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Behavior of angle cut cylinder excavation by cut reinforced earth work method

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ABSTRACT: When structure such as bridge pier is constructed in a mountainous district full of steep slopes, earth cutting or earth retaining by soldier pile method is commonly used. However, cutting on a steep slope will produce a large-scale cut slope, and will cause a substantial modification of natural environment, raising problems in the treatment of surplus soil in construction and increase in the management area. Furthermore, the soldier pile method requires long piles to be driven in a steep slope; this takes a wide construction yard. Further, this work requires a concurrent use of ground anchors, which results in a longer construction period and greater construction costs. Under these circumstances, the authors of this paper propose the earth retaining method (angle cut cylinder earth retaining method) mainly based on the cut reinforced earth method, and clarify the behaviors of the ground and structures by measurement. At the same time, they are currently investigating the designing method. This method ensures a high degree of stability without tipping earth pressure balance very much, and minimizes modification of the natural environment. This paper reports the deformation characteristics of angle cut cylinder excavation form based on the 3D plasticity analysis, and the behaviors of ground and structures obtained from the result of measurement in field tests.

1 INTRODUCTION

The cut reinforced earth was first adopted by Japan Highway Public Corporation (hereinafter referred to as "JH") for the first time in 1982. Since then, there has been a rapid increase in the number of the cases of construction work. In the year of 1999, the annual extension of construction of the express-way become 100,000 meters. The Figure 1 shows the breakdown of construction site. Excavation of a steep slope of 1 to 0.5 or greater, for example, a bridge pier shown in Figure 2, is adopted in about 50 percent of the construction sites. This is attributable to the following reason: In the construction of the expressway passing through steep mountains, a slope face of great length and size will result from excavation at a standard gradient. However, when the present method is used for excavation of a steep slope, the slope face can be reduced, and the surrounding negative environmental impact and the volume of excavated soil can be reduced. In 1998, JH established "Designing and Construction Procedure for Cut Reinforced Earth Work Method"(JH Procedure) <1> to promote adoption of this method.

However, there are still problems to be solved in future. In the construction for the project of the Second Tomei Expressway and Meishin Expressway, large-diameter caisson type piles are more frequently used as a bridge foundation on a steep slope. In this context, designing in the cut reinforced earth method with consideration given to mechanical characteristics by circular excavation is not yet established.

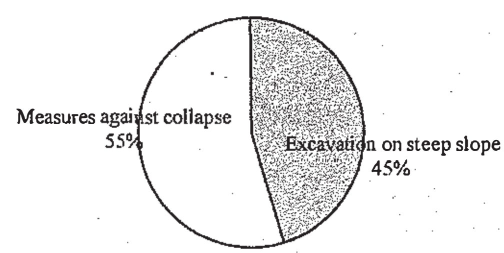

Figure 1. Breakdown of construction site.

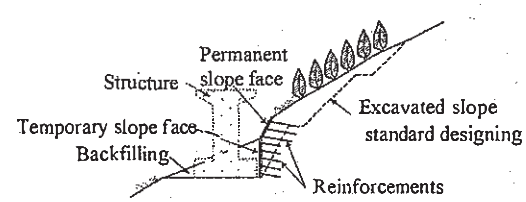

Figure 2. Excavation on steep slope.

Against this backdrop, JH is conducting field tests on the earth retaining method (angle cut cylinder earth retaining method) mainly based on the cut reinforced earth method. This method ensures a high degree of stability without tipping earth pressure balance very much, and which minimizes modification of the natural environment, as shown in Fig-

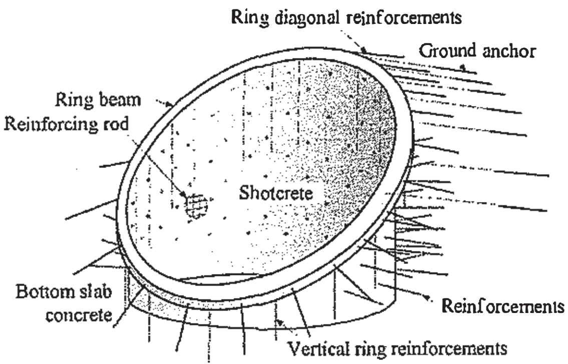

Figure 3. Angle cut cylinder earth retaining.

ure 3. Through these tests, JH is clarifying the behaviors of the ground and structures by measurement, and is currently examining the designing method.

