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Evaluation of the Effects of Track Wire Connections on Rail Fatigue Life

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Summary

The Association of American Railroads' Strategic Research Initiative (SRI) on Track-Signal Interfaces has an objective of improving the reliability of these track wire connections. Failed track wire connections are a major source of service interruptions for many railways; however, track wire attachment methods that have the best conductivity may damage the rail, potentially reducing its fatigue life. An analysis of the potential effects of track wire connections to rail on rail fatigue life was conducted by the Transportation Technology Center, Inc. (TTCI).

Using finite element analysis (FEA) techniques**,** TTCI evaluated the effects of track wire connection type (i.e. drilled hole or weld) and location with respect to the neutral axis of the rail. The FEA focused on currently used attachment methods that require a hole or weld be made to the web of the rail. The fatigue analysis simulated typical heavy axle load conditions with the track wire being placed on the rail web between crossties. The findings from the study include:

- A hole in the web of the rail will create a stress raiser that can increase maximum principal stresses by 500 percent, which can reduce predicted fatigue life by orders of magnitude. However, the practical effect on rail life may be nil, as the predicted life with a hole in the web is still well above typical rail service lives.
- A rough (irregular shaped) hole has a larger negative effect on predicted rail fatigue life than a smooth (round) hole. A rough hole was used to simulate either a poorly drilled hole or a weld that thermally damaged the rail. Rail fatigue life decreased by 24 percent, as compared to a smooth hole.
- The effect of the location of the hole with respect to the neutral axis of the rail can be significant, as well. Moving the connection above and below the neutral axis by 0.5 inch can decrease predicted fatigue life by as much as 22 percent for smooth holes and 10 percent for rough holes. Locations below the neutral axis had a shorter predicted life and locations above had a longer predicted life in this analysis. Only the worst case (for rail bending) loading scenario was evaluated, with the wheel load centered between ties.

The above findings on predicted rail fatigue life are intended to provide insight into the relative effects of track wire connection parameters. In all cases evaluated, the predicted fatigue lives for 286,000-pound car wheel loads are above 6,000 million gross tons. Thus, a properly made hole or weld is not likely to affect rail service life. Other failure modes are likely to determine rail life. Yet, track wire connection caused rail failures do occur. The effects of dynamic loading, cracks propagating from the weld metal, or other hole shapes may be more significant than what was simulated; therefore, the SRI will focus on developing track wire connections that do not require significant heating of the rail or the drilling of holes.

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INTRODUCTION

Track wires are used to connect wayside signals to the rail. They are typically attached to the web of the rail using a thermite weld, a lower temperature brazing, or a mechanical connection. These connections provide a good electrical path for the signal wire, but may cause thermal or mechanical damage to the rail. The damage may result in a fatigue defect in the rail.

To assess the potential effects of track wire connection methods and installation parameters on rail fatigue, TTCI conducted a theoretical analysis of rail fatigue at the track wire connection. The results of the study can be used to evaluate the relative effects of various track wire connection parameters.

STRESS ANALYSIS RESULTS

The maximum principal stress was calculated for rails with no hole (base case) and with holes at various locations within an inch of the neutral axis of the rail. A hole is used in this analysis to represent a wedge pin connection and an aluminothermic weld. Figures 1 to 3 show examples of FEA plots. These plots show maximum principal stress for a standard rail section, a section with the hole on the horizontal neutral axis, and a section with the hole 1.0 inch below the neutral axis. Table 1 is a summary of the maximum principal stress in the web for each model. For the purposes of comparison, the results of the analysis using a rough hole are also included. The rough hole was used to represent a welded track wire connection, which may have some thermal damage to the rail. The analysis shows that even though the stress levels are somewhat higher for the rough hole at most positions on the web, that is not always the case, and the differences are not very significant.

