EMERGENCY ROADWORKS AND SUGGESTIONS TO IMPROVE THE OCCUPATIONAL SAFETY AFTER THE JI-JI EARTHQUAKE

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Abstract: It is found that most road damages triggered by the Ji-Ji earthquake occurred in the Taichung City, the Taichung County, and the Nantou County. The main causes for these road damages are landslides and rockfalls. Therefore, in the emergency roadwork to repair these roads it is not only necessary to remove the debris that blocked the roads but also necessary to stabilize the roadside slopes to prevent further collapses. This article studies the current conditions in emergency roadworks and investigates the reasons of slope failures. It is hoped that this study will help the roadwork crew to quickly finish the repairs and increase their awareness of dangerous slopes to protect their own safety.

Keywords: slope failures, Ji-Ji earthquake, monitoring systems, labor safety

1. INTRODUCTION

The Ji-Ji earthquake and its aftershocks caused numerous damages to the roadway systems in central Taiwan. Many of the roadways are still being repaired. It clearly demonstrated the difficulties of the post-earthquake reconstruction. These roadway damages hampered the rescue missions immediately after the earthquake. Then, numerous accidents and injuries were also reported during the repair and the reconstruction of the roadways. Consequently, it is widely believed that more efforts should be made to mitigate natural disasters such as earthquakes and to prevent injuries and economic losses in emergency rescues operations.

2. THE INVESTIGATON RESULTS OF SLOPE FAILURES TRIGGER BY THE JI-JI EARTHQUAKE

Most of the road closures after the Ji-Ji earthquake were due to slope failures and debris flows. According to the investigation report of the National Center for Research on Earthquake Engineering [1], the distribution of slope failures after the Ji-Ji earthquake spreads from Miaoli southwardly towards Chiai, and is densest in the Taichung County, the Taichung City, the Nantou County, and the Nantou City. Within the boundaries of the Taichung County, the landslides are especially numerous near Ching-Shan along the Trans-central Highway, whereas the worst landslide in the Nantou County occurred at the Chiu-chiu-feng, where 950 hectares of land was destroyed. Most of the landslides were classified as collapses of surface gravels and weathered soils. In the Yunlin County, landslides concentrate in the Gukeng village, including the astonishing Chao-lin landslide that destroyed an area of 400 hectares with 120 million cubic meters of soils and rocks. The resulting debris even dammed the adjacent river valley and formed a temporary lake named after the landslide--the Chao-lin Lake.

According to this report by NCREE, the most common reason of the landslides is the block movement and debris flow of rocks (Fig. 1). The total number of occurrences is 218, and accounts for 63% of the slope failures. The next common reason is rockfalls and toppling failures of rocks. This type of failures usually blocks roads and totals 77, representing 23% of all landslides. If we analyze the distribution of landslides according to slope angles, we can see that the number of landslides increases with the angle of the slope (Fig. 2). The only exception is the group with slope angles greater than 75 degrees. The total number of landslides in this group is slightly lower than that of the group with slope angles between 60 and 75 degrees (124 occurrences vs. 110 occurrences). We think the reason is because the 75+ degree slopes are most susceptible to collapses. Therefore, they are least likely to exist in a stable state. As a result, the total number of 75+ degree slopes were less than those with slope angles between 60 and 75 degrees, and this contributed to the lower occurrences of landslides in the 75+ group. Also, comparing Fig. 1 and 2, it seems that the dominant types of failures for slopes steeper than 60 degrees are likely to be rockfalls, toppling failures, debris flows, and block movements.

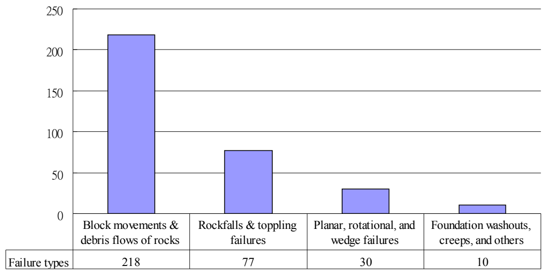

Figure 1. The types of slope failures (data from [1])

