TECHNOLOGY DIGEST
TD-08-040
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TIMELY TECHNOLOGY TRANSFER

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Evaluation of the Feasibility of Automated Joint Bar Inspection

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Summary

Laboratory evaluations, performed by researchers at the Transportation Technology Center, Inc. (TTCI), have shown that rail joint bars can be ultrasonically inspected to detect cracks located at the top center of the joint bar.

Approaches are now being identified to perform the nondestructive inspections (NDI) in track, as part of the Association of American Railroads' Strategic Research Initiatives Program to evaluate the feasibility of automated ultrasonic joint bar inspection.

TTCI's feasibility study of rail joint bar inspection using NDI techniques resulted in the following:

- About 2/3 of the joint bar defects reported are service failures (i.e., broken bars) with the remaining 1/3 being detected cracks. This suggests that improved inspection has the potential to reduce the number of service failures and derailments significantly.
- A large majority of joint bar defects (97 percent) are reported as being located in the top center of the joint bar.
  - A sample of 50 joint bars removed from revenue service showed that most bars with cracks had flaws that originated at the top center. However, broken bars had a majority of flaws originating at the bottom or at a bolt hole.
- Inspection using contact ultrasonic approaches is feasible. Lab tests of inspection configurations using artificial and revenue service defects show that nonvisible flaws of 0.5-inch long on the top of the bar can be found reliably.
- Prediction of joint bar crack growth was conducted to determine the likely inspection window of opportunity. Finite element modeling suggests that joint bar flaws can grow from detectable size to failure in 10 to 50 MGT in heavy axle load service.
- A rail joint bar inspection model was developed to assess the effects of various joint bar inspection, defect occurrence, and growth and maintenance cost parameters on rail operating costs. Key parameters are:
  - Inspection cost
  - Inspection reliability
  - Flaw crack growth rate
  - Line tonnage rate

Rail joint bar failures are not one of the leading causes of track related accidents according to industry safety records. However, they do represent a category that is increasing with the rate of traffic. Currently, joint bars are inspected visually, which is labor intensive and only allows inspection of less than half of the joint bar. Additionally, there is no automated inspection method that finds defects before there is a significant risk of service failure. Automated visual inspection is a significant improvement over manual methods. However, visual inspection requires the defect to be visible (i.e., on the outside of the joint bar) and fairly large. Thus, further improvement in inspection methods is needed.

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INTRODUCTION AND CONCLUSIONS

Automated inspection of rail joint bars is expected to improve the safety and reliability of the railroad network. Currently, a high percentage of joint bar flaws are found as service failures. This suggests the current inspection regime (methods of inspection and frequency) are not sufficient to find and remove most flaws (i.e. joint bar cracks) prior to them developing into service failures.

Analysis of joint bar inspection records submitted by U.S. railroads to the Federal Railroad Administration shows that most defects occur in the center of the joint bar (i.e., within the middle 4 bolt holes) and at the top of the joint bar.[1] This is the location where inspections should be targeted, as Figure 1 shows.

Figure 1. Cracked Joint Bar

Additional analysis of revenue service joint bars with detected flaws or service failures revealed some interesting findings. Joint bars found with cracks are likely to have the crack originate at the top center of the joint bar. Broken joint bars are more likely to have flaws that originated from bolt holes or the bottoms of the joint bars.

Inspection of the top of the joint bar, using contacting ultrasonics is technically feasible. Laboratory testing of inspection configurations was conducted by TTCI using service induced (fatigue cracks) and artificial flaws (saw cuts). The preferred inspection configuration was determined for a top of joint bar inspection.

As with rail, it may not be possible to inspect the whole joint bar cross-section with a system that contacts the component at its top. Evaluation of the feasibility of inspecting the entire cross-section of the bar continues.

Determination of the likely window of opportunity for finding joint bar cracks was done using a crack growth model. Combined with information about inspection costs and capabilities, a joint bar inspection cost-benefit model was developed. The model evaluated potential joint bar inspection methods.

