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Numerical analysis of reinforced concrete beams containing bending and shear opening and strengthened with FRP sheet

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A B S T R A C T

Various methods are available to reinforce concrete members and structures. Wrapping the concrete beams with composite sheets is one of the suggested methods for increasing the load bearing capacity of concrete beams and specially those containing opening. In this paper, the influence of using two composite sheets reinforced with carbon (CFRP) and glass (GFRP) is studied on increasing the strength of concrete beams having opening. A number of concrete beams with and without openings were modeled in ANSYS and using the nonlinear analyses, the initial cracking load, ultimate failure load, cracking pattern and deflection were determined numerically for each beam. Different wrapping schemes were examined for increasing the load bearing capacity of the opening section and it was concluded that wrapping from both inside and exterior of opening with the mentioned composite patches provide the most enhancement in the opening zone. Also the CFRP patch showed better performance in comparison with the GFRP wrapping.

1. Introduction

Beam openings normally appear in different shapes and sizes. These structural components are usually located close to the supports where shear loads are dominant. In practice it is common to provide convenient passage of environmental services which reduce the heights of buildings and weight of concrete beams. Openings should be located on the concrete beams to provide chords with sufficient concrete area for developing ultimate compression block in bending and adequate depth for providing effective reinforcement against shear loads (Amiri & Masoudnia, 2011). Hanson (1969) tested a typical joist floor with square and circular openings on the web and found that an opening located adjacent to the support had no significant effect on the reduction of strength. Floruţ et al. (2014) conducted some experimental tests on reinforced concrete slabs with cut-out openings to investigate the effects of cut-

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out on the response of concrete. Salam (1977) investigated a number of beams with rectangular cross section under two symmetrical point loads. Mohamed et al. (2014) predicted the behavior of reinforced concrete deep beams containing web openings by means of finite element method. Siao and Yap (1990) stated that the beams fail prematurely by sudden formation of a diagonal crack in the compression chord when no additional reinforcement is provided in the members near the opening (chord members). Hafiz et al. (2014) investigated the influence of opening type on strength and behavior of reinforced concrete (RC) beams using numerical analyses. Godat et al. (2010) studied the size effect on the behavior of RC beams using experimental and numerical analyses. Abdalla et al. (2003) used fiber reinforced polymer (FRP) sheets to strengthen the opening region in their experiment. The studies are limited due to the problems in providing the materials and the proper conditions to conduct the experiments and scarcity of usage of materials which are constituted according to certain size and number of elements (Amin et al. 2013). More recently Popescu et al. (2015) reviewed the effects of opening on the behavior of concrete structures and walls under compressive loads.

The openings are usually provided in concrete beams to have an access for utility ducts like air conditioning, electricity or a computer network without further increases in ceiling head room. However, these openings may weaken the concrete structure noticeably and therefore, several researchers studied the effects of opening on the strength behavior of RC beams and methods for increasing the load bearing capacity of such components containing opening (e.g. Rashid & Kabir, 1996; Ahmed et al., 2012; Damian et al., 2001; El-Maaddawy & El-Ariss, 2012; Hawileh et al., 2012; Pimanmas, 2010; Pellegrino & Modena, 2002). Hence, analyzing such structural components under applied loads is of practical importance for civil engineers and designers. Finite element method can solve complex and difficult physical problems such as the beams containing opening with different reinforcement systems. Since, concrete is a material showing nonlinear behavior during loading. In this research, the behavior of a typical structural concrete beam reinforced with two commercial CFRP and GFRP composite sheets (i.e. composite patches reinforced with carbon and glass fibers, respectively) and containing openings are analyzed numerically using nonlinear analyses in ANSYS finite element code. The effect of using the mentioned patches in the interior or exterior part of the opening is investigated to obtain the best method of wrapping of the openings. In the next sections the finite element models of beams with and without opening and with different reinforcement methods are described and analyzed.

