14 Aug 2008, 4:30pm - 6:00pm

Case History of Labor Accident Due to Slope Failure During Slope Excavation and Its Countermeasure Work

Kazuya Itoh
National Institute of Occupational Safety and Health, Tokyo, Japan

Sahaphol Timpong
National Institute of Occupational Safety and Health, Tokyo, Japan

Yasuo Toyosawa
National Institute of Occupational Safety and Health, Tokyo, Japan

6th International Conference on
Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008

CASE HISTORY OF LABOR ACCIDENT DUE TO SLOPE FAILURE DURING SLOPE EXCAVATION AND ITS COUNTERMEASURE WORK

Kazuya Itoh
National Institute of Occupational Safety and Health,
Tokyo, Japan 2040024

Sahaphol Timpong
National Institute of Occupational Safety and Health,
Tokyo, Japan 2040024

Yasuo Toyosawa
National Institute of Occupational Safety and Health,
Tokyo, Japan 2040024

ABSTRACT

About 15 to 20 workers die annually in labor accidents attributed to slope failure or rock fall during slope excavations in Japan. In this paper, a case history of slope failure occurred during the reconstruction of retaining wall is presented. The geotechnical centrifuge model tests are conducted to investigate the mechanism of slope failure. This paper focuses on the influence of wall stiffness and embedded depths of sheet piles or pipes on the prevention of slope failure. Based on the centrifuge test, it was found that the simple temporary wall used during the trench excavation in this case history could not protect to worker from the slope failure.

INTRODUCTION

Mountains and hilly terrain account for 70% or more of Japanese national land area. Japan is located in one of the world's premier organic belts and in the past, intense crystal disturbances had taken place, which formed precipitous features with weak and complicated geological structures. Moreover, the feature of Japanese climate, such as rainy seasons, typhoons with localized severe rain, and freeze-thaws in cold districts, which make landslides, cliff failures, rock falls, and avalanches of rocks and earth more likely to occur. However, the main transportation networks of railways and roads run below steep slopes in mountain areas or along the coastline, and urban development reaches the hilly zones and the bases of mountains. Many houses are constructed close to slopes and cliffs. In many cases, such advanced and over-concentrated land usage poses risks of slope failure accidents.

The number of fatalities resulting from labor accidents caused by construction industry, land collapses or sliding debris, and slope excavation in Japan is shown in Fig. 1. While the number continues to drop, the situation is such that about 500 workers a year die as a result of labor accidents in construction industry. In recent years, the number of fatalities caused by land collapses or sliding debris decreased by 50%, compared with 1990. However, the number of fatalities resulting from slope excavation is still about 15-20 annually. According to the labor accident reports from the Japan Construction Safety and Health Association, most of labor accidents caused by the slope excavation are likely to occur during the slope stabilization by retaining wall methods as presented in Fig. 2. The slope failure often occurred during the assembling and dismantling of formworks (20 cases), ground/slope excavation (14 cases), smoothing of base (12 cases) and excavation of the base (9 cases). This can be explained by the fact that the construction of retaining walls generally includes the excavation of steep and unstable slopes, and the risk of slope failure is relatively high during these types of construction work as can be seen in Fig. 3.

In this paper, firstly a case history of labor accident caused by slope failure occurred during the slope excavation work for reconstruction of retaining wall is presented. Secondly, the results of geotechnical centrifuge model tests that simulated the slope failure accident are mentioned and discussed. In addition, this paper focuses on the influences of wall stiffness and embedded depths of sheet piles or pipes on the stability of slope by conducting a series of centrifuge model tests.

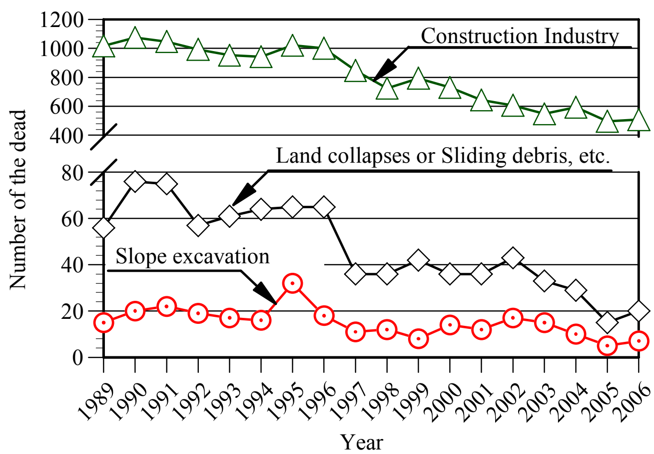


Fig. 1. Number of fatalities due to labor accidents in Japan.

