NCREE NEWSLETTER

September 2013 VOL. 8 NO. 3



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National Center for Research on Earthquake Engineering

International Collaborative Research Program on NCBF

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Andrew D. Sen, Graduate Student, UW

Introduction

An international team composed of researchers from the Taiwan National Centre for Research on Earthquake Engineering (NCREE), the University of Washington (UW), and the University of California, Berkeley (UCB) is investigating the behavior of non-seismic concentrically braced frames (NCBF) through experimental and analytical methods. NCBFs are steel braced frames used for buildings located in regions of high seismic risk, such as Taiwan and the west coast of the United States, that were designed prior to the adoption of modern capacity design principles in the 1980s. In concentrically braced frame capacity design, the braces act as ductile fuses and are the main source of energy dissipation in an earthquake. This is achieved through brace buckling in compression, and yielding in tension. Thus, the frame is designed to accommodate the forces and deformations associated with these actions. However, many NCBFs lack connection details and frame members that meet today's requirements. They are therefore prone to unpredictable behavior and are expected to exhibit brittle failure modes during seismic events.

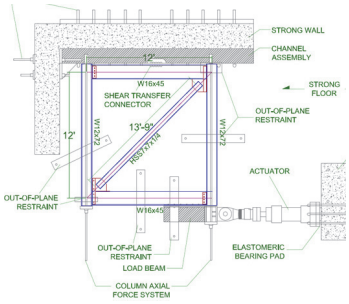


Fig. 1. Test Setup in UW

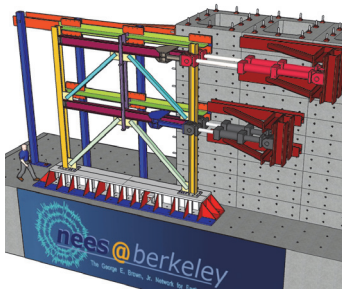


Fig. 2. Test Setup in UCB

Collaborative Research

The goal of this international research program is to evaluate both the performance of NCBFs and strategies for retrofitting and repairing damaged structures. As shown in Fig. 1, testing conducted at UW's Structural Research Laboratory utilizes a single-story diagonal brace test apparatus to explore the local response of the brace and gusset plate connections. An extensive testing program is necessary due to the great variety of connection types in older braced frames that have rarely been subjected to experimental testing and are no longer common in modern seismic design. However, other aspects of NCBF behavior cannot be captured by these tests, and, therefore, two-story frame testing at the nees@berkeley Laboratory at UCB (Fig. 2) and the NCREE Laboratory (Fig. 3) provides vital insight into system-level performance.

Tests at the NCREE

The tests at the NCREE are further distinguished by the presence of concrete slabs. The inclusion of the slabs allows researchers to test the effects of composite action, or the lack thereof. In addition, the slabs were not blocked out to permit gusset plate deformation in the NCBFs, so these tests can also study the effects of slab embedment on connection performance. The NCREE test frame is also reusable, and is therefore extremely valuable as a tool for studying retrofits and repairs that may improve the seismic performance of NCBFs.

During this summer, three full-scale frame tests were conducted at the NCREE. UW assigned a graduate student and an undergraduate to Taiwan to work with NCREE staff and the students from National Taiwan University (NTU) on preparing and conducting the tests (Fig. 4). The first test examined a two-story NCBF in the inverted-V configuration under cyclic loading. This specimen contained a bottom story beam that is considered weak in capacity design and representative of many NCBFs. Test results showed that significant inelastic deformation of such a beam has the potential to accelerate brace buckling and subsequently cause brace fracture at low drifts. The ductility of the frame was further inhibited by the use of older connection details and non-seismically compact braces.

The second NCREE test examined a post-earthquake repair scenario using the damaged test frame. The bottom story braces and gusset plates were removed and replaced with seismically compact braces with connections designed for in-plane buckling. The third NCREE test examined another repair by replacing the bottom story braces and connections with wide flange braces and connections designed for out-of-plane buckling. Test results show that these retrofits and repairs can effectively improve the seismic performance of an NCBF.

