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Worldwide Rail Wear Limit Practices on Freight Railroads

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Summary

Results from a survey recently completed by Transportation Technology Center, Inc., to establish the scope for increasing rail life by allowing increased wear limits, indicate that freight railroads around the world have common track problems and appear to be converging on common track practices.

The survey also indicates that major freight railroads have rail wear limit policies that lead to nominal calculated maximum tensile rail base bending stresses of about 14 ksi and nominal calculated maximum compressive railhead bending stresses of 21-24 ksi. Note that these values are for nominal calculated stresses. In practice, railroads design track to also withstand higher stresses applied by dynamic loads; for instance, from isolated out-of-round wheels. Railroads (including North American Class I railroads) that use the highest nominal calculated stresses do not accept higher levels of rail defects (in terms of defects per mile per year) before re-railing.

Other results from the survey include:

- Over 85 percent of the railroads that replied use head-hardened rail as well as standard rail.
- While one very heavy axle load railroad uses head-hardened rail in all track, most railroads only use head-hardened rail in curves above a given curve limit. The most common limit is at a 3-degree curve.
- Eighty-six percent of railroads use head loss or a combination of head and side loss to quantify wear; whereas, 14 percent use loss of head cross-section. Seventy-eight percent use automated rail wear measurement systems.
- The criterion for when to re-rail because of rail defects varies only between 2 and 4 defects per mile per year.
- Transverse defects were the most commonly mentioned rail defects leading to rail removal.

The survey was part of the Association of American Railroads Strategic Research Initiative on Wheel/Rail Profile Maintenance. The survey was mailed to over 80 railroads known to carry only, or predominantly, freight traffic. Replies, most giving full information, were received from 27 railroads worldwide, including North and South America, western and eastern Europe, Australia, and Asia. Three out of seven major Class I North American railroads replied.



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Transportation
Technology Center, Inc.

Work performed by
a subsidiary of the Association of American Railroads

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INTRODUCTION

Railroads are highly capital-intensive industries, and one of the largest capital costs that railroads have to bear is the cost of rail. For example, the North American freight railroads have over 40-million tons of rails installed in track and purchase upwards of 600,000 tons annually. Increasing the life of rails in track decreases railroad capital and maintenance costs.

Wear is the primary cause of rail removal on freight railroads. Hence, longer rail life can be achieved by reducing the rate of wear and by allowing more wear to occur before rail is removed. Reductions in wear rate can be gained by the use of harder rail steels, by improved lubrication, and by the adoption of trucks with improved steering performance. Most railroads are already pursuing one or more of these avenues. This digest focuses on the scope for increasing rail life by allowing more wear to occur before rail is removed.

Allowable rail wear can be highly railroad specific, depending among other things on tie spacing, track condition, age and grade of rail, railroad policy on rail defects, axle loads, and local economics. In track with significant numbers of joints, allowable rail wear can depend on joint bar design, and whether or not wheel flanges strike the bars.

Therefore, this study was confined to determining worldwide wear limit practices on freight railroads. Increasing the amount of wear in the rail leads to increases in bending stresses, and thus potentially to higher defect rates. Hence, the principal goal was to determine the range of bending stress allowed in the rail through the different allowable wear limits. It was hoped that this would allow railroads to quickly and easily benchmark themselves against worldwide practice. The survey that was mailed to railroads asked for a range of other information. Some of the other information received is also included here.

RAILROAD SURVEY

A six-page survey was sent out to over 80 railroads known to carry only, or predominantly, freight traffic. The survey asked for information on:

- Rail wear limits, by track category, and the method of definition
- Means used to measure rail wear

- The main rail sections and grades used
- Tie types and spacings
- The main types of rail defects, and the criteria used for removing rail for defects
- The non-destructive examination techniques commonly used and inspection intervals
- Traffic types and speed, axle loads, and annual traffic

Replies were received from 27 railroads worldwide, and most gave full information, including North and South America, western and eastern Europe, Australia and Central Asia. Replies included three of the seven major Class I U.S. freight railroads.

