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DIRECTOR

Kuo-Chun Chang

EDITORS

Kuang-Wu Chou

Chi-Hao Lin

National Center for Research on Earthquake Engineering

Using Earthquake Loss Estimation Technique for Benefit Assessment of Building Retrofit Countermeasure

Cheng-Tao Yang, Associate Researcher, Lee-Hui Huang, Assistant Researcher, Chi-Hao Lin, Associate Researcher, NCREE

After the Meinong earthquake on Feb. 6th in the beginning of this year (2016), seismic retrofit of buildings and urban renewal have again become an important issue. Since Taiwan is located in the circum-Pacific belt, earthquakes occur frequently. The Taiwan government has continuously invested considerable resources to identify effective measures for earthquake disaster mitigation since the 921 (Chichi) earthquake. For instance, seismic retrofit, earthquake insurance, preferential housing loans, and badge rewards have all been discussed and studied seriously. Seismic retrofit for all private buildings is a strongly emphasized countermeasure. However, there are too many private buildings to retrofit over a few years. Furthermore, the formulation of relevant laws and policies related to seismic retrofit needs to be considered carefully because they affect the rights of the people and the government's annual budget.

Considering the limited resources, it would be better to identify regional earthquake risks and to analyze the quantity, structure type, occupancy classification, and seismic capability of buildings in the very beginning. For example, if we plan giving priority to the 30-year-old buildings that have less seismic capacity in Taipei City, we need to understand the cost and the benefit of the countermeasure. Earthquake Loss Estimation Technique can help assess the benefit (the loss) of the 30-year-old buildings before and after seismic retrofit. The NCREE has developed an earthquake loss estimation system in Taiwan, named the Taiwan Earthquake Loss Estimation System (TELES). TELES can help simulate the distribution of ground shaking intensity, ground failure probability, building damage, casualties, post-earthquake fires, debris, lifeline interruptions, economic losses, *etc*. The following instance describes how TELES can be used for benefit assessment of building seismic retrofit countermeasures in Taipei City.

The Seismic Scenario in Taipei City

The seismic scenario in Taipei City is shown in Fig. 1. In this scenario, an extreme large earthquake is caused by the Sanchiao fault. The earthquake source parameters are listed as follows

- Epicenter is in Shihlin district (121.589E, 25.139N)
- $M_L = 6.9$
- Rupture Length 56 km
- Rupture Width 20km
- Focal depth 8km
- Dip angle 50°

This seismic scenario is used to estimate building damage and casualties in three different retrofit situations. (1) The current situation: All department stores, shopping malls, supermarkets, markets, shops, nightclubs, discos, cafes, restaurants, karaoke bars, restaurants, theaters, entertainment venues, swimming pools, and school buildings in Taipei City (hereafter, public buildings) are inputted into TELES to estimate the degree of damage to the buildings and the casualties under the seismic scenario. (2) Situation 50%: A specified number of public buildings are without seismic design (hereafter, weak public buildings). All weak pubic buildings obtained a construction permit before the seismic code legislation was enacted. In this situation, we assume that half of the weak public buildings have been reinforced to enhance their seismic capacity. (3) Situation 100%: We assume that 100% of the weak public buildings have been enhanced to increase their seismic capacity. The earthquake loss estimations under the three different situations are compared in Table 1.

Table 1. Earthquake loss estimations of the three situations

Damaged area of building (m^2)			Casualties		
Current Situation	Situation 50%	Situation 100%	Current Situation	Situation 50%	Situation 100%
1,193,247	1,091,290	989,332	460	385	339

As listed in Table 1, the damaged area of a building is defined as the sum of the floor areas of seriously damaged and collapsed buildings. "Seriously damaged" means that the buildings' columns, beams, walls, or slabs have been damaged and are not safe without appropriate repair. The casualties comprise the total numbers of seriously injured people (those who will die without immediate assistance) and the dead. To compare the three different earthquake losses, we can simply compare the benefits of situation 50% and situation 100%. Thus, an earthquake loss estimation technique can estimate and compare the benefits of earthquake disaster mitigation countermeasures whilst considering the available resources.

