International Journal of Engineering

Journal Homepage: www.ije.ir

Precast Concrete Column Beam Connection Using Dowels Due to Cyclic Load

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PAPER INFO

Paper history:
Received 21 August 2021
Received in revised form 22 September 2021
Accepted 05 October 2021

Keywords:
Column Beam Connection
Cyclic Load
Dowels Due
Earthquake-resistant Buildings
Precast Concrete

ABSTRACT

The beam-column connection plays an important role in the building structure, especially when the load is cyclic. The main problem that must be solved is the beam and column connection panels. The purpose of this study was to analyze the characteristics of the hysteresis loop of the displacement load relationship with the control displacement of the precast beam-column connection due to cyclic loading. The research method used is the experimental method with a measurable object design test and a special testing method. The results of this study indicate that normal concrete has a compressive strength of 26.43 MPa, while grouted concrete has a compressive strength of 36.97 MPa. The findings of this study also show that the bond stress grouted concrete increases by 102.4% from normal concrete for D13 diameter screw reinforcement, while for D16 diameter, the adhesive stress increases by 51.63%. The findings of this study also show that in the ultimate condition, the load obtained in the tensile load is 13.58 kN with a displacement of 87.58 mm, while the compressive load is 12.62 kN with a displacement of 88.30 mm. This study concludes that the behavior of precast beam-column joints with dowels is stronger in resisting cyclic loads.

doi: *10.5829/ije.2022.35.01a.09*

NOMENCLATURE

BR	*V*	*U*	Horizontal components of velocity (m/s)
C_c	Cunningham correction factor	V	Vertical components of velocity (m/s)
c_k	Discrete lattice velocity in direction (k)	U_i, U_j	Random numbers between 0 and 1
c_S	Speed of sound in Lattice scale	**Greek Symbols**	
d^p	Particle diameter (μm)	ρ	Density (kg/m^3)
f_k^{eq}	Equilibrium distribution function	τ	Lattice relaxation time
g	Gravity (m/s^2)	$\tau_p = \frac{\rho^p c_c (d^p)^2}{18\mu}$	Particle relaxation time (s)
$\emptyset y = \Delta y$	Displacement at melting L (test object height)	Δt	Lattice time step
$\emptyset u = \Delta u$	Ultimate current shift L (test object height)	ν	Kinematic viscosity (m^2/s)
Pu	Beban ultimate	λ	Gas mean free path (μm)
Py	Tegangan leleh baja	**Subscripts**	
$\emptyset y$	Perpindahan t	p	Particle
$S = \rho^p / \rho^g$	Particle Specific density	g	Gas

1. INTRODUCTION

Structural design is very important to pay attention to the column beam connection elements as the main point to withstand cyclic loads. Cyclic loads can be caused by earthquakes. The part of the building structure that is susceptible to cyclic loading is at the connection of the beam and column panels [1]. This is due to the specific nature of the radiated energy and the occurrence of very large shear forces, especially at the beam-column connection. These shear forces can frustrate the joint panel core either because the shear capacity is exceeded

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Please cite this article as: H. A. Tumengkol, R. Irmawaty, H. Parung, A. Amiruddin, Precast Concrete Column Beam Connection Using Dowels Due to Cyclic Load, ***International Journal of Engineering, Transactions A: Basics***, Vol. 35, No. 01, (2022) 102-111

or because the reinforcement bonds in the joint are damaged.

The beam-column connection is a vital component in a building structure. This section is very important because it has a major role in transferring the forces in one element to other elements in the structure [2-3]. Due to the influence of lateral forces such as cyclic loads, these beam-column joints experience greater shear and horizontal forces than adjacent beam and column elements [4-6]. The flow of force through the beam-column joint can be disrupted if this connection is not able to provide adequate shear strength. If the shear capacity at this interface is insufficient, cracks can occur, and eventually, structural failure occurs.

The connection of precast concrete beam-columns is one solution to anticipate the failure of the building structure. Precast concrete is a component or structural element that is not cast at the place where the element is installed, but is cast in a place where the casting process and maintenance are carried out properly according to existing methods [7-8]. Precast concrete has many advantages compared to conventional concrete, including being able to speed up project execution time [5]. The many advantages of precast concrete make its use increased in recent years.

Hysteresis characteristics of load-displacement relationship loop with control displacement of precast beam-column joints due to cyclic loading [9-11]. The problem that arises is the difficulty of mapping the load-displacement characteristics of the beam of building precast column beams due to cyclic loading [12-14]. Precast beam-column joints, which are specific to the area of connection of precast parts. The construction will then be given a cyclic loading. The purpose of this study was to analyze the hysteresis characteristics of the load-displacement relationship with the controlled displacement of the precast beam-column connection due to cyclic loading. This study is intended to examine the behavior of beam-column joints for each model made. The results of this study can be a recommendation or input to construction implements regarding the behavior and concept of connection planning in precast concrete.

