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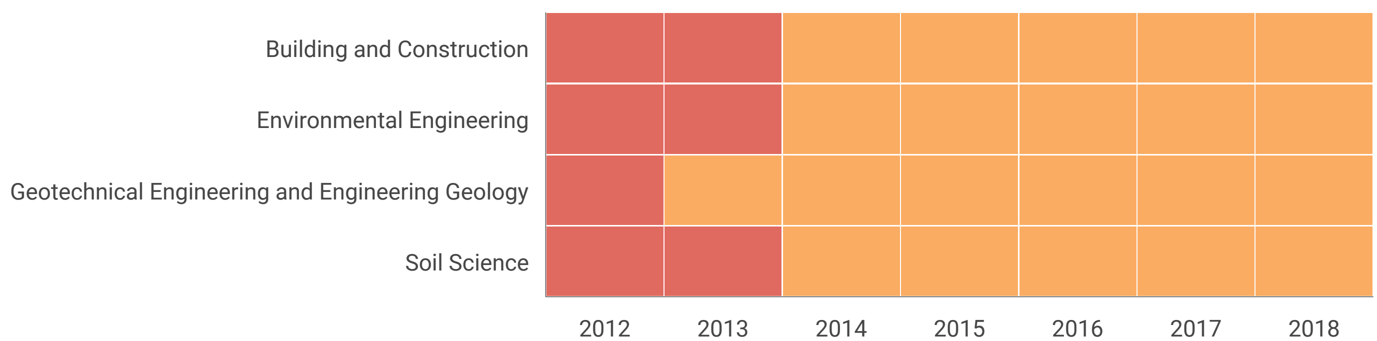

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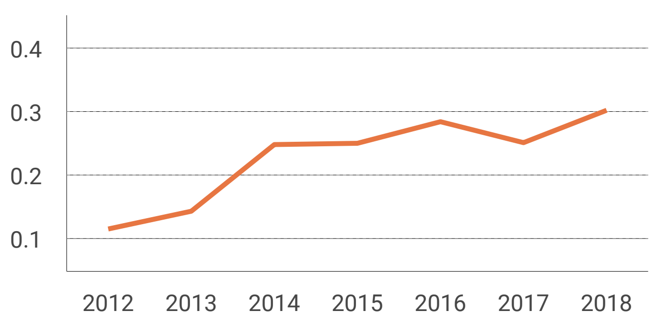

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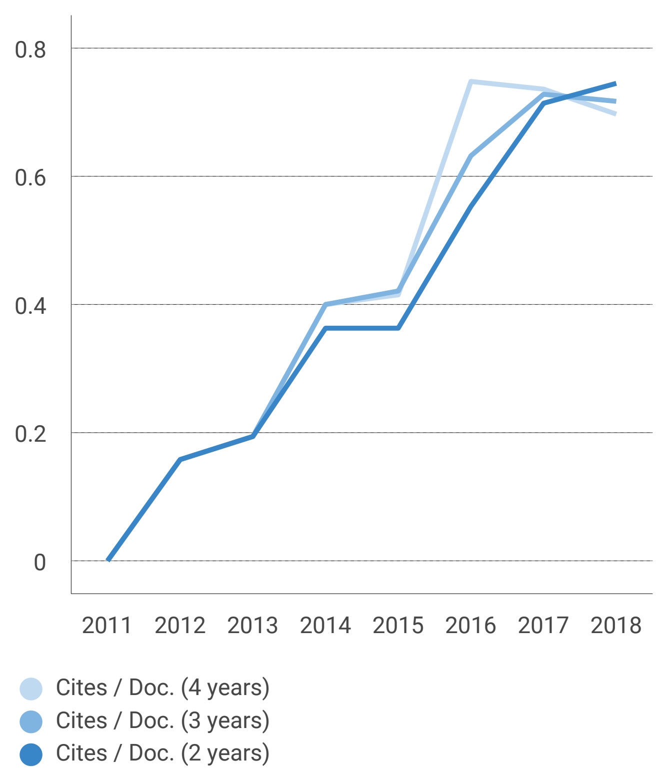

