DEVELOPMENT OF INTERMEDIATE MOMENT FRAMES CONSTRUCTED USING PRECAST CONCRETE FOR SEISMIC RESISTANCE IN THAILAND

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1. INTRODUCTION

The use of precast concrete (PC) structures for low-to-mid-rise building construction is gaining popularity in Thailand due to its cost-effectiveness and ease of construction. However, many manufacturers have developed their own systems for connecting the precast beam-column-footing together, which unfortunately do not consider seismic safety in the design.

Although there are several recommendations for precast moment frame systems in international publications, most of them are designed for strong seismic regions and may not be suitable for Thailand. This is because contractors in Thailand may not consider seismic design due to the fear of project cost overrun. This paper discusses the development of a precast beam-column structural system suitable for seismic resistance in Thailand.

2. METHODOLOGY

A flowchart in Figure 1 describes the activities of the project. Information regarding state-of-practice for construction using precast was gathered. Engineers in the industry were invited to participate in the conceptual design of test specimens and to discuss their requirements and concerns regarding the precast beam-column-footing structure.

This part proposes two new configurations of beam-column connection aiming for moderate seismic area. The design of the new connections emphasizes maintaining the ease of construction and the cost-effectiveness of the currently available methods. Two sets of precast beam-column joints were designed to emulate the cast-in-place behavior according to ACI PRC-550.1-09 [1]. The design of the beam-column connections considered the requirements of the intermediate moment resisting frame, which in addition, the summation of the nominal moment capacity of columns at the joint are kept larger than beams.

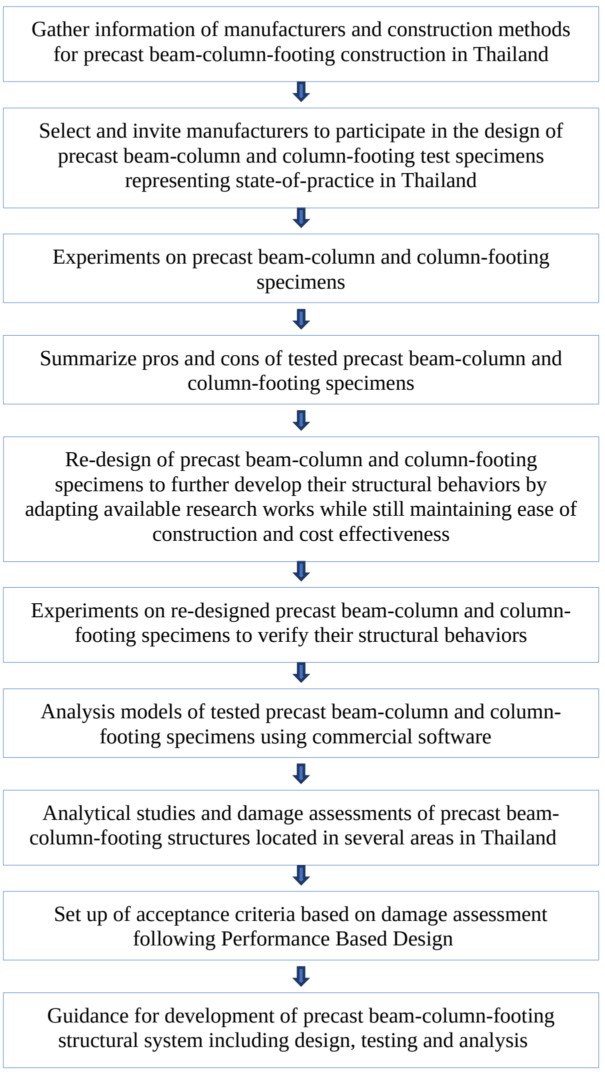

Figure 1. Overall Project Activities

Two specimens of precast beam-column joints, BC1S and BC2J, were tested. The specimen BC1S, shown in Figure 2, is a refined version of a typical connection used in Thailand in which the top and the bottom reinforcements from each side of the beam were connected by welding to dowel bars. A small indentation at the top edge of the beam allows more space for workability inside the joint area. The top column was connected to the bottom one via a dowel bar while resting on a seat plate welded to the beam reinforcement inside the joint. Non-shrink grout was finally poured to fill up the joint.

