

Strategy for Seismic Upgrading of Public School

Shyh-Jiann Hwang¹, Fu-Pei Hsiao¹, Lap-Loi Chung¹, Yeong-Kae Yeh¹, Wen-Yu Jean¹, Wen-Cheng Shen¹, Tsung-Chih Chiou¹, Te-Kuang Chow¹, Yao-Sheng Yang¹, and Yi-Feng Chao¹

¹National Center for Research on Earthquake Engineering, Taiwan
200, Sec. 3, Xinhai Rd., Taipei 10668, Taiwan, R.O.C.
sjhwang@ntu.edu.tw

Abstract

School buildings of all types of construction were seriously damaged by the 921 Chi-Chi Earthquake. Seismic evaluation and retrofit of these numerous vulnerable school buildings is an important societal issue to be resolved. The National Center for Research on Earthquake Engineering (NCREE) assisted the Ministry of Education with the arrangement of the program to accelerate the retrofit and rebuilding of elementary school, junior high school, senior high school and vocational school buildings, as part of the Economic Recovery Act. Currently, the program plans to spend 18.27 billion NTD between 2009 and 2012, and has proceeded with the seismic evaluation and retrofit of school buildings in Taiwan. In addition, NCREE established a School Project Office for this program to ensure that the work will be carried out in the most economic and effective manner. The purpose of the office is to provide administrative and technical support, and to hold training programs and workshops for school administrators and professional engineers. A three-tiered strategy for screening with existing school buildings also has been proposed by NCREE for execution of this program. This paper reports the strategy and progress of this seismic upgrading project in Taiwan.

Keywords: seismic upgrading, public school, screening

INTRODUCTION

Taiwan locates on the circum-pacific seismic zone. Earthquakes are common experiences for people in Taiwan. There were lots of severe earthquakes happened and often caused schools to be damaged seriously in the past years. In 1999, the Chi-Chi Earthquake caused nearly half of the school buildings in the affected area of Taiwan either collapsed or damaged seriously. A total of 656 primary and secondary school buildings were damaged in that earthquake. This disaster revealed that the seismic capacities of existing school buildings in Taiwan are quite insufficient. 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. To avoid casualties in the future earthquakes is the most important job in Taiwan. Retrofitting these seismically insufficient school buildings is a major solution to reduce those possible casualties.

The global economy went into a slump in 2008 as the impact of the international financial crisis spread. The whole economy has been heavily affected by this turn of events, and the unemployment rate has risen swiftly. On December 30 in 2008, the Taiwan government announced that it will directly inject NT\$858.5 billion to rescue Taiwan's economy over the next four years. The project involves 20 key public work projects and 64 special investment plans, and aims to achieve 6 major objectives. A total of NT\$500 billion will be invested under the project. The focus of the policy will be on expanding public work projects, promoting major private investment projects, and fostering developing of industries that display a high degree of competitiveness. One of these projects is about the retrofitting or reconstruction of school buildings which is superintended by the Ministry of Education. Before the retrofitting the seismic capacity of school buildings should be evaluated with a reliable method. A three-tiered strategy for screening with existing school buildings (Fig.1) was proposed by the National Center for Research on Earthquake Engineering (NCREE). These three tiers are simple survey, preliminary evaluation and detailed evaluation. Simple survey is conducted by school administration while preliminary and detailed evaluations by professional engineers.

After a stage is completed, a summary report is submitted through internet to NCREE where a data base is established (Hwang et al. 2005). Based on the statistical analysis result from the data base, decision on seismic upgrading of school buildings can be made by the executives. Moreover, it is a good reference for the engineering community. Through the processes of preliminary evaluation, detailed evaluation, retrofit design and retrofit implementation, seismic upgrading of school buildings will be completed.