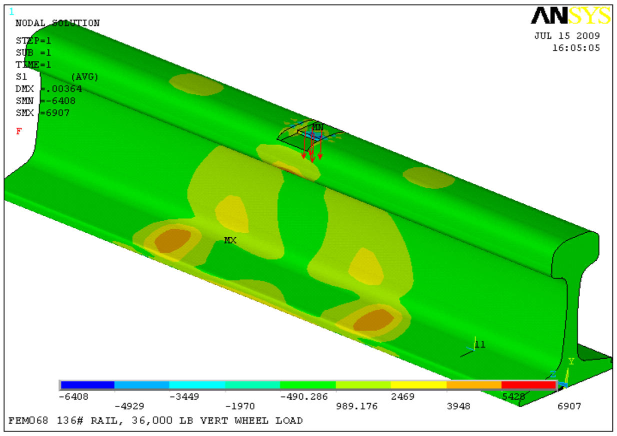

Figure 1. Maximum Principal Stress, No Hole

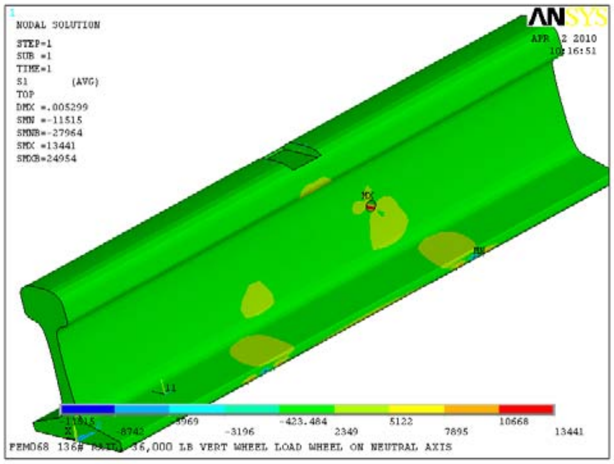

Figure 2. Maximum Principal Stress, Hole on Neutral Axis

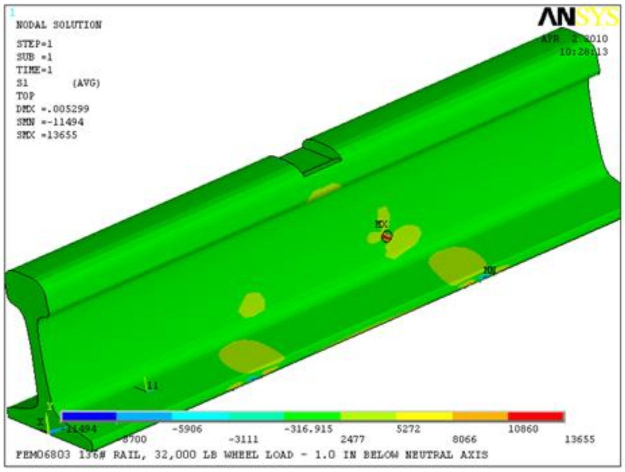

Figure 3. Maximum Principal Stress,
Hole 1.0 inch below Neutral Axis

Table 1. Summary of FEA Results

Hole Location	Maximum Principal Stress in Web (psi)	
	Rough Hole	Smooth Hole
No Hole	2,706	
On Neutral Axis	14,036	13,441
0.25 inch Below Neutral Axis	13,232	13,724
0.50 inch Below Neutral Axis	14,267	14,037
1.0 inch Below Neutral Axis	13,293	13,654
0.25 inch Above Neutral Axis	14,189	12,607
0.50 inch Above Neutral Axis	13,701	13,041
1.0 inch Above Neutral Axis	12,403	12,377

As Figure 4 shows, the trend of maximum principal stress versus hole position is more pronounced or defined for the smooth hole than for the rough hole. For both types of holes, the general trend is decreasing stress as the hole is moved upward in the web. One reason for the greater variability with the rough hole could be the presence of the added variable of geometry.

It is likely that the stress values did not vary much with hole location because maximum principal stress is a function of both longitudinal and vertical stress in the web. Because the web has a constantly varying cross section, neither component stress varies linearly with distance from the neutral axis.

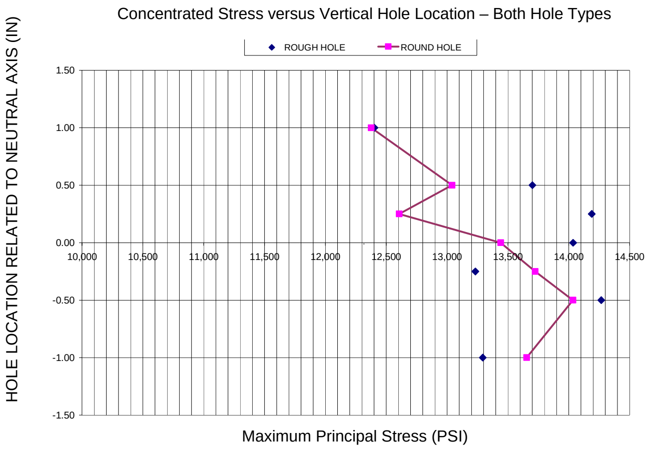

Figure 4. Maximum Principal Stress versus Hole Position

Table 2 is a summary of estimated fatigue life in terms of million gross tons (MGT). The presentation of the results in ranges reflects the use of the two types of stress life curves: (1) Axial and (2) Torsional. This fatigue life estimation is based on crack initiation, not complete failure. These figures also reflect a survival rate of 50 percent (and, therefore, a failure rate of 50 percent), because it was assumed that the stress life curves used represented the mean value of the test data points at each stress level. Estimated life for a rail without a hole could likely be considered infinite. The addition of the hole reduces the estimated life significantly, but it may still be considered infinite, depending on desired life and assumed traffic density. These results reflect the comparative nature of the stress levels in Table 1 with not much significant difference in predicted life between a smooth hole and a rough hole.

