



When Civil Structures Bump into Automation Technologies:

An interview with Dr. Kuo-Chun Chang

Director of the National Center for Research on Earthquake Engineering

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NCREE Dr. Kuo-Chun Chang talks about Automation for Civil Engineers and Disaster Prevention.

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Automation technologies are extensively adopted in the fields of mechanics and manufacture. Thanks to continuous progress in scientific development, automation has been used increasingly in civil structures and structural monitoring. Through the interview of the director of NCREE, Dr. Kuo-Chun Chang, we hope that readers can examine the future developments and limits of automation technology on application in the field of civil engineering.

Automated Technologies in Bridge

Dr. Kuo-Chun Chang: From the perspective of engineering, numerous public engineering projects have been done by mechanized production; therefore, could be categorized in the field of automation technology. Although bridges were the earliest public projects on applying automation engineering, even to this day, a bridge foundation still cannot be completed solely with automation technologies. Bridge construction can only be fully automated once the foundation has been completed. “Prefabrication” is an automation technology often used in typical architectural structure projects. For example, the National Taiwan University new Civil Engineering Research Building across from the Center for Research on Earthquake Engineering was constructed using the prefabrication method. During the process, precision and mechanization are required. The prefabrication method can accelerate the construction progress while maintaining the requisite quality.

The most representative automation technology for bridge piers is the “pre-stressed prefabricated segmental

bridge piers”; which is also the first such technology applied in Taiwan, which is located in an area of strong earthquake activity. This year, the American National Science Foundation invited me to address a speech on the technology transfer of prestressed prefabricated segmental bridge piers at a forum discussing the establishment of a Technology Transfer Center. Research on this technology began in 2000, when the Taiwan Area National Expressway Engineering Bureau commissioned us to assess the feasibility of constructing an expressway across national parks. Our initial recommendation was not to build the construction road, but to use the drilling method to construct foundation, which had been applied in the Taichung expressways. All of the concrete was poured from the top of the structure, and the steel bars of the foundation were hung from above. Once the foundation was complete, each segment was connected and finally prestressed. However, because Taiwan suffers from earthquakes, we reinforced the foundation using several seismic designs. Because of the aging bridges in the U.S., and the need for a significant number of new bridges to replace them, an accelerated bridge construction (ABC) program was proposed in 2005; they cooperated with us in conducting research. Though the initial planned construction site, the eastern highway,



Dr. Kuo-Chun Chang



Vital statistics

Born 1953
Married, with 2 children

Education

Graduated with a Ph.D. in Civil Engineering in 1984 from the State University of New York at Buffalo

Career highlight

National Center for Research on Earthquake Engineering (NCREE)
(2010-present)
Director
Section Chief

Nation Taiwan University (NTU)

(2004-2010)
Chairman,
Dept. of Civil Eng.
(1996-1999)
Director, Center for Earthquake Engineering Research (1991-present)
Professor,
Dept. of Civil Eng.
Associate Professor,
Dept. of Civil Eng.

State University of New York at Buffalo

(1984-1991)
Associate Professor,
Dept. of Civil Eng.
Assistant Professor,
Dept. of Civil Eng.

Fast facts

Holds 20 patents for optical fiber sensor for bridge monitoring, seismic isolation bearing, and Landform Monitoring System.

Responsible for the design and conduction of the monitor system of BiTan bridge.

didn't get approval to construct at the end, some other cases have been benefited from this project and adopting the developed technology, for example one section of the Taichung area expressway in the Taichung residential area. The bridge on this highway became the first prestressed prefabricated bridge pier project in the world to be completed in an earthquake zone. The piers in this construction method were primarily completed in a prefabrication factory; only construction procedures for standard engineering were required to complete the project smoothly. The method we employed ensures the structure is highly seismic resistant, saves construction time, and reduces disruption to transport. Currently, the prefabricated method is being considered for a project on an elevated road crossing the harbor in Kaohsiung because of the high volume of traffic.

