NCREE NEWSLETTER

June 2014 VOL. 9 NO. 2



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Shaking Table Test and Numerical Analysis of Medical Equipment Fixed on a Light-Weight Partition Wall

Ren-Zuo Wang, Associate Researcher, NCREE

This article is concerned with the mechanical properties and friction characteristics of rubber bearings under seismic loading. To understand the force transmitted from a superstructure to a substructure, a shaking table test of a scaled-down simply supported bridge was performed. Fig. 1. shows the scaled test model and Fig. 2. shows the simulation model obtained using SAP2000 software.

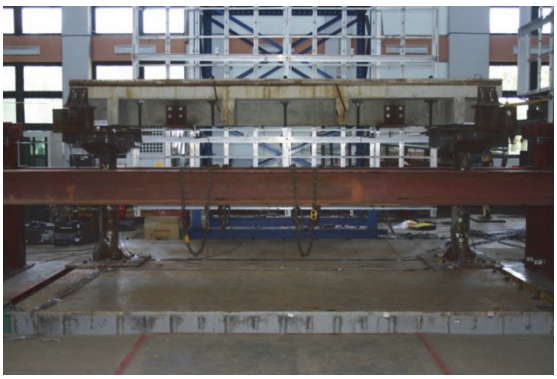


Fig. 1. The scaled test model

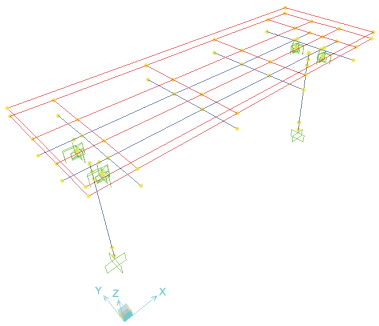


Fig. 2. Numerical model of the shaking table test

This experiment has two different bearing settings. One end is a rubber bearing (RB end) while the other end is a rubber bearing with PTFE (PTFE end). The acceleration time history of the El Centro earthquake was chosen for this study. The magnitude of this earthquake was 200 gal. From the experimental data, we can set the parameters of the elements, as shown in Table

RB end	Rubber element	$K_{rV}\ (N/cm)$	337716
		$K_{rh}\ (N/cm)$	954
	Friction element	$K_{fV}\ (N/cm)$	337716
		$K_{fh}\ (N/cm)$	954000
		μ_{RB}	0.56
		F (N)	13783

PTFE end	Rubber element	$K_{rV}\ (N/cm)$	337716
		$K_{rh}\ (N/cm)$	954
	Friction element	$K_{fV}\ (N/cm)$	337716
		$K_{fh}\ (N/cm)$	954000
		μ_{PTFE}	0.11
		F (N)	2707

A comparison of results of the proposed analytical model with those of the experimental (Fig.3.) demonstrates the accuracy of the proposed model. It shows that FBM can separate the deformation into rubber shear deformation and sliding displacement. In the case of the El Centro time history (200 gal) shown in Fig. 3, we use two different simulation methods for the rubber supporting pads. The first one uses a frictional isolator and the second one uses FBM. The analysis results, specifically the displacement time histories of the deck, are shown in Fig. . The black line represents the experimental results, the red line represents the analysis results of the three-link element, and finally the blue line represents the results of the frictional isolator. As can be seen, all analytical results are close to the experimental results.

