ABSTRACT

As railroad traffic increases, railroads are looking for longer lasting ties for their bridge decks. This paper describes recent developments in the quest for alternative structural ties for open deck bridges. Norfolk Southern (NS) Railway has been a leader in this initiative and has conducted laboratory tests to determine bending behavior, tie plate cutting, lateral gage restraint, and spike pullout resistance of alternative material bridge ties. Selected ties that pass the laboratory tests have been installed on a trial basis on open-deck steel bridges on the NS system. The most recent installation features Fiber-reinforced Foamed Urethane (FFU) ties similar to those that have been used in Japan for a number of years. In-service monitoring is underway in conjunction with Transportation Technology Center, Inc. (TTCI) as part of the mega-site revenue service testing program.
TTCL has conducted complementary laboratory tests on alternative ties, as well as benchmarking tests on common species of solid sawn timber ties. TTCL has installed both glued-laminated timber ties and FFU ties on the steel bridge at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado. Glued-laminated ties have been used by the Union Pacific (UP) Railroad on selected bridges. TTCL engineers also worked with AREMA Committee 30 on the development of recommended practices for alternative bridge deck ties as new AREMA recommended practices. The new practice references existing AREMA recommended practices for performance as a track tie, with additional recommendations for structural bending ties, as are common on steel deck plate girder spans.

INTRODUCTION

Railroad bridge engineers have noted increasing expenses and decreasing life of traditional solid sawn timber bridge decks in revenue service. This has prompted interest in alternatives that might provide lower life-cycle costs. This interest has prompted the NS, other Class I railroads, and TTCL to investigate alternatives to solid sawn timber ties for open deck bridges.

Plastic composite ties have been used for many years in selected applications for track on grade. But for open deck bridge use, such ties in many cases also serve as structural members, depending on the configuration of the supporting members, and sometimes they are referred to as span ties. In order to perform adequately as structural members on open deck bridges, these ties require additional bending strength, shear strength, and limited deflection, as compared to conventional track ties. Until recently, lack of design guidelines hindered development of alternative ties for open deck bridge applications.
NORFOLK SOUTHERN LABORATORY EXPERIMENTS

NS has been a leader in experimenting with alternative ties for open deck steel bridge applications. The design recommendation NS provided to potential suppliers was to meet or exceed the performance of a traditional timber tie in that application. NS considered factors such as workability for machining and framing, as well as ability to be installed by NS bridge tie machinery. NS performed laboratory tests to evaluate the performance of various ties in terms of spike insertion and pullout resistance, tie plate cutting, lateral gage restraint, and bending. The bending test provides an indication of the performance of the tie as a structural member. The other tests quantify aspects of the ability of a tie to hold gage, surface, and alignment.

Some previous experimental ties that passed the laboratory tests were installed on selected bridges on NS. One early experiment with a steel-reinforced plastic composite tie was initially successful. But issues such as unsatisfactory quality control and fire resistance led to discontinuance of use of that particular tie design.

Most recently, NS has tested FFU ties. FFU is essentially a fiberglass material. These ties are produced by Sekisui in Japan and have been used for a number of years on railways in that country. Two grades are available: standard and premium.

In laboratory tests for selected track-tie performance measures, the FFU ties performed very well in comparison to various species of timber ties. Table 1 shows spike insertion and spike pullout resistance forces with pre-drilled holes. Table 2 shows spike insertion and spike pullout resistance forces without pre-drilled holes. Data are shown for both standard and premium variations of FFU ties. The FFU ties performed favorably compared with many of the timber species.
TABLE 1. Spike Forces with Pre-Drilled Holes

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TABLE 2. Spike Forces without Pre-Drilled Holes

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Compression Testing for Likelihood of Tie Plate Cutting

NS conducted compression tests to determine the ability of the FFU material to resist deformation and cutting under compressive loads. A 9-inch-long section of 115 RE rail (5 1/2-inch base width) was placed on the top surface of a sample of each grade of FFU tie. A 24,000-pound load was applied downwards through the rail section. The heights of the ties were measured just prior to testing and immediately upon removal of the load. Deformation of tie samples was barely discernible after the test. Measurements indicated that both the standard and premium samples showed a 0.001-inch change in cross section at the load area. These results are much better than for any previously tested materials.
Lateral Gage Restraint Testing

Testing was also performed by applying a cyclic lateral load that varied between 100 and 2,000 pounds to a cut spike driven into the tie. The maximum lateral deflection per cycle was monitored. The total lateral movement under load was also monitored. Over 5-million cycles were applied with the cumulative deflection only totaling about 0.06 inch. Based on past NS experience, sufficient cycles were accumulated to indicate that the FFU material performs better than any other timber or plastic composite tie materials previously tested.

