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Capacity Analysis of Variation Emulative Precast Beam-Column Joints with Finite Element Method

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Abstract.
The construction of multistory buildings is currently increasing rapidly. Optimal construction methods are needed particularly in the construction of high-rise buildings. There are two construction methods for multistory buildings that are currently developing, cast-in-place and precast methods. Beam-column joint is important things in both construction methods. In precast systems, the element components and planning affect the structural performance and overall design. Beam-column joint capacity and performance of a plastic hinge relocation method needs to be tested. Testing of the cruciform beam-column joint was carried out using the nonlinear finite element method and compared with the results of laboratory test data. There are 8 beam-column joint models with 2 of them not using plastic hinge relocation method. The results of beam-column joint capacity analysis from manual and finite element methods at yield condition generally give smaller values with a difference of 0,17% - 8,32% than the reference data. While at the ultimate condition, the beam-column joint capacity of the finite element analysis produces a greater value with a difference of 0,52% - 13,83%. The yielding of reinforcement in each model occurs in the predetermined relocation area especially for CBJ90, CBJU and CBJR models.

INTRODUCTION

The increase in population, and demands for activities, as well as limited land are the basis for the rapid construction of tall buildings, especially in big cities. Optimal construction methods are needed in multistory building, especially high-rise buildings. There are two methods of building high-rise buildings that are currently developing, cast-in-place methods and precast methods. In addition, building design must also be done properly so that each structural element can carry and distribute service loads. Precast structural systems consist of precast concrete components that are joined together by mechanical way. However, joining components together is not just a matter of fixing the elements together, but the structural integrity of the entire structure must be ensured [1].

Seismic building structures are generally designed against lower than design earthquake force. This design is known as capacity design method. This method is used so the structure can behave inelastically when resisting the design earthquake force, resulting in the dissipation of earthquake energy through the formation of plastic hinge in the structure. However, while behaving inelastically, the structure must not collapse when it receives the design earthquake force or a larger earthquake force. Therefore, this design procedure is generally applied to structural elements of beams, columns, beam-column joints (BCJ) and walls [2].

There are two types of seismic precast concrete system construction, emulative and jointed construction. Emulative construction is precast construction with joints designed and detailed to make the performance (lateral strength, stiffness, and energy dissipation) of the precast structure comparable to a conventionally designed equivalent monolithic reinforced concrete structure with the correct detailing [3]. Connections in emulative construction can use either ductile connections or strong connections. According to Indonesian National Standart (SNI) 7833:2012, a ductile connection is a connection that experiences yielding due to earthquake design displacement while a strong connection remains elastic while the structural components experience yielding due to earthquake design displacement.

Several studies and tests have been conducted to examine the seismic performance capabilities of beam-column strong connections with strengthening methods to relocate beam plastic hinge zone away from the column face for cast-in-place construction methods. This strengthening method has not been widely researched and used for emulatif precast concrete. . Eom, Park, Hwang, & Kang (2016) researched and tested the strengthening and weakening method in emulative precast BCJ. These tests concluded that the use of strengthening and weakening methods in joints can dissipate energy well and reduce bond-slip and diagonal cracking [4]. This study was conducted to compare the results of the capacity analysis of emulative precast BCJ with plastic hinge relocation method using the finite element method against laboratory tests. The finite element method is a fairly effective and more economical method to determine the nonlinear behavior of structures and materials. Based on the description above, the author will conduct research with the title Capacity Analysis of Emulative Precast Concrete HBK Variations with Finite Element Method.

PLASTIC HINGE RELOCATION

The plastification of beams essentially results in a ductile structural behavior. Other structural elements that are not expected to undergo plastification must continue to behave elastically during the design earthquake force [2]. The building is analyzed under the design loads to determine the required flexural strengths at beam plastic hinges. An objective in the design of special moment frames is to restrict yielding to specially detailed lengths of the beams. If the beam is relatively short and/or the gravity loads relatively low, producing small gravity load moments compared with seismic design moments, then beam yielding is likely to occur at the ends of the beams adjacent to the beam-column joints. The beam plastic hinges undergo reversing cycles of yielding as the building sways back and forth. This is the intended and desirable behavior [5].

The formation of plastic joints at the beam ends will cause significant damage to the BCJ especially in emulative precast concrete construction due to the weak connection between the precast beam shell and the cast-in-place concrete. To prevent failure occur in beam-column joint, beam plastic hinge must be relocated further away from the column face. As the beam plastic hinge zone moves, diagonal cracking and bar bond-slip are expected to decrease in the joint. This implies that the joint region can be better confined by using plastic hinge relocation methods. Thus, the effects of plastic hinge relocation methods are equivalent to those of the confinement provided by transverse beams on the joint faces [4].