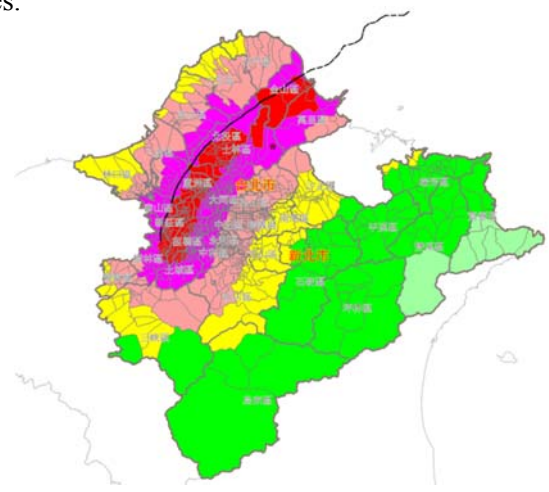


Fig. 1. The distribution of peak ground acceleration in the seismic scenario for Taipei City

Seismic Assessment of Steel Liquid Storage Tanks

Gee-Yu Liu, Research Fellow, NCREE

Steel tanks are used extensively for bulk storage of crude oil and liquid fuel in oil terminals, refineries, and petrochemical factories all over the world. They are also used for the storage of hazardous liquid materials, such as chemicals used for coagulation, sedimentation, and disinfection in water treatment plants. In areas of high seismicity, the safety of these steel liquid storage tanks is crucial. A rational approach to assess the seismic safety of such tanks is greatly needed.

In this study, a seismic assessment procedure for steel liquid storage tanks is proposed, as depicted in Fig. 1. It is based upon "Appendix E: Seismic Design of Storage Tanks" in API 650 Welded Steel Tanks for Oil Storage, which provides the minimum seismic requirements for on-grade welded steel tanks. Physically, it considers two vibration modes of a tank and its contents: impulsive and convective. The proposed procedure applies to anchored steel tanks, which are the most commonly used variety, and is of high seismic concern in Taiwan. A checklist has been recommended for assessing (1) the total base shear against tank sliding failure, (2) the total combined hoop stress in the shell against wall breaking, (3) the anchor load against anchor bolt and strap failure, (4) the maximum longitudinal shell compression stress against wall buckling, (5) the overturning stability, and (6) the height of sloshing waves for roof safety. The calculations in this procedure are incorporated with the seismic demand specified in the Taiwan Building Seismic Design Code.

Two 300-ton chemical storage tanks, depicted in Fig. 2, were selected for assessment. They are located at different water treatment plants in northern Taiwan. One stores a PAC (poly-aluminum chloride) solution and is mounted on a circular reinforced concrete pedestal via anchor bolts, while the other stores a NaOH solution and is mounted on a circular reinforced concrete mat via anchor bolts. Before the assessment, the fundamental frequency of the reinforced concrete pedestal was determined using finite element analysis. It was found to be much higher than the frequencies of the impulsive and convective modes of the tank–liquid system. Therefore, the tank can be assumed to be anchored on-grade.

Following the assessment procedure mentioned above, it was found that both tanks have insufficient anchorage. API 650 requires an allowable tensile stress for anchor bolts and straps equal to 80% of the published minimum yield stress. This requirement is not satisfied. In addition, one of the two tanks was found to have insufficient freeboard. The roof of the tank is very likely to be hit and damaged by sloshing waves under design earthquake excitation. Therefore, the utility owner has decided to add more anchor bolts to the tanks to meet the requirement specified in API 650, and to lower the liquid level, if necessary, to ensure sufficient freeboard.