2 DEFORMATION CHARACTERISTICS IN EXCAVATION BY ANGLE CUT CYLINDER EARTH RETAINING METHOD

2.1 *Analysis conditions*

The 3D elastoplastic analysis was used to find out the deformation characteristics of angle cut cylinder excavation form.

Analysis models used two cases shown in Figure 4; the angle cut cylinder excavation and circular excavation. The stress and deformation of the ground were compared. In creating the model, attention was focused on the shape effect, and supportless excavation was formulated into the model. In angle cut cylinder excavation, analysis of repeated excavation step by step was made with consideration given to the possibility of using the inverted lining method. The physical properties of general rocks were used to represent values for physical properties of the ground to be analyzed, based on the studies made so far <2>. Drucker-Prager failure conditions were used as failure conditions. As analysis conditions used under the Drucker-Prager yield condition, soft rocks were used as bed rocks in order to estimate the extreme looseness on the model slope, and different two constants were utilized for analysis. The constants for analysis are given in Table 1.

Table 1. Constants for analysis

	Sand	Clay	Soft rock
Young's modulus(kN/m^2)	68,646	68,646	245,166
Cohesion(kN/m^2)	19.6	49.0	196.1
Internal friction Angle (Deg)	32	21	37
Unit weight (kN/m^3)	19.6	19.6	21.6
Poisson's ratio	0.35	0.35	0.30

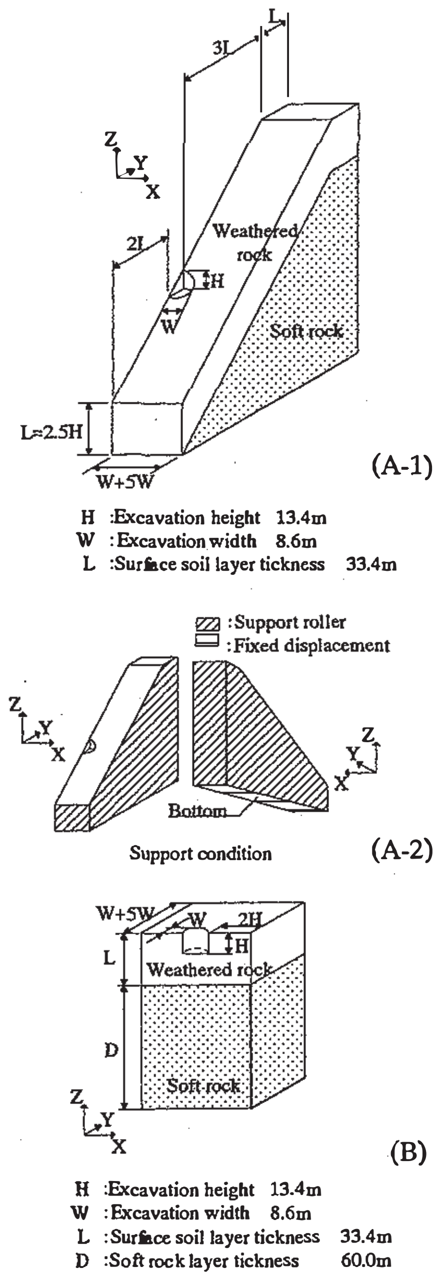

Figure 4. Analysis modles.

2.2 *Result of analysis*

Figure 5 shows the excavation displacement and the result of analysis in plastic area. A common point for the angle cut cylinder excavation and circular excavation is a building form, independently of the ground. Displacement is greater in angle cut cylinder excavation. This is because deviatoric stress in the initial stress of the ground is greater and stability is poorer in the angle cut cylinder excavation than in the circular excavation on the flat ground. In angle cut cylinder excavation, the plastic area at the maximum height of excavation is greater than plastic

Material	Sand		Clay	
Excavation type-ed	Circular	Angle cut cylinder	Circular	Angle cut cylinder
Cohesion	19.6 (kN/m2)		49.0 (kN/m2)	
Internal friction angle	32 (Degrees)		21 (Degrees)	
Unit weight	19.6 (kN/m2)		19.6 (kN/m2)	
Elastic modulus	68646 (kN/m2)		68646 (kN/m2)	