2. Modeling and analyzing of concrete beam by ANSYS

Fig. 1 shows the drawing of the considered reinforced concrete beam with dimensions of 150 × 1200 × 250 (mm^3) and a post rectangular opening with dimensions of 200×100×150 mm^3. Also the specifications of steel reinforcement used in this beam are as follows:

-Top rebar: 2ø10mm
-Bottom rebar: 3ø10mm, Stirrup: 2 legged ø8 mm @ 100 mm c/c

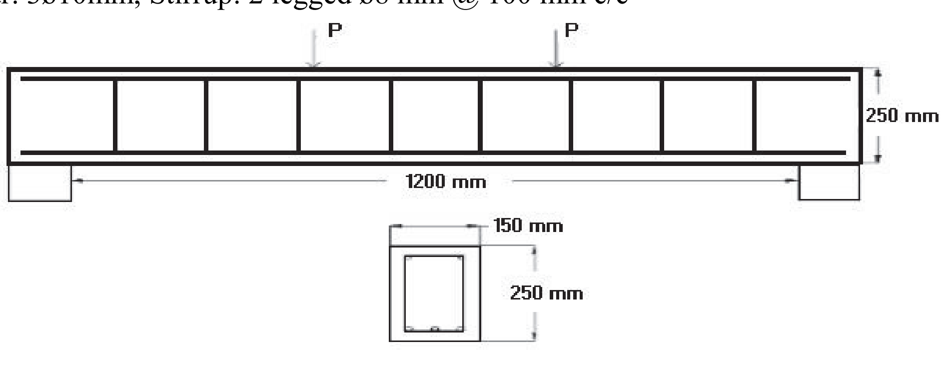


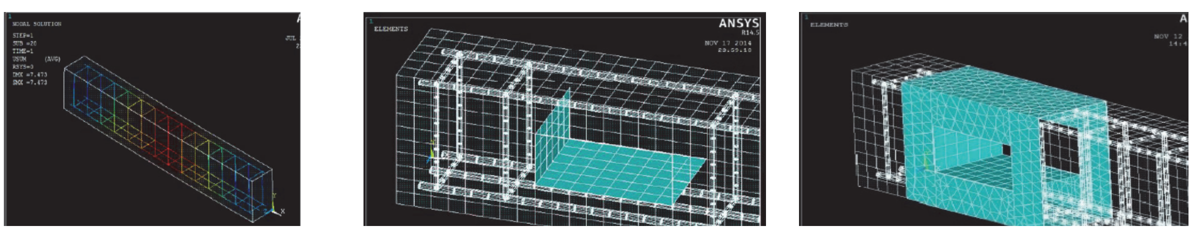
Fig. 1. Gometry and dimension of beam and its opening.

SOLID65 is used for the 3-D modeling of the concrete. The element is defined by eight nodes having three degrees of freedom at each node i.e. translations in the nodal x, y and z directions. The most important aspect of this element is its ability for considering nonlinear material properties (Huang, 1987). The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation and creep. Concrete was assumed to behave as both linear elastic and multilinear inelastic material. Compressive strength of concrete was assumed as 25 MPa and its tensile strength was assumed to be 9% of concrete compressive strength. Poisson's ratio of 0.2 was also used for the analyzed concrete model.

For modeling the reinforcing bar, LINK8 (which is defined by two nodes) was used. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, swelling, stress stiffening and large deflection capabilities are included in this element (Huang, 1987, Yogesh & Lakshmi, 2012). Reinforcing bars was assumed to be both linear elastic and bilinear inelastic material. Yield strength of longitudinal reinforcements and stirrups were 415 MPa. Poisson's ratio of 0.3 was used. To ensure that the model behave in the same way as the real beam, suitable boundary conditions were needed to be applied at nodes in the supports. Accordingly, the supports were modeled to create fixed supports. The force P was applied on all nodes through the entire center line of top fibers of the beam at equal distances from the mid span.

In this research, a convergence study was carried out to determine an appropriate mesh density. Various mesh sizes were examined in ANSYS. It was observed that the obtained ultimate load for mesh size 25 mm (77021 N) is nearest to the ultimate load of experimental data for the same beam (i.e. 80000 N given in Alsaeq (2013)). For this reason, the mesh size was chosen equal to 25 mm for the created finite element method.

