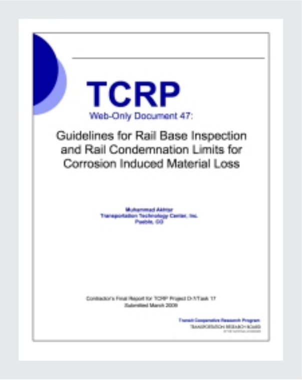

TCRP

Web-Only Document 47:

Guidelines for Rail Base Inspection and Rail Condemnation Limits for Corrosion Induced Material Loss

Guidelines for Rail Base Inspection and Rail Condemnation Limits for Corrosion-Induced Material Loss

DETAILS

0 pages | | PAPERBACK

ISBN 978-0-309-43066-1 | DOI 10.17226/21941

AUTHORS

ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) in cooperation with the Transit Development Corporation. It was conducted through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

COPYRIGHT PERMISSION

DISCLAIMER

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

Copyright National Academy of Sciences. All rights reserved.

Contents

List of Figures

List of Tables

TCRP D-7/Task 17

Rail Base Corrosion Study

SUMMARY

Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), under funding from Transit Cooperative Research Program (TCRP), has studied the causes and effects of corrosion on rail base. Phase I of this project covered several topics including finite modeling, corrosive environment, effects of corrosion on microstructure, and corrosion prevention.[1] In this phase, Phase II, the maximum allowable material loss in the rail base was assessed.

The transit systems have reported loss of material at the rail base due to corrosion. This loss of material is mainly attributed to the presence of stray direct currents that promote the acceleration of rail corrosion mainly at the rail base.

Inspection of corroded in-service rail was conducted at various transit agencies. Rail samples were collected from condemned rails and studied in detail at TTCI's facility. Generally, most of the material loss due to corrosion occurs under the rail base, where it makes contact with the tie plate. The other most common location of material loss is under or around the fasteners. The maximum depth of corrosion at the rail base measured approximately 1/4 in. The bottom surface of corrosion usually tends to be flat and free from sharp edges and corners. Under or around rail toe fasteners, the maximum width of the corrosion pit measured 3/4 in. The total material loss however tends to be higher at the rail base bottom than at the rail base edge. As opposed to rail base bottom, corrosion pits at the rail base edge usually have sharp corners and edges.

TTCI developed a finite element model to study the effects of location and size of the corrosion pits. Corrosion pits can affect the rail integrity in at least three ways: (1) reduced shear and bending strength, (2) reduced fatigue life, and (3) possibility of rail rollover.

The model predicts that the maximum allowable material loss should not be more than 1/4 in. at the bottom of rail base and 1 in. at the rail base edge. Material loss beyond that may compromise rail integrity. This is a conservative estimate based on a worst case load scenario, which has a low probability of occurrence. It assumes unsupported corrosion pits, which may happen due to rail creep or hanging ties. Corrosion pits of even higher widths may be allowed if this load scenario is avoided by timely inspection and maintenance.

Modern rails are designed for removal due to railhead wear, not for strength concerns. Rail strength is usually much higher than required. Further increase in allowable material loss without compromising safety is certainly possible and may be desired from an economic point of view. However, that is only possible through laboratory and in track testing of each case.

Stress concentration outputs from the finite element model were used to predict the fatigue life of rail. Under the assumed load conditions and the material parameters, the model predicts 10-million load cycles to initiate a crack with 1-in. maximum material loss due to rail base corrosion. An additional 0.5-million load cycles may cause the crack to grow to critical size.

Fatigue life cycles were estimated using variables that change from location to location. Thus, fatigue life may change with changes in loading and environment, as well as with variation in material parameters.

Material loss from top and bottom of the rail base may reduce fastener toe load.[*] This may increase the possibility of rail rollover or track gage widening on sharp curves. Even so, no transit systems have reported any incidents or accidents due to loose fasteners.

---

[*] This could become a problem if toe load loss occurs in consecutive fasteners.

CHAPTER 1: INTRODUCTION

Corrosion at the rail base is a serious problem in some North American transit systems. Transit systems have reported metal loss at the rail base due to corrosion. The factors responsible for corrosion, corrosion prevention, and techniques to decelerate corrosion rates have already been studied and reported in an earlier work.[1]

Rail base corrosion compromises the integrity of the rail. The metal loss directly causes the rail to become more susceptible to failure. If undetected, the metal loss will result in a loss in structural strength due to a reduction in cross sectional area. In addition, corroded material is susceptible to corrosion fatigue, which can initiate and grow cracks. Material loss at the rail base bottom and rail base edge can also reduce or eliminate fastener toe load.

Currently, transit systems do not have standard guidelines for rail base inspection procedures and rail condemnation limits. Because the corrosion mostly occurs around fasteners and on the bottom of the rail base where the rail makes contact with the tie plate, and because different transit systems use different kind of fasteners, corrosion may not always be visible or detectable. Manual inspection is done because currently no reliable automated inspection is available. Material loss may be critical at one location but may not be of serious concern at another. This study recommends guidelines to help transit operators make decisions on where to look for corrosion-induced material loss, how to measure material loss, and when the rail should be condemned.

Corroded rail was inspected on the tracks of New York City Transit (NYCT) and Southeastern Pennsylvania Transit Authority (SEPTA) to characterize rail base corrosion. Rails removed from track due to excessive corrosion-induced material loss were also inspected in the yards of SEPTA, NYCT, and Port Authority Transit-Huston (PATH).

Based on the rail base corrosion characterization and finite element analysis, rail models were created to study the effects of corrosion on rail strength, fatigue life, and rail rollover. Material properties and other parameters for this analytical study were selected from available literature.

CHAPTER 2: INSPECTION OF CORRODED RAILS

PATH Corporation operates a 600 VDC third rail traction, passenger transit system with 50 miles of track. Wheel loads of 10,000 pounds operate over 100 lb/yard rail at a maximum speed of 60 mph. An average of eight corrosion related rail breaks occur each year. Although the negative return current grounding through the rail is the major contributor to rail base corrosion, leaks from the ground water or Hudson River salt water also accelerate corrosion as a result of the humidity.