Table 2. Summary of Fatigue Life Results

Hole Location	Estimated Life — MGT	
	Rough Hole	**Smooth Hole**
No Hole	79,056,000 to 447,480,000	
On Neutral Axis	8,816 to 12,863	7,542 to 10,753
0.25 inch Below Neutral Axis	5,875 to 8,014	6,422 to 8,946
0.50 inch Below Neutral Axis	9,115 to 13,266	7,319 to 10,390
1.0 inch Below Neutral Axis	6,458 to 8,934	8,262 to 11,938
0.25 inch Above Neutral Axis	6,062 to 8,305	11,995 to 18,313
0.50 inch Above Neutral Axis	7,391 to 10,508	9,853 to 14,609
1.0 inch Above Neutral Axis	13,198 to 20,430	13,360 to 20,718

Figure 5 shows predicted rail fatigue life for a rail with no hole, a rail with a track wire mechanical connection (i.e., a smooth hole), and a rail with a thermally damaged weld connection (i.e., a rough hole). Note the predicted fatigue lives for the rails with the holes are significantly shorter than the plain rail, but still above 6,000 MGT.

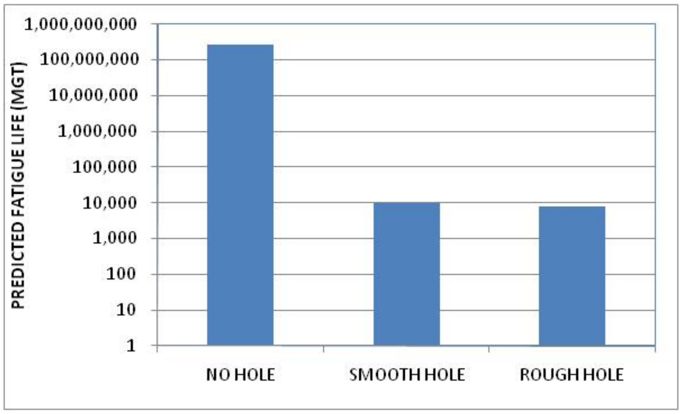

Figure 5. Predicted Fatigue Life of Rail with No Hole, Smooth Hole, and Rough Hole

Figure 6 shows the effects of hole shape and location on the predicted fatigue life of the rail. Variations in the shape of the hole and its location (within 1 inch of the intended neutral axis) can change the predicted fatigue life by 10 to 22 percent. Predicted fatigue lives have been normalized to the smooth hole on the neutral axis case.

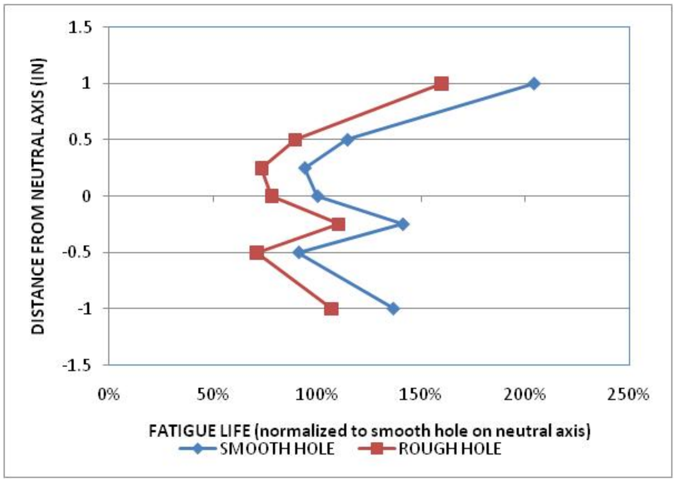

Figure 6. Effect of Location and Hole Shape on Predicted Fatigue Life

ANALYSIS PROCEDURE

The FEA model used an AREMA 136 RE rail section. The rail section spanned two ties. Flexible restraints were used to simulate 9-inch wide crossties spaced 19.5 inches apart. A 36,000-pound load was applied over approximately 0.25 square inches (0.5 x 0.5) located midway between the two crossties.

Analysis included a rail with no unusual features and rails with a 0.5-inch diameter smooth hole through the web. Analysis was completed with the hole in the seven locations listed in Table 1.