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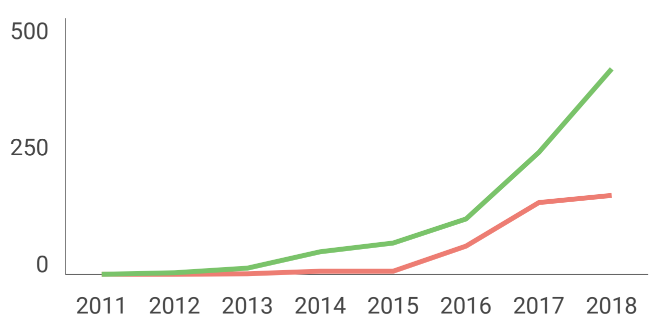

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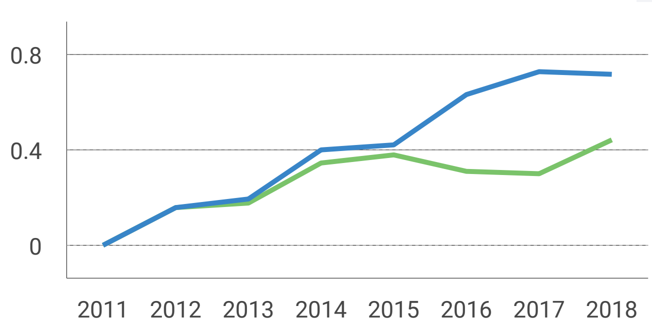

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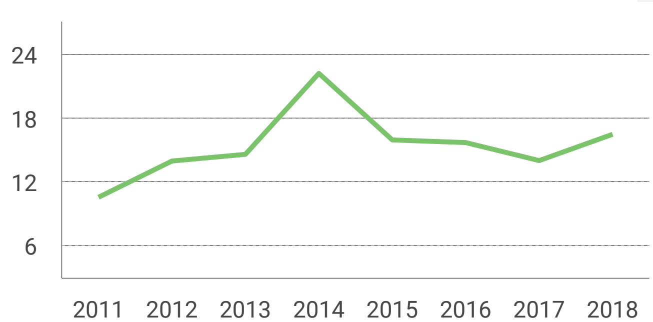

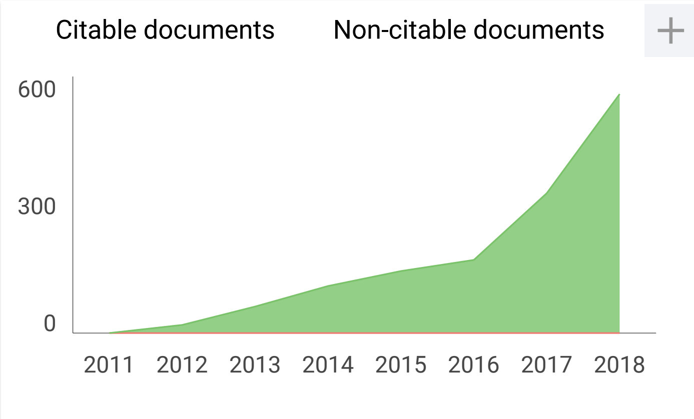

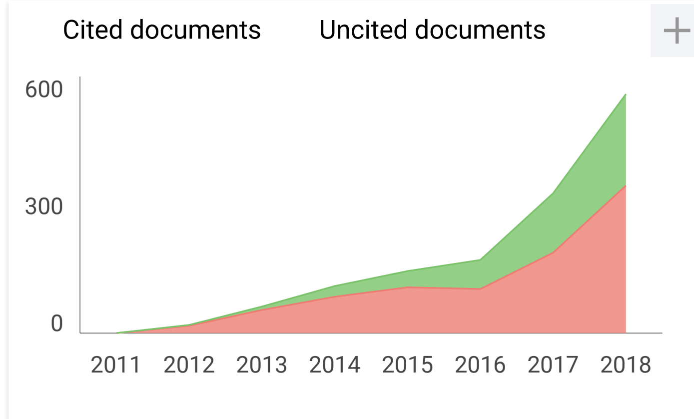

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Mohammed Ali Al-Bared 1 year ago