Joint Bar Use

Joint bars are used to make rail joints (or mechanical joints) in track. Rail joints are often needed in continuously welded rail (CWR) track for temporary and permanent joints. The temporary joints are often the result of rail replacements due to defects. When a rail defect is found, either by automated inspection or by becoming a service failure, a segment of rail containing the defect is replaced. The replacement rail is often installed in track with at least one end having a mechanical joint. Since joints are re-used as needed on temporary joints, there is little chance of knowing their history.

Thus, they are likely to be re-used until they are damaged or fail in fatigue. There has been a small increase in joint bar related accidents in recent years. This increase corresponds to the increase in traffic seen on the railway network.

Failure locations have been documented from inspection reports filed by the railroads and published July 2008 in *Railway Track & Structures.*[1] These reports suggest that most flaws originate in the top, center of the joint bar. (See Figure 2, which is a copy of Table 1 in the RT&S article.)

Table 1. Combination of Failed Joint Bars[1]
(based on first half of 2007 data)

		Gage Side Failure									
		Center Break	BH Break	Other Break	TC Crack	BC Crack	IBH Crack	OBH Crack	Other Crack	None	Total
Field Side Failure	Center Break	310	3		20	1	2			786	1,122
	BH Break	1	18							45	64
	Other Break				1					11	12
	TC Crack	67	2		122	1				526	718
	BC Crack	8			1	12				99	120
	IBH Crack		1				12			39	52
	OBH Crack									8	8
	Other Crack								3	12	15
	None	972	72	16	436	104	38	5	17	15	1,675
	Total	1,358	96	16	580	118	52	5	20	1,541	3,786

BH-Bolt Hole TC-Top Center BC-Bottom Center
IBH-Inside Bolt Hole OBH-Outside Bolt Hole

Figure 2. Tabulation of Rail Joint Failures from Inspection Reports

The failure mode data suggests that improved inspection methods are needed since roughly 2/3 of the reports are service failures. This suggests that more capable inspection is needed to reduce the occurrence of derailments and service interruptions.

Crack Growth Modeling

Joint bar crack growth modeling was conducted to better assess the performance requirements of potential inspection systems. Using a finite element analysis (FEA) model (Figure 3) of a standard 36-inch bar joint, crack growth lives were predicted for joints with the following traffic types:

- 110-ton cars (36-kip wheel load) unit trains

- Intermodal freight trains – a mix of 70-, 100- and 125-ton cars
- General freight trains – a mix of loaded and empty 70-, 100- and 110-ton cars
- Passenger trains – low static wheel loads (below 22 kips) operated at higher speeds

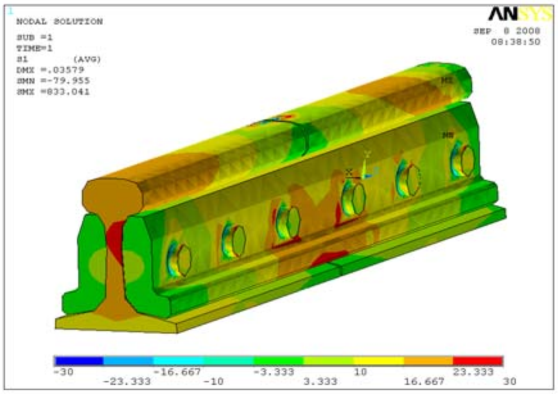

Figure 3. Finite Element Analysis Model showing Joint Bar Crack Growth

FEA models built for previous studies of insulated joints were employed to determine the effects of dynamic loading on crack growth life. The model started with a 0.05-inch long flaw in the joint bar at mid-span. The load cycles or tonnage needed to grow the defect to failure was then determined from the simulations, using the four traffic types noted above.

