IN-SITU TEST OF SCHOOL BUILDING STRUCTURE IN TAIWAN

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ABSTRACT

The 1999 Chi-Chi earthquake revealed the poor performance of the RC school buildings in Taiwan. It also indicates an urgent need of seismic evaluation and retrofit for the remaining schools. In order to realize the behavior of a typical school building subjected to lateral load, an in-situ test for an existing 2-story school building was carried out. Two experiments were conducted: static push over test to identify the strength, stiffness and toughness of the building, and vertical load test to study the vertical load carrying mechanism after part of members failed. In the static push over test, a 6-classroom building constructed in 1964 was cut in the middle where jack was set for monotonic loading alone the longer axis of building. One half of this building was reinforced by steel bracings to provide reaction support, while the other half was pushed to failure. The vertical load test employed only one of the classrooms. Inner columns of 1F of the classroom were cut off in the middle to simulate that they are failed prior due to the short-column effect. The remaining frames with thick brick in-filled walls as partitions were expected to carry the weight of and prevent collapse. Water was added into two tanks set at the 2F and RF slabs as vertical loading. Results of these tests are reported, analyzed and interpreted in this paper.

INTRODUCTION

In Taiwan, many typical school buildings suffered severe damage by the Chi-Chi earthquake, 1999. Most of old school buildings were designed according to a standard plan that is functional for getting natural light and ventilation. The typical plan has all the openings and a

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corridor in the longitudinal direction and many partition walls in the transverse direction. Some common failure patterns were found because of the typical type of school buildings, such as failure in the longitudinal direction due to lack of walls, short-column effect due to constrain by windowsills, and strong-beam-weak-column effect due to non-ductile reinforcement and slabs that connect with the beams. For preventing possible damage in the future, it is urgent to develop the seismic assessment and retrofit technology for the existing schools. Although there are already some assessment methods developed by international researchers, usually they are verified by small -scale or partial structural assemblages but not full-scale structure. It is still questionable that if test results in the laboratory can represent the true behavior of actual buildings. Therefore, an in-situ push over test of an existing school building is carried out for realizing the real structural behavior.

Indebted to the Hualien County Government and Hsin-Cheng junior high school, the research team composed of crews of the National Center for Research on Earthquake Engineering (NCREE), the National Taiwan University of Science and Technology (NTUST), the Dahan Institute of Technology (DHIT) and the National Taiwan University (NTU) were allowed to use an old school building that is about to be demolished as the subject of push over test. Except for providing verification for seismic assessment and retrofit technology, this test also gives further understanding of seismic ability of existing school buildings.

DESCRIPTION OF THE TEST

The site plan of Hsin-Cheng junior high school is shown in Fig. 1. The specimen is one of the buildings parallel to each other. The building with 2 floors contains 6 classrooms and a hallway in the middle. Longitudinal axis of the building is in North-South direction. The oldest part of the test building was originally built in 1966. Its main structure is made of reinforced concrete

(RC), but the partitions and windowsills are made of 1-brick-thick brick walls. The building had no visible damage before the test, as shown in Fig. 2.

There are two primary tests: push over test and vertical load test, prepared and executed from January 20th to 29th, 2005. The north half of the building was used as the specimen of push over test. After the push over test, one classroom of the south half was then used as the specimen of vertical load test. Details of description of the two tests are as below.

PUSH OVER TEST

Test Desciption

Fig. 3 shows the layout of the push over test. Three classrooms at the north half of the subject building was cut apart from the south half to be pushed over. Fig. 4 shows the structural plan of the specimen. Each 10m wide classroom is consist of 3 spans, lies along the longitudinal direction. About half of the columns in B-frame and all the columns in D-frame have 90-110cm high windowsills that usually cause the short-column effect besides them. Short-column effect happens because the column constrained by windowsills that were not considered in design, effective height of the column is then shortened and cause larger shear stress or even shear failure. However, since the specimen is higher (1F: 3.9m, 2F: 3.6m) then ordinary school building, the effects of short columns here are not really severe.

