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Insitu test of steel-nailing reinforcement for cut slope with alternating sandstone and mudstone

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ABSTRACT:In order to clearly understand the behavior of the nailed steel bar, an insitu test had been carried out for about two years at Nichinan in southern part of Kyushu, Japan. After analysis of the monitoring strain data of the steel bar, the tendency of distributions of bending and axial strain in the steel bar would become clear and the sliding surface of the slope with alternating sandstone and mudstone could be estimated. About two years after inserting the steel bars in the slope, some were picked up from the slope to compare the deformed shape of the steel bar with the distribution of bending strain and to identify the sliding surface of a slope. Considering these test results, many types of deformation of the steel bars including the shearing and creeping types were gotten. Furthermore the effect of bending strain for resisting the sliding of slope becomes important in some sliding cases.

1 INTRODUCTION

The slopes along the Nichinan Sea Coast of Southern Kyushu,Japan, expose the Tertiary deposit, alternating sandstone and mudstone soil as shown in photo 1. Landslide or slope failure often occurs in this kind of slopes by some causes. The main cause is that the strength of mudstone decreases more easily than that of sandstone with an increase of soil water content by heavy rain. Therefore, it is apparent that once the sliding of a slope occurs, the sliding surface will be along mudstone layer,i.e. in the mudstone zone or between mudstone layer and sandstone layer.

Generally, several ways can be used to prevent the sliding of the slope. Among them, steel-nailing reinforcement for the slope with alternating sandstone and mudstone are extremely extensively applied in Southern Kyushu. It is very effective to insert the steel bar into the slope for stability of the slope. Of course the use of steel bar as a reinforce material is widely practiced over all of Japan for many kind of slopes.

While the practicability of steel-nailing has developed, the theory of its mechanism has also been studied at the same time. Nevertheless, the speed of the former is faster than that of the latter. As known, there are many factors which influence the effect of steel bar to resist landslide. The information on spacing of the nailing, soil profile, and top-plates of soil-reinforcement can be found from Tatsuoka,F.(1984–1985), Hayashi,S. (1986), Kitamura,T. (1987). In the above the material of the slope is homogeneous or the slope does not have potential sliding

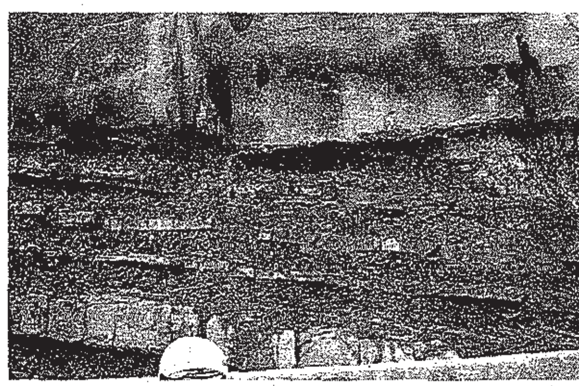

Photo 1 Tertiary deposit, alternating sandstone and mudstone soil

surface. The other case where the slope is inhomogeneous, with the alternating sandstone and mudstone, have been researched by Yokota,H (1992,1993). This paper is a continuation of the latter.

About the in-situ test, this paper shows the distributions of bending and axial strain of steel bar, discuses the effects of two kinds of strain on resisting landslide, deduce the potential sliding surface of slope and confirm it by the observing deformation of steel bar by comparing the deformation of steel bar and the strain including bending and axial strain and so on.

The result of lab. test is also shown in this paper. Comparing the results between in-situ test and lab. test, more detail information about effect of bending strain of steel bar can be obtained.

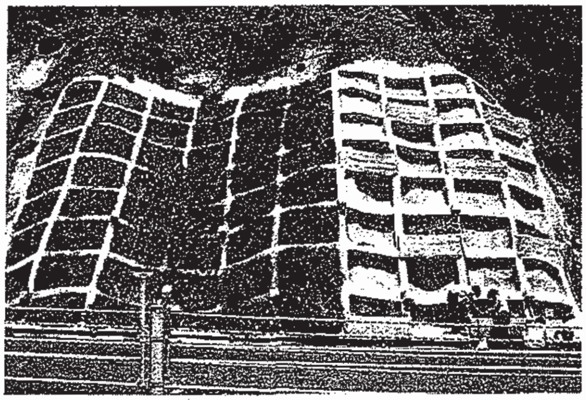

Photo 2 Mesh frame and vegetation box were constructed in the surface of mortar slope

