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# Field monitoring procedure of cut slopes reinforced with steel bars

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ABSTRACT: The design of cut slopes reinforced with steel bars is not always reliable due to many unknown soil properties of the natural ground. Monitoring trial excavations is a suggested method to overcome this problem. If the performance of a trial reinforced cut slope is observed, collected data are useful for the safe construction of the reinforced cut slope.

The authors have constructed about 60 cut slopes reinforced with steel bars and have used monitored trials on some excavations.

As a result of these observations, it is confirmed that a monolithic reinforced zone was formed by inserting steel bars in the natural ground which then behaved like a concrete retaining wall.

## 1 INTRODUCTION

In recent years, many reinforced soil works have been constructed, though guidelines for the design have not been established. The mechanism of soil reinforcement have been studied in various laboratory tests (Hamada et al. 1984, Tatsuoka and Hamada 1984), field trials (Kitamura et al. 1987) and field monitoring (Noritake and Innami 1986). As a result, some design methods were proposed (Gässlar and Gudehus 1983). However, the actual behaviour of the reinforced cut slope may be significantly different from the behaviour predicted by these design methods, because of the non-uniformity of the natural ground. The authors considered that trial monitoring could be applied as effectively to reinforced cut slopes as to other earthworks e.g. embankments.

It is important to clarify the fundamental behaviour of a reinforced cut slope. This paper describes the monitored trial and the FEM prediction used for the construction of a cut slope reinforced with steel bars.

## 2 CONSTRUCTION PROCEDURE

The reinforced earth method is applied to a cut slope. This stabilizing technique is applied to the cut slope soon after each bench has been excavated so that the slope surface does not become loose due to the relaxation of stress. The construction sequence is as follows:

a) Excavation with bench height of 1.0 to 2.0 m
b) Shotcreting to protect the slope face
c) Boring holes, usually 45 mm diameter, in the ground at the designed spacing; inserting steel reinforcing bars into the bored holes and grouting.

This sequence is repeated for every bench until the designed cut slope is completed.

## 3 APPLICATION OF TRIAL MONITORING

### 3.1 Outline

A slope was excavated adjacent to a railroad track for the construction of a bridge pier.

Photograph 1 shows the excavation to which the reinforced earth technique was applied (Suda et al. 1984). Figure 1 shows a cross section of the reinforced cut slope.

1) Deformed bars (25 mm diameter, 3.0 to 7.0 m length) were inserted in the slope at a rate of $1/m^2$ of the slope surface.
2) The gradient of the cut slope was 1:0.5 and the height was 11.6 m.

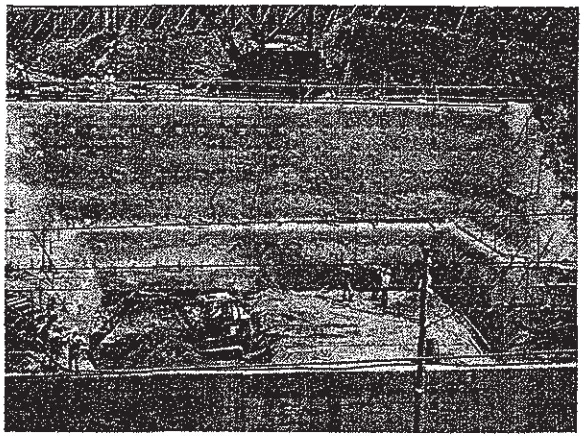

Photo. 1 View of reinforced slope

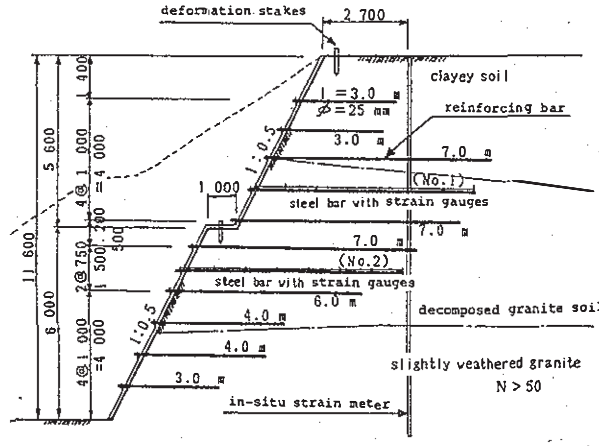


Fig. 1 View of reinforced slope and arrangement of field measuring equipment

3) The slope surface was protected with 7.0 cm thick wire-mesh reinforced shotcrete.
4) The slope was excavated by cutting benches.
5) The height of each bench was 1.0 m to 2.0 m.
6) The excavation took 20 days to complete.

The ground consists of three layers as shown in Figure 1. The first layer is clayey soil, the second layer is decomposed granite soil and the third layer is slightly weathered granite.

