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of Transportation

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WHEEL-PEELING EXPERIMENT-ANALYSIS OF COMMUTER RAIL WHEEL THERMAL CRACKS

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Cameron Stuart

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ENSCO, Inc.
5400 Port Royal Road
Springfield, Virginia 22151

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This report outlines the procedures used and presents the data obtained during the wheel peeling portion of the Cracked Wheel Investigation. The procedure was conducted by ORX, Inc., Tipton, Pennsylvania from April 6 to April 9, 1992. Its purpose was to measure and record the physical characteristics of thermal cracks present in two, selected, railroad wheels. These wheels had ben removed from routine service on New Jersey Transit Rail Operations, (NJTRO). Various measurements were taken to describe the thermal cracks in these wheels, both on the tread surface as well as in the rim bulk. Annotated test data were gathered and forwarded to the Volpe National Transportation Systems Center (VNTSC) for analysis in conjunction with the overall investigation of wheel cracking phenomena occurring in commuter rail wheels sponsored by the Federal Administration.

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SUMMARY

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The following observations were made during the experimental procedure and while the test data were prepared for VNTSC.

1. All wheel rim thermal cracks were relatively evenly spaced along the circumference of the tread except on wheel #1419 which had a 10 inch-long section of tread with no visible thermal cracks

2. Wheel #1419 had fewer visible thermal cracks than wheel #1501, but their overall length was greater. For example, wheel #1419 had 69 total thermal cracks that measured greater than 0.5" in length, ninety per cent of these were between 0.7" and 1.15" long. Wheel #1501, on the other hand, had over 160 thermal cracks greater than 0.5" long, ninety per cent of which were between 0.5" and 0.8" long. Maximum measured thermal crack length on wheel #1419 was 1.1" and on wheel #1501 was 0.9".

3. No measured crack depth, into the rim bulk, exceeded 0.325".

4. No crack was found, on either wheel, that was not visible on the tread surface.

5. Thermal crack propagation on the tread surface was approximately parallel to the axial direction of the wheel. Inside the rim bulk, the majority of the measured cracks did not propagate in the radial direction but curved left or right, or were S-shaped. Also, individual crack shapes were not uniform within the rim. With a few exceptions, their direction of propagation was not consistent between each increment of rim machining.

6. All observed cracks appeared to remain tightly closed, both on the tread surface and in the rim bulk.

The appendices at the end of the report illustrate the results of this procedure in graphical and tabular formats.

1. INTRODUCTION

1.1 Background

This report is the seventh in a series on the results of an engineering study of the effects of service loads on railroad vehicle wheels. The study, entitled Cracked Wheel Investigation, was initiated in September 1991 in response to a request for assessment of contributing factors and corrective actions taken regarding high rates of crack occurrence in certain multiple unit (MU) powered cars used in commuter service. The ultimate goal of the study is the evaluation of safe limits on performance demand (weight carried per wheel, maximum speed, vehicle braking rate) as a function of wheel design, material selection, and manufacture as well as percentage of braking effort absorbed through the wheel tread in service. Engineering tests to support this study include a review of wheel maintenance records of the affected railroads to confirm the general nature of the crack occurrence patterns, destructive saw-cutting of new and service-worn wheels for purposes of estimating the residual stresses in their rims, and a test analyzing the thermal environment of commuter rail wheels under revenue service conditions. Metallurgical examinations of wheel samples, including metallographic and fractographic studies as well as hardness tests, were also conducted by the Volpe National Transportation Systems Center (VNTSC).

Test reports covering the thermal measurement and the wheel saw-cutting procedure are being published separately; other reports pertinent to the investigation are available from VNTSC. The results from all tests were used by VNTSC as empirical references in the formulation of finite element computer modeling programs designed to analyze the thermal and mechanical stress state of railroad wheels and to evaluate the potential for different types of wheels to resist cracking under various combinations of service conditions. The models developed in the study are intended to provide the capability for similar engineering design analyses of other railroad vehicle wheels besides the types used on MU cars.

The purpose of the wheel peeling procedure was to measure and record the physical characteristics of thermal cracks located on the running surface of two railroad wheels. The wheels were "L" grade, straight plate, 32 inch diameter, transit wheels, manufactured by Edgewater Steel and were previously used in routine service by New Jersey Transit Rail Operations (NJTRO). Both wheels were removed from service due to thermal cracking; wheel numbers were 1501 and 1419. Wheels were shipped to ORX, Inc., Tipton, Pennsylvania, by NJTRO for the experimental procedure.

Data presented in this report have been forwarded to VNTSC for use in the overall investigation. The scope of this report is therefore limited to the reporting of the experimental objectives and procedure, and a presentation of the data including general observations that were made during data collection and the preparation of this report.

1.2 Test Objectives

The objectives of this procedure were to:

1. Obtain a census of the thermal cracks on the tread surface of both wheels. To include: total number, relative circumferential location, overall length, and basic shape (i.e. straight, curved, S-shaped, etc.) of visible thermal cracks.

2. Determine the extent of crack propagation in the rim bulk.

3. Determine any relationship that may exist between crack length on the tread surface and crack depth in to the rim by peeling the wheel face in predetermined increments and measuring crack depths.

4. Describe the shape of the cracks in the rim bulk relative to the radial direction of the wheel.

1.3 Location and Dates

The test procedure was conducted from April 6 through April 9, 1992 at the wheel shop facilities of ORX, Inc., Tipton, Pennsylvania.

1.4 Participants

Dick Fisher	FRA, Office of Safety
Oscar Orringer	Chief Engineer, VNTSC
Tom Lutz	Inspector, FRA
Bob McCown	Task Manager, ENSCO, Inc.
Shawn Yu	Engineer, ENSCO, Inc.
Cameron Stuart	Engineer, ENSCO, Inc.
Machinists, Technicians	ORX, Inc.

1.5 Equipment List

- NDT Magnaflux #20B: Fluorescent concentrate, wet, magnetic particle testing with DC current, 700 Amp.
- Vertical Boring Lathe
- Machinist's rules, tape rules, cameras, videotape recorder, and a laptop computer

2. PROCEDURE

2.1 Wheel Preparation

The wheels were stored outside prior to the testing date and, therefore, had acquired a layer of surface rust and oxidation. Steel brushes were used to clean the wheels for the measurement procedure. Once clean, the wheels were magnetized with the NDT Magnaflux machine and then sprayed with fluorescent concentrate to make the thermal cracks easier to view. When viewed under an ultraviolet (UV) light source, the crack indications were visible as fluorescent lines. Photographs and a videotape were utilized to visually record all the crack indications on both wheels.

2.2 Surface Crack Measurements

The following measurement procedures were performed on each wheel.

