Fifth Australia-New Zealand
Conference on Geomechanics
Sydney, 22-23 August 1988

Excavation Characteristics of a Slope Cutting Reinforced by Tensile Inclusions

T. MATSUI
Professor of Civil Engineering, Osaka University, Japan
K.C. SAN
Graduate Student, Osaka University, Japan

SUMMARY Field excavation test on a reinforced slope cutting incorporated with a road widening project was performed. Finite element analysis of the field excavation test is performed. Slope stability analysis of the slope cutting by using finite element method is also presented. Based on the analytical results together with the field measurements, the excavation characteristics of a reinforced slope cutting are discussed.

1 INTRODUCTION

In a road widening project root piles which is an in-situ soil reinforcing technique were employed to stabilize some parts of cut slope works. In order to monitor the safety of the reinforced cutting, to ensure the effect of reinforcement and to examine the stability mechanism, a full scale field test incorporated with this road widening project was performed. The field test consisted of a field loading test and a field excavation test. The reinforcement mechanism of the reinforced slope under surcharge load has been examined (Matsui and San, 1987).

In this paper, comparisons between the analytical results and field measurements of the field excavation test and its considerations are presented. Slope stability analyses of the slope cutting by using finite element method are performed. The factors of safety of reinforced and unreinforced slope cuttings are compared. Based on the analytical results together with the field measurements, the excavation characteristics of the reinforced slope cutting are discussed.

2 COMPARISONS OF MEASURED AND ANALYTICAL RESULTS AND ITS CONSIDERATIONS

2.1 Field Excavation Test

The plan and the section of the reinforced slope cutting works are shown in Figs.1 and 2, respectively. The site is located on a mountainous region in the suburbs of Osaka, Japan. The site consists dominantly of gneiss-granite deposit. The nearby area of the site previously had a landslide.

The slope consists of an inclined soft rock stratum overburdened by a residual soil layer of several meters. The data interpreted from back analysis of the previous landslide and the information obtained from site investigation show that 7m thick residual top soil is completely decomposed granite. The field excavation test was carried out by excavating the lower part of slope up to about 5m depth after the sandbags, which were used in the field loading test, were removed (see Fig.2).

The instrumentation consisted of numbers of strain gauges on the reinforcement, six dial indicators on the surface of the cutting, an inclinometer in the borehole and two settlement plates on the top of cut slope, as shown in Fig.2.