Three-Point Bend Testing

NS conducted a three-point bending test using a 6-foot span. Both the standard and premium FFU samples performed well. The standard FFU tie was tested to fixture capacity at a load of 51,125 pounds and a deflection of 1.39 inches. The premium FFU tie was tested to fixture capacity at a load of 51,780 pounds and a deflection of 1.04 inches. Figure 1 shows the load and deflection curves for the two tests. The ties tested both had 10- by 10-inch cross sections. The total bending moment sustained by each tie was more than 153,000 foot-pounds. Note that the premium FFU tie is somewhat stiffer than the standard tie, as its deflection was 0.35 inch less at the maximum test load.
Figure 1. Three-Point Bending Test Results for Two FFU Tie Samples

NS noted that machining the FFU ties produced a fine glass dust, causing itching to unprotected skin. The manufacturer stated that the dust does not present a respiratory concern but that normal precautions for working with fiberglass and in a dusty environment should be followed.

NORFOLK SOUTHERN REVENUE SERVICE INSTALLATION

Based on acceptable performance in laboratory testing, as well as acceptable performance in complimentary laboratory tests and field installation by TTCI (described below), NS made a pilot installation of FFU ties on an open deck steel bridge near Princeton, West Virginia, in December 2011. Figures 2 and 3 show the installation process. Figure 4 shows the completed installation. Note that for this installation, the ties were dapped. However, no provision was
made to provide relief for the protruding rivet heads on the top flange of the span. Instead, the
ties were allowed to settle onto the steel under the weight of passing trains. The ties were
installed using standard NS bridge tie insertion machinery. They are similar in weight and size to
timber ties that have traditionally been used in this application. Girder spacing on this bridge is
6.5 feet center-to-center. For this spacing, the ties function as span ties, but the bending moments
are much smaller than on spans with wider girder spacings, commonly up to 9 feet.

Figure 2. Installation of FFU Bridge Ties on Norfolk Southern
Figure 3. Partially Completed Installation of FFU Bridge Ties on Norfolk Southern

Figure 4. FFU Bridge Ties Installed on Norfolk Southern near Princeton, West Virginia
This bridge is located in the TTCl revenue service mega-site test area, which is part of the NS test program. Under this revenue service test program, TTCl is monitoring performance of the ties on this bridge. Periodic measurements include tie deflections and track gage restraint. The NS installation is on a track that carries primarily empty coal trains and mixed freight traffic. Maximum normal car weight is 286,000 pounds gross rail load. Annual tonnage is about 26 million gross tons (MGT) per year.

STEEL BRIDGE INSTALLATIONS AT FAST

On the steel bridge at FAST, TTCl has installed two types of alternative ties as well as various solid sawn timber bridge ties.(1)

For the installation of the vintage steel span in late 2009, UP donated Douglas fir glued-laminated (glulam) timber ties for testing. UP has used glulam timber since the mid-1990s to replace stringers, but not ties, in timber bridges, a practice begun by predecessor Southern Pacific.(2,3) One UP bridge near Krotz Springs, Louisiana, has had glulam timber ties installed for more than 10 years. Until recently, this was a unique installation for glued-laminated bridge ties on UP.

Sekisui in early 2011 donated FFU ties for testing on the steel bridge at FAST. These ties are similar to those that were tested and installed on the NS.

Solid sawn timber ties installed on the steel bridge vintage span at FAST include species, such as white oak, Douglas fir, and southern yellow pine, donated by NS, Canadian Pacific Railway, and BNSF Railway respectively. The solid sawn timber ties are serving as benchmarks for comparison.
TTCI testing consisted of initial laboratory load applications, followed by installation on the vintage riveted steel deck-plate-girder test span at FAST for testing in track. This span is much like many of the open deck steel spans still in revenue service in North America today. It has 8-foot girder spacing making it an excellent test bed for structural bridge ties. The test span is subjected to 100-150 MGT per year of heavy axle load (HAL) traffic.

**Testing at FAST**

Figure 5 shows the tie layout for the FFU ties. Note that there is one 18-foot-long Douglas fir walkway support tie separating two adjacent 5-tie panels.