2 THE CASE OF INSITU TEST

The in-situ test is carried out on a cut slope besides national road No.220 near the Nichinan Sea Coast. Twenty-three years ago, the surfaces of the cut slope was treated by mortar-shotcreting to prevent weathering by the influence of climatic variations and occurrence of failure by weathering. However,the mortar is weathered and fissures. As a repair of the deteriorated mortar slope, the mesh frame and vegetation box, are directly applied to the above surface of mortar slope as shown in photo 2. The mesh frame and vegetation box were constructed in the slope area of 8m x 15m (height x extension).The steel bar is inserted at the crossing point of the mesh frame. Here the steel bar has two functions: first for preventing landslide and, secondly for fixing the frame on the slope.

The slope of the test is about 20m high and the average angle of the slope to horizontal is about 60 degrees. The geological profile of the slope consists of weathered layer (WL)for the first layer, predominantly mudstone (MS)for the second layer and sandstone (SS)for the third layer, as well as mudstone (MS) for the fourth layer (see Fig.6). The average thickness of the layers are 0.43m WL, 1.0m MS, 0.44m SS and 1.1m MS. Therefore, this is a typical slope of alternating sandstone and mudstone.

Nine steel bars (SD30, 25mm in diameter and 3.0m in length) were put into holes that were almost vertical to the slope plane as shown in Fig.1. The rest of the space of

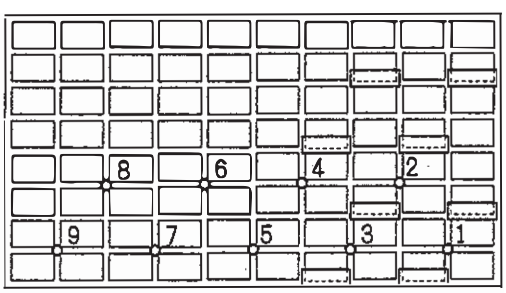

Fig.1 Position of the inserted steel bars

each hole was filled with mortar. One end of the steel bar was fixed by a plate (150×150× 9) and a nut (M24). Twenty-four gauges were set on both sides of each steel bar to measure the strain on some sections of the steel bar. The pitch between them was 25mm.The mesh is 1500×1200 (length × height) and the frame is 20cm width.

All works for installing steel bars were finished before December 20, 1993. The first strain data obtained by monitoring gauges on Dec. 25 were termed as the primary data. This means that the measured data after a period should to be less the primary data and the change would indicate the variation in strain of steel bar in this period. The last time to observe the data of strain was on Nov. 10, 1994, nearly one year.

3 RESULTS OF IN-SITU TEST AND DISCUSSION

The strains of each steel bar were observed in every measurement. After dealing with these data, the distributions of bending and axial strains were plotted for all steel bars. As space is limited, only the results of two steel bars, No.8 No.7 are presented here.

3.1 Strain and potential sliding surface

3.1.1) The steel bar No.8

Figs. 2a, 2b, 2c and 2d, 2e, 2f give the distributions of the axial and bending strains for steel bar No.8, respectively. These figures show the developing process of the strain for one year. In Fig.2a the maximum value of axial strain is about 100μ and the minimum value is larger than −400μ. The absolute maximum value of bending strain is less than 200μ in Fig.2d. The data of most sections of the steel bar is unstable from Jan. 8 to Mar. 2. This phenomenon happened not only in steel bar No. 8, but also in each other steel bar. In addition, the values of axial and bending stains are like that of steel bar No. 8 and relatively small.

It is obvious that there is relatively stable variation of the strain values in every section from Jun.17 to Sept.22 in Figs.2b and 2e. For example, in Fig.2b the data of axial strain at the 2250mm section gradually increases from about 2000 to 4000μ. It is observed that the tensile strains in the lower 1/3 steel bar (from 2000mm to 3000mm) increased as the month progressed. Specially, a peak value of the tensile strain about 4000μ occurs at section 2550mm. On the other hand the tensile strains in the upper 2/3 steel bar (from 250nun to 1750mm) go down and become negative at the 1500mm section,i.e. the tensile stain changes to compressive strain. This means that there is an effect of the frame on the steel bar loading. At the same time in Fig.2e the bending strain goes up at the 2500mm and 3000mm sections and the increment is almost 750μ. It goes down at the 2000mm, 2250mm and 2750mm and the maximum reduction is about 500μ. Up to Sept.22,

