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Behavior and control of cable duct in proximity to ground excavation work

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ABSTRACT: Large-scale open-cut ground excavation work was performed in the central part of the City of Hiroshima. This report summarizes the behavior and control results of an NTT cable duct located in close proximity to the work site. It was found that the work had large effects on the cable duct such as a cavity displacement of 3 to 7 mm, an inclination of 0.20 to 0.23 degree toward the excavation side, and occurrence of cracks of lining concrete. However, by comparing the measured values with the analysis values obtained by a preliminary study on the cable duct stress, the stress was estimated to be no higher than the allowable stress, and it was verified that no structural problems were caused. Also, the danger of damage to the cables caused by the peeling-off of concrete was eliminated by taking protective measures for the cables.

1 INTRODUCTION

Large-scale open-cut ground excavation work was performed in the central part of the City of Hiroshima in association with the construction of a new transportation system.

When starting this work, it was worried that the work might have an adverse effect on the NNT cable duct (hereinafter referred to as the cable duct) located nearby in parallel with the work position. In the cable duct, communication cables and electric power cables are laid. They were performing important functions for maintaining the social activities, and damages on these cables would have a large effect on society. Therefore, measurement control was carried out to analyze the effect caused by the work and to take countermeasures if necessary.

The cable duct is composed of a primary lining (t =200 mm) of reinforced concrete segments and a secondary lining (t =100mm) of plain concrete. It would not be possible to know the stress state inside of the primary lining after the work was completed. Also it would be difficult to directly measure the incremental stress caused by the excavation. Therefore, the behavior of the cable duct was analyzed in advance of the work by the finite element method (hereinafter referred to as the FEM). The initial stress, incremental stress, displacement, and inclination of the lining were estimated. Since the displacement and inclination were able to be measured, the control standard values were set based on the results of the preliminary analysis, and the work was controlled by comparing the measured values with the control standard values.

This report describes the results of the preliminary analysis of the cable duct behavior, the measurement control plan, the actual behavior of the cable duct, and the control results.

2 OUTLINE OF OPEN-CUT EXCAVATION WORK AND PROXIMITY OF CABLE DUCT

Figure 2 shows horizontal and vertical views of the open-cut excavation work, and the relative position of the cable duct. The excavation was carried out in the horizontal dimension of 199 m x 16m and to the depth of 15.5 m. The ground condition is poor as a soft alluvial clay layer accumulates below the depth of about 9 m from the ground surface with a thickness of about 14m. There is confined groundwater in the gravel layer below the alluvial clay layer. The deep impermeable wall method (a ground improvement method by chemical injection) was adopted to prevent the ground from being heaved by the confined water during the excavation.

The cable duct has a diameter of 4.55m, and is about 4.1m away from the landslide protection wall made of steel pipe sheet piles of 600 dia x 9 @ 690. The cable duct is in close proximity to the work, and lies in the area which might be affected

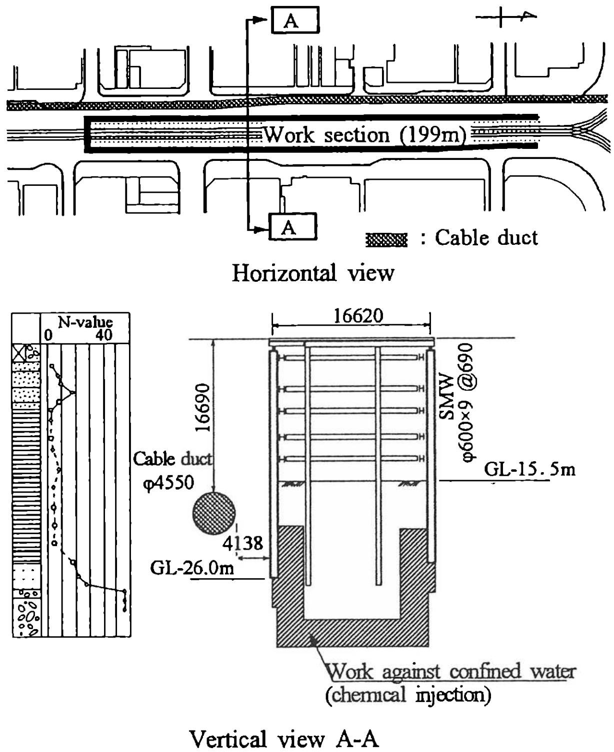

Figure 1. Positional relationship between open-cut work and cable duct.

by the ground displacement caused by the open-cut excavation.

