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Finite element analysis of reinforced concrete beams with opening strengthened using FRP

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Abstract Transverse openings are often provided through reinforced concrete beams to accommodate utility ducts and pipes. Finite element analysis has been used in order to study this problem. Fifty-seven beams analyzed using finite element program ANSYS V12. The analysis results compared with fifteen experimental beams had been done by Ibrahim. Study beams have opening width and height of dimensions 200 × 100 mm and 300 × 100 mm. The centerline of the opening is at distance of 225, 300, 350 and 400 mm from the near support. Strengthening of all beams with opening came out to six types of different scheme around the opening using fiber-reinforced polymer (FRP). Scheme (1) is vertical and horizontal carbon fiber sheets around the opening, scheme (2) is inclined at 45° carbon fiber sheets around the opening in addition to horizontal one, schemes (3) and (4) are same of schemes (1) and (2) respectively but with glass fiber sheets, while schemes (5) and (6) are same as schemes (3) and (4) respectively but with an additional strengthening at flexural area at the middle of the beam with U shape. The reinforced concrete beams were modeled in 'ANSYS V12' Program under statical load. The failure loads, crack pattern, strain progress, mode of failure and energy absorption were analyzed here in this study.

1. Introduction

Web openings in beams have important applications in practice as they provide convenient passages of electrical and mechanical conduits. Fiber-reinforced polymer (FRP) is currently emerging as a popular option to repair and strengthen reinforced concrete structures. This strengthening technique was usually used for concrete flexural members, and it is generally desirable that bending rather than shear governs the ultimate strength. However shear deficiencies do often exist and in such cases there is a need for strengthening and retrofitting for increased shear capacities. In these situations, the external bonding of FRP stirrups is considered a promising method to increase the shear capacity.

The presence of a rectangular opening leads to a decrease in both cracking and ultimate strengths as well as stiffness of RC beams. The amount of reduction is significantly affected by opening proximity to support, opening height, and opening

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length, but is slightly affected by tension and compression reinforcement ratios [1]. In fact, the importance of this parameters has emerged from the relation established the required strengthening scheme of FRP laminates and the type of strengthening CFRP or GFRP [2]. The opening in the shear zone of the reinforced concrete beams significantly reduces the loading capacity of the beam [3]. The presence of openings near the compression zone can significantly influence the ultimate capacity and deflections of the beams as the size of the opening becomes larger, the ultimate capacity of the beam is significantly reduced, and the modes of failure of the tested beams with openings were predominantly shear related cracks initiated around the opening and propagated through the compression zone. The repaired beams exhibited a much softer response and attained a lower ultimate load compared to the original beams.

Wrapping the compression zone of the beam provided good confinement for the compression block [4]. Extending the vertical layers over the entire span of the beam reduces the diagonal cracks so that the longitudinal fibers are fully used and the load carrying capacity of the beams is significantly increased. The use of CFRP plates on the bottom and sides of the beam improves the response in comparison with using CFRP plates only at the bottom of the beam [5]. The optimum amount of FRP laminates, which provides maximum strengthening effect, must be established for each FRP system, depending on its thickness and mechanical properties [6]. On this study various strengthening schemes are used around the opening. This investigation includes both experimental program and a corresponding numerical analysis.

2. Program of study

2.1. Specimen design and materials

The numerical analysis was carried out on fifty-seven reinforced concrete beams of 1800 mm span, nine of these beams are control beams, one of them is without any opening, four beams are with opening dimensions $a \times h$ equal 200×100 mm created at distances 225, 300, 350 and 400 mm from centerline of the opening to the edge support and the last four control beams are with opening 300×100 mm created at 225, 300, 350 and 400 mm also. Another forty-eight reinforced concrete beams strengthened around the opening using carbon and glass FRP, these beams are divided into six groups according to the type of strengthening scheme, and each group contains eight beams similar to those beams which are in control beams. The ultimate compressive strength of concrete was 25 N/mm^2. The samples codes are illustrated in Table 1, while the applied load and beam dimensions and reinforcement indicated in Fig. 1.

The experimental beams done by Ibrahim [2] took into consideration the effect of uniform distributed load; thus, in the numerical analysis program, the applied load was represented by eight equidistant concentrated loads exactly as in the experiments.

2.2. Strengthening scheme

Strengthening scheme (1) is one layer horizontal and vertical carbon fiber sheets around the opening, strengthening scheme (2) is inclined at 45° carbon fiber sheets around the opening in addition to horizontal one, and strengthening schemes (3) and (4) are same of schemes (1) and (2) respectively but with glass fiber sheets, while schemes (5) and (6) are same as schemes (3) and (4) respectively but with an additional strengthening at flexural area at the middle of the beam with U shape. Carbon laminate thickness is 0.12 mm while glass laminate thickness is 0.23 mm. Before bonding the composite material to the concrete surface, special care was given to the surface preparation, sandblasting was used to roughen the concrete surface until the aggregate was exposed, and this was followed by compressed air cleaning to remove dust and loose particles. Once the surface was prepared to the required standard, the epoxy resin was mixed in accordance with the manufacturer's instructions. The epoxy resin was set to the concrete surface. Then the FRP laminate was placed against epoxy. The details of scheme types are illustrated in Fig. 2.

3. Numerical analysis

A three dimensional finite-element program 'ANSYS' was used for the numerical analysis of the fifty-seven beams. In the analysis, appropriate material models were employed to

Table 1 Sample codes of all specimens.

Control beams	Without opening	**B1**							
	With opening	Opening dimensions							
		$a \times h = 200 \times 100$ mm				$a \times h = 300 \times 100$ mm			
	S (mm)	225	300	350	400	225	300	350	400
	Without strengthening	**B2**	B3	B4	B5	B6	B7	B8	B9
One layer carbon FRP	Scheme (1)	**BC1**	BC2	**BC3**	BC4	BC9	BC10	BC11	BC12
	Scheme (2)	**BC5**	BC6	**BC7**	BC8	BC13	BC14	BC15	BC16
One layer glass FRP	Scheme (3)	**BG1**	BG2	**BG3**	BG4	BG5	BG6	BG7	BG8
	Scheme (4)	**BG9**	BG10	**BG11**	BG12	BG13	BG14	BG15	BG16
Two layers glass FRP	Scheme (5)	**BG17**	BG18	**BG19**	BG20	BG21	BG22	BG23	BG24
	Scheme (6)	**BG25**	BG26	**BG27**	BG28	BG29	BG30	BG31	BG32

Bold samples carried out experimentally.
a: length of the opening, *h*: height of the opening, BG: beam strengthening with glass FRP, BC: beam strengthening with carbon FRP.

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