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SYNOPSIS: This paper presents a case study on the collapse accident of a temporary earth support structure. The examination of the design plans and investigations of the construction site where the accident occurred has been carried out to throw light on the accident situations. Some causes of the accident occurrence which have been derived from these examinations and countermeasures for prevention of these types of accidents are discussed.

INTRODUCTION

Every year a lot of accidents take place in the construction industry. Recently occupational accidents associated with construction work amounts to about 30% of all occupational accidents and represent nearly half of the number of deaths for all industry in Japan. Especially, accidents due to earth collapse tend to become serious cases resulting in death and the importance of countermeasures to prevent such collapsing accidents has been recognized in the past.

The large collapse accident of a temporary earth support structure occurred in 1989. Five workers were killed and two others were injured in this accident. Ministry of Labor immediately organized an accident investigation mission to investigate causes of the collapse accident and establish effective countermeasures for the prevention against these types of accidents. The examination of design plans and the investigations of the construction site have been carried out to clarify the basic understanding of accident situations.

This paper presents the results of the accident investigations. Direct or indirect causes of the accident occurrence which have been derived from these examinations are explained in detail and effective countermeasures for preventing these types of accidents are discussed as well.

OUTLINE OF THE CONSTRUCTION WORK

This accident occurred at the building construction site. The ground plan of the construction site is shown in Fig.1. The construction area was divided into three construction sites. The collapse occurred at A construction site which had an excavation area of 17.6 meters wide (north-south direction) and 30.3 meters long (west-east direction).

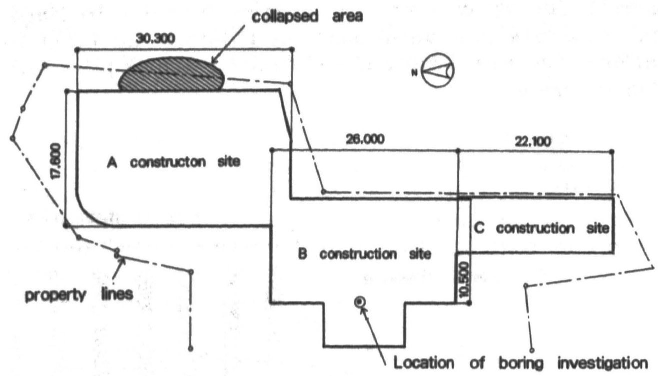

Fig. 1 The ground plan and the location of boring investigation

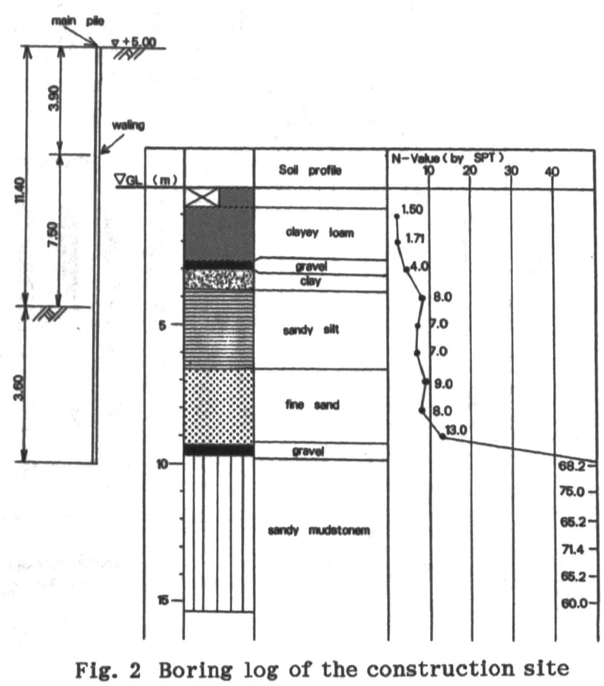

Fig. 2 Boring log of the construction site

Geological survey of A construction site was not performed. However, only one boring investigation had been conducted for the construction of the foundation piles. The location of the boring is shown in Fig. 1. Fig. 2 is the result of the boring investigation. According to this boring log, the ground consisted of cohesive soil (Kanto Loam) from ground level (GL) to -4 meters, sandy silt from -4 to -6.5 meters, fine sand from -6.5 to -9.5 meters and sandy mudstone below -10 meters. The N-value of the sandy mudstone was around 60 and other soil was less than 10. The ground water level was GL-1.5 meters.

