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REHABILITATION OF TRANSPORTATION INFRASTRUCTURE IN WEST VIRGINIA WITH FRP WRAPS

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ABSTRACT

Transportation infrastructure in the United States, particularly concrete highway bridges, are gradually exposed to the deleterious effects of environmental attacks, leading to environmental degradation of the concrete materials. This is due to, for example, carbonation and chloride contamination that eventually break the alkali barrier in the cement matrix, and the steel reinforcement in the concrete becomes susceptible to corrosion. As a consequence, the concrete may deteriorate at the reinforcement level, leading to cracking and spalling of the concrete owing to volume increase of the steel reinforcement. One solution to overcome steel corrosion in concrete for new construction is to use Fiber-Reinforced Polymer (FRP) materials for internal reinforcements instead of steel. More significant is the beneficial application of FRP for structural rehabilitation of deteriorated concrete structures. FRP composite materials in the form of fabrics, laminates, and bars have been externally bonded to concrete structures to increase structural capacity and provide longer service-life. The application of this technology in practice has been highly successful. This paper presents few case studies of the use of FRP composites for rehabilitating bridge structures in the state of West Virginia. Cost of few FRP-wrap projects by West Virginia Department of Transportation (WVDOT) and other state DOTs is addressed. Details of few FRP-retrofitted projects in West Virginia are provided. Purpose of the FRP wraps and retrofit details are documented. Overall conditions of all highway bridges in the state of West Virginia are reported. These data are extracted from the latest National Bridge Inventory by U.S. Department of Transportation, Federal Highway Administration.

Keywords: Concrete bridges, deterioration, structural rehabilitation, FRP composites, externally bonded, case studies

INTRODUCTION

FRP composites are a promising material due to their excellent mechanical characteristics such as high strength-to-weight ratio, corrosion free, favorable maintenance/labor costs, ease of handling and installation, and rapid construction. They have been used in construction field to rehabilitate, retrofit, and strengthen reinforced-concrete structural members for more than three decades. Major FRP bridge applications include FRP deck/panel, FRP beam/girder, concrete deck with FRP rebar/grid, FRP cable/tendon, FRP abutment/footing, FRP parapet/barrier/sidewalk, and FRP column/piling. West Virginia has been recognized as a pioneer in the use of FRP composites. According to American Composites Manufacturers Association (Busel 2016), FRP composites have been used in the construction of approximately 220 bridges nationwide and 35 of those bridges are in West Virginia. WVDOT Division of Highways (WVDOT-DOH) began a program to employ FRP composites for bridge construction and rehabilitation in 1996. The first vehicular bridge with FRP rebar reinforced concrete bridge deck in the United States (Buffalo Creek bridge; a.k.a. McKinleyville bridge) was built in 1996 in McKinleyville, the Northern Panhandle of West Virginia. Following the

TABLE 1. List of Bridges in West Virginia using FRP composites

No.	Bridge Name	WV County	Year Built/Reconstructed or Rehabilitated	Total Length (ft)	Deck Width (ft)	Bridge Type (Main)	FRP System
1	Goat Farm	Jackson	2004	42.3	15	SSWB	FRP deck
2	Kite Creek	Monroe	2004	34.7	24.2	SSWB	FRP deck
3	Howell's Mill (a.k.a. "Rimmer-White")	Cabell	2003	237.5	32.5	CSBM	FRP deck
4	Robert C. Beach (a.k.a. West Buckeye)	Monongalia	2003	148.7	36.0	Timber Arch – Through Type (STTA)	FRP deck/panel
5	La Chein	Monroe	2003	42.8	24.0	SSWB	FRP deck
6	Market Street	Ohio	2001	180.5	56.0	SSPG	FRP deck
7	Boy Scout Camp	Raleigh	2001	33.1	25.2	SSWB	FRP deck
8	Wickwire Run	Taylor	1997	34.5	21.8	SSWB	FRP deck
9	Hanover	Pendelton	1976/2010	118.4	28.2	SSWB	FRP deck/panel
10	Katy Truss	Marion	1912/2001	90.1	13.9	SSPT	FRP deck
11	Martha Queen's	Lewis	2001	49.5	30.1	SCBB	Deck with GFRP C-bar and abutment with GFRP rebar
12	Montrose	Randolph	2001	40.7	27.5	SSWB	Deck with FRP rebar/grid
13	Dans Run Slab	Mineral	2000	25.3	24.3	SCSL	Deck with FRP rebar/grid
14	Buffalo Creek (a.k.a. McKinleyville, 1st vehicular bridge with FRP rebar in the US)	Brooke	1996	180.0	29.5	CSWB	Deck with FRP rebar/grid
15	North Kayford	Kanawha	1940/2000	43	24.2	SCBB	Deck with FRP rebar/grid
16	North Acme	Kanawha	1940/2001	35.3	24	SCBB	Deck with FRP rebar/grid