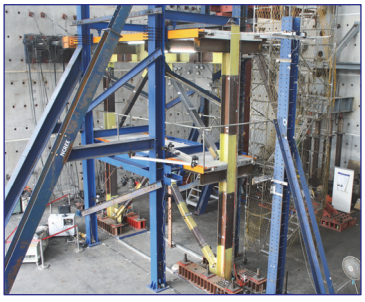


Fig. 3. Test Setup at NCREE



Fig. 4. Group photo of the international collaborative research team

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Design of Seismic Confinement of RC Columns

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Shyh-Jiann Hwang and Guann-Jye Hwang, National Taiwan University

Transverse reinforcement plays many important roles in structural elements, such as fastening the longitudinal bars to avoid buckling, strengthening the confinement of the core concrete under high axial load, and improving resistance to shear force. In the past, NCREE has found that the design of seismic confinement in the present design code is not suitably conservative, and improving the current situation will be an important issue. The main objective of this research is to revise the design equation for seismic confinement. NCREE proposes a new equation in which the axial load parameter is considered; this is not considered in the present code. However, little testing has been carried out to confirm the superiority of this approach.

To verify the suitability of the proposed equation, the multi-axial testing system (MATS) was used to confirm the behavior of the seismic confinement of a column. The test setup is shown in Fig. 1. The cross section of the columns is 60 cm by 60 cm, and the height is 180 cm. Three experimental parameters were tested: (1) the use of normal strength materials and high strength materials, (2) the addition of more transverse reinforcement, and (3) the difference of transverse steel on the end bending degree. In addition to transverse steel, spiral steel was also trialed in the research. Eight specimens were designed in order to test all the experimental parameters described.



Fig.1. The test setup for a specimen

Three conclusions can be drawn from the test results. First, the drift ratio of the T30-1 specimen is less than 3%, as is clearly shown in Fig. 2 (by the solid blue line). As the influence of the axial load is not considered in the present design code, it will permit the use of columns with poor deformation capacity under high axial load. Second, the T30-2 specimen is designed on the basis of the proposed equation; the drift ratio of this specimen exceeds 3%, as shown in Fig. 2 (by the dashed red line). More transverse steel helps produce better behavior under high axial load and lateral force. It is worth noting that the influence of the transverse steel bending detail is not obvious in the test results. Finally, the displacement corresponding to the maximum lateral force when using a high strength material is greater than when using a normal strength material. A comparison of deformation capacity with normal strength and high strength materials is shown in Fig. 3.

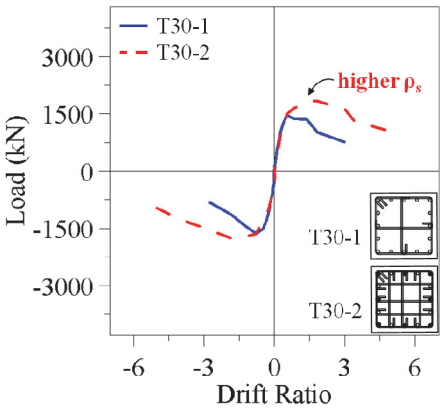


Fig.2. The deformation capacity of the column is increased by adding more transverse reinforcement

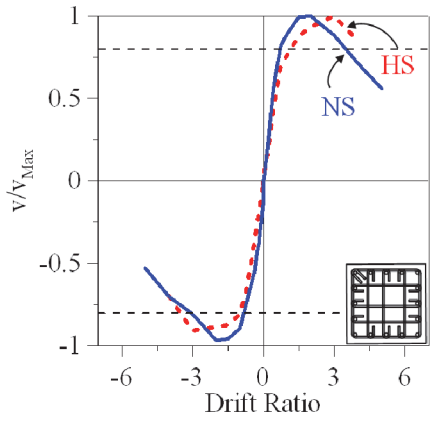


Fig.3. A comparison of the test results of normal strength and high strength materials

The deformation capacity of a column is improved by adding more transverse reinforcement or by using a seismic hoop. The suitability of the proposed equation has also been confirmed. The seismic behavior of columns with different confinements or material types is shown in this research, and the conclusions may be used as a reference for modifying the existing equation used in the design of seismic confinements of RC columns.

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Recommendations of Ultrasonic Testing Inspection and Fabrication Details for Electro-Slag Welding between Steel Plate of Box Column and Internal Diaphragm

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Introduction

Internal diaphragms installed in steel box columns, located adjacent to beam flanges, are common in Taiwan's steel structural design practices, and are employed to efficiently transfer beam moments into the box column. For convenience in fabrication, and for thermal stress symmetry while welding the diaphragm into the box column, one pair of opposing joints between the column plate and the diaphragm typically uses electro-slag welding (ESW) and the other adopts complete joint penetration and groove welds, as shown in Figure 1.