Three 150t and three 300t hydraulic actuators were set at the cut beam end of A, B, and D frames of 1F and 2F, respectively. They were designed to push the specimen in its weak axis. Behind the actuators, 2 spans of the south classroom were reinforced by added steel bracings to provide reacting support. Fig. 5 shows the actuator and steel bracings.

During the test, the actuators were controlled through their cylinder areas to keep the loading put on 1F and 2F being 1:2, which is the proportion of lateral load distributed by the fundamental mode. The loading was monotonic, but in every 0.05% drift, the actuators were hold for 15-20 minutes, so that the staff can mark cracks and record the damage condition. The specimen was loaded until it's strength descended to 67% of the maximum strength. For preventing doing any harm to the neighbor in the north side and safety of the staff, two steel supports were set in the classrooms in 1F to prevent complete collapse of the specimen.

Instrumentations for story displacement, member rotation, and shear deformation at beam-column joints were set. Fig. 6 shows the position of primary displacement gauges, they were set at both side of specimen and actuators in case of the reacting part moves contrarily.

Test Result

Fig. 7 shows the final scene of the specimen at a roof drift ratio of about 4%. However, most deformation happened at 1F, while the 2F seemed remain undamaged, so the drift ratio at 1F was actually nearly 8%. Fig. 8 shows the push over curve of the specimen. The maximum base shear P is 2915kN when the roof displacement Δ_2 reached 150mm. Some indentations showed when the actuators were hold for recording damages, however the shape of curve is still smooth and shows very good ductility.

As shown in Fig. 7, the normal columns at A-frame obviously failed by flexural bending and concrete at the compressive side crushed. Other normal columns in B-frame showed the same failure pattern. Otherwise, the short columns mostly failed by both bending and shear. Both horizontal and diagonal cracks showed in these columns' ends, as shown in Fig. 9. The diagonal cracks caused by shear stress show that the short-column effect did happened. While all of the columns had failed, the beams and slab still remained almost undamaged. This phenomenon, so-called strong-beam-weak-column, was also found in those school buildings damaged by the Chi-Chi earthquake.

Strengths of the materials sampled from different height of columns were found to be scattered and irregular. The average compressive strengths of concrete are 23.3MPa in 2F and 21.8MPa in 1F, while yielding strength of steels are distributed between 314 and 480MPa.

VERTICAL LOAD TEST

Test Description

Objective of vertical load test is to know that if a school building still has vertical sustainability after the prior failure of short columns. So as shown in Fig. 10(a), a classroom of the south half of the subject building was chosen to be the specimen. Six inner columns were cut off in the middle, and the other 6 ones with the partitions were left to simulate the situation that part of columns has been failed by short-column effect. The vertical load is supposed to be carried by the beams and passed on to the remaining partition walls and columns, as shown in Fig. 10(b). Two tanks were set on top of 1F and 2F, where water would be added as vertical loading. A draw-line gauge was set under the center of 1F slab to measure its sag.

Test Result

It took two days to fill the tanks, but even though the two tanks were both filled, beams and slab of 1F were only slight cracked, as shown in Fig. 11. Most cracks closed after unloaded; apparently the steels in them still remained elastic. Fig. 12 shows the progress of loading and sag of 1F slab. Because of errors in water line reading, the curve is not very smooth. But it's clear that loading at 2F top has less influence on the sag of 1F slab then loading at 1F top does, probably due to the participation of 2F beams and columns. The specimen sustained 105 tons of extra loads, which are about 1.5 times of its self-weight. The test result shows that brick partition walls may be a useful support against vertical failure.

COMPARISON OF TEST RESULT AND ANALYTICAL METHOD

An analytical method, simplified push over method (Tu 2004), is employed to calculate the analytical push over curve for comparison with test result. This method was developed according to the strong-beam-weak-column behavior of typical low-rise RC buildings in Taiwan. Base on the behavior, it is assumed that the beam and slab are rigid and seldom fail. So the structure deforms like a shear building, and the story shear strength is provided by vertical members only, as shown in Fig. 13. Since a rigid slab means all the vertical members connected to the slab must have a common deflection at the same time, the story shear can be obtained by superposing shear forces of every vertical member at a certain deflection. Then, by assuming that the vertical distribution of horizontal load and shear building deformation, base shear and roof displacement can be get.