17	South Acme (FRP Rebars)	Kanawha	1940/2001	34.4	24.1	SCBB	Deck with FRP rebar/grid
18	Barrackville Covered	Marion	1853/1999	150	15.3	STCO	FRP tendon/cable
19	Laurel Lick	Lewis	1997	20.0	16.0	All-composite	FRP deck, beam, and substructure

successful use of FRP composites in this bridge, many other FRP-bridge projects (FRP deck or concrete deck reinforced by FRP rebar/grid) in the WV state were completed during 1996-2004 period (Table 1). Major FRP-retrofitted bridge projects in the state of West Virginia are listed in Table 2. It has been found that candidate structures/elements suitable for FRP retrofit include, but not limited to, beams/girders, slabs, bents, columns/piles/pier caps, and abutments/footings.

Note: SSWB = Simple Steel Wide-Flange Beam; SSPT = Simple Riveted Pony Truss Spans; CSBM = Continuous Steel Stringer/Multi-Beam or Girder; STCO = Single-Span Timber Covered Bridge; SCTB = Simple-Span Concrete T-Beams; SSPG = Structural Steel Plate Girder; CSWB = Continuous Steel Wide-Flange Beam; SCBB = Simple Prestressed Concrete Box Beam; SCSL = Single Reinforced Cast-In-Place Concrete Slab Spans.

Table 2. List of FRP-Retrofitted Bridges in West Virginia

No.	**Bridge Name**	**WV County**	**Year Built/Retrofitted**	**Total Length (ft)**	**Deck Width (ft)**	**Bridge Type (Main)**	**FRP System**
1	Madison Avenue Overpass	Cabell	1966/2014	118.2	64.8	SSWB[1]	GFRP Wraps
2	East Street Viaduct	Wood	1907/2001, 2012	64.7	N/A	Concrete slab/tunnel	GFRP Wraps
3	Muddy Creek	Preston	1943/2000	129.0	29.7	SCTB[2]	CFRP Wraps
4	Flag Run	Preston	1940/2002	43.2	27.0	SCTB[2]	CFRP Wraps
5	East Lynn Lake Campground	Wayne	1969/2014	126.5	NA	NA	GFRP Jacket/Wraps
6	Pond Creek Road Overpass	Wood	1967/1998, 2009	NA	NA	NA	GFRP Jacket/Wraps

Note: [1] Simple Steel Wide-Flange Beam (SSWB); [2] Simple-Span Concrete T-Beams (SCTB)

