MOBILIZATION AND ORGANIZATION OF PROFICIENTS TO COLLECT CRITICAL DATA IMMEDIATELY AFTER A NATURAL DISASTER

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***ABSTRACT*:** In 2009, right after the typhoon Morakot swept southern Taiwan on August 8th, people were shocked by the unexpected storm. During the first week after Morakot's struck, most engineers concerned the immeasurable injury to infrastructures but wondered how to contribute their proficient. Before the official agencies started to investigate the overall loss of the event, the China Engineering Consultants, Inc. (CECI) organized human resources from universities and societies of professional engineers forming 6 reconnaissance teams to investigate all the reported damaged bridges within 14 days (August 21st to September 2nd). Since a complete evidence recording is necessary to evaluate and to diagnose the cause of bridge damage, several important bridges were examined and recorded by advanced equipment before any rehabilitation commencing. This part of work was helped by special technical companies. Three months later, a reconnaissance report was printed to reveal the inclusive bridge loss in the event. There were 114 bridges entirely destroyed or partially damaged from the mountain area to plain field by debris flow and flood. Detailed causes-to-damage investigations were conducted on some collapsed bridges by nondestructive methods, including unmanned micro aerial vehicle (UMAV), 3D Laser scanner, underwater sonar, underwater ground penetration radar (GPR), and electric resistivity image (ERI). Based on the investigation of 120 damaged bridges, the findings and lessons are summarized. Furthermore, learning from the past experiences, it is aware some equipment and techniques need to be improved or enhanced for rescue operating more quickly and efficiently. The industry can devote to develop any likely techniques to apply in relieving the victims of a disaster in the future.

KEYWORDS: data collection, reconnaissance, bridge

1. INTRODUCTION

CECI is a legal foundation and aims to dedicate to public benefit activities. The Institute of Bridge Engineering of CECI was established on August 1st 2009. Just one week before the centurial typhoon Morakot's struck.

At the first moment of disaster report was dispatched, it is known the rescue action should be the first priority. As confronting such a massive calamity, following reconstruction is another challenge and should start as early as possible. Consequently, some preparation actions need to be done to make reconstruction work smoother in the future.

Dr. Liao, the chairman of CECI, has experienced from Chi-Chi Earthquake (1999) and Wenchuan Earthquake (2008) and knows the necessary procedures for reconstruction very well. A complete survey of infrastructure loss is a primary measure. Therefore, the organized reconnaissance group cored with CECI began to devote into investigation of bridge damage.

2. INVESTIGATION COMMENCING

After August 8th, more and more bridge destroyed news were revealed gradually, but most were returned only by individual government agency. The overall bridge loss condition still remained uncertain. Hence, CECI decided to call volunteer engineers and scholars to throw into field investigation. All the actions initiated from a "reconnaissance & reconstruction workshop" on August 18th. Before the workshop, Dr. Chen (the author) went to Chiayi County to investigate some reported destroyed bridges on 15th August. In that trip, some primary understandings about data collecting for the overall inspection were founded. Thereafter, a framework of largely investigation was proposed. [*CECI, 2009*]

2.1 Participants

Since most of bridge management agencies of public domain were busy at dealing with emergency repair to recover fundamental traffic function in the follow-up weeks after disaster, CECI thus invited mainly academic people and some technicians from professional engineers associations to join. Notwithstanding these bridge management agencies were occupied with emergent affairs, Directorate General of Highways and Taiwan Railways Administration still provided vehicles and much help to assist the reconnaissance job. Since this investigation was a spontaneous activity, CECI funded the expense of board and lodging for all the participants.

2.2 Objectives

The goal of this overall investigation is to build up a database of bridge destruction records. From the lesson taught by Morakot, to realize what are the critical factors for bridges to be destroyed or survived. The causes to bridge destruction were analyzed for updating the future design work as feedback, and the reconstruction works afterward were also kept on tracing.