General Survey Results

The survey provided much useful general information, which tended to indicate that railroads around the world have common track problems and appear to be converging on common practices.

- Over 85 percent of railroads use head-hardened rail, as well as standard rail.
- While one heavy axle load railroad uses head-hardened rail in all track, most railroads use the rail only in curves above a given limit. The most common limit is 3-degree curves (582-m radius). (As a rule of thumb, conventional 3-piece trucks should start to contact the high-rail gage face when the curve reaches approximately 3 degrees.)
- Eighty-six percent use head loss or a combination of head and side loss to quantify wear; whereas 14 percent use loss of head cross-section.
- Seventy-eight percent of railroads use automatic rail wear measurements.
- The criterion for when to re-rail because of rail defects varied only between 2 and 4 defects per mile per year.
- Transverse defects were the most commonly mentioned rail defects.

Railroads were asked to rank their main rail defect types. Figure 1 summarizes the replies. After transverse defects, the most common defects are vertical split heads, field welds (aluminothermic), plant welds (flash butt), horizontal split heads, and bolt hole defects.

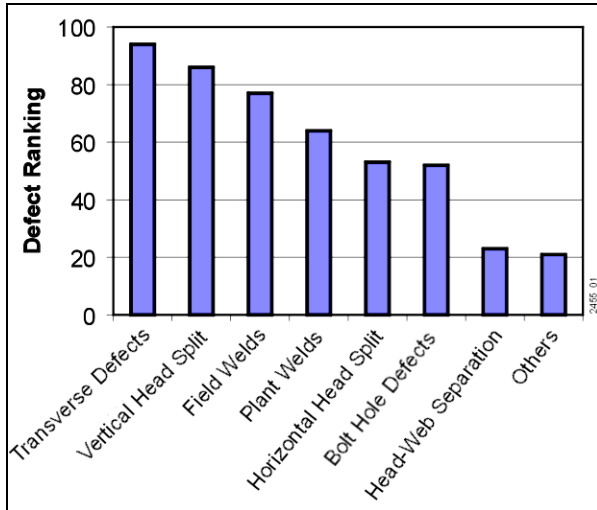


Figure 1: Main Types of Rail Defects Reported

Rail Stresses

Nominal rail-bending stresses as used in this study can be calculated using a simple model that assumes the rail is supported on a continuous elastic foundation. This is the “Winkler” model. The modulus of foundation (load per unit length of rail needed to produce a unit foundation deflection, k) depends among other things on tie type and sleeper spacing. Smaller tie spacings increase k ; larger ones decrease it.

The maximum bending moment (M_{max}) and the maximum nominal bending stress (σ_B) are related to a single wheel load (P) by:

$$\sigma_B = \frac{M_{max} \cdot y}{I} = \frac{P \cdot y}{4I} \sqrt{\frac{4EI}{k}} \quad (1)$$

where,

E is rail elastic modulus, y is distance from the neutral axis, and I is moment of inertia. (A single wheel load gives the highest rail bending stress. Because of the rail uplift effect, multiple wheels, for example, from adjacent trucks lead to a slight decrease from this maximum.) Using Equation 1 and results from the surveys, the maximum rail bending stresses allowed in the railhead and base, for new rails and rails worn to their maximum limits, were calculated as follows:

- Values of k were calculated for the given tie types and spacing, assuming a common ballast formation with average properties.
- Moments of inertia were calculated for new rail sections and for rails worn to their wear limits.

Where survey replies gave either a rail area wear limit, or a combined head and side wear limit, several values of I were calculated assuming different combinations of head and side wear.

- Values of y were calculated for new and worn rails. Values were calculated from the neutral axis to the top and bottom of the rail.
- Head (compression) and foot (tensile) bending stresses were then found for the wheel loads as determined from the survey replies.

Figures 2 and 3 show results of the calculations. Figure 2 shows the maximum calculated nominal stress values in the head for both new and worn rails. Solid data points refer to new rail stresses; open points refer to worn rail stresses. The data points are ranked in order of increasing stress in the new rail condition. Figure 3 shows similar stress values found in the rail foot. These calculated values are for rail in mainline track, for the highest axle loads given in the survey results.

