coal produced at the Chikuho area which was the background of the heavy industry in Kitakyushu. Recently, it has been assigned as the base of the timber import. The construction of the timber storage and its relative facilities was started in 1972 for the expence of about thirty hundred million yens and then they had been completed in 1977. When the wharf facility for the timber and the factories of the timber relative industries are constructed, the port of Kanda involving the Matsuyama area where the fill was completed by using the resinous mesh must be an international base port for importing and manufacturing the timber. In addition, since the big factory of the Japanese famous automoble company was constructed on the reclaimed land of the port of Kanda near the Matsuyama area, the amount of the invisible trade in Kanda has been rapidly accumulated. For these reasons, the necessity of the road construction has come up, which is expected to connect this wharf with the national highway Route 10 as one of the arteries of Kyushu. The outline of the layout of the

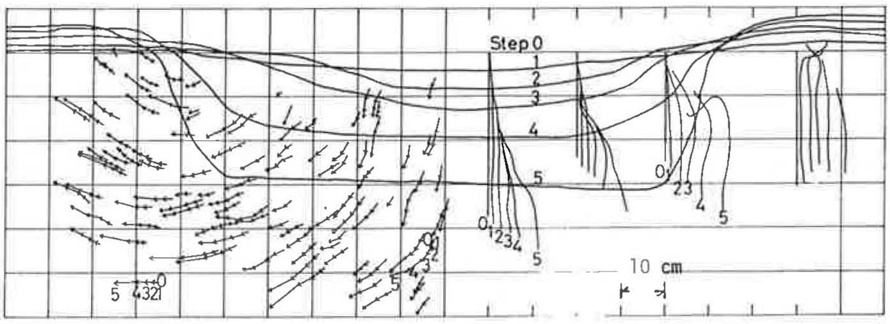


Fig. 6 Movements of soil particle and soil mass due to step loading (test series (3))

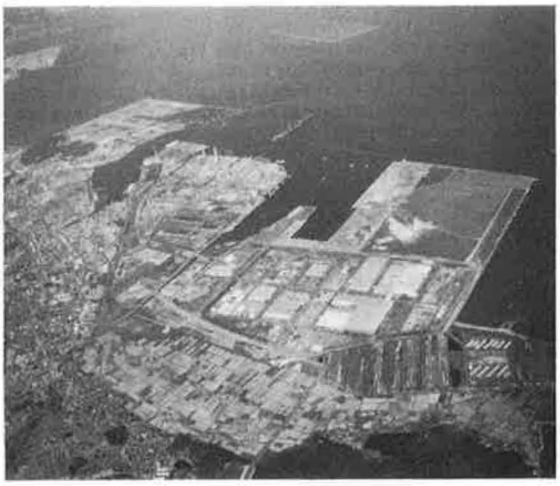
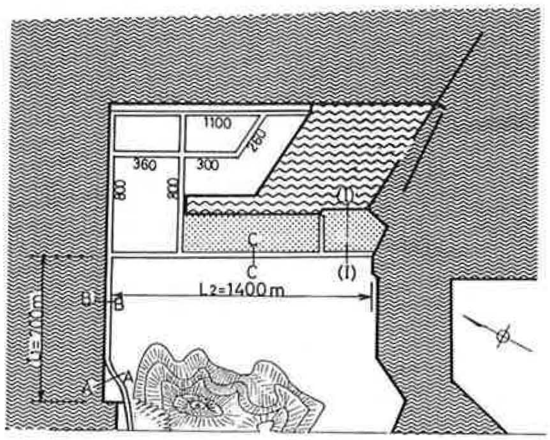


Fig. 7 General view of the port of Kanda

facilities and the planned line of the road in the Matsuyama area is illustrated in Fig. 8. The road passing through the wharf facilities for such as the storage of timbers and the factory site are constructed over the extremely soft reclaimed land at Kanda of northern Kyushu. The cross section along the I - I line in Fig. 8 is reproduced in Fig. 9. The partitioning bank between the reclaimed land and the sea is built to surround the desired area of the sea (step 1). The soft soil sometimes including the sand seam is poured through dredging into the shallow sea compartment divided by the surrounding