SEISMIC DEFICIENCY OF PUBLIC SCHOOLS IN TAIWAN

Most school buildings in Taiwan were designed based upon the standard floor plan developed in 1966. Typically there is a corridor outside of the classrooms. The floor or roof above the corridor is often cantilevered without columns, and classrooms have been configured side by side in a row. Based on the damage statistics, a lack of seismic resistance appears to be a common problem in the existing school buildings in Taiwan. Some of the major characteristics of seismic deficiency in school buildings are: (1) lack of integral planning; (2) collapse along corridor; (3) effect of short columns; (4) imbedded pipelines; and (5) lack of transverse reinforcement.

Lack of integral planning

In Taiwan, a large number of old buildings in elementary and secondary schools appear lacking of an integral planning in advance (Chung and Hsu 2000). In stead, many old school buildings have been constructed and later on expanded in a patchy

way. It was due to the population growth in the school district and the rising of multifarious branches of teaching, the number of existing classrooms was no longer enough. Hence the school authorities had strived for funding from year to year. When the budget allowed, new classrooms were added to the existing ones in the horizontal or vertical directions at different times in order to solve the problems of under-supply of classrooms. If the new classrooms were added horizontally, the structural system of the old school building could be spoiled. If the new classrooms were built on top of the old ones, seismic and gravity load demands on the old classrooms would be significantly increased. The new classrooms expanded in the horizontal direction are rather closely adjacent, if it is not connected, to the old ones so as to maintain the continuity of activity space for pupils and teachers. Having constructed at different times, the old and the new classrooms could be different in height, weight or stiffness. Thus, the two structures may possess different fundamental vibration periods. When an earthquake occurred, the old and new classrooms would vibrate not in-phase. Under this circumstance, if the adjacent seismic gaps were not wide enough, those classrooms could have pounded each other, as shown in Fig. 2. The pounding could cause the complete failure and collapse of columns in the adjacent building.

Collapse along corridor

Most school buildings in Taiwan were designed based upon the standard floor plan developed in 1966. According to the standard floor plan, classrooms have been configured side by side in a row (Fig. 3). Typically there is a corridor outside of the classrooms. The floor or roof above the corridor is often cantilevered without columns. Transverse to the corridor, classrooms are typically partitioned by using brick walls which are continuous in the gravity direction. However, along the direction of the corridor, doors and windows have been constructed for entrance and natural light. Only small amount of walls could be continuous. The noted cantilevered corridor may be convenient for students' activities on the first floor. Thus, it often leaves only 2 reinforced concrete frames along the corridor direction. Unfortunately, these two frames typically consist of short columns. These short columns are resulted from the concrete or brick windowsill constructed between the columns. The adverse effects of the short column on the seismic performance of RC frame structures will be highlighted later in this article. Based on the worldwide observations on school building damages, there is strong evidence that school buildings tend to collapse along the corridor, as shown in Fig. 4. There seems no case recorded that school buildings collapse transverse to the corridor direction.

Effect of short columns

In order to gain lighting and ventilation, the two exterior sides of the classrooms have been built with windows and doors. At the upper portion of the columns, it is often constrained by concrete or brick lintel above the window. At the lower portion of the columns, it is typically constrained by the noted infill below the windowsill. Thus, the effective length of the column has been significantly shortened. During an earthquake, the shear demand on the shortened column is therefore greatly increased. Unfortunately, these columns have been constructed with poor concrete and without sufficient shear reinforcement. Consequently, the columns have been found frequently failed in the shear mode, with X-shape cracks commonly observed, as shown in Fig. 5. As a matter of fact, if a seismic gap had been cut between the column and the infill, the effective length of the column would not be shortened. In this manner, a more desirable flexural failure mode could be achieved. The seismic gap could be filled with compressible but watertight material.

Imbedded pipelines

Utility lines, including water supply, drainage and electricity have been embedded inside the columns, as shown in Fig. 6. Consequently, the effective area of the columns is substantially reduced. The cross-sectional area of the columns is typically about 25 to 30 cm square. After a 5-cm diameter minimum drainage pipe is embedded, the column cross-sectional area is greatly reduced. The strength of the column has been evidently reduced and was never carefully taken into account. It is obvious that a complete separate space for running the utility lines is needed.

