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An investigation of the durability of the soil nailing method

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ABSTRACT: It is not too much to say that the soil nailing has been applied to permanent slopes without verifying its long-term durability. Therefore, to investigate its long-term durability, we checked the stability of nine slopes, which were constructed about 10 years ago, making reconnaissance of them, and carried out the examination of the corroded condition of reinforcing bars collected by means of over-core boring, the material testing and so on. The corroded area ratio and the depth of corrosion were measured. In addition, a tensile test of the same reinforcing bars was carried out. As a result of of the authers investigation of the corrosion of reinforcing bars, the information suggesting that the following two factors of the cause of corrosion were obtained; at first, corrosion due to insufficient injection of grout into the part around the top of a reinforcing bar, secondly, corrosion due to insufficient grout cover in a deep part and insufficient injection of grout into such part.

1 INTRODUCTION

Soil nailing is a method of increasing the strength of cut slopes and natural slopes by inserting reinforcing bars into their natural grounds to prevent their failure and to make slopes steeper and shorter. Since 1985 or so, Japan Highway Public Corporation among other companies and institutes has performed many experiments and tests for the effect of this method and this has been adopted widely in the field. Because of its short history, however, a rational durability design method based on some verification result of the long-term durability have not yet been developed.

To study the long-term durability, we investigated the corrosion condition of reinforcing bars of soil nailed slopes about 10 years old by over-core boring, material testing, etc. (Matsuyama et al.,1994, 1995)

2 INVESTIGATION METHOD

2.1 *Reconnaissance of slopes*

The investigation was conducted in 1993 and 1994 at the nine slopes shown in Table 1. Their construction years and geologies are also described in the table. In 1986, these slopes were subjected to our reconnaissance and the conditions of the faces of the slopes were recorded on their slope-face developments. In the investigation this time, the reconnaissance of the slopes was conducted as well to draw their slope-face developments and they were compared with those of 1986 to study the changes of their conditions.

Table 1. Summary of investigation sites.

Inv. year	Inv. site	Const. year	geology
1993	A	1983	Mesozoic, lightly weathered sandstone
	B	1985	Paleozoic, lightly weathered tuff
	C	1984	Talus-cone deposit and cohesive soil containing gravel
	D	1984	Paleozoic, weathered sandstone
1994	E	1979	Paleozoic sandstone and crystalline schist
	F	1985	Neocene mudstone and sandstone
	G	1987	*Kanto* loam
	H	1984	Neocene andesite and tuff
	I	1985	Middle Paleozoic sandstone and mudstone

2.2 *Investigation of corrosion of reinforcing bars*

In case of reinforcing bars of which the heads were covered by concrete spraying, etc., the heads of three bars were chipped out at each slope and the corrosion conditions were observed visually. Then, at seven of the nine slopes, three reinforcing bars each were sampled by over-core boring. The outer diameter of the over-core boring was 116 mm. In accordance with the "Evaluation Methods of Corrosion of Steel in Concrete" edited by Japan Concrete Association, corrosion products were removed from the bar samples and the corroded area ratios at regular intervals of 10 cm and the depths of pitting corrosion were measured, the former being the ratio of the corroded area to the sectional area of a bar. Besides, tension tests using the same samples were conducted.

2.3 *Pull-out tests*

In the site D, further three reinforcing bars were subjected to pull-out tests. They were tested under repeated loading of the load degree of 4.9 kN and the loading rate of 4.9 kN/min. in accordance with the "Pull-out Test Method of Rock Bolts, JHS 705-1992 (Japan Highway Public Corporation, 1992)." Since these bars were reinforcing material of the permanent structure, they were grouted over the whole length, unlike pre-execution test grouting with a short anchorage length to check the anchor strength.

2.4 *Soil and water analyses*

Spring water from, and soil of, the slopes were sampled to determine the pH, specific resistance, and the concentrations of Cl^-, SO_4^{2-}, and NO_3-N with Table reference to the Japanese Industrial Standard.

3 RESULTS OF INVESTIGATION

3.1 *Conditions of faces of slopes*

At all the slopes except that of the site D, earth-reinforcing work was executed to prevent them from their deformation and/or prevention of their failure. As the result of the investigation, no indication of unstabilization of any slope was found, though some deterioration of sprayed concrete was observed.

