

FINAL
CONTRACT REPORT
VTRC 10-CR3

**RAPID REPLACEMENT OF TANGIER ISLAND
BRIDGES INCLUDING LIGHTWEIGHT AND DURABLE
FIBER-REINFORCED POLYMER DECK SYSTEMS**

THOMAS E. COUSINS, Ph.D., P.E.
Professor
Via Department of Civil and Environmental Engineering
Virginia Tech

JOHN J. LESKO, Ph.D.
Professor
Via Department of Civil and Environmental Engineering
Virginia Tech

PRASUN K. MAJUMDAR, Ph.D.
Postdoctoral Fellow
Department of Mechanical Engineering
University of South Carolina

ZIHONG LIU, Ph.D., P.Eng., P.E.
Project Engineer
MMM Group



Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 10-CR3	2. Government Accession No.:	3. Recipient's Catalog No.:	
4. Title and Subtitle: Rapid Replacement of Tangier Island Bridges Including Lightweight and Durable Fiber-Reinforced Polymer Deck Systems		5. Report Date: September 2009	
		6. Performing Organization Code:	
7. Author(s): Thomas E. Cousins, John J. Lesko, Prasun K. Majumdar, and Zihong Liu		8. Performing Organization Report No.: VTRC 10-CR3	
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS):	
		11. Contract or Grant No.: 82671	
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation Federal Highway Administration 1401 E. Broad Street 400 North 8th Street, Room 750 Richmond, VA 23219 Richmond, VA 23219-4825		13. Type of Report and Period Covered: Final Contract	
		14. Sponsoring Agency Code:	
15. Supplementary Notes: This project was financed with a grant from the FHWA Innovative Bridge Research and Deployment Program at an estimated cost of \$158,587.			
16. Abstract: <p>Fiber-reinforced polymer (FRP) composite cellular deck systems were used as new bridge decks on two replacement bridges on Tangier Island, Virginia. The most important characteristics of this application were reduced self-weight and increased durability for an FRP deck system over a reinforced concrete bridge deck. Tangier Island is in the Chesapeake Bay and is accessible only by water or air; each bridge is over saltwater. The two bridge deck systems used were from different manufacturers: Strongwell Corp. and Zellcomp, Inc. The deck system from Strongwell was virtually identical to a previous application by the Virginia Department of Transportation (VDOT) in Covington, Virginia. Because of the extensive testing of this system conducted as part of a prior Innovative Bridge Research and Deployment project, further investigation of its behavior was not warranted. The objectives of the testing of the Zellcomp deck system were four-fold: (1) investigate connection behavior under simulated pseudo-static service load; (2) examine flexural strength and failure mode of connections and deck; (3) explore fatigue behavior during simulated cyclic wheel loading and residual strength after fatigue loading; and (4) investigate viability of transition connection.</p> <p>Two test sections were constructed in the Structures and Materials Laboratory at Virginia Tech. The test sections included sections of the Zellcomp deck attached to supporting steel stringers. The first was flat, 11 ft by 8 ft in plan, and subjected to static and simulated truck loadings. The second included a transition connection and was 17 ft by 8 ft in plan. Of special interest during this testing was the investigation of the static and cyclic behavior of all Zellcomp deck connections (top plate to supporting T-sections, T-section to T-section, and T-section to supporting stringers).</p> <p>The flat Zellcomp deck test specimen had a 1.4 safety factor against sustaining permanent damage and a 2.4 safety factor against failure when subjected to an HL-93 wheel load of 22 kips. There was no measured composite action between the top plate and supporting T-section. Generally, the specimen performed well during the fatigue test. However, there was some indication of deterioration of the lap joint connections at 1 million cycles of load and loss of stiffness at about 2.5 million cycles of load. The bent lap joint connection was difficult to construct. A permanent gap between the top plate and supporting T-sections resulted because of inherent construction tolerances. The slope Zellcomp deck specimen underwent significant deterioration during the first 600,000 cycles of load. Numerous top plate screw connections loosened, with several completely fracturing. The damage to the deck increased for the next 400,000 cycles. .</p> <p>The study recommended that VDOT's Structure and Bridge Division (1) not use the sloped deck transition on any application considering its use on any bridge structure that has truck traffic. The Tangier Island Bridge is subjected to very light truck traffic, and the Zellcomp system proved to be adequate for this specific application only.</p>			
17 Key Words: Fiber-reinforced polymers, bridge deck systems, rapid replacement		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 22	22. Price:

FINAL CONTRACT REPORT

**RAPID REPLACEMENT OF TANGIER ISLAND BRIDGES INCLUDING
LIGHTWEIGHT AND DURABLE FIBER-REINFORCED POLYMER DECK SYSTEMS**

Thomas E. Cousins, Ph.D., P.E.

Professor

**Via Department of Civil and Environmental Engineering
Virginia Tech**

John J. Lesko, Ph.D.

Professor

**Department of Engineering Science and Mechanics
Virginia Tech**

Prasun K. Majumdar, Ph.D.

Postdoctoral Fellow

**Department of Mechanical Engineering
University of South Carolina**

Zihong Liu, Ph.D., P.Eng., P.E.

Project Engineer

MMM Group

Project Manager

Jose P. Gomez, Ph.D., P.E., Virginia Transportation Research Council

Contract Research Sponsored by the
Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

September 2009

VTRC 10-CR3

DISCLAIMER

The project that is the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

Copyright 2009 by the Commonwealth of Virginia.
All rights reserved.

ABSTRACT

Fiber-reinforced polymer (FRP) composite cellular deck systems were used as new bridge decks on two replacement bridges on Tangier Island, Virginia. The most important characteristics of this application were reduced self-weight and increased durability for an FRP deck system over a reinforced concrete bridge deck. Tangier Island is in the Chesapeake Bay and is accessible only by water or air; each bridge is over saltwater. The two bridge deck systems used were from different manufacturers: Strongwell Corp. and Zellcomp, Inc. The deck system from Strongwell was virtually identical to a previous application by the Virginia Department of Transportation (VDOT) in Covington, Virginia. Because of the extensive testing of this system conducted as part of a prior Innovative Bridge Research and Deployment project, further investigation of its behavior was not warranted. The objectives of the testing of the Zellcomp deck system were four-fold: (1) investigate connection behavior under simulated pseudo-static service load; (2) examine flexural strength and failure mode of connections and deck; (3) explore fatigue behavior during simulated cyclic wheel loading and residual strength after fatigue loading; and (4) investigate viability of transition connection.

Two test sections were constructed in the Structures and Materials Laboratory at Virginia Tech. The test sections included sections of the Zellcomp deck attached to supporting steel stringers. The first was flat, 11 ft by 8 ft in plan, and subjected to static and simulated truck loadings. The second included a transition connection and was 17 ft by 8 ft in plan. Of special interest during this testing was the investigation of the static and cyclic behavior of all Zellcomp deck connections (top plate to supporting T-sections, T-section to T-section, and T-section to supporting stringers).