1. Measured wheel geometric parameters including wheel tread and flange diameters and rim thickness.

2. Marked an origin and direction of rotation on the tread surface to establish a reference point for measurements.

3. Counted and numbered all cracks having a visible length of at least 0.5"[1]. <u>Note</u>: all cracks were analyzed on wheel #1419, but due to the large number of cracks on wheel #1501 the crack census was limited to one-half of the tread circumference. Crack indications were similar on the unmeasured half.

4. Defined location and marked boundaries of the crack band in reference to the front rim face.

5. Beginning at the origin, measured the circumferential location of each crack.

6. Measured the length of each crack.

7. Defined and marked a circumferential section along the tread, approximately six inches in length, which contained a representative sample of cracks on each wheel. Cracks in this section were analyzed during the peeling procedure.

8. Located and marked four to six of the longest cracks within the crack band on each wheel for further investigation during the peeling procedure.

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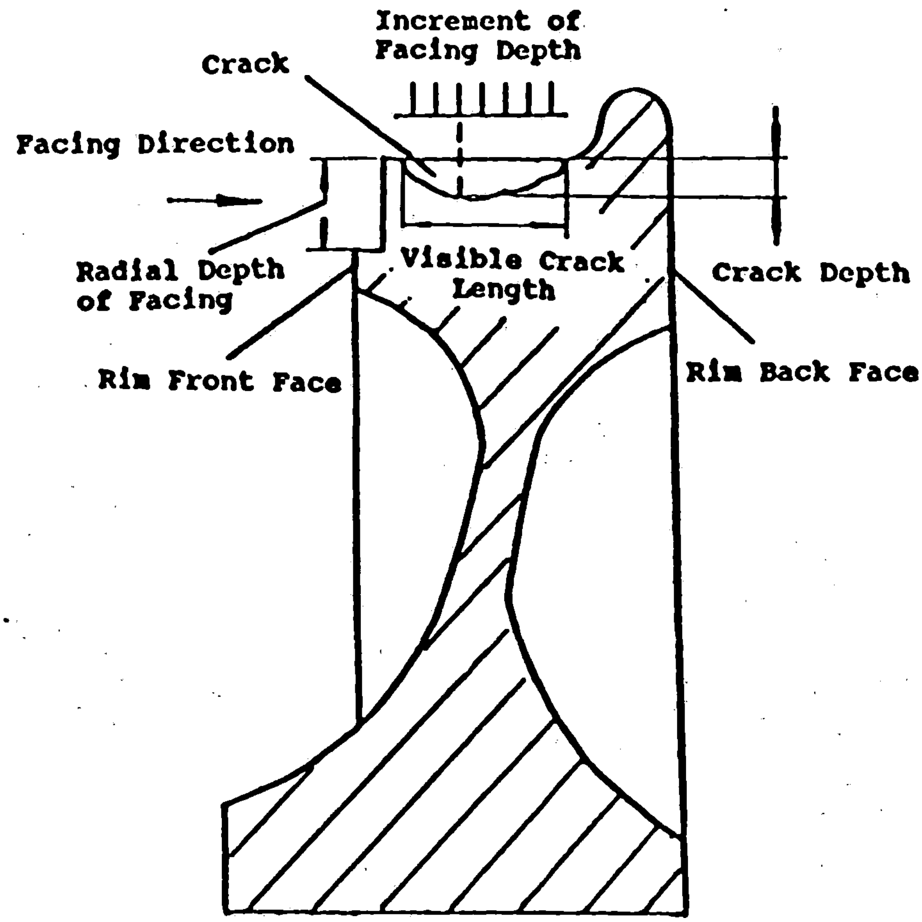
[1] All cracks discussed in this report were over 0.5" in length. Very few cracks were seen that were shorter than 0.5" on either wheel.

2.3 Wheel Peeling And Crack Depth Documentation

Figure 1 illustrates the wheel peeling process and provides a reference to the terms and conventions used to describe the thermal crack measurements.



<u>Figure 1:</u> Wheel Peeling Procedure

After the preliminary measurements were made, the wheel peeling process was begun. What follows are the main steps involved in this procedure.

1. Mounted and clamped wheel on the rotating table of the vertical boring lathe with the front rim face up.

2. Selected the radial depth of wheel facing. The maximum visible crack length on the tread of either wheel was 1.2". Our original hypothesis was that the crack length-to-depth ratio would be approximately 2:1. A radial cut depth of 0.5" was considered adequate to view the internal crack propagation.

3. The wheels were machined in large increments until reaching the crack band in the tread. Thereafter, the peeling depth increment was set at 0.1". At each incremental depth the following measurements and observations were made and recorded.

   A). Measurements were made to determine the radial depth of cracks in the marked section of interest and at the previously marked locations elsewhere in the crack band.

   B). Variations in crack width inside the rim bulk were made.

   C). The direction of crack propagation, within the wheel rim, relative to the radial axis of the wheel, was noted.

   D). Photographs were taken and a videotape recording was made.

4. The peeling procedure was concluded when the crack depths began to decrease and the peeling cuts had passed the approximate center of the crack band on the tread surface. Interior crack shapes were assumed to be symmetric around the center of the visible crack length on the tread.

3. TEST RESULTS

3.1 Basic Wheel Geometry

Wheel #1419:	Tread Diameter	30.080"
	Flange Diameter	32.070"
	Rim Width:	5.530"
Wheel #1501:	Tread Diameter:	29.921"
	Flange Diameter:	32.229"
	Rim Width:	5.598"

3.2 Thermal Crack Census

Wheel #1419:	Number of Cracks.	69
	Position of Crack Band[2]:	1.530"
	Average Crack Length	0.925"
Wheel #1501:	Number of Cracks:	There were over 160 cracks, but only 76 cracks were measured.
	Position of Crack Band:	2.957"
	Average Crack Length:	0.650"

[2] The position of the crack band was defined as the distance between the center of the crack band (axially) and the front rim face of the wheel. (See Figure 1)

