SEISMIC UPGRADING FOR PUBLIC SCHOOL BUILDINGS IN TAIWAN

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ABSTRACT**:** Recent reconnaissance reports revealed that elementary and high school buildings are the particularly vulnerable structures in Taiwan. Therefore, enhancements to the seismic capacities of the school buildings through retrofitting are urgently required. However, there are 3,621 elementary and high schools in Taiwan, and the total number of buildings may be as high as approximately twenty thousands. Without careful planning, the budget could easily be exceeded due to the large number of buildings. Adopting an effective strategy using economical technologies and systematic prioritization is essential for this school retrofitting project to be successful. The government of Taiwan has launched a project to upgrade the seismic performance of school buildings within three years, and a total of $17.6 billion NTD (New Taiwan dollar) was budgeted from 2009 to 2011. The objective of this paper is to report on the strategy, method, and progress of this seismic project for school buildings in Taiwan.

KEYWORDS: seismic upgrading, school buildings, strategy

1. INTRODUCTION

Taiwan is in the region of the circum-pacific seismic zone. Earthquakes are common experiences for people in Taiwan. People are used to earthquakes and even ignore them. In the morning of September 21, 1999, the Chi-Chi earthquake awoke the people of Taiwan with its huge destructiveness. It told us the importance of the seismic capacities of structures. The Chi-Chi Earthquake caused nearly half of the school buildings in the central area of Taiwan to collapse or damage seriously. 656 primary and secondary school buildings were damaged in that earthquake. This disaster told us the seismic capacities of existing school buildings in Taiwan are probably not sufficient. Due to the existence of windowsill in traditional school buildings, the short-column effect caused the weak seismic capacity along the direction of the passage. Serious casualties and losses may result from the collapse of school buildings under strong earthquakes. To avoid casualties in the future earthquakes is the most important job in Taiwan. To retrofit these bad seismic performance school buildings is one solution to reduce the probable casualties. Before the retrofitting the seismic capacity of school buildings should be evaluated with a reliable method.

Based on the damage statistics, a lack of seismic resistance appears to be a common problem in the existing primary and secondary school buildings in Taiwan. Significant casualties and property losses could be resulted from the collapse of these school buildings under strong earthquakes. Furthermore, school buildings might have to be assigned as emergency shelters immediately after a severe earthquake. For the purposes of conducting seismic performance evaluation and retrofit of these noted structures, a three-stage strategy for screening with existing school buildings has been proposed by the National Center for Research on Earthquake Engineering (NCREE). These three stages are simple survey, preliminary evaluation and detailed evaluation. Simple survey is conducted by school administration while preliminary and detailed evaluations by professional engineers. Simple survey and preliminary evaluation are based on the common structural types, seismic resistance, possible failure modes and available experimental data. Detailed evaluation with the capacity spectrum method proposed by ATC-40 also has been adopted in this paper (ATC, 1996). After three stages of seismic evaluation, several practical seismic retrofitting methods which examined in the in-situ tests are purposed to improve the seismic performance of existing school buildings. The verifications with in-site tests and typical school buildings damage by the Chi-Chi earthquake are discussed in this paper.

There are 3,621 elementary and high schools in Taiwan, and the total number of buildings may be as high as approximately twenty thousands. Adopting an effective strategy using economical technologies and systematic prioritization is essential for this school retrofitting project to be successful. The government of Taiwan has launched a project to upgrade the seismic performance of school buildings within three years, and a total of $17.6 billion NTD (New Taiwan dollar) was budgeted from 2009 to 2011. The strategy and progress of this seismic project for school buildings in Taiwan are also reported in this paper.

2. STRATEGY

Fig. 1 shows the strategy for upgrading the seismic capacity of school buildings in Taiwan (Hwang et al., 2005). The strategy is divided into four stages, i.e., simple survey, preliminary evaluation, detailed evaluation, and retrofitting design and construction. The stages of simple survey, preliminary evaluation, and detailed evaluation are useful for determining the retrofitting priority of each building. These procedures identify school buildings with inadequate seismic capacity, and by using seismic performance indices, the retrofitting priority for each building is determined. The detailed evaluation and retrofitting design would then undergo reviews to ensure the quality of the analysis and the design, and the retrofitting construction would be inspected by engineers to ensure the quality of construction. The results for each stage are submitted into the Taiwan School Buildings' Seismic Performance Data Bank. By analyzing this data, it is possible to understand the progress of the project, the quality and specific characteristics of the operations, and to provide information for references in decision making. All the stages for upgrading seismic performance of school buildings are described separately in the sections below.