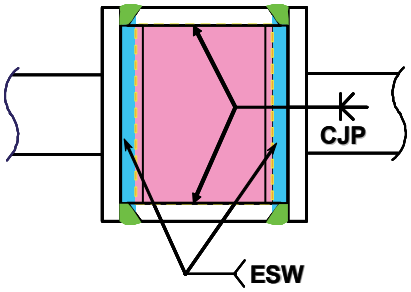


Fig. 1. Schematic welding diagram between the box column and diaphragm

Fracture at the ESW

For most of Taiwan's steel structural factories, the welds formed by ESW are made by the simplified electro-slag welding process with non-consumable elevating tip (SESNET). This is a high-efficiency welding process that reduces labor cost. In addition, the nozzle is capable of oscillating automatically to weld thicker work pieces with a larger melt pool and avoid incomplete weld fusion. Nevertheless, test results have shown that, in the assembly of beam-to-column connection specimens, ESW made by SESNET failed by brittle fracture due to incomplete fusion in the biased weld, as shown in Fig. 2.

UT Inspection and Results

This article aims to briefly report on the results of inspection by ultrasonic testing (UT) for ESW test pieces between the column plate and the internal diaphragm. In this inspection, four straight-beam contact transducers were used to scan two of the interface's edge lines at the ESW weld; recording took place at 20 mm intervals. The transducers are 20 mm/2 MHz and 20 mm/5 MHz in conformance with Taiwan's CNS 12618 Appendix A standard, 10 mm/5 MHz in conformance with AIJ standard for steel structures, and 14 mm/2.5 MHz. To evaluate the accuracy of UT inspection using these transducers, the ESW test piece was composed of two 28-mm-thick column plates and one 25-mm-thick diaphragm as shown in Fig 3; four sections were cut through the piece to permit observation of the actual edges between the ESW welds and the column plate. The UT inspection results and the results of direct inspection of the ESW edges by measuring the cut profiles are shown in Fig 4. This figure shows that the errors of the 20 mm/2 MHz, 20 mm/5 MHz, 14 mm/2.5 MHz, and 10 mm/5 MHz transducers were 2–7 mm, 2–5 mm, 3–4 mm, and 0–1 mm, respectively. The 10 mm/5 MHz transducer demonstrated the highest accuracy of the four transducers. The largest observed error was approximately 5 mm.

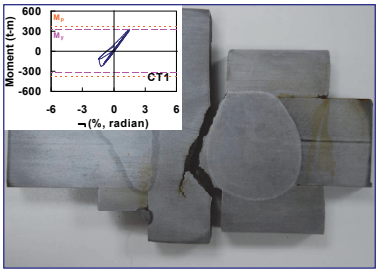


Fig. 2. Facture of the ESW



Fig. 3. Fabrication of the ESW test piece

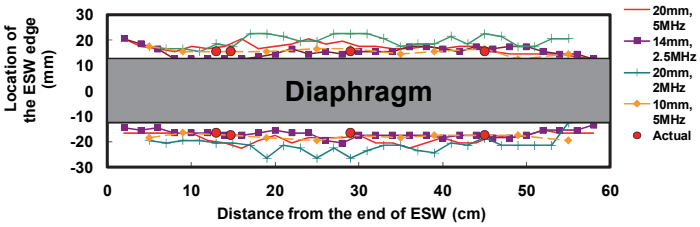


Fig. 4. Results of UT inspections and profile measurements at the ESW weld edge

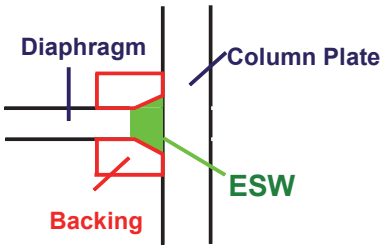


Fig. 5. Proposed fabrication details of the ESW

Improving Fabrication Details for ESW

To achieve good quality ESW, improvements to the fundamental fabrication are proposed here. As shown in Fig 5, they include the addition of a bevel on two backing bars. The bevel angle was approximately 1:2 (the ratio of the column plate direction to the normal direction). A dimension of at least 5 mm adjacent to the column plate is advised.

