

Ductility of Precast Concrete Column Beams Using Dowels

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ABSTRACT

Precast concrete structures are considered as monolithic structures, flexural reinforcement and beam column joint shear can be planned based on design capacity. This research is an experimental study. The objective is to assess the ductility of precast concrete column beams utilizing dowels. The test specimens comprise three configurations: monolithic beam column (BN), 2 post precast beam column (BG 1), and 4 post precast beam column (BG 2), with respective displacement values of 37.4 mm, 42.7 mm, and 47 mm. This research was carried out in the stages of calculating displacement ductility using displacement parameters, and curvature ductility using parameters of cross-sectional curvature or curvature values and load values due to cyclic loads. The research results show that the displacement ductility values for test specimens BN, BG 1 and BG 2 are 2.34, 2.21 and 2.06 respectively. The curvature ductility value for test specimens BN, BG 1 and BG 2 is more than the value required in ASCE 41-17, namely 0.01 in the LS condition and in the CP condition it is 0.015. Additionally, these values surpass the stipulated requirements. This leads to the conclusion that beam column connections, whether monolithic or precast, exhibit exceptional performance in withstanding earthquake loads under both moderate seismic conditions (moderate earthquakes) and severe seismic conditions (strong earthquakes)

INTRODUCTION

Meeting demands for the speed of construction development is increasing, especially in big cities. The cause is that the land is getting narrower and the traffic is getting denser, so a short construction time is needed (Niken, 2000). The answer to this demand can be met with precast concrete column beams (Zhu et al., 2021), (Baran et al., 2021), but it cannot yet be used widely because the reliability of the connections between the elements is still an obstacle, especially against earthquake loads (Simbolon1 et al., 2019), (Ghayeb et al., 2020), (Clementi et al., 2016). In precast concrete planning, the main problem faced is the connection. In this research, the connection used is a dowel, which is used as a connecting material between structural components. Therefore, planning of building structural elements really needs to pay attention to strength and ductility (Kang & Tan, 2015), (Breccolotti et al., 2021), (Tafsirojjaman et al., 2021), as well as consideration for evaluating the performance of the dowel connection system (Ghayeb et al., 2020). Precast concrete joints use a variety of configurations, including: (a) Angle joints and steel bars with or without reinforcement; b) joints using steel plates and bars; (c) Use of cast-in-place (CIS) concrete for joints; (d) especially bolted joints (Ying Zhou et al., 2022).

Increased level of security for the average population, as well as so that structures such as buildings and bridges have good performance and are easy to repair after an earthquake (Zhu et al., 2021), (Tong et al., 2021), appropriate column footing connections are needed (Won et al., 2020), efforts to overcome these problems are Joints in precast concrete must be strong. Self-centering (SC) precast concrete wall structures have been devised as earthquake-resistant structural systems known for their low structural damage and manageable residual drift. (Ying Zhou et al., 2022). Ding et al. developed a new precast concrete beam column connection for earthquake resistance (Ding et al., 2021). Comprehensive tests were conducted on two connections utilizing grade 5.6 and 8.8 bolts, respectively. The evaluated connection demonstrated outstanding performance in withstanding seismic loads. In a recent investigation, Zhou et al.

Two half-scale concrete beam column models (one monolithic and one precast) were studied to assess the potential risk of progressive collapse during failure of the central column. (Yun Zhou et al., 2020). Furthermore, through the utilization of pushover analysis and the nonlinear seismic dynamic time analysis, the maximum global displacement flexibility requirement of the structure and the maximum flexibility requirement of the column curvature are determined. (J.Zhou et al., 2014).

Therefore, this research is very important for testing the ductility value of precast concrete column beams using dowels. The aim of this research is to analyze/measure the displacement ductility and curvature ductility values of precast concrete which can support earthquake loads.

TINJAUAN PUSTAKA

The problem that occurs is that Indonesia occupies a very active tectonic zone due to its geographical location and conditions so it is very prone to earthquakes, making the use of precast concrete construction quite risky. Typically, structures are prone to progressive collapse when they experience the loss of one or more load-bearing elements, such as columns, as a result of severe events like blast loads, impacts, seismic activity, or fire. (Elsanadedy, 2021). The collapse of concrete buildings due to earthquakes (Bovo & Savoia, 2019), (Wang et al., 2018) As one of the most critical failure scenarios, progressive collapse is a matter of significant concern within the structural engineering community. (Elsanadedy et al., 2017). The reinforcement of concrete structures involves a delicate balance between ensuring structural safety and managing costs. Steel-jacketing (SJ) stands out as a widely adopted and effective strengthening technique, employed to enhance the ductility and shear capacity of concrete structural elements. Nevertheless, the utilization of steel-jacketing comes with notable drawbacks, such as considerable invasiveness, substantial economic costs, and downtime, which pose limitations on its overall sustainability. (Di Trapani et al., 2021). The challenge at hand pertains to the beam column connection's ability to facilitate relative displacement without compromising the beam seating and to efficiently transmit lateral horizontal forces from the beam to the column without diminishing its load-bearing capacity. (Clementi et al., 2016).

