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Research Progresses on Taiwan New RC Project

Ker-Chun Lin, Research Fellow, NCREE

In 2009, the National Center for Research on Earthquake Engineering (NCREE) launched a long-term project known as the "Taiwan New RC Project" to develop a new Taiwan Reinforced Concrete (RC) Building Structural System using high-strength reinforced-concrete materials in Taiwan. The NCREE hosted relevant researchers and engineers to establish a research group called the "Taiwan New RC Group" that focuses on studying and developing design and construction technologies of high-strength RC buildings in Taiwan.

Objectives

According to Taiwan's existing engineering practices and design codes regarding RC in building engineering, steel reinforcement materials whose strength grades exceed 420 MPa are not allowed and the strength of concrete used in Taiwan's building engineering practices is within 28 MPa and 64 MPa. For this Taiwan New RC Project, the strengths of steel reinforcements are aimed at strength grades of 685 and 785 MPa for the main bar and the transverse bar, respectively, and the strength of concrete is varied from 70 MPa to 100 MPa. The material strength relationship of traditional RC and new RC building structures is shown in Fig. 1.

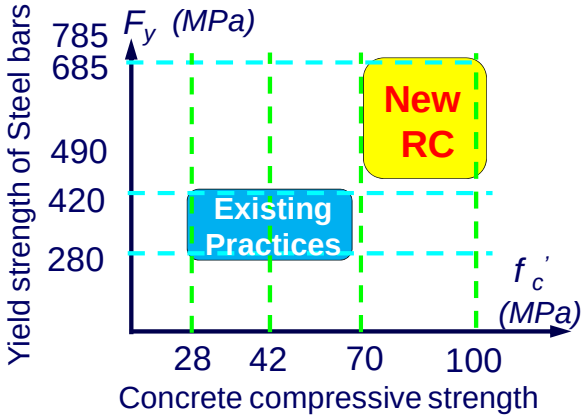


Fig. 1. The strength relationship of traditional and new RC building structures

However, the principal purpose of researching and developing the new Taiwan RC Building Structural System is to pave the way to the first new RC building in Taiwan. In order to get the benefits on upgrading strengths of RC materials used in this Taiwan New RC Project, it is necessary to comprehensively investigate the applicability of existing building design provisions to high-strength RC materials. Developing local design and construction guidelines is an important strategy in this project to solve problems on strength restrictions of the existing design code. Some limited and specific experiments were planned and completed to relax the strength restrictions to the existing design code of RC buildings.

Organization

To efficiently execute the Taiwan New RC Project, NCREE established a research team called the "Taiwan New RC Group" that gathers powers from academia, industry, society organization and research capacities of NCREE. NCREE sought cooperative partners in industry who had the capacity to make high-strength concrete and precast members or to manufacture high-strength reinforcements. To draw up new material specifications and to promote the new RC building structural system in Taiwan, it is needed to invite a society organization to join this project. NCREE also invited the most notable researchers from academia. Fig. 2 lists all the companies, societies, and research units that participated.

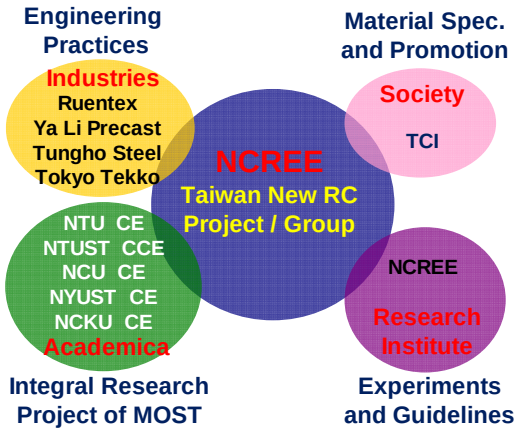


Fig. 2. Organization of the Taiwan New RC Group

Recent Progresses

Based on theoretical and experimental research efforts over the past years, many fruitful results were produced by this research team. These results include drawing up steel specifications of SD 685 and SD 785, manufactured confirmation of 100 MPa concrete, bond performance of high-strength RC using threaded bars, and mechanical behaviors of structural members. Consequently, two guidelines of design and construction for the new RC building structural system in Taiwan are expected to be published at the end of 2015.

