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Experimental Study on the Performance of Concrete Beams Including Holes Reinforced with Glass Fiber Polymer

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Abstract. This paper carried out An examination of the performance characteristics of concrete beams including openings that were reinforced with Glass Fiber Reinforced Polymer (GFRP) bars. This investigation studied five reinforced concrete (RC) beams with both longitudinal and transverse GFRP reinforcement with openings in two directions (horizontal and vertical) were studied. Both the orientation of the openings and the number of openings were considered to be the main parameters in this research. These holes are located in the beams' flexural region. The results demonstrate that relative to the reference beam, the vertical openings significantly reduced the maximum load of the tested beams by 27.8% and increased the mid-span displacement by 39% relative to the control beam. In addition, the research results demonstrated that the strength of the beam was scaled down if one equivalent opening was used to substitute for two adjacent openings.

Keywords: GFRP bar, openings, flexure, concrete beams.

1. INTRODUCTION

A significant number of pipes and ducts are required in the construction of modern buildings so that important services, including the water system, electricity, telecommunications, and network devices, can be provided. These pipes and ducts are put on the exterior of a construction member, where they are subjected to the environment. This can lead to a decline in their mechanical integrity [1]. In general, utility pipes make it possible for designers to significantly decrease the needed story level by using the space upon the soffit of beams, which ultimately results in a design with a lower overall height [2]. In recent years, a web of beams and conduits has been utilized to protect these pipes from the damaging effects of inclement weather and enhance structures' appearance. Holes can be made in existing reinforced concrete (RC) beams by disrupting the normal stress distribution, hence decreasing the beam's capacity and stiffness. Service loads can produce great displacement in an RC beam if its stiffness is scarce, leading to a considerable redistribution of internal forces and moments. The ultimate load route (the line connecting the load to the support points) was significantly reduced due to holes. Flexural strengths of transverse web openings in reinforced concrete beams have been studied. However, there is less literature available on vertical openings [3].

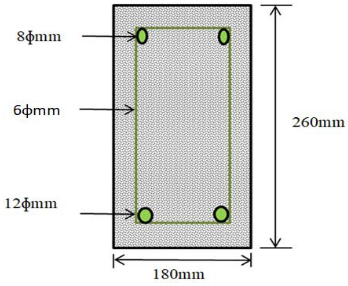
Glass fiber-reinforced polymer is a superior composite material with exciting new applications in the building industry. This material has a higher tensile strength than steel and exhibits a linear stress–strain response up to failure. In addition, the modulus of elasticity of GFRP is substantially less than that of steel [4]. Corrosion of steel reinforcement represents the most restricting issue During the service life of construction materials, and GFRP material's high resistance, high grade-to-weight ratio, magnetic apathy, and simple installation make it a potentially excellent for implementation when standard steel is unable to provide enough performance in reinforced concrete [5,6]. The majority of previous research investigated the performance of RC beams with holes reinforced by standard steel bars, while the others investigated the beams reinforced by FRP bars [7,8, 9-11]. Therefore, this research aims to experimentally examine the effect of openings in the flexure zone of GFRP-reinforced concrete beams.