3.2 *Corrosion environment*

Table 2 shows the results of the soil and water analyses. Described in the sections of "Remarks" with reference to the literature are the conditions under which reinforcing bars are vulnerable to corrosion. Although the soil and water of some slopes presented weak acidities, the acidity of pH $\leqq$ 4 which would cause heavy corrosion was observed nowhere. Specific resistance, which is dependent upon the water and salt contents of the soil, is a main factor which influences the circuit resistance of corrosion cells. Low specific resistance promotes corrosion, and it is said that corrosion becomes heavy when the resistance goes down below 700 Ω/cm. The site F showed a comparatively low specific resistance of 800 Ω/cm, suggesting a corrosive environment. The

Table 2. Results of the soil and water analyses.

Investigation site	Soil analysis		Water analysis				
	pH	Specific resistance (Ω/cm)	pH	Specific resistance (Ω/cm)	Cl^- (ppm)	SO_4^{2-} (ppm)	NO_3-N (ppm)
A	8.64	12,300	8.10	3,570	4.06	22.77	N.D.
B	5.70	50,250	7.28	9,840	4.38	5.31	0.78
C	6.12	29,500	6.85	11,380	4.38	6.95	1.73
D	10.90	2,440	8.10	4,440	7.62	8.33	0.80
E	11.41	1,770	8.32	2,793	9.41	30.93	N.D.
F	7.98	7,752	5.76	800	120.02	448.98	N.D.
G	7.30	14,706	7.30	14,706	1.07	4.98	1.70
H	5.95	15,385	7.06	6,667	7.62	12.13	1.52
I	5.58	27,777	7.56	2,817	17.55	21.49	1.61
*Remarks	serious if ≤ 4	serious if < 700	serious if ≤ 4	serious if < 700	affected if several hundreds	affected if several hundreds	

* Japan Highway Public Corporation, 1992

Table 3. Corrosion condition of reinforcing bars.

Inv. site	Specifications of earth reinforcing work			Corrosion of reinforcing bar				Result of tension test		Reference strength	
				Above ground	Below ground						
	Bar & bore*1	cover-ing (mm)	Type of facing	Bar head	M. C.A.R (%)*2	L.M.C. (cm)*3	M.D. P.C. (mm)*4	Yield strength (MPa)	Tensile strength (MPa)	Yield strength (MPa)	Tensile strength (MPa)
A	D = 25, SD35 L = 1.2 ø = 40	7.5	I	Ob-served	74	0 - 10	5.76	— — —	559 539 588	343 or more	490 or more
B	D = 19, SD30 L = 3.0 ø = 46	13.0	I	Ob-served	95	0 -10	1.75	— 363 363	549 549 559	294 or more	480 - 617
C	D = 29, SD30 L = 8.0 ø = 90	30.6	II	Nil	0	—	Nil	392 392 392	608 698 608	294 or more	480 - 617
D	D = 22, SD30 L = 2.4 ø = 66	22.0	II	Ob-served	38	10 - 20	Nil	353 — 353	559 559 539	294 or more	480 - 617
E	D = 25, SD30 L = 2.0 ø = 42	8.5	II	Nil	38	0 - 10	1.40	421 382 441	608 669 627	294 or more	480 - 617
F	D = 32, SD30 L = 2.0 ø = 46	7.0	II	Nil	100	140 - 190	1.87	363 412 412	549 608 608	294 or more	480 - 617
G	D = 25, SD30 L = 5.0*5 ø = 40	7.5	IV	Nil	9	390 - 400	0.84	392 392 392	578 578 578	294 or more	480 - 617
H	D = 25 L =4.0*5 ø = 46	10.5	III	Nil	—	—	—	—	—	—	—
I	D = 25 L = 4.0 ø = 66	20.6	IV	Ob-served	—	—	—	—	—	—	—

*1: Diameter (D mm), material (SD), and length (L m) of reinforcing bars and diameter (ø mm) of bore
*2: Maximum corroded area ratio
*3: Location of maximum corrosion (Distance from ground surface)
*4: Maximum depth of pitting corrosion
*5: Galvanization

concentrations of Cl^-, SO_4^{2-}, and NO_3-N are also influential upon corrosion and those in the site F were a little high.

