NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING
2019 Pacific Conference on Earthquake Engineering
TURNING HAZARD AWARENESS INTO RISK MITIGATION
4 – 6 April | SkyCity, Auckland | New Zealand

Structural behavior of a retrofitted reinforced concrete building under near-fault earthquake

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ABSTRACT

The near-fault effect on buildings is a significant issue in Taiwan due to numerous active faults. Its special characteristics with large displacement and high velocity can be observed. However, it is difficult to reproduce the near-fault earthquake record by existing test facilities of National Center for Research on Earthquake Engineering (NCREE). Thus, the experimental studies on the near-fault effect are rare. Furthermore, many buildings were severely damaged in recent earthquake events. Among them, some of mid-to high-rise buildings were severely damaged and caused numerous casualties. In Taiwan, more and more mix-used residential and commercial buildings were constructed due to the dense population. Thus, the casualty risk caused by the collapse of those buildings should not be underestimated, and the method of seismic assessment to identify the building with high collapse risk becomes a critical issue. A high-performance seismic simulation testing system which can simulate the near-fault motions has been established in NCREE Tainan Laboratory. After the NCREE Tainan Laboratory is completed, NCREE provided better seismic experimental services to the government agencies, academia, and industry which is beneficial to improving public safety against earthquake disasters.

This study based on an experimental result of retrofitted reinforced concrete (RC) structure tests on the novel shaking table system. The experimental result will compare with the non-retrofitted specimen in order to verify the retrofitting benefit. This experiment can offer abundant information of RC frames and response of retrofitting members under near-fault earthquake.

1 INTRODUCTION

Taiwan locates on the Pacific seismic belt, in particular, there are numerous activity faults in Taiwan. The near-fault earthquake would cause drastic damage even collapse on neighboring buildings. These threaten to safety and properties of residents. Thus, studying the near-fault earthquake effect on buildings is our major issue.

The characteristics of the near-fault earthquake within large ground displacement and high velocity can be observed near the fault, as shown in Figure 1, which recorded from Chi-Chi near-fault earthquake. This earthquake caused serious disaster and a lot of casualties at that time.

In addition, the similar situations also were observed in 2016 Meinong and 2018 Hualien earthquake. During the post-earthquake investigation, it found out there are several mid-to high-rise buildings were severely damaged even collapsed. Those collapsed buildings were found out with weak story problem, the story lateral stiffness is quite different from the adjacent story, as shown in Figure 2.

Thus, the current major issue is how to grasp the behavior of mid-to high-rise RC structure under near-fault earthquake and develop different retrofitting methods in order to cope with different construction conditions. Hence, NCREE designed two half-scale seven-story RC structure dynamic experiments tested by new shaking table equipment. These experiments can offer abundant dynamic responses, it can help researchers study on behavior of the mid-high building and the response of retrofitting members under the near-fault earthquake.

