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Full scale testing and numerical analysis for polymer grid reinforced embankment

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ABSTRACT: Using the polymer grid (hereinafter grid) as a reinforcing material for earth embankment is a new way of steep and high embankment construction. The present research is undertaken with a view to verify the design procedur and construction technique that are to be adopted in constructing grid reinforced embankments.

The works include the construction of a full scale test embankment, an observation of dynamic behaviour of the embankment, and a series of FEM analysis. The parameters of the embankment are : height-14 m, base width-55 m, slope 1:0.5 up to a height of 6 m and 1:0.8 from 6 m to 14 m height, a case of embankment without grid reinforcement, 4 cases with reinforcement. Comparative studies of test embankments were conducted through the back analyses of the observed dynamic data. The reinforcing mechanism is established and the reinforcing effects evaluated. From the results of the studies it is confirmed that there exist as a result of grid reinforcement an increased strength and a decreased deformation in the grid reinforced zone of the embankment. Moreover the laying of reinforcing grids in a checkered pattern is found to be structurally effective.

1 INTRODUCTION

Recently the use of grid as a reinforcing material in the earth embankment is becoming very popular in Japan, and the authors are also engaged in the laboratory testing of grids (Fukuda et al. 1987).

The reinforcing material and reinforcing methods are various. The application of grids to actual construction works is more advanced than ever. But the design considerations and reinforcing mechanism are not clarified as yet.

In that the present research in this paper is undertaken by constructing a full scale grid-reinforced embankment model and testing it through destruction in line with the embankment works for the site preparation of a housing complex in Okayama prefecture, Japan. The observed data of the test were brought under analysis by using FEM simulation and the reinforcing effects evaluated. The field measurement of grid stresses and strains, and embankment deformation are conducted with a view to confirm the dynamic behaviour of the embankment.

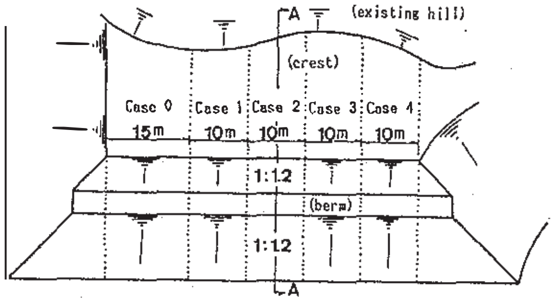
On the other hand the elasto-plastic analysis by the finite element method which is the back analysis using the observed data is carried out with an aim to evaluate quantitatively the effects and mechanism of grid reinforced embankment design. It is to be concluded that the breaking pattern obtained from in-situ destruction tests reveals the reinforcing mechanism and effects quantitatively. The elastic modulus (E) and the cohesion (C) of the reinforced zone are increased in the same pattern with the stress-strain relation.

2 FIELD TESTING

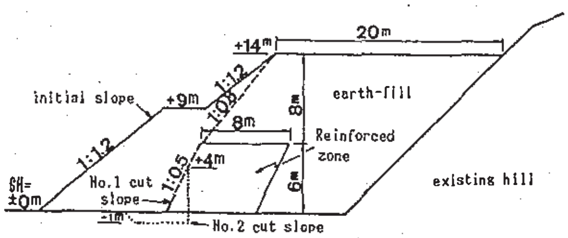
2.1 Test Cases

The test embankment is as shown in Fig. 1. In each case the embankment has a width; 10 m (15 m without reinforcement), height : 14 m. After filling the whole embankment with a side slope of 1:1.2 (initial slope), the slope is again cut to a finished slope of 1:0.5 for the lower 6 m and 1:0.8 for the upper 8 m (No.1 cut slope). The section reinforced by grid is 6 m high and 8 m wide. The upper 8 m fill section is constructed as a surcharge.

The reinforcing pattern is as shown in Fig. 2 with the Case 1 reinforced by one grid layer and Case 3 by 2 grid layers and Case 4 by 4 grid layers in a continuous pattern, and Case 2 by 5 grid layers in a checkered pattern, and Case zero is without reinforcement. Thus the quantities of grids laid in the embankment from Case zero to Case 4 are in the ratio of 0:1:2:2:4.

