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Effect of Size of Holes on Flexural Response of Strengthened Concrete Beams with CFRP Rope

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Abstract. The electro-mechanical pipe systems that run through longitudinal or transverse holes in the secondary reinforced concrete (RC) beams can enhance the maximum floor height of the building. In this work, the effect of longitudinal hole size on the flexural behavior of RC beams has been studied experimentally. Furthermore, studies were conducted to determine whether carbon fiber reinforced polymer (CFRP) may enhance the flexural response of hollow-sectioned reinforced concrete (RC) beams. The ultimate load and related deflections were reduced by the holes, regardless of their size. Regardless of the size of the hole and the CFRP arrangement, the application of CFRP increased the ultimate loads and cracking loads of beams by a maximum of 22% and 14%, respectively. Every tested solid beam exhibited flexural shear behavior. In the end, using CFRP rope for strengthening led to a 22% increase in energy dissipation; however, as the hole's size increased, this increases reduced.

Keywords: Holes, CFRP rope, ultimate load, cracking load, energy dissipation, ductility, stiffness

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INTRODUCTION

The weight of the structure is essential since the cost of the building is crucial. The use of hollow beams to reduce building costs, construction costs, and the environmental impact of using concrete is one of the key recommendations made by numerous studies. To prevent lowering the floor height, mechanical and electrical equipment might be placed inside the beams. [1, 2]. Using hollow reinforced concrete (RC) beams is one method to do this. The use of hollow reinforced concrete beams to lower the dead load of RC beams has been the subject of numerous studies [3-7]. It is achievable to increase serviceability, decrease building costs, and decrease self-weight [8]. In addition to the loss resulting from the beam's hollow portion, the previously mentioned problem may considerably reduce the structural performance of hollow reinforced concrete beams. Near-surface-mounted (NSM) CFRP ropes have been employed as one of the repair methods due to its advantages, which include easy installation, high tensile strength, and corrosion resistance [9-10].

Ismael and Hameed [3] examined five beams with various longitudinal hollow-core sizes made from recycled plastic tubing and one solid slab to study the structural effectiveness of hollow-core reinforced self-compacting concrete beams. The conclusion is that self-compacting concrete beams have lower concrete by percentages ranging from 5.4 to 14.2, lower ultimate strength by 2.3 to 10.5%, and lower first crack load by 9.1 to 22.7%. Pareed et al. [4]

examined the flexural behavior of RC beams while accounting for the depth and shape of the cores. The results showed that as the hollow core gets deeper, the ultimate load decreases.

Elamary et al. [11] conducted experiments on four hollow reinforced concrete beams, including one solid beam, in order to study the flexural behavior of these beams. The maximum load of the beam was decreased by 5% upon the addition of 10% longitudinal hollow. The longitudinal hollow's width reduces the ultimate beam load capacity by more than 15% when it surpasses 50% of the beam width.

Sirisonthi et al. [12] investigated the effectiveness of CFRP in enhancing the flexural response of RC beams with hollow sections. Regardless of the hole's size or CFRP configuration, the adoption of CFRP raised the beams' ultimate loads. However, this improvement was limited to debonding and CFRP rupture. Al-Huthaifi et al. [13] numerically investigated the effectiveness of many strengthening methods utilizing near-surface mounted carbon fiber reinforced polymer (NSM-CFRP). The results showed that around the neutral axis with the least amount of stiffness and strength reduction was the ideal place for unstrengthened RC beams with a large hole.

The findings of earlier research published in the literature suggest that a number of variables, including the size and placement of holes related to the neutral axis, the location of the CFRP rope in relation to the holes, and newly flexible CFRP rope, have not yet been fully examined. Therefore, the main objective of this work was to determine how the opening hole's diameters influenced the structural behavior of hollow section RC beams. The aim of this study is to learn more about how to strengthen rectangular hollow beams using CFRP rope material in order to improve their flexural strengths. CFRP rope is applied to the beams in various configurations so that the flexural capacities of hollow beams can be compared and the best design may be selected. To achieve the objectives of the study, five RC hollow section beams were built and tested utilizing a four-point bending approach.

