EFFECTS OF DIAGONAL WEBS IN FRP BRIDGE DECKS

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Abstract

Early FRP bridge deck designs used parallel rectangular tubes bonded together and covered with face sheets to create a sandwich type structure. It was found that this type of structure was unstable in the lateral direction. This led to the introduction of trapezoidal tubes creating, in effect, a mix of diagonal webs and vertical webs. Further refinement of the design has shown that these diagonal webs contribute significantly to the local and global response of the bridge deck material. In addition to increased lateral stability, these webs caused the deck to behave significantly different than the plate-like behavior of more traditional deck materials. Local and global deformations are dependant on the orientation of the webs. The strength and fatigue response are also affected; with the failure mode and location varying depending on the orientation of the diagonal webs. Modeling is also affected; simple plate models, which do not reflect the internal geometry of the deck lead to erroneous solutions. Full three-dimensional models are currently required to capture the full response of the deck.

Introduction

The Latest Martin Marietta Composites' DuraSpan™ FRP bridge deck [1] consists of pultruded tubes bonded together with polyurethane adhesive. These tubes have both vertical and diagonal internal webs in order to provide optimal bending stiffness and lateral stiffness.

The first FRP bridge decks of this style consisted of rectangular tubes bonded together and covered with face sheets on the top and bottom. The concepts using these configurations were identified as Generations 1 & 2. These decks were found to be sufficiently stiff but showed lateral instability due to the lack of lateral support. The next design was the Generation 3 deck, which consisted of trapezoidal tubes bonded together to make 45-degree webs, figure 1. It was found that these webs created a much more stable deck. Generation 4 decks, fabricated by Glasforms, Inc. [2], simplified manufacturing by combining two tubes during the pultrusion process.

Figure 1: Trapezoidal tubes used to form FRP deck

Testing of Generation 4 Decks

Testing of Martin Marietta's Generation 4, DuraSpan™ deck was performed at the University of Delaware [3,4,5] and consisted of static and fatigue test. These tests were performed in support of the installation of a deck on SR 47 over Wooding Run, Darke County, Ohio. The fatigue test simulated wheel loads over a 75-year life (10.5 million cycles). The maximum load for these tests was 14.2 kips. The first test was done without additional face sheets on the tubes. During this test a small fatigue crack under the tire contact patch was observed. A finite element analysis of the test sample was conducted before the test and predicted the "hot spots" at the top of the diagonal webs, figure 2, where the local failures occurred. This figure shows the interlaminar peel stress calculated for the ply drop-off.

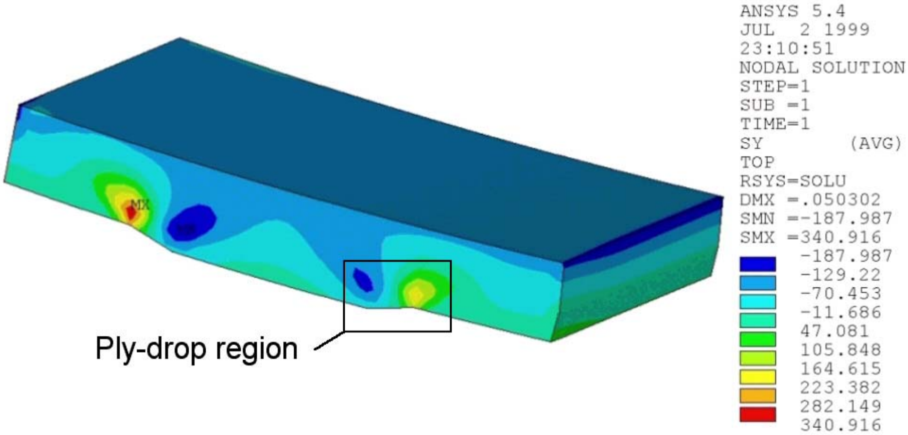

Figure 2: "Sy" interlaminar normal stress distribution (peeling stress)

Later, another test was conducted with the additional face sheets and no local damage was found, figure 3 shows the setup of this test.