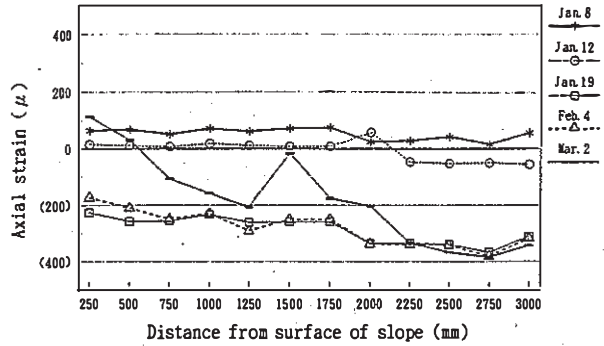

Fig.2a Distribution of axial strain (No.8)

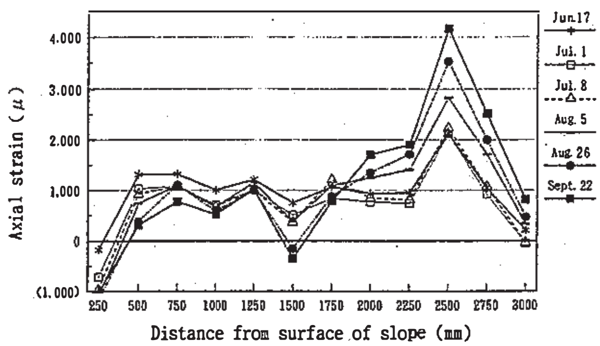

Fig.2b Distribution of axial strain (No.8)

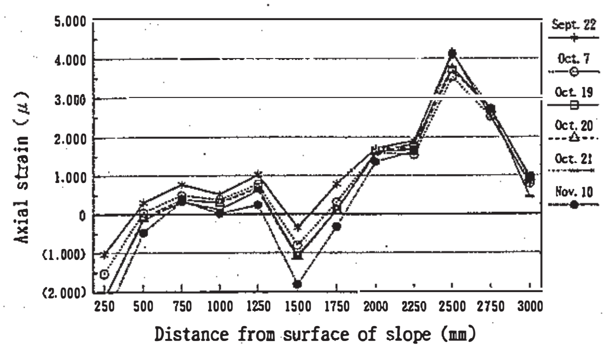

Fig.2c Distribution of axial strain (No.8)

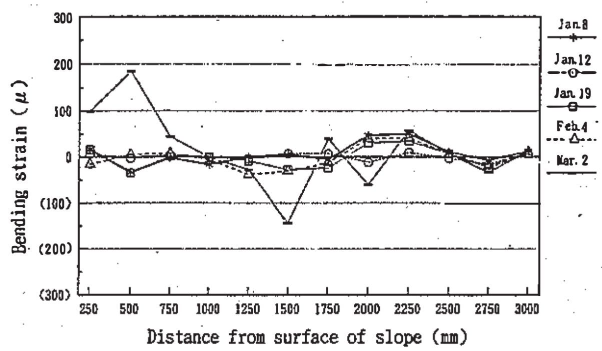

Fig.2d Distribution of bending strain (No.8)

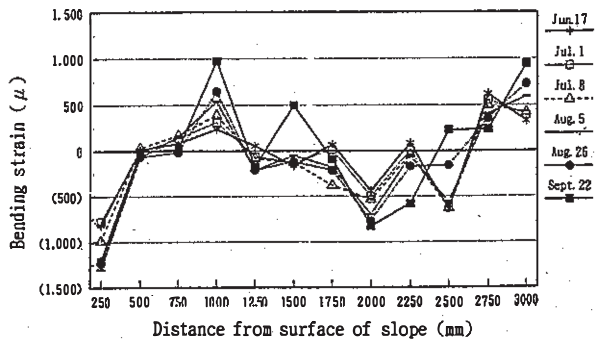

Fig.2e Distribution of bending strain (No.8)

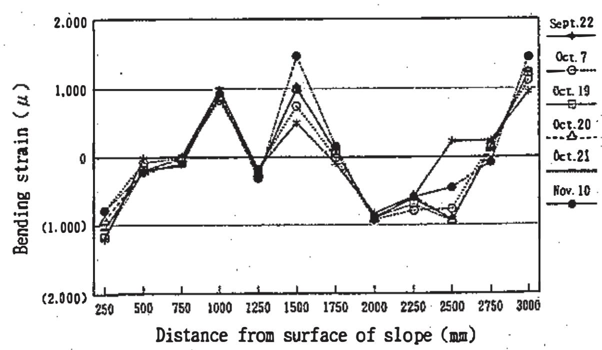

Fig.2f Distribution of bending strain (No.8)

the bending strain at the 2000mm, 2500mm and 3000mm section are about −900μ, 250μ and 1000μ, respectively.