2. SPECIMENS AND TESTING METHOD

2. 1. Test Object Design

For the beam-column connection specimen, there are 3 models, namely monolith beam and column, grout connection with 2 pegs and grout connection with 4 pegs. (Figures 1, 2 and 3).

For columns measuring 30 cm x 30 cm with a length (ln) of 295 cm. As for the beam measuring 20 cm x 30 cm with a length of 145 cm.

The test was carried out at the Structure and Materials Laboratory, Faculty of Engineering, Hasanuddin University. Cyclic testing equipment used with an

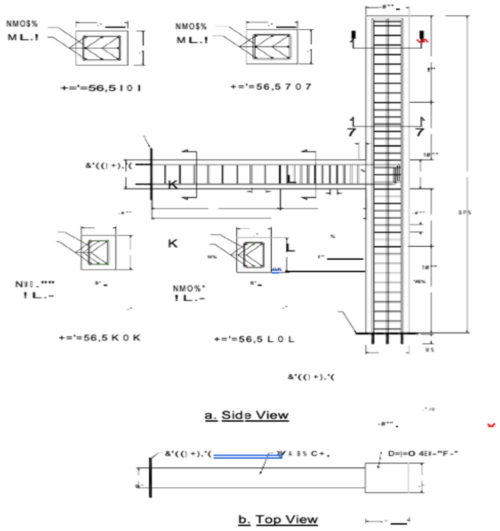


Figure 1. Monolith column beam test object (BN)

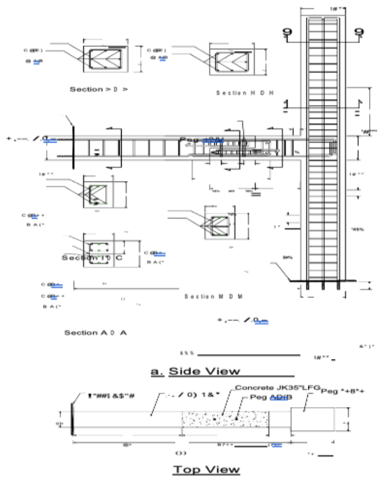


Figure 2. Test object for connection of 2 pegs(BG-1)

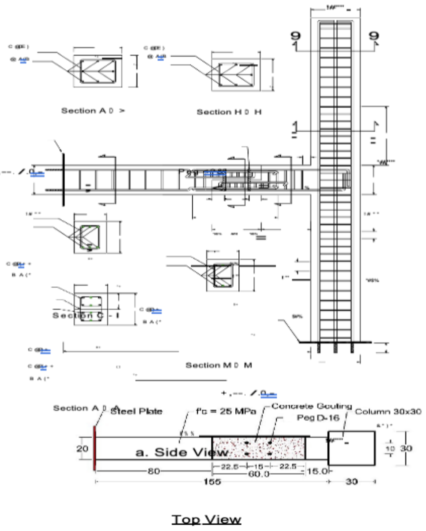


Figure 3. Test object 4 stake connection (BG-2)

actuator capable of 1500 kN with a maximum displacement of ± 20 cm.

The setup for testing the BN, BG-1, and BG-2 specimens is shown in Figure 4.

In addition, at the bottom, a plate with a thickness of 2 cm is installed and mounted on a strong floor with a thickness of 1.5 m through a rod measuring 1.5” (38 mm).

