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The Impact of Shear Connector Numbers on the Flexural Performance of Composite Geopolymer Reinforced Concrete Beams with Big Transverse Web Openings.

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ABSTRACT

Geopolymer concrete is a sustainable alternative to conventional Portland cement-based concrete, utilizes industrial by-products like fly ash and slag. Renowned for its reduced carbon footprint and exceptional durability, geopolymer concrete is gaining global recognition in eco-friendly construction practices. Steel composite reinforced geopolymer concrete beams combine the strength of steel with the sustainability of geopolymer concrete, offering a sturdy structural solution. This collaborative approach results in a composite material with excellent crack resistance and durability, harnessing the advantageous properties of both steel and geopolymer concrete. These beams present a promising option in construction by striking a balance between structural performance and environmental considerations through the incorporation of geopolymer technology.

The focus of the current study is to investigate the impact of steel connectors on the flexural behavior of composite reinforced geopolymer concrete beams that have big transverse web opening through experimental methods. The experimental program involves casting four geopolymer beams, with one being a traditional geopolymer-reinforced concrete beam (Control). The remaining three specimens are composite reinforced geopolymer concrete beams, each featuring a bottom 3 mm steel plate with six, twelve, and eighteen connectors near each support. The beams share common dimensions, with a total length of 1600mm, a height of 250mm, and a width of 180mm. The results showed that increasing the number of connectors near supports increased the resulted flexural behavior of beams. Such connectors decreased the first crack load from 15.56% to 6.67% while the service load decreased from 26.16% to 15.35%. the load-carrying capacity was also decreased from 28% to 16%. Finally, the mode of failure was moved from traditional tension failure to concrete crushing.

1. Introduction

The collaboration between concrete and steel in composite construction brings about notable advantages [1-5]. As indicated by several sources in the literature, the advantages of composite construction encompass [6-8]:

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1. Rapid Steel Framework Erection: Composite construction allows for a quick and efficient erection of the steel framework, saving time during the construction process.
2. Enhanced Structural Strength and Performance: The combination of concrete and steel results in structures with increased resilience and satisfactory performance during their service life.
3. Reduced Weight and Material Cost: Composite construction leads to a substantial decrease in structures weight and the overall materials cost, making it a cost-effective choice for construction projects.

Contemporary composite construction follows a specific sequence of actions. Initially, the steel framing elements are lifted into position, forming a robust structure capable of supporting various construction loads. Subsequently, the composite action takes place, where concrete or another material is introduced to provide resistance to external loads. Additionally, the stiffness and strength of the structure are significantly improved by the combined effort [9–10].

Serviceability requirements are critical in modern design [10–16], and controlling deflections and vibration response is just as important as ensuring load resistance. The principal objective is to investigate advanced composite building technology that integrates the cooperative application of steel sections and in-situ concrete [17–25]. This construction technique reduces material costs, speeds up construction, allows for larger spans, and improves overall efficiency in a variety of building construction scenarios [26–28].

Applying composite construction approaches wisely can unlock an array of benefits and optimize operational capabilities within the domain of service complexity [29–30]. Exploring the rich tapestry of conventional composite building reveals a story in which concrete slabs and steel beams perform together in perfect harmony to support applied loads on the structural frame. For composite slabs, steadfast guardians in the quest for increased structural integrity, adding more than just parts, acting as conduits for stiffness and strength, and creating an elaborate story within the architectural system [31–35].

However, in this delicate dance of materials, there is an inherent weakness that shows itself when the connection between the concrete slab and the steel beam is neglected. Imagine that loads are applied to the structure, and that the basic basis of structural stability is threatened by relative slippage in the absence of a strong connection. The grand symphony of performance is threatened by this possible slippage, a covert enemy that raises questions about the safety citadel and structural efficiency [36–40].

In the complex movement of structural harmony, preventing the potential danger of relative slippage becomes critical, requiring the coordination of a connection that is not only functional but perfectly should be engineered and built.

Frequently appearing stud and shear connectors are essential techniques in structural engineering. They function like virtuosos, skillfully tying together steel beams and concrete slabs into a seamless, melodic ballet. When these components are linked, they become defenders of unity, transforming various parts into a single composite object. Witness the magic as concrete and steel come together, dancing to enhance the building's ability to bear weight and improve its overall structural performance. This process of alchemy is crucial for creating a robust and durable structure [40-45].