In Fig.2c, the axial strain almost goes down from Sept.22 to Nov.10. At the 250mm section the axial strain reaches −2500μ and at the 1500mm section it goes down to −1900μ. All the axial strain is nearer to 100μ at the 750mm and 1250mm sections. It illustrates that there is small friction force on the surface of the steel bar between 750–1500mm. At the lower 1/3 of the steel bar the variation of the axial strain is not so large compared to the upper 2/3 steel bar and at the 2500mm section it is still 4000μ. It will be thought that the friction force is concentrated in both areas,i.e. 1750–2500mm and 2500–3000nun and the directions of two friction forces are opposite.

In Fig.2f, except the bending strains at the 1500nun, 2500mm and 3000nun sections, the others at the rest of the sections do not change so much from Sept.22 to Nov.10. The bending strain at the 2000mm decreases to −1000μ and It at the 3000nun is goes up to 1500μ. It is clear that the section with the bending strain equal to zero is near to the 2500mm section and there is the effect of bending strain for resisting the sliding of slope.

As it is known where there is the largest tensile strain in the steel bar there will be a potential sliding surface. From this view in steel bar No.8 the point between 2500nun and 2750mm is considered as a potential sliding surface. At the section 2500mm the axial strain is of an extremely large value exceeding 4000μ on Nov.10 in Fig.2c. The curve of bending strain on Nov.10 at the range 2000–3000mm appears anti–symmetric about the section 2500mm shown in Fig.2f and it is similar to the distribution of steel bar in the range 8.2–24.2cm. of lab. test (see Fig.7).

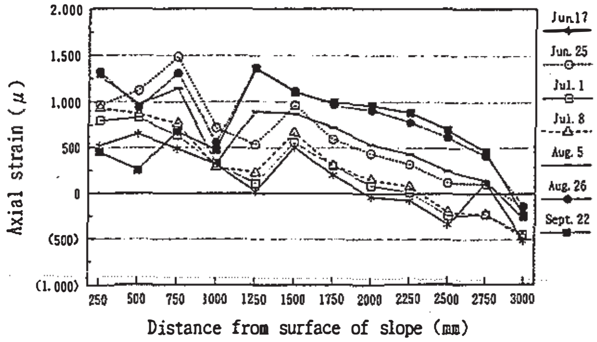

Fig.3a Distribution of axial strain (No.7)

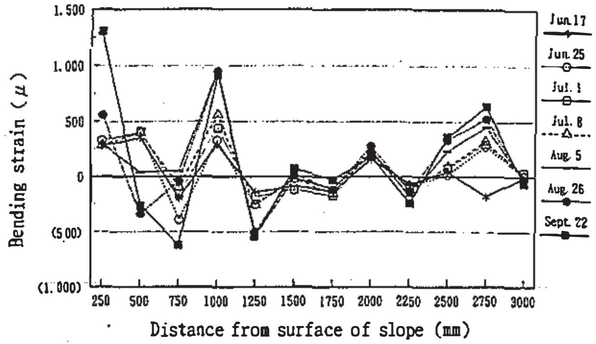

Fig.3c Distribution of bending strain (No.7)

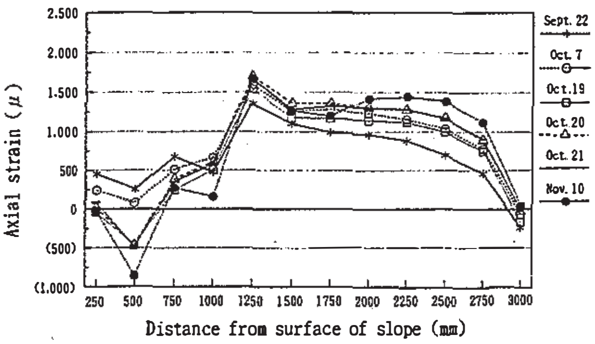

Fig.3b Distribution of axial strain (No.7)