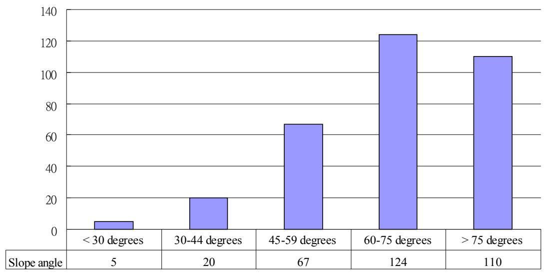

Figure 2. The distribution of slope angles (data from [1])

3. THE SURVEY OF EMERGENCY ROADWORK AFTER THE JI-JI EARTHQUAKE

The numerous landslides triggered by the Ji-Ji earthquake blocked the roads leading to the disaster areas and hampered the arrivals of rescue workers and emergency supplies. In order to provide access to the disaster areas, a large number of construction workers and roadwork crew participated in the emergency roadwork to restore traffic connection in and out of the disaster areas. However, since the earthquake was unexpected, the safety measures in the emergency roadwork were not well implemented. Coupled with the uncertainties of the job site environments and the frequent aftershocks, the safety of the roadwork crew is unfortunately compromised. In order to learn from this experience, this study aims to investigate the common landslide hazards and the related safety problems. It is hoped that valuable lessons can be learned and better safety precautions can be adopted in the future.

This study is conducted by asking participants of the post-earthquake emergency rescue operations to fill out survey forms, and the participants are not limited to construction workers or roadwork crew. The entire survey handed out 333 questionnaires, and collected 243, a response rate of 73%. Among the usable responses, 44% are from fire fighters (Fig. 3), followed by construction workers (35%), military personnel (12%), and the roadwork crew of the Highway Bureau (9%).

Among the respondents, 98% are men because few women work in the construction trades. If analyzed by the distribution of age (Fig. 4), it is found that the 31-35 age group is the highest, representing 23% of all respondents. This age group is followed by the 36-40 age group (19%) and the 41-45 age group (16%). Together, the rescue workers age 31-45 stand for 58% of the entire rescue force. These middle-age men are likely to have family responsibilities. Therefore, it would devastate the families involved if accidents should happen to these workers.

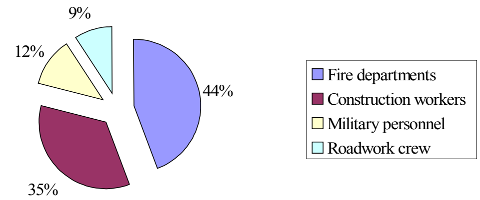

Figure 3. The background of respondents

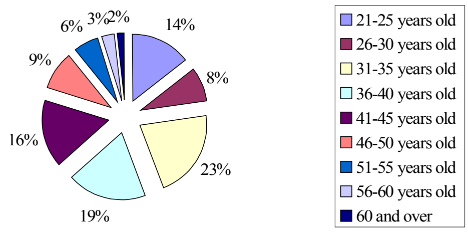

Figure 4. The age distribution of respondents

Regarding the locations of emergency work, although there were also building damages in northern Taiwan, most of the respondents were in central Taiwan to perform emergency rescues and roadworks. According to our survey, 32% were in the Nantou County and 28% were in the Taichung County (Fig. 5).

Then, analyzed against the jobs that the workers performed, as expected, building rescue represents the primary rescue activity. However, a considerable amount of people also participated in roadworks, bridge repairs, and tunnel repairs (Fig. 6).

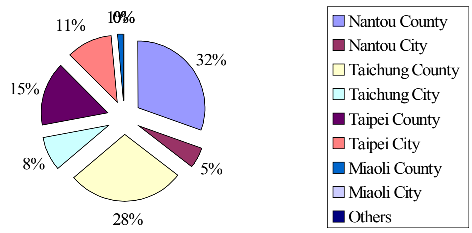

Figure 5. The locations of rescue work

When the respondents were asked about the most likely hazard during the rescue operations (Fig. 7), building collapses triggered by aftershocks was the number one concern, whereas falling objects were the second choice. This result is different from the previous consensus of occupational hazards. According to the literature [4, 5; cited from 6], there were 6 million construction workers in the US, representing only 6% of the total labor force. However, the construction trade was one of the most dangerous occupations with one of the highest job-related mortality rates. According to the statistics in 1996, construction workers suffered 16.9% (or 1039 persons) of all job-related deaths. Among the fatalities, fall in construction was the leading cause and accounted for 31% of all job-related casualties.