There are many advantages to composite construction, including increased stiffness, increased load-bearing capability, and better material use. As is frequently noted, the combined strength of steel and concrete regularly offers a dependable and economical structural solution in the construction of multi-story buildings and bridges [46–49].

Other materials, such as pre-stressed concrete, aluminum, foam core, and timber, can be utilized in composite construction, depending on specific design requirements and application, although steel and concrete are the more prevalent choices for composite beams [50-53].

In fact, concrete is far stronger when compressed than when it is stretched. It has high compressive strength but relatively low tensile strength. On the other hand, steel is an excellent material for resisting tensile forces but can be susceptible to buckling under compression [54-56].

Overall, composite beams provide a versatile solution to optimize the performance of different materials and create efficient and durable structural elements for various construction applications.

2. Study Significance

This study aims to make a substantial contribution to the research field by obtaining dependable findings performance of composite geopolymer concrete beams. Accurate experimental data are crucial for researchers trying to understand the relationship between the mechanical properties of geopolymer concrete and the structural performance of these beams.

3. Experimental Program

3.1 Materials

3.1.1 Fly Ash

"EUROBUILD" high low calcium flay ash utilized as the source material for producing geopolymer concrete (GC).

3.1.2 Sand

The maximum size of the sand used in this research is 4.75mm. however, the grading analyses was done in accordance with No.45/1984 as shown in Fig 1.

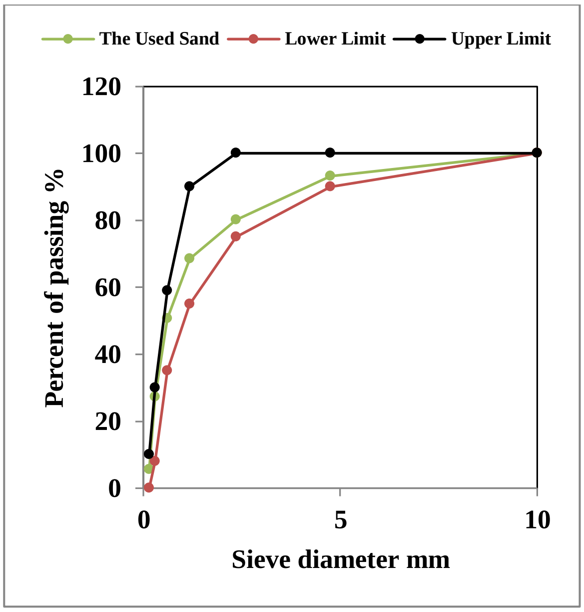


Fig. 1. Sand grading curves

3.1.3 Gravel

Fig.2 illustrates the grading analyses of the gravel that used in the present study in accordance with B.S 882/1992. the maximum size of this gravel is 10mm.

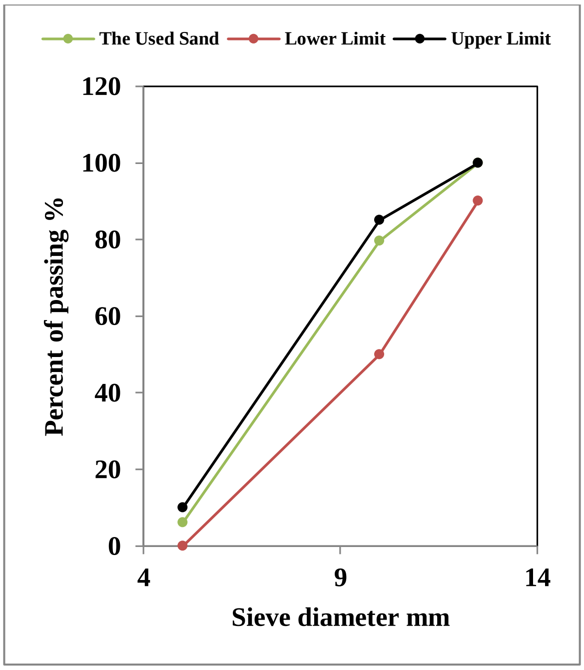


Fig. 2. Gravel grading curves.

3.1.4 Sodium Hydroxide NaOH

Sodium Hydroxide flakes were used to prepare 10 M concentration to compound the alkali solution. The purity of such flakes is 98%.

3.1.5 Sodium Silicate Na_2SO_3

The water glass is compound with NaOH to prepare the required alkali solution. According to the manufacturer, this sticky solution is about 55%.

3.1.6 Reinforcing Bars

Steel rebar diameter that used in this study are of 6mm and 8mm respectively. 8mm and 12mm are the diameters used in this study. The bars was tested in accordance with American Testing Standard Measurements (ASTM) A615.

