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Taiwan-Thailand Seismic Retrofitting Collaborative Project of School Buildings in Thailand

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ABSTRACT

Recent reconnaissance results revealed that several school buildings were damaged due to the weak and/or openings of ground-floor in northern Thailand of the 2014 Mae Lao Earthquake. Those kinds soft-story structures are particularly prone to collapse during an earthquake. Therefore, enhancements to the seismic performance of the existing school buildings are urgently required. The government of Taiwan promote seismic performance upgrading of school buildings since 2009. In order to exchange and share experiences with people from different countries, a collaborative project between Taiwan and Thailand was carried out. There are three school buildings were retrofitted by RC column jacketing method. The objective of this paper is to introduce the background works, technology and progress of this seismic retrofitting collaborative project for school buildings.

Keywords: seismic retrofitting, school buildings, RC column jacketing, Taiwan, Thailand

INTRODUCTION

In the past, Thailand is generally thought to be located in an area with low seismic risk. However, a magnitude 6.3 earthquake occurred in Mae Lao, Chiang Rai Province, on May 5th, 2014, and several schools and other buildings were damaged [1]. The earthquake strongly demonstrated the vulnerability of school buildings in seismically active areas in Thailand. Seismic strengthening of these buildings has become a crucial safety issue. Similarly, a large number of school buildings in Taiwan were severely damaged or collapsed during the 1999 Chi-Chi earthquake. After the earthquake, researchers in Taiwan invested a lot of time in research on earthquake engineering. Moreover, the government of Taiwan promote seismic performance upgrading of school buildings since 2009. According to this promotion policy, a large number of school buildings have undergone seismic assessment and retrofitting work. More than 6,000 school buildings have been retrofitted since 2009. In order to exchange and share seismic retrofitting experiences with engineers from different countries, a collaborative project between the National Center for Research on Earthquake Engineering (NCREE), Taiwan, the Asian Institute of Technology (AIT), and the King Mongkut's University of Technology (KMUTT), Thailand, was carried out to assess the techniques for retrofitting of these buildings. Three school buildings were selected for retrofitting in a pilot project to evaluate suitable technology for Thailand and to serve as demonstration sites (Figure 1). This paper focuses on summarizing the Taiwan-Thailand collaborative project. Background works that formed the basis for this Taiwan-Thailand project are presented. Relevant technical details of seismic assessment and retrofitting are also presented in this paper.

EARTHQUAKE THREAT IN THAILAND

The 2014 Mae Lao earthquake

Earthquake damage poses a major threat to the northern area of Thailand. The Mae Lao earthquake struck at 18:08:43 local time on 5 May 2014. The magnitude was estimated by the United States Geological Survey (USGS) [2] to be 6.1 M_w and the epicenter was located at a point 9 km south of Mae Lao District, 27 km southwest of Chiang Rai, Thailand (Figure 1). Based on the research [1], the earthquake was believed to have occurred along the northeast-southwest left-lateral strike slip Mae Lao fault. This fault is part of the Phayao active fault zone in the northern part of Thailand. Several aftershocks followed the main shock, typical for an earthquake of such magnitude. The highest PGA of the main shock as recorded by the instruments nearby was 0.33g at Mae Suai Dam (MSAC) station located approximately 14 km away from the epicenter. Even though this station was located at the top of the dam and the recorded data was likely to be influenced by the dynamic response of the dam, the ground shaking was considered to be one of the highest in Thailand modern time [1]. The ground shaking intensity near the epicenter was estimated to be in the range of Modified Mercalli Intensity (MMI) VII to VIII causing damage to building structures in the 50 km radius.