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LABORATORY TEST DATA

Five (5) types of BCJ specimens were tested by Eom, Park, Hwang, & Kang. The net column height of the specimen between top and bottom hinge was 2.100 m and the beam length between two vertical rollers was 4.760 m.

The dimension column size used was $h_c \times b_c$ = 550 × 500 mm and the beam size was $b_b \times h_b$ = 350 × 500 mm. The

thickness of precast U-Shell beams is 75 mm for both sides (right and left) and 50 mm at the bottom. The concrete
strengths and reinforcement strengths used in the specimens varied according to the specimen components. The
predicted load capacity (P_n) was calculated based on the moment capacity of the beam critical section by section analysis including precast concrete and cast-in-place core concrete. A summary of the laboratory test results can be
seen in TABLE 1 and FIGURE 1.

TABLE 1. Test Result and Prediction Load Capacity [4]

Specimens	Load Capacity	
	Test Result, P_u (kN)	**Prediction, P_n (kN)**
PC	351	325
PC-W	336	330
PC-S1	370	331
PC-S2	378	335
RC	380	349

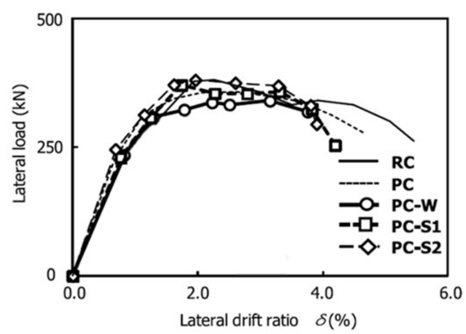

FIGURE 1. Laboratory test lateral load vs lateral drift graph [4]

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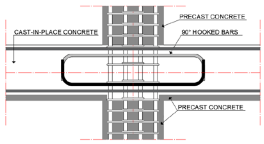
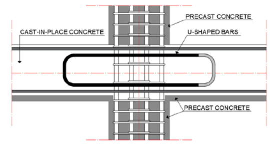
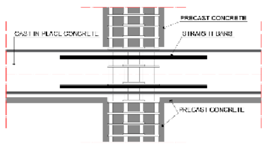
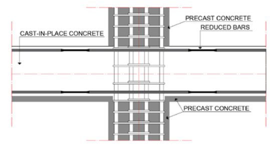
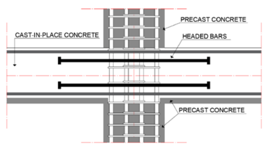
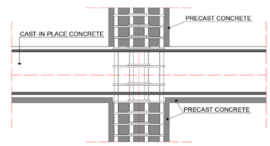
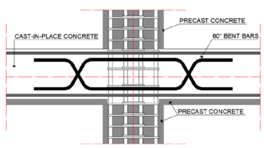
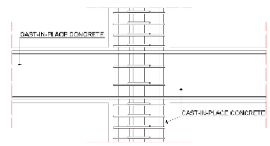
FINITE ELEMENT ANALYSIS

There are six (6) plastic hinge relocation methods in emulatif precast concrete structures that will be tested using finite element method. BCJ without plastic hinge relocation method will also be modeled in emulative precast and conventional concrete as shown in **TABLE 2**.

TABLE 2. Finite Element Specimens

No	Code	Relocation Method	Beam-Column Joint Details	No	Code	Relocation Method	Beam-Column Joint Details
1	CBJ90	90° Hooked		5	CBJU	U-Shaped Bars	
2	CBJL	Straight Bars		6	CBJR	Reduced Bars	
3	CBJK	Headed Bars		7	CBJBP	-	
4	CBJ60	60° Bents		8	CBJBK	-	

Concrete strengths, reinforcement strengths and number of reinforcement bars are similar to the laboratory tests conducted by Eom, Park, Hwang, & Kang. Finite element modeling will use MIDAS FEA software. The BCJ was modeled as Cruciform with the size used in the laboratory tests and with static loading such as **FIGURE 2**. The analysis in the program is performed with nonlinear static in order to obtain the ultimate capacity and the location of plastic hinge formation in the specimens.

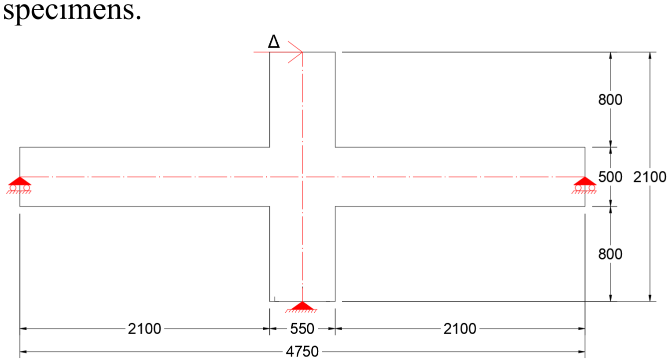


FIGURE 2. Beam-Column Joint Cruciform and Loading Models

An example of emulative precast BCJ finite element model with their reinforcement bars can be seen in **FIGURE 3** and **FIGURE 4**.