3 FEM ANALYSIS OF EFFECTS ON CABLE DUCT

3.1 *Analysis conditions*

1) Analysis method: Two-dimensional elastic FEM analysis
2) Analysis cross section: Cross section A-A (Fig. 1)
3) Ground condition, etc.: Table 1 gives the physical properties of the ground and the particulars of beam elements. The primary and secondary linings are of an overlapped wall structure, and their rigidity was determined by considering the joining conditions.
4) Analysis procedure: Firstly the initial stress state of the cable duct was analyzed, and six work stages from the primary to final excavation were sequentially analyzed.

3.2 *Analysis results*

(1) Displacement of cable duct

Figure 2 is the displacement diagram at the final excavation stage.

The displacement of the landslide protection wall was 45 mm at the bottom of final excavation, and the settlement of the ground surface above the

Table 1. Physical properties of ground and particulars of beam element.

Depth (GL-m)	N-value	γ (kN/m^3)	C (kN/m^2)	ϕ (deg)	ν	E (kN/m^2)
2.1		16.0		23	0.333	19600
9.2	7	18.0		23	0.333	19600
13.4	4	16.5	40.0		0.375	8400
15.4	6	17.0		26	0.333	16800
23.1	3	16.5	55.0		0.375	11550
23.9	20	19.0		27	0.333	56000
	50	22.0		42	0.333	140000

	ν	E (kN/m^2)	A (m^2/m)	I (m^4/m)
SMW	0.333	2.1E+08	2.422E-02	1.057E-03
0-2 stage strut	0.333	2.1E+08	1.048E-02	6.920E-05
3-5 stage strut	0.333	2.1E+08	1.549E-02	1.400E-04
Primary lining	0.167	3.6E+07	2.000E-01	6.967E-04
Secondary lining	0.167	2.5E+07	1.000E-01	8.333E-05
Primary lining and Secondary lining	0.167	3.6E+07	3.000E-01	7.545E-04

cable duct was 15mm. The horizontal displacement of the cable duct, and its inclination to the excavation side were 21mm and 0.12 degree, respectively. The vertical cavity displacement was 9 mm.

(2) Axial force and bending moment of cable duct

Figure 3 is the distribution diagram of axial force and bending moment at the initial state before starting the open-cut work (before excavation) and their increment at the final state after completing the open-cut work (after excavation).

After the excavation, there were relatively large tensile axial force and negative bending moment acting at two locations: the crown and the lower right corner on the excavation side of the cross section of the cable duct.

(3) Lining stress of cable duct

Table 2 gives the maximum values of reinforcing bar tensile stress and concrete inside-edge stress in the primary lining and the secondary lining. The values for the primary lining were determined at the crown by superposing the incremental stress after excavation to the initial stress before excavation. The values for the secondary lining was determined at the lower right corner on the excavation side from the incremental stress after excavation.

The primary lining stress was 132 MPa against the allowable stress of 176 MPa, and the secondary lining stress was 1.3 MPa against the allowable tensile stress of concrete of 2.1 MPa. Thus, the calculation showed that the stresses in both the primary and secondary linings were within the allowable levels.

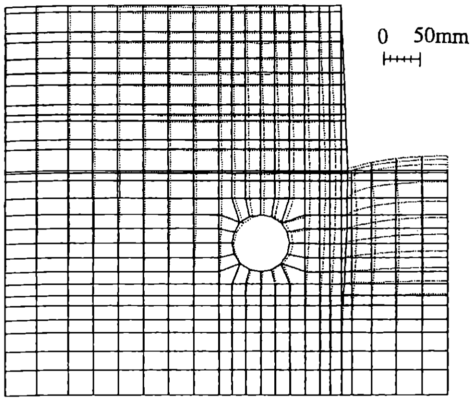

Figure 2. Results of displacement analysis at the time of excavation (final excavation stage).