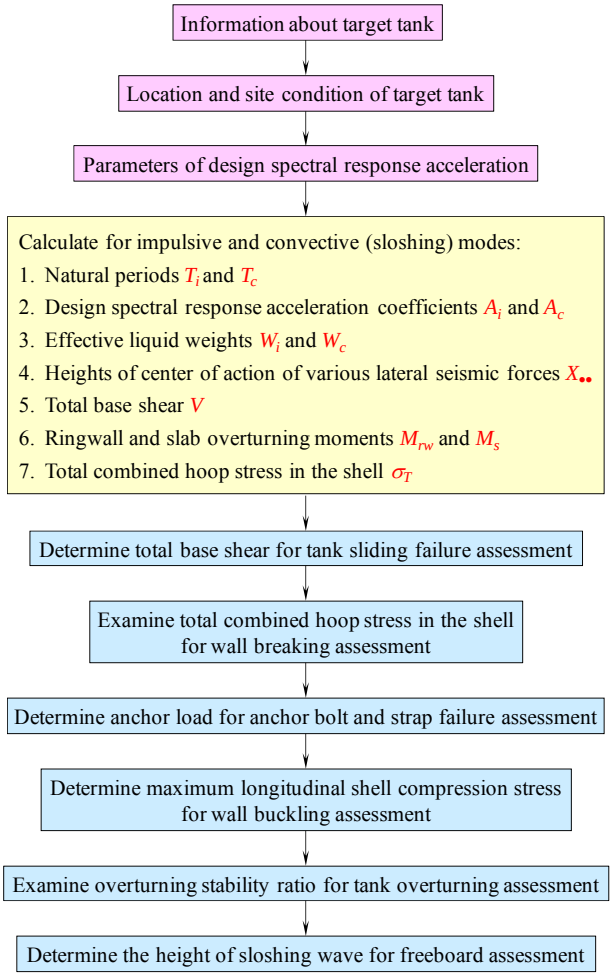


Fig. 1. Seismic assessment procedure for steel liquid storage tanks following API 650, App. E requirements



Fig. 2. Two 300-ton chemical storage tanks seismically assessed in this study

Seismic Fragility of Critical Facilities in Water Supply Systems

Gee-Yu Liu, Research Fellow, NCREE

The seismic performance of a water supply system relies not only on the ruggedness of the pipeline network, but also on the robustness of the facilities in the system. For seismic hazard mitigation of water supply systems, it is very important to take into account the seismic fragility of these facilities. During the Chi-Chi earthquake, water distribution reservoirs and pipe bridges were severely damaged, which had a huge impact on water transmission and distribution in central Taiwan. Improved fragility models for these facilities based on local characteristics and damage data are urgently needed.

In Taiwan, distribution reservoirs and clear water tanks (CWT) in water treatment plants (WTP) are reinforced concrete (RC) structures. Occasionally, pre-stressed RC structures are employed for large circular reservoirs. RC structures can be divided into two different classes based on their structure: "framed" structures that share a moment-resisting base–wall system founded on a common mat, and "non-framed" structures that lack this feature. Theoretically, a framed structure has a better seismic performance than a non-framed structure. Water distribution reservoirs can also be divided into two classes based on the place of installation. The first is called "on grade" (*i.e.*, above ground) and the other is buried/partially buried. Due to the confinement effect from the surrounding soil, the latter class of distribution reservoirs performs better than the former under seismic excitation. Therefore, it is recommended that the seismic fragility due to both ground shaking (peak ground acceleration) and permanent ground deformation should be considered for on-grade RC distribution reservoirs. Meanwhile, for buried and partially buried RC distribution reservoirs, only seismic fragility due to permanent ground deformation should be considered.

In Taiwan, most water pipe bridges are very simply constructed. The pipe, with or without stiffening measurement, supports itself as the girder of a bridge. Under such circumstances, the entire superstructure is structurally weaker than the lower structure of the bridge. Since there is no deck in the superstructure, the width of the bridge is narrow and the piers consist of single-column bents instead of multiple-column bents or pier walls. In this study, they are termed "simple/stiffened" pipe bridges. On the other hand, some water pipe bridges are complex in design. The water pipes in these bridges are supported by steel girders or arches, or they are trussed, cable-stayed, or suspended superstructures. These water pipe bridges generally have sophisticated engineering and, as a result, have complex seismic behaviors. These bridges are called "special" pipe bridges. It is further recommended that water pipe bridges should be classified according to whether they are conventionally or seismically designed, which can be determined by the year of construction (before or after 1995).