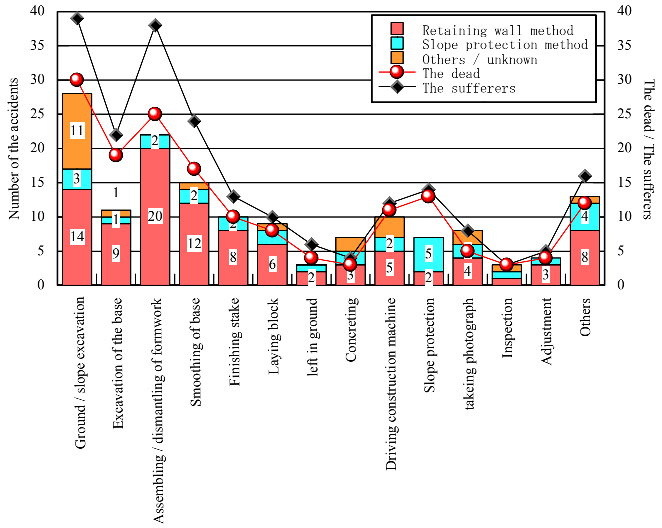


Fig. 2. Number of labor accidents classified by types of construction works.

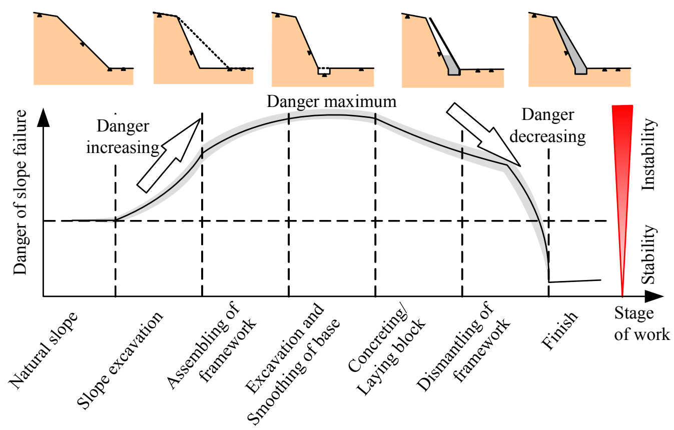


Fig. 3. Risk of slope failure during retaining wall construction.

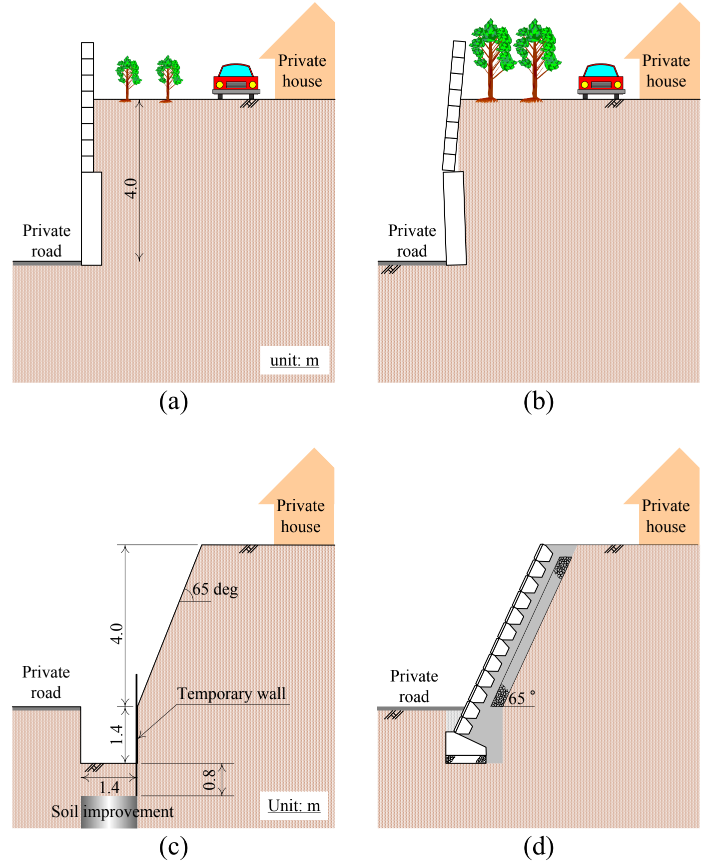


Fig. 4. Sequence of the retaining wall construction.