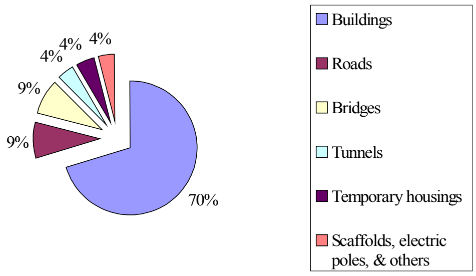

Figure 6. The types of work performed

Although the workers worried about occupational accidents, the percentage of workers with insurance was still too low (Fig. 8). It is alarming that about 13% of the workers did not have any insurance. Coupled with the fact that approximately 57% of the rescue operations did not have temporary supports to stabilize the target structures during the operations, it is obvious that the workers were indeed exposed to extremely high risks and the results could be unthinkable (Fig. 9).

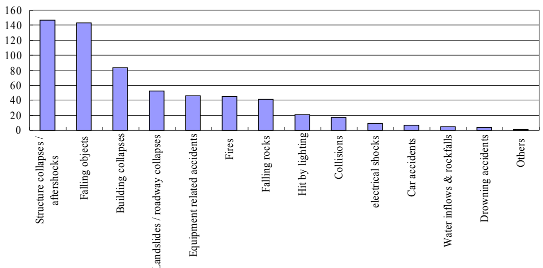

Figure 7. The most likely types of accidents

Finally, when analyzed against the possibility of repeated slope failures (Fig. 10), the respondents said that the most likely reason for a repeated slope failure is soft unstable soils and rockslides. This argument can be supported by the newspaper report (The China Times, 5/17/2000) of numerous landslides triggered by aftershocks that again blocked the Trans-central Highway. As for the electrocution hazard, 31% of the fallen power lines and electric poles were not properly cut off from power sources or isolated, which could lead to accidents. Examining the safety measures that are in place while roadwork crew repaired damaged roads, it is found that site control was most lacking and needed the most improvements (Fig. 11).

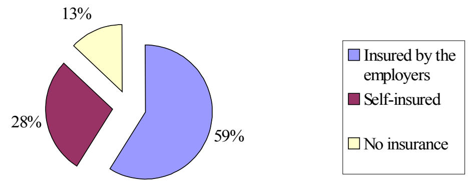

Figure 8. The percentage of workers with insurance

It is obvious from the above analysis that if we are to reduce the injury rates in emergency roadworks, we need to focus on the emergency stabilization of slopes and the continuous monitoring of potentially unstable slopes.

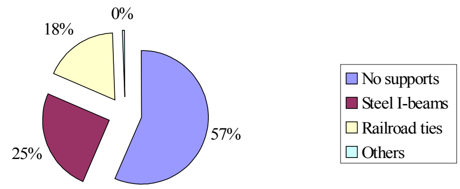

Figure 9. The use of temporary supports on unstable structures

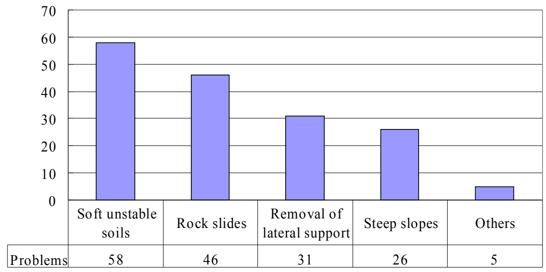

Figure 10. The reasons of repeated slope failures

4. THE STUDY OF TEMPORARY STABILIZATION OF SLOPES

As mentioned earlier, block movements and debris flows of rocks are the leading causes of slope failures in the Ji-Ji earthquake, which total 218. Also, according to our survey, rockfall is the principal hazard. As such, if there are innovative ways to quickly stabilize the roadside slopes, the occurrences of accidents to the roadwork crew can be greatly reduced.