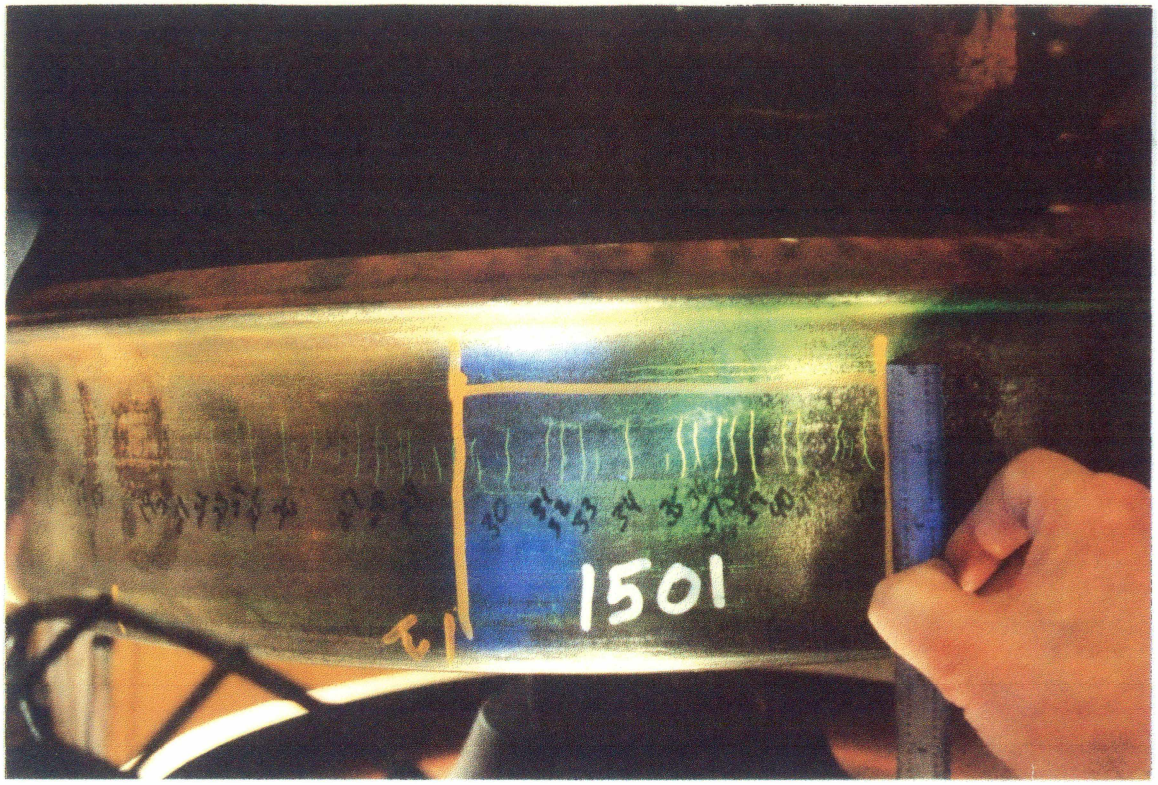
3.3 General Observations

Photographs 1 and 2 capture both wheels during the crack census portion of the experiment. Differences between wheel #1501 and wheel #1419, in terms of thermal crack population density and length, are well illustrated in these photographs. Wheel #1419 had fewer visible thermal cracks than wheel #1501, but their overall length was greater. Of the 69 total cracks measuring greater than 0.5" on wheel #1419, ninety per cent of these were between 0.7" and 1.15" in length. On wheel #1501 though, ninety percent of the over 160 thermal cracks that were observed were between 0.5" and 0.8" long. The maximum measured crack length on wheel #1419 was 1.1" and on wheel #1501 was 0.9". Wheel census data of the measured thermal cracks on each wheel is given, in tabular and graphical form, in Appendix 1 of this report.

Photograph 1: Wheel #1419

Wheel #1419 also had numerous smaller crack indications between the longer thermal cracks within the crack band. During the peeling process these smaller cracks were not seen to propagate within the rim bulk and flaked off during the machining process. These indications were therefore considered to be heat checks.

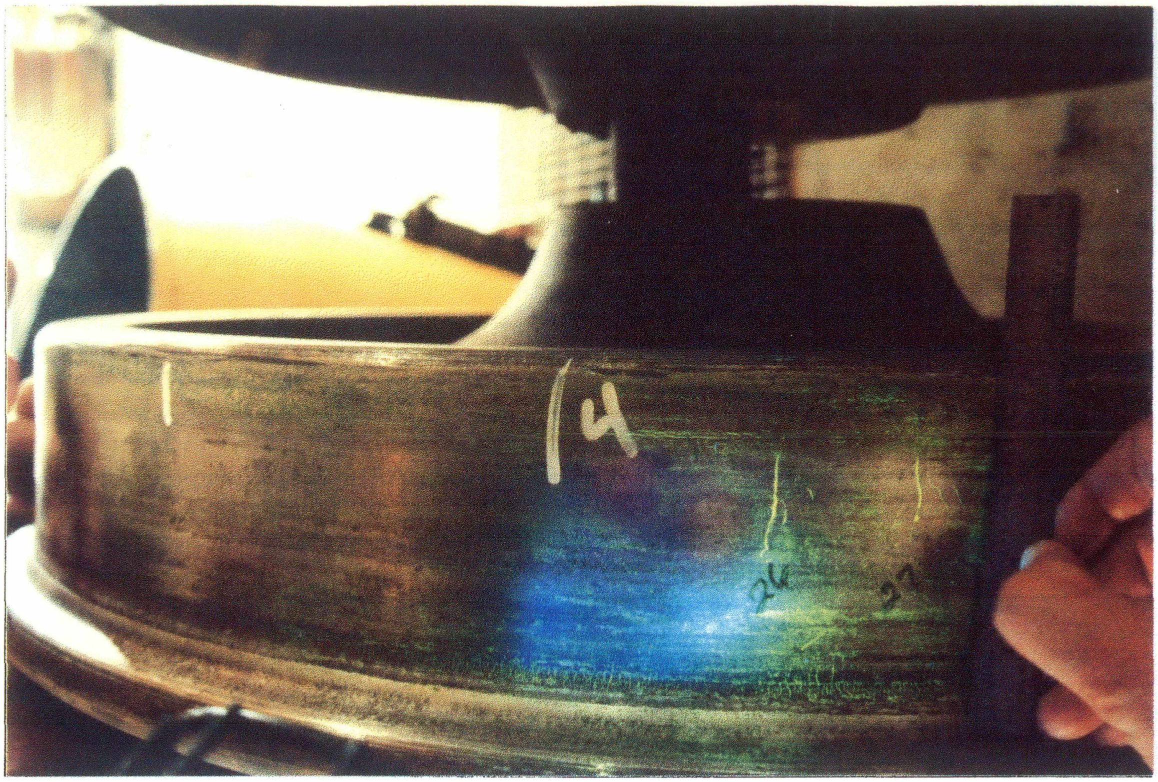
Another observation made during the census procedure was that the thermal cracks on both wheels appeared to be relatively evenly spaced along the circumference of each wheel. The most notable exception to this rule was a 10 inch-long section of tread on wheel #1419 which contained no visible thermal cracks. A portion of this section of wheel #1419 is shown in Photograph 3. No immediate explanation for this phenomena was made from observations of the wheel. More information regarding the service life of this wheel may yield clues as to why this crack-free section exists. As of the end of the wheel peeling procedure no firm action items regarding the further investigation of this wheel were made.



