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FINITE ELEMENT ANALYSIS ON BEAM TO COLUMN CONNECTION IN IBS PANEL

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Abstract

In recent years to develop Industrialized Building System (IBS) panel system, many experimental researches have been tested out on beam to column connections, as it is the most vital part that influence the rigidity and strength of the precast concrete structures. In this paper, three precast beam to column connections types, namely; monolithic, endplate and corbel connections have been modelled using three dimensional (3D) finite element model software package ABAQUS. With the purpose to analyse the structural performance of the beam to column connections, all the models were statically loaded, and then investigated for the strength, deformation capacity and their stiffnesses and compared with existing experimental results. The concrete material is simulated using constitutive law of concrete damage plasticity in order to model the concrete stress strain behaviour. The comparison shows good accuracy based on the load displacement graph, moment-rotation behaviour and observed crack patterns. The failure mode identified for the beam to column connections are mainly joint shear failure for all types of connections. The availability of the 3D simulation proves a robust and reliable investigation on the nonlinearity behaviour of the connection.

Keywords: Industrialised building system, precast structure, beam to column connection, static loading, nonlinear behaviour, finite element analysis.

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1. Introduction

Industrialised Building System is now being developed towards modern construction as precast construction which is also widely used in the construction industry. The precast consist of component such as beam, column, slab and shear wall which are then assembled and connected by joint connections in between the component (CIDB Committee, 2013). The joint connections are considered as the most vital part in reinforced precast concrete buildings that transmit the load, carry the structural integrity and the stability of the whole frame construction system. The types of precast beams to columns connections are basically known and classified as pinned and rigid connections. However, these types of connection have its advantages and disadvantages corresponding to its rigidity and ductility, resulting the need of investigation in order to improve the actual strength that can be optimized in the future. (Magliulo, Ercolino, Cimmino, Capozzi, & Manfredi, 2014). Many experimental studies were conducted (Rathodi & Shelke, 2016), (Chakravarthy, Janani, & Ilango, 2018), however, such experimental studies have faced some limitation and constraint on the cost, manpower, huge instruments, which leads researchers to find alternative way and solution to investigate more in depth in their study using numerical studies along with their experimental studies (Sadeq, Hejazi, & Sarah, 2017). However, precast systems have been experiencing problem such as poor-detailing joint which causes common functional defect such as water seepage problem in high rise building (Rahman, Zainordin, & Ahmad, 2017). Thus, the study of the behaviour on precast beam to column is continuously being developed to improve the structural integrity to enhance its strength and ductility.

2. Problem Statement

Understanding the mechanism of the structure of beam-column connection in static loading is essential to measure its members capacity towards its maximum strength and required before proceeding towards the next step of determining the strength in other loading condition such as cyclic loading, the progressive collapse (Rashidian, Abbasnia, Ahmadi, & Nav, 2016). Patil and Manekari (2013) has examine the strength of exterior and interior beam to column joint under monotonic loading through load-displacement results of deformation, maximum stress capacity, joint stiffness variations. Subsequently, parametric study is then performed computationally by numerical analysis to enhance its joint efficiency (Barma, 2017). With the presence of advanced computer technology, a greater number of finite element software has been created that are able to carry out finite element analysis and allow to simulate the numerical analysis into a realistic manner. One of popular commercial finite element software is ABAQUS, that can capture the realistic behaviour of the beam-column joint accurately than other software especially in deformations and failure. (Chaudhari, Mukane, & Chakrabarti, 2014), (Long & Lee, 2015). However, the importance of understanding the technical background on how the software functions and its process is required in order to perform the numerical test to acquire results accurately (Najafgholipour, Dehghan, Doshabi, & Niroomandi, 2017).