Experiment on 1/13 Scaled RC Containment Vessel

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Introduction

Primary containment vessels contain reactor systems and prevent the spread of radioactivity released from a reactor. The structural behavior and failure mechanism of a 1/13 scaled Reinforced Concrete Containment Vessel (RCCV) shell specimen was investigated by a collaborative program between NCREE and the University of Houston, USA.

Experimental Program

The prototype of the cylindrical shell had an outer diameter of 33 m, a wall thickness of 2 m, and a clear height of 29.5 m. This resulted in a shell specimen design with an outer diameter of 250 cm, a thickness of 15 cm, and a clear height of 225 cm. Fig. 1 shows the cyclic loading test setup and lateral support system. The pre-test simulation results showed that the ultimate lateral strength of the specimen was about 5880 kN. To be conservative, eight 980 kN actuators were employed in the lateral direction to apply reversed cyclic loads, and four 980 kN actuators in the vertical direction to maintain double curvature and constant axial load of the specimen.

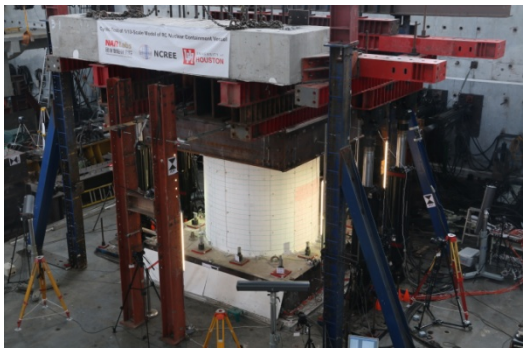


Fig. 1. Test setup of the lateral support system

Experimental Results

Fig. 2 shows the hysteretic loop of loading deformation of the RCCV specimen. The ultimate lateral strength was 5580 kN, while the drift ratio was 0.75%. The test was terminated at 1.0% drift while the residual strength was 40% of the ultimate strength (2227 kN). At this stage, shear-sliding failure occurred at the top of wall. Fig. 3 shows the crack distribution in the cylindrical wall of the RCCV. The red line and the blue line indicate the pushing and pulling directions, respectively. The cyclic loading was applied along the east-west direction.

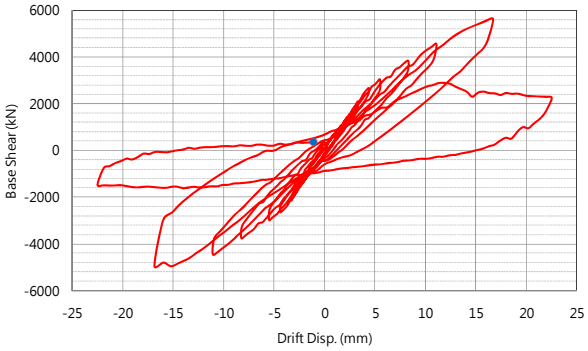


Fig. 2. Relationship between lateral loading and displacement

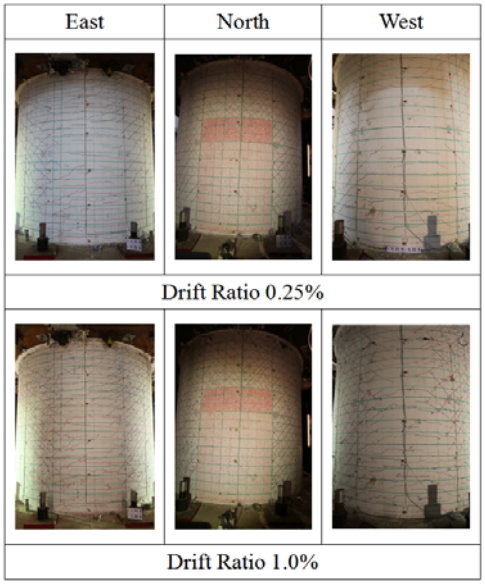


Fig. 3. Crack patterns

Conclusions

A 1/13 scaled RCCV specimen was planned, designed, and constructed that highly correlated with the prototype structure. It is the first experiment in Taiwan to investigate the shear capacity of an RCCV subjected to a cyclic loading test. This investigation provides a reliable finite element analysis for the design and safety assessment of a nuclear containment vessel.