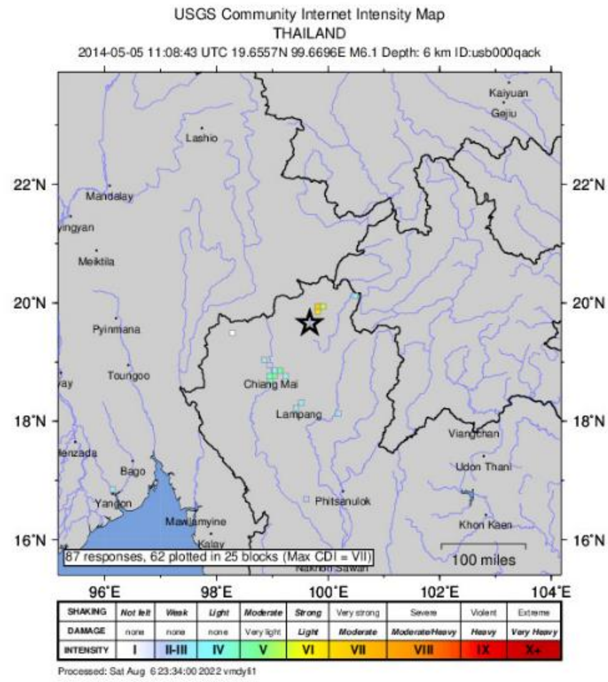


Figure 1. Intensity map of the 2014 Mae Lao Earthquake from USGS. [2]

The structural characteristics of the typical school building

Immediately after the earthquake, the authors conducted a reconnaissance damage survey of several school buildings in the area. Although the buildings inspected were only a small fraction of the buildings damaged by the earthquake, the inspection did provide valuable information as to the strengths and weaknesses of existing school building structures in Thailand. The construction of a typical Thai school is generally based on standard drawings issued by the government with minor modifications to suit local requirements. The design and drawings are normally prepared by engineers appointed by the relevant agency. Because of this, these buildings share similar architectural and structural features. They are usually 2-4 stories in height and are constructed using reinforced concrete (RC). Masonry infill walls are used as partitions. The infill walls are normally made from concrete masonry units, 7 cm thick, with plaster, 2-3 cm thick, on both sides. The plan is rectangular in shape. There are normally 6-8 bays in the longitudinal direction and only 1-2 bays in the transverse direction. Although these schools can be considered engineered buildings and many can be considered well-built, most of them were constructed prior to the enforcement of seismic design regulations and were designed only for gravity loads. Hence, some of these schools lack the lateral strength and ductility required to sustain the ground shaking.

Several other factors also contributed to the vulnerability of these school buildings. The school buildings are generally designed in such a way that they have wide open spaces in the first story for assembly and school activities with a minimal amount of infill walls. Compared to the upper stories where classrooms are located and infill walls are used to separate the rooms, the first story is generally much weaker. Under an earthquake, the deformation tends to concentrate in the first story where the story shear is generally the largest. In addition, because of the wide open spaces, the beams tend to be generally stronger than the columns exacerbating the soft story problem. The result is that the columns will be damaged while the beams remain almost intact. Figure 2 shows one particular school and its damage pattern. This school building is a 3-story frame structure located in Phan around 20 kilometers south of the epicenter. On one side of the building, masonry infill walls were provided around the staircase. The rest of the ground floor was fully open. The columns were severely damaged as seen in the figure. The damage pattern indicated that the building moved in a twisting manner in addition to the characteristic soft-story deformation. There was no observable damage to the beams indicating the building responded as a “strong beam-weak column” frame. This pattern was undesirable as it could lead to excessive sideways, potentially leading to collapse.

Figure 2. School Building Damaged by Soft Story and Torsional Irregularity.

EXPERIMENTAL STUDY CONDUCTED ON JACKETING COLUMNS

Design of test specimens

As mentioned, the typical Thai school buildings lack lateral strength through the soft story problem. Increasing the lateral strength is desirable for the soft-story frame. In the Concrete Jacketing method, concrete columns are enlarged by casting new concrete around existing columns. Several retrofitting schemes for RC frames developed in the past were evaluated. It was found that concrete jacketing provided one of the best solutions in terms of performance, cost, and constructability. It is well known that the bond interface between new and existing concrete is crucial in creating a compatible response between new and existing concrete [3]. In addition, the design is governed by minimum practical requirements for the thickness of the jacket as well as the minimum amount of longitudinal reinforcement in the new concrete.