Recently, Najafgholipour et al. (2017), Allam, Elbakry, and Arab, (2018), Long and Lee, (2015) investigated using 2-D numerical models of reinforced concrete beam-column joints using the finite element analysis, ABAQUS (2018) to measure the strength and its deformation capacity under monotonic loading. The concrete material is simulated using constitutive law of concrete damage plasticity in order

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to model the concrete stress-strain behaviour in compressive and tensile damage. However, the numerical analysis results are obtained in different accuracy and stiffer than the experimental results as more problems has been addressed on convergence issues, and the consideration of bond-slip effect of the reinforcement bar. Thus, initiative is taken to proposed numerical model by using various technique such as the application of translator element, steel ductile damage, to collaborate the bond-slip behaviour, examine the mesh sensitivity, and viscosity parameter in comparing to the experimental results. As a result, the joint failure is successfully captured by the propagation of crack observed, and the stiffness of the numerical results is improved. Furthermore, parametric study is conducted using different concrete strength, number of joint stirrups and reinforcement using load deflection result being investigated to capture joint failure.

3. Research Questions

In contrary to the failure mode that occurred in conventional reinforcement beam to column connection, there are three failure modes identified on precast connection consisting three types which are shear, flexural and reinforcement bond failure mode (Allam et al., 2018). By using the numerical analysis procedure, the failure mode can be determined and assessed for the precast beam to column connection.

This research is conducted to answer the following question:

- How to determine and assessed the failure mode for the precast beam to column connection by using the numerical analysis procedure, focussed on the strength, stiffness, and deformation capacity??

4. Purpose of the Study

The purpose of this paper is to evaluate the behaviour of precast beam to column connections under static loading and to identify the types of failure modes using finite element analysis. The limitation in this study are only focusses on the strength, stiffness, and deformation capacity of three different types of connections subjected to static monotonic loading.

Three different types of beam to column connection were experimentally tested in Universiti Teknologi Malaysia (UTM) by Rahman and Leong (2006) and Rahman, Akhir, and Hamid (2015) to examine the behaviour of precast concrete beam to column in static loading. This paper presents a nonlinear FE simulation of the experimental work on three types of precast beam to column connection. The results of behaviour of connections are defined by load-deflection graph for monolithic structure (PC-1) in (Figure 1a), and precast connection using steel plate (PC-2) in (Figure 1b), and corbel connection as (PC-3) in (Figure 2). In this paper, the three types of connections are referred as model PC-1, PC-2 and PC-3 hereafter.