Experimental Study on Retrofit of School Buildings by Adding Reinforced Concrete Shear Walls with Openings

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Introduction

The purpose of this study was to retrofit low-rise buildings by reinforced concrete (RC) shear walls with openings since such retrofits are very effective in enhancing the strength and stiffness of structures. This study focused on retrofits of school buildings, lighting and ventilation can be satisfied using RC shear wall with large area openings. Seismic performance of school buildings can also be achieved.

However, no experimental study exists on retrofitting of buildings by an RC shear wall with openings in Taiwan. It's not to ensure the interface shear force behaviors of embedded steel bars of new and original concrete. Therefore, three RC frames were designed and fabricated. Two of them were used to retrofit by adding RC shear walls with openings. The results of the experiment verified the effectiveness of embedded steel bars and retrofitting.

Experimental Specimens

Three one-story one-bay specimens were designed: one pure RC frame, one retrofitted specimen by adding RC walls with large-area door openings, and one retrofitted specimen by adding RC walls with large-area window openings. All RC frames were designed based on the non-ductile type of reinforcement details. The spacing of the 10 mm diameter stirrups of the column was 250 mm. The steel ratio of the wall in both the horizontal and vertical directions was 0.3%. This study suggests that the concrete cover must be removed before embedding steel bars. Further, a 10 mm diameter steel bar was used to embed a 100 mm depth. The fabrication details of the specimens are shown in Fig. 1.

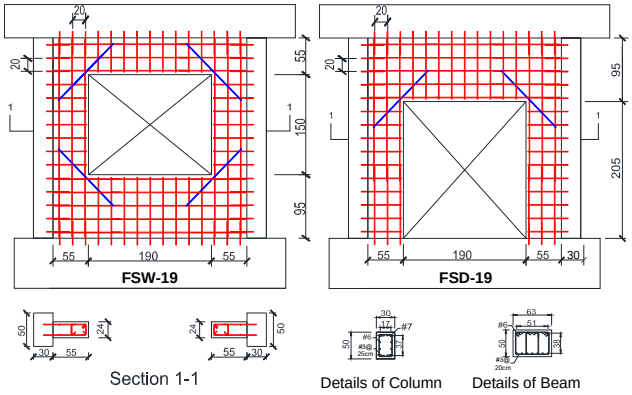


Fig. 1. Details of Retrofitted Specimen

Experimental Results

Fig. 2 shows the shear failure of the retrofitted specimens. When the story drift ratio was +1.5%, specimen FSW-19 experienced a major shear crack on the right side of the opening; likewise, when the story drift was +1.5%, specimen FSD-19 experienced a major shear crack on the left side of the opening.

As shown in Fig. 3, the opening area of specimen FSD-19 was larger and longer; therefore, the stiffness and lateral force were smaller than that of specimen FSW-19. However, specimen FSD-19 had better displacement capacity.