Table 1 shows the physical properties of the clayey soil and the decomposed granite soil obtained from laboratory and field tests.

Figure 1 shows the measuring apparatus used for monitoring the reinforced cut slope. One in-situ strain meter, nineteen deformation stakes and two reinforcing bars with strain gauges were used.

### 3.2 Results

Figure 2 shows the maximum value of the measured horizontal deformation in the ground with elapsed time from the ground surface to a depth of 7.0 m and the settlement of the ground surface. Progressive deformation occured during the excavation. The rate of deformation decreased after completion of the excavation. The slope was left for about one month until the construction of the pier was completed. The rate of deformation was very low after excavation.

Table-1 Physical properties of decomposed granite soil

| | | unit | clayey soil | decomposed granite soil | |
|---|---|---|---|---|---|
| unit weight | $\gamma$ | $tf/m^3$ | 1.5~1.6 | 1.8~ 2.0 | |
| water content | $\omega$ | % | —— | 1.5~ 21.0 | |
| internal frictional angle | $\phi$ | degree | 10~16 | 28~ 36 | direct shear test |
| cohesion | C | $tf/m^2$ | 0.05~0.12 | 0.1~ 0.2 | |
| coefficient of permeability | $\kappa$ | cm/sec | —— | $6.3\times10^{-5}$ | |
| modulus of elasticity | E | $kgf/cm^2$ | 32~59 | 140~ 180 | plate loading test |

These results show that the elastic deformation of the slope was caused predominantly by the release of the in-situ stress in the ground during excavation with more gradual deformation after completion of the excavation. The elastic deformation represented 85 to 90% of the total deformation and occurred during the period of excavation. It is necessary to observe the reinforced cut slope carefully to assess its stability. Measuring apparatus must be set up before the excavation, because the data from the beginning of the excavation are necessary to estimate and analyse the stability of the slope.

Figure 3 shows the measured surface deformation of the reinforced cut slope after excavation. Although the slope showed displacement, it remained flat and there was no cracking on the shotcrete surface. These results showed that the reinforced cut slope behaved as a rigid body. However, it was predicted from the results of an FEM analysis that a non-reinforced cut slope would not behave as a rigid body.

Figure 4 shows the measured displacement in the ground. From this figure, it was found that the displacement from the ground surface to a depth of 7.0 m was constant, and the first and second layers moved laterally as a rigid body. The conclusion drawn from this was that the area reinforced with steel bars behaved as a rigid body.

The displacements of the slope surface and the cracks in the shotcrete must be carefully observed. Elsewhere, irregular deformation of the slope surface and cracking of the shotcrete were observed at another temporary cut surface for which the reinforcement was insufficient.

Figure 5 shows the relationship between the axial forces in the reinforcing bars and elapsed time. Axial force worked in a complicated manner. A compressive force was observed in the section near the slope surface of both reinforcement bars and the compressive force increased gradually with time after completion of excavation. At the same time, the tensile force which occurred in the rest of the steel bar decreased slowly.

From these results it was confirmed that the area reinforced with steel bars behaved as a rigid body and showed the same behaviour as a concrete retaining wall.

