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

Lessons Learned from Slope and Trench Failures in Japan

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

LESSONS LEARNED FROM SLOPE AND TRENCH FAILURES IN JAPAN

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ABSTRACT

This paper presents case histories of slope and trench failure accidents in Japan during the period of 1989 to 2001 based on the database from construction industrial labor accident reports. The major risk factors of the failures are identified by considering the location of slope and trench failures, types of construction, slope and trench geometries, scale of slope failure, time of occurrence and characteristics of worker involved in the failures. It was found that it is necessary to improve the safety standards and provide more safety education and training especially in the small construction projects to prevent the slope and trench excavations in future.

INTRODUCTION

Slope and trench excavations are one of the most hazardous operations in geotechnical works. In many cases slope and trench failures are likely to occur rapidly without any clear signs of failure, most of construction workers have insufficient time to escape from the excavation sites and hence, the labor accidents generally take place. In Japan, the slope and trench excavations have caused a number of fatalities and injuries of construction workers throughout time. Figures 1 and 2 show the example of labor accidents caused by slope and trench excavations, respectively. The number of labor accidents and fatalities caused by slope and trench excavations in Japan is shown in Fig. 3. During the period of 1989 to 1996 about 24 and 37 workers were killed each year in trench and slope excavations, respectively. However, the number has decreased from 1996 onwards and it was about 11 and 25 workers per year for slope and trench excavations, respectively. The possible reasons for the decrease in the number of fatalities were development of laws relating to safety measures on construction sites and impacts of economy and employment conditions. As can be seen in the figure, the number of labor accidents caused by trench excavations is generally 2 times higher than that of slope excavations. This is probably due to the fact that the trench excavation work not only presents all the special challenges of a confined space environment, but it also puts the workers at risk of being struck by objects and of being caught in a trench cave-in. The labor accidents are costly in terms of direct and indirect cost to the construction industry. The direct costs associated with each slope and trench failures include compensation insurance, penalties and fines for violating safety standards, rescue operation and body recovery. The indirect costs include work schedule delays, time and effort to training a new worker.

Fig. 1. Labor accident caused by slope failure.

Fig. 2. Labor accident caused by trench collapse.

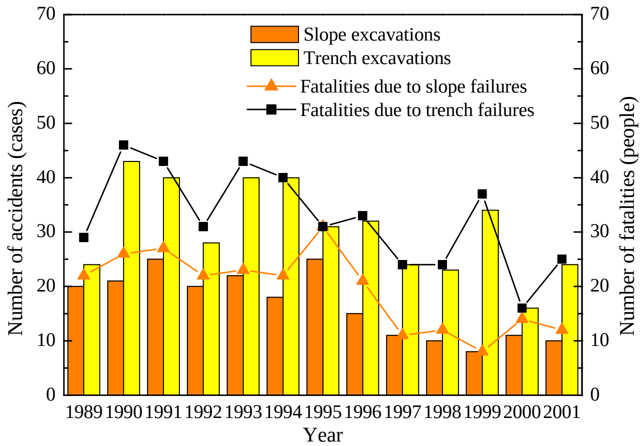

Fig. 3. Number of labor accidents caused by slope and trench excavations in Japan during 1989-2001.

In order to establish effective measures to prevent the labor accidents caused by slope and trench excavation works in future, this paper investigated the labor accidents and analyzed them from various perspectives. The information of the labor accidents occurred during the slope and trench excavations in Japan during the period of 1989-2001 was obtained from the construction industrial labor accident reports of the Japan Construction Safety and Health Association (JCSHA). The main information extracted from each report was location of accident, types of construction, slope and trench geometries, scale of failure, time of occurrence and characteristics of worker involved in the accidents. It should be noted that some reports have incomplete data.