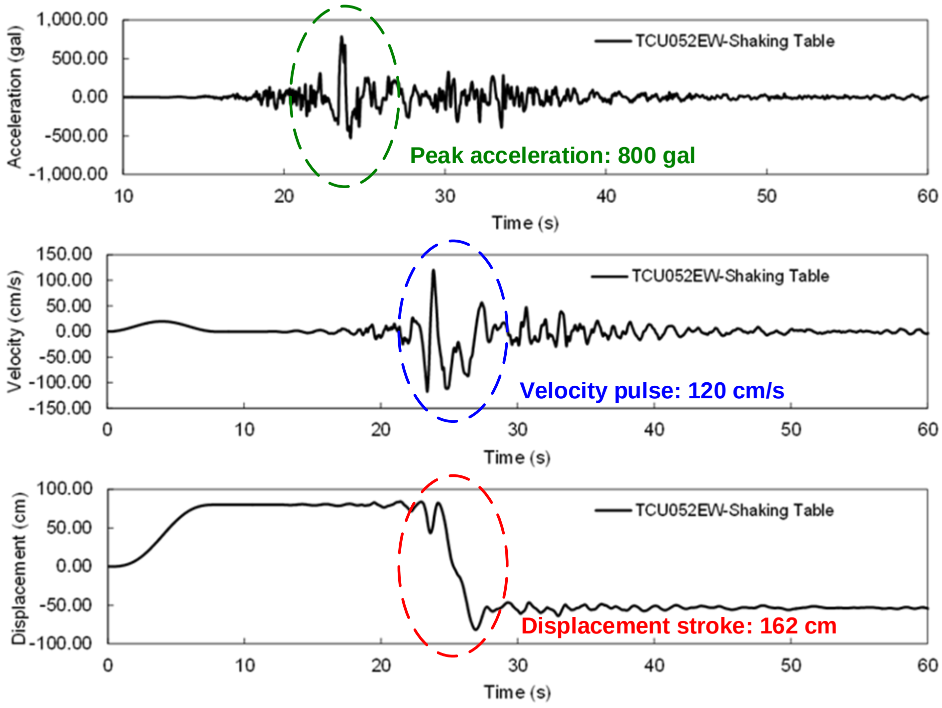


Figure 1: Characteristics of the near-fault earthquake.

(a) Before earthquake (2016)

(b) After earthquake (2016)

(c) Before earthquake (2018)

(d) After earthquake (2018)

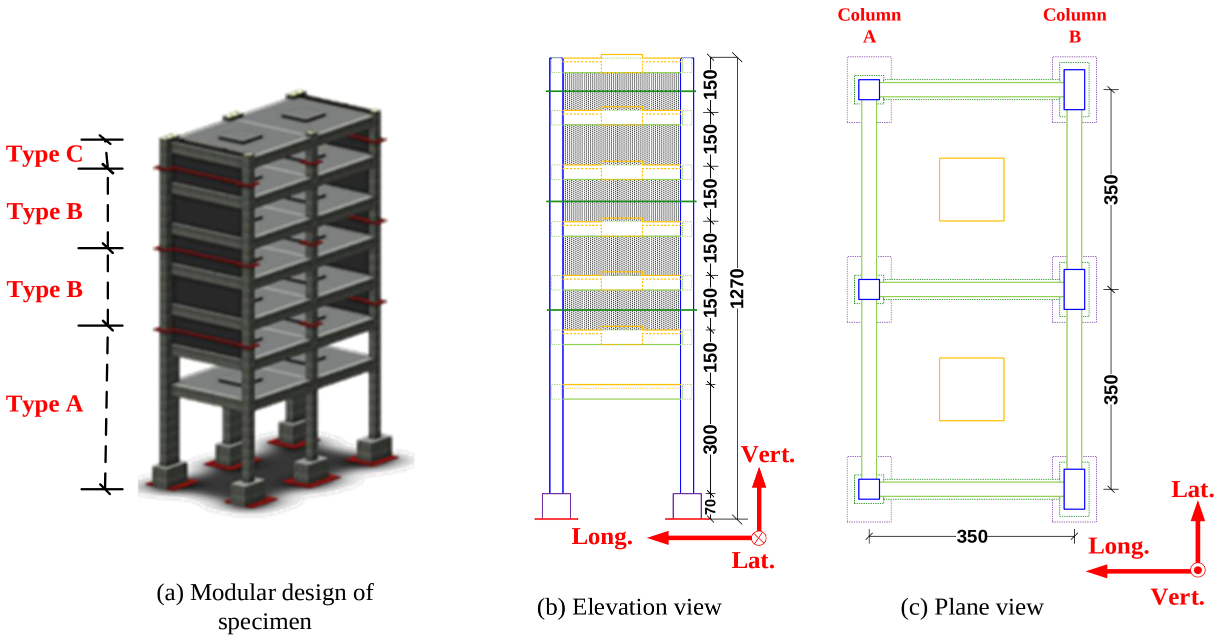
Figure 2: The recent earthquake disaster in Taiwan.