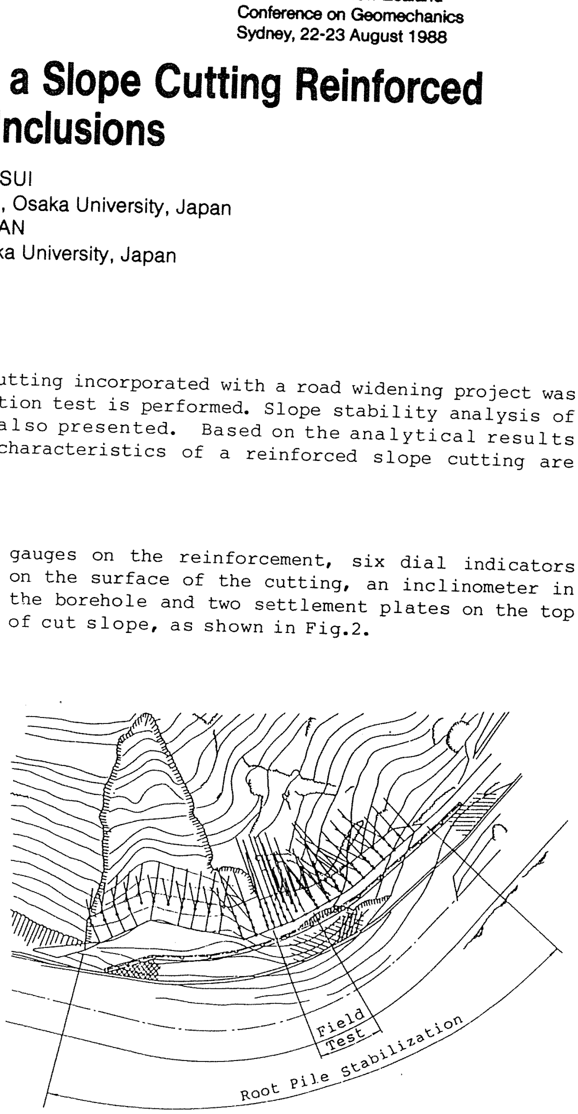

Figure 1 Plan of the reinforced slope

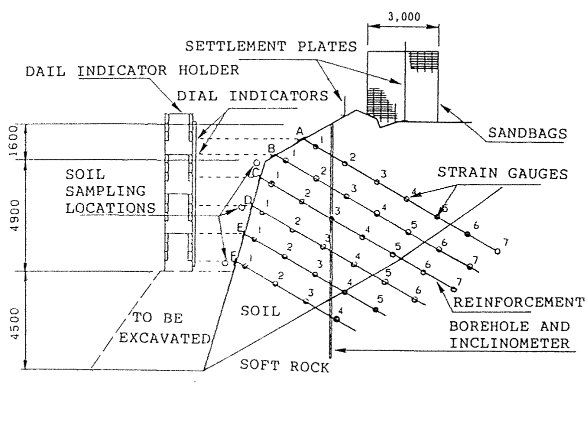

Figure 2 Section of the reinforced slope

2.2 Finite Element Analysis

The operation of the analysis program is illustrated by a simplified flow diagram as shown in Fig.3 . The mesh used in the analysis is given in Fig.4. The original ground is assumed as horizontal. The excavation is divided into two parts. The first excavation simulates an erosion process to form the natural slope and the second part of excavation simulates the actual construction sequence to form the reinforced slope cutting. The simulation of excavation in the finite element analysis is performed by applying the changes in stress to the excavation surface (Duncan and Dunlop, 1969).

The soil is assumed to be nonlinear elastic with a hyperbolic tangent modulus (Duncan and Chang, 1970) and the soft rock linear elastic. The slippage between the reinforcement and the surrounding medium and between the soil and the rock is modeled by an elastoplastic joint element (Matsui, Abe and San, 1986, Matsui and San, 1988). The reinforcement is considered as one dimensional bar element. The material properties used in the present analyses are summarized in Table 1.

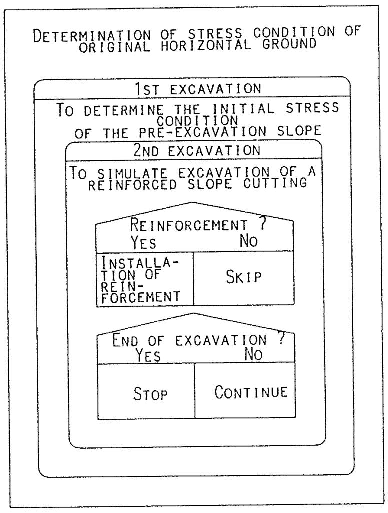

Figure 3 Simplified flow diagram

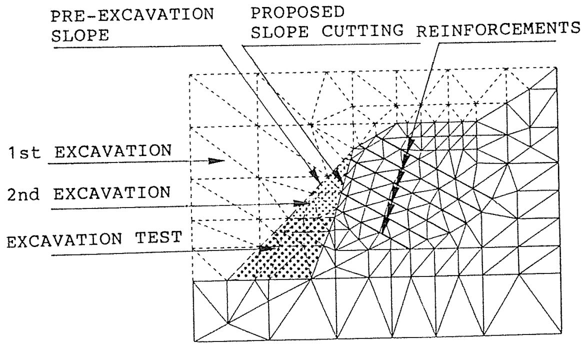

Figure 4 Finite element mesh

2.3 Short Term Slope Stability in Excavation Test

Analyses of the field excavation test were performed by 4 steps. The effect of excavation is considered by unloading nodal forces corresponding to removal of lateral and overburdening pressures during excavation process. Such unload forces due to excavation will be applied to the excavation surface. The unload forces are assumed to distribute to the slope surface evenly, because of the effect of the rigidity of the cement-mortar facing. Moreover the simulation analyses are carried out by increasing the unload force produced by excavation to 3 ,5 and 10 times of the actual one, to examine the behavior in greater deformation condition of the ground.