The flat Zellcomp deck test specimen had a 1.4 safety factor against sustaining permanent damage and a 2.4 safety factor against failure when subjected to an HL-93 wheel load of 22 kips. There was no measured composite action between the top plate and supporting T-section. Generally, the specimen performed well during the fatigue test. However, there was some indication of deterioration of the lap joint connections at 1 million cycles of load and loss of stiffness at about 2.5 million cycles of load. The bent lap joint connection was difficult to construct. A permanent gap between the top plate and supporting T-sections resulted because of inherent construction tolerances. The slope Zellcomp deck specimen underwent significant deterioration during the first 600,000 cycles of load. Numerous top plate screw connections loosened, with several completely fracturing. The damage to the deck increased for the next 400,000 cycles.

The study recommended that VDOT's Structure and Bridge Division (1) not use the sloped deck transition on any applications of the Zellcomp bridge deck system; (2) consider close inspection of all screw connections on the Zellcomp deck during regularly scheduled bridge inspections; and (3) consider additional more rigorous full-scale testing of the Zellcomp deck system before considering its use on any bridge structure that has truck traffic. The Tangier Island Bridge is subjected to very light truck traffic, and the Zellcomp system proved to be adequate for this specific application only.

FINAL CONTRACT REPORT

RAPID REPLACEMENT OF TANGIER ISLAND BRIDGES INCLUDING LIGHTWEIGHT AND DURABLE FIBER-REINFORCED POLYMER DECK SYSTEMS

Thomas E. Cousins, Ph.D., P.E.

Professor

**Via Department of Civil and Environmental Engineering
Virginia Tech**

John J. Lesko, Ph.D.

Professor

**Department of Engineering Science and Mechanics
Virginia Tech**

Prasun K. Majumdar, Ph.D.

Postdoctoral Fellow

**Department of Mechanical Engineering
University of South Carolina**

Zihong Liu, Ph.D., P.Eng., P.E.

Project Engineer

MMM Group

INTRODUCTION

The Virginia Department of Transportation's (VDOT) Hampton Roads District scheduled two bridges on Tangier Island for replacement during 2004. Figure 1 shows a photo of the pre-replacement condition of the two bridges. The harsh environmental conditions of the Chesapeake Bay present a durability challenge to the bridges of Tangier Island. Complicating the accessibility to repair and retrofit of these structures is the limited accessibility to the island: i.e. only by air or water. Two bridges were replaced with 55 ft single span bridges of the type shown in Figure 2. The superstructure of each bridge is parallel galvanized steel through trusses with fiber-reinforced polymer (FRP) deck panels to reduce maintenance and increase durability. Moreover, the modularity and lightweight nature of the FRP decks allowed for rapid replacement of these bridges, ensuring continued accessibility of emergency vehicles to the inhabitants of Tangier Island.

The superstructure configuration was selected to promote prefabrication of as much of the bridge as possible. The galvanized steel through trusses were partially assembled on the mainland and moved to the bridge sites. The lightweight FRP deck panels likewise were shipped to a location on Tangier Island where they were transported on land to the bridge sites. The lightweight FRP deck panels were plant fabricated with wearing surface applied and of suitable dimension and weight to ensure ease of handling and installation.



Figure 1. Tangier Island timber bridge

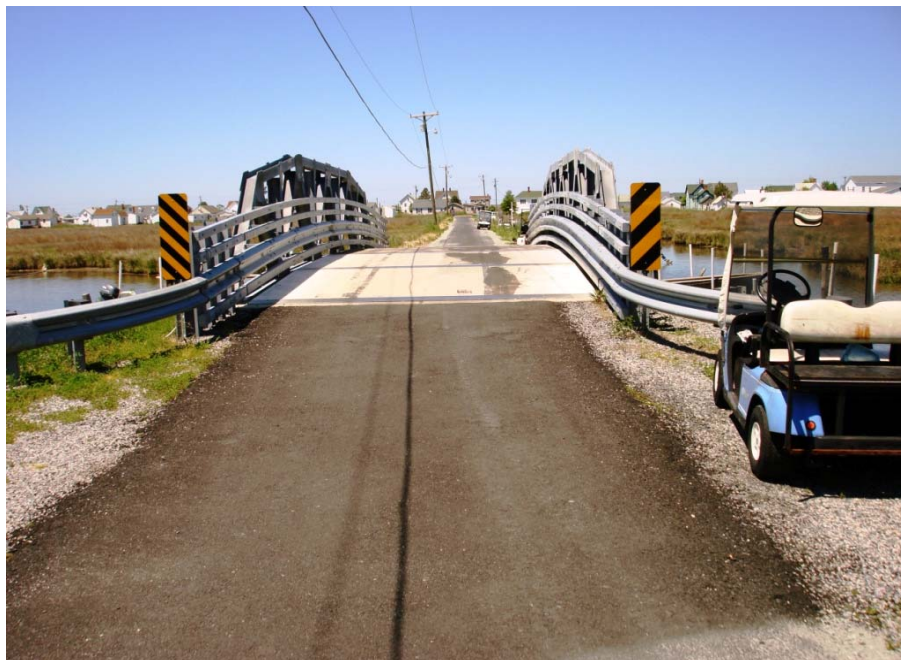


Figure 2. Completed replacement structure for Tangier Island

Two bridge deck systems were used on the two bridges: the Strongwell, Corp., deck and the Zellcomp, Inc., deck. A photograph of a section of the former deck and an adhesively bonded panel-to-panel connection is shown in Figure 3. The deck panels are composed of pultruded square tubes and plate and are shop fabricated using the vacuum bag technique. The panel-to-panel connection is an adhesively bonded tongue and groove type connection that is done in the field.

A similar use of the Strongwell deck is the Hawthorne Street Bridge in Covington, Virginia. The performance of the Strongwell FRP deck was extensively investigated as part of a previous IBRC (Innovative Bridge Research and Construction Program) project awarded in 2003 (2007a). The panel-to-panel connections were accomplished using full width, adhesively (structural urethane adhesive) bonded tongue and groove splices with scarfed edges. To ensure proper construction, serviceability, and strength of the splice, a full-scale two-bay section of the bridge with three adhesively bonded panel-to-panel connections was constructed and tested in the Structures and Materials Laboratory at Virginia Tech. Test results showed that no crack initiated in the joints under service load and no significant change in stiffness or strength of the joint occurred after 3,000,000 cycles of fatigue loading. The proposed adhesive bonding technique was installed in the bridge in August 2006. The Hawthorne Street Bridge was opened to traffic during the fall of 2006.



Figure 3. End view of the Strongwell FRP deck

The Zellcomp, Inc., deck is composed of pultruded shapes mechanically connected in the field. The bottom plate/T assembly is the result of a unique pultrusion dye and the $\frac{1}{2}$ in thick top plate is standard pultruded sheet. The top sheet and bottom plate/T assembly are joined together using stainless steel screws. Also, the adjacent bottom plate/T assemblies are connected at a 2 in lap joint using stainless steel screws. A cross section of the Zellcomp deck is shown in Figure 4.