3.2 Mix Proportions

The concrete mix composition for the experimental program was determined based on the research by Abdul Aleem and Arumairaj (2012). The final mix proportions used for casting the specimens are detailed in Table 1.

Table 1. The mix proportions

Material	Sand	Gravel	Fly ash	10 Molar NaOH	Sodium Silicate
Quantity (kg/m^3)	571.2	1305.6	408	41	103

3.3 Specimens Description and Study Variables

3.3.1 Specimen Description

Fig. 3. and Figure 4. depict the features of the tested beams in this experimental program. The stirrups, spaced at 120 mm, are of φ 8mm. The beam reinforcement includes 2 φ 8mm bars at the top and 2 φ 12mm bars at the bottom. The total section height of 250 mm while the width is of 180 mm. The total length is 1600 mm while the center-to-center span of 1500 mm.

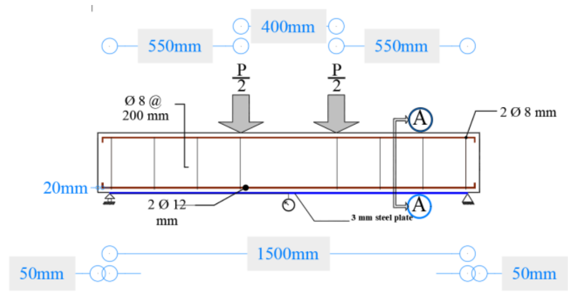


Fig. 3. Longitudinal section

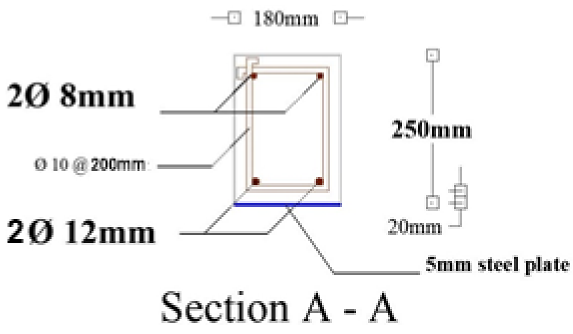


Fig. 4. Cross section

The first digit is either (O) which refers to the existence of a transverse web opening. The second digit is (B) which means (Big transverse web opening). The last digit is a number that refers to the number of the shear connectors.

The first specimen is a solid geopolymer RC composite beam that have six bolts (three at the left and three at the right support). The second specimen is a solid geopolymer RC composite beam that have twelve bolts (six at the left and six at the right support). The third specimen is a solid geopolymer RC composite beam that have eighteen bolts (nine at the left and nine at the right support). as shown in Fig. 5 and Table 2.