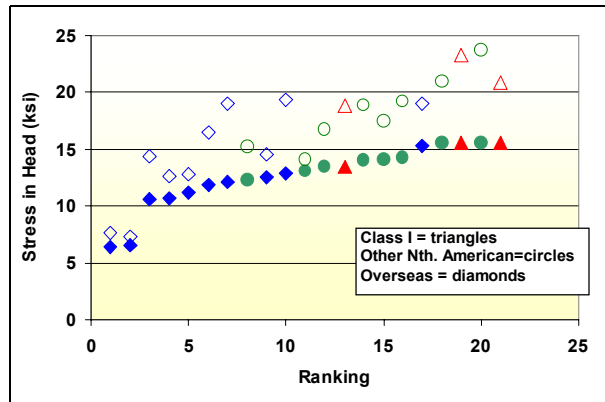


Figure 2: Calculated Railhead Stresses for New and Worn Rails

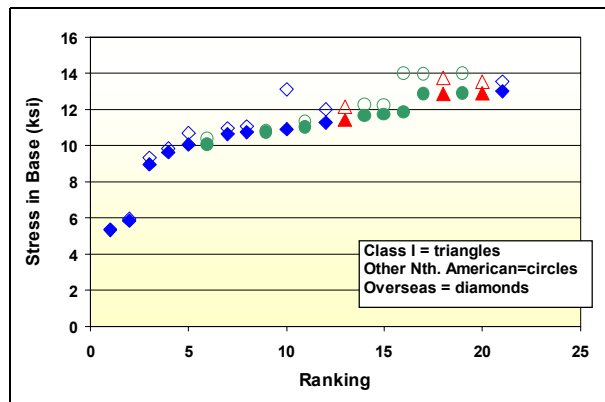


Figure 3: Calculated Rail Base Stresses for New and Worn Rails

There are several points to note from these figures.

- Rail wear has only a small effect on nominal bending stress in the rail base (Figure 3). This is a consequence of the design rail shape. For constant wheel loads and track conditions, the bending stress is proportional to y divided by the 3/4-root of I (Equation 2).

$$\sigma_B \propto \frac{y}{I^{3/4}} \quad (2)$$

As the rail wears, I reduces, but so does the distance of the rail base from the neutral axis. The net effect is that the rail base stress varies little with railhead wear.

- In contrast, railhead wear causes a large increase in nominal head stress (Figure 2). But the maximum stress in the head is compressive, which is less damaging in fatigue.
- The maximum nominal stress allowed in the head varies considerably between railroads, reaching a maximum of 21-24 ksi. Variation in the base is smaller, reaching a maximum of about 14 ksi. Note that these values are for nominal calculated stresses. In practice, railroads design track to also withstand higher stresses applied by dynamic loads; for instance, from isolated out-of-round wheels.
- North American railroad practices show nominal head and base stresses at the top end of the range of calculated stresses.

It is interesting to note that there was no correlation between allowed rail stress and the re-railing criterion for rail with defects. Railroads that allowed higher stresses in the rail did not allow higher levels of defects before re-railing.

SUMMARY AND CONCLUSIONS

Determining recommendations for the rail wear that can be allowed before rail defect rates increase to a particular level is not a straightforward matter. It requires accurate knowledge of rail stresses (live, residual, and thermal) and realistic fatigue models. Even with these, given the statistical nature of fatigue, calculations can only give indications of fatigue risk. Setting rail wear limits only based on calculations (that are likely to be highly conservative) leads to the risk of removing rails prematurely. Hence, calculations of rail stresses need to be used in conjunction with historic rail defect records and engineering judgment.

These survey results provide extra information on which to base judgments on rail wear limits. They suggest that it is possible to use nominal calculated rail base stresses of 14 ksi and practices show head stresses of 21-24 ksi. However, the scope for a significant relaxation of wear limits on North American railroads may be limited because North American railroads already allow stresses at the top end of those allowed worldwide. Given the robust safety regulations for North American railroads, it is safe to assume that rail can be, and is, managed to contain these relatively high nominal stresses safely and economically.

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