2. EXPERIMENTAL TEST PROGRAM

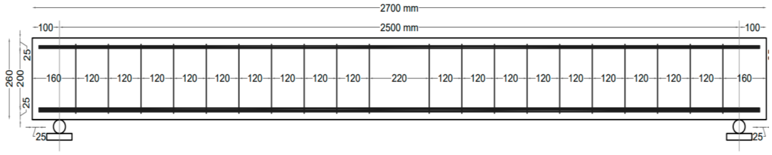
2.1 Description of Tested Beams

This research looks into the flexure behavior of simply supported RC beams with holes in both the vertical and transverse directions. The opening size and opening orientation are the two main variables examined. The experimental program involves testing five specimens to evaluate the behavior of concrete beams with openings reinforced with GFRP bars as bending and shear reinforcement. These beams measure 2700 mm × 180 mm × 260 mm. One of these specimens is devoid of openings and serves as a control (reference) beam. The rest four (4) specimens have openings installed in the flexure zone; two beams have two adjacent openings fabricated from a PVC pipe with a 63mm diameter; the openings in the first beam are installed vertically in the mid-width, while the openings in the second beam are installed horizontally in the flexure compression zone. The remaining two beams in this set are similar to previous beams with the exception of a single 89mm-diameter PVC pipe opening that is approximately equal to the two-opening size of the previous beams. All beams have the same inner GFRP reinforcing. The longitudinal flexural tensile reinforcement consists of deformed (2ø12 mm) GFRP bars, while the longitudinal compression reinforcement consists of deformed (2 ø8 mm) GFRP bars. At the same time, the design of the vertical reinforcement (stirrups) is (6@120 mm). Figure 1 shows the typical GFRP reinforcement for specimens tested.

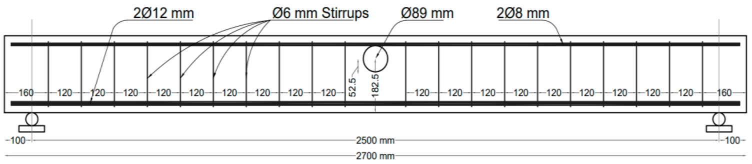
The orientation of the holes (both horizontally and vertically) and the number of holes are the main parameters examined in the research. These openings are placed within the flexure region of the beams. The described beams that were tested may be seen in Figure 1 and Table 1.



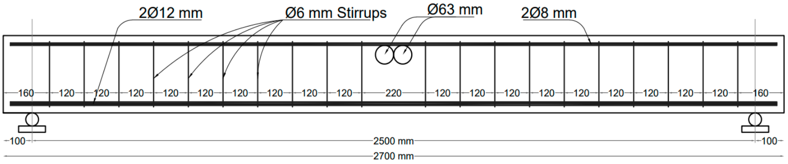
(Beam Cross section)



(GB)



(GB-FO-H1)



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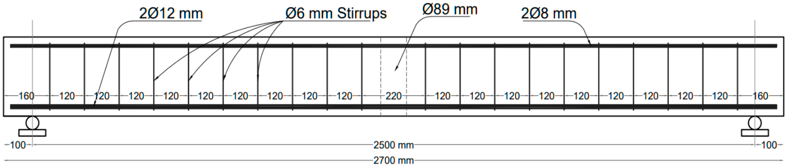
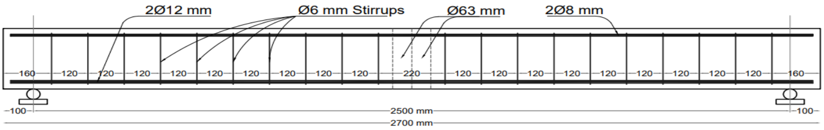


(GB-FO-V1)



(GB-FO-V2)

Figure 1. Schemes of the tested beams

Table 1: Description of the tested beams.

Beam designation	Number of openings	Diameter of openings(mm)	openings direction
GB (control)	NA	-	-
GB-FO-H1	1	89	horizontal
GB-FO-H2	2	63	horizontal
GB-FO-V1	1	89	vertical
GB-FO-V2	2	63	Vertical

2.2 Material Properties and Prepare Casting

The materials' characteristics in this investigation were determined by experimentation. To guarantee that the compressive strength of each beam was equal, they were all cast at the same time and subjected to the same curing conditions. At 28 days, concrete had an average compressive strength of 36 MPa, as measured by the cube test. Deformed GFRP bars of 12 mm diameter were subjected to a direct tensile test. The tensile strength was 1380 MPa. Five plywood molds were prepared to accommodate the reinforcement cages, and strain gauges were submitted on flexure reinforcement at mid-span. The opening was created using PVC pipe inserted in the beam before casting. Figure 2 displays the mold's outside look with the reinforcing cage still inside at the moment of casting.

Figure 2: Reinforcing and casting of the tested beams.

