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SEISMIC CAPACITY EVALUATION OF KOUHU ELEMENTARY SCHOOL BUILDINGS

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ABSTRACT

In order to understand seismic capacity of early built primary and secondary school buildings correctly, in Aug. 2005, NCREE performed three in-situ pushover tests in Kouhu Elementary School at Yunlin County, including one original frame and the other two frames retrofitted with either RC walls or brick walls. Before the test, a competition was announced to encourage individuals to evaluate seismic capacity of these frames numerically. In this paper, the champion work is presented. The paper focuses on how to use nonlinear static analysis to evaluate traditional elementary school buildings including the assumptions used in the analysis such as material properties and its degradation, RC wall simulation, hinge properties assignment, member failure mechanism, etc. By comparing the capacity curve and the failure modes of the test and numerical results, it is shown that all numerical results are close to the test results. Some member failure behavior is difficult to simulate using the widely used analytical package. Finally, suggestions on possible improvement are made.

Keywords: Seismic capacity evaluation, School building, Pushover

INTRODUCTION

Evidence from Ruei-Li and Chichi earthquake indicated that early built primary and secondary school buildings in Taiwan were most seriously damaged. It is an urgent task to assess seismic performance of existing school buildings with and without retrofit so that the young generation will be well protected. Therefore, in Aug. 2005, National Center for Research on Earthquake Engineering (NCREE) performed three in-situ pushover tests in Kouhu Elementary School at Yunlin County, including one original frame and the other two frames retrofitted with either RC wing walls or brick wing walls. The applied lateral load pattern is shown in Fig.1. The brick wing wall building was pushed first (Fig. 2). Before other two tests, a competition was announced to encourage individuals to evaluate seismic capacity and predict the damage mechanism of the other two frames numerically. The one who obtains the closest results to the experiment will win the championship. This paper presents the champion work of this competition with focus on the geometry and material properties assignment, model simulation, hinge properties assumption, etc. It is our hope that this paper will be helpful for engineers to evaluate seismic performance of such school buildings as actually as possibly.

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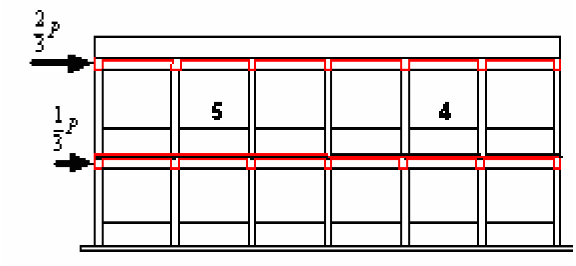


Figure 1. Pushover Test Load Pattern

Figure 2. The Retrofitted Brick Wall Frame Test

SEISMIC EVALUATION OF EXISTING SCHOOL BUILDING

Pushover analyses presented in this study are performed using the ETABS 8.4.8 nonlinear version[1]. Other nonlinear (FEM software, such as SAP2000[2], PISA3D[3], DRAIN2D+[4] etc.) analysis packages are also applicable. Correct structural modeling is more important than choosing of a complicated but accurate analysis tool.

Geometry and Material Properties

Most data associated with structural layout, member sizing and material property have been provided by the organizers. Since this building was built in 1963, there were not enough original design data including material properties, member sizing and detailing, etc. It is necessary to make some reasonable assumptions and engineering judgments during the analysis.

- Building dimensions are obtained from the field measurement.
- Concrete compression strength $f_c^{'}$ is estimated through tests of coring specimen.
- Steel rebar yielding strength f_y is assumed according to existing research reports [5][6], which provided the average value of f_y for the same type of primary schools of the same age. According to the corrosion rate test of the beam steel rebar, yielding strength f_y for reinforcement of the first and second floors are taken as 60% and 80% of the original value, respectively.
- Standard material properties of brick are used.

