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Model experiment on stability analyses of steel mesh reinforced embankment

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ABSTRACT : This paper proposes a new method of slip-circle stability analysis for reinforced embankment on soft clay foundation. The reinforcing material is rhombus steel mesh. The new method takes into account the restraining effect of reinforcements on earth and gives a more accurate safety factor than the conventional one that applies only the reinforcement's tensile strength to the limit-equilibrium equation. The reinforcing mechanism in embankment is clarified by conducting loading tests on a laboratory model of 1/50 of the prototype under four conditions: unreinforced, one-layer reinforced, two-layer reinforced with vertical spacing (s) and two-layer reinforced with vertical spacing (2 X s).

1 INTRODUCTION

Using the rhombus steel mesh (hereinafter steel mesh) and geotextile as reinforcing materials in embankment construction is becoming a new practice for ensuring the stability of embankment on soft foundation. This kind of reinforcing technique has such advantages as speedy construction, low construction cost, etc. and it does not require such heavy equipment as those employed in the foundation stabilization method. Thus the practice of this method is increasingly popular now-a-days.

The present design method considers only the tensile strength (hereinafter tension) of the reinforcing material as resisting force or moment in the slip-circle stability analysis. However it is learnt from the results of instrumented measurements at the actual embankment or test embankment that the tension is acting in most cases less than that is assumed in the design. This means that the present design method is considered to give results on a considerably safe side as viewed from the stability stand-point of the embankment.

Consequently the embankment-model testing is conducted with an objective of clarifying the reinforcing mechanism and establishing a proper efficient design method. Moreover the data obtained from the in situ measurements and model studies are analysed to confirm the effectiveness of reinforcing mechanism.

This paper presents a new method of stability analysis of reinforced embankment on soft ground taking the result of the studies as a basis.

2 RESULT OF IN SITU MEASUREMENT

The construction method of reinforced embankment that is usually practised in highway works is chiefly the method of using steel mesh (JISG3552, tensile strength 17.1tf/m). This is due to the fact that the material can be obtained at low price and uniform quality throughout the country and also the material itself is comparatively high in tension.

From the results of actual construction works the following points are clarified.

1) Under the same conditions the unreinforced and reinforced embankments are constructed and the result is that all unreinforced embankments suffer from slope failure but the reinforced ones can be constructed with an adquate stability to the planned height.

2) With the increase of embankment load the tension of steel mesh increases; thus the steel mesh is effectively working for

the stability of the embankment.

3) Contrary to the expectation the measured tension of steel mesh is of the order of 2.5tf/m to 4.5tf/m which is 1/4 of the designed tension.

4) The settlement of embankment and the horizontal displacement of foundation are rather big and the foundation's displacement is considered to be large although the stability of the embankment is ensured.

3 MODEL TEST

The model is an embankment with a similitude of 1 to 50 of the prototype and it is constructed on soft ground in the laboratory for testing with an objective of confirming the failure conditions of embankment, foundation and reinforcement at the ultimate state (test series 1). And again the pull-out tests (test series 2) of the reinforcements are also conducted using a small-size soil container to confirm the restraining effect of reinforcement on fill-material.

3.1 Laboratory test for model embankment (test series 1)

(1) Test procedure

The model soil container and its dimensions are as shown in Fig. 1. The foundation is made up in the soil container by adjusting the degree of consolidation of kaoline clay for all tests at more than 90%. The embankment material is composed of Toyoura standard sand and lead grains and the composition is adjusted so that the unit weight becomes 2.20gf/cm^3 and the cohesion 1.40kgf/cm^2. The embankment is filled up at 2cm per layer taking 90 minutes to

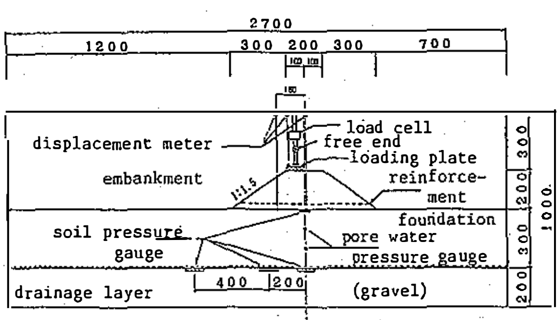

Fig.1 Model set-up

Table 1 Properties of nylon mesh

Tensile strength	Modulus of elastisity	Mesh spacing
44.0 kgf/m	8,000kgf/cm^2	8.0 mm

complete.