Automation and Disaster Prevention

Dr. Kuo-Chun Chang: For the use of automation in disaster prevention, we can begin by discussing active and passive control in structures. To decrease the structural response to external dynamic force, structural engineering began to study the automatic control of aerospace engineering at around 1970; the so-called active control. During the 1980s, this type of active

control was often utilized to control vibrations created by wind. For example, the wind damper in the KaohSiung Tuntex Building is an active-two mass-damper (ATMD). The principle is the same as that used in aerospace to balance an aircraft, only with different equipment and control algorithms. The control algorithms used in civil engineering differ significantly from the algorithms used in aerospace and mechanics. Despite the similar basic theory and methods, the control algorithms used in civil engineering are excessive, and the material properties are relatively complex because of the differing objects handled. Unlike aerospace or mechanics, which can apply one common case interchangeably, each structure in construction or architecture is often unique; requiring the development of unique control algorithms and equipment specific to the conditions of the given structure. Using active control in civil engineering is more difficult, and therefore not widely applied.

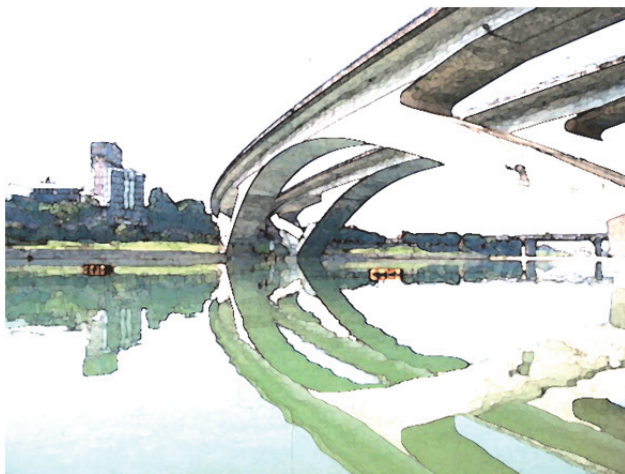
Since the 1995 Kobe earthquake in Japan, engineers have gradually begun to realize that pure active control is less than ideal. The aerospace control system automatically begins control operations when the aircraft is in the air, and the system is continually verified and adjusted. Structural active control, however, needs to operate only when an earthquake occurs. The system is often unable to operate continuously, but the computer must remain on and the system cannot crash when an earthquake



occurs. Furthermore, with advances in information engineering, the software and algorithm for aircraft control is able to update and revise simultaneously. However, because active control systems in civil structures that have been embedded-in for years ago cannot be synchronized and or updated with present systems. Therefore, the computers used to control buildings and bridges differ from those used in aerospace engineering. These systems have gradually transformed into semi-automatic control or hybrid control systems. When the active control system cannot function properly, the passive control system sustains operations. This transformation has been the general trend since 1995. However, passive control has been proven to be the more effective and durable system, and is more practical.

In summary, two characteristics are emphasized in civil engineering: **reliability** and **durability**. This differs dramatically from the trend in electronics. For example, we use an excessive variation of micro-electromechanical system (MEMS) sensors to measure pier erosion. These sensors are buried directly beneath the piers, measuring the depth of erosion by sensing the pressure above. Some MEMS sensors can even vibrate and harvesting energy for itself. Nevertheless, these sensors get disadvantages like other consumer electronics that are short lifespan and are susceptible to water and interference, thereby violating the two emphases of civil engineering: reliability and durability. Therefore, we currently adopt multiple sensing solutions to address these problems.

Around 1992 and 1993, the Department of Civil Engineering at National Taiwan University undertook two large bridge projects: the YuanShan Bridge project and the BiTan Bridge project. Because of these projects, we began close contact and cooperation with the Taiwan Area National Expressway Engineering Bureau, an



The BiTan Bridge

organization that provides us with extensive support. At that time, the BiTan Bridge project was already using the most up-to-date technology: digitalized the sensed information and trigger the sending out process by phone. Acquiring data only involved calling the phone installed at the monitoring site, and the data would be transmitted through a modem. Later, in cooperation with the Taiwan Area National Expressway Engineering Bureau between 1997 and 1998, we introduced a seismic isolation technology for bridge and applied fiber optics to establish a monitoring system for installation in National Highway No. 3, which is still in use today.