Fig. 14 shows the comparison between test and analytical result. The analytical prediction about failure mode of columns corresponds with the test result. But the analytical push over curve obviously underestimates the strength and stiffness of the specimen. A possible reason of the error is the out-of-plane contribution by the partition brick walls. As shown in Fig. 15, the brick partition walls connected to the columns tightly and seemed provide some out-of-plane strength. But the out-of-plane behavior of brick wall still remains to be studied.

CONCLUSION

In-situ test provides a precious chance to realize the behavior of a real building and to verify the analytical methods. The push over test result confirmed the damaging behavior of school buildings observed in the Chi-Chi earthquake. Typical failing characteristics of school buildings, such as short-column effect and strong-beam-weak-column behavior, did happen to the specimen.

The experimental push over curve shows well ductility and strength more than expected. An analytical method is compared to the test result and shows conservative outcome. The vertical load test result shows that beam and slab are strong enough to sustain the vertical load after part of columns failed and pass the load on to the remaining partition frames. Results of the two tests show that the brick partition walls might be able to provide not only vertical support but also out-of-plane strength.

Further research subjects would include study on out-of-plane behavior of brick walls, retrofit measures for resisting horizontal and vertical loads, and improving the analytical method.

ACKNOWLEDGEMENT

The authors appreciate the National Science Council and Ministry of Education for sponsor the test, the Hualien County Government and Hsin-Cheng junior high school for providing so much help, the staff and students from NCREE, NTUST, DHIT and NTU for their contribution.

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Tu, Y. H.(2004), "Shaking Table Test and Seismic Analysis of RC School Building Structures," PhD dissertation, National Cheng-Kung University, Tainan, Taiwan.

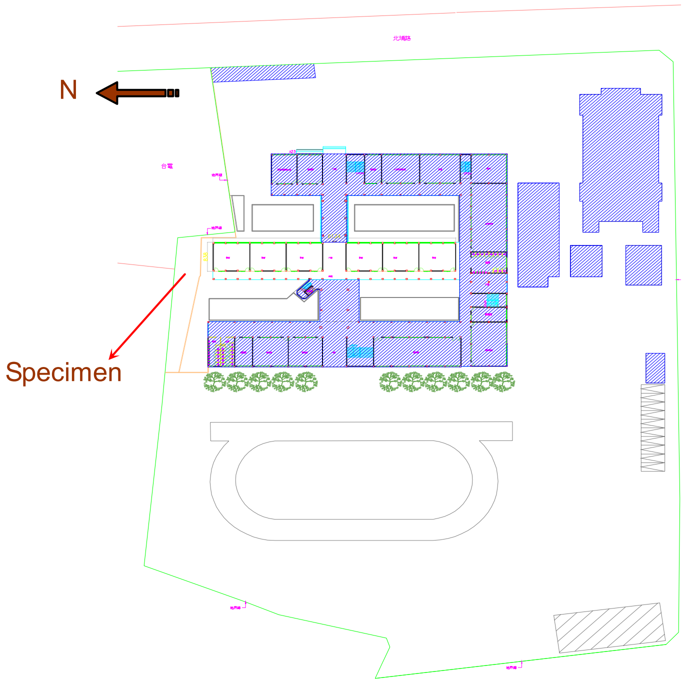
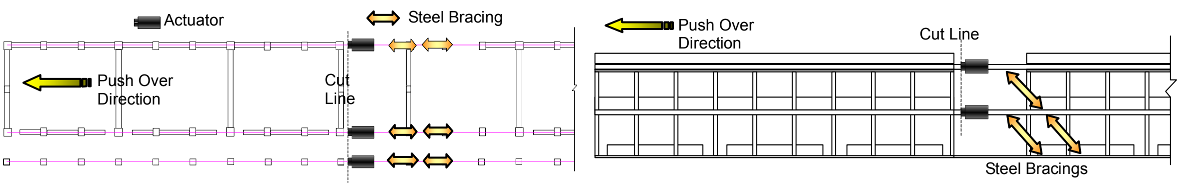