Lack of transverse reinforcement

The spacing of column transverse steel reinforcement in many old buildings has been found exceeding 20 cm (Fig. 7(a)). Furthermore, the column transverse reinforcement is equipped with 90-degree hooks at its ends (Fig. 7(b)), which becomes ineffective after spalling of concrete cover. Transverse steel reinforcement is essential in confining core concrete, prolonging buckling of longitudinal reinforcement and prohibiting shear failure. The lack of lateral reinforcement should help to explain why the school building columns have often been failed in a brittle shear failure mode. The ductility of this kind of columns can be effectively enhanced by seismic retrofit using steel or carbon fiber jacketing.

STRATEGY AND STATISTICS OF SEISMIC UPGRADING

Three-tiered strategy for screening

In order to effectively tackle the seismic deficiency problems for school buildings in Taiwan, three tiers have been proposed for screening, including simple survey (Chung et al. 2005), preliminary evaluation (Chung et al. 2004) and detailed evaluation (Chung et al. 2008). The simple survey is conducted by school administrators. In a simple survey, a chart has been developed for collecting school data and building data. School data include street address of the school, the number and the identification of school buildings. Building data include the number of stories, the year of design or construction, condition of the building, floor dimension, number of columns and the cross-sectional dimension of the typical column in each frame, number of walls and the cross-sectional dimension of the typical wall in each frame. After the survey chart is filled, data entries are submitted through internet. Before the extensive simple survey was launched across all school districts, workshop has been held to train school administrators responsible for conducting the survey.

The seismic performance of school buildings can be evaluated from its seismic capacity to demand ratio, as shown below.

$$\frac{Capacity}{Demand} = \frac{\tau_c A_c + \tau_w A_w}{a_g \times w \times \Sigma A_f} \quad (1)$$

The seismic capacity of the school buildings is computed by superimposing the shear strength of various vertical members such as walls and columns. The seismic demand is determined from the weight and location of school buildings. The seismic performance is further modified according to the conditions of the buildings. Simple survey has been conducted by school administrators such as director of general affairs, section chief of general services, or teacher with knowledge on civil engineering or building maintenance. The information of the survey has been submitted to the computer server in NCREC through internet.

The second tier of screening, preliminary evaluation is conducted by professionals. In a preliminary evaluation, a chart has been developed for the professionals to carry out the evaluation. In addition to the identification of the school and the building, the data include design ground acceleration, number of stories, floor area above the first story, cross-sectional areas of columns, reinforced-concrete walls, four-side and three-

side bounded brick walls, and conditions of the building. The capacity to demand ratio to determine the seismic capacity of the school buildings is shown below.

$$\frac{Capacity}{Demand} = \frac{\tau_c A_c + \tau_{RCW} A_{RCW} + \tau_{BW} A_{BW}}{a_g \times w \times \Sigma A_f} \quad (2)$$

The third tier of screening is the detailed evaluation conducted by professional engineers. The push-over method using commercial computer program such as ETABS has been adopted in Taiwan. Only the third tier of screening needs the push-over analysis. Seismic retrofit design is conducted by professional engineers. Four seismic retrofit techniques for school buildings have been verified experimentally in NCREE. It includes reinforced concrete jacketing of columns, steel jacketing of columns, wing walls addition adjacent to columns and composite columns addition to partition brick walls (Chung et al. 2008), as shown in Fig. 8.

The proposed strategy of seismic evaluation and retrofit of these school buildings has been accepted and implemented by the Ministry of Education. It has been recommended by NCREE research team that detailed evaluation and retrofit design of a school building be conducted by the same professional engineer so that the responsibility can be clearly defined. Moreover, it is also suggested that the detailed evaluation and retrofit design must be reviewed by a panel so that the engineering work quality can be guaranteed. In the final stage of retrofit construction, inspection has been prescribed.

Statistics of seismic database for school buildings in Taiwan

In Taiwan, there are 3,497 elementary and junior high schools. Among them, 3,419 schools (about 98%) completed the simple survey and submitted school data and building data to NCREE. The data base possesses data for 12,650 school buildings and the data for 11,060 school buildings (about 87%) are valid.