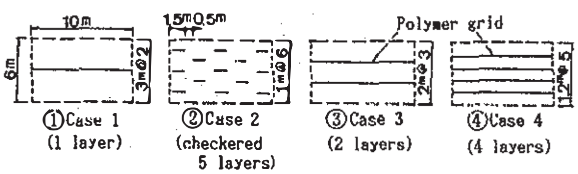


(a) Plan

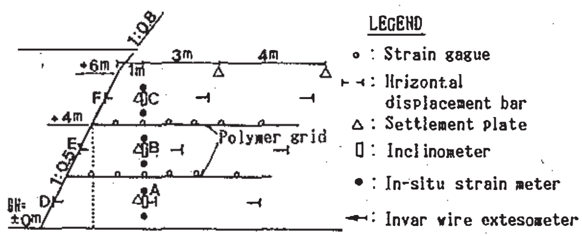


(b) Cross Section (A-A)

Fig. 1 Plan and Section of Test Embankment



(a) Laying Patterns of Polymer Grids



(b) Layout of Instruments (Case 3)

Fig. 2 Grids Laying Pattern and Instrumentation Layout

2.2 The Features of the Test Embankment

(a) Embankment Material: It is a highly weathered rock of greenschist and pelitic schist. Its properties are as shown in Table 1.

(b) Foundation of the Embankment: The foundation is the same kind of soil as the embankment material or filled up by a better quality soil.

(c) Reinforcing Material : Bi-axial stretched polymer grids are used. Tensile strength is 1.8 tf/m at a strain rate of 8 %.

2.3 Compaction

The fill material is spread out by bulldozers forming a layer of 50 cm thickness. Each 2-layer is compacted by 1~2 runs of vibrating rollers. The dry density of soil after compaction is 1.59 t/m³ at 90 % degree of compaction.

Table 1 Index Properties of Soil

Natural water content Wn (%)	21.30
Specific gravity Gs	2.71
Gravel fraction (%)	4
Sand fraction (%)	51
Silt fraction (%)	32
Clay fraction (%)	13
Compaction test method (by JIS)	2.5.b
Optimum moisture content Wopt (%)	15.00
Maximum dry density ρdmax (t/m³)	1.76

2.4 Field Measurement

The following parameters of soil are measured using the measuring apparatus shown in Fig. 2:- ① the grid strain by foil strain gauge, ② relative horizontal displacement of the fill material from the slope by displacement bar, ③ the settlement of embankment by settlement plate, ④ horizontal displacement of embankment by inclinometer, ⑤ fill-material strain by strain gauge attached to a vinyl pipe, ⑥ horizontal displacement of slope by invar wire wire extensometer.

Measurement for ①, ④ and ⑤ are done by an automatic measuring and recording system and ⑥ by an automatic recording device; and measurement for ② and ③ by manual recording.

3 RESULTS OF MEASUREMENT

3.1 Deformation of the No.1 Cut Slope

The No.1 cut slope is completed by cutting the initial slope but no slope failure takes place.

In so doing, for Case zero the crest area around 8 m from the top of the slope was covered with several cracks with an opening of 2~3 mm and width 10 m. The horizontal displacement of the embankment after cutting of the initial slope is 1~3 cm as shown in Fig. 3. The deformation is decreased and the strength gain sharply noticed with an increase of reinforcing grids.

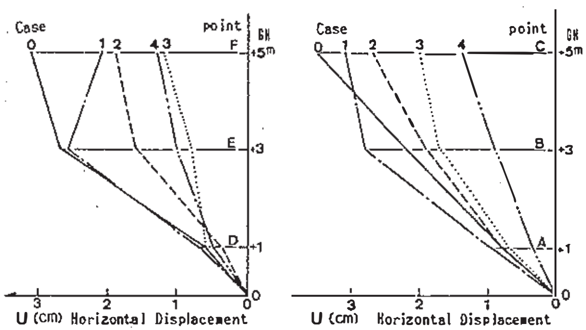
The grid strain distribution is as shown in Fig. 4. It is in such a trend that the grid strain is higher as it approaches the slope. When grids are laid in several rows the upper ones have higher strain values than the lowers. These results are approximately the same as those obtained from laboratory testing (Kutara et al. 1987).

3.2 Destruction by Vertical Cutting

The vertical cutting of the No.1 cut slope (Fig. 1) does not lead to sliding although the horizontal displacement of the embankment is 1~4 mm/day within a period of 5 days.