In this study, a database was established that contains 38 major distribution reservoirs (including CWTs) and four water pipe bridges in central Taiwan circa 1999, as depicted in Fig. 1. Their structural properties and damage states (DS) during the Chi-Chi earthquake have been calibrated. Eight of them actually experienced damage. Measured ground shaking and permanent ground deformation were used to determine the actual hazards that each was exposed to during the earthquake. These were then employed to develop the fragility curves at various damage states for each type of facility described above. Table 1 summarized the actual and simulated damage states of the damage facilities. On the whole, they are in good agreement with each other.

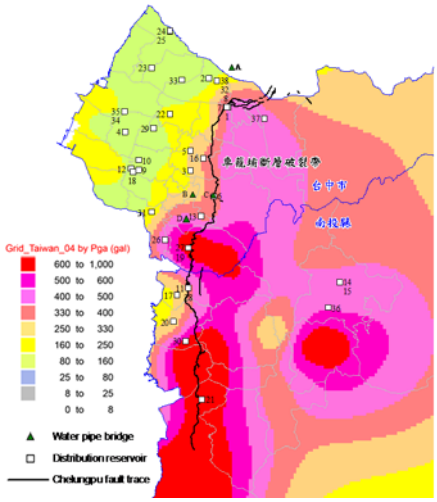


Fig. 1. Locations of water distribution reservoirs and pipe bridges on a plot of the distribution of peak ground acceleration during the Chi-Chi earthquake

Table 1. Comparison between actual and simulated damage states (DS) of the damaged water supply facilities during the Chi-Chi earthquake

ID	Facility name	Class	Actual DS	Simulated DS
1	50,000-ton CWT, Feng-Yuan 2nd WTP	Non-framed, Buried	Extensive	Complete
6	Now-Guan 18,000-ton Distribution Reservoir	Non-framed, On-grade	Complete	Complete
7	17,000-ton CWT, Feng-Yuan 1st WTP	Non- framed, Partially buried	Complete	Complete
8	15,000-ton CWT, Feng-Yuan 1st WTP	Non-framed, Partially buried	Complete	Complete
11	6,000-ton CWT, Cao-Tun WTP	Non-framed, Buried	Slight	Complete
17	4,000-ton CWT, Lin-Zi-Tou WTP	Non-framed, Partially buried	Slight	Slight
37	1,000-ton CWT, Dong-Shi WTP	Non-framed, On-grade	Extensive	Complete
C	Yi-Jiang Water Pipe Bridge	Simple pipe, Conventionally designed	Complete	Complete

Twater：A Seismic Risk Analysis Tool for Water Supply Systems

Gee-Yu Liu, Research Fellow, NCREE
Chin-Hsun Yeh, Research Fellow and Division Director, NCREE

Disruption of water supply following earthquake may cause severe inconvenience to the daily activities of people in the disastrous areas. Medical caring, sanitation and fire-fighting may be seriously affected, too. It is eagerly needed to facilitate water authorities with a seismic risk analysis tool for estimating the likely damage in water systems and loss of their functionality in earthquake scenarios. Measures could be taken then to enhance the seismic preparedness and emergency response appropriately and timely.

Similar to the development and implementations of TELES (Taiwan Earthquake Loss Estimation System), NCREE has recently developed a tool called Twater. It is a sub-system of TELES and is specialized for the scenario-based seismic risk analysis of water systems. It is fully geographical information system (GIS) facilitated. As illustrated in Fig.1 for its graphical user interface, Twater is capable of simulating the hazards of ground shaking and failure and the resulted damages in the distributed pipelines and the damage state of each of the facilities (e.g. distribution reservoirs, pump stations and water pipe bridges) of a water supply system given an earthquake condition.