According to the statistics analysis, the means of the length and depth for the floor plans of school buildings are 52.9m and 11.5m, respectively. The mean of the number of stories for school buildings is 2.8. The mean of the floor area of the first floor for school buildings is 616m². The mean of the spans along the corridor for school buildings is 4.0m. The mean of the ratio of column area to floor area for school buildings is 57.0cm²/m². The seismic design codes of buildings were revised in 1982 and 1997. 39% of school buildings were built before 1982, 41% between 1982 and 1997, 15% after 1997 and 5% unknown. 80% of the school buildings scored with fundamental seismic performance less than 80, 18% between 80 and 100, 38% above 100. After consideration of the conditions for the school buildings through modification factor, 55% of the school buildings scored with seismic performance indices less than 80, 16% between 80 and 100, 29% above 100.

ACTIVITIES IN SEISMIC UPGRADING PROJECT

School buildings of all types of construction were seriously damaged by the 921 Chi-Chi earthquake. Soon after, NCREE started to develop technologies for seismic evaluation and retrofit. As a result of the achievements of laboratory and in-situ experiments, NCREE developed several seismic technologies, including a simple survey method, a preliminary evaluation process, a detailed evaluation process, and a retrofit design method. NCREE then used these research results in their "Technology Handbook for Seismic Evaluation and Retrofit of School Buildings (Chung et al. 2008)." By holding training programs and workshops, NCREE provides professional training in those technologies to school administrators and professional engineers in Taiwan.

During the past several years, NCREE assisted the Ministry of Education with establishing a seismic database for the assessment and retrofit of school buildings, and with collecting basic information as well as the results of the evaluation and

retrofitting for all school buildings in Taiwan. By establishing the actual seismic capacity of all school buildings in Taiwan, this internet database has become the foundation of the plan for their seismic capacity improvement. In addition, NCREE assisted the Ministry of Education with the arrangement of the program to accelerate the retrofit and rebuilding of elementary school, junior high school, senior high school and vocational school buildings, as part of the Economic Recovery Act. Currently, the program plans to spend 18.27 billion NTD between 2009 and 2012 (Table 1), and has proceeded with the seismic evaluation and retrofit of elementary school, junior high school, senior high school and vocational school buildings in Taiwan (Table 2). In addition, NCREE established a School Project Office for this program to ensure that the work will be carried out in the most economic and effective manner. The purpose of the office is to provide administrative and technical support, and to hold training programs and workshops for school administrators and professional engineers. To date, NCREE has held 41 training programs since 2009, including preliminary evaluations, detailed evaluations, retrofit designs and review committee conferences (with 3,833 people participating). NCREE also held 16 training workshops, authored and produced a technology handbook, developed a seismic evaluation method (Capacity Spectrum Method) and developed seismic rehabilitation method for school buildings, in cooperation with 1,721 professionals. Finally, NCREE assisted the Ministry of Education with conducting 3,432 peer reviews of retrofit designs, with 1,638 school buildings passing the final reviews (Table 3). Of these, 626 buildings have completed their retrofit. Additionally, six observation/evaluation workshops held in Wan-Fang elementary school, Da-Tong elementary school, Bei-Bin elementary school, Hai-Shan vocational school and 921 Earthquake Museum by NCREE showcased the advantages of retrofit implementation (with 914 school teachers participating).

CONCLUSIONS

In Taiwan, the Ministry of Education has launched a project on upgrading the seismic performance from 2009 to 2012. A three-tiered strategy for screening with existing school buildings has been proposed by NCREE. These three tiers are simple survey, preliminary evaluation and detailed evaluation. Preliminary evaluation of school buildings is conducted in sequence according to the seismic performance indices of school buildings from simple survey. Detailed evaluation of school buildings is carried out in sequence according to the seismic performance indices of school buildings from preliminary evaluation. Retrofit design and implementation of school buildings are executed in sequence according to the capacity and demand ratios from detailed evaluation. In this project, thousands of school buildings will be benefitted through the processes of preliminary evaluation, detailed evaluation, retrofit design and retrofit implementation to compete against the next seismic hazard.

