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Vehicle Load Tests and Long-Term Monitoring of Bridge No. 24 of Provincial Highway 86

Zheng-Kuan Lee, Fang-Yao Yeh, Chun-Chung Chen, Bo-Han Lee, Chia-Chuan Hsu, Lu-Sheng Lee, NCREE
Yu-Chi Sung, Professor, National Taipei University of Technology

Abstract

The Meinong Earthquake in Southern Taiwan on February 6, 2016, resulted in damage to Bridge No. 24 of Provincial Highway 86. After emergency responses from the Fifth Maintenance Office of the Directorate General of Highways, reconstruction and reinforcement design by CECI Engineering Consultants, construction work by a general contractor, and evaluation and vehicle load tests by the National Center for Research on Earthquake Engineering (NCREE), the bridge was reopened to traffic on May 20, 2016. This study briefly describes the bridge repair process, as well as the post-earthquake investigations, vehicle load tests, and long-term monitoring by this center.

Bridge Status and Post-Earthquake Investigation

Provincial Highway 86 begins in the west on Provincial Highway 17, extending eastward through Provincial Highway 1 in Rende District, intersecting the Rende System Interchange of Freeway 1, and finally ending at the Guanmiao Interchange of Freeway 3. It is a crucial road network in Tainan City that connects Tainan Airport, Tainan Station of the Taiwan High Speed Rail, and the access road to Anping Harbor [1]. The Meinong Earthquake on February 6, 2016, which the Xinhua seismic station of the Central Weather Bureau near the bridge site measured as intensity 7 (N–S PGA = 285 gal, E–W PGA = 401 gal), caused damage to Underpass Bridge No. 24 of Provincial Highway 86. The seismic damage was as follows: residual lateral displacement of the beam, severe damage of the bearing (Fig. 1), shear microfractures on the surface of the bridge pier (Fig. 2), external microfractures on the box girder, and longitudinal microfractures on the internal roof plate of the box girder (Fig. 3).



Fig. 1. Residual lateral displacement of the beam, and severe damage of the bearing

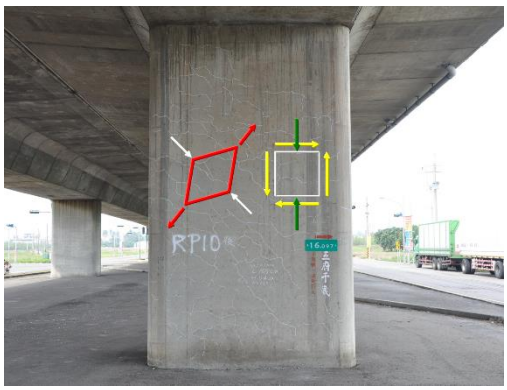


Fig. 2. RP10 shear microfractures on the surface of the bridge pier



Fig. 3. External microfractures and internal longitudinal microfractures of the box girder

Lateral Lifting Restoration of the Beam

Fig. 4 presents the residual lateral displacements along the eastbound beam and the westbound beam after the earthquake, which required lateral restoration. The lateral lifting and bearing pad replacement processes were designed and planned by CECI [2] and then executed by the general contractor (see Fig. 5). After the lateral lifting and bearing pad replacement, the authorities commissioned the NCREE to conduct vehicle load tests on May 17, 2016, to inspect whether the beam conformed to the design loading requirements.