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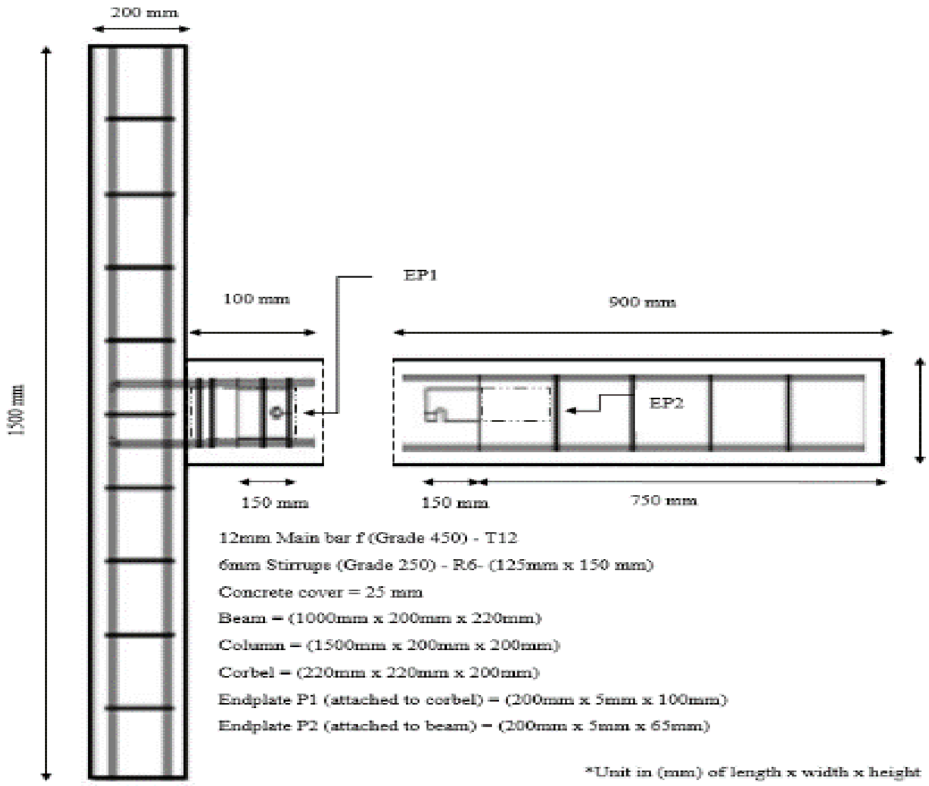
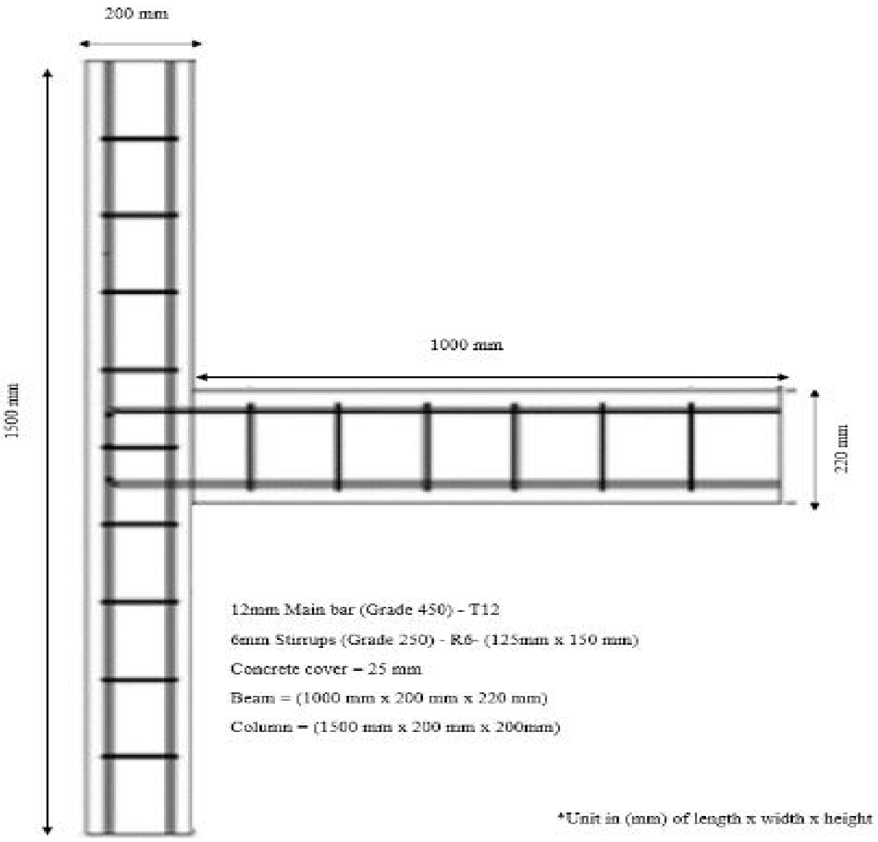


(a)



(b)

Figure 01. Types precast beam to column connection model

Source: Modified from Rahman et al., (2015)