<u>Photograph 2</u>: Wheel #1501

The wheel peeling procedure produced consistent results from each wheel. Observations were made of all visible crack indications in the wheel rim bulk after each wheel peeling increment, but depth measurements were limited to only those cracks which were marked in the defined area of interest on the tread surface and a few of the longest cracks elsewhere on the wheels. Our original hypothesis that crack propagation into the rim bulk would be approximately one-half that of the measured length on the tread proved to be inaccurate. The overall ratio of depth propagation-to-tread length was approximately 1:3 instead of 1:2. The maximum depth of crack propagation in to the rim was 0.325".

Crack behavior in the rim bulk was also observed and recorded. Inside the bulk, the majority of the cracks did not run in the radial direction as presumed, but curved either left or right (referenced to the peeling direction), or were S-shaped. Also, individual crack shapes were not uniform within the rim. With a few exceptions, their direction of propagation was not consistent between each increment of machining. On the tread surface, all measured cracks were oriented in the axial direction of the wheel. No crack was found inside the rim bulk which was not first visible on the tread surface. Finally, all observed cracks appeared to remain tightly closed, both on the tread surface as well as in the rim bulk. Appendix 2 contains the results of the data collection procedure, graphically depicting crack depth in relation to length on tread and describing the crack shapes after each incremental peeling operation in tabular form.



<u>Photograph 3</u>: Wheel #1419 Crack-Free Section

In conclusion, the results of this procedure satisfied the original goals of the exercise and provided insightful information regarding the physical characteristics of thermal cracks typically found in routine transit service on NJTRO. After the experimental procedure was concluded, pie-slice sections were cut out of each wheel and sent to VNTSC for further metallurgical analysis. The data collected during this exercise has been forwarded to VNTSC for review.

APPENDIX 1

CRACK CENSUS RESULTS

DEFINITION OF TERMS

POSITION: Circumferential position of crack relative to a fixed, predetermined origin on the tread surface

PEELING DEPTH: Total depth of cut as measured from the front rim face

CRACK SHAPE: Shape of crack propagation as viewed from tread surface, field side up, looking towards the wheel hub

CRACK SHAPE SYMBOLS:

S	=	Straight
CR	=	Curves Right
CL	=	Curves Left
SR	=	Slants Right
PT	=	Point (too small to discern direction)
Curve	=	Very slight curvature
Branch	=	Crack has visible branches

TABLE 1: WHEEL #1419 CRACK INCIDENCE

Crack Number	Position Inches	Length Inches	Crack Shape	Crack Number	Position Inches	Length Inches	Crack Shape
1	1.1	1.1	CR	36	63.2	1.2	S
2	2	1.1	S	37	64.1	1.1	S
3	2.5	0.9	CR	38	70.4	1.1	S
4	2.9	1.2	S	39	71.6	1	S
5	3.1	0.7	CL	40	72.2	0.6	S
6	3.5	1	CL	41	74	0.8	S
7	3.7	1.1	CL	42	74.7	0.6	CL
8	4.8	1	S	43	75.2	0.9	S
9	5.1	0.7	S	44	76.1	0.6	CR
10	5.5	0.7	CR	45	76.5	0.9	CL
11	6.7	1.2	CR	46	77.5	0.8	CL
12	7.2	1.2	S	47	78.5	0.9	S
13	8.5	1	S	48	78.7	0.9	S
14	13.5	1	CR	49	79.2	1.1	S
15	16.5	1	S	50	79.8	1	CR
16	16.8	0.9	S	51	80.5	0.9	S
17	17	1	CR	52	81.1	1.1	S
18	21.2	1.1	S	53	82	0.6	S
19	24.7	1.1	CL	54	82.6	1	S
20	27.3	1.1	S	55	83	0.6	S
21	28.2	0.9	S	56	83.3	1.1	S
22	29.7	1	S	57	84.2	1.1	S
23	32.2	0.7	S	58	84.6	0.8	CR
24	37.1	0.8	S	59	86.1	0.8	CR
25	38	0.7	S	60	86.5	0.6	CR
26	50.7	1.2	S	61	86.8	0.8	CR
27	52.5	1	CL	62	87.4	1.1	CR
28	55.1	1	CL	63	88.4	0.7	S
29	55.5	1	S	64	87.8	1.1	S
30	56.5	0.9	S	65	89.8	1	S
31	56.8	1.1	S	66	91	0.9	S
32	57.5	0.8	CL	67	91.7	1	S
33	58.5	1.1	CL	68	94.8	1	S
34	60.5	1.1	S	69	95.5	1.1	S
35	62.2	1.1	S				
36	63.2	1.2	S				

