Resilient Structures and Sustainable Construction
Edited by Pellicer, E., Adam, J. M., Yepes, V., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-4-8

A RETROFIT METHOD FOR OLD PRECAST PANEL BUILDING

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This study is devoted to the development of improved methods and computer programs for predicting the seismic performance of existing precast panel structures. It is necessary to establish an experimental investigation as well as to develop a more detailed analysis and design procedures related to seismic design considerations for existing precast panel structures. The nonlinear behavior of precast panel buildings depends on the panel contact zones and this feature should be incorporated into the analytical models for the elasto-plastic nonlinear analysis. This study presents a newly designed finite element program developed on Fortran software for the nonlinear analysis of typical precast panel buildings. With the aid of this finite element program, eight different analytical models were designed and performed to simulate the nonlinear behaviors of panel contact zones under lateral loading. The analytical models were composed of four control models without any retrofitting and four models retrofitted using a steel bolted plates at the both horizontal and vertical joints between associated panels. A two-dimensional elasto-plastic nonlinear analysis with pushover method was performed on the analytical models, to obtain lateral force and displacement relationship. The simulation results illustrate the comparisons of lateral force-displacement curves for both the non-retrofitted and the retrofitted models. It was observed that all the retrofitted models showed a significant increase in strength and ductility.

Keywords: FEM, Interface element, Stiffness, Bearing wall system, Elasto-plastic nonlinear analysis, Lateral strength.

1 INTRODUCTION

There is little existing research related to the seismic performance evaluation of precast panel buildings in Mongolia. Russian literature explaining precast panel buildings has shown the good seismic behavior under seismic conditions. However, the earthquake resistance of these structures were demonstrated when they were subjected to severe earthquakes in the Soviet Union, include the 1976 Gazli, Uzbekistan earthquake with M7.0, and the 1977 Bucharest, Armenia earthquake with M7.3 on the Richter scale. Those precast panel buildings in the area affected by the 1976 Gazli earthquakes were not designed with seismic provisions. Most such buildings performed well in the first earthquake (M7.0), but more damage was observed in the second earthquake that occurred the same year (M7.3), as some buildings had been already weakened by a previous earthquake (Brzev and Perez 2002). In fact, the most damages in the structure were occurred in the contact zones between associated panels, which feature a welded steel bar filled with mortar cement.

At the end of the 1950s, there were several housing construction projects proposed by the former Soviet Union in Mongolia, particularly in the city of Ulaanbaatar (UB) and they continued constructing the precast panel buildings from the 1970s, 1980s, and into the early 1990s. Today, more than 20% of the over 1 million UB's population lives in these types of buildings. In total over 1077 of the five to twelve story precast panel buildings, there are three types of building that accommodate approximately 159,100 residents. The buildings built in 1980s, 1990s were reasonably well built, but the buildings, built before the 1980's are in an inadequate state due to their age, freezing damage, poor or non-existent maintenance, lack of insulation and the ongoing alterations in their structures.

The Research Center for Astronomy and Geophysics of the Mongolian Academy of Sciences (RCAG) has developed the seismic map of UB in the 2016s. The research reveals earthquakes of magnitude 8 are possible around city. It means that Ulaanbaatar is exposed to the danger of serious earthquakes, and old precast panel buildings need to be retrofitted against potential earthquake disaster.

The seismic retrofit of precast panel buildings has become an important problem in those countries, which are the most earthquake-sensitive and vulnerable. This paper introduces a simple retrofit method for existing precast panel building. The method focuses on the weakest point of the precast panel structure, particularly by installing reinforcement at the panel contact zones, since it recognized that those areas are the most vulnerable. Thus, it is necessary to find out the behavior of panel connection members in nonlinear range with defined force and displacement values. Therefore, the structural analysis gives the results with respect to the response of the panel system under lateral force.

2 A SIMPLE RETROFIT METHOD

Most of the damage to precast panel building cause of earthquake shock was concentrated on the connection of the panels because of low shear capacity of the connection. For this reason, the element-based retrofit method chosen in this study. This method has element such as steel bolted plates at the joints between associated panels, and plates might have a positive effect in terms of the shear reinforcement concept.

