Stress Redistributions in Elastic Structural Components Strengthened with Externally Bonded Fiber Composite Sheets

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Abstract

There are many different problems related to deterioration of structures in Puerto Rico. One of the most important concerns is the damage of concrete slabs of bridges. These problems may be due to static and dynamic overloads or by reduction of slab thickness due to deterioration of concrete cover. A convenient method for repairing is by using fiber reinforced composite materials bonded to the external surfaces of the damaged concrete. This work deals with the mechanics of behavior of simply supported beams strengthened with composite layers. A Finite Element Analysis computer program, called ALGOR is employed as the tool for the linear analysis of the structure. The results show the stress redistributions, which occur as a consequence of strengthening.

1. Introduction and Motivation

The deterioration of bridges in Puerto Rico leads to structural problems that may affect their concrete slabs. These problems may be caused by static and dynamic overloads or by reductions of slabs thickness due to deterioration of the concrete cover. The first reason mentioned involves large traffic volumes and heavier wheel loading, while the last reason is associated to construction defects.

One of the consequences of deterioration is that the stiffness of the structure is reduced, leading to larger deflections. Also the strength of the slab and the fatigue life of the structure are reduced.

Strengthening these bridges with traditional methods is extremely costly and time consuming. A convenient and more effective way to repair this kind of damage described is by means of fiber-reinforced composite materials bonded to the external surfaces of the damaged concrete. This procedure calls for covering the repaired concrete with a laminated material on the tensile part of the slab, so that the tensile action required from the damaged concrete is recovered.

Carbon fiber reinforced polymer (CFRP) will be considered in this research because of its favorably properties. A layer of woven carbon fiber can be wrapped around or over weakened concrete members onto which epoxy has been spread to bond the carbon fabric in place, forming an external strengthener that helps to support loads and prevent excessive deflection. CFRP works well, particularly in increasing concrete's ability to withstand tension and flexural and minimizing cracking and deflection.

In this paper we only refer to initial models on an acrylic beam employed as an educational tool to understand the behavior of a reinforced member. It is expected that this behavior will also be found in more complex, nonlinear reinforced concrete structures.

2. Finite Element Analysis

A Finite Element Analysis package called ALGOR has been used as the computational method to predict the behavior of the beam and the reinforcing layer.

The basic model studied consists of a simple supported beam bonded to the external surface under the beam with composite laminas on the middle of it. Because of its symmetry, only the half of the beam is modeled.

For the initial model of the beam we have considered a Linear Static Stress analysis. The 2D model was drawn using four-node-quadrilateral elements. The problem was modeled by reinforcing a beam with two layers of composite, on the 20% length of the beam located at the center. The basic model does not include any adhesive; figure 1 shows a zooming of the 2D model showing the part with the composite.

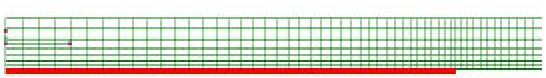

Figure 1 – 2D model with refined mesh and the composite

For the analysis the beam is modeled with plane stress elements and using isotropic material, while an orthotropic material is used the finite element analysis for the composite. The increasing of element number on a FEA model give accuracy to results and permit the evaluation of the individual behavior of elements.

3. Results from computational analyses

When running the analysis of the model, the results are visualized on the Superview screen of ALGOR. For this problem the most important results are the displacements and the stress distributions in the beam with composite.

Figure 2 shows the displaced beam with respect of the undisplaced one.

Figure 2 – Displaced beam

Different factors are consider on the process of modeling the beam reinforced with composite sheets, which are the following:

- Influence of reinforcing the beam using different number of composite layers.
- Influence varying the length of the reinforcement along the beam.
- Influence of the fibers orientation of the composites.
- Considering epoxy adhesive between the beam and the laminas of composite.
- Varying the number of elements for the model.

Figure 2 and 3 show the influence of the composite strengthening on the displacements of the structure.

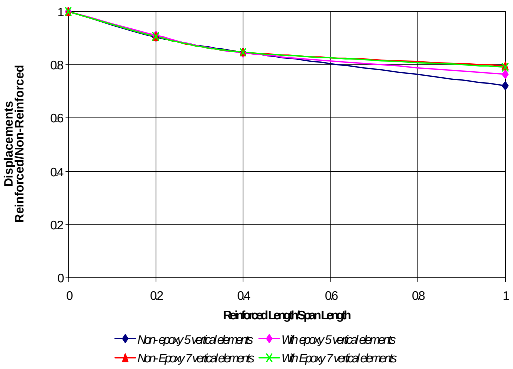

Figure 2 - Displacements comparison using different reinforcement length along the beam