METODOLOGI

Test Object Design

The nonlinear seismic dynamic historic analysis determines the global maximum shear ductility requirements of the structure and the maximum bending ductility requirements of the columns, as well as the 2 pin and 4 pin mortar connections, as shown in Figures 1, 2 and 3. Column size is 30cm x 30cm, length is 295cm, beam size is 20cm x 30cm, length is 145cm.

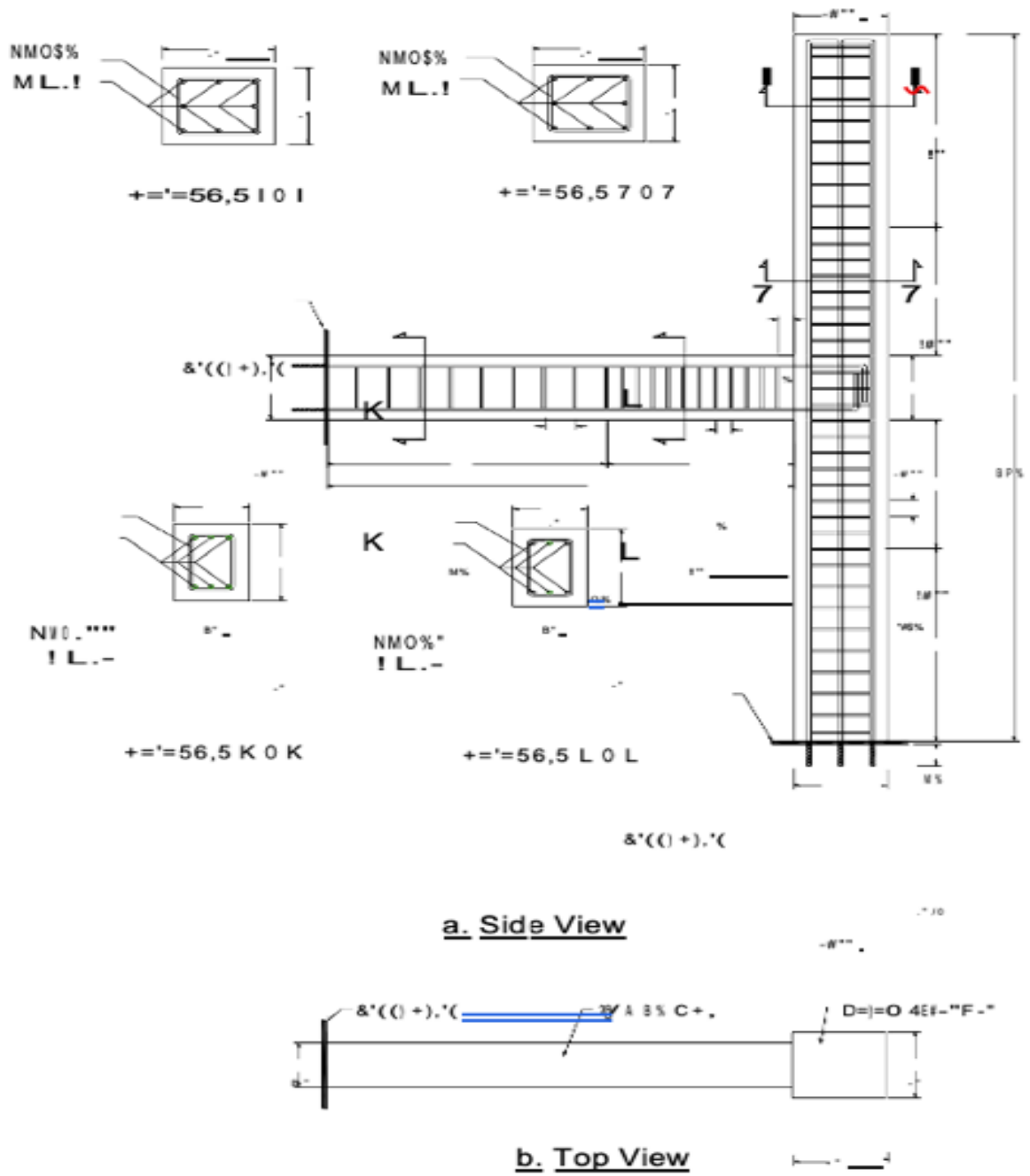


Figure 1. Monolith Column Beam Test Object (BN)