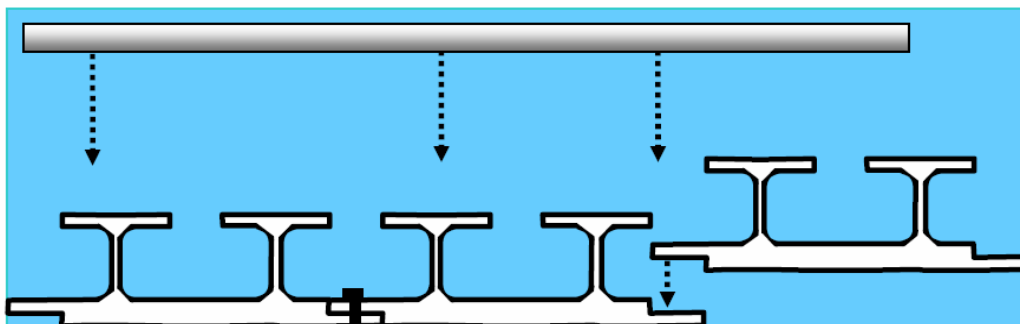


Figure 4. Cross section of the Zellcomp FRP deck

PURPOSE AND SCOPE

Two FRP bridge deck systems were used on the two Tangier Island Bridges (Strongwell FRP bridge deck system and Zellcomp FRP bridge deck system). Because of the extensive testing of the Strongwell FRP bridge deck system conducted as part of a previous IBRC project (2007a), further investigation of its behavior was not warranted.

The objectives of the testing of Zellcomp FRP bridge deck system were four-fold: (1) investigate connection behavior under simulated pseudo-static service load; (2) examine flexural strength and failure mode of connections and deck; (3) explore fatigue behavior during simulated cyclic wheel loading and residual strength after fatigue loading; and (4) investigate viability of transition connection.

In order to evaluate the structural behavior and constructability of the Zellcomp FRP bridge deck system, two test sections were constructed in the Structures and Materials Laboratory at Virginia Tech. The test sections included sections of the Zellcomp deck attached to supporting steel stringers. The first was flat, 11 ft by 8 ft in plan, and subjected to static and simulated truck loadings. The second included a transition connection and was 17 ft by 8 ft in plan. Of special interest during this testing was investigation of static and cyclic behavior of all Zellcomp deck connections (top plate to supporting T-sections, T-section to T-section, and T-section to supporting stringers).

METHODS

Flat Zellcomp FRP Bridge Deck Test Section

A one bay mock-up (11 ft by 9 ft in plan) of the Tangier Island Bridge was constructed in the Structures and Materials Laboratory at Virginia Tech. Other details of the test specimen are as follows:

- The center-to-center stringer spacing used was 4 ft and the center-to-center floor beam spacing was 10 ft 9 5/8 in. Figure 5 shows a plan view of the test panel with floor beam, stringer, and lap joints noted.
- The steel member sizes selected were matched to the actual stringer and floor beam sizes used.
- The top plates were attached to the supporting T-sections mechanically using regularly spaced screws. The screws were spaced at one foot intervals along the length of the supporting T-sections with screws on either side of the T-section web. The attachment of the top panels to the supporting T-sections is shown in Figure 6.
- Rubber pads were used between the deck panels and the stringers and floor beams.
- As per Zellcomp standard practice, the mating lap joint surfaces for adjacent deck panels were cleaned before application of sealant on these surfaces.
- The adjacent bottom panels were joined using mechanical fasteners spaced 1 ft apart.

- The deck panels were connected to the steel supporting structure using mechanical fasteners. This connection is shown in Figures 7 and 8.
- The top plates are available in 8 ft by 4 ft by 1/2 in thick panels. The panels were arranged on the supporting T-sections in such a way as to minimize negative bending moment at the plate joint.