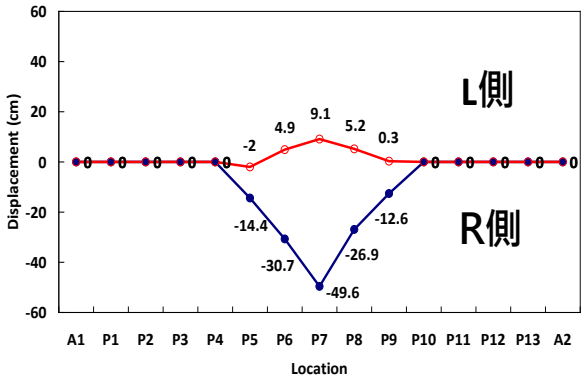


Fig. 4. Residual lateral displacements of the beams

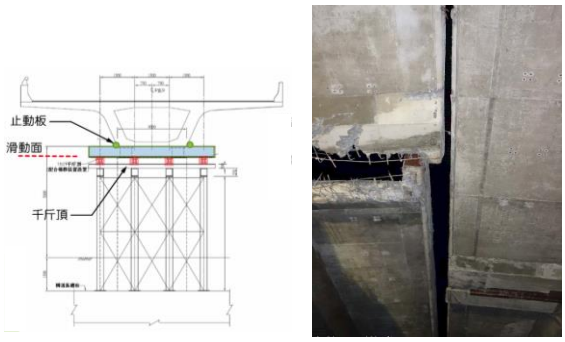


Fig. 5. Lateral lifting restoration of the beams (the eastbound and the westbound)

Vehicle Load Tests

Consider the fifth span loading test of the eastbound route as an example. Under a planned load with a force of 48 tf + 48 tf + 48 tf (equivalent to six 24-ton trucks), the anticipated deflection of the structural design was 7.13 mm (Fig. 6); according to the test results, the laser rangefinder measured a 7.0 mm deflection, whereas the linear variable differential transformer (LVDT) on the scaffolding measured a 7.9 mm deflection (Fig. 7). The two measurements approximated the anticipated deflection of 7.13 mm, thus the authorities determined that the structure still conforms to the utility performance, and the bridge was reopened to traffic on May 20, 2016.

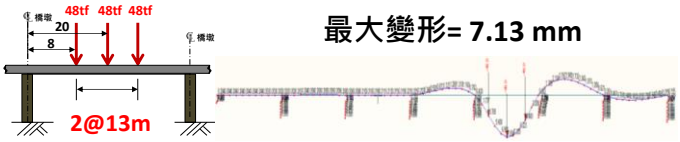


Fig. 6. Anticipated 5th span deflection, by structural analysis under the planned load, equal to 7.13mm

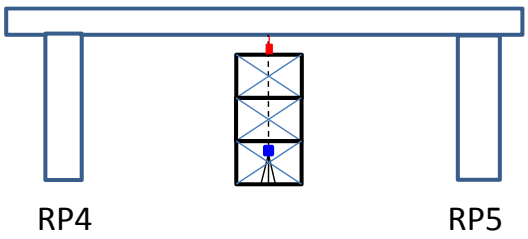


Fig. 7. Measurement system: the laser rangefinder and the linear variable differential transformer mounted on the scaffolding

Seismic Retrofitting of the Bridge Pier

After the section was reopened to traffic on May 20, 2016, the seismic retrofitting of the bridge pier continued until July 20, 2016. Fig. 8 shows of the pier and the bearing after the reinforcement.



Fig. 8. Reinforcement of the pier and the bearing

Long-Term Monitoring

Because of the external microfractures on the box girder and its internal roof plate, the bridge authority commissioned this center to implement a two-year monitoring plan to confirm the long-term safety of the bridge. This monitoring focused on the deflection changes of the beam, as well as the height difference variation in the adjacent pier. Fig. 9 illustrates the layout of the settlement sensors. Using the example of the fifth span S5, the mid-span deflection change was lower than 1 mm (Fig. 10), indicating the bridge to be normal on the fifth span.

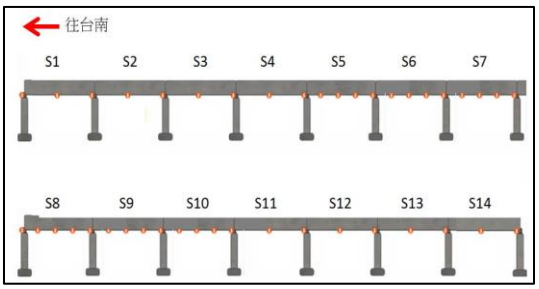


Fig. 9. Layout of settlement sensors (round dots)