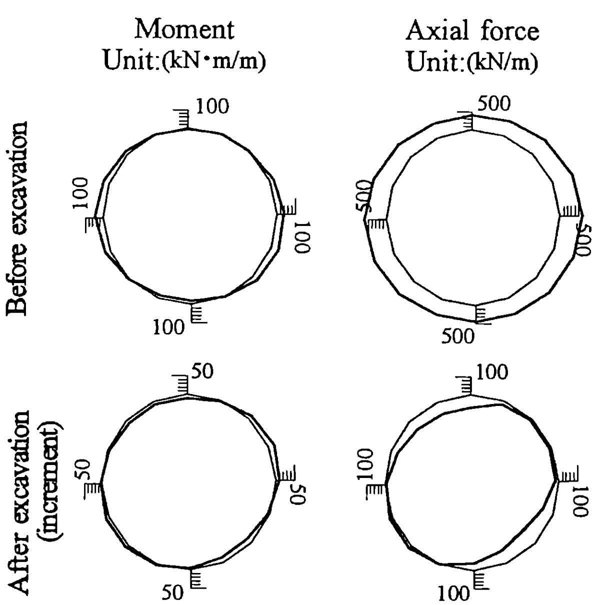

Figure 3. Calculation results of axial force and bending moment.

Table 2. Superposed results of lining stresses of cable duct.

Primary lining (crown)

	① Initial stress	② Incremental stress (FEM analysis)	③ Superposed results (①+②)
Bending mmoment M	-32.5 kN·m	-10.2 kN·m	-42.7 kN·m
Axial force N	390 kN/m	-76 kN/m	314 kN/m
Stress	79 MPa	53 MPa	132 MPa

Secondary lining (lower right comet on excavation side)

	Incremental stress
Bending moment M	-1.9 kN·m
Axial force N	20 kN/m
Stress	1.3 MPa

4 MEASUREMENT CONTROL PLAN

4.1 *Measured items and arrangement of measuring instruments*

Figure 4 shows the measurement items and the arrangement of measuring instruments. The deformation of the landslide protection wall, settlement of the surrounding ground, and inclination of the cable duct were measured at two points: the measurement point [2] in the cross section A-A and the measurement point [5] in the cross section B-B. The vertical and horizontal displacement and cavity displacement were measured in each cross section at measurement points [1] to [8].

4.2 *Control standard values and policy for countermeasures*

Table 3 gives the control standard values and the specific policy for carrying out countermeasures when the control standard values were exceeded.

The control standard values were divided into three classes: the primary standard values, secondary standard values, and tertiary standard values. They are 30%, 60%, and 100% of the tertiary standard values respectively. The level of countermeasures is raised according to the class.

The control standard values were set for four measurement items for the cable duct: the vertical displacement, horizontal displacement, inclination, and cavity displacement. For three items among these (the vertical displacement, horizontal displacement, and inclination), the allowable tensile strength of concrete was taken as a limit value giving attention to the tensile strength of the secondary lining concrete, and the measurement values corresponding to it were set to be the tertiary standard values. For the cavity displacement, giving attention to the reinforcing bar stress in the

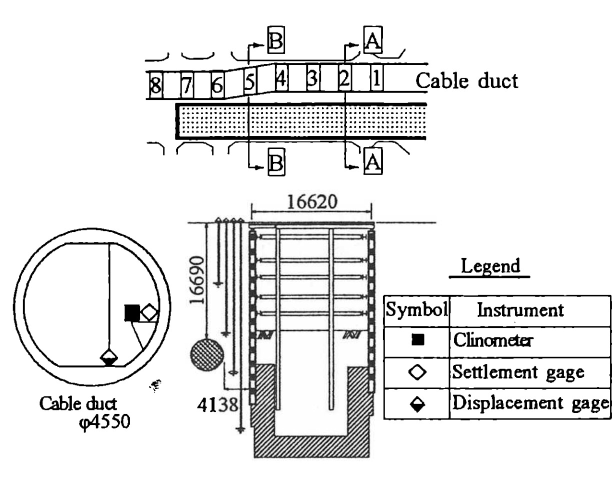

Figure 4. Arrangement of measuring instruments.

Table 3. Control standard values and policy for countermeasures.

