

Near-surface mounted FRP Reinforcement:

application of an emerging technology

Introduction

Of the approximately 590,000 bridges in the National Bridge Inventory of the United States Federal Highway Administration, around 50,000 are classified as structurally deficient, 89,000 functionally obsolete and 54,000 both structurally deficient and functionally obsolete. These numbers indicate that over 40% of the nation's bridges need imminent repair or replacement. Budget constraints prohibit many states from repairing or replacing all of these bridges: several states have to place signs near their bridges indicating that there are load restrictions. This is a temporary solution until more funds become available.

Fibre-reinforced polymer (FRP) material systems – fibres embedded in a polymeric matrix – have several properties that make them suitable as structural reinforcement. FRP composites are anisotropic and characterised by excellent tensile strength in the direction of the fibres. They do not exhibit yielding, being elastic up to failure. They are also corrosion-resistant, and should demonstrate better weather resistance than other construction materials.

Structural retrofit work has become increasingly important in response to the worldwide ageing infrastructure problem. This situation, together with revisions to structural codes which better accommodate natural phenomena, create the requirement for development of successful structural retrofit technologies. The most important factors relating to remediation are the predominance of labour and shutdown costs as opposed to material costs, time and site constraints, long-term durability, difficulty in methodology selection and design, and evaluation of effectiveness.

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Figure 1: Three-span concrete slab bridge.

The use of near-surface mounted (NSM) FRP bars is emerging as a complementary technology to externally bonded FRP laminates, which have already proved an effective upgrade technique for reinforced concrete (RC) structures⁽¹⁾. The technique involves embedding a bar. A groove is initially cut in the concrete surface along the desired direction. Groove depth is minimal so that it does not significantly affect the concrete cover of the steel reinforcement and the groove is half-filled with epoxy paste. The FRP bar is then lightly pressed into the paste. Finally, more paste is added and the surface levelled. The NSM FRP technique is an attractive way of increasing the flexural and shear strengths of deficient RC members^(2, 3) together with strengthening unreinforced masonry walls⁽⁴⁾. These areas of research are being investigated at the University of

Missouri-Rolla. Aslan 500 FRP tape, supplied by Hughes Bros, was used. The NSM FRP technique does not require any surface preparation and, after groove cutting, installation is much quicker than for FRP laminates. Another advantage is the feasibility of anchoring the bars into members adjacent to that being strengthened. This technique becomes particularly attractive for strengthening in negative moment regions, where external reinforcement would be subjected to mechanical and environmental damage, requiring protective cover that could interfere with the driving surface.

Applying the technique

This article focuses on the use of NSM FRP by examining an ongoing project conducted by University of Missouri-Rolla. The bridge selected for demonstration of the FRP strengthening



Figure 2: Longitudinal crack in soffit slab.

technology is on old Route 66, now Martin Springs Outer Road, in Phelps County, Missouri (Figure 1). The bridge was commissioned in 1926 and was originally on a gravel road. In 1951, the last miles of US Route 66 through Phelps County were concrete-paved, and in 1972 Route 66 was replaced by I-44. Commissioning of I-44 led to a significant decrease in traffic along Route 66. Load restrictions were placed on the bridge around 1985. This has a significant impact on

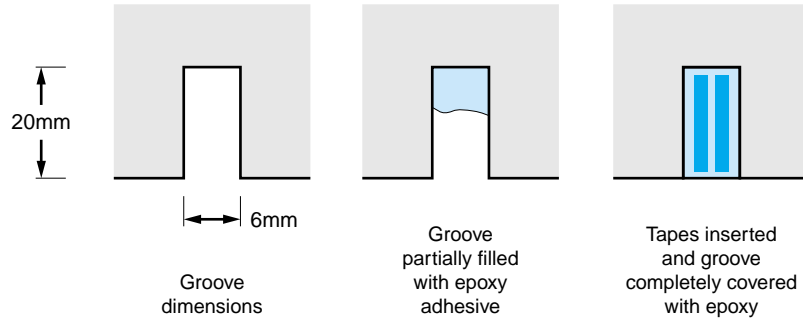


Figure 3: Lateral cross-section of strengthening with tapes (not to scale).

the local economy for, whenever I-44 is closed, heavy unauthorised traffic has to cross this bridge. It is expected that restrictions will be removed after the proposed strengthening scheme.

The bridge consists of three simply supported 360mm-thick solid RC slabs. Each span is 6.71m long and 6.86m wide. From visual inspection and NDT testing, it was determined that the slabs are reinforced longitudinally with 25.4mm steel reinforcing bars at 130mm centres and that no transverse steel reinforcement is present.

The bridge represents an ideal case for the application of FRP composites since its deficiency is primarily due to a lack of transverse reinforcing steel. The

area where the FRP is to be installed showed excellent surface integrity. A single crack, over 25mm wide in places (Figure 2), extends longitudinally through the three spans along the centre-line. There is no significant cracking elsewhere and only minor reinforcement corrosion was detected.