The reinforcing material is selected in such a way that the selected material can easily conform to the deformed embankment and the embankment failure that is the rapture of the reinforcement occurs within the limit of forced loading capacity during testing of preliminary tests. The material is a nylon mesh with the properties as shown in Table 1.

The test cases are the following four cases: ① unreinforced ② one layer reinforced ③ two-layer reinforced (layer vertical spacing 1.5cm) ④ two-layer reinforced (layer vertical spacing 3cm). The laying position of reinforcement of the lower layer is in all three cases 2cm above the foundation level. The loading is done on half of the top area of the embankment through the Acryl plate with 50cm in length and 10cm in breadth which is attached to the top of the Bellofram cylinder after the filling of the embankment is completed.

(2) Test results

The conditions of embankment deformation due to loading in four cases of tests are as shown in Fig. 2. For unreinforced embankment (case ①) the sliding failure has already occurred at the time of embankment making and the sliding becomes remarkable with the forced loading. Contrary to this the reinforced embankments in the other cases (② ~ ④)

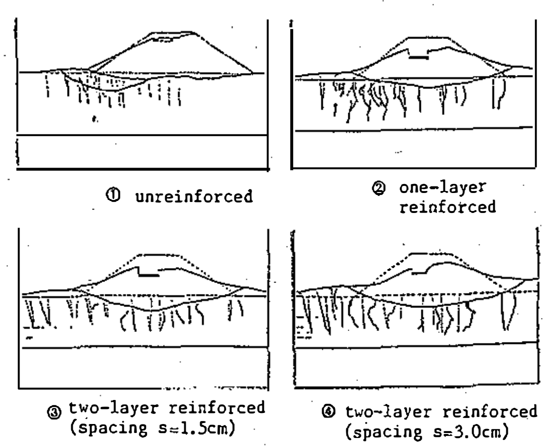

Fig.2 Embankment deformation

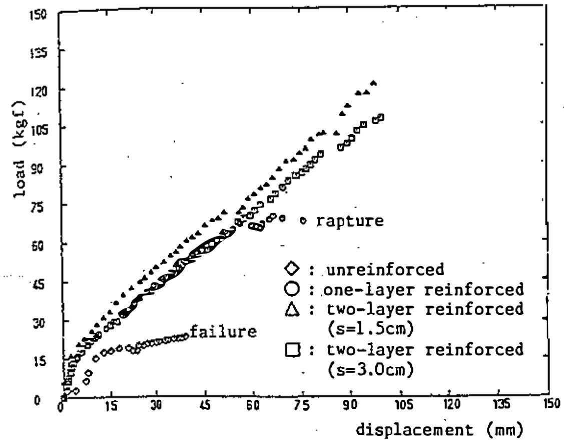

Fig.3 Relationship between load and displacement

can be made maintaining adequate stability but a slight heaving of the foundation is recorded due to lateral displacement. Thus the phenomenon of the actual embankment can be reproduced at the model tests.

Fig.3 describes the relationship between load and displacement of loading plate. The unreinforced embankment (case ①) is in a failure state at the time of embankment completion and it collapses beyond use when the forced loading 20 kgf is applied. In the case of one-layer reinforced embankment (case ②) the embankment collapses at about 3 times loading of case ① that is 70 kgf. At this time the reinforcement is raptured at the middle portion throughout the laying length. This means that one layer of reinforcement can carry a load of 50 kgf that is the difference of case ① and case ②. And the failure mode of the reinforcement is not a pull-out failure but a rapture.

In the cases of ③ and ④ the loading is applied until the maximum displacement of Bellofram cylinder is approximately 10cm and a bigger resistance is recorded at case ③. From this it is to be considered that the reinforcement layers with narrower spacing of case ③ work effectively.

Fig.4 describes the distribution of the maximum strain of the reinforcement in the cases ③ and ④ and in both cases the maximum strain occurs at the middle portion of the embankment. In case ③ the strains are distributed almost uniformly at lower and upper reinforcements and in case ④ the strain at the lower layer reinforcement is bigger than that of the upper layer. The partial breaking