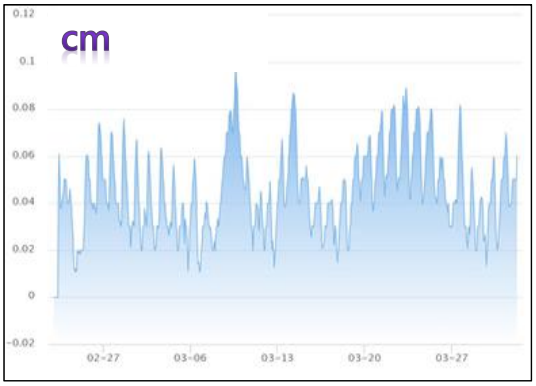


Fig. 10. Mid-span deflection change at the fifth span (February and March, 2017)

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Structural Behavior of PCI Beam-type Bridge and Non-destructive testing Applications for Its Damage Detections

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Introduction

Non-destructive testing (NDT) applications are necessary to determine the safety conditions of existing concrete bridges. In fact, their deteriorating is mainly due to the increasing overloading and progressive structural aging. In order to determine the important parameters defining their load-carrying capacity, a monitoring system for concrete beam-type bridges was developed based on short-term experimental measurements and numerical modeling. A series of dynamic and static tests were first executed on a full-scale PCI beam in the laboratory. Vibration and static loading testing were imposed to the PCI beam to establish its structural condition. Displacement gages, FBG-DSM sensors and accelerometers were installed along its axis to measure short-term changes in terms of vertical displacements and accelerations. Then, the results of the numerical modeling based on theoretical formulas were used to compare with the in lab experimental data.

In-Lab Full-Scale Non-Destructive Testing

A full-scale PCI beam-type bridge of 450 mm width and 900 mm height was adopted for the test. The straight tendon has an eccentricity of 220 mm with respect to the cross-section centroid and is composed of 15 seven-wire strand cables of 15.2 mm diameter, inserted in a unique metallic duct embedded along the beam length. The metallic duct was not injected. In order to create pinned-end restraints, two supports were placed at the beam ends, resulting in a clear span L of 14.5 m (Fig. 1). The elastic modulus of concrete was experimentally evaluated by compression tests after 28 days of curing and during each day of the experiments in the lab.

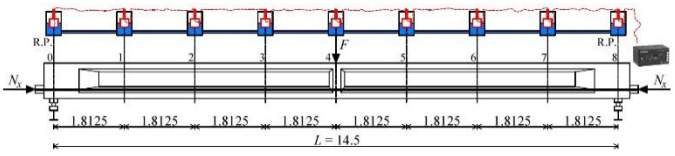


Fig. 1. Test layout of the PCI beam. Units: m

The PCI beam was inserted in a test frame using a test rig (Fig. 2a). At one beam end, a hydraulic oil jack with 4000 kN force capacity was used to assign the prestress forces pulling the strand outward. At both ends, respectively, a 4000 kN load cell each with an accuracy of 2 mV/V was placed for measuring the applied prestress loads. Totally, four different prestress forces N_x were assigned: approximately 1575 kN, 1737 kN, 1839 kN, and 1939 kN. For every prestress load N_x applied, an additional vertical load F (Fig. 1) was applied by a transversal steel beam at the mid-span of the PCI beam, under the control of four hydraulic oil jacks (Fig. 2a). For every prestress load N_x applied, shock vibrations were also imposed by releasing a steel bar anchored at the beam span after its rupture.



(a) (b)

Fig. 2. Test rig (a). LVDTs and FBG-DSM sensors (b).

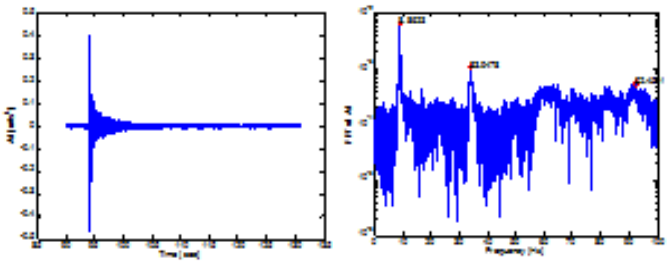


Fig. 3. Vibration testing. FFT function from acceleration time-history analysis of one accelerometer

Nine linear variable differential transformers (LVDTs), nine FBG-DSM sensors (Fig. 2b), and nine accelerometers were positioned along the beam length corresponding to the cross-sections i = 0, ..., 8, according to the test layout shown in Fig. 1. In particular, FBG-DSM sensors were connected with optical wires along the span and linked with a connecting pipe. A static full spectrum optical interrogator was used as data logger for acquiring the FBG-DSM signals. All dynamic and static test measurements were recorded every second during 200 seconds by a data acquisition unit.