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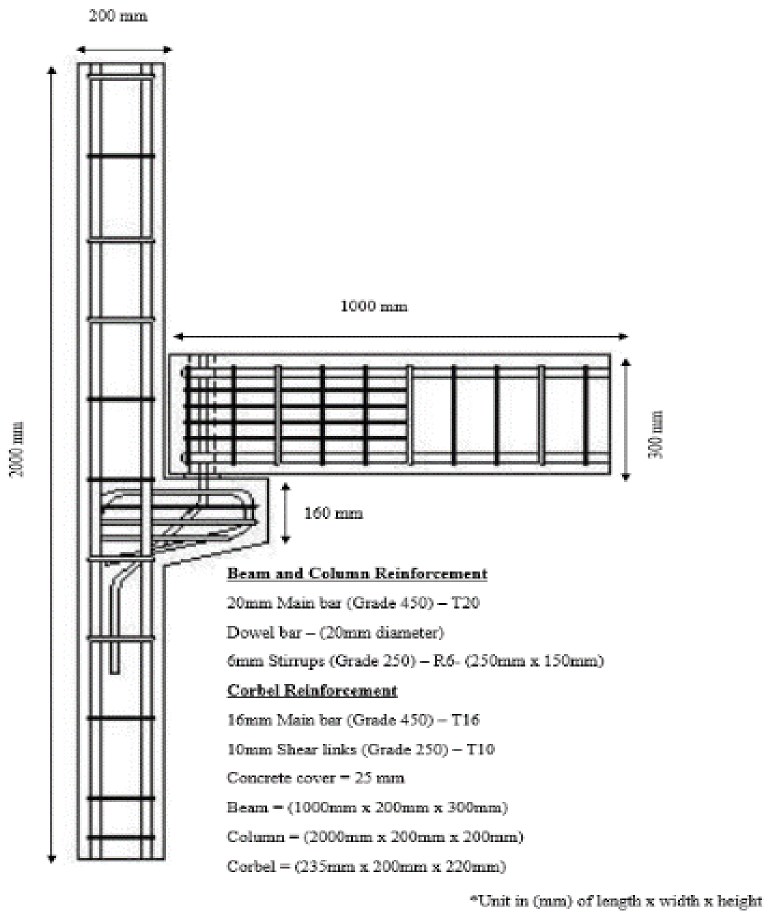

Figure 02. Type precast beam to column connection model Source: Modified from Rahman and Leong (2006)

5. Research Methods

5.1. Model geometry

The geometries of the models are based on the experimental setup by Rahman et al. (2015) which is depicted in Figure 1 and Rahman and Leong (2006) in Figure 2. Model PC-1 connection has a cross sections of the beam of 150 mm x 200 mm in width and depth, with a length of 1000 mm. The size of the column is 180 mm x 180 mm with 1800 mm in length. The concrete strength used is 30N/mm^2 at 28 days. Model PC-2 connection has similar cross sections as PC-1 but with corbel attached at the column face and connected by steel endplate which is embedded both in the corbel and beam. The concrete strength used connected the beam component filled with grout. The beam comprises a cross-section of 200 x 300 mm with total length of 1000 mm and is jointed with a supported corbel of 200mm wide and 220mm depth. The precast column has dimension of 200 x 200 mm with total length of 2000 mm. The strength of concrete used for this precast is 40N/mm^2 at 28 days. All types of connection for the beam and column are reinforced with main bar of 12 mm diameter high yield steel bars of grade 450 and 6 mm for stirrups in grade 250. All the concrete cover are 25 mm and the main reinforcement bars are spaced at 130 mm intervals. The steel plate and the dowel are both in grade 275.

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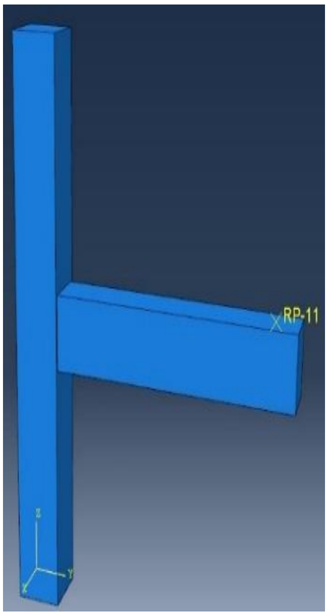
5.2. Material, Interactions, Loading and boundary conditions and Mesh size

In the ABAQUS software, the concrete damaged plasticity (CDP) is adapted in order to define concrete and steel material as shown in Table 1. In this study, the CDP models is calculated based from (Dere & Dede, 2011; Wahalathantri, Thambiratnam, Chan, & Fawzia, 2011) to obtain the compressive and tensile stress-strain of concrete strength used in order to generate any cracks formation in concrete against the loading (Hanif, Ibrahim, Ghaedi, Ahad, & Sardar, 2018). The interaction used are embedded region method and tie constraint contact technique to create bond interaction between the truss element of steel reinforcement and the concrete element, meanwhile embedded-region was used as interaction to constraint the two-node beam elements steel reinforcement and the surrounding concrete element in order to simulate and assume full perfect bond behaviour as recommended by (Najafgholipour, Dehghan, Doshabi, & Niroomandi, 2017). A point load is assigned on top of beam end at length of 900 mm at each precast model, each specimen was loaded up to its maximum force at the Reference-point known as RP shown in Figure 3. The boundary conditions were set all in the specimens as the column top and bottom end was restrained to all six (D-O-F) degrees of freedom. For the mesh size, 20 mm was considered for overall elements in concrete part of beam and column, solid element type (C3D8R) were used to model the concrete while for the reinforcement main bar and stirrups, truss element (T3D2) were used.

