

Field measurement of reinforcement strain and discrete limit analysis

M.Hada, K. Kagawa & S. Fukushima
Fuji Corporation, Tokyo, Japan

ABSTRACT: This paper describes the behavior of strain of reinforcing materials in two embankments; one is the example at the heavy rain and the other is the example by the overburden. On the other hand, current design methods for earth reinforcements provide no explicit information of deformation. The numerical analysis using the Rigid-Bodies and Spring Model (RBSM) proposed by T.Kawai (Kawai 1977) is applied to these earth reinforcements. It is clear that the discrete limit analysis using RBSM is capable to take into account the strain by the banking load.

1 INTRODUCTION

Recently, many steep slopes reinforced with geotextiles, geogrids or the other materials tend to be constructed in Japan. Various kinds of method for the design have been proposed and the most current design methods are based on the limit equilibrium equation which is not able to account for the displacement of soils and reinforcing materials. It is, however, desired that a new method with which properties of reinforced embankment can be assessed more exactly for the construction of these new type fills:

Ochiai et al. (1987) carried out a Finite element analysis using the joint element to express the property of pull-out resistance of geogrids in soils. Taki et al. (1988) applied the same method to the full scale test embankment reinforced with polymer grids. These FEM methods, however, are based on continuity of soils excepting the contact plane between soils and reinforcing materials. On the other hand, it is well known that the most slope failures show the slip of soil blocks indicating the discontinuity of soils.

The discrete limit analysis using RBSM are not only applied to the stability of soil slopes but also to many kind of other discontinuous problems (Hada et al.1988). The present work is an attempt to evaluate strain of reinforcing materials in steep slope embankments applying RBSM to two field embankments reinforced with geogrids.

2 SELECTION OF PARAMETERS

In RBSM analysis, the interface between the reinforcing materials and soils is modeled by the beam element and

the plane element. Stress of RBSM is transmitted by two types of spring (the normal spring and the shearing spring) distributed over the contact surface of two adjacent rigid elements (see fig. 1). The stiffness of these springs is defined by two constants; Young's modulus and Poisson's ratio. The determination of these parameters is classified into two cases depending on the property of reinforcing materials.

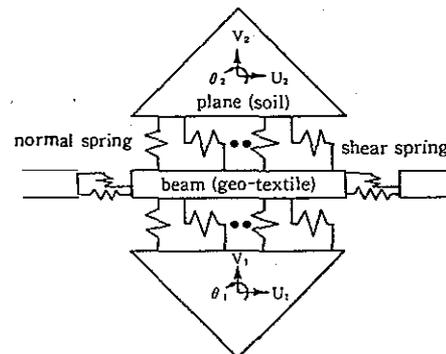


Fig.1 Model of the interface between the reinforcing materials and soils

Fig.2 shows the result of triaxial compression test using different sizes of specimen, 240cm high and 20cm high, which are reinforced with the same geotextiles. In case of small sizes, the reinforcing effect from the beginning to about 5% of axial strain is smaller than the non-reinforced specimen. This difference indicates that the compressibility of geotextiles affects the reinforcing mechanism (Fukushima et al. 1987). Fig.3 shows the

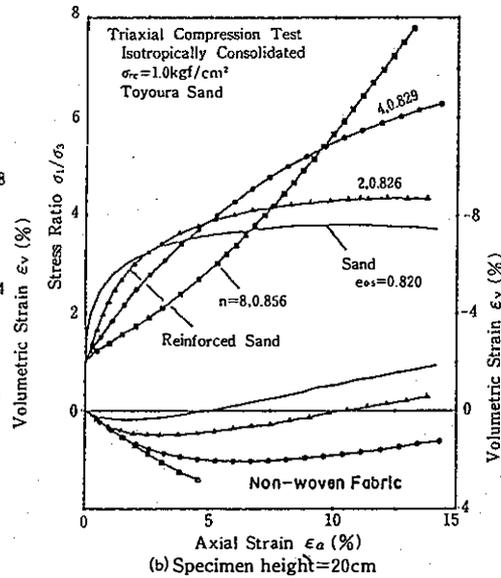
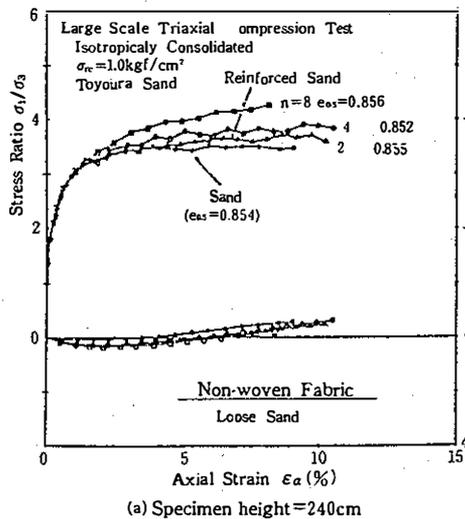