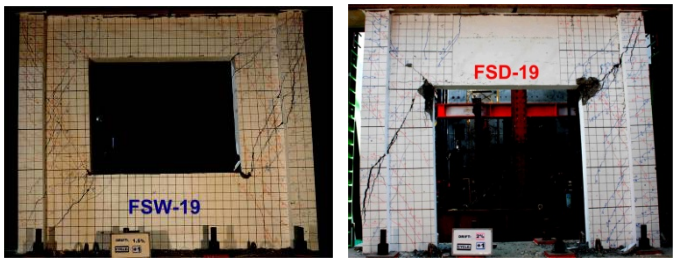


Fig. 2. Shear failure of the retrofitted specimens

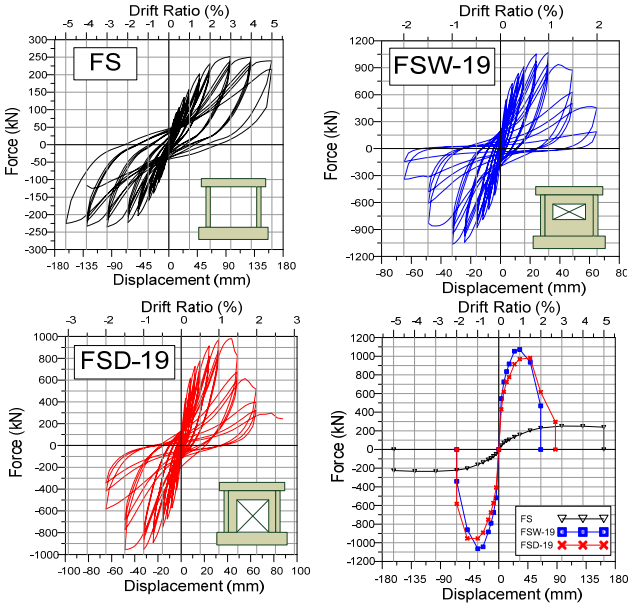


Fig. 3. Hysteresis Loops and Envelope Curve

Conclusions

From the experimental results, it was evident that no significant failure occurred at the interface between new and original concrete. This indicates that the embedded steel bars method of this study can be applied effectively.

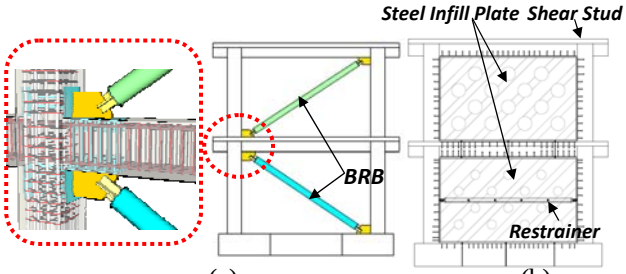
The experimental results showed that the maximum story drift ratio of the retrofitted specimen was 2% at least. The strength of the retrofitted specimen can be enhanced four times and the stiffness can be enhanced thirteen times compared with the pure RC frame specimen. This indicates that the retrofitting of low-rise buildings by an RC shear wall with openings was suitable.

Research on RC Frames Equipped with BRBs or SPSWs

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Hsun-Horng Yang, Jie-Luen Huang, Wei-Jun Hung, Wan-Chu Lee, Graduate Student, NTU
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Introduction

Buckling-restrained braced frames (BRBF) and steel plate shear walls (SPSW) are generally acknowledged as being excellent and economical lateral force resisting systems (LFRS) in steel structural buildings. Thus, installing buckling-restrained braces (BRBs) or SPSWs into a reinforced concrete (RC) frame to construct a composite system is considered a good substitute for the conventional LFRSs in RC buildings, such as RC shear walls. It is anticipated that a BRB or an SPSW would efficiently provide substantial lateral stiffness and strength for the system. In addition, the robust and ductile behaviors of the BRB and the SPSW, which have been confirmed by extensive experiments, could be a guarantee of the good performance of the composite system. As the current research on this type of promising system is quite limited, a collaborative project between the National Center for Research on Earthquake Engineering (NCREE) and the National Taiwan University (NTU) is being conducted to investigate the seismic behavior and design of RC frames equipped with BRBs or SPSWs.



(a) (b)

Fig. 1 Configurations of RC frames equipped with (a) BRBs and (b) SPSWs

Key Issues

The key to the success of the proposed composite system lies in the connection between the RC frame and the steel-made element (BRB or SPSW). As shown in Fig. 1a, this study proposes various types of special steel connectors embedded in the RC members to have steel gusset plates installed adjacent to the RC beam-to-column joints. The vertical and horizontal edges of each gusset plate are mounted to the adjacent column and beam ends, respectively. The BRBs are then installed into the RC frame through the gusset plates. For an RC frame with an SPSW, as shown in Fig. 1b, T-shaped steel elements are mounted on the RC beams and columns by shear studs. Steel infill plates are then installed into the RC frame through the T-shaped elements.