CASE HISTORY OF LABOR ACCIDENT DUE TO SLOPE FAILURE DURING SLOPE EXCAVATION

Scenario of the accident

The private house was rebuilt to extend a new room at the first floor. It was necessary to construct new retaining wall because the existing retaining wall was in danger of collapse as shown in Fig. 4(b). This retaining wall is composite structures made by cinder block wall on concrete gravity wall. The existing concrete gravity wall moved forward as a bottommost portion of the wall is fixed and the cinder-block wall moved as bottommost portion of the wall is freed. The owner and contractor had a plan to make a new 4.0 m high concrete block retaining wall, according to the construction plan; a finished shape of new retaining wall is shown in Fig. 4(d). The construction comprises excavating a 1.4 m x 1.4 m trench at the base of the retaining wall for concrete foundation (Fig. 4(c)). In this construction site, soil cement column was used for settlement control of natural soft ground supporting a weight of new retaining wall. The target unconfined compressive strength c_u was 1.1 MPa, and maximum embedded depth was 8.0 m under a bottom of the trench. Because a shoring plan was not formulated, a simple temporary wall system was used during the trench excavation. Steel pipes for temporary construction were driven with a spacing of 0.5 m into the ground using a mini excavator. Composite panels were placed directly against the front of the pipes as a soldier pile wall system. The embedded depth of steel pipe was only 0.8 m due to a stiff improved ground under the bottom of trench. The accident occurred on the second day after constructing a base of retaining wall. On the day of accident, only three workers worked in the construction site. Worker A operated the mini excavator to excavate the trench, worker B (victim) remained in the trench for checking designed excavation depth and worker C (victim) smashed the soil cement column using a portable breaker for smoothing of the base and after that the worker C smashed concrete of private road in the trench. The labor accident took place around 11:30 a.m., a sudden slope failure occurred without any clear signs of failure (Fig. 5). According to the slope failure, the simple temporary wall that collapsed was not shored or otherwise protected from earth movement. A section of trench caved in, striking and burying the victims to their whole bodies and two workers lives were lost in slope failure. In the case history mentioned above, the occurrence of slope failure might be caused by the influence of wall stiffness and embedded depth of wall on prevention of slope failure. This influence will be examined by means of centrifuge model tests.

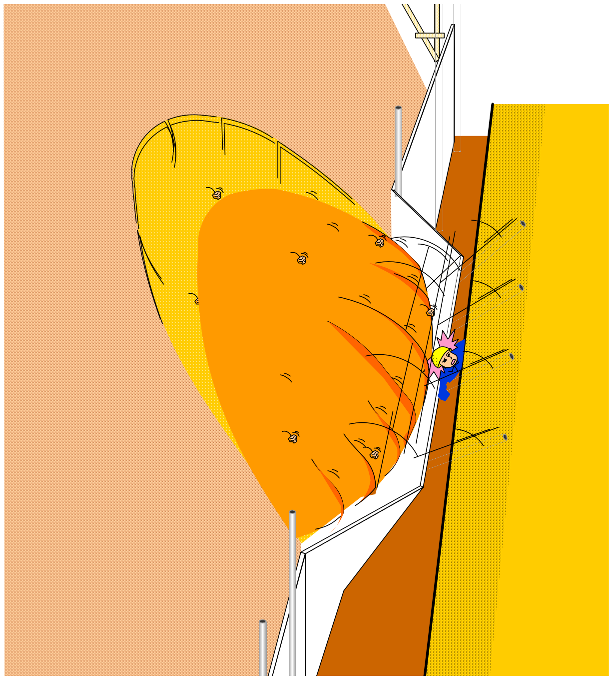


Fig.5. Labor accident cased by slope failure.