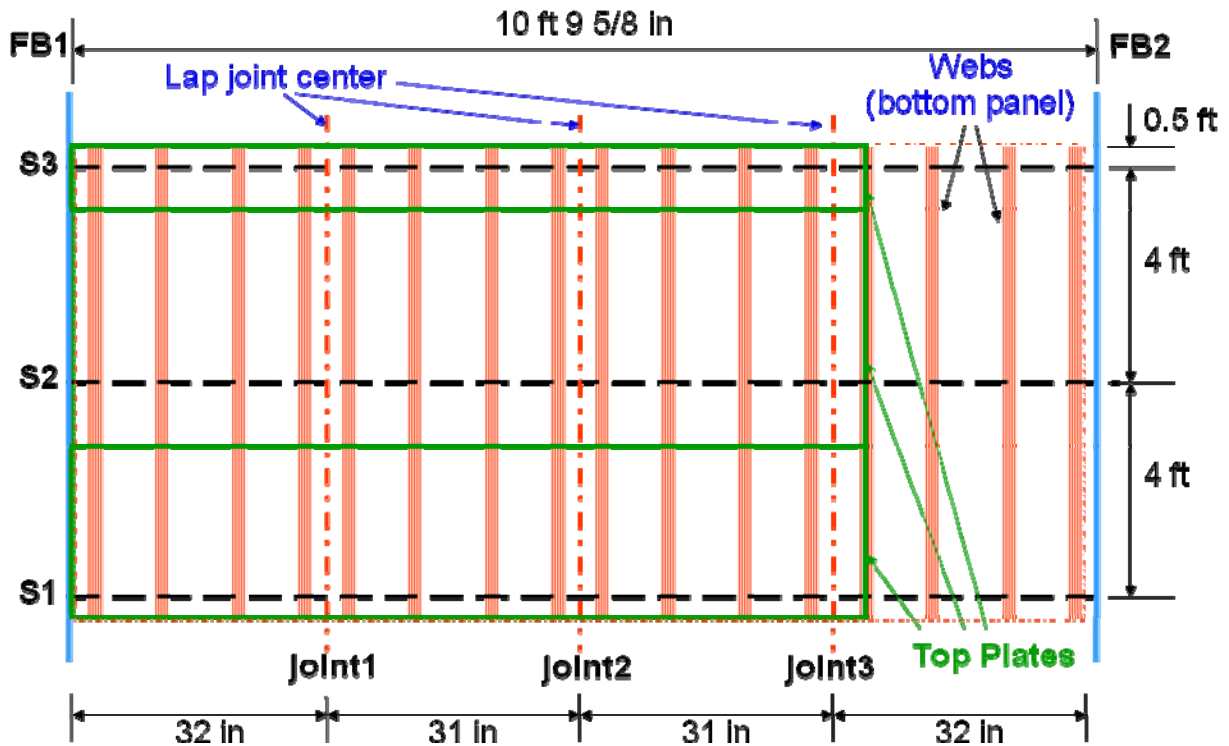


Figure 5. Orientation of top plate and bottom part

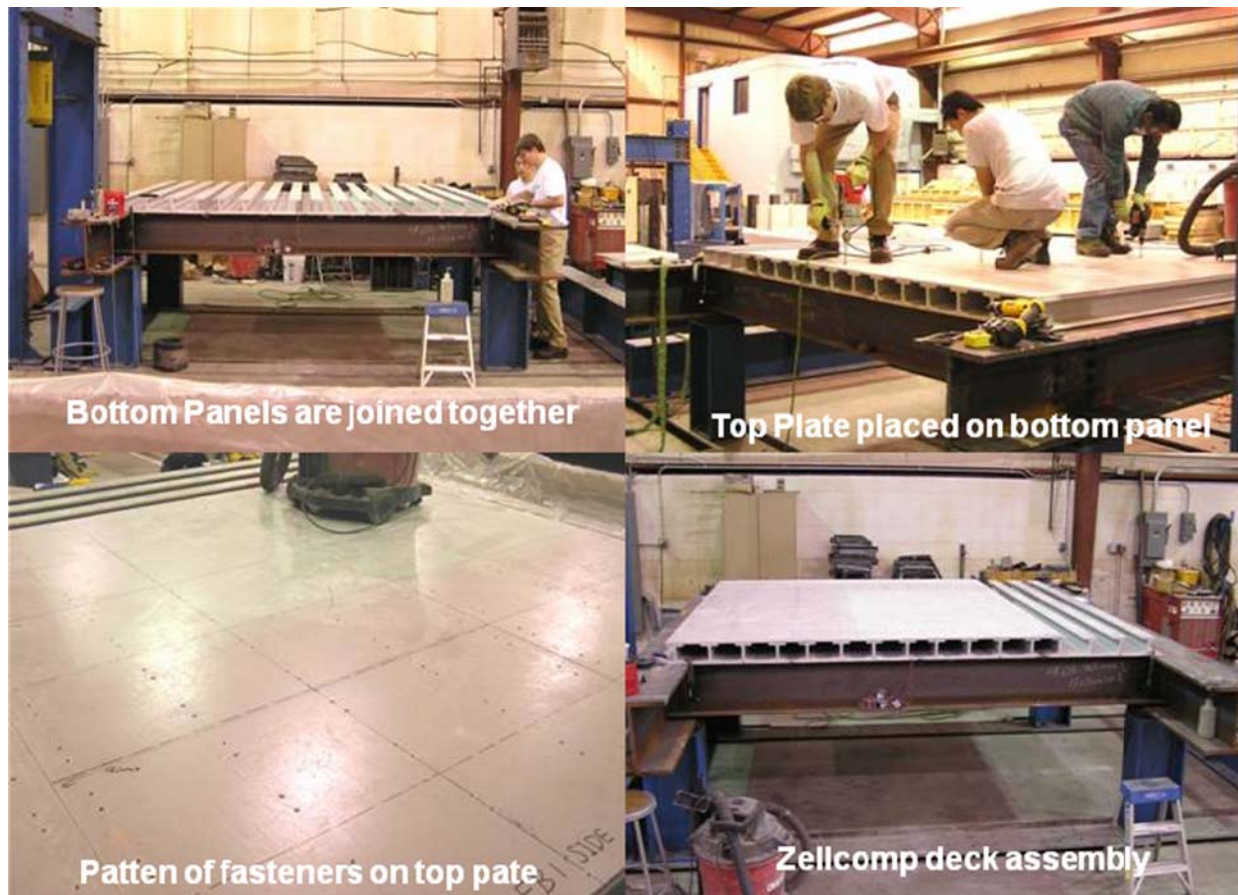


Figure 6. Construction of the panels

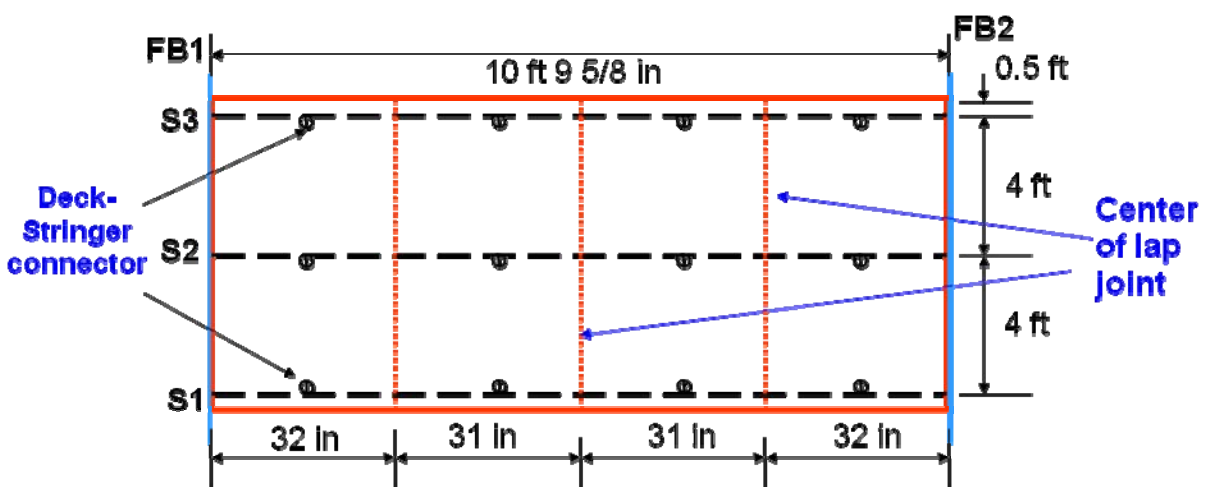


Figure 7. Location of deck-to-girder connectors

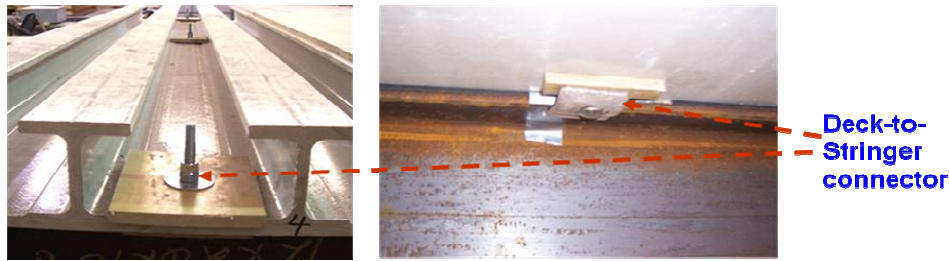


Figure 8. Deck-to-girder connector

Test Plan

The test plan was designed to investigate the service load, strength, and fatigue limit states for the Zellcomp deck system. Details of the testing methodology for each of these limit states are as follows:

Service Load Tests

The purpose of the Service Load testing was to investigate the performance of the deck under simulated static and unfactored loads. For a bridge deck designed according to AASHTO LRFD Bridge Design Specifications (2007) the design service load for one wheel is 21.3 kips (the HL-93 16 kip wheel load increased by 33% to account for dynamic effects). The service load was rounded up to 22 kips for the purpose of this project. A tire patch (partially filled with silicone) was used to mimic the stiffness of an actual tire on a truck wheel loading a bridge deck. Previous research by Parsun et al. (2009) has shown that this type of contact surface more accurately reproduces the pressure surface of an actual tire than previously used stiff loading systems. Figure 9 shows a close-up view of the deck loading system. Multiple tests of the deck



Figure 9. FRP deck loading system

panel to the design service load were conducted. Three repetitions of identical tests were conducted at four locations on the deck as shown in Figure 10:

- Two tests were performed above lap joints connecting the bottom panel sections.
- Two tests were performed mid-way between lap joints and the supporting T-sections.