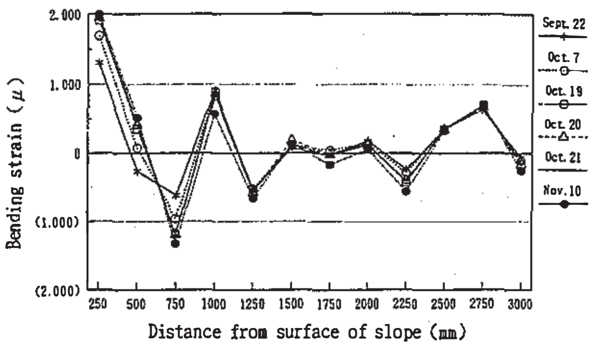

Fig.3d Distribution of bending strain (No.7)

3.1.2)The steel bar No.7

From Jan.8 to Mar.2 strains of both axial and bending in the steel bar were very small and unstable similar to steel bar No.8. So here they are omitted. Figs.3a,3b and Figs.3c,3d show the distributions of the axial and bending strains,respectively.

In Fig.3a the tensile axial strain developed fast from the upper part of steel bar to the lower part from Jun.7 to Aug.26. The distribution of axial strain show wholly the tendency of decrease from upper part to lower part of the steel bar. It means that friction stress between steel bar (mortar) and rock around the steel bar is positive, i.e. steel bar resist slope failure at all most sections of steel bar. In Fig.3b the axial strains in the four upper sections (250–1000mm) go down from about 500 on Sept.22 to nearly zero or negative on Nov.10. Conversely the axial strains in the lower part (1250–3000mm) of steel bar increase and axial stains of steel bar in the range 1500–2750mm are roughly same. It is clear that the friction force is very small and the soil become weak in the ranges of 0–1150mm and 1500–2750mm. Two axial strains at the section 1250mm and 2750mm are noted. Maybe there are sliding surface in those two places.

Comparing Figs 3c and 3d, the bending strains developed faster in the former than in the latter. The bending strain at the 250mm, 750mm,1000mm, 1250mm,2750mm sections stably increased to 2000μ,–1400μ, 500μ, –750μ and 750μ on Nov.10 shown as Fig.3d. Between the range 250–1000mm,the bending strains is caused by the weak soil (discussed above) loads on the steel bar which two ends were locked by the frame and sandstone zone (1150–1550mm, see Fig.3b).

From Fig.3b there is no peak tensile strain in the steel bar. At both sections 1250mm and 2750mm with large (turning point) axial strains 1600μ and 1100μ there are bending strains of about –750μ and 750μ. The bending strains in both two sides besides the two sections become to zero. It is can be estimated that there is no obvious sliding surface in the two sections (1250mm and 2750mm of the steel bar No.7) if there are some settlements in this slope.

3.2 The process of the strain developing

After the above analysis of axial and bending strains in steel bars No.8 and No.7, the developing process can be realized as follows: a)the first stage: From the beginning of the steel bar inserted to three months late, the strain in the steel bar varies from unstable to stable. b)the second stage: From Mar.2 to Jun.8, the strain in the steel bar is in growing period. c)the third stage: From Jun.8 to Sept.22, the tendency of the strain has been formed. d)the fourth: the strain goes to the adjustment period after Sept.22.

The reasons for the development of the four stages are that a)The steel bar, mortar and some soil are reformed to unify a whole body; b)There is rain in May and June and this causes the variation of the internal stress in the slope.