Conclusions

Results have indicated that the monitoring data from LVDTs, FBG-DSM sensors, and accelerometers (Fig. 3) can be effectively simulated by numerical models. The prestress force and flexural rigidity of the beam were detected based on the combination of existing NDT methods and theoretical formulas. The “compression-softening” theory holds for PCI beams with prestress loads that satisfy the decompression serviceability limit state. Finally, based on all experimental and numerical data recorded, the proposed monitoring system could be applied on any beam-type bridge belonging to concrete bridge decks.

Load Serviceability Verification of a Concrete Bridge

Chun-Chung Chen, Bo-Han Lee, Chi-Rung Jiang, Bridge Engineering Division, NCREE
Yu-Chi Sung, Professor, National Taipei University of Technology

Introduction

The research describes the instrumentation used for monitoring the structural behavior and presents load test results of full-scale static and dynamic tests on an old concrete bridge. The bridge contains various AASHTO-type girders and was designed to carry two lanes of HS20-44 loading. The critical spans were instrumented at a quarter span (L/4) using deflection transducers and mid-span (L/2) using deflection transducers and accelerometers. The apparatus used for the bridge load testing includes a portable vibration monitoring system and four load testing vehicles, designed to deliver the ultimate live load specified by the AASHTO Code. For static testing, the bridge was incrementally loaded up to the full ultimate design live load. The test vehicles were loaded to be equivalent to HS-20-44 truck loading. At each load step, the instruments were monitored and the results were compared to the bridge status before proceeding with the next load step. The dynamic load tests were performed with the four testing vehicles traveling at 20 kmph and the two testing vehicles traveling at 40 kmph and 20 kmph.

Static Load Testing

Testing started with static tests during which four 20-ton trucks were used. The static load test was performed on span 2 and 8. Figure 1 shows the load position of the testing vehicles during the static test. The mid-span deflections were measured at different loading stages during the static test; a linear relationship exists between the applied load and the measured deflection. These results indicated a maximum measured deflection of 0.56 cm for span 8. Neither cracking nor other signs of distress were observed at the maximum applied load.

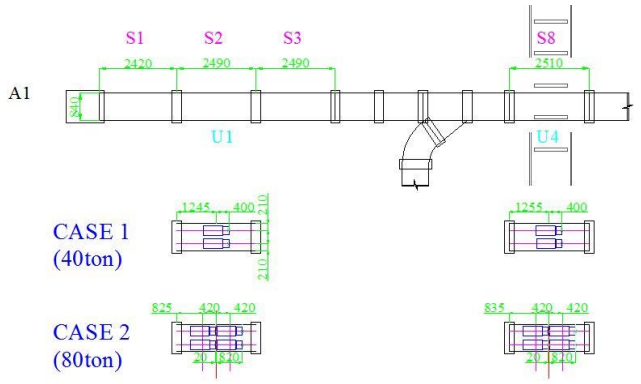


Fig. 1. Load pattern of static load testing

Dynamic Load Testing

In addition to the information on the natural frequencies and damping ratios of the bridge, the dynamic tests provide a picture of the variation with speed. The test was conducted using four trucks after the static load test is completed.

The initial readings of all the instruments were recorded with no vehicles on the bridge. The two trucks were then driven over the bridge parallel to each other at a constant speed of 20 kmph and 40 kmph. The data for deflection and acceleration were collected and stored in the data acquisition media and then transferred into the host computer system for data reduction and presentation. The data were obtained at a sampling rate of 200 Hz for an approximate time of 240 seconds. The same test was repeated with four trucks at a speed of 20 kmph. A real-time display of deflection and acceleration results is monitored on the computer screen as the vehicles move over the bridge. Figure 2 shows the location of accelerometers at mid-span (L/2) of each beam span. The Fast Fourier Transformation (FFT) technique was used to find the bridge fundamental frequencies. The experimental results indicated dominant vibration frequencies of 5 Hz for span 4 to 7 and 3 to 4 Hz for other spans.