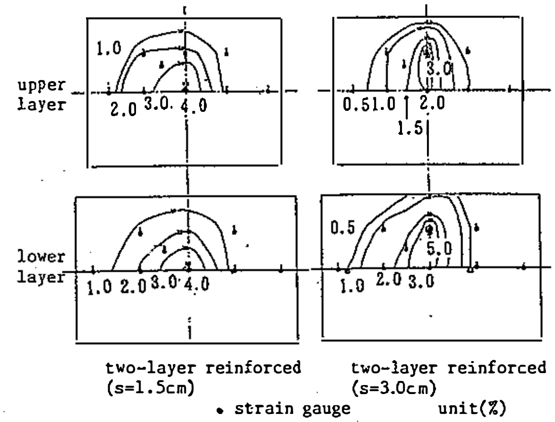

Fig.4 Maximum strain distribution (plan view)

condition of the lower layer reinforcement is bigger in the case ④. This means that the reinforcements work less effectively when placed in large or sparsely spaced layers, but at a particular spacing the inner earth and reinforcements are integrated into one unit and works effectively.

(3) Result of analysis

The phenomena and results obtained from the test series 1 are brought under analysis. The analysis is performed using the rigid body spring model (RBSM) on account of the following reasons. a) the embankment and foundation are brought under analysis under a largely deformed state. b) the embankment is under limiting failure state c) the RBSM is effective to the foundation failure.

As to the case ② the analysis is done assuming the reinforcements as beam-elements and as a result the heaving and settlement of the lateral foundation soil can be expressed in addition to the deformation and stability of the embankment as shown in Fig.5 a. The reinforcement's element failure occurs at the loading of 35kgf (50% of the load during testing). Thus some effect can be expected from the reinforcement apart from a beam-element, and the analysis is conducted with the assumption that the zone 5mm below and above the reinforcement is a restraining area where the reinforcement and fill-material are rigidly combined. The input values are as shown in Table 2. The zone is, as a result, not subjected to failure or rapture. The deformed state of foundation (Fig.5 b) is the same as that obtained from the reinforcement-only condition as

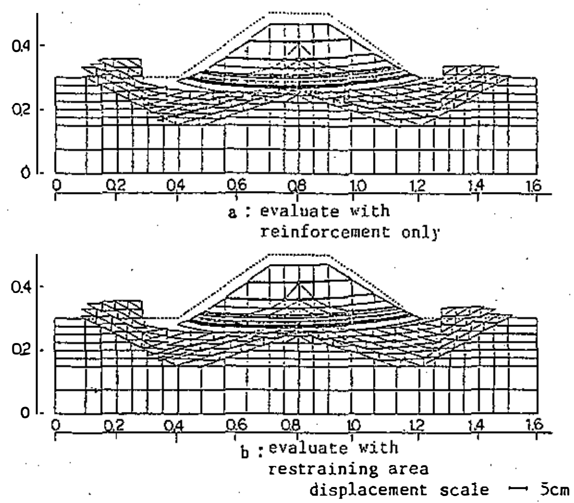

Fig.5 Deformation sketch by RBSM

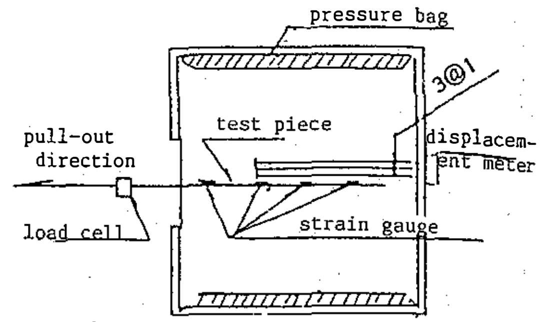

Fig.6 Small-size soil container

Table 3 Properties of geotextile

Mesh spacing (mm)	5	10	25
Tensile strength (kgf/m)	450	350	700

shown in Fig.5 a. This means that the combined effect of reinforcement of two cases, one for the reinforcement only and the other for the restrained zone of the rigidly combined unit of reinforcement and fill-material, can be evaluated. Refer to Fig.5 b.

3.2 Pull-out tests (test series 2)

The reinforcement's pull-out tests are conducted using the small soil-container as shown in Fig.6 to confirm the restraining force and scope of restraining between the reinforcing material and fill-material with due consideration of the results obtained from test series 1.

The reinforcing material is a plastic net which is the so-called geotextile. Its properties are as shown in Table 3.

56 cases of pull-out tests in total are conducted using 4 kinds of reinforcement's mesh, 4 kinds of grain-size of fill-soil, 3 kinds of confined pressure, 2 kinds of reinforcement layer (one-layer and two-layer) and three kinds of vertical spacing for two-layer reinforcement.

The results obtained from the 10mm-mesh reinforcement with the largest number of tests are as follows.