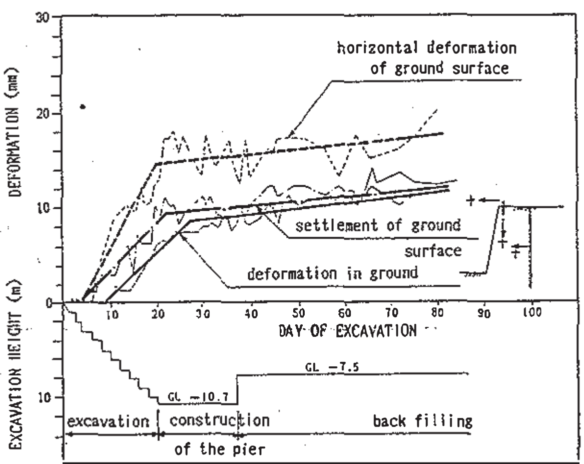


Fig. 2 Measured deformation and settlement with time

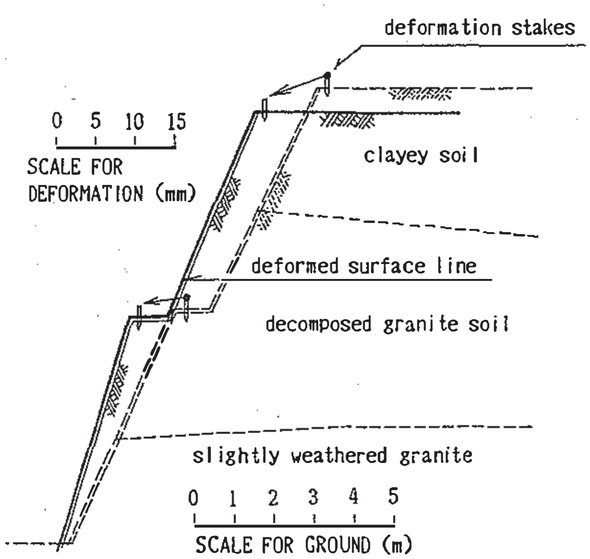


Fig. 3 Deformation of cut slope surface

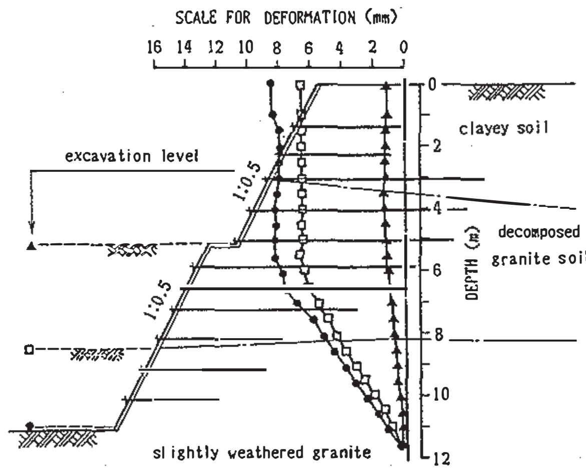


Fig. 4 Measured deformation in the ground

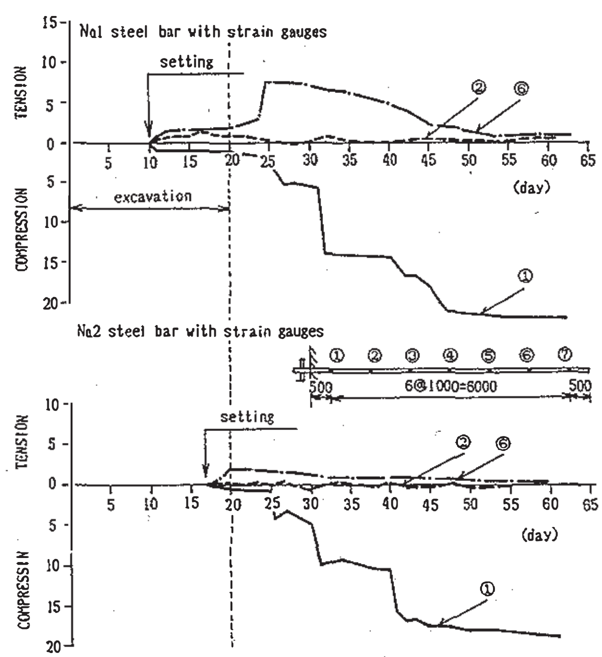


Fig. 5 Relationships between the axial force and elapsed time

## 4 TRIAL MONITORING

The trial monitoring takes the following process: design, trial construction, monitoring, analysis, judgement and full construction.

An FEM analysis (Kitamura et al. 1988) which considered the discontinuity between the reinforcement and the natural ground was used with the trial monitoring.

Figure 6 shows the calculated deformation of the reinforced cut slope using the FEM analysis and Table 2 shows the physical properties assumed for the analysis. The figure shows that the calculated slope remained a plane surface and was similar to the observed results.

Figure 7 shows the observed and the theoretical deformation at the position of the in-situ strain meter after completion of the excavation, and both deformations show the same tendencies and characteristics.

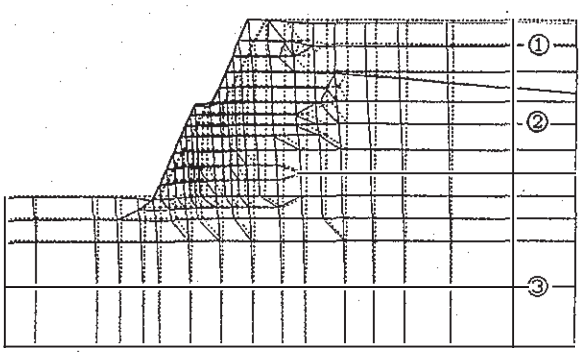


Fig. 6 Calculated deformation by FEM analysis

Table-2 Physical properties used for analysis

| | | unit | stratum① | stratum② | stratum③ | steel bar |
|---|---|---|---|---|---|---|
| modulus of elasticity | E | tf/m² | 400 | 1500 | 5000 | 104600 |
| unit weight | γ | tf/m³ | 1.6 | 1.9 | 2.0 | 1.92 |
| poissons ratio | ν | | 0.40 | 0.35 | 0.20 | 0.3 |
| cohesion | C | tf/m² | 1.0 | 1.5 | 10.0 | — |
| internal frictional angle | φ | degree | 15 | 30 | 3 | — |
| c & φ between soil and bar | | φ=30° c=2.63 tf/m² | | | | |

Figure 8 shows the measured and theoretical axial force distributions. The measured axial force was smaller than the theoretical one because the steel bars with strain gauges had to be placed after the excavation of each bench. However, the observed axial force distribution was similar to the theoretical one. The axial force in the lower steel bar with strain gauges was not so significant because the excavation was completed 4 days after the bar was set.