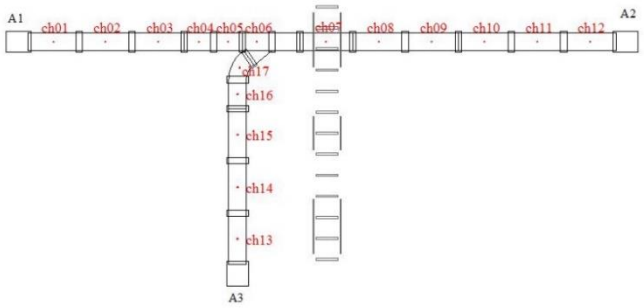


Fig. 2. Accelerometer locations for the dynamic load testing

Conclusions

This research presents interesting results that reveal the performance and the behavior of bridge under loaded and unloaded conditions. The following summary and conclusions can be drawn from the results of this field test:

1. The extra data acquired by repeating each load pattern have been very valuable to validate the effectiveness and reproducibility of the test procedure and reliability of the instrumentation.
2. The fundamental mode frequency of the bridge in the vertical direction can be derived from the acceleration time history.
3. The measured field test results indicated that the bridges have greater residual strength than predicted by analytical methods.

Precast Segmental Bridge Piers Constructed using a Modular Methodology

Hsiao-Hui Hung, Chi-Rung Jiang, NCREE
Yu-Chi Sung, Kuan-Chen Lin, National Taipei University of Technology (NTUT)

A new precast segmental bridge pier system inspired by the stacking of toy blocks is proposed in this study. The proposed system, as shown in Fig. 1, contains multiple segmental layers with several small precast modular reinforced concrete segments for each layer. The connections between the precast segments in the upper and lower segmental layers are hybrid connections containing shear keys, unbounded prestressing tendons, and bonded bar reinforcements. The bonded bar reinforcements running continuously between segments can provide strength and energy dissipation capability, and prestress force in the unbounded tendons can provide re-centering force as the joints between the segments are open. In particular, each precast segment of each segmental layer is connected with two neighboring precast segments of the neighboring segmental layer using mortise-and-tenon joints in order to provide interlocking bonds between the segments in the horizontal direction.

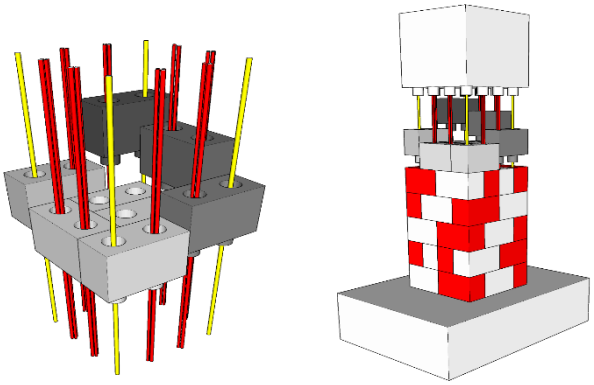


Fig.1. Conceptualization of modular precast segmental bridge piers

Based on this proposed construction methodology, the segments can be fabricated into a single type in a precast factory, and then be assembled into a column of a required cross-section according to demands. As a result, the efficiency of segment fabrication can be enhanced and the manufacturing cost of steel molds can be reduced. Moreover, small segments can be conveniently stored and transported, implying that no additional precast field is needed at a construction site, and construction need not rely on large-scale transport and hoisting equipment. Specifically, in this system, each segmental layer can include a number of the aforementioned precast segments and have the required cross-section through a proper arrangement of precast segments in the horizontal plane.

According to the aforementioned concept of modularization, two modular bridge pier specimens stacked by two types of modular segments are designed and constructed in this study: modular segments with (1) RC shear keys (MRCSK) and (2) steel bar shear keys (MSSK). These two specimens have the same dimension, except that the MRCSK specimen has a solid section, while the MSSK specimen has a hollow section. To investigate the seismic performance of the proposed precast segmental columns, cyclic loading tests were conducted on these two specimens at NCREE. Fig. 2 illustrates the test setup.