The MTA-NYCT network has approximately 660 miles of passenger service track and 180 miles of nonrevenue service track (e.g., in subway yards). Energy is supplied by a third rail system using a 600 VDC. The track has 100 and 115 lb/yard rail. The track has direct fixation type. The wheel load is 16,250 pounds and the maximum speed is 50 mph. Rail is inspected six times a year.

SEPTA includes light and heavy rail transit systems. The systems run between 2 and 3 MGT per year on 100 and 115 lb/yard rail. Usually, the corrosion is observed at the tie plates and rail fasteners in the tunnels. The tracks are ultrasonically inspected on a yearly basis. Usually, the corrosion runs from the base to the web of the rail. In general, the fastening system is severely affected. SEPTA has reported rail failures due to corrosion. In these events, rail fasteners are destroyed as well as the rail.[1]

CHAPTER 3: CHARACTERIZATION OF RAIL BASE CORROSION

During inspections of condemned rail, 15 rail samples were selected for detailed study. A visual inspection showed that corrosion was generally at two places: at or around the fasteners on the rail base edges, and on the bottom of the rail base, where the tie plate and the bottom of rail base make contact. Material loss due to corrosion on the rail base bottom tends to be flat, and the maximum measured depth of corrosion was 0.4 in. No stress risers, such as sharp corners, were observed. Maximum material loss at the edge of rail base towards the rail web was measured up to 0.7 in., with 0.5 in. being the average. Figure 1 shows how the material loss was measured. Figure 2 shows the maximum vertical and horizontal measurements.

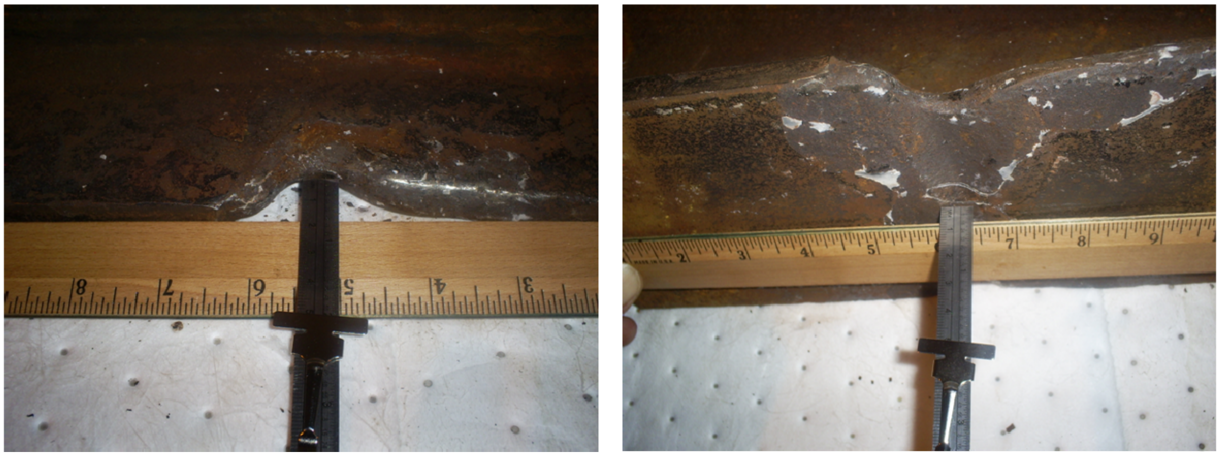

Figure 1. (Left) Rail Base Edge and (Right) Rail Base Bottom.

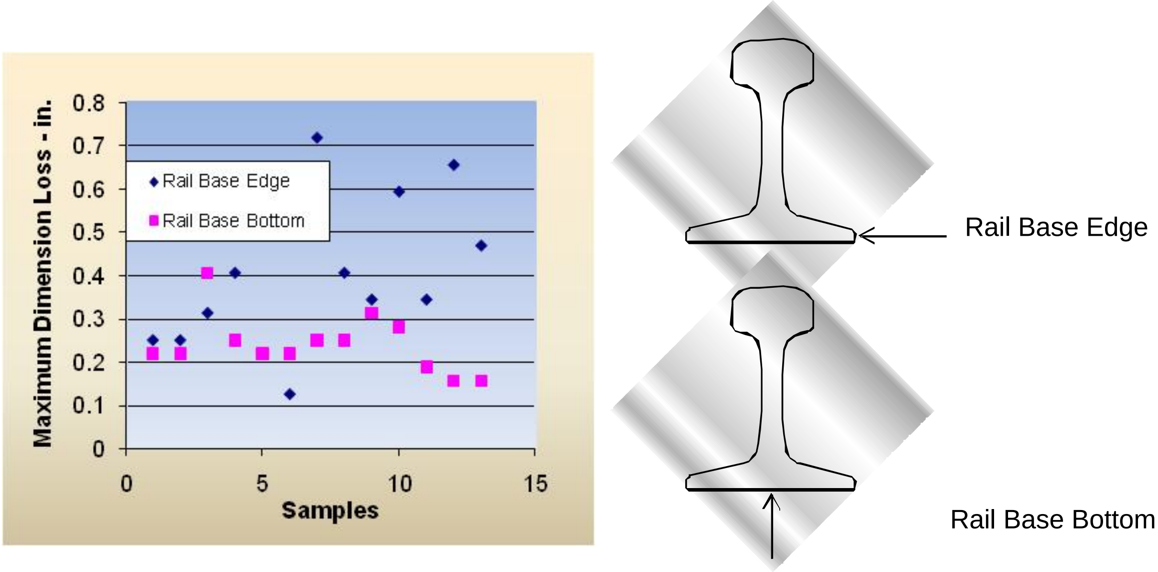

Figure 2. (Left) Material Loss Measurements, Maximum for Each Sample.
(Right) Sketches Define Rail Base Edge and Rail Base Bottom.