Traditionally, there are three major methods of slope stabilization—surface protection, drainage, and retaining structure [3]. Each method has its own restrictions in terms of applicability and effectiveness. The determining factor is the site condition. Sometimes, it requires the combination of different methods to stabilize a given slope, which will be a big challenge for the temporary stabilization of unstable slopes.

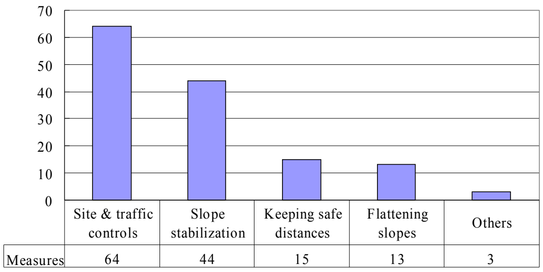

Figure 11. The safety measures of emergency roadwork

Dealing with the massive amount of slope failures in the Ji-Ji earthquake and the resulted potentially unstable slopes, we believe that it is necessary to accelerate the researches in the quick stabilization of slopes. Maybe the traditional methods need to be revised to shorten the construction time, or new techniques should be invented. In this respect, we have the following preliminary suggestions:

1. New studies on the blasting techniques: Efforts should be made to select the proper amounts of explosives and the detonation sequences to stabilize slopes with only one blast. No subsequent trimmings of the slopes should be needed.
2. New studies on shotcrete: Efforts should be made to select the proper types of shotcrete and wire meshes to prevent possible rock avalanches.
3. New studies on tie-back walls in road embankments: Efforts should be made to reduce the construction time to quickly stabilize the slopes.
4. New study on barriers such as Gabion baskets: Efforts should be made to accelerate the construction of reinforced earth retaining walls to stabilize slopes.

5. THE SLOPE MONITORING AND AUTOMATIC WARNING SYSTEM

In addition to the quick stabilization of dangerous slopes, a monitoring system is also necessary to reduce the risk of landslides that could injure the work crew. Especially with an automatic warning system, the alarms will sound when slope movements are detected. It is the most ideal type of monitoring equipment.

Generally speaking, a monitoring and warning system is composed of five different functional units—the sensoring unit, the recording unit, the data transmission unit, the alarm unit, and the power supply unit [2]. The selection of these monitoring systems depends on the in-situ soil conditions. More importantly, an emergency evacuation plan should be in place before the landslides occur.

Currently there are a number of sensors available [3]: (1) Multi-sectional slope indicators or little dippers, (2) Electronic theodolites and total stations, (3) Long distance slope movement sensors, (4) Tiltmeters, (5) Electronic settlement cells, (6) Accelerographs, (7) Piezometers, (8) Soil pressure cells, (9) Rain gauges, and (10) Rock or soil anchor load cells. The type of instrumentation selected depends on the project and the site conditions.

6. THE INCORPORATION OF SAFETY MEASURES INTO ROADWORK

In order to prevent injuries in emergency roadwork, it is necessary to incorporate the safety measures into the road repair work. If the safety precautions are properly emphasized, then the occupational injuries can be reduced. Fig. 12 is an example of incorporating safety measures into the emergency roadwork.

7. CONCLUSIONS

According to the Central Weather Bureau of ROC, there were eight major aftershocks with magnitude 6.0 or greater on the Richter Scale after the Ji-Ji earthquake. One of the aftershocks that occurred on May 17, 2000 caused massive rock avalanches on the Trans-central Highway. Many road crews were injured by the falling rocks. It clearly demonstrated the high risks involved in road repairs after the Ji-Ji earthquake. The government is aware of the seriousness of this occupational hazard and is considering methods to improve the situations. Therefore, we review the possible risk factors in this study by conducting surveys to help address this problem.

According to our survey and other related injury reports, it is learned that there are many work related hazards in emergency roadwork such as rock avalanches, falling rocks, falls, and electrocutions. In order to prevent similar accidents from happening again, it is necessary to research new construction techniques to stabilize slopes quickly and to monitor the movements of slopes. That is why this study emphasizes so much on the issue of slope stability for roadwork. We hope that this article can provide recommendations to the road crew, and we hope that the authorities can plan safety measures accordingly to prevent secondary hazards and accidents.