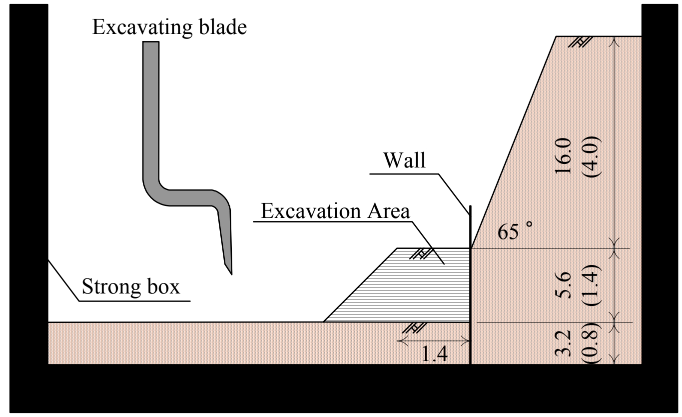


Fig. 8 Experimental setup.

Table 1. Test cases

Case	Type of wall	Embedded depth of wall
1	Simple temporary wall	3.2 cm (0.8 m)
2		1.6 cm (0.4 m)
3	Sheet pile wall	3.2 cm (0.8 m)

Notes) numbers in parenthesis are prototype scale

CENTRIFUGE MODEL TEST

All the tests described here were conducted using the NIIS Mark II Centrifuge (Horii *et al.*, 2006) at the National Institute of Occupational Safety and Health, Japan (JNIOSH) as shown in Fig. 6. Unlike other centrifuges, the arms of the NIIS Mark are asymmetric, which is its special feature. One side of the arm is provided with a bridge plate where the swinging platform is fixed to its inner end plate with the help of a pair of hydraulic suspension jacks when the platform is lifted up (dynamic platform). In order to balance this portion (weight of the end plate) of the dynamic side arm while swinging, two counterweights are hung over the two sides of the opposite arm, which is used for non-shaking or static tests (static platform). In the type of medium-size centrifuge used here, it is possible to obtain a longer radius and larger platform, similar to large-size centrifuges. In this paper, the static platform was used for the slope model test.

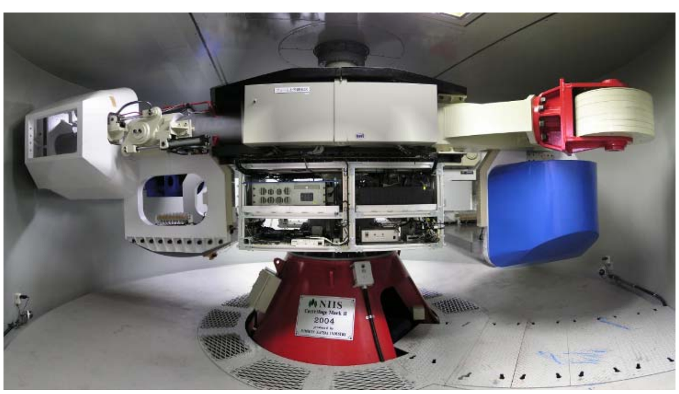


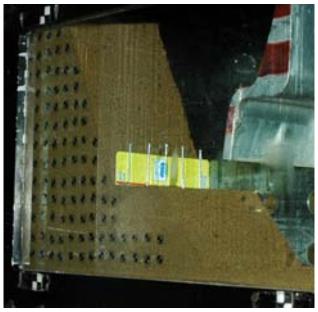
Fig. 6. The NIIS Mark II Centrifuge.

Experimental Setup

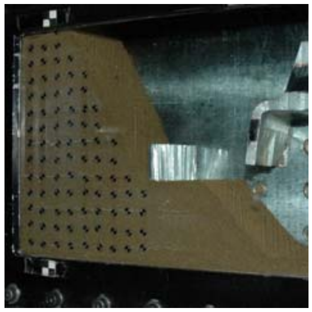
Figure 8 shows the experimental setup and Table 1 shows the test condition for investigating the influence of wall stiffness and the embedded depth of wall on prevention of slope failure. Narita sand (particle density of soil ρ_s = 26.12 kN/m^3, mean particle size D_{50} = 0.19 mm) was used as model soil. This sand is classified as SF (Sand with fines ≤15%) (JGS0051-2000). The Narita sand was thoroughly mixed with pre-determined water content w of 17% and kept in plastic bag for several days. The soil mixture was then placed in a model box (0.45 m x 0.20 m x 0.272 m) and statically compacted in a number of layers at 70 kPa by the Bellofram cylinder. The thickness of each layer was about 0.05 m and compaction time for each layer was about 5 minutes. Once the compaction was completed, front and back panels of the model box were removed and the resulting block of model ground was then trimmed to required slope geometry as shown in Fig. 8.

