U.S. Department of
Transportation

**Federal Railroad
Administration**

Testing and Validation of Special Trackwork for Automated Cracked Wheel Detector

Office of Research,
Development
and Technology
Washington, DC 20590

DOT/FRA/ORD-20/35

Final Report
August 2020

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 2020	3. REPORT TYPE AND DATES COVERED Technical Report February 2013-Present

4. TITLE AND SUBTITLE

Testing and Validation of Special Trackwork for Automated Cracked Wheel Detector

5. FUNDING NUMBERS

DTFR53-C-00012

Task Order 328

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation
Federal Railroad Administration
Office of Railroad Policy and Development
Office of Research, Development and Technology
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DOT/FRA/ORD-20/35

11. SUPPLEMENTARY NOTES

COR: Monique Ferguson Stewart

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the FRA website.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

In 2013, Transportation Technology Center, Inc. (TTCI) performed testing on the gage widened special trackwork segment designed for the ultrasonic automated cracked wheel detector system; and continues to perform well in 2020. The trackwork is assessed for the risk of wheel drop and back of flange climb derailments. No undue derailment risk was discovered. TTCI determined lateral and vertical stiffness of the trackwork and measured dynamic loads with an instrumented wheelset to assure that there was no unreasonable loading at the gage transitions. TTCI also performed a tolerance analysis to verify acceptability of the special trackwork for all the Association of American Railroads' (AAR) freight car wheels.

14. SUBJECT TERMS

Automated cracked wheel detector, gage widened, special trackwork, NUCARS®, track stiffness, dynamic loads, wheel and track interaction, ultrasonic sensors, wheels, track, rolling stock, testing

15. NUMBER OF PAGES

21

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by
ANSI Std. 239-18
298-102

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1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
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1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
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1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME** (APPROXIMATE)		
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1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
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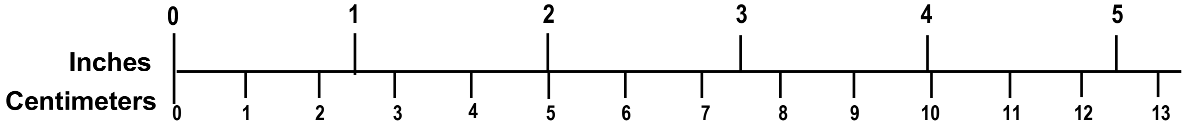

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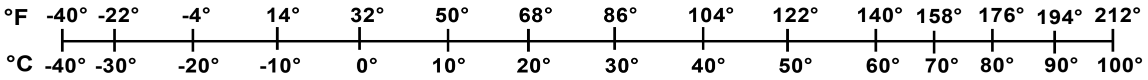

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Updated 6/17/98

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Executive Summary

This report summarizes the findings of the special trackwork testing that began in 2013 when the trackwork was originally installed at the Transportation Technology Center (TTC). The work was performed by Transportation Technology Center, Inc. (TTCI), with funding by the Federal Railroad Administration (FRA), to evaluate the fitness of service for the ultrasonic automated cracked wheel detector (ACWD) from China and continues to perform well in 2020. The special trackwork was assessed at the TTC for the risk of wheel drop and back of flange climb derailments. TTCI measured the lateral and vertical stiffness of the trackwork and ran trains over the trackwork to demonstrate performance. TTCI applied static loads to the trackwork using the Track Loading Vehicle (TLV) and measured dynamic loads with a railcar equipped with an instrumented wheelset. TTCI also performed a tolerance analysis to verify acceptability of the trackwork for all freight car wheel types that meet Association of American Railroads' (AAR) specifications. The measured values are being used in a NUCARS®[1] model to predict vehicle/track interaction in regimes that are not practical for testing in track. The ongoing NUCARS® analysis will determine the maintenance and tolerance limits required to assure ongoing safety of the special trackwork.

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[1] NUCARS® is a registered trademark of Transportation Technology Center, Inc., Pueblo, CO.