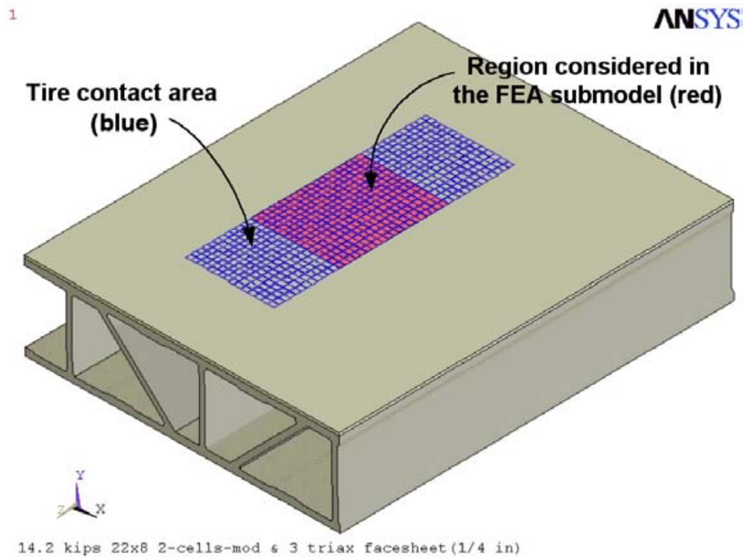

Figure 3: Test set-up for fatigue test and finite element model.

Deck Redesign

Adding face sheets to the deck solved the fatigue problem but increased cost significantly. In 1999, a major redesign was undertaken to create the Generation 5 deck, which was fabricated by Creative Pultrusions, Inc. [6].

The main objective of the redesign was the elimination of the additional face sheets without changing the amount and type of material used in the manufacturing of the pultruded section. Changing the geometry and integrating the face sheets into the pultruded section eliminated the need for additional face sheets.

One of the solutions considered for improving the performance of the bridge was to change the angle of the diagonal web. It was assumed that an increase in the web angle might solve the local fatigue problems by reducing the span between the vertical and diagonal webs and improving the capacity of the diagonal web to carry bending load. The concerns with the modification were that elimination of additional face sheets could produce a significant decrement in the global stiffness (transverse deflection) and lateral stiffness of the deck.

FEA Analysis

Four different finite element models were created for the understanding of the effects of a web angle change [7]. SOLID 45 ANSYS finite elements were used to model the decks. Figure 4 shows the 60, 75 and 90-degree web angle models. The overall dimensions of the models were 1016 mm (40 in) wide, 1829 mm (72 in) long and 127 mm (5 in) thick. The 254 mm (10 in) x 610 (24 in) tire contact area was centered in the models. A 116 KN (26 kips) static load was applied over the load pad in all the FEA simulations. The material properties used in the model were from material testing performed by Delsen Testing Laboratories, Inc. [8] and verified by independent testing at North Carolina State University.

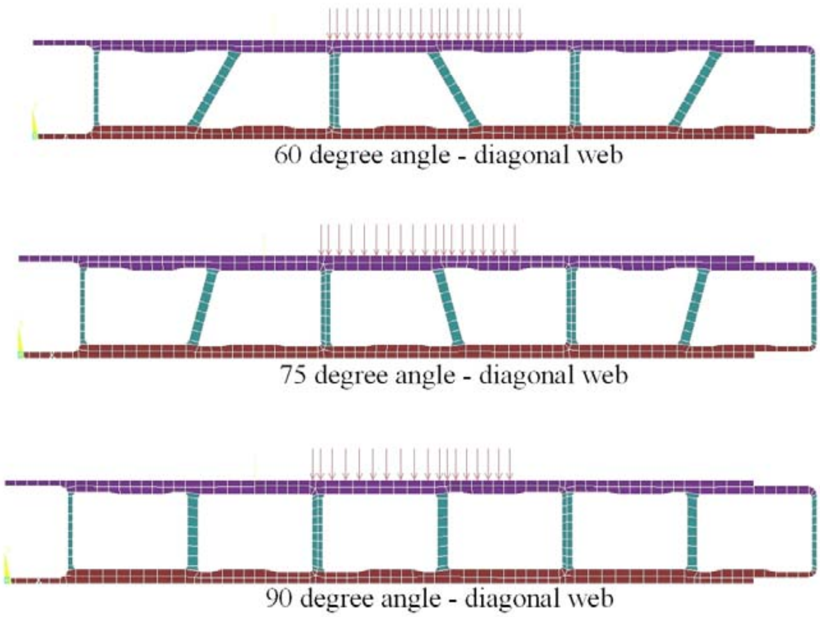

Figure 4: Finite element models of DuraSpan™ bridge deck with 60, 75, and 90-degree web angles.

Figure 5 shows the FEA transverse node deflections of the centerline in the tension surface of the models. Although some variations are presented in the curves for the different models, the maximum deflection practically remained the same for all the cases. One can conclude that the changes in the diagonal web angle did not present a significant variation in the global stiffness of the deck due to the nearly identical maximum deflection values for the four cases.

