Influence of precast concrete joints on the ductility of beam elements

B Bunyamin¹ *, M Silviana² and L Lindawati³

¹ Department of Civil Engineering, Faculty of Engineering, Universitas Iskandar Muda, Banda Aceh, Indonesia, 23234.
² Department of Civil Engineering, Faculty of Engineering, Universitas Al Muslim, Bireun, Indonesia, 24261.
³ Department of Mechanical Engineering, Faculty of Engineering, Universitas Abulyatama, Aceh Besar, Indonesia, 24115.

*E-mail: Bunyamin_23civil@yahoo.com

Abstract. This study aims to determine the effect of precast concrete joints on the resulting ductility. The research method was experimentally in a laboratory-based on ASTM (American Society for Testing and Materials) and ACI (American Concrete Institute). The design of concrete compressive strength was 14.50 MPa. The specimen used in this research consist of four beams, which are TRC (Top Reinforcement Concrete), THB (Top Hollow Block), BRC (Bottom Reinforcement Concrete), and BHB (Bottom Hollow Block). The size of beam used was 15 x 20 x 210 cm with the diameter of reinforcement bar were 12 mm (threaded steel) and 10 mm meanwhile the diameter of plain steel was 6 mm. The result showed that the ductility of TRC beam was 2.024, the ductility of THB beam was 2.526, the ductility of BRC beam was 1.237, and the ductility of BHB beam was 1.611. The ductility for hollow block is greater than normal reinforced concrete beam. Meanwhile, the load that occurs for hollow blocks is smaller.

1. Introduction
Reinforced concrete beam is a structural element consisting of cement, fine aggregate, coarse aggregate, water, and reinforcement. Concrete and steel are building materials that are often used in the construction world. The two building materials have different properties in accepting loads. Concrete is brittle and can deform due to compressive loads. Steel is ductile and has the ability to withstand tensile loads. Concrete and steel have a limit ability to accept loads, which is indicated by the yielding strain of concrete and steel. There are many ways to increase the strength of reinforced concrete beams, one of which is adding compressive reinforcement. The addition of compressive reinforcement is an effort to increase the strength, stiffness and ductility of reinforced concrete beam. The addition of compressive reinforcement to reinforced concrete beams only slightly contributes to the strength and stiffness of the beam, but has a major effect on increasing the ductility of the curvature of reinforced concrete beams [1].

Hollow block concrete is a combination of several precast of concrete where has been widely used for the construction of houses for people affected by natural disasters such as earthquake and tsunami. The forming materials for hollow block concrete beam consist of cement, fine aggregate, coarse aggregate, water, and reinforcement with the quality of concrete is K-175. The precast concrete has hooks above and below it so that it can be joined with other precast concrete [2]. Precast concrete is
concrete that is moulded using a moulding machine where the hardening time can be achieved faster than conventional concrete. Precast concrete is concrete that is cast or cast outside where the project work is carried out [3]. Precast concrete that has reached one day of hardening age can be directly used as hollow block concrete beam [4]. Hollow block concrete combined into one unit will certainly have an effect in accepting the loading. Concrete and steel strains need to be reviewed how they affect the ductility of hollow block concrete beams.

Ductility is the ability of a structural element to act due to deformation before the structure collapses. If the load on the structure element is increased, then the structure will tend to change plastically and the effect of the addition of the load will be distributed to other structural elements, so that it will be under-reinforced structure element [5]. Ductility is the ratio between the maximum design deviation and the initial yield deviation of the studied structural elements. Ductile material can experience a relatively long strain after reaching the yield point and the load can still increase slightly until it reaches the point of collapse. Meanwhile, brittle material is a material that cannot deform properly and will collapse suddenly when it reaches its maximum load [6]. Ductility is the ability of a structure or sub-structure to withstand the dominant inelastic response in carrying loads so as not to collapse [7]. The types of ductility are as follows:

1. Strain ductility is the ratio of the maximum strain to the strain at yield point in a beam that is subjected due to tensile or compressive axial loading.
2. Curvature ductility is the ratio of the maximum angle of curvature with the yield curvature angle of the structural element due to the flexural moment.
3. Rotational ductility is the ratio between the maximum rotation of the plastic hinge to the rotation of the yield angle.
4. Displacement ductility is the ratio of the maximum displacement (deformation) of the structure (lateral direction) under post-elastic conditions to the displacement (deformation) of the structure at yield point.