CHARACTERISTICS OF LABOR ACCIDENTS CAUSED BY SLOPE AND TRENCH FAILURES

Location of Slope and Trench Failures

Japan is officially divided into 8 main geographical regions: Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku and Kyushu (including Okinawa) regions as presented in Fig. 4. Figure 5 shows the distribution of the location of labor accidents in slope and trench excavations, the region with the highest percentage of accident was Chubu, followed by Kanto, Kinki and Kyushu regions. Since no data were available on the total number of slope and trench excavations in each region, so it was not possible to determine that slope and trench excavations in these regions were statistically more or less safe than other regions. However, it should be noted that most of natural landslides and slope failures in Japan commonly occur in these regions.

Types of Construction

Figures 6 and 7 show the labor accidents classified by type of slope and trench excavations, respectively. In case of slope excavation most of slope failure occurred due to destabilization of slope when the lower part of a natural slope is removed or a part of the slope is steepened. There are two general construction methods for stabilizing slope: retaining wall and slope improvement methods. Based on the labor accident reports, it was found that about 73% of the labor accidents occurred during works involving slope stabilization by the retaining wall method. In contrast, the number of accidents that occurred during works using the slope improvement method was smaller (about 15%). This is probably due to the fact that the retaining wall construction generally includes the excavation of steep and unstable slope, and it also requires the workers to work in a narrow space between the retaining wall and the excavated ground such as assembling/dismantling of formworks, smoothing of base and etc. Therefore, the workers have no sufficient time to escape from such narrow space when slope failure occurred.

Fig. 4. Geographical regions of Japan.

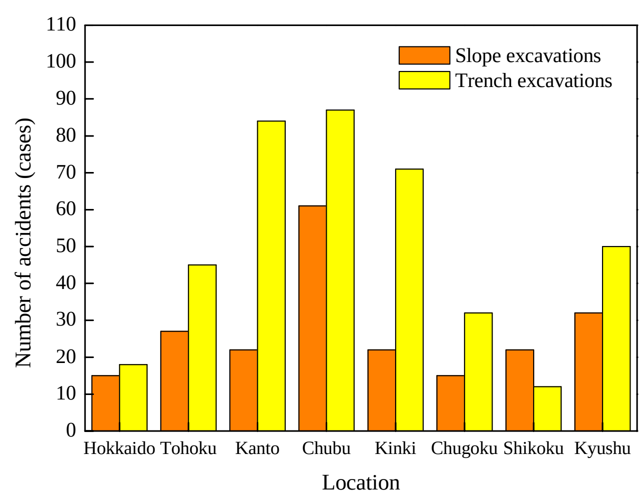

Fig. 5. Location of slope and trench failures.

As presented in the Fig. 7, the sewer, water supply and drainage pipes installations are the most frequent type of trench excavation when the trench collapse occurred. By consider the project cost and construction period of slope and trench excavations the possibility of labor accident was higher in the construction work with a lower amount of project cost and relatively short construction period. Figure 8 shows the number of workers presented at the time of slope and trench failures; approximately 85% and 91% of the accident occurred in slope and trench excavation projects with less than 8 workers on the construction site. Because the number of workers can be related to the size of the contractor, so the possibility of accident is higher with the small contractor. This may be explained by the fact that the small contractors may not have operation chief and/or worker with appropriate knowledge concerning construction safety and they may not have sufficient budgets to provide adequate safety equipments.

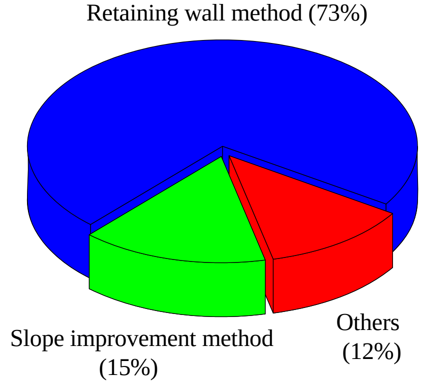

Fig. 6. Types of slope excavation.