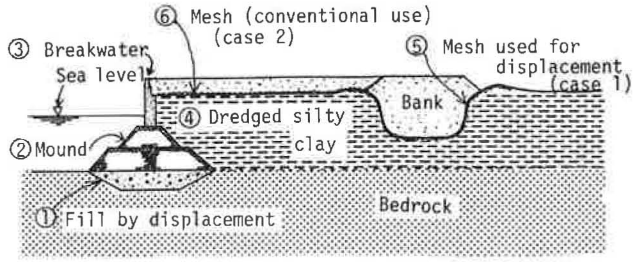


(Dimension in distance : m)

Legend

- Sea
- Revetment bank (step 1)
- Reclaimed land (step 2)
- Road by the case 1 (step 3)
- Wharf site by the case 2 (step 3)

Fig. 8 Outline of the reclaimed land where road fill is constructed using resinous mesh (Matsuyama area)



(Number in the figure shows the order of earthwork)

Fig. 9 Cross-sectional view at the I-I portion in Fig. 8

bank (step 2).

Index properties of the soft soil taken from the site for the road embankment using the mesh are tabulated in Fig. 10.

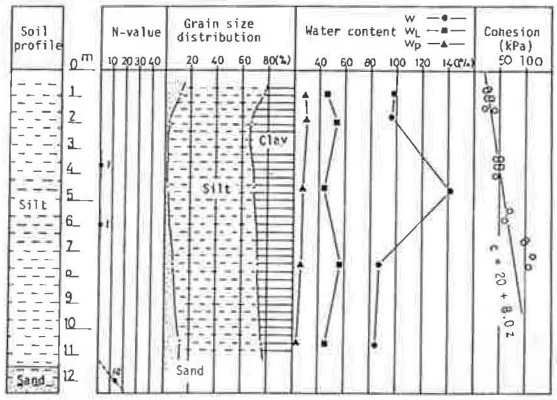


Fig. 10 Index properties of the soft soil before embankment

In the case history described in the present paper, fill for the road is carried out by following the procedures :

1) The resinous mesh is laid over the surface of the soft ground to acquire the trafficability of the heavy construction machines as shown in Fig. 11 (a). At the beginning of laying over the ground, the resisting force of the mesh is exerted. Movement and settlement of the ground are controlled by restrainment developing between the soil and the mesh.

2) To reinforce the mesh, as was already pointed out in the model test, the woven fiberous rope is tied to the mesh at intervals of about 1 m as shown in Fig. 11 (b).

3) The fill material transported from the hillside near the Matsuyama area is laid over the mesh by the bulldozer. Then, after laid soil by 30-40 cm depth, the soil is uniformely compacted under repetition of travelling. This procedure is repeated several times. The restrained layer between the mesh and the soils is formed to resist the settlement due to consolidation and plastic flow.

4) According to the rapid embankment, the lateral plastic flow is occurred. Then, the softsubsoil is replaced by the fill material. Thus, the fill and the ground remains stabilized. Typical cross section was schematically shown in Fig. 3.

5) Due to the lateral flow, heaving is extended over the

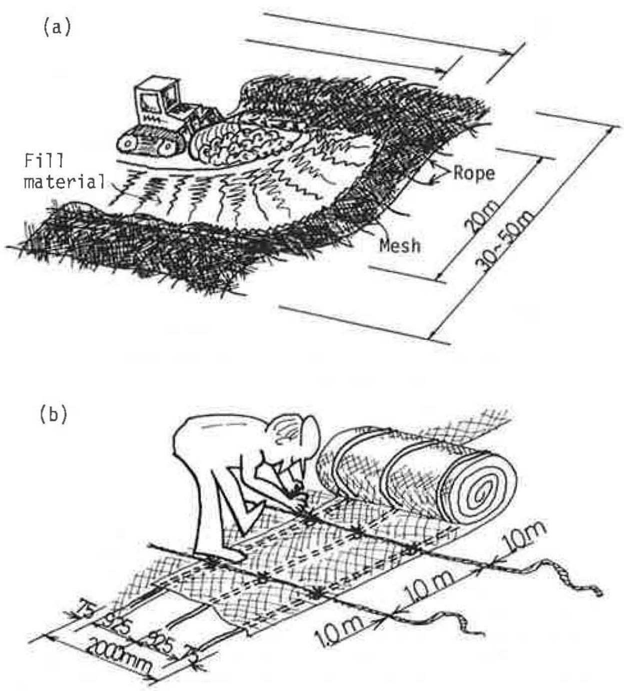


Fig. 11 General view of performance using resinous mesh

surface with 60 m on the both sides of the fill. The heaving surface functions as the counter weight.