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A Seismic Retrofitting Method using a Steel Frame with Bracing

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Ruei-Yan Lin, National Taiwan University

Introduction

There are many effective retrofitting methods for existing buildings, such as the installation of RC wing walls, RC walls, and RC jacketing columns. However, in some cases, it is impractical to use these traditional retrofitting methods due to limitations of space or the environment. A steel frame with bracing can be used to overcome this limitation, because this method has the advantages of rapid construction, good utilization of lighting and ventilation, and low environmental pollution during construction. However, the design guidelines for steel bracings are still uncertain, especially for the detailed design of the interface between the steel frame and the concrete frame.

Purpose of the Experiment

The purpose of this study is to investigate a connecting design method for the interface between a steel frame and a concrete frame. A transitive zone is grouted between the steel frame and the concrete frame to transfer the shear force via studs and adhesive anchorage. Thus, the number of studs and anchors are important in the design of the interface.

This study arranged five test specimens, as shown in Table 1, where the PF denotes a pure RC frame with non-ductile detailing, X denotes a steel frame with dual diagonal bracing, and D indicates a steel frame with diamond shape bracing. The steel sections of the frame and braces were H150×150×7×10 with ASTM A36. Double layers of D13 shear studs were arranged around the steel frame with a spacing of 24 cm for the retrofitting specimens. Moreover, the number of adhesive anchors around the RC frame was specified as M16@24 and M20@24.

Table 1. The test arrangements (units: cm)

specimen	PF	PFX-M16	PFX	PFX-M20	PFD-M16
Brace type	non	X	X	X	Diamond
Shear stud	non	2-D13@24			
Adhesive anchor	non	M16@24	non	M20@24	M16@24
Number of anchor	0	48	0	48	48

Test Result

The specimens underwent cyclic loading tests on the strong floor and reacting wall testing system in the National Center for Research on Earthquake Engineering (NCREE). Figure 1 shows the hysteretic loops and the failure patterns of the specimens. The test result indicates that the steel frame with bracing can enhance the lateral strength of an RC frame; however, the deformation capacity is reduced because the steel frame with bracing has a high stiffness. Compared with the hysteretic loops of PFX-M16 and PFX, the adhesive anchors can transfer the shear strength from the steel braces to enhance the lateral strength of the RC frame. However, the specimen PFX without adhesive anchors can only support the lateral force by the contact points at the four corners. In addition, the specimen PFX-M20, with a high number of adhesive anchors, has higher lateral strength and the cracks in the transitive zone develop uniformly. For the specimen PFD-M16, the braces connected at the centers of the steel beams and columns, and thus the lateral force can be received at the connecting points instead of at the four corners. Consequently, the deformation capacity of PFD-M16 is better than that for the specimen PFX-M16.