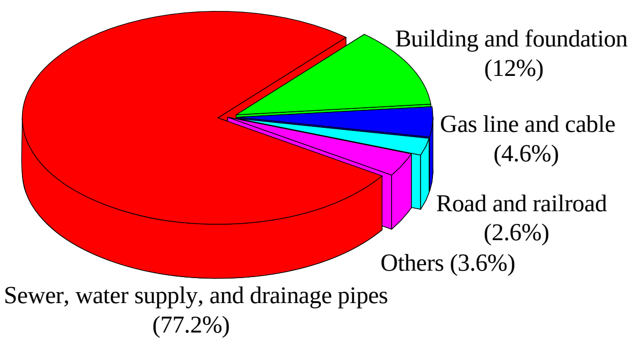

Fig. 7. Types of trench excavation.

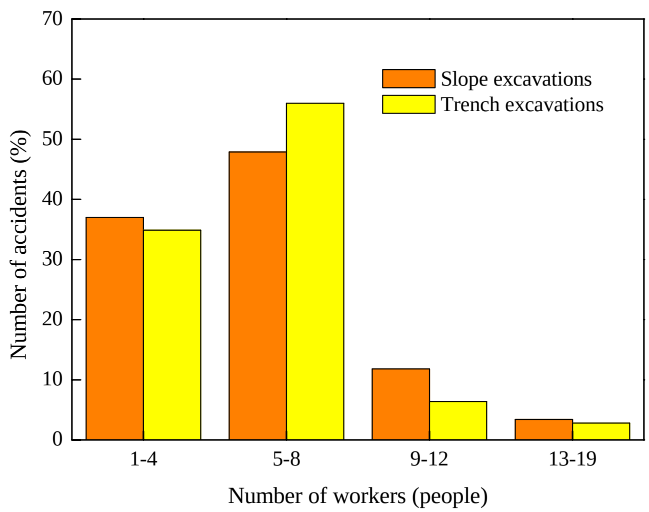

Fig. 8. Number of workers presented at the time of failure.

<u>Slope and Trench geometries</u>

Figure 9 shows the number of slope and trench failures according to the slope angle. In case of slope excavation, most of slope failure (50%) occurred when the slope angle was 60 to 75 degrees. Because the minimum construction cost for trench excavation is generally achieved by adopting the steepest possible trench wall slope angles, unsurprisingly, about 77% of the accidents occurred in trenches with the slope angle of 90 degrees as shown in the figure. According to the study on natural slope failures in Japan by Monma *et al.* (1999), the slope failures occurred most frequently with the slope angle of about 40 to 49 degrees. Therefore, the frequency of failure of steep slope during slope and trench excavations is higher than that of the natural slope. Figure 10 shows the labor accidents caused by slope excavations classified by slope height. It was found that most of slope failures (55%) occurred with the slope height of 2 to 10m. Figure 11 shows the number of accidents according to trench depth, about 80% of trench collapses were reported in trenches shallower than 3m and only 2% of accidents occurred in trenches deeper than 5m. It should be noted that only 4% of slope failures occurred in slope height less than 2m, however, in case of trench excavation about 40% of trench collapses was observed in trenches shallower than 2m.

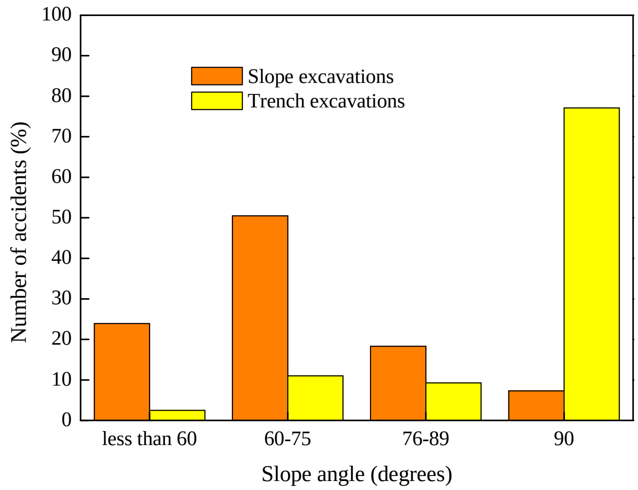

Fig. 9. Number of slope and trench failures by slope angle.

