RETROFITTING OF ARCHED HYDRAULIC STRUCTURES USING CFRP

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1- INTRODUCTION

Apart from structural problems, arched hydraulic structures are subjected to aging and problems from direct exposure to harmful environments. Therefore, the probability of deterioration and cracks initiation in these structures is increased. Challenges to retrofit and strengthen those structures are attributed with finding a suitable material that can easily be installed, consume less energy and time. Moreover, that material would have high strength, durable against chemical attacks and corrosion. Carbon Fiber Reinforced Polymers (CFRP), a light weight material with high tensile strength causing no effect on the structure geometry, have been recommended by many experts to be used for strengthening or repairing of deteriorated structures [Islam et al., 2005]. The current study was an attempt for strengthening one-vent prototype arched model that is extensively used in regulators. In General, the internal forces among these structures are probably in compression and are carried directly by concrete, while the lateral forces are usually resisted with reasonable lateral restraints or sometimes carried by an external tie. The effect of using CFRP to carry the desired tensile forces, enhance the overall performance, prevent crack initiation, and to increase the structure capacity are studied. Combinations for CFRP strengthening were conducted. Load-strain curves were plotted and the behavior of the specimens was described.

2- EXPERIMENTAL PROGRAM

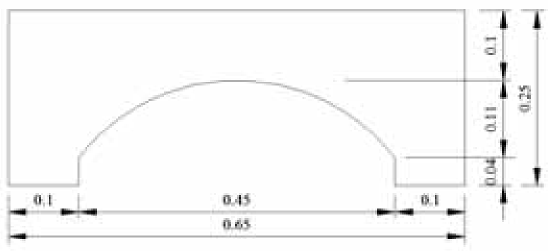

Figure 1: Typical concrete dimensions

In the current work, five plain arched concrete specimens were prepared. Figure 1 shows the typical dimensions of the arched specimens. The concrete mixture was designed as per American Concrete Institute specifications [ACI 211.1, 1977]. At 28 days, the experimentally tested characteristic compressive strength, flexure strength and the modulus of elasticity was 40 N/mm^2, 6 N/mm^2 and 350 KN/mm^2, respectively. Before pasting CFRP, the required surface in each specimen was polished then left in open for an extra day for complete dryness. Uni-directional CFRP sheets, 0.111 mm thickness, were then pasted in the required positions. Figure 2 shows the strengthening positions for each specimens. As per the manufacturer, CFRP tensile strength, and modulus of elasticity are 3400 N/mm^2, and 2.45×10^5 N/mm^2, respectively. The CFRP pasted concrete specimens were kept for an extra 5 days at normal room temperature for epoxy curing. Combination of CFRP strengthening included; soffit, sides, and combination between them were adopted. The arched specimens were then subjected to a single point load applied at the mid-span of specimen.

3- RESULTS AND DISCUSSION

Usually, the full strength of the CFRP composites can not be achieved due to their interfacial debonding mode of failure [Bo Gao et al., 2006]. Therefore, using an effective strain value for the CFRP material or using a limiting shear stress for the bonded concrete, are the ways to incorporate the effect of the bonded reinforcement in any suitable strength prediction method for the structure [Islam et al., 2005]. In the current research, all the noticed modes of failure ended with interfacial debonding mode. For specimen, S2, the most stressed part of concrete, corresponding to the maximum tensile stress, was fully strengthened with CFRP sheet. It consequently lead to maximize the total section capacity, as high as 85% more than the reference sample, S1. The cracks actually started in the mid-span and propagated towards the CFRP ends in a brittle manner with little or no given indication of failure [Maalej et al., 2005]. For specimens S3, and S4, the strengthened part of the concrete was subjected to variation in tensile stresses, which consequently generated variation of tensile strains along the CFRP width.

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This behavior started the interfacial debonding from the first moment of loading and subsequently accelerated the interfacial debonding mode. For that reason, the enhancement in the section capacity was only 38% and 6% for S3 and S4, respectively. However, in these cases, S3 and S4, noticeable strains were recorder and a ductile mode of failure was achieved. For S5, the best section capacity was achieved with a ductile failure mode; the bottom strengthening worked towards increasing the section capacity and minimizing the tensile strains at the most stressed layer of concrete, while the sides strengthening worked towards preserving the structure integrity and keeping the structure in a stable form. The enhancement in section capacity for S5 was 180% more than the control specimen, S1. Figures 3-a, and 3-b show the load- mid span strain graphs for bottom and sides strengthened, and specimens with a combined strengthening, respectively.