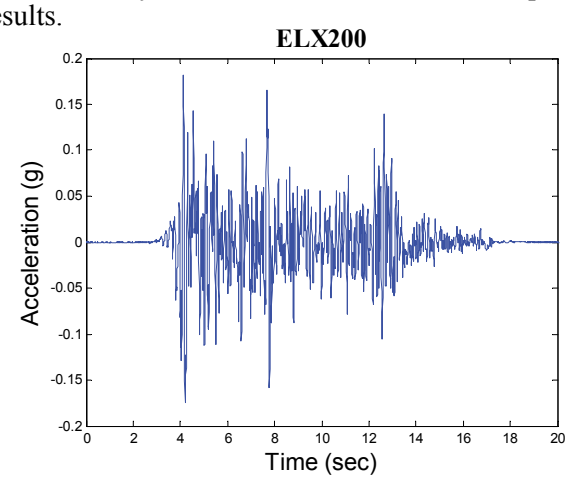


Fig. 3. The input ground acceleration of the El Centro earthquake

From the displacement time history of FBM in each element, we know that the sliding displacement of the RB end is almost zero. Under the conditions of the El Centro earthquake, the PTFE rubber bearing induces a frictional sliding mechanism. The maximum sliding displacement is 2.5 mm.

Constitutive Model for Equivalent Uniaxial Strain of Concrete

Ren-Zuo Wang, Associate Researcher, NCREE

Abstract

This study proposes a concrete material hypoplastic model to explain the complicated nonlinear behavior of concrete structures. This model is based on the concept of equivalent strain proposed by Darwin & Pecknold and a series of methods created by Balan *et al*. By decoupling the behavior in multiple axes into three or two unitary axes, the calculations required are simplified. Two parts are considered, namely the failure surface of the material and the uniaxial stress–strain curve. The Menetrey–Willam model developed by Menetrey & Willam is considered and the cap model is applied to account for the triaxial compressive strength. This model is also referred to as the Closure Menetrey–Willam (CMW) model. Saenz proposed a convenient equation that can describe not only the ascending branch but also the descending branch of a stress–strain curve. By combining a Finite Element Model (FEM) and a hypoplastic model, the nonlinear behavior of concrete can be predicted effectively.

3D Concrete Model

A 3D hypoplastic orthotropic model is considered in this work. Considering the small deformation, the stress–strain relation is represented in vector incremental form as:

$$\mathbf{d\sigma}=\mathbf{D}_L\mathbf{d\varepsilon} \tag{1}$$

The reference coordinate in Eq. (1) is the local coordinate. The term $\mathbf{D}_L$ should be transformed into global coordinates:

$$\mathbf{D}_G=\mathbf{T}^T\mathbf{D}_L\mathbf{T} \tag{2}$$

and turned into $\mathbf{D}_G$ using a rotation matrix $\mathbf{T}$. The incremental form could then be added into the total form.

Equivalent Uniaxial Strain

Darwin & Pecknold proposed the concept of equivalent strain as being not a real strain, but rather a fictitious strain without any physical meaning. The most important function of equivalent strain is to decouple the multi-axial behavior. Stress can be obtained using equivalent strain as follows:

$$d\sigma_i = \mathbf{D}_L d\varepsilon_i = \mathbf{E} d\varepsilon_{iu} \tag{3}$$

Uniaxial Envelope

Saenz proposed an equation that is convenient to use. With a simple equation:

$$\sigma_i = \sigma_{ic} K \left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right)\left(1 + A\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right) + B\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right)^2 + C\left(\frac{\varepsilon_{iu}}{\varepsilon_{ic}}\right)^3\right)^{-1} \tag{4}$$

strain hardening and softening are both considered. Material strength σ_{ic} and ε_{ic} could be obtained using the CMW model, which is introduced next.

Closure Menetrey Willam Model

If a point $M_c(\sigma_1,\sigma_2,\sigma_3)$ on the loading trajectory in principal stress space represents the current stress state of the material in Fig. 1(a), then a line that extends from the origin through the current stress point penetrates the ultimate strength surface at point $M_r(\sigma_{1c},\sigma_{2c},\sigma_{3c})$, which represents the current concrete strength. Figure 1(b) is the Closure Menetrey–Willam Model with the cap model.