COST OF FRP WRAPS

Despite high material cost associated with FRP composites, the initial cost of the FRP wraps is only a fraction of the total retrofitting cost. The remaining cost is attributed to the labor, maintenance, and application costs (Manukonda 2011). The ease of installing, storage, handling and transportation benefits of FRP wraps leads to a great reduction in the overall cost of the rehabilitation. According to Lee (2005), the cost of rehabilitation was estimated at 25% of the cost of bridge replacement. Cost effectiveness of FRPs in the rehabilitation of existing structural system has been confirmed by many researchers (Buyukozturk and Hearing 1998, Hassan & Rizkalla 2002, Teng et al. 2007, Ilki et al. 2008, Del Vecchio et al. 2014). FRP composites also possess potential lower life cycle costs (Karbhari and Zhao 2000). The life cycle cost associated with the FRP wraps consists of fabrication and erection cost, maintenance cost (e.g. labor, material, and equipment cost), inspection/repair costs, and the disposal costs (Pamulaparthy 2015). Table 3 shows the total cost of few FRP-retrofitted projects in the state of West Virginia (South Branch Valley Railroad, SBVR), and other states including Wisconsin, California, Indiana, Michigan, Hawaii, Florida, Ohio, Mississippi, Iowa, Alabama, and Cobb County Government – Georgia (Manukonda 2011). As can be seen, the cost is varied from state to state depending on many factors such as total retrofitted areas, labor rates, material/equipment/overhead costs, etc.

Table 3. Total Contract Values of FRP-Retrofitted Projects by State DOTs (Manukonda 2011)

Project Description	**State**	**Retrofitted Element**	**Number of Elements**	**Application**	**Year**	**Retrofitted Material**	**Number of Layers**	**Area (ft^2)**	**Contract Value**
Wisconsin DOT I-90	WI	Column	12	Corrosion repair	2004	Glass fabric[2]	2	3,700	$40,000
SR-22 Bridge	CA	Column	6	Column strengthening	2005	Glass fabric[2]	4	10,500	$111,000
Indiana DOT	IN	Column	26	Concrete repair/protection	2006	Glass fabric[2]	2	2,700	$39,780
Michigan DOT	MI	Column	6	Concrete repair/protection	2006	Glass fabric[2]	2	2,000	$32,100
Hawaii DOT	HI	Column	3	Seismic retrofit	2006	Glass fabric[2]	5	4,700	$155,000
Florida DOT	FL	Pile	16	Corrosion protection	2008	Glass fabric[2]	3	5,500	$219,000

Hawaii DOT[*]	HI	Bent cap	38	Seismic retrofit	2009	Carbon fabric[3]	3	6,400	$178,000
Ohio DOT I-74	OH	Bent cap	4	Shear reinforcement	2005	Carbon fabric[3]	2	600	$32,000
Mississippi DOT	MS	Girder	5	Impact damage	2006	Carbon fabric[3]	1	1,800	$49,000
Iowa DOT	IA	Girder	12	Reinforcing	2006	Carbon fabric[3]	2	3,000	$102,000
Alabama DOT	AL	Girder	9	Tension strengthening	2008	Carbon fabric[3]	4	3,200	$00,000
Cobb County DOT	GA	Girder	50	Shear reinforcement	2008	Carbon fabric[3]	1	5,000	$160,000
SBVR[1]	WV	Pile	2	Pile repair/protection	2010	Carbon fabric[3]	2	46	$1,194
SBVR[1]	WV	Pile	3	Pile repair/protection	2010	Carbon fabric[3]	2	112	$2,928
SBVR[1]	WV	Pile	12	Pile repair/protection	2010	Carbon fabric[3]	2	394	$10,289
SBVR[1]	WV	Pile	3	Pile repair/protection	2010	Carbon fabric[3]	2	137	$3,573
SBVR[1]	WV	Pile	8	Pile repair/protection	2010	Carbon fabric[3]	2	185	$4,827
SBVR[1]	WV	Pile	2	Pile repair/protection	2010	Carbon fabric[3]	2	69	$1,801
SBVR[1]	WV	Pile	4	Pile repair/protection	2010	Carbon fabric[3]	2	88	$2,300
SBVR[1]	WV	Pile	7	Pile repair/protection	2010	Carbon fabric[3]	2	196	$5,109

SBVR[1]	WV	Pile	2	Pile repair/protection	2010	Carbon fabric[3]	2	25	$653
SBVR[1]	WV	Pile	9	Pile repair/protection	2010	Carbon fabric[3]	2	179	$4,657
SBVR[1]	WV	Pile	5	Pile repair/protection	2010	Carbon fabric[3]	2	54	$1,408

Note: [1] South Branch Valley Railroad (SBVR); [2] Tyfo® SEH-51A glass fabric; [3] Tyfo® SCH carbon fabric

