USING THE STATIC PUSHOVER PROCEDURES IN PISA4SB FOR APPLICATIONS IN THE TAIWAN SCHOOL BUILDING SEISMIC RETROFIT PROGRAM

VICKI P LAI
Undergraduate, Department of Structural Engineering
University of California, San Diego, U.S.A

ABSTRACT

The National Center for Research on Earthquake Engineering (NCREE) has developed a customized program, the Platform for Inelastic Structural Analysis of School Buildings (PISA4SB), for the implementation of static pushover procedures for the detailed seismic evaluation of school buildings. PISA4SB allows the user to construct analytical models for typical low-rise school buildings in Taiwan. A nonlinear static pushover analysis is conducted on the model and the resulting capacity curve of the structure can be found. The process of evaluating a building using PISA4SB and the comparative results of PISA4SB to analytical results using the software ETABS is discussed.

1. INTRODUCTION

Taiwan is located on the Pacific Rim in an area where earthquakes commonly occur. Although the majority of earthquakes cause little to no damage to buildings and infrastructure, destructive earthquakes can and do take place. In 1999, the Chi-Chi earthquake destroyed nearly half of the school buildings in Central Taiwan. This earthquake demonstrated the need to evaluate and reinforce the seismic resistance of existing school buildings. According to the Capacity-Spectrum Method proposed by ATC-40 (ATC 1996), NCREE has developed a method for detailed seismic evaluation. Using the software PISA4SB (Chuang et al. 2010) derived from the Platform of Inelastic Structural Analysis for 3D systems (PISA3D) (Lin et al. 2009), the seismic performance of school buildings can be determined. This project focuses on the application of pushover procedures in PISA4SB for the evaluation of school buildings. The seismic capacities of the buildings are found and the results are compared to requirements for the location of the structure and the results provided by NCREE-09-023 (Chung et al. 2009).

2. INTRODUCTION OF SCHOOL BUILDING A

2.1 Basic Information

The school building investigated is one of the buildings on the Lujhou Junior High School campus situated in northern Taiwan. The Lujhou Junior High School is comprised of several buildings constructed in a quad formation adjacent to one another. The lack of proper spacing between buildings affects the seismic performance of the structure and will possibly cause pounding damage during major earthquakes. This document will cover the Puying building, which will be referred to as Building A.

Unlike other buildings at Lujhou, Building A has an attached storage area that affects the building's seismic response. The floor plan shown below, Figure 2.1, is similar to most school buildings built in Taiwan, with classrooms side by side and a long cantilevered corridor along one side of the building. The long cantilevered corridor is neglected during analysis and is therefore not shown in Figure 2.1. This layout contains 11 classrooms, two stairwells, and a bathroom. Typical of school buildings in Taiwan, Building A is constructed with brick wall partitions and windowsills that limit the effective length of the columns they are constructed against. Except for the attached storage area on the left, as well as the leftmost area used as a bathroom and the rightmost area used as a classroom, Building A has a symmetrical floor plan.

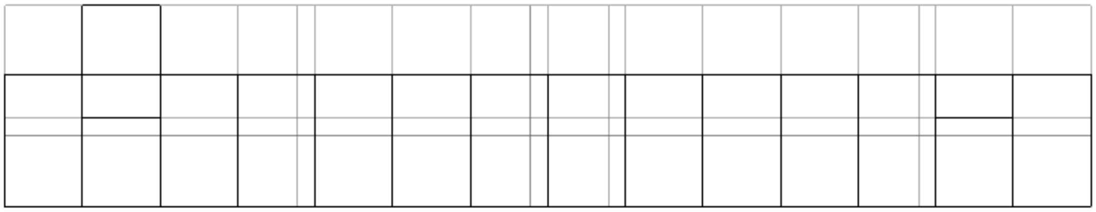


Figure 2.1. Floor plan of Building A

2.2 Structural System

As seen in Figure 2.1, the overall structural system of Building A is simple. The columns and beams of the building are constructed out of reinforced concrete. The RC beams utilized are L-Beams and T-Beams. In Taiwan, brick windowsills and partitions are used heavily in school buildings. The brick windowsills are built closely to columns and therefore produce a short column effect, which reduces the effective length of the column.

2.3 Material Strengths

Sample cores are drilled into the structure to find the actual material strengths of the Building A. The compressive strengths are found to vary by floor. Standard strengths are used for the yielding strength of the rebar and compressive strength of the brick wall. The various material strengths are shown in Table 2.1 below.