SITUATIONS OF THE ACCIDENT OCCURRENCE

On the morning that the accident occurred, workers were readjusting the bottom of the excavation site and were treating the heads of the foundation piles. At around 10 o'clock on that morning, they noticed that the H-steel piles on the east side (17th, 18th and 19th from the north side) had not penetrated below the excavation bottom. The field engineer in charge felt there was a danger of a collapse, so, he changed the readjustment work from the east side to the west side and ordered ready mixture concrete delivered before the evening in order to finish blind concrete placing as soon as possible. He tried to reinforce the main piles and additional remedial plies with blind concrete.

At around 1:15 P.M., central 15 meters of the temporary earth support structure on the east side collapsed and 200 cubic meters of earth, 7 ~ 8 meters high and maximum thickness 4 meters, slid into the excavation area. Due to this collapse, 11 of the H-steel piles toppled. Four workers at the bottom of the excavation site were buried alive and three workers were struck by H-steel piles. As a result, five workers were killed and two others were injured. The elevation of the collapsed earth support structure is shown in Fig. 3.

OUTLINE OF THE TEMPORARY EARTH SUPPORT STRUCTURE

The temporary earth support structure was designed by the design division of the main construction company and the main piles with lateral wooden sheetings method were introduced as a temporary earth support system. The length and the interval of main piles were 15 meters and 1 meter, respectively. The ground anchors were designed by a sub-construction company. The diameter of the ground anchors was 117 millimeters, the length was 20.5 meters (effective length 5.0 meters) , the angle was 45 degree and the horizontal interval of the anchors was 2.5 meters.

In first design plan, the main pile had a 300*300 H-steel pile, the penetration depth of the main piles was 3.6