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Thanks again

reply

M

Mohammed Al-Bared 1 year ago

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Geotechnique, Construction Materials and Environment

FLEXURAL BEHAVIOR OF FLY ASH-BASED GEOPOLYMER R/C BEAM WITH BAUXITE MATERIAL AS COARSE AGGREGATES

*Ade Lisantono[1], Johanes Januar Sudjati[2] and Angelina Eva Lianasari[3]

[1,2,3]Faculty of Engineering, Universitas Atma Jaya Yogyakarta, Indonesia

*Corresponding Author, Received: 09 Oct. 2019, Revised: 12 Nov. 2019, Accepted: 16 Dec. 2019

ABSTRACT: Bauxite materials are provided in Indonesia especially in Batam Island. Based on the previous research, this material can be used as coarse aggregates in fly ash-based geopolymer concrete. To study the behavior of fly ash-based geopolymer reinforced concrete beam subjected to bending, this research is conducted. Two fly ash-based geopolymer reinforced concrete beams were made and tested. The first beam was made from normal concrete as a reference beam, while the second beam was fly ash-based geopolymer concrete which was using bauxite as coarse aggregates. Both beams had the same size of 120 mm width and 240 mm in height. Two longitudinal reinforcements with a diameter of 16 mm as tensile reinforcements and a diameter of 13 mm as compressive reinforcements. The stirrups using diameter 6 mm with spacing 100 mm along the span of the beam. Two loading points were applied to the beam using monotonic loading. The beam is a simple beam. The load-carrying capacity of the normal beam and fly ash-based geopolymer concrete beam were compared. Section analysis was also conducted to check the experimental program with the theory. The result shows that the flexural behavior of both beams was similar. Both beams show as ductile beams. The maximum load of the normal concrete beam was 63.00 kN. While the maximum load of the fly ash-based geopolymer concrete was 66.15 kN. The section analysis of both beams closed to the experimental result indicated that the theory can be applied to the fly ash-based geopolymer concrete with bauxite material as coarse aggregates.

Keywords: Fly ash-based geopolymer concrete, Bauxite coarse aggregates, Flexural behavior, Load-carrying capacity.

1. INTRODUCTION

Several years ago the utility of Portland cement in concrete was reduced due to carbon dioxide (CO_2) in the production of Portland cement [1]. Therefore, geopolymer concrete was developed several years ago. Material for replacement of Portland cement in geopolymer concrete must have a high of silica and alumina because these materials will react with alkaline liquid to make the polymerization process in geopolymer concrete [2]. Research in geopolymer concrete was developed by some researchers [3-6]. This research used fly ash with low calcium to developed geopolymer concrete. While [7,8] used fly ash with high calcium to developed geopolymer concrete.

There are some parts of Indonesia that provide bauxite materials. Batam Island is part of Indonesia which provides bauxite materials. According to [9] that bauxite material can be used as a coarse aggregate in concrete. Lisantono et al. [10] conducted research that used bauxite materials for coarse aggregates in fly ash-based geopolymer concrete. The result showed that compressive strength can reach up to 47 MPa. This indicated that the fly ash-based geopolymer concrete with coarse aggregates of bauxite materials can be used for building materials especially for the region which has plenty of bauxite material but very difficult to find natural coarse aggregates.

To study the application of fly ash-based geopolymer concrete with bauxite material as coarse aggregates for an element of structures, this experimental program was conducted.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Normal concrete

Normal concrete was made from Portland cement, water, sand as fine and gravel as coarse aggregates. The fine and coarse aggregates for normal concrete were taken from Krasak River which is located in the Northern part of Yogyakarta Province and Progo River which is located in the Western part of Yogyakarta Province, respectively. Mix design of normal concrete can be seen in Table 1.

Table 1 The mix design of normal concrete

Material	Requirement per m^3	Unit
Cement	446	kg
Water	205	liter
Sand	830	kg
Gravel	899	kg

2.1.2 Fly ash-based geopolymer concrete

Fly ash-based geopolymer concrete was made from fly ash, sodium hydroxide and sodium silicate as activators, sand as fine aggregates and bauxite material as coarse aggregates.