As Figure 2 shows, a majority of the rail base edge measurements were significantly higher than the corresponding rail base bottom measurements. The average material loss at the rail base edge appeared to be under 0.25 in. for most of the rail base edge measurements. The rail-tie plate contact area is larger than fastener-rail contact area. Current flow density is higher through the rail base than the rail base edge. Although rail base edge measurements appear to higher, total material volume loss (depth X contact area) is higher at the rail base bottom than at the rail base edge.

Figure 2 shows that defects located in the rail base edge show more material loss than those located on the rail base bottom (in one dimension). Actually, the loss of material volume is lower for the rail base edge than for the rail base bottom. Because the rail base is mostly well seated on the ties, material loss may not be critical. However, the corrosion pits have sharp edges and corners and may act as stress risers. So corrosion pits may be more critical from a fatigue point of view, but may be less significant from loss of strength point of view.

As mentioned before, the majority of the rail base edge measurements was significantly higher than the rail base bottom measurements. This observation may lead to the option that the corroded rail removal decision should be made based on the inspection and measurement of just the rail base edge. It will be more practical and convenient to measure material loss at the rail base edge than at the bottom of the rail base.

Figure 3 concentrates only on the maximum material loss under and around the fasteners. Corresponding widths and lengths of corrosion pits were measured for each sample as shown. Because the strength of rail depends on section properties, the length of a corrosion pit, although much higher than the width, is less important from a loss of strength point of view. The width of a corrosion pit directly affects the section properties; therefore, decisions to remove corroded rail from service should be made based on the width of the corrosion pit, not the length. Figure 3 also shows that material loss at condemned rail has width less than 1 in. at fastener locations.

The marking on one sample shows that the rail was rolled in 2002. The width of the corrosion pit is 0.34 in., and the rail was removed during 2007. Assuming a linear relationship, the corrosion rate appears to be 0.085 in./year. This rate of corrosion is by far the highest for the rails tested in a laboratory corrosive environment.[1] This rate might suggest that material parameters determined in the laboratory corrosive environment may not be applicable to rail corrosion due to stray current.

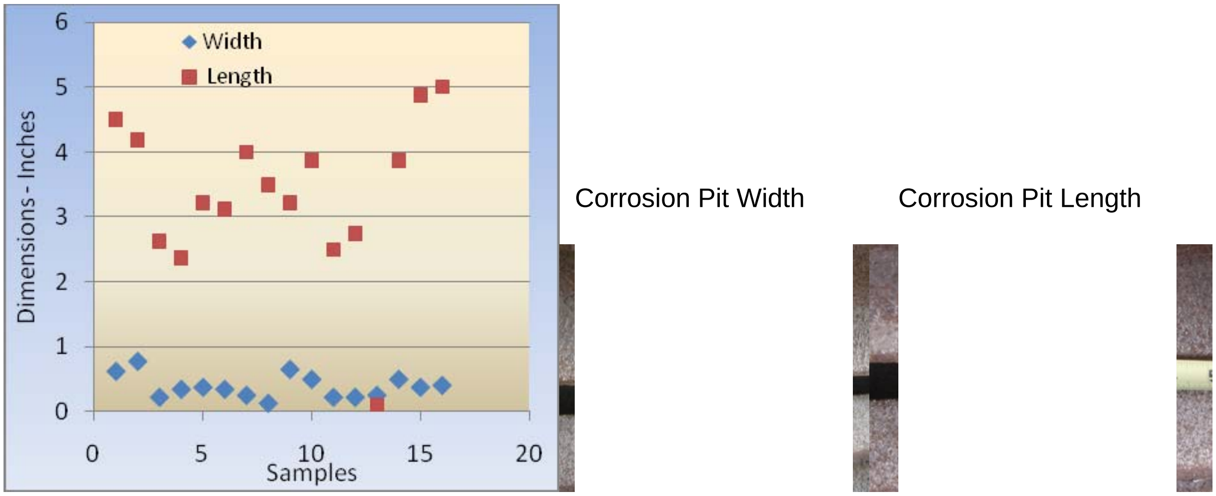

Figure 3. Material Loss at the Rail Base Edge—Length and Width of Corrosion Pits.

CHAPTER 4: NUMERICAL SIMULATION

Rail base corrosion causes material loss from the rail section and creates sharp edges. Sharp edges and sharp corners are a source of higher stresses. Stress intensities at sharp corners and sharp edges can be an order of magnitude higher than the nominal stress in noncorroded rail. Design criterion for modern rails is wear at the railhead. Accordingly, the rail sections generally have a high factor of safety against structural failures. Transit rails are generally removed due to structural concerns. These structural concerns are related to possible shear and bending, fatigue failures, and rail rollover. Material loss due to corrosion affects all of these factors.

Using mostly finite element simulations and experimental data available in the literature, such effects due to corrosion-induced material loss are discussed in detail in the following sections.

4.1 Shear and Bending Strength of Rail

A finite element model using ANSYS® software was created and analyzed for noncorroded rail to best determine the nominal stresses under design loads. The vertical and lateral wheel loads were applied as point loads along the rail length. Load location was either on the center of the railhead or on the gage corner of the rail to simulate the loading conditions during operation on tangent track and operation in curves, respectively. Similarly, load location was either in the crib center, where generally bending stresses are higher, or over a tie, where shear stresses are higher. The objective of the analysis was to build a matrix of all possible loading scenarios (Table 1(a)).

TABLE 1(a). Load Assumptions.