WHEEL FROM NJT 1419; CRACK INCIDENCE

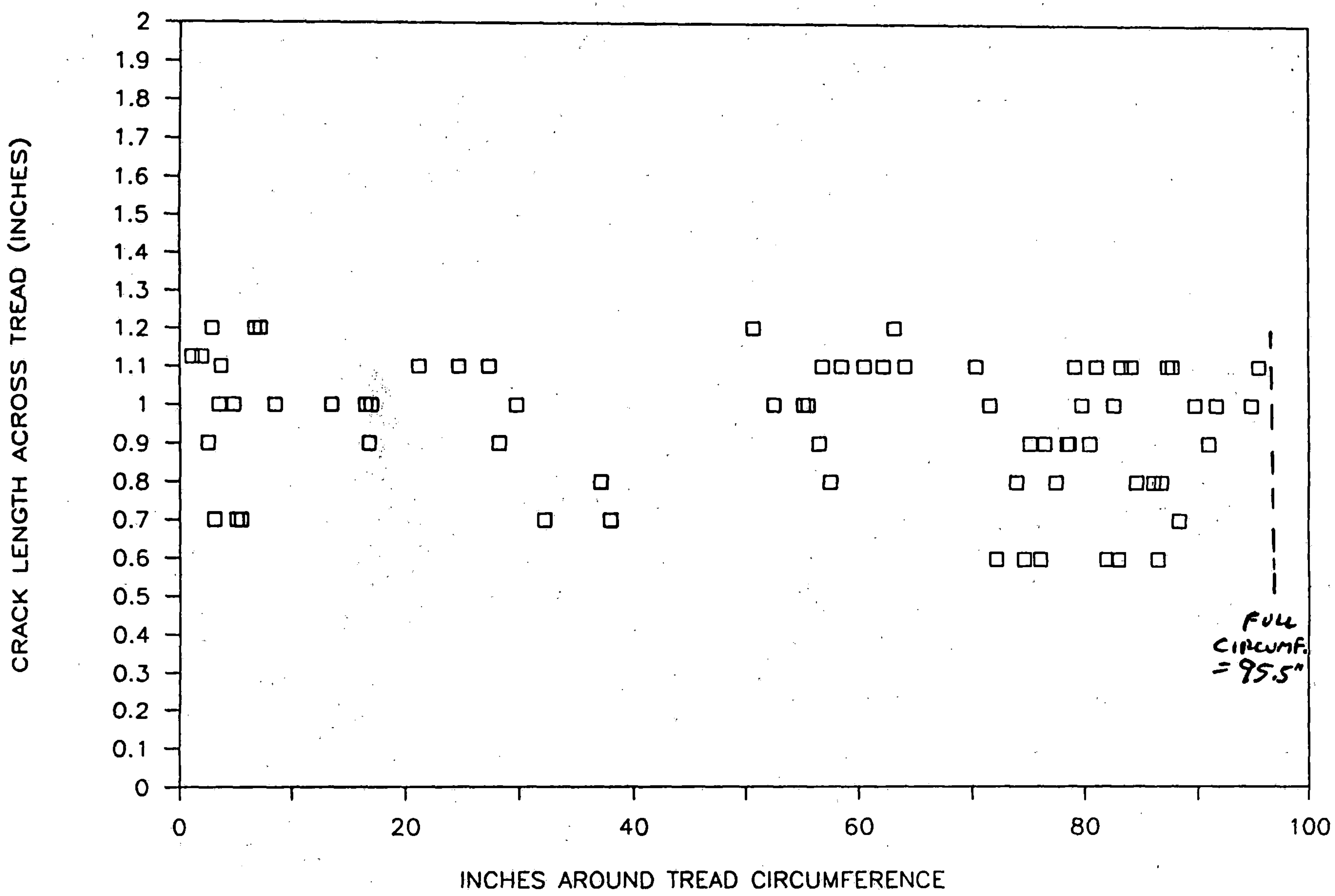
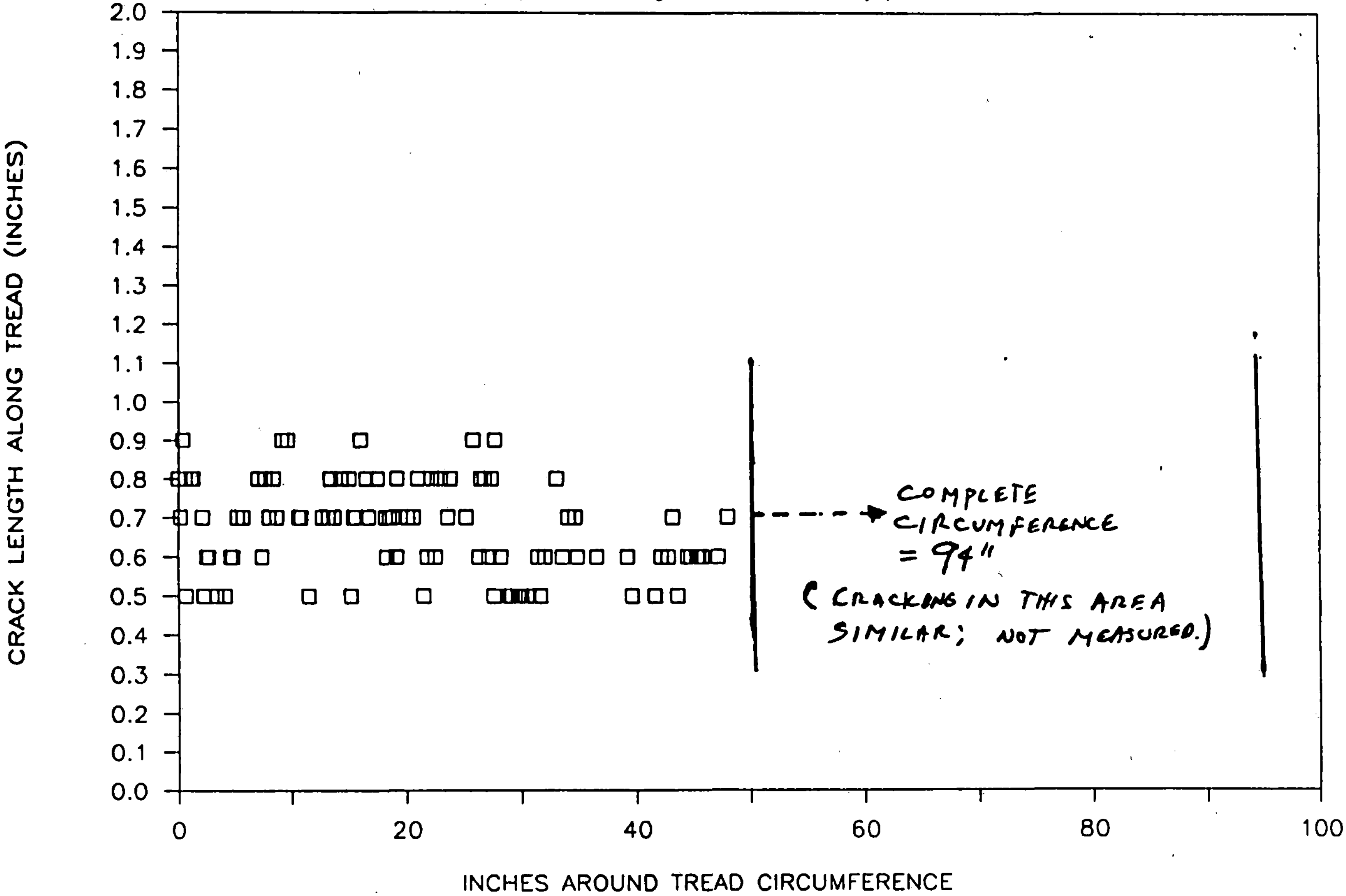