To obtain the mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. The concentration of the NaOH solution was taken as 8M. While the proportion of fly ash vs activator was taken as 74%:26% by weight. The mix design of fly ash-based geopolymer concrete can be seen in Table 2.

Table 2 The mix design of geopolymer concrete

Material	Requirement per m^3	Unit
Fly ash	505	kg
Na2SiO3	56	liter
NaOH	23	liter
Bauxite	305	kg
Sand	1526	kg
Superplasticizer	20	lt

The chemical content of fly ash that was used in this study can be seen in Table 3. According to [11] class F of fly ash contains CaO ≤ 10%, and SiO2+ Al2O3+ Fe2O3 ≥ 70%. As shown in Table 3 that the fly ash used in this study contains CaO ≤ 10%. So the fly ash has low calcium.

Table 3 The chemical content of fly ash

Chemical content	By mass (%)
SiO_2	34.2
Al_2O_3	10.9
Fe_2O_3	18.5
SiO_2+ Al_2O_3+ Fe_2O_3	63.6
CaO	1.4
Na_2O	0.09
K_2O	0.5
MgO	1.25
SO_3	0.3

2.2 Specimens

2.2.1 Cylinder specimens

Cylinder specimens were also made for testing the mechanical properties of concrete (compressive strength, tensile strength, and modulus of elasticity). Eighteen cylinder specimens were made and tested. Nine specimens for normal concrete, and nine specimens for geopolymer concrete. Three specimens were tested for each parameter at the age of 28 days.

2.2.2 Beam specimens

Two beams specimens were made in this study. The first beam was made from normal concrete as a reference beam, while the second beam was fly ash-based geopolymer concrete which was using bauxite as coarse aggregates.

Both beams had the same size of 120 mm width and 240 mm in height. Two longitudinal reinforcements with a diameter of 16 mm were used as tensile reinforcements and two reinforcements with a diameter of 13 mm were used as compressive reinforcements. The shear reinforcement used diameter 6 mm with spacing 100 mm along the span of the beam.

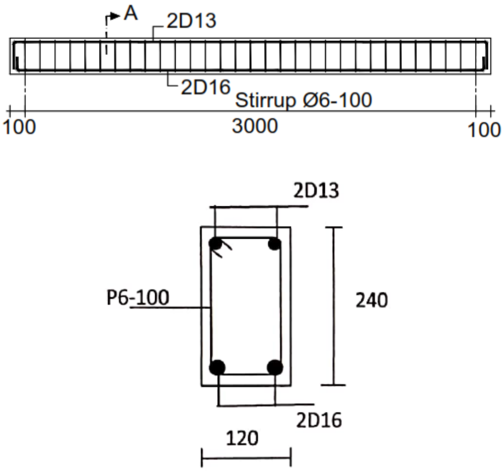

Fig. 1 Reinforcement Detail of the Beam

2.3 Setup of Beam Testing

Two-point loads testing was applied to examine the flexural behavior of the beams. The setup of beam testing was shown in Fig. 2. A transfer beam was used to divide the force from the load cell into the two-point load at the symmetrical position (see Fig. 3).

Linear Variable Differential Transformers (LVDT) was used to measure the deflection at the mid-span of the beam. Measured data of loads, deformations and strains of the beams were read through a computer-driven data acquisition system

Fig. 2 Two-Point Load Test Setup

The bending moment diagram of the beams for analytical theory can be drawn in Figure 3.

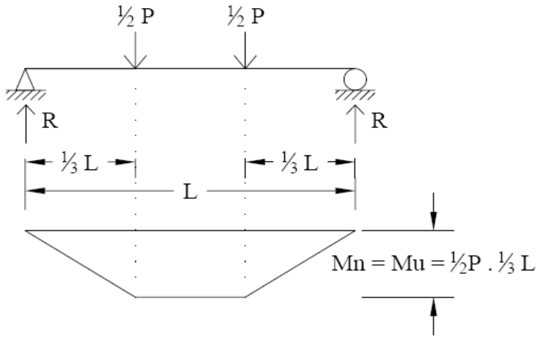

Fig. 3 Bending Moment Diagram

3. RESULT AND DISCUSSION

3.1 Material Testing

The mechanical properties of normal concrete and fly ash-based geopolymer concrete is shown in Table 4.