Figure 4 shows the results of the crack growth study. Note that the curves display the typical exponential shape seen for crack growth in most materials. The rate of growth increases as the crack gets larger. The rate of growth is affected by the maximum vertical load. Thus, unit train traffic is more damaging than mixed freights at the same speeds. Actual crack growth rates are likely to be lower due to the assumptions of loading (all loaded cars) and support (constant conditions) used in the model.

The occurrence of flaws in the joint bars was assumed to be traffic related. A Weibull process was used to generate the flaws in the analysis. This same methodology has been used for evaluating rail flaw inspection scenarios.[2] Similar parameters were used to generate joint bar flaws.

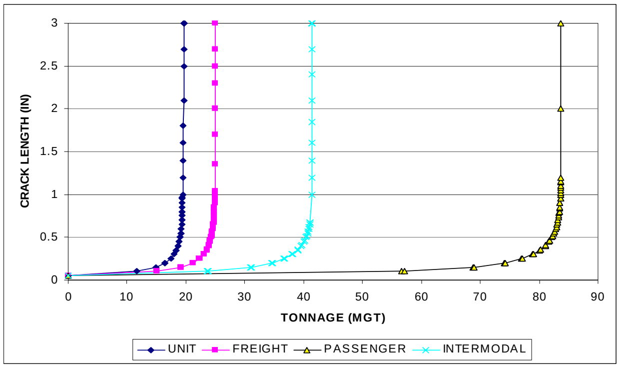

Figure 4. Predicted Joint Bar Crack Growth vs. Tonnage for Various Traffic Types

Joint Bar Inspection

Inspections of the joint bars were simulated using the assumed capabilities of an ultrasonic NDI system. Initial evaluations of the feasibility of joint inspection suggest that it is possible. Figure 5 shows the potential relationship between likelihood of detecting a joint bar flaw and its size. The relationship used represents somewhat lower capability than is currently possible with railhead flaw detection using contact ultrasonic inspection systems.

Current methods of joint bar inspection are much less capable than that shown in Figure 5. Visual inspection requires a defect to be visible from outside the joint. Most defects are expected to originate at locations contacting the rail (i.e., rail/joint bar fishing surfaces). Thus, most cracks will consume most of their crack growth life before becoming visible. As was shown in the crack growth simulations, this will leave little opportunity to find a crack with visual methods.

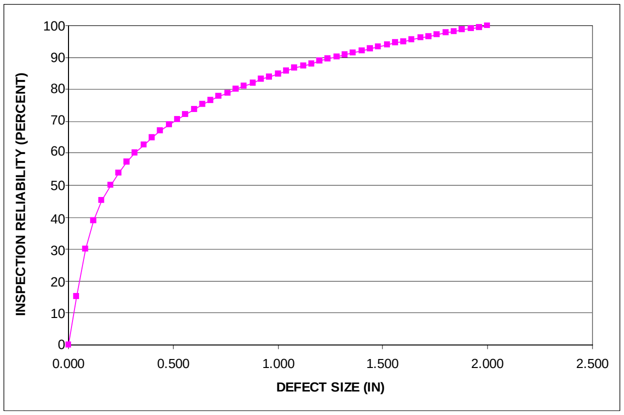

Figure 5. Joint Bar Inspection Capability

The inspection records indicate that about 2/3 of the reported defects are service failures (broken bars), with 1/3 being detected cracks. This corroborates the predicted crack growth curves, which suggest the window of opportunity to visually find a crack is rather small.

Cost Benefit Analysis

A cost benefit analysis was conducted using a joint bar inspection simulation model developed by TTCI. The model looks at the cost of inspecting joint bars, the generation of joint bar defects, the likelihood of finding a defect before failure, and the costs of having a defect. This tonnage-based simulation allows evaluation of the economics of various joint bar inspection scenarios.

Preliminary findings from inspection simulations include:

- A joint bar inspection with good reliability, as in Figure 5, and low cost can provide economic benefits over existing inspection methods.
- There is an optimal inspection interval that depends on the crack initiation rate and crack growth characteristics.

