LTRC Technical Summary Report 441
LTRC Proj. No. 07-4TIRE ~ State Proj. No. 736-99-1447

March 2009

Louisiana Transportation Research Center

4101 Gourrier Ave., Baton Rouge, LA 70808

# A Novel Technique for Stiffening Steel Structures

## Introduction

The use of composite materials for strengthening the ailing infrastructure has steadily gained acceptance and market share. Employing composite materials in strengthening of steel structures is the subject of this study. There are several challenges that face strengthening steel structures using composite materials. The superior mechanical properties of steel result in a reduction in the efficiency of composite strengthening. Hence, it is often cited that high modulus composites are needed to improve the effectiveness of the strengthening system. This study explores a novel composites strengthening technique that is particularly suited for thin-walled steel structures. The proposed technique relies on improving the out-of-plane stiffness of buckling prone members by bonding pultruded fiber reinforced polymers (FRP) sections as opposed to the commonly used strengthening approach that relies on in-plane FRP contribution.

## Objective

The goal of this project was to identify the feasibility of using low-modulus pultruded glass FRP (GFRP) sections to stiffen thin-walled steel plates and to assess the improvement in strength resulting from employing the propped technique.

## Scope

The proposed strengthening technique has the potential of enhancing the strength of thin-walled steel structures for a wide range of applications. Examples of such applications include web stiffening for improved shear strength and compression flange stiffening for improved flexural strength. The research conducted in this project is limited to shear strengthening where pultruded FRP sections were employed as stiffeners to a buckling critical web. Various types of pultruded FRP sections may be utilized for the same purpose. In this study, only GFRP sections are used, which are among composites with low modulus of elasticity. Sections with higher modulus of elasticity were not covered in this study. However, because of their higher stiffness, their performance may be expected to at least match, if not exceed, that of GFRP stiffeners.

**LTRC Report 441**

**Principal Investigator:**

Ayman Okeil, Ph.D., P.E.

**LTRC Contact:**

Walid Alaywan, MSCE, P.E.
Phone: (225) 767-9106

**Louisiana Transportation Research Center**

*Sponsored jointly by the Louisiana Department of Transportation and Development and Louisiana State University*

4101 Gourrier Avenue
Baton Rouge, LA 70808-4443
www.ltrc.lsu.edu

## Research Approach

A thorough literature review was first conducted. Pertinent information related to FRP strengthening of steel structures, bonding composite materials to steel surfaces, and an analysis of FRP-strengthened steel structures was summarized. An exploratory experimental program has been carried out where two types of specimens were tested to demonstrate the difference in behavior between both strengthening techniques (in-plane and out-of-plane). Axial tension specimens were first tested with and without GFRP sections bonded to the steel surface. This in-plane contribution was found to increase the stiffness of the tension specimen by 13 percent, which is a modest gain that may not justify the use of composite materials for strengthening steel structures. Beam specimens were also tested. The purpose of the beam tests was to explore the proposed out-of-plane strengthening technique.

Cont'd on Back

The results showed that stiffening the beam delayed web shear buckling (designed mode of failure) and that the failure load was 56 percent higher than the buckling load for the unstiffened beam. The behavior of the stiffened beam was ductile, yet to a lesser extent than the unstiffened beam, which is common with most FRP strengthening techniques. This study presents the results from an experimental investigation where axial tension and beam specimens were tested to explore the feasibility of the proposed technique. Based on the results, one can conclude that this strengthening technique has great potential for altering failure modes by delaying the undesirable instability (buckling) failure mode. Preliminary analyses were also conducted and are presented in the study.

## Conclusions and Recommendations

GFRP sections were bonded to thin-walled steel plates in an orientation that contributes to the out-of-plane stiffness of the plate more than the in-plane strength as is the common practice in most FRP strengthening applications. The two parameters contributing to the out-of-plane stiffness were the geometric and material properties of the GFRP stiffener. Because of the GFRP stiffener orientation, it is possible to use low modulus FRP materials rather than the more expensive high-modulus materials.

No code provisions exist for estimating the shear capacity of steel beams with FRP stiffeners. These provisions, which are developed for steel stiffeners and do not account for debonding, estimate a 219% increase in strength. Thus, it can be stated that there is a need to develop new formulas for estimating the strength of GFRP-stiffened steel webs. This will require a concerted research effort to cover the various parameters that may affect the performance of the proposed technique such as: (1) the ratio between out-of-plane geometric and material properties of the GFRP stiffener and the bare steel member, (2) the contact area between the GFRP stiffener and the steel member, (3) the orientation of the GFRP stiffener, (4) mechanical properties of the epoxy used to bond the GFRP stiffener, (5) the impact of cycling loading on the performance of the strengthening technique, and (6) the original mode of failure of the unstiffened beam (i.e., full plasticization, inelastic buckling, and elastic buckling).

Finally, the proposed stiffening technique is not limited to shear strengthening. The same approach can be used for any buckling prone member. For example, a compression flange may be stiffened in a similar manner by bonding a GFRP stiffener to its top or bottom surface. In other words, this study opens new venues for a wide range of new applications of FRP materials for structural strengthening.

The positive outcome of this study proves that the proposed strengthening technique has great potential for many of the ailing steel bridges in the national inventory. It also demonstrates that extensive research is needed to study the behavior of the complex strengthening system and to establish practical design aids for engineers involved in strengthening and rehabilitation projects.