NUMERICAL INVESTIGATION ON PERFORMANCE OF A PRECAST COLUMN-TO-FOUNDATION CONNECTION UNDER QUASI-STATIC CYCLIC LOADING

K.K. Wijesundara[1*], D. Bolognini [1] and R. Nascimbene [1]

[1*] Corresponding Author, European Training and Research in Earthquake Engineering (EUCENTRE) Via Ferrata 1, 27100 Pavia, Italy, Email: kushan.w@saitm.edu.lk

[2] European Training and Research in Earthquake Engineering (EUCENTRE) Via Ferrata 1, 27100 Pavia, Italy.

ABSTRACT

During past earthquakes, precast structures designed only for the gravity loads have subjected to extensive damages due to inadequate connections between the beams and the columns, and many of the columns have failed at their bases. This problem gave researchers incentive to examine the performance of the existing column-to-foundation systems under cyclic loading. However, this study is limited to investigate the seismic response of a particular type of column-foundation system through steel column shoes and anchorage bolts proposed by the Peikko Group for the gravity load carrying system.

The main objective of this study is to simulate the response of this particular column-to-foundation system numerically under a quasi-static loading and compare the response with the experimental response. For this purpose, a numerical model is developed using MIDAS finite element programme. The strength, the loading and unloading stiffness and the pinching phenomenon are the key parameters used to validate the accuracy of the numerical model. From results of the numerical model, significant degradation in the stiffness and the energy dissipation are observed as increasing of the ductility of the system. The reduction of energy dissipation capacity is mainly due to the pinching phenomenon.

***Keywords*:** Precast structures, pinching phenomenon, interface elements, hysteretic response

1. INTRODUCTION

Prefabrication of reinforced concrete and prestressed reinforced concrete members are more commonly used in the construction of industrial and commercial buildings than conventional cast-in-situ reinforced concrete members due to the increased speed of construction, the reduction in site labour, higher quality of the materials and improved durability. However, precast structures exhibit a relatively high degree of lateral flexibility due to the structural system which composed of monolithic columns fixed at the base and free at the top with pinned beams supported on corbels. As a consequence, precast structures have subjected to extensive damages during the past earthquakes [3].

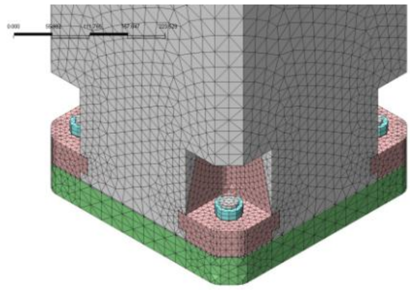
This problem gave researchers incentive to examine the performance of the existing column-to-foundation systems under cyclic loading. However, this study is limited to investigate the response under a quasi-static cyclic loading of a particular type of column-foundation system through steel column shoes and anchorage bolts proposed by the Peikko Group for the gravity load carrying system.

The main objective of this study is to simulate the response of this particular column-to-foundation system numerically under a quasi-static loading. For this purpose, a numerical model is developed using MIDAS finite element program [1]. The strength, the loading and unloading stiffness and the pinching phenomenon are the key parameters used to validate the accuracy of the numerical model. From the results of the numerical model, significant degradation in the stiffness and the energy dissipation are observed as increasing of the ductility of the system. The reduction of energy dissipation capacity is mainly due to resultant pinching phenomenon.

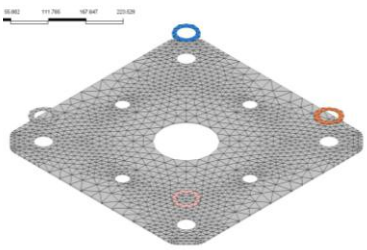
2. MODEL DESCRIPTION

A detailed finite element model is developed in hexahedrons using the MIDAS finite element (FE) programme to simulate the response of the precast column-to-base connection under the quasi-static cyclic loading. The model consists of the concrete column and the basement including the embedded reinforcement bars, the four steel shoes and the layer of mortar. The column size is 400 x 400 mm in the cross section and 2150 mm in the height. The material nonlinearities of the concrete and the steel are represented by the total crack strain model and the Von Mises yield criterion, respectively. The detailed description of the material models are presented in the next section. A refined mesh is used in the region where the large inelasticity is expected.