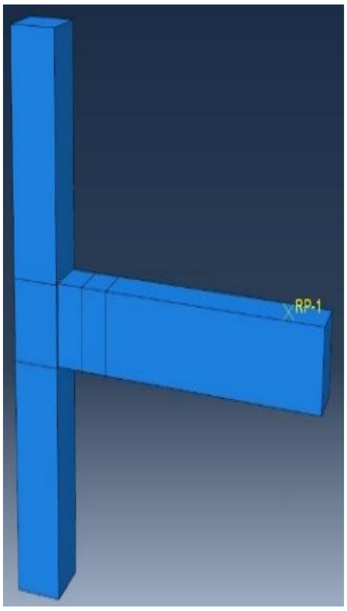
Table 01. The parameters values used for concrete and steel

Parameters of concrete damaged plastic model	
Dilation angle	38°
Eccentricity	0.1
fco/fco	1.16
K	0.67
Viscosity parameter	0.0001

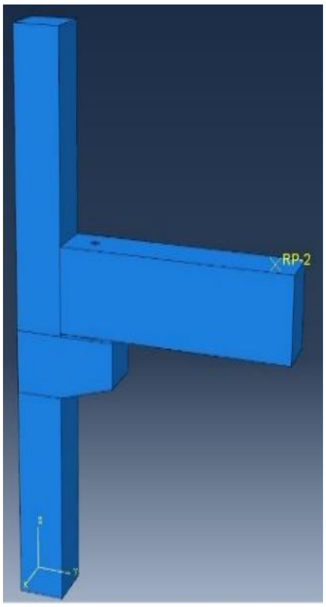
CDPM Parameters	Mass Density (Kg/m^3)	Poisson Ratio, *v*
Concrete	2400	0.2
Steel	7800	0.3



(a) PC-1



(b) PC-2



(c) PC-3

Figure 03. The numerical model of three types precast beam to column connection

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6. Findings

The numerical analysis results of the three types of precast beam-column connections subjected to static loading are presented in terms of load-displacement graphs for PC-1 and PC-2, and moment-rotation graph for PC

6.1. Model PC-1

A comparison between the load-deflection graph of the experiment for monolithic connection (Rahman et al., 2015) and the numerical analysis is presented in Figure 4. In the initial loading phase, the numerical model results show nonlinear behaviour and stiffer response in the elastic phase range up to 6.18 kN, while the experimental (Rahman et al., 2015) shows a lower load deflection at 2kN. The experimental results undergo yielding due to the resistance response from the steel bar reinforcement. The numerical model undergoes cracking stress which starts to propagate when loaded at approximately 6kN. The numerical model has its maximum peak at 22.7kN while the experimental result was depicted at 22.5kN. The beam to column connection model has been identified to encounter joint shear failure during the maximum load, and the cracking pattern in the joint region obtained by numerical model matches the cracking propagation as in experiment results as Figure 5(b). The stresses of reinforcement bar (S,Mises) at yielding and ultimate load are shown in Figure 5(c).