Fig. 1 Site plan of Hsin-Cheng junior high school, Hualien

Fig. 2 Pictures of the subject building



(a) Plan

(b) Elevation

Fig. 3 Test layout

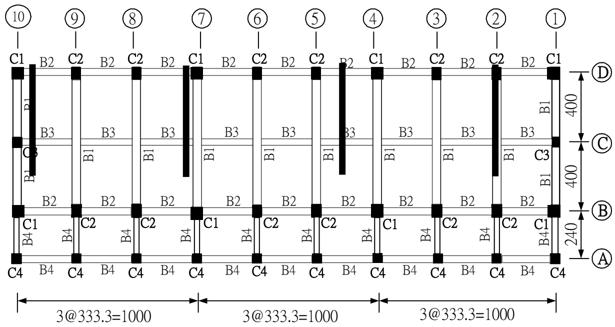
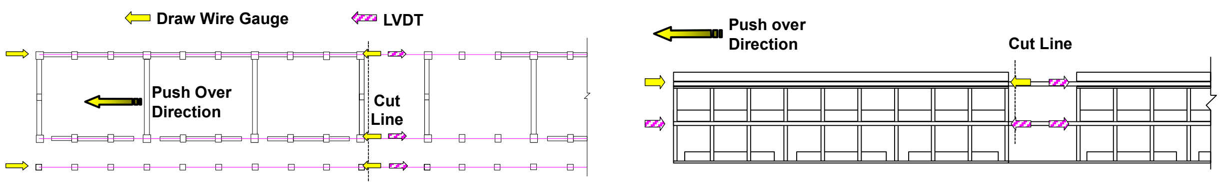


Fig. 4 Structural plan of the specimen of push over test

(a) Set up of actuator (b) Steel bracings

Fig. 5 Actuator and steel bracings



(a) Plan (b) Elevation

Fig. 6 Layout of Instrumentation

Fig. 7 Specimen: after the test

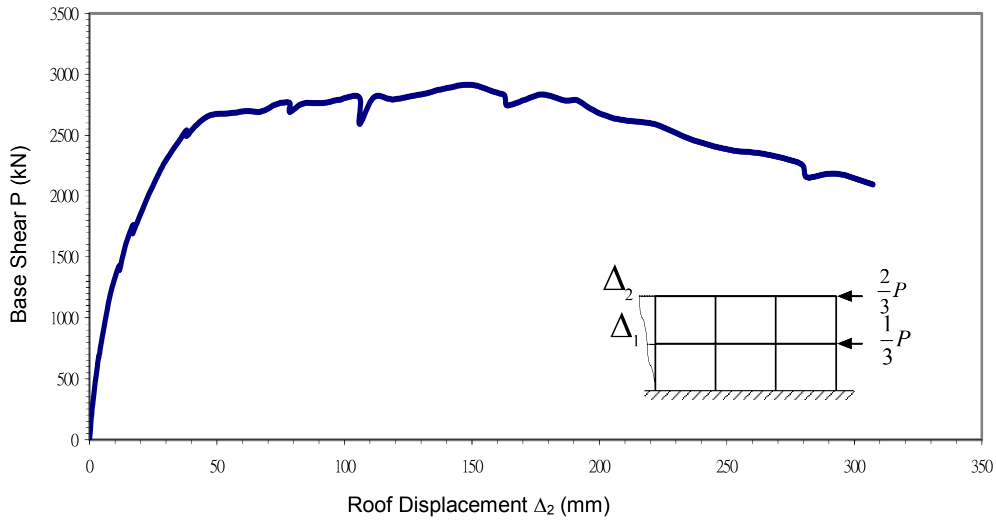
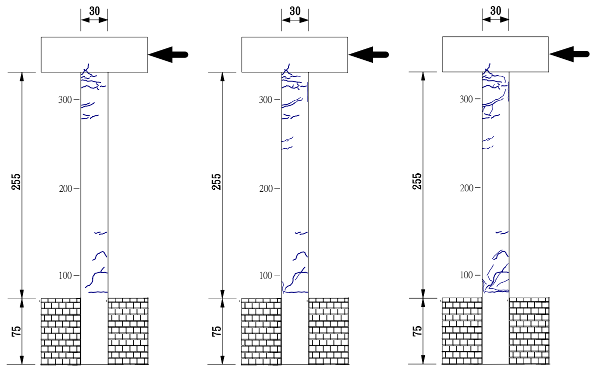
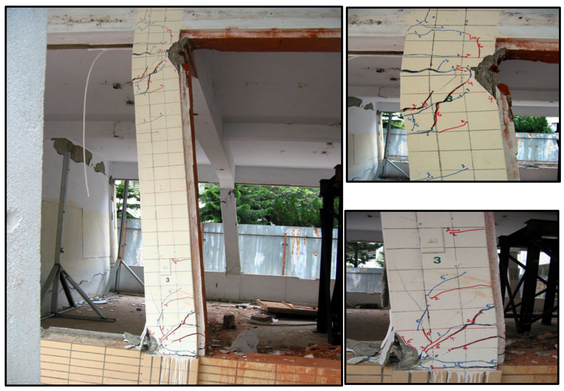