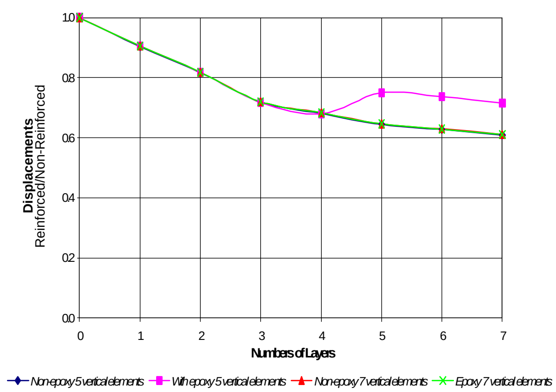

Figure 3 - Displacements comparison using different numbers of composite laminas

In figure 2 and 3 it can be see that a convergence was obtain when increasing the mesh of the model. The first case shows that for a 20% reinforcement of the beam the total deflection is reduced by a 10% and for a totally reinforced beam the displacements are approximately an 80% of those on the original beam. On the other hand, the addition of more composite laminas helped to control the displacements, but this trend was only detected up to a certain number of layers. This occurred approximately at the fifth lamina as seen on figure 3, and no further displacement change was detected for more layers added to strengthen the beam.

Another aspect considered is the failure criteria using Von Mises (σ_e). Figure 4 shows how the stresses are distributed along the area in which failure may occur.

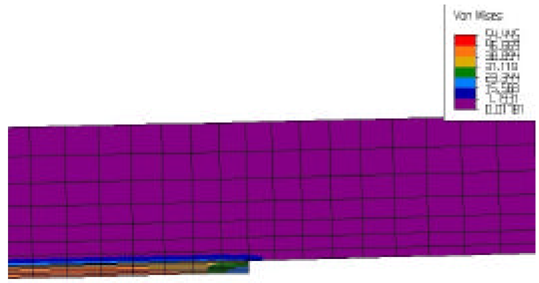

Figure 4 - Von Mises stress behavior using seven elements in the vertical direction of the beam

The maximum value of σ_e is 54.44 N/mm^2.

Finally the stress distributions in the X direction (σ_{11}) were obtained. The positive values show the elements on tension and the negative values show the elements in compression. Figure 5 shows the stress distribution along the part of the beam, in which the composite is applied.

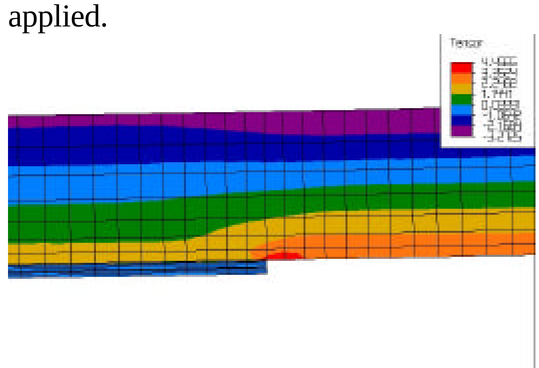

Figure 5 - σ_{11} stress distribution using 7 division elements on vertical direction

The results for the model were validated by means of convergence studies. Next, the same beam but now including the adhesive was investigated and the same analysis was performed. The adhesive is an epoxy and the properties are based on having an elasticity modulus of 587.5, which is a fourth of the acrylic's modulus, a poisson of .35, a mass density of 146e-8 and a thermal coefficient of 10e-6. The behavior of Von Mises stresses is shown in figure 6 where the maximum value is 54.47 N/mm^2.

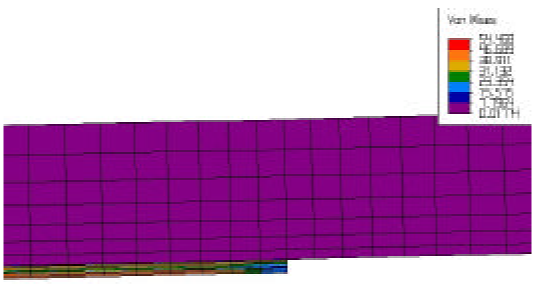

Figure 6 - Von Mises stress considering epoxy between the beam and the composite

The stress distribution of $\sigma_{11}$are shown in figure 7. The elements in tension are on the area where the numbers are positive and correspond to the area where the composite and the epoxy are located.

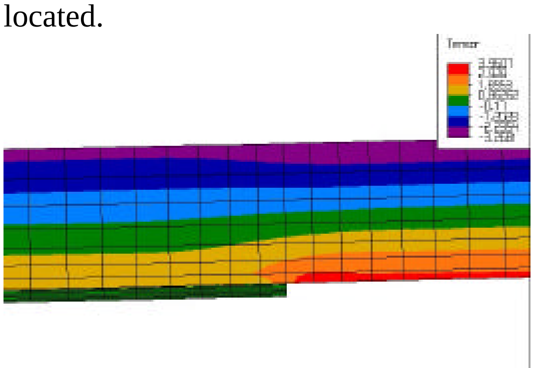

Figure 7 - σ_{11} stress distribution considering epoxy between the beam and the composite lamina

4. Conclusions

This paper has considered a very simple structure (a beam) and the reinforcement by means of a composite. The results show that the adhesive plays an important role in the stress field, and should be included in more complex situations. ALGOR was identified as an adequate tool to provide an understanding on how the flexural part of the beam is affected and how this can be improved by using composites.

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