FRP-RETROFITTED BRIDGE PROJECTS BY WVDOT

Two typical FRP-retrofitted bridge projects in West Virginia are introduced in this section. The FRP wraps externally bonded to the concrete surface to compensate for strength lost due to corrosion, deterioration, or fire/impact damage. The use of FRP wraps allows the rehabilitation of the existing concrete, resulting in an economic repair as substructure replacement generally requires replacing the entire bridge. These repairs have saved the WVDOT thousands of dollars compared to conventional repairs. Bridge data provided herein are compiled from inspection reports provided by the WVDOT-DOH.

Madison Avenue Overpass Bridge

Madison Avenue overpass bridge (Figure 1) is located 0.57 miles north of Interstate I-64 in Huntington, West Virginia (District 2, Cabell county). This bridge was built in 1966 with four lanes of traffic and 16,900 average daily traffic (as of 2012). According to WVDOT 2016 bridge inspection report, the structure consists of three steel-beam spans (SSWB) with span lengths of 30’-0”, 57’-6” and 25’-6” centerline to centerline of bearings. It is supported at both ends by reinforced concrete stub abutments, which are founded on spread footings, and intermediately by two open-type reinforced concrete piers. The elevation of the bottom of the footing is 567.16 at Abutment No. 1, 551.00 at Piers No. 1 and 2, and 565.79 at Abutment No. 2. The overall length (end to end) of this bridge is 118’-2 ½”. The 7” reinforced concrete deck, which includes a ½” wearing course, is 62’-5” wide (parapet to parapet). The asphalt wearing surface is an average 6” thick. The deck width (out to out) is 65’-2”. WVDOT 2012 interim inspection report revealed that pier #2 was severely spalled and delaminated. Deck and superstructure were in very good condition while piers and pier caps are in poor condition. The geometry of the bridge was such that the two ends are at different elevations with south end at lower elevation and north end at higher elevation. As the pier caps on the south end were at lower elevation, they are affected severely by the rainwater seeping from this end (Kotha 2013). Pier caps were scheduled for repair beginning March 2012 and they were rehabilitated utilizing concrete patch and GFRP wraps. According to William (2016), total repair cost of this bridge is approximately $47,637 ($42 per square feet) while estimated costs to replace piers and/or entire bridge are from 1.2 to 2.5 million dollars. This indicates the cost effectiveness of the FRP-strengthening system. It is predicted that more than one thousand bridges in the state of West Virginia will benefit from this cost-effective repair system using FRP jackets.

(a) Bridge elevation (looking west) (courtesy: WVDOT 2018 routine inspection report)

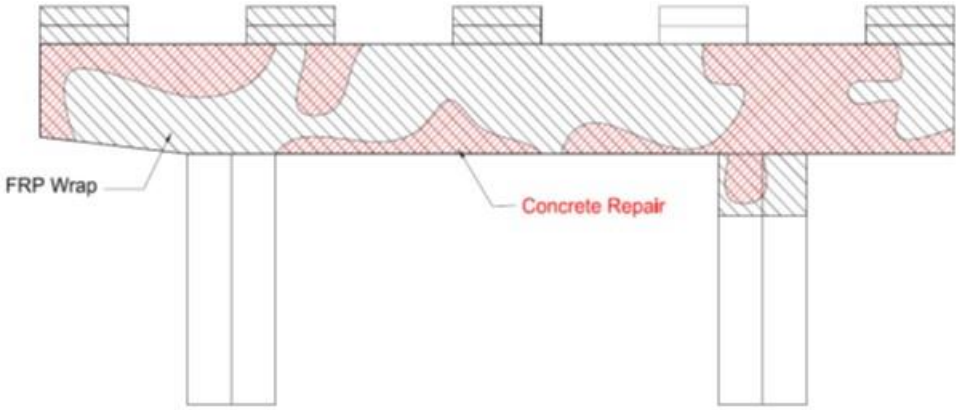
Spalling and exposed rebar on east cap, pier #2

