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Modeling Track Mechanical Behavior with Under Tie Pads and Under Ballast Mats

SUMMARY

Railroads have begun to use under tie pads (i.e., pads) and under ballast mats (i.e., mats) in railroad tracks to better distribute train loads, reduce track support stiffness, and increase tie-to-ballast contact area. Track locations with a shallow ballast layer and numerous tunnels and bridges are areas of stiff track support that may benefit from pad and mat use.

Under the sponsorship of the Federal Railroad Administration (FRA), researchers at the Volpe National Transportation Systems Center developed a finite element (FE) track model to understand track mechanical behavior with pads and mats. The track model used monitoring data gathered during the Virginia Avenue Tunnel project (Liu et al., 2023) and estimated the track behavior without pads or mats. The model simulated ballast behavior as granular materials which form load chains that may lead to localized damage and may increase the rate of track degradation.

The modelling results highlight the individual effects of pads and mats on load distribution in track structure. Pads and mats reduced the average stress on the tie bottom and tunnel floor by 20 percent. Pads reduced the peak stress at the corner of the tie bottom by approximately 75 percent and mats reduced the peak support stress resulting from ballast load chains by 77 percent.

BACKGROUND

Pads and mats are used in railroad track to reduce track stiffness by better distributing train loads to the track elements. These resilient elements are made of elastomeric material with varying properties and allow track engineers to tune the track stiffness for optimum performance.

The Virginia Avenue Tunnel, built between May 2015 and June 2018 in Washington, DC, is a stiff track system transitioning from track on subgrade outside the tunnel to a concrete-supported ballast track in the tunnel. The tunnel track is constructed with 8-inches of granite ballast and prestressed concrete ties at a spacing of 20 inches on a 36-inch-thick concrete floor. Engineers designed the track with a 0.39-inch-thick mat and 0.28-inch-thick pads. The mat is made from resin-bonded rubber and the surfaces are bonded with a polypropylene non-woven geotextile. The pads are resin-bonded rubber with a tensile strength of 138 psi. The pads attach to the bottom of the tie with a micro-filament bonding technique.

Researchers from the University of Florida (UF) instrumented a section of the Virginia Avenue Tunnel to monitor track performance during the first 20 months of service (July 2018 through February 2020) (Stuart & Riding, 2022). The project plan included a comparison track test without pads and mats, but this arrangement was not available for testing. Instead, Volpe researchers developed computer-based simulations to compare the track performance with and without pads and mats.

OBJECTIVE

This study developed a FE track model of the Virginia Avenue Tunnel to:

(1) compare the difference in track mechanical behavior with and without resilient pads and mats

(2) investigate the effect of resilient elements on stress distribution and track component loads, and
(3) provide data to support the development of future field tests and improve the design and specifications of resilient pads and mats.

METHODS

Figure 1 shows an overview of a half-track static FE model. The model (Figure 1b) represented a 21-tie-long section of the tunnel construction described above. It included an elastic fastening system (i.e., e-clip, shoulders, and nylon insulator), rail pads, and 136 RE rail (Figure 1c).

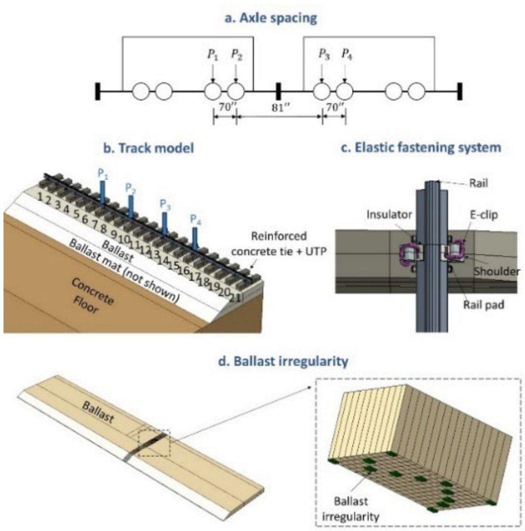

Figure 1. Track Model Overview

Ballast is a granular material that supports the ties and distributes the applied tie load to the supporting concrete. Loose ballast can lead to load chain development where a series of ballast particles transmit load directly from the tie to the support layer without significant load distribution (Liu et al., 2017). These conditions result in high stresses that increase the rate of structural degradation. In order to capture the localized stress concentration effect in the FE model, 12 cuboids measuring 0.5-in-long × 0.5-in-wide × 0.5-in-high were created at the bottom of the ballast layer (see Figure 1d). These cuboids mimicked ballast particle irregularities that develop as load chains.

The static model simulated the track response from four wheels of a coupled pair of freight cars (Figure 1a). Wheel load P_3 was located above the center of Tie #13, and the other loads were applied based on axle spacing.

The material properties for each component are summarized in Table 1. Interactions between neighboring components were defined with contact pairs and an appropriate coefficient of friction. Constraints were established between rail and insulator, rail and rail pads, and concrete tie and tie pad. Relative motion between these elements was restricted in the simulation. The team constructed and tested four models: with pads and mats, only with pads, only with mats, and without pads and mats.