The slope angle for each slope model test was fixed at 65 degree; model wall was installed behind the excavation area as presented by shaded portion. In this paper, two wall types were used in the centrifuge test in order to investigate the effect of stiffness and embedded depth of wall on protection from earth pressure due to slope failure. One is simple temporary wall for simulating this slope failure accident, which is combination of steel pipe for temporary construction and composite panels (Fig. 9(a)), and another is sheet pile wall (Fig. 9(b)). For the simple temporary wall, the embedded depth of wall was 0.8 m and 0.4 m corresponding to the prototype scale.

A model steel pipe for temporary construction and composite panels were 2 mm diameter aluminum stick (flexural rigidity,

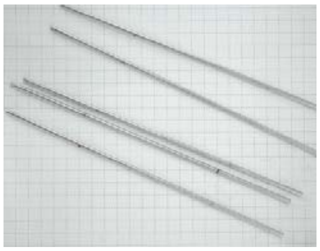


(a) Simple temporary wall



(b) Sheet pile wall

Fig. 9. Types of model wall for centrifuge model test.



(a) Model steel pipe for temporary construction using aluminum stick

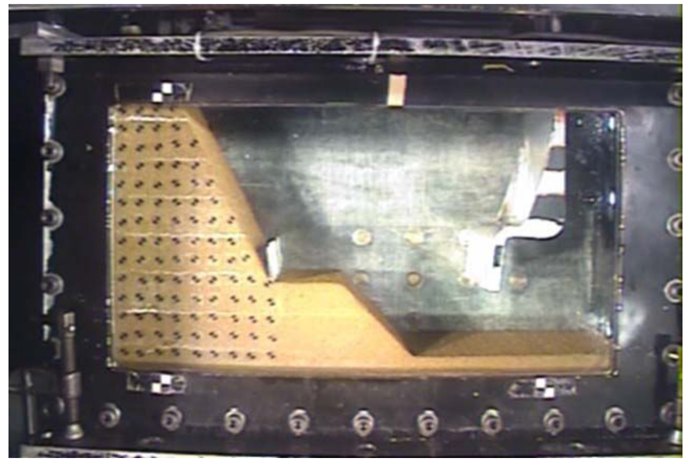
(b) Model composite panels using telephone cards

(c) Model sheet pile wall using aluminum corrugated plate

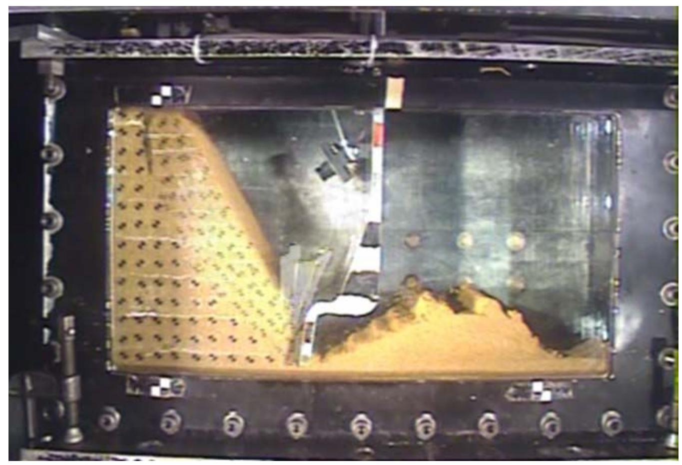
Fig. 10. Model wall materials.

EI = 1.08 x 10^4 kNm^2/m) and telephone card, respectively. A model sheet pile wall was 0.3 mm thickness of aluminum corrugated plate (EI = 1.78 x 10^5 kNm^2/m).