Another critical issue is the capacity design of the boundary RC members, which are the beams or columns adjacent to the BRBs or SPSWs. The purpose of the capacity design is to ensure the boundary RC members having sufficient strength to anchor the BRBs or SPSWs and allow them developing their full load-carrying capacity. Considering the RC members are usually vulnerable under the tension and shear forces, this study proposes the K-type brace frame layout (Fig. 1a) to reduce the tensile axial load in the RC beam members. For the RC frame with SPSW, as shown in Fig. 1b, the use of perforated infill plates and restrainers can reduce the shear demands of the RC boundary elements.



(a) (b)

Fig. 2 Test setup of the specimens of RC frames equipped with (a) BRBs and (b) SPSWs

Test Program

In this research, a series of tests of two full-scale two-story RC frames each equipped with BRBs (Fig 2a) or SPSWs (Fig 2b) were conducted at NCREE in May 2015. The main objective of the tests was to validate the effectiveness of the proposed connection details between RC members and steel elements (BRBs or SPSWs), the efficacy of the recommended capacity design of the RC boundary elements, and the accuracy of the suggested analytical models.

In order to investigate the seismic behavior of the specimens under various levels of earthquakes and aftershocks, each specimen was tested under three pseudo-dynamic loads using ground motion acceleration records of LA43, LA9, and LA22, which represent frequently occurring earthquake (FOE), design basis earthquake (DBE), and maximum considered earthquake (MCE), respectively. Each specimen was subjected to earthquakes of progressively increasing intensity. After the specimens were tested under the three levels of earthquake loads, the specimen with BRBs was tested under the MCE load again while the DBE and MCE loads were again imposed to the specimen with the SPSW. The two specimens exhibited a robust behavior under the aftershocks.

Generalized Optimal Locations of Viscous Dampers in Asymmetric-Plan Buildings

Jui-Liang Lin, Research Fellow, NCREE

Introduction

Finding an effective method of placing viscous dampers in a building is a common issue in earthquake engineering practice. This issue may be considered from the viewpoint of optimal damper placement. In general, the optimal damper configuration might be different if the performance index is selected differently. Additionally, the optimal placement of dampers depends on the applied seismic ground motions. The aim of this research is to provide a simple approach for finding the generalized optimal locations of viscous dampers in two-way asymmetrical buildings. No complicated optimization algorithms or mathematical models will be adopted in this approach. In addition, the outcome of optimizing the damper locations will be independent of the response states of the building systems subjected to varied seismic ground motion inputs.

The Energy-Based Approach

When a single-degree-of-freedom (SDOF) oscillator is subjected to a unit impulse, its displacement response is the unit impulse response function $h(t)$. The unit impulse response function is the inverse Fourier transform of the frequency response function, which is a general dynamic property of the oscillator that is independent of the characteristics of the input excitations. The strain energy of the SDOF oscillator, denoted by E_S, is:

$$E_S(t) = \frac{1}{2}kh(t)^2 = \frac{1}{2m\left(1-\xi^2\right)}e^{-2\xi\omega t}\sin^2(\omega_D t) \quad (1)$$

where m, k, ω, and ξ denote the mass, stiffness, vibration frequency, and damping ratio of the SDOF oscillator, respectively, and $\omega_D = \omega\sqrt{1-\xi^2}$. Thus, the damping ratio ξ of the SDOF oscillator can be approximated from Eq. 1 as:

$$\xi \approx \frac{\xi}{\sqrt{1-\xi^2}} = \frac{1}{4\pi}\ln\left(E_S(t)\Big/E_S\left(t+\frac{2\pi}{\omega_D}\right)\right) \quad (2)$$

