instead of wrapping up the beam for a more practical strengthening idea. The FRP arrangement is also used in beam BR6 perpendicular to the shear cracks. But this time, the number of CFRP bands are increased and their width are reduced to 5 cm and the beam is strengthened in only one side. The sharp edges of the beam are rounded to prevent stress concentration in these areas.

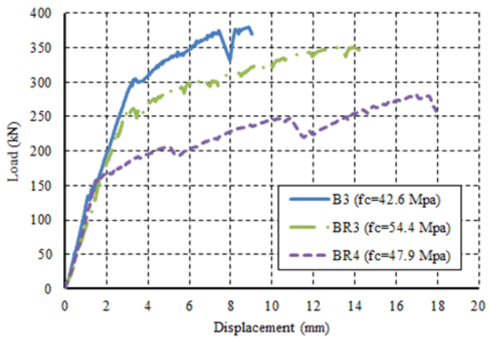

Fig. 3. Load-deflection curves of the second group

Beam BR5 experienced shear failure along with the bearing of one of the supports. Shear cracks formed under FRP sheets after the rupture of FRP. The ultimate load of this specimen increased about 6% compared to the specimen without FRP as shown in Figure 4. Beam BR6 failed gradually and the specimen did not fail by rupturing or debonding of each bond due to the strength of other FRP bands. Despite the fact that strengthening was performed only on one side of the beam, this beam failed at a load of about 622 kN that was 8% higher than the ultimate load of the beam without strengthening.

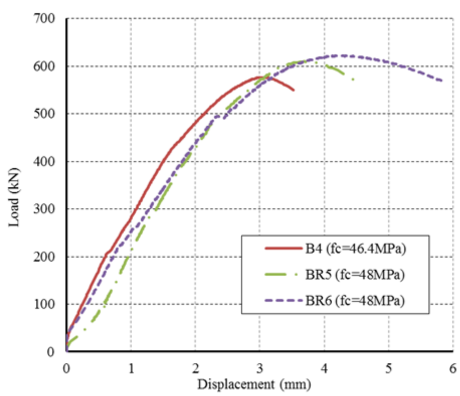

Fig. 4. Load-deflection curves of the third group

4- Conclusions

The experimental program indicates that in order to increase the ultimate load of deep beam it is better to use more FRP bands with smaller width instead of using fewer CFRP bands with larger width.

Also, a comparison implemented between the experimental results with the obtained results from the existing relations in the literature shows that there are no appropriate code recommendations specifically for deep beams strengthened with FRP. The only existing relations are the ones obtained by Zhang et al., in 2004 whose results are very conservative. Thus, none of the existing relations in the investigated references can predict the behavior of deep beams strengthened with FRP tested in this paper properly.

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CFRP Effects on Reinforced Concrete Deep Beams

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1- Introduction

Deep beams are the type of beams whose behavior is different from conventional beams because of their particular geometry. The number of studies on deep beams strengthened with FRP is much less than the research works on conventional deep beams. Since the bridges strengthened with FRP are the most important applications of these materials in civil engineering, more research studies are necessary about deep beams strengthened with FRP. In this paper, an experimental study is performed on 10 deep beams and various arrangements of unidirectional FRPs are considered for retrofitting.

2-Experimental program

The specimens are simply supported and classified in three groups. The first group is the deep beams with two layers of reinforcement and the thickness of 10 cm; the second group is deep beams with 10 cm thickness and one layer of reinforcement and the third group is deep beams with two layers of reinforcement and 14 cm thickness as shown in Figure 1. All specimens have 80 cm clear span and their heights are 40 cm. In other words, the length to depth ratio of 2 is considered. The selection of this ratio is because of consistency with all existing codes.

BR1 and BR2 are the part of the first group of deep beams that have been strengthened with two arrangements of CFRP. CFRP sheets are pasted at the front and the back sides of the beam BR1 with dimensions of 10 x 30 cm. The sheets lengths are considered in the direction perpendicular to the diagonal crack and only in the web of the beam. Another arrangement of CFRP is considered for beam BR2 and anchoring length of CFRP is increased by continuing of CFRP to the flange area.

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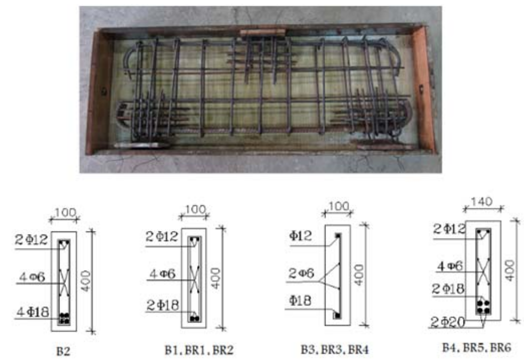

Fig. 1 Details of the specimens

3- Discussion on experimental results

According to experimental observations, the type of CFRP arrangement used in BR1 does not affect its ultimate loading capacity. However, it causes fewer cracks, increases first shear cracking load more than twice and decreases the beam deflection by 28% as it is shown in Figure 2. Fracture of BR1 was sudden and brittle with severe impact that has occurred concurrent with the debonding of CFRP. Beam BR2 had crack width and deflection more than BR1 and the number of cracks were less than BR1. The flexural cracks became wider by increasing the load on BR2 and the beam failed in shear due to the weakening of the shear direction after CFRP debonding.

The two specimens BR3 and BR4 of the second group were respectively strengthened similar to BR1 and BR2. The experimental observation did not show an increase in ultimate load resulting from the use of FRP as it is shown in Figure 3.

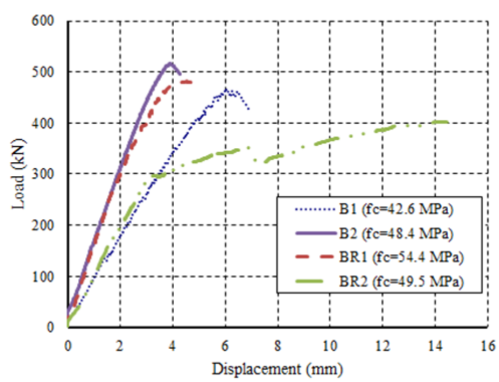

Fig. 2. Load- deflection curves of the first group

The two new arrangements of CFRP are used in the third group. Beam BR5 is strengthened by U-shaped CFRP sheets. In using FRP for retrofitting, the upper part of the beam is usually covered by a member that is placed on the beam and there is no possibility of putting FRP on the top of the beam. For this reason, a U-shaped arrangement is used