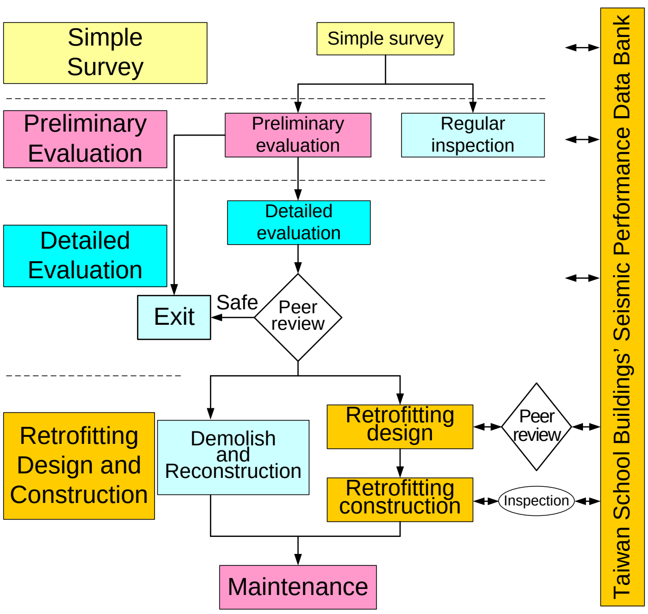


Figure 1. strategy of seismic upgrading of school buildings in Taiwan

2.1 Simple Survey

The screening standard for simple survey is defined by the strength-to-demand ratio. Most of the damages occurred in the vertical structural members on the first floor, causing the buildings to collapse along the direction of the corridor. Thus, the strength-to-demand ratio for simple survey is defined as (Chung et al., 2005)

Simple survey was conducted by the school administration under the mandate issued by the Ministry of Education. The office of general affairs of the schools carried this out by measuring the cross-sectional areas of all of the vertical structural members on the first floor, and the floor areas of all of the floors above the first floor. Since the members of the offices of general affairs are not professionals in civil engineering, it is difficult for them to differentiate between reinforced concrete and brick wall with finish. To be conservative, all the walls are considered to be brick walls. The data were then submitted via the internet to the NCREE. In order to train the members of the offices of general affairs on how to fill out the forms for simple survey properly, NCREE conducted workshops in each of the twenty five counties and cities throughout Taiwan.

Simple survey of school buildings was completed in 2005, and data for approximately 12,500 public elementary and junior high school buildings were gathered. The validity of the data was around 87%. There are two functions of simple survey of school buildings. The first one is to screen out the school buildings with less seismic capacity concern. NCREE suggested that the buildings with a seismic performance index, IS, of less than 80 undergo the preliminary evaluation stage. The second function of simple survey is to help draft a proposal for seismic upgrading of school buildings. From simple survey, the total floor areas of school buildings in Taiwan and the corresponding seismic performance indices can be collected economically. The information can be further used to estimate the number of school buildings that need to be retrofitted, and the required budget. Although the seismic upgrading plan of school buildings is important, it is difficult for the government to make a commitment without a clear estimate of budget. Therefore, simple survey is also an important part in drafting a proposal for seismic upgrading of the school buildings.

2.2 Preliminary Evaluation

The preliminary evaluation of school buildings was conducted by professionals in structural engineering. A table for preliminary evaluation (Su, 2008) was made; the evaluation standard was based on the geometrical dimensions of the vertical structural components and their average lateral strength, and was performed by professionals on site at the selected school buildings. They did not have to find the material strength, and did not have to look for the original design plans. Half a day was allocated for preliminary evaluation of each school building with a fee of $6,000 NTD. The results of the preliminary evaluation had to be submitted to the NCREE website, which are then used for further monitoring and adjustment of the project. The goal of the preliminary evaluation was to further identify school buildings with seismic capacity concerns and to assign priorities for the selected buildings to go through the detailed evaluation stage.

2.3 Detailed Evaluation

NCREE suggested that the detailed evaluation of the seismic capacity of school buildings should be carried out using the method of performance based design (Chung et al., 2008; Chung et al., 2009), i.e., first conduct the nonlinear lateral pushover analysis to find the capacity curve of the school building, and then carry out the spectrum analysis to obtain the performance curve of the school building. By selecting the performance point, the associated peak ground acceleration can be determined, as shown in Fig. 2. For most school buildings, the goal is to ensure the safety of students and teachers if the buildings should suffer medium level of damage by being subjected to the design earthquake with 475-year return period. For buildings used as emergency shelters, the goal is to provide useful shelter if the buildings should suffer slight damage subjected to the design earthquake with 475-year return period. Based on the aforementioned goals, the selection of the performance point in the detailed evaluation of the seismic capacity should refer to the school building handbook (Chung et al., 2009).