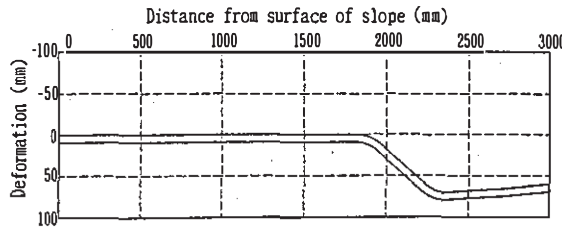

Fig.4a Deformation of steel bar No.8

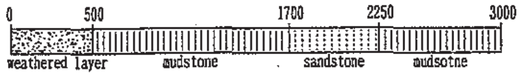

Fig.4b Geological profile of site of steel bar No.8

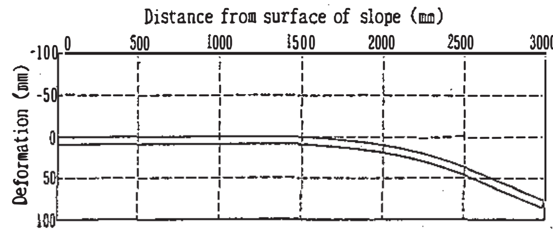

Fig.5a Deformation of steel bar No.7

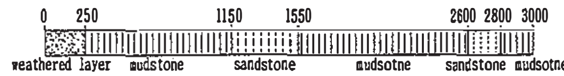

Fig.5b Geological profile of site of steel bar No.7

So this variation leads to the production of strain in the steel bar; c)It is a typhoon season from Jul. to Sept.i.e. heavy rains often come. It is reasonable to produce settlement and sliding surface in the slope. Therefore it is normal that the strain in the steel bar develops fast in this period than other period. d)There is a little rain in Oct. and in Nov., so the stress in the slope is relative stable and has a relative adjustment that cause the small change of the strain in the steel bar.

4 DEFORMATION OF STEEL BAR

In order to realize the deformation of the steel bars and to improve the accuracy of deducing the sliding surface from the distributions of axial and bending strains, five steel bars were picked up carefully from the slope by boring holes with 200mm diameter. As space is limited, the deformations of steel bars No.8 and No.7 are only represented here.

The largest deformation of steel bar No.8 is about 70mm at a depth of 2330mm as shown in Fig.4a and this site lies in the mudstone zone (Fig.4b). There is hardly any deformation from the surface to depth of about 1835mm. At the depth of 3000mm the deformation is about 60mm. From the shape of the steel bar No.8 it is obvious that this steel bar has a deformation of shearing type. The force acted on the steel bar in range of 2250–3000mm. Therefore, the estimation of sliding zone from strain distribution agree well with the deformation of steel bar.

From Fig.4a it is reasonably obtained that the difference of settlement between both ranges of 0–2250mm and 2250–3000mm in this slope is very large and there is a surface in this section in which steel bar No.8 was inserted where the settlement is not continuous.

Fig.5a gives the deformation of steel bar No.7. There is no deformation between range 0–1500mm and this means that there is no settlement too in this range. The largest deformation is about 77mm in the under depth 3000mm. In the range of 1500–3000mm the deformation gradually increases. This means that the settlement in this section is continuous. This deformation may show that the slope failure force applied to the lower part of the steel bar like steel bar No.8, for example, in the range of 2800–3000mm. Namely, the slope surface and upper part of steel bar may carry out the anchor function.

These two deformations of steel bars turned out contrary to our general experience. The deformation appears at the back of steel bar. This means that settlement at the deep part in the slope is larger than at the shallow part. Recently, we had the chance of geological investigation of the slope adjacent to this insitu test site. Fig.6 shows the section of the slope.The distance from this section to the sites of steel bar No.8 and No.7 is almost 15m. It is confirmed that there is a fault zone in the deep part of this slope. Once the sliding surface occurs along this fault zone, the movement at point far from the center of sliding circle is larger than that at near site. As the slope surface repaired by mesh frame and vegetation box does not show any signs of failure, the slope surface and shallow (upper) part of steel bar may play a role of anchor to the sliding force. It is possible that the above anomalous phenomenon comes up.

About the difference between deformations of steel bar No.8 and No.7, it is caused by many factors. It can be seen that the sandstone zone, 1700–2250mm in Fig.6b, has no settlement and it makes that the surface of noncontinuous settlement occurs in this section of the slope in which the steel bar No.8 was inserted in. On the other hand although the site of the depth 1560mm in Fig.5b is located to the mudstone zone the deformation in that section of steel bar No.7 is roughly to zero. This means that the settlement of the mudstone at the depth 1560mm is roughly zero too. There is the sandstone zone, 2600–2800mm in Fig.5b, too, it still has the settlement because the thickness of it is relative thin. The settlement of the slope in which the steel bar No.7 was inserted is continuous. Whether the settlement is continuous or not in the slope will influence occurrence of the kind of deformation of the steel bar.