2 INTRODUCTION OF TEST

2.1 Introduction of Specimen

Two half-scale experiments have been tested at NCREE Tainan Laboratory in July 2018. One is retrofitted and the other is the original. The dimension and information of the specimen and cross-section of RC members are shown in Figure 3 and Figure 4. The specimen was designed as modular (Shen et al. 2018), it is very conveniently assembled for different story specimen, as Figure 3(a) shown. Hence, the experimental specimen was assembled for seven-story in order to simulate the mid-to high-rise building. Its design referee to the mixed-use residential and commercial building, and the bottom story is frame system only in order to create the weak story effect. Besides that, the bottom module with slight damage since it was tested in 2017.

The material properties were tested before the experiment. The average yielding strength of longitudinal bar and stirrup were 4630 kgf/cm^2 and 3569 kgf/cm^2, respectively. The average strength of concrete cylinders was 238 kgf/cm^2 at 28 days.



(a) Modular design of specimen (b) Elevation view (c) Plane view

Figure 3: The dimension of the specimen (unit in cm)

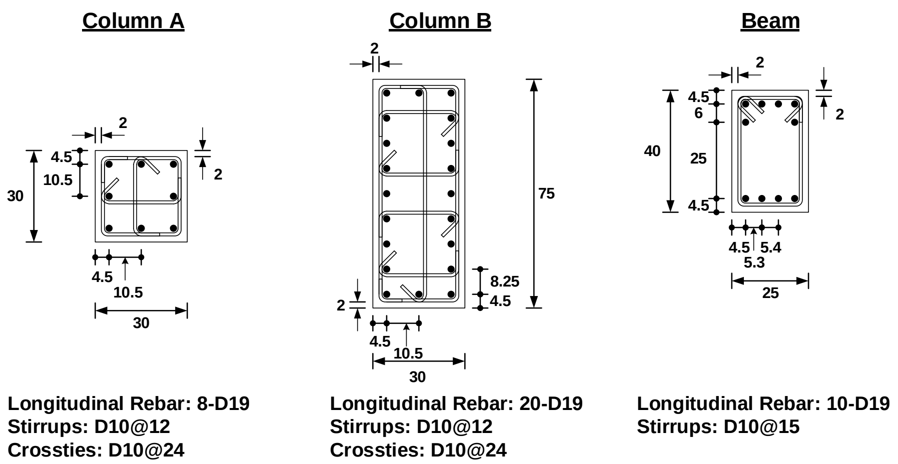


Figure 4: The information of cross-section (unit in cm)

2.2 Introduction of the retrofitting method

The conventional retrofitting methods can effectively improve the seismic capacity of building, like RC column jacketing, adding wing wall, infilled RC wall and steel frame with steel braces and any more. However, those constructions are complex and need to enhance the tension capacity of RC frame by post-installed rebar and anchor bolt. It would also produce noise pollution and a lot of dust while constructing. These would interfere with the resident's daily life. Thus, conventional methods have hardly been accepted.

Therefore, NCREE modified the disadvantages of conventional methods and developed a new retrofitting method (Tsai et al. 2018; Kono and Watanabe 2006; Kono and Katayama 2009). It is called "Self-Jointing Compression Brace", which characteristic is compression capacity only. This method can fully utilize the advantage of reinforced concrete which compression strength is higher than tensile strength. Furthermore, it can be prefabricated and easily constructed without a lot of post-installed rebars and anchor bolts. In particular, it produces less dust and noise during the construction, reduce construction period and without interference from construction.

In the future, NCREE will propose many different retrofitting methods to cope with difficult construction conditions and satisfy the resident's requirements. Thus, this test took this method as a paradigm. The test specimens and retrofitting members as Figure 5 shown.