Fig. 8 Push over curve of the specimen



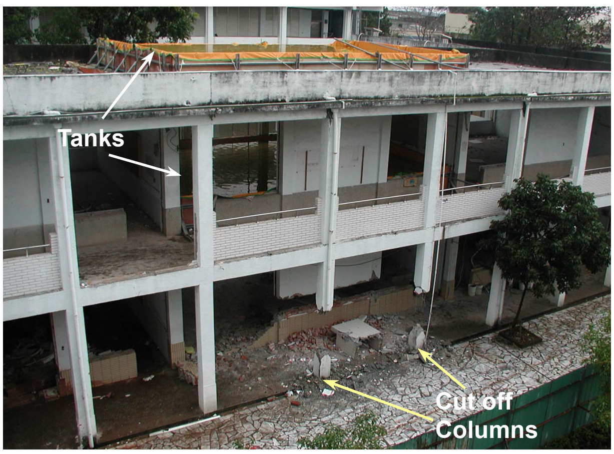
Drift=0.5% Drift=1% Drift=2%

(a) Crack development

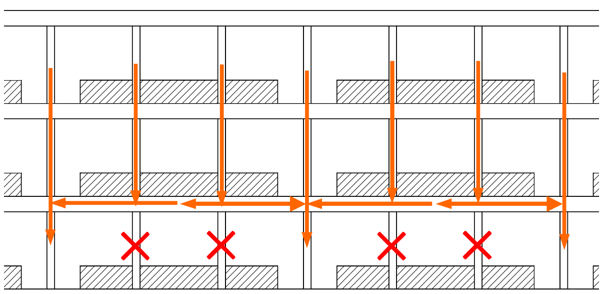


(b) Picture of final stage

Fig. 9 Column failed by bending-shear



(a) Specimen



(b) Expected vertical stress flow

Fig. 10 Vertical load test

Fig. 11　Cracked beams after the vertical load test