Table 1. Track Component Material Properties (Yu, 2017)

Component	Young's Modulus (psi)	Poisson's Ratio
E-Clip	2.9×10^7	0.30
Rail	3.0×10^7	0.30
Insulator	3.6×10^5	0.40
Concrete Tie	4.6×10^6	0.20
Rail Pad	3.6×10^5	0.40
Shoulder	1.8×10^7	0.25
Ballast	2.5×10^4	0.30
Tunnel floor	3×10^6	0.20
Mats	2×10^3	0.45
Pads	2×10^3	0.45

RESULTS

Figure 2 shows the track deflection along the track for the models with and without pads and mats. The four deflection basins are the rail deflection from the wheel loads. The result with pads and mats shows approximately 10 percent more rail deflection, indicating a lower structure stiffness.

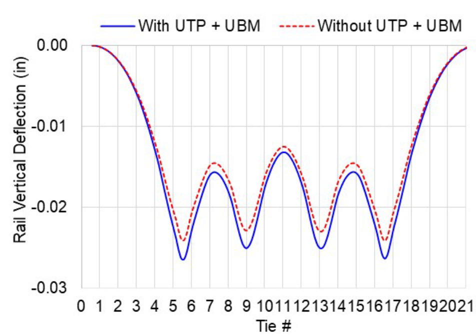

Figure 2. Rail Deflection Comparison

Figure 3 shows the average pressure at the tie-ballast interface near Tie #13. The third wheel load (P3) was applied directly above the center of Tie #13, producing the highest ballast pressure. With pads, more of the load is distributed to adjacent ties, resulting in an approximate 20 percent reduction of the peak tie-ballast pressure under Tie #13.

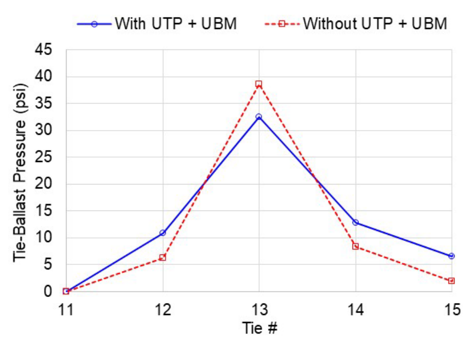

Figure 3. Tie-Ballast Pressure Variation

Figure 4 compares the tie-ballast contact pressure at Tie #13 with and without pads (both models contained mats). In both cases, stress concentrations appeared at the edge of the tie. Without pads, the maximum stress was up to 310 psi at the corner of the tie bottom, which exceeds the AREMA-recommended maximum tie-ballast pressure. With pads, the peak stress at the corner was reduced (by 75 percent) as well as the peak stress along the edge of the tie.

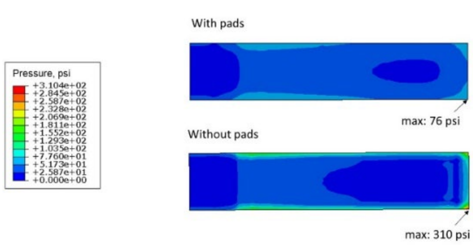

Figure 4. Comparison of Tie-Ballast Contact Pressure

Figure 5 compares the tunnel floor pressure distribution below the rail seat of Tie #13 with and without mats (both models contained pads). The effect of load chains was simulated as irregularities in the ballast interface with the concrete floor. The model results reveal a better stress distribution when mats were installed. The peak stress was reduced by 77 percent compared to the model without mats.

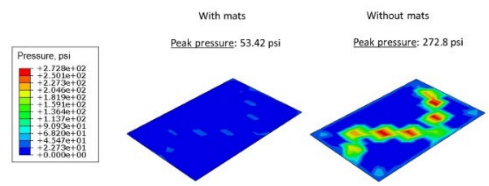

Figure 5. Comparison of Tunnel Floor Pressure Variations (unit: psi)

Figure 6 presents a parametric study of mat thickness and elastic modulus. The mat thickness varied from 0.2 inch to 0.8 inch and the elastic modulus varied from 1000 psi to 4000 psi. For a given thickness, the peak stress on the concrete floor increased with mat modulus; for a given elastic modulus, the peak stress on the concrete floor decreased with an increase in mat thickness.

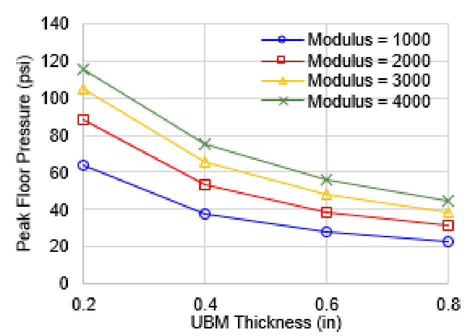

Figure 6. Effect of Mat Thickness and Modulus

CONCLUSIONS

Volpe researchers developed a half-track static FE model to estimate the effect of pads and mats on track stress. The team noted the following conclusions for pad and mat use:

- Pads and mats increased rail deflection by 10 percent, indicating a reduced track stiffness.
- Mats distributed wheel forces over more ties.
- Pads reduced peak tie edge stress by 75 percent.
- Mats reduced the peak stress on the concrete floor due to the load chains developed by ballast by 77 percent.

- Thicker mats with a lower modulus of elasticity produced the lowest predicted tunnel floor stresses.

FUTURE ACTION

Future research will further explore the use of pads and mats to reduce track stress through computer-based simulations, laboratory experiments, and field testing. The elastic elements will be characterized to provide industry practitioners with guidance for pad and mat applications for a variety of track conditions considering their durability and stability. This information could help improve the state of good repair and advance the state of track design, especially in high tonnage locations where track might have a short life span due to stiff track conditions.

REFERENCES

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