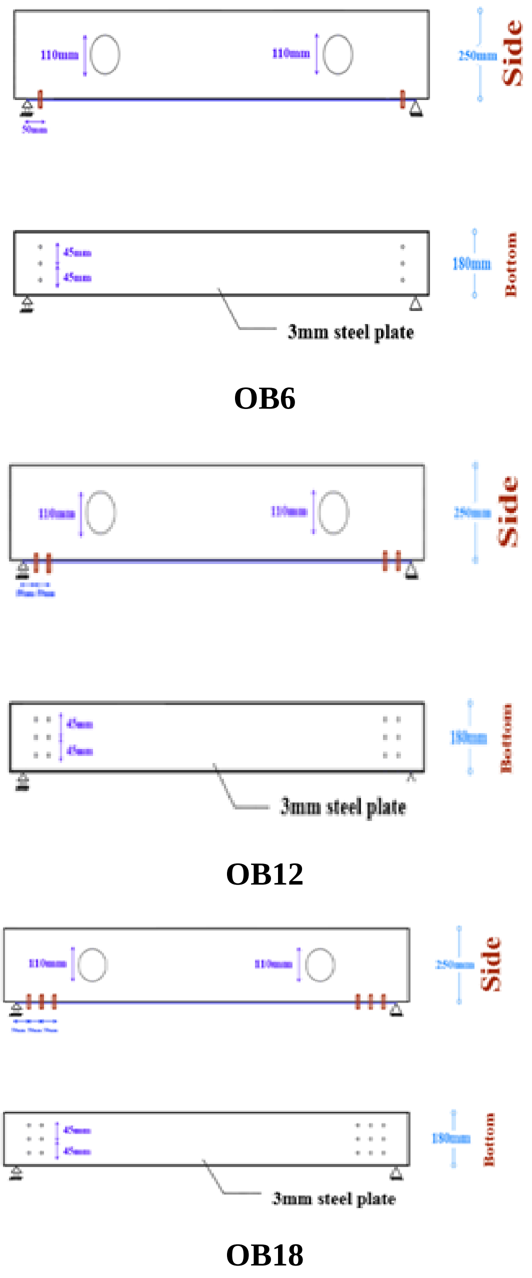


Fig. 5 Map of the current study

Table 2. Map of the current study

Specimen designation	Number of connectors
Reference	/
OB6	6
OB12	12
OB18	18

3.4 Molds

In the current experimental program, molds were created to cast specimens, and these molds were tailored to accommodate the required rebar. Their design allows for the easy adjustment of sides, ensuring precise dimensions for both the flange and web of section. As shown earlier, the total section depth of 250mm and a width of 180mm. Commercial bolts were welded to the 5 mm plate at the specified location before installing the rebar mesh. For the second and third group, the required transverse web opening was made by installing Poly Vinyl Chloride (PVC) pipes.

3.5 Mixing

The blending process in this study program involved a series of carefully carried out processes to ensure perfect specimen preparation and casting. The following is a summary of the involved procedure:

3.5.1 Mixer Preparation: The rotary mixer was thoroughly cleaned before every mixing session to get rid of any residue from previous use. Maintaining the integrity of the ensuing mixes required this step.

3.5.2 Mold Preparation: After being cleaned, the casting molds were lubricated with an appropriate motor oil coating. This treatment enabled simple demolding and improved the cast specimens' overall quality.

3.5.3 Solution Preparation: Solutions of Na_2SiO_3 and NaOH were carefully produced at the necessary molar concentrations before the mixing process was started. The presence of consistent and precisely measured activators was guaranteed by this thorough preparation.

3.5.4 Material Mixing: Three materials were mixed together—sand, gravel, and fly ash—in the rotary mixer for sixty seconds. The uniform dispersion of aggregates and other elements was encouraged during this early mixing phase.

3.5.5 Addition of Activator Solution: The pre-made NaOH and Na_2SiO_3 solutions were fed into the rotary mixer, and the mixing process continued for 180 seconds. This period of time was chosen to ensure that the activators were thoroughly combined with the aggregate mixture.

3.5.6 Casting and Leveling: The well-mixed quantity was promptly cast into the prepared molds. A suitable trowel was employed to level the surface of the cast specimens, ensuring uniformity and precision in their form, as depicted in Fig. 7.

3.5.7 Curing Initiation: Following the casting process, the specimens were demolded after 24 hours, marking the initiation of the curing phase. The specimens underwent curing under laboratory ambient conditions, setting the stage for subsequent testing.

Fig. 6. The used mixer

Fig. 7. Leveling the casted specimens

3.6 Testing Process

To test all geopolymer concrete beam samples, the apparatus depicted in Fig 8 was utilized. Prior to testing, the samples underwent brushing and were coated with white paint to enhance the visibility of any emerging cracks. Using a steel loading plate placed on a thin rubber strip for stability, two concentrated loads were applied to the samples. Initial readings from the strain gauge and dial gauge were obtained at the start of each experiment to set baseline values. The load was incrementally applied in each experiment, and readings of deflection, strain, and load were documented at each step to monitor the behavior of the samples. The load was gradually increased until failure occurred, enabling the observation and documentation of the progression of structural failure and associated changes in deflection, strain, and load.

Fig. 8. Testing machine

4. Results and Discussion

4.1 P_{cr}, P_s and P_u

P_s and P_u of composite geopolymer RC beam with big transvers web opening

By the inclusion of the big transvers web opening, increasing the number of connectors from 6 to 12 and 18 decreased P_{cr} by 15.56%, 13.33%, and 6.67% respectively. Furthermore, such changes decreased Ps by 26.16 %, 25.68% and 15.35% respectively for the same order above. Regarding Pu and with the presence of big transverse web opening, increasing the number of connectors from 6 to 12 and 18 decreased this value by 28%, 24% and 16% respectively. , P_{cr} P_s and P_u levels are less the control readings. This behavior can be ascribed to the additional loss in flexural rigidity due to the extra concrete volume subtraction. Additionally, the levels P_{cr} P_s and P_u are still understood with respect to connectors numbers.

However, understanding the impact of the subtracted concrete volume to the resulted P_{cr}, P_s and P_u is a rich source for the future research.