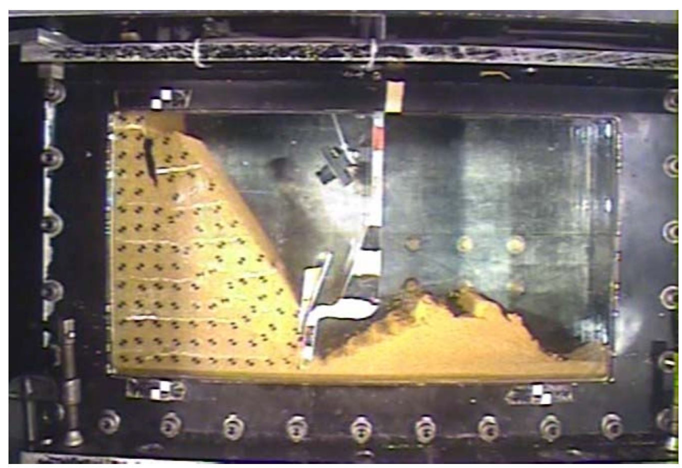
After making the model slope, the side panels were attached to the model box, in order to reduce the friction between the model slope and the model box panels, a thin film of silicon oil was applied to the panels. The model box was then installed onto the centrifuge platform and the in-flight excavator (Toyosawa *et al.*, 1998) was positioned above the model box in such a way that its excavating blade could move freely within the model box. In this test, for the excavation, the excavating blade of 0.2 m width was used. It could move up, down, left and right directions by two stepping motors during the centrifuge test. In addition, the movement of excavating blade in a horizontal direction makes it possible to shift away the excavated material smoothly from the model slope. The operation of the in-flight excavator could be controlled manually or in semi-automatic way in real time from the operating room.



(a) Initial condition



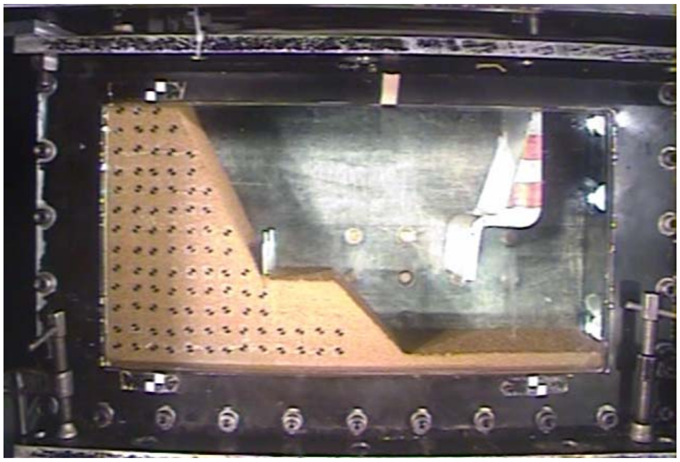
(b) Just failure (1.4 m excavation)



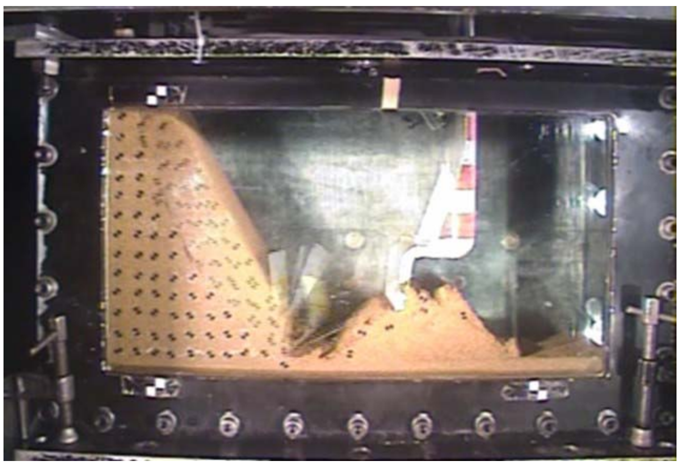
(c) After failure

Fig. 11. Model Slope during the centrifuge test (case 1).