For each of the configurations above and for the standard (no hole) configuration, a fatigue analysis was performed to estimate the fatigue damage resulting from 10 wheel passes. The total life until crack initiation in terms of wheel passes was then estimated.

Two stress-life curves were used in the fatigue life estimations. The first curve was developed from large specimen tests under axial/tensile stress conditions. The ratios of minimum stress to maximum stress for each cycle was approximately -1, and it was assumed that the data represented the mean values for multiple samples tested at each stress level. This curve was then modified to account for differences in load type and the effects of surface finish. Figure 7 shows the specimen test curve and final component curve.

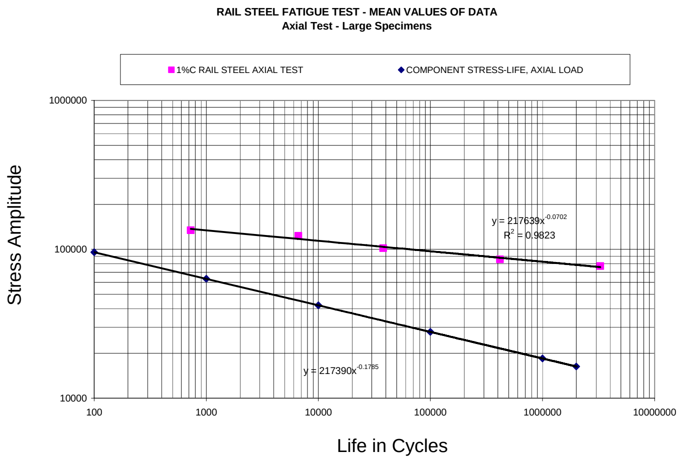

Figure 7. Stress-Life Curve, Specimen Data from Axial Stress Rail Steel Test

The second curve was developed from specimen tests under torsional (shear) stress conditions. The ratios of minimum stress to maximum stress for each cycle was assumed to be -1, and it was also assumed that the data represented the mean values for multiple samples tested at each stress level. Then, this curve was modified to account for the effects of surface finish.

Figure 8 shows the second specimen test curve and final component curve. It was assumed that both stress-life curves had constant slopes and no fatigue limit beyond which no damage occurred. For each load/stress cycle, it was assumed stress varied from zero to maximum and back to zero in a sinusoidal manner as a wheel travelled from one crosstie to the next.

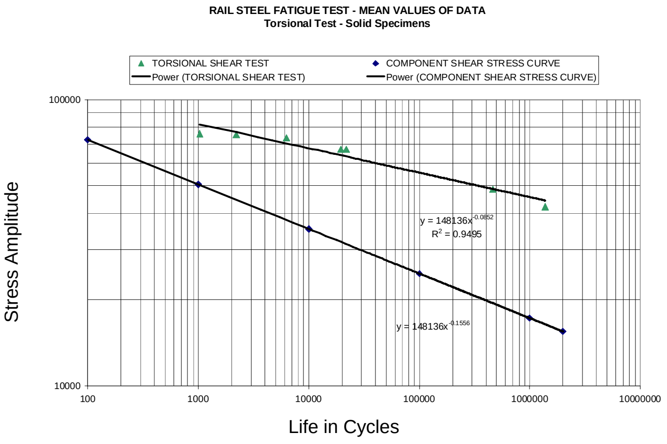

Figure 8. Stress-Life Curve, Specimen Data from Torsional Stress Rail Steel Test

CONCLUSIONS

The findings from the study include:

- A hole in the web of the rail will create a stress raiser that can increase maximum principal stresses by 500 percent, which can reduce predicted fatigue life by orders of magnitude. However, the practical effect on rail life may be nil, as the predicted life with a hole in the web is still well above typical rail service lives.
- A rough (irregular shaped) hole has a larger negative effect on predicted rail fatigue life than a smooth hole. A rough hole was used to simulate either a poorly drilled hole or a weld that thermally damaged the rail. Rail fatigue life decreased by 24 percent, as compared to the smooth hole.
- The effect of the location of the hole with respect to the neutral axis of the rail can be significant, as well. Moving the connection above and below the neutral axis by 0.5 inch can decrease predicted fatigue life by as much as 22 percent for smooth holes and 10 percent for rough holes. Locations below the neutral axis had a shorter predicted life and locations above had a longer predicted life in this analysis. Only the worst case (for rail bending) loading scenario was evaluated, with the wheel load centered between ties.

FUTURE WORK

Partial verification of the effects of wire attachment location will be attempted at the Facility for Accelerated Service Testing and in revenue service tests. While track wire attachment location can be significant to service life, it is likely to be a significant effect only when the attachment method damages the rail. Thus, developing and implementing an attachment method that does not damage the rail remains the main focus of this SRI project.