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Particle-Based Methods and Earthquake Engineering

Wei-Tze Chang, Assistant Researcher, NCREE

Particle-Based Methods (PBMs) are numerical methods that use mass points as their core concept. The mass point can be a single object (such as a steel reinforcing bar or bridge column), solid material, fluid field, or probe points without physical meaning. Since each PBM has its advantages and constraints, this paper briefly introduces the characteristics and potential of several popular PBMs used in earthquake engineering.

PBMs and Their Potentials

Molecular Dynamics (MD)

MD was proposed in the 1950s for research in physics. In MD, atomic and molecular particles are considered and the attractive/repulsive forces acting between them as well as the constraint of angles are used for modeling. Because the particles are of nanometer scale (10^{-9} m), the quantum effect cannot be ignored, so statistical physics should be introduced to take this into account. This limits the size of the problem that can be handled by MD. MD applications over the past few decades have focused on material engineering. Due to the rapid development of nanomechanics and Additive Manufacturing (AM), MD began to be used in the design of new materials in structural and earthquake engineering.

Discrete Element Method (DEM)

In all PBMs, the DEM directly relates to civil engineering. The DEM was initially used for modeling large-scale block rock systems (Cundall, 1971). Particles on the DEM can be used to present physical materials in average or to present real objects with a suitable geometric shape. For example, a cylindrical particle can be treated as a steel reinforcing bar, or a polyhedral particle can be treated as a rock. The interaction between particles includes impulse, friction, or binding force, suitable for modeling a discrete system with a complex interface. DEM covers a micro- to macro-scale range, that is, it can model a piece of concrete material to a whole mountain. In the past few decades, DEM has been used for realizing many interaction models of various issues in earthquake engineering, such as landslides, debris flow, soil liquefaction, bridge pier scour, or concrete failure.

Smoothed-Particle Hydrodynamics (SPH)

Unlike the DEM, which focuses on discrete systems, SPH focuses on modeling continuum media with the introduction of continuum mechanics. The physical properties, such as temperature, pressure, velocity, or acceleration, of a particle in a position are calculated from the averaging effect of neighborhood. Thereby, SPH utilizes “smoothing” and is suitable for modeling fluid dynamics. Compared with Computational Fluid Dynamics (CFD), SPH describes a free surface more easily. Tsunamis or complex disasters caused by earthquakes are the target of SPH.

Material Point Method (MPM)

The MPM was developed by Sandia National Laboratories, the United States, in 1994 (Sulsky, *et al.*, 1994) and it focuses on continuum systems. Compared with SPH, the MPM deals with the interface between different states of matter more efficiently, such as the interaction between solids, liquids, and gases. Different from other PBMs, the MPM includes additional continuous meshes in the background for determining physical gradient, thus taking advantage of both particle-based and non-particle-based methods. The MPM is suitable for modeling debris flow or bridge pier scour. Another paper with the title, “Application of Material Point Method in Civil Engineering Problems”, in this newsletter has introduced MPM; therefore, we will not discuss it here.

PeriDynamics (PD)

PD is a novel method proposed by Sandia National Laboratories in the United States (Silling, 2000); in this method, particle systems and continuum systems are connected, especially focusing on material failure and crack. Before PD, macro-scale phenomena of materials were often described by continuum-mechanics-based methods, while micro-scale phenomena were described by MD, and it is not easy to establish a relationship between these phenomena. Starting from a particle system, PD builds a theory to convert the formulas to a continuum-mechanics form, describing a failure/crack in the micro-scale system as a break in the connection between particles. This principle has enabled a widespread application of PD in various engineering fields since twenty years. Currently, the development of PD is almost complete and can be applied for modeling various types of solid materials, such as elastic, elastoplastic, viscoelastic, or brittle materials, and is suitable for describing failure and crack progress of structural materials in earthquake engineering.

Summary

With the rapid development of High-Performance Computing (HPC) technologies, PBMs have exhibited great potential and have become more powerful than before. Researchers can find some open-source or commercial engineering software based on them. Five widely used PBMs are briefly introduced in this paper, which can facilitate new ideas and inspiration on application them on earthquake engineering to the readers.