Spalling and exposed rebar on bottom of a cap, pier #2

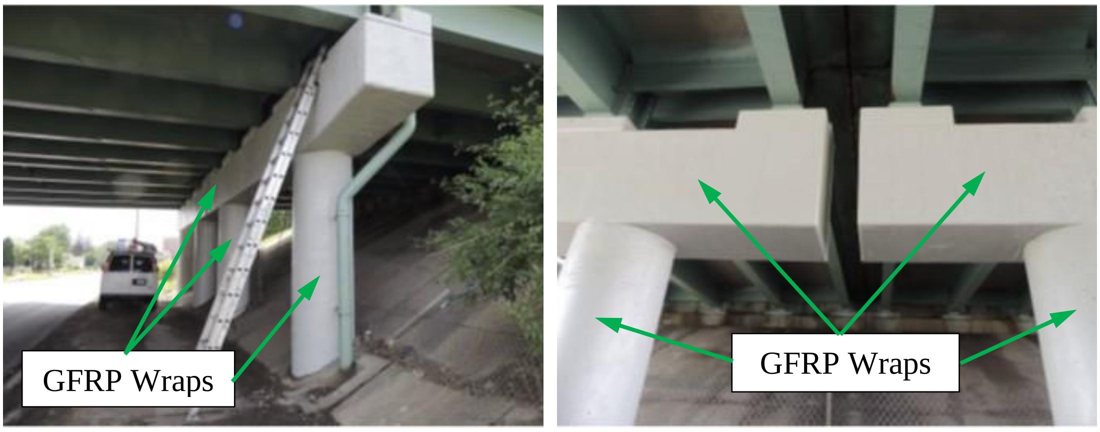
Cracking on column #1, pier #2

Cracking and delamination on pier #2

(b) Bridge condition before rehabilitation (courtesy: WVDOT 2012 interim-condition inspection report)



(c) Applied concrete patch (top) and locations of GFRP wrap and concrete repair (bottom) (images courtesy of Williams, 2016)



Pier #1

Pier #1 cap

(d) Rehabilitated Piers using FRP wraps (courtesy: WVDOT 2014 periodic inspection report)

Figure 1 Details of Madison Avenue overpass bridge

Flag Run Bridge

Flag Run bridge (Figure 2) is located 0.03 miles north of county route 72/6 in Preston county (District 4), West Virginia. This reinforced concrete (RC) bridge was built in 1940 with two lanes of traffic and 650 average daily traffic (as of 2014). It has a single span with total length of 43.2 ft. and a span length of 40 ft. According to WVDOT 2016 bridge inspection report, the bridge superstructure consists of four RC T-beams (33 in. high and 16.5 in. wide) topped with cast-in-place RC slab and supported by two full-height concrete abutments. Entire bottom face and side faces at both ends of T-beams were wrapped with CFRP composites in 2002 to achieve an HS-25 design loading. Abutments were also wrapped with CFRP and the backwalls were patched.

Bridge elevation

CFRP wraps in abutment #1 and underside of a T-beam

Overview of CFRP wraps in T-beams and an abutment

CFRP wraps at the end of a T-beam

Figure 2. Details of Flag Run bridge (courtesy: 2016 WVDOT bridge inspection report)

SUFFICIENCY RATING AND OVERALL BRIDGE CONDITIONS

Table 4 shows general condition ratings guideline for evaluating deck, superstructure, and substructure by Federal Highway Administration (Report No. FHWA-PD-96-001 “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridge”). Overall bridge conditions can be obtained by a sufficiency rating formula given in Equation 1.

$$\text{Sufficiency Rating} = S_1 + S_2 + S_3 - S_4 \tag{1}$$

where S_1 = Structural adequacy and safety (e.g. superstructure, substructure rating); S_2 = Serviceability and functional obsolescence (e.g. main structure type, deck condition); S_3 = Essentiality or public use (e.g. detour length, average daily traffic); and S_4 = Special reductions (e.g. traffic safety features, main structure type).

The result of this formula is a percentage in which 100 percent would represent an entirely sufficient bridge and zero percent would represent an entirely insufficient or deficient bridge.