For a multi-story asymmetrical building, the first and third peak values of the elastic strain energy history, which represent the two peaks that occurred in the same direction during the first cycle of vibration, are used in Eq. 2. In addition, in order to consider two-way asymmetrical buildings under the excitation of bi-directional ground motions, the two loading cases are used to excite the multi-story buildings. The first case is a pair of in-phase impulses applied as the ground accelerations in the two horizontal directions. The second case is a pair of 180°-out-of-phase impulses applied as the ground accelerations in the two horizontal directions. The index of the dissipation rate of the elastic strain energy, denoted by I_E, is defined as the average of ξ_1 and ξ_2, where ξ_1 and ξ_2 represent the damping ratios computed from Eq. 2 for the building under the exertion of the first and second loading cases, respectively. The control target used in the proposed approach is to maximize the value of I_E.

Numerical Validations

Two nine-story example buildings were investigated in this study. The x- and z-directional eccentricity ratios were 20% and 15%, respectively. This study applied a total of twenty pairs of ground motion records to each example building. There were ten linear viscous dampers to be diagonally installed in each example building. This numerical validation assumed that there was only one damper at each optimal damper location. For the purpose of comparison, the optimal damper locations were also designed based on the well-known Simplified Sequential Search Algorithm (SSSA) approach. The proposed approach is designated as Generalized Optimal Locations of Dampers (GOLD). The numerical examples show that the arrangements of the ten dampers in buildings obtained by using GOLD were more effective at dissipating the strain energy than those obtained by using the SSSA approach. In addition, the average peak story drifts on the four floor sides obtained using GOLD were more uniformly distributed along the building height than those obtained using the SSSA approach.

Conclusions

This study demonstrated a satisfactory approach for finding the generalized optimal locations of viscous dampers by maximizing the dissipation rate of the overall strain energy of two-way asymmetrical buildings under the excitation of two pairs of unit impulses. The optimized damper configuration obtained by using the proposed approach is generalized, (i.e., it is not aimed at any specific set of seismic ground motions). This proposed approach is straightforward and suitable for engineering practice.

Near-Term Research Plan in NCREE's Southern Laboratory: Overview

Task Group for Development of Near-Term Experimental Plan in NCREE's Southern Laboratory

In Taiwan, there are twenty Holocene (i.e., Category-I) active faults according to the Central Geological Survey. Based on this fact, 2.5 million buildings and 8.6 million residents live within a 10 km perimeter of these faults. As such, the Ministry of Science and Technology, National Development Council, National Applied Research Laboratories, and National Cheng Kung University (NCKU) jointly support the construction of NCREE's Southern Lab in NCKU Kuei-jen (歸仁) Campus to enable research applied to mitigate potential near-fault catastrophic threats. A near-term research plan, immediately following the new facility's inaugural operation in 2017, comprises eight major directions:

Strong Ground Motion Characteristic and Design Basis Earthquakes for Near-Fault Sites

A considerable number of active faults are located near densely populated regions in Taiwan (e.g., the Chelungpu fault near the great Taichung metropolitan area, the Shanchiao fault near the great Taipei metropolitan area, and the Hengchun fault near Hengchun City). In order to reduce disastrous consequences, the strong ground motion characteristics and design basis earthquakes for near-fault sites should be carefully considered. The first stage of this study is to clarify and quantify the near-fault ground motion characteristics such as directivity, directionality, hanging wall effect, and vertical ground motions by construction of a near fault ground motion database. The second stage of this study is to construct a probabilistic seismic hazard analysis procedure to evaluate seismic demands for near-fault sites. The final stage of this study is to propose Design Basis Earthquakes for near-fault sites in Taiwan. The results are intended to serve as references for future revisions of the design parameters in seismic design codes for near-fault sites.

Seismic Evaluation and Retrofit of Low-Rise Concrete Street Houses under Near-Fault Earthquake Excitation

In response to the central government's "Pilot Project for Facilitating Seismic Assessment and Retrofitting of Older Private Buildings," the study will build three types of concrete frames including (1) full-scale bare concrete frames before retrofitting, (2) concrete frames with brick/RC infills before retrofitting, and (3) concrete street houses after retrofitting. The specimens will be tested using NCREE's new triaxial 8 m × 8 m earthquake simulator in its Southern Lab to reproduce the effect of near-fault excitations. The goal is to publish a handbook documenting reliable analytical models for critical structural components, retrofitting methods, construction schemes, and important practices for seismic evaluation and retrofitting of existing low-rise concrete street houses. The handbook will provide convenient and standard assessment procedures for practicing engineers.