(1) Test results

Fig.7 describes the recorded values of displacement meter laid in the soil against the pull-out forces and it is confirmed that the scope of reinforcement effect that is the area acting as if it is a reinforcement is 15mm at most. This means that the resisting effect works in a definite area around the center of the reinforcement as the reinforcement and soil are restrained.

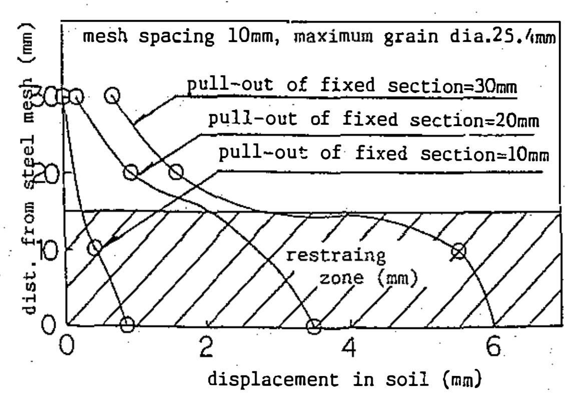

Fig.7 Soil displacement by pull-out

Table 2 Input values for rigid body spring model

Parameters	Embankment	Mesh layer: Material (Beam element)	Mesh layer: Model as a plate effect	Soft foundation: GL-0~ -7.5cm	Soft foundation: GL-7.5 ~-15cm	Soft foundation: GL-15~ -22.5cm	Soft foundation: GL-22.5 ~-30cm
Unit weight (tf/m^3)	2.20	0.03	2.20	1.56	1.58	1.60	1.62
Modulus of elasticity (tf/m^2)	50	80,000	76	0.17 ~0.41	1.53 ~0.90	1.90	5.80
Poisson's ratio ν	0.450	0.350	0.450	0.495	0.495	0.495	0.495
Cohesion c (tf/m^2)	0.14	—	4.54	0.024 ~0.039	0.046 ~0.061	0.076	0.150
Angle of internal friction ϕ (°)	28.4	—	28.4	0	0	0	0

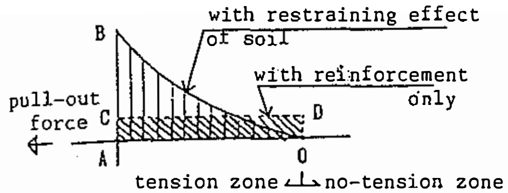

Fig.8 Pull-out resistance

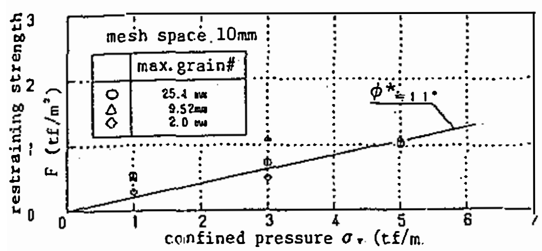

Fig.9 Relationship between restraining strength and confined pressure

Again the pull-out force recorded by the load cell is exceeding the tension of reinforcement that is shown in Table 3, and when estimated from the reinforcement's strain distribution the distribution of resistance is obtained as shown in Fig.8. This means that the restraining strength between soil and reinforcement is to be taken as the value obtained from deducting the tension distribution of the reinforcements only (□ACDO) from the tension distribution with restraint (△ABO). Let this area difference be F and the relationship between F and the confined pressure is as shown in Fig.9. From this figure it is to be inferred that the restraining strength depends upon the confined pressure and this relationship can be expressed by the following equation.

$$F = \sigma_v \cdot \tan\phi^* \qquad (1)$$

where

σ_v : the confined pressure that is acting on the reinforcement

ϕ^* : the angle of internal friction between the reinforcement and soil

4 PROPOSED STABILITY ANALYSIS METHOD

In the case of a reinforced embankment on soft ground the displacements of the foundation and embankment are big as stated in the results of model tests and these are the phenomena that occur not within the scope of elasticity but within the scope of plasticity. The failures of both embankment and foundation do not occur at the same time. Hence it is to be considered that the elasto-plastic FEM and the RBSM are well suited for the stability analysis. However when viewed from the aspect of the future interchangeable usage for the design it is desirable to establish a practical and simple design method.

Here reviewing the present design method the viability of the equation that takes into consideration the restraining strength of reinforcement is brought under close scrutiny in the limit-equilibrium slip-circle stability analysis method.