Assumptions	Value	Notes
Static wheel vertical load	16,500 lb*	Fully loaded
Static+50% dynamic wheel load	25,000 lb	
Lateral load on tangent	4,125 lb	25% of static wheel load
Lateral load on curves	8,250 lb	50% of static wheel load
Thermal load	0	Temperature in tunnels is nearly uniform
Rail type (jointed/CWR)	Jointed	Jointed rail, more conservative than CWR
Vertical track modulus	15,000 lb/in/in	Direct fixation track
Traction	None	
Rail tensile strength	120,000 psi	

*12,500 lb for 100 lb/yard rail, subsequent loads adjusted accordingly

A rail section 48 in. long on both ends was modeled. The model consists of SOLID 45 elements, which are defined by eight nodes having three translational degrees of freedom at each node. A finer mesh was used near the corrosion pits. Ties were simulated using spar elements. Spar elements have two nodes at each end with three translational degrees of freedom. To simulate the track modulus, deflections at supports were computed for each load condition, using beams on an elastic foundation models.[2] This deflection was then used in Hooks law[3] to calculate the modulus of elasticity. The calculated modulus of elasticity was assigned to the spar elements to model ties under the rail.

In Table 1(b), the first four load cases are for a single crib. The last two cases are for hanging tie scenarios. All ties do not always support the rail base. Some times, due to rotting wood ties or excessive corrosion related material loss, the rail base may not make contact with the tie plate. This condition is normally referred to as a hanging tie, and the rail spans over two cribs. Similarly, rotting wood ties can also create this kind of scenario.

As Table 1(b) shows, the maximum principle shear in the rail section is up to about 9,500 psi, and the principle bending tensile stress is 13,000 psi. Maximum shear occurs at the support face and maximum bending occurs in the center of the rail span. The yield stress of a material under shear is usually estimated to be about 60 percent of the material's yield strength in bending. Although shear stress is less than bending stress, shear stress is critical. In other words, shear stress will reach the shear yield strength (54,000 psi) before bending stress reaches the bending yield stress (90,000 psi). Thus, other parameters being equal, the likelihood of crack initiation due to shear stress is higher than bending stress. Similarly, the likelihood of the crack location in the rail base is greater near the tie plate. This is where shear stress is at its maximum.

TABLE 1(b). Load-Stress Matrix—Finite Element Analysis Results.

Tangent/Curve		**Span**	**Wheel Load**		**Load Location on Railhead**	**Load Location on Rail**	**Bending (psi)**	**Shear (psi)**
			Dynamic (X static)	**Lateral (X static)**				
Case I	Tangent	Single	1.5	0.25	Center	Crib Center	5333-7889	2778-5333
Case II	Curve	Single	1.5	0.50	Gage	Against Support	2778-5333	5333 - 7889
Case III	Tangent	Single	1.5	0.25	Center	Crib Center	9444-12222	6667-9444
Case IV	Curve	Single	1.5	0.50	Gage	Against Support	3889-6667	5333-7889
Case V	Tangent	Double	1.5	0.25	Center	Crib Center	5000 - 8333	6667-9444
Case VI	Curve	Double	1.5	0.50	Gage	Crib Center	10400-13000	6667-9444

The model also predicts that stresses in the rail base over tie plates are negligible. That may suggest that corrosion pits might not pose a problem as long as they are supported.

Next, finite element models were created for corroded rail. The dimensions of the corrosion pits were similar to what was found in the corroded rail samples (see Figures 4a and 4b). The width of material loss under and around fasteners varied from 0.3 in. to 1 in. in the simulations. The length of the defects was held constant since it has a negligible effect on the cross section of the rail. Also, the depth of material loss under the rail base was kept constant at 1/4 in. This is because for almost all corrosion pits with varying widths, the depth was uniform.

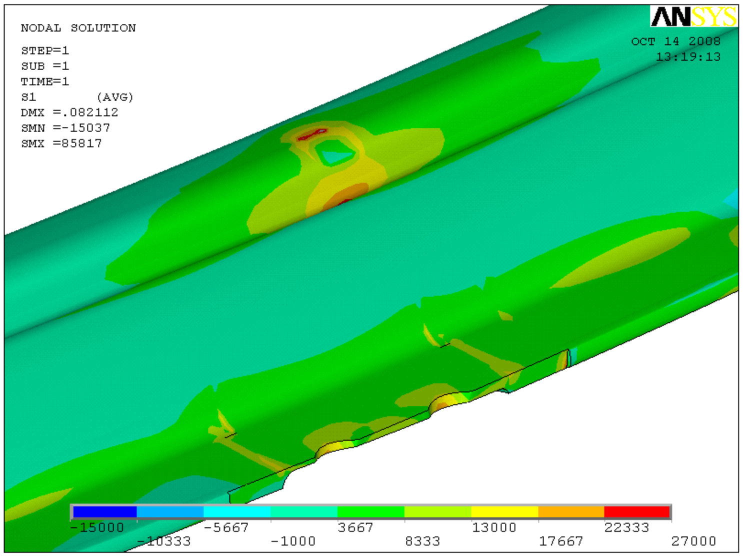

Figure 4a. Principle Stresses at a Corrosion Pit at a Fastener (Top) 0.3 in. Wide.