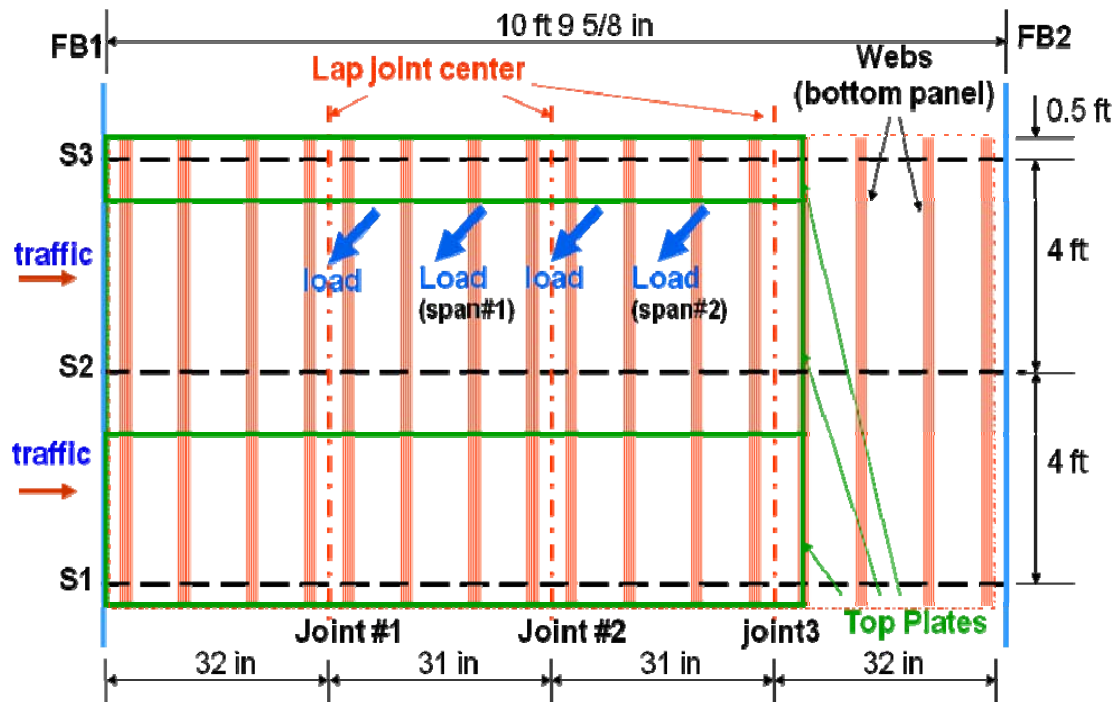


Figure 10. Loading plan for service load test

Strength Test

The purpose of the strength test was to evaluate the performance of the deck system, primarily the panel-to-panel lap joint, up to and including failure. The same deck loading system as used for the service load tests was used for the strength tests. The strength test was carried out at Joint 1 mid-way between stringers S1 and S2 as shown in Figure 10.

Fatigue Test

The purpose of the fatigue test was to evaluate the fatigue behavior of the deck during a repeated wheel load. The load was applied to the deck over Joint 2 mid-way between stringers S1 and S2 as shown in Figure 10. The fatigue test was done after the test to failure at Joint 1 was completed and no damage to Joint 2 was observed at the conclusion of the strength test. The fatigue test was conducted in load control mode at a frequency of 2 Hz and load ratio of $R = 0.1$. The load was applied as a sine wave, varying from a minimum load of 2.2 kips to a maximum load of 22 kips. The fatigue cycles were interrupted at regular intervals and static service load tests were conducted to check for any stiffness change. The deck panel was inspected for signs of deterioration as well during these tests. Figure 11 shows a photograph of the fatigue test set-

up. Note that the flexible deck loading system was not used for the fatigue test. The flexibility of this system affects pump performance resulting in an increased test time. Also, this flexibility led to stability problems during fatigue testing as well as movement or walking of the tire patch. Steps were taken during testing to prevent these issues from occurring.



Figure 11. Fatigue test setup at joint 2

Instrumentation

During testing strains, load, and deflections were continuously recorded using a high-speed data acquisition system. The load applied to the load patch was recorded using a homemade load cell or, during the fatigue test, a load cell that was part of the servo-controlled hydraulic actuator. Vertical deflections were measured (using a wire pot linear variable differential transformers) on the underside of the bridge deck directly under the point of load application. Figure 12 shows the typical strain gage arrangement near a loading point during any of the tests. In addition, a specially fabricated crack detection gage was attached to the underside of the bridge deck to determine when and if cracking or opening of the lap joint connecting panels occurred during testing.

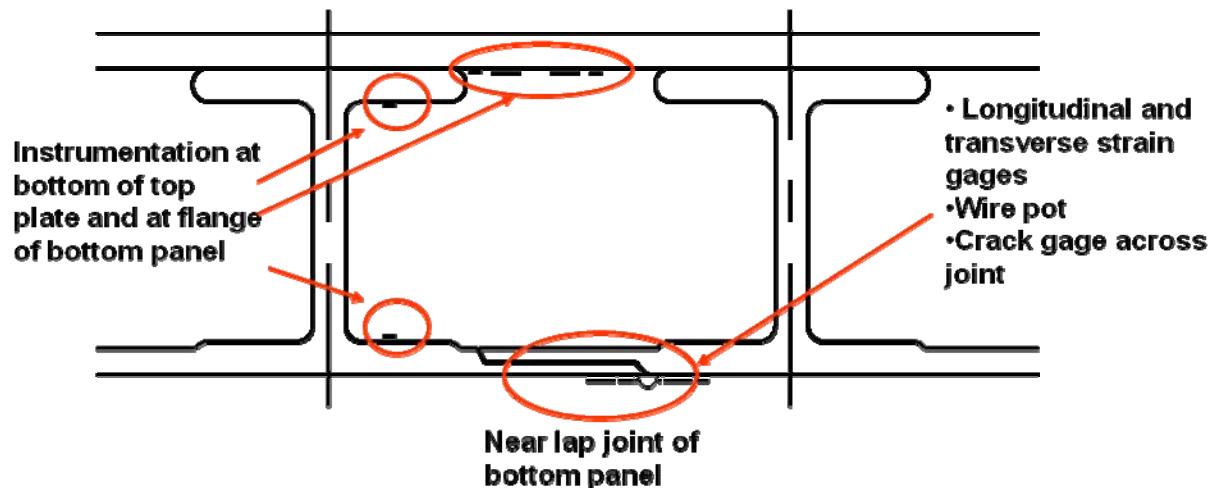


Figure 12. Instrumentation plan

Sloped Zellcomp FRP Bridge Deck Test Section

A two-bay section of the Tangier Island bridge containing the Zellcomp deck was fabricated in the Structures and Materials Laboratory at Virginia Tech to evaluate the performance of the sloped deck transition. The sloped Zellcomp deck specimen mimicked the change in slope of the Zellcomp deck at the supporting floor beams. Figure 2 shows an elevation view of both Tangier Island replacement bridges and the change in slope of the deck is evident. The deck manufacturer proposed a method for accomplishing this change in slope, which required experimental evaluation. The proposed method was to extend the top plate (which is screwed to the supporting T-sections) across the transition. The extended end of the top plate would then be screwed to the supporting T-section on the other side of the joint. This resulted in the top plate having a small amount of permanent strain. The two-bay test section was fabricated using the same dimensions, construction methods, and materials as were used in the actual bridge (as described in the previous section of this report). Figure 13 shows the sloped deck test specimen under construction as well as during testing.