For investigating the influence of reinforcement on the behavior of concrete beam, a total number of nine beams were modeled and analyzed. Accordingly, three beam categories including (i) control beam without reinforcing, (ii) RC beam with GFRP wrapping in the opening zone and (iii) RC beam with CFRP wrapping in the opening zone were investigated numerically. Fig. 2 shows the finite element models created for these three groups.



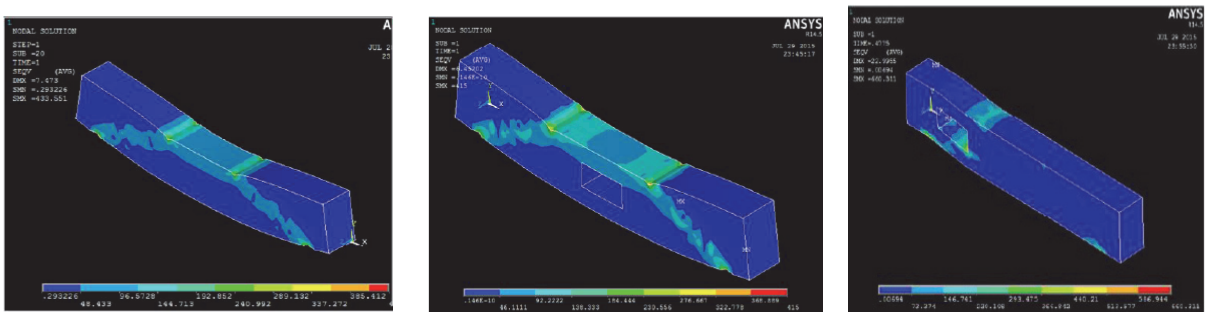
(a) (b) (c)

Fig. 2. Finite element models of (a) normal RC beam without opening (b) beam containing opening and wrapped from inside and (c) beam containing opening and wrapped from both enterior and exterior of opening.

3. Results and discussion

3.1. Control beam-analysis

Among the nine types of the investigated beams, three beams (i.e. a normal beam without opening, beam with bending opening, beam with shear zone opening) were modeled under control conditions. No reinforcement with GFRP and CFRP wrapping was applied for these control beams. Figs. 3 and 4 present some typical contours for deflection and stress distribution in these three. From the numerical load-displacement curves presented in Fig. 5 for these three beams, the ultimate load bearing capacity of the RC beam containing shear opening showed the highest reduction but its loading capacity did not present significant reduction for the case of bending opening. In other words, when the opening is located in the shear zone of loading the most reduction in the failure load of RC beam is happened and hence, the middle of beam is the best place for considering an opening. Thus the main aim of the numerical studies of this research was to improve the shear zone opening strength by composite patching.



(a) (b) (c)

Fig. 3. Stress contours of control RC beam (a) without opening (b) with bending opening and (c) with shear opening