- Detection capability is important because the crack growth life will allow few opportunities for detection of a defect.

Figure 6 shows the effects of inspection interval on rail joint bar costs. A simulation was conducted on a 1,000-mile route that had CWR rail and 60 MGT/yr of unit traffic. The inspection interval was varied from 5 MGT to 100 MGT. The costs of inspection and the costs of joint bar failures, including joint replacement, service failures, and derailments were calculated. Figure 6 shows there is an optimum inspection interval for this case: 20 MGT.

Figure 7 shows the effect of inspection cost in $/mile on joint bar costs. For this case, the "break even" price for inspection is between $50 and $100 per mile. Comparing the "No Inspection" Life Cycle Cost on this graph to the $1/mile inspection cost shows the magnitude of potential savings in service failures and derailments that are possible from improved joint bar inspection.

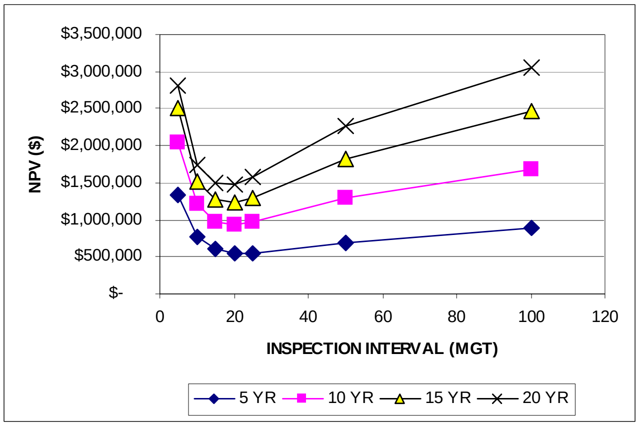

Figure 6. Effect of Inspection Frequency on Rail Joint Life Cycle Costs

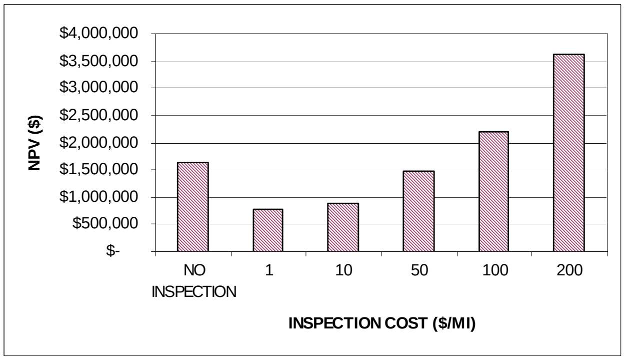

Figure 7. Effect of Inspection Cost on Inspection Economics

The base case used in the analysis is representative of a mainline track with CWR. Annual tonnage consists of unit trains at the rate of 60 MGT/ yr. Table 1 lists the relevant input parameters.

Table 1. Input Factors

Annual Traffic (MGT)	60
Traffic Type	Unit
Joint Bars (#/mi)	4
Bar Replacement ($/ bar)	350
Service Failure ($/joint)	440
Derailment Cost ($) (w/Hazmat)	1.1 M
Joint Bar Flaw Generation Rate (#/MGT)	0.169 increases with tonnage
Crack Growth Life (MGT)	40
Inspection Reliability	See Figure 3
Inspection Cost ($/mi)	100

FUTURE WORK

Development of a prototype joint bar inspection system will proceed. The economic analysis suggests that a "stop and go" inspection system may be economic for some applications. However, an automated system will be economic for freight railroad use. The static system development is a logical first step towards developing the automated system.

In addition, TTCI intends to continue work to design an improved performance rail joint. This effort will explore improved designs, materials, and installation methods. Prevention of failures is certainly preferable to detection of incipient failures in the field.

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