In structural planning, there are 3 (three) main factors to be considered, namely strength, stiffness and ductility. There are several ways to increase ductility in unfettered beams [8], namely:

1. Decrease the tensile reinforcement ratio,
2. Increase the compression reinforcement ratio,
3. Decrease steel grade,
4. Improve concrete quality,
5. Increases concrete strain,
6. Provides confinement. Confinement is the most effective way among other ways to increase ductility. There are weaknesses if it is decreased, namely in terms of decreasing nominal capacity when there is an increase in ductility. This is different with confinement, by giving confinement to concrete, it can increase the ductility of its curvature.

![Figure 1. Graph of relationship between load and deflection](image)
Ductility can be calculated through the graph of the relationship between load and deflection as shown in Fig. 1. If $\Delta_p$ is the deflection that occurs when the steel reinforcement begins to yield, while $\Delta_u$ is the ultimate deflection, then the deflection will increase after strain yields to the ultimate condition before it collapses. As soon as the collapse occurs, the ability of the section to accept the load decreases and the curve forms a negative slope and the load does not increase again when the concrete strain reaches 0.003. Ultimate deflection occurs before the load and deflection curves reach a negative slope or when the compressive strain of the concrete reaches 0.003 [9]. When evaluating ductility, the most important parameter is the maximum deformation that the material can sustain prior to failure. However, two different materials or members having a similar magnitude of maximum deformation at failure can have different stress–strain or load–deflection behaviours and therefore different ductility [10]. The formula of ductility of reinforcement concrete beam by using this formula:

$$\mu = \frac{\Delta_u}{\Delta_p}$$

where $\mu$ is the ductility, $\Delta_u$ is the ultimate ductility (cm), and $\Delta_p$ is the tensile steel reinforcement begins melted (cm). Previous research is experimental research on fibrous reinforced concrete beams and hollow beams. This study aims to see the ductility ratio between fibrous reinforced concrete beams and hollow beams. The results showed that fibrous reinforced concrete beams experienced flexural failure, while hollow beams experienced flexural shear failure. The load acting on fibrous reinforced concrete beams is greater than that of hollow beams. However, the ductility that occurs for hollow beams is greater than for fibrous reinforced concrete beams [11]. The results of other studies indicate that the addition of compressive reinforcement to reinforced concrete beams does not contribute much to the increase in beam strength but is very helpful in increasing the ductility of the cross-sectional curvature. This is due to the increased strength in the compressive area of the beam section [1].

Other researchers stated that the cross-section of reinforced concrete beams which less tensile reinforcement area tends to have a large curvature ductility value, but the strength is lower. This is due to the weakening in the tensile area, resulting in the steel reinforcement in the tensile area being forced to melt faster [12]. The results of other studies indicate that sections with large deflections are advantageous in terms of moment capacity and utilization of the concrete compression section but tend to be brittle compared to small deflections. The Section with small deflections will have a smaller concrete compression zone than sections with large deflections [13]. Another research on beam ductility is to test flexural beam with the number of test objects is 7 beams. The aim of this research is to examine the ductility of the beam when spiral reinforcement is applied in its compressed region. The test object model is a beam measuring 200 x 300 mm with a length of 4.060 mm and given a spiral on the compressed part of the beam. The beam model is compared to a beam without spiral in its compressed zone. The results showed that beams without spiral are very brittle in failure, whereas beams with continuous spiral can deform for a long time. The use of steel spiral aims to wrap concrete in the compressed area of the beam, thereby increasing the ductility and performance of the beam [14]. This study aims to determine the effect of precast concrete joints on the resulting ductility. The research method was experimentally in a laboratory-based on ASTM (American Society for Testing and Materials) and ACI (American Concrete Institute).

2. Experimental method
The method used in this research based on the ASTM (American Society for Testing of Materials) and ACI (American Concrete Institute) regulations. It was conducted in the Laboratory of Department Civil Engineering of Universitas Syiah Kuala.

2.1 Concrete mix design
A concrete mix design of normal concrete beam and hollow block concrete beam was carried out based on the ASTM [15], ACI 211.1-91 [16], dan ACI 211.3R-02 [17]. The design of concrete compressive strength was 14.50 MPa. The cement used was type 1 with a slump of 75-100 mm, fine aggregate used
was that passed the sieve size of 4.76 mm and 9.52 mm and the maximum diameter of the coarse aggregate was 31.5 mm [2]. The diameter of reinforcement bar were 12 mm (threaded steel) and 10 mm, meanwhile the diameter of plain steel was 6 mm. The water used in this research was in the Laboratory of Department Civil Engineering of Universitas Syiah Kuala.

