NLFEA of Flexural Performance of RC Beams Strengthened with CFRP Sheets

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Abstract

This paper summarizes the results of comprehensive NLFEA models to evaluate the behaviour of CFRP strengthened beams exposed to environmental conditions in terms of degradation in epoxy bond strength. Based on the NLFEA results and observations from the stress and strain investigations, it was concluded that CFRP repairs and strengthening have excellent durability under all possible environmental exposures if they applied correctly. The damage in concrete and CFRP repair were discussed in terms of CFRP delamination profile, ultimate load, and ultimate deflection which represent the overall performance of structure. Therefore, the results reveal that the damage percentage in concrete had a parabolic relation with the ultimate strength of control beams.

Keywords: contact mechanics, concrete, cracks, damage, material properties, non-linear elasticity

1. Introduction

The alarming deterioration of world's infrastructure has caused engineers to seek new ways of rehabilitating aged structures. Heat water cycles, freeze and thaw cycles, and salt water cycles are considered to be the major cause of deterioration in concrete infrastructure facilities such as bridges, buildings, marine and waterfront constructions, and chemical plants. The utilization of advanced composite materials shows great potential in the area of structural rehabilitation. Composites offer many advantages in structural uses, such as higher strengths and lighter weights, corrosion resistance, design flexibility that enables the creation of large and/or complex shapes. Therefore, there is a need for assessment of composite performance durability under environmental conditions to simulate the natural weathering conditions. The objective of this section is to investigate the bond degradation and concrete strength in order to provide guidelines and procedures for designers and researchers.

2. Specimens Details and Material Properties

Twenty one identical RC beams strengthened with different configurations of CFRP sheet layers were modeled using NLFEA (ANSYS V.9). Ten control beams were analyzed as static analysis with different concrete compressive strength to study the degradation in concrete strength, nine beams with different bond layer strength to study the degradation in bond strength, and two beams with different CFRP configurations to study the effect of CFRP bond surface with concrete and number of layers. The tested parameters include CFRP configurations, number of CFRP layers, concrete compressive strength, and bond layer strength.

The length of all specimens was 1170 mm with a cross section of 150 by 230 mm. The beams were reinforced with 3#4 bars at the bottom, 2#2 bars at the top, and #2 stirrups spaced at 75 mm on centres. The different configurations of CFRP sheets include one layer, 150 mm in width, one layer of two identical strips, 100 mm total width, and two layers of two strips, 200 mm total width. The beams strengthened with one layer and two layers of CFRP strips had a contact width of 100 mm with the concrete, and the beams strengthened with one layer of CFRP sheet had a contact width of 150 mm with the concrete.

3. Discussion of Results

3.1. Delamination Profile

Figure 1 shows the effect of CFRP sheet layers schemes on the delamination profile of beams strengthened with different configuration. Inspection of Fig. 1 reveals that the initial delamination length of the beams strengthened with 2/3 CFRP sheet, 1 CFRP sheet, and 2 CFRP sheet was 18.75 mm, 16.25 mm, and 15 mm, respectively, and continued in the same trend till the failure of the beam.