Fig.2 Difference of the reinforcing effect (triaxial test)

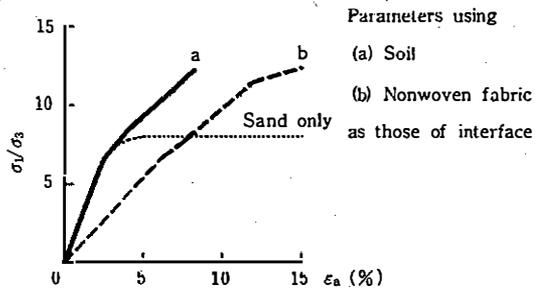


Fig.3 Computed example of the reinforced specimen (plane strain condition)

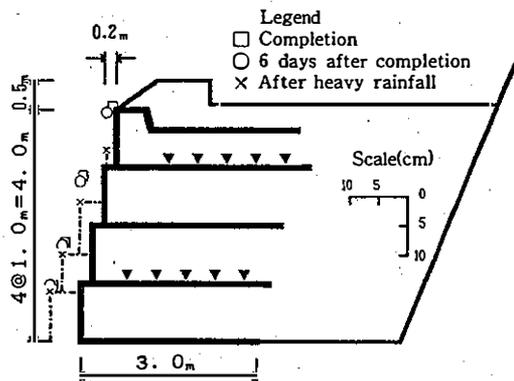


Fig.4 Deformation at the crest of the fill

similar effect which is computed by the present method applied to the plane strain condition test. The broken line shows the result using parameters (Young's modulus and Poisson's ratio) of geotextiles. Therefore, parameters of the interface may be used those of the soil

adjacent the reinforcing material of which compressibility is neglected.

3 FILL TEST

The 4.5m high embankment reinforced with geogrids was constructed. This embankment was used for the construction road. The fill material is the well-graded gravel. The arrangement and spacing of geogrids were decided by the limit equilibrium design method presented by Jewell et al. (1986). The procedure adopted in construction was the "wrap-around" principle. Fig.4 shows the displacement at the crest of the embankment. The strain of geogrids was measured at the 2nd and 4th layer marked by black triangles. Fig.5 shows the distribution of strain in each layer. Black circles indicate computed values when the embankment was completed. Four lines in this figure indicate observed values. Each line corresponds to the following stage:

- 1 After compacting the 0.5m thick fill laid on the geogrid ;
- 2 The same as 1.0m thick fill ;
- 3 Completion;
- 4 37 days after the completion.

Comparing of test results at the 3rd stage with computed values, the behavior of strain caused by the banking load seems to be evaluated by the present method. After the completion, however, the partial settlement at the crest had taken place by the heavy rainfall. It seems that this rainfall induced the strain increment of the upper geogrid.

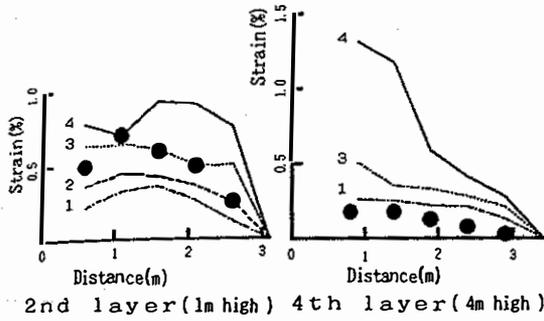


Fig.5 Distribution of strain

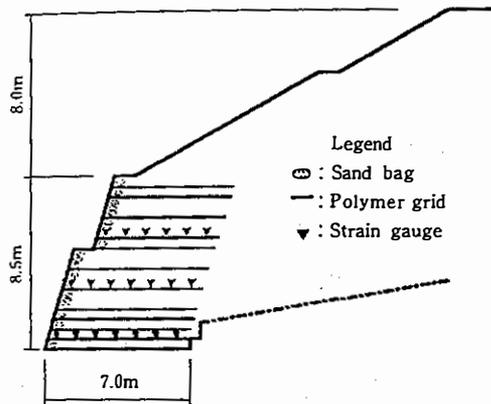


Fig.6 reinforced fill with the overburden

4 REINFORCED FILL WITH THE OVERBURDEN

The 8.5m high and 70m long reinforced embankment with the 8m high fill was built on the stabilized foundation. The embankment reinforced with polymer grids is a slope of 1 : 0.3 and the upper fill is a slope of 1 : 1.8 (see Fig.6). Fill materials are mainly the gravelly soil including the fine fraction. Therefore, it took a long constructing period for avoiding the settlement after the completion.

Fig.7 shows the distribution of strain of polymer grids at three constructing stages; finished banking the reinforced fill, suspended for a month, completed the whole embankment. In this figure, strain marked by circles are unreliable because a gauge of the pair was unstable.