EXPERIMENTAL PROGRAM

Beams Description

Five hollow sections of RC RC beams were constructed specifically for this study. Every RC beam is the same size, measuring 1200 mm in length, 300 mm in depth, and 200 mm in length. They also all have the same reinforcement. All RC beams were intended to fail through the ductile flexural mode. The solid/hollow beam strengthening characteristics are shown in Figure 1. The circular hole was created using PVC (plastic) pipes. Every examined specimen's features are shown in Figure 1.

The specimen identification (e.g., B-R2BE-h75 refers to the beam, fixing with two CFRP rope at the bottom edges of hole with diameter of 75 mm) relates to the beam, strengthening, number of CFRP rope, placement of CFRP ropes, size of hole, and location of hole. Conversely, the specimen B-R2BC60-h75 indicates that the beam is strengthened with two CFRP ropes spaced 60 mm apart in the middle of the beam. The positions of the holes and details about each examined specimen are shown in Figure 2. After that, the beams were kept moist for 28 days in preparation for testing.

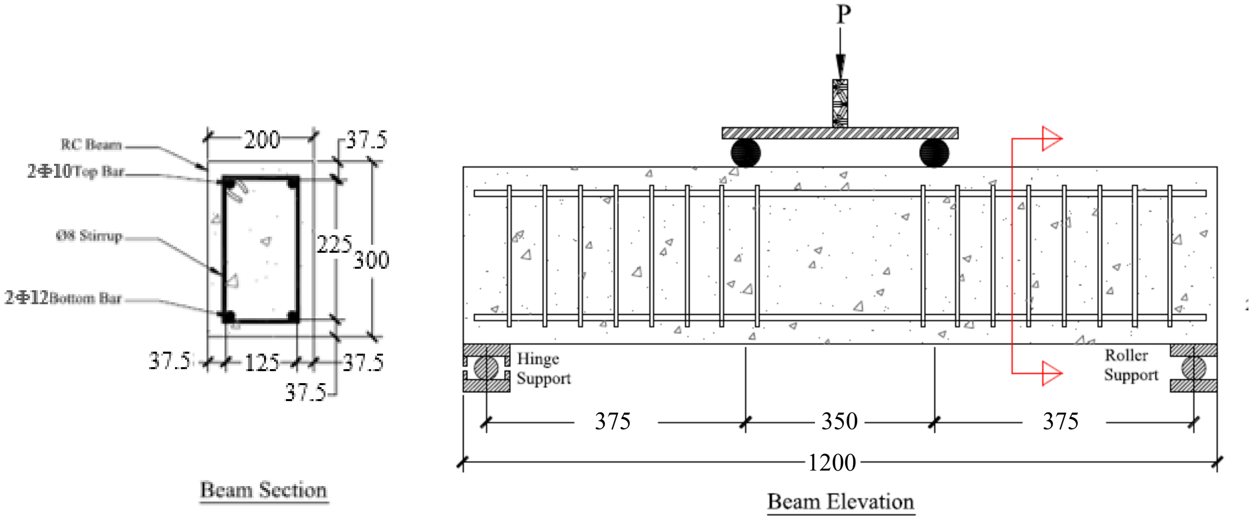


FIGURE 1. Reinforcement details and cross-section dimensions of tested beam.

Materials Properties

This work used ready-mix concrete to cast the specimens at a compressive strength of 20 MPa at 28 days. The mixture used in all five of the RC beams was the same. This ensured that each specimen has the same strength and mechanical properties and confirmed that the mixture would be prepared under quality-controlled process. The longitudinal steel bars had fy = 420 MPa and fu = 570 MPa, which correspond to ASTM-615 M Grade 60. The top and bottom reinforcements had diameters of 10 mm and 12 mm, respectively. The mild steel Grade 40 stirrup reinforcements had an 8 mm diameter (fy = 270 MPa and fu = 420 MPa).