There were two primary objectives associated with this testing:

1. Evaluate the constructability of the sloped transition joint.
2. Investigate the effect of the permanent strain in the top plate on the performance of the sloped connection.

Figure 13. Sloped deck test setup

Test Plan

The first phase of the test plan was fabrication of the two-bay test specimen. The construction plan and methods used for the actual Tangier Island bridge utilizing the Zellcomp deck were mimicked. Specifically, the method for attaching the top plate to the supporting T-sections was used as prescribed in the bridge plans and specifications. Observations obtained while attaching the top plate will be presented in subsequent sections.

After fabrication was complete, the two-bay test section was tested under a fatigue loading. The load was applied as two patch loads which were spaced 2 feet on either side of the transition joint (as shown in the right photograph in Figure 13). The deck was subjected to the fatigue load for 1,000,000 cycles at a load range of 1.75 to 17.5 kips per patch and at a frequency of 2 cycles/second.

Photographs of the sloped deck test set-up included in this report show a wearing surface applied to the top of the top plate. This wearing surface was not used on the actual Tangier Island bridges and will not be discussed further in this report.

Instrumentation

During testing strains, load, and deflections were continuously recorded using a high-speed data acquisition system. The load applied to the load patch was recorded using a load cell that was part of the servo-controlled hydraulic actuator. Vertical deflections were measured (using a wire pot) on the underside of the bridge deck directly under the point of load application.

RESULTS AND DISCUSSION

Flat Zellcomp FRP Bridge Deck Test Section

Service Load Test

During the service load tests the Zellcomp deck panel was loaded at four locations with three repetitions of load performed at each location. The load range was from 0 to 22 kips. Strain, load, and deflections were recorded continuously using a data acquisition system. Strain and displacement responses were approximately linear up to the service load (22 kips) with no visual or audible indication of damage or of failure. Tables 1 through 4 show critical values of strain (in $\mu\epsilon$) and deflection at 22 kips of load. The largest strains measured were about 5000 $\mu\epsilon$ and were transverse to the direction of the webs in the bottom of top plate. The data from the crack detection gage is not shown, however, the data from this gage indicated that there was no cracking at or opening of the lap joints connecting bottom panels during the service load tests. During the strength test the first indication of damage to the deck occurred at about 7000 $\mu\epsilon$ and failure occurred at 11,900 $\mu\epsilon$. This yields a safety factor of about 1.4 before damage to the deck would be sustained due to the design service load and a safety factor of 2.4 against failure.

Table 1. Service load test data at joint 1

Test No.	Longitudinal strain bottom of Top plate	Transverse strain bottom of Top plate	Longitudinal strain bottom panel	Transverse strain bottom panel	Deflection Bottom panel (in)
1	877	3550	1120	N/A	0.286
2	855	3510	1130	N/A	0.287
3	842	3460	1120	N/A	0.282

Table 2. Service load test data at joint 2

Test No.	Longitudinal strain bottom of Top plate	Transverse strain bottom of Top plate	Longitudinal strain bottom panel	Transverse strain bottom panel	Deflection Bottom panel (in)
1	737	3790	1480	-222	0.325
2	711	3700	1480	-227	0.323
3	695	3630	1480	-230	0.318

Table 3. Service load data at span 1

Test No.	Longitudinal strain bottom of Top plate	Transverse strain bottom of Top plate	Longitudinal strain bottom panel	Transverse strain bottom panel	Deflection Bottom panel (in)
1	1390	4530	1320	208	0.300
2	1360	4430	1320	204	0.297
3	1370	4410	1330	203	0.300

Table 4. Service load data at span 2

Test No.	Longitudinal strain bottom of Top plate	Transverse strain bottom of Top plate	Longitudinal strain bottom panel	Transverse strain bottom panel	Deflection Bottom panel (in)
1	1299	5010	1370	193	0.300
2	1266	4950	1380	191	0.300

3	1214	4790	1370	187	0.295
---	------	------	------	-----	-------

An interesting question that was addressed during the service load tests was whether the top panel and bottom panel act compositely. The location of the calculated neutral axis assuming no composite action was within less than 0.1 in than that determined during testing. This indicates that there is no composite action between the top panel and bottom panel.

Strength Test

The strength test was carried out at Joint 1 with a tire-patch loading. The load was increased in increments until a sound was heard coming from the deck at about 43 kips. The location or cause of the sound was not determined but was probably due to internal fiber breakage. The test was continued in increments until no higher load could be resisted. The amount of sound coming from the deck increased as the load increased. Failure occurred at 77.9 kips with a loud cracking sound and sudden drop in load, strain, and deflection. Table 5 shows critical strains (in $\mu\epsilon$) and deflection at 42.6 kips (when sounds were first heard) and at 77.9 kips (failure). For a bridge deck designed according to AASHTO LRFD Bridge Design Specifications (2007) the strength design load for one wheel is 37.2 kips (the HL-93 16 kip wheel load increased by 33% to account for dynamic effects and further increased by a 1.75 load factor). A 2.09 factor of safety against failure was achieved when comparing the failure load from the test with the strength design load.

Table 5. Failure test results

Load	Longitudinal strain bottom of Top plate	Transverse strain bottom of Top plate	Longitudinal strain bottom panel	Deflection Bottom panel (in)
42.6 kips (first sound)	2000	7080	2590	0.60
77.9 kips (failure)	3150	11900	5110	1.125

Approximately linear load versus deflection behavior was observed during these tests with the exception that a small deviation from linearity in load versus deflection behavior was observed at around 45 kips. This also indicates the beginning of damage accumulation within the deck. After completion of the strength test the deck panel was dismantled so an autopsy of the damaged deck could be performed. Figure 14 shows a view of the area of damage immediately under the load point. The damage is characterized by cracking of the top plate and severe damage to the web and flange of the bottom panel.