The RC column jacketing method was chosen for this retrofitting project. RC column jacketing method is one of the most commonly used retrofitting methods in Taiwan. Different from the past column jacketing method, dowel bars were not used and a thick expanded dimension is used instead of a thin expanded dimension in Taiwan. The advantage is that it can save construction costs and reduce construction time. To study the performance of different types, an experiment was conducted to evaluate the effect of the dowel bars on the overall strength and stiffness of the jacketed column. Two columns were tested including the retrofitted column with and without dowel bars. Figure 3 shows the column section and detailing of test specimens. The existing column section is 30 cm x 30 cm with six deformed bars D16 for longitudinal reinforcement and spacing 15 cm deformed bar D6 for hoops. The Column A is the specimen built without dowel bars. The jacketing column size is 60 cm x 60 cm with twelve deformed bars D16 for longitudinal reinforcement and spacing of 15 cm deformed bar D10 for ties/transverse steel. For the convenience of steel bar binding, two L shape steel with 135-135 hooks to assemble a transverse hoop. The other specimen (Column B) was built with the spacing of 15 cm deformed bar D10 for the dowel anchor. The dowel bars were embedded 10 cm depth into the existing column section by chemical adhesive. The other detailing was same as the Column A.

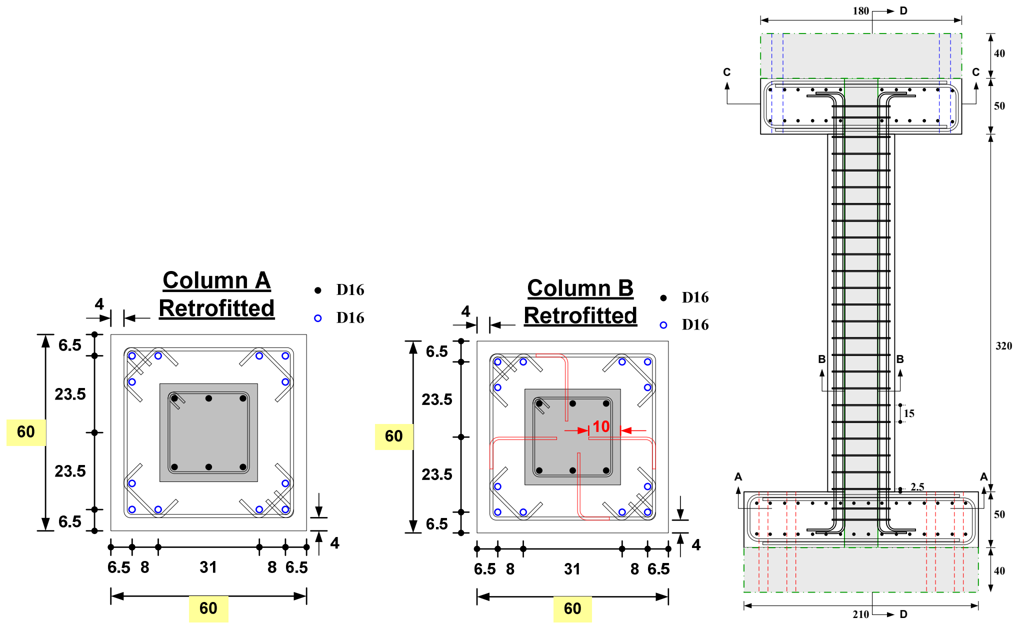


Figure 3. Column section and detailing of test specimens.

Experimental setup

Figure 4 shows the test setup for the experiment. The experiment was conducted by applying in-plane quasi-static cyclic lateral loads. The lateral load is generated by the hydraulic actuators attached to the reaction wall and connected to the platen multi-axial testing system (MATS)[4] in NCREE. The specimen is attached to the steel cross beam and platen of MATS through the top beam and foundation beam, respectively. The top beam and foundation beam were designed to be strong and stiff enough to resist the lateral force.