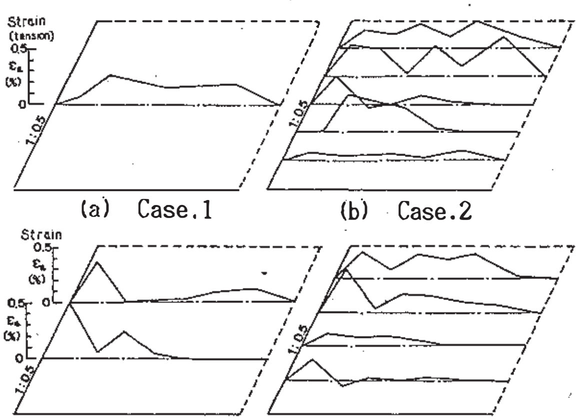
But the slope failure occurs in each case with Case zero after 20 minutes and all other cases after 6~9 hours as shown in Fig. 5 and Photo. 1. The larger the reinforcement quantity of grids is, the more the sliding will be deep and severe, and grids break round about the sliding plane. Just before sliding, the horizontal displacement has gone up to 10 cm and grids's maximum strain is 2~3 % which is the limit of strain measurement.

The strain distribution is the same as that of the No.1 cut slope. The inner strain at



(a) Slope (b) Internal Earth

Fig. 3 Measured Horizontal Displacements of Slope and Internal Earth (No.1 Cut Slope)



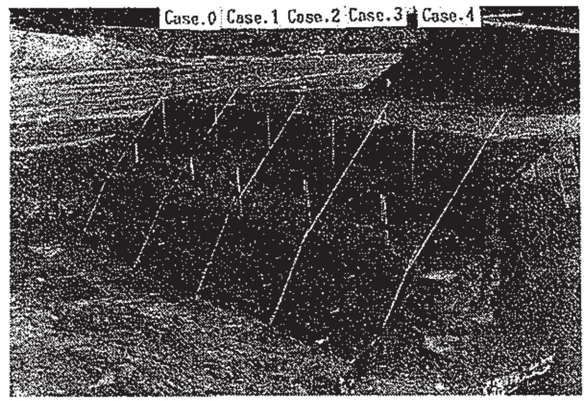
(a) Case.1 (b) Case.2

(c) Case.3 (d) Case.4

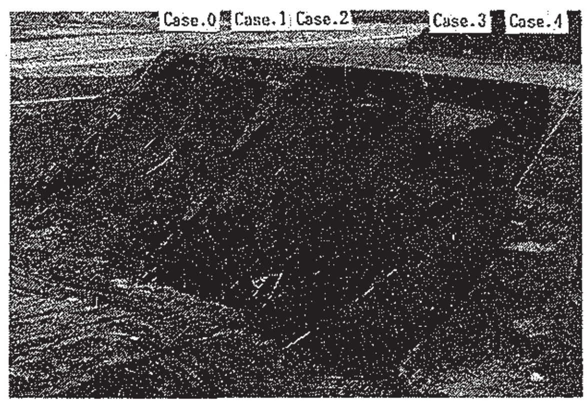
Fig. 4 Distribution of Grid-Strains (No.1 Cut Slope)

1.5 m from the inner edge of the grid is found to be as small as 0.1~0.3 % and hence the laying length of grids is considered to be sufficient.

Moreover, in Case 2 the reinforced section only stands firm but it is displaced forward as affected by the sliding force of the adjoining surcharge fill. This means that the embankment with the reinforcing grids laid evenly distributed just like a checkered pattern is found to be effective from the structural point of view.

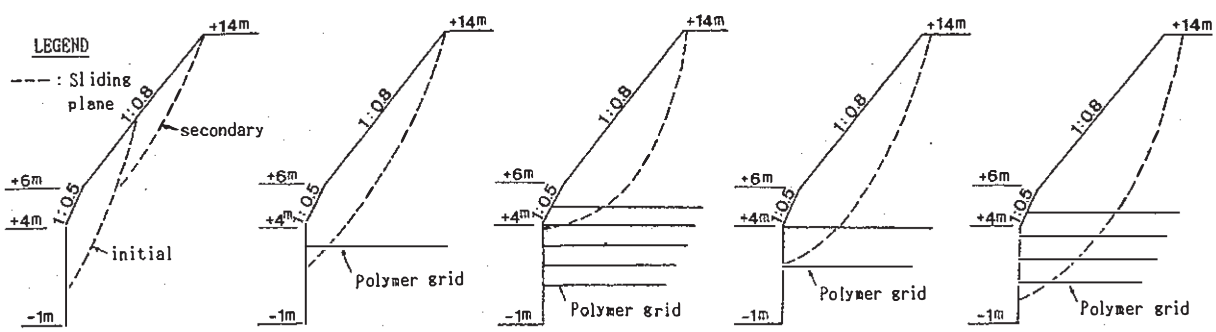


(a) No.1 Cut Slope



(b) Final Filure State (for No.2 Cut Slope)