![FFU Bridge Deck Ties Being Installed on Vintage Steel Span at FAST](image)

*Figure 5. FFU Bridge Deck Ties Being Installed on Vintage Steel Span at FAST*
The Douglas fir glulam ties are installed in two similar panels at the east end of the span. Nominal tie size for both the glulam and FFU ties is 10 inches wide by 12 inches deep by 12 feet long.

TTCI fastened the ties to the steel girder using hook bolts every fourth tie. Rail and tie plates were fastened using cut spikes. All ties were fastened to an outside spacer timber with lag screws. Note that this installation is typical of North American bridge installation practice; in this case, closely following plans used by NS, the donor of the vintage span.

At FAST, the ties are subjected to 315,000-pound HAL traffic at 40 mph. The test train at FAST operates in both directions over these ties. The Douglas fir glulam ties have accumulated more than 350 MGT of HAL traffic at FAST. The FFU ties have accumulated more than 170 MGT.

Measurements of tie deflections were taken at mid-tie and at each rail seat. Figure 6 shows the reference frame under the span at FAST.
Figure 7 shows the average deflection values at center of tie and beneath the rail seats for two different ties of five various types: (1) southern yellow pine, (2) Douglas fir (solid sawn), (3) white oak, (4) Douglas fir glulam, and (5) FFU. These deflections are all within the recommended range of values for alternative bridge ties. The Douglas fir glulam ties are slightly stiffer than the white oak ties. The FFU ties are slightly less stiff than the southern yellow pine ties. The Douglas fir glulam ties have essentially the same deflections as the Douglas fir solid sawn ties. As expected, the tie center deflections are greater than those under the rail seats for all tie types. The deflection values measured at FAST for the various tie types reflect the same relative deflection trends as measured in laboratory tests.

This trend provides additional support for the recently recommended laboratory guidelines.
Figure 7. Average Deflection of Various Solid Sawn Timber and Alternative Ties under the Test Train at FAST

Figures 8 and 9 show tie deflections measured at FAST for two different FFU ties beneath both rail seats (inside and outside) as well as at center of tie. Also shown are the deflections in the same locations measured during laboratory testing.
Figure 8. FFU Tie 1 Deflection Comparisons Laboratory vs. FAST

Figure 9. FFU Tie 2 Deflection Comparisons Laboratory vs. FAST
For the laboratory testing, a 27,000-pound load was applied at each rail seat. This load is based on a Cooper E-80 wheel load of 40,000 pounds with 100-percent impact, distributed evenly over three ties, per AREMA Chapter 15.(6) At FAST, the nominal wheel loads are 39,375 pounds, nearly the same as the design load. Experience at FAST suggests that the impact is not as high as 100 percent, because the test train at FAST usually does not have any flat wheels, and the rail over the bridge at the time of measurement was continuously welded with no rail joints. Actual distribution of wheel loads to ties has not been measured on the steel bridge at FAST. Considering the known reduced impact at FAST, the laboratory test load and design distribution seem reasonable in light of these test results. These tests are similar to those conducted previously on various timber ties.(5) The FFU tie deflections are more similar to those measured for southern yellow pine ties.

**TRANSPORTATION TECHNOLOGY CENTER, INC. LABORATORY EXPERIMENTS**

A test rig, based on one designed by Sweeney and Madsen,(7) was set up in the laboratory (Figure 10). The test rig simulates the girder spacing of the span and load points of the rail. Spacing of the reaction points was set up to replicate center-to-center girder spacing (8 feet). Spacing of the load points was 60.0 inches for standard gage track.
For both the Douglas fir glulam ties and the FFU ties, two randomly chosen ties were tested in the laboratory. These ties were checked for defects before testing. A deflection test and a design load test were performed in the laboratory. Each test was performed twice, once with the load applied in approximately 2 to 5 minutes and once with the load applied more slowly, over 20 minutes.

The deflection test measured minimum and maximum tie center deflection under loads of 27,000 pounds (live load before factor of safety) at each rail seat. Values were compared to previously defined minimum and maximum deflection values. (4)
In addition, a design load test was performed. For this test, a load of 53,000 pounds per rail (live load including factor of safety) was applied. A visual inspection was made to the tie after this test to check for any damage.

After these tests, the bottoms of the FFU ties were milled so they would fit over the protruding rivet heads on the top surface of the vintage girder on the bridge at FAST, where they were installed for in-service testing. Figure 11 shows the milling for one girder flange on the bottom side of an FFU tie. There are two lines of rivets on each of the top flanges. The milling pattern allows the ties to move longitudinally along the top flange. During installation at FAST, the milling facilitated quick and accurate lateral location of the ties on the girders. The milling of the FFU ties to clear the rivets was performed based on the vendor's recommendation. None of the timber ties installed on the span was milled. The timber ties were set directly on top of the rivets and allowed to seat under train traffic, as were the FFU ties in the NS installation.