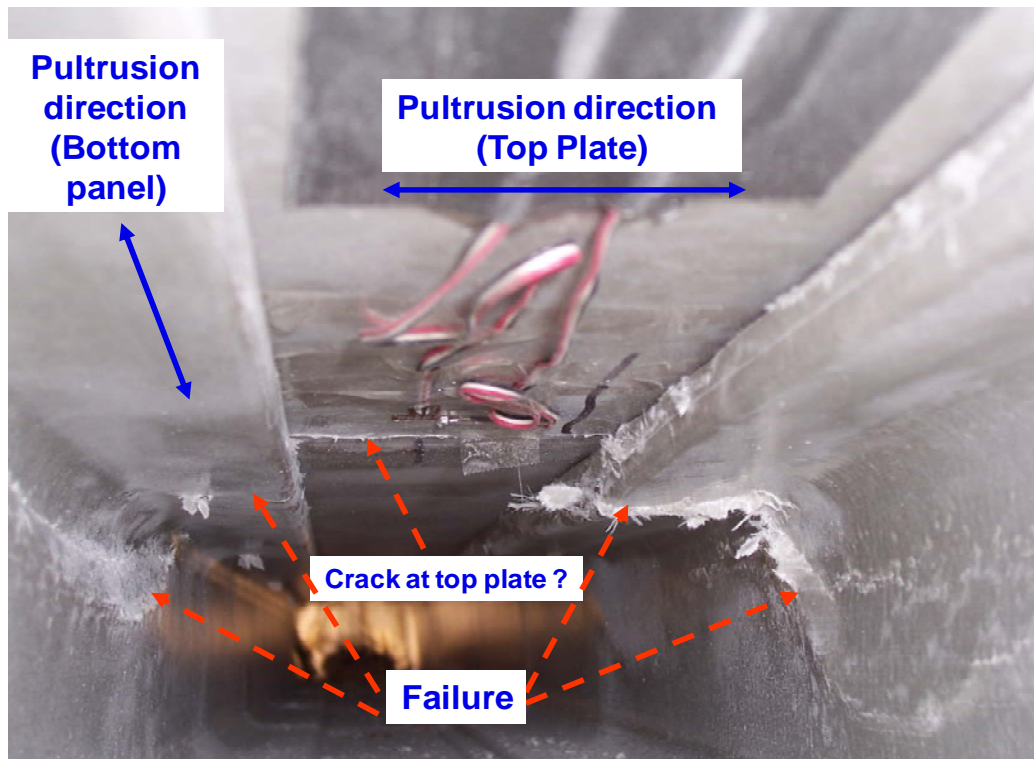


Figure 14. Failure mode under loading patch

Fatigue Test

A fatigue test of the flat test panel was conducted at Joint 2. The fatigue test was done after the test to failure at Joint 1 but no damage was observed at Joint 2 due to the strength test conducted at Joint 1. The fatigue test was performed for 5,000,000 cycles. A slight loss in stiffness was observed during the test and no change in the longitudinal strains was noted. There were significant changes in recorded transverse strain and readings from the crack detection gage. Figure 15 shows a plot of transverse strain on the bottom of the top plate during the fatigue test. Note the sharp increase in measured strains at about 2,500,000 cycles. This may indicate the beginning of damage to the screw fasteners that attach the top panel to the bottom T-section. Also, the crack detection gage readings showed a change in response at about 1 million cycles of load indicating the lap joint had deteriorated somewhat. An autopsy of the deck after the fatigue test was completed did not reveal any visual evidence of structural deterioration at or near the lap joints. However, the changes in stiffness and crack detection readings described above are an indication of the onset of damage to the fasteners.

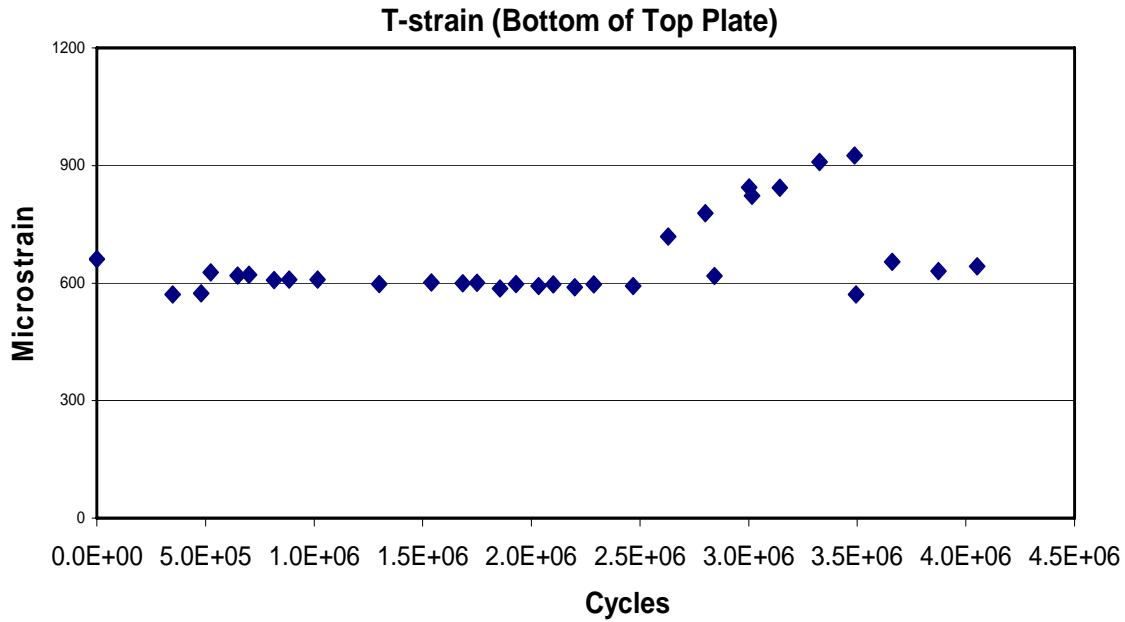


Figure 15. Transverse (along fiber of top plate) strain at bottom of top plate

Sloped Zellcomp FRP Bridge Deck Test Section

The constructability of the continuous, bent top plate was a primary focus of the testing program. After screwing one end of the top plate to the supporting T-sections, the other end was forced down to the supporting T-section on the other side of the joint. Unfortunately, the top plate could not be bent enough to close the gap completely. There was a 1/8 in gap between the top plate and supporting T-section on one side of the top plate as shown in Figure 16. There was a small difference in elevation of the supporting stringers. This difference, although consistent with typical bridge construction tolerances, resulted in the gap between the top plate and supporting T-sections. Another constructability consideration was the large number of screws needed to secure this connection. This is a manpower issue that should be considered when using the Zellcomp deck in similar applications.