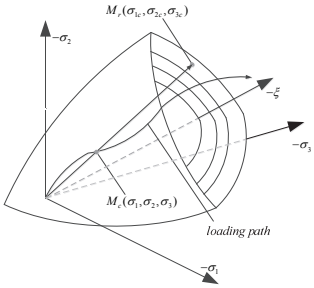


Fig. 1(a)

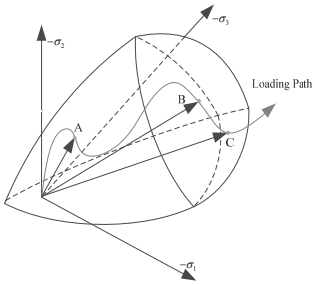


Fig. 1(b)

Case Study

A comparison of the results to the analysis of Kupfer *et al.* shows a perfect overlap, as can be seen in Figs. 2(a) and (b)

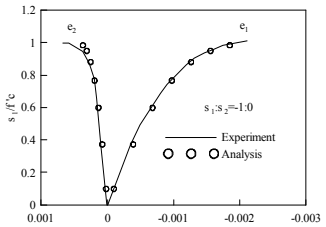


Fig.2(a). Uniaxial compression test

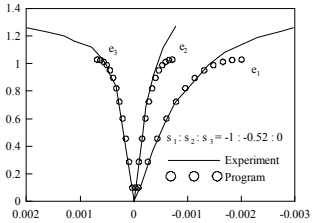


Fig. 2 (b). Biaxial compression test

1. Darwin, D., and Pecknold, D.A., "Nonlinear Biaxial Stress-Strain Law for Concrete," ASCE, 1977;103(2):229-241.
2. Balan, T.A., Spacone, E. and Kwon, M., "A 3D Hypoplastic Model for Cyclic Analysis of Concrete Structures," Engineering Structures, 2001; 23:333-342.
3. Willam, K.J, and Menétrey, P.H., "Triaxial Failure Criterion for Concrete and Its Generalization," ACI Structural Journal, 1995;92:311-8.
4. Saenz, I.P., "Discussion of equation for the stress-strain curve of concrete, by P. Desay and S. Krishan" ACI Journal ,1964:61(9):1229-35.
5. Kupfer, H.B., and Gerstle, K.H., 1973, "Behavior of Concrete under Biaxial Stresses," Journal of the Engineering Mechanics Division, Vol.99, pp. 853-866.

A Cloud Service for Seismic Design of Buckling-Restrained Braces and Connections

Ming-Chieh Chuang, Keh-Chyuan Tsai, Pao-Chun Lin, An-Chien Wu, NCREE

The welded end-slot buckling restrained brace (WES-BRB) (Fig. 1) has been developed at Taiwan's National Center for Research on Earthquake Engineering (NCREE). A steel frame equipped with the WES-BRB can offer a cost-effective solution to satisfy inter-story drift and earthquake-resistant requirements for seismic steel buildings. According to the WES-BRB and connections design procedure, there exist seven items that must be checked for a buckling-restrained braced frame (BRBF) design. In order to assist an engineer in designing the WES-BRBs and their connections, an innovative cloud service named Brace-on-Demand (BOD) has been constructed by the NCREE. The BOD server provides an up-to-date and on-demand service for users to effectively and automatically find the complete design results of the WES-BRBs and connections that meet all seismic design requirements.

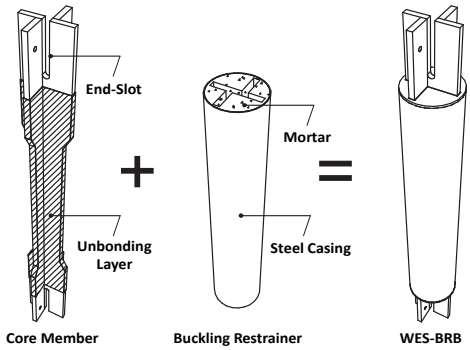


Fig.1. Schematic of WES-BRB

As shown in Fig. 2, the BOD service consists of a client-server architecture utilizing a BOD server in the NCREE and a BOD browser on the client side. When the server receives a request sent from the client-side BOD browser, the function of performing the WES-BRB design and connections will be invoked automatically before returning the results to the client-side browser. The BOD browser (Fig. 3) provides a user-friendly interface to display the results. It allows designers to evaluate all the BRBs, connection detail dimensions, and Demand-to-Capacity Ratios (DCR).