2. 2. Testing Method

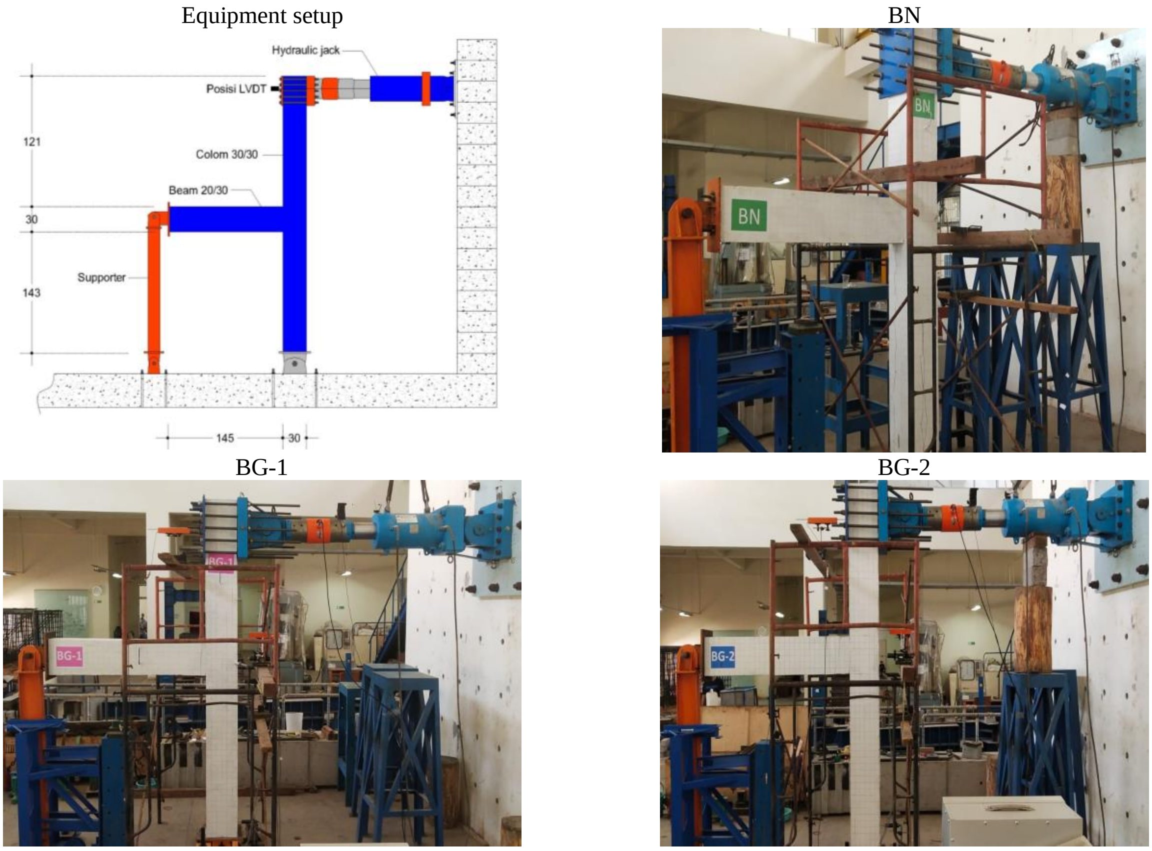
1. Strain Gauge in Reinforcement and Concrete

For the strain gauge installed on steel reinforcement to determine whether the reinforcement has experienced yielding and on the concrete to determine whether the concrete has reached its ultimate condition.

For strain gauge reinforcement type FLK-6-11-5L installed on horizontal reinforcement and transverse reinforcement (see Figure 5).

2. LVDT

To measure the displacement of the beam-column joint test object, a linear variable displacement transducer (LVDT) was installed.

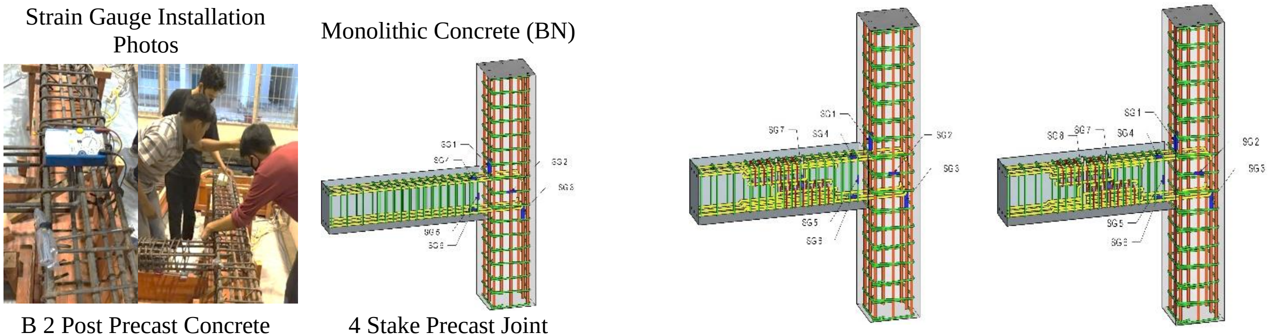

Equipment setup

BN

BG-1

BG-2

Figure 4. Cyclic testing equipment setup


Strain Gauge Installation Photos

Monolithic Concrete (BN)

B 2 Post Precast Concrete Joints (BG-1)

4 Stake Precast Joint Concrete (BG-2)

Figure 5. Strain gauge on steel

There are 6 LVDTs installed with capacities of 100 mm and 50 mm. For LVDT with a capacity of 100 mm, it is installed to measure the horizontal displacement at the top of the column and the center of the column, while LVDT with a capacity of 50 mm is installed at the bottom of the column and in the middle of the beam span (see Figure 6.)

2. 3. Cyclic Testing Procedure For testing with cyclic loads refer to SNI 7834:2013 regarding test methods and criteria for acceptance of precast reinforced concrete moment-bearing frame structures for buildings referring to ACI 374.1-05 concerning Acceptance Criteria for Moment Frames based on Structural Testing.

The conditions are explained as follows:

1. The specimen shall be loaded by a sequence of displacement control cycles that represent the expected displacement between floors at the joint during an earthquake;
2. Three full cycles must be applied to each deviation ratio;
3. The initial deviation ratio must be within the range of the linear elastic behavior of the specimen. The next deviation ratio must be not less than 5/4 times and not more than 3/2 times the previous deviation ratio.
4. The test must be continued by increasing the deviation ratio gradually to the minimum deviation ratio value is 0.035. (See Figure 7).