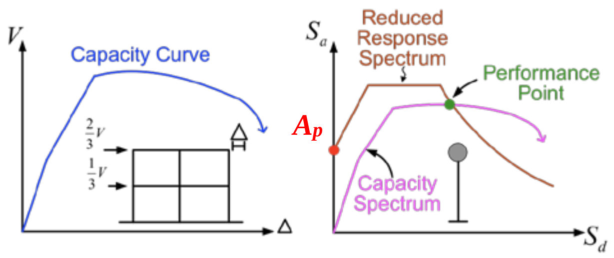
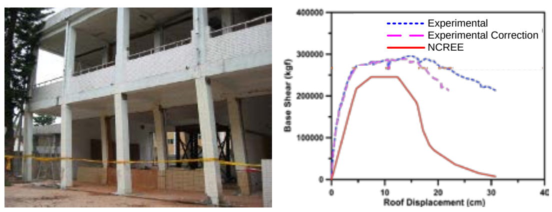
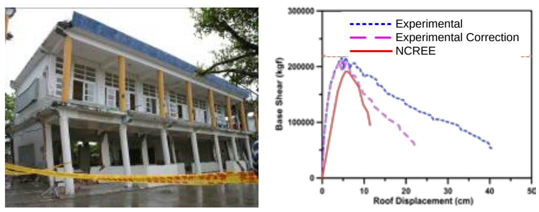


Figure 2. detailed evaluation for seismic capacity

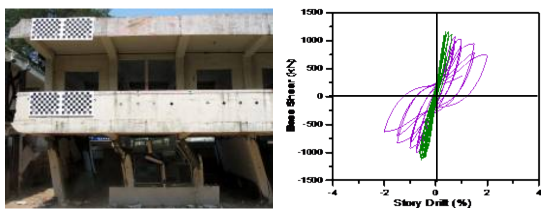
The lateral pushover analysis suggested by NCREE (Chung et al., 2009) was verified by experiments onsite. The experiments were performed on targeted school buildings which had already been assigned to be demolished. A uni-directional static lateral pushover test, pseudo dynamic test, and cyclic loading test were conducted during the winter and summer vacation period (Jaung et al., 2008a; Jaung et al., 2008b; Chiou and Hwang, 2008; Weng et al., 2008; Chung et al., 2007; Chiou et al., 2008a; Chiou et al., 2008b; Chiou et al., 2008c). These experiments were conducted on Taiwan's existing school buildings and the results were quite reliable. Fig. 3 shows the in-situ experimental verification of NCREE's lateral pushover analysis. The two main points of verification were the accuracy of the damage mode predicted by the analysis model, and the accuracy of predicted capacity curve due to lateral force. The result of the lateral pushover analysis by NCREE showed that, after the school buildings were subjected to lateral forces, the building frame underwent a shearing type behavior. The damage was due to failure of the vertical columns on the first floor (Jaung et al., 2008a; Jaung et al., 2008b; Weng et al., 2008; Chiou et al., 2008b), which was the same as that observed in the in-situ tests (Fig. 3). In addition, the rigidity, strength, and ductility were found to be conservative compared to the values measured onsite in NCREE's predicted building capacity curve due to lateral force (Fig. 3).



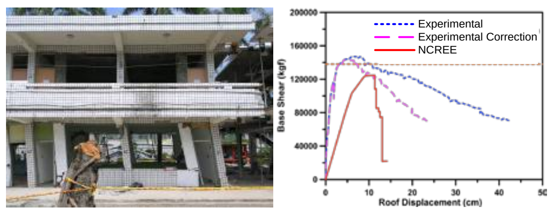
(a) Hsin-Cheng Junior High School (Jaung et al., 2008a)



(b) Kou-Hu Elementary School (Jaung et al., 2008b)



(c) Ruei-Pu Elementary School (Weng et al., 2008)



(d) Guan-Miao Elementary School (Chiou et al., 2008b)