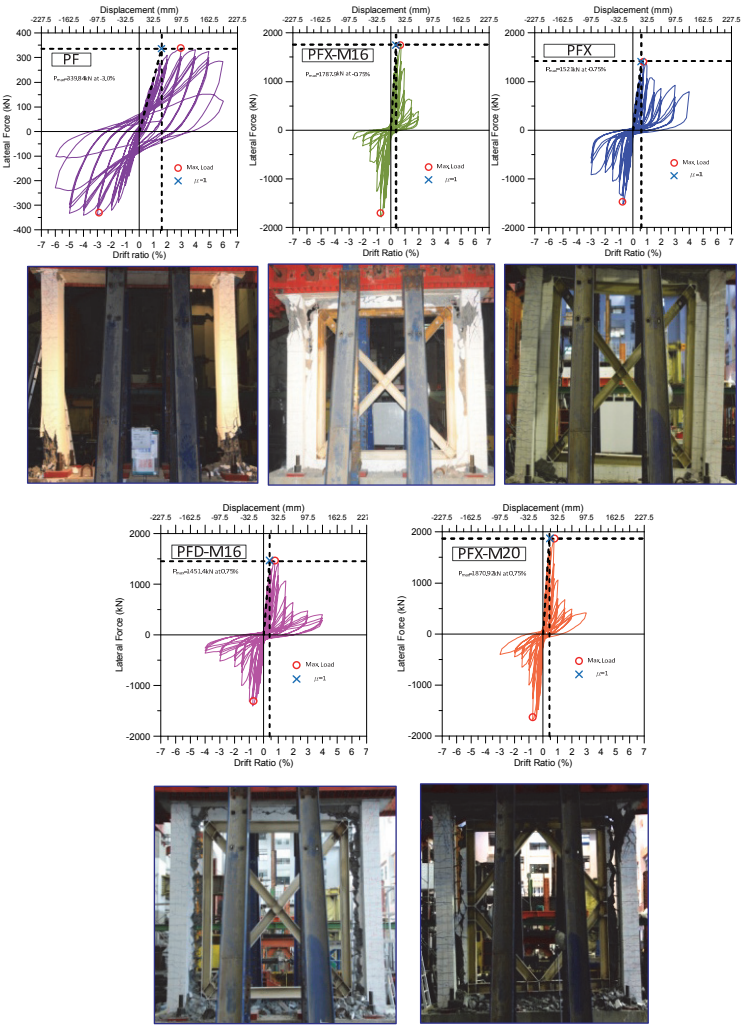


Fig. 1. The hysteretic loops and the failure patterns of the specimens

Conclusion

This study reported the cyclic behavior of an RC frame retrofitted by a steel frame with bracing. Test results indicated that the transitive zone is a weak layer if the compressive strength of the mortar is poor. Consequently, a detailed design and quality control of the mortar is essential for the transitive zone.

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The June 2, 2013 M_L-6.5 Nantou Earthquake in Taiwan

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On June 2 (0602), 2013, at 13:43:3.7 local time (05:43:3.7 UTC), an M_L 6.5 earthquake occurred in the mountainous area of Nantou in central Taiwan. According to the report of Central Weather Bureau (CWB), the epicenter of the mainshock was located at 120.97 °E and 23.86 °N, about 32 km east of the Nantou County Government building. The focal depth was originally determined to be 10.0 km, but this was later revised to a deeper depth of 14.54 km. On the other hand, the USGS estimated the moment magnitude M_W as 6.2, the epicenter at 121.133 °E and 23.794 °N, and the focal depth as 17.0 km. This earthquake was felt all over the island of Taiwan (Fig. 1).

The focal mechanisms calculated from institutes in Taiwan and in the US are very similar. This report used the P-wave first motion solution from the CWB, as shown in the bottom left of Fig. 1. According to the distribution of aftershocks and the tectonic settings near the hypocenter, we are convinced that the strike angle of the real fault plane solution is 2°, with a dip angle of 22° to the east, and slipped along a rake angle of 83°, which is very similar to the earthquake on March 27 (0327). As of June 30, more than 1000 aftershocks were observed after the mainshock, but the largest magnitude of these was only M_L 4.4 at almost the same epicenter of the mainshock. The aftershock distribution pattern is approximately parallel to the strike.

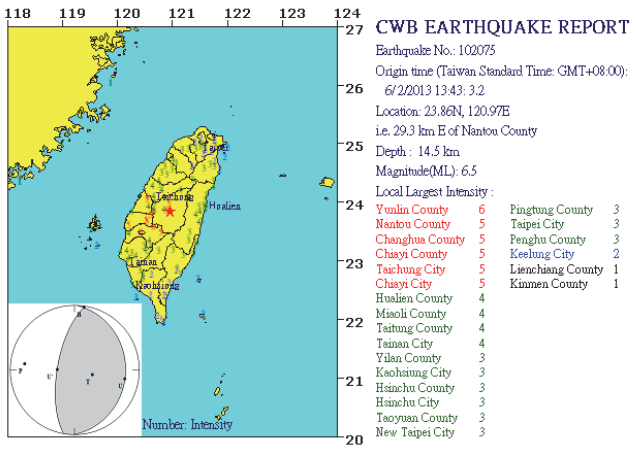


Fig. 1. The report of the 0602 earthquake

According to the earthquake report from CWB, the real-time strong ground motion station CHN5 had the largest PGA of 266.84 gal in the E–W direction. The ground shaking level was intensity 6 (PGA 250–400 gal) at this station. The shaking intensities of other regions in Taiwan are shown in Fig. 1. However, after the recordings from free-field strong motion stations in Taiwan became available, station TCU148 with an epicentral distance of 10.86 km recorded the strongest peak ground accelerations of 433.68 gal (intensity 7) in the E–W direction. This station also recorded a PGA of 483.4 gal with an intensity of 7 during the 0327 earthquake.

Nantou County has experienced more than ten strong earthquakes of magnitudes larger than 4 this year. The last one occurred on August 24 with a magnitude of M_L 4.4, approximately 38.8 km east of the Nantou County Government building. This area ought to be closely monitored and prepared for other possible earthquakes.