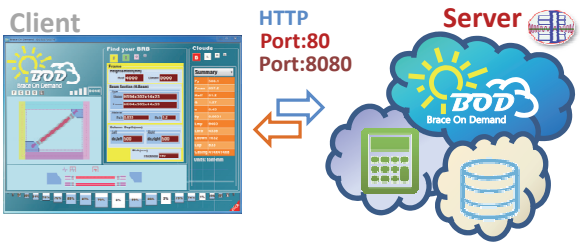


Fig. 2. Client-server architecture of BOD

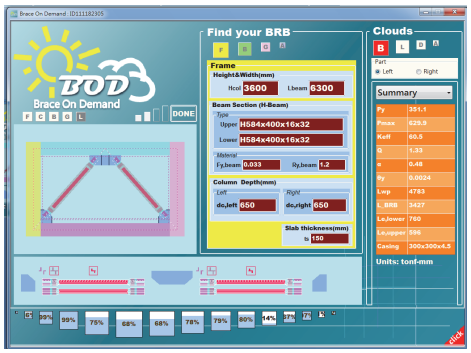


Fig. 3. BOD client browser

Specifically, the BOD server provides a cloud service using the RESTful web service. DataSnap was also incorporated into the server. The DataSnap server can provide the RESTful web service using a Uniform Resource Locator (URL). Therefore, every time BOD cloud computing is invoked, the client issues a request to the BOD server via Hypertext Transfer Protocol (HTTP). Based on the client-server architecture of the BOD cloud service, any up-to-date service can be dynamically achieved in this BOD server. Some possible changes, such as new developments in steel grade or steel casing size, can all be updated immediately when necessary.

After the BOD server completes all the designs and checks, the corresponding WES-BRB dimensions and connection design results of the final design can be archived into structural calculations for download in text file (.txt) and spreadsheet (.xls) formats. The spreadsheet is innovatively used not only for archives but also for double-checking the accuracy of the calculations. For example, the BRB effective stiffness, *Keff*, is recomputed in the spreadsheet using the dimensions obtained from the BOD. In addition to showing the BOD results for WES-BRB, connections, and DCRs for all the limit states, all the numerical functions corresponding to the design procedure are also entered into the spreadsheet. Hence, these numerical functions and results allow the designer to trace the source of the results and verify the accuracy of the BOD computation. In contrast to the stereotype of the black box, BOD is a transparent computing service. BOD also provides standard drawings that designers can conveniently use for the calculations, spreadsheets, and standard drawings to prepare the construction documents. The BOD service has been available for more than two years, and a number of applications have confirmed that it is effective for users engaged in seismic building design research and practice. Currently, BOD is in service and the BOD browser can be downloaded for free from the website (http://bod.ncree.org.tw).

Development of Versatile Engineering Simulation Environment

Wei-Tze Chang, Ren-Zuo Wang, NCREE
Shang-Hsien Hsieh, National Taiwan University

Coupled continuous–discontinuous simulations can be applied in studying complex engineering problems of solid–liquid interaction, such as estimating the impact on structures of an earthquake, debris flow, and tsunamis. The National Center for Research on Earthquake Engineering (NCREE) under the National Applied Research Laboratories (NARLabs) in Taiwan has integrated two numerical methods, the Vector Form Intrinsic Finite Element (VFIFE) method and the Discrete Element Method (DEM), to design a Versatile Engineering Simulation ENvironment (named VESEN, a Norwegian word meaning "being" in the spiritual sense), for the purpose of modeling multi-hazard phenomenon.