Table 1: Budgets (in million NTD)

Year	2009	2010	2011	2012
Preliminary Evaluation	36	-	-	-
Detailed Evaluation	238	306	135	99
Retrofit Design	71	162	70	32
Retrofit Implementation	3155	4032	1795	1469

Table 2: Number of School Buildings in Various Stages

Year	2009	2010	2011	2012
Preliminary Evaluation	6,000	-	-	-
Detailed Evaluation	660	850	375	276
Retrofit Design	198	450	195	88
Retrofit Implementation	171	420	187	153

Table 3: Achieved Percentage of Scheduled Progress

	Targeted Buildings	Implemented Buildings	Completeness Ratio
Preliminary Evaluation	6,000	8,551	142.5%
Detailed Evaluation	3,061	4,035	131.8%
Retrofit Design	1,513	1,638	108.3%
Retrofit Implementation	1,513	626	41.4%

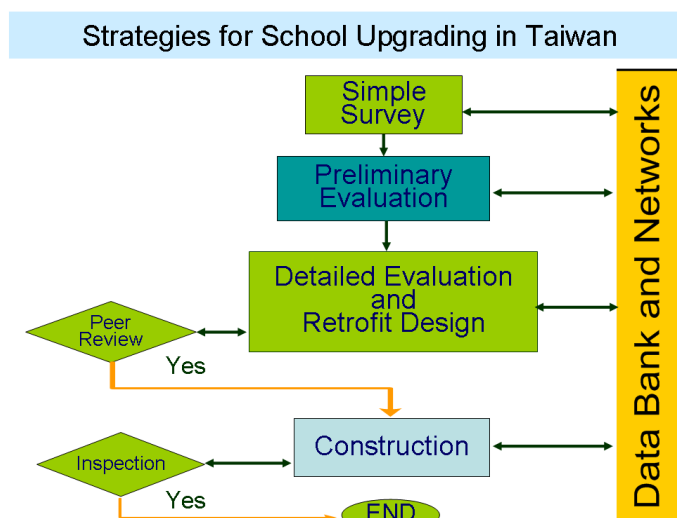


Fig. 1: Strategy of Screening Buildings

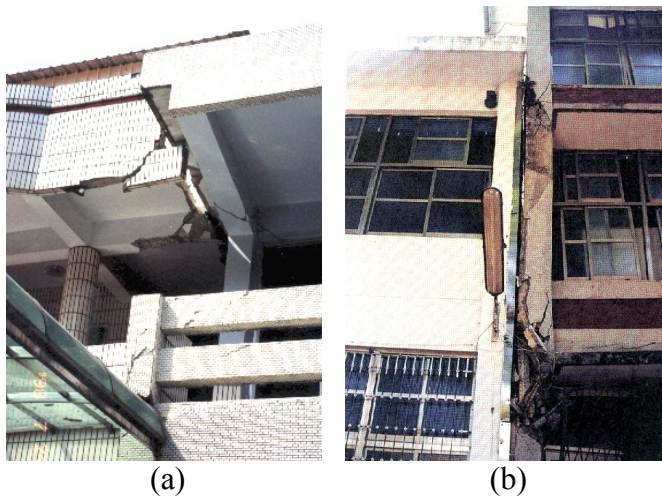


Fig. 2: Pounding of Adjacent Buildings

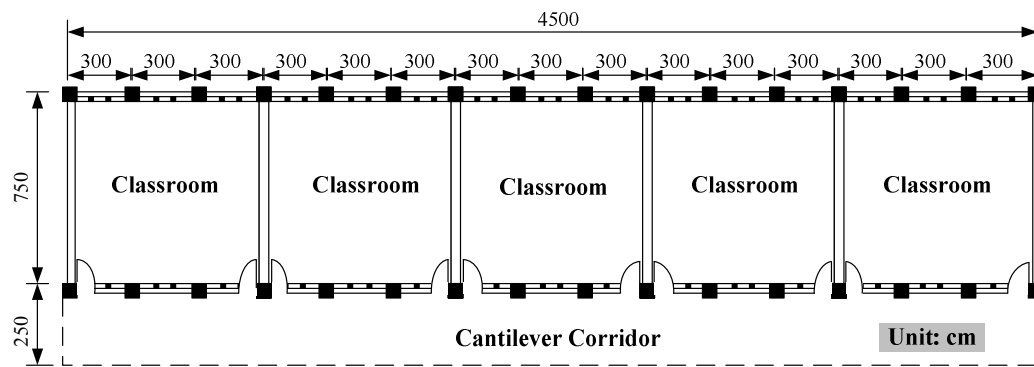


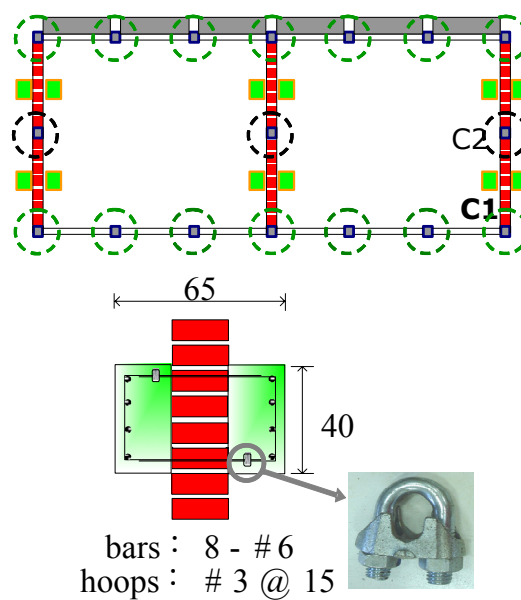
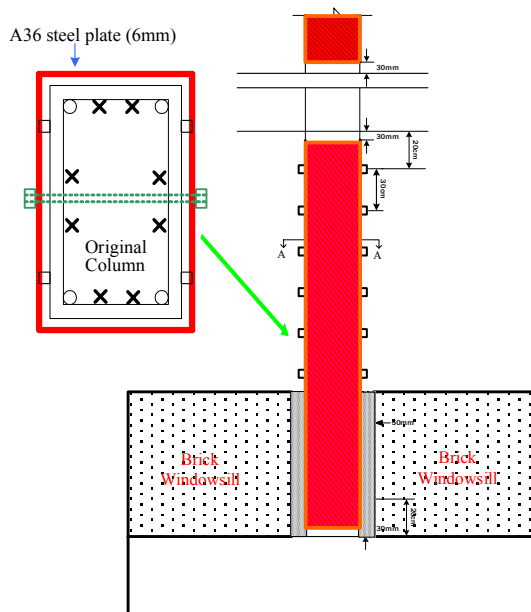
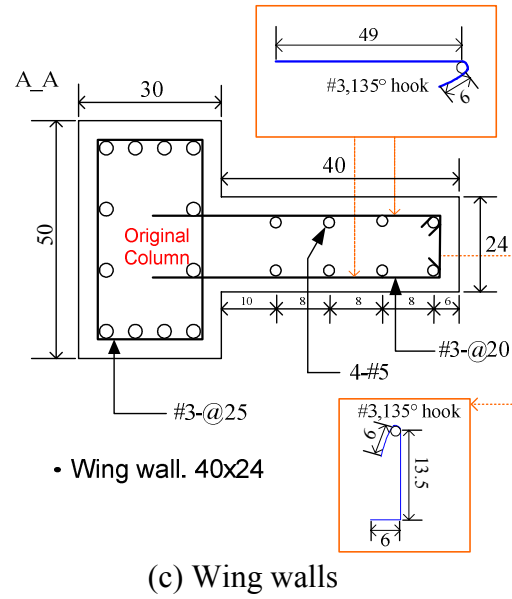
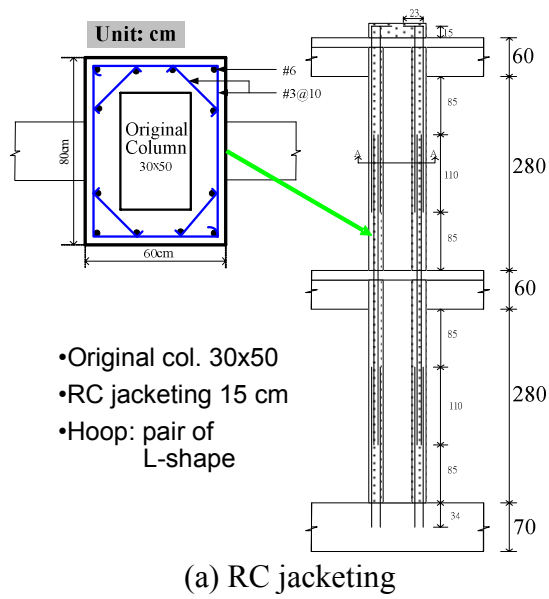
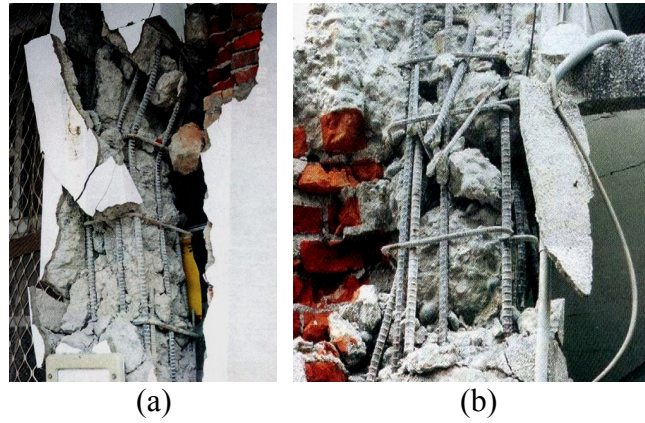
Fig. 3: Typical Plan of School Buildings