ETABS model and Hinge Properties

A column enhanced with windowsill is treated as two different columns separated by the interface. A column enhanced by either RC wing walls or windowsill is simulated as a single equivalent column element using composite section properties. Restraint and boundary condition of this equivalent element ought to be set properly to fit the real structure behavior. Partition walls with brick material are simulated with shell element in order to perform out-of-plane stiffness. For lack of proper modeling of nonlinear behavior of shell elements in ETABS, the stiffness and strength of such elements must be reduced properly to account for cracking effect. The ETABS model of RC wing wall specimen is shown in Fig. 3.

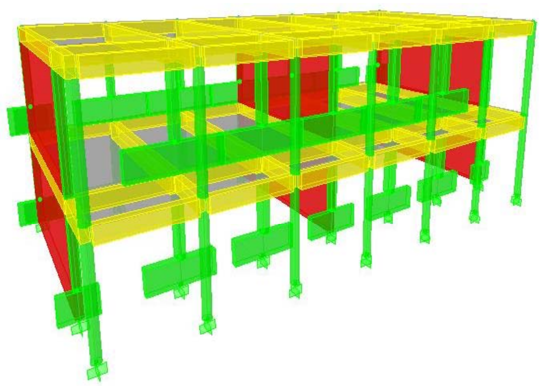
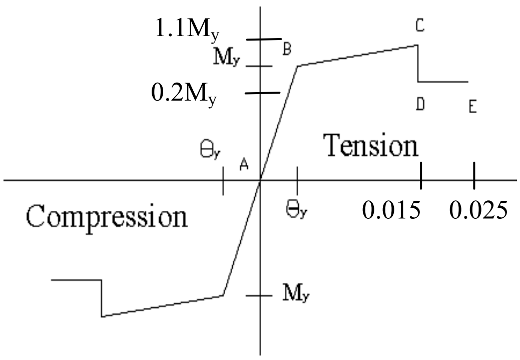


Figure 3. ETABS Model

According to ATC-40[7], NCREE report [6] and engineering judgments, the following structural and member behavior are assumed. The behavior of the traditional low-rise school buildings in Taiwan could be considered as shear frames. Therefore, all beam elements are assumed to be elastic in this analysis. Column elements without wall enhancement are assumed to have flexure failure mechanism at both ends and shear failure mechanism in the middle of the column. The column flexure failure mechanism is simulated by the default PMM hinge property (Fig 4) in ETABS, which uses the average data of Table 9.6 "Modeling Parameters for Nonlinear Procedures" of ATC-40. Shear failure mechanism is simulated by the user-defined V2 hinge property in ETABS. Shear yielding strength is taken as $V_y = 0.93\sqrt{f_c^{'}}A + A_v f_y \frac{d}{s}$ instead of the code suggested value to obtain an actual seismic capacity instead of a conservative one. The residual strength is $0.2V_y$. The plastic rotation θ_D is 1.5% and the failure rotation θ_E is 3% as shown in Fig5. Column elements enhanced with RC wall are assumed to have shear failure mechanism in the middle of the equivalent column. They are simulated by similar V2 hinge properties as above with θ_D equals to 1.0% and θ_E equals to 3% (Fig. 5). Column elements associated with windowsill enhancement are assumed to keep elastic.



ETABS calculates M_y and θ_y automatically

Figure 4. ETABS default PMM Hinge

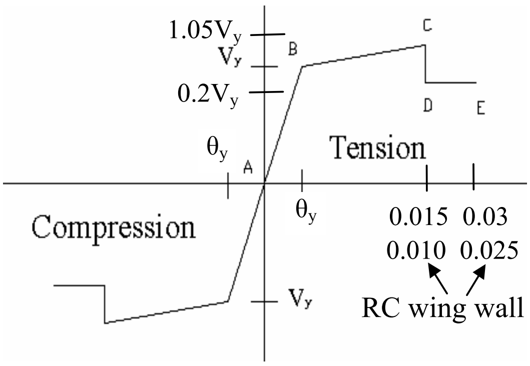


Figure 5. ETABS user-defined V2 Hinge

PUSHOVER CAPACITY CURVE COMPARISON

Figs. 6 and 7 illustrate comparison of the analytical results with the test values in terms of base shear versus interstory drift ratio regarding the bare frame and the RC wing wall retrofitted frame, respectively. Almost all analytical initial stiffness, ultimate strength and ductility agree well with the experimental values and are relatively conservative. However, the predicted ultimate strength of the RC wing wall frame has been somewhat overestimated.