2.3 Test Setup

Hydraulic testing equipment with a capacity of 600 kN was utilized in order to apply two-point loads to each beam until the beams collapsed. The specimens were placed on a roller at one end, and at the other, they were placed on a hinge. It was possible to achieve a simply supported length of 2500 mm by positioning the supports 100 mm from either end of the beam. The shear length was 833 mm, and the distance between loads was also 833 mm. In order to impart the load on the beam that was being inspected, a spreader steel beam was installed. To prevent the local crushing of concrete at supports and loading points, bearing plates with the dimensions 100 mm on the long side and 75 mm on the short side and a thickness of 12 mm were employed. During the test, LVDTs were utilized at the mid-span section and were maintained in a vertical position. This allowed for the measurement of the deflection of the beams that were being tested. The rise in load was 5 kN.

The records of crack growth on the concrete beams were marked with a thick felt pen to make it easier to position and identify cracks during and after the test. Figure 3 presents the configuration setup for a beam test.

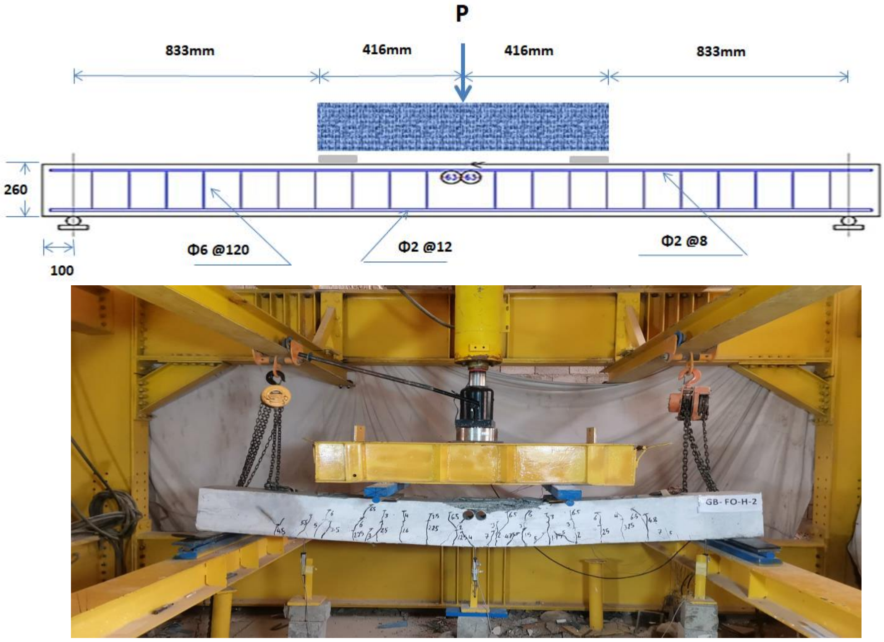


Figure 3: Beam setup for test.

3. RESULTS AND DISCUSSION

Flexure cracks were noticed in all beams of tested beams and were observed at the soffit of tested beams. During the crack development phase, it was noted that cracks occur at random sites and are typically vertical, beginning in the middle zone of tested beams and spreading towards supports covering the entire flexural region. These cracks grew and propagated upwards over the test until failure happened. The cracks and manner of failure of the examined beams are illustrated in Figure 4. Table 2 displayed a summary of the tested beams' load-carrying capacity, deflections, and the mode of failure for examined beams.