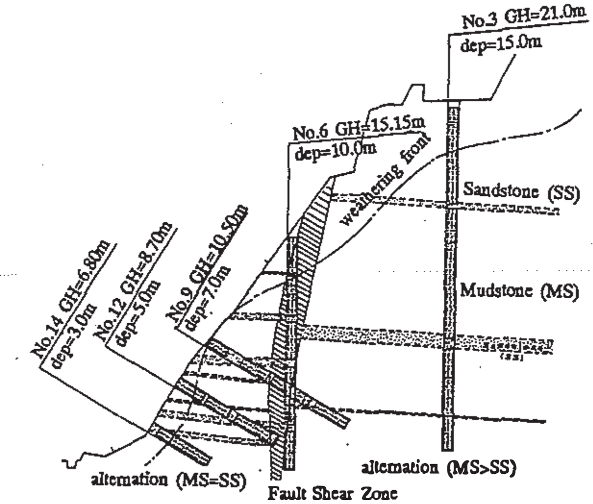

Fig.6 Geological profile of a section of the slope

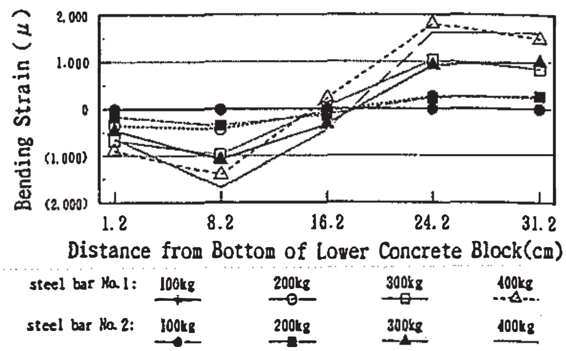

Fig.7 Distribution of bending strain of steel bar

5 Results of the bending strain in lab. test

Here distributions of the bending strain of steel bar in lab. test is presented as shown in Fig.7. In this test one concrete block is put on the other. The lower one is fixed and the upper one is loaded by a horizontal force. There is a mudstone layer with 2cm thick between two concrete blocks and this layer acts as a sliding surface. Two steel bars are vertically inserted to the sliding surface from the upper concrete block to the lower one and the load acted on steel bars is vertical to them. Therefore the deformation of steel bar is a pure shearing type.

In Fig.7, the large bending strains occur near two centers of the upper concrete block and the lower concrete block. The values are about 1800μ and -1800μ. In the crossing point between sliding surface and steel bars, the bending strains in two steel bars are roughly to zero for every load. The distributions of bending strain seem to be anti-symmetric around the crossover point between the sliding surface and steel bar. In tbis test the axial strain is roughly zero and the bending strain plays a main role in resisting the sliding force.

6 CONCLUSIONS

The analysis of information from a insitu test on a cut slope with alternating sandstone and mudstone leads to the following conclusions:

1)The possibility of occurrence of the sliding or settlement of the slope in rain season is large, specially in typhoon season.

2)It is possible that the settlement at the deep part is larger than at the shallow part in a slope if the slope is with a fault zone.

3)In the same slope alternating sandstone and mudstone layers deformations of steel bar are different from each other whether there is a surface of noncontinuous settlement or not.

4)Deduction of a sliding surface can be made from the distributions of axial and bending strains in the steel bar when the axial strain has a large value at one point of the steel bar and the bending strain roughly appears anti-symmetric about that point. In this slope the settlement is not continuous.

5)If the slope failure force acts on the lower part of steel bar, the deformation of shallow (upper) part steel bar may be larger than that of deep (lower) part of steel bar.

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REFERENCES

Tatsuoka,F. and Hamada,E. 1984-1985. Laboratory Study on Reinforcing of Sand slope with steel Bars ([I]-[V]), Technical Report of Production Technique Institute, No.10, Vol.36-No.2, Vol.37. Tokyo University

Hayashi,S., Ochiai,H., Tayama,S., and Sakai,A. 1986. Effect if top plates on mechanism of soil-reinforcement of cut-off slope with steel bars, JSCE, No,367,VI.

Kitamura,T., Okuzono,S., Ymada,N. and Sano,N. 1987. Theory and practice of reinforced slopes with steel bars, soil and foundation, JSSMFE, Vol.35, No.358.

Yokota,H,, Zhou,J.M., Nakazawa,T., Imai,F. and Fujimoto,H. 1992. Nailing effects on cut slope with alternating sandstone and mudstone, Proceedings of the international symposium on earth reinforcement practice, Vol.1. Fukuoka, Japan

Yokota,H,, Zhou,J.M., Nakazawa,T., Imai,F. and Mitsukura,T. 1993. Reinforcement effects of nailing for the Tertiary mudstone slope, Proceedings of an international symposium on geotechnical engineering of hard soils - soft rocks, Vol.2. Athens, Greece. II