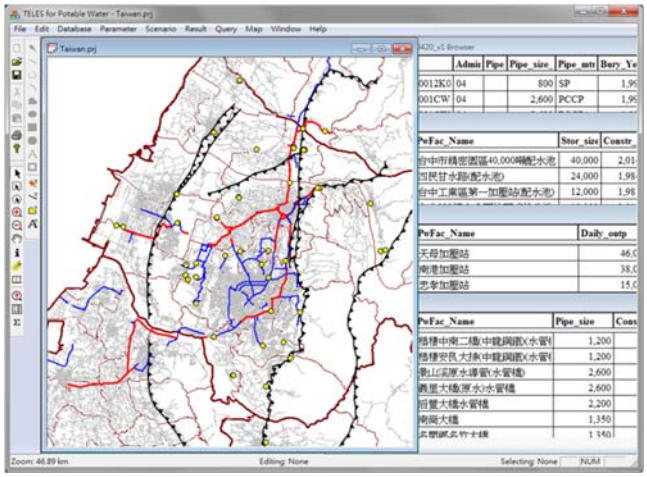


Fig.1. The graphical user interface of Twater

Twater has been employed in regional planning for enhanced preparedness of water supply systems against seismic hazards. Fig.2 illustrates water transmission mains, locations of active faults, and distribution of soil liquefaction potential in Tainan and Kaohsiung. The seismic exposure, namely the fault crossings and the pipelines lying in areas of high liquefaction potential, can be identified by Twater. Given a scenario earthquake, it can predict the likely numbers and distribution of breaks and leakages of water pipelines, the areas suffering water suspension and how long it wound last, and, accordingly, the cost and required time and repair teams to fully restore the water supply. The amount of water needed for shelters and fire fighting from earthquake disasters can be estimated, too. Twater has been employed to identify the hot spots of liquefaction-induced pipeline damages. A cost-and-benefit analysis has also been carried out for the pipe replacement against earthquake hazards.

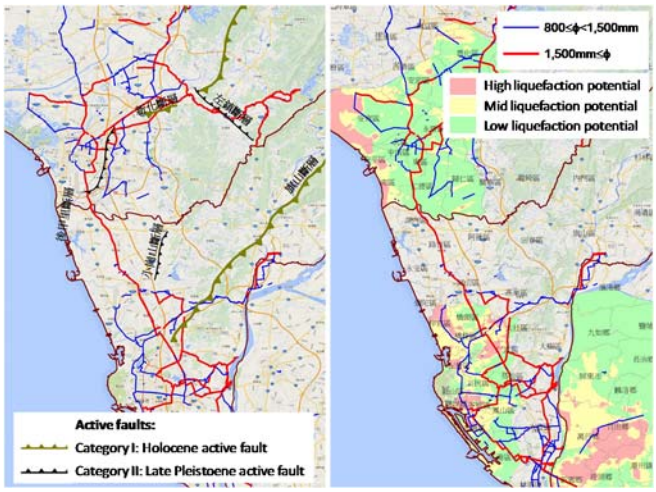


Fig. 2. The seismic exposure of water pipelines in Tainan and Kaohsiung by Twater (left: fault crossings; right: areas of high liquefaction potential)

With the help of Twater, NCREE's service of early seismic loss estimation (ESLE) has been extended to all water utilities in Taiwan at the end of 2015. Since then, their emergency personnel can be notified with the estimates of damages in water systems in one minute whenever the Central Weather Bureau (CWB), MOTC, announces the occurrence of an earthquake. Based on the experience in the Feb. 6, 2016 Meinong earthquake, based upon the limited information of the earthquake from CWB's announcement, the ESLE estimates indicated that Tainan's water system (under the Sixth Branch of Taiwan Water Corp.) was badly damaged in its pipeline network. Improved estimates were obtained 3 hours later when Twater was manually operated and a better seismic source was input. Tab.1 summarizes the actual and estimated numbers of pipeline damages in Tainan. It is worth mentioned that the ESLE notification did successfully accelerate the targeted startup of emergency operation of Taiwan Water Corp. in this earthquake.

Table1. Estimated and actual numbers of damage in Tainan's water pipelines from the Feb. 6, 2016 Meinong earthquake

	Number of pipeline damages (ϕ≥100 mm)
ESLE estimate (1 minute after CWB announcement)	409
Manual Twater estimate (3 hours after earthquake)	206
Actual	171