Fig. 4: Buildings Collapse along the Corridor



Fig. 5: Failure of Captive Columns



(b) Steel jacketing

Fig. 8: Retrofit Techniques for School Buildings

References

- Chung, L. L. and Hsu, T. Y., (2000). Seismic damage of school buildings in Taiwan, Proceedings of First International Conference on Structural Stability and Dynamics. Taipei, Taiwan, pp. 647-652. (in Chinese)
- Chung, L. L., Sheu, D. Y., Jean, W. Y., Liao, W. I., Chiu, C. K., and Chow, T. K., (2004). Preliminary seismic evaluation of primary and secondary school buildings. International Conference in Commemoration of 5th Anniversary of the 1999 Chi-Chi Earthquake, Taiwan, pp. 100. (in Chinese)
- Chung, L. L., Chien, W. Y., Yeh, Y. K., Hwang, S. J. and Sher, C. W., (2005). Simple Seismic Survey for Typical Building Structures of Primary and Secondary Schools. NCREC Report, NCREC-05-007. (In Chinese)
- Chung, L. L., Yeh, Y. K., Chien, W. Y., Chai, J. F., Hsiao, F. P., Shen, W. C., Chiou, T. C., Chow, T. K., Chao, Y. F., Yang, Y. S. and Hwang, S. J., (2008). Technology Handbook for Seismic Evaluation and Retrofit of School Buildings. NCREC Report, NCREC-08-023. (In Chinese)
- Hwang, S. J., Yeh, Y. K., Chung, L. L., Jiang, W. G., Chien, W. Y., Chen, H. M., Chao, Y. F., Chow, T. K., Shen, W. C. and Kao, W. K., (2008). Database for Seismic Assessment and Retrofit of School Buildings. NCREC Report, NCREC-08-035. (In Chinese)