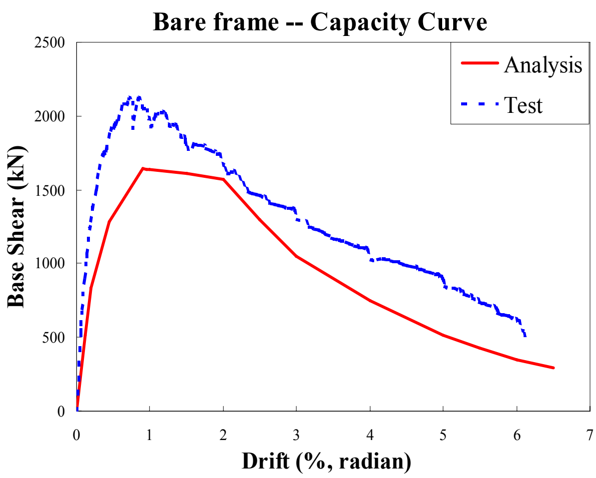


Figure 6. Bare Frame Capacity Curve

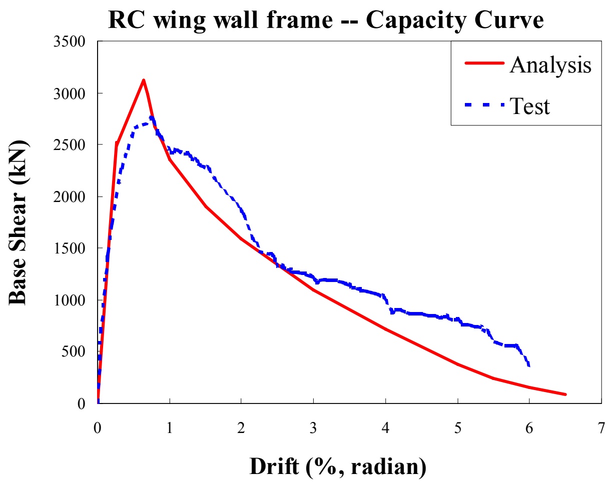


Figure 7. RC wing wall Frame Capacity Curve

According to the test results, after base shear reached the peak value, the structure experience nearly 10 times of displacement before collapse and the maximum story drift ratio can come to 6%. It is hard to trace a perfect down loading part of the capacity curve using this analytical package because structure behavior is complicated and unpredictable under real earthquake due to a lot of uncertainties. The residual strength and the member ductility are usually conservative in the analysis model, such as ATC-40 and FEMA356. In addition, using ETABS pushover analysis to simulate this type of frame strength degradation behavior correctly is also difficult. For competition purpose, accuracy of the residual strength should not be neglected. Some non-numerical methods have to be used. Although nobody could know the ductility of this kind of building is so good before testing, results of the previously pushed brick wing wall experiment serves as very good reference and provide helpful information because it represented the practical experience about this kind of test. Accordingly, the down loading part of the capacity curve is predicted through inference.

FAILURE MODE PREDICTION

From the failure modes of these tests (Fig.8a,8b,8c), these low-rise school buildings acted as shear frames. All failure occurred in the first floor owing to the larger shear force than second floor. Beam elements were all kept elastic due to the extra high rigidity of the floor slabs. The global failure mode from ETABS nonlinear pushover analysis seems to be same with test result (Fig.9). With V2 and PMM hinge assignment, elastic behavior, shear failure in the middle or flexural failure at both ends of column elements not constrained by wing wall or windowsill can be captured in the analysis. Fig.10 (picture A,B,C,D,E,F) represent these phenomena in the tests, the analysis results almost match the test results. Column elements constrained by windowsill remain elastic in the test that was in accordance with our expectation. It has been found that the columns constrained by the infill wall were also elastic (Fig.10 B,F). The infill walls and floor slabs should provide the frame structure with considerable stiffness and lateral resistance.