Photo. 1 The Scenes of Test Embankment



(a) Case.0 (b) Case.1 (c) Case.2 (d) Case.3 (e) Case.4

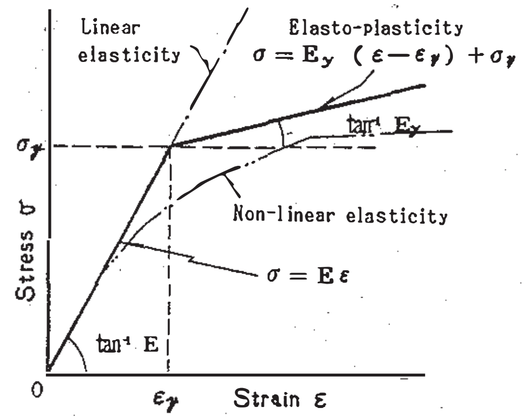
Fig. 5 Predicted Sliding Planes

4 METHOD OF NUMERICAL ANALYSIS

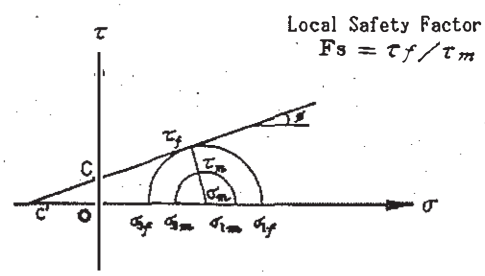
The analysis is done by elasto-plastic model of finite element method assuming that the integrated body of grids and earth forms a complete elasto-plastic body. And the constitutive equation is the relationship by Drucker-Prager and the grids laid horizontally in layers in the fill body is considered as a spring element of the elasto-plastic type.

Stress-strain relationship of the earth and local safety factors are as shown in Fig. 6. Here the local safety factor Fs is determined by using the Mohr-Coulomb's failure criterion for a stress condition of each element.

The analysis model and the properties of the material used in the model are shown in Fig. 7 and Table 2 respectively. The properties of the fill material in the Table 2 are obtained from the back analysis of the observed data of the embankment, without reinforcement (Case zero). And the elastic modulus and cohesion of the reinforced zone are determined numerically by the back analysis using the observed data from Case 1~4.



(a) Stress-strain Curve



(b) Local Safety Factor

Fig. 6 Explanation of Stress-Strain Curve and Local Safety Factor

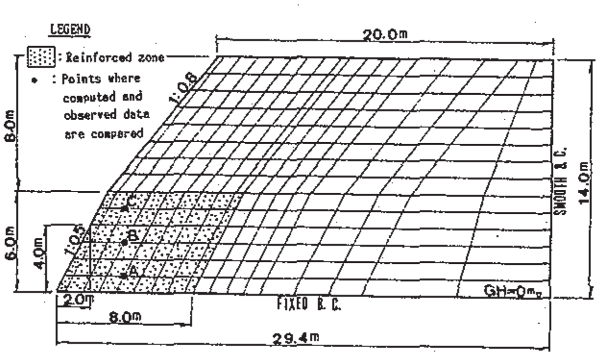


Fig. 7 Finite Element Mesh and Boundary Conditions

Table 2 Properties of Materials

Earth fill (Drucker-Prager model)	Unit weight (wet)	γt (t/m³)	1.90
	Elastic modulas	E (tf/m²)	1400
	E after yield	Ey (tf/m²)	5
	Poisson's ratio	ν	0.30
	Cohesion	c (tf/m²)	0.50
	Angle of shear resistance	ϕ (°)	35.00
	Apparent tensile	C (tf/m²)	0.50
Polymer grid (Spring model)	Spring modulas	AE (tf)	50 (20)
	AE after yield	AEy (tf)	1
	Tensile strength	T (tf)	1.8 (0.7)
	T after yield	Ty (tf)	0

Note : Numbers in ( ) are for Case 2.