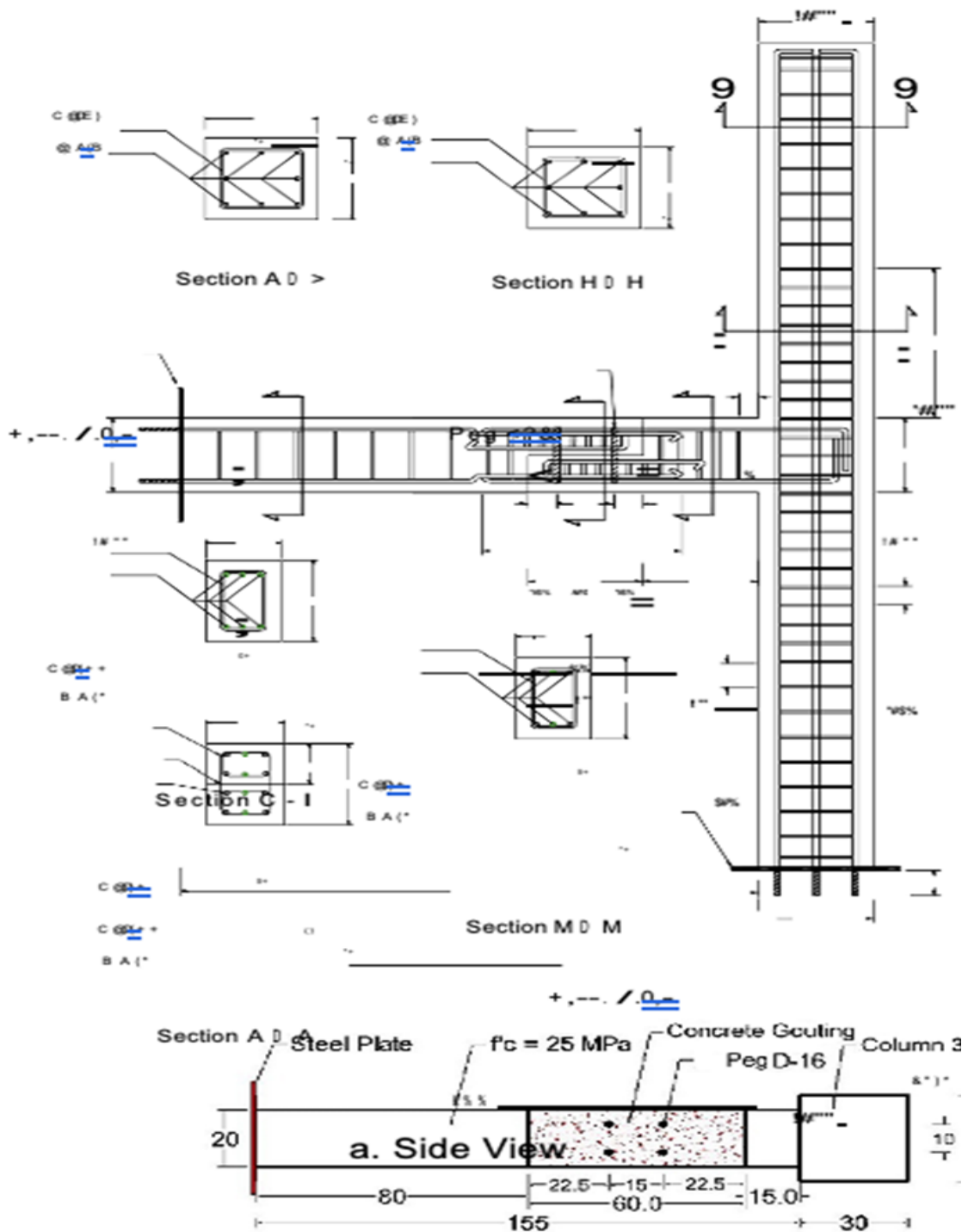


Figure 3. Test Object 4 Stake Connection (BG 2)

Experiments were carried out at the Structure and Materials Laboratory of the civil engineering department of Hasanuddin University. Cyclic testing was carried out utilizing equipment equipped with an actuator having a capacity of 1500 kN and a maximum displacement of ± 20 cm. The configuration for testing the BN, BG 1, and BG 2 specimens is depicted in Figure 4.