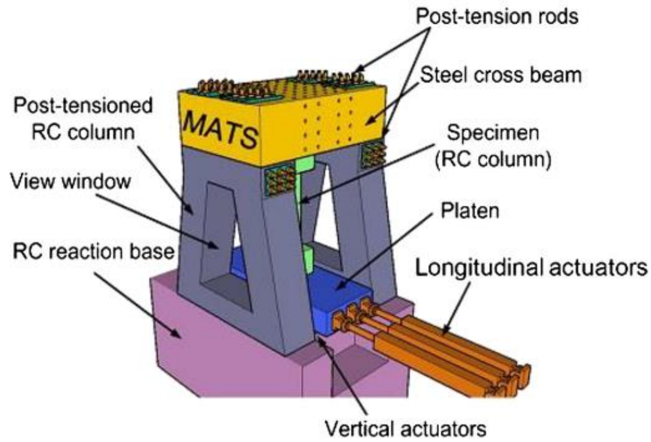


Figure 4. Test setup of RC column at the multi-axial testing system (MATS)[4] in NCREE.

The test was conducted by applying in-plane quasi-static cyclic lateral loads. The specimens were tested with a fixed axial load of 10% $f_c'A_g$. The lateral load is applied using displacement control based on the measured relative lateral deformation of the top beam and foundation beam of the specimen. Loading protocol was applied following ACI 374.1-05 [5] recommendation as presented in Figure 5. The experiment was conducted until the structure collapsed.

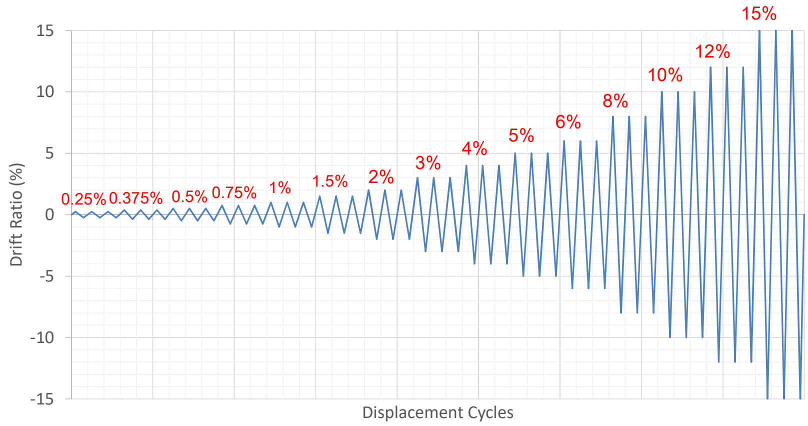
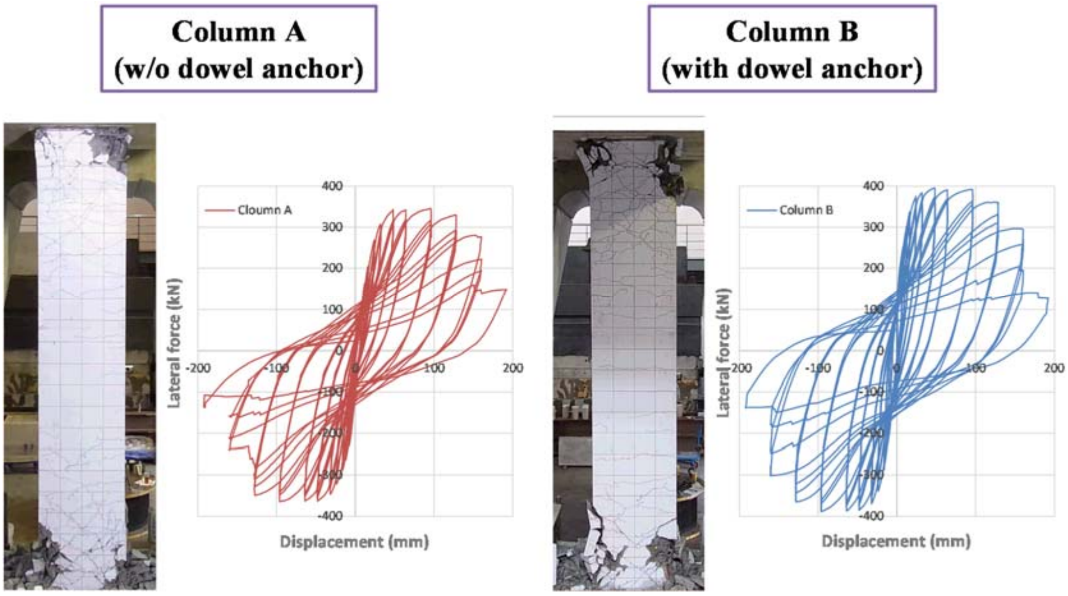


Figure 5. Loading protocol.