Reference

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2. Silling, S.A. (2000). “Reformulation of Elasticity Theory for Discontinuities and Long-range Forces,” *Journal of the Mechanics and Physics of Solids*, Vol. 48, pp. 175-209.

Advanced Hybrid Simulations with Online Model Updating Using a Gradient-based Parameter Identification Method

Ming-Chieh Chuang, Assistant Researcher, NCREE

In hybrid simulation (HS), also called hybrid testing, the target structure can be partitioned into multiple substructures, which are broadly categorized as numerical and physical substructures. The displacements calculated from time-step integration are imposed onto each substructure to determine the restoring forces associated with the degrees of freedom of the structural system. Based on the retrieved restoring forces, the command displacements of the next step can be predicted with time-step integration. Thus, HS allows numerical and physical substructures to be integrated such that the interaction between the substructures can be taken into account in the seismic performance assessment. Therefore, HS can offer a cost-effective alternative to the shaking table test. However, conventional HS is often restricted by the limited numbers of facilities and specimens. Some or many structural elements that are similar to or the same as the physical substructures must be modeled in HS, which results in inaccurate modeling of the numerical substructures and, hence, limiting the applicability of HS. To address this problem, the researchers in National Center for Research on Earthquake Engineering (NCREE) developed an online model updating (OMU) technique and a gradient-based parameter identification (PI) method to advance HS.

Hybrid Simulation with Online Model Updating

Figure 1 shows the setup of the advanced HS with OMU conducted at NCREE recently for a six-story steel frame equipped with steel panel dampers (SPDs). One of the installed SPDs is selected for the physical substructure (PS), which is represented with a SPD specimen. The rest of the frame is the numerical substructure (NS). The auxiliary numerical model (ANM) is subjected to the same displacement history as the PS. Note that the boundary conditions of the ANM must be compatible with those of the corresponding PS. Through the examination of the simulation results of the ANM (Fig. 2), the proper parameter values of the constitutive model (e.g., a two-surface plasticity model) can be identified by using optimization methods. Using those identified proper parameter values, the material models of relevant SPDs in the NS can be rectified online during the HS. In short, errors in the nonlinear modeling of the NS can be reduced by updating the model with the parameter values that are identified online from the measured PS responses. The accuracy of hybrid simulations can be improved accordingly.

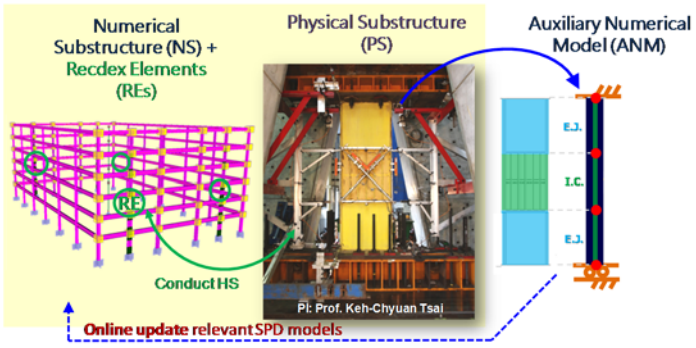


Fig. 1. Advanced hybrid simulation with online model updating

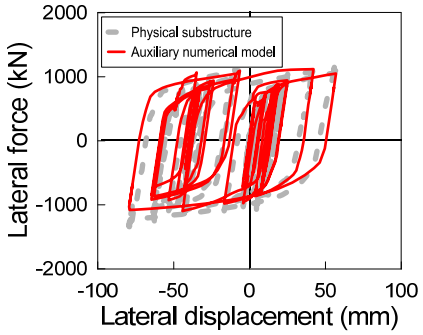


Fig. 2. Simulation of SPD using the two-surface plasticity model

Features of the Proposed Gradient-based Parameter Identification Method

The proposed PI method can fix parts of parameters during identification for different stress states (Fig. 3); this will result in a reduction in the number of design variables to be determined. The computation time for the gradients can be reduced accordingly to improve the identification efficiency. The effectiveness of the proposed gradient-based PI method for OMU has been verified by using the aforementioned HS of the six-story frame equipped with SPDs.

