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Composite Tie Fastening System Performance – Tie Plates

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Summary

Transportation Technology Center, Inc. (TTCI) is conducting research to evaluate the performance of engineered polymer composite (EPC) ties and improve design guidelines and industry recommended practices. This digest presents testing and modeling results on the effects of different tie plate sizes and tie moduli on plate stresses. This work is part of ongoing research funded by the Association of American Railroads' Strategic Research Initiatives Program and the Federal Railroad Administration.

The railroad industry seeks to further the development of EPC ties as a one-for-one alternative for wood ties, particularly in areas of high rot and decay. Development has focused on ties that can safely and efficiently be integrated into existing tie handling and installation practices and provide compatibility with existing wood tie fastening systems. Mechanical properties of EPC ties can greatly affect how the fastening system interacts with these ties.

TTCI developed a comprehensive finite element model to represent typical freight rail operating conditions in North America to investigate the effects of tie stiffness and size of tie plate. Three types of American Railway Engineering and Maintenance of Way Association (AREMA) tie plates (13-inch, 14-inch, and 18-inch) were considered in the modeling. Additionally, four tie types (soft composite, stiff composite, soft wood, and stiff wood), representing a wide range of properties, were modeled. AREMA plate compression and tie bending tests were used to tune model parameters for actual composite and hardwood tie samples. Two loading conditions representing heavy axle load tangent track and curve track were simulated.

Results from this study show:

- Larger 18-inch plates experience higher bending stresses on composite ties due to increased plate bending and lower tie compressive modulus than on hardwood ties.
- The 13-inch plates experience lower bending stresses on composite ties than both 14-inch and 18-inch plates. Results suggest that 13-inch plates may be a cost-effective alternative to 14-inch plates on composite ties.
- While 13-inch plates generate the highest plate-tie contact stresses, composite ties appear more resistant to plate cutting than wood ties.

As part of the broader evaluation, TTCI is also evaluating EPC tie performance through laboratory testing, in-track testing at the Facility for Accelerated Service Testing, and in revenue service test zones. Testing results will be used to develop improved guidelines and practices to be published in the AREMA *Manual for Railway Engineering*.



INTRODUCTION

TTCI is conducting research on the performance of EPC tie and fastener systems as an alternative for wood ties. This digest presents testing and modeling results on the effects of different tie plate sizes and tie moduli on plate stresses. This work is part of an ongoing collaborative research effort between the AAR Strategic Research Initiatives Program and the Federal Railroad Administration to improve design and testing guidelines for composite ties in *AREMA Manual for Railway Engineering*, Chapter 30 – Ties.¹

Ties and fasteners act together as a system to transfer vertical and lateral loads applied on the track into the ballast, and to maintain proper track geometry. Composite ties, EPC ties specifically, offer an alternative to wood ties, particularly in areas of high rot and decay, where deteriorated ties are replaced more frequently to maintain track performance. EPC ties, composed primarily of recycled plastic, are a manufactured product and have different mechanical properties than wood ties. Properties such as tie bending modulus, tie compressive modulus, and resistance to plate cutting affect how fastening systems, particularly tie plates, interact with ties. Severe plate cutting, exacerbated by wood decay, can necessitate earlier tie replacement or adzing maintenance. The railroad industry seeks to further the development of EPC ties as a potential one-for-one alternative for wood ties – ties that can be integrated into existing tie handling and installation practices and provide compatibility with existing wood tie fastening systems.

BACKGROUND

Previous research on tie plate performance on composite ties has documented increases in plate breakage and plate bending stresses, but a reduction in observed plate cutting compared to wood ties.^{2,3} Two EPC tie test zones with 14-inch AREMA plates – one installed in 2000 and the other installed in 2004 – exhibited high-rail plate cutting of less than 1/8-inch after accumulating 2,155 and 1,690 MGT, respectively at the Facility for Accelerated Service Testing (FAST).² This compares to plate cutting up to 3/8-inch in a control hardwood tie zone after 970 MGT. Figure 1 illustrates this comparison. FAST operates in an arid climate and any significant wood tie rot/decay in other climes would likely exacerbate plate cutting.