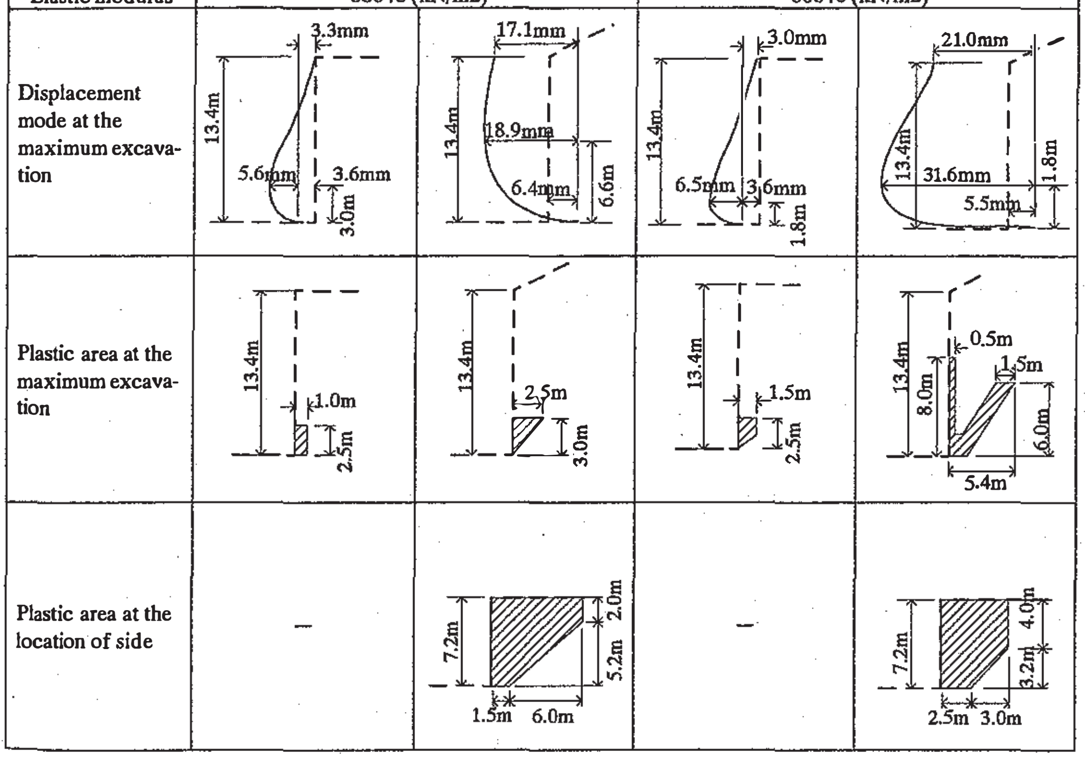

Figure 5. Excavation displacement and plastic area.