5 RESULTS OF BACK ANALYSIS (SIMULATION)

Fig. 8 describes the typical results obtained from FEM analysis:- (a) the deformation pattern (b) the vector diagram of principal stresses (c) the contour diagram of local safety factors The changes of elasto-plastic zone and horizontal displacement of fill body are described in Fig. 9. The results obtained from the analyses in all cases are in close conformity with those observed values of the fill body displacement. Thus the analyses are found to be precise and reliable. The horizontal displacement is reduced as the grid reinforcement is increased.

The effects of grid reinforcement can be confirmed by the occurance of the decreased deformation. And from Fig. 9 (b) it is obvious that in the case of vertical cutting of the No.1 cut slope i.e No.2 cut slope the stresses are not converged to an equilibrium state for both cases: Case zero and Case 1 and the failure of the embankment is expected. On the other hand in the cases, Case 2, 3, 4, the developments of plastic zone are in progress. But the embankments are structurally safe as latters are limited. The plastic zone has developed rapidly in the case of the surcharge fill as compared to the reinfoced zone of the embankment; thus it is to be surmised that the effect of reinforcement is obvious since an increase of strength is observed in the reinforced zone of embankment.

On the other hand the grid strain distribution is as shown in Fig. 10. The conformity of the computed grid strains with observed ones is of a lesser degree but they are considered to be satisfactory. Although the grid reinforcement quantity is the same in Case 2 and Case 3, Case 2 has relatively bigger strains. And with respect to Case 3 the No.2 cut slope