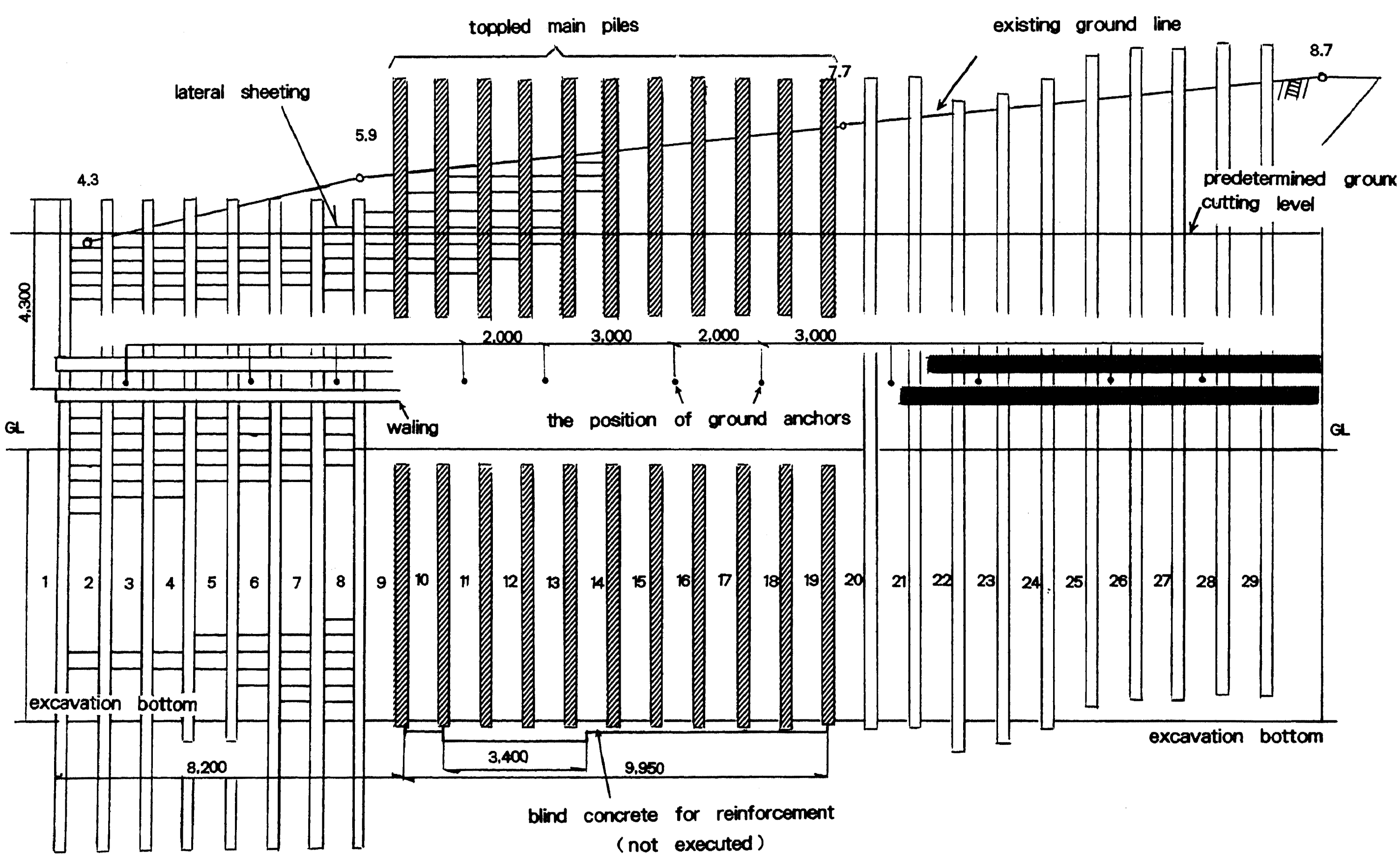

Fig. 3 The elevation of the collapsed earth support structure

meters and the 2-stage ground anchors were adopted. However, by the judgement of the field engineer, the design plan was changed to use a single-stage ground anchor and a 350*350 H-steel pile. Finally, 300*300 H-steel piles were used as the main pile (see Fig. 4).

According to the calculation sheet of the temporary earth support structure, the safety factor for overturning of the main piles was 1.2 and the penetration depth of the main pile was 3.6 meters. Hydraulic pressure was not taken into account in the design, because ground water was drained from a gap of lateral sheeting.

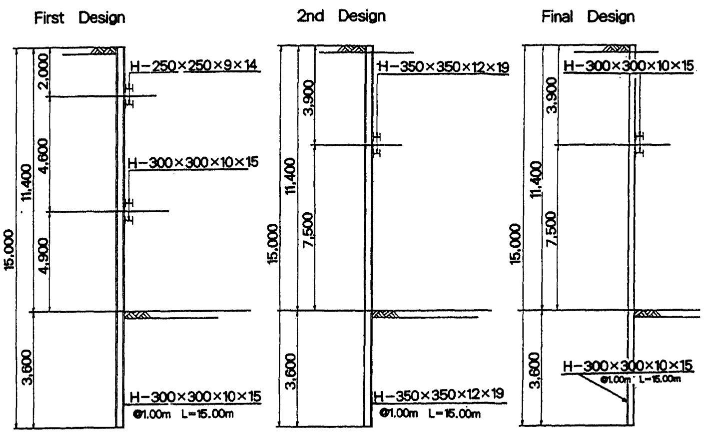

Fig. 4 Designs of main piles and ground anchors

ESTIMATION OF MECHANISM AND CAUSES OF THE COLLAPSE OCCURRENCE

Following findings have been derived from the examination of the design plans and the survey of the accident site.