Additionally, a finite element modeling effort on a standard AREMA 14-inch plate on wood and composite ties in higher degree curves has shown higher bending stresses for these plates in composite tie and fastener systems.⁴ The existing body of research supports that a 14-inch plate may fatigue and crack more frequently on EPC ties than on wood ties, but EPC ties appear more resistant

to plate cutting. TTCI further studied the influence of different tie plate sizes over a range of tie moduli.



Figure 1. Plate Cutting at the High Rail of (a) An EPC Tie after 1690 MGT and (b) A Control Hardwood Tie after 970 MGT (both installed in a 6-degree curve at FAST)

FINITE ELEMENT MODEL

Figure 2 shows the schematic of the finite element track model used in this study. It contains two 65-foot rails, two tie plates, one tie, and a section of ballast layer. The model has four contact pairs: rail bottom and rail seat area; lateral surface of the rail’s base and lateral surface of the tie plate’s ridge; bottom of the tie plate and top surface of the tie; bottom surface of the tie and top surface of the ballast layer. Each contact pair is connected by frictional type connection with a contact-target relationship.

For efficient computing, only one detailed tie was modeled. Adjacent ties and ballast support were simulated as simple vertical and lateral spring connections to the rail. Longitudinal movements were set to zero at rail ends, and elastic supports were applied inside the spike holes to represent cut spikes.

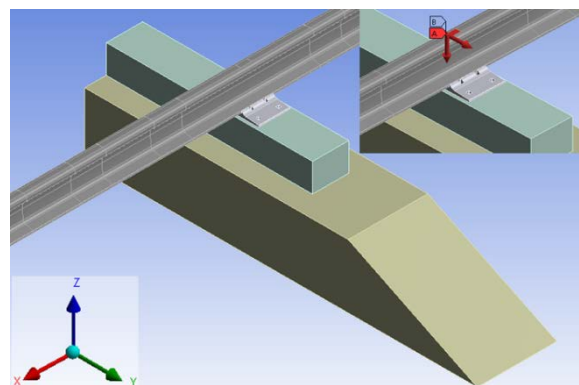


Figure 2. Finite Element Track Model – Detailed Tie Plate (14-inch AREMA Plate Shown)

The simulation matrix included three AREMA standard rolled tie plate widths (13-, 14-, and 18-inch). Orthotropic material properties were used for composite and wood. Upper and lower bound bending moduli (E_y) were determined from recent laboratory AREMA bending tests for composite and wood ties to categorize four tie types – soft composite, stiff composite, soft wood, and stiff wood.⁵ The compressive modulus (E_z) was estimated for each tie type based on AREMA plate compression test results.¹ Results from these tests showed that modern

polymer composite ties have compressive moduli 25 to 50 percent that of wood ties. Moduli in the vertical and longitudinal directions (E_x and E_z) were assumed to be equal for all ties. Figure 3 shows the two laboratory tests (tie center bending and plate compression). Model parameters are listed in Table 1.



Figure 3. Tie Center Bending Test and Plate Compression Test used to Tune Model Parameters

Table 1. Model Parameters

Rail-Plate Friction Coefficient	0.4	
Plate-Tie Friction Coefficient	0.2	
Tie-Ballast Friction Coefficient	0.7	
Rail Vertical Support (kip/ft ³)	11,500	
Rail Lateral Support (kip/ft ³)	6,400	
Subgrade Support (kip/ft ³)	1,600	
	Modulus	
Tie Type	E_y (psi)	E_z (psi)
Soft Composite	120	50
Stiff Composite	330	50
Soft Wood	500	91
Stiff Wood	1,740	217

To represent a wide range of loading environments, tangent track and curve track were simulated. For tangent, a 36-kip vertical wheel load (no lateral loading) was applied at the head of the rail. For the curve, which simulated heavy axle load overbalanced operation at FAST, a 45-kip vertical load and a 5.6-kip lateral load were applied, based on previous instrumented wheelset measurements in a 5-degree curve at FAST.

