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Evaluation of long-term reliability of reinforcing materials

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ABSTRACT: To evaluate the long-term durability of reinforced soil structures is important and complicated process when the engineers design them. One of the most significant factors having an influence upon the long-term durability of such structures is corrosion of the reinforcing materials.

During the process of performing some expressway widening works, the authors took the reinforcing steel bars out from a reinforced slope that had been constructed more than 20 years before. The authors found that the reinforcing materials, which had simply been protected with mortar grout without any particular anti-corrosion treatment, were almost free from corrosion and cross-sectional loss.

This paper describes the results of tests made on those reinforcing materials and proposes concepts for determining safety factors of reinforcing materials.

1. INTRODUCTION

Reinforced earth method has been used in Japan for the past 20 to 30 years to stabilize the cut slopes. A lot of construction records have been accumulated for these years. However, this method is used for temporary work in most cases. Although several design methods have been proposed and used in design and calculation, many issues, such as the standardization of safety factors and research into optimization are remaining. Durability evaluation is a topic that particularly requires further consideration, since there has thus far been little experience with reinforced as permanent structures.

For designing of the reinforced earth, the safety factors should be considered to the load, resistance force of the ground and reinforcing materials.

However, engineers cautiously substitute safety factors of similar structures for that of reinforced slopes, since the permanent reinforced slope is one of the unexperienced soil structure. It is unclear how much allowance such safety factors will give for the structures. In order to take both economic efficiency and safety into consideration, it is necessary to determine the safety factors in accordance with the soil conditions, significance and service life of the reinforced ground slope. This paper referrs the safety factors concerning on the durability of reinforcing materials.

2. PARTIAL SAFETY FACTORS

The circular slip kinematical limit analysis shown in Figure 1 is one of the design methods for reinforced cut slope. This method employs the safety factors shown below:

1) Safety factor for slope failure (Fs1)
2) Safety factor for anchor strength of the reinforcing materials (Fs2)
3) Safety factor for taking account of deterioration in the strength of the reinforcing materials (Fs3)
4) Safety factor concerning protection structures of the slope surface (Fs4)

To find the appropriate safety factor for permanent reinforcement, engineers may borrow it from the safety factors used in similar soil structures. For items 1) and 4), it is possible to collect a relatively large amount of reference data. The safety factors of 1.2 to 1.5 adopted in the slope stability standards of major organizations may be of use for item 1) for instance. However, there is little reference data available for items 2) and 3) except for earth anchor data. Accordingly, engineers have no choice but to use safety factors with

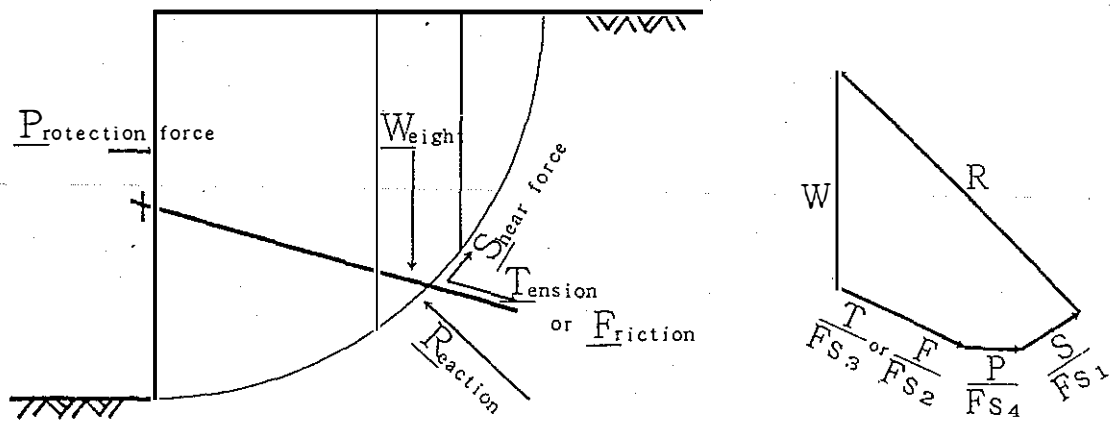


Figure 1. Circular slip kinematical analysis

some degree of uncertainfy. And although earth anchors appear to be a similar form of construction, they are actually quite different in structure. Thus the engineers cannot adopt also the earth anchor data unconditionally. If a corrosive reinforcing material is used, how should the engineers take the corrosion of the material, deterioration of anchor strength and cross-sectional loss into account? In the following, how to determine item 3) out of the two types of safety factors is considered based on the results of the author's investigation.