1. Mechanism of the collapse

Since the readjustment work was performed on the excavation bottom in spite of insufficient penetration of the main piles, the position of toe of some of the main piles was above the excavation bottom. The main piles, however, were supported by the ground anchors with an angle of 45 degrees from the horizontal plane, lower part of the main piles moved forward around the point of walings (at the position of ground anchor) and walings were apart from the main piles. Finally, earth pressures acted to cause the earth support structure to become unstable causing a large earth collapse to occur. Still, additional remedial piles had been installed in front of the main piles, but these plies were not sufficient enough to prevent the collapse.

2. Cause of insufficient penetration of the main piles

The east side of the construction site where the collapse occurred was a hill shape of GL+5 ~ +10 meters (see Fig. 3). According to the construction plan, after this hill had been cut to GL+5 meters level, then 15 meters main piles would have penetrated the ground. However, the field engineer performed ground cutting without checking the excavated ground level with the assembly diagram, therefore the hill shaped ground was not cut to the designed ground level. In spite of the lack of ground cutting (GL+8 ~ +9 meters), the penetration work of the main piles were carried out. As a consequence, it follows that 21 of the main piles had not penetrated to the predetermined ground level (except for 8 piles on the north side) as shown in Fig. 3.

DISCUSSIONS AND CONCLUSIONS ON PREVENTION OF EARTH COLLAPSE ACCIDENTS

1. Ground surveys

Since excavation work is concerned with natural ground, geological surveys and soil investigation which were conducted before the execution of the construction are very important. In this construction site, only one boring investigation for the construction of the foundation piles had been performed. No ground surveys were performed around the area where the collapse occurred. In cases where the ground is of a complex shape or the ground condition is not clear, the preliminary ground surveys should be conducted. Surveys during the construction are as important as the preliminary survey. Detailed changes in ground conditions could not be known by the preliminary survey and the behavior of the ground caused by the execution of excavation could be known, and based on them, if necessary the construction plan should be properly modified and the remedial work should be carried out as soon as possible.

2. Design of a temporary earth support structure

In this construction, the temporary earth support structure was designed from the economical point of view or by the reason of material procurement at the site. For example, the 2-stage ground anchors were changed to single-stage anchors and the size of the H-steel piles were reduced (see Fig. 4).

According to the calculation sheet, the safety factor for overturning of the main piles was 1.2 and penetration depth of the main pile was 3.6 meters. The greatest part of the penetration portion was the fine sand and only 30 centimeters of the pile toe penetrated into the sandy mudstone (see Fig. 2). Resisting moment due to this 30 centimeters penetration portion covered about 40% of total resisting moment.

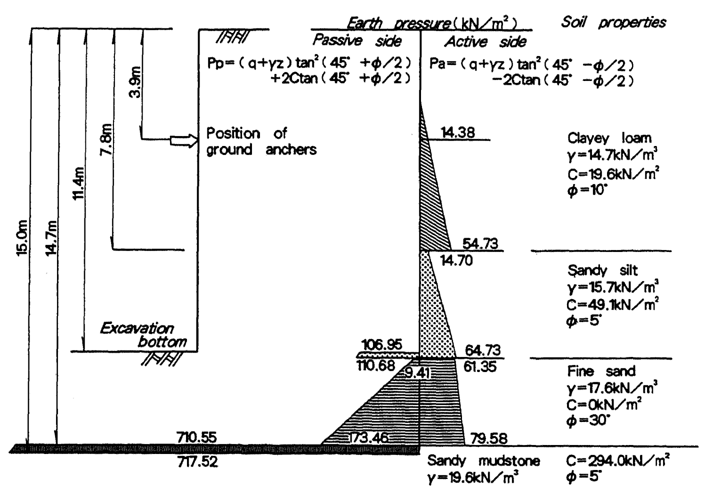

Fig. 5 The earth pressure distributions for the determination of the penetration length of main piles

Earth pressure distributions for determination of the penetration length of the main piles are shown in Fig. 5. If there was a lack of penetration of 30 centimeters, the safety factor for overturning was reduced to 0.7. Considering the accuracy of the penetration work of piles and the uncertainties of the ground conditions in this construction site, these design procedures, in which about 40 % of total resisting moment of the main piles was covered with the lowest 30 centimeters penetration portion, are undesirable.