Seismic Performance of Mid- to High-Rise Buildings with Structural Irregularities under Near-Fault Earthquake Excitation

The project plans to build full-scale concrete subassemblage frames as well as reduced-scale steel benchmark frames using modular components that can be assembled and connected in many ways. Shaking table experiments can be used to investigate the influence of near-fault effects on performance of mid- to high-rise buildings with structural irregularities, and thereby reliable analytical methods can be developed through experimental verification. The goal is to propose advanced engineering remedies and revision suggestions for next generation seismic design codes to mitigate disastrous consequence from near-fault earthquakes.

Experimental Study on the Seismic Performance of Bridge Structures Considering Near Fault Effect

Considering the research demand and to enhance knowledge of seismic performance of bridge structures that are located near or across active faults, a three-year project is proposed with a focus on studying the velocity pulse effect on bridge piers with different vibration periods under near-fault earthquakes. The scale down bridge pier specimens will be designed based on the characteristics of near-fault earthquakes, and shaking table tests with near-fault ground motion inputs will be conducted in the first year. The experimental results will provide the observations necessary to define the possible failure modes of bridge piers under near-fault earthquakes and help improve bridge evaluation and monitoring technologies in the second year of the project. In the third year, the advanced retrofit and design methods for near-fault bridges will be studied. The short-term objective of the project is to preliminarily clarify the seismic performance of bridge structures under near-fault earthquakes; thus, the long-term research on various issues relating to practical engineering design and disaster prevention strategies have to be deliberated.

Application of Structural Control Technology to Buildings in Near-Fault Regions

In this research, first, the influence of velocity pulse characteristics of near-fault earthquakes such as the pulse period (T_p), peak ground acceleration (PGA), peak ground velocity (PGV), maximum incremental velocity (MIV), peak ground displacement (PGD), and maximum incremental velocity (MID), on the dynamic responses of a single degree of freedom system with varied periods of vibration and damping ratios will be analytically studied. Then, in addition to numerically discussing a series of passively controlled building models subjected to near-fault earthquakes, some representative full-scale and scaled-down building models with passive control technologies will be schemed and tested by using the long-stroke and high-velocity shaking table and dynamic biaxial testing system at the NCREE Southern Laboratory. Finally, based on the numerical and experimental results, some strategies for the current passive seismic isolation and energy dissipation systems against near-fault earthquakes will be provided.

Seismic Performance of OFCs to Near-Fault Ground Motions

The most important issue for essential buildings (e.g., hospitals and emergency response centers) in a disaster area is to maintain their functions after strong earthquakes. Therefore, the objective of this research is to provide proper seismic design and improvement methods for Operational and Functional Components in buildings (OFCs) considering near-fault ground motion effects. Due to a lack of information about seismic behavior of OFCs under near-fault ground motions, this research will carry out full-scale shaking table tests to exhibit seismic responses of specified OFCs (i.e., fire sprinkler systems, spring-isolated equipment, suspended ceiling systems, and precious instrument and artwork). A test bed including a transfer system and a rigid adapter for suspended large-area OFCs will be established to reproduce the floor response of essential buildings under near-fault ground motions in the full-scale shaking table tests. Cyclic-loading tests for OFCs will be carried out as well to increase the accuracy of numerical analyses.