Figure 11. FFU Tie Milled to Clear Rivet Heads on Top Flange
After milling, the ties were tested again in the laboratory before being installed at FAST. Figure 12 shows the deflection differences for one FFU tie before and after milling. Testing of a second FFU tie yielded similar results. Under the live load of 27,000 pounds, both ties stayed below the recommended maximum deflection of 0.38 inch for tie center deflection for an 8-foot girder spacing. Both FFU ties provided tie center deflections greater than the 0.11-inch recommended minimum for an 8-foot girder spacing. Both ties also performed well under the 53,000-pound load. No damage was observed. The maximum bending moment under this loading condition is about 106,000 foot-pounds, which is somewhat less than that experienced in the NS bending test.

Figure 12. FFU Tie 1 Deflections under 27,000 Pounds, 2-5 Minute Loading, Pre- and Post-Milling
Figure 13 shows the difference in deflection when the ties were loaded slowly (20 minutes) and when the ties were loaded more quickly (2-5 minutes). There is no significant difference in the performance of the ties at the two loading rates.

Figure 13. FFU Tie 1 Deflections under 27,000 Pounds, Post-Milling, at Two Loading Rates

Laboratory test results for the Douglas fir glulam ties were reported previously.\(^{(5)}\) Deflections for these ties under laboratory test loads were closer to the minimum recommended value for an 8-foot girder spacing.

**FUTURE TESTING**

The performance of the test ties will be monitored at NS and FAST for a period to be determined. Ideally, bridge deck ties should last for thousands of MGT of traffic. Subject to tie
condition and other test requirements, TTCI anticipates that the tests will continue for several years. Inspectors will visually inspect the condition of the ties and observe them under traffic on a regular basis. The failure criteria noted under the laboratory tests will apply.

In addition, fastener condition and the ability to hold track geometry will be assessed. Once a service history has been established, the inspection period may be extended. Deflection tests will be repeated after additional tonnage accumulation.

**SUMMARY**

In an effort to investigate alternatives to solid sawn timber ties for open deck bridges, NS and TTCI are testing two alternative tie types. FFU bridge ties are being tested on the NS and on the steel bridge at FAST. Glued-laminated Douglas fir ties are being tested at FAST.

Both types of ties underwent laboratory testing before being installed on the open deck steel bridges on the NS and at FAST. Performance of the ties is being monitored by visual observations and deflection measurements.

Observations to date:

- Laboratory tests by both NS and TTCI indicated satisfactory performance of FFU ties for installation in field service tests.
- Glued-laminated Douglas fir ties have accumulated over 350 MGT of HAL traffic at FAST with no maintenance required.
- FFU ties have accumulated over 170 MGT of HAL traffic at FAST with no maintenance required.
• Both types of ties meet the preliminary structural performance guidelines for alternative engineered ties for open deck bridges.

• Solid sawn timber ties of three species (white oak, Douglas fir, southern yellow pine) on this span, serving as comparison ties, have accumulated over 350 MGT of HAL traffic at FAST with no maintenance required.

Additional tonnage exposure is needed to quantify long-term performance of these tie types both on the NS and at FAST.

ACKNOWLEDGEMENTS

The authors are grateful for the assistance and contributions of Tim Ward, Bob Blank, Brad Kerchof, and Jim Carter of NS. TTCI acknowledges the donations of glued-laminated timber ties from UP and FFU ties from Sekisui Chemical Co. Ltd., represented in North America by Sumitomo Corporation of America.

Thanks are also given to the AREMA Committee 30 (Ties) subcommittee on engineered composite ties, chaired by Richard Lampeau, for their work on the development of the new AREMA recommended practices for engineered composite bridge ties. AREMA Committee 7 (Timber Structures), chaired by Dr. Gary Fry, also provided valuable input and assistance in developing the new AREMA recommended practices.