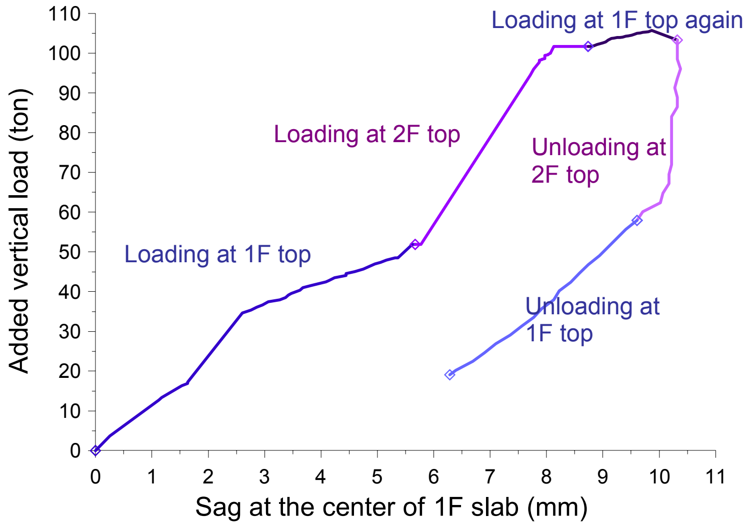


Fig. 12　Relationship between vertical loading and sag at the center of 1F slab

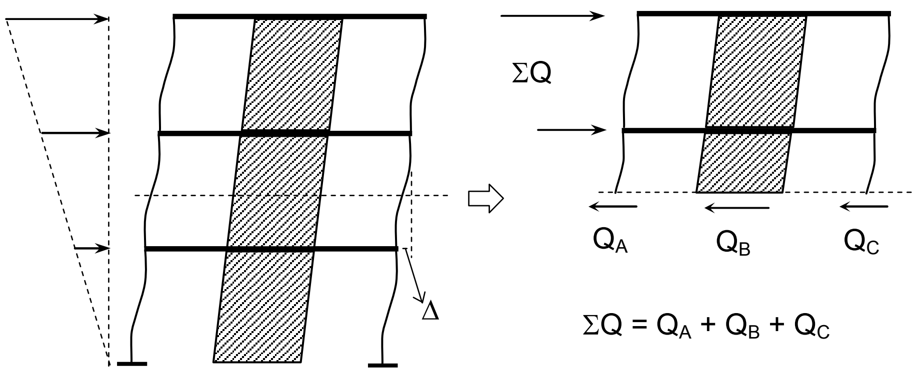


Fig. 13　Concept of calculation story shear by simplified push over method

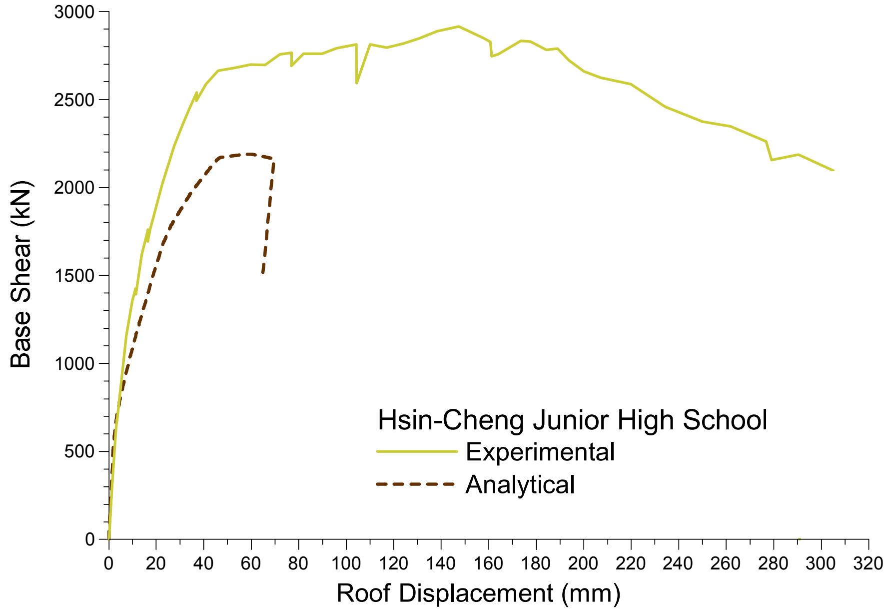


Fig. 14 Comparison of test and analytical push over curve

Fig. 15 Brick partition wall deflected in out-of-plane direction