

The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

### Key Findings:

- Test results showed a non-linear trend between the modulus of elasticity (MOE) and the center bending of ties: the higher the MOE, the lower the center strains will be.
- Based on the field observations and laboratory tests, the tie center cracking is likely induced by internal defects in ties.
- The two ties that failed in the laboratory tests were found to have internal defects at the failure plane by slicing the center 30 inches of the ties. This indicates that the proposed setup is capable of identifying EPC ties with internal defects that cause center cracking.
- The range of the input strain applied in the laboratory tests was shown to be sufficient to identify an EPC tie with internal defects, but will not overload and fail a good quality tie.

# Development of Laboratory Fatigue Tests for EPC Ties: Stage II

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[Transportation Technology Center, Inc. \(TTCI\)](#) has developed laboratory fatigue tests to evaluate engineered polymer composite (EPC) tie performance under repeated train loads. This research will be proposed for inclusion in the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* to improve design, quality control, and fatigue performance criteria for EPC ties. This research is funded by the Association of American Railroads' (AAR) Strategic Research Initiatives Program.

Since the early 2000s, evaluations of EPC tie performance in revenue service and in track at the Facility for Accelerated Service Testing (FAST) show that center fatigue cracking is one of the major failure modes of EPC ties. This fatigue failure normally initiates at internal voids or stress concentrations inside of the tie cross section. Existing laboratory qualification testing procedures in the AREMA manual have not proven effective in identifying bending fatigue performance issues prior to in-track installation/qualification of tie design; highlighting the need for a more representative test.

### BACKGROUND

Previous research has documented the development of the laboratory fatigue test setup developed by TTCI.<sup>1</sup> EPC ties have been shown to break at inclusions/voids occurring along the cross section of the tie. Based on this information, a deflection-controlled, four-point bending test was chosen as an appropriate and effective test to quantify fatigue performance because the maximum bending moment can be applied to a constant bending moment zone along a tie. This continuity is more beneficial than having only a maximum bending moment at a single point in a three-point bending test. The proposed test criterion is up to 1.5 million loading cycles (equivalent >200 million gross tons, or MGT, of heavy axle load traffic) or tie failure; whichever comes first.

Stage I of this research documented in a previous *Technology Digest*<sup>1</sup> focused on the development of a test setup using the results of field and laboratory tests. The input load used in Stage I was double the average

bending strain measured in the field tests for each type of tie. However, this procedure differed from the others in that it presented a practical difficulty that required testers to measure in-track bending strains for each type of tie before running the laboratory test. To make this test more practical for the railroad industry, the input load should be accessible for any type of EPC ties and should represent the EPC tie in-track loading environment. This publication focuses on the second stage of this research: developing a standardized input load for the test.

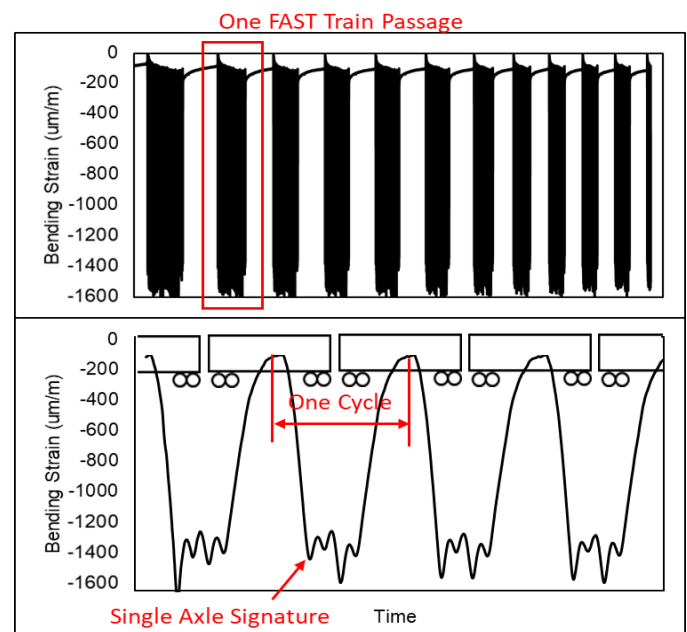
### FIELD BENDING STRAIN MEASUREMENTS

Center bending strain data was collected for various EPC tie types, train speeds, and loads both in revenue service and FAST located at the Federal Railroad Administration's Transportation Technology Center, Pueblo, CO.<sup>1,2</sup> A total of 15 ties (three consecutive ties in each test zone) have been tested. Table 1 lists the center strains of each tie. The ties in each zone were selected specifically by TTCI test engineers to ensure that no severely hanging ties or ties with loose plates were chosen. Overall, the ties chosen were representative of the ties in the test zones. In general, FAST cars have higher axle loads than cars in revenue service. As expected, the strain values of the cars at FAST were higher than the values of those in revenue service. Therefore, the center bending strain values at FAST were the baseline values used to develop the laboratory fatigue test.