Test results

Figure 6 shows the hysteretic loops and the crack patterns of each specimen. Speaking of strength, the maximum strength of the specimen without dowel anchors (Column A) is 346 kN and -365 kN of positive and negative direction, respectively. However, if the jacketing column has dowel anchors, the strength would increase to 396 kN and -388 kN (Column B). The strength increase was approximately 10 percent. On the other hand, speaking of deformability, specimens with or without dowel anchors possess the same deformability. Although these two specimens were retrofitted with different methods, the hysteresis loops and the crack patterns look very similar. The failure modes of Column A and Column B were flexural failure both.



(a) *(b)*

Figure 6. Test results of jacketed columns: (a) without dowel anchor, (b) with dowel anchor.

RETROFITTING OF SCHOOL BUILDINGS

Details of prototype school buildings

Three school buildings were selected for retrofitting in a pilot project to evaluate suitable retrofitting technology for Thai school buildings. Based on the observed weakness described previously, it was decided that the soft-story was the most important aspect to eliminate. The overview of one of the buildings and the key plans are shown in Figure 7.

Figure 7. The overview of the study building before retrofitting.

Retrofitting design

In this project, selective columns were jacketed. The final design consisted of jacketing alternate columns as shown in Figure 8. The rest of the columns were covered with brick walls to have the same size as the jacketed column for architectural reasons. Figures 9 and 10 show the details of the retrofitting plan. As expected, the specimen with dowel bars showed larger strength. However, the strength increase was approximately 10 percent only. More importantly, there was no discernable change in the ductility between the two specimens. For this reason, the design without the dowel bars was eventually adopted. Construction began in 2021. Figure 10 shows the jacketed columns during construction. As can be seen, the jacketing was also done for the columns below the ground level with the new rebars fully embedded into the foundation. The three buildings after the retrofitting are shown in Figure 11.

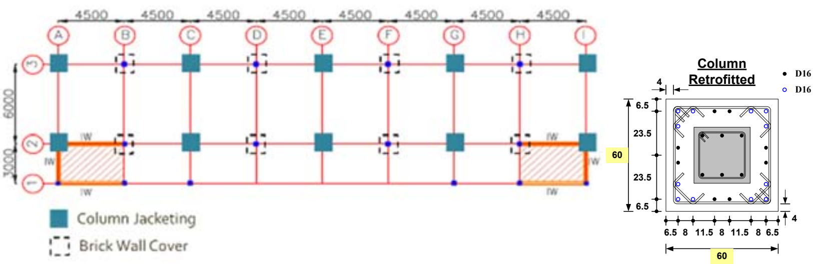


Figure 8. Building Plan and Location of Column Jacketing.