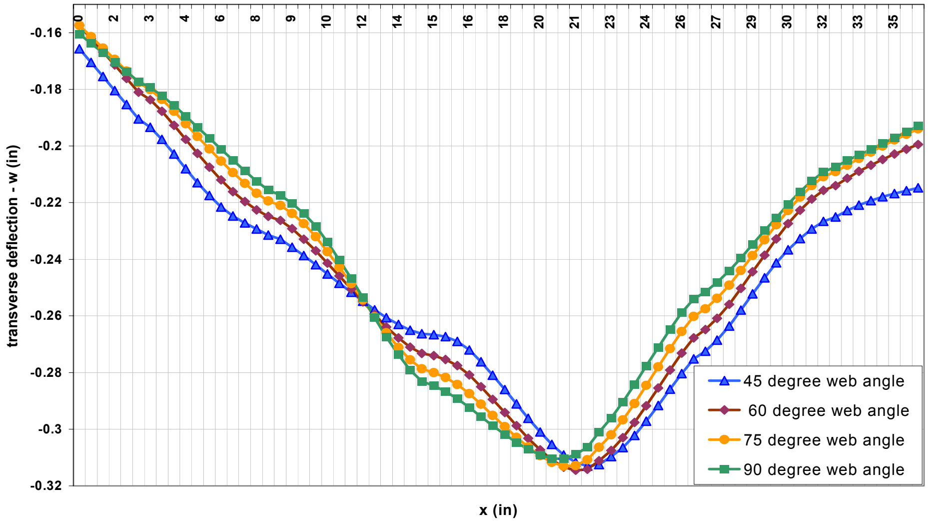

Figure 5: Transverse deflection of the different web angle models

In general, as the diagonal web angle changes from 45-degrees to 90, the reactions at the supports become less distributed.

A 75-degree diagonal web angle was selected to be the best configuration for the redesign of the deck. This angle resulted from a compromise between the reduction of the distance between the webs to improve the local fatigue resistance and provide sufficient lateral stiffness in the deck.

Figure 6 shows the model of the deck with 90-degree webs. This model is able to capture the local dimpling in the region of the load pad. Rubber pads were used under the load plate to keep it from digging into the composite. These shell models capture both the local dimpling effects under the load pad and also the global stiffness very well, however, when they are used to model a large bridge the number nodes and elements grow rapidly. A simpler model is needed due to the large number of elements needed to model the web geometry in a large bridge.

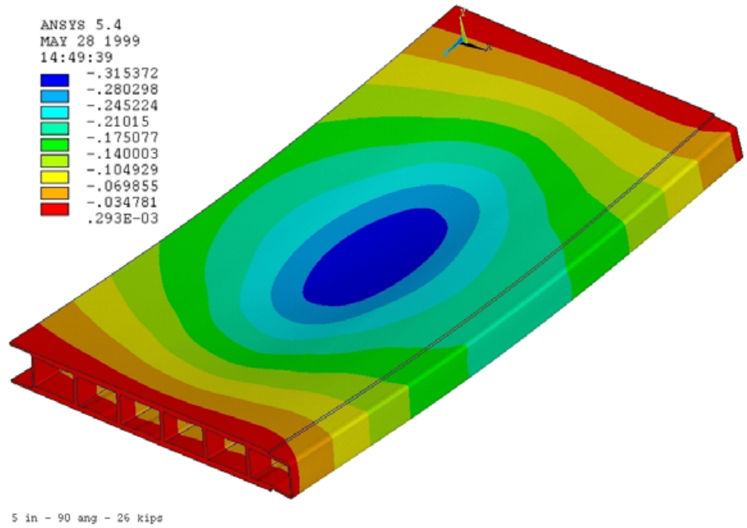

Figure 6: Shell model of DuraSpan™ bridge deck with all 90-degree webs.

A representative plate model, figure 7, was therefore created to simulate the deck behavior. The material properties for this model were adjusted to mimic the global behavior of the deck. This plate model does not accurately model the local dimpling of the deck but the overall stiffness agrees with the larger models especially when used along with bridge girders.