After analyzing concepts from research on VFIFE and DEM (Chang and Hsieh, 2009; Wang, 2005), this study identified eight major concepts for designing the VESEN framework: (1) constitutive law, (2) contact detection algorithm, (3) elements, (4) failure criterion, (5) geometric shapes for illustrating element boundaries, (6) points, (7) interaction solvers, and (8) cross-sections of structural members. This study modifies and extends the VErsatile Discrete Objects (VEDO) framework to develop VESEN's object-oriented framework that includes all of the above concepts in classes.

An object with physical meaning in VESEN is divided into two parts, namely the data and the solver. This design uses the "bridge pattern" in software engineering (Gamma *et al.*, 1995) to decouple the data from the implementation of solution methods and reduce the complexity of adding new models. To make things easier for model designers in adding and testing new models without the need to touch the core of VESEN, we design a "solver pool" for managing these models. Initially, the main program imports all solvers into the "solver pool" as candidates for simulation. The name of a solver (reported by the class itself) is the index for searching the solver in the pool. Next, VESEN gets the parameters (data) and the name of the solver from the input file. At this step, the relationship between the element and the designated element solver is built. With the help of the "bridge pattern" mentioned above, the function of the "ElementSolver" is independent of the data in "Element". Only two lines of codes need to be added into the main function and all existing codes would remain untouched when importing a new solver into the VESEN (see Fig. 1). This design provides convenience for designers of new models and protects the technology of individual models.

Currently, the prototype of the VESEN has been developed with 25 numerical models in 8 types and has been used to study large-scale deformations of a truss system (Fig. 2). Once the necessary implementation for modeling building structured (such as VFIFE frame elements) is completed, the VESEN will be used to study the seismic performance of bridges with functional bearing systems and the collapse behavior of structures. The results simulated will be verified using experimental data obtained at the NCREE.

```
#include <sandbox/interfaces/ESMembrane.h>

void CreateSolverPool ()
{
                    :
SolverPool* spp = SolverPool::Instance ();
spp -> AddElementSolver (new ESMembrane3P);
                    :
};
```

Fig.1 The main function imports an element solver with only two lines of code (words in red)

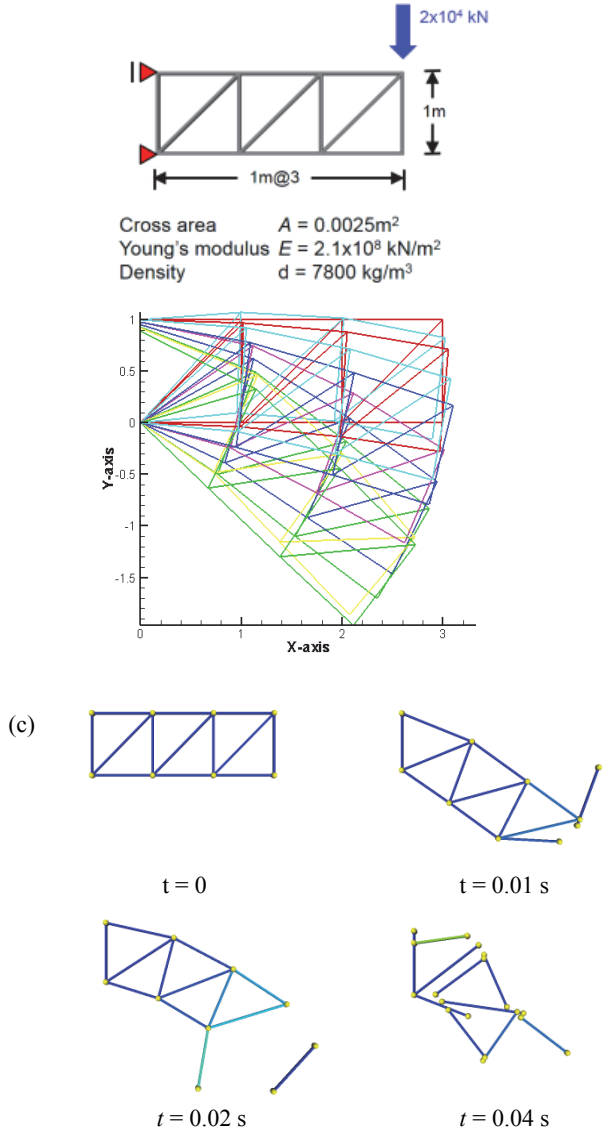


Fig.2 Application of the VESEN to study large-scale deformations of a truss system: (a) setup, (b) dynamic response with large-scale deformation, and (c) dynamic response and failure behavior