TABLE 2: WHEEL #1501 CRACK INCIDENCE

Crack Number	Position Inches	Length Inches	Crack Shape	Crack Number	Position Inches	Length Inches	Crack Shape
1	0	0.8	S	39	16	0.9	S
2	0.2	0.7	S	40	16.5	0.8	CR
3	0.4	0.9	S	41	16.7	0.7	CR
4	0.6	0.8	S	42	17.5	0.8	CR
5	0.7	0.5	S	43	18.2	0.7	CR
6	1.1	0.8	CR	44	18.3	0.6	CR
7	1.3	0.8	S	45	18.5	0.7	S
8	2.1	0.7	S	46	18.8	0.7	CR
9	2.2	0.5	S	47	19.1	0.6	S
10	2.3	0.5	S	48	19.2	0.6	S
11	2.5	0.6	S	49	19.2	0.8	CL
12	2.7	0.6	S	50	20.1	0.7	S
13	3.4	0.5	S	51	20.6	0.7	S
14	4.1	0.5	S	52	21	0.8	CR
15	4.6	0.6	S	53	21.5	0.5	CL
16	4.8	0.6	CL	54	21.8	0.6	S
17	5.2	0.7	CR	55	22.2	0.8	CR
18	5.7	0.7	CR	56	22.5	0.6	S
19	7	0.8	CR	57	22.7	0.8	S
20	7.4	0.6	CR	58	23	0.8	CR
21	7.6	0.8	CR	59	23.6	0.7	S
22	8	0.7	S	60	23.8	0.8	S
23	8.4	0.8	CR	61	25.2	0.7	S
24	8.7	0.7	S	62	25.8	0.9	CL
25	9.1	0.9	S	63	26.3	0.6	S
26	9.6	0.9	S	64	26.5	0.8	S
27	10.6	0.7	CL	65	26.8	0.8	S
28	10.8	0.7	S	66	27.2	0.6	S
29	11.5	0.5	S	67	27.4	0.8	CR
30	12.7	0.7	CL	68	27.6	0.5	S
31	13.2	0.7	S	69	27.7	0.9	S
32	13.4	0.8	S	70	28.2	0.6	CL
33	13.7	0.7	CL	71	29	0.5	CL
34	14.3	0.8	CL	72	29.2	0.5	C
35	15	0.8	CL	73	29.7	0.5	S
36	15.2	0.5	S	74	29.8	0.5	S
37	15.4	0.7	CL	75	30	0.5	S
38	15.6	0.7	CR	76	30.6	0.5	S

WHEEL FROM NJT 1501; CRACK INCIDENCE

(Cracks longer than 0.5" only.)



APPENDIX 2

WHEEL PEELING RESULTS

DEFINITION OF TERMS

POSITION: Circumferential position of crack relative to a fixed, predetermined origin on the tread surface

PEELING DEPTH: Total depth of cut as measured from the front rim face

CRACK SHAPE: Shape of crack propagation as viewed from tread surface, field side up, looking towards the wheel hub

CRACK SHAPE SYMBOLS:

S	=	Straight
CR	=	Curves Right
CL	=	Curves Left
SR	=	Slants Right
PT	=	Point (too small to discern direction)
Curve	=	Very slight curvature
Branch	=	Crack has visible branches

TABLE 3: WHEEL #1419 CRACK DEPTH AND SHAPE

Cut #		4		5		6		7		8		9		10	
Peeling Depth		1.07		1.16		1.27		1.36		1.46		1.58		1.67	
Crack No.	Max. Depth	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape
2	0.28	0.06	S	0.17	CL	0.22	S	0.25	CL	0.28	S	0.28	CL,B	0.28	S
4	0.22	0.8	S	0.16		0.22	S	0.22	CL	0.19	CL	0.16	S	0.16	S
11	0.28			0.15	CL	0.19	SR	0.25	CL	0.25	S	0.28	CL	0.25	S
12	0.28	0.09	CR	0.2	CL	0.22	S	0.25	S	0.28	CL	0.28	S	0.25	S
18	0.31	0.1	CR	0.25	CR	0.31	CL	0.31	S	0.31	CL	0.28	CL,B	0.31	S
26	0.25			0.17	CL	0.22	CL	0.25	CL	0.25	S	0.25	branc	0.19	CL
34	0.28	0.1	CL	0.2	CR	0.25	CL	0.28	S	0.28	CL	0.28	CL	0.22	CL
36	0.25	0.15	CL	0.25	CL	0.25	CL	0.28	S	0.25	CL	0.25	CL	0.25	CL
47	0.19			0.11	CR	0.19	CL	0.19	CL	0.19	CL	0.19	CL	0.19	CL
48	0.19					0.16	CL	0.16	S	0.19	S	0.19	CL	0.16	CL
49	0.22			0.15	CR	0.19	CL	0.22	CL	0.22	S	0.22	S	0.22	CL
50	0.25			0.11	S	0.19	CL	0.22	CL	0.22	CL	0.25	CL	0.22	CL
51	0.22					0.09	CR	0.22	CL	0.22	CL	0.22	CL	0.19	CL
52	0.22			0.13	CR	0.19	CR	0.22	CL	0.22	CL	0.22	CL	0.22	CL,B
53	0.19								PT	0.16	CL	0.19	CL	0.19	CL
54	0.28			0.15	CL	0.22	CL	0.22	CL	0.28	CL	0.25	CL	0.25	CL
55	0.13					0	PT	0.06	CL	0.13	S	0.13	curve	0.09	
56	0.28			0.12	S	0.22	CL	0.25	CL	0.28	CL	0.25	CL	0.25	CL

NOTE: Cuts 1, 2, and 3 were excluded from the chart because no cracks were visible at these depths.