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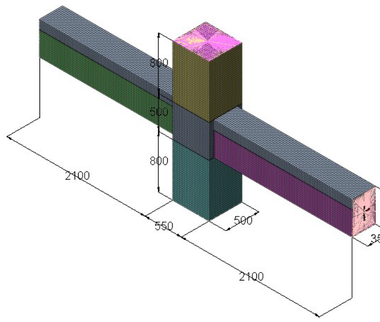

FIGURE 3. Emulatif precast concrete beam-column joint model

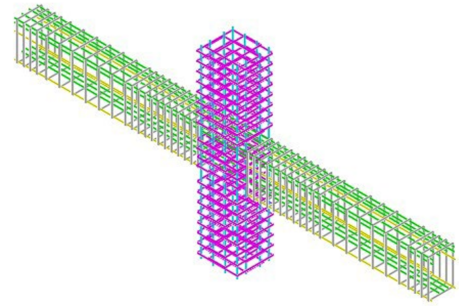

FIGURE 4. Emulatif precast concrete beam-column joint reinforcement model

BEAM-COLUMN JOINT YIELD CAPACITY CALCULATION

Manual calculations were carried out to determine the BCJ capacity when yielding occurs in the beam. The results of the manual calculation of beam nominal moment and BCJ capacity for all specimens are summarized in **TABLE 3**.

TABLE 3. Calculation summary of beam nominal moment and beam-column joint capacity

Specimens	$M_{n(+)}$ (kNm)	$M_{n(-)}$ (kNm)	P_n (kN)
CBJ90	194,36	349,79	329,79
CBJL	194,36	349,79	332,45
CBJK	194,36	349,79	332,45
CBJ60	194,36	349,79	329,79
CBJU	194,36	349,79	329,79
CBJR	192,32	345,40	328,53
CBJBP	231,24	381,72	323,86
CBJBK	257,63	392,68	350,13

FINITE ELEMENT ANALYSIS RESULTS

Based on the analysis carried out with the MIDAS FEA program, data on reinforcement stress, deformation, and crack patterns on the tested specimens were obtained. The data for specimen CBJ90 can be seen in **FIGURE 5** through **FIGURE 9**.

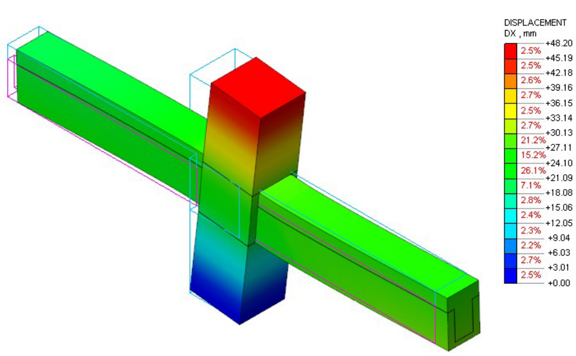

FIGURE 5. Deformation of CBJ90 at ultimate condition

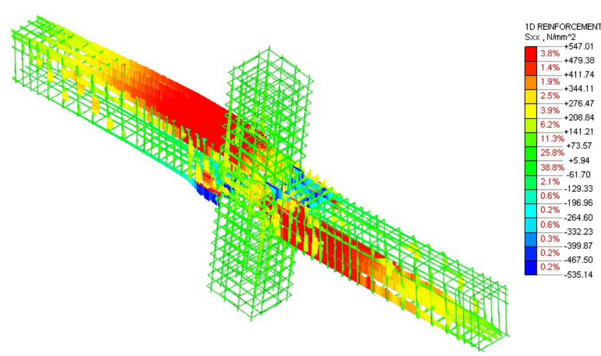

FIGURE 6. Reinforcement stress of CBJ90 at ultimate condition

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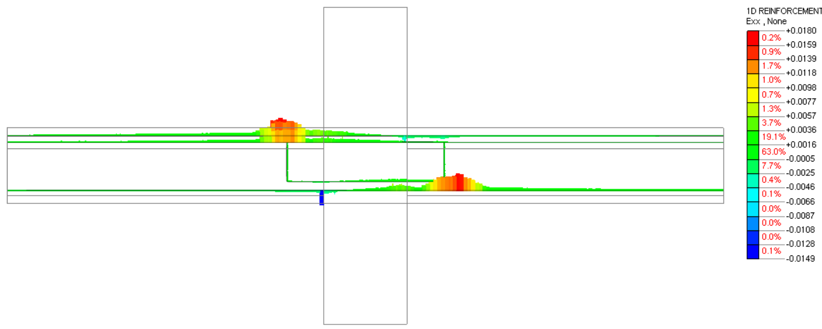