2.2 Preparation of hollow block concrete
Hollow block concrete was formed by using a concrete machine according to the planned specifications with the design of concrete compressive strength is 14.50 MPa. As many as 7 (seven) pieces of hollow block concrete with a size of 15 x 20 x 30 cm are prepared to be combined into one-unit hollow block beam. For this study, the number of hollow blocks used was 28 pieces.

2.3 Equipment used
The equipment used were concrete mixer, oven, iron diameter 16 mm with length 60 cm, ruler, aggregate filler spoon, cylindrical steel container, soaking bucket, sand cone mold with 15 mm diameter iron pounder with 25 cm long, glass (jar) with a glass plate lid, basin, brass brush, digital scales of 5 kg, a set of ASTM standard filters, and Abram's cone and a 45 cm x 45 cm x 45 cm steel plate, 4 (four) mold of beam with size of 15 cm x 20 cm x 210 cm, an electric strain gauge, load cell with capacity of load is 50 Ton, hydraulic jack, monitor computer with data logger.

2.4 Preparation of beam specimen
The specimen used in this research consist of four beams, which are TRC (Top Reinforcement Concrete), THB (Top Hollow Block), BRC (Bottom Reinforcement Concrete), and BHB (Bottom Hollow Block). The size of beam used was 15 x 20 x 210 cm with the diameter of reinforcement bar were 12 mm (threaded steel) and 10 mm meanwhile the diameter of plain steel was 6 mm. To measure the strain on the main reinforcement, an electric strain gauge is installed with a length of strain is 5 mm. Then the strain gauge leg is connected to an electric cable of 150 mm long for easy reading. The casting of concrete is carried out in accordance with the mixture design of concrete. Making the specimen is done by inserting the reinforcement and mixing the concrete into the mold of reinforcement concrete beam. Meanwhile, the hollow block concrete beam begins by compiling 7 pieces of hollow block concrete into a mold. Then the hollow block concrete cavity is filled with reinforcement and mortar mixture.

2.5 The ductility of beam test
The ductility of Beam test done at the age of 28 days based on ASTM C.293 rules. The test was conducted by weighting the beam gradually by means of a deflection measuring instrument that is a transducer [18]. Transducer was placed as many as 2 (two) pieces on the left side of the beam and 2 (fruit) in the middle of the beam. The beams were supported by 2 pedestals; they are joints and rolls with 1800 mm spacing and loaded with 2 centralized loads.

3. Result and Discussion
The study was carried out experimentally in a laboratory based on ASTM and ACI rules. The results of ductility of beam test using TRC (Top Reinforcement Concrete) specimen, THB (Top Hollow Block) specimen, BRC (Bottom Reinforcement Concrete) specimen, and BHB (Bottom Hollow Block) specimen when the test specimen at 28 days old were shown in Figs. 2, 3, 4, and Fig. 5. The figures show that the deflection of normal reinforced concrete beams is similar with hollow block concrete beam, namely at the beginning of loading the curve moves closer to linear until it reaches the ultimate load, then the curve moves down until the beam collapses. The ductility calculation is carried out based on the ratio of the ultimate deflection to the melted deflection of tensile reinforcement. Based on the graph, the ultimate deflection value is taken at peak load, while the yield deflection of tensile reinforcement is taken based on the value of the load at the time of melted tensile reinforcement from
the load-strain relationship of steel that occurs in the flexural test of reinforced concrete beams and hollow block concrete beams.

Figure 2. The result of ductility of TRC Beam test.

Figure 3. The result of ductility of THB Beam test.

Figure 4. The result of ductility of BRC Beam test.

Figure 5. The result of ductility of BHB Beam test.