Table 3. P_{cr} P_s and P_u of composite geopolymer RC beams with big transvers web opening.

Specimen Designation	**Reference**	**OB6**	**OB12**	**OB18**
P_{cr} (kN)	22.5	19	19.5	21
P_{cr}%	/	-15.56	-13.33	-6.67
P_s (kN)	103.6	76.5	77	87.7
P_s %	/	-26.16	-25.68	-15.35
P_u (kN)	125	90	95	105
P_u %	/	-28	-24	-16

4.2 Service Deflection ∆s Maximum Deflection ∆m and The Relevant Load Deflection Curves

Table (4) and Figure (8) shows the effect of connectors numbers to the and of composite geopolymer RC beam that include big transvers web opening.

With presence of big transvers web opening, increasing the Table 3 show the effect of connectors to the P_{cr}, number of connectors from 6 to 12 and 18 increased by 16.37% for 6 connectors and decreased by 3.67% and 15.53% for 12 and 18 connector respectively. For , the intended levels were decreased by 5.05%, 10.69% and 14.41% for 6, 12 and 18 respectively.

It can be noticed from these results that there is further decrease in stiffness due to increase in concrete subtraction, this led 6 connector readings to be less than the reference. Fig. 9 shows the load deflection diagram of the Reference, OB6, OB12 and OB18 respectively. The same phases were repeated within the current group. For the referential specimen, it can be noticed that the first phase (Phase I) is the elastic one till reaching the first cracking limit. At the end of this limit, the cracks will appear clearly.

The second Phase (Phase II) begins after the first cracking load when the cracks begin to be more in number and its width is progressed more and more till the Ps. After this limit, the last phase (Phase III) which included more cracking width and the final fracture at the end of load capacity of beam.

For the composite beams, the same phases were observed including some observed differences. The cracking were appeared at the extreme fiber of compression as a consequence to the redistribution of stresses that originally resulted from the strengthening in the tension zone.

For all specimens, the point of inflection between Phase I and Phase II is also obvious and P_s is also clear irrespective of the number of connectors.

Table 4. Δ_s and Δ_m of composite geopolymer RC beams with big transvers web opening.

Specimen Designation	Δ_s (mm)	Δ_s %	Δ_m (mm)	Δ_m%
Reference	9.53	/	16.65	/
OB6	11.09	16.37	15.81	-5.05
OB12	9.18	-3.67	14.87	-10.69
OB18	8.05	-15.53	14.25	-14.41

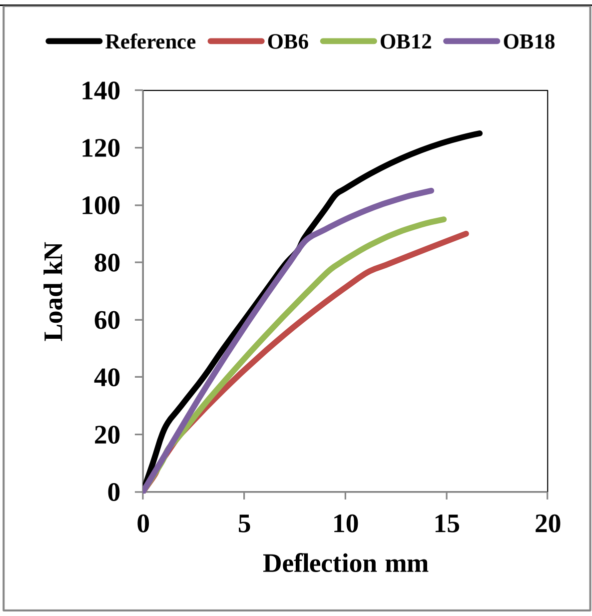


Fig. 8. Load deflection diagram of composite geopolymer RC beams.

4.3 Stiffness Ratio (k)

Throughout the present study, the stiffness behavior of composite geopolymer RC beams is characterized by the stiffness ratio (k):

$$k = \frac{P_s}{\Delta_s} \qquad (1)$$

Where :

k= Stiffness Ratio (kN/mm).

P_s= Service load (kN).

Δ_s= Service deflection (mm).

Table 5. shows the number of connectors effect to k of composite geopolymer RC beam with big transvers web opening.

With the presence of small Increasing the number of connectors from 6 and 12 decreased the relevant k by 36.55% and 22.84% respectively while it increased slightly by 0.25% for 18 connectors. Increasing the number of bolts increased the stiffness of beam. This is usually understood due to the relevant levels of P_s and Δ_s.