Fannin et al. (1988) found that polymer grids laid in the field embankment were influenced by the long-term load. Kutara et al. (1988) showed that the long-term strain of polymer grids increased from about 0.5% to about 2% by their pull-out test. Therefore, it seems that increasing of strain for the suspended term, without rainfall, was caused by the long-term deformation of polymer grids themselves. So, the strain by the self-weight load at the completion should be equal to the value which was given by deducting the long-term strain increment from the strain measured. Fig.8 shows

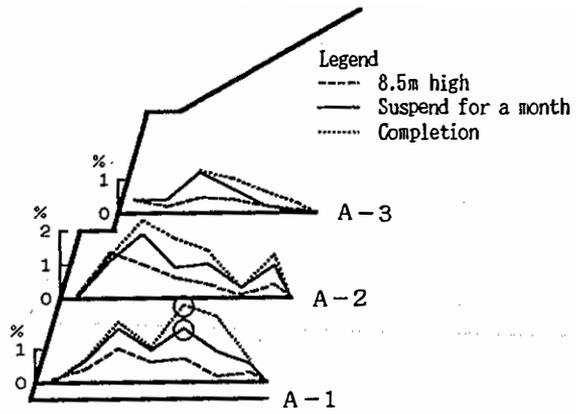


Fig.7 Distribution of strain

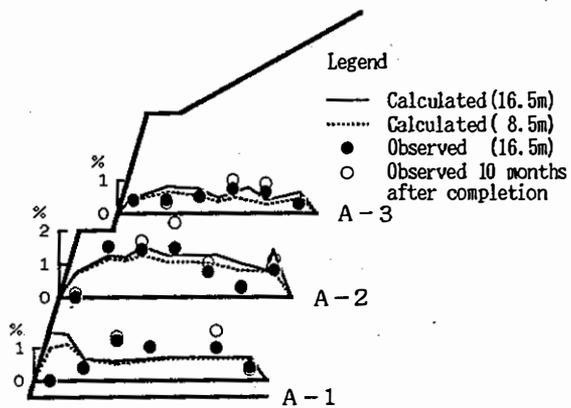


Fig.8 Comparison of calculated values with the strain by deducting the long-term deformation

Table 1 Material parameters used for the present method

material	γ KN/m ³	E MPa	ν	ϕ (deg)	c KPa
Fill (reinforced)	17.6	1.96	0.43	30.0	19.6
Fill (upper part)	19.6	1.96	0.43	30.0	19.6
Facing (sand bag)	17.6	1.96	0.43	30.0	39.2
Interface	—	1.96	0.43	20.0	19.6
Polymer grids	0.0	E · t=490 (KN/m)			

that calculated results by the present method are consistent with the strain modified by deduction. Furthermore, the observed strain at 10 months after the completion shows that the strain of polymer grids would not tend to be more increasing. Parameters used for computing by the present method is shown in table 1.

5 CONCLUSIONS

Numerical results by the discrete limit analysis using

RBSM show explicitly the nonlinearity of reinforced soils caused by the banking load. However, the behavior of soils reinforced with geogrids and other reinforcing materials in the field is more complicated. Especially, the rainfall effect has to be considered in Japan and other heavy rainfall countries. In this work, the rainfall effect was only calculated by increasing the unit weight of fill materials as well as current design methods.

REFERENCES

- Fannin, R.J. and Herman, S. 1988. Field Behaviour of Two Instrumented, Reinforced Soil Slopes. IGS on Theory and Practice of Earth Reinforcement: 277-282
- Fukushima, S. Mochizuki, M and Kagawa, K. 1987. Strength of Sand Reinforced with Full Scale Reinforcement Material in Large Scale Triaxial Compression Test. Proc. 2nd Geotextile Symposium, J.P.IGS. :63-69 (in Japanese)
- Hada, M. Taguchi, Y. and Kagawa, K. 1988. Application of RBSM analysis to earth reinforcement method. IGS on Theory and Practice of Earth reinforcement: 395-400
- Jewel, R.A., Paine, N and Woods, R.I. 1984. Design Methods for Steep Reinforced Embankment. Symposium on Polymer Grid Reinforcement in Civil Engineering, ICE 1984, paper No. 3.1.
- Kawai, T. 1977. A New Discrete Model for Analysis of Solid Mechanics Problems. Seisan-Kenkyu, Vol.29 No.4: 14-16
- Kutara, K. Aoyama, N. Yasunaga, H and Kato, K. 1988. Long-Term Pull-Out Tests of Polymergrids in Sand. IGS on Theory and Practice of Earth Reinforcement: 117-122
- Ochiai, H. and Sakai, A. 1987. Analytical Method for Geogrid-Reinforced Soil Structures. Proc. 8th ARCSMFE 1. Kyoto : 483-486
- Taki, M. Renge, S. Hachiman, T. Morioka, Y. Matsuda and Natori, J. 1988. Full Scale Testing and Numerical Analysis for Polymer Grid Reinforced Embankment. IGS on Theory and Practice of Earth Reinforcement: 479-484