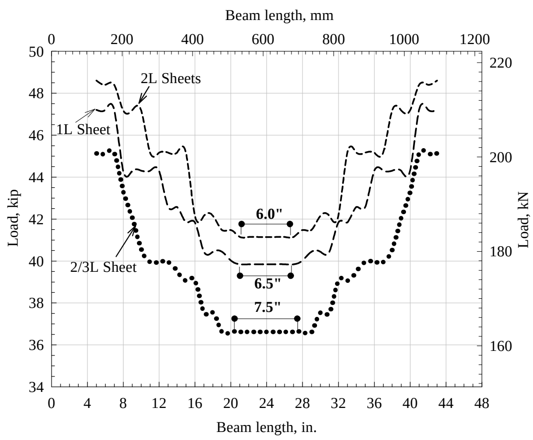

Figure 1: CFRP delamination profile vs. number of CFRP layers

3.2. Effect of Concrete Strength Degradation

Figure 2 shows that the damage percentage in concrete had a parabolic relation with the ultimate strength of control beams. Inspection of Fig. 2 reveals that the damage percentage in concrete strength of freeze and thaw beams of 167 kN ultimate load capacity was 3.2% (53.2 MPa) which almost 2 times the reduction in ultimate load capacity with respect to the control beam under room temperature. Also, the damage percentage of the salt and hot water beams was 4.8% (31.7 MPa) and 23.0% (42.4 MPa), respectively, which corresponded to almost 2 times the reduction in ultimate load capacity with respect to the control beam under room temperature. In the real life, the beams always subject under more than two conditions and some times all the conditions. Therefore, the damage percentage for the beams subjected to freeze-thaw and salt water cycles was 8% (50.6 MPa) as shown in Fig. 2. The damage percentage for the beams subjected to hot and salt water cycles was 26.7% (40.2 MPa). For all conditions, the damage percentage was 29% (39.1 MPa) as shown in Fig. 2. As a result, Fig. 2 provided guidelines for designers and researchers to find the reduction in concrete strength at any ultimate load capacity or RC beams.

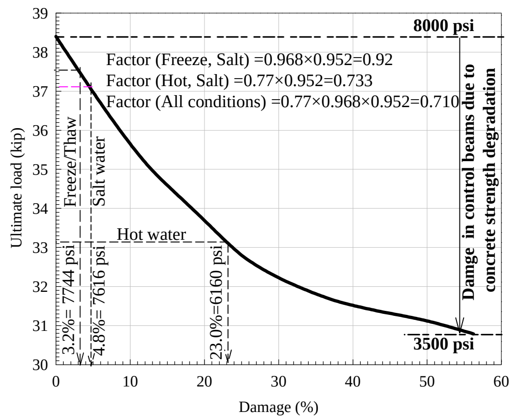

Figure 2: Damage percentages vs. ultimate load capacity of control beam.

3.3. *Effect of Bond Strength Degradation*

Figure 3 shows bond strength degradation on ultimate load capacity. Inspection of Fig. 3 reveals that the bond strength degradation of freeze and thaw beams of 167 kN ultimate load capacity was 18% which almost 10 times the reduction in ultimate load capacity with respect to the beam under room temperature.

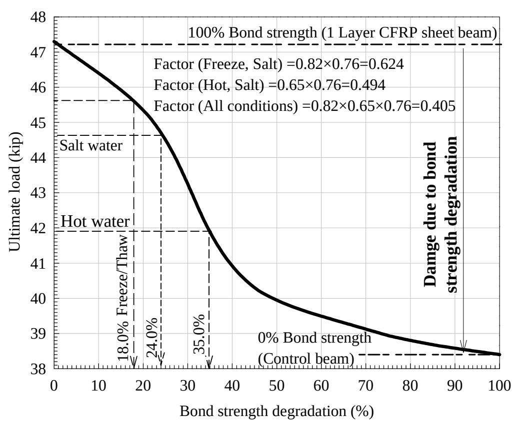

Figure 3: Bond strength degradation vs. ultimate load capacity of control beam.

In addition, the bond strength degradation of the salt and hot water beams was 24% and 35%, respectively, which corresponded to almost 9 times and 3 times the reduction in ultimate load capacity with respect to the beam under room temperature. For the beam subjected to freeze-thaw and salt water cycles, the bond strength degradation was 37.6%. For the beam subjected to hot and salt water cycles, the bond strength degradation was 50.6%. For all conditions, the bond strength degradation was 59.6% as shown in Fig. 3. As a result, Fig. 3 provided guidelines for designers and researchers to find the bond strength degradation at any ultimate load capacity or RC beams.

4. Conclusions

The alarming deterioration of world's infrastructure has caused engineers to seek new ways of rehabilitating aged structures. Heat water cycles, freeze and thaw cycles, and salt water cycles are considered to be the major cause of deterioration in concrete infrastructure facilities such as bridges, buildings, marine and waterfront constructions, and chemical plants. Therefore, there is a need for assessment of composite performance durability under environmental conditions to simulate the natural weathering conditions.

Based on the presented results and observations, the principal conclusion is that CFRP strengthening/repair can have superior durability under severe environmental exposures with minor degradation in the bond strength or in the ultimate strength capacity of the strengthened members. Such superior performance of the CFRP composites can only be achieved by implementing adequate surface preparation of the members, use of strong epoxy materials, and by careful implementation of the manufacturer's recommendations for the application of the CFRP-composites.

References

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