1. Introduction

In the early 2000s, an ultrasonic automated cracked wheel detector (ACWD) system was developed for the North American railroad network. This technology has since seen limited application in revenue service. Mechanical complexity with high maintenance requirements, remote in-yard location, and the resulting low throughput capacity have limited the application of this technology, and thus limited the availability of its benefit. Railroads are demanding higher capacity ACWD systems that can be placed on or near mainline routes so they can economically monitor a greater percentage of wheels. The ultrasonic ACWD system that was tested in this effort is currently used in China for inspecting locomotive wheels at speeds of approximately 5 mph. The system was installed at the Transportation Technology Center (TTC) with upgraded special trackwork that is intended for inspection speeds up to 20 mph. The testing program described in this report was carried out in 2013 and continues to perform well in 2020 with joint funding by the American Association of Railroads (AAR) and the Federal Railroad Administration (FRA) to assess the safety of this special trackwork.

1.1 Background

Special trackwork is required on any ultrasonic ACWD designed for inspecting the treads of wheels on a moving train. The special trackwork exposes the wheel tread so the ultrasonic probes can contact the wheel. Common special trackwork designs are flange bearing or wide gage. The ACWD system from China installed at the TTC uses a track gage of 61.50 inches. This will require a waiver from FRA's Title 49 Code of Federal Regulations Part 213, Track Safety Standards, specifically § 213.53 when installed in revenue service. Figure 1 shows the gage widened section for exposing the wheel tread.

Figure 1. Gage Widened Section for Exposing the Wheel Tread for Ultrasonic Inspection

The gage is sufficiently wide enough that the wheels could drop between the rails. Guardrails are used to prevent wheel drop. The guardrails are positioned to butt up to the backs of the wheels and keep the axles centered on the track while the wheels ride on the outermost portion of the tread.

Derailment concerns arise from the potential for wheel drop, gage spreading derailment, and from back-of-wheel climb on the guardrails. Analysis and testing are required to assure that typical variations in wheel dimensions, including tread width, profile, and back-to-back spacing will not lead to a potential derailment. In addition, the lateral stiffness of the track must be great enough to keep the rails and guardrails from flexing out of position when under load. Finally, the dynamic response of rail vehicles to the gage widened segment is acceptable at the intended operating speed. This testing and analysis program is intended to ensure that train performance is safe on the wide gage trackwork up to the intended test speed of 20 mph. The analysis also determines the tolerance and maintenance requirements.

1.2 Objective

The objective of this test program was to assess the special trackwork specified to accommodate the ACWD with regard to derailment concerns and vehicle dynamic performance at speeds up to 20 mph, and to measure critical track parameters to be used in subsequent NUCARS® modeling. This testing qualifies the special trackwork by documenting the measured performance of the track and the vehicle responses to it.

1.3 Overall Approach

The special trackwork validation used both testing and modeling/analysis. Testing was conducted to demonstrate the adequacy of the special trackwork for nominal railway operating conditions. The testing also provided measurements for use in validating NUCARS® models. NUCARS® modeling/analysis will be used to assess vehicle/track configurations not practical for testing in track. This approach will assess the safety of vehicle and track combinations that fall within AAR specifications.

The special trackwork tested was a special wide gage segment produced by Progress Rail. It has guardrails to keep the railcar axles centered on the track. Figure 2 shows the detail of the guardrail and flangeway clearance at the test segment installed at the TTC.

Figure 2. Guardrail and Flangeway Clearance at the Gage Transition

The track is similar to that used in China for 5 mph service, but is updated with North American components. The special trackwork is mounted to a rigid concrete foundation on elevated pedestals. The pedestals provide room under the rails for mounting the ultrasonic sensors. Rubber isolator pads separate the mounting plates from the concrete. Shims are used to adjust the guardrail spacing and flangeway clearance.

Testing ranged from static load tests to dynamic operation of a rail vehicle at speeds 15 percent above the intended inspection speed. The initial static load test was conducted to measure track deflections. The track loading vehicle (TLV) was used to input lateral loads into the track structure. Test measurements included stiffness and displacements at critical locations. The TLV was not capable of loading the track at the center of the test segment due to interference from the guardrails. Dynamic tests were conducted at increasing speeds to demonstrate the stability of the track. A railcar equipped with an instrumented wheelset was used to measure dynamic loads and to provide baseline wheel/rail force data for validating the NUCARS® models.

1.4 Scope

This testing and analysis project verifies the adequacy of the ACWD special trackwork for all operating conditions within AAR specifications [1]. It does not account for the case of damaged wheels with missing tread. A wheel with a vertical split rim failure that has lost a substantial portion of tread may not be safe on this special trackwork. Additional measures may be necessary to prevent such wheels from entering this special trackwork.