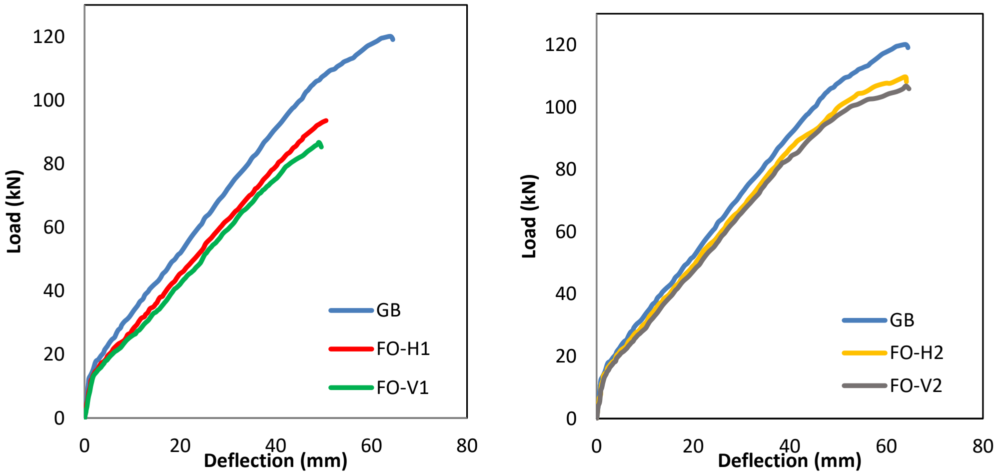
Figure 4: Mode of failure for the tested beams.

Table 2: An overview of the experimental result and the tested beams' failure mode.

Specimen designation	Ultimate load	Max. deflection (mm)	Decreasing in ultimate load (%)	Mode of failure
GB	120.12	63.9	----	Flexural compression
GB-FO-H1	93.6	50.5	22	Flexural compression
GB-FO-H2	109.7	63.5	8.6	Flexural compression
GB-FO-V1	86.7	48.9	27.8	Flexural compression
GB-FO-V2	106.7	63	11.17	Flexural compression

3.1 Opening Direction Effect on The Load- Deflection Response

Generally, the placement of holes within beams causes a decline in ultimate load and an increase in mid-span deflection. The effect of the opening direction on the load-deflection curves of the tested beams is seen in Figure 5. These diagrams show that compared to the reference beam (GB), the vertical openings cause a greater reduction in ultimate strength and a rise in mid-span displacement. This is due to the vertical opening greatly reducing the concrete at the critical region. For beams with a single opening relative to the reference beam, the percentage reduction in ultimate strength for vertical and horizontal openings was approximately 27.8 and 22%, respectively, as displayed in Figure 5a. In contrast, for beams with double openings in Figure (5-b), the proportion decrease in ultimate load was around 11% for vertical openings and 8.6% for horizontal openings relative to the control beam. Furthermore, for a specific load (the maximum load of a beam has a vertical opening), switching the opening's direction from horizontal to vertical causes the mid-span deflection to rise to around 32% and 39% for beams with a single opening, respectively. However, when comparing beams with two openings to the control beam, these percentages were approximately 18% and 30%, respectively, as shown in Figure 5b.



(a) Single opening (b) Double opening

Figure 5: Load-mid-span deflection response for tested beams (effect of opening orientation).

3.2 Effect of Number of Openings on Load-Deflection Response

Load-deflection diagrams for investigated tested beams are displayed in Figure 6 below, where the effect of opening number (1 or 2) is indicated. Single opening has a greater influence than two openings on decreasing ultimate strength and steadily rising mid-span deflection relative to the reference beam. This can be because a single aperture, as opposed to two adjacent apertures, can have a more substantial effect on the amount of concrete removed from the critical section. The percentage reduction in ultimate load for beams with one and two horizontal openings was 22% and 8.6%, respectively, as shown in Figure (6-a). In contrast, for beams with vertical apertures in Figure (6b), the proportion decline in ultimate load was around 27.8% for one opening and 11.1% for two openings relative to the reference beam. Conversely, at a certain load value (considered the maximum load of a beam with a single opening), increasing the openings from single to double increases the mid-span deflection by 32% and 21%, respectively, for beams with horizontal holes (Figure 6). (6a). Whereas these percentages increased to around 45% and 25% for beams with vertical holes in Figure (6b) relative to the control beam.