Table 4 Mechanical Properties of Concrete

	f_c' (MPa)	f_t (MPa)	E (MPa)
NC	25.98	2.98	20147
GC	32.22	2.54	11558

Note: f_c'= compressive strength; f_t= tensile strength; E= modulus of elasticity; NC= normal concrete cylinder; GC= fly ash-based geopolymer concrete cylinder

Three parameters were obtained from the mechanical properties testing. Firstly, the compressive strength of geopolymer concrete was 24% higher than the normal concrete. Secondly, both specimens had a similar tensile capacity, shown by a 15% difference between the ultimate stresses. Thirdly, the modulus of elasticity of the geopolymer concrete was significantly lower by 45% than of the normal concrete.

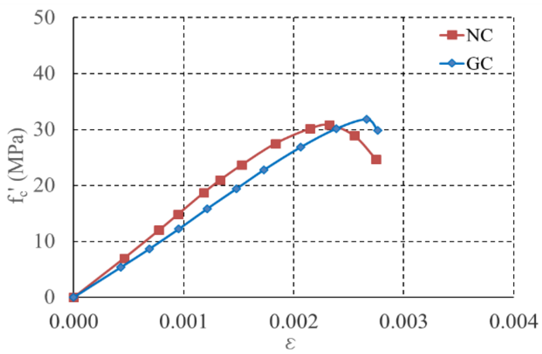

Fig. 4 Stress-Strain Curvature of Concrete Cylinder

A separate test was conducted to examine the stress-strain relationship of the concrete specimens. It was observed that geopolymer concrete could reach up to 0.27% strain at its peak stress of 31.82, slightly larger than the stress-strain of the normal concrete (0.23% strain at 30.80 MPa stress).

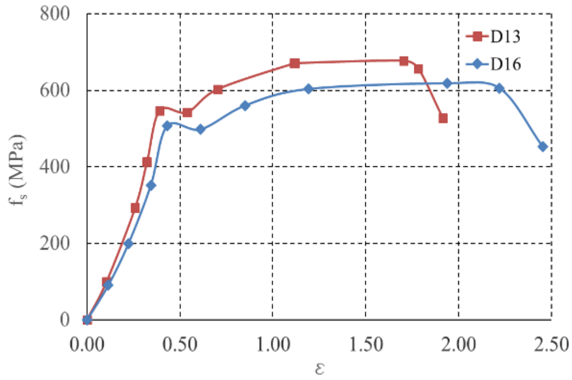

Fig. 5 Stress-Strain Curvature of Reinforcing Bars

The yield strength (f_y) was examined by conducting a tensile test of the reinforcing bars, with 547.15 MPa for the D13 bar and 506.50 MPa for the D16 bar. These values were higher than the expected value of 400 MPa, by 37% and 27% for D13 and D16 respectively. The strength of the reinforcing bars had influenced the ductile behavior of the beam.

3.2 Load-Carrying Capacity

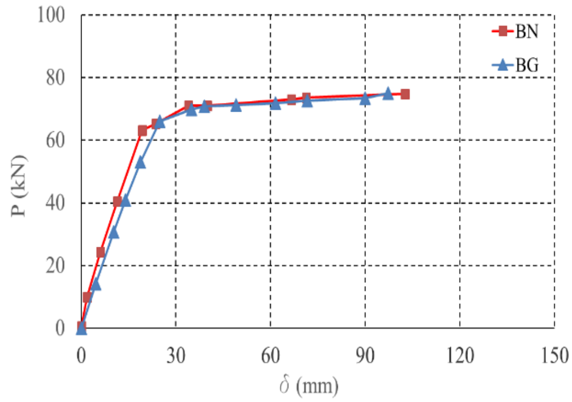

Fig. 6 Load-Displacement Relationship of 120/240 Beam

The load-displacement relationship of the beams is shown in Fig. 6. Both specimens were failed under flexural rupture. Table 5 summarizes the load and displacement at yielding and maximum point.