3. REINFORCED GROUND SLOPE

The examined reinforcing material had been constructed into the cut slopes on the former Tomei Expressway more than 20 years before. Figure 2 shows the cross section of the reinforced cut slope.

Table 1. Outline of the previous reinforced slope

Soil composition	Talus sediment and strongly-weathered tuff bressia
Reinforcing material	SD30, ϕ =32 mm no anti-corrosion treatment
Boring dia.	ϕ =66 mm
Grout	all-out bond type mortar grout
Location	Yamakita project area, Tomei expressway

Table 1 shows the soil and ground conditions of the slope and the reinforcing conditions.

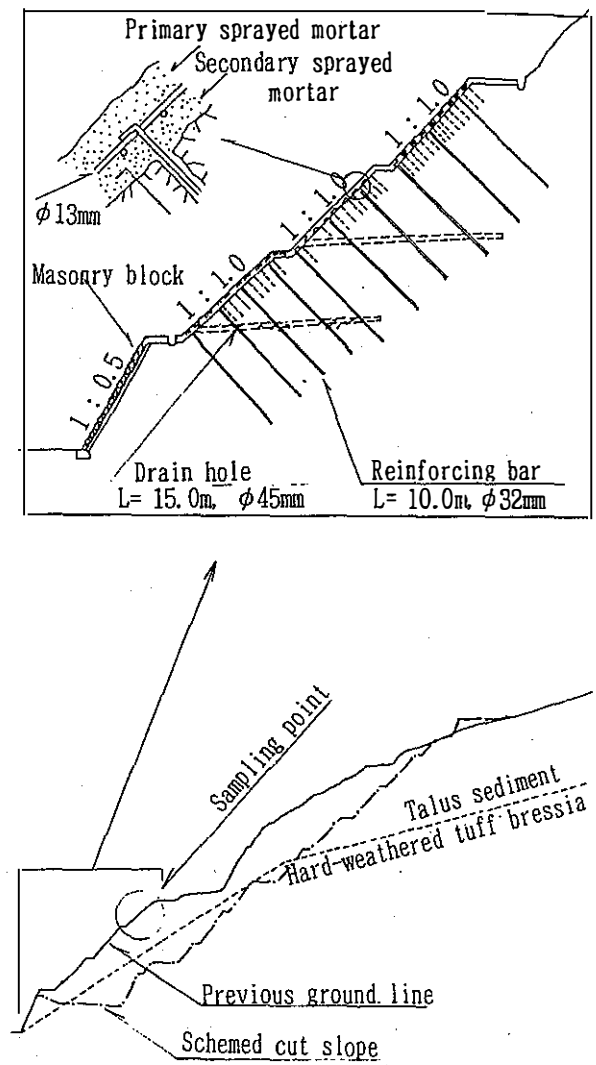


Figure 2. Cross section of the reinforced cut slope on Tomei Expressway

4. SAMPLING AND MATERIAL TESTS

The reinforcing materials were carefully dug out by a back hoe. They were checked for corrosion visually and were examined for deterioration in strength using tensile strength tests in compliance with the JIS Z 2241 Method of tensile strength testing for metallic materials. Average stress increment by the loading was 20 Mpa/s. The authors randomly selected five samples from the extracted reinforcing materials, cutting them into pieces 50 cm in length.

5. RESULTS OF VISUAL INSPECTION AND STRENGTH TESTS OF REINFORCING MATERIALS

From the results of the visual inspection and tensile strength tests, the authors found the following:

(1) Most of the sampled reinforcing bars had been well covered and anchored with mortar grout, as shown in Figure 3.

(2) Ribs and nodes on the extracted reinforcing bars were preserved clearly, as shown in Figure 4. They were almost free from rust even though they had been in the ground for more than 20 years. Neither had the reinforcing bars suffered any cross-sectional loss. This applies to virtually all of the reinforcing bars. The authors could not find any partial corrosion on any of the reinforcing bars.

(3) Table 2 shows the results of the tensile strength tests. It is clear from the Table that samples No.1 to No.4 had not experienced any deterioration in strength. Their yield points, tensile strength and elongation were equivalent to SD30, i.e., the initial mechanical properties of steel bars for concrete reinforcements specified in JIS of those days. There was almost no variation in the properties of the test samples.