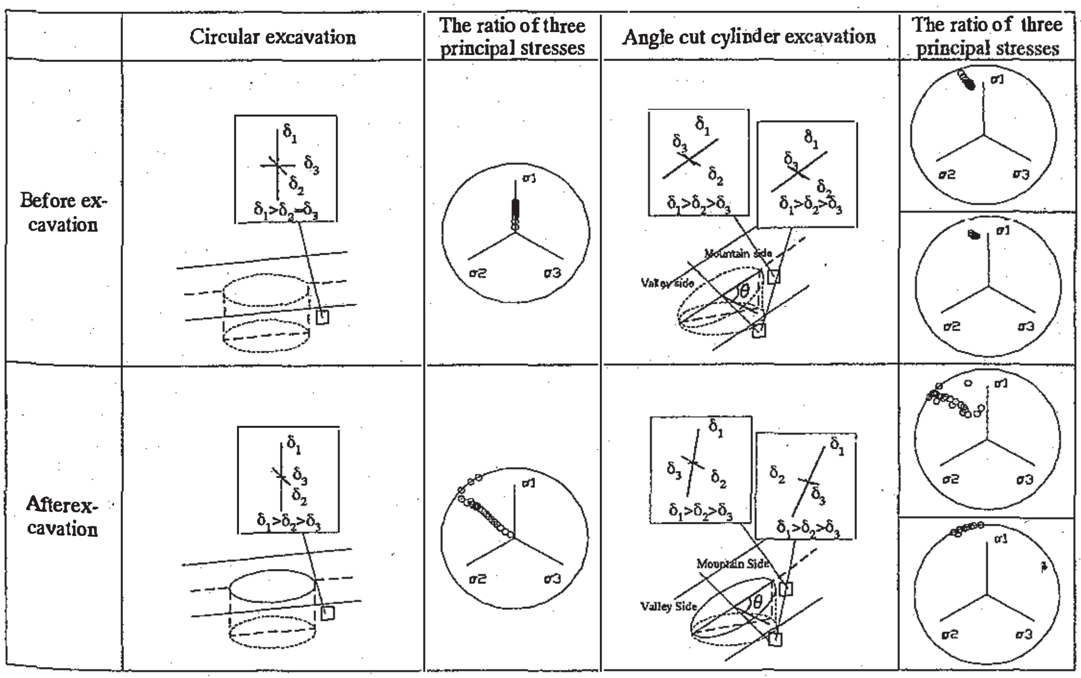

Figure 6. Stress transition

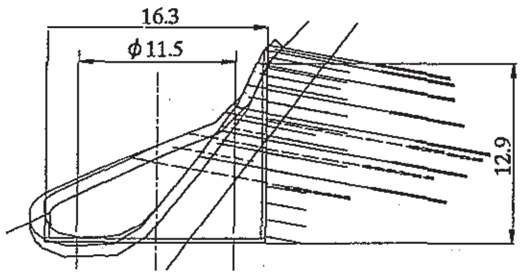

Figure 7. Plan and cross section for angle cut cylinder earth retaining

Table 2. Structural particulars Pl descending bridge pier

Excavation particulars	
Excavation height:	12.9m Diameter: 16.1m
Ring beam	
Cross section:	1.2×0.8m Upper: Five 2D16; Lower: Five 2D16
Ground anchor	
Designed force:	588kN
Fixed length:	5.5m Free length: 8.0 to 13.0m
Number of anchors installed:	13
Bore diameter:	135mm
Tendon:	7 PC steel stranded wires (11.1mm in diameter)
Grout:	24N/mm^2
Virtical and diagonal reinforcements	
Reinforcements:	Deformed reinforcing bar 6.0m (25.6mm in diameter)
Bore diameter:	90mm
Bore length:	5.5m
Grout:	24N/mm^2
When reinforcement is 6m	
Reinforcement:	Self-drilling bolt 31mm in diameter
Bore diameter:	50mm
When reinforcement is 3m	
Reinforcement:	Deformed enforcing bar D25
Bore diameter:	50mm
Inverted lining wall	
Wall thickness:	300mm
Reinforcing rod:	D25ctc300

area on the side. The Figure 6 shows the transition under stress. The stresses at the maximum height of excavation in circular excavation and angle cut cylinder excavation are represented by the maximum main stress rotating in the vertical upward direction. In this case, there is an increase in intermediate main stress facing in the circumstantial direction of the excavated cross section. This reduces the increase in the deviaplastic area is reduced. In the meantime, the maximum main stress is in the inclined direction on the side of angle cut cylinder excavation, with the result that deviatoric stress grows, and the plastic area of the ground increases. This makes it possible to expect that the stress similar to that in circular excavation occurs at the point close to the maximum height of excavation independently of the ground, as

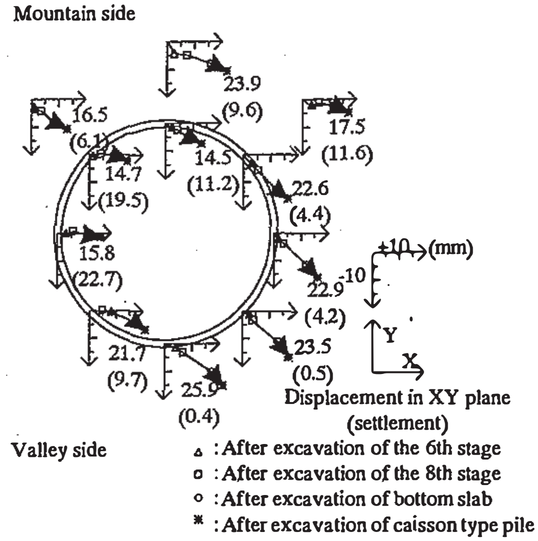

Figure 8. Ground surface displacement

a deformation characteristic in angle cut cylinder excavation. On the side, however, it is more difficult to get circular stress as the ground plasticity due to stress concentration of the ground is greater.

2.3 *Overview of the test*

The field tests were conducted to observe the behaviors of the ground and structural members. The test site is located at a steeply inclined (38 deg.) mountainous district with an elevation of 150 meters. Geographical features mainly consist of the sedimentary rock of the Tertiary Hamishigaku Deposit, and unconsolidated deposits of the Quaternary period covering it. The Figure 7 provides a plan and cross section for angle cut cylinder earth retaining. It should be noted that sectional form, ground anchor and the number of anchors installed in the cut reinforced earth method conform to the measurements obtained from the past tests and the result of the FEM 3D elasticity analysis <2> <3>.