4.1 Equation for stability computation

The conventional stability-analysis method makes use of the equation that takes into account only the reinforcement's tension in the direction of the slip-circle's tangent. The following proposed stability equation determines the safety factor F_s using the equation of the conventional method plus the restraining effect of the reinforcement on the fill-material as shown in Fig.10 the schematic diagram.

$$F_s = \frac{M_r + (T_h + F_h)\cdot r + (T_v + F_v)\cdot \tan\phi \cdot r}{M_d} \qquad (2)$$

where

M_r : resisting moment of soil shear

M_d : acting moment

T_h : the tangential component of reinforcement's tension

T_v : axial component of reinforcement's tension

F_h : tangential component of restraining force

F_v : axial component of restraining force

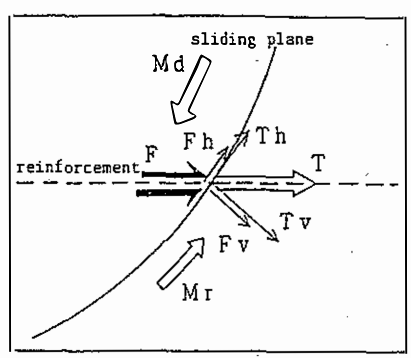

Fig.10 Forces acting on sliding plane

ϕ: angle of internal friction of fill-material

r: radius of slip circle.

Morover the restraining strength is determined by the equation (1).

4.2 Case study of analysis

From the results of test series 1 it is learnt that the two-layer reinforcement has an almost uniform behavior when the vertical spacing is taken as 1.5cm. When computed using the similitude of the model the actual spacing becomes

$1.5 \times 50 = 75$cm.

In the preceding example of construction the spacing of reinforcements is less than 75cm, hence the same behavior is assumed to happen in the analysis.

In the case study of construction work at Ise region the stability analyses for such cases as unreinforced, conventional and proposed methods are conducted and their results are as stated in Table 4. Under the unreinforced condition $M_d = 504$ tf.m/m and $M_r = 390$ tf.m/m and $F_s = 0.77$. The deficient moment $\Delta 114$ tf.m/m is to be carried by the reinforcements only. The required tension for one layer of reinforcement is computed to be $T = 9.5$ tf/m for the case with the tension of the conventional method, but in the proposed method with the consideration of restraining effect $T = 3.2$ tf/m . This value is almost the same as the in situ measured value 2.5 tf/m. It is to be considered that the restraining effect that agrees roughly to that of the real practice can be actually evaluated.

Table 4 Comparison of results from stability analyses (Ise)

Parameters	Stability analysis		
	Unrein-forced	Conven-tional	Pro-posed
Acting moment (tf•m/m)	504	504	504
Acting force per 1-mesh layer (Fs=1) (tf/m)	—	9.5	3.2
Resisting moment (2-mesh layer) (tf•m/m)	390	595	809
Safety factor during construction	0.77	1.18	1.60

5 FUTURE PROBLEMS

A more practical design method (with stability analysis) which is economically functional is proposed in this paper but for the time being the following problems remain to be solved.

(1) In computing the tension of steel mesh the test method that takes into consideration the model with real and to some extent restrained state cannot be practically and completely established. And the creep effect, the fixation of strain level that is suitable for earth structures, etc. are the future problems.

(2) The present test is concerned with the restraining effect of the steel mesh of the model. But it is required to confirm whether the effect is the same or not as that of the real embankment.

In future it is planned to conduct in situ testing for tension, comparative studies, etc. with the real-size embankment. And the authors hope that a further refined method of stability analysis would be established on the basis of the present one.

REFERENCES

Mishima, N.,Toyama, M., Kawaida, M.1991. Stability analysis of the embankment on soft foundation using rhombus steel mesh as reinforcement, Proc. 26th Research Conference, JSSMFE: 2147~2148.(in Japanese)

Monda. S., Toyama, M., High embankment construction on soft foundation in narrow valley, Civil Engineering Vol. 46, No.12(in Japanese).

Mishima, N., Toyama, M., Kawaida, M., Nishi, 1992. Stability analysis of reinforced embankment on soft foundation, Proc.27th Research Conference, JSSMFE.(in Japanese)

Kawai, T., Takeuchi, N., Limit dispersal analysis programming, Baifuhkan (in Japanese).

Research Association on Application of Geotextile: Design method of retaining wall and embankment with the application of geotextile, Proc. Symp. Geotextile Application,1990(in Japanese).