Citation: Hamidon, N.Z., T. Kabeyasawa (2023), Seismic performance of precast reinforced concrete Beam-to-column connection, Synopsis of IISEE-GRIPS Master's Thesis.

SEISMIC PERFORMANCE OF PRECAST REINFORCED CONCRETE BEAM-TO-COLUMN CONNECTION

Nurul Zawani binti HAMIDON[1] **Supervisor:Toshikazu KABEYASAWA[2]**
MEE22708

ABSTRACT

This research aims to analyze the behavior of precast structures in Malaysia when subjected to seismic activity, specifically focusing on the connection between beams and columns. To achieve this, a new method called the Beam-Line Method (BLM) has been developed and utilized to model and analyze the seismic performance of these connections in precast frames. The study employs non-linear static pushover analysis and non-linear dynamic time history analysis to comprehensively evaluate the structural response under seismic loads. Additionally, the seismic performance of the building is assessed by combining the seismic capacity curve obtained through pushover analysis with the elastic response spectrum curve of the earthquake. Furthermore, the study investigates the significance of connections in the overall structural performance by calculating moment rotations in the beam-to-column connection. These are then utilized in the seismic analysis of the entire frame. The outcomes of this research provide valuable insights into the seismic behavior of precast reinforced concrete beam-to-column connections, thus informing future design and construction practices to enhance the seismic resilience of such structures.

Keywords: Seismic Response, Precast Structures, Beam-to-Column Connection, Beam-Line Method

1. INTRODUCTION

Malaysia's rapid urbanization and construction development have ushered in an era of increased utilization of precast reinforced concrete (PRC) due to its multiple benefits. These advantages include enhanced speed, efficiency, cost-effectiveness, quality control, and the reduction of on-site errors and waste. The government's focus on regulating and promoting this technology through the Construction Industry Development Board (CIDB) has further augmented its growth. From 2015 to 2020, there has been a significant rise in the adoption of the precast technique in public projects in Malaysia, soaring from 24% to 85.3%. The trend toward hybridization, combining traditional methods with modern technology, has emerged as an optimal solution, with joint guidelines developed by the government and academics. However, Malaysia's geographical location near the Pacific Ring of Fire introduces severe seismic considerations. The region has been the center of catastrophic earthquakes, including the devastating 2004 Indian Ocean earthquake and other significant seismic events in surrounding areas like Thailand and the Philippines. This study explores the seismic performance of PRC beam-to-column

[1] Public Work Department, Malaysia.
[2] Associate Professor, Tokyo Metropolitan University.

connections, a critical aspect of construction in a seismically active region. Through a thorough examination of recent trends, the implementation of the PRC, and an analysis of the seismic activities around Malaysia, the study aims to provide a comprehensive understanding of how the PRC can be utilized effectively and safely in an area prone to earthquakes. Therefore, the research aims to analyze the moment resistance of the proposed precast beam-to-column connection using the beam-line method, along with obtaining the load-deformation curve from non-linear analyses. The study seeks to enhance construction practices and seismic safety in Malaysia's rapidly expanding precast industry by exploring these areas.

2. TARGET BUILDING

Malaysia's Public Works Department (PWD) has developed a catalog of pre-approved plan (PAP) buildings to streamline the design process for various ministries. Among over 100 buildings, the Clinic Type 3 building, a popular choice across Malaysia, is prominently featured. However, most of these PAP structures, including the Clinic Type 3 building, were designed based on the non-seismic code EN 1992, without considering seismic load requirements. This is a significant concern, particularly in regions prone to earthquakes like Sabah state. The study focuses on the base shear coefficient, a key seismic design parameter, and reveals that a coefficient of 0.44 implies a seismic force constituting 44% of the structure's total weight. Such a significant force highlights the urgent need to address seismic considerations in the design of PAP buildings. Detailed calculations and understanding of the seismic factors emphasize the necessity to adapt design standards to ensure structural safety in earthquake-prone regions. Figure 1 shows one of the precast connection details that has been used for this study.