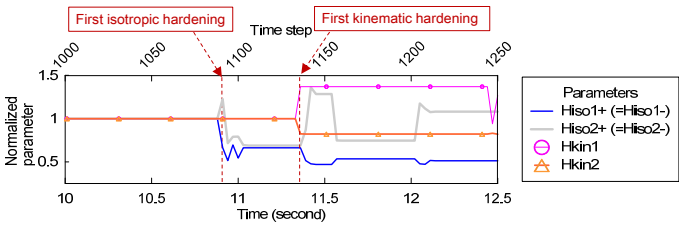


Fig. 3. Results of the parameter identification using the proposed gradient-based method

Application of Material Point Method in Civil Engineering Problems

Wen-Chia Yang, Project Assistant Researcher, NCREE

Computer modeling and simulation have become important tools to understand and predict complex engineering problems that are difficult or inefficient to be represented with mathematical models and physical experiments. The Material Point Method (MPM) was introduced by Sulsky et al. [1] and is particularly suitable for problems involving large deformation, trans-phase behaviors, and multi-material interactions. This article provides a brief introduction of MPM and civil engineering applications in the literature.

The MPM is a continuum-based particle method. Similar to the finite element method (FEM), finite continuum material domains in the MPM are discretized and mapped to Lagrangian meshes/grids, which are used to evaluate time evolution of field variables. However, instead of recording the time-dependent values at the grid nodes, the method encapsulates deformation, velocity, and all other variables at a finite number of *material points*/particles representing the continuum domain. Since no data are recorded on the grids, meshes in the MPM are often called (background) *computational grids* in the literature.

The typical computational cycle of the MPM consists of four steps. First, grid values (e.g., nodal mass, momentum, and forces) are computed via mapping from material points. Second, the time evolution of field variables (e.g., velocity and coordinates) is evaluated on the grids. Third, the updated material states (e.g., displacement and deformation) are interpolated back onto particles. Finally, computational grids are rewound (or reselected, if desired)..

Applications of the MPM vary widely, ranging from problems of contact, penetration, and explosion, and to the simulation of snow in the Walt Disney animation, Frozen. In the field of civil engineering, applications are majorly in soil mechanics problems (involving large displacement and deformation as well as water–soil interaction) in addition to a few in wood mechanics and tsunami modeling.

The dynamic behavior of granular media is interesting and challenging to simulate because granular media may involve phase transfer from solid to liquid when they are forced to move (such as in landslide). Both of these phases can be commonly observed simultaneously in debris flow, and individual grains may switch phases depending on their present states. Figures 1 shows an application of the MPM in landslide simulation..

Moreover, researchers are also trying hard to promote the MPM in offshore dredging and pile installation simulation. To date, some studies have been conducted to validate and verify MPM simulations in water–soil interaction problems, e.g., seepage problems; some have been conducted to develop modeling schemes for pile installation (Fig. 2). Future work remains for further improvement in this issue.

The MPM provides a unified multi-material interaction platform with the potential to model complex soil–water–structure or solid–water interaction problems involving inelastic behavior of materials and large deformation/displacement. This numerical tool is definitely worth exploring further by researchers and engineers.

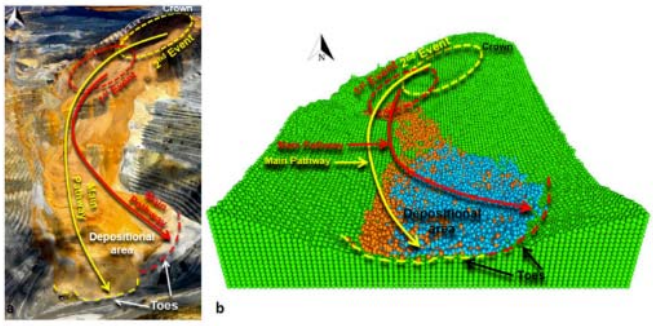


Fig. 1. Panoramic view of Bingham Canyon mine pit wall slides: (a) photograph, and (b) MPM simulation [2]