Unidirectional NSM-CFRP rope from SIKA was used for strengthening the RC specimens (see to Figure 4). Using the Sikadur®-330 and Sikadur®-52 adhesives, the rope was fixed to the concrete surface and the groove was filled. Sikadur® 52 LP adhesive is composed up of two parts: hardener (part B) and resin (part A), mixed two to one. CFRP ropes, however, are bonded with Sikadur® 330 LP. Two chemicals, hardener (part B) and resin (part A), are combined in a 4:1 weight ratio to create it. In Figure 3, we see the CFRP-Rope.

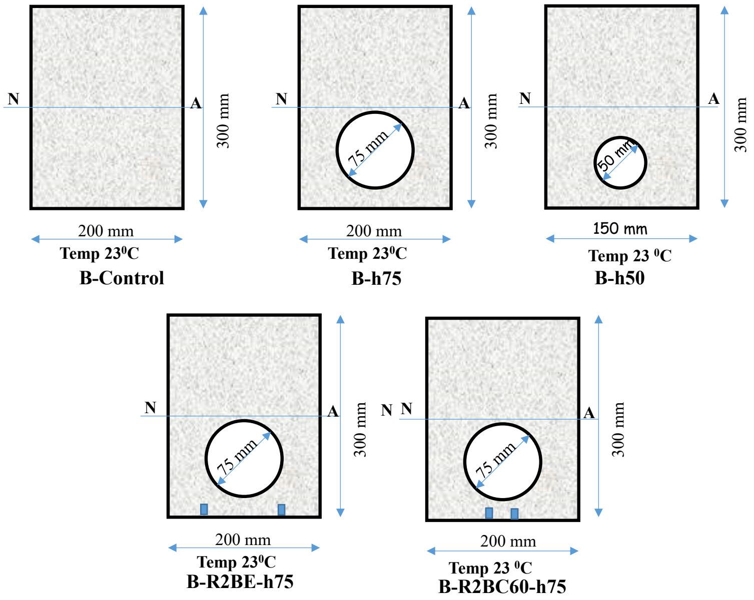


FIGURE 2. Cross-section details of all tested RC beams

FIGURE 3. CFRP-Rope

Concrete Casting and Curing

The steel cages and PVC pipes have been placed within the molds, as shown in Figure 4. The concrete mix was poured into the wooden molds in three layers, and an electrical vibrator was used to enhance compaction and avoid honeycombing. The upper faces of the beams have been polished. There was a 28-day curing period for the beams.

FIGURE 4. Preparation process of the beams.

Installation CFRP ropes in RC beams

The following is the procedure for installing Sika Wrap-FX 50 C ropes in an RC beam:

1. The Sika Wrap-FX 50 C installation was completed after the RC beam surface was thoroughly dried.
2. In accordance with the arrangements, a groove of 10 mm in width and 25 mm in depth was created along the RC beam. Dust and other impurities needed to be removed from the grooved beam once again.
3. The saturated mixture was made by combining the components of Simadur-52.
4. After measuring and cutting the required length of Sika Wrap-FX 50 C, it was time to soak it with the previously prepared saturating mixture.
5. The Sikadur-330 was put into the indentation.
6. The ropes for the Sika Wrap-FX have been put into the grooves. It was then covered with the Sikadur-330 mixture and smoothed over.

Testing Program

Utilizing the universal testing apparatus (Figure 5) that may be found in the structural laboratory of the University of Jordan. Two-point flexural loads were applied to each test specimen until they failed. The flexural load has been steadily increased over time with the load control tool. Two linear variable displacement transducers were utilized to record the deformation (LVDT). The specimens' center is where the LVDTs are located. There was 400 mm between each point load and 100 mm between the supports and the beam edges.