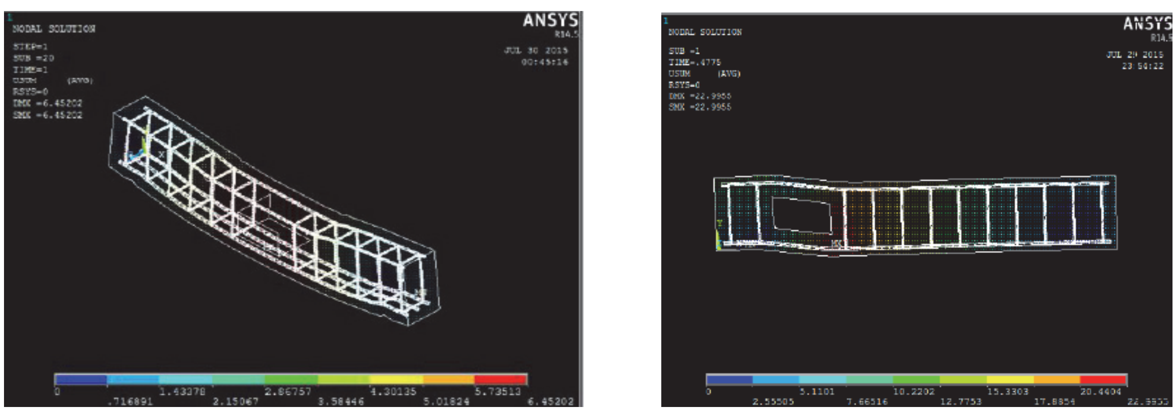


Fig. 4. Deflection of RC beam (a) with bending opening and (b) shear opening

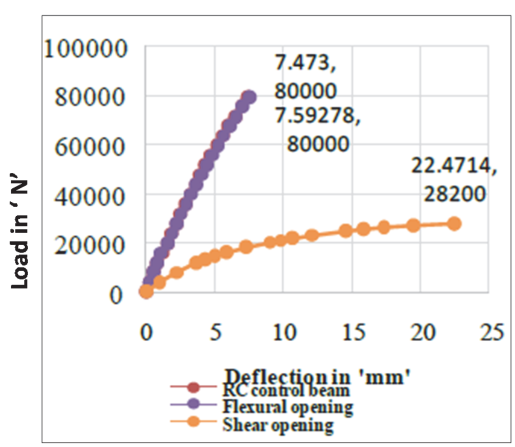


Fig. 5. Corresponding load-deflection curves obtained three beams (i.e. RC control with no opening, with bending opening and with shear opening)

3.2 Shear Zone Strengthened By GFRP Sheet

The shear behavior of reinforced concrete beam containing openings and strengthened by GFRP sheets was also simulated and analyzed. The opening section was reinforced in three manners (i) wrapping GFRP inside the opening (i.e. beam B4), (ii) wrapping GFRP around the opening (i.e. beam B5) and (iii) wrapping GFRP both inside and around the opening section (labeled by beam B6). The material properties of GFRP employed in the numerical analyses have been presented in Table 1. Fig. 6 presents the contours of stress and deflections for the RC beams wrapped with the GFRD reinforcements in the shear opening. The influence of different wrapping methods on the load-displacement behavior of investigated beam have also compared in Fig. 7. Based on this Figure, the opening reduces both the load bearing capacity and stiffness of control beam. However, using the GFRP composite for reinforcing the opening has a noticeable positive effect, such that the beams B4, B5 and B6, showed enhancement in the value of load bearing capacity up to 15.49%, 36.35% and 46.1%, respectively in comparison with the non-strengthened beam B3 (RC beam with rectangular post opening) studied in Diggikar et al. (2013). Indeed, GFRP wrapping with both inside and around the opening provides the best performance against failure in the beams containing opening.

Table 1
Material Property of GFRP

FRP Composite	Elastic modulus(MPa)	Major Poisson's ratio	Tensile strength(MPa)	Shear modulus(MPa)	Thickness of laminate(mm)
GFRP	EX=21000	$\nu_{XY} = 0.26$	600	GXY=1520	1.3
	EY=7000	$\nu_{XZ} = 0.26$		GXZ=1520	
	EZ=7000	$\nu_{YZ} = 0.30$		GYZ=2650	