2.3.1 Deformation of the Slope and Axial Forces of Reinforcements

The deformation of the slope just after the excavation and the horizontal displacement of the surface of slope obtained from finite element analysis are shown in Figs.5 and 6. Fig.7 shows the horizontal displacement at the borehole location, comparing both measured and analytical results. Both results show that the horizontal displacement within the slope is large at the upper portion while with negligible movement at the lower portion.

Table 1 Material Properties

	Decomposed granite	Soft rock	Reinforcement
Elastic modulus E (MPa)	2.2×10^3	1.4×10^5	2.1×10^7
Unit weight γ (kNm^{-3})	18	20	-
Poisson's ratio ν	0.3	0.3	0.3
Friction angle ϕ (degree)	19	45	-
Cohesion c (MPa)	1.0	1.0	-
Coefficient of earth pressure at rest K_0	0.67	0.67	-
Hyperbolic constant K	210	-	-
Hyperbolic constant K_{ur}	420	-	-
Hyperbolic constant n	1.02	-	-
Failure ratio R_f	0.69	-	-
Cross section area A (m^2)	-	-	5.2×10^{-4}

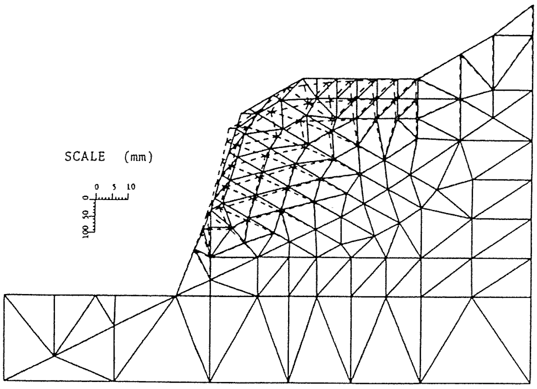

Figure 5 Deformation of the slope

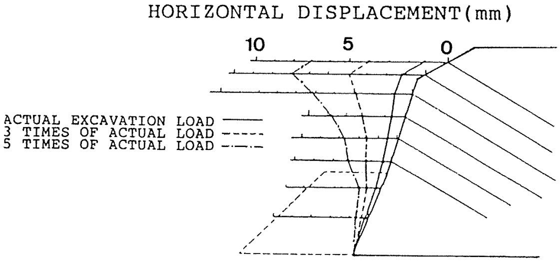

Figure 6 Horizontal displacement of the surface of slope

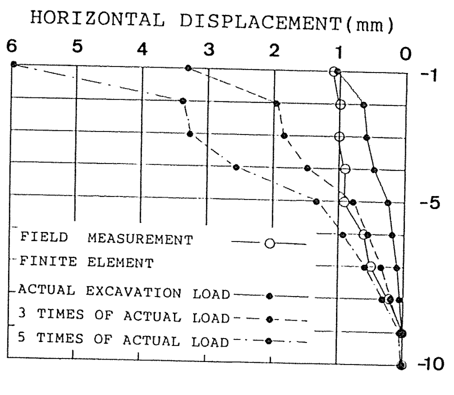

Figure 7 Horizontal displacement at the borehole location

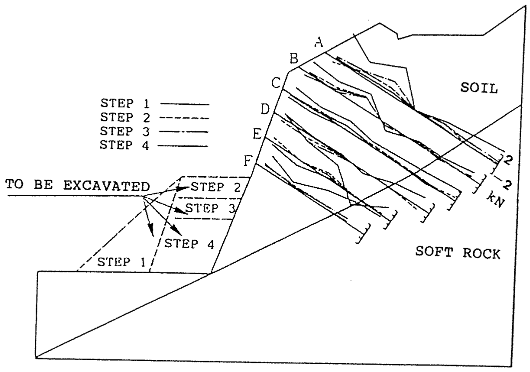

Figure 8 Measured axial force distribution of reinforcement

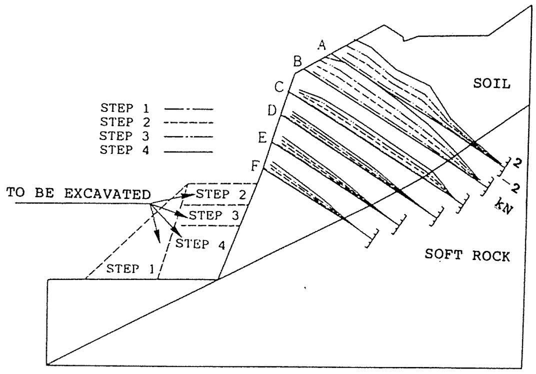

Figure 9 Analytical axial force distribution of reinforcement

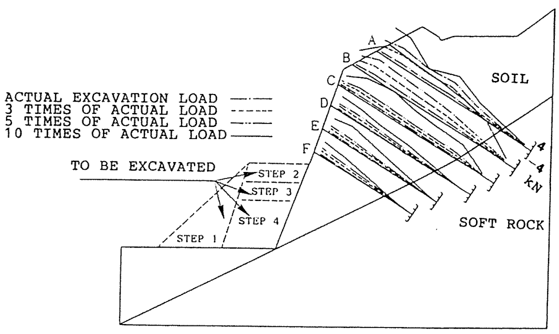

Figure 10 Analytical axial force distribution of reinforcement at higer loading level

The analytical results of higher levels of unload forces produced by excavation suggest that the above-mentioned trend of the deformation will continue as increasing the unload forces, and that the slope will finally reach failure as the upper part of the slope moves away with negligible movement of the toe.

Figs.8 and 9 show the axial force distribution of reinforcements obtained from field measurement just after excavation and analyses. As the data obtained from field measurement are fluctuated, it may be difficult to exactly compare with analytical result. However, both of them show such a common trend that the axial force are mainly in tension with its maximum near the slope surface.

Fig.10 shows the axial force distributions along the reinforcements under higher unload force levels. It is clear in the reinforcement A that as the unload force increases, the increment rate of the axial force is reduced due to the slippage of the reinforcement. The sliding of reinforcement may cause the failure of the reinforced slope.

2.3.2 Shear Strength of Reinforced Soil Mass

Figs.11 and 12 show the distribution of total principal stress in the reinforced and unreinforced slopes, respectively. It can be seen that the minor principal stress is significantly increased in the reinforced soil mass. It is very clear that the increase in the minor principal stress contributes to increasing the shear strength of the reinforced soil mass.