1.5 Organization of the Report

This report outlines the findings from the testing and analysis in the following sections:

Section 1 introduces the purpose for the project.

Section 2 discusses the results in detail.

Section 3 provides a conclusion along with suggestions for future testing.

Appendix A offers the clearance calculations of the automated cracked wheel detector.

2. Results

2.1 Wheel Spacing, Tread Width, and Flangeway Clearance

The data used for this portion of the analysis was obtained from published AAR standards [1]. This first step of the analysis assures that the design of the special trackwork is suitable for all railcar designs conforming to AAR specifications. For interchange service, wheel back-to-back spacing and tread width variation are limited by AAR standards. The gage and flangeway clearance limits of the special trackwork must be set to accommodate the entire range of allowable variation.

In the as-new wear condition and with a standard railhead profile, the wheels engage the top of rail squarely. Figure 3 shows how a nominal wheel gage fits the test segment track.

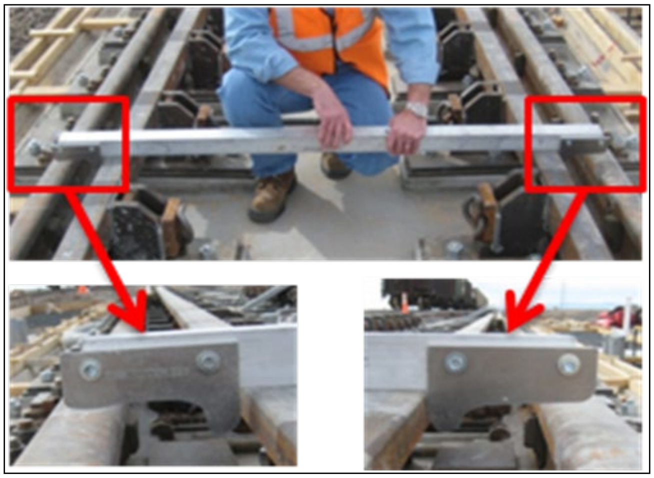
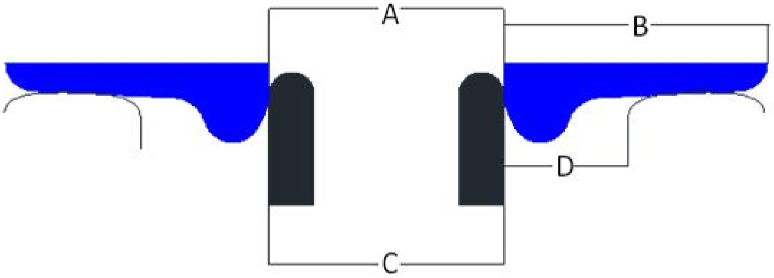


Figure 3. Wheel Gage Fit to the Test Segment

Tolerance variations for wheel width and spacing will change the amount of engagement between the wheel tread and the rail. The entire range of allowable variation was tabulated in a spreadsheet in order to evaluate the extreme cases. Figure 4 depicts the dimensions of concern for the tolerance study.



A = Wheel back-to-back spacing
B = Wheel width
C = Guard Face Gage
D = Flangeway

Figure 4. Wheel and Rail Parameters for the Tolerance Study

Appendix A shows the array of values. The worst-case combination occurred with a standard AAR narrow flange wheel having a cylindrical tread contour, with minimum chamfer, at maximum back-to-back spacing, minimum gage rail spacing, and maximum flangeway clearance. The engagement value, amount that D is less than B, is 0.375 inch in this case. This value represents the amount of tread on the rail before the start of the chamfer when the back of the wheel is against the guardrail. This minimal engagement occurs only with the chamfered narrow-flange wheel design. Moving the guardrails to maximum spacing results in 0.437-inch engagement, which is the second worst condition. All other combinations had at least 0.625-inch engagement. Most have more than 1-inch engagement and range up to 3.8-inch engagement. The adequacy of this minimal value will be determined through NUCARS® analysis.

2.2 Worn Wheels

Wheel wear affects the engagement of the wheel on the track. Figure 5 shows how a wheel of the TLV engaged the special trackwork.