In general, temporary structures are liable to be designed where priority is given to economic restrictions. From an engineering viewpoint, a design which realizes the importance of safety should be used to prevent collapse accidents.

3. Execution of earth support structures

Since the field engineer had executed the earth support structure without checking the excavated ground level with the assembly diagram, the main piles were driven into the ground without sufficient ground cutting. As a result, most of the main piles did not penetrate the predetermined level. To eliminate such a mistake, the construction of the earth support structure must be executed according to the assembly diagram in which materials, dimensions, arrangements of structural members, assemble schedule and assemble sequence are clearly shown. Moreover, it is important to ensure construction accuracy using the measurement.

In this construction site, insufficient penetration of the main piles on the east side was found just after the first excavation had finished and the remedial work had been done using H-steel piles available at the site. Additional remedial piles were driven in front of the main piles and the schematic diagram of remedial piles is shown in Fig. 6.

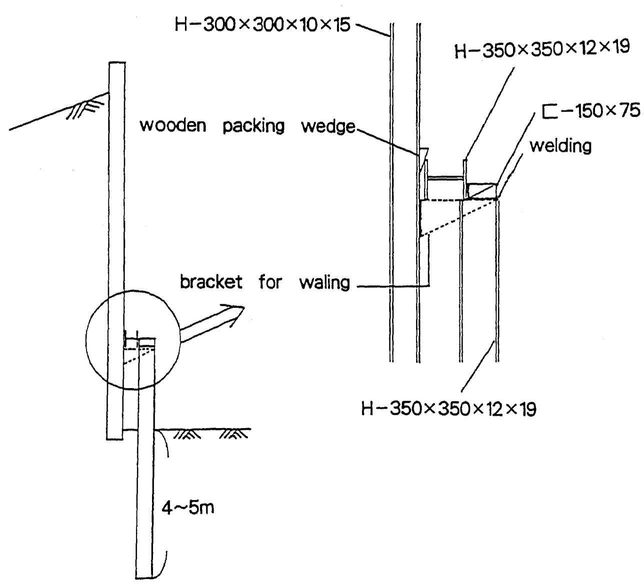

Fig. 6 The schematic diagram of remedial piles

However, the strength of remedial piles had not been examined at all. In cases where such mistakes are recognized during construction, a detailed checking of such mistakes has to be made and effective remedial countermeasures should be taken immediately.

Hydraulic pressure was not taken into account in the design as described previously. This is based on the assumption that the drainage of water have completely carried out. In a case of heavy rainfall, the seepage of the rainwater occasionally caused an increase in the earth pressure. The drainage at the ground surface is important to prevent the occurrence of dangerous situations.

4. Observational control

In construction control, the adoption of various measuring instruments becomes increasingly important. The existence of danger associated with the uncertainties of the natural ground involved in a construction work causes occupational accidents and trouble. The danger can be decreased by executing a preliminary survey and establishing a construction plan. If the survey and observation during construction, however, are further performed using measuring instruments, the changes in the behavior of the concerned ground can be accurately known. If slight symptoms possibly resulting in accidents and phenomena not expected in the preliminary survey or in the stage of the construction plan can be detected, the construction method should be properly modified.

The measurement of earth pressures, displacements, stresses, etc. have been already generally performed at large construction projects, and it is desired that such observational control take root as an indispensable practice in the construction control.

ACKNOWLEDGMENTS

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