Table 5 Summary of Load-Carrying Capacity

	P_y (kN)	δ_y (mm)	P_u (kN)	δ_u (mm)
BN	63.00	19.20	74.87	102.70
BG	66.15	24.87	75.01	97.30

The use of geopolymer concrete (BG) did not significantly increase the load-carrying capacity (P_u) compared to the normal concrete beam (BN). The difference in the ultimate load (P_u) between the two samples was merely 1%.

The ductile behavior of the two samples was examined by comparing the load and deflection at yield and ultimate condition, represented by Eq.(1) and Eq.(2).

$$\frac{\Delta P}{P_y} = \frac{P_u - P_y}{P_y} \times 100\% \quad (1)$$

$$\frac{\Delta \delta}{\delta_y} = \frac{\delta_u - \delta_y}{\delta_y} \times 100\% \quad (2)$$

The geopolymer beam allowed an increase of 291% in deflection and 13% in the load-carrying capacity after yielding. Meanwhile, the normal concrete beam provided an extra capacity of 435% in deflection and 19% in load. This post-crack behavior is determined by the ductility of the concrete mixture and bond strength between concrete and reinforcing bars.

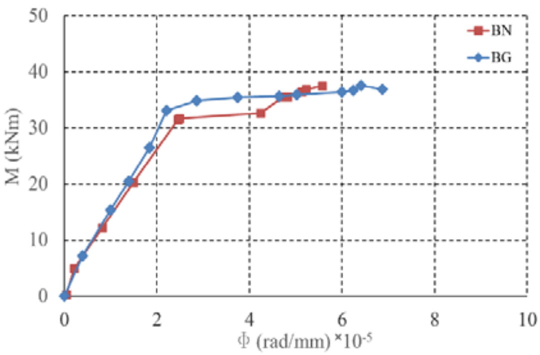

Fig. 7 Moment-Curvature Relationship of 120/240 Beam

The moment-curvature relationship at mid-span is plotted in Fig. 7. In Fig. 3, the bending moment diagram of the test setup is presented. The nominal moment (M_n) and mid-span curvature (Φ) are calculated using Eq.(3) and Eq.(4).

$$M_n = \frac{1}{6} P_u L \quad (3)$$

$$\phi = \frac{1}{R} = \frac{\varepsilon}{y} \quad (4)$$

Note: L= beam span; e= axial strain of rebar; y= between the center point of rebar to the neutral axis

Table 6 Summary of Moment-Curvature Relationship

	M_y (kNm)	Φ_y (rad/mm)	M_u (kNm)	Φ_u (rad/mm)
BN	31.66	2.48×10^{-5}	37.43	5.57×10^{-5}
BG	33.08	2.20×10^{-5}	37.50	6.87×10^{-5}

Both beams developed a similar behavior in their plastic state where an increase of curvature after yielding point was formed, with 124% for normal concrete and 211% for geopolymer concrete. The increase is calculated using the following equation.

$$\frac{\Delta \phi}{\phi_y} = \frac{\phi_u - \phi_y}{\phi_y} \times 100\% \quad (5)$$

3.3 Crack Pattern

Table 7 Load at First Crack

	First Crack Load (kN)
BN	8.23
BG	7.01

Table 7 shows the load comparison at the initial crack. The first crack of normal concrete beam and fly ash-based geopolymer concrete were in accordance with their respective material tensile strength (see Table 4). The cracking pattern is presented in Fig. 8 to Fig. 11.