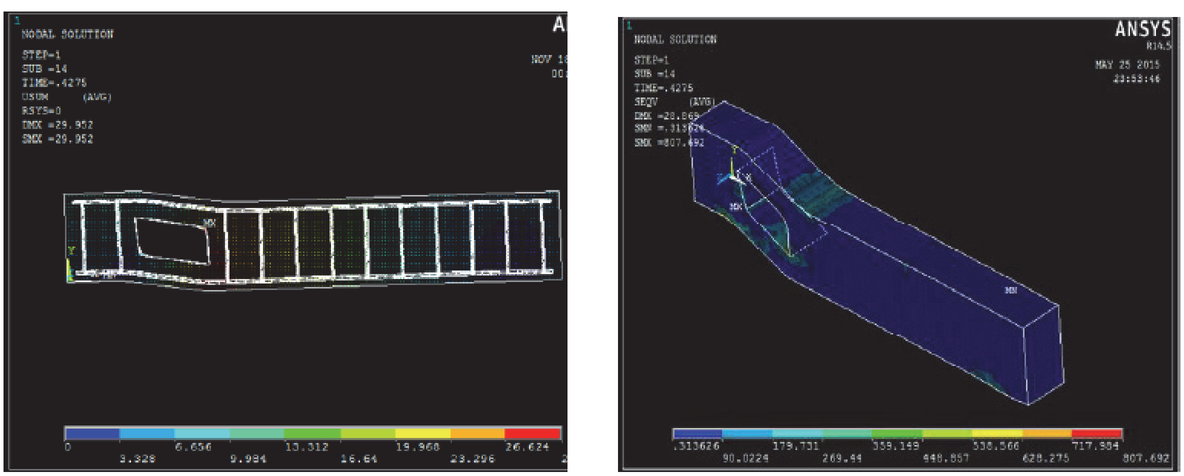


Fig. 6. deflection and stress contour of shear beam opening wrapped with GFRP composite patch

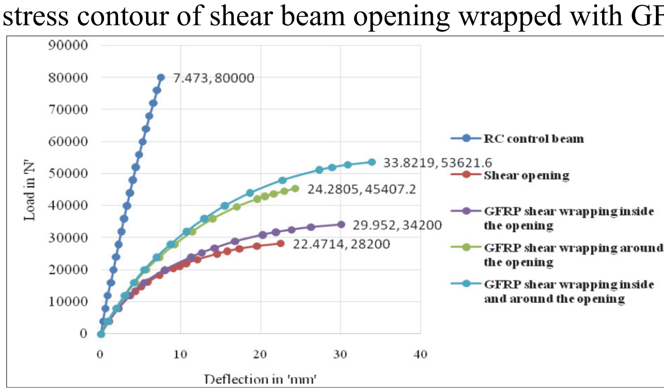


Fig. 7. Comparison of load-deflection of investigated RC beams with different GFRP Wrapping techniques

3.3. Shear Zone Strengthened By CFRP Sheet

In addition, in order to study the influence of another wrapping composite sheet, the opening section of investigated concrete beam was strengthened by CFRP sheets. Accordingly, three concrete beam labeled by B7, B8 and B9 were modeled and analyzed by ANSYS. While the inside of the B7 RC beam was wrapped with CFRP, only the exterior boundary of opening was wrapped in B8 beam. Moreover, both inner and exterior sections of RC beam was wrapped with CFRP in B9 type beam. The mechanical properties of CFRP composite used in the finite element simulations have been presented in Table 2. Similar analyses performed in the previous section for B4, B5 and B6 beams were performed again for B7 to B9 beams. Fig. 8 shows the load- displacement curves of different beams (including control one and wrapped beams with CFRP composite). Results obtained for these three beams showed that wrapping of the opening section with CFRP composite sheet can strengthen the concrete beam in general. Indeed, the load bearing capacity of control beam (i.e. B3) can increase up to 36.62% ,59.18% and 63.87% for beams B7, B8 and B9 beams, respectively. In other words all three wrapping method have positive influence on reinforcing the beam with CFRP, but as it is clear, the B9 beam (which wraps the opening from both inner and exterior side) provides the highest enhancement in the value of load bearing capacity of control beam.