Scour Monitoring System

Dr. Kuo-Chun Chang: The National Center for Research on Earthquake Engineering (NCREE) began actively developing a composite disaster monitoring system following the Chi-Chi earthquake. To safeguard the system during emergencies, such by maintaining the expected function of piers during their scour, we developed various scour sensors. In addition to the MEMS sensors described previously, fiber optic and axial pressure sensors were also used. By burying the fiber optic and axial pressure sensors in the ground under streams, they are exposed to different water flow speeds in the pores of soil and in the stream. Because the impact differs, when the sensors are pushed out of the soil by the water and are carried quickly by the stream, the impact produces a vibration signal that can be differentiated from other signals to determine the scour conditions. There are two additional types of scour sensors which we call scour bricks: one is fixed, and the other is buoyant. Scour bricks typically do not produce electrical power when not in motion, but will vibrate and generate electricity and light once they are washed away. The vibrations and generation of electricity and light is a combination of interdisciplinary technologies that currently has yielded excellent results in laboratory experiments. The next step is to test whether the sensors can sustain normal operations after being installed underground for an extended period. This technology is also currently being tested on actual bridges.

The monitoring system previously described is a comprehensive scour sensing system that can record earthquakes, and measure and record normal vehicle vibrations, scour, water levels, and water pressure. Experts from different fields studying these results together can interpret the problems differently. For bridges, this system enabled us to study information related to the earthquakes, floods, and scour that affect



bridges. We also conducted laboratory experiments. For example, we performed an erosion experiment by placing a bridge model in a sink large enough to hold numerous sensors at the bridge foundation to simulate the erosion anticipated at the actual site.

While conducting the research, we discovered that the laboratory simulation experiment was inconsistent with the results of the computer calculations, making the issue extremely complex. For example, the calculations indicated that the piers would lean left from the erosion, but they actually leaned to the right. This type of situation is fairly common. This is primarily because professors in the field of irrigation study the water; professors in the field of soil study the soil; and professors in the field of structure study the structure; no combined investigation is conducted. Therefore, our understanding is incomplete. Fortunately, the National Science Council's integration program led by the NCREE examined the actual site and the theoretical research as a whole picture. The turning point was the collapse of the HouFeng Bridge two years ago. Prior to the HouFeng collapse, bridges were collapsing in succession because of scour, and the Executive Yuan proposed applying hi-tech methods to monitor bridge scour. Because the NCREE had conducted related research continuously, the program could begin immediately. Originally, the NCREE did not study flooding because it is not directly related to earthquake engineering. However, we discovered that after the Chi-Chi earthquake, numerous bridges collapsed due to mudslides or scour as soon as they were hit with a flood. This is a typical complex disaster. The earthquake loosens the soil, which then flows down from the mountains with the stream, creating an especially large scour force against bridges. Almost each year after the Chi-Chi earthquake, a bridge has collapsed due to mudslides or scour.

Monitoring systems required for disaster preparedness and response face various issues due to the location of vital bridges in remote areas, which thereby require technology such as material and signal equipment to be integrated and improved. From the perspective of engineering, a monitoring system itself is a result of large-scale interdisciplinary integration. Civil engineering itself must be integrated — from the foundation to the structure, the ground, the materials, and the water. A bridge set on a river has a set of interrelated problems, including the water, scour, and its soil foundation. Thus, civil engineering itself requires interdisciplinary study for application.

Additionally, because of the immense size and complexity of the structure of a building with numerous

signal sources, evaluating structural conditions using a few signals is difficult. Currently, most measurement signals employ a back calculation method to infer the problem point, which creates various possibilities. Although this problem is a popular research topic, and is normally investigated using two methods, it is yet to be resolved. The first method uses only the vibration signals to determine the problem point. The second method assumes that the vibration signals provide a reference; however, the monitoring and study of various sensors deep in the area is still required.

When the bridge foundation experiences scour, we believe that merely depending on vibration signals to determine the depth of scour is exceedingly difficult because understanding of the basic mechanics is inadequate. Returning to the previous discussion, prior studies assumed that structures deal with structures and water deals with water; but the actual situation involves an interaction between bridge structure and the water. How differences in the depth and flow speed in water mass impact the structural vibration signals, and how large amounts of water impact the structure's dynamic properties are questions that demand further exploration. Therefore, the aim of this study was to examine relevant theories, obtain diverse on-site measurements, and conduct comparisons. These are the processes we are currently applying.