2.3 Scope

Until August 19th, 2009, the reported bridge loss was 90. There were still some areas remaining unknown because of traffic interruption. The actual bridge losing condition, thus, would be more terrible than reported. Moreover, the scope of bridge data collecting is not restricted within only damaged bridges but also intact bridge. The roughly estimated number of bridge database may exceed 200 at commencing stage.

2.4 Participant grouping

The command center of the investigation action was set at CECI in Taipei. The command center had to understand the road condition to access to the bridges, to communicate with local highway agencies to search for help. All the information was delivered and returned to command center at the very first moment. Each reconnaissance team was composed by at least 4 members, led by a professor and a professional technician. Six teams were formed finally as listed in Table 1 and their survey areas are plotted in Figure 1.

Table 1 List of 6 reconnaissance teams

Team	University	Surveying area
1	Chaoyang Uni. of Tech.	Nantou County /Chiayi County
2	Nat. Yunlin Uni. of Sci. & Tech.	Chiayi County
3	Nat. Chen Kung Uni.	Tainan County
4	Nat. Central Uni.	Kaohsiung County
5	Nat. Taiwan Uni.	Pingtung County
6	Ching Yun Uni.	Taitung County

The reconnaissance action was set to accomplish a round within 3 days, which means each team could have a break after 3 days field work. If each team could investigate 4 bridges per day, 8~9 working days were expected to finish 200 bridges by 6 teams. In consequence, the reconnaissance action would be carried out in early September. Parenthetically, the participants were asked to avoid any investigating behaviors with danger since safety is the first priority.

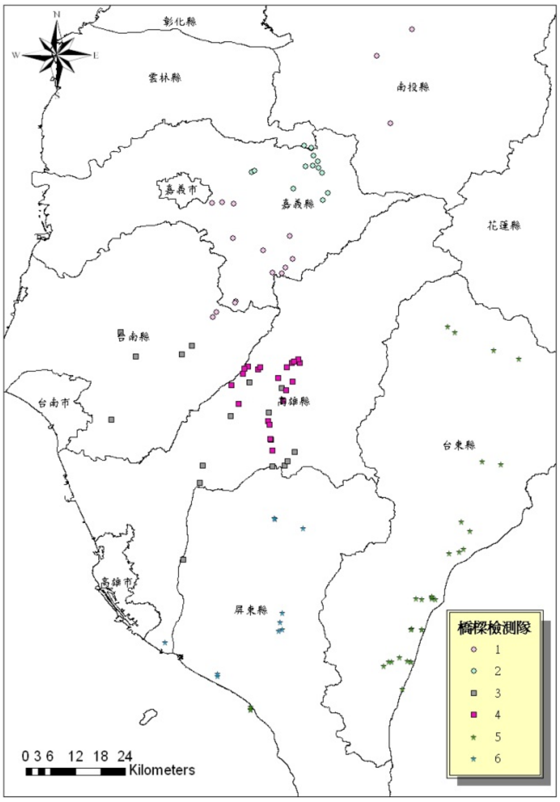

Figure 1 Location of damaged bridges investigated by 6 reconnaissance teams

2.5 Working items

The reconnaissance actions included five working items as follows:

1. Preparation: contacting with the local engineering agencies to grasp the regional road condition. Organizing the bridge list to investigate and planning the route everyday. Informing the local reception agencies about meeting time and place, and confirmed it in advance. Checking available fundamental data (dimension, structure type, route and coordinate etc.) of the investigated bridge from Taiwan Bridge Management System (T-BMS), as well as satellite images, aerial photos, rainfall and river flow records.
2. Field inspection: filling an investigation form illustrated as Table 2 for each bridge and taking pictures as the items on the investigation form indicates. Table 2 contains the factor of bridge structure, river channel, road slope and other environmental conditions were also included. In addition, analyzing the major factors of causing bridge damaged, collapsed, or non-damaged.
3. Mechanical analysis: for some crucial bridges, building digital model by 3D Laser scanning, and evaluating the possible failure mechanism with back analysis.
4. Tracing reconstruction works: sketching the emergency repair methodology if it had been applied, collecting the afterward reconstruction plan, methods, time table and cost as detailed as possible.
5. Delivering investigation report: sending a document including pictures, descriptions of bridge damage, investigation forms and others to feed into database.