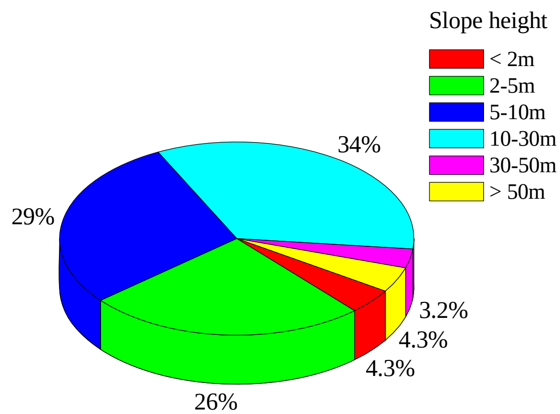

Fig. 10. Number of slope failures by height of slope.

This indicated that even in shallow trenches the possibility of accidents still exists due to the confined space environment of trench excavation. Figure 12 shows the number of trench failures based on the trench depth and length ratio, D/L. It was found that 85% of accidents occurred in trenches with D/L less than 0.6. Because longer trenches have a tendency to be affected more by surcharge load from spoil pile and vibration of construction machines.

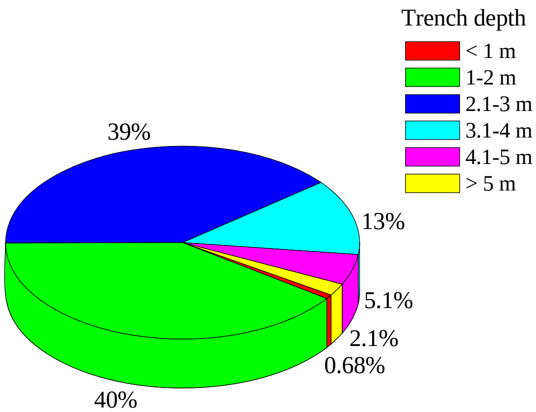

Fig. 11. Number of trench failures by depth of trench.

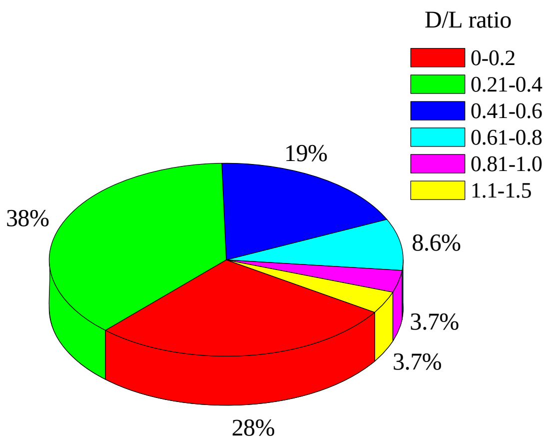

Fig. 12. Number of trench failures by D/L ratio.

Scale of Slope Failure

Figures 13 and 14 show the estimated amount of collapsed soil that observed in the slope and trench failures, respectively. As expected, the amount of collapsed soil in the slope excavation is generally larger than that of the trench excavation. It was found that 59% and 55% of slope failures occurred when the amount of collapsed soil was less than 50m^3 and 2m^3 for slope and trench excavations, respectively. By comparing to the size of excavations, the amount of collapsed soil is generally small, therefore, the scale of slope failure at the time of accident could be classified as small-scale slope failure. Because the small-scale slope failure generally occurs rapidly, so the workers tend to suffer from the labor accidents since they have almost no time to escape from the working area especially in the confined space environment in the retaining wall construction and the trench excavation.

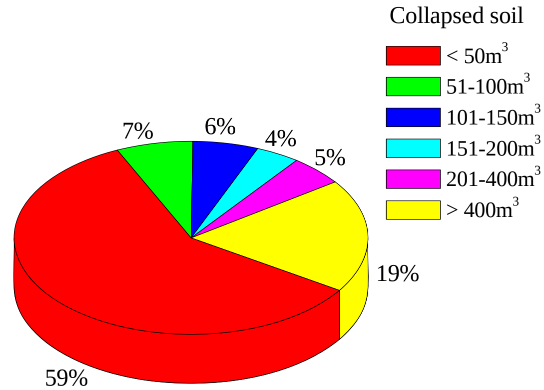

Fig. 13. Number of slope failures by collapsed soil volume.