The specimen BC2J in Figure 3 has a larger zone of indentation at the top of the beams allowing for lap splice of top reinforcements through the joint. On the contrary, the bottom reinforcements were still connected by welding to the dowel bars similar to the case of BC1J. The precast column of the BC2J specimen has a gap in the middle provided for the joint area. Non-shrink grout was finally poured into the joint to complete the construction.

Quasi-static reverse cyclic tests were carried out for the two specimens following the percent drift ratio protocol according to the ACI 374.1-05 [2].

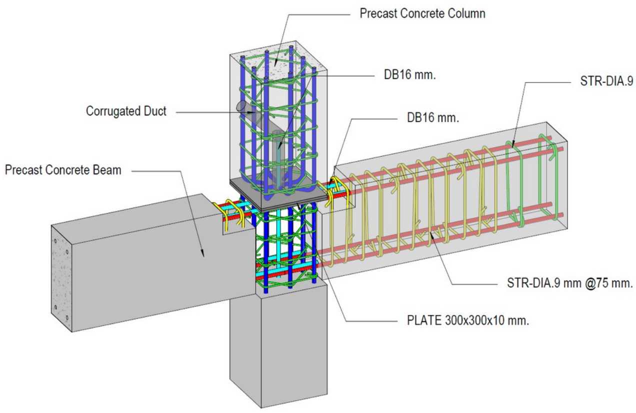

Figure 2. BC1S Precast Beam-Column Specimen

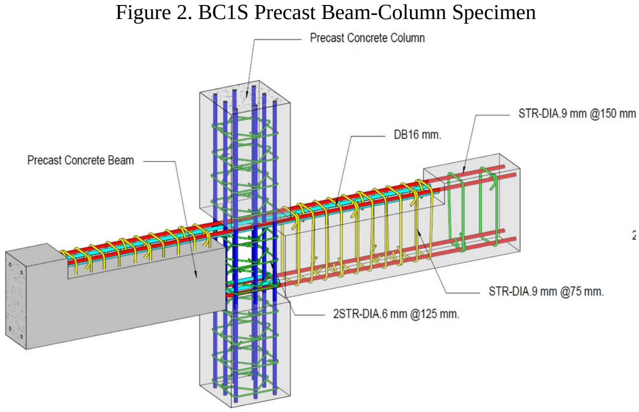

Figure 3. BC2J Precast Beam-Column Specimen

3. RESULTS

The BC1S specimen started showing cracks in beams on both sides at a drift ratio of 0.75%, while the crack in the beam-column joint was observed at a drift ratio of 1.50% and propagated extensively since 2.75% drift. The maximum load of 71.35 kN was observed at -4.50% and the specimen could withstand the deformation up to 6.00% where the load capacity dropped for more than 25% of its maximum with extensive damage in the beam. The load-drift ratio relationship plot of the BC1S specimen is shown in Figure 4, while Figure 5 displays the specimen condition at the failure drift ratio of 6.00%.

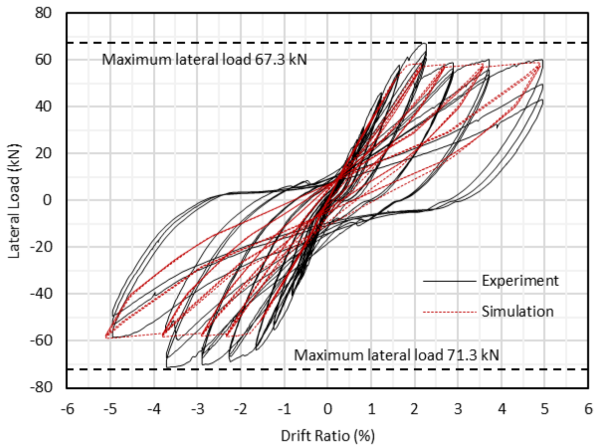

Figure 4. Load–drift ratio relationship of BC1S specimen

Figure 5. Failure of BC1S specimen at 6.00% drift ratio

On the contrary, the load-drift ratio relationship of the BC2J specimen is shown in Figure 6. The first crack was observed inside the beam-column joint at a drift of 0.25%. The crack then formed extensively at the bottom part of the precast beam at 0.75% drift, while the crack in the column was observed at 1.50%. The maximum load of 81.10 kN was reached prior to the concrete spalling at the bottom part of the PC column at +4.50% drift. The BC2J specimen could sustain the load capacity up to a drift ratio of 6.00% with extensive damage in the beam-column joint as shown in Figure 7.