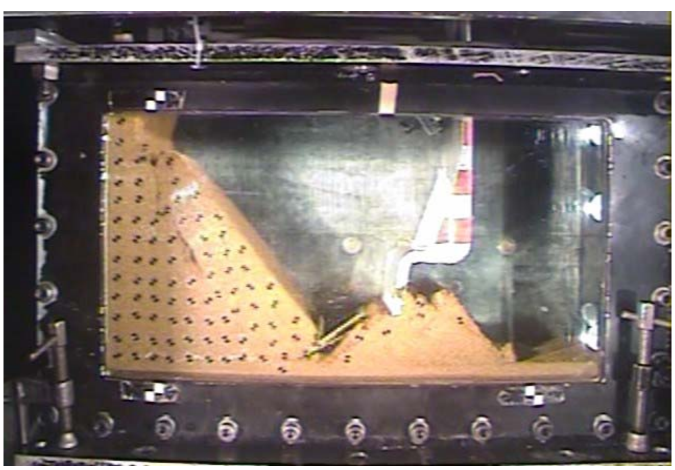
Digital video and CCD cameras with a frame rate of 30 pictures per second were installed at the excavating blade and in front of the model box to monitor the behavior of the slope excavation work during the centrifuge test. The vertical displacement of the slope crest was recorded by the linear variable differential transformers (LVDT).



(a) Initial condition



(b) Just failure (before 1.4 m excavation)



(c) After failure

Fig. 12. Model slope during the centrifuge test (case 2).

Test Procedure

After the experimental setup was completed, in all tests, the acceleration was increased gradually in step by step from 1g to 25g where the model slope will represent a 4 m high slope with a slope angle of 65 degree corresponding to the prototype scale. Once the vertical displacements from the displacement transducers become constant at 25g, the excavation process was started. The excavation was started from the top of the excavation area horizontally outward from the model slope. The height of each excavation of the model slope was about 0.25 m in the prototype scale and the excavation was continued until slope failure occurred.

However, if the slope failure does not occur with the excavating of 1.4 m height (in prototype scale) as presented at the time of the slope failure accident, the self-weight of model slope will gradually increased by increasing the centrifuge acceleration until the slope failure could be observed.

Experimental Results and Discussions

Simple temporary wall

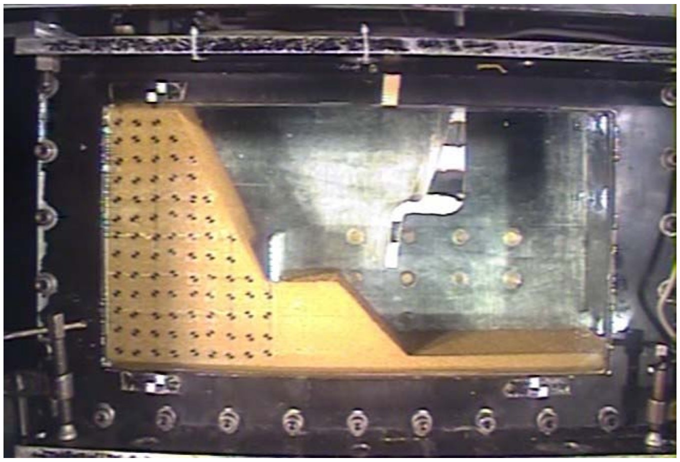
Figures 11 and 12 show the recorded images of the model slopes during the centrifuge tests for the simple temporary wall with the embedded depth of 0.8 m and 0.4 m, respectively. In the model slope case 1 (actual condition at the time of labor accident), rapid deformation and slope failure were observed at the excavating process of 1.4 m as can be seen from the blurring failure images captured by the digital CCD camera. (Fig. 11(b)). In the model slope case 2 with a shallower embedded depth, slope failure occurred rapidly after the excavating process of 1.3 m (Fig. 12(b)).

This indicated that the toppling failure of simple temporary wall is likely to bury workers in the trench and there was no sufficient time for the workers to escape from the trench. In addition the plastic deformation of model steel pipe, which is considered to be caused by yield strength of the model steel pipe due to large load by slope failure, was also clearly recognized. In other words, the simple temporary wall used during the trench excavation in this case history could not protect to worker from the slope failure.