6) The alternative repetition of laying the mesh, filling the soil and compacting the layer continues along the traverse direction of the road.

Movement and behavior of the ground due to embankment are observed by the pore-water pressure indicator, the settlement indicator, lateral inclinometer and the displacement pile which are installed under the ground in depth and the surface. Among them, it is worth paying attention to the movement of the piles at the surface. Based on the the observations of the movement of the pile, it is concluded that the depth and extent of the heaving and displacement along the longitudinal section after final fill, as visualized in Fig. 12, varies depending on the index property, the sand seam and the speed of filling.

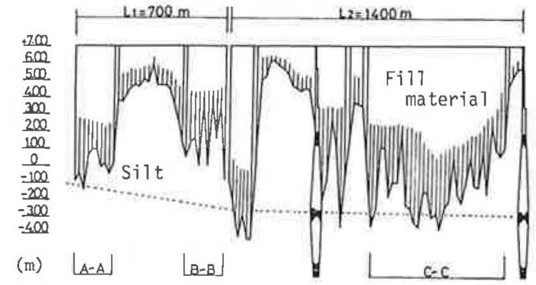


Fig. 12 Profile of ground with the base established by displacement

Every symbol in Fig. 12 corresponds with that in Fig. 8. The typical scene where the mesh is laid over the soft soil is demonstrated in Fig. 13.

5 TENTATIVE DESIGN PROCEDURE

The displacement method using the resinous mesh is proved to be valid even for embankment over the extremely soft ground. However, the design procedure at field has not been established. It is also too difficult to estimate the settlement due to the displacement because settlement contains consolidation and a large amount of plastic flow arising from the rapid embankment. The key to the design of this method seems to exist on the comprehension of the interactions between the mesh and the

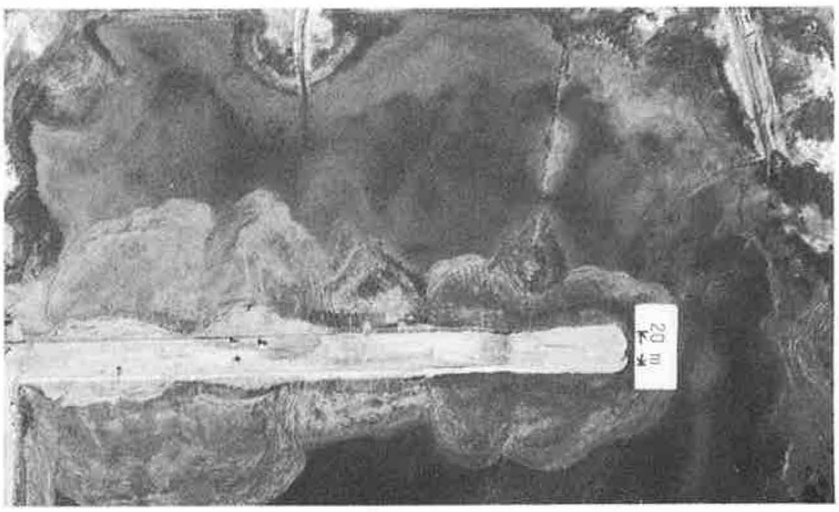


Fig. 13 Embankment over the reclaimed land using resinous mesh

soil accompanied by loading. Yamanouchi et al. (1970) run the experiments at laboratory for the understanding of this mechanism.

Owing to the review of methods for calculating the allowable bearing capacity of clay strata, the following formula is adopted to propose the method for estimating the amount of the transported fill material needed for embankment.

$$q_a = \gamma H + 5.3\,c \qquad (1)$$

where q_a ; allowable bearing capacity, H ; depth of the fill, c ; cohesion of silt. Fig. 14 schematically shows the profile of the subsoil after embankment with its base established by displacement.

