Increased Design Life in New England Bridges Using HPC/FRP Materials

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New England Bridges are commonly subjected to de-icing salts at a rate of over 5 tons per lane mile. To compound the problems associated with the imposed corrosive environment, a typical New England bridge will experience over 100 freezing and thawing cycles per winter season. The New Hampshire Department of Transportation (NHDOT) in partnership with the University of New Hampshire (UNH) are investigating the use of high performance concrete (HPC) and fiber reinforced polymeric (FRP) composites to achieve more cost effective corrosion and freeze and thawing resistant bridge decks. The specific design characteristics and material choices selected for field evaluations are used in two experimental New Hampshire bridges; the Route 104 Bridge in Bristol, NH constructed with HPC and the Rollins Road Bridge in Rollinsford, NH to evaluate HPC mixtures and FRP products. The primary focus of this paper is the use of FRP products with HPC as incorporated in the Rollins Road Bridge.

Introduction: The simply supported 110' Rollins Road Bridge spans the Boston Main Railroad and Main St. in Rollinsford, NH. Prestressed concrete bulb tee girders support the two-lane exposed HPC deck. The bridge's 8" thick deck is reinforced exclusively with FRP composite grids. The positive and negative flexure reinforcement consists of C19 grids and C13 splice grids. Similar to the specified development lengths for splicing steel reinforcement, FRP grids require a certain amount of overlap to transfer forces between grids. The primary (C19) grids are joined using overlapping C13 grids to transfer force over butt joints.

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Figure 1: Before (left) and after construction (right) photos of the Rollins Road Bridge.

The NHDOT design uses the HS-25 truck load case. An impact factor of 1.3 was used in accordance the AASHTO Standard Specification. From the loading conditions investigated by the NHDOT, the applied maximum moment from factored loads is 14.81kN-m (10.92 k-ft). The design capacity of the slab in bending is estimated to be 18.26kN-m (13.46 k-ft), which is sufficient to resist the applied maximum moment.

HPC Mixture: Table 1 lists the experimental materials and additives used in the HPC mixture cast in the exposed bridge deck.

Material	Saturated Surface Dry Weight, kg/m^3 (lb/yd^3)
coarse aggregate	1074 (1805)
fine aggregate	717 (1205)
silica fume-blended cement	313 (526.4)
ground granulated blast furnace slag	78 (131.6)
water	148.4 (250)
Additives	**Dosage per yd^3**
WRDA w/ HYCOL	195.4 ml / 100 kg of cement (3 oz / 100 lbs of cement)
DAREX II	44.4 ml (1.5 oz)
DARICEM 100	1172 ml / 100 kg of cement (18 oz / 100 lbs of cement)

Table 1: Mix Design Used in Experimental HPC Deck

The actual Rollins Road Bridge deck mixture varied slightly as different material suppliers were used. Several of the HPC performance characteristics surpass the minimum HPC performance specifications (Trunfio, 2001). The 56-day compressive strength of the concrete averaged 45.8 MPa (dry cure), which qualifies it as "HPC Grade 1" (Goodspeed, 1996). Additional HPC performance characteristics are given in Table 2.

Performance Characteristic	**Performance of Experimental Concrete**	**FHWA HPC Performance Grade**
modulus of elasticity	25.5 Gpa (3,700 ksi)	n/a
56-day compressive strength	45.8 Mpa (6636 psi)	1
56-day drying shrinkage	723 με	1
56-day chloride penetration	900 - 1600 coulombs	2

Table 2: Concrete Performance Compared To HPC Definitions

Table 3 displays the mixture characteristics of the fresh concrete.