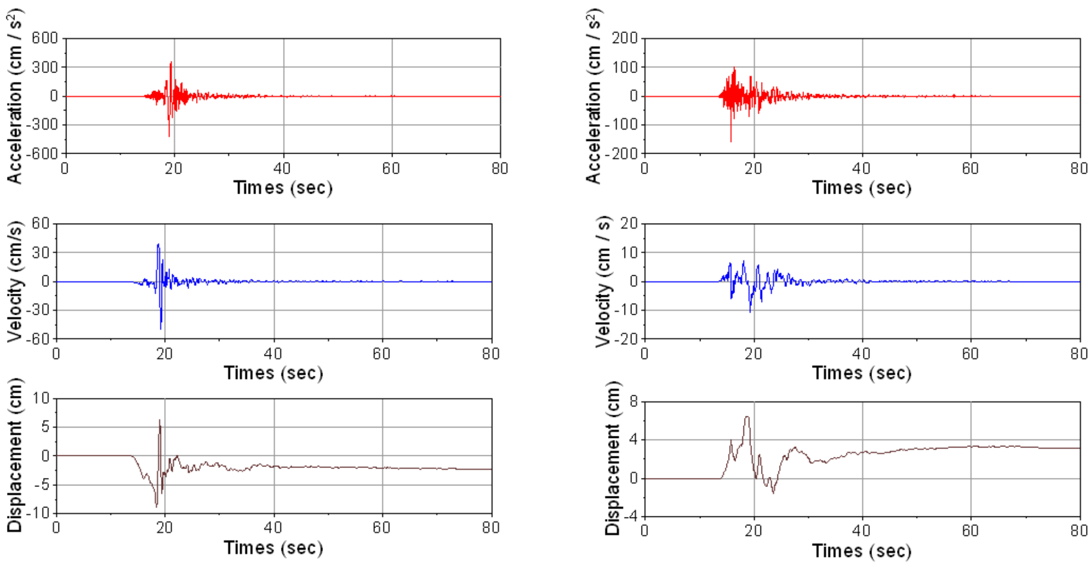
(a) Original (b) Retrofitted (c) Retrofitting members

Figure 5: The retrofitted and original specimen.

2.3 Input ground motion

The specimens was tested by bi-directional ground motion in the Long. and Vert. direction, as Figure 3(c) shown. This consideration in order to avoid occurring the torsion effect. The selected input ground motion is the record of 2016 Meinong earthquake which was measured at the CHY063 station. As Figure 6 shown, the velocity record shows the input motion has an instantaneous velocity pulse feature, which was similar to the characteristic of the near-fault earthquake. The peak acceleration, velocity pulse and ground displacement stroke in the Long direction is 410 gals, 45 cm/s, and 8cm, respectively.

Although the test sequence includes far-field and the near-fault earthquake. But, this study will focus on the near-fault earthquake test.



(a) Long direction (b) Vert direction

Figure 6: Input ground motion

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2.4 Instrumentation scheme

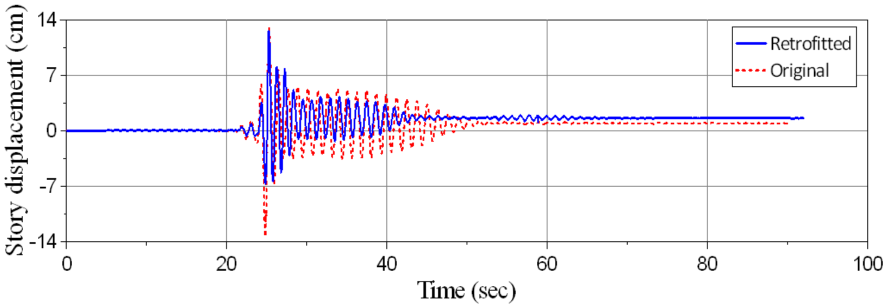
The motion of the shaking table and response of specimen were monitored by the instrument include accelerometer, displacement transducer, string pot, and the motion capture system.

The tri-axial accelerometers were distributed on each floor central to measure the acceleration. The displacement transducers were arranged from 1st floor to 3rd floor to record the internal story displacement in three dimensions. In addition. There are 48 strain gauges were attached on the retrofitted braces where used to measure the deformation to estimate the energy dissipation. The string pots were arranged on the retrofitted braces in order to record the axial displacement of braces.