A simplified model is capable to predict the strength and the initial stiffness adequately accurate compared to the experimental data, but the pinching phenomenon resulted in loosing the contacts between the nuts and the shoes during the unloading and the reloading phases can not be simulated by a simplified model due to the limitation on modelling perspectives. Therefore, to capture this phenomenon accurately, discrete cracking interface elements are introduced in the detailed model. The interface elements are introduced to each interface between the nut and the shoe and between the shoe and the mortar. Moreover, the surface interface elements are also introduced to the interface between the concrete column and the mortar layer in the detailed model. Figure 1 illustrates three dimensional view of the model and all the interface elements introduced in the model.



(a)



(b)

Figure 1. (a) 3-dimensional view of the model (b) interface elements

3. MATERIAL MODELS

Unlike the elastic material behaviour, plastic material behaviour exhibit the permanent deformation even after the unloading applied to the structure. To reflect such properties, the total strain crack model and the Von Mises plasticity model are used for concrete and steel, respectively. MIDAS uses the total strain crack model classified under the smeared crack model. It can be further classified as the fixed crack model and the rotating crack model depending on the reference crack axes. The fixed crack model assumes that the axes of cracks remain unchanged once the crack axes are defined. The rotating crack model assumes that the directions of the cracks are assumed to continuously rotate depending on the changes in the axes of principle strains. In both models, the first crack at the integral points always initiates in the directions of the principle strains. The materials exhibit isotropic properties prior to cracking and anisotropic properties after cracking. MIDAS treats the properties of concrete as orthotropic materials after cracking. The constitutive model on the basis of total strain is founded on the Modified Compression Field Theory proposed by Vecchio and Collins [3]. This theory was formulated on the basis of two-dimensional models. MIDAS has been implemented with an extension into 3-dimensional models based on the theory proposed by Selby and Vecchio. Note that the fixed crack model is used in this model.

4. RESULTS AND DISCUSSION

This section describes in detail how the combination of those interface elements can represent the phenomenon of pinching shown by the experimental base shear-top displacement hysteretic response. For this purpose, four key points are selected in the hysteretic response as shown by the red circles in Figure 2 and then, the states of the stress and the deformation of each interface element is described referring the each red point.

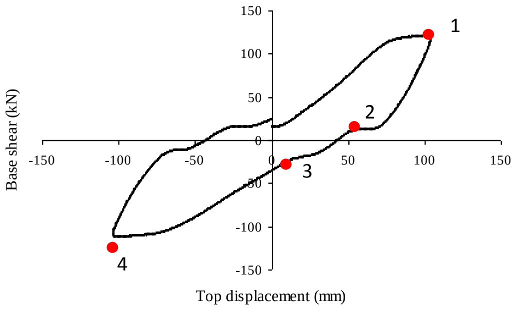
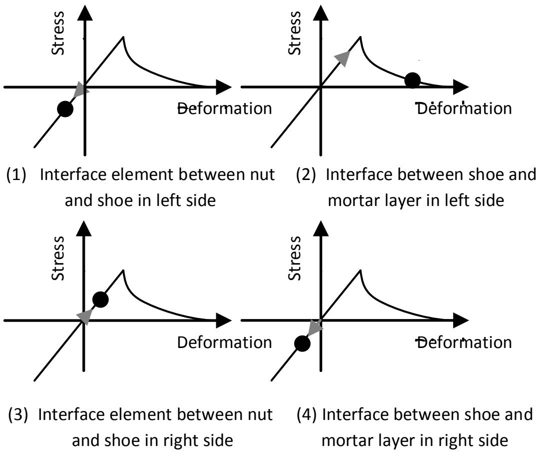


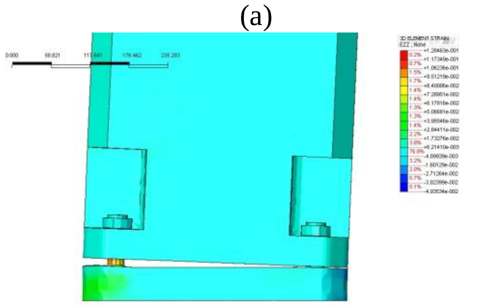
Figure 2: Base shear-top displacement hysteretic response

As increasing the lateral displacement from the unloaded condition to the value corresponding to the point 1, the compressive stresses on the left interface elements between the nuts and the shoes, and the tensile stresses on the interface elements in the same side between the shoes and the mortar layer are increased. While the tensile stresses reach to the peak resistance, the contact between the shoes and the mortar layer is going to be loosened. In contrast to the left interface elements, those in the right side between the nuts and the shoes, and between the shoes and the mortar layer are subjected to tensile and compressive stresses, respectively. Figure 3(a) illustrates the state of deformation of each interface element in reference to the point 1 in the global hysteretic response while Figure 3(b) shows the enlarged view of the deformed shape at the connection region corresponding to the point 1.