Measurement item	Measuring instrument	Control standard value		
		Primary	Secondary	Tertiary
Settlement	Settlement gage	2 mm	4 mm	6 mm
Horizontal displacement	Transit	10 mm	20 mm	34 mm
Inclination	Clinometer	0.05degree	0.10degree	0.18degree
Cavity displacement	Displacment gage	3 mm	5 mm	8 mm
Policy for coutermeasures		Closer communicasion	Consultation on cable protection, Strengthening of control,system, Paying attention trend	Execution of cable protection Execution of cable duct protection

primary lining segment, the allowable tensile strength of reinforcing bar was taken as a limit value, and the cavity displacement corresponding to 1/2 of it was set to be the tertiary standard value to ensure the safety. The relationship between the allowable stress of lining and the measurement value was established by using the results of the FEM analysis. Its detail is described in Section 6.

5 ACTUAL BEHAVIOR OF CABLE DUCT

Figure 5 shows the cable duct behavior over time. This diagram indicates the following.

(1) Vertical displacement (settlement or lift)
After a lift of 3 to 6 mm generated by chemical injection performed as the countermeasures against confined water after the secondary excavation, the cable duct settled gradually as the excavation proceeded, and finally returned to nearly zero.

(2) Horizontal displacement
Viewing the data throughout the measuring period, a displacement of about 10 mm to the back side was found at the time of chemical injection, and a displacement of about 10 mm to the excavation side was found during the excavation work.

(3) Inclination
The open-cut excavation work had notable effects on the inclination. Although it was pushed back by about 0.02 degree to the back side at the time of chemical injection, an inclination of 0.20 to 0.23 degree to the excavation side was found in the end.

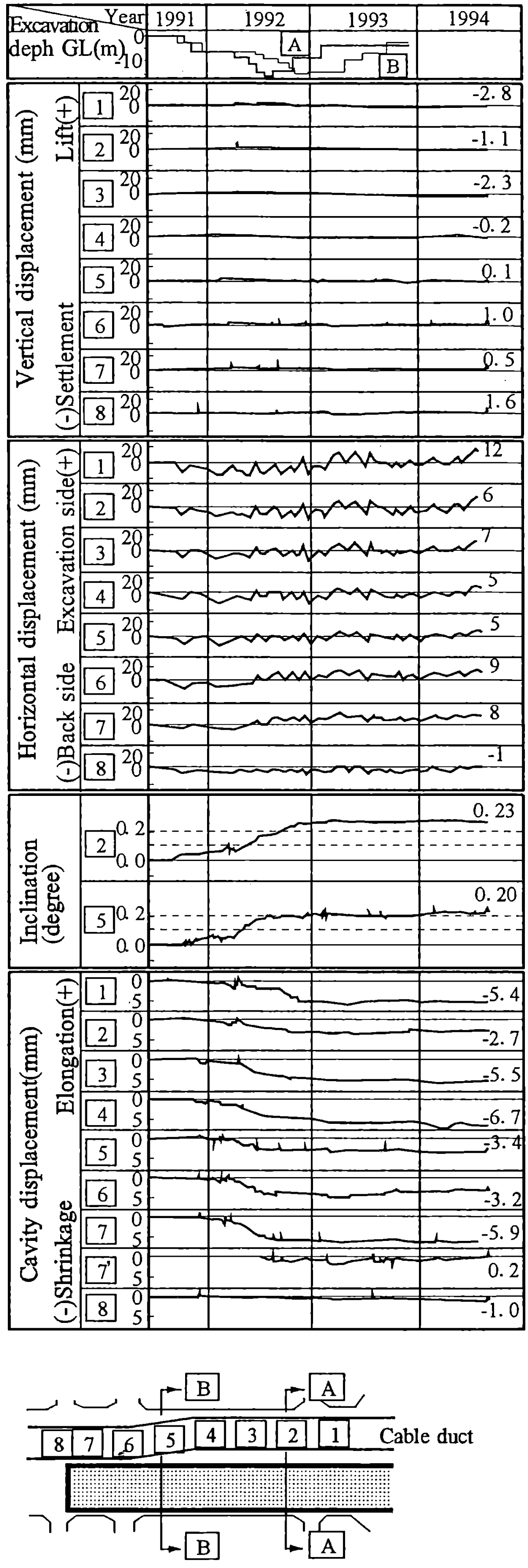

Figure 5. Change of measured values over time.