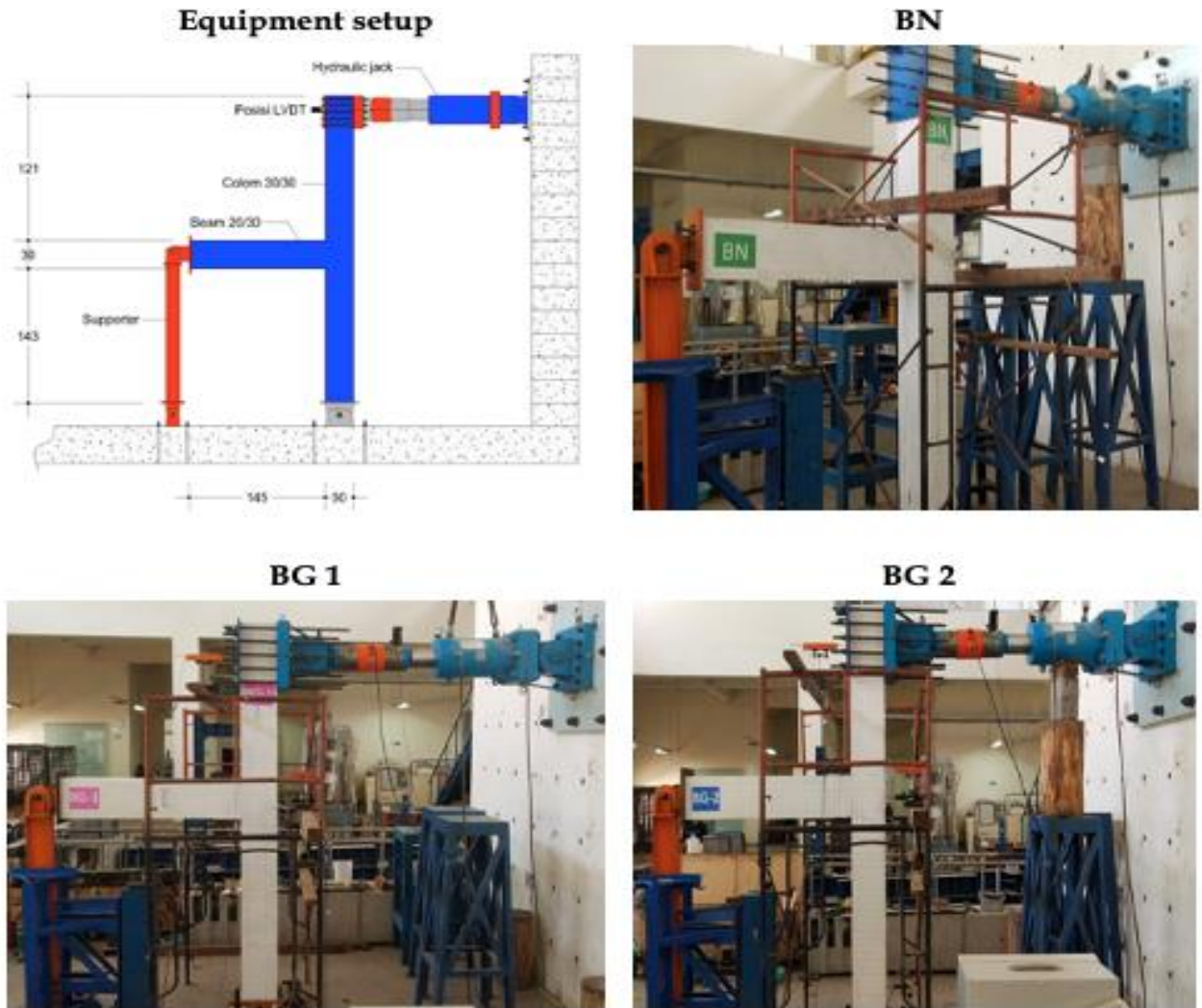


Figure 4. Cyclic Testing Equipment Setup

Additionally, a 2 cm thick plate is positioned at the base and affixed to a sturdy floor with a thickness of 1.5 m using a 1.5" (38 mm) rod.

Testing Method

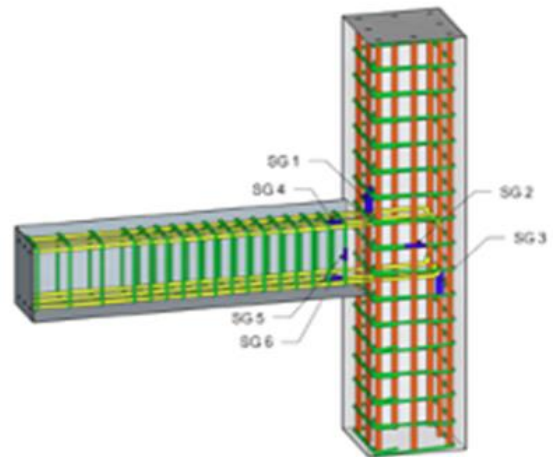
1. Tensiometer bar and concrete

The purpose of installing strain gauges in steel reinforcement is to lower the strain gauges so that the material applied to the concrete reaches its final state.