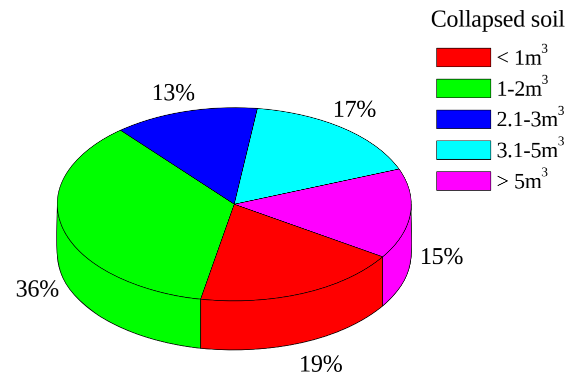

Fig. 14. Number of trench failures by collapsed soil volume.

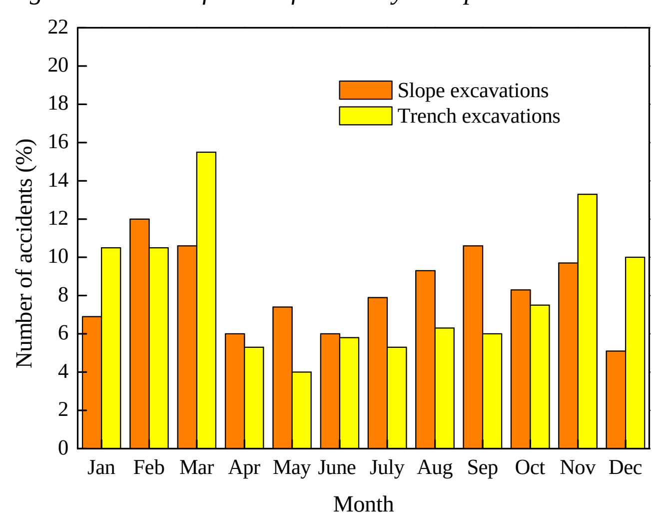

Fig. 15. Number of slope and trench failures by month.

Time of Occurrence

The distribution of accidents based on month of the year is shown in Fig. 15. It is also possible that the economic pressure to complete the projects before the end of budget and before the winter can lead the high number of accidents as shown in March and November, respectively. Figure 16 shows the number of slope and trench failures by the time of occurrence, the accidents mainly occurred before lunch break (10-11a.m.), after lunch break (2-3p.m.) and before the end of working time (4-5p.m.). However the reason for this situation is unclear.

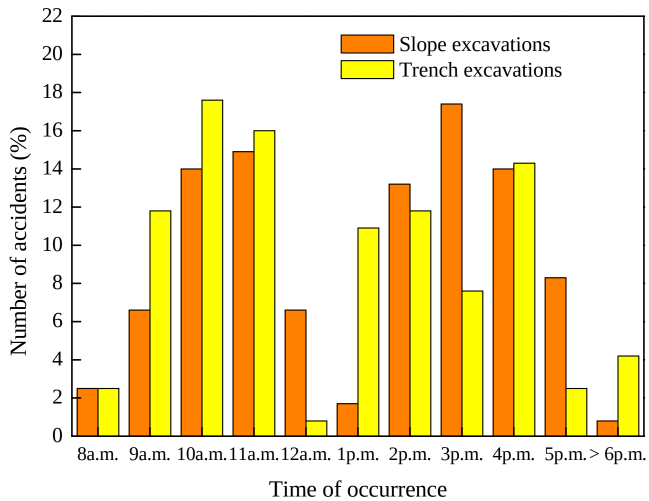

Fig. 16. Number of slope and trench failures by time.