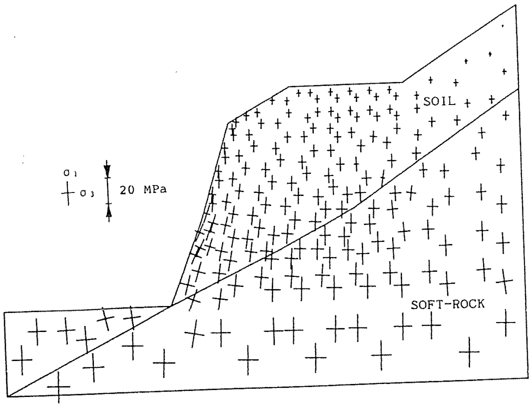

Figure 11 Principal stress distribution of the unreinforced slope

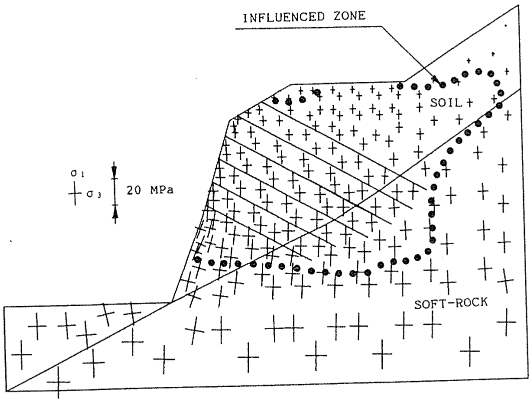

Figure 12 Principal stress distribution of the reinforced slope

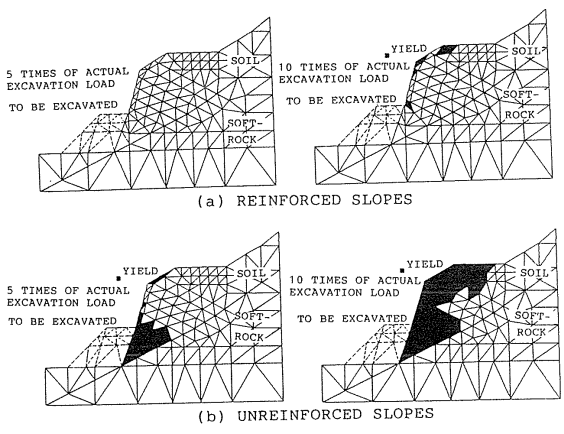

Figure 13 Comparison of failure pattern between unreinforced and reinforced slopes

Fig.13 shows the comparison of yielding pattern between reinforced and unreinforced slopes under loading of 5 and 10 times of actual unload force produced by excavation. It can be seen that extent of yielding elements in the reinforced slope is much smaller than in the unreinforced one. The zone of yielding in the unreinforced slope develops at the toe first and extends to all over the slope as the unloading level increases.

2.4 Long Term Slope Stability in Excavation Test

Typical measured maximum tensile force developed in the reinforcements, such A and C, versus the elapsed time is shown in Fig.14. From Fig.14 it can be seen that it took about two weeks for the tensile force developed in the reinforcement to reach a stable stage under an effect of excavation. This delayed response of the development of tensile force in the reinforcement may be due to the effect of the relic joint in the decomposed granite. The stress relief produced by excavation may cause the relic joint to expand. Such a swelling process is slow, because water absorption needs time for the water to penetrate. The field measurement shows that such a process takes about two weeks to reach a stable stage.

Fig.15 shows the axial force distribution of reinforcements at the stable condition,

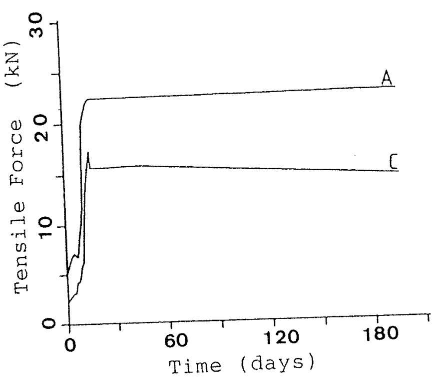

Figure 14 Measured tensile force versus day after excavation

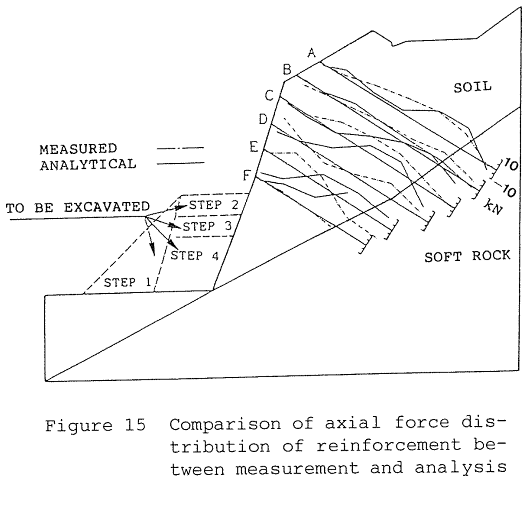

Figure 15 Comparison of axial force distribution of reinforcement between measurement and analysis

being obtained from field measurement and analyses. It should be noted that the unload force produced by excavation is applied only to the excavation surface in such cases of analysis. Both results show that the maximum tensile force is located at near the end of the reinforcements.