Figure 5. TLV Wheel on Trackwork (Back of Flange Spacing is Same on Other Side)

In this nominal condition, the wheel engages near the edge of the rail, but is still on a nearly horizontal plane. No substantial gage spreading forces are expected.

2.3 Rail Profile

Testing under this project was carried out using new rail profiles. The engagement between the wheel and rail changes as the railhead wears. A worn rail profile could have a more profound effect on gage spreading forces. These effects will also be evaluated as part of the NUCARS® analysis of the special trackwork. Additionally, the NUCARS® analysis will be used to determine if it would be beneficial to prescribe a unique railhead profile to increase engagement under the worst case conditions. The results of the NUCARS® analysis will be presented in a future report.

2.4 Chamfered Locomotive Wheels

Locomotive wheels in North America have a chamfer on the edge of the tread. This chamfer reduces the effective width of the wheelset and increases the risk of gage widening derailment. Figure 6 shows a chamfered locomotive wheel.

Figure 6. Locomotive Wheel with Chamfer

Locomotive wheels are generally wider than freight car wheels, so the worst case for locomotive wheels in good condition should be better than the chamfered narrow flange freight car wheel. The wheels of each locomotive used in the initial test consist were measured to ensure safety. The wheels of all three locomotives measured very close to nominal and performed safely on the ACWD special trackwork.

2.5 Track Displacement and Stiffness

2.5.1 Track Stiffness

Rail lateral and vertical stiffness measurements are required inputs for the NUCARS® analysis. The TLV was used to measure these values at the points of interest in the special trackwork. Both vertical and lateral stiffness were very high, as would be expected. Figure 7 shows the stiffness measurements in kilopounds per inch (kip/in) at each measurement location. The TLV could not measure at the mid test section due to interference from the guardrails. Due to construction similarities, vertical and lateral stiffness at the mid section should be similar to the values measured before and after the transition.

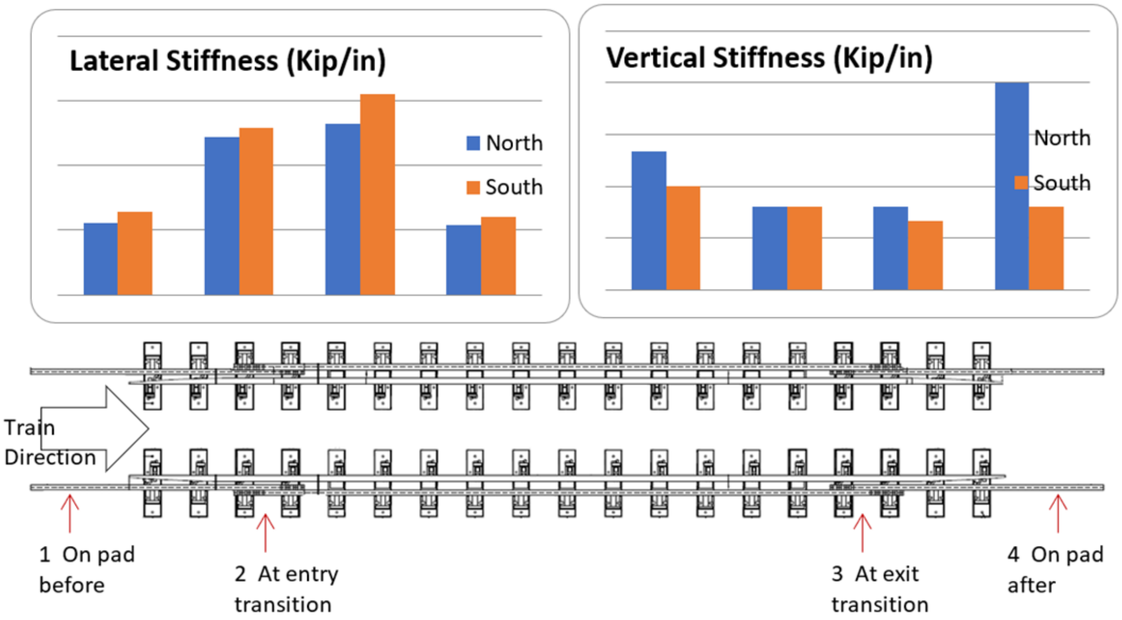


Figure 7. Lateral and Vertical Stiffness Measurements at Various Locations

2.5.2 Track Displacements

Lateral Displacements
The lateral stiffness of the special trackwork is very high. Lateral deflection at the top of the rail measured just over 0.0625-inch under an 18-kip load from the TLV. Consequently, the risk of a wheel drop derailment due to gage spreading is very low unless there are abnormal lateral loads. All lateral loads observed during the testing were less than 7 kips. NUCARS® modeling will be performed to predict lateral loads and gage spreading for a representative range of wheel and rail profiles.