3. RESULT AND DISSCUSION

3. 1. Hysteretic Behavior of Beam-column Joints

3. 1. 1. Load–Displacement Relationship This section discusses the load-displacement relationship due to cyclic loading for specimens for monolith beam-column joints, precast beam-column joints of 2 and 4 posts. Table 1 summarizes the value of displacement loads for the three types of beam-column connections.

Figure 6. LVDT on test pieces and installation photos

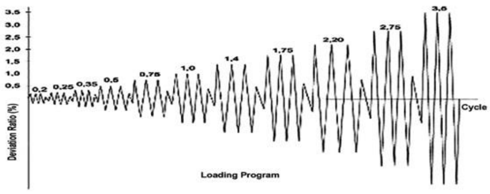


Figure 7. Loading program according to SNI 7834:2012

Monolith (BN) Beam-Column Joint Test Objects

Figure 8 Shows the results of cyclic testing for monolithic beam-column (BN) connections. In the ultimate condition, the load obtained in the tensile load is 13.58 kN with a displacement of 87.58 mm. Meanwhile, when the compressive load is 12.62 kN with a displacement of 88.30 mm. The load that occurs at the first yield is 11 kN with a displacement of 37.44 mm. For the first crack, the load is 3.5 kN and the displacement is 7.08 mm.

Precast Beam-Column Joint Test Objects 2 Posts (BG-1)

Figure 9 Shows the load and displacement relationship for the BG-1 test specimen due to cyclic loading. In the first crack condition, the load is 3.90 kN with a deviation of 9.15 mm. While for the first yield condition, the load value is 12.89 kN with a deviation of 42.66 mm. In the ultimate condition at the time of tensile load, the load value is 18.54 kN with a deviation of 94.42 mm. At the time of compressive load, the value of the load is 14.01 kN with a deviation of 96.88 mm.

Precast Beam-Column Joint Test Objects 4 Posts (BG-2)

The load obtained at the ultimate tensile load is 20.80 kN and the displacement is 96.80 mm. Meanwhile, when

TABLE 1. Load–displacement of BN, BG1, and BG2 test specimens

Test Object	First crack		First Yield		Ultimate			
					Press		Pull	
	P_{cr}	Δ_{cr}	P_y	Δ_y	P_u^+	Δ_u^+	P_u^-	Δ_u^-
	(kN)	(mm)	(kN)	(mm)	(kN)	(mm)	(kN)	(mm)
BN	3.5	7.08	11.00	37.44	12.62	88.30	13.58	87.58
BG-1	3.90	9.15	12.89	42.66	14.01	96.88	18.54	94.42
BG-2	4.30	9.91	13.11	47	16.41	98.90	20.80	96.80

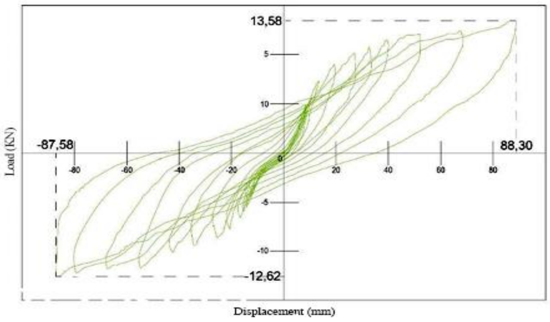


Figure 8. The load-displacement relationship due to cyclic loads on the BN test object

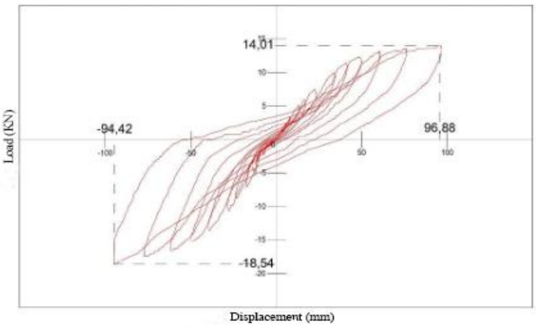


Figure 9. Relationship of load – displacement due to cyclic load on the test object BG-1

the ultimate compressive load is 16.41 kN with a displacement of 98.90 mm. The load at the first yield is 13.11 kN with a displacement of 47 mm. For the first crack, the load is 4.30 kN and the displacement is 9.91 mm (see Figure 10).

Load Capacity of Monolith Beam-Column Joints and Precast Beam-Column Joints with Pegs

From Table 1, it can be concluded that the load capacity at the time of the first crack for precast beam-column joints is greater than the load capacity of monolith beam-column joints. The load capacity of precast 4-post beam-column joints is greater than the load capacity of 2-post precast joints.