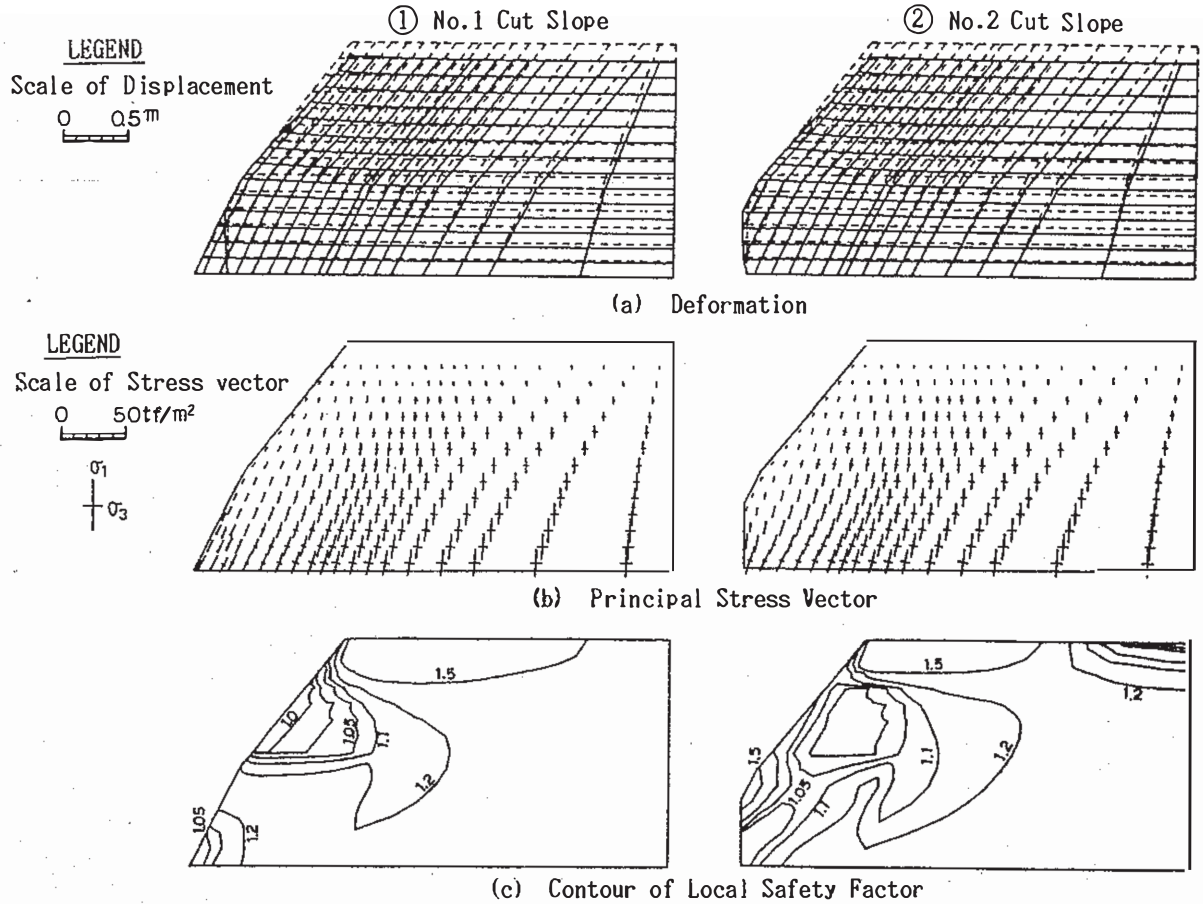


Fig. 8 Results of Finite Element Analysis (Case 2)

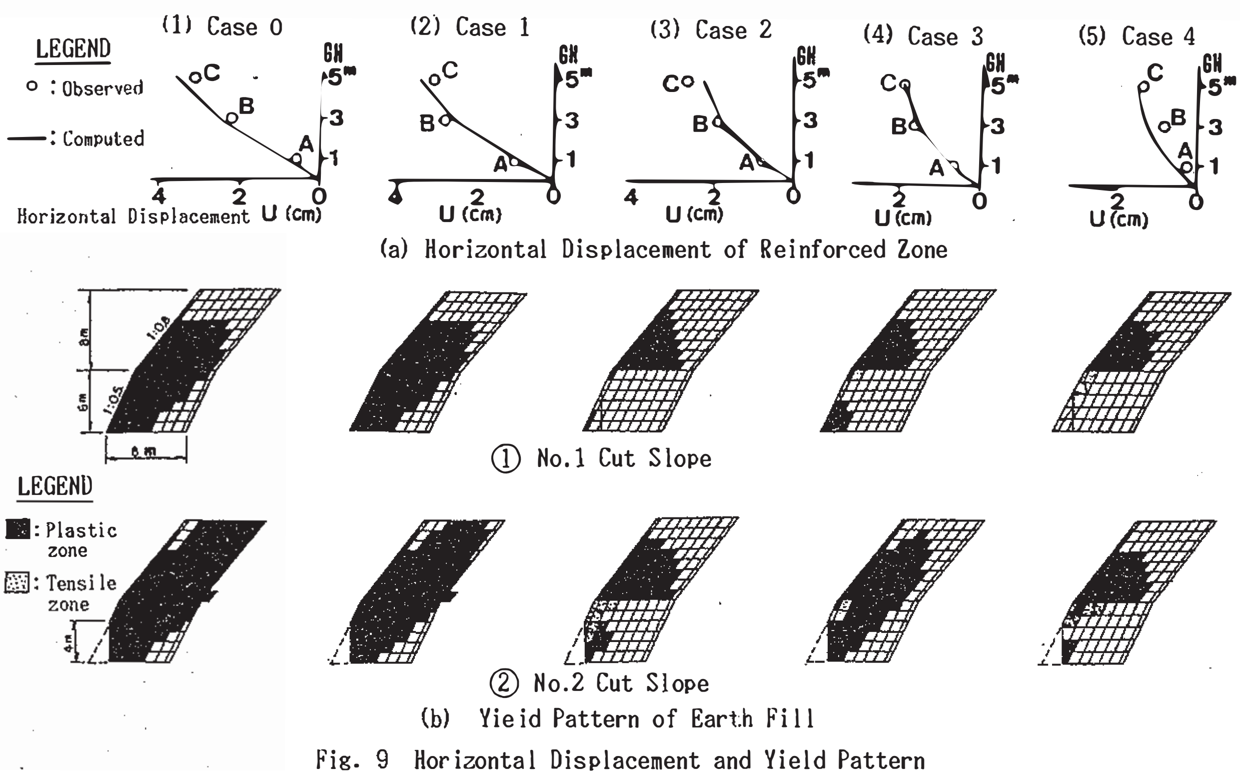
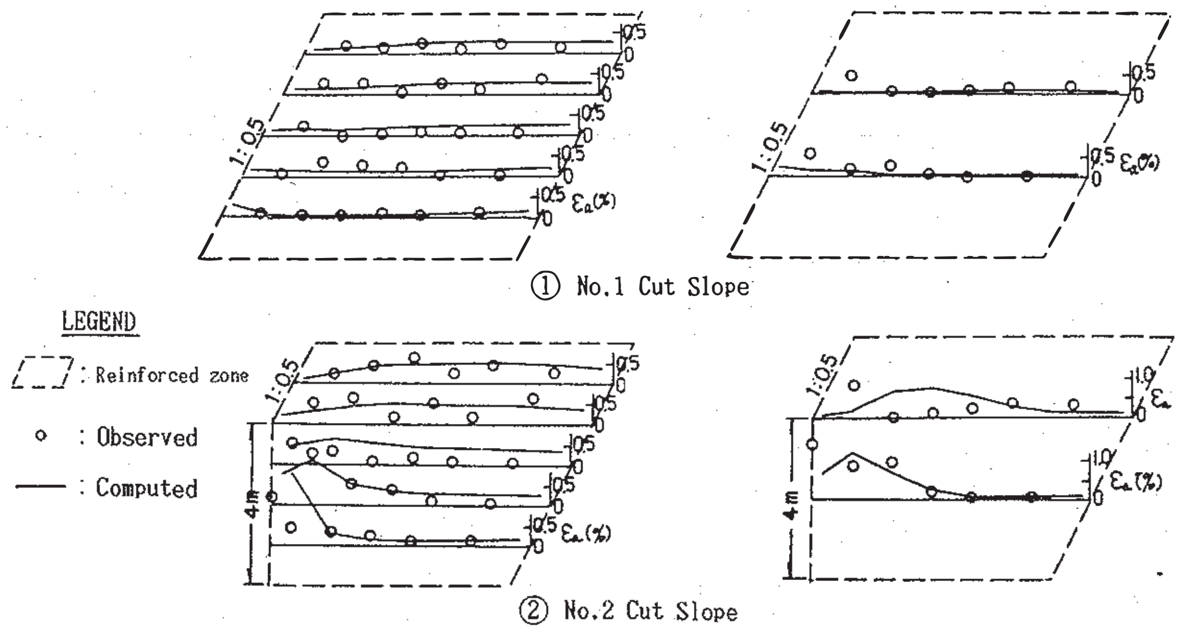