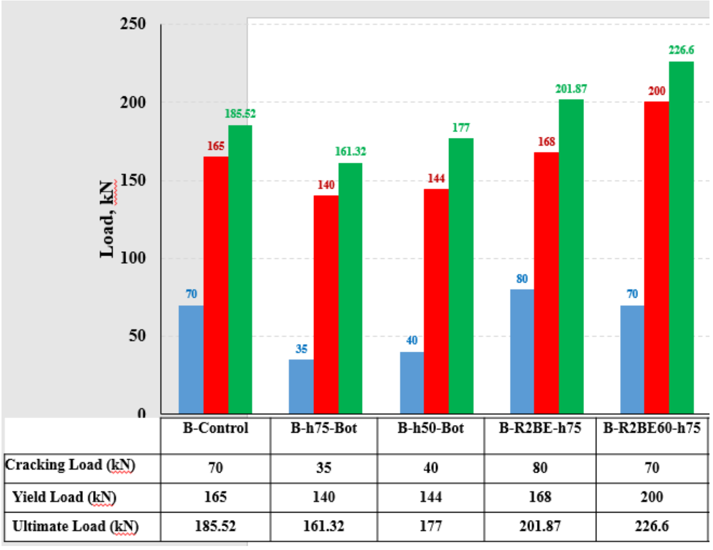
FIGURE 5. Two-Point load test setup

RESULTS AND DISCUSSION

The flexural behavior of the examined specimens was assessed in terms of ultimate axial load, axial deflection, ultimate secant stiffness (Ku), and ductility using the load-deflection curves. The basic trend of the load-deflection curve was evident in every specimen. A typical axial load-deflection curve was taken into consideration in order to establish the final load on the beams. This caused the loading to suddenly decrease, the laden member's ability to transfer flexural stresses to be lost, and the beam to deteriorate and disintegrate. Table 1 provides a summary of the key features of the experimental load-deflection curve for the test specimens. Energy dissipation is computed as the area under the actual load-deflection curve up to the ultimate load. The ratio of the ultimate load (Fu) to the corresponding flexural deflection (Δu) represents the ultimate secant stiffness (Ku). The ductility ratio is defined as the ratio of the flexural deflection at maximum load (Δy) to the maximum flexural deflection at failure (Δmax). The ultimate load capacity, yield, and cracking for every examined specimen beam are displayed in Figure 6.

TABLE 1. Experimental results of tested specimens

Specimen name	Load capacity (kN)	Cracking Load (kN)	Maximum deflection at failure(mm)	Stiffness (kN/mm)	deflection at maximum load (mm)	Ductility ratio	Energy dissipation (kN.mm)
B-Control	185.52	70	20	24.75	9	2.22	1853.90
B-h75	161.32	35	14.3	22.58	8.3	1.72	1152.94
B-h50	177	40	16	25.61	9	1.77	1416.50
B-R2BE-h75	201.87	80	17	23.99	10.1	1.68	1734.21
B-R2BE60-h75	209	60	18	27.5	10	1.80	1881.11



	B-Control	B-h75-Bot	B-h50-Bot	B-R2BE-h75	B-R2BE60-h75
Cracking Load (kN)	70	35	40	80	70
Yield Load (kN)	165	140	144	168	200
Ultimate Load (kN)	185.52	161.32	177	201.87	226.6

FIGURE 6. Comparison of Experimental loads of all beams

Effect of Hole Size on the Flexural Behavior of Hollow RC Beams

As shown in Figures 6 and 7, the specimens (B-Control-B-h50 and B-h75) with 50 mm and 75 mm holes in RC hollow sections had demonstrated load capabilities of 185.52 kN, 177 kN, and 161.32 kN. Specimens B-h50-Bot and B-h75-Bot had lower load capacities than the control beam, by 4.06%, 13.04%, and 33.69%, respectively. This suggests that the load capacity of the hollow RC beam reduced as the hole size rose. This decrease may be explained by how the hole size affects the hole approach to the compression zone and the moment of inertia.