It is very important to note that even though three sets of interface elements remain in linear elastic branch during the loading excursion as shown in Figure 3(a), the yielding of the anchor bolts in tension cause to reduce the stiffness of system drastically at the larger displacement level and create significant gap between the shoe and the mortar layer as shown in Figure 3(a).



(a)

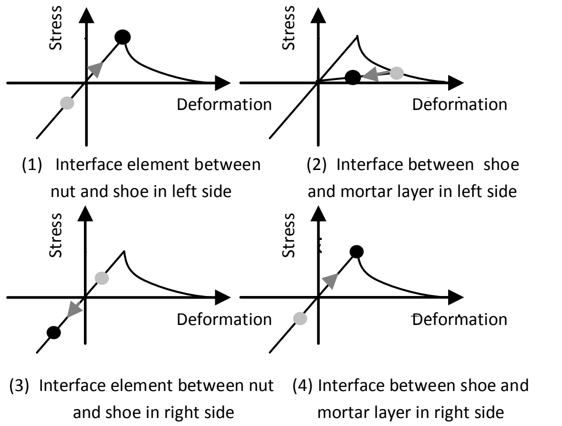


(b)

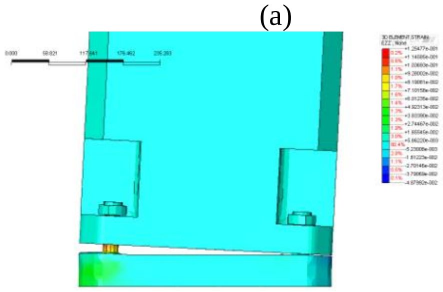
Figure 3: (a) Deformation of each interface elements in reference to point 1 (b) Enlarged view of deformed shape in reference to point 1

During the unloading excursion from point 1 to 2, the compressive stresses on the contact elements in the left side between the nuts and the shoes, and the tensile stresses on the elements between the shoes and the mortar layer are decreased. Note that unloading of the compressive stresses follow elastic stiffness while the unloading of the tensile stresses on the left interface elements follow the secant stiffness as shown in Figure 4(a). Similar to the loading excursion, the right interface elements behave opposite to the left interface elements. The behaviour of the three sets of surface interface elements and the bolts remain in linear elastic range and hence, full stiffness of the system can be gained. Figure 4(b) shows the deformed shape on the connection in reference to the point 2.

During the unloading excursion from point 2 to 3, the gap created between the shoe and the mortar layer in the left side of the system due to the elongation of the anchor rods during previous loading excursion should be closed. Figure 5(b) illustrates that no connectivity exists between the nuts and the shoes and between the shoes and the mortar layer in left side of the system when unloading from point 2 to 3. As a consequence of that, the system displays almost zero lateral stiffness and strength in the branch of unloading excursion. Figure 5(a) shows the states of deformation of the interface elements in reference to the point 3.



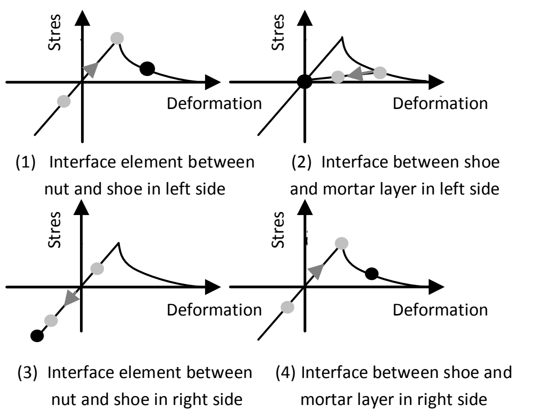
(a)

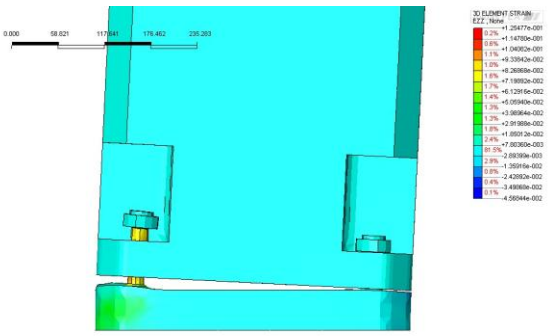


(b)

Figure 4: (a) (a) Deformation of each interface elements in reference to point 2 (b) Enlarged view of deformed shape in reference to point 2

Loading the column in opposite direction, the stiffness is regained because the contacts between the shoes and the mortar layer in the left side are reactivated in compression after closing the gap. In the large displacement, the stiffness of the system reduces due to yielding of the anchor rods in the right side of the system.