Strain Gauge Installation Photos



Monolithic Concrete (BN)



B2 Post Precast Concrete Joints (BG 1) 4 Stake Precast Joint Concrete (BG 2)

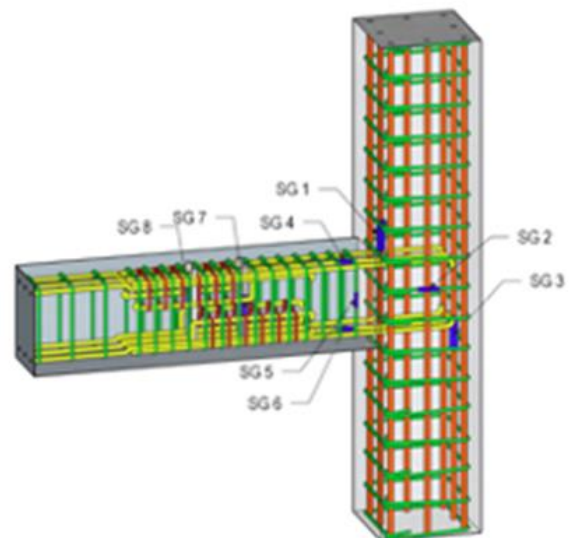
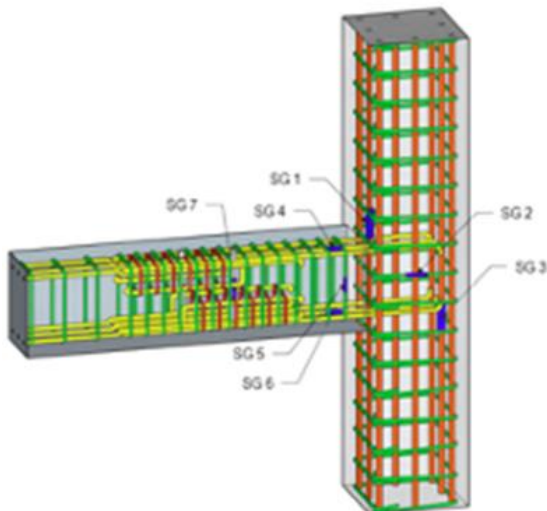


Figure 5. Strain Gauge on Steel

FLK-6-11-5L (Strain Gauge Type) reinforcement is applied to horizontal and transverse reinforcement, see Figure 5.

2. LVDT

Measuring the displacement value of the beam column connection test object is a linear variable displacement transducer (LVDT).



Figure 6. LVDT on Test Pieces and Installation Photos

Six LVDTs, with a capacity of 100 mm and 50 mm, for measurement purposes the 100 mm LVDT is positioned to measure horizontal displacement values at the top and middle of the column, and the 50 mm LVDT is positioned at the bottom of the column and at the midpoint of the beam span (see Figure 6).

Cyclic Testing Procedure

Cyclic load testing, based on SNI 7834:2013 as a guideline for testing precast reinforced concrete moment-bearing frame structures for buildings, with reference to ACI 374.1-05 which outlines Moment Frame Acceptance Criteria based on Structural Testing. The test conditions are described as follows:

1. The specimen undergoes loading through a sequence of displacement-controlled cycles, mimicking anticipated displacements between floors at the joint during an earthquake.
2. Each deviation ratio requires application in three complete cycles.
3. The initial deviation ratio should fall within the linear elastic behavior range of the specimen. Subsequent deviation ratios must be between 5/4 and 3/2 times the preceding ratio.
4. Gradually increase the deviation ratio until reaching a minimum value of 0.035 (refer to Figure 7).