Vertical Stiffness
The vertical stiffness values are on the order of 1,000 kip/in where the rail is continuous and approximately 75 kip/in at the bolted transitions. This track will provide a stable platform for the ultrasonic sensors.

2.6 Instrumented Wheelset Testing

TTCI operated a test car equipped with instrumented wheelsets through the special trackwork at speeds from 5 mph to 23 mph. Vertical and lateral wheel/rail forces were monitored during the test, and lateral/vertical (L/V) ratios were calculated to assess the potential for a wheel climb derailment. Table 1 shows a summary of the results of these measurements. The wheel/rail forces and L/V ratios generated in the gage widened special trackwork are not substantially different than those generated in negotiating a turnout.

Table 1. Instrumented Wheelset Results

Speed (mph)	Minimum Vertical Load (kip)	Maximum Lateral Load (kip)	Maximum L/V Ratio
5	28.48	6.20	0.17
5	27.72	5.56	0.15
5	27.69	5.66	0.15
10	27.83	5.78	0.16
10	27.94	5.53	0.16
10	27.80	5.38	0.15
15	26.52	5.89	0.15
15	26.97	5.40	0.14
15	28.25	6.54	0.16
21	27.71	5.34	0.15
21	27.08	6.74	0.17
21	27.14	6.35	0.16
23	27.51	5.67	0.14
23	27.43	5.28	0.14

The minimum vertical loads represent dynamic wheel unloading. A minimum vertical load of zero indicates wheel lift and suggests imminent derailment. For safety, this value should always be above 10 percent of the static wheel load. The minimum vertical load values trend downward slightly as speed increases, but all vertical loads stay well above the threshold even at the maximum test speed.

The L/V ratio is another indicator of potential derailment. When the lateral load exceeds the vertical load on a given wheel resulting in an L/V ratio above 1.0, then wheel climb is a concern. In all cases, the maximum L/V ratio is very low. Wheel climb is not indicated. Overall, this testing indicates safe dynamic vehicle performance for the configuration tested.

Depending on car type and load state, a critical state may be reached. A critical state is a speed where a vehicle resonant mode (e.g., vertical bounce) is excited that could cause wheel unloading. NUCARS® modeling will be used to investigate this possibility for other car types and operating scenarios.

2.7 Other Concerns

Any special trackwork, such as turnouts or crossing diamonds, will change the loading on the wheel. Changing the point of load application on the wheel changes the stress state within the wheel. Wheels with severe damage could pose a derailment risk. A wheel with a vertical split rim defect could be too narrow to engage the ACWD trackwork. Figure 8 shows wheels with vertical split rim defects. The risks posed by such wheels operating over the ACWD special trackwork are not within the scope of this project. Additional inspection measures may be required to exclude grossly damaged wheels from entering this detector. Technologies to find this sort of failure are being investigated under a separate project.