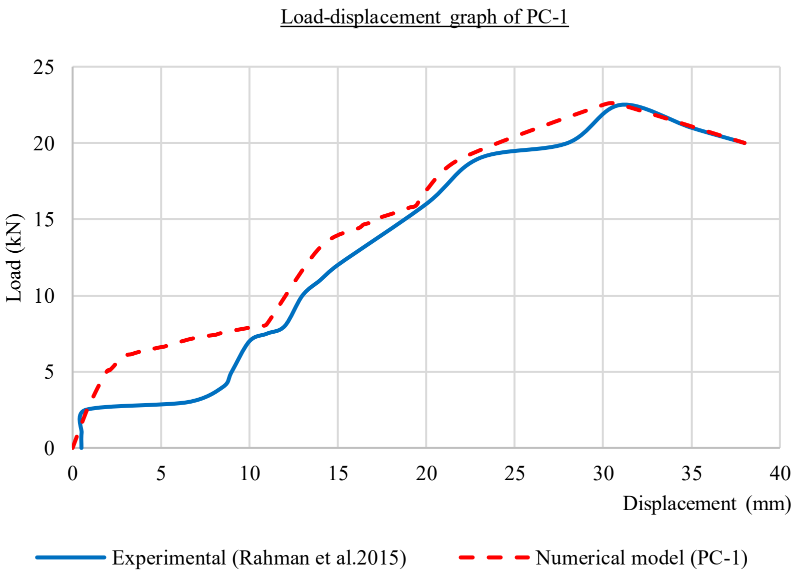

Figure 04. Comparison results of experimental results and numerical results (PC-1)

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a) Crack diagram of concrete b) Crack based experimental c) Stress diagram of rebar

Figure 05. Comparative analysis of the experimental test and numerical analysis at the maximum loading

6.2. Model PC-2

The load-deflection response of Model PC-2 under maximum loading is shown in Figure 6. The numerical Model PC-2 displays nonlinear behaviour in the elastic region between the cracking initiation point up to the steel yielding point, which reflects the dependency of the reinforcement and the endplate joint on the steel components upon the initiation of the loading at 6 kN. The initial loading deflects in linear behavior through the elastic phase that take places until 12 kN which indicates the presence of the slip bonding between the steel reinforcement and the concrete towards the load-deflection. However after it reaches its ultimate strength at 15kN, both the numerical analysis and experimental shows the same pattern of capacity decreased when plastic deformation initiated. The beam to column connection model undergoes beam shear failure as crack propagates at the joint shown in Figure 7(a) as according to crack based experimental in Figure 7 (b). The stresses of reinforcement bar (S,Mises) at yielding and ultimate load are shown in Figure 7(c) with the main reinforcement bar highly stressed at the upper main reinforcement bar.

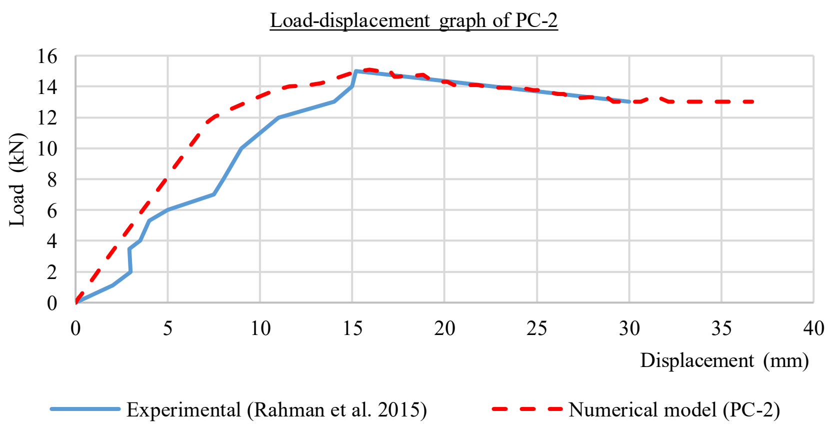

Figure 07. Comparison results of experimental results and numerical results (PC-2)

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a) Crack diagram of concrete b) Crack based experimental c) Stress diagram of rebar

Figure 08. Comparative analysis of the experimental test and numerical analysis at the maximum loading.

6.3. Model PC-3

The comparison of experimental and numerical model of precast corbel connection in moment-rotation response under static load are shown in Figure 8. The numerical model depicted the maximum moment-rotation load is depicted at 19 kNm while in the experimental was 18.5 kNm corresponding to rotation of 65.5 millirad. Both the numerical model and the experimental results (Rahman & Leong, 2006) exhibits low rotational stiffness during the initial loading in the elastic range phase which indicates it is a pinned behaviour type of connection. As the loading initiates, the numerical model results show a higher bending moment curve at 3 kN compared to experimental results by differences of 36%. The beam-column connection model attributes joint shear failure at the corbel as the dowel bar yield and the beam crushes on corbel.

