CHAPTER 7

Conclusions, discussions and recommendation

7.1 Conclusion

The research presents the experimental and numerical results on the seismic response of precast concrete connections designed for earthquake resistance. Six precast subassemblage frames were tested under cyclic loading to observe the hysteresis behavior and seismic performance of their connections. Furthermore, the numerical program in this study showed the ability of nonlinear fiber FE modelling to predict the response of the concrete structures under reversal cyclic loading. The numerical results were verified against the experimental results. Then the parametric study was performed to predict the seismic response including a second order P-Δ effects.

The experimental and numerical results lead to the following main conclusion:

- The monolithic specimen represents seismic behavior very well. The column and joint failure is prevented by forming potential plastic hinge at the beam ends, close to the column faces. The seismic performance is very well obtained seismic parameters.
- The P6 specimen shows the best performance in terms of shear capacity, ductility, energy dissipation and stiffness degradation among all precast specimens because the plastic beam hinges are successfully relocated from the column faces, especially without bond problem in this connection detail.
- The precast specimens without lap splice on the top of joint region (P5 and P6 specimen) show better seismic performances compared with other precast specimens in terms of ductility and energy dissipation, because of that the plastic hinges are relocated into the beams. However, the dowel bars connected to the steel inserts in the P5 specimen are too short to develop bonding and connect at the high flexural stress region, causing a few splitting

cracks appearing at the lap splice regions in precast beam which is difference with P6 Specimen.

- The nominal flexural capacity of the beam section at one effective beam depth away from the column face is 1.25 times larger than the maximum anticipated moment capacity of the other beam section. The test result of P5 and P6 precast specimens show better seismic performances compared to the other precast ones. The relocation of potential plastic region distinctly exhibits, taken away at around distance of *d* from the beam-column adjacent.
- For specimens P1, P2, P3 and P4, the splitting cracks are a major failure mode in the precast specimens. At joint region, the top reinforcement composing of a longitudinal lapped splice with high strength non-shrink grout concrete is the weakest point. The cracks are developed along the splice length at the top of the precast beam section, leading to both slippage and bond degradation of overall frame specimens.
- The maximum strength of the P1, P2, P3, P4 and P5 precast specimen were lower than the expected maximum strength because the splitting cracks along the splice length in high strength non-shrink region appeared.
- All developed precast connections (P2-P6 specimens) are successfully able to improve the story shear capacity better than the current precast P1 connection.
- Shear capacity and stiffness degradation of specimen P6 is better than the monolithic reference specimen and other precast specimens.
- The splitting cracks in high strength non-shrink region result in the dramatic degradation of story shear capacity after peak loading.
- The stiffness degradation of specimens M1, P1, P2 and P5 are very similar, especially at higher levels of drift ratio. At the end of the last cycle, the loss of initial stiffness of the three specimens was approximately 10 -15 percent. For the precast specimens P3 and P4, the secant stiffness were dramatically dropped after the formation of the splitting cracks along lap-splices in the high strength grout region.
- Regarding equivalent damping ratio, the precast specimens with longitudinal lap splice located on the top of joint region are obviously very low due to

forming longitudinal spitting cracks of lap splice. It can be seen that the hysteresis loops exhibit the pinching effect during reversal movement, especially the P1 specimen designed mainly for gravity loading.

- The design of the precast concrete beams with lap splice is needed for a longer lap length and should be done at the beam, mid span or in the low flexural stress region.
- The numerical prediction shows a good agreement against the experimental study although the maximum strength was slightly different.
- The maximum story shear of P1-FEM series at the column load level of $0.50f_c'A_g$ is severely dropped by 0.49 times comparing to the $0.10f_c'A_g$ column loading.
- For the P2-FEM, P3-FEM and P4-FEM series, the shear capacities at the $0.50f_c'A_g$ column load dropped significant to around 0.58-0.63 times against maximum strength at the level of $0.10f_c'A_g$ column load.
- Rates of average deterioration in terms of the lateral loading capacity (*H*) including a P-Δ effects of precast P5 and P6 numerical series were around 7% - 11% for the rate of increment in each 0.10 times of the axial loads.
- The elastic stability indices of FE models excepting P1-FEM series with lower 20% of column capacities were not exceeded 0.15, unnecessary consideration of the *P-Δ* effect. For the P1-FEM series, the *P-Δ* effect consideration should be necessary if the carried column load is greater than 10% of column capacities due to the elastic stability index exceeds a limit state of 0.15.
- The P6 precast connection was the best performance for stability consideration.

7.2 Discussion and recommendation

- To apply more effectively the study to real structures, the precast structure should be considered an earthquake effect, especially the strong column-weak beam mechanism. Because it is a big difference of failure mode in the study. If the nominal flexural strength of the beam element is larger than the column element, the column element will be damaged before the beam during an earthquake ground motion shacking the structure.

- For the repairing the precast concrete structure undergone an earthquake ground motion, the P6 connection is easier than the current P1 joint. Because an inelastic deformation penetrated into the joint core of the current P1 connection. However, the critical yielding deformation of beam reinforcement did not penetrate into the P6 precast joint.
- The use of the double T-section steels connection for the precast moment resisting frame is less practical for constructability. Because it lead to reinforcing congestion in the beam-column joint. The precast connection can be efficiently applied to the dual structural system such as, a precast moment frame combining with precast panel wall.