Fig. 8 Normal concrete R/C Beam (BN 120/240), Post-Loading

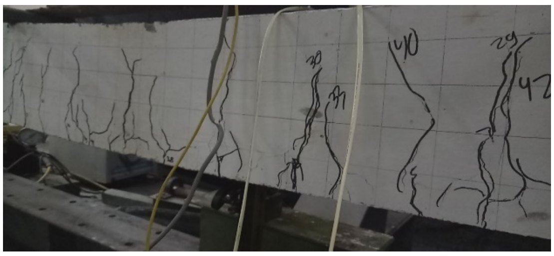

Fig. 9 Normal concrete R/C Beam (BN 120/240), Mid-Span Detail

Fig. 10 Geopolymer R/C Beam (BG 120/240), Post-Loading

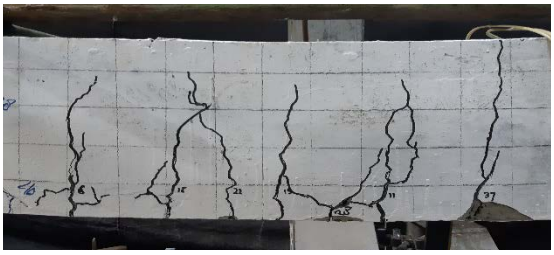

Fig. 11 Geopolymer R/C Beam (BG 120/240), Mid-Span Detail

As shown in Fig. 9, it was observed that the crack width in the normal concrete beam was smaller and the spacing was narrower than in the geopolymer beam (Fig. 11).

3.4 Section Analysis

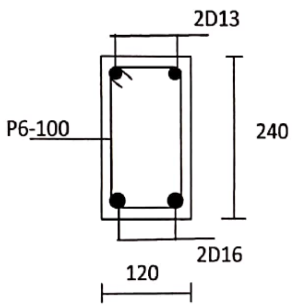

Fig. 12 Cross Section of Beam Specimens (unit in mm)

Doubly-reinforced beam analysis is used to determine the theoretical capacity of the specimen. The nominal bending moment is given by Eq.(6) and summarized in Table 7.

$$M_n=C_c\left(d-\frac{a}{2}\right)+C_s\,(d-d') \tag{6}$$

Where: C_c= compression force on concrete; C_s= compression force on steel; d'= centroid depth of compression reinforcement from extreme compression fiber, a= depth of neutral axis from extreme compression fiber.

A comparison of load-carrying capacity between theory and the experimental program can be seen in Table 8.

Table 8 Comparison load-carrying capacity between theory and experimental program

Beams	Theory	Experiment
	P_u (kN)	P_u (kN)
BN	73.37	74.87
BG	80.61	75.01

Table 8 shows that the load-carrying capacity based on the theory is closed to the experimental result. The differences are only 2% and 7% for normal and geopolymer concrete beams, respectively. This result indicated that the analytical theory of section analysis can be applied for a fly ash-based geopolymer concrete beam.

4. CONCLUSION

Based on the experimental results, the following conclusions can be drawn:
1. The load-carrying capacity of the normal concrete beam and the fly ash-based geopolymer concrete were 74.87 kN and 75.01 kN, respectively. This indicated that the fly ash-based geopolymer concrete beam had the load-carrying capacity as the normal concrete beam.
2. The load-deflection relationship of the fly ash-based geopolymer concrete had the same behavior as the normal concrete beam. The curve initially increases linearly, after reaching the yield the curve deformed horizontally up to failure. This indicated that both fly ash-based geopolymer concrete and normal concrete beams showed as the ductile beams.
3. Both concrete beams had similar behavior in their plastic state with the curvature increase of 124% and 211% for normal concrete beam and fly ash-based geopolymer beam respectively.
4. The result of section analysis based on the theory is close to the experimental program for both normal concrete and fly ash-based geopolymer concrete. This result indicated that the analytical theory of section analysis can be applied for a fly ash-based geopolymer reinforced concrete beam with bauxite materials as coarse aggregates..
5. This research studied about flexural behavior of fly ash-based reinforced concrete beam with bauxite materials as coarse aggregates. The future work to continue this research is to study about shear behavior of fly ash-based geopolymer reinforced concrete beam with bauxite as coarse aggregates, so that the behavior of the fly ash-based geopolymer reinforced concrete beam can be applied for the real element of building structures.

5. ACKNOWLEDGMENTS

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