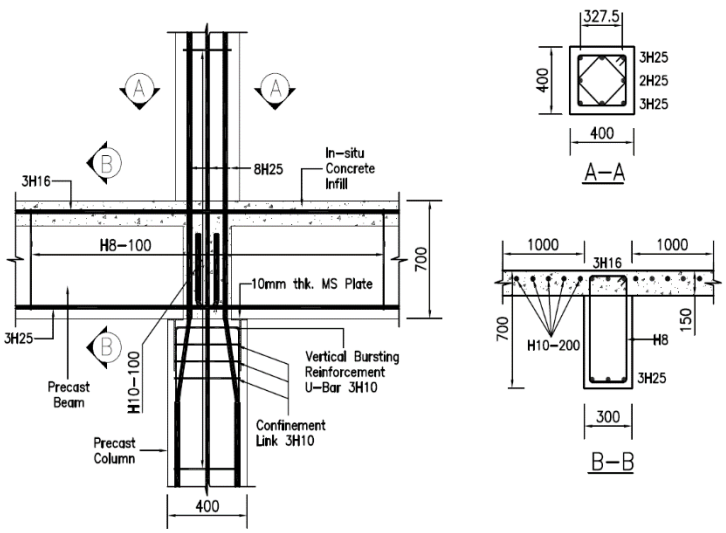

Figure 1. Details of the connection were located at 3/G at 2F story or X8/Y7 referring to the CANNY model. All measurements are in millimeters.

The Clinic Type 3 building in Malaysia was designed following EC2 for gravity load and EC8 with Malaysia National Annex for earthquake load. Key design parameters included a peak ground acceleration of 0.16g, medium ductility class (DCM), an essential building factor ($\gamma 1$) of 1.5, and ground type E with over 30m deep sediment to bedrock. These specifications reflect the building's vital function as a clinic and the need for seismic considerations. Table 1 shows the base shear force value that has been obtained for this target building.

Table 1. Story lateral force calculation for the target building

Story	Height, Z_i (m)	Mass, m_i (kN)	$Z_i.m_i$ (kNm)	$Z_i.m_i$ / $\Sigma Z_i.m_i$	F_i (kN)
RF	11.85	5501.18	65189.02	0.174	5416.10
3F	9.30	15522.93	144363.22	0.386	11994.13
2F	4.80	34287.55	164580.23	0.440	13673.82
GF	0	34486.72	0	0.000	0
		Total $\Sigma Z_i.m_i$:	374132.47	1.00	

3. METHODOLOGY

In this study, the strength of the entire connection of the target building has been evaluated using two methods. The first method employed is the Architectural Institute of Japan (AIJ) method, which is considered the conventional approach for the AIJ model. Equation 1 outlines the moment resistance for AIJ method. On the other hand, for the precast method, the Beam-line method (BLM) has been applied to the BLM model. The equation for this method is detailed in the book "Precast Concrete Structure" by Kim S. Elliott, as indicated in equation 2 (K.S Elliott, 2016).

$$M_R = 0.9.\alpha_t.\alpha_y.d \tag{1}$$

$$\frac{M_E}{M_R} = \left[\left(\frac{L + (2 \times l_P)}{L}\right) + \left(\frac{2.22 \times E_{cm} \times I_{cr}}{A_s \times E_s \times d^2}\right)\left(\frac{l_e}{L}\right)\right]^{-1} \tag{2}$$

Furthermore, the flexural cracking moment was also determined as part of the analysis. The cracking moment is an important parameter that indicates the onset of cracking in the structural elements. The equation of the cracking moment, M_c can be referred to as equation 3 (Mukai, 2022);

$$\mathrm{M_c} = 0.56\left(\sqrt{\sigma_B}\right).\mathrm{Z_E} + \frac{\mathrm{ND}}{6} \tag{3}$$

The Sugano formula calculates a structural element's stiffness degradation, α_y. Stiffness degradation is an important parameter in structural engineering as it helps understand how an element's stiffness decreases under deformation. This is particularly important in seismic design. The formula provided is shown in equation 4 (Mukai, 2022):

$$\alpha_y = \left(0.043 + 1.64\frac{E_s}{E_c}p_t + 0.043\frac{a}{D} + 0.33\eta_0\right)\left(\frac{d}{D}\right)^2 \tag{4}$$

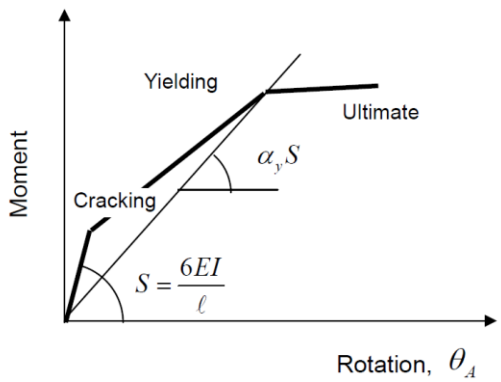

Figure 2. Member-end moment-rotation relation from Japan Technical Standard Manual for Building Structures