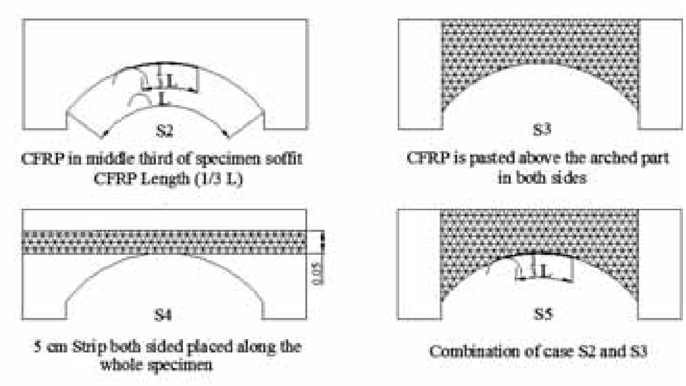

Figure 2: Schematic showing different CFRP strengthening

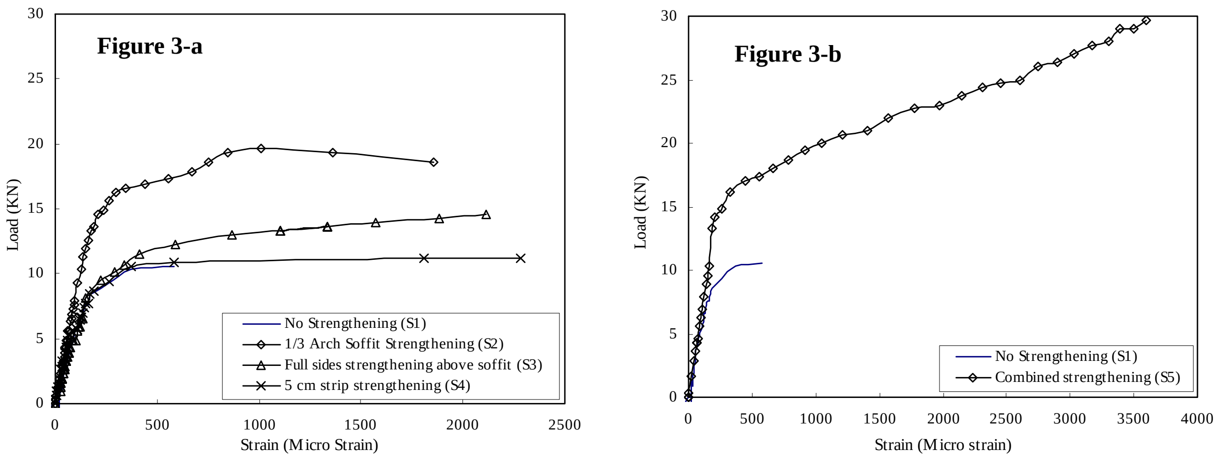

Figure 3 a, b: Load – Strain curves for bottom, sides, and combined strengthening

4- CONCLUSION

This paper discusses different strengthening conditions for one-vent arched structures. The main aim of the strengthening is to minimize the development of cracks, preserve the integrity of structure, and to increase section capacity. The most important findings of this research are:

1- Using CFRP is a promising way in strengthening and repairing of structures only if it is placed properly and in appropriate positions. In addition, it is an effective way if provided with complete monitoring system to counter any undesirable damages in the earliest time.
2- Bottom repair only (S2) provided a very good section capacity enhancement with brittle mode of failure.
3- Sides repair only (S3, and S4) allowed for a ductile failure mode, but the enhancement in the section capacity was lower than (S2).
4- Combinations of both bottom and sides repair (S5) seemed to be the optimum way for strengthening; the section capacity achieved 180% more than the reference specimen (S1), and at the same time ductile mode of failure was observed.

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