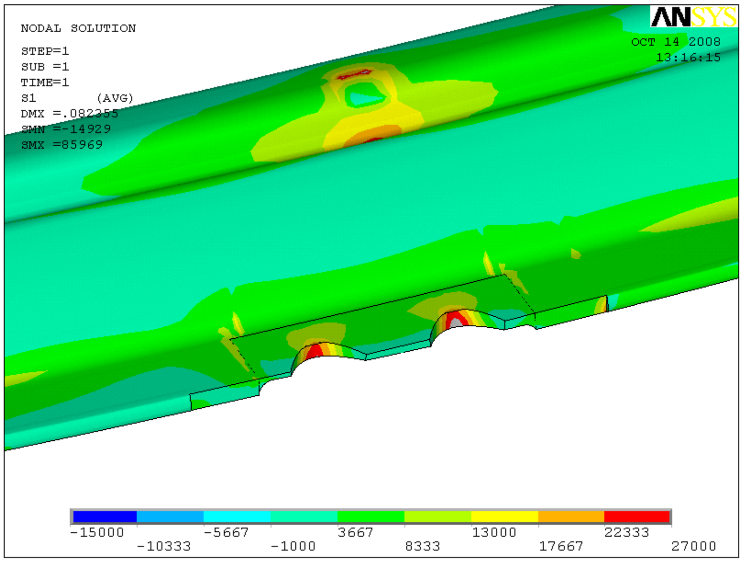

Figure 4b. Principle Stresses at Corrosion Pits (Bottom) 1 in. Wide

Figure 4c shows the principle stress in 115 lb/yard rail increased from 18,000 psi to 27,000 psi. The Factor of Safety (FOS) reduced from 5 (=90,000/18,000) to 3 (=90,000/27,000). The analysis suggests that corrosion pits beyond 1-in. width along the rail may compromise the strength of the rail and should be removed from service. The FOS for 100 lb/yard rail is similar. One-degree Fahrenheit changes thermal stress by 200 psi. Where rail temperatures vary significantly, this stress per degree change temperature should be added to the bending stress, and FOS should be recalculated accordingly.

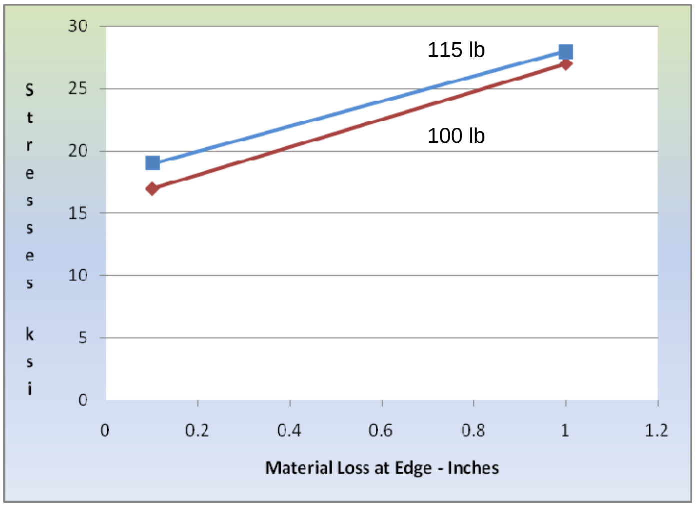

Figure 4c. Material Loss and Principle Stress Relationship.

Because traction caused rail creep is negligible, the chances of corroded rail section away from the tie plate are low. The stresses at the rail base edge, where fasteners make contact with the rail base, are expected to be low when properly seated. Therefore, not considering other effects, material loss at the rail base edge may not cause crack initiation. However, material loss at the rail base bottom can cause reduced shear stress resistance because of the reduced cross sectional area. Shear stresses at the support face tend to be higher than any other point on the rail within the crib. Material loss and stress concentration due to corrosion at the bottom of rail base tends to increase shear stress, which may cause crack initiation and crack growth.

4.2 Corrosion Fatigue Analysis

Corrosion fatigue (CF) is fatigue in a corrosive environment. It is the mechanical degradation of a material under the joint action of corrosion and cyclic loading. CF reduces the Fatigue Endurance Limit (FEL). FEL is the stress level below which no damage occurs and fatigue life is infinite. Also, material loss due to CF creates sharp corners and sharp edges, increasing the stress concentrations. So a structural member subjected to CF may have a fatigue life an order of magnitude lower than the fatigue life of a member that does not have CF. For example, as Figure 5 shows, the fatigue life of a steel sample reduced considerably after it was tested in aerated 3-percent NaCl. Further, the sample tested in aerated 3-percent NaCl did not have any fatigue threshold. That is, every stress cycle, no matter how small, caused damage to the sample.

Once a crack has initiated, corrosion can significantly increase its growth rate. The stress intensity factor (ΔK) is a measure of crack growth. A lower stress intensity factor means higher crack growth. The stress intensity factor for AISI 4340 steel in sea water was measured as 1/3 of that in air, as Figure 6 shows.

Increase in fatigue life with increase in material strength is a well-established phenomenon. However, corrosion fatigue life appears to be independent of material strength.[6]

Locations where local material loss due to CF occurs are supported; therefore, stress levels are low. However, due to rail creep the corroded locations can move to locations where stresses are higher, which can certainly increase the possibility of cracks.

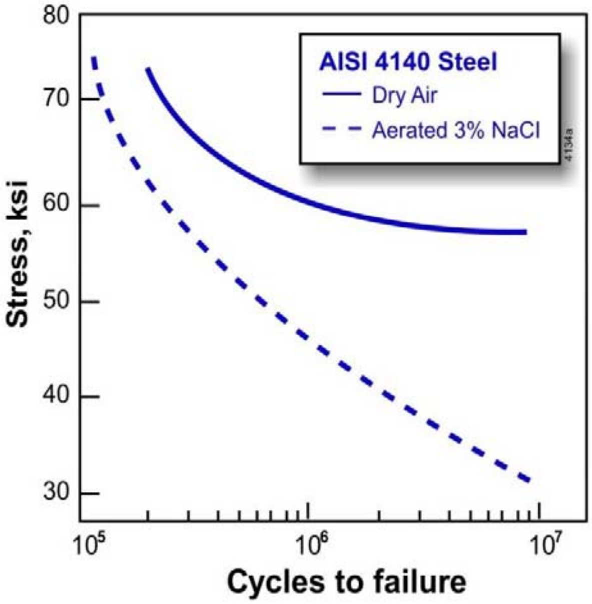

Figure 5. S-N Curves for Steel in Dry Air and a Corrosive Environment.[4]