Damage to Buildings

This earthquake damaged several buildings in the Yunlin and Nantou areas. An investigation team organized by NCREE investigated fifteen buildings, including private houses, temples, government offices, and public buildings. There were no building collapses in this earthquake. Most damaged buildings incurred damage only to non-structural masonry walls, and, therefore, the major structural components remained intact. The following summarizes the seriously damaged buildings.

As shown in Fig. 2, the YingZhou community near the Yunlin Douliou train station was a 14-story mixed residential/commercial RC building. Major damage to this structure was focused on the southwestern side between the first and fourth stories, and the northeastern side above the fifth story. Shown in Figs. 3-4 is a privately owned, five-story reinforced brick street house in Jhushan Township, Nantou; the left column at the front of the property appears to have succumbed to shear failure, and the brick wall on the first floor had obvious shear cracks. As shown in Fig. 5, the SingSing recreation grange was a three-story RC building in Lugu Township, Nantou; this earthquake caused serious glide at the retaining wall.

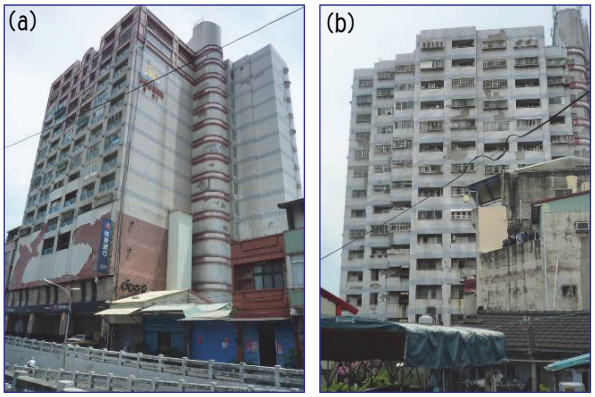


Fig. 2. Damage to the YingZhou community building: (a) southwestern side and (b) northeastern side

Damage to School Buildings

The damage to school buildings can be separated into structural and nonstructural. The structural damage was light, except at three schools in Nantou County, namely Lugu Junior High School, Shuang-Long Elementary School, and Xin-Yi Junior High School. The damage to these three schools is discussed in detail below.



Fig. 3. Shear failure in a reinforced brick street house in Jhushan Township, Nantou: (a) damage on the front side and (b) shear failure on the left column



Fig. 4. Shear cracks on the first floor of the reinforced brick street house



Fig. 5. Serious glide at the retaining wall in SingSing recreation grange

Lugu Junior High School is located in the mountainous area of Lugu Township. There are several damaged sections in a slope retaining wall in the school area. Fig. 6 shows punch cracks at the expansion gap between the retaining wall and the side retaining wall; the width of these cracks is over 20 cm. Fig. 7 shows the gap between the retaining wall and the rearward slope. Several lateral splitting cracks were also observed on the ground near the slope. The building known as the bell tower near the damaged retaining wall was inclined due to foundation rocking, as shown in Fig. 8. Fig. 9 shows the separation of the expansion joint between the bell tower and the adjacent school building.

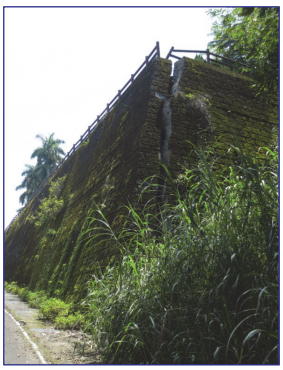


Fig. 6. Punch cracks at the expansion gap between the retaining wall and the side wall



Fig. 7. The gap between the retaining wall and the slope

Several cracks were clearly visible on columns after the earthquake in Shuang-Long Elementary School and Xin-Yi Junior High School. Figs. 10(a) and (b) show a shear crack on a column in Shuang-Long Elementary School. The depth of the crack reached the core concrete of the column. For safety reasons, school attendees must move to other buildings. Damage to another school building is shown in Figs. 11(a) and (b) due to the higher windowsill. In order to avoid damage from the short column effect in the future, one possible remedy is to cut the windowsill along the line between the column and the windowsill.