The same applies to load capacity at the time of the first yield. For the load capacity of the precast beam-column connection of 4 pegs more than the precast beam-column connection of 2 pegs and monolith. Figure 10 and Table 2 show the ultimate load capacity for monolithic and precast beam-column connections using dowels.

In the ultimate condition, the load capacity of precast beam-column joints with dowels is more than the load capacity of monolith beam-column connections. At the compression load, the load capacity of the precast beam-column connection with 2 posts increased by 13.9% and for the precast beam-column connection with 4 posts increased by 30% compared to the load capacity of the monolith beam-column connection. At the tensile load, the load capacity for the precast beam-column connection with 2 posts increased by 36.5% and for the precast beam-column connection with 4 posts, it increased by 53.2% compared to the load capacity of the monolith beam-column connection.

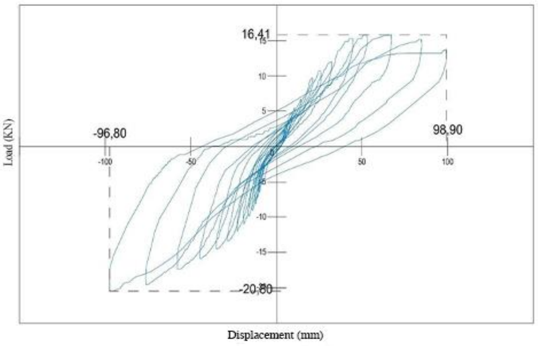


Figure 10. Load-displacement relationship due to cyclic load on the BG-2 test object

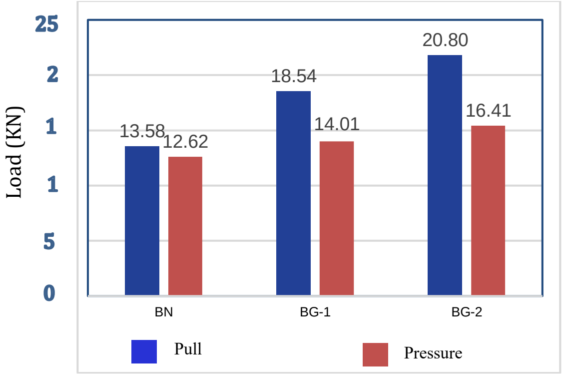


Figure 11. Ultimate load of SBK BN, BG-1, and BG-2 specimens

TABLE 2. The increase in the Pu value of precast SBK against monolithic SBK

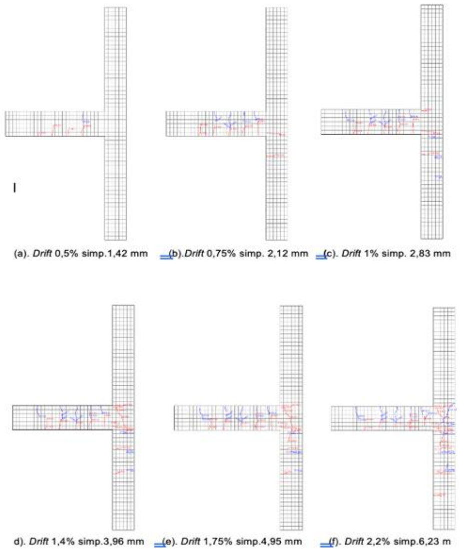
Load	BG – 1	BG – 2
Pressure	13.9 %	30 %
Pull	36,5 %	53,2 %

In general, the increase in load capacity at the precast beam-column connection is due to the area being grouted with a strength of 36.97 Mpa, which is greater than the compressive strength of the concrete used in these elements. The greatest strength in the area causes the connection to become stiffer so that the load capacity increases [15-18].

3. 2. Crack Pattern

Figures 12(a), 13(a), and 14(a) are images of the initial crack pattern at a drift of 0.5% for monolithic connections and precast 2 (two) and 4 (four) posts. More cracks occurred in monolith joints compared to BG-2 precast (4 pegs) and BG-1 precast (2 pegs) joints. For cracks as a whole occur in the beam area. Figures 5(b), 6(b), and 7(b) are images of the fracture pattern of monolith joints and precast joints at a drift of 0.75%. For cracks that occur more tightly in the beam area for monolithic connections (BN) when compared to 2-post precast connections (BG-1) and 4-post precast connections (BG-2). In the column, especially the lower column, the cracks that occur are more for the BG-1 and BG-2 precast joints when compared to the monolith (BN) connection [19-22].