**Table 1. Summary of center strain measurements for all four types of ties at FAST**

Tie Type	MOE (ksi)	Tie Number	Center Strain ( $\mu\epsilon$ )	Avg. Center Strain ( $\mu\epsilon$ )	MGT when Measured
<b>FAST Measurements</b>					
A	212	1	1718.1	1701.5	146 MGT 10.20.2016
		2	1681.1		
		3	1705.4		
B	133	1	1718.8	1778.5	151 MGT 11.03.2016
		2	1780.6		
		3	1836.1		
D	405	1	1437.4	1471.9	125 MGT 4.29.2019
		2	1382.8		
		3	1595.2		
<b>Revenue Service Measurements</b>					
A	212	1	1381.4	1338.8	300 MGT 4.4.2018
		2	1258.5		
		3	1376.4		
C	181	1	1211.3	1364.2	300 MGT 4.4.2018
		2	1431.7		
		3	1449.6		

Figure 1 is an example of the center bending strain data collected at FAST for a certain tie type. Based on the enlarged view (bottom plot) of the field strain data, EPC ties experienced one bending fatigue cycle for each car length (center-to-center length of two adjacent cars). In comparison, the fastener/rail seat area generally experienced a full load cycle for each truck.<sup>2</sup> The wear/abrasion test (AREMA Test 6), which is a fatigue test on the tie and fastening system, ran at a baseline of 3 million cycles. Therefore, each fatigue cycle in Test 6 was one truck, instead of one car. To establish a similar test duration, it is recommended that 1.5 million cycles be performed for the EPC tie bending fatigue test. This is equivalent to approximately 200 MGT of heavy axle load traffic.



**Figure 1. Strain measurements taken at FAST for tie type D**

### BENDING STRAIN BY FINITE ELEMENT (FE) MODELING

An FE model consisting of a nine-tie track panel was built to investigate how tie moduli and ballast support conditions affect the bending strain in EPC ties. Different ballast support conditions were achieved by changing the gap between the bottom of the ties and the top of the ballast.

Figure 2 presents the simulation results for center bending strain changes with different ballast support conditions of EPC ties and different MOE. As can be seen, uniformly supported ties had the lowest bending strain. However, even a slight center bound condition could cause

a significant increase (more than four times greater) in the tie bending strain. As the tie modulus increased, the center strain value decreased; therefore, simulation results indicate a non-linear relationship between the tie modulus and the center strain, which means the strain value did not decrease at the same rate that the tie modulus increased.

The crosses in the plot indicate the in-track bending strains of three types of EPC ties at FAST (labeled A, B, and D). Even though the field strain data does not follow the exact non-linear trend as the simulation results (possibly due to tamping, ballast conditions, weather, etc.), the field strain data still follows the trend of the higher the modulus, the lower the bending strains. Based on the simulation results and field strain data, it can be determined that the tie modulus is an important factor in developing the input load.

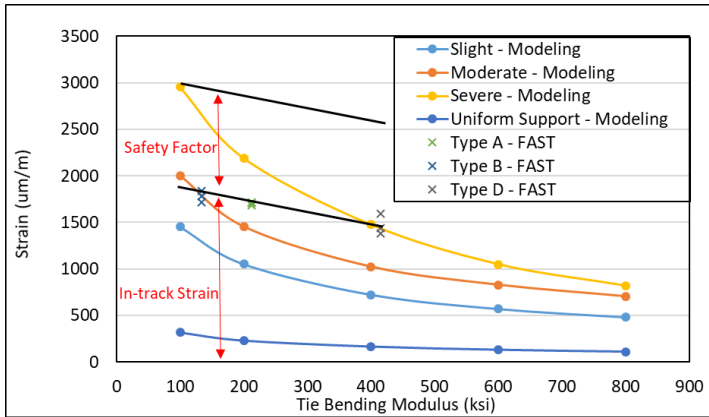


Figure 2. Center bending strains for different ballast support conditions of EPC ties with different MOE

**ANALYSIS AND RECOMMENDATIONS**

Table 2 summarizes nine test runs using the proposed EPC tie fatigue test setup.