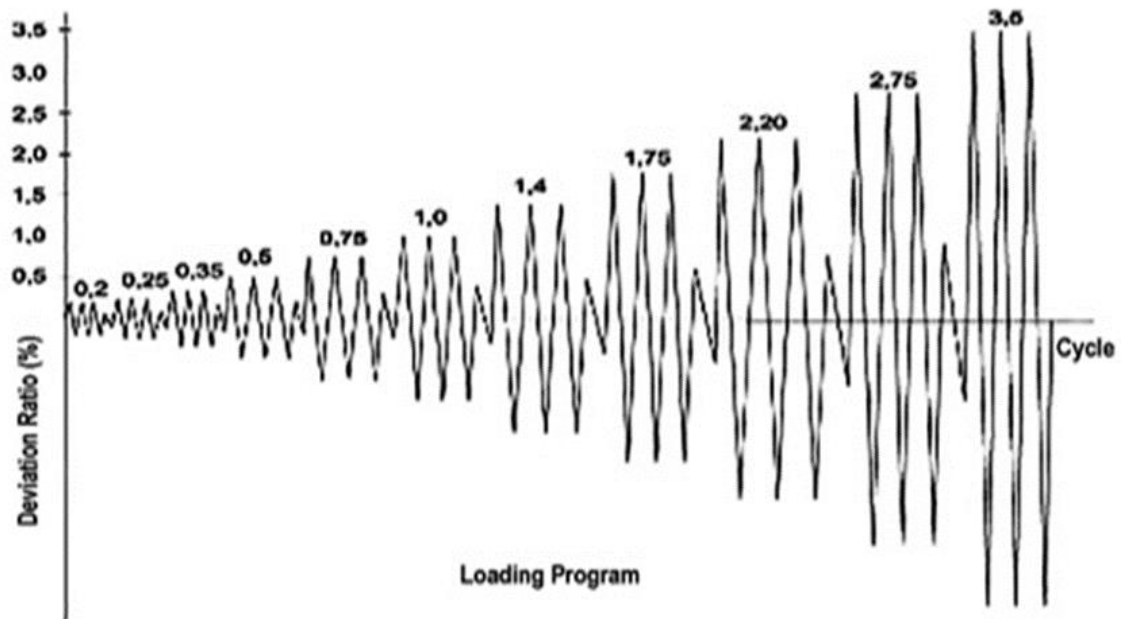


Figure 7. Loading Program According to SNI 7834:2012

RESULT AND DISCUSSION

Ductility of beam column connections

This section experiments the behavior of joints between beams and columns in ductility which occurs at two critical conditions: the ultimate condition, which is characterized by structural failure in the first yield of the reinforcement. The displacement under these conditions is obtained from the load-displacement hysteresis curve generated during the application of a cyclic load.

Ductility parameters at displacement, especially the position of the initial yield point of the reinforcement (Δ_y), and at the ultimate condition, which indicates structural failure (Δ_u). Calculation of displacement ductility involves the use of displacement parameters, while curvature ductility includes the curvature or curvature of the cross-section and the load value resulting from cyclic loads.

1. Displacement Ductility

Table 1 shows the initial yield condition of the reinforcement and the ultimate condition which is related to the displacement value. You can also see the Δ_y and Δ_u values on the Backbone curve.

Table 1. Shifting to Yield and Ultimate Conditions

Test Objects SBK	<i>First Yield</i>	<i>Ultimate</i>	Ductility
	Δ_y (mm)	Δ_u (mm)	
BN	37,4	87,6	2,3
BG 1	42,7	94,4	2,2
BG 2	47	96,8	2,1

The yield point, which was observed in the monolithic beam column joints (BN), 2 post-precast beam column joints (BG 1), and 4 post-precast beam column joints (BG 2) was 37.4 mm, 42.7 mm, and 47 mm, respectively at the intersection.

Comparing the displacement in the ultimate condition with the displacement in the melted condition, the ductility values derived from the calculation data for test specimens BN, BG 1, and BG 2 respectively are 2.3, 2.2, and 2.1, respectively, which can be seen in Table.

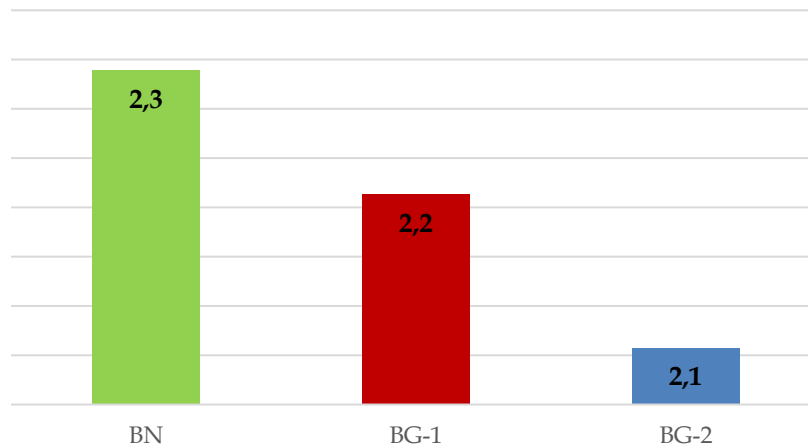


Figure 8. Ductility Values for Test Specimens BN, BG 1, BG 2

The ductility value in the treatment of the BN specimen was 2.34, and the BG 1, BG 2 specimens had values of 2.21 and 2.06 as shown in Figure 8. The conclusion from this observation is that the beam column connection (BN) monolithic has a higher ductility value than precast beam column connections that use dowels (BG 1 and BG 2).

The ductility value of a 2-pile precast beam column connection is 0.94 times that of a monolithic beam column connection, which experienced a decrease of 5.56%. On the other hand, in precast beam column connections with 4 studs, the ductility value is 0.88 times, indicating a decrease of 12%. The level of ductility of the connection using 4 pegs is lower than the precast beam column connection with 2 pegs.