Since the extended width of the heaving was three

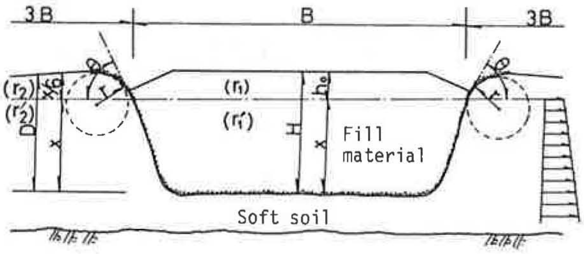


Fig. 14 Assumed cross-section for estimating the quantity of the transported soil

times of the width of the bank (3B = 60 m) at the field observation, the average height of the heaving is reduced to $(1/2)\cdot B\cdot x \div 3B = x/6$. An attempt to take the effect of the tensile strength of the mesh into consideration in settlement computation is based on the method proposed by Yamanouchi et al. (1979). They obtained the approximate equation for calculating the allowable bearing capacity with consideration of the tensile strength of the mesh as follows :

$$q_a = \frac{1}{F}\left[5.3\,c + T\left(\frac{\sin\theta}{B} + \frac{1}{r}\right) + D_f F_s\right] \qquad (2)$$

where symbols may be referred to Fig. 14. From the balance of the forces acting on the plane between the soil and the mesh shown in Fig. 14, we have

$$\gamma_1 h_o + \gamma_1' x = \gamma_2' x + \gamma_2 \cdot \frac{x}{6} + 5.3\,c + T\left(\frac{\sin\theta}{B} + \frac{1}{r}\right) \qquad (3)$$

Substitution of every value of unit weights per volume (γ_1 = 18 kN/m^3 γ_1' = 18 kN/m^3, γ_2 = 14 kN/m^3, γ_2'=15 kN/m^3) and cohesion (c = 20 + 0.8 z) into Eq. (3) gives

$$H = 1.16\,x + 1.22 \qquad (4\text{-a})$$

or

$$h_o = 0.14\,H + 1.06 \qquad (4\text{-b})$$

Thus, we can obtain the relationship among the height of the fill, h_o, the depth of the displacement, x, and the total height of the fill, H, computed by Eq. (4-a) as shown in Fig. 15. Therefore, by utilizing Fig. 15, we can estimate the amount of the transported soil mass and then the reasonable design and the economical estimation

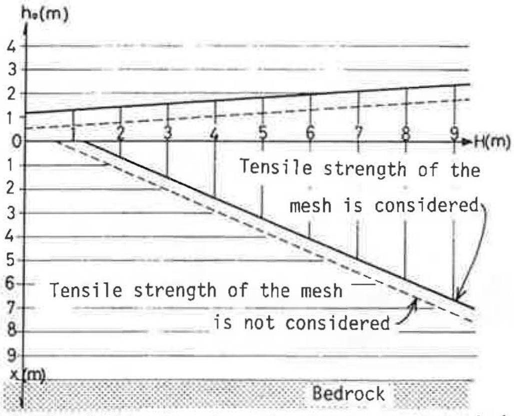


Fig. 15 Design chart for displacement method using resinous mesh

can be carried out before earthwork using the resinous mesh.

6 CONCLUSION

From the model tests and the field earthworks, the new embankment method using the resinous mesh was suggested to become one of the most economical and reasonable methods for improving both the surface and the subsoil in depth of the extremely soft reclaimed land. This method was resultantly used for displacement of the soft soil. Hence, this method should be separately considered from the improvement of the broad area of the soft ground which has been conventionally ever adopted. By strengthening through the connection of the fiberous rope with the mesh each other, the replacement is reasonably advanced by the mesh and the ground in a body.

The road in the Matsuyama area improved by this displacement method is now under opening to traffic after paving. A portion of the embankment filled up by the preloading was removed because the road body has remained completely rigid and there have been occured no troubles so far.

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Interessantes Verfahren: Moorverdrängung durch rasche Lastaufbringung
Grundbruchbildung, seitliche Hebung vermeiden