Seismic Performance of Embankment Dams under Near-Fault Earthquakes

Embankment dams can be built using field materials and as their requirements for geological and topographical conditions are not as strict as RC dams, they are widely used in Taiwan. However, there are several important reservoirs with embankment dams in Taiwan located within 10 km of Holocene active faults. Therefore, it is necessary to investigate the seismic behavior of embankment dams, which are subjected to earthquakes with near-fault characteristics. The mechanical behavior of soil materials is generally more sensitive to the shear strain and the excitation duration. However, for the failure mode with a specific sliding surface, it is possibly sensitive to the velocity. In addition, near-fault motions usually have higher spectral values in the range of intermediate to long periods, which may have more influence on relatively flexible geotechnical structures such as embankment dams. Hence, this study aims to utilize the high-performance shaking table in the Southern Laboratory of NCREE to conduct scale physical model tests for the investigation of the difference in the seismic responses and failure modes of embankment dams subjected to near-fault and far-field earthquakes. Furthermore, the discrepancy in the behaviors of the embankment dams will be studied when incoming near-fault velocity pulses are along or perpendicular to the dam axis. The results of this study can be applied to improve the seismic design and evaluation of embankment dams to protect the lives and properties of residents.

Development and Integration of Advanced Hybrid Experimental Technology

Experimental testing has been extensively used to investigate the behavior of structures in earthquake engineering. However, actual seismic responses of structures may not be observed by performing quasi-static testing and shake table testing due to applying loading rates and the limitation of a specimen scale, respectively. During the past decades, NCREE has developed pseudo-dynamic and real-time hybrid testing techniques to provide researchers with more accurate seismic simulations in a laboratory. As the NCREE Southern Laboratory is being established, further integration of hardware and software as well as the application of advanced testing methods become essential. In the future, NCREE aims to develop an experimental platform to evaluate the seismic responses of non-structural facilities in high-rise buildings by introducing modern control theories and mechanical design. In addition, hybrid testing for structures with multi nodes and multi degrees-of-freedom will be conducted by integrating the existing hardware and software as well as the two test facilities in the north and south laboratories connected by computer networks. The accomplishment of the proposed novel experimental scheme can provide an effective approach for conducting seismic simulation of complex structures.

The International Training Program for Seismic Design of Structures 2015

Chi-Hao Lin, Assistant Researcher, NCREE

Recent major earthquakes around the Pacific Rim have resulted in serious loss of life and damage to property. In order to promote seismic design technology to mitigate seismic hazards in high-seismicity regions such as in South-East Asia and Latin America, the Ministry of Science and Technology (MOST) of Taiwan has continuously sponsored the National Center for Research on Earthquake Engineering (NCREE) to hold the International Training Program for Seismic Design of Structures (ITP). This training program allows participants from the aforementioned regions to learn about earthquake engineering research and practices in Taiwan, exchange ideas, and share experiences.

The ITP has been held annually since 2002. From 2002 to 2014, 413 participants from 23 different countries have attended the training programs. ITP2015 will be held from October 12 to 17, 2015 at NCREE. A total of nineteen technical lectures will be scheduled in this program, including topics on seismic observations and hazard analysis; seismic design force; seismic design of structures, bridges, and foundations; seismic evaluation and retrofitting; energy dissipation and isolation systems; seismic loss estimation; and the latest research programs conducted at NCREE. Thirty-one participants from Guatemala, India, Indonesia, Jordan, Malaysia, the Philippines, Thailand, Turkey, Vietnam, El Salvador, Mongolia, Honduras, Saudi Arabia, Haiti, Lao People's Democratic Republic, and Nicaragua will be invited to attend the training program.

In fulfillment of the goals of ITP2015, the seismic design technology and earthquake-resisting capabilities of the participating countries will be steadily improved. We believe that this training program will be successful in strengthening international relationships as well as in sharing experiences on earthquake hazard mitigation.

IDEERS 2015

Mu-Hsuan Li, Associate Technologist, NCREE

In order to encourage student participation in science games and stimulate their creativity, an earthquake engineering education project titled "Introducing and Demonstrating Earthquake Engineering Research in Schools (IDEERS)" will be held by the National Applied Research Laboratories (NARL), the National Center for Research on Earthquake Engineering (NCREE), and the British Council in Taipei on September 18–20, 2015.

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 cheap 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://w3.ncree.org/ideers/2015/.

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