Acknowledgments

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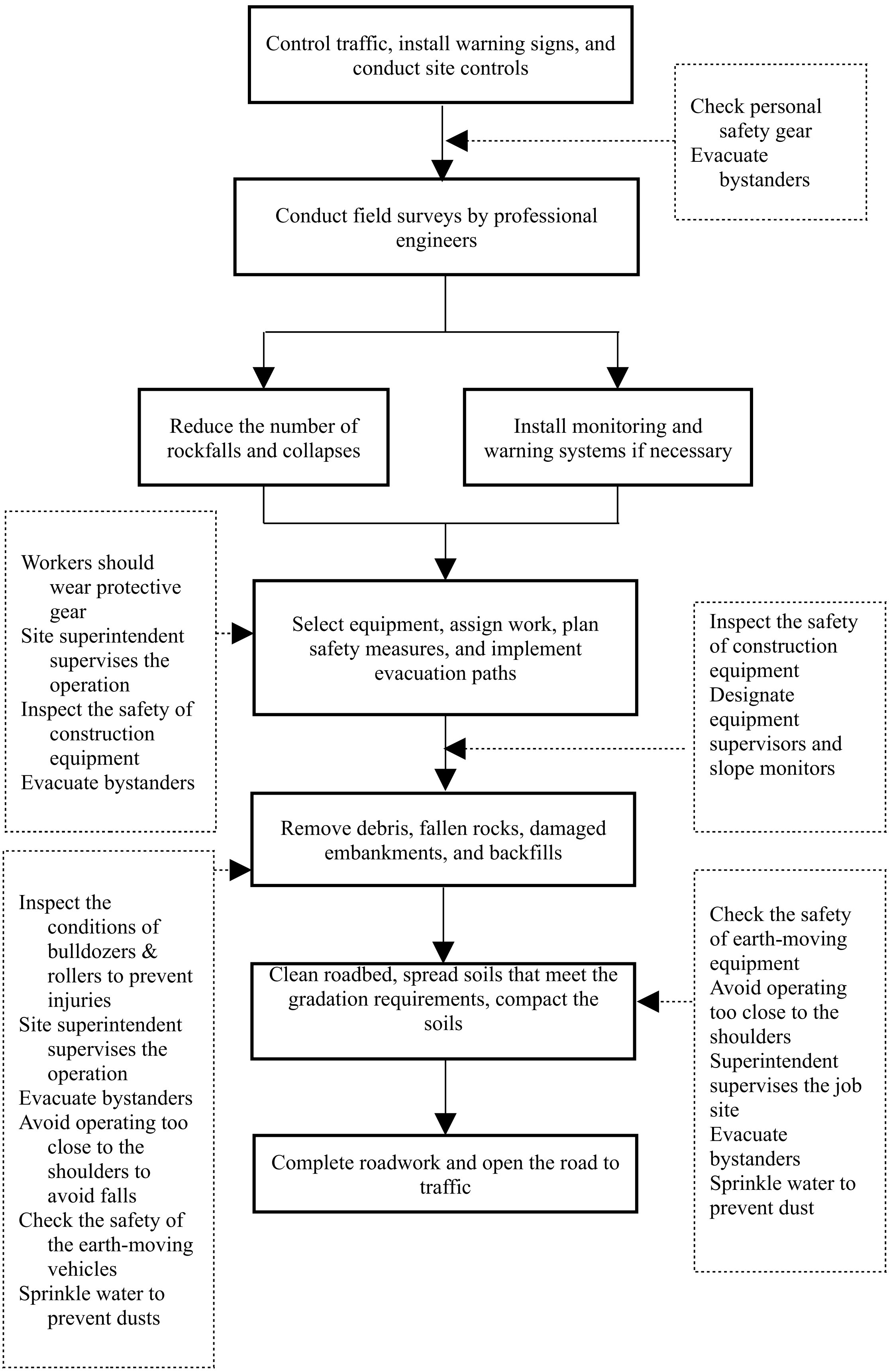

Figure 12. Emergency roadwork and safety measures