Fig. 8. The bell tower was inclined due to foundation rocking

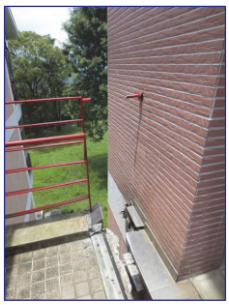


Fig. 9. The expansion joint between the two buildings was separated



(a) Outdoor (b) Indoor

Fig. 10. Shear crack in a classroom column



(a) Outdoor (b) Indoor

Fig. 11. Shear crack occurring due to a high windowsill

Damage to Nonstructural Components and Systems

A survey of damage to nonstructural components and systems was conducted by NCREE on June 3rd and 4th, 2013, on public facilities located in the seismic-affected area. This reconnaissance report summarizes the major nonstructural damage in the Chia-Yi City Government (CYCG) building, the Min-Ho Junior High School (MHJHS), and the Jhong-Liao Township Office (JLTO).

In the CYCG building, the major nonstructural damage was the broken fire sprinkler piping system and the suspended hinted-grid ceiling system above the corridor at the ninth floor. The severe relative movement

between the piping system and the suspended ceiling system caused damage to the ceiling panels. Additionally, the rupture of the pipe component caused a flood on the ninth floor. The leakage of water also caused the elevators to malfunction.

In the MHJHS, several hollow-block partitions at the first floor were separated from the adjacent steel structural components. Spalling-off of the surface material, penetration cracks, and 45° angle cracks were also observed at damaged partitions.

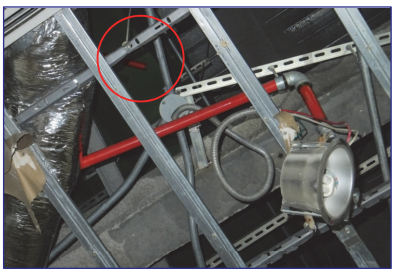
In the JLTO, the anchorage of the compressor at the sixth floor failed during this earthquake. The expansion anchors were detached due to concrete breakout. In addition, masonry blocks at the top of the east gable fell down. Damaged suspended ceiling systems were also observed in the office, library, and the auditorium areas on the third, fourth, and fifth floors, respectively.

Table 1. Survey locations and distances from the epicenter

Location	MHJHS	JLTO	CYCG
distance (km)	11.5	23.8	70.4
Evaluated PGA (gal)	380.47	269.41	40.82



The damage to the ceiling system at CYCG



The broken fire sprinkler piping system in CYCG



Damaged partitions in the MHJHS



Anchorage failure of the compressor in the JLTO

Fig. 12. Seismic damage to nonstructural components and systems.

Reconnaissance team members: Juin-Fu Chai, Jiunn-Shyang Chiou, Tsung-Chih Chiou, Te-Kuang Chow, Fu-Pei Hsiao, Han-Wei Huang, Shieh-Kung Huang, Jai-Hui Jiang, Yung-Yen Ko, Chun-Hsiang Kuo, Zih-Yu Lai, Che-Min Lin, Fan-Ru Lin, Pei-Yang Lin, Zhen-Yu Lin, Wen-Cheng Shen, Jia-Cherng Song, Chien-Chuang Tseng, Ren-Zuo Wang, Pu-Wen Weng, An-Chien Wu, Chiun-lin Wu, Fang-Yao Yeh

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The International Training Program for Seismic Design of Structures

Chun-Chung Chen, Associate Researcher, NCREE

The National Center for Research on Earthquake Engineering (NCREE) of the Republic of China (ROC) (Taiwan) provides a variety of research programs related to earthquake engineering. These programs encompass basic research on issues related to seismic design and engineering of buildings and bridge structures. In order to achieve "International Cooperation on Research and Training Programs" of the National Science Council, ROC, a short-term training program is organized and scheduled on October 21st to 25th, 2013.

The training program was first held in January 2002. The project is in the form of short-term workshops to train government officials and engineers from selected countries. By these kinds of activities, the disaster-prevention technology and earthquake-resistance capability of these countries can be largely improved to reduce the impact and losses caused by earthquakes.

Two main goals of this project are described briefly as follows:

1. The preparation and design of disaster-prevention and seismic material. The professional content will include a comparison of codes, design methods, flow charts, some design examples, and other details. These related materials can also be used as a reference for domestic disaster-prevention institutes in their practical training programs.
2. The ability of the host disaster-prevention and seismic workshop to promote networking. By inviting the appropriate officials and engineers from around the Pacific Rim to attend the workshop, cooperative relationships can be greatly improved.

Information about the upcoming training program may be found at http://w3.ncree.org.tw/ITP/2013.

Published by

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