3.3 *Corrosion of reinforcing bars*

Table 3 summarizes the results of the corrosion investigation. No sample bars presented a strength lower than the reference strength in the tension tests, though partial corrosion and pitting corrosion were observed in some parts. The values of the yield point strength and the tensile strength were constant in the sites C and G where no corrosion was observed, whereas those in the other sites varied.

Table 3 shows the coverings of grout and the types of slope facings as relevant data. The slope facings were classified into four types shown in Fig. 1.

Now let us see the relation between the slope facing types and corrosion of the bar heads. Such corrosion was observed in the sites A and B where adopted was the type I facing under which the pressure-bearing plates contacted directly with the natural ground and in the site I where adopted were the type III and IV

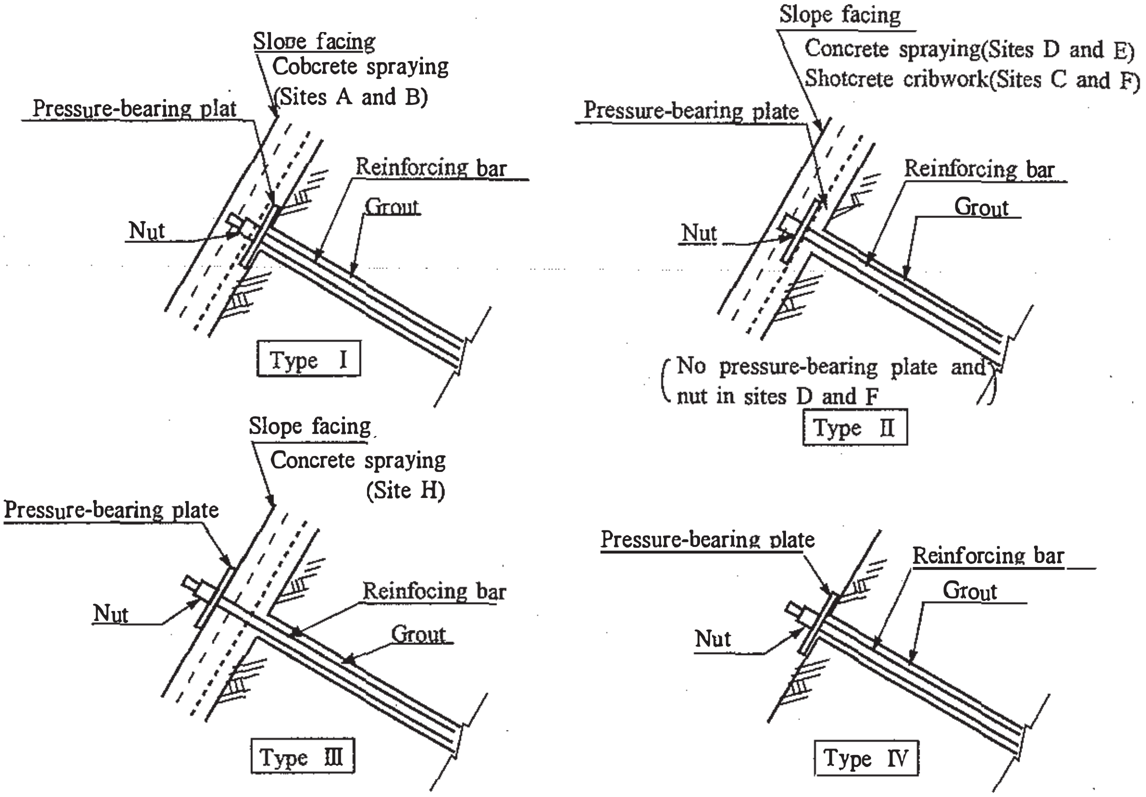

Fig.1 Type of slop facings.