3 SLOPE STABILITY ANALYSIS

The local safety factor of element i is defined as,

$$FS_i = \frac{(2c\cos\phi + 2\sigma_3 \sin\phi)}{(\sigma_1-\sigma_3)\cdot(1-\sin\phi)} \quad (1)$$

The safety factor of a slip surface is defined as the average of the local safety factors of elements along the slip surface. The minimum factor of safety can be evaluated by a number of trial slip surfaces once the stress distribution within the slope is determined using the finite element method. The typical trial slip surfaces are given in Fig.16.

Table 2 shows the values of the factor of safety of the unreinforced slope at each excavation steps obtained by using the method of slices and the finite element method. The factors of safety obtained by using finite element method are close to that obtained by using the method of slices.

Limit equilibrium stability analysis methods have been used widely and successfully in the practice. However, in case of a reinforced slope cutting the limit equilibrium method could provide misleading safety factors due to its inability to represent the stress relief producing by excavation and the interaction between the soil and the reinforcement. Consequently, Table 3 shows the comparisons of factors of safety between the reinforced and unreinforced slopes at each excavation step, obtained by using finite element method. For all cases the factors of safety of a reinforced slope are significantly larger than those of the unreinforced slope. From the analytical values of factor of safety and the field observation, the success of slope stabilization using tensile inclusions, such as root piles, has been demonstrated.

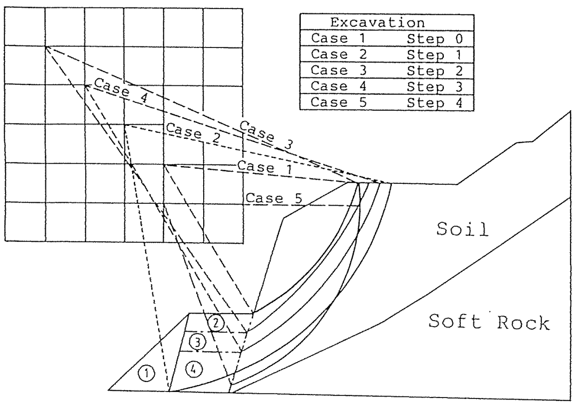

Figure 16 Typical trial slip surfaces

Table 2

Factors of safety of unreinforced slope at each excavation steps

Case	Method of slices	Finite element
1	0.84	0.89
2	0.76	0.83
3	0.70	0.78
4	0.67	0.69
5	0.62	0.61

Table 3

Comparisons of factors of safety between the reinforced and unreinforced slopes obtained by using the finite element method

Case	Unreinforced	Reinforced
1	0.89	1.24
2	0.83	1.05
3	0.78	1.03
4	0.69	1.01
5	0.61	1.00

4 CONCLUSIONS

Based on the analytical results together with the field measurements, some excavation characteristics of a reinforced slope cutting are summarized as follows:

(1) The axial forces developed in the reinforcements increase with elapsed time and reach a stable condition after two weeks. Just after excavation the maximum of axial force locates at near the surface of slope while in the stable condition at near the end of the reinforcement.

(2) The minor principal stress is significantly increased in the reinforced soil mass under the effect of the tensile inclusions. Consequently, the factor of safety significantly increases in the reinforced slope.

5 REFERENCES

Duncan, J.M., and Dunlop, P. (1969). Slope in stiff-fissured clayes and shales. J. Soil Mech. and Found. Engg. Div., ASCE, SM2, Vol.95, pp449-492.

Duncan, J.M., and Chang, C.Y. (1970). Nonlinear analysis of stress and strain in soils. J. Soil Mech. and Found. Engg. Div., ASCE, SM5, Vol.96, pp1629-1653.

Matsui, T., Abe, N., and San,K.C. (1986). A simple mechanistic model for slippage with application to reinforced soils. Proc. of 21st National Conf. JSSMFE, pp1093-1096.

Matsui, T., and San, K. C. (1987). Reinforcement mechanism of cut slope with tensile inclusions. Proc. 8th Asian Reg. Conf. SMFE., Kyoto, Vol.1, pp185-188.

Matsui, T., and San, K.C. (1988). A model forinterface slippage with application to reinforced soils. Soils and Foundations. (to be published)