Test	**Results**
slump	108mm (4.25")
unit weight	2260 kg/m^3 (140.7 lb/ft^3)
air content	6.00%
W/C ratio	0.443

Table 3: Fresh Concrete Characteristics

FRP Reinforcement: The experimentally determined modulus of elasticity of the FRP used in the deck was determined to be 71.8GPa (10,410ksi). According to the NEFMAC Technical Leaflet, the FRP has a fiber volume of 43.2%. From Schmeckpeper's dissertation (1992), the ultimate strength of the FRP is 1.17Gpa (170ksi). The ultimate strain for carbon/vinylester composite material is estimated to be 14,000με (NEFMAC Technical Leaflet 2000). FRP does not yield and fails in a brittle mode resulting in a design approach that balances a concrete compression failure to 25% of the ultimate strain in the FRP. Although this creates an over-reinforced slab, it provides a factor of safety against rupture at 4. The area of each C19 FRP bar is 0.248 in^2. The 4" spacing of the primary reinforcement provides 0.744 in^2 of reinforcement per foot of deck. Since identical grids are used for positive and negative moment reinforcement, there is an equal amount of reinforcing in the top and bottom layer of

FRP. Although the area of reinforcement required for temperature and shrinkage is 0.104 in^2 per transverse foot of deck width, the 12" spacing provides 0.248 in^2.

As shown in Figure 2, the cells in the FRP grid become more tightly spaced near the ends. Cells sizes change from 4" x 12", to 4" x 6" where the splice grids overlap. The C13 splice grids span four rows of cells (two for each C19 grid that it joins). The uninterrupted concrete that exists in the 4" x 6" cells transfers the forces between the grids. The strength of the splice between C19 and C13 FRP grids was investigated and determined to be sufficient in tests conducted by Trunfio (2001) at UNH. A full-scale slab test was conducted at UNH to simulate the loading for the Rollins Road Bridge deck.

FRP GRID SIZES

GRID	SIZE	LENGTH	WIDTH	QTY
A	C19	5'-11"	9'-3"	4
B	C19	7'-4"	9'-3"	28
C	C19	5'-11"	7'-1"	4
D	C19	7'-4"	7'-1"	28
E	C19	2'-3"	11'-10"	4
F	C19	2'-3"	7'-5"	2
G	C19	7'-4"	11'-10"	30
H	C19	7'-4"	7'-5"	15
LES	C13	2'-4"	9'-3"	30
LIS	C13	2'-4"	7'-1"	30
UES	C13	2'-4"	11'-10"	32
UIS	C13	2'-4"	7'-5"	16

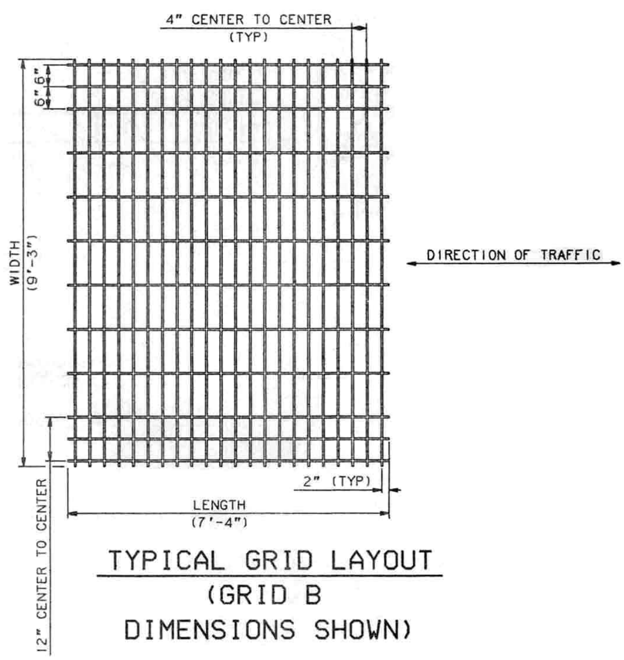

Figure 2: Grid Dimensions and Nomenclature

The following figures show the FRP grid locations for the entire deck of the Rollins Road Bridge. Figure 3 shows the layout of the FRP grids that were placed in the bottom of the slab. Figure 4 shows the layout for the top layer of FRP. The minimum cover for all FRP in the deck is specified as 50mm (2"). Figure 5 and 6 show the cross-sectional details marked in Figures 3 and 4.