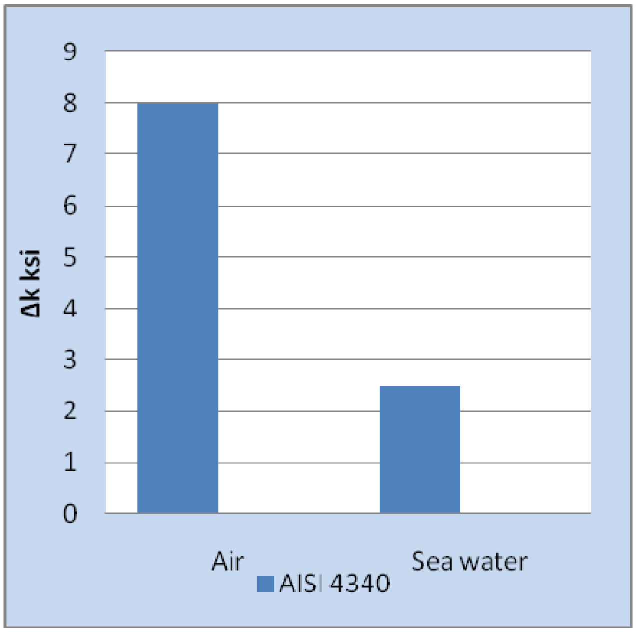

Figure 6. Comparison of Stress Intensity Factor in Corrosive and Noncorrosive Environment.[5]

A S-N curve for high carbon steel in a corrosive environment appears to be nonexistent. However, a generalized S-N curve for polished samples using mechanical strength parameters was developed. This curve was then modified using an approximate reduction factor to simulate the corrosive environment.[7]

Using tensile strength (σ_u) of high carbon steel of 120 ksi, an S-N curve for a polished sample can be developed by using $S_{100} = 0.9\ \sigma_u$ and $Se = 0.5\ \sigma_u$. Se is the fatigue threshold (or endurance limit) corresponding to 1-million cycles. This data was reduced by 43 percent to get an S-N curve for CF.[8]

The material loss increases continuously over the service life of rail, and so does the level of stress concentrations. Assuming a linear relationship, as Figure 4c shows, fatigue life was calculated at 2 points. An average was determined as probable rail fatigue life under corrosive environment, which comes to 10-million cycles. Figure 7 shows the procedure graphically.

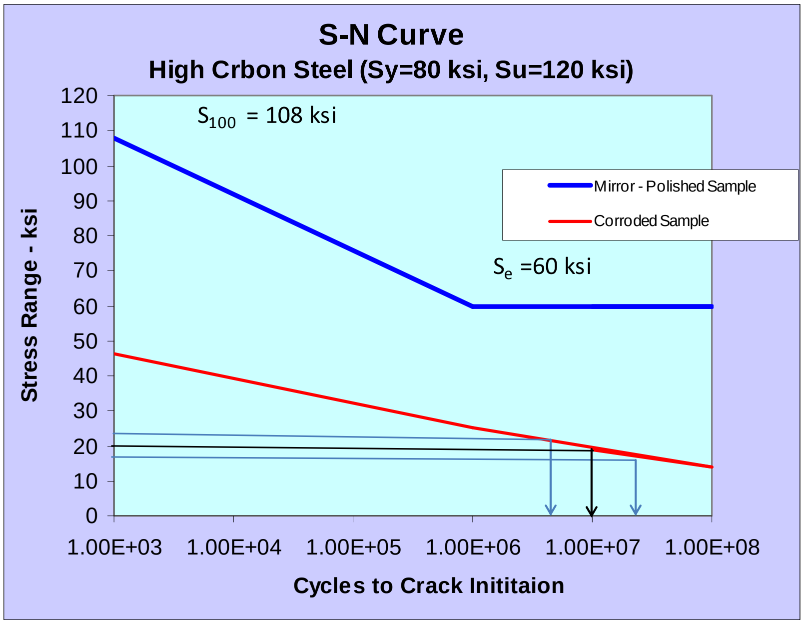

Figure 7. Likely Cycles Required for Crack Initiation at a 1-in. Wide Corrosion Pit.

Stress concentration at the corrosion pit, as determined using finite element analysis, was used as input to analyze crack growth. Cycles required to grow the crack can be calculated using principles of fracture mechanics. Crack growth software AFGROW®, which has a large database of metal properties, was used to determine the number of cycles that will grow a flaw of 0.05 in. into a critical crack size.

Wheel loads of cars are usually believed to be of constant amplitude; that is, all wheels produce the same stress range. Maximum stress occurs when track is loaded and minimum stress occurs when track is unloaded. Minimum stress is essentially zero. So the ratio of minimum to maximum stress, a parameter required as input, is also zero

Besides stress, the software also requires crack shape and size, material properties, and input parameters. Material properties having similar yield and strength properties were used for the database.

After all the inputs were provided, the program calculated that about half a million cycles may grow a flaw to critical size (see Figure 8). The stress at the tip of critical flaw has a stress level close to the yield strength of the material. This stress level can cause sudden failure.

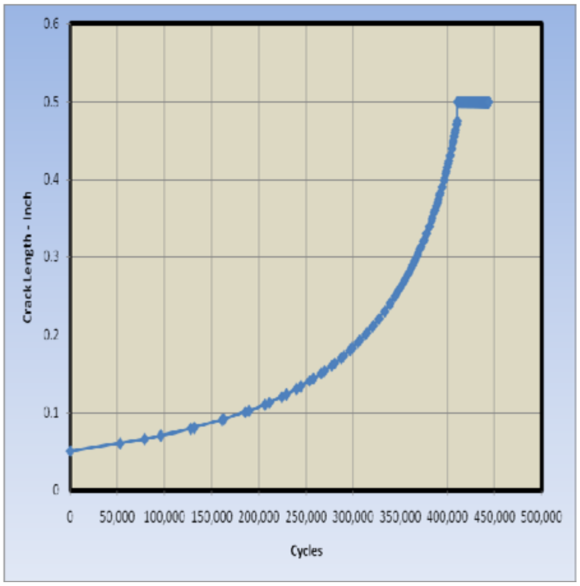

Figure 8. Number of Cycles to Grow a 0.05-in Crack to Critical Crack.