Table 2. Laboratory test summary

Tie Type	Input Center Strain	Test Results
A	3,100 $\mu\epsilon$	Reached 1.5 million cycles
A	2,500 $\mu\epsilon$	Reached 1.5 million cycles
B	1,800 $\mu\epsilon$	Broke at 1.37 million cycles
B	2,500 $\mu\epsilon$	Reached 1.5 million cycles
B	3,100 $\mu\epsilon$	Reached 1.5 million cycles
C	2,400 $\mu\epsilon$	Broke at 1.31 million cycles
C	2,500 $\mu\epsilon$	Reached 1.5 million cycles
D	2,500 $\mu\epsilon$	Reached 1.5 million cycles
D	2,000 $\mu\epsilon$	Reached 1.5 million cycles

Different input strains were chosen to run the fatigue tests on the ties. Two ties (one Type B and one Type C) failed due to center cracking. All nine tested ties were sliced to examine the internal conditions after the tests were performed. The two failed ties had internal defects (Figure 3), but the seven non-failed ties visually had better internal conditions (denser materials, no voids). The two failed ties that had internal defects were cracked by 1,800  $\mu\epsilon$  and 2,400  $\mu\epsilon$ , while the other seven ties tested at higher strain values met the test requirements.

Key takeaways from the laboratory tests include:

- Internal defects are likely to be a major cause of the EPC tie center cracking.
- The test setup is capable of identifying the internal defects, which could induce center cracks under repeated loading.
- It can be assumed the two failed ties would have failed at higher strain values. The presence of the defect is the key factor for generating the failure.

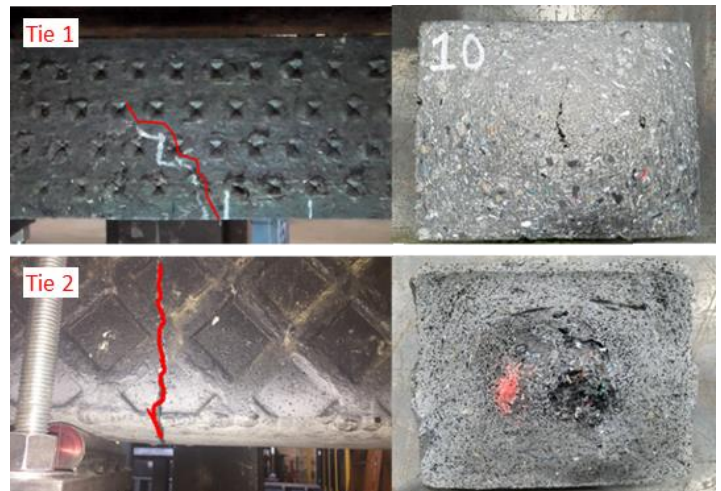


Figure 3. The internal defects of the two failed EPC ties

Center cracking occurs in the center 30 inches of a tie. Therefore, the tie with the worst internal condition (maximum allowable defects/voids/inclusions by x-ray quality control) should be selected for testing. It is recommended that the tested tie is sliced to verify the internal condition by x-ray scanning. Additionally, this slicing test method could be used to learn more about acceptable defect types and locations to improve EPC tie quality control.

Based on the test data and the simulation results effort, an input strain from 2,500  $\mu\epsilon$  to 3,000  $\mu\epsilon$  is recommended for EPC ties with moduli ranging from 400 ksi to 130 ksi, respectively. Stiffer ties (400 ksi) should be tested at 2,500  $\mu\epsilon$ , and less stiff ties (130 ksi) should be tested at 3,000  $\mu\epsilon$ . Strain range for other ties with a modulus in between can be interpolated.

The rationale of the recommended strain range is supported by the previous laboratory and in-track test results. The laboratory tests show that the strains in this range can fail a tie with internal defects. As the strain range is obtained based on field test results, a safety factor is used to increase the test severity to account for the severe loading/support conditions shown in Figure 2. This range represents a conservative range of strains that exceed the in-service demand of an EPC tie in center bending with an approximate safety factor of 1.7. Recommendations for a more conservative (higher safety factor) test could be developed in the future.

### CONCLUSION

Based on the field/laboratory tests and simulation results, the following findings are reported:

- The simulation results and field test data showed a similar trend that the higher the tie MOE is, the lower the center bending strain will be. This indicates that the MOE of EPC ties is an important factor that will affect the bending behavior.
- The laboratory tests showed that internal defects are likely to be one major cause of the EPC tie center cracking. In addition, the proposed setup is capable of identifying EPC ties with internal defects. The ties with internal defects will break even if the input strains were not as high as the input strains on good quality ties.
- All the tested EPC ties were with an MOE ranging from 130 ksi to 400 ksi. Based on the test results, an input strain ranging from 2,500  $\mu\epsilon$  to 3,000  $\mu\epsilon$  was sufficient to identify an EPC tie with internal defects, but will not overload and fail a good quality tie.

A tie with the worst condition indicated by the quality control procedures should be selected for this test. Slicing ties can be an effective way to verify the tie internal conditions evaluated by the the quality control procedures.

### Acknowledgments

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### References

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