Stress contours for all tie plate and tie combinations confirmed previous studies' conclusions that peak stresses are generated near the corners of the rail spike holes,^{2,4} as Figure 4 shows. Tie plate maximum equivalent stresses and maximum deflections were output and are shown in Figure 5. Results show that a larger 18-inch plate produces higher bending stresses when coupled with softer composite ties compared to a 14-inch plate. The deflected shape of the tie plates was evaluated and is shown in Figure 6 for the soft composite and stiff wood ties curve simulations. The 13-inch plates showed the lowest maximum stresses on composite ties. This can be explained by greater penetration of the 13-inch plate into the composite tie, but less overall bending.

Maximum bending stresses for the 18-inch plate remained similar to the 14-inch plate on the two wood tie

types. Maximum tie plate deflections for a given tie type remained similar for all tie plate sizes, suggesting that tie modulus tends to govern maximum plate deflection.

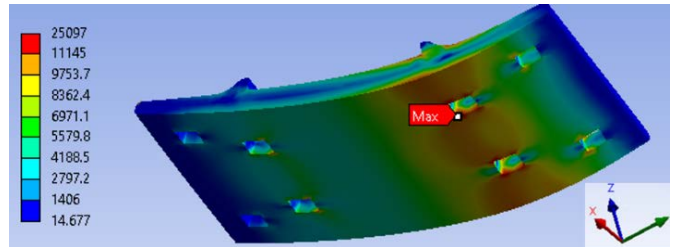


Figure 4. General Location of Peak Stress. 14-inch Plate on Stiff Composite Tie for Curve Simulations Shown (psi)

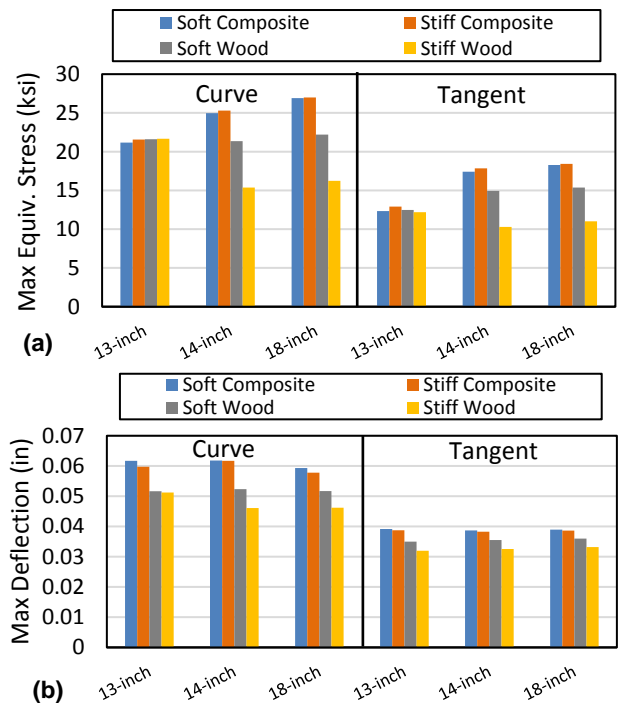


Figure 5. (a) Maximum Equivalent Stress of Tie Plates and (b) Maximum Deflection of Tie Plates

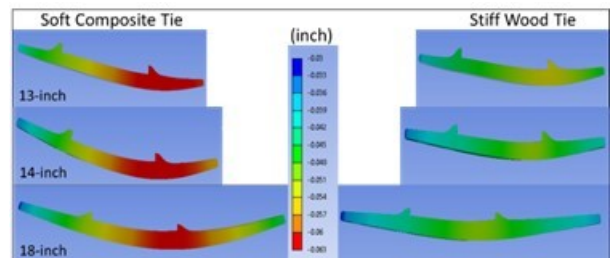


Figure 6. Vertical Deflection of High Rail Tie Plates for Curve Track Simulations. (a) Soft Composites and (b) Stiff Wood ties (exaggerated by factor of 100)

Figure 5 clearly shows higher total plate deflections on composite ties for all tie plate sizes when compared to wood ties. However, the relative deflection (the maximum deflection minus the minimum deflection), is lowest for the 13-inch plate on composite ties. Due to their relatively low compressive and bending moduli, composite ties appear to

produce higher relative bending deflections across the larger span length of an 18-inch plate.