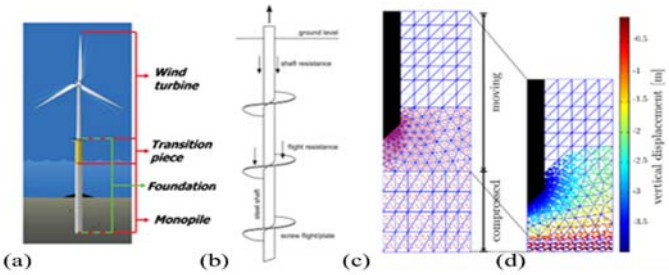


Fig. 2. (a) Monopile foundation, currently widely used for wind turbine foundation; (b) the schematic of a screwpile; 2D simulation of pile installation in (c) the initial configuration and (d) the deformed configuration [3]

Reference

[1] Sulsky, D., Zhou, S.-J., &Schreyer, H. L. (1995). Application of a particle-in-cell method to solid mechanics. *Computer Physics Communications*, *87*(1–2), 236–252.

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[3] Wang, L., Coombs, W. M., Augarde, C. E., Brown, M., Knappett, J., Brennan, A., Richards, D., Blake, A. (2017). Modelling Screwpile Installation Using the MPM. *Procedia Engineering*, *175*, 124–132.

Unveiling Ceremony of NCREE-NTUCE Joint Artificial Intelligence Research Center

Wei-Tze Chang, Assistant Researcher, NCREE

Recently, Artificial Intelligence (AI) has rapidly expanded in various fields because of the development of algorithms, big data, and computing hardware. However, over the past decades, the development in earthquake engineering has depended on computing simulation, on-site and experimental data, and experience of domain experts. Civil engineers are currently seeking to explore the advantages that AI can beget in the field.

With the objective of applying AI to improve earthquake engineering, in July the National Center for Research on Earthquake Engineering (NCREE) under the National Applied Research Laboratories (NARLabs) formally set up the NCREE-NTUCE Joint Artificial Intelligence Research Center (NCREE-NTUCE AI Research Center) with the Department of Civil Engineering of National Taiwan University (NTUCE) in July. The resources including experimental data and AI technology in NCREE and NTUCE will be shared through this new research center.

The unveiling ceremony of the NCREE-NTUCE AI Research Center was held on July 6th in 2018 (Fig. 1). Director general Shyh-Jiann Hwang (NCREE), director Chuin-Shan Chen (NCREE-NTUCE AI Researcher Center), and director Shang-Hsien Hsieh (NTUCE), four new deputy directors of the center (Dr. Albert Y. Chen, Chia-Ming Chang, Jen-Yu Han, and Shu-Wei Chang), and dozens of researchers from NCREE and NTUCE attended this ceremony. In the future, the NCREE-NTUCE AI Researcher Center will promote AI and data science technologies in the research of earthquake engineering, disaster prevention, and civil engineering. The research center is expected to play an important role and have a significant impact in the world.

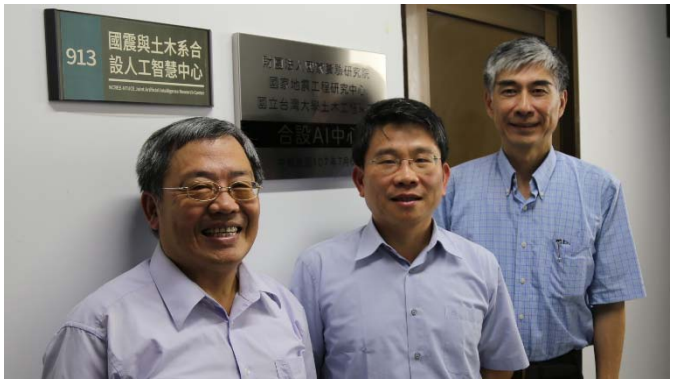


Fig.1. Unveiling ceremony of the NCREE-NTUCE joint artificial intelligence research center: (from left to the right) director general Shyh-Jiann Hwang (NCREE), director Chuin-Shan Chen (NCREE-NTUCE AI researcher center), and director Shang-Hsien Hsieh (NTUCE)