Taiwan-Russia Academic Exchange Activities

Chun-Chung Chen, Associate Researcher, NCREE

The 3rd All-Russia (International) Conference on Concrete and Reinforced Concrete (RCC III) was held on May 12–16, 2014, at the Moscow headquarters of the Russian Academy of Sciences in Moscow, Russia. The conference was mainly organized by the Russian Academy of Science and the Russian Engineering Academy. With the help of the Taiwan Chapter of the International Academy of Engineering (TCIAE), a 14-member Taiwanese delegation was assembled and led by Prof. Kuo-Chun Chang, Director of the National Center for Research on Earthquake Engineering (NCREE) and President of the TCIAE, who was also the principle investor in the joint research project between NCREE and the Siberian Branch of the Russian Academy of Science (SB RAS) according to the program of Taiwan–Russia research cooperation supported by the Ministry of Science and Technology. The delegates from NCREE and several universities, including the National Taiwan University, National Taiwan University of Science and Technology, National Taipei University of Technology, National Chiao Tung University, and Ruentex Engineering and Construction Co. Ltd., were invited to attend the RCC III and carry out bilateral academic exchange activities.

During RCC III, Taiwanese participants gave twelve oral presentations, exchanging research with Russian and other international researchers on topics including innovative construction technologies, material experimental studies, analysis and simulation, monitoring and evaluation, and seismic performance assessment of reinforced concrete structures. The presentation received enthusiastic responses from the audience at the conference. It set a good foundation for academic cooperation between Taiwan and Russia for the present and future. Furthermore, the TCIAE arranged for the Taiwanese delegation to visit the Russian International Academy of Engineering, the D. Mendeleev University of Chemical Technology of Russia (MUCTR), and the Moscow State University of Civil Engineering (MSUCE). The rectors of MUCTR and MSUCE and the vice-rector of MSUCE met the Taiwanese delegation in person (Figs 1 and 2). The MUCTR is among the leaders of Russia's technical universities, and has the highest rating among Russia's chemical technology schools. Meanwhile, the MSUCE chairs the Association for Education and Methodology in Civil Engineering, as well as the International Association of Institutions of Higher Education in Civil Engineering, uniting 142 institutions of higher education in Russia and the Commonwealth of Independent States countries. Both MUCTR and MSUCE graduates occupy leading positions in the areas of research and production, government authorities, and small and large businesses. The Taiwanese delegation's visit to Russia will enhance existing cooperation, establish new relations, and begin collaboration in new research areas carried out both in Russia and Taiwan. Through these exchange activities, both Taiwan and Russia have gained a great body of knowledge on the discussed research topics and have come to an agreement on future academic cooperation.

In addition to the exchange activities mentioned above, the researchers involved in conducting the Taiwan–Russia joint project entitled "Experimental and theoretical methods for the study of seismic stability of high-rise buildings and monitoring technologies" transferred to Novosibirsk to participate in the project meeting organized by the SB RAS following the activities in Moscow (Fig. 3). The joint project has been approved and is granted by the Ministry of Science and Technology, Taiwan R.O.C. (Project No. 103-2923-E-492-001-MY3) from 2014 to 2016. According to the project schedule, Taiwanese researchers should pay a brief visit to Russia to attend the project meeting in the first year. The purpose of this project meeting is to discuss the details of joint research work and clarify the scope of data sharing.