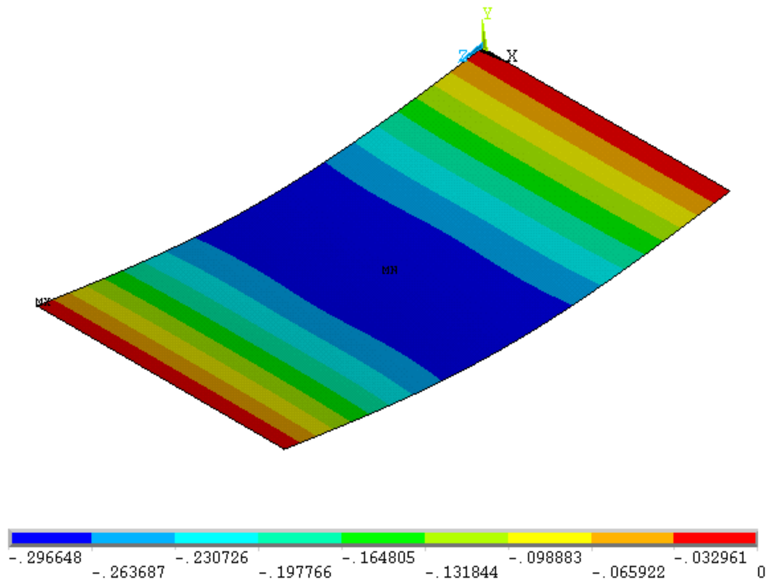

Figure 7: Three point bending of plate model

Deck Testing at North Carolina State University

Several larger sections of the new, Generation 5 DuraSpan™ deck have been tested at North Carolina State's Construction Facilities Lab (CFL) [9]. These sections were tested in three point bending and load, deflection, and strain were analyzed. This test data was also compared to the finite element models to verify their accuracy.

The first tests conducted at the CFL consisted of single tubes, figure 8, loaded both from the top and the bottom (diagonal web leaning to one side or the other). The purpose of these tests was to gain additional knowledge about the behavior of the web geometry.

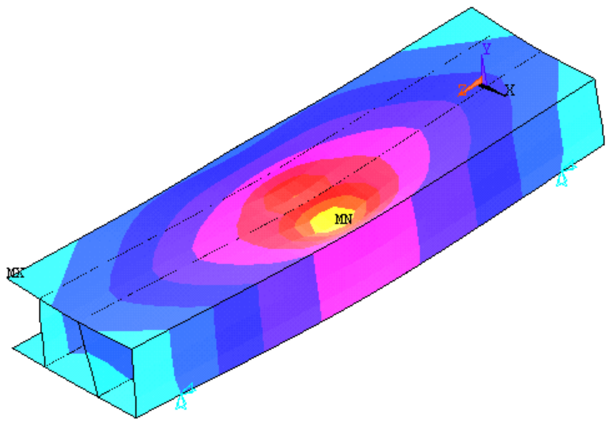

Figure 8: Deflection of single beam loaded in three point bending

These tests resulted in the beams collapsing to the side when the load became too large. This was expected since the beam did not have another beam next to it with the diagonal in the opposite direction to support the lateral deflection. Figure 9 shows the local stresses in the webs and face sheets when a single beam is loaded. The stress concentrations at the top of the angles web are due to the beams tendency to fall to the side without another beam to support it laterally. When two or more beams are bonded together these stress concentrations are practically eliminated.

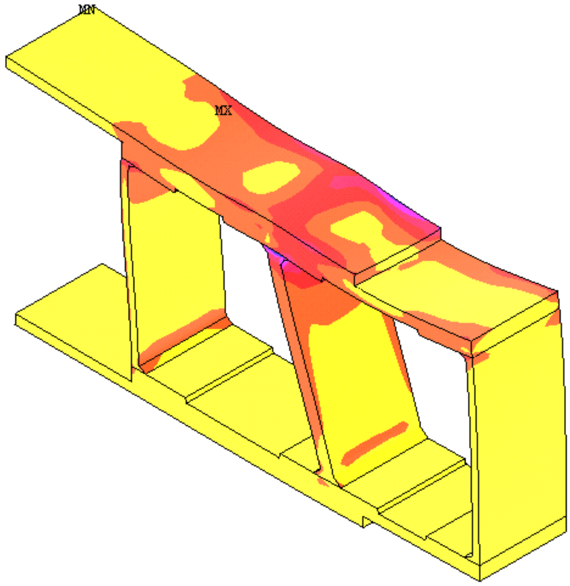

Figure 9: Stress concentration under the load pad in a single beam when loaded n three point bending.

Further tests were conducted in order to determine how well the loads were carried laterally from beam to beam. For these tests the number of beams was increased to two and then to four tubes bonded together. The angle of the webs is alternated in the bonded beams in order to distribute the load laterally through the deck.

The results of these tests and finite element models have shown that the Generation 5 deck transfers the lateral load much better than the previous decks. The local problems at the top of the webs have also been greatly reduced. The failure modes of these decks are usually a buckling of the vertical web at a much higher load than it would ever see in use.

References

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9. Dr. Sami H. Rizkalla, Director, Constructed Facilities Laboratory (CFL), Campus Box 7533 2410 South Capability Drive Centennial Campus, North Carolina State University, Raleigh, NC 27695