There is a decrease in ductility using dowels, when compared with monolithic beam column connections, due to grouting in the beam connection area. has an impact on increasing the stiffness of the cross-section due to the higher compressive strength of the concrete in that area.

2. Ductility Classification of Beam Column Connections

Table 2 presents the ductility classification of the test specimens in accordance with ASCE 41-17.

Table 2. Ductility Classification of Test Specimens According to ASCE 41-17

Test Objects	Ductility	Category	ASCE 41-17
BN	2,3	Moderate ductility	< 2, low ductility
BG 1	2,2	Moderate ductility	2 to 4, moderate ductility
BG 2	2,1	Moderate ductility	> 4, high ductility

In the ductility classification according to ASCE 41-17, there are three categories: low ductility, medium ductility, and high ductility. Low ductility refers to values below 2, while medium ductility is in the range of 2 to 4, and high ductility applies to values exceeding 4. Based on Table 2, the ductility values of monolithic beam column (BN) connections and precast beam column connections (BG 1 and BG 2) are 2.3, 2.2, and 2.1, respectively. Taking these values into account, it can be concluded that the monolithic and precast beam column connections in this test fall into the category of structural elements with moderate ductility.

3. Curvature Ductility

Based on the relationship between load and displacement (drift), curvature ductility calculations are carried out. Generally, the load is normalized to the load at yield, and the displacement can be expressed as a value of curvature, drift (in %), or chord rotation. Table 3 details the normalized load and curvature values for specimens BN, BG 1, and BG 2.

Table 3. Load and Curvature for Test Specimens BN, BG 1, BG 2

Test Objects	P _y (kN)	P _u (kN)	P _u /P _y	Δ _y (mm)	ϕ _y [*]	Δ _u (mm)	ϕ _u ^{**}
BN	11,00	13,58	1,23	37,44	0,013	87,58	0,031
BG 1	12,89	18,54	1,43	42,66	0,015	94,42	0,033
BG 2	13,11	20,80	1,59	47	0,016	96,80	0,034

Information:

$$* \phi_y = \frac{\Delta y \text{ (Displacement during melting)}}{L \text{ (height of the test object)}}$$

$$** \phi_u = \frac{\Delta u \text{ (Transfer at ultimate)}}{L \text{ (tinggi benda uji)}}$$

In the BN object test, it was recorded that the curvature value in the melted condition reached 0.013, while in the ultimate condition it increased to 0.031. At the same time, the BG 1 specimen shows a curvature value of 0.015 in the melting condition, and increases to 0.033 in the ultimate condition. Meanwhile, for BG 2 objects, the curvature value in the melted condition reaches 0.016, while in the ultimate condition it reaches 0.034. The visualization of the curvature ductility of test specimens BN, BG 1, and BG 2 is clearly depicted in Figure 9.

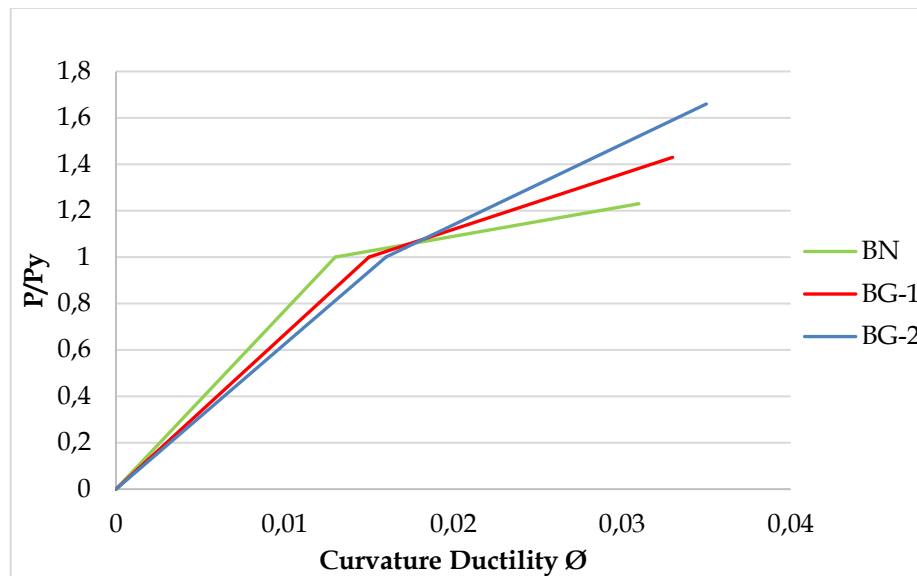


Figure 9. Curvature for Test Specimens BN, BG 1, BG 2

In the melted state, the curvature ductility values of test specimens BN, BG 1, and BG 2 are 0.013, 0.015, and 0.016, respectively. This fact shows that the curvature ductility value of precast beam column connections using dowels exceeds the curvature ductility value of monolithic beam column connections, with a ratio of 15.38% (BG 1 compared to BN) and 20% (BG 2 compared to BN).