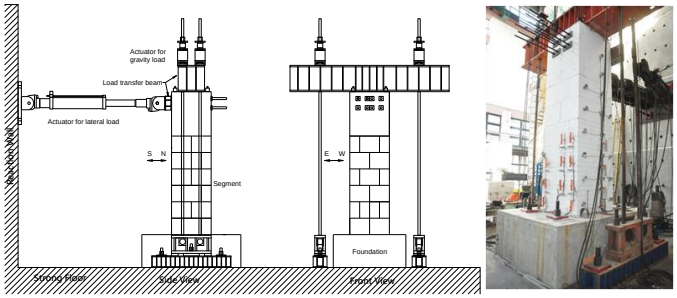
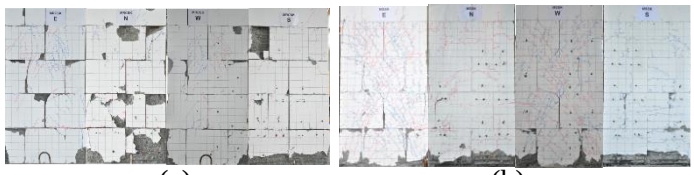


Fig. 2. Experimental setup

Photos of the final failure states of these two specimens after the cyclic loading tests (up to 70% drift) are provided in Figs. 3(a) and (b). Both specimens exhibited a bending failure mode and the failure pattern of the small segments manifested as minor cracking or peeling of the concrete cover. No stirrup break occurred. This type of damage can be retrofitted quickly after major earthquakes. The photo of the MRCSK specimen shows that almost all the fractures were distributed across the specimen, and each small segment had cracks and some crushed concrete. The crushed concrete was mainly concentrated in the interfaces between segments. The results indicate that the MRCSK specimen can transmit force to each small segment, thereby dispersing the force evenly. The MSSK specimen exhibited a failure mode similar to that of the MRCSK specimen. The cracks were distributed evenly across the surface of the specimen; however, the cracks were mainly hairline cracks and less concrete crushing occurred between segments. The most severe concrete failure for the MSSK specimen occurred at the bottom of its column.

From the experimental results and construction practices of the developed system, the seismic resistance and constructability of the proposed column are confirmed to be satisfactory.



(a) (b)

Fig.3. Photographs of specimens after cyclic loading tests: (a) MRCSK and (b) MSSK specimens

10th Taiwan-Japan Workshop on Structural and Bridge Engineering and the 3rd Workshop with NCREE and Kyushu University

Chun-Chung Chen, Associate Researcher, NCREE

The 10th Taiwan–Japan Workshop on Structural and Bridge Engineering was held during March 31–April 02, 2017 at Yoshida Campus, Kyoto University in Kyoto, Japan. The objective of the workshop was to exchange information of the latest research and practical experience and to address future challenges in structural and bridge engineering.

Prof. Kuo-Chun Chang, former director of NCREE, was nominated coordinator of the workshop, and 10 Taiwan delegates from several universities were invited to give oral presentation, exchanging research with Japanese participants. The topics of this workshop focused on five parts: (1) Structural Engineering, (2) Bridge Engineering, (3) Earthquake Engineering, (4) Structural Monitoring, and (5) other problems that structural and bridge engineers are currently facing.

The 3rd Workshop with NCREE and Kyushu University was conducted on April 04, 2017 at the campus of Kyusyu University. The workshop was hosted by Kyusyu University and Nippon Engineering Consultants Co., Ltd. this year. Some delegates from Taiwan also joined the workshop. The challenges in civil engineering, research issues, and practical applications were discussed in the workshop.

A total of 70 participants, including professors, engineers, researchers, and students, participated in these two workshops. It is believed that the success of these events can contribute to the development and promotion of structural and bridge engineering in both countries and researchers and engineers can acquire useful information.



Fig. The 10th Taiwan-Japan Workshop on Structural and Bridge Engineering



Fig. Participants of the 3rd Workshop with NCREE and Kyushu University

2nd Conference on River-Basin-Disaster Prevention: Implementation of Monitoring and Early-Warning Technologies

Xiao-Qin Liu, Assistant Researcher, NCREE

In 2015, National Applied Research Laboratories (*NARLabs*) officially initiated a project aimed at "Focusing and Expanding the Sensing and ICT Technological Inventions to Create Reliable IoT-Based River-Basin-Disaster-Prevention Technologies". To achieve this goal, *NARLabs* coordinates six of its subordinate research institutes and scholars from prestigious universities to develop a real-time, robust system for bridge scour monitoring and early-warning applications. To enhance cross-disciplinary collaboration and knowledge exchange among the project participants, NCREE hosts a regular conference each year.