Table 1. The result of ductility of beam test.

| The name of beam | $f_c$ (MPa) | $f_y$ (MPa) | $\varepsilon_y$ | $P_y$ (kg) | Deflection (cm) | Ductility |
|------------------|-------------|-------------|-----------------|------------|-----------------|----------|
| TRC              | 16.27       | 303.03      | 0.00146         | 910        | 1.0785          | 2.183    | 2.024 |
| THB              | 16.8        | 303.03      | 0.00101         | 870        | 0.927           | 2.3415   | 2.526 |
| BRC              | 18.43       | 297.74      | 0.00229         | 2520       | 1.6025          | 1.9815   | 1.237 |
| BHB              | 16.56       | 297.74      | 0.00086         | 1450       | 1.2555          | 2.022    | 1.611 |

Table 1 shows that the ductility value obtained greatly affects the area of the amount of tensile reinforcement and the beam model used. The total area of tensile reinforcement in hollow block concrete beams is less than normal reinforced concrete beams. Hollow block concrete beams have a higher ductility value than normal reinforced concrete beams. In addition, the joints of the precast concrete also function to improve the behaviour of the beam in deforming to the working load. However, the strain of steel in hollow block beams is very small, reaching a state of yield limit below 0.002.
4. Conclusion
The test result shows that the ductility value for TRC beam was 2.024, THB beam ductility was 2.526, BRC beam ductility was 1.237, and BHB beam ductility was 1.611. Hollow block concrete beams have a higher ductility value than normal reinforced concrete beams. The model of Top Beam has a higher ductility value than Bottom beam. This means that the smaller the amount of tensile reinforcement, the higher the ductility value of a beam.

References
[1] Nur O F 2009 Analisa Pengaruh Penambahan Tulangan Tekan Terhadap Daktilitas Kurvatur Balok Beton Bertulang J Rekayasa Sipil 5 123–34
[2] Bunyamin 2019 Comparison of deflection of hollow block concrete blocks with normal reinforced concrete beam AIP Conference Proceedings p. 20039
[3] Bunyamin B 2020 Pengaruh Sambungan Beton Pracetak Hollow Block terhadap Pola Retak yang Timbul J Serambi Eng. 5 2
[4] Sianturi N M 2012 Tinjauan Penggunaan Balok Beton Bertulang Dengan Menggunakan Perkuatan CFRP Dan GFRP 2012 J Ranc Sipil 1 1 10–20
[5] Radujković A 2019 Estimation Of Ductility At Global And Local Level For Ultimate Limit States 2019 The 7th International Conference Contemporary achievements in civil engineering 23–24 April (Subotica, SERBIA)
[6] Nurlina S, Suseno H, Hidayat M T and Pratama I M Y 2016 Perbandingan Daktilitas Balok Beton Bertulang Dengan Menggunakan Perkuatan CFRP Dan GFRP 2016 Rekayasa Sipil 10 1 62–9
[7] Paulay T and Priestley M J N 1992 Seismic design of reinforced concrete and masonry buildings (John Wiley & Sons, Inc.)
[8] Park R, Paulay T 1975 Reinforced concrete structures (John Wiley & Sons)
[9] Shetty M S and Jain A K 2019 Concrete Technology (Theory and Practice) 8e. (S. Chand Publishing)
[10] Pam H J, Kwan A K H and Islam M S 2001 Flexural strength and ductility of reinforced normal- and high-strength concrete beams Proc Inst Civ Eng Build. 146 4 381–9
[11] Abbass A, Abid S and Özakça M 2019 Experimental investigation on the effect of steel fibers on the flexural behavior and ductility of high-strength concrete hollow beams Adv Civ Eng, Article ID 8390345
[12] Priastiwi Y A, et al. 2014 Behavior of ductile beam with addition confinement in compression zone Procedia Eng. 95 132–8
[13] Mansor A A, Mohammed A S and Salman W D 2020 Effect of longitudinal steel reinforcement ratio on deflection and ductility in reinforced concrete beams IOP Conference Series: Materials Science and Engineering 12008
[14] Hadi M N S and Schmidt L C 2002 Use of helixes in reinforced concrete beams Struct J. 99 2 191–8
[15] ASTM 2004 Annual Book of ASTM Standard Section 4 Vol. 04.02 (Concrete and Aggregates Int. Stand.)
[16] ACI 2005 ACI Manual of Concrete Practice Part I, Report: ACI 104-71 (97) to ACI 223-98, Selecting Proportions For Mass Concrete (ACI 211.1-91) (Detroit, Michigan: Am Concr Institute)
[17] Htay H H, Aung H T and Kyaw N M 2017 Experimental Study on Previous Concrete with Various Mix Ratios IPTEK J Proc Ser. 3 6
[18] ASTM C293 2002 Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading (Am Soc Test Mater)