Table 2.1. Material Strengths of Building A

Floor	**Compressive Strength, fc' (kg/cm^2)**
RF	147
4F	146
3F	149
2F	144
Material	**Yield Strength, fy (kg/cm^2)**
Steel Rebar	2800
	Uniaxial Compressive Strength (kg/cm^2)
Brick Wall	f_{mc} = 100 (mortar) f_{bc} = 150 (brick) Type II Bond

2.4 Loads

In the analysis of Building A, both dead and live loads derived from the self-weight of the building are applied. Additionally, pushover analyses are conducted by creating the load cases PUSHX and PUSHZ for loading in the X and Z direction respectively.

2.5 Seismic Resistance Requirements

The seismic resistance requirements are determined by the peak ground acceleration found using the following equation, $A_T = 0.4S_{DS}$. This is the required peak ground acceleration for Taiwan for a 475-year earthquake. The variable S_{DS} is 0.6 for Building A due to it is location in the seismic region designated as 1st Taipei District. The peak ground acceleration is calculated as $A_T = 0.4(0.6) = 0.24g$, meaning that the peak ground acceleration for buildings in this location must be greater than 0.24g to have sufficient seismic resistance.

3. NUMERICAL MODELING OF SCHOOL BUILDING A

3.1 Import using s2k file format

The basic model is created by professional engineers on ETABS. On ETABS, the model is an edb file, but is exported as an s2k file. The s2k file is then imported to PISA4SB for modification and use on PISA4SB. On PISA4SB, the brick walls are remodeled as trusses from the beams and columns on ETABS. The s2k file is then converted by PISA4SB to its native file format, .ipt, when saved.

In the file imported from ETABS, the model contains details that seem inaccurate. The brick walls on the back of the building do not span the entire length of the classroom. Instead, it is similar to the front of the classroom with a gap for the doorway. However, there was no doorway in the back of the classroom. Furthermore, there are brick walls on the entire back portion of the actual Building A, yet brick walls have only been modeled on every other classroom. For comparative reasons, the model is not adjusted to correct this discrepancy.

3.2 Define RC Sections and Brick Walls

Once the file is imported into PISA4SB, a text file with the sections for the columns, T-beams, L-beams, and brick walls is imported into PISA4SB. This file includes all the sections used in the original building plans. The properties defined are for the type and location of rebar as well as the overall dimensions of the section. The brick walls are modeled by truss elements.

3.3 Define Constraints, Rigid End Offsets, and Restraints

The floors are fixed to a point to move as a unique rigid diaphragm. The rigid end zones of columns are set based on the beam depth and the rigid end zones of beams are set based on half the width of adjacent columns. The brick walls are offset half the thickness of the columns. The columns of the first floor are fixed.

3.4 Define the Loads

4 load cases are created for this model: DL (Dead Load), LL (Live Load), PUSHX (Force going in the X direction), and PUSHZ (Force going in the Z direction). The dead and live load are modeled as area loads set on the nodes. The dead load is the self-weight found through calculating the density of the section and the section size. The live load is taken from building code. The pushover load case of the building is set at the center of mass on each floor in proportion to the amplitude of story height and mass (1, 2, 3, 3.07).

3.5 Define the Force Groups

The force group, F1, is comprised of all the columns on the first story. The force group would encompass the whole length of the column except for one slight exception; on the right side of the brick wall the bottom portion of the column connected to the brick wall is neglected from the force group.

3.6 Define the Hinge Properties

The hinge properties are determined through PISA4SB according to the procedure specified by NCREE-09-023.

3.7 Assignment of Elastic Properties

Due to the presence of brick walls, the beams above and below the brick walls are modeled to exhibit an elastic response.

4. PUSHOVER ANALYSES

The model is analyzed under a gravity and push load. The gravity analysis is comprised of the dead and live loading. The push loading is set to a maximum displacement in the push direction with 1000 steps. Several cases for analyses are created to consider the responses due to different elastic properties. They are defined as follows:

CASE A – All beams and columns are plastic.

CASE B – The beams of the storage area and the edge of the building along the push direction are found to be elastic. All other beams and columns are plastic.

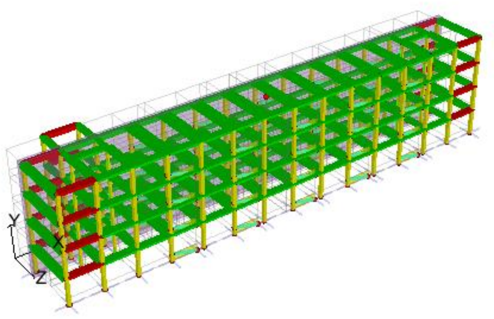


Figure 4.1. CASE B (X-direction)

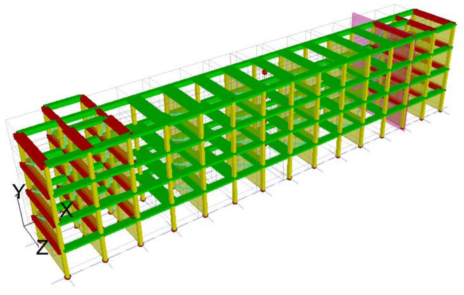


Figure 4.2. CASE B (Z-direction)

CASE C – The beams of the storage area, edge of the building, and with an attached brick wall along the push direction are found to be elastic. All other beams and columns are plastic. In the analysis for the push in the X-direction, Case C is omitted. The brick walls in this direction are not tall enough to alter the elastic properties of the beams.