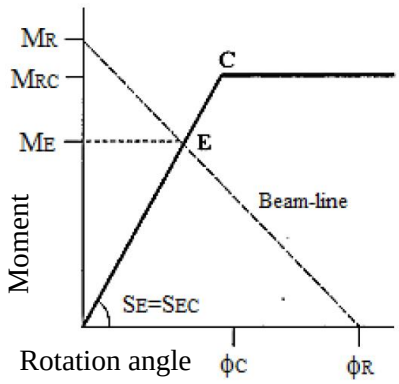

Figure3. Intersection of moment-rotation line with beam-line (Elliott et al., 2003)

Figure 2 illustrates the correlation between a structural member's bending moment and its rotation. The curve is vital for comprehending beam behavior under bending loads and identifying connection types, such as rigid, semi-rigid, or pinned. A notable observation from the graph is the stiffness degradation, indicating a decline in beam stiffness with increasing deformation, represented by the stiffness degradation ratio. In structural engineering, the choice of connection type is vital, especially in earthquake-prone regions where allowing rotation can help absorb ground movement energy. The moment-rotation curve, coupled with the beam-line, as shown in Figure 3, helps determine two key connection properties: the allowable moment capacity (M_E) and the secant stiffness (S_E).

4. RESULTS AND DISCUSSION

3.1. Simulation Results of the Non-linear Static Pushover Analysis

Figures 4 and 5 depict the relationship between the base shear and story drift for the AIJ and BLM models. The base shear refers to the total horizontal force a structure must withstand during an earthquake. The story drift refers to the displacement between two consecutive building floors. The base shear coefficient of the frame at yielding is about 0.15 in AIJ model, and 0.12 in BLM model. This result suggests the strength of the BLM model is smaller compared to AIJ model due to the failure of the column-beam connections. The story drift concentrates on 2nd story in the AIJ model compared to the BLM model. The shear coefficient of the design seismic force is 0.44 in the rigid model, so that it exceeded the yielding strength of the building. Both models have a near-similar threshold before failure. Precast-designed buildings might fail sooner during seismic events compared to conventionally designed ones, with the latter showing higher ductility.

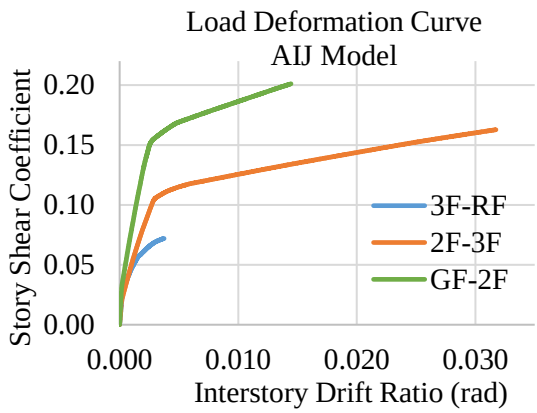

Figure 4. Load-deformation curve for the AIJ model obtained from the PA

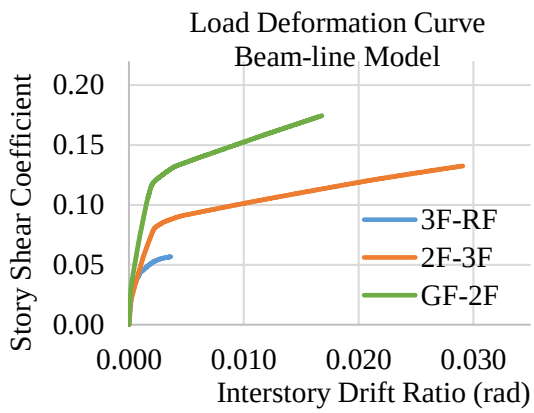

Figure 5. Load-deformation curve for the BLM model obtained from the PA

The seismic capacity curves obtained from the PA with the elastic response spectrum curve of the earthquake and the specific building must be compared to accurately determine the building's seismic performance. Regarding Figure 6, the spectral displacement decreases as the period increases around the point of maximum response (cross point). It shows the AIJ and BLM models exhibit a similar response in terms of deformation, without significant differences. An analysis of these graphs showed that the AIJ model had a yield point of 8.6 cm, while the BLM model had a yield point of 6.7 cm. Note that the yield point was outside the earthquake ground motion and response spectra range. The spectral displacement values were determined as 5.15 and 1.0 cm for El Centro and Ranau, respectively. The primary objective of identifying the seismic performance point was to observe the building's displacement during an earthquake. The performance point or the target displacement was then compared with the hinge formation to determine the building's state when the displacement was reached.