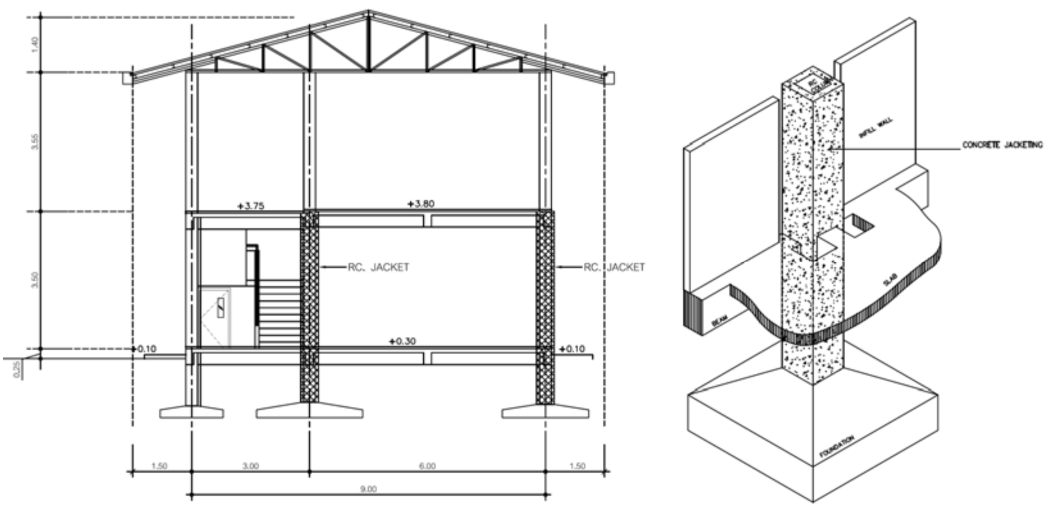


Figure 9. RC Jacketing Detail

Figure 10. Column Jacketing during construction.

Figure 11. Three selected schools after retrofitting.

Numerical analysis

In this study, ETABS software [6] is used for modeling the typical Thai school building and performing Taiwan Earthquake Assessment for Structures by Pushover Analysis (TEASPA) method. The TEASPA method is a modified capacity spectrum method developed in the NCREE handbook [7]. The TEASPA method has been used to analyze the seismic performance of district office buildings and has been verified can well predict the failure mode to actual damage [8]. The capacity curves were determined by static nonlinear pushover analysis under displacement control in ETABS. The plastic hinges of structural members were defined by the backbone curve models which were presented in TEASPA [7]. The maximum base shear, roof displacement, peak ground acceleration A_p, and the seismic performance of the analytical model are presented in Table 1.

Table 1. Analysis results of the typical Thai building by TEASPA method in different directions.

Item/Direction		Max. base shear (tf)	Roof displacement (cm)	$A_{P,Vmax}$ (g)	A_p (g)	A_T (g)	Capacity demand ratio (CDR)
non-retrofitted building	+X	131.6	3.24	0.194	0.182	0.3	0.61
	-X	131.6	3.24	0.194			
	+Y	108.2	3.13	0.191			
	-Y	107.1	3.09	0.182			
retrofitted building	+X	315.3	7.38	1.040	0.611		2.04
	-X	313.1	7.38	1.032			
	+Y	351.2	5.03	0.611			
	-Y	325.1	8.35	0.621			

The pushover curves of the typical Thai school building are shown in Figure 12. From the base shear–roof displacement curves, we find that the pushover curves of the Thai school building before and after retrofitting, while the retrofitted building has higher curves. The maximum base shear of the retrofitted Thai school building is almost two times higher than those of the non-retrofitted building (Table 1). Meanwhile, the roof displacement of the retrofitted Thai school building is almost two times more than those of the non-retrofitted building. Based on the capacity spectrum method, the TEASPA can be used to find the relative peak ground acceleration A_p at a given performance point [8]. The TEASPA method recommended that the maximum base shear point of the pushover curve can be the performance point of a building, and the seismic performance of the building can be evaluated by comparing the peak ground acceleration A_p and the demand ground acceleration A_T from the seismic building code requirement. Thus, the response peak ground acceleration A_p of the non-retrofitted school building is about 0.182 g, and the A_p of the retrofitted building is 0.611 g (Table 1). The seismic capacity of the retrofitted building is higher than non-retrofitted building. The comparison of the max. ground acceleration A_p and the demand ground acceleration A_T (CDR) are presented in Table 1. The CDR of the non-retrofitted building is less than 1.0. This means that the typical Thai school building needs to be retrofitted. The CDR of the retrofitted building is 2.04. This means that the retrofitting of the school building is effective. Based on the comparison of CDRs, the TEASPA method can assess the seismic performance of the typical Thai school building.