Strengthening details

Analysis of the bridge before and after strengthening was conducted according to the American Association of State Highway and Transportation Officials (AASHTO)⁽⁵⁾ and the Missouri Department of Transportation (MoDOT) Design Specifications⁽⁶⁾. For both moment and shear, the

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		Tape*	Laminate*
Ultimate tensile strength	f_{tu} (MPa)	1380	3790
Ultimate rupture strain	ξ_{fu} (mm/mm)	0.0134	0.017
Tensile modulus of elasticity	E_f (GPa)	138	228
Nominal thickness	t_f (mm)	2.0	0.165

Table 1: FRP material properties.

* Tape properties are related to gross cross-section; laminate properties are related to fibre content.

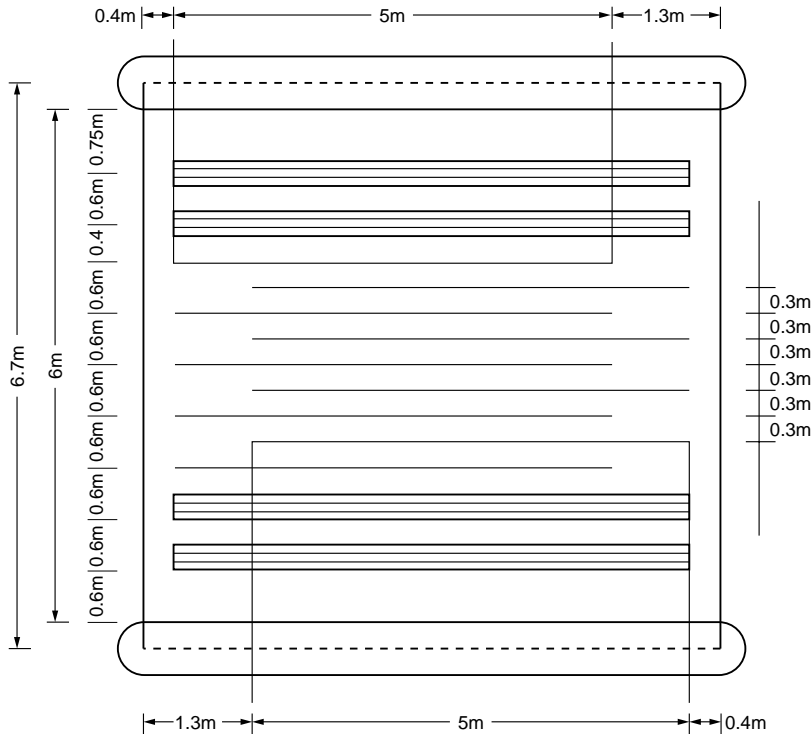


Figure 4: Strengthening layout.

capacity before strengthening exceeds the demand on the structure; consequently, no longitudinal strengthening is needed.

The aim of strengthening is to provide the necessary transverse reinforcement so that load restrictions can be removed. Since there was no transverse reinforcement, minimal strengthening is required to achieve transverse design moment capacity that is equal to or greater than the cracking moment. Two commercially available carbon FRP systems – NSM tapes and externally bonded laminates – are used in combination for this project, but the structure could have been strengthened using either technique. Some material specifications relative to the selected systems are presented in Table 1. Other systems of equivalent characteristics are available in the marketplace. Figure 3 illustrates the lateral cross-section of the NSM tape-strengthening method, while Figure 4 shows the layout of the strengthening scheme proposed for one of the three spans.

The unit cost of the materials for this project could be about \$3.5/m (£2.44) for the FRP tape and a further

\$3.5/m for the epoxy paste. The labour cost for the FRP tape, including preparation of the structure, could be around \$11.5/m (£8). It should be



Figure 5: Bridge load test before strengthening.

noted that these values are highly dependent on the market and labour availability and do not include profit or company overhead.

Future work

Martin Springs Bridge will be field-tested elastically before and after strengthening. Load testing will be performed to complement the analytical results with the measured deflections, illustrating the additional system stiffness achieved and with the main objective of removing the load restrictions on this bridge. The performance of the structure under service loads will be verified and the two FRP systems directly compared.

As of March 2002, the load test before strengthening had been conducted to evaluate the performance of the structure (Figure 5). Strengthening will be conducted by the contractor, under University of Missouri-Rolla supervision, once the weather is favourable. Afterwards, a load test will be conducted and the results analysed.

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Further information

University Transportation Centre, University of Missouri–Rolla website: www.utc.umr.edu/Project
 ACI COMMITTEE 440 Guide for the design and construction of concrete reinforced with FRP bars, ACI 440.1R-01, *Manual of concrete practice*, American Concrete Institute, Farmington Hills, 2002, p.41.