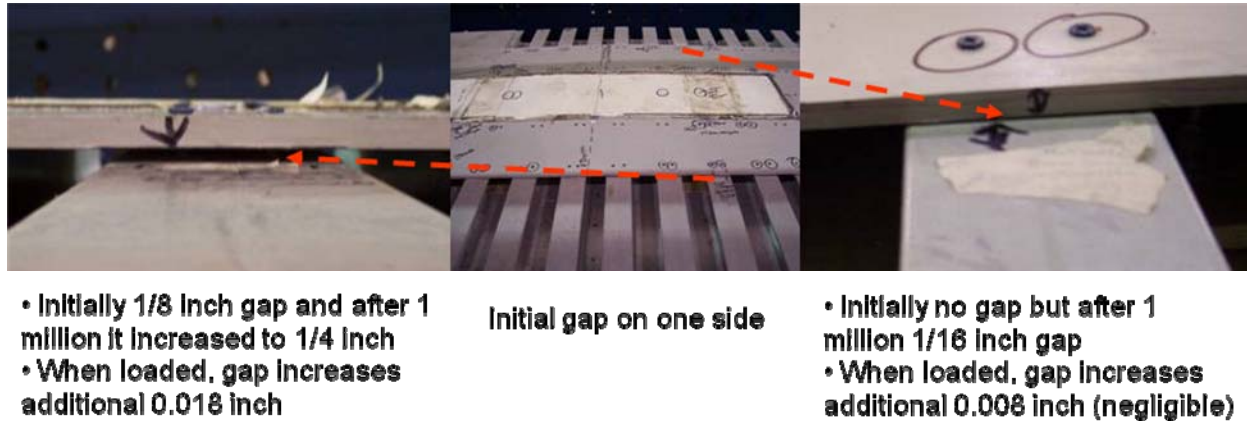


Figure 16. Opening of gap between top plate and bottom part

After fabrication of the Zellcomp deck system was complete, fatigue testing of the test specimen commenced. Based on load versus strain and deflection data, no discernable pattern of change or loss of stiffness was noticed. However, significant loosening of the screws began being observed after 250,000 cycles of loading. The test was stopped at 600,000 cycles of load and the screw connections were closely inspected. Approximately two thirds of the visible connections were visually determined to have loosened with the most loosened screws pultruding as much as 0.25 in above the surface of the top plate. Several of these loosened screws good be further loosened by hand. Note that the tops of screws under the wearing service could not be seen, therefore, there performance could not be evaluated. Figure 17 shows a plan view of the test specimen after 600,000 cycles of loading with the loosened screws labeled. In addition to the loosened screws, several screws heads fractured during testing. Figure 18 shows photographs of loosened screws as well as one broken screw at after 600,000 cycles of load.



Figure 17. Loose screws

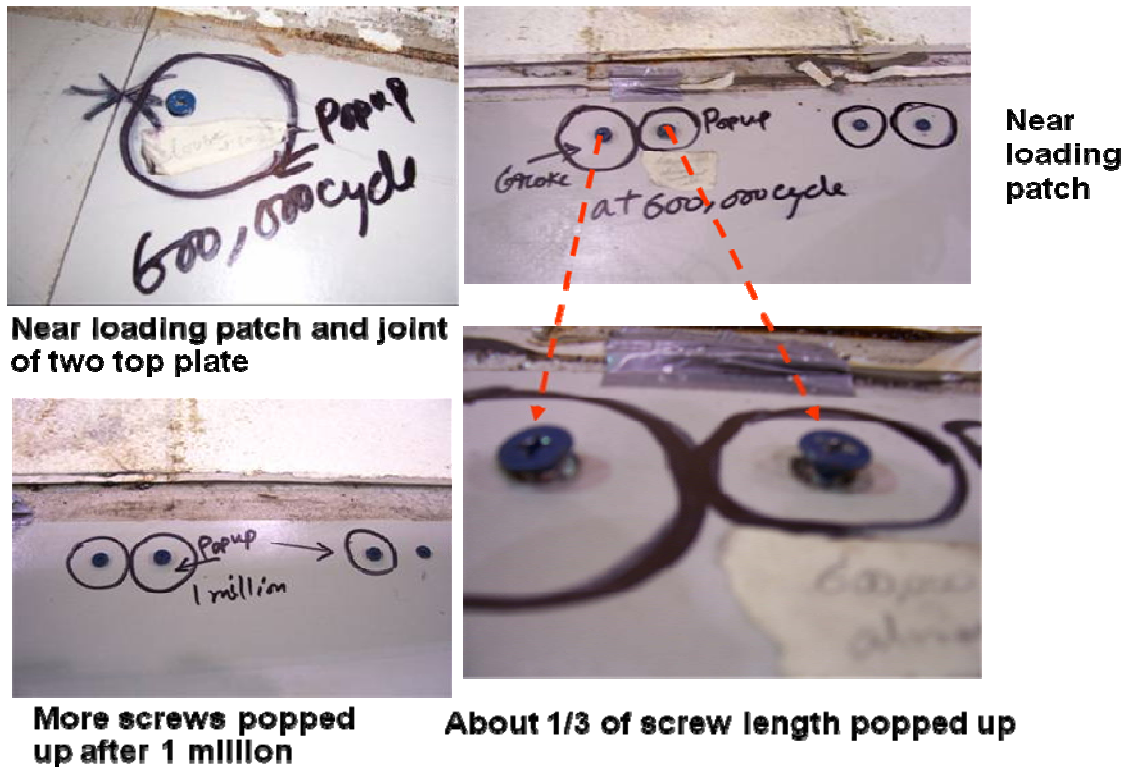


Figure 18. Pop-up of screws

The test was continued for an additional 400,000 cycles of load and then stopped. The following additional observations of the performance of the screws were observed at this point:

- More screws were observed to have loosened.
- Several more screws fractured.
- A horizontal or sliding movement was noted between the top plate and supporting T-section during testing.
- The size of the built-in gap between the top plate and T-section doubled.

CONCLUSIONS

- The flat Zellcomp deck test specimen had a 1.4 safety factor against sustaining permanent damage and a 2.4 safety factor against failure when subjected to an HL-93 wheel load of 22 kips.
- There was no measured composite action between the top plate and supporting T-section.
- The sloped deck transition did not perform well during testing.
- Generally, the flat Zellcomp deck test specimen performed well during the fatigue test. However, there was some indication of deterioration of the lap joint connections at 1 million cycles of load and loss of stiffness at about 2.5 million cycles of load.
- The bent lap joint connection was difficult to construct. A permanent gap between the top plate and supporting T-sections resulted due to inherent construction tolerances.
- The slope Zellcomp deck specimen experienced significant deterioration during the first 600,000 cycles of load. Numerous top plate screw connection loosened with several completely fracturing. The damage to the deck increased for the next 400,000 cycles.

RECOMMENDATIONS

1. *VDOT's Structure and Bridge Division* should not use the sloped deck transition on any applications of the Zellcomp bridge deck system.
2. *VDOT's Structure and Bridge Division* should consider close inspection of all screw connections on the Zellcomp deck during regularly scheduled bridge inspections.

3. *VDOT's Structure and Bridge Division* should consider additional more rigorous full-scale testing of the Zellcomp deck system before considering it on any bridge structure that has truck traffic. The Tangier Island Bridge is subjected to very light truck traffic, and the Zellcomp system proved to be adequate for this specific application only.

BENEFITS AND IMPLEMENTATION PROSPECTS

Both the Strongwell and Zellcomp deck systems were successfully installed on the Tangier Island bridges. Given the limited accessibility of the island and little or no truck traffic, both systems should provide years of maintenance free service, resulting in savings to VDOT. Further testing and evaluation of these systems is warranted should they be considered for applications where they will be exposed to any truck traffic.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support provided by FHWA and the Innovative Bridge Research and Deployment Program and the Virginia Department of Transportation.

REFERENCES

- American Association of State Highway and Transportation Officials (AASHTO). 2007. *AASHTO LRFD Bridge Design Specifications, Fourth Edition*, Washington, D.C.
- P. K. Majumdar, J. J. Lesko, T. E. Cousins, Z. Liu. 2009. Conformable Tire Patch Loading for FRP Composite Bridge Deck. *ASCE Journal of Composites for Construction*.
- Z. Liu, P. K. Majumdar, T. E. Cousins, J. J. Lesko. 2007. Development and Evaluation of an Adhesively Bonded Panel-to-Panel Joint for a Fiber-reinforced Polymer Bridge Deck System. Final Contract Report, VTRC 07-CR14.