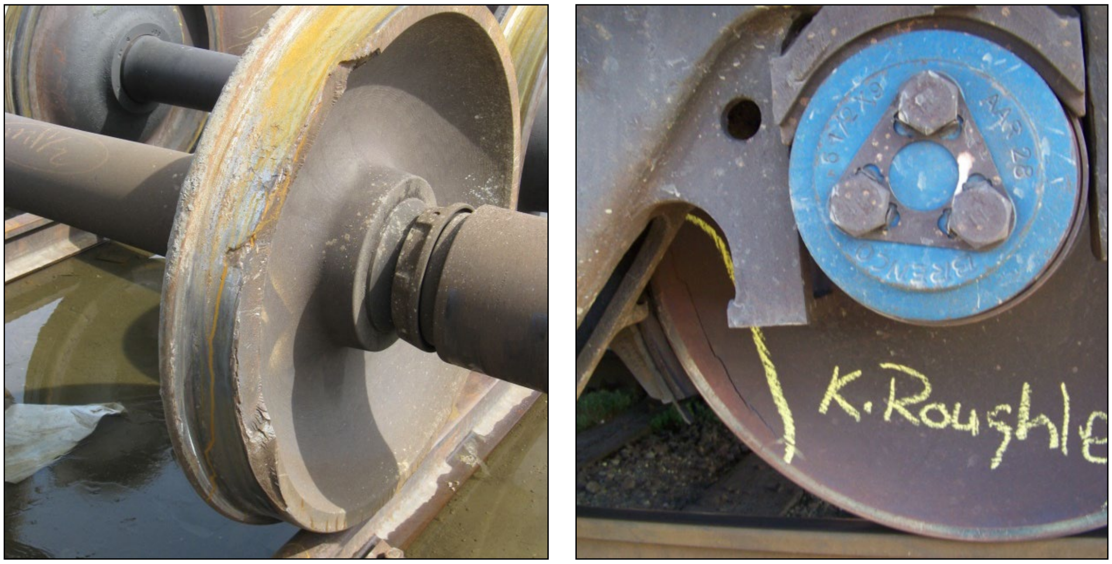


Figure 8. Severely Damaged Wheels Should be Excluded from the ACWD Trackwork

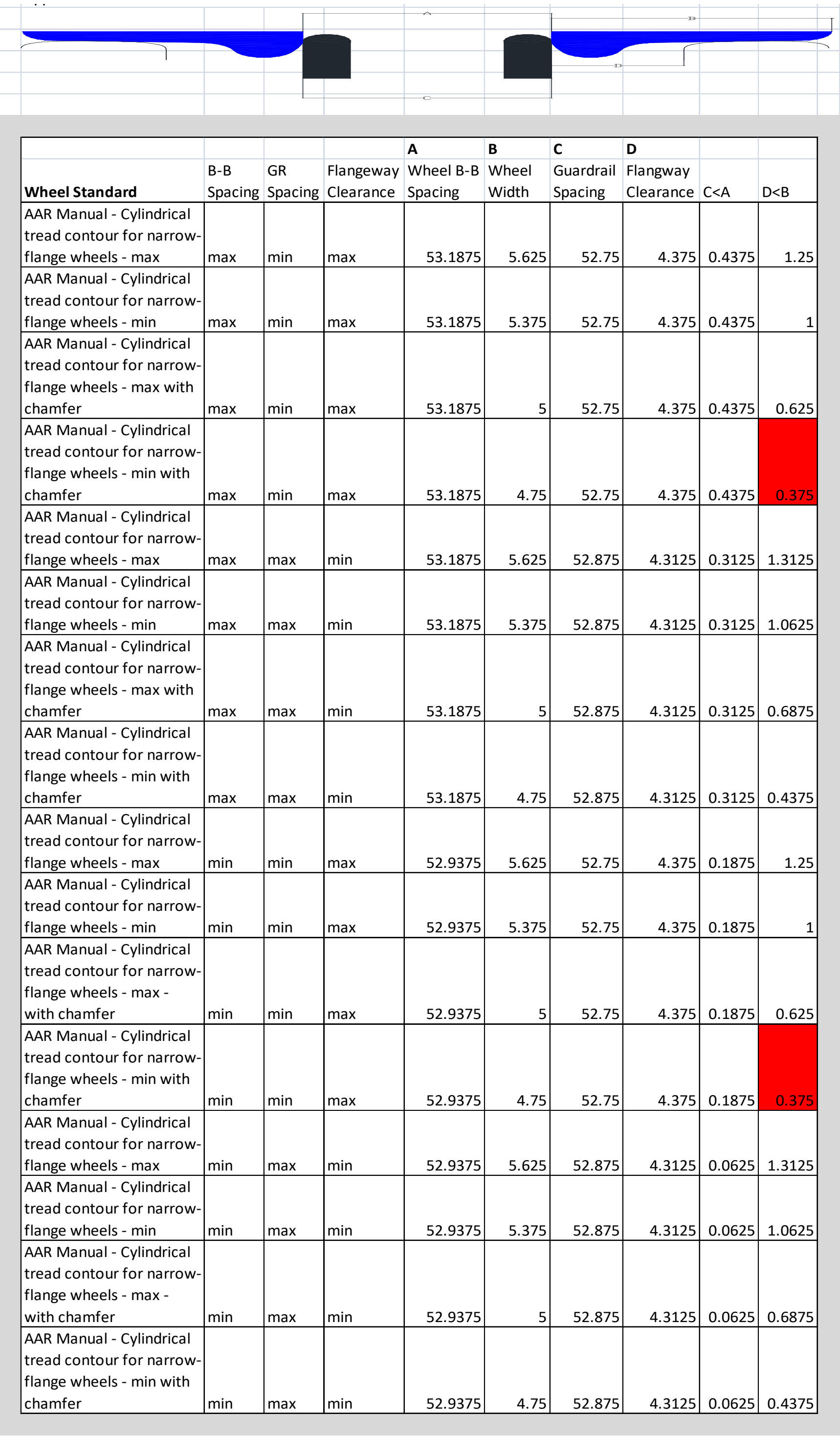
3. Conclusion

In 2013, TTCI completed a test program to evaluate the suitability of the gage widened special trackwork to accomodate the ultrasonic ACWD system. On the basis of nominal guardrail spacing and flangeway clearance values, the worst-case combination of wheel width and wheel back-to-back spacing results in a 0.375-inch engagement for wheels meeting AAR specifications. The test train was operated at speeds up to 23 mph and no vehicle/track interaction performance issues were encountered. Measured vertical wheel unloading and lateral wheel/rail forces were minimal. There was no indication of flange climb derailment. With high track stiffness and low lateral loads, there is no indication of wheel drop derailment for wheels meeting AAR specifications. This testing did not address the interaction of a compromised wheel, such as a vertical split rim defect, with the ACWD trackwork. Additional measures may be required to assure that no severely damaged wheels enter the ACWD track segment. This testing validates the performance of the special trackwork at speeds exceeding the maximum intended test speed of 20 mph for the vehicle/track conditions tested. NUCARS® modeling is ongoing to validate other vehicle/track scenarios that are not practical for testing in track.

4. References

1. Association of American Railroads. 2013. *Manual of Standards and Recommended Practices.* Section G, “Wheels and Axles.” Washington, DC.

Appendix A.
Clearance Calculations for Automated Cracked Wheel Detector



				A	B	C	D		
Wheel Standard	B-B Spacing	GR Spacing	Flangeway Clearance	Wheel B-B Spacing	Wheel Width	Guardrail Spacing	Flangway Clearance	C<A	D<B
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max	max	min	max	53.1875	5.625	52.75	4.375	0.4375	1.25
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min	max	min	max	53.1875	5.375	52.75	4.375	0.4375	1
