Research Proposal II.6

UMR Node

Fiscal Year 2006

RB2C repair of buildings & bridges with composites

ANALYSIS OF CONCRETE BRIDGE GIRDERS STRENGTHENED WITH FRP LAMINATES UNDER SERVICE AND EXTREME LOADING CONDITIONS (CONTINUATION)

SUMMARY

Externally bonded carbon fiber reinforced polymer (FRP) laminates are a feasible and economical alternative to traditional methods for strengthening and stiffening deficient reinforced concrete and prestressed concrete girders as shown in Fig. (1). Although extensive research has already been undertaken to investigate the behavior of FRP strengthened bridge girders, the majority of work conducted to date has been experimental in nature. Furthermore, while some studies have proposed design models and methodologies to identify the necessary number of laminates to achieve a target strength or stiffness, many important design issues still remain unresolved, particularly issues related to delamination and degradation under reversed cyclic loading typical of seismic excitations.

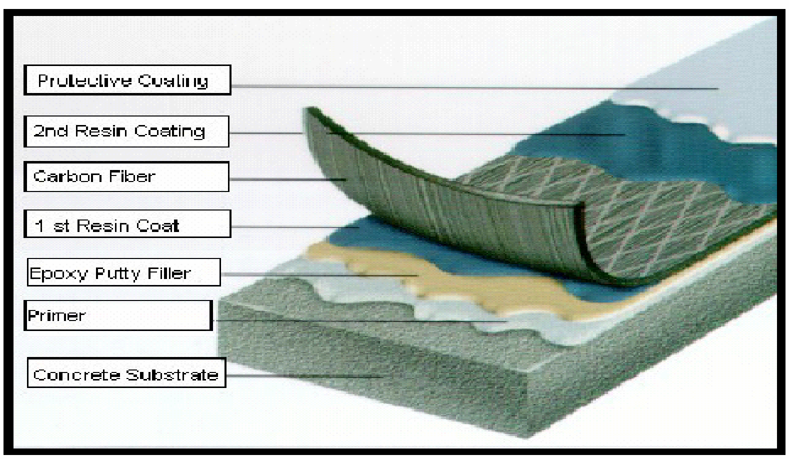

Figure 1 External Bonding with FRP Laminates

BACKGROUND

An on-going investigation focused on developing a nonlinear numerical software for analysis of concrete girders strengthened with FRP laminates. The model was based on section discretization into fibers. Nonlinear constitutive material laws were assigned to the concrete, steel and FRP fibers as shown in Fig. (2). In addition, a continuous interface element was developed to model to the interfacial bond between the FRP laminate and concrete.

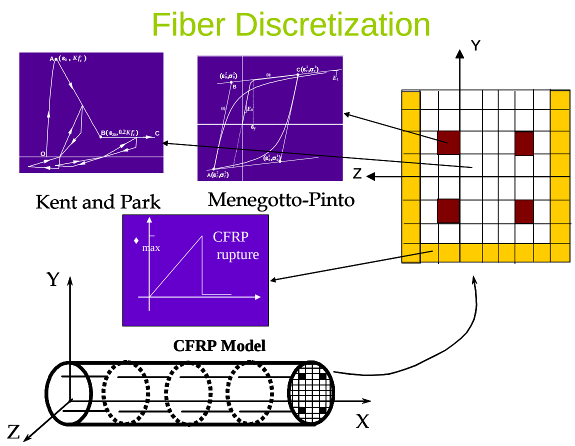

Figure 2 Modeling of FRP-Strengthened RC Girders

The software was used to model a series of FRP-strengthened concrete girders with different number of layers tested in the laboratory under monotonically increasing load. The model successfully described the global inelastic behavior of the girders and the corresponding distribution of flexural, axial and bond stresses along the girder length, as shown in Figures (3) and (4). The model in this form could be used by designers to evaluate the stress in the FRP sheets under different loading conditions, the necessary number of layers to achieve a certain level of strength; and to detect the failure mode and whether it's due to bond delamination, rupture, or concrete crushing.