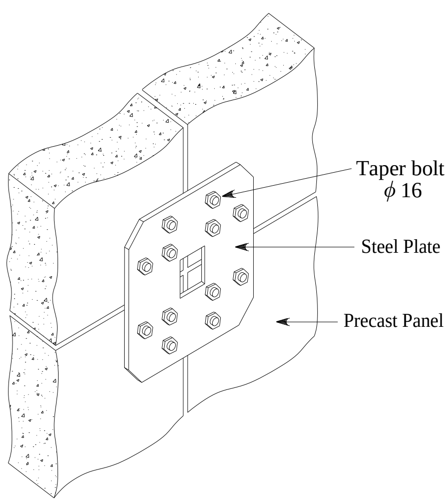

Figure 1. Steel bolted plate system.

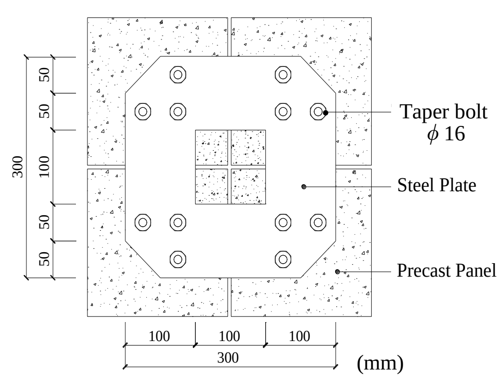

Figure 2. Detail of steel bolted plate.

The main purpose of such a steel bolted plate system is to improve seismic capacity, such as the stiffness, strength and ductility of structures. Steel plate with 8mm thickness, which has a 20-mm holes at the corners, relates to taper bars (diameter, 16 mm) as shown in Figures 1 and 2.

3 METHOD OF ANALYSIS

3.1 Structural Analysis on Precast Panel Structure

This study describes a newly designed finite element program for the elasto-plastic nonlinear analysis of a simple bearing wall system, which is two-dimensional model of typical precast panel building. The finite element program written in well-known Fortran software and it's employed to investigate the linear and nonlinear behavior of joints between adjacent ends of panels under lateral force. In case of precast panel structures, the linear behavior of the panel was assumed, and all nonlinear behavior concentrated in the joints between associated panels (Fischinger *et al.* 1987) for the simplification.

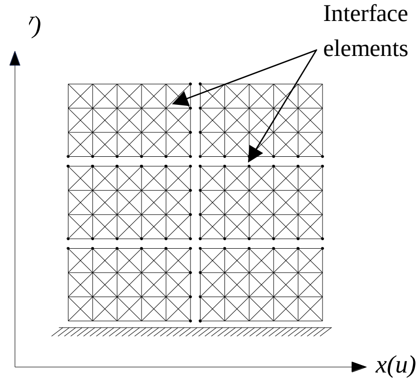

Figure 3. A simple bearing wall system.

The bearing wall system transformed into a discrete system consisting of triangular finite elements and interface elements as shown in Figure 3. All panels entered in terms of features, which discretized into 3-node triangular finite elements to perform the analysis. In both, the vertical and the horizontal joints modeled by using 4-node interface elements, proposed by Goodman (1968). The formulation of 4-node interface element based on elasto-plastic theory. The element has eight degrees of freedom, and the thickness is often assumed zero. For this reason, interface element chosen to analyze nonlinear responses of joints.

To determine global stiffness matrix for the entire system is probably the most important formulation used in the finite element program. Two individual elements have different stiffness, Triangular element: (K_T) and Joint element: (K_J). Their stiffness matrices assembled to obtain the global stiffness matrices ($[K]$) that related all of displacements and forces. The global stiffness matrix is a non-symmetric band matrix, which evaluated the Eq. (1) below:

$$[K] = [K_T] + [K_J] \tag{1}$$

After the global stiffness matrix for entire system performed, the incremental displacements can found by solving the system of linear Eq. (2).

$$[K]\{\Delta u\} = \{\Delta F\} \tag{2}$$

where, $\{\Delta F\}$ and $\{\Delta u\}$ are incremental force and incremental displacement vector, respectively.

3.2 Analytical Models

To simulate the actual linear and nonlinear behavior, the following analytical models chosen for the elasto-plastic nonlinear analysis. The analytical model's configuration and dimensions are shown in Figure 4. Lateral force applied on each analytical model, which has a 2-kN increment for each story, and incremental loading step is set with adjusting appropriately.