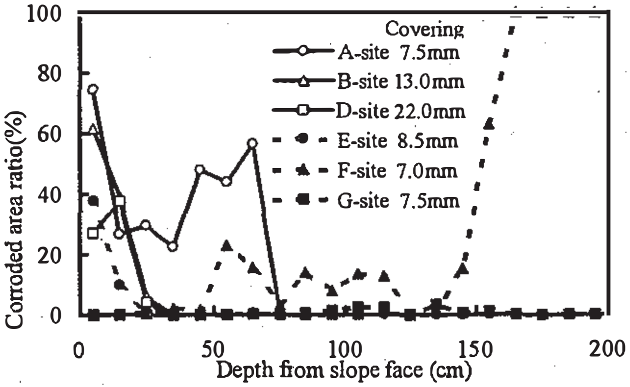

Fig.2 Distribution of corroded area ratio.

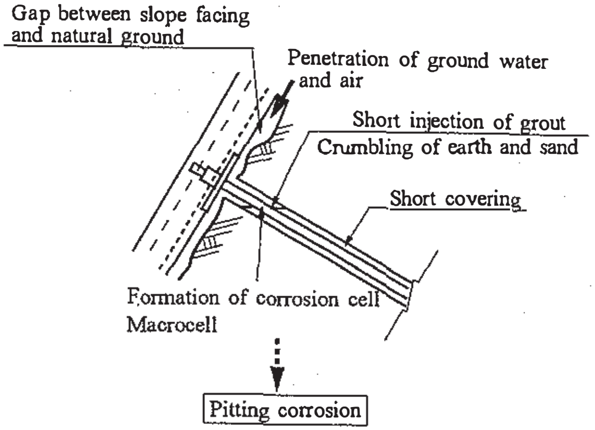

Fig.3 Corrosion factors presumed.

facings which exposed the pressure-bearing plates to the open air. The bars in the sites G and H had galvanized heads and corrosion was slightly observed in their threaded areas in the site H only. No bar-head corrosion was observed in the sites of the type II, except the site D where the bars bent in advance contacted the natural ground in part where corrosion was observed.

Fig. 2 shows the distribution of the corroded area ratios of the representative bar of every site. In case of the site C, no corrosion was observed at all. Fig. 3 is a typical illustration of corrosion factors, of which the discussion follows. About a half of the reinforcing bars in the sites A, B, D, and E presented corrosion in the depth of up to 30 cm from the ground surfaces, and some of them pitting corrosion, too. It appears to be the cause of this corrosion that some of the grout permeated into the soil after injection, creating a shortage in the upper space of the bore.

The reinforcing bars in the sites A, F, and G (just slightly, here) presented corrosion in deep areas. Photo 1 shows the condition of a sample which was collected from the depth and the corrosion products were removed from. On the other hand, no corrosion in the

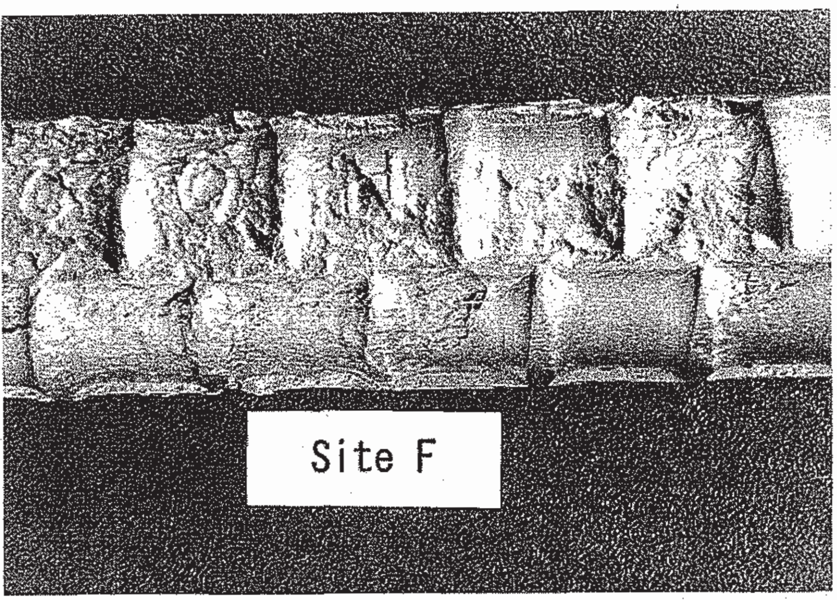

Photo 1 Corrosion of reinforcing bar (Site F).