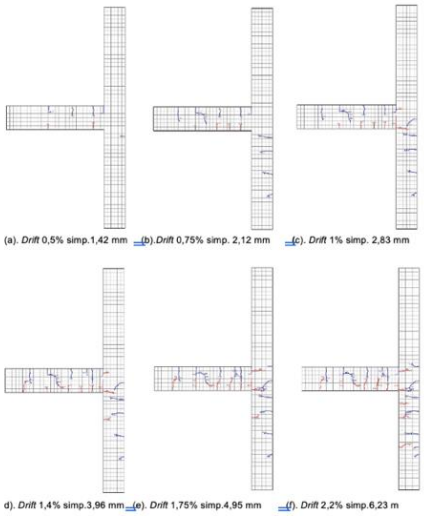
Figures 12€, 13€, and 14€ are crack patterns for monolithic and precast beam-column joints at 1% drift. In this condition, the crack pattern is almost the same as



(a). *Drift* 0,5% simp.1,42 mm (b).*Drift* 0,75% simp. 2,12 mm (c). *Drift* 1% simp. 2,83 mm

d). *Drift* 1,4% simp.3,96 mm (e). *Drift* 1,75% simp.4,95 mm (f). *Drift* 2,2% simp.6,23 m

Figure 12. Pattern of monolithic beam-column (BN) joint cracks



(a). *Drift* 0,5% simp.1,42 mm (b).*Drift* 0,75% simp. 2,12 mm (c). *Drift* 1% simp. 2,83 mm

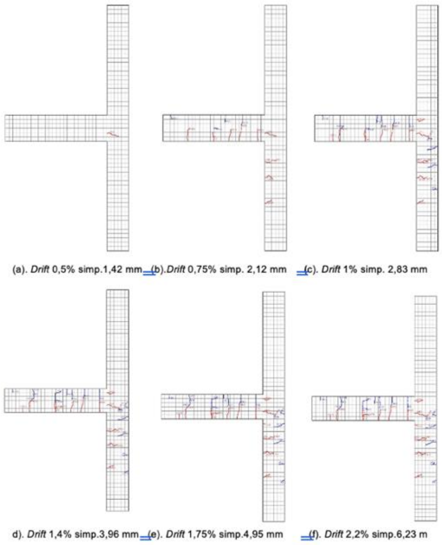
d). *Drift* 1,4% simp.3,96 mm (e). *Drift* 1,75% simp.4,95 mm (f). *Drift* 2,2% simp.6,23 m

Figure 13. Crack pattern of 2-post precast beam-column connection (BG-1)

the crack pattern that occurs at a drift of 0.75% with an increase in the number of cracks.

Figures 10(d), 11(d), and 12(d) show the crack patterns for beam-column joints at 1.4% drift. Cracks are more common in the beam area for monolithic beam-column (BN) connections and precast beam-column joints BG-1 and BG-2.

In the column, cracks have started to increase but only occur at the bottom of the column. Especially in the monolith beam-column connection, cracks have occurred at the beam-column meeting area.



(a). *Drift* 0,5% simp.1,42 mm (b).*Drift* 0,75% simp. 2,12 mm (c). *Drift* 1% simp. 2,83 mm

d). *Drift* 1,4% simp.3,96 mm (e). *Drift* 1,75% simp.4,95 mm (f). *Drift* 2,2% simp.6,23 m

Figure 14. Crack pattern of 4-post precast beam-column connection (BG-2)

Figures 12€, 13€, and 13€ show the crack pattern for beam-column joints with a drift of 1.75%. The crack pattern was almost the same with a 1.4% drift and an increasing number of cracks. In this condition, cracks have occurred in the area where the beam-column meets for the precast connection of 2 pegs (BG-1) and 4 posts (BG-2).

Figures 12(f), 13(f), and 14(f) are crack pattern images for joints at 2.2% drift. The crack pattern model is the same as the crack pattern at 1.75% drift with more cracks.

3. 3. Ductility of Beam-column Joints

This section discusses the behavior of beam-column joints in relation to ductility. Ductility is related to the displacement that occurs in the ultimate condition, namely the condition when the structure collapses and the displacement that occurs in the first yield condition of the reinforcement.

The displacement at the ultimate condition and yielding condition in the reinforcement is obtained from the load hysteretic curve – displacement when given a cyclic load [23]. Parameters related to ductility are displacements, especially in the first yield condition of the reinforcement (Δy) and in the ultimate condition, namely structural failure (Δu). To calculate displacement ductility, displacement parameters are used, while curvature ductility uses curvature value parameters or cross-sectional curvature and load values due to cyclic loads.

3. 4. Displacement Ductility

Table 3 shows the displacement values at the first yield condition of the reinforcement and at the ultimate condition. The values of Δy and Δu can be seen in the Backbone curve.

In yield conditions, the displacements that occur at the monolithic beam-column connection (BN), the precast 2-pin beam-column connection (BG-1), and the 4-post precast beam-column connection (BG-2) are 37.44 mm, 42.66 mm, and 47 mm, respectively. The ductility value is calculated based on the ratio of the displacement value in the ultimate condition to the yield condition. From Table 3, the ductility values for the BN, BG-1, and BG-2 specimens are obtained, 2.34, 2.21 and 2.06, respectively.