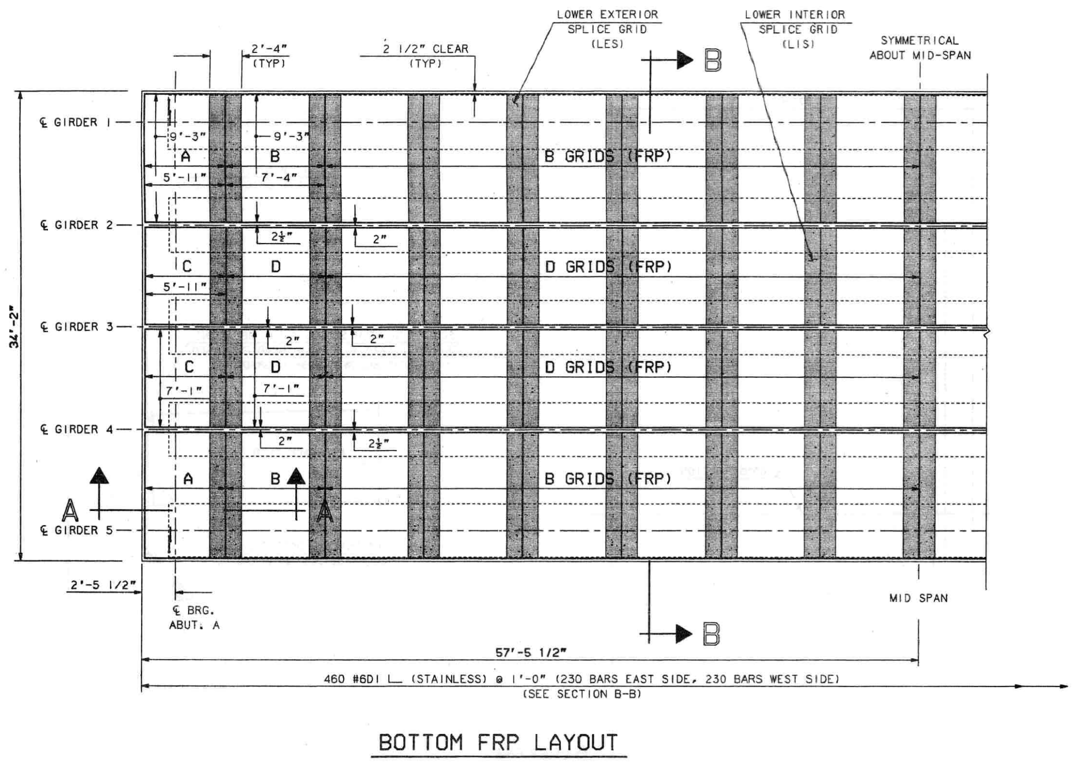

Figure 3

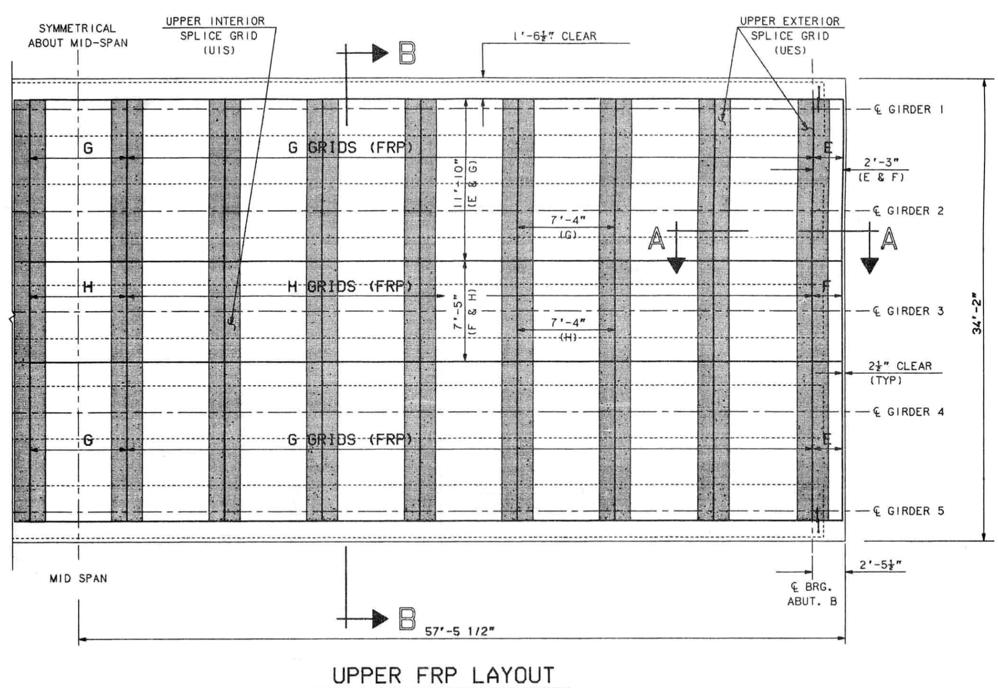

Figure 4

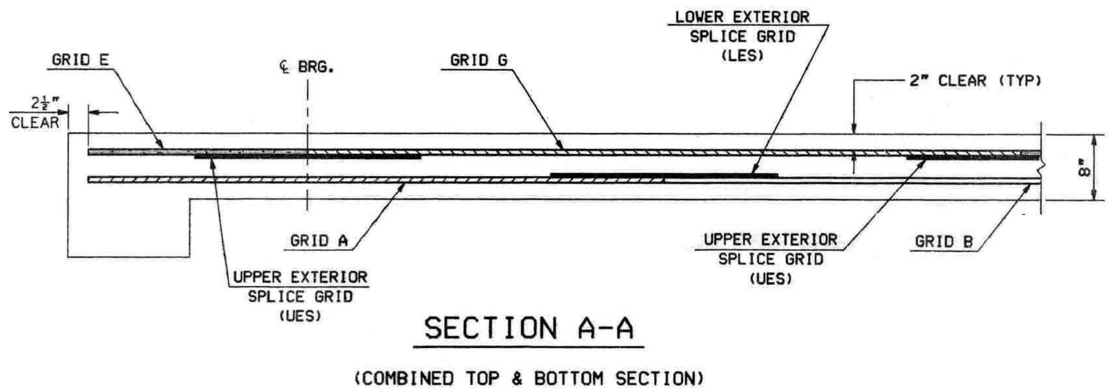

Figure 5: Refer to Figure 2 and 3 for Location of Section A-A

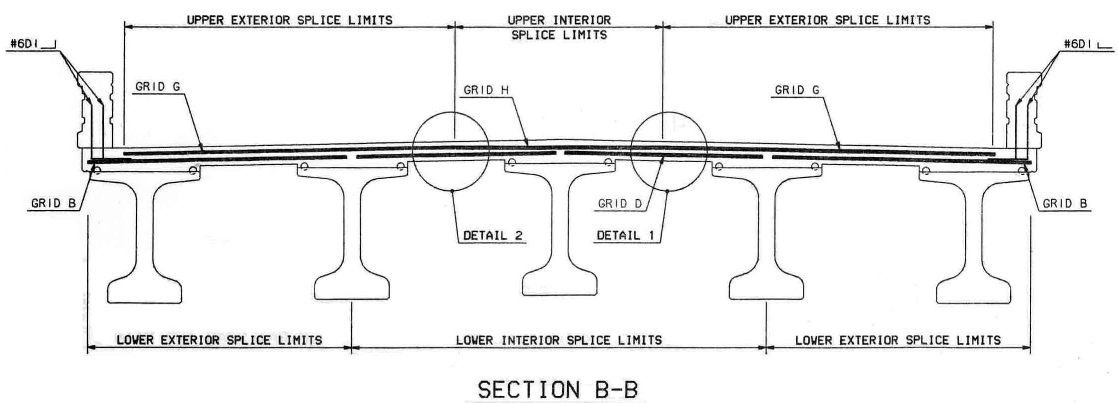

Figure 6: Refer to Figures 2 and 3 for Location of Section B-B

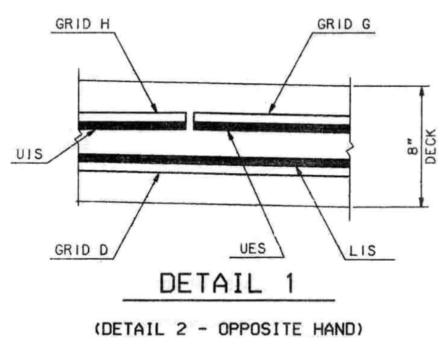

Figure 7: Refer to Figure 5 for Location of Detail 1 and 2

For Figures 5 – 7, refer to Figure 2 for information regarding dimensions and nomenclature of FRP grids.