6. VIEW OF DURABILITY

The partial safety factors used for the limit state design methods of soil structures are roughly classified into load coefficients and resistance coefficients. Resistance coefficients are mainly used with regard to the shearing force of the ground. In addition, reinforced ground implies that the reinforcing material has some degree of resistive force. Thus, two types of resistance coefficients should be adopted. One is the resistance coefficient of the reinforcing material, which is called the reinforcing material coefficient in the following, in relationship to the durability of the reinforcing material.

If the degree of corrosion cannot be predicted during design, expensive mate-

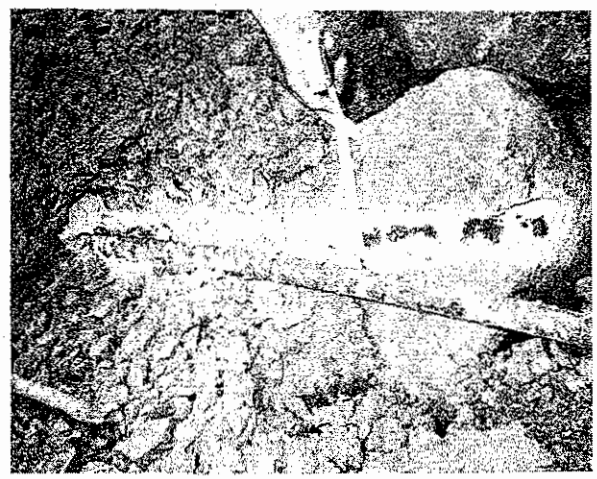
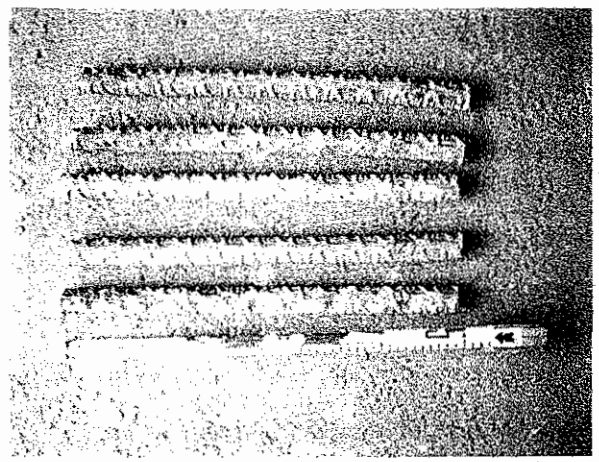


Figure 3. Condition of mortar grout



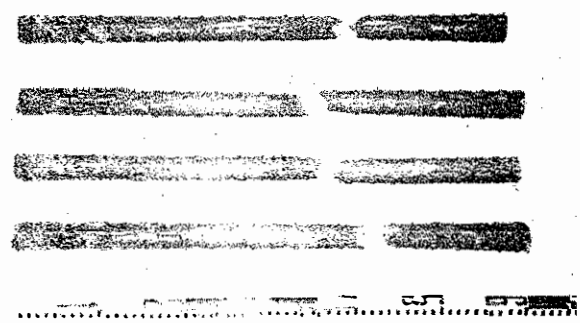


Figure 4. Sampled reinforcing steel bar

Table 2. Results of tensile test for reinforcing steel bar

Specimen	Yield load (kN)	Failure load (kN)	Yield stress (MPa)	Tensile strength (MPa)	Extensibility (%)
No. 1	249	398	314	500	23.3
No. 2	249	407	314	513	29.3
No. 3	247	404	311	509	25.0
No. 4	248	400	313	511	24.5
No. 5	——	415	——	522	——
JIS provision for SD30			over 294	480~617	over 18

rials that will not corrode should be used, or a generally-used corrosion margin should be introduced. Assuming that a reinforcing bar 32 mm in diameter will be corroded by 0.3 mm in thickness every year for 20 years, its original cross sectional area of approximately 8 cm^2 will be reduced to approximately 5.3 cm^2 for instance. Thus, a safety factor of 1.0 to 1.5 should be taken into account as the reinforcing material coefficient. If a reinforcing bar will be virtually free from cross-sectional loss or deterioration in strength due to corrosion, the reinforcing material coefficient may be set approximately to 1.0, resulting in a remarkably economical design.

7. CONCLUSION

The authors reached the conclusion that reinforced bars protected with mortar grout will be free from cross-sectional loss or deterioration of properties even if they are left under the ground more than 20 years.

With further advance in limit state design methods, it will be necessary to determine ranges for various safety factors and choose the value of the safety factors by engineers within those specified ranges. The authors will be pleased if the information presented in this paper proves to be helpful in designing the safety factors for permanent slopes of reinforced ground.

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