NCREE and UH Signed Bilateral Agreement on Scholarly Exchange and Collaboration

Cheyu Chang, Assistant Researcher, NCREE

To further strengthen the long-term research partnership between the National Center for Research on Earthquake Engineering (NCREE), Taiwan and the University of Houston (UH), USA, Department Chair Roberto Ballarini of the Civil and Environmental Engineering Department and Director Mina Dawood of the Thomas T.C. Hsu Structural Research Laboratory (THSRL) visited NCREE on May 15–17. Director General Kuo-Chun Chang of NCREE and Department Chair Roberto Ballarini of UH jointly signed the official 5-year Agreement on Scholarly Exchange and Collaboration on May 16. The signing ceremony began with a welcome remark delivered by Director General K.C. Chang, followed by an appreciation remark by Department Chair Roberto Ballarini. Deputy Director General Shyh-Jiann Hwang introduced NCREE's organization, facilities and recent R&D achievements, and extended the introduction to NCREE's Southern Laboratory currently under construction at the Gueiren Campus of National Cheng Kung University in Tainan City. Then, Professor Roberto Ballarini introduced the organization and R&D achievements of the UH Civil and Environmental Engineering Department. On May 17, Professor Mina Dawood introduced the facilities and R&D achievements of THSRL. Professor Yin-Nan Huang of National Taiwan University described the results of reversed cyclic experiments of steel-plate composite walls that had been conducted over the past few years at NCREE. Dr. Shiang-Jung Wang of NCREE introduced a UH–NCREE joint project collaborating with Professor Yi-Lung Mo on developing innovative period foundations for small modular reactor power plants through shaking table tests at NCREE. The 2-day activity, jointly planned by Deputy Director General Shyh-Jiann Hwang and Professor Thomas T.C. Hsu, was very successful.



Director General Kuo-Chun Chang of NCREE and Department Chair Roberto Ballarini of UH jointly signed the official agreement on scholarly exchange and collaboration on May 16, 2016.

2016 the 9th Taiwan–Japan Workshop on Structural and Bridge Engineering

Fang-Yao Yeh, Research Fellow, NCREE

The M_L-6.6 Meinong earthquake hit Taiwan at 3:57 am on February 6, 2016, and 551 people were injured and 117 people were killed. The No. 24 bridge on Provincial Highway 86 caused the east affected displacement by the earthquake, and there are many piers supporting damage. The bridge damage due to this earthquake was significant. The M_L-7.3 Kumamoto earthquake hit Japan at 1:25 am on April 16, 2016, and 262 people were injured and 59 people were killed, and many bridges and transportation facilities were also damaged. After these disastrous earthquakes, researchers have paid more attention to bridge damage due to earthquakes and multiple hazards.

The 2016 9th Taiwan–Japan Workshop on Structural and Bridge Engineering, jointly organized by Kyoto University and the National Center for Research on Earthquake Engineering (NCREE), was held over May 24–25, 2016, at NCREE in Taipei, Taiwan. The objective of this workshop was to exchange information on their latest research and practical experiences, and to address future challenges in structural and bridge engineering. Some outstanding professors and senior researchers were invited to present their achievements in structural and bridge engineering and to share their experiences. Workshop attendees came from Japanese organizations, including Kyoto University, Osaka City University, Kyushu University, the Public Works Research Institute, and the Hanshin Expressway Company Ltd., and from Taiwanese organizations including National Taiwan University, National Chiao Tung University, National Taiwan University of Science and Technology, CECI Engineering Consultants Inc., and the NCREE. There were four main topics of this workshop, namely (1) structural engineering, (2) bridge engineering, (3) a damage report on the 2016 Kumamoto Earthquake, and (4) other problems currently faced by structural and bridge engineers. It is believed that the success of this event contributed to the development and promotion of bridge engineering in Taiwan and that local researchers and engineers gained useful information.



Fig. 1. Participants of the 2016 9th Taiwan–Japan Workshop on Structural and Bridge Engineering

IDEERS 2016

Mu-Hsuan Li, Technologist, NCREE

In order to encourage student participation in science games and to 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 9–11, 2016.

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 entering the competition will construct models using inexpensive materials at NCREE and have them tested on the "Tri-Axial Seismic Simulator". Models will be shaken to destruction and the best-designed models will win prizes.

For further information, please visit the IDEERS website: http://www.ncree.org/ideers/2016/.

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National Center for Research on Earthquake Engineering

200, Sec. 3, XinHai Rd., Taipei 106, Taiwan, R.O.C.

Phone: 886-2-6630-0888

Fax: 886-2-6630-0858

Website: http://newsletter.ncree.org

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