Fig. 9 Horizontal Displacement and Yield Pattern



(a) Case 2 (b) Case 3

Fig. 10 Comparison of Computed Grid-Strain with Observed Data (Case 2 and Case 3)

has a peak strain which is distinguished from the others. These phenomena are considered as an indication of the grid and earth integration effect due to the reinforcements the checkered pattern of which is especially effective uniformly bearing the stresses on the embankment.

The summary of the results obtained from the FEM analyses of the above cases is shown in Table 3. As obvious from this table the effects of reinforcement which are the increased strength of the earth-fill and the decreased deformation of the embankment are pronounced with an increase of the reinforcement quantity in the embankment.

Table 3 Results of Computed Reinforcing Effect by FEM

Parameters		Case 0	Case 1	Case 2	Case 3	Case 4
Elastic modulus E (tf/m^2)		1400	1400	1700	2000	2500
Cohesion c (tf/m^2)		0.5	0.5	3.0	2.0	4.0
Horiz. displacement U (cm)	point C(GH=5m)	3.53	3.42	2.21	1.95	1.47
	point B(GH=3m)	2.55	2.50	1.81	1.63	1.43
	point A(GH=1m)	0.86	0.86	0.77	0.69	0.68
Maximum strain of polymer grid ε_{max} (%)		--	0.48	0.33	0.20	0.09

Note : Locations of points A,B,C are shown in Fig.2 and Fig.7.

6 CONCLUSION

The major works that are done in this research include the construction of a full scale grid reinforced embankment, the destruction test with a change of slope and elasto-plastic model analysis by finite element method which verify the reinforcement effects and mechanism. The computed results by FEM are found to be in close conformity with the observed data both dynamically and quantitatively. It can be concluded that this analysis is a useful tool to solve the reinforcing mechanism of grids laid in the embankment. It is clarified that there exists an increase of strength accompanied by a decrease of embankment defomation as a result of the grid reinforcement. And the method of reinforcement like the checkered pattern is quite effective as it results in the grid-earth integration accompanied by the uniform bearing of the stresses on the embankment.

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