Another research efforts should be devoted to understand and quantify the relation between the subtracted concrete volume and the relevant stiffness of composite beams.

Table 5. k for composite geopolymer RC beams with big transverse web opening

Specimen Designation	Δ_s (mm)	P_s (kN)	k kN/mm	k %
Reference	9.53	103.6	10.87	/
OB6	11.09	76.5	6.90	-36.55
OB12	9.18	77	8.39	-22.84
OB18	8.05	87.7	10.89	0.25

4.4 Ductility Factor (d)

During this study, the ductility behavior of composite geopolymer RC beams is characterized by the ductility ratio (d):

$$d = \frac{\Delta_m}{\Delta_s} \qquad (2)$$

Where :

d= Ductility factor.

Δ_m= Maximum deflection (mm).

Δ_s= Service deflection (mm).

The inclusion of big transverse web opening inhibited the d by 18.40% and 7.29% for 6 and 12 connectors while it is increased slightly by 1.32% for 18 connectors. Another research programs should be done to investigate the effect of concrete subtracted volume to the composite ductility.

Table 6. d for composite geopolymer RC beams with big transvers web opening.

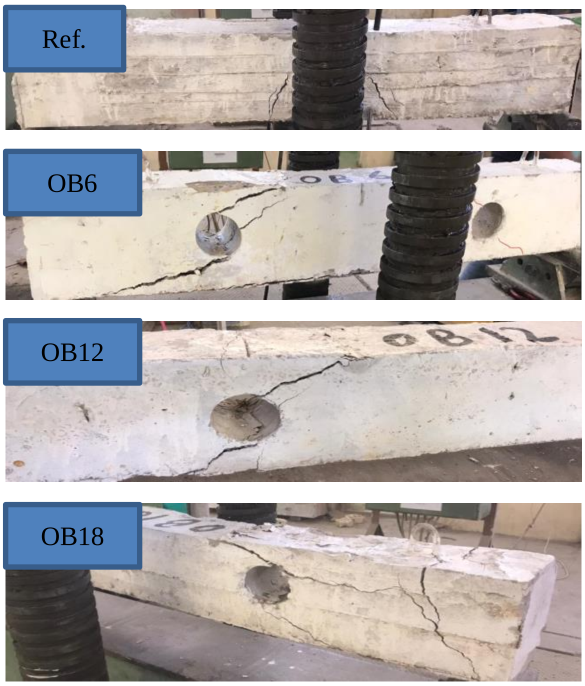
Specimen Designation	Δ_s (mm)	Δ_m (mm)	d	d %
Reference	9.53	16.65	1.75	/
OB6	11.09	15.81	1.43	-18.40
OB12	9.18	14.87	1.62	-7.29
OB18	8.05	14.25	1.77	1.32

4.5 Failure Mode: Visual Observation

Fig. 9. shows the failure mode to the composite geopolymer RC beams with big transvers web opening For OB6 and OB12, the type of failure

is known as (Frame Shear Failure) where the cracks didn't exerted the center line of transverse web opening.

In OB18, the failure occurred outside the transverse web opening and the cracks begin to be appeared from the point load application and the connectors zone simultaneously. This is happened because of the excessive number of connectors and the relative discontinuities between steel and concrete. However, this circumstance didn't break the order of Pcr, Ps and Pu because the of the lateral component of strength of the resulted fragment. Finally, the last view of failure is the pull-out of concrete cover and lateral separation.



5. Conclusions

The following conclusions can be drawn from the current study:

1. Increasing the numbers of connectors improves the subsequent flexural performance of composite reinforced geopolymer beams with transverse web openings.
2. The first cracking load, the service load, the load carrying capacity were increased directly to the number of connectors.
3. The stiffness and ductility factors of composite RC geopolymer beams were increased with increasing of connector numbers according to the levels of service load, service deflection and maximum deflection.
4. The same common three phases of load deflection response of RC beams were observed for composite RC geopolymer beams.

6. Recommendation

1. Additional research is required to explore the extent of correlation between the numbers of shear connectors and the resulting characterization parameters of structural behavior in specific boundary conditions of composite reinforced concrete beams.
2. Further investigation is required to comprehend and measure the association between the quantity of connectors and the resulting stiffness of composite RC geopolymer beams.

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Conflict of interest

The authors assert that there are no conflicts of interest in connection with the publication of this manuscript.

Author Contribution Statement

Authors 1: Proposed the research problem.
Author2: Collected and discussed the literature.

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