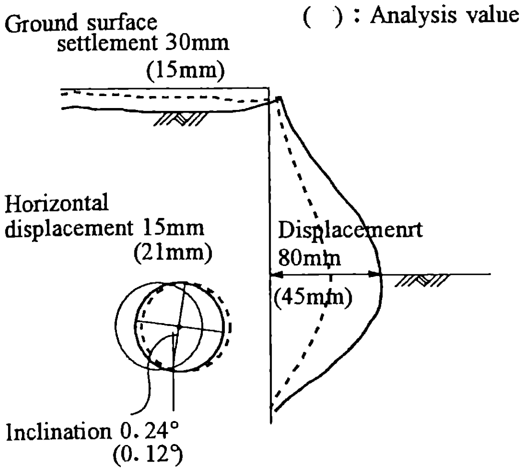

Figure 6. Deformation of landslide protection wall and behavior of cableduct (at completion of excavation: section A-A).

(4) Cavity displacement

Like on the inclination, the excavation work had large effects on the cavity displacement, but it stabilized after the excavation was completed. Although an elongation of about 1.5 mm was generated at the time of chemical injection, a shrinkage of 3 to 7 mm was generated in the end. As the shrinkage of the cavity progressed, many cracks began to develop in the lining concrete and existing cracks widened.

Figure 6 shows the relationship between the deformation of the landslide protection wall and the behavior of the cable duct. The displacement of the landslide protection wall increased gradually as the excavation progressed, and the displacement reached 80 mm at the bottom of excavation when the excavation was completed. At the same time, the backside ground settled gradually, and a settlement of 30 mm was found on the ground surface above the cable duct when the excavation was completed. It is presumed that the cable duct itself was moved by the flow of earth in the backside ground caused by the deformation of the landslide protection wall, and thus the displacement and deformation of the cable duct were generated. The figure shows the values from the preliminary FEM analysis together with the measured values. The analysis values well explain this displacement mechanism. Strictly speaking, although generally the behavior of the cable duct was well reproduced, there were slight differences between the analysis values and the measured values for the displacement of the landslide protection wall and the settlement of the surface of the surrounding ground, and the measured values were slightly larger than the analysis values. However, the control standard values were established based on the analysis values, resulting in the values on the conservative side.

6 CONTROL RESULTS AND COUNTERMEASURES

While the vertical and horizontal displacement of the cable duct were within the primary standard values, the inclination exceeded the tertiary standard value. Also, the cavity displacement exceeded the primary standard value at many points, exceeding the secondary standard value at some points.

Figure 7 shows the relationship between the measured values and the lining stress of the cable duct. Assuming that the relationship between the incremental displacement (inclination) of the cable duct and the incremental lining stress is simply proportional, the limit value was determined from the intersection of the straight line passing through the value from the preliminary FEM analysis and the allowable stresses of the primary and secondary linings. This limit value was used as a basis for setting the control standard values for the primary and secondary linings. This figure also shows, for reference, the limit values for the displacement of the landslide protection wall at the bottom of the final excavation. For this, the results obtained by two methods are shown. One was based on the preliminary analysis in the same manner as in the above, and the other was derived from the analysis of correlation between the inclination and wall displacement and between the cavity displacement and wall displacement based on the actual measurement.

By comparing these limit values with the maximum measured values (marked by ★ in Fig. 7), the following were found. First for the primary lining, the measured values of the cavity displacement and wall displacement were within the limit values, each corresponding to 46% and 99% of the primary lining limit value. Also, the wall displacement determined by utilizing its correlation with the inclination and cavity displacement does not exceed the limit value unless it was larger than 130 mm. That the actual wall displacement would settle at about 80 mm was predicted based on the reverse elasto-plasticity analysis for the landslide protection wall performed during the intermediate stage of the excavation. Therefore, the primary lining was estmated to have a stress lower than the allowable stress, and pose no structural problems. The seondary lining, on the other hand, although its measured vertical displacement and horizontal displacement were small, the inclination and wall displacement exceeded the secondary lining limit values. This estimation was verified by the increase, elongation, and widening of cracks found on the surface of the secondary lining concrete.