By comparing the test results to the acceptance criteria according to ACI 374.1-05, both proposed precast beam-column joints could be considered satisfactory.

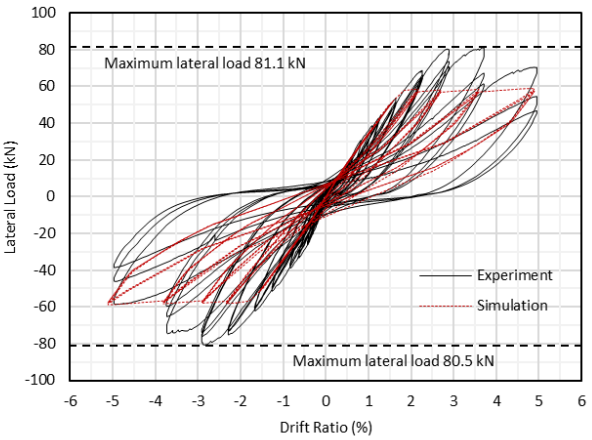

Figure 6 Load–drift ratio relationship of BC2J specimen

Figure 7 Failure of BC2J specimen at 6.00% drift ratio

4. ANALYTICAL STUDIES

An analytical study was carried out to investigate the seismic performance of low to mid-rise PC beam-column building structures, which are designed and detailed according to the guidelines formulated in this study. Two to six story example buildings located in three different provinces of Thailand with distinct seismic characteristics will be designed and analyzed in order to confirm the safety of PC building structures as well as to obtain in-depth understanding on the behavior of this type of structures which will aid formulation of the final guideline.

A conventional computational model generally available in modern commercial software was chosen for simulating the seismic response of PC beam/column members. The chosen model is shown in Figure 8. Although this model is intended to be used for simulating seismic behavior of reinforced concrete (RC) frame members, it is expected to be applicable also to PC beam/column members designed to conform the guidelines developed in this study which are formulated with the aim to emulate the behavior of cast-in-place concrete structures. As seen in the figure, the model consists of two primary components: elastic frame element and zero-length fiber section elements. The former is capable of simulating quasi-elastic response outside of plastic hinge zones, of which modeling parameters are assigned to achieve effective stiffnesses recommended by ASCE 41-13 [3]. Meanwhile, the latter are adopted for simulating nonlinear flexural responses inside plastic hinge zones; the seismic response of confined/ unconfined concrete and rebar fibers are governed by multilinear hysteretic relationships whose behavior follows Mander and Takeda models, respectively. In order to verify the adopted modeling techniques, computational models for specimens BC1S and BC2J were constructed in software Perform3D. The computational and experimental responses are compared in terms of strengths, stiffnesses, and energy dissipation capacity, examples of which are depicted in Figure 4 and 6. It was found that the computational and experimental results generally match with satisfactory degree of accuracy.

It is strongly believed that the adopted model, which is formulated mainly on the theoretical basis without a need for calibration constants, is valid for PC frame members other than those experimented in this study as long as the nonlinear behavior is controlled by the flexural response of plastic hinge zones. The adopted model will be utilized to investigate the seismic performance of PC beam-column building structures as mentioned earlier.

5. CONCLUSIONS

Two new PC beam-column connection configurations of intermediate moment resisting frames aiming for the moderate seismic zone in Thailand were proposed. The test results showed that both configurations performed well conforming to the acceptance criteria of the ACI 374.1-05. Adopted nonlinear computational model representing these PC beam-column configurations was validated and found to provide acceptable degree of accuracy when compared to the test results. This model will be further used to study and confirm the seismic safety of building structures constructed with the newly proposed PC connection configurations.

6. REFERENCE

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[3] American Society of Civil Engineers (ASCE), Seismic Evaluation and Retrofit of Existing Buildings, ASCE 41-13, 2014, Reston, Virginia.

7. AUTHOR BIOGRAPHIES

Ekkachai Yooprasertchai works as a civil engineering lecturer at King Mongkut's University of Technology Thonburi (KMUTT). He obtained his master's and D.Eng. in structural engineering from the Asian Institute of Technology. His research focuses on seismic-resistant precast concrete structures and strengthening of concrete structures.

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