To fully understand the performance of various tie and plate combinations, the plate-tie contact conditions were evaluated for each simulation. Figure 7 shows a qualitative comparison between 13-inch and 14-inch plate-to-tie contact areas for the same curve simulations (soft composite and stiff wood ties) depicted in Figure 5.

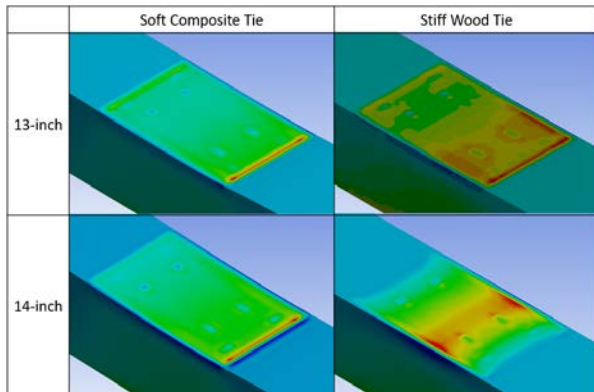


Figure 7. Qualitative Depiction of Plate-Tie Contact for Soft Composite and Stiff Wood Ties

For soft composite ties, the 13-inch and 14-inch plates generally showed the stress concentration at the plate edge on the field side. For stiff wood ties, the stress distribution at the plate-tie contact area significantly changed as the ties become stiffer. The 13-inch plates still had the stress concentrated at the plate edge, which might cause plate cutting issues. Therefore, 14-inch plates are often used on wood ties. However, 13-inch and 14-inch plates on composite ties may not have evident difference in performance since the composite ties better resist plate cutting.

Figure 6 demonstrates that for composite ties, the compressive stiffness of the tie has a larger influence on the plate-tie contact area than the size of the plate – tending to produce concentrated stresses on the field side edge of the plate. Figures 4, 5, and 6 indicate the advantage of a 14-inch plate over a 13-inch plate on wood ties – namely lower bending stresses, and more favorable load distribution. However these same advantages do not appear to hold on composite ties. The 13-inch plates appear to reduce plate bending stresses on composite ties, which have been shown to cause tie plate fatigue failures in 14-inch plates at FAST.² While 13-inch plates generate higher plate-tie contact stresses, composite ties appear more resistant to plate cutting in practice. These results suggest that 13-inch

plates may be a cost-effective alternative to 14-inch plates on composite ties. Use of larger tie plates on composite ties may not increase performance substantially.

Results from this study are indicative of elastically supported ties. Plate bending stresses may be higher for poorer tie support conditions, such as ties with weak support directly under the rails (which may cause higher rail seat positive bending of the tie).

CONCLUSION

Testing and modeling results on the effects of different tie plate sizes and tie moduli on plate stresses for EPC ties installed on fastening systems developed for wood ties show the following:

- Under similar loading, tie plates on wood ties have smaller deflections and lower bending stresses than on composite ties
- Larger plates (such as 18-inch AREMA plates) produce larger bending stresses and higher relative plate deflections on composite ties compared to smaller plates due to the tie materials' lower bending and compressive modulus and the plates larger span.
- Modeling and in-track observations suggest that 13-inch plates may perform sufficiently on composite ties, which are more resistant to plate cutting. Additional testing is needed.

This digest focuses primarily on tie plates. Additional work is being conducted to understand spike-tie interaction and performance. EPC ties and various fastening systems will continue to be evaluated in-track at FAST and in revenue service. Failure modes observed during testing will guide further evaluations and recommendations.

REFERENCES

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