Figure 3. experimental verification of pushover analysis by in-situ school tests

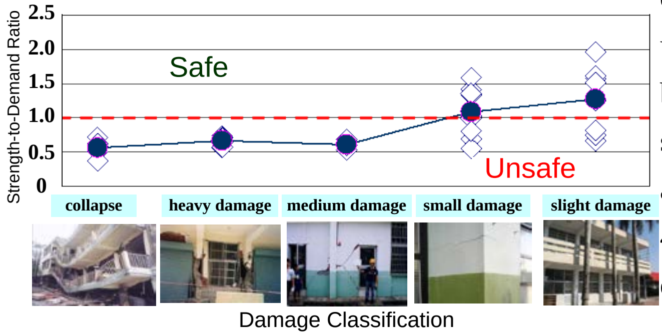
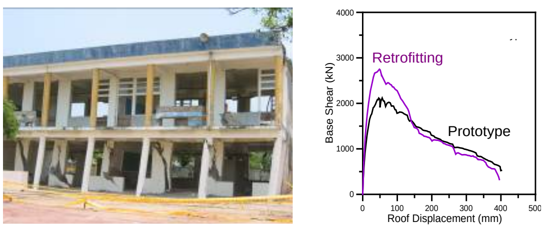


Figure 4. verification of evaluation method by 921 seismic damage data bank of school buildings

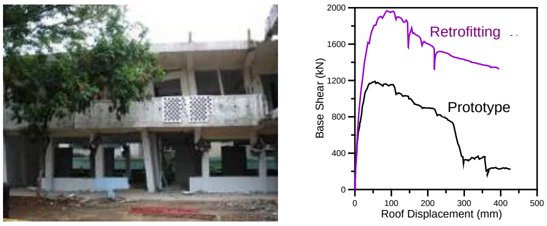
The spectrum analysis and criteria for the selection of performance points suggested by NCREE were verified by using data from the 921 seismic damage data bank of Nantou's school buildings (Liu, 2008; Tseng, 2010). These data included the blueprints of the school buildings' structural design, records of the ground acceleration at the 921 seismic site, and records of seismic damages. Through understanding the structural characteristics of the school buildings, the intensity of the earthquake, and the extent of the damages, a comparative study and verification could be conducted on the selection of the performance point, and the accuracy of the spectrum analysis. Fig. 4 shows the contents of Nantou's 921 seismic damage data bank (Tseng, 2010), in which the five levels of damages were identified as collapse, heavy damage, medium damage, small damage, and slight damage. The levels were determined from photographs of the damaged buildings and records of interviews. The strength-to-demand ratio was determined by the peak ground acceleration obtained by NCREE's detailed evaluation divided by the design ground acceleration at the site. It can be seen from Fig. 4 that the strength-to-demand ratio determined from NCREE's analysis had a positive relationship with the levels of 921 seismic damages. Based on the strength-to-demand ratio, the method of NCREE seismic capacity evaluation required that all damaged buildings classified as collapse, heavy damage, and medium damage in Fig. 4 should undergo retrofitting. However, in the predicted behavior of buildings with small and slight damage shown in Fig. 4, the NCREE considers them safe according the average values. It can be seen from Fig. 4 that NCREE's method of seismic capacity detailed evaluation (lateral pushover analysis, spectrum analysis, and selection of performance points, etc.) could effectively determine the seismic capacity safety level of each building, and is also more conservative.

2.4 Retrofitting Design

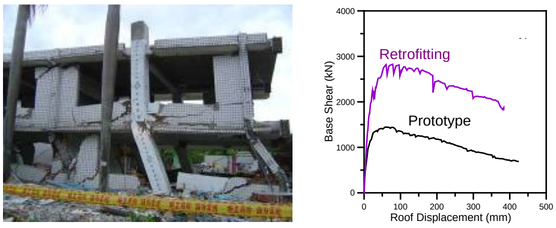
From the reconnaissance of the 921 damaged school buildings, typical school buildings of Taiwan were mostly damaged by the failure of vertical structural members on the first floor, and led to the collapse of the buildings along the direction of the corridor. Therefore, increasing the number of vertical structural members, or improving the strength and ductility of existing columns are effective methods of retrofitting. Fig. 5 illustrates several traditional methods of retrofitting applied to the buildings (Jaung et al., 2008b; Chung et al., 2007; Chiou et al., 2008b; Chiou et al., 2008c), some of which were already explained in the school building handbook (Chung et al., 2009).