Figure 8a. Bare Frame Failure

Figure 8b. RC wing wall Frame Failure

Figure 8c. Brick wing wall Frame Failure

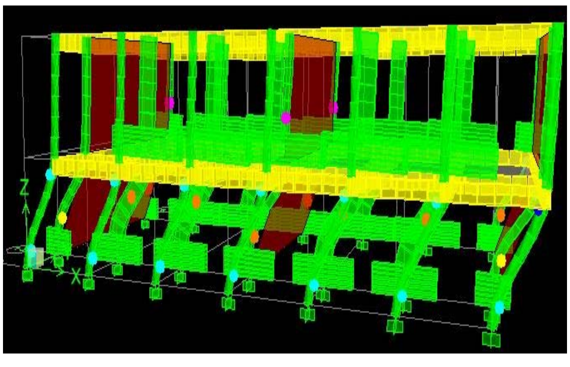


Figure 9. ETABS Pushover Failure

A B C D E F G

Bare Frame RC wing wall Frame

Figure 10. Column Failure Types

The plastic hinges occurred at the ends of first-story columns. The extremely high rigidity of the floor slabs constrained the girder from further deformation. As a result, the test model failed in column sway mechanism.

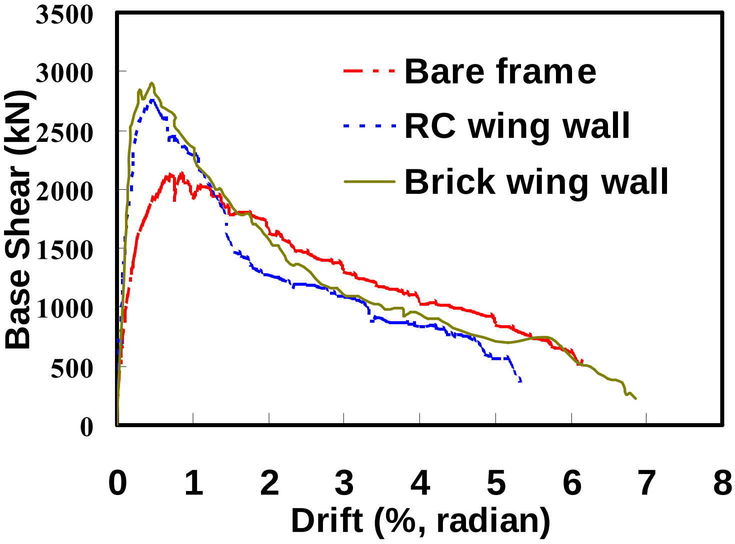


Figure 11. Test Capacity Curves Comparison

CONCLUSIONS

Seismic evaluation of existing buildings must be carried on with well understanding of structural present situation. Collecting enough data, theoretical foundation, engineering judgment and experience are all very important. The lateral load pattern is known in this test. Because different load pattern will influence the seismic evaluation results seriously, it should be noted that the structure behavior under this load pattern might not represent the true behavior in the earthquake.

The ultimate strength and ductility from the test results are higher or better than what the majority competitor have obtained numerically. The behavior of infill partition wall and the floor slabs need to be considered in further studies. Even though the infill walls and floor slabs were only considered for mass contribution during design, they provide the frame structure with considerable stiffness and lateral resistance. Furthermore, according to the capacity curves of the three tests(Fig.11), school buildings retrofitted with additional brick walls or RC wing walls seem only to increase the ultimate strength, how to improve the ductility of structures is the important direction in the future studies.

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