FIGURE 7. Reinforcement strain of CBJ90 at ultimate condition

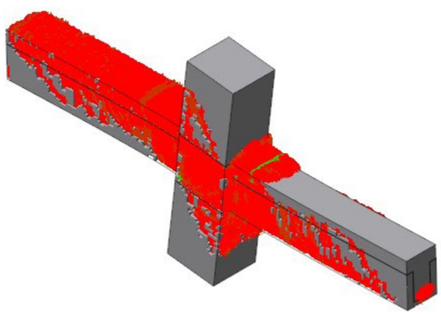

FIGURE 8. Crack pattern of CBJ90 at ultimate condition

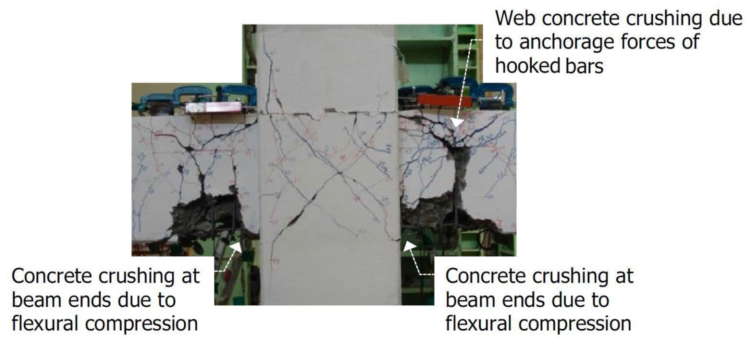

FIGURE 9. Crack pattern of PC-S1 laboratory test [4]

COMPARISON

The results of the BCJ capacity analysis from manual calculation and finite element method at yield condition generally give smaller values with a difference of 0.17% - 8.32%. While at the ultimate condition, the BCJ capacity of finite element analysis generate a greater value than the reference data with a difference of 0.52% - 13.83%. The value of BCJ capacity for each specimens at two condition and the comparison can be seen in **TABLE 4** and **TABLE 5**.

TABLE 4. Comparison of beam-column joints at yield capacity

Specimens	Yield Capacity (P_n)			Deviation		
	Manual (kN)	FEA (kN)	Data (kN)	Manual vs FEA (%)	Data vs Manual (%)	Data vs FEA (%)
CBJR	328,53	329,08	330,00	0,17	0,45	0,28
CBJBP	323,86	311,15	325,00	3,92	0,35	4,26
CBJ90	329,79	326,86	331,00	0,89	0,37	1,25
CBJK	332,45	322,87	335,00	2,88	0,76	3,62
CBJBK	350,13	331,06	349,00	5,45	0,32	5,14
CBJL	332,45	331,79	-	0,20	-	-
CBJU	329,79	324,34	-	1,65	-	-
CBJ60	329,79	357,23	-	8,32	-	-

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TABLE 5. Comparison of beam-column joints at ultimate capacity

Specimens	Ultimate Capacity (P_u)		Deviation
	FEA (kN)	Data (kN)	Data vs FEA (%)
CBJR	382,48	336,00	13,83
CBJBP	374,41	351,00	6,67
CBJ90	371,97	370,00	0,53
CBJK	370,32	378,00	2,03
CBJBK	381,99	380,00	0,52
CBJL	368,03	-	-
CBJU	368,13	-	-
CBJ60	414,09	-	-

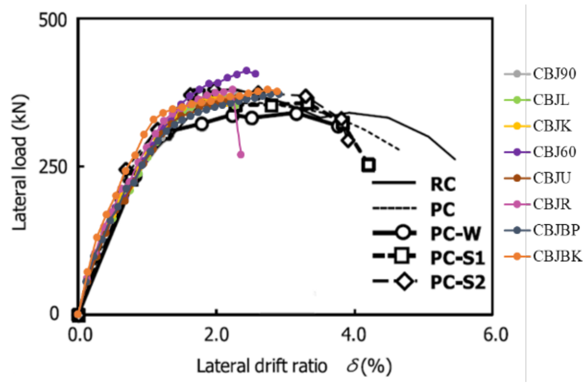

FIGURE 10. Graph comparison of finite element analysis with laboratory test reference data

CONCLUSIONS

Based on the results of the study and data analysis that has been done, some conclusions can be obtained as follows:

- The results of the beam-column joints capacity analysis of the manual calculation and finite element methods at yield condition generally generate smaller values than the reference data with the largest deviation of 5.14%.
- The ultimate capacity of beam-column joints analyzed by the finite element method gives fairly accurate results with deviation to laboratory test reference data of 0.52% - 13.83%.
- Yielding of reinforcement in each model occurred in the predetermined relocation region especially for CBJ90, CBJU and CBJR specimens. For the models without relocated reinforcement, reinforcement yeilding occurred at the column face which could damage the integrity of the beam-column joint.

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