This number can be useful when determining the inspection intervals per year. If the inspection intervals are smaller than 0.5-million cycles, there is high probability of detecting the crack before the rail breaks.

For 1-in. rail material loss (maximum) by corrosion, the total fatigue life, sum of cycles required for crack initiation and crack growth, comes to about 10.5-million cycles. Fatigue life, in terms of trains, can be determined by dividing the number of cycles by the number of wheels per train. Similarly, fatigue life, in terms of tonnage, can be determined by multiplying the cycles with wheel weight (in tons). This fatigue life is approximate and depends on the assumptions made in this study.

4.3 Fastener Toe Load

The vertical rail base force generated by the deflection of an elastic rail fastener, known as the toe load, or the fixation of a bolted rigid fastener, restrains longitudinal and rotational movements of the rail. Elastic fasteners exhibit load/deflection behavior that is typically linear and elastic and design toe loads are between 2,000 and 5,000 pounds. The rigid fastener generates similar vertical forces on the rail base via the clamping action of the clip that is generated by tightening the fastener hold-down bolt.

Corrosion on the bottom of the rail base across the width of the base or on the top of the rail base under the fastener can reduce elastic clip deflection and toe load, as Figure 9 shows. The loss of rail base material will also reduce the clamping force of a rigid fastener due to loss of the hold-down bolt torque.

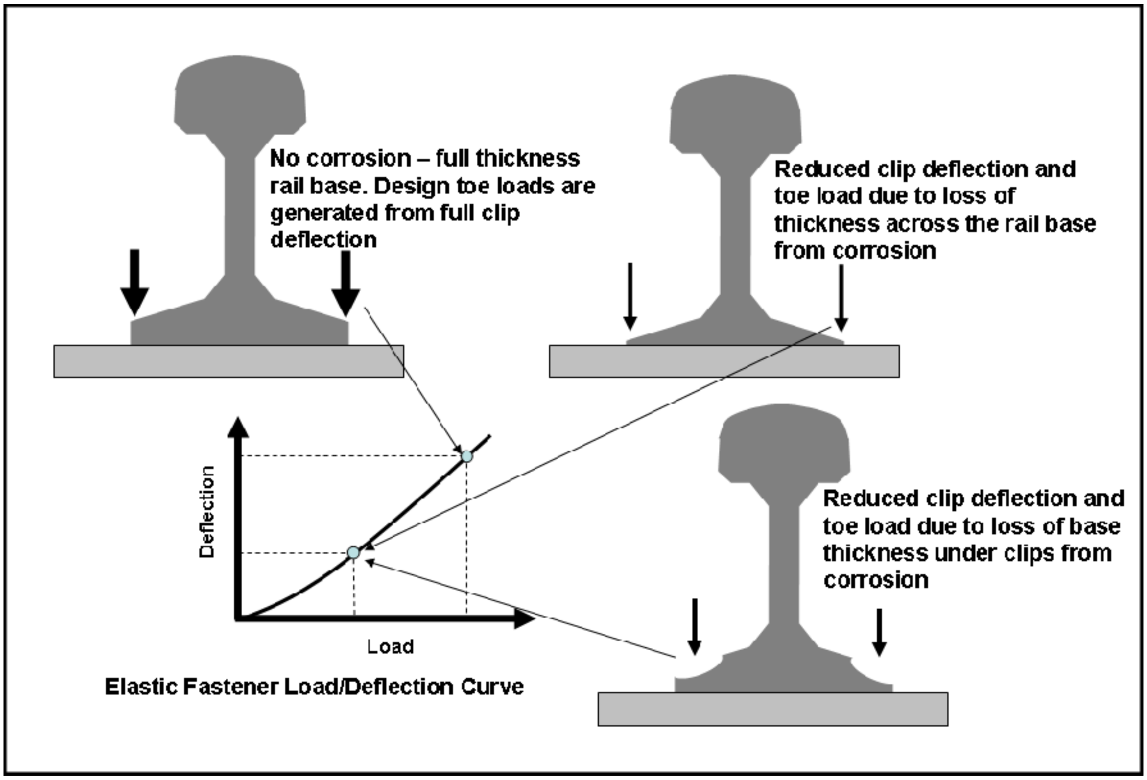

Figure 9. Effect of Rail Base Corrosion on Elastic Fastener Toe Load.

Unless the rail base has corroded to the point where the fastener deflection is small and clips are loose or have very low toe loads on consecutive ties, the effect of rail base corrosion on elastic fastener performance is not considered to be highly significant. The transit agency's rail fastener inspection and maintenance standards should apply with the caveat that special attention should be given to fastener condition where the rail base is corroded.

The loss of base thickness, however, can be more problematic for bolted rigid fasteners than for elastic fasteners. The loss of a small amount of rail base material to corrosion can cause a rigid clip to lose most or all of its vertical clamping force. To restore its functionality, the fastener hold-down bolts must then be retightened; although, the process of retightening may further damage or weaken the corroded rail material. Once again, the transit agency's track inspection and maintenance standards should take into account the possible effects of corrosion on rigid fastener performance.

Because the rail fastener redundancy provided by the rail seat spacing, field and gage-side fasteners, multiple hold-down devices, and positive lateral stops in rail is inherent in typical track designs, single clip failures; i.e., loss of toe load, may not create unacceptable safety risks. Multiple failures on consecutive rail seats are required before safety begins to be compromised.

Further, the rotational-lateral force restrained by the fasteners is generated by vehicle curving, and the longitudinal force restrained is generated by changing rail temperatures. Therefore, any negative effect of rail base corrosion on fastener performance is basically limited to rail on curves where significant curving forces are present and/or on open track that is not in tunnels or underground where significant rail temperature changes are taking place.