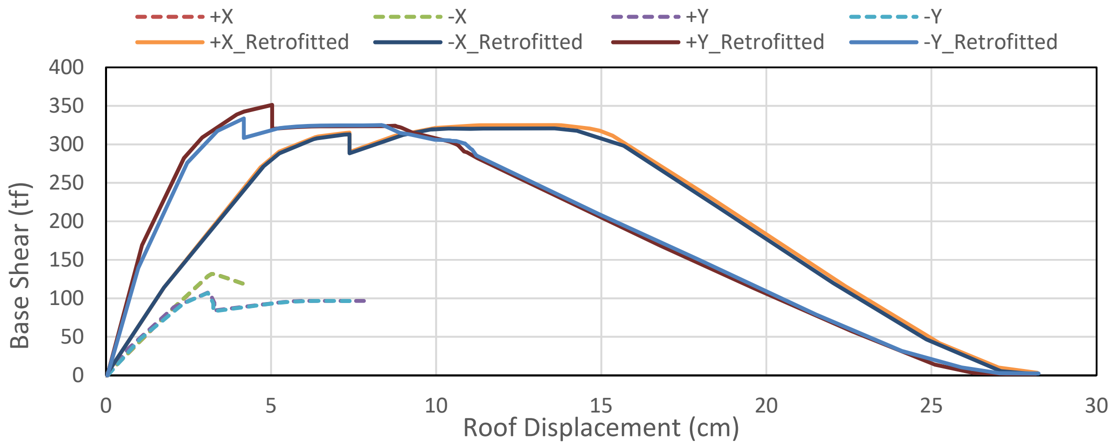


Figure 12. The base shear–roof displacement curves of the school building before and after retrofitting.

CONCLUSIONS

This paper summarizes the collaborative project between Taiwan and Thailand on seismic strengthening of soft-story school buildings in northern Thailand. A collaborative research effort between Taiwan and Thailand was carried out to assess the techniques for strengthening these buildings. RC column jacketing was selected as the most versatile and effective way to strengthen this type of structure as it could significantly increase the strength and stiffness of the structure. Three school buildings located in northern Thailand having the same structural framing and details were strengthened using this technique. The project was completed in 2021.

ACKNOWLEDGMENTS

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REFERENCES

[1] Ornthammarath, T, and Warnitchai, P. (2016) “5 May 2014 MW 6.1 Mae Lao (Northern Thailand) Earthquake: Interpretations of Recorded Ground Motion and Structural Damage” *Earthquake Spectra*, 32 (2): 1209–1238.

[2] U.S. Geological Survey (2014) “M 6.1 - 13km NNW of Phan, Thailand” United States Geological Survey, USA. https://www.usgs.gov/

[3] Vandoros, K.G. and Dritsos, S.E. (2008) “Concrete jacket construction detail effectiveness when strengthening RC columns” *Construction and Building Materials*, 22, 264–276.

[4] Wang, K.J., Chuang, M.C., Tsai, K.C., Li, C.H., Chin, P.Y., Chueh, S.Y. (2019) “Hybrid testing with model updating on steel panel damper substructures using a multi-axial testing system” Earthquake Engng Struct Dyn. 48(3): 347– 365. https://doi.org/10.1002/eqe.3139

[5] ACI 374.1-05 (2005). “Acceptance Criteria for Moment Frames Based on Structural Testing and Commentary” American Concrete Institute, 374 pp.

[6] Computer and Structures, Inc. (2016) ETABS Software v16.2.0. Computer and Structures, Inc., Berkeley, California.

[7] Hsiao, F.P., Chung, L.L., Yeh, Y.K., Chien, W.Y., Shen, W.C., Chiou, T.C., Chow, T.K., Chao, Y.F., Weng, P.W., Yang, Y.S., Tu, Y.S., Chai, J.F., Hwang, S.J. (2013). “Technology handbook for seismic evaluation and retrofit of school buildings (Third edition)” National Center for Research on Earthquake Engineering (NCREE) Report, NCREE-13-023, Taipei, Taiwan. (in Chinese)

[8] Weng, P.W. Li, Y.A. Hsiao, F.P. Hwang, S.J. and Kim, I. (2018). “Seismic Assessment of District Office Buildings under 2016 Meinong Earthquake in Taiwan”, *Eleventh U.S. National Conference on Earthquake Engineering (11NCEE)*, Los Angel, 25-29 June, USA.