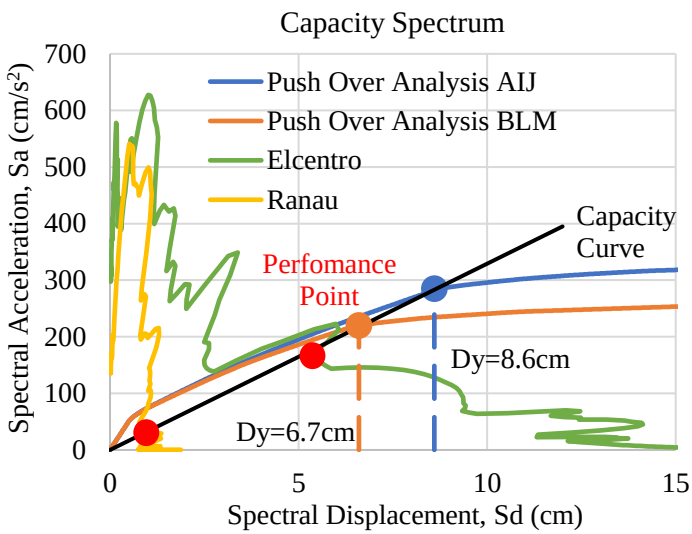

Figure 6. Comparison of the capacity spectra of the AIJ and BLM models (earthquake).

3.2. Simulation Results of the Non-Linear Dynamic Time History Analysis

The structure's response to the El Centro and Ranau ground motions was meticulously analyzed using the AIJ and BLM models. The results of these analyses are shown in Table 2. The load–deformation curves of the AIJ (Figure 7) and BLM (Figure 8) models, specifically for the Ranau ground motion, were included to comprehend the load–deformation behavior of the target building. Figures 9 and 10 depict both models' load–deformation curves under the El Centro ground motion.

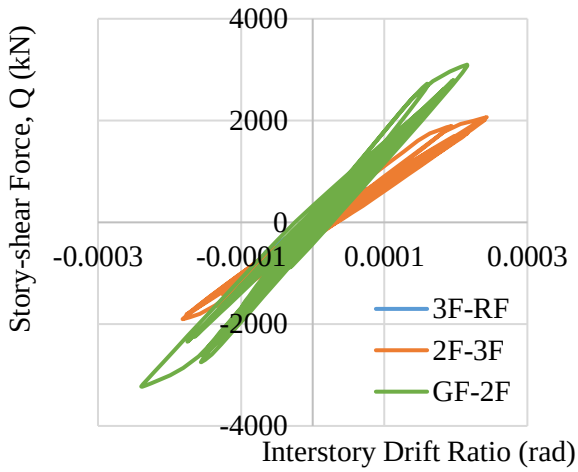

Figure 7. Load–deformation curve for the AIJ model under the Ranau ground motion.

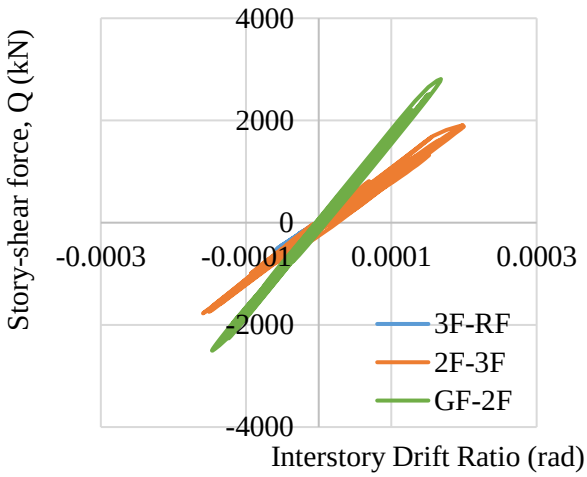

Figure 8. Load–deformation curve for the BLM model under the Ranau ground motion.

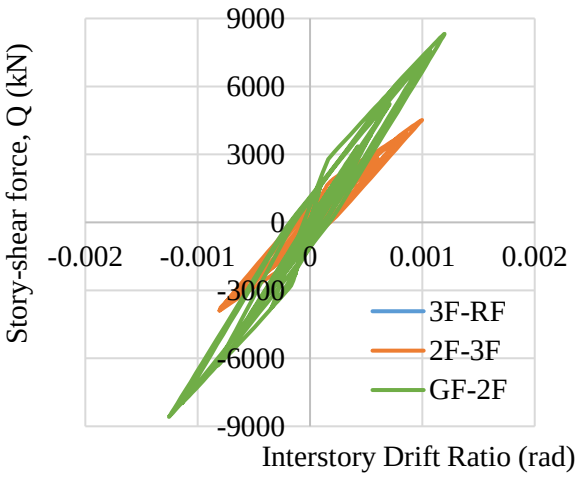

Figure 9. Load–deformation curve for the AIJ model under the El Centro ground motion.