This study was funded in part through the Association of American Railroads’ Strategic Research Initiatives Program.
REFERENCES


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Figure 3. Partially Completed Installation of FFU Bridge Ties on Norfolk Southern
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Figure 13. FFU Tie 1 Deflections under 27,000 Pounds, Post-Milling, at Two Loading Rates
Developments in Alternative Ties for Open Deck Bridges

Duane Otter, PhD, PE – TTCI
Ronald D. Patton – NS
Richard B. Joy, PE – TTCI
Alternative Ties for OD Bridges

• Overview of Presentation
  – Motivation for Study
  – NS Lab Tests
  – NS Field Test
  – TTCI Test at FAST
  – TTCI Lab Tests
  – Summary
  – Acknowledgements
Alternative Ties for OD Bridges

- Motivation for Study
  - Reduced life of solid sawn timber decks
  - Increased expenses for timber decks
  - Alternative ties available for open track
  - Additional structural demands for span ties
  - To meet or exceed timber tie performance
Alternative Ties for OD Bridges

- NS Lab Tests
  - Spike insertion and pull out
  - Lateral gage restraint
  - Tie plate cutting
  - Bending
Alternative Ties for OD Bridges

• NS Lab Tests
  – Fiber-reinforced Foamed Urethane (FFU)
  – Fiberglass-like material
  – Used on railways in Japan
  – Made by Sekisui Chemical Co. Ltd.
  – Imported by Sumitomo Corp. of America
Alternative Ties for OD Bridges

- Spike Insertion and Pull Out Resistance – With and without pre-drilled holes

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Alternative Ties for OD Bridges

- Compression Test for Tie Plate Cutting
  - 115 RE rail pressed onto tie with 24,000-pound force
  - 0.001-inch indentation for FFU tie
  - Less than for any other materials tested
Alternative Ties for OD Bridges

• Lateral Gage Restraint Testing
  – 2,000-pound lateral load cyclically applied to cut spike in FFU tie
  – 5 million cycles
  – Cumulative deflection 0.06 inch
  – Less than for any other materials tested (timber and plastic composites)
Alternative Ties for OD Bridges

• 3-Point Bending Test on 6-Foot Span
  – 51,000-pound load on 10-inch x 10-inch FFU ties
Alternative Ties for OD Bridges

- NS Revenue Service Installation
  - FFU ties on 67-foot DPG near Wills, WV
Alternative Ties for OD Bridges

- NS Revenue Service Installation
  - 6.5-foot girder centers
Alternative Ties for OD Bridges

- NS Revenue Service Installation
  - 26 MGT per year (mixed freight, coal MTs)
Alternative Ties for OD Bridges

- FAST Bridge Tie Tests
  - 55.5-foot riveted DPG
  - 8.0-foot girder centers
  - 150 MGT per year (315,000-pound GRL cars)
  - Five tie types
    - Douglas fir
    - White oak
    - Southern yellow pine
    - Glued-laminated (Douglas fir) (UP donation)
    - Fiber-reinforced Foamed Urethane (FFU)
Alternative Ties for OD Bridges

• FAST Bridge Tie Tests
  – FFU tie installation (2 panels of 5 ties each)
Alternative Ties for OD Bridges

- FAST Bridge Tie Tests
  - FFU Ties only – milled for rivet lines
  - No machining for rivets on NS bridge
Alternative Ties for OD Bridges

• FAST Bridge Tie Tests
  – Tie deflection measurement frame

String potentiometers under each rail seat and at mid tie

Deflection frame attached to top flange of span
Alternative Ties for OD Bridges

• FAST Bridge Tie Tests
  – Tie deflections under FAST train

[Bar chart showing deflections for Southern Yellow Pine, Douglas Fir, White Oak, Douglas Fir Gulum, and FFU]
Alternative Ties for OD Bridges

• TTCI Laboratory Tie Tests
  – Tie test frame
Alternative Ties for OD Bridges

- TTCI Laboratory Tie Tests
  - Effects of milling on FFU tie performance
Alternative Ties for OD Bridges

• Performance at FAST to date
  – Glu-lam ties 382 MGT of HAL traffic
  – FFU ties 202 MGT of HAL traffic
  – Timber ties 382 MGT of HAL traffic
  – No maintenance required to any ties
Alternative Ties for OD Bridges

• Summary and Conclusions
  – Glu-lam and FFU ties showing promise as alternatives to solid sawn timber
  – In-service trials ongoing at NS, FAST, and Union Pacific (glu-lam)
  – New AREMA 30 guidelines for engineered composite ties in 2012 manual
  – Both FFU and glu-lam ties can meet guidelines with reasonable tie sizes
Alternative Ties for OD Bridges

• Acknowledgements
  – Jim Carter, Brad Kerchof, Bob Blank, and Tim Ward of Norfolk Southern
  – UP RR and Sumitomo for FAST tie donations
  – AREMA Committees 30 and 7 for development of new guidelines
  – Association of American Railroads for research funding