In summary:

- Rail base corrosion must be relatively severe, affecting both field and gage side fasteners on consecutive rail seats before fastener performance and track safety is compromised significantly.
- Elastic clips require more loss of base thickness than rigid clips before the clamping force is lost.
- Compromise of the fastener's ability to restrain rotational forces, due to corrosion, only applies to rail on curves higher than 2 degrees and nominal vehicle speeds higher than 25 mph.
- Rail in tunnels is not exposed to changing rail temperatures and thermal forces; therefore, the fastener's function of restraining longitudinal forces only applies to rail outside of tunnels.

Figure 10 shows many different types of fasteners attached to a rail with a 6-in. base. The minimum width on the rail base edge necessary for good contact is about 3/4 in. However, this width may differ among the transit agencies depending on the type of fastener used. Most of the fastener requires at least 0.06-in. deflection to develop full toe load.

Figure 10. Rail Base Fasteners: Top Left, Norfast; Top Right, Pandrol e-clip; Bottom Left, Sonneville; and Bottom Right, Pandrol-fast.

CHAPTER 5: ASSUMPTIONS AND CAVEATS

Rates of corrosion vary from location to location within a transit agency. Each agency has different environments in the tunnels depending on the proximity to sea water and sewer systems. Also, physical and metallurgical properties of rail vary from manufacturer to manufacturer. Similarly, track support conditions and fastening systems are different at each agency. Most importantly, the type and load frequencies also vary from agency to agency.

The assumptions made in this study are common to most of the transit agencies, and do not represent a particular transit system. Recommended guidelines should be implemented by a particular agency only when the assumptions of this study matches with that of the actual track and environmental conditions of the agency.

CHAPTER 6: RECOMMENDED GUIDELINES

- The rate of corrosion on the rail base appears to be significantly higher than that measured in standard laboratory tests. Thus, the only reliable method to find corrosion rate is actually measuring the corrosion pits during every inspection, and logging the rail installation and removal date. This data will help transit operators make decisions about when and how often to inspect particular track sections.
- Rail inspection intervals should be planned to detect possible crack growth. The number of cycles for a crack to grow to critical length may be used for this purpose. Corrosion pits under and around fasteners generally have sharp corners and sharp edges. Bottom of base rail is generally flat. Thus, the likelihood of finding cracks at the rail base edge is higher than the bottom of rail base. If a crack is found, the rail should be removed immediately, no matter how small the corrosion pit is.
- Under assumed loading conditions, 1 in. is the maximum corrosion width at the rail base edge that may be allowed considering structural strength. Maximum corrosion induced depth loss at the rail base bottom should not be more than 1/4 in. Beyond these dimensions, rail is recommended to be removed from track.
- Although, no incident or accident has been reported by any transit agency, there might be a possibility of gage spreading and rail rollover due to loose fasteners. This may be a concern especially on curves. It is recommended that if four consecutive fasteners are found loose due to corrosion induced material loss, the rail should be removed.
- The design of fasteners should be customized to allow proper inspection and measurement of corrosion pits under and around toe fasteners. For proper inspection, the fasteners should make contact with rail about 1 in. or more away from the edge of the rail. Another suggestion is to use bolted fasteners that can be tightened, when loose.
- Agency inspectors should look for any hanging or rotting ties. If corroded rails move off the tie plate, measures should be taken to reverse the movement. Corroded rail areas must always be seated.

CHAPTER 7: FUTURE WORK

- These guidelines were evaluated as a result of an extensive parametric study based on numerical simulations and observations of condemned rails. The guidelines are based upon standard design principles and are conservative. Laboratory and in-track testing is recommended to verify these guidelines. More liberal guidelines may be possible for specific situations without compromising safety. Such guidelines may result in less rail removal and increased rail inspection intervals.

- Within a transit agency, environment and the load frequency varies to a great extent. The same guidelines may not be economical for each route. Exact load history spectrum and actual material characteristics are necessary to recommend guidelines for individual routes.

ACKNOWLEDGMENTS

Our gratitude to Anthony Bohora of SEPTA, Anthony Cabrera of MTA-NYT, and Steve Abramopaulos of PATH for their help in providing information and guidance during this study. Special thanks and acknowledgement are also given to the personnel who helped during the site visit and for the donation of the corroded rail base samples.

REFERENCES

1. Robles Hernández, F. C., K. Koch, and G. Plascencia Barrera. “Rail Base Corrosion Study” TCRP D-7/Task 14, TRB, Washington, D.C., March 14, 2007.

2. Hay, W. *Railroad Engineering*, Second edition, John Willey & Sons, Inc. ISBN 0-471-36400-2. N.Y., 1982.

3. Timoshinko, S. *Strength of Materials*. Krieger Publish Co. ISBN-0-07248673-2. Fla., 1976.

4. Lee, H. H. and H. H. Uhlig. *Metallurgical Transaction*, Vol. 3, 1972, pp. 2949-2957.

5. Suresh, S. *Fatigue of Materials*, Second Edition, Cambridge University Press, ISBN. 13 978-0-521-57046. Page-578, 1998.

6. Novak, S. R. “Corrosion-Fatigue Crack Initiation Behavior of Four Structural Steels,” *Corrosion Fatigue: Mechanics, Metallurgy, Electrochemistry and Engineering*. ASTM STP801, American Standards for Testing of Material, 1983.

7. Shigley, J. *Mechanical Engineering Design*. McGraw Hill, ISBN # 0-07-056 881-2. 2003.

8. Socie, D. www.FatigueCalculator.com. Founder and Moderator, Professor Emeritus, Mechanical Engineering, University of Illinois at Urbana, Ill., 2008.

9. Hertzberg, R. *Deformation and Fracture Mechanics of Engineering Materials*, John Wiley & Sons, ISBN. 0-471-37385-0. P-473, 1996.

10. Harter, J. *AFGROW Users Guide and Technical Manual*, Air Vehicles Directorate, 2790 D Street, Ste 504, Air Force Research Laboratory, WPAFB OH 45433-7542, July 2008.