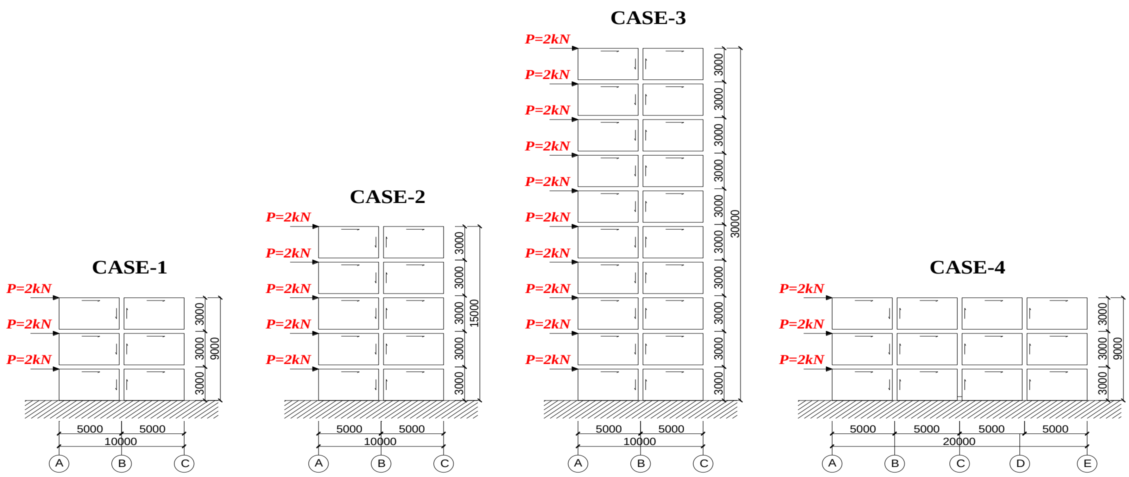

Figure 4. Analytical models.

The original size of panel unit is 3 x 5 m, and the intervening space between panels is 10 cm. The compressive strength of the panel is equal to 14.5 MPa. The young's modulus of panels and joints were $3x10^4$ MPa and $2.4x10^4$ MPa, respectively. The poison's ratio is ν =0.2. The unit weight of concrete is equal to 23.6 kN/m^3. The joint shear strength and the joint compressive strengths are 0.75 MPa and 8.5 MPa, respectively. The joint shear stiffness and normal stiffness are $1x10^8$ kPa/m and $2.4x10^8$ kPa/m, respectively. The friction coefficient is μ =0.5.

To simplify the analytical simulation, the following assumptions made for model formulation:

- The panel remains always in linear range
- All nonlinear deformations occur in the panel contact zones
- Basement and foundation structures remain always rigid

These assumptions for analytical simulation can accept only under the condition that the bearing wall system is constructed in way that linear and nonlinear range. The analytical simulation performed both the elastic and elasto-plastic calculation.

After analyzing the simulation, these models retrofitted with a steel-bolted plates at the both vertical and horizontal joints are calculated and incorporated once again in the program. Those retrofitted models investigated by comparing the results of first models without retrofit. This comparison will particularly important in a view of the elasto-plastic nonlinear analysis of retrofitted precast panel building in practice. It should be noted that both the non-retrofitted and the retrofitted models were loaded in the same incremental lateral loading steps.

For retrofitted models, the young's modulus of steel plates is equal to 2.058×10^8 kN/m^2. The poison's ratio of steel is ν =0.3. The ultimate tensile strength and yield strength are 1.764×10^5 kPa, and 1.247×10^5 kPa, respectively. The proposed retrofitting will be significant reducing the shear slip failure, gap opening and lateral displacements of system.

4 SIMULATION RESULTS

In Figure 5, 6, 7 and 8, the force-displacement curves are illustrated: the force values (divided by total weight of structure) corresponding to the lateral displacement of the top-story (divided by total height of structure) level are pointed out by blue (retrofitted) and green (non-retrofitted) lines, indicating a substantial over strength of the both models, as designed.