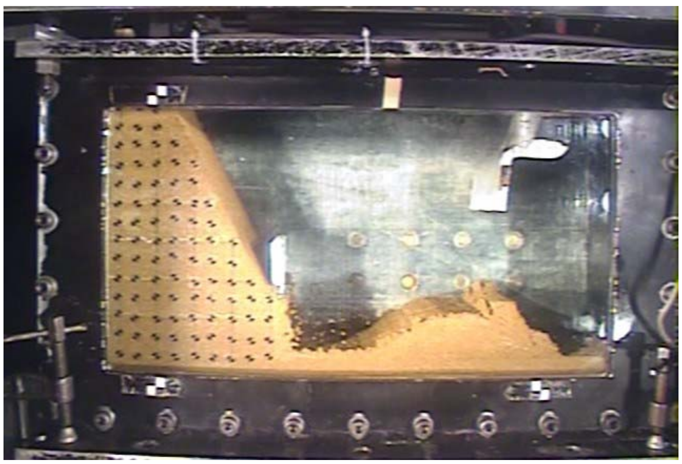
Sheet pile wall

As mentioned above it is necessary to provide a better shoring system to prevent the worker from the slope failure. In this paper the sheet pile wall method was purposed. Figure 13 shows recorded images of the model slope case 3 at different stages. In this case, slope failure did not occur with the excavating of 1.4 m at 25g, and the model sheet pile wall rarely or never develop to large deformation as can be seen in Fig. 13(b). In order to investigate the mechanism of slope failure in this case, the self-weight of the model slope was gradually increased until failure occurred.

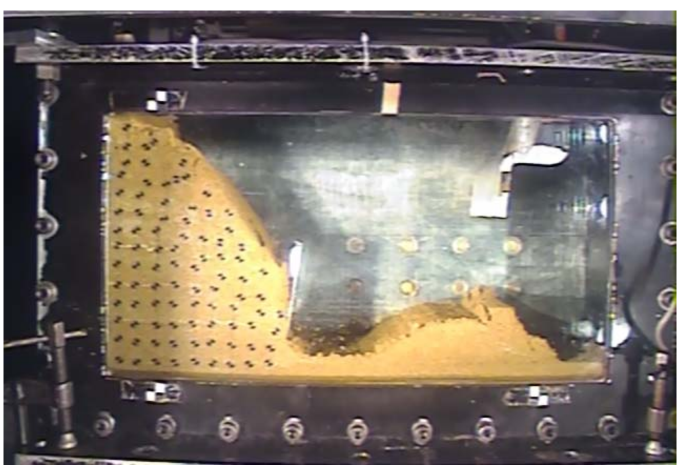
When the centrifuge acceleration reaches to 36g where the excavation depth was about 5.8 m in the prototype scale, it can be seen that the displacement increase gradually such as in the case of landslide, it indicates that the slope reach the failure state (Fig. 13(c)). By comparing to the failure in the simple



(a) Initial condition



(b) After 1.4 m excavation



(c) Failure at 36 g

Fig. 13. Model slope during the centrifuge test (case 3).

temporary wall, it was found that the use of sheet pile wall as a shoring system can protect the worker’s life from the slope failure. In addition it is possible that the workers can escape safely from the trench because deformation caused by slope failure is suppressed by the sheet pile wall.

CONCLUSIONS

This paper presented a case history of the slope failure accident during the slope excavation work for re-constructing the retaining wall. On the basis of this accident, a series of centrifuge model tests were carried out, the mechanism of failure and deformation of the slope were investigated. In the case of simple temporary wall which is combination of steel pipe for temporary construction and composite panels used at the time of the accident, it was found that sudden toppling failure of the wall is likely to bury worker in the trench. In contrast, in the case of sheet pile wall with a high stiffness, it is possible that the workers can escape safely from the trench because this wall suppresses a deformation caused by the slope failure. Because the objective of this study has narrowed down to investigation of case history of labor accident, the collection of experimental data on earth pressure under various conditions is also important for the future study.

REFERENCES

Japanese Geotechnical Society (JGS0051-2000). [2000]. “Methods of classification of Geomaterials for Engineering Purposes,” Soil testing methods and explanation, pp. 213–245.

Japan Construction Safety and Health Association [1989-2004] “Construction industrial labor accident reports. Construction Safety and Health Yearbooks”.

Horii, N., Itoh, K., Toyosawa, Y., and Tamate, S. [2006]. “Development of the NIIS Mark-II geotechnical centrifuge,” The 6th International Conference on Physical Modeling in Geotechnics, Hong Kong, pp. 141-146.

Toyosawa, Y., Horii, N., and Tamate, S. [1998]. “Deformation and failure behavior of anchored retaining wall induced by excessive excavation in centrifuge model tests”, Research reports of the National Institute of Industrial Safety, NIIS-RR-97, pp. 35-46.