Fig. 1. The Taiwanese delegation and the rector of the MUCTR



Fig.2 The Taiwanese delegation and the rector and vice-rector of the MSUCE



Fig.3 The Taiwanese and Russian researchers of the joint research project between NCREE and SB RAS

2014 Taiwan-Japan Workshop on Structural and Bridge Engineering

Fang-Yao Yeh, Research Fellow, NCREE

Owing to extreme climate change, typhoons, floods, and earthquakes have become the greatest natural disasters to threaten Taiwan in recent years. After the 2011 Great East Japan Earthquake, researchers have paid more attention to bridge damages due to multiple hazards, to disaster prevention and reduction, and to assistance and recovery from disasters. The 2014 Taiwan–Japan Workshop on Structural and Bridge Engineering, jointly organized by Kyoto University and National Center for Research on Earthquake Engineering (NCREE), was held over May 21–22, 2014, at the NCREE, Taipei, Taiwan.

The objective of this workshop was to exchange information on the latest research undertaken 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, Iwate University, Kanazawa University, Public Works Research Institute, Hanshin Expressway Company Ltd., Tokyo Construction Company Ltd., and SHO-BOND Corporation, and Taiwanese organizations, including National Taiwan University, National Central University, National Chung Hsing University, National Taipei University of Technology, National Taiwan University of Science and Technology, CECI Engineering Consultants Inc., and NCREE. The topics of this workshop focused on four parts, namely: (1) structural engineering, (2) bridge engineering, (3) multi-hazards on bridges, 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 2014 Taiwan–Japan Workshop on Structural and Bridge Engineering

IDEERS 2014

Mu-Hsuan Li, 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 Center for Research on Earthquake Engineering (NCREE), the British Council in Taipei, the National Science and Technology Center for Disaster Reduction (NCDR), and the National Applied Research Laboratories (NARL) on September 19–21, 2014..

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 make models using cheap materials at the NCREE and have them tested on the “Tri-Axial Seismic Simulator” (or shaking table). Models will be shaken to destruction, and the best-designed models will win prizes.

For further information, please see the IDEERS web-site: http://w3.ncree.org/ideers/2014/

2014 Taiwan-Japan-New Zealand Seismic Hazard Assessment Meeting

Che-Min Lin, Chun-Hsiang Kuo, NCREE

Seismic Hazard Assessment (SHA) is the foundation of earthquake disaster reduction. Several earthquakes occurred recently, including 2011 Tohoku earthquake in Japan and 2011 Christchurch earthquake in New Zealand, emphasized that the defective SHA may underestimate the seismic hazard and result in the inexpectant disasters. The modern SHA should focus on the updates of data and techniques to evaluate the precise distribution of seismic hazard for any possible earthquake in the future.

Since 2012, Taiwan Earthquake Model (TEM), Taiwan and National Research Institute for Earth Science and Disaster Prevention (NIED), Japan begin to hold a joint workshop to share the experiences on seismic hazard and risk assessment every year. In 2014, GNS Science, New Zealand was invited to join the workshop. The 2014 Taiwan-Japan-New Zealand Seismic Hazard Assessment Meeting was held by the TEM with the co-sponsoring of Ministry of Science and Technology, Taiwan Earthquake Research Center , National Cheng Kung University and NCREE on 19-23 May in NCREE, Taiwan. The workshop sequentially discuss the eight topics, including current status of SHA for each country, active faults and paleoseismology, geodetic strain, sub-surface structure mapping, ground motion prediction, earthquake scenario simulation, probabilistic seismic hazard assessment (PSHA) , and PSHA applications. In every topic, speakers from three countries took turns introducing their researches. Participants hotly took part in discussions of all topics, and show their passions in the SHA.

NCREE has researched the SHA of Taiwan for over one decade, and widely apply the results in seismic design of structures, building codes, earthquake disaster assessment and policy planning of disaster prevention. NCREE will continue to participate in the international workshop to improve the techniques and applications of SHA for the development of earthquake engineering.



Fig.1 Group photo of 2014 Taiwan-Japan-New Zealand Seismic Hazard Assessment Meeting

Published by

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