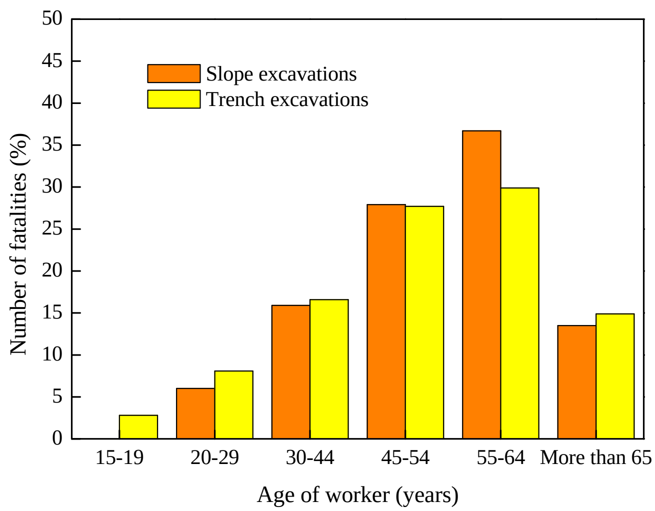

Fig. 17. Number of fatalities by age of worker.

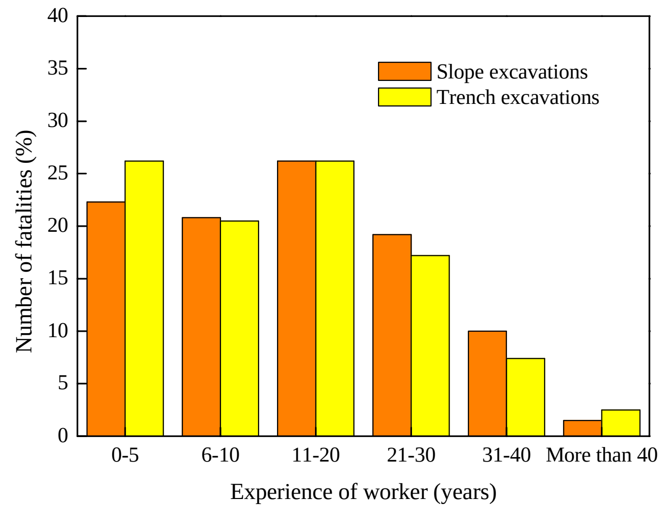

Fig. 18. Number of fatalities by experience of worker.

<u>Characteristic of Workers involved in Labor Accidents</u>

The distribution of worker age observed in the labor accidents is shown in Figure 17. It was found that about 78% and 72% of the accidents involving workers older than 45 years for slope and trench excavations, respectively. This indicated that the older workers tend to be involved in the labor accidents. In addition, inexperienced workers tend to have more accidents compared to experienced workers as shown in Fig. 18. Because experienced workers can sometimes detect the instability of slope for example from tension cracks and changes in soil texture, however, inexperienced workers are less likely to detect these signs. Although the experienced workers may have received more training concerning construction safety, it was found that about 30% of workers working in construction site at least 21 years before they were involved in the slope and trench failures. Because the experienced workers could be related to the older workers and in many cases the experienced workers tend to take unnecessary risks.

CONCLUSIONS

The case histories of slope and trench failures in Japan during the period of 1989-2001 were presented in this paper. The failures are likely to occur in the small construction projects conducted by the small contractors. Most of slope and trench failures occurred in works involving the slope stabilization by retaining wall method and the installation of pipelines. The scale of slope failure at the time of accident is generally small and the failure occurs rapidly so the workers have almost no time to escape from the confined space working area. Most of slope failures occurred when the gradient of slope was 60° to 75° with the slope height of 2-10m. In case of trench excavations, most of trench collapses occurred in the trenches shallower than 3m with slope angle of 90°. By considering the time of occurrence, the slope and trench failures mainly occurred before/after lunch break and before the end of working time, the economic pressure can also lead the high number of slope and trench failures. Based on the characteristic of workers, the older and inexperienced workers tend to be involved in more labor accidents. These findings emphasized that it is necessary to improve the safety standards and provide more safety education and training especially in the small construction projects to prevent the failures in future.

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