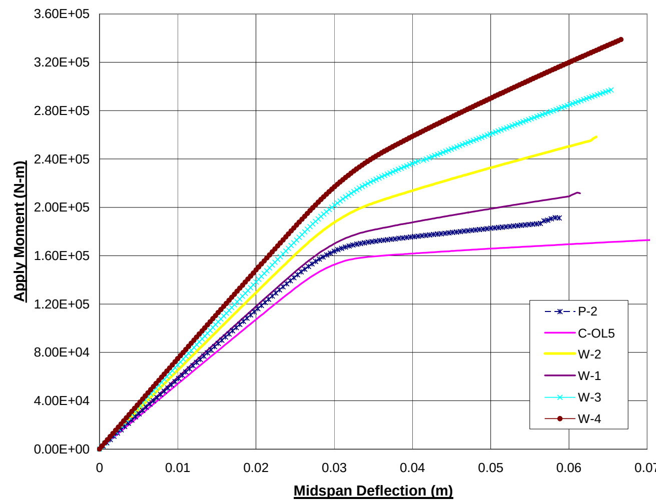

Figure 3 Load-Deformation of FRP-Strengthened RC Girders

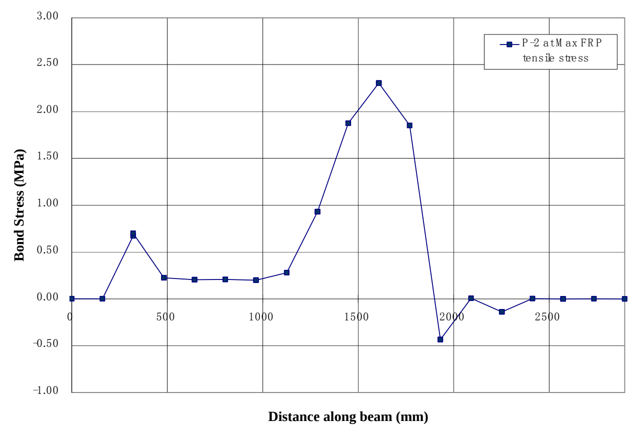

Figure 4 Interfacial Bond Distribution

OBJECTIVE

The work was initially proposed to be performed over a 2-year period. In the second year, the development of the numerical work will continue and will focus on the tasks described below.

WORK PLAN

The research work in Year 2 consists of the following tasks:

Task 1: Evaluation of degradation effects due to seismic excitations:

The development of design specifications related to the application of FRP laminates to strengthen concrete girders in seismic regions has been the focus of ACI committee 440 lately. However, issues related to seismic demand evaluation of FRP-strengthened concrete girders, particularly to degradation under reversed cyclic loading is not fully understood. The objective of this task is to extend the current model to consider cyclic effects. For this purpose, the constitutive models of concrete, steel, FRP, and bond will be extended to account for damage under reversed cyclic loading.

Task 2: Evaluation of design specifications under monotonic and cyclic loads:

The design specifications of committee 440 recommend using a limitation on the strength of FRP sheets using a bond dependent coefficient κ_m given below, in order to prevent debonding of the FRP laminate (Equation 9.2 in the design specifications):

$$\kappa_m = \frac{1}{60\varepsilon_{fu}}\left(\frac{1-nE_f t_f}{2,000,000}\right) \leq 0.9 \;\; for\; nE_f t_f \leq 1,000,000$$

$$\kappa_m = \frac{1}{60\varepsilon_{fu}}\left(\frac{500,000}{nE_f t_f}\right) \leq 0.9 \;\; for\; nE_f t_f \geq 1,000,000$$

This limitation, however, was derived based on visual observations and experience, and is considered to be conservative. With the development of the new software, accurate evaluation of the potential for debonding is possible. A series of numerical simulations of different concrete specimens will be performed, which will result in a thorough evaluation of the aforementioned design specifications. Furthermore, recommendations for a similar expression for the case of seismic excitations, where severe degradation under cyclic loads is expected, will be made.

Task 3: Development of Windows-Based Graphical Interfaces:

While the developed software has numerous structural capabilities, it is not in its current form Windows-supported. The goal of this task is to produce a user-friendly version of the software that relies on graphical-based pre and post processors. This extension will facilitate the use of the software by practicing structural engineers.

Task 4: Development of elements to model concrete girders reinforced by FRP bars:

Modeling of concrete girders reinforced by FRP bars, is very similar in concept to modeling of concrete girders strengthened with FRP sheets. The objective of this task is to extend the capabilities of the software to model this type of structures. Similar to the previous model, this new element will consider seismic effects, and damage under cyclic loading. A series of numerical simulations will be also performed in order to propose design recommendations for concrete girders reinforced by FRP bars to committee 440.

BUDGET

Budget for this project will cover only support for a graduate student for a period of one year for a total amount of $15,000.

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