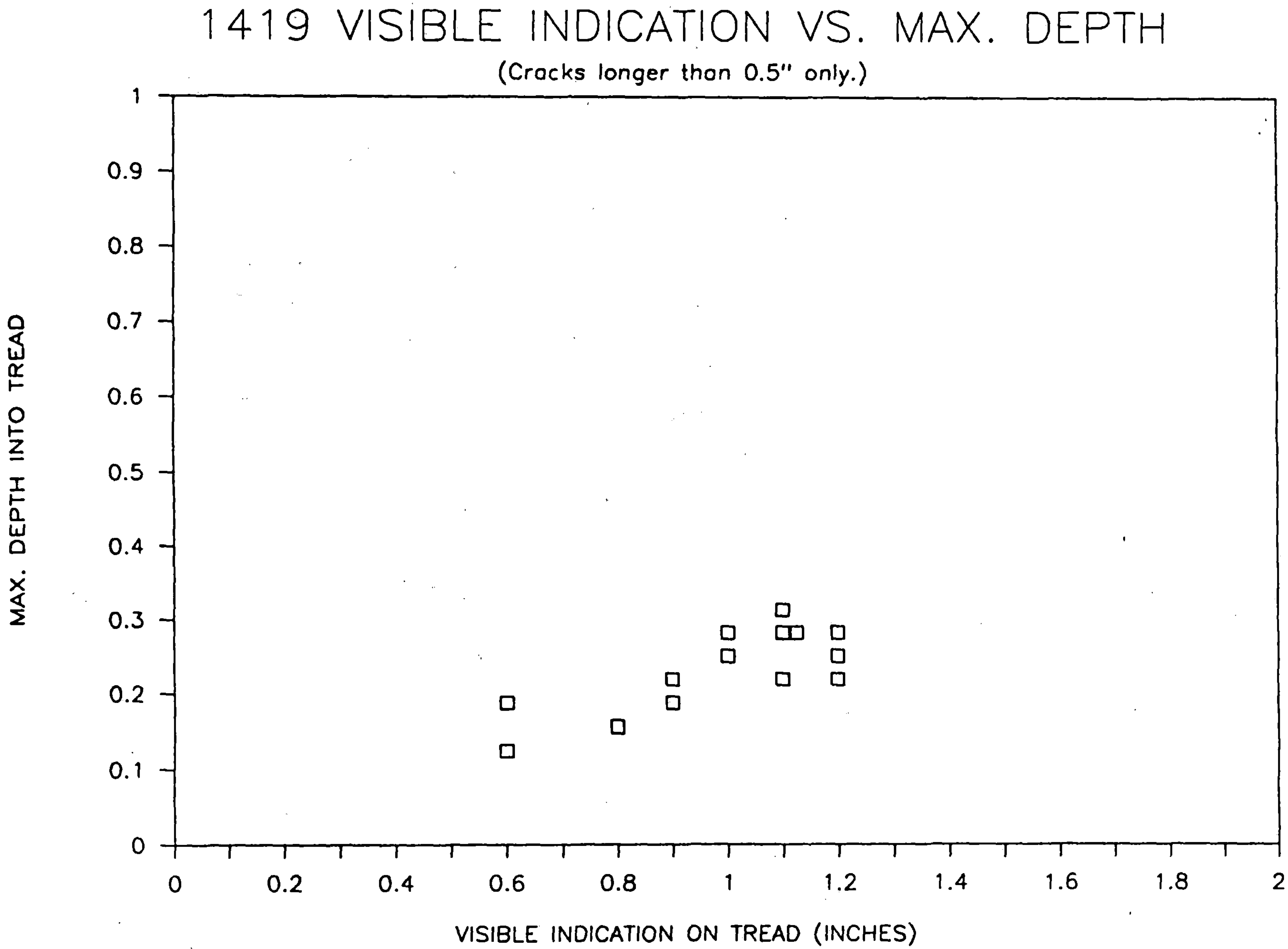
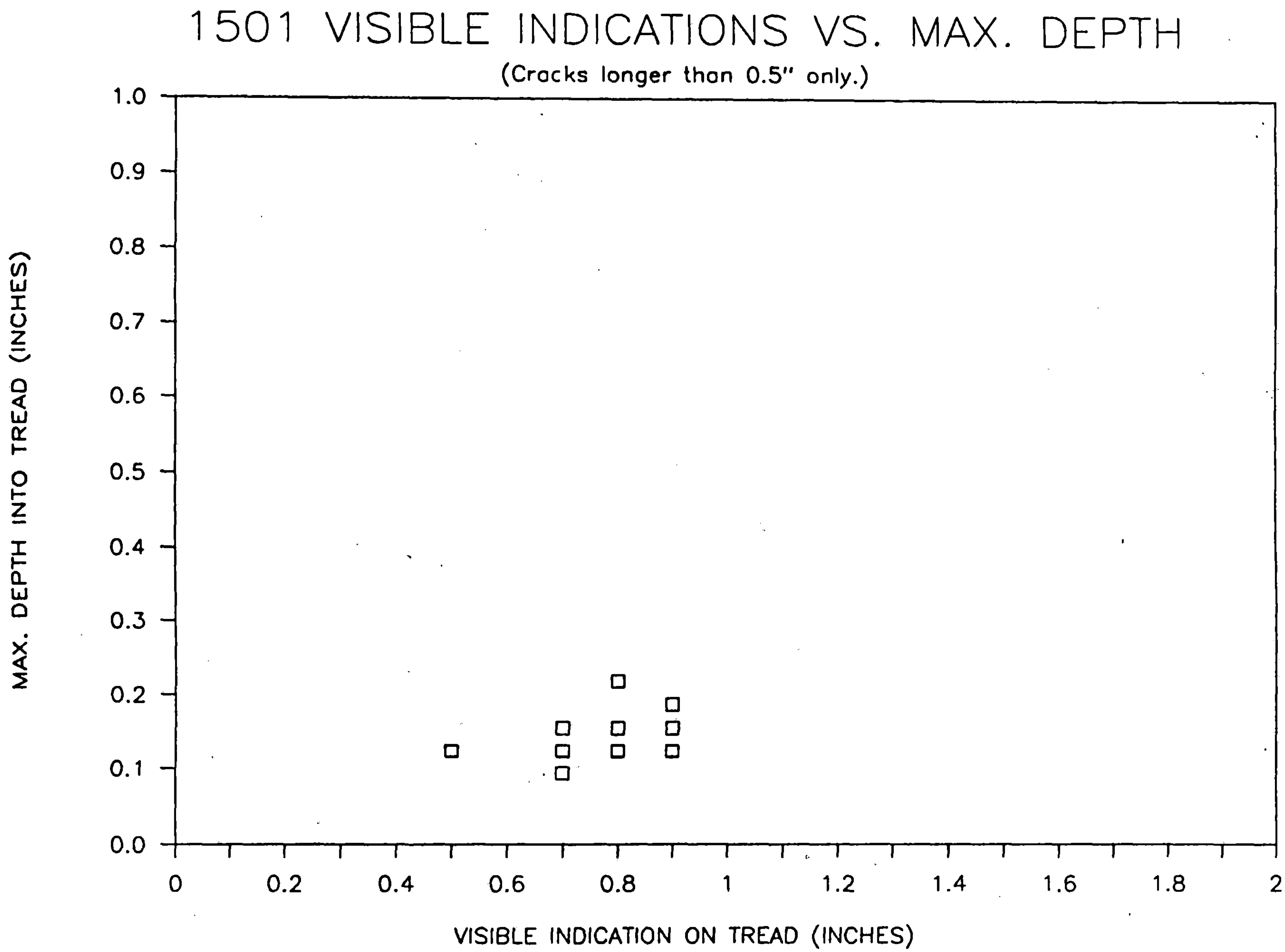
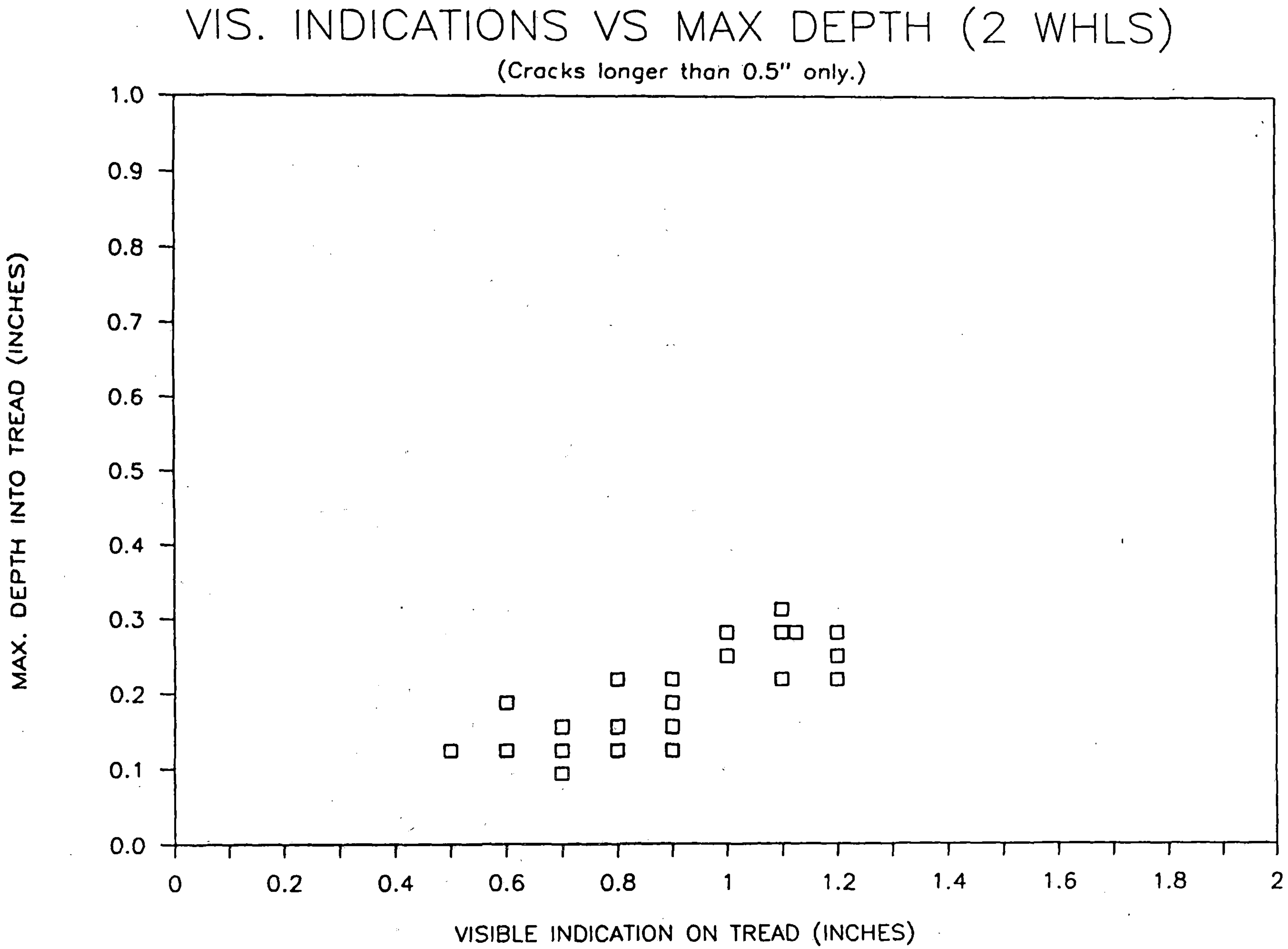