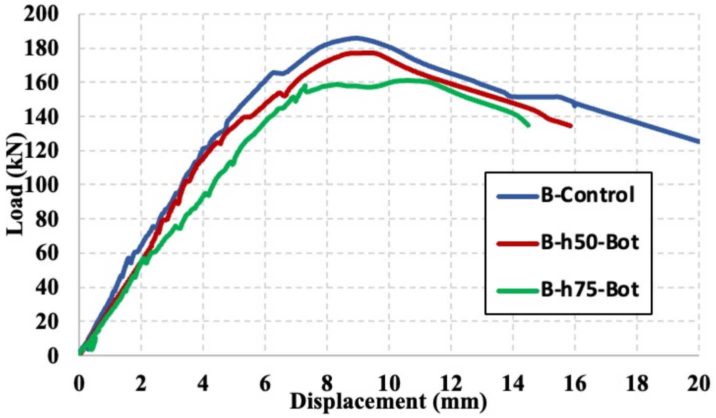


FIGURE 7. Load-deflection curve for specimens with different hole sizes

Effect of CFRP Ropes Configuration on Flexural Behavior of Hollow RC Beams

Figure 8 displays the load-deflection curves for the specimens strengthened with a varying configuration of CFRP rope (B-R2BE60-h75, B-R2BE-h75, and B-h75-Bot). As shown in Table 1 and Figures 6 and 7, the load capacity increased by 30.61% when the RC beam was strengthened with two CFRP ropes spaced 60 mm apart along the hole B-R2BE60-h75. In contrast, the load capacity increased by 26.14% when the beam was strengthened with two CFRP ropes at its bottom along the edges of the hole B-R2BE-h75-Bot, as compared to the control specimen B-h75-Bot. CFRP ropes were put into the beams to reinforce them, and because of their high tensile strength and elastic modulus, the beams' load capacity has improved. According to the experimental findings, the CFRP ropes have improved the secant stiffness, and ductility for RC beams. In comparison to the control specimen B-h75-Bot.

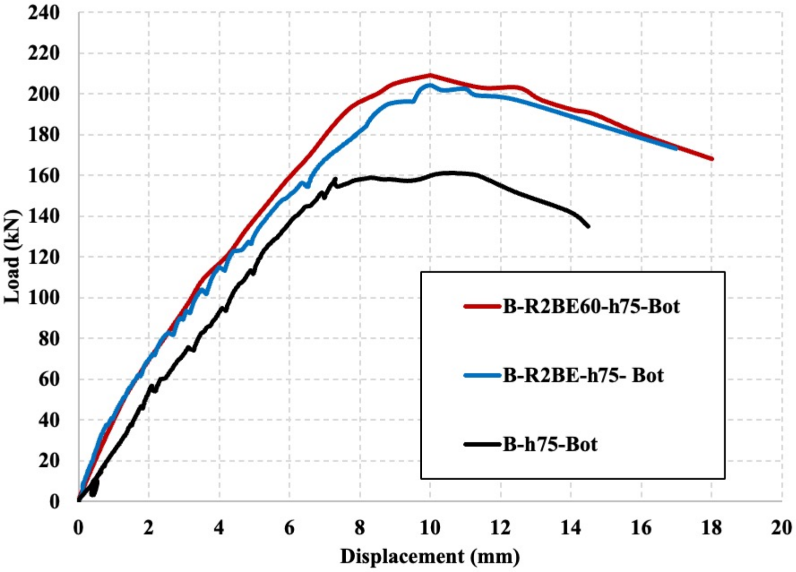


FIGURE 8. Load-deflection curve for specimens with different CFRP ropes configuration

Effect CFRP Ropes on Flexural Behavior of Hollow RC with 110 mm Diameter

The load capacity of the hollow RC beam with a 110 mm hole diameter (B-h110-Bot) and the hollow RC beam with a 110 mm hole diameter that is strengthened with two CFRP ropes at the bottom of the beam along the hole edges (B-R2BE-h110-Bot) decreased by 14.9% and 38.8%, respectively, in comparison to the control RC beam (B-Control) as shown in Figure 9. In comparison to the control beam (B-Control), the deflection at maximum load capacity has dropped for B-h110-Bot by 11.1% and for B-R2BE-h110-Bot by 16.7%. Based on the experimental findings, it was determined that the B-h110-Bot specimen's secant stiffness reduced by 17.93%. This decrease was attributed to the beam's hole causing a decrease in moment of inertia. In contrast, B-R2BE-h110-Bot specimen's secant stiffness decreased by 31.55% as compared to the control beam B-control. In comparison to B-control, specimen B-h110-Bot and specimen B-R2BE-h110-Bot showed a 25.3% and 27.84%, respectively, increase in ductility ratio.