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max with chamfer	max	min	max	53.1875	5	52.75	4.375	0.4375	0.625
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min with chamfer	max	min	max	53.1875	4.75	52.75	4.375	0.4375	🟥 0.375
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max	max	max	min	53.1875	5.625	52.875	4.3125	0.3125	1.3125
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min	max	max	min	53.1875	5.375	52.875	4.3125	0.3125	1.0625
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max with chamfer	max	max	min	53.1875	5	52.875	4.3125	0.3125	0.6875
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min with chamfer	max	max	min	53.1875	4.75	52.875	4.3125	0.3125	0.4375
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max	min	min	max	52.9375	5.625	52.75	4.375	0.1875	1.25
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min	min	min	max	52.9375	5.375	52.75	4.375	0.1875	1
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max - with chamfer	min	min	max	52.9375	5	52.75	4.375	0.1875	0.625
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min with chamfer	min	min	max	52.9375	4.75	52.75	4.375	0.1875	🟥 0.375
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max	min	max	min	52.9375	5.625	52.875	4.3125	0.0625	1.3125
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min	min	max	min	52.9375	5.375	52.875	4.3125	0.0625	1.0625
AAR Manual - Cylindrical tread contour for narrow-flange wheels - max - with chamfer	min	max	min	52.9375	5	52.875	4.3125	0.0625	0.6875
AAR Manual - Cylindrical tread contour for narrow-flange wheels - min with chamfer	min	max	min	52.9375	4.75	52.875	4.3125	0.0625	0.4375

Figure A1. Clearance calculations of the automated cracked wheel detector

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AAR	Association of American Railroads
ACWD	Automated Cracked Wheel Detector
FRA	Federal Railroad Administration
kip/in	Kilopounds Per Inch
L/V	Lateral/Vertical
TLV	Track Loading Vehicle
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)