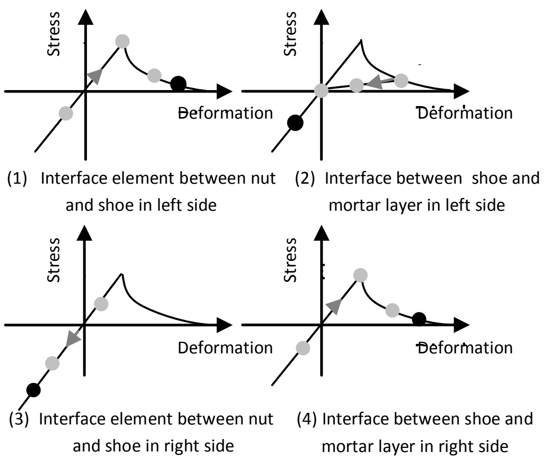




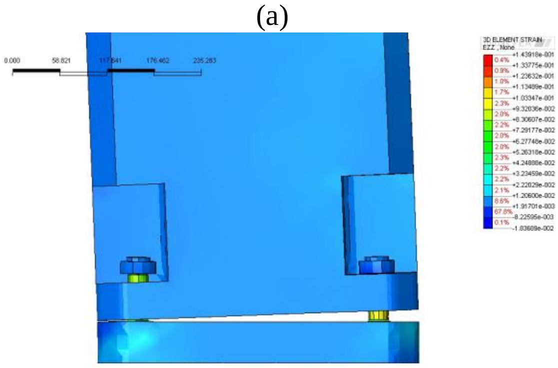
(b)

Figure 5: (a) Deformation of each interface elements in reference to point 3 (b) Enlarged view of deformed shape in reference to point 3

As mentioned before, the yielding of the rods causes to create the significant gap between the shoes and the mortar layer in the right side as shown in Figure 6 (b).



(a)



(b)

Figure 6. (a) Deformation of each interface elements in reference to point 4 (b) Enlarged view of deformed shape in reference to point 4

Figure 7 illustrates the comparison of lateral force-displacement hysteretic response obtained from the numerical model with the experimental data. It is clear that the model predicts the strength, the loading and the unloading stiffness and the pinching phenomenon adequately accurate compared to the experimental data.

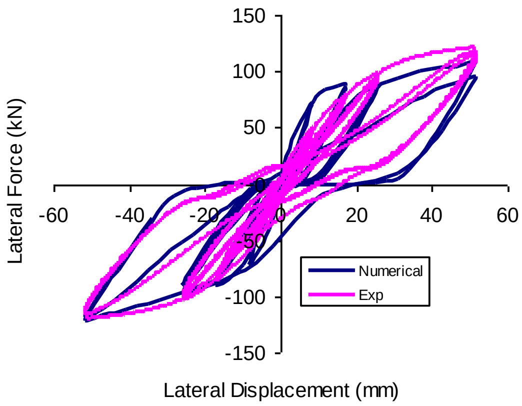


Figure 7. Lateral force-deformation curve

5. CONCLUSION

This study mainly investigates the capability of the numerical model in predicting the hysteretic response of the beam-to-column system. From the comparison of hysteretic response from the numerical model with the experimental response, it can be concluded that the numerical model with the series of interface elements can predict the pinched hysteretic response accurately.

6. REFERENCES

[1]. MIDAS FEA V 2.8. Nonlinear and Detail FE Analysis System for Civil Structures. FEA Analysis and Algorithm Manual; 2008.

[2]. Saatcioglu M., Mitchell D., Tinawi R., Gardner N.J., Anthony G. Gillies, Ghobarah A., Anderson D.L. and Lau D. "The August 17, 1999, Kocaeli (Turkey)earthquake — damage to structures". Canadian Journal of Civil Engineering, V. 28, pp. 715-737, 2001.

[3]. Vecchio, F.J., Collins, M.P., "The Modified Compression Field Theory for Reinforced Concrete Elements Subjected to Shear", ACI Journal, Proceedings V. 83 No. 2, pp. 219-231, 1986.