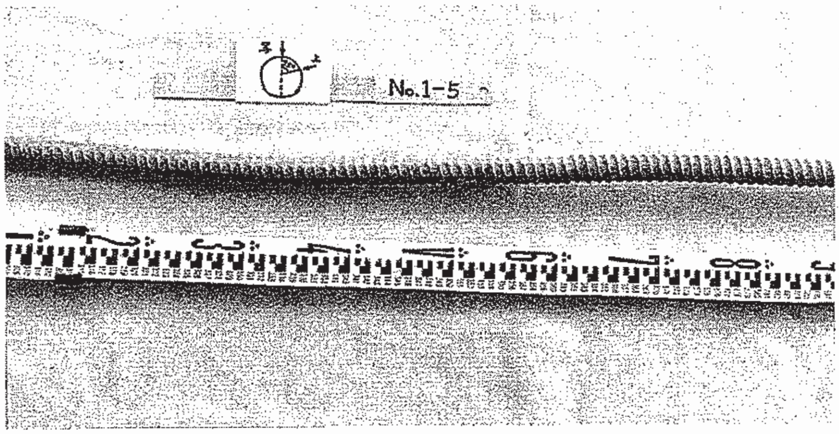

Photo 2 Bend of reinforcing bar (Site G).

depth was observed in the sites B, C, and D where the coverings were over 10 mm. These observation results suggest that short coverings and inadequate injection of grout caused the corrosion in the depth. Besides, the site F was located in a corrosive environment, which should have furthered the corrosion.

3.4 *Results of pull-out tests*

The pull-out tests were performed on three reinforcing bars in the site D, and the result of the representative case is shown in Fig. 4. No yielding or pulling out was observed in this load range. Besides, the displacement under the load of 100 kN was only of the order of a few millimeters and the residual displacement only about 0.5 mm. It appeared from these results that this reinforcing bar and the grout were still functioning well.

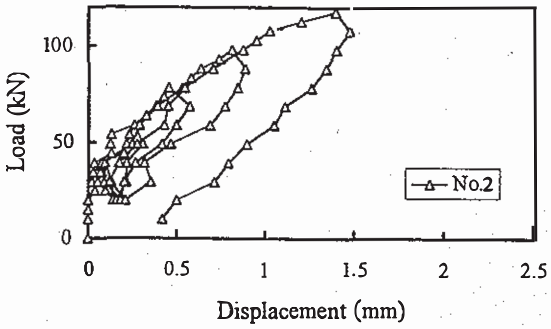

Fig. 4 Result of pull-out test.

3.5 *Deformation of reinforcing bars*

Some of the reinforcing bars sampled in the sites A, B, C, E, and G were bent. Photo 2 shows the bending condition of a bar of the site G, which seems to have been taking a bending resistance. A reinforcing bar in the site A had a bend near the ground surface and, therefore, its preexistence could visually be confirmed during the first several tens of centimeters of the boring.

4 CONCLUSIONS

Although the number of the investigated sites this time was limited to only nine, the following findings could be obtained:

(1) The causes of corrosion were (i) shortage of grout at the top areas of reinforcing bars and (ii) short coverings and inadequate injection of grout in deep areas. Besides, the treatment methods of the heads of reinforcing bars may be a factor of the corrosion.

(2) As the result of the pull-out tests of three reinforcing bars at a site, it was ascertained that the reinforcing bars and grout were still functioning well.

REFERENCES

Matsuyama, H. ,T. Naruse and S. Tayama. (1994). Investigation of long-term stability of soil nailing, *Proc. 49th Annual Conf. on JSCE*,Part 3 pp.1618-1619 (in Japanese)

Matsuyama, H. ,T. Naruse, S. Tayama, H. Maeno and M. Muramatsu.(1995).Investigation of durability of soil nailed cut slopes, *Proc. 50th Annual Conf. on JSCE*,Part 3 pp.1588-1589 (in japanese)

Japan Highway Public Corporation. (1992). *Test Methods of Japan Highway Public Corporation.* (in Japanese)

The Japanese Society of Soil Mechanics and Foundation Engineering. (1990). *Standards for Design and Construction of Ground Anchors, Manual for Design and Construction of Ground Anchors.* (in Japanese)