Principally, this investigation was an overall checkup action. It means a bridge should be explored from as many perspectives as possible, but not restricted to personal interesting field only. Moreover, if any sensitive questions were encountered brought up by local journalists, reconnaissance team members should avoid answering any kind of responsibility belonging. Finally, when a team finished its responsible bridges earlier could help to survey other areas.

2.6 Schedule

The major investigating phase started from

August 24th to September 2nd, totaled up to 10 days. The whole bridge investigation was planned to finish by September 3rd, and most teams dismissed thereafter. For the remaining bridges, due to road close, were carried on by some specific teams. The team member absorbed every useful clue from anywhere at that moment. Figure 2 indicates Professor Yao of National Central University was listening to a military officer about the traffic condition to some disaster areas on high speed railway train.

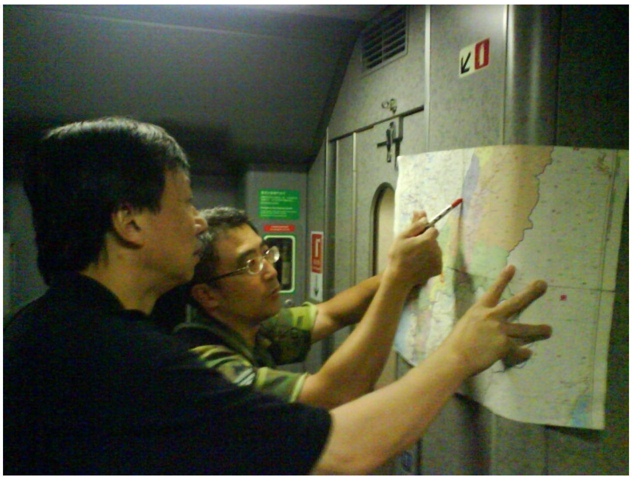

Figure 2 A brief intelligence-exchange on high speed railway train

Since the command center needed to update the statistic of bridge loss every day, the reconnaissance team had to return a simplified daily report after one-day's survey work. 2~4 pictures which can depict the bridge situation approximately were asked to be attached for each case. The planned itinerary for the next day and attending members were also included. According to the damage-factor-based investigation results, "Collapse of river bank", "Failure at the abutment and embankment", "Bridge foundation and protection works impacted by drifting woods or rocks", and "Close to cliff", in a descending order, are the most 4 important factors causing bridge damages in this event. [*Liao et al. 2010*]

3. INSPECTION WITH INSTRUMENTS

As well as visual inspection done by 6 reconnaissance teams, CECI also invited some technical companies to do inspection with special instruments. These technologies included AUMAV (Autonomous Unmanned Micro Aerial Vehicle), 3D LiDar scanner, underwater GPR, sonar and Electric Resistivity Image (ERI). These instruments were applied at different bridges. Most of these special inspections were finished within one month after Morakot's strike. Similar to the reconnaissance teams, these technical companies provided voluntary labor to do inspect without service rewards.

3.1 AUMAV reconnaissance

The AUMAV is designed to perform tasks in the field of documentation, coordination, exploration, surveying, communication, inspection and observation. They can fly by remote control or autonomously with the aid of GPS waypoint navigation system. This equipment was provided by *LinkFast Technology Co. Ltd.* They helped to take aerial picture of Shuang-Yuan Bridge above the bridge, and represented an opposite viewpoint which cannot be seen from abutment as shown in Figure 3. Furthermore, they also took a long ride into deeply the severest disaster area, just to take another aerial picture of Namashia Township devastated by debris flow (Figure 4). Through such an aerial picture, the actual flood region as well as flow path could be recorded entirly.