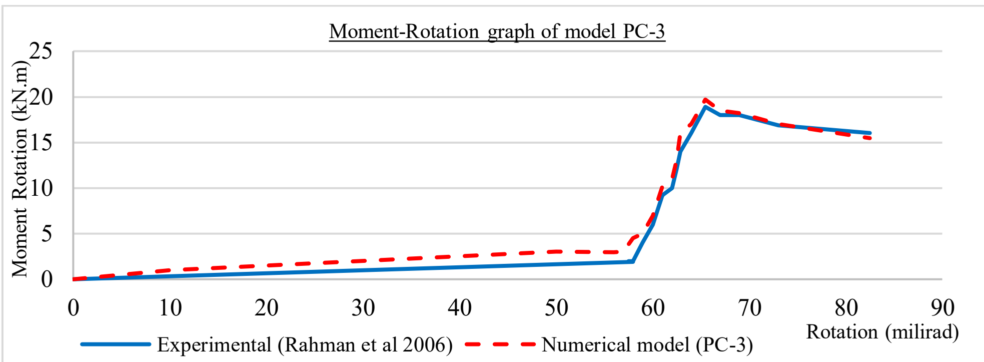

Figure 09. Comparison results of experimental results and numerical results (PC-3)

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a) Crack diagram of concrete b) Crack based experimental c) Stress diagram of rebar

Figure 10. Comparative analysis of the experimental test and numerical analysis at the maximum loading

From the observations by (Rahman & Leong, 2006), it is observed that the column, corbel and beam area does experience slight crack after being loaded but the corbel. The maximum stress levels in steel at ultimate load which is corresponding to the moment rotation of 19.2 kNm are shown in Figure 8. There is tension crack stress at the joints as shown in Figure 9(a). The crack patterns at the corbel are shown in Figure 9(a) however shown slightly than the crack patterns as observed in the experimental program and shown in Figure 9(b). As the beam to column connection is joint by a dowel of length of 100 mm from the corbel to beam, the S Mises in Figure 9(c) shows significant stresses on dowel bar embedded with reinforcement bar in the corbel as the beam rotates to reach the maximum load.

From the above results model PC-1, PC-2, and PC-3 have achieved load resistances of 22.5 kN, 15.5 kN and 16.8 kNm respectively before reaches the failure. Among the three results, the monolithic connection of PC-1 depicted the highest load resisting capacity, while the endplate connection of PC-2 has the lowest load resisting capacity. Although the load resistance for PC-3 yielded very low in the stage before it reaches its failure, however, the it manages to obtain its load resistance higher than the endplate model PC-2. It is found that the presence of endplate in precast model CP-2 did not significantly increase the load deflection, as the ultimate load capacity of beam was 15.1 kN with deflection of 15.5 mm does not surpass the ultimate load monolithic as it could not take applied loads but only with the increasing in deformation capacity, which lacks behind the monolithic connection and corbel connection.

7. Conclusion

The finite element analysis results confirm the capability to develop the finite element model in prior to assess the precast beam-column connection behaviour to be further investigated and optimised with parametric studies. Based on the numerical results, it is concluded that, Model PC-2 with endplate connection behave utmost lack in deflection characteristics compared to connections with corbel and monolithic. The model has poor load capacity of maximum only at 15.2 kN attained at 15mm displacement. Also, the deformation capacity is attained is lower than PC-1 and PC-3. While the model PC-3 yields very low in the first initial yield stage and attained maximum load capacity of 15 kN attained at 60 mm displacement slightly higher than model PC-2 however it has highest deformation capacity than

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model PC-1 and PC-2. Based on results, the precast Model PC-1, PC-2 and PC-3 exhibit joint shear failure in the joint area region considering the importance of joint shear failure influences on strength, stiffness and deformation of precast beam to column connection.

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