Therefore, at the stage at which the secondary lining limit value (tertiary standard value) was ex-

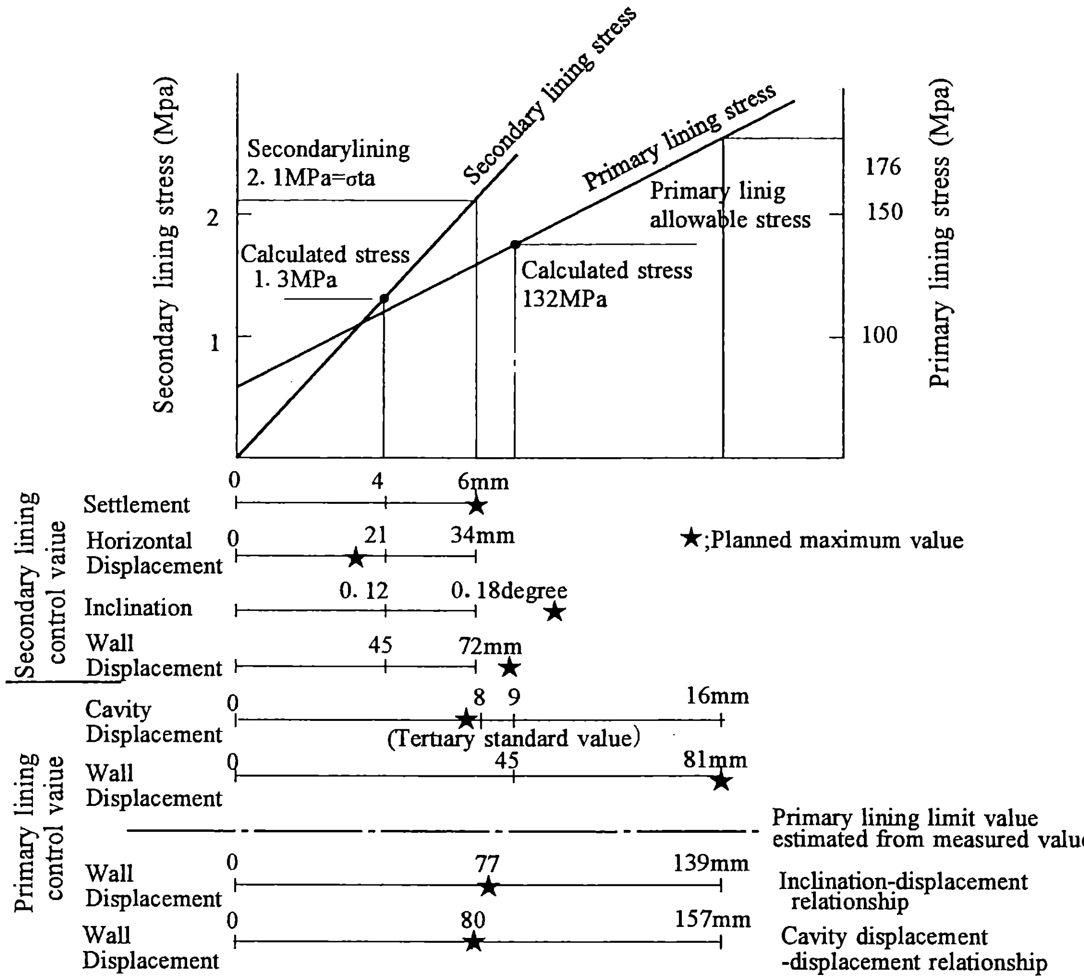

Figure 7. Relationship between measured values and cable duct lining stress.

ceeded, repair was carried out, which included in--jection of the joint filler to the cracks. At the same time, the communication cables were directly protected from being damaged by the peeling-off of concrete by installing plates and protective nets over the cables.

7 CONCLUSIONS

The behavior of cable duct and the control results are summarized below.

1. The excavation had large effects on the cable duct, such as an inclination of 0.20 to 0.23 degree to the excavation side, a cavity displacement of 3 to 7mm, and the occurrence of cracks of lining concrete.
2. Although there were slight differences in the displacement values of the landslide protection wall, etc., between the results from the preliminary FEM analysis and the actual measurement, generally the behavior of the cable duct was well reproduced, and the preliminary analysis was judged to be mostly adequate.
3. From the comparison between the analysis value and the measured value, the primary lining was estimated to have a stress lower than the allowable stress, and it was judged to pose no structural problems.
4. Countermeasures against the danger of damage to the cables caused by the peeling-off of concrete were taken by providing cable protection.

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