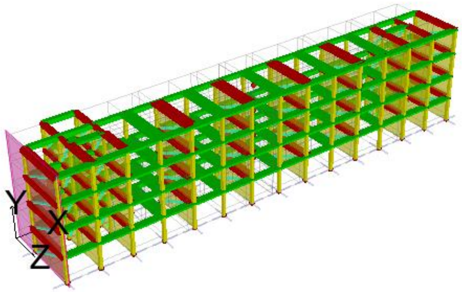


Figure 4.3. CASE C (Z-direction)

CASE D – All beams and columns are elastic.

The pushover analysis on PISA4SB is continually modified until the critical roof displacement is found for each case. When considering the most realistic case for the pushover analysis, CASE B for PUSHX and CASE C for PUSHZ are chosen. CASE A and D are analyzed assuming that the beams and columns of Building A are entirely plastic or elastic. In reality, there would be both elastic and plastic regions in the structures. For the pushover in the X direction, the stairwell and outer walls may be considered elastic because of the rigid brick walls that would not behave in a plastic manner. However, the other brick walls, used as windowsills, are not high enough to consider elastic behavior. Therefore, it is likely that Building A would perform in a similar manner to CASE B in a pushover analysis in the long direction. In the pushover analysis in the Z direction, there are brick walls between classrooms. These brick walls are built from floor to ceiling and would therefore affect the elastic properties of the beam above and below the brick wall. Therefore, it was reasonable to conclude that CASE C would be the best case for an accurate analysis for a push in the Z direction.

5. EVALUATE THE SEISMIC CAPACITY OF BUILDING A

5.1 Determine the performance point

The results from the pushover analysis can be seen from Table 5.1 below. In the push X direction the max displacement is found to be 16.50cm for CASE B. The resulting Ap is 0.2165g and Vmax is 7330kN. In the push Z direction the max displacement is found to be 10.95 cm for CASE C. The resulting Ap is 0.3626g and Vmax is 12130kN. The capacity curves for CASE B in X and CASE C in Z are shown in Figure 5.1 and 5.2. With the peak ground acceleration being A_T = 0.24g, reinforcement will be required for Building A in the X-direction, but not the Z-direction. From PISA4SB, the maximum lateral capacity is found to be 8150kN from PUSHX and 17170kN from PUSHZ. From Table 5.1, all cases are not pushed to full capacity. In the X-direction, CASE A is not pushed to its full capacity as seen in Figure 5.3. In this case, the building stays completely elastic.

Table 5.1 Pushover Analysis Results

PUSH	CASE	Ap (g)	Vmax (kN)	Displacement (cm)	Vmax/Max Lateral Capacity
X	A	0.1286	5690	9.62	0.698
X	**B**	**0.2165**	**7330**	**16.50**	**0.899**
X	D	0.1897	7740	14.00	0.950
Z	A	0.286	10690	7.65	0.623
Z	B	0.3579	11910	10.85	0.694
Z	**C**	**0.3626**	**12130**	**10.95**	**0.706**
Z	D	0.3689	12430	11.07	0.724