3 FIELD TEST RESULTS

3.1 *Ground surface and underground displacement*

The Figure 8 shows the ground surface. The ring beam was generally displaced toward the lowest point. This is considered to have been caused by the following reason: Displacement from the maximum excavation height to the valley was assumed in the designing stage, and sliding preventive reinforcing rods of the ring beam were placed on the side of the maximum excavation height. Therefore sliding resistance effective in the direction of actual displacement is considered to have failed to work.

The Figure 9 shows the underground displacement measured by a multi-stage inclinometer. In the measurement data, the value for underground dis-

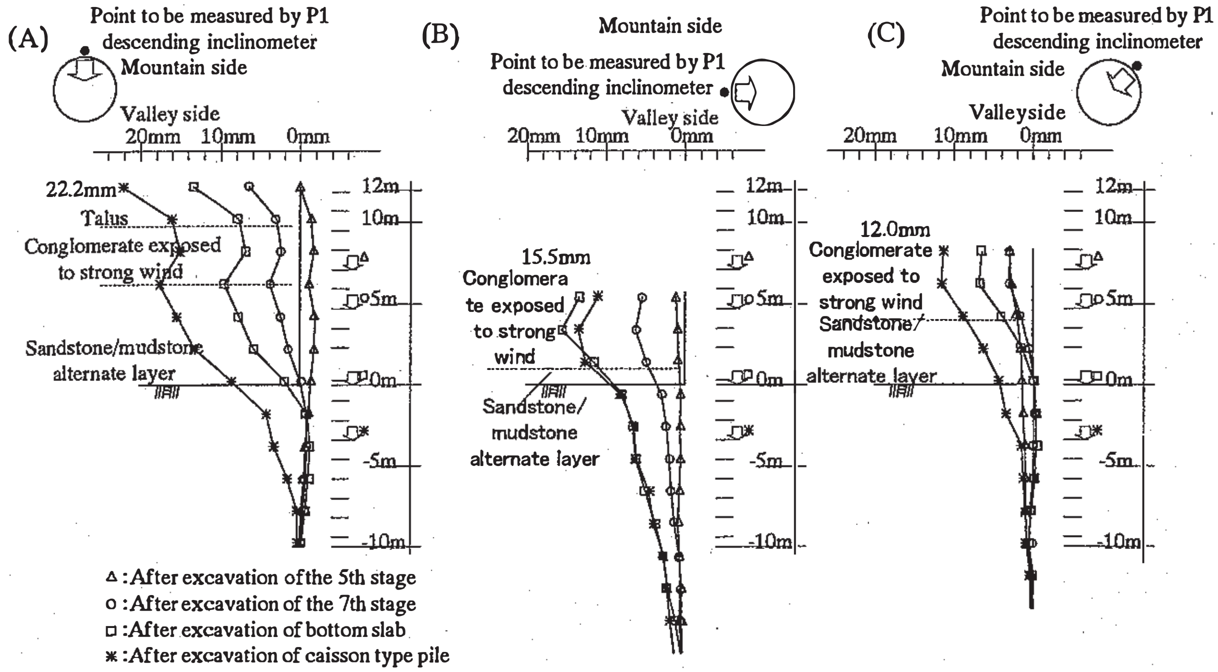

Figure 9. Underground displacement

placement after prestressing of ground anchors is assumed as an initial value. Underground displacements at all three positions were tilted toward the excavated side, and there was an increase in displacement at the time of excavation by caisson type piles. Especially, point <2> has an excavation height H = 5.9m, the lowest in three positions. Despite that, the horizontal displacement $\delta/H(\gamma)$ on the top of slope was 0.26 %, the maximum figure in three sites. This is considered to be due to the following topographic features: This area from the surface lowered by cutting to the excavation bottom was covered with the conglomerate exposed to strong wind. When measured by a settlement gauge, the settlement was about 22.7mm at this point, as compared to about 10mm in other two positions. Namely, the settlement at this point was double than in other positions. In addition to these geographical features, another reason is the stress concentration of the ground as discussed in "2.2 Result of analysis".