Table 4. General Condition Ratings for Evaluating Deck, Superstructure, and Substructure

Code	**Description**
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted
7	GOOD CONDITION - some minor problems
6	SATISFACTORY CONDITION - structural elements show some minor deterioration
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service
0	FAILED CONDITION - out of service - beyond corrective action

According to 2017 National Bridge Inventory (NBI) database (FHWA 2017), West Virginia has 7,228 highway bridges and 19% of these bridges (1,372 bridges) were rated as structurally deficient (SD). In addition, 1,394 bridges (19.3%) were rated as functional obsolete (FO). As shown in Table 5, the bridge type (categorized based on bridges' main structure type) with a large population of SD bridges includes slab type (32.5% deficient out of 517 bridges), girder and floorbeam system type (46.7% out of 229 bridges), tee beam type (47.1% out of 104 bridges), truss – thru type (43.3% out of 180 bridges), arch – deck type (39.8% out of 399 bridges), channel beam type (54.8% out of 115 bridges).

Table 5. Bridge Conditions in West Virginia

Main Structure Type	**Code**	**SD (a)**	**FO (b)**	**Bridge Total (c)**	**a/c (%)**	**b/c (%)**
Slab	***01***	***168***	***144***	***517***	***32.5***	***27.9***
Stringer/Multi-beam or Girder	02	592	516	3085	19.2	16.7
Girder and Floorbeam System	***03***	***107***	***41***	***229***	***46.7***	***17.9***
Tee Beam	***04***	***49***	***25***	***104***	***47.1***	***24.0***
Box Beam or Girders - Multiple	05	92	401	1905	4.8	21.0
Box Beam or Girders - Single or Spread	06	2	8	55	3.6	14.5
Frame (except frame culverts)	07	5	14	52	9.6	26.9
Orthotropic	08	0	2	2	0	100
Truss – Deck	09	0	4	11	0	36.4
Truss – Thru	***10***	***78***	***35***	***180***	***43.3***	***19.4***
Arch – Deck	***11***	***159***	***134***	***399***	***39.8***	***33.6***
Arch – Thru	12	1	2	8	12.5	25.0
Suspension	13	2	1	3	66.7	33.3
Stayed Girder	14	0	0	3	0	0
Movable – Lift	15	NA	NA	NA	NA	NA
Movable – Bascule	16	NA	NA	NA	NA	NA
Movable – Swing	17	NA	NA	NA	NA	NA
Tunnel	18	NA	NA	NA	NA	NA
Culvert (includes frame culverts)	19	46	36	539	8.5	6.7
Mixed types	20	1	0	1	100	0
Segmental Box Girder	21	1	1	3	33.3	33.3
Channel Beam	***22***	***63***	***25***	***115***	***54.8***	***21.7***
Other	00	6	5	17	35.3	29.4
Total		**1,372**	**1,394**	**7,228**	**19.0**	**19.3**

Note: SD = Structurally Deficient; FO = Functionally Obsolete

SUMMARY

This paper presents an overview of FRP wraps for rehabilitation of bridges in WVDOT inventory. Cost of few FRP-wrap projects by West Virginia Department of Transportation (WVDOT) and other state DOTs is addressed. Details of few FRP-retrofitted bridge projects by WVDOT are provided. Overall conditions of all highway bridges in the state of West Virginia are reported. These data are extracted from the latest National Bridge Inventory by U.S. Department of Transportation, Federal Highway Administration.

According to the most recent comprehensive survey on the use of FRP in highway infrastructure (Kim 2017), FRP composites have not been widely adopted by state DOTs and agencies yet. This is due to one or more of the following challenges: (1) Lack of design guidelines and specifications; (2) Lack of skilled workers, designers, and contractors; (3) Inadequate procurement procedures; (4) Limited budget; and (4) Safety concerns (e.g. risk of fire and vandalism). Despite great efforts of many researchers in the field of FRP strengthening/retrofitting, additional research such as long-term durability of in-situ FRP are required to generate more technical data and to convince DOT engineers.

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