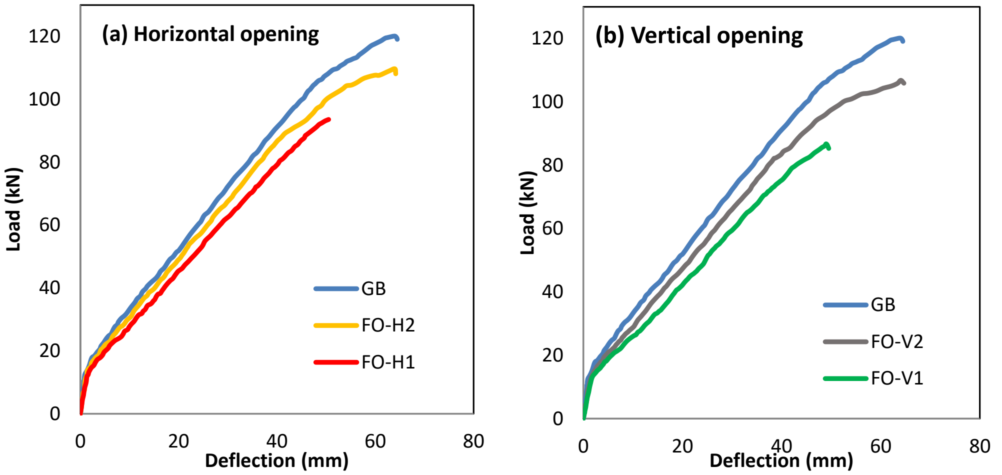


Figure 6: Load-deflection response for tested beams (effect of openings number).

3.3 Opening Direction Effect on The Load- GFRP Strain Response

The opening direction installed within the examined beams had the main influence on the load strain for longitudinal flexural GFRP bars in the tested beams, as shown in Figure 7. In general, the installation of openings within beams steadily raises the strain on the GFRP main bars. This graph demonstrates that vertical openings have a more significant influence than web openings on raising the GFRP strain relative to the reference beam. This can be due to the vertical opening significantly reducing the concrete at the critical region, which resulted in rising the longitudinal GFRP bars strain. Furthermore, for a specific load (the maximum load of a beam with vertical holes), When the opening is turned from horizontal to vertical, the GFRP strain increases by about 20.7% and 34.85%, respectively, for beams with a single opening, Figure 7a. However, when comparing beams with two openings to the control beam, these percentages were approximately 11.5% and 19.6%, respectively, as shown in Figure 7b.

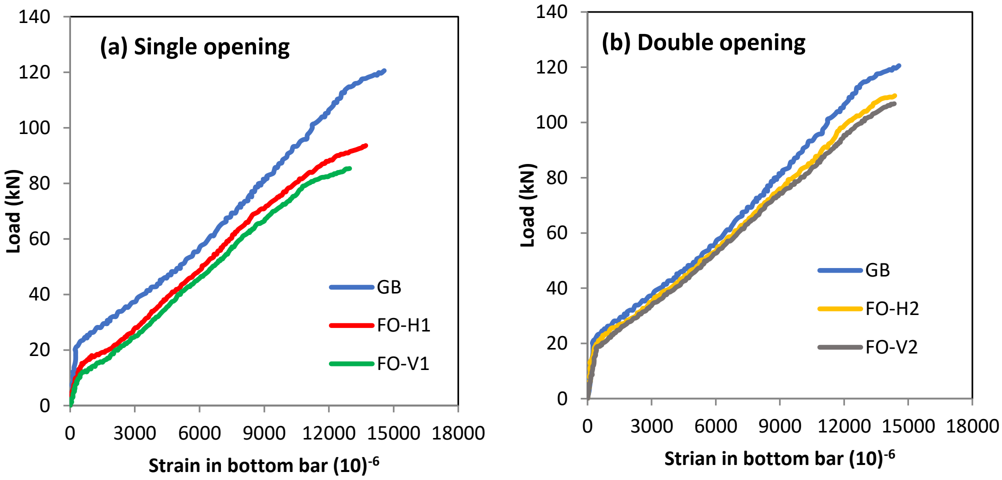


Figure 7: Load- flexure GFRP reinforcement strain for the tested beams (effect of opening direction).