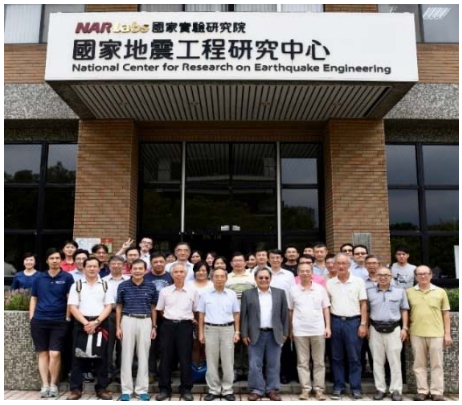
Retirement Party for NCREE Former Director-General Chin-Hsiung Loh

Ling-Yu Kung, Assistant Administrator, NCREE
Chiun-lin Wu, Research Fellow, NCREE

NCREE's former Director-General Chin-Hsiung Loh retired from the Department of Civil Engineering, National Taiwan University on July 31, 2018. NCREE hosted a retirement party for Professor Loh at Auditorium 101 of NCREE in appreciation of his invaluable contributions during his service. NCREE Director-General Shyh-Jiann Hwang delivered an opening remark and was followed by Deputy Director-General Chien-Chih Hsu's recitation of a poem he wrote for Professor Loh:

> Constantly sowing, blossoming, and sowing again;
> All growing strong roots to become great shelters;
> Our deep appreciation for being such a great guardian for twenty years;
> iPhone will help break the distance barrier of more than ten thousand kilometers between us.

Thirty-one former graduate students coming from all over the country joined Professor Loh's retirement party; particularly, Professor Kuan-Hsoung Chen of National Quemoy University flew a long distance overseas to say goodbye. All these graduates together prepared a commemorative book as a retirement gift for Professor Loh in which they expressed their gratitude. Many graduates gave speeches to express their appreciation for Professor Loh's teaching as their great career mentor. In addition, NCREE Division Directors Jenn-Shin Hwang and Kuo-Liang Wen also shared their memories of working with Professor Loh in the past. During his service as the Director-General of NCREE from 1997 to 2003, Professor Loh made successful progress and led NCREE to become an internationally renowned research center. After his retirement, Professor Loh will begin his new teaching career at the University of California, San Diego, where he will continue devoting himself to advanced academic research. NCREE conveys its best wishes to Professor Loh for every success and good health in the United States.



Group photo of Professor Chin-Hsiung Loh, his former graduate students, NCREE Director-General Shyh-Jiann Hwang, and his colleagues

Earthquake Engineering Communication between Taiwan and Chile

Chung-Han Yu, Assistant Researcher, NCREE
Shiang-Jung Wang, Associate Professor, NTUST

Similar to Taiwan, Chile is located on the Circum-Pacific Seismic Belt. Owing to the intersection belt of the Nasca Plate and South America Plate, most of Chile's narrow and long territories are vulnerable to earthquake. The most severe earthquake event in the past decades was the 1960 Chile Earthquake with a magnitude up to 9.5M_L. It also caused eruptions of six volcanos and the accompanying tsunami attacked not only the coastal areas of Chile but also all other countries located along the Pacific Ocean. The event claimed the lives of 6000 people. Furthermore, in 2010 and 2014, two dramatic earthquakes of magnitude greater than 8 M_L occurred in Chile, resulting in the casualties of hundreds of people and damage to many structures. Therefore, the Chilean government has begun paying great attention to the seismic performance of structures. Through the Taiwan Well Link Industry Corporation's and Prof. Patricio Quintana's assistance, Prof. Shiang-Jung Wang, who represents the Chinese Taiwan Society for Earthquake Engineering (CTSEE), and Dr. Chung-Han Yu, who represents the National Center for Research on Earthquake Engineering (NCREE), were invited to present in several seminars and workshops held by the Federico Santa María Technical University and the Chilean Association of Seismology and Earthquake Engineering (ACHISINA). This is an opportunity for both sides to mutually share experiences of research results, practical applications, and earthquake reconnaissance. More importantly, the research partnership of both sides was launched officially.

Federico Santa María Technical University

The Federico Santa María Technical University, which was founded in 1926, is one of the top three engineering universities and one of the civil engineering research leaders in the Latin American area. In the seminar held in this university, Prof. Wang shared the latest seismic isolation and energy dissipation research results at NCREE as well as the testing capacities of NCREE Taipei and Tainan laboratories, with local scholars and students, as presented in Fig. 1.