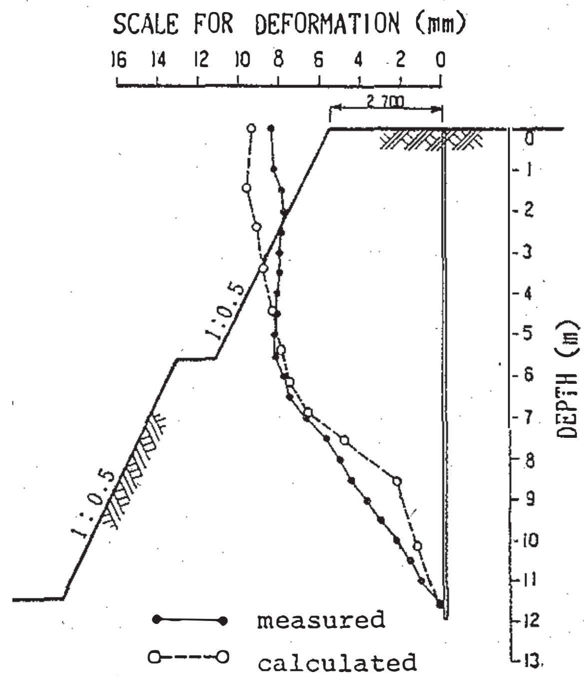


Fig. 7 Comparison of measured and analysed deformations

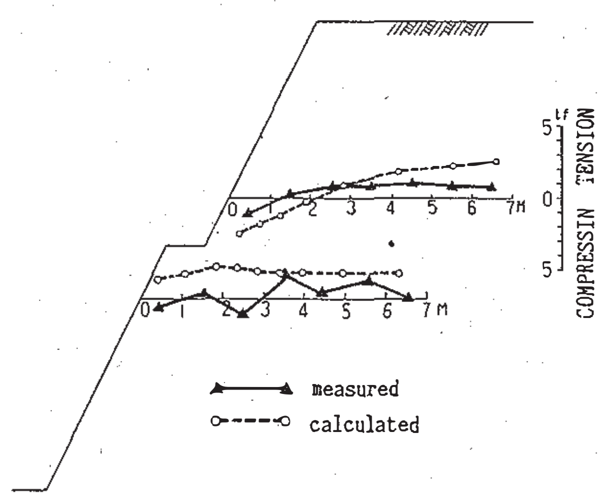


Fig. 8 Comparison of measured and analysed axial force distribution

Figure 9 shows the safety factor distribution calculated from the FEM analysis. This figure shows that the unstable elements are found only near the slope surface and it means that the effect of the reinforcement does not work satisfactorily near the slope surface. Therefore an appropriate protective work, such as shotcrete, fulfills an important function for stabilizing the slope.

It was confirmed that FEM analysis can be carried out as an effective part of the trial monitoring procedure.

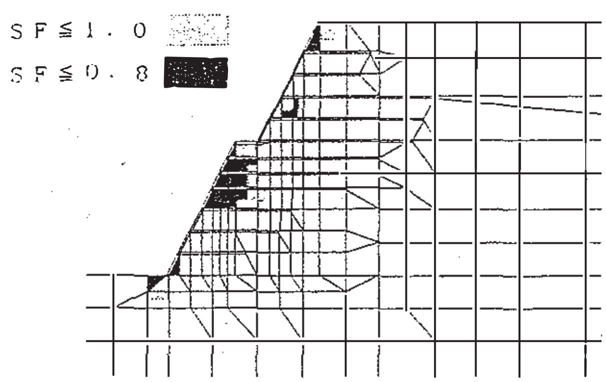


Fig. 9 Safety factor distribution by FEM analysis

## 5 CONCLUSIONS

The main conclusion obtained are as follows:

1) A reinforced cut slope shows the same characteristics and behaviour as a concrete retaining wall, because the area reinforced with steel bars behaves as a rigid body.
2) It is confirmed that the monitoring of elastic displacements during excavation is important for ensuring the stability of the reinforced cut slope. Thus, displacement of the slope and ground surface have to be measured, and deformation and cracking of the slope surface have to be observed.
3) An FEM analysis which considers the discontinuity between the reinforcing members and the ground is able to simulate the behaviour of the reinforced cut slope satisfactorily and it gives confidence in the trial monitoring procedure.

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