3.4 Effect of Number of Openings on Load- GFRP Strain Response

Figure 8 illustrates how the number of openings within the beams affects the load-strain in the flexure GFRP reinforcement for the tested beams. Generally, a reduction in the number of holes within beams increases the strain on the GFRP main reinforcement. This diagram demonstrates that increasing the number of apertures in the GFRP beam relative to the control beam causes one opening to have a more significant effect than two. Compared to the control beam, the GFRP bottom bar strain percentages increased by approximately 30 % for beams with single openings and 9.3% for beams with double openings in Figure 8a. Figure 8b shows that the strain in the bottom bar increased by 34.85% for a beam with a single vertical opening, and by 13.1% for a beam with two vertical openings compared to the control beam.

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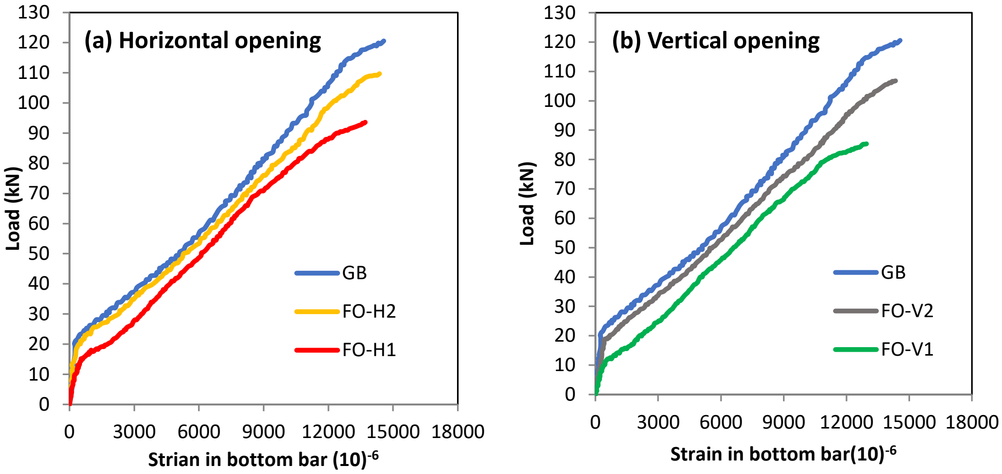

Figure 8: Load- strain of bottom GFRP reinforcement for the tested beams (effect of openings number).

The results in terms of ultimate load and ultimate deflection are summarized in Table 3.

Table 3: Illustrated ultimate load and strain in GFRP flexural reinforcement for the tested beams.

Specimen designation	Number of openings within beam	Opening diameter (mm)	Direction of openings	Ultimate load (kN)	Ultimate strain bar $(10)^{-6}$
GB	NA	-	-	120.12	14565
GB-FO-H1	1	89	horizontal	93.6	13708
GB-FO-H2	2	63	horizontal	109.7	14369
GB-FO-V1	1	89	vertical	86.7	12959
GB-FO-V2	2	63	vertical	106.7	14364

4. CONCLUSIONS

This research examined the effect of installed openings with different numbers and sizes in both directions (vertical and horizontal) on concrete beams reinforced with GFRP reinforcement. The principal conclusion is as follows:

- Openings within RC beams significantly affect the overall performance by reducing the ultimate strength, raising the mid-span displacement, and reinforcing strain.
- The research demonstrated that a single opening is more effective than two adjacent openings of the same size and position in decreasing the carrying capacity of beams.
- The highest reduction in ultimate load for beams with GFRP reinforcement with openings in the flexure zone was around 27.8% for the specimen with single vertical openings compared to the specimen without an opening (control beam).
- The highest increase in deflection for the specimen with a single opening with vertical orientation in the flexural region was around 39% at the identical ultimate load.
- Under the same load level, the highest rise in tension GFRP reinforcement strain was around 34.85% for the specimen with a single opening with a vertical direction in the flexural region.

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