Fig.1 Prof. Wang's address in the Federico Santa María Technical University

After the seminar, Prof. Patricio Bonelli arranged a visit for the participants to a seismically isolated building under construction. Different from the often seen structural systems in Taiwan, the wall system for this isolated superstructure is designed to have a higher stiffness and natural frequency. This design guarantees that the structure remains elastic under great earthquakes, which allows the isolation design have a much better serviceability and functionality than the traditional seismic design.

Chilean Association of Seismology and Earthquake Engineering

ACHISINA serves as an important bridge between local academia and industry in the aspect of research and engineering communication and cooperation. The current president of ACHISINA is Prof. Rodolfo Saragoni Huerta. In the workshop held by ACHISINA in Santiago, the audience included local scholars and engineers. In addition to presenting information regarding the latest passive control research results and testing capacities at NCREE, Prof. Wang presented the details of two representative seismic isolation designs in Taiwan.

Subsequently, Dr. Yu shared the experiences and lessons learned from the 2016 Meinong and 2018 Hualien Earthquakes, as presented in Fig. 2.



Fig. 2 Dr. Yu's address in ACHISINA

At the end of the workshop, Prof. Wang and Prof. Rodolfo Saragoni Huerta officially signed a memorandum of understanding (MOU) between CTSEE and ACHISINA, as presented in Fig. 3. The MOU contents emphasize the cooperation between Taiwan and Chile for joint research, exchange of research information and publications, participation in seminars and conferences, and interaction of researchers and engineers.

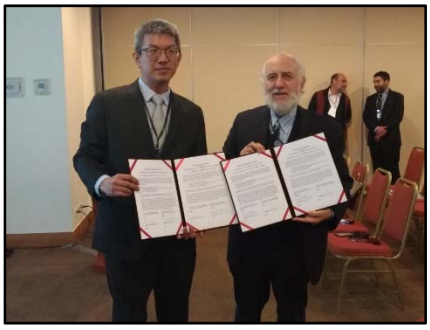


Fig. 3 MOU signature ceremony

2018 NCREE Conference on Experiments

Kung-Juin Wang, Technologist, NCREE

To facilitate developments in the field of earthquake engineering, a conference “2018 NCREE Conference on Experiments (2018NCE)” was held in NCREE on July 16, 2018. Several research groups that executed their experimental projects by using the NCREE facilities (the Tri-Axial Seismic Simulator, the Reaction Wall and Strong Floor Test System, and the Multi-Axial Testing System) in 2017 were invited to disseminate their latest findings via oral presentation. This conference provided a unique opportunity for sharing the knowledge and experience among the academic researchers and industry experts in the field. In addition, it also served as a vehicle that attempts the exchange of relevant details about planning and executing experimental projects. Finally, via this opportunity, the NCREE laboratory also expected to be aware of and learn from the experiences and prospects of its clients, which can help in achieving further technical development and more contribution in the field of earthquake engineering in the future.

A total of 18 oral presentations were given in this event. The topics include advanced construction methods, investigation of pre-stressed RC blocks for bridge piers, damage assessment of and retrofitting applications using RC walls with openings, novel techniques of measurement of structural member internal force, seismic behavior of newly developed structural devices including various base isolators and energy absorbers, investigation on the effect of soil liquefaction on bridge piers, and an investigation on testing earth dams by using the shake table. About 90 attendees participated in this event, which included more than 30 engineers from the industry and more than 20 individuals from domestic universities and colleges in addition to the NCREE staff. In a session of free discussion, participants indulged in vibrant discussion focusing on the mechanical behaviors and application examples of several newly developed structural components. Abundant engineering experiences were also communicated and exchanged. It is obvious that the society holds high interest and expectations toward NCREE's research works.



Fig.1. 2018NCEE participants

Seoul Delegation on Seismic Upgrading of School Buildings

Ching-Chieh Chen, Senior Technician, NCREE

It has been 9 years since NCREE has been supporting the Ministry of Education (MOE) for the School Retrofitting Project in Taiwan. Recently, we accepted a visit request from Seoul Metropolitan Government Safety Management Headquarters to gain knowledge from the School Retrofitting Project. This visit was arranged for July 20, 2018.