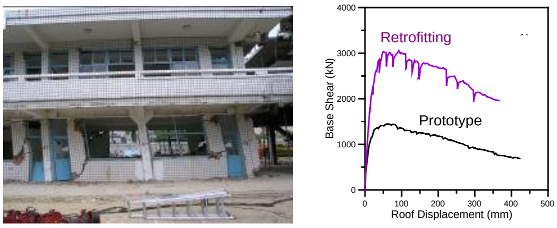
(a) Wing Wall (Jaung et al., 2008b)



(b) Composite Column (Chung et al., 2007)



(c) RC Jacketing (Chiou et al., 2008b)



(d) Steel Jacketing (Chiou et al., 2008c)

Figure 5. experimental verification of retrofitting measures by in-situ school tests

3. ACCOMPLISHMENT

Due to the importance of the safety of school buildings, from 2009 to 2011, the government allocated a budget of NT$17.6 billion (1USD=30TWD) as part of the ongoing economic revival plan to upgrade the seismic capacity of public elementary, junior and senior high school buildings. The progress of the planned work and the budget for each year are shown in Tables 1 and 2. At the request of the Ministry of Education, NCREE established the Project Office for the Seismic Upgrading of School Buildings to provide technical and administrative assistance to the project. In terms of technical assistance, the NCREE provided methods for the school buildings' seismic evaluation and retrofitting. In terms of administrative assistance, the Project Office established operation specifications, gave seminars, popularized good retrofitting examples, and established a data bank.

Table 1. Taiwan school retrofitting project budgets (in millions of twd).

Year	2009	2010	2011	SUM
Preliminary Evaluation	36	—	—	36
Detailed Evaluation	589	306	320	1,215
Retrofit Design	171	242	139	552
Retrofit Implementation	5,800	6,120	3,854	15,780

Table 2. number of school buildings in the various project stages.

Year	2009	2010	2011	SUM
Preliminary Evaluation	6,000	—	—	6,000
Detailed Evaluation	1,560	850	888	3,298
Retrofit Design	450	650	311	1,411
Retrofit Implementation	423	620	368	1,411

By the end of this year (2011), the three-year project on seismic upgrading of existing school buildings for primary and secondary education will be finished. By March 7, 2012, 9,801 school buildings had had their preliminary seismic evaluations completed, 4,992 buildings had detailed seismic evaluations, 3,363 buildings had seismic retrofit designs and 1,738 buildings had had seismic retrofitting work carried out. The rates of completion of the stages of the preliminary evaluation, the detailed evaluation, the retrofit design and retrofit work are 163%, 151%, 238% and 123%, respectively, compared to the project schedules (Fig. 6). The 1,738 retrofitted school buildings house 275 thousand students and teachers who were exposed to a high risk of earthquake disaster before the project was launched.

After the school buildings were seismically upgraded, the safety of those students and teachers has been secured.

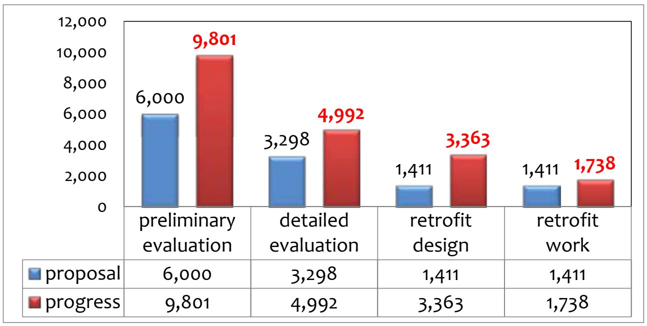


Figure 6. progress of seismic upgrades of school buildings.

All of the results from the four stages (simple survey, preliminary evaluation, detailed evaluation, and retrofit design and construction) have to be summarized and submitted by the practicing engineers to the database established and maintained by the NCREE. The data bank has collected the results on the preliminary evaluations, detailed evaluations, retrofit designs and construction of 11,091, 4,992, 3,363, and 1,738 buildings, respectively. From statistical analysis of the data, the magnitude of the problem of seismic deficiencies in school buildings can be determined. The priority for a school building to move from one upgrade stage to the next is based on the results of a screening process, so that the seismic risks to school buildings can be systematically minimized sequentially. The statistical analysis results also help in the decision making for allocating budget for the seismic upgrading of school buildings.

4. CONCLUSIONS

Taiwan's plan for school building seismic evaluation and retrofitting has been carried out smoothly. The current task is to continue the work effectively, and should be evaluated to improve the quality. The most important task is to quickly finish the census of the basic seismic capacity data for all of the public elementary and high schools so that the requirements of improving the seismic capacity of all school buildings can be accomplished.

It is hoped that, by seismic evaluation and retrofitting of school buildings, the general public of Taiwan would understand the importance of seismic retrofitting. This work may be continued and extended to other existing buildings in order to create a more secure homeland in Taiwan.

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