From Figure 15, it can be seen that the ductility value of the BN test object is 2.34, while the BG-1 test object is 2.21 and the BG-2 test object is 2.06. Based on this value, it can be concluded that the monolithic beam-column connection (BN) has a higher ductility value than the precast beam-column connection using dowels (BG-1 and BG-2).

For the ductility value of the precast beam-column connection of 2 pegs, it is 0.94 times the ductility value of the monolith beam-column connection or reduced by 5.56%. Meanwhile, in the precast beam-column connection with 4 pegs, the ductility value is 0.88 times or reduced by 12%. For the precast beam-column connection with 2 pegs, the ductility value is greater than the precast beam-column connection with 4 posts.

The ductility of precast beam-column joints using dowels is smaller than the ductility of monolithic beam-column joints due to the presence of grouting in the beam connection area which makes the cross-section stiffer due to the greater compressive strength of the concrete in that area [24-25].

TABLE 3. Displacement in yield and ultimate conditions

SBK Test Object	First Yield	Ultimate	Ductility
	Δ_y (mm)	Δ_u (mm)	
BN	37.44	87.58	2.34
BG-1	42.66	94.42	2.21
BG-2	47	96.80	2.06

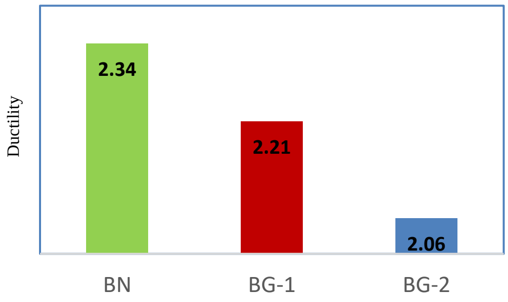


Figure 15. Ductility values for BN, BG-1, BG-2. Specimens

3. 1. 2. Classification of Ductility of Beam-column Joints

Table 4 shows the classification of ductility according to ASCE 41-17.

ASCE 41-17 divides ductility according to 3 categories, namely low ductility, moderate ductility, and high ductility. For low ductility, it has a value of less than 2, while medium ductility has a value between 2 to 4. For high ductility, it has a value of more than 4 [26-27].

From Table 4, for monolithic beam-column connection (BN) and precast beam-column connection (BG-1 and BG-2), the ductility values are 2.34, 2.21, and 2.06, respectively. Based on these values, it can be concluded that the specimens for monolithic and precast beam-column joints are categorized as structural elements with moderate ductility values.

3. 5. Curvature

The curvature ductility is calculated based on the load and displacement relationship (drift). Generally, the load is normalized to the load at yielding conditions, while the displacement can be converted to the value of curvature (curvature), drift (in units of %), or chord rotation (rotation).

Normalized load and curvature values for BN, BG-1, and BG-2 specimens are presented in Table 5.

Note:

$$* \quad \varnothing y = \frac{\Delta y\ (Displacement\ at\ melting)}{L\ (\ test\ object\ height)}$$

$$** \ \varnothing u = \frac{\Delta u\ (Ultimate\ current\ shift)}{L\ (\ test\ object\ height)}$$

For BN specimens, the curvature value of the melting condition is 0.013 and in the ultimate condition is 0.031. In the BG-1 test object, the curvature value is0.015 for

TABLE 4. Classification of test object ductility according to ASCE 41-17

Test Object	Ductility	Category	ASCE 41-17
BN	2.34	*Moderate ductility*	< 2, *low ductility* 2 to 4, *moderate ductility* > 4, *high ductility*
BG-1	2.21	*Moderate ductilty*	
BG-2	2.06	*Moderate ductility*	

TABLE 5. Load and curvature for BN, BG-1, BG-2 . specimens

SBK Test Object	P_y (kN)	P_u (kN)	P_U/P_y	Δ_y (mm)	$\varnothing_y^{*}$	Δ_u (mm)	$\varnothing_u^{**}$
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

the melting condition and 0.033 for the ultimate condition. While in BG-2, the curvature value of the melting condition is 0.016 and in the ultimate condition is 0.034.

Figure 16, shows the curvature ductility for the specimens BN, BG-1, BG-2.

In the melting condition, the curvature ductility for the specimens BN, BG-1, and BG-2 were 0.013, 0.015, and 0.016, respectively. From this value, it can be seen that the curvature ductility value for precast beam-column joints using dowels is more than the curvature ductility value for monolith beam-column connections or an increase of 15.38% (BG-1 against BN) and 20% (BG-2). Against BN).

Based on ASCE 41-17 (Tables 10-11), the required ductility value under life safety (LS) conditions is 0.01. The curvature ductility values for the specimens BN, BG-1, and BG-2 are more than the values required in ASCE 41-17. This means that beam-column connections, both monolithic and precast using dowels, have good performance in carrying earthquake loads under moderate seismic conditions (medium earthquakes).