Figure 3 Shuang-Yuan Bridge failed in scoring photoed by AUMAV

Figure 4 Namasia township swept by debris flow photoed by AUMAV

Inspections with underwater GPR, sonar, and ERI were performed for detecting the positions of breakage pieces and evaluating the scouring depth after the catastrophic failure at Shuang-Yuan Bridge. Underwater GPR inspection with different antenna frequencies, 200, 450, and 900 MHz, was conducted by *Ching Yun University* to measure the stream bed elevation on August 27th, 2009, as shown in Figure 5. A deepest depth 13 m between ex-foundation piers P15 and P16 was identified in the test. [*Helsin Wang et al., 2010*]

Figure 5 Underwater GPR and sonar inspection to Shuang-Yuan Bridge

3.2 3D LiDar scan

3D LiDar scanner is a powerful scanning device of producing digital coordinate data of scanned target efficiently, and was employed to record some selected significant structures. *Strong Engineering Consulting Co., Ltd.* kindly assisted to scan Liouguei Bridge (Figure 6), ChiWei Bridge, ShinChiWei Bridge and Shuang-Yuan Bridge. *Ching Yun University* helped to scan Dajin Bridge and some highway slopes. These digital coordinate data can benefit greatly in building the numerical model for mechanism analysis and evaluation. *China University of Technology* utilized the point cloud and built a numerical model of Liouguei Bridge as illustrated in Figure 7.

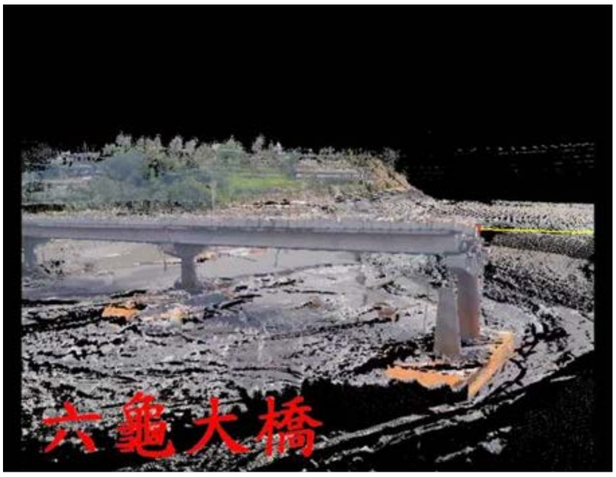

Figure 6 3D LiDar scanning result of Liouguei Bridge

Figure 7 Numerical model of Liouguei Bridge

3.3 ERI

The Electric Resistivity Image (ERI) involves the measurement of the apparent resistivity of underground materials as a function of depth and position. The electrodes are injected into the earth with fixed spacing, and measurements are taken at successive intervals along a profile. The results are normally presented as profiles or contour maps and interpreted qualitatively. *HCK Geophysical Company* joined to perform this examination. A successive application was employed at Dajin Bridge.

Figure 8 is a picture of Dajin temporary steel bridge destroyed in Morakot, which reveals the steel frame were bended by formidable force by debris flow. The deformed structure shape was scanned and recorded with 3D LiDar as Figure 9.

Figure 8 Severe debris flow destroyed Dajin temporary steel bridge

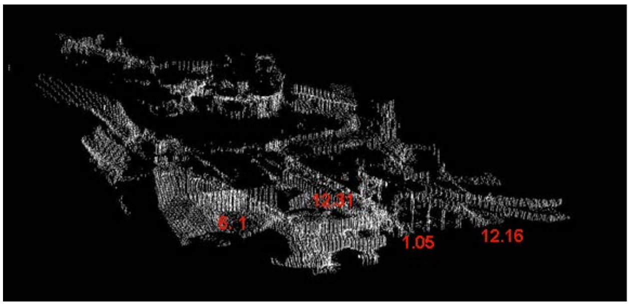

Figure 9 3D LiDar scanning result of the bended steel frames

People wondered if the pier foundations of Dajin Bridge were totally flushed away in the flood, or still existed beneath the ground. Because the truly failure mode needs to be proven by exactly exploring the existence of foundations. For that reason, ERI investigation is a rather economic and confident method to answer this tough question.