ASCE 41-17 (Table 10-11), the ductility value required for Life Safety (LS) conditions is 0.01. In fact, the curvature ductility values of test specimens BN, BG 1, and BG 2 exceeded the values determined by ASCE 41-17. In conclusion, monolithic and precast beam column connections, including those using dowels, show excellent performance in bearing earthquake loads in moderate earthquake conditions.

In Collapse Prevention (CP) conditions, ASCE 41-17 stipulates a required curvature ductility value of 0.015, while the curvature ductility values for BN, BG 1, and BG 2 exceed this requirement. Hence, it can be concluded that both monolithic and precast beam column connections exhibit excellent performance in withstanding earthquake loads during severe seismic conditions, such as strong earthquakes.

Following the testing process, a comparison of the ductility of beam column connections, particularly those employing dowels, was considered essential. This aimed to assess the alignment or comparable effectiveness of these connections with findings from other pertinent research. Parastesh et al. (2014)

introduced a novel ductile moment-resisting concrete frame connection, incorporating precast concrete beams with hollow U-shaped cross-sections connected to precast concrete columns via longitudinal reinforcing bars in the cast-in-place zone. Their research, inclusive of variables such as stirrup type and distance in the beam connection zone, yielded results aligned with Herman's study, affirming the efficacy of precast joints in providing ample strength, ductility, and energy dissipation capacity compared to monolithic joints—a viable solution for seismic areas.

Similarly, Breccolotti et al. (2016) developed a connection system utilizing loop bar joints at the ends of precast concrete beams, ensuring continuity between beams and columns through loop joints and cast-in-place concrete with steel fibers. Experimental results verified the successful design of joints to emulate cast-in-place concrete joints, demonstrating strength, ductility, and energy dissipation capacity. Bahrami et al. (2017) introduced two new types of beam column connections, connecting precast beams to precast columns with steel corbels using bolts and welded joints. Finite element analysis indicated comparable lateral resistance to the reference monolithic joint, with ductility and energy dissipation ranging from 70–80% of the monolithic joint.

Ghayeb et al. (2017) experimented with bolted beam column joints, where beams were connected via projecting steel plates embedded in precast columns. Although the proposed joints exhibited increased deformation capacity (30–90%), they experienced a reduction in strength (2–30%) and significantly lower energy dissipation compared to monolithic joints. Mhanna et al. (2020) explored parameters such as anchor dowel diameter, highlighting that CFRP anchors delay debonding, enhance shear strength, and significantly increase ductility in beam specimens.

In this research, the ductility values used straight pegs for the test objects (BN, BG 1, and BG 2) in the reinforcement in the ultimate condition at the first yielding condition. The resulting ductility values of 2.3, 2.2, and 2.1 respectively categorize the test object as a structural element with moderate ductility according to ASCE 41-17. The curvature values in yield and final conditions, as well as life safety and collapse prevention conditions, exceed the required values, indicating excellent performance in carrying earthquake loads in both moderate and severe seismic conditions for monolithic and precast beam column connections.

CONCLUSION AND RECOMENDATION

From the conducted research and tests, several conclusions can be derived. The displacement values for BN, BG 1, and BG 2 at the first yielding condition in the reinforcement and at the ultimate condition, with cross-sectional dimensions of 37.4 mm, 42.7 mm, and 47 mm, respectively, resulted in ductility values of 2.3, 2.1, and 2.1 for test specimens BN, BG 1, and BG 2, respectively. According to ASCE 41-17, the ductility classification based on these values categorizes both monolithic and precast beam column connection specimens as structural elements with moderate ductility values. The curvature values for the BN test specimen in the yielding condition are 0.013 and 0.031 in the ultimate condition, for BG 1, the

values are 0.015 in the yielding condition and 0.033 in the ultimate condition, and for BG 2, the values are 0.016 in the yielding condition and 0.034 in the ultimate condition. In life safety conditions, the ductility values for test specimens BN, BG 1, and BG 2, exceeding the required 0.01, indicate the good performance of both monolithic and precast beam column connections with dowels in bearing earthquake loads under moderate seismic conditions. Furthermore, in collapse prevention conditions, surpassing the required value of 0.015, it can be concluded that both monolithic and precast beam column connections exhibit excellent performance in carrying earthquake loads during severe seismic conditions, such as strong earthquakes.

FURTHER STUDY

This research still has related limitations, so it is necessary to carry out further research on the topic of Ductility of Precast Concrete Column Beams using Dowels in order to perfect this research and increase the reader's insight.

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