For example, approximately 10 years ago, after the collapse of the KaoPing River Bridge, the government proposed that all bridges be monitored. However, following the implementation of this policy, many of the businesses that won these contracts were equipment companies, which was unsuitable and resulted in considerable distress to relevant companies. Because these equipment companies responsible for monitoring bridges and related mechanics, they were incapable of determining the reason for abnormal signals. Although they did not understand the warning signals, they could only close the bridge following a warning signal. Thus, bridges were often closed without a cause or reason. This led to the bridge management companies and the public losing confidence and considering bridge monitoring unreliable. We are currently working to improve this situation.

We believe that a warning signal does not require an immediate bridge closure. Instead, a warning signal alerts the engineers to observe the situation closely. A bridge should be closed only after the engineers have confirmed the warning. This is a more appropriate system. Therefore, we currently both test the system to


improve reliability, and train engineers to have a basic concept of how to determine conditions. For example: the current standard is to close a bridge once water levels reach a certain height. However, prior experience suggests that the water level is not a determining criterion; bridges occasionally collapse when water levels decrease. Therefore, knowing the water level is not the only determining factor; conditions under the water, such as the depth of scour and water flow, must also be understood. In addition to reliable signals, engineer training is also an indispensable component of bridge closure determination.

Current Disaster Prevention Systems and Applications

Dr. Kuo-Chun Chang: NCREE has a “Taiwan Earthquake Loss Estimation System” (TELES), in which we established a large evaluation database for earthquake disasters in Taiwan, with a relatively complete section of data on buildings and bridges and sections on pipelines and other life-support facilities, which are still being compiled. The data in the database is categorized by the earthquake vulnerability curves for different categories of structures, which have been calculated and put through earthquake simulations. Taiwan and the ocean within 100 km of its coast were designated into grids, and the anticipated impact that an earthquake could have on each region of Taiwan was calculated in each grid. In the future, providing the epicenter of the earthquake is located on these grids, the possible loss to Taiwan created by the predicted earthquake, including the areas that will be more heavily affected, can be obtained using the TELES. This system was introduced and rewritten from the earlier U.S. HASUS system, with the disaster model changed to reflect the specific conditions of Taiwan. Currently, the system has produced excellent results, and is the primary earthquake loss estimation system in Taiwan. When an earthquake occurs, the Central Weather Bureau transmits information. Approximately three minutes after the system receives this information, it automatically transmits data to the relevant organizations and individuals. These three minutes are required for the system to clarify the location, epicenter, and depth of the earthquake, and compare them with the database. The content in the database includes the earthquake’s assumed intensity, epicenter, depth, and its effect on each location in

Taiwan. After consulting the information detected by the Central Weather Bureau on the earthquake’s epicenter, location, depth, and size, the data which most closely matches this information is then transmitted in brief news form, allowing relevant disaster prevention and rescue personnel to receive first hand information.

Another system related to information automation is the “Earthquake Early Warning System,” which provided Tokyo with several seconds of reaction time before the earthquake occurred in northeastern Japan this year. This system currently being developed by the Central Weather Bureau is regional, using monitoring stations to measure the earthquakes as they occur, and estimating the subsequent earthquake’s size and time of occurrence at each location. The NCREE is also developing an onsite system for detecting earthquakes via seismometers installed in various locations. The moment an earthquake occurs, the seismometers receive P waves that are then used to determine the distance to the epicenter and the size of the earthquake. P waves are faster than S waves, and can therefore predict when the larger S waves arrive. This system currently being developed by NCREE is already being tested in ILan, Hualien, Chiali, and at Chung Cheng University. Thus far, it has an 80 % accuracy rate in predicting earthquake size, plus or minus one level. The accuracy rate is almost as precise as that of Japanese system; its time prediction is also excellent.

We are currently planning for the future linking of this system’s technology with automation. Locations in Taiwan are at a close distance from earthquake epicenters. Tokyo was 300 or 400 km from the northeast earthquake’s epicenter; but in Taiwan, an earthquake occurring several dozen km in the ocean is considered distant. Therefore, if an earthquake were to occur on the island itself, similar to the 921 Chi-Chi earthquake in 1999, according to our system, the warning would only be approximately 20 s before the earthquake traveled from the epicenter and reached Taipei. A warning of only 20 s seems inadequate and of little benefit. However, by automating the system, elevator companies can receive the earthquake warning and immediately locate and open elevators; fireproof door companies can open and maintain escape routes; and gas systems can be shut off promptly to avoid secondary disasters. These are only a few examples of the numerous applications that will decrease the effects of disasters by linking automation systems. 

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