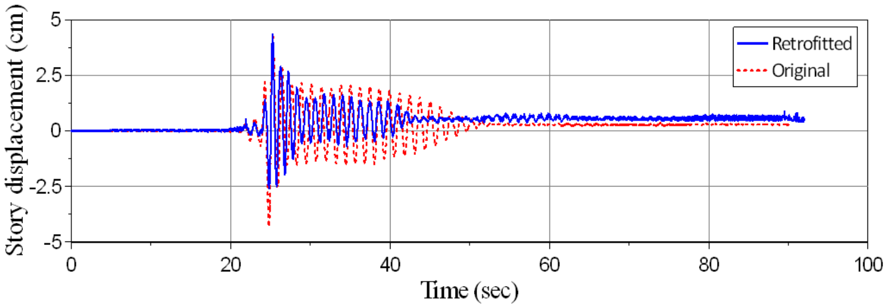
The motion capture system named OptiTrack (OptiTrack 2017) was adopted to capture the entire specimen motion during the test by deploying 169 markers around the specimen. The movements of markers were recorded by high performance camera system.

2.5 Experiment result

This study is focusing on the displacement of the weak story and the response of retrofitting members. The internal story displacement at the 1st and 2nd story of the original and retrofitted specimen. As Figure 7(a) shown, the peak displacement at the 1st story in negative direction for the retrofitted and original specimen is 6.6 cm and 13.3 cm, respectively. The retrofitting members could contribute an extra lateral strength to the specimen, as well as effectively restrain the displacement response at the retrofitted story. Besides that, the displacement decreasing rate of the retrofitted specimen is faster than the original specimen after the peak response. Furthermore, it also finds out there is a phase lag from the comparison. From the above observations, it can speculate the stiffness changed while the braces had acted, it means that the retrofitting members assist RC frame resisting the seismic. However, the displacement is not different in positive direction due to the characteristic of the members. A similar observation was found in the 2nd story, as shown in Figure 7(b).



(a) 1st Story displacement



(b) 2nd Story displacement

Figure 7: The comparison of story displacement.

Figure 8 shows energy dissipation of the brace which estimates by the strain gauge. Taking the brace at the 2nd story as an example, it clearly observed that the energy dissipation concentrated at the compression side. This behavior is as same as expectation, the tension capacity of the brace is eliminated. So that the pull-out failure will not occur on the RC frame which was caused by the brace. These retrofitting members can contribute the extra lateral strength to the specimen to resist the seismic force and restrain the displacement response.

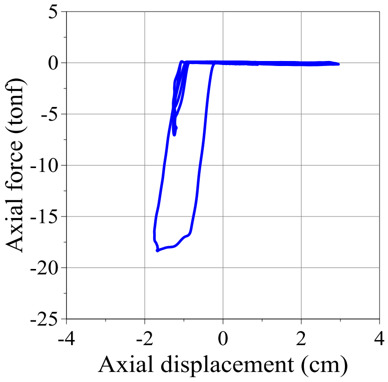


Figure 8: The energy dissipation of brace at 2nd story

3 CONCLUSION

Almost one-third of the population would be affected by the near-fault earthquake in Taiwan. Moreover, the population continues growing up and the majority of new buildings develop upward, this cause many mid-to high-rise buildings has been increasing. From the recent earthquake disasters, it can be found the significant effect on the mid-to high-rise buildings caused by the near-fault earthquake. Thus, we need to conduct more researches on the mid-to high-rise building under near-fault earthquake. Moreover, the seismic design code has to be improved to prevent the structures from severe damages and collapse.

By the new established high performance earthquake simulation system in NCREE Tainan Laboratory, which can reproduce the characteristics of near-fault earthquake. These experiments can offer abundant structure behaviors and responses. These can help researchers and engineers comprehend the responses of the structure under the near-fault earthquake, also improve the seismic design code for new and retrofitted buildings.

4 REFERENCE

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