The 2nd Conference on River-Basin-Disaster Prevention, hosted by NCREE, was held on May 3, 2017 at NCREE. The discussion topics were as follows:

- Bridge early-warning system development for multiple hazards (*NARLabs* NCREE)
- Application of hydrological simulation technology in predicting bridge scour (*NARLabs* Typhoon and Flood Research Institute)
- Bridge-site maintenance and remote communications (*NARLabs*, Instrument Technology Research Center)
- Application of big data analyses and cloud services in river-basin-disaster prevention and warning (*NARLabs*, National Center for High-Performance Computing)
- Application of river-basin-disaster monitoring and early warning (NTU Hydrotech Research Institute)
- Application of wireless broadband communication technology in bridge scour monitoring (National Taipei University of Technology)
- Application of real-time rainfall measurement technology in bridge scour monitoring (NTU Department of Electrical Engineering)

Seeking for collaborative opportunities with Japanese research scholars, this conference also invited Hao Zhang, professor in Kochi University, Japan, to share his research that is related to river-basin safety monitoring technology.



Fig.1 Participants of the 2nd conference on river-basin-disaster prevention

2017 JCI-TCI Joint Seminar on Evaluation, Repair and Strengthening of Cracked Concrete Structures

Fu-Pei Hsiao, Research Fellow, NCREE

The 2017 JCI-TCI Joint Seminar on Evaluation, Repair, and Strengthening of Cracked Concrete Structures was held in NCREE on March 31st, 2017. This seminar invited Prof. Hiroshi Yokota (Professor at the faculty of engineering, Hokkaido University), Prof. Kei-ichi Imamoto (Professor at the department of architecture, Tokyo University of Science), Dr. Tekeshi Yamamoto (Senior Research Engineer at the Central Research Institute of Electric Power Industry, Japan) and other famous Professors from Taiwan to give lecture. As shown in Fig.1, many engineers from consultant company joined this seminar to learn the technology on evaluation, repair, and strengthening of cracked concrete structures.

In spite of the numerous efforts to eliminate cracks from concrete structures, many cracked concrete structures still exist. Some cracks are very harmful and should be repaired as soon as possible, while others are harmless currently. Therefore, a good guideline on how to deal with cracks in concrete structures has long been needed. JCI published "Practical Guideline for Investigation and Repair of Concrete Structures" in 1980; a second version followed in 1987 and a third and fourth versions were followed in 2003 and 2009, in which English edition was also published. The fifth and the latest version was published in 2013; it is titled "Practical Guideline for Investigation, Repair and Strengthening of Cracked Concrete Structures -2013-". This guideline is believed to be helpful in dealing with cracks detected in existing concrete structures in both Japan and overseas. This seminar was aimed to popularize this guideline in Taiwan. The widespread use of this guideline is expected to benefit our engineers in Taiwan.



Fig.1 Photo of 2017 JCI-TCI Joint Seminar on Evaluation, Repair and Strengthening of Cracked Concrete Structures

IDEERS 2017

Han-Wei Huang, Assistant engineer, NCREE

In order to encourage student participation in science games and stimulate their creativity, an earthquake engineering education project titled "Introducing and Demonstrating Earthquake Engineering Research in Schools (IDEERS)" will be held by the National Applied Research Laboratories (Narlabs), the National Center for Research on Earthquake Engineering (NCREE), and the British Council in Taipei on September 21–23, 2017.

IDEERS is a science-based project with a competition developed by the Earthquake Engineering Research Center at Bristol University. The target participants of the IDEERS competition are graduate and undergraduate students majoring in civil engineering-related subjects and high school students. Students participating in the competition will construct models using cheap materials at NCREE and have them tested on the "Tri-Axial Seismic Simulator", which will shake the models to destruction. The best-designed models will win prizes

For further information, please visit the IDEERS website: http://www.ncree.org/ideers/2017/..

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