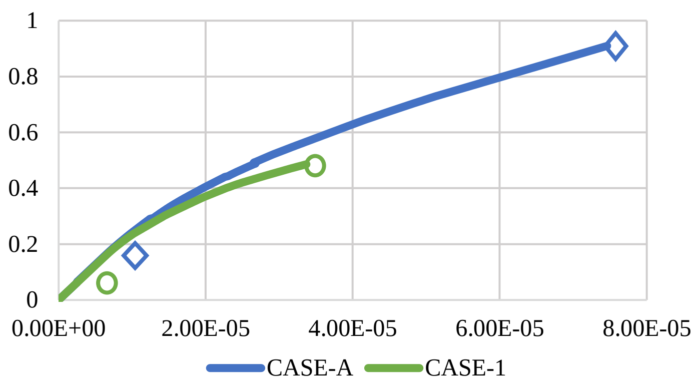

Figure 5. Force-displacement curves for Case-A and Case-1.

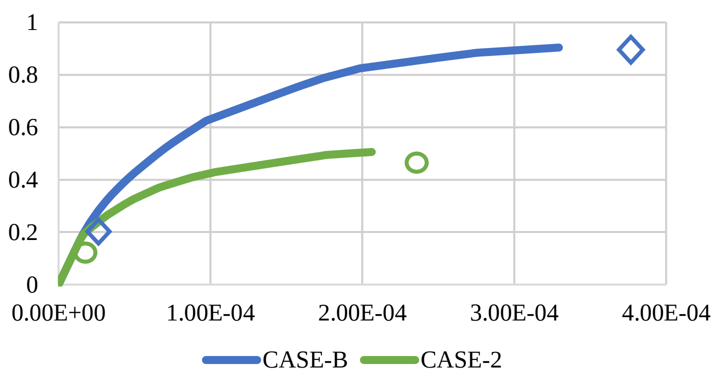

Figure 6. Force-displacement curves for Case-B and Case-2.

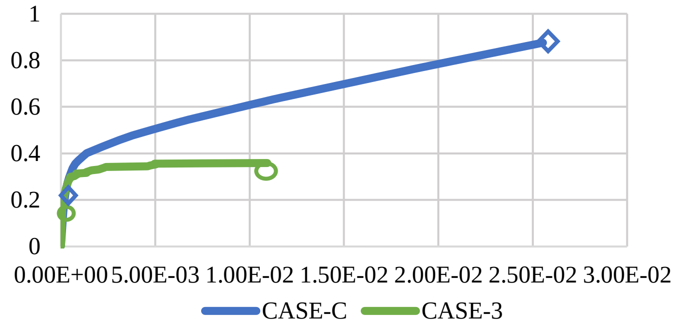

Figure 7. Force-displacement curves for Case-C and Case-3.

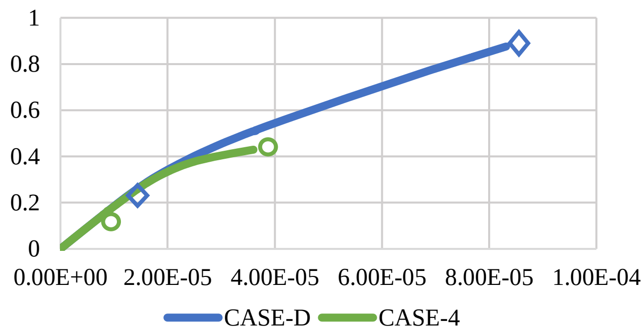

Figure 8. Force-displacement curves for Case-D and Case-4.

5 CONCLUSIONS

The four non-retrofitted and retrofitted models of typical precast panel building chosen to estimate nonlinear behavior of panel contact members under incremental lateral loading. Special attention was given to elasto-plastic nonlinear analysis or lateral force and displacement characteristics, due to their effects on building, such as gap openings and shear slip along the contact zones of the panels. Comparison of the force-displacement curves between the non-retrofitted and the retrofitted models with steel bolted plates indicates that the proposed simple retrofit technique produced two or three times higher values of lateral bearing force than the corresponding non-retrofitted ones. It is observed that retrofitting makes a significant increase in lateral strength. Further research on the other retrofit methods or special computer program (3D model under seismic loading, large assemblies with entire structures) for existing precast panel structures needed. In addition, more experimental investigations and tests using shaking table facilities are needed to find out the nonlinear behavior of the contact zones of the panels in the dynamic behavior.

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