In the collapse prevention (CP) condition, the curvature ductility value required in ASCE 41-17 is 0.015, while the curvature ductility value for BN, BG-1, and BG-2 is more than the required value. It can be concluded that beam-column connections, both monolithic and precast, have excellent performance in carrying earthquake loads under severe seismic conditions (strong earthquakes).

From the results of the discussion in the previous section, it can be explained that the empirical findings are as follows:

Precast beam-column joints with dowels have a greater load capacity than monolithic beam-column joints. For precast SBK 2 pegs increased 11.01% - 36.52% and SBK 4 pegs increased 30.03% - 53.2% due to compressive and tensile loads.

The ductility value for monolithic SBK is greater than that of precast SBK with pegs, but the curvature ductility of precast SBK is still higher than normal SBK. SBK monolith and precast have good performance at moderate and strong earthquake levels, according to ASCE 41-17.

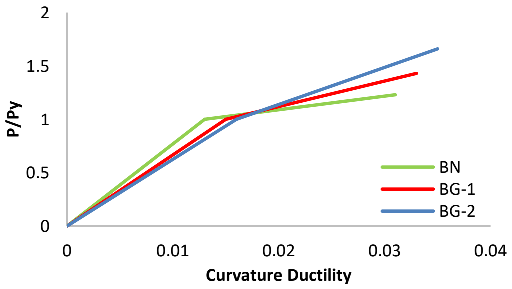


Figure 16. Bending ductility of BN, BG-1, BG-2

The stiffness degradation for precast SBK with 2 pins (5.23%) and 4 posts (4.90%) is smaller than monolith SBK (5.36%), stating that precast SBK with pegs is stiffer compared to SBK monolith.

Precast beam-column joints using dowels have a higher energy dissipation value than monolith beam-column joints, an increase of 3.42% for SBK 2 pegs and 7.97% for SBK 4 pegs.

For the connection of precast concrete column beams with dowels, it has good performance in terms of strength, ductility, stiffness, and energy dissipation. The connection of precast concrete column beams using 2 pegs is good enough to be applied at work, this is also to facilitate implementation in the field.

4. CONCLUSION

This study concludes that the hysteresis characteristics of the load-displacement relationship with displacement control of precast beam-column joints are very good for cyclic loads. The fact that the results of laboratory tests have shown that the capacity of monolithic beam-column (BN) connections is at a compressive load of 12.62 kN, while the load for 2 precast SBK increases by 11.01%-36.52% to a load value of 18.54 kN with a deviation. of 94.42 mm, and for 4 post precast, SBK increased by 30.03% - 53.2% of ultimate tensile load is 20.80 kN and the displacement is 96.80 mm compared to the load capacity of SBK monolith. This study concludes that by using 2 and 4 pins in the beam-column connection, the results are better. This study also concluded that the ductility value of SBK precast 2 pegs was 2.21 smaller than the actual SBK monolith ductility value of 2.34 or decreased by 5.56%. Meanwhile, in precast SBK 4 pegs the ductility value was 2.06 or decreased by 8.55%. Thus, this study concludes that the use of posts with 2 and 4 posts can reduce the ductility value.

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Persian Abstract

چکیده

اتصال تیر و ستون نقش مهمی در ساختار ساختمان ایفا می کند ، به ویژه هنگامی که بار چرخه ای است. مشکل اصلی که باید حل شود ، پانل های اتصال تیر و ستون است. هدف از این مطالعه تجزیه و تحلیل ویژگی های حلقه پسماند رابطه بار جابجایی با جابجایی کنترل اتصال تیر و ستون پیش ساخته به دلیل بارگذاری چرخه ای بود. روش تحقیق مورد استفاده روش آزمایشی با آزمون طراحی شیء قابل اندازه گیری و روش آزمایش ویژه است. نتایج این مطالعه نشان می دهد که بتن معمولی دارای مقاومت فشاری ۲۶.۴۳ مگاپاسکال است ، در حالی که بتن دوغابدار دارای مقاومت فشاری ۳۶.۹۷ مگاپاسکال است. یافته های این مطالعه همچنین نشان می دهد که بتن دوغاب تنش پیوند ۱۰۲.۴ درصد از بتن معمولی برای تقویت پیچ با قطر D13 افزایش می یابد ، در حالی که برای قطر D16 ، تنش چسبندگی به میزان ۵۱.۶۳ درصد افزایش می یابد. یافته های این مطالعه همچنین نشان می دهد که در شرایط نهایی ، بار به دست آمده در بار کششی ۱۳۸/۵۸ کیلو نیوتن با جابجایی ۵۸/۸۷ میلی متر است ، در حالی که بار فشاری ۱۲/۶۲ کیلو نیوتن با جابجایی ۸۸/۳۰ میلی متر است. این مطالعه نتیجه می گیرد که رفتار اتصالات تیر و ستون پیش ساخته با رولپلاک در مقاومت در برابر بارهای چرخه ای قوی تر است.