The ERI investigating result is presented in Figure 10. The electrodes were placed along the pier foundation (if existed), and the image profile was displayed in contour map. From this survey, the pier foundations of Dajin Bridge were clearly observed at the spacing of 25 m and to depth of around 5 m. According to the straight evidence, the bridge designer for reconstruction can be confident with the scour depth was not too deep in that event.

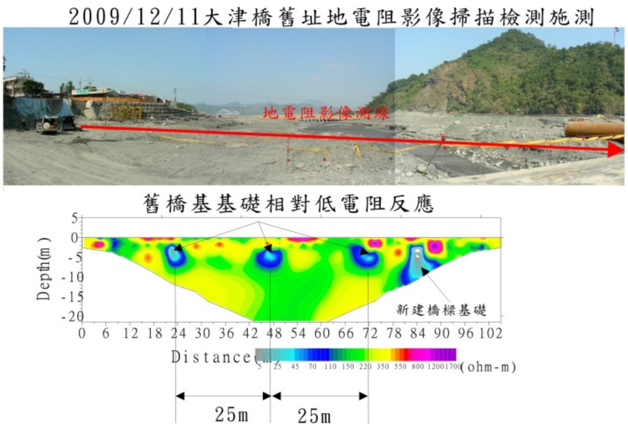

Figure 10 RIP investigating result of the existed pier foundations of Dajin Bridge

4. GUIDELINES OF RECONSTRUCTION

Considering the urgent need of guidelines in the subsequet rebuilding stage, CECI separately invited some administrative officers, well-known professors and experienced engineers to form a committee to establish "Guidelines of Reconstruction" in one month. 9 instructions which include functions and levels to restore, sequence of restoring, restoring principles and strategies, engineering coordination among different administrations, and planning -bidding recommendations were addressed. The committee also suggested that bridge government agencies should collaborate to develop a joint mechanism of mountain-river-road-bridge management systems under the threats of multi-hazard.

5. DEVELOPING EMERGENCY BRIDGE

As learning from the past experiences, it is aware some equipment and techniques need to be improved or enhanced for rescue operating more quickly and efficiently. Emergency bridge is one of useful rescue equipment, and is under developing by CECI. It is designed to construct a bridge to replace a damaged one in few days. Such a bridge does not need to carry heavy loading. For maintaining the essential transition requirement, building a bridge which allows motorcycle passing is an acceptable standard. The industry can dedicate to develop any likely techniques to apply in relieving the victims of a disaster in the future.

6. CONCLUSIONS

More than 100 bridges in Taiwan were destroyed by a single typhoon event. A temporal reconnaissance group of gathering dozens of engineers and professors was successfully organized to achieve the amazing investigation task in very a short time. UAMAV, 3D LiDar, underwater GPR, underwater sonar, and ERI were requested to inspect at some bridges. The overall reconnaissance results were edited and printed in 3 months after the event. It is believed this collaboration experience is an excellent example and creates a definitely practicable operation model in the future. Besides, crucial improvement items, including sustainable operation, cooperative mechanism of mountain-river-road-bridge management systems among governments, manpower incubation, and prognostic and diagnostic technologies, are the keys to enhance the capacity and efficiency of hazard reaction and mitigation on bridges in Taiwan.

ACKNOWLEDGEMENTS

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Table 2 Check table for damage factors on inspected bridges (CECI, 2009)

No.	Factor	Description
I	River merge	□Yes; □No
II	River concentration	□Yes; □No
III	Located at river bend	□Yes; □No
IV	Braided rivers	□Yes; □No
V	Close to cliff	□Yes; □No
VI	Less discharge on opening	□Yes; □No
VII	Steep river bed	□Yes (bed degree ____); □No
VIII	Hydraulic structures in the up and down streams	□Yes (structural type ____); □No
IX	Collapse of river bank	□Yes (position and distance); □No
X	Hydraulic fall or hydraulic jump	□Yes; □No
XI	Bridge foundation and protection works impacted by drifting woods or rocks	□Yes; □No
XII	Failure at the abutment and embankment	□Yes; □No
XIII	Material of debris flow	□Gravel; □Drifting wood; □Sand; □No
XIV	Repairing method	
XV	Cause of damaged/undamaged	