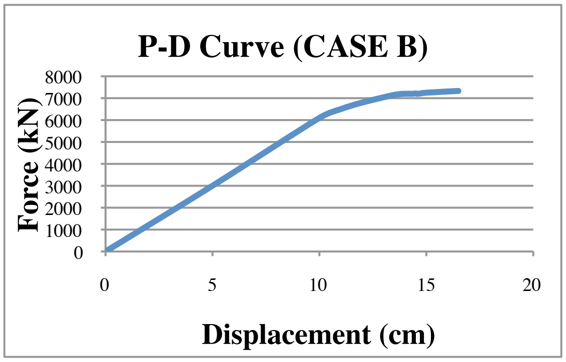


Figure 5.1 P-D Curve for PUSHX for CASE B

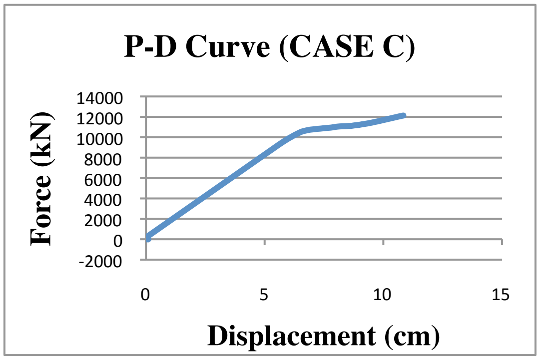


Figure 5.2 P-D Curve for PUSHZ for CASE C

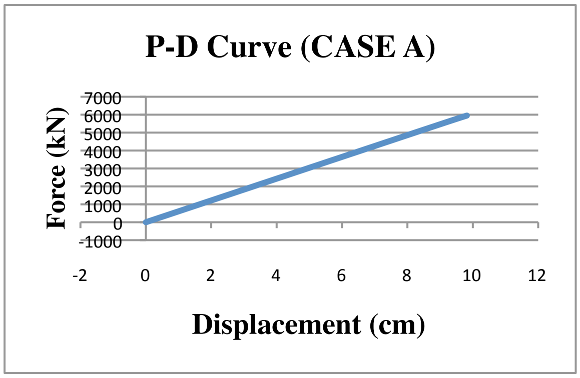


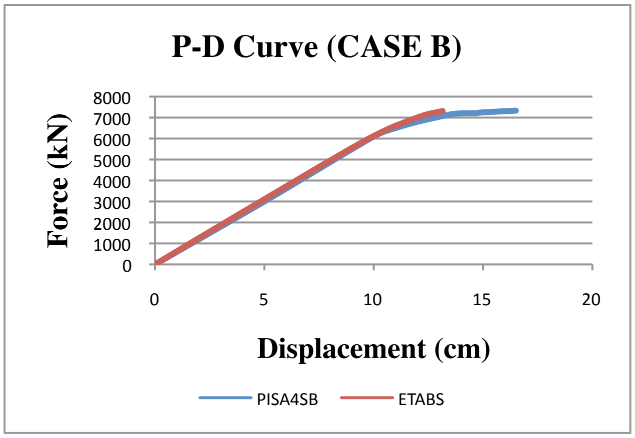
Figure 5.3 P-D Curve for PUSHX for CASE A

5.2 Validation of the model A

To confirm the results of the pushover analysis using PISA4SB, the data from professional engineers is referenced. Table 5.2 below shows a comparison between the analyses done with PISA4SB and ETABS. Figures 5.4 and 5.5 compare the force-displacement curves on PISA4SB and ETABS.

Table 5.2 Pushover Analysis Comparison

PUSH	Ap	Vmax (kN)	Displacement (cm)
X_PISA4SB	0.2165	7330	16.5
Z_PISA4SB	0.3626	12130	10.95
X_ETABS	0.180	7310	13.157
Z_ETABS	0.348	13230	10.45



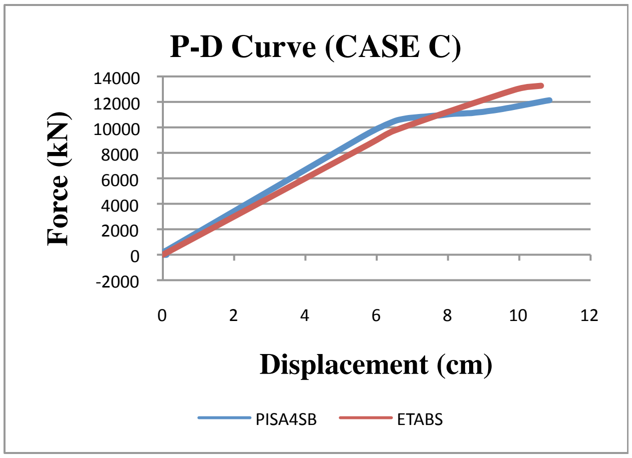


Figure 5.4. Comparative Graph X-Direction

Figure 5.5. Comparative Graph Z-Direction

5.3 Results of Analyses

Previously, professional engineers have analyzed Building A using ETABS. The comparative results are shown in Table 5.2 above. The values found with PISA4SB are similar to ETABS and validate the application of PISA4SB for analyzing school buildings. While the maximum displacement for PUSHX is 16.5 cm in PISA4SB and 13.157 cm in ETABS, this 3 cm difference can be attributed to the incorrect assignation of hinge properties in the ETABS model. This could explain the larger Ap value as well. In PUSHZ, there are minor discrepancies that can be attributed to the different equations used by both programs as well as the incorrect assignation of hinge properties. Although there are differences in the exact values, the overall conclusion that reinforcement in the X-direction is needed is the same.

After the analysis using PISA4SB was concluded, the professional engineers responsible for the evaluation of Building A were contacted. This showed that the analysis was conducted using a previous standard, NCREE-08-023, whereas PISA4SB uses the current NCREE-09-023 standard. This also contributes to the difference in the results of the analysis.

6. REFERENCES

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