1419 VISIBLE INDICATION VS. MAX. DEPTH
(Cracks longer than 0.5" only.)
MAX. DEPTH INTO TREAD
VISIBLE INDICATION ON TREAD (INCHES)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

TABLE 4: WHEEL #1501 CRACK DEPTH AND SHAPE

Cut #		5		6		7		8		9		10		11	
Peeling Depth		2.61		2.71		2.82		2.94		3.02		3.12		3.23	
Crack No.	Max. Depth	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape	Crack Depth	Crack Shape
3	0.13			0.06	CL	0.13	S	0.13	S	0.13	S	0.09	S	0.09	CR
24	0.16	0.01	CL	0.09	CL	0.16	S	0.16	CL	0.16	S	0.16	S	0.13	branc
25	0.19	0.01	CL	0.13	CL	0.19	S	0.16	CL	0.16	S	0.16	S	0.13	branc
26	0.16			0.09	CR	0.16	CR	0.16	CR	0.16	CR	0.16	S	0.16	CR
30	0.16			0.06	S	0.09	CR	0.13	CR	0.16	CR	0.16	S	0.13	CR
31	0.13				PT	0.03	CR	0.06	CR	0.09	curve	0.13	curve	0.09	CR
32	0.13			0.09	CR	0.09	CR	0.09	CR	0.13	CR	0.09	S	0.09	CR
33	0.16			0.09	CR	0.09	CR	0.13	CR	0.16	S	0.13	S	0.09	S
34	0.22			0.13	CR	0.16	CR	0.19	S	0.22	S	0.16	S	0.16	S
35	0.16			0.03	CR	0.13	CR	0.13	CR	0.16	CR	0.13	CR	0.09	branc
36	0.13				PT	0.06	CL	0.09	CL	0.13	CR	0.09	CR	0.06	CR
37	0.13			0.06	CR	0.09	CR	0.13	CR	0.13	CR	0.13	CR	0.13	CR
38	0.09			0.03	CR	0.09	S	0.09	CL	0.09	CL	0.09	S	0.06	CR
39	0.19	0.06	PT	0.13	CL	0.16	S	0.16	S	0.16	S	0.19	S	0.13	CL
40	0.13			0.09	CR	0.13	S	0.13	S	0.13	CR	0.09	S	0.09	CR
41	0.16			0.09	CL	0.09	CL	0.16	S	0.16	S	0.16	S	0.13	CL
42	0.16			0.09	CL	0.13	S	0.13	S	0.16	S	0.16	S	0.13	branc

NOTE: Cuts 1, 2, 3, and 4 were excluded from the chart because no cracks were visible at these depths.


1501 VISIBLE INDICATIONS VS. MAX. DEPTH
(Cracks longer than 0.5" only.)
MAX. DEPTH INTO TREAD (INCHES)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
VISIBLE INDICATION ON TREAD (INCHES)


VIS. INDICATIONS VS MAX DEPTH (2 WHLS)
(Cracks longer than 0.5" only.)
MAX. DEPTH INTO TREAD (INCHES)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
VISIBLE INDICATION ON TREAD (INCHES)

Wheel-Peeling Experiment-Analysis of Commuter
Rail Wheel Thermal Cracks, US DOT, FRA,
Cameron D Stuart, 1994 -12-Safety