3.2 *Stress of ring beam*

Concerning the inside of the ring surface, one place was found out where all the reinforced rod and concrete stresses were turned into tension with values very small. Maximum values were smaller than the permissible stress (20 N/mm^2 of the maximum tensile stress of the reinforcing rod and 0.2 N/mm^2 of the maximum compressive stress of concrete). As to the outside, some places were found out where all stresses were turned into tension in the same way of the inside, but the values were also small.

3.3 *Sliding prevention work*

The maximum tensile axial force of 70kN was measured. Since this corresponds to 70 % of the designed axial force (90kN), it is considered that the sliding preventive reinforcements have been effective to the sliding of the ring beam. However, the reinforcements, which were driven in parallel, were not effective to the ground surface displacement.

3.4 *Stress of reinforcing rods and axial stress of reinforcement on the wall surface*

The Figure 10 shows the axial stress of reinforcement and stress of reinforcing rods on the wall surface. A maximum axial force of about 70 kN (60%) occurred to the reinforcement with respect to a design axial force of 118kN. According to the cases of steep slopes excavated so far, the axial force occurring to the reinforcements was about 30% of the permissible reinforcement force in most cases. Hence, the value of axial force having occurred can be considered as great. Further, the trend of reinforcements axial force is that greatest axial force occurred on the top of excavation, and a small value was recorded on the lower portion of excavation. This exhibits approximately the same distribution as that of underground displacement. For the stress of reinforcing rods and concrete on the wall surface, the compressive stress of concrete is 0.1 N/mm^2 or less in both longitudinal and lateral directions, and the tensile stress of the reinforcing rods is 1N/mm^2 or less. Only a very small stress was measured, as compared with the axial force of the reinforcement.

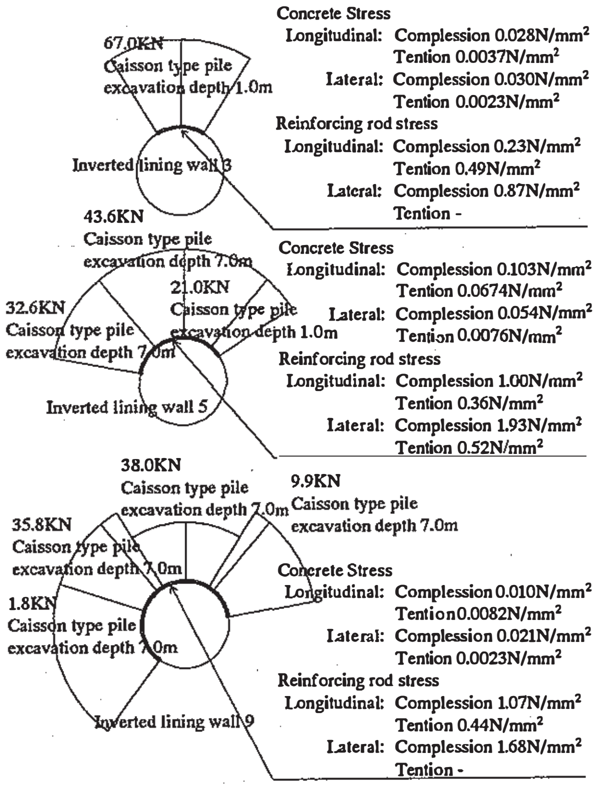

Figure 10. Reinforcement axial force and wall surface stress

4 SUMMARY

The following describes the conclusion gained in the present paper:

<1> Regarding the angle cut cylinder deformation characteristics, the same shape effect as that of the circular excavation is obtained at the position close to the maximum excavation position. On the side, however, the plastic area is increased by stress concentration of the ground, according to the result of analysis and field measurements. It is considered difficult to get the effect of circular stress.

<2> In the case of angle cut cylinder earth retaining horizontal displacement γmax. on the top of slope does not always occur at the position of maximum excavation height. This makes it necessary to perform stability management at the time of construction on the side as well.

<3> In the ring beam sliding preventive work, it is not always effective to drive reinforcements in one direction because of the trend of displacement.

<4> While stress of the reinforcing rods and concrete on the wall surface is very small, reinforcements axial force is great. This makes it possible to consider that ground deformation by excavation is reduced by the reinforcements integrated in one body, thereby reducing the earth pressure.

5 CONCLUSION

Based on the results discussed in this paper, we will study the designing procedures for each member, and continue to perform tests, thereby collecting and analyzing measurement data for each members in an effort to establish logical designing procedures.

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