Although the deck is essentially "steel-free," stainless steel is used to anchor the 810mm (32") guardrail. The rail is a concrete parapet with raised panels, and is not considered a NHDOT standard design. #6 bent stainless steel bars extend from the HPC deck into the rails. The bars extend approximately 510mm (20" into the cast-in-place rail, and are spaced 305mm (12") o.c. The rails are longitudinally reinforced with stainless bars and C19 FRP grids.

Girders: Five Prestressed New England Bulb Tee (NEBT) girders support the deck of the Rollins Road Bridge. The girders are specified as NE1400, where the "NE" represents New England, and the "1400" represents the girder's depth in millimeters. The compressive strength of the concrete in the girders is 8 ksi. The prestressing strands are uncoated 15.2mm (0.6") diameter seven wire strands made of grade 270 low relaxation steel. Figure 8 shows the strand pattern for the girders at midspan. A total of 40 strands per girder are used to produce the NE1400 prestressed girders used for the Rollins Road Bridge.

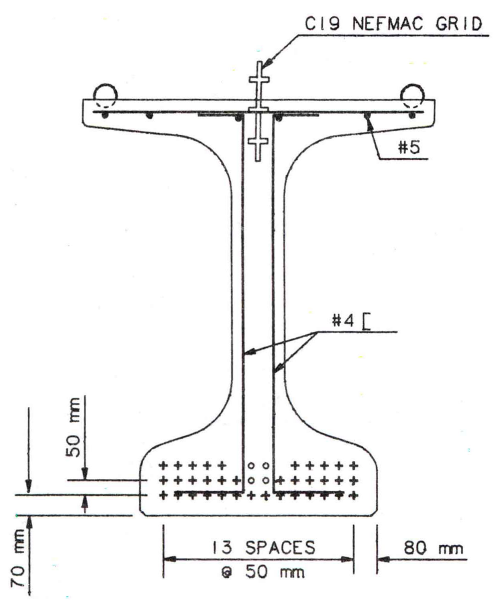

Figure 8: Cross-section of a NEBT1400 Prestressed Girder

Two separate mechanisms contribute to the composite behavior of the Rollins Road Bridge. First, the top surface of the upper flange of the prestressed girders was raked with 6.4mm (¼") grooves perpendicular to the centerline of the bridge span. Once the cast-in-place deck cures, these grooves provide a surface on which the HPC deck can transmit shear forces. Next, FRP composite shear studs were cast into the upper flange of the girders. The studs were cut from C19 NEFMAC grids, and extend approximately 75mm (5”) into the deck. The studs are spaced 610mm (24”) o.c. along the centerline of each girder for the entire length of the bridge. The NHDOT estimates that 68% of the shear force between the girders and the deck is carried by the roughened surface of the girders, while the remaining 32% is transferred by the FRP shear studs.

Conclusions: While it is simple to express the increase in initial investment associated with using HPC and FRP, it is more difficult to express the savings associated with these materials due to the changes in service life. For the Rollins Road Bridge, the use of FRP cost the NHDOT approximately $200,000 (materials only). The estimated cost for steel reinforcing for the same job was $30,000. Although the cost for FRP is many times more expensive than steel, it is lighter and prefabricated into grids which translates into fewer man-hours for installation and no onsite crane is required. For the Route 104 Bridge in Bristol, NH, it is estimated that the use of HPC increased the superstructure cost of the bridge by 10 – 20%. Although the increases in initial investment are significant, there are clear benefits associated with these high performance products.

In the Rollins Road Bridge deck, the use of FRP along with the low permeability and high strength of the deck concrete produces a corrosion-free environment. In harsh environments such as the chloride-rich, freeze-thaw situation imposed by a typical New England winter, the service and maintenance costs for a bridge can outweigh the initial cost. FRP and HPC can extend the service life of bridge decks subjected to these harsh conditions, therefore reducing the life-cycle cost of the structure.