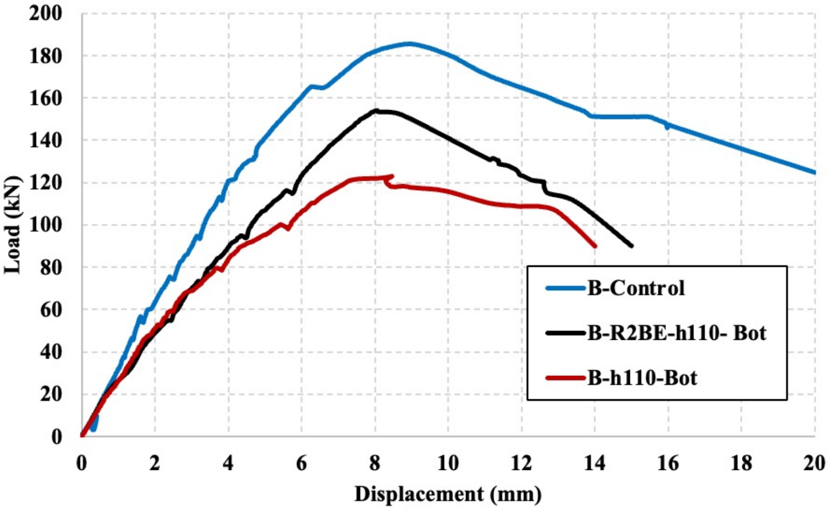


FIGURE 9. Load-deflection curve of specimens with hole size of 110 mm

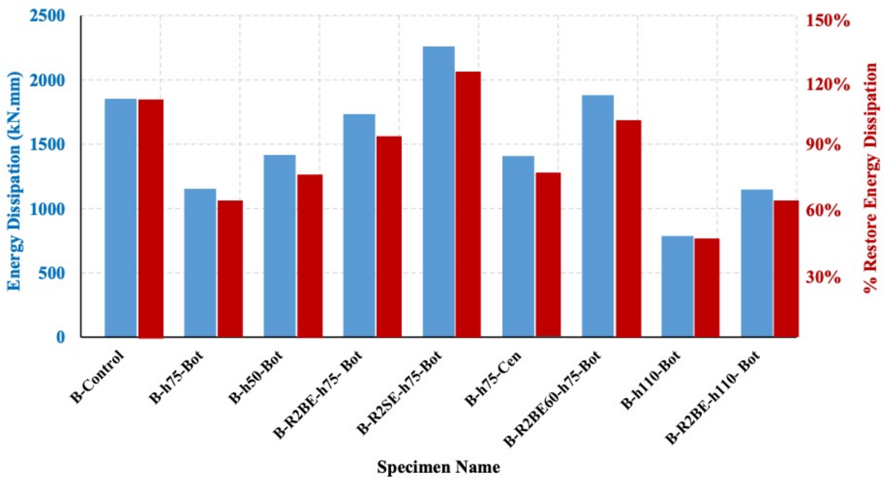


FIGURE 10. Changes on the energy dissipation according to the specimens

CONCLUSIONS

Five beams in all, divided into three groups based on the size of the holes as well as the presence or absence of CFRP ropes, were examined. Studying the benefits of the CFRP rope and how hole and size affect RC beam flexural response were the objectives. The primary findings and conclusions of this study are summed up as follows:

1. The energy dissipation decreased as the hole size increased. However, using the CFRP rope increased the energy dissipation about 50%-96% as of hollow beam.
2. Using CFRP rope to enhance the flexure behavior of beam
3. The highest values of load capacity, stiffness, modulus of elasticity, deflection, ductility ratio, and energy dissipation were obtained by strengthening hollow RC beams with two CFRP ropes at the center of the beam with 60 mm spacing, according to the experimental results.

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