Table 2
Material Property of CFRP composite patch

FRP Composite	Elastic modulus(MPa)	Major Poisson's ratio	Tensile strength(MPa)	Shear modulus(MPa)	Thickness of laminate(mm)
CFRP	EX=230000	$\nu_{XY} = 0.22$	3500	GXY=11790	1
	EY=17900	$\nu_{XZ} = 0.22$		GXZ=11790	
	EZ=17900	$\nu_{YZ} = 0.30$		GYZ=6880	

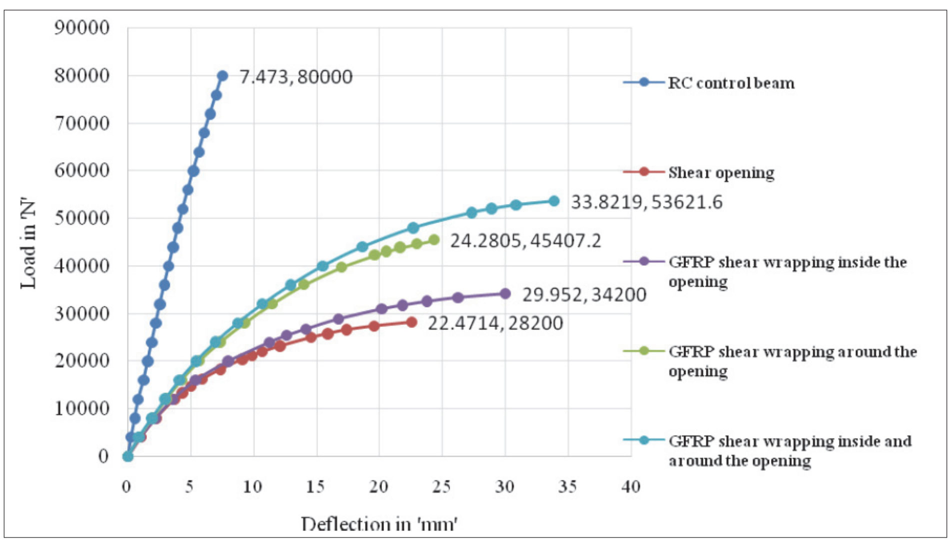


Fig. 8. Comparison of load-deflection of investigated RC beams with different CFRP Wrapping techniques

3.4. Compassion of CFRP and GFRP wrapping

Fig. 9 compares also the influence of GFRP and CFRP composite wrapping on the ultimate load bearing capacity of concrete beams containing opening. The percentages of increase in the failure load of different investigated beams are also given in Fig. 10.

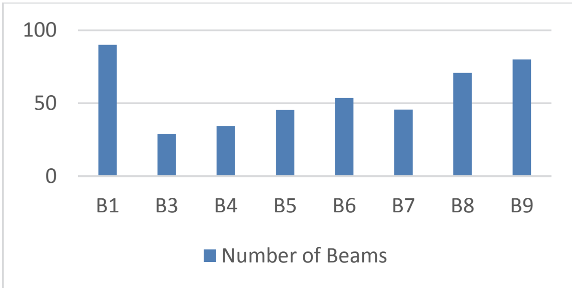


Fig. 9. Ultimate Load bearing Capacity of both GFRP and CFRP Strengthened Beams with Opening at Shear Zone

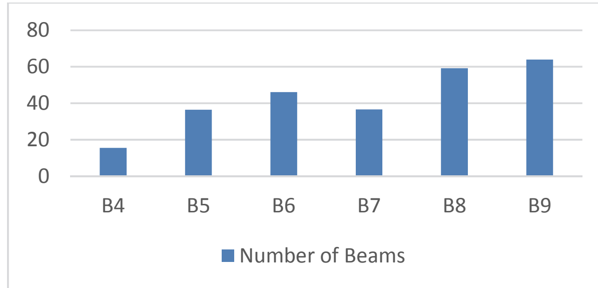


Fig. 10. Percentage of increase in the ultimate load bearing capacity of both GFRP and CFRP strengthened beams with opening at shear zone

4. Conclusions

- Shear behavior of reinforced concrete beams containing openings strengthened by GFRP and CFRP sheets was investigated numerically.
- Wrapping of the opening region with CFRP and GFRP sheets from the exterior zone was more effective than wrapping it from the inside of opening.
- Combined patching method (i.e. wrapping from both interior and exterior of opening zone) showed the most enhancement in the failure loads of the investigated RC beam.
- CFRP showed significantly better results in reinforcing the beam in comparison with the GFRP wrapping method.

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