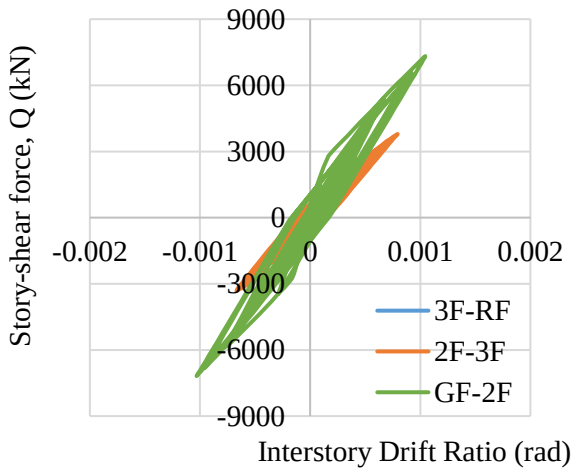

Figure 10. Load–deformation curve for the BLM model under the El Centro ground motion.

Table 2. Comparison of the maximum story drifts for the AIJ and BLM models with the THA

Earthquake	Maximum story drift of the AIJ model	Maximum story drift of the BLM model
El Centro	0.0012	0.0010
Ranau	0.00024	0.00020

5. CONCLUSIONS

From this study, the base shear coefficient for the target building was determined as 0.44 based on the EC8 seismic design. The base shear coefficient calculation depended on various behavior factors (e.g., soil factor, building important factor, and natural period of the building). The target building was designated with a medium-ductility class that has a specific rule for additional reinforcement, that is, the number of reinforcements must be higher than that of the low-ductility class. The number of reinforcements impacts the building's seismic performance differently, especially for the beam‑column connections, regardless of method (i.e., conventional or precast).

The seismic capacity curves of the target building were established by using non-linear static PA. The overall results showed that the maximum story drift for the BLM model was less than that for the AIJ model designed using the conventional method. In other words, under seismic events, the building with the BLM model will undergo plastic hinge formation sooner than that with the AIJ method. Referring to the base shear values for both methods, the AIJ and BLM models can be used to achieve similar displacements. However, the AIJ model showed stiffer values when compared to the BLM model due to the maximum story drift obtained from the PA. This was because the BLM model experienced deterioration.

The seismic performance point for the target buildings was achieved. The load under the target building is safe under 0.16 g PGA if the building is designed under the Type E ground condition. This is because the maximum story drift for the El Centro ground motion was 0.0069 as the plastic hinges were being formed beyond the O and IO states. Meanwhile, the maximum story drift for the Ranau ground motion was 0.0013, in which the plastic hinges were formed before the O state.

The analysis of the THA results showed that the maximum story drifts of both the AIJ and BLM models under the El Centro and Ranau ground motions were very small and almost identical. Only a slight difference, which was caused by the limitation in the calculation of Canny's program for the deteriorated BLM model, was found in the results for the El Centro ground motion. In the BLM model analysis, the results could not be obtained when deterioration occurred. Therefore, the El Centro ground motion intensity was reduced from 1.0 to 0.35 to obtain the results. These values depicted a 65% or 0.65 decrease in absolute terms. For the Ranau ground motion, the original intensity was already smaller than the seismic resistance of the target building.

ACKNOWLEDGEMENTS

This research was conducted during the individual study period of the training course "Seismology, Earthquake Engineering and Tsunami Disaster Mitigation" by the Building Research Institute, JICA, and GRIPS.I would like to express my sincere gratitude to my supervisor, Dr. Toshikazu Kabeyasawa, for their invaluable guidance and unwavering support. Their insightful suggestions and encouraging words have significantly contributed to the accomplishment of this project. In the same light, my advisor, Yuri Otsuka has my sincere appreciation. Their expert advice, thorough critique, and nurturing mentorship have been instrumental in my work and thought processes throughout the study.

REFERENCES

Architectural Institute of Japan (2001). Data for Structural Calculation of Reinforced Concrete Building

K.S Elliott. (2016). Precast Concrete Structures 2nd Edition. CRC Press.

Mukai. (2022). Lecture notes on Reinforced Concrete 1.

Elliott, K. S., Davies, G., Ferreira, M., Halil, G., & Mahdi, A. A. (2003). Can Precast Concrete Structures be Designed as Semi-Rigid Frames? Part 1: The Experimental Evidence. The Structural Engineer, 81(16), 14-27.

Council Japan Association of Structural Engineers. (2015). Technical Standard Manual for Building Structure.