The group visited Fu-Lin Elementary school, Taipei City and Tai-Ping Elementary school, Taipei City. Professor Li-Lai Chung, the principal investigating officer and coordinator of the Retrofitting Project Office, introduced to the visitors the sights they would be visiting during the trip as well as the building positions and the administrative process of the school retrofitting project. In addition to the MOE, the Taipei City Government was part of the event. Further, the Director of General Affairs Division of both schools presented their experiences during this project.

In recent years, numerous earthquake events have occurred on our earth. Fortunately, Taiwan’s building laws and regulations have been refined and people are paying more attention to seismic safety of buildings. Retrofitting of old school buildings, one of Taiwan’s long-term goals, will soon be achieved with the help of the MOE, local government, school teachers, engineers, and construction companies. With the success of this project, we expect better safety for the people of Taiwan during future seismic events.



Fig.1. The professional from Seoul visiting school buildings under construction



Fig. 2. Group picture.

Experimental Study on Seismic Performance and Improvement Strategies of Critical Nonstructural Components under Near-fault Ground Motions

Fan-Ru Lin, Associate Researcher, NCREE

The seismic performance of structures of prominent buildings in Taiwan (such as hospitals, high-tech fabs, and power plants) is effectively improved with the development of seismic design technology. However, interior equipment and key facilities such as high-tech processing equipment, electrical cabinets, hospital medical freezers, and liquid storage tanks located in critical buildings have suffered damages in recent earthquakes (e.g., MeiNong earthquake and Hualien earthquake). Considering the fact that Taiwan is situated on densely distributed faults, the National Center for Research on Earthquake Engineering (NCREE) conducted a collaborative experimental research named the "seismic performance and improvement strategies of critical nonstructural components (NSCs) under near-fault ground motions" to improve the seismic capacity of critical facilities in important buildings under near-fault ground motion. A series of tests were executed on the long-stroke high-speed shaking table at the NCREE Tainan Laboratory from July 17th to August 14th. This program consists of three research groups led by Dr. Chai from NCREE, Prof. George-C. Yao from the Department of Architecture in National Cheng Kung University, and Prof. Jack Moehle from the University of California, Berkeley. The purpose of this research program is to observe the dynamic behavior of NSCs under near-fault ground motions to investigate the accuracy of the seismic evaluation method and energy-absorption capacity of anchorages. In addition, an adequate advanced spring-magnetic device was initially developed.

During the series of tests, original-scale near-fault ground motions recorded during the Northridge earthquake, San Salvador earthquake, Kobe earthquake, Chi-Chi earthquake, the Hualien earthquake, etc., were successfully simulated using NCREE Tainan Laboratory's long-stroke high-speed shaking table. The influence of high-speed velocity pulses of near-fault ground motions on the dynamic characteristics of NSCs was observed during the series of tests; this provides conservative seismic demands for seismic resistance devices to prevent overturning or damage of equipment.

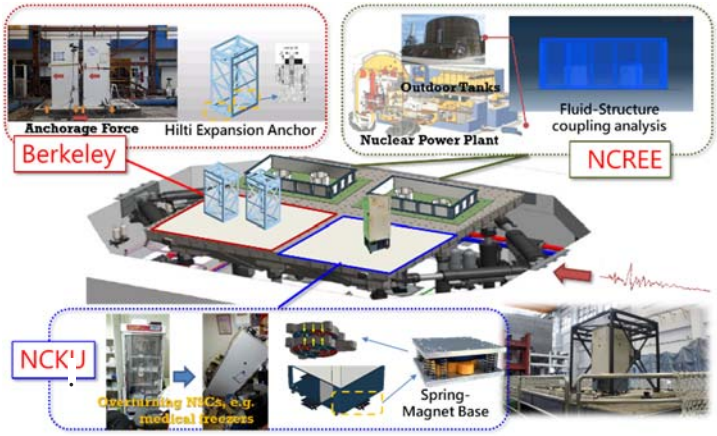


Fig. 1. Test configuration of the research program on NSCs

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