REPORT NO. UMTA-IN-06-0009-83-3

COLD WEATHER TRANSIT TECHNOLOGY PROGRAM

VOLUME 3 – INVESTIGATION OF THE HIGH INCIDENCE OF RAIL PULL APARTS ON CONTINUOUS WELDED RAIL

Vought Corporation
Post Office Box 225907
Dallas, Texas 75265

May 1983

FINAL REPORT

Prepared for
University of Notre Dame
College of Engineering
Notre Dame, Indiana 46556

and

U.S. Department of Transportation
Urban Mass Transportation Administration
400 Seventh Street SW
Washington, D.C. 20590

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16. Abstract

This report presents the results of an investigation of the high incidence of rail pull aparts occuring on the Massachusetts Bay Transit Authority's rapid transit system during the winter of 1981-82. This investigation was accomplished as part of the Cold Weather Transit Technology (CWTT) Program under a Federal grant from the Urban Mass Transportation Administration to the University of Notre Dame. The CWTT Program is a project to improve transit operations in severe ice, snow and cold environments. The rail pull apart investigation was made to determine the probable cause for the increased failure rate and to recommend corrective actions to prevent or reduce recurrence of this problem. The investigation involved site, literature and industry surveys, laboratory analyses of the failures and a test and analyses program to define the process and/or operational methodology to reduce the failure rate.

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PREFACE

This report is one of a series of reports associated with the U. S. Department of Transportation Urban Mass Transportation Administration's Cold Weather Transit Technology Program.

The objective of the program is to develop new and more effective solutions for cold weather problems experienced by urban mass transportation systems.

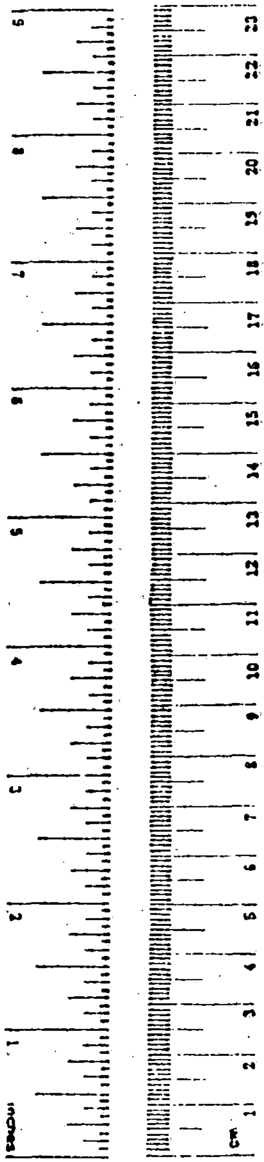
This report presents the findings made as a result of the investigation of MBTA's (Massachusetts Bay Transit Authority's) high incidence of running rail pull aparts experienced during the winter of 1981-1982.

Appreciation is hereby expressed to TSC (Transportation Systems Center, Cambridge, MA) for their invaluable support in coordinating this investigation with MBTA; to MBTA for their cooperation in the provision of rail pull apart samples, failure history and operational data; to Calorite and U. S. Thermit Companies for supplying personnel and materials for testing; and to all the transit and railroad properties that participated in the investigative survey of the rail pull apart problem.

METRIC CONVERSION FACTORS

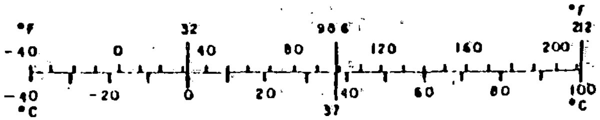
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

COLD WEATHER TRANSIT TECHNOLOGY PROGRAM

HISTORY AND DESCRIPTION

The expansion of and the need for urban mass transportation systems caused by the cumulative pressures of urban congestion, auto pollution and energy shortages coupled with annual winter weather occurrences emphasized by the prolonged heavy snow and cold periods of 1977-78 and 1978-79 have highlighted the operational problems of transit systems in cold weather.

To answer this need, the United States Congress authorized the initiation of the Cold Weather Transit Technology (CWTT) Program to develop new and effective methods for assuring the dependable operation of transit systems in severe cold, ice and snow. A separate complimenting study was also authorized to investigate the need for a National Cold Weather Transit Technology Research Center.

The CWTT Program is being implemented by the U. S. Department of Transportation Urban Mass Transportation Administration (UMTA) through a grant to the University of Notre Dame with the Vought Corporation as the principal contractor. The program thrust was initially directed to solutions for Automated Guideway Transit (AGT) system cold weather problems in support of the Downtown People Mover (DPM) Program. However, curtailment of the DPM program in November 1981 caused DOT/UMTA to redirect the focus of the program to obtain solutions for cold weather problems of existing transit systems. This redirection was implemented under the program extension.

The results of the work accomplished by Notre Dame and Vought during the initial CWTT grant are discussed in detail in a series of UMTA reports. The nine volumes which comprise this series of reports are as follows.

REPORT NUMBER	TITLE
UMTA-IN-06-0009-82-1	Executive Summary
-2	Physics of Ice and Snow at the Interface with Transitway Surface
-3	Characteristics of Ice and Snow at the Interface with Transit Vehicle Surfaces
-4	Advanced Countermeasures for Combatting Ice and Snow Problems
-5	Transitway Design Concepts for Improving System Performance Under Cold Weather Conditions
-6	Planning for a National CWTT Research Center
-7	Lightweight Transit Vehicle Traction Performance on Ice and Snow
-8	Development of Transitway Countermeasures for Combatting Ice and Snow Problems
UMTA-IN-06-0009-82-9	Development of Vehicle Countermeasures for Combatting Ice and Snow Problems.

The directed objective of the extended CWTT Program is to provide near term solutions for problems of existing transit systems operating in cold weather. The tasks being implemented to accomplish this objective resulted from a survey of the transit properties to determine the nature and extent of their problems. The identified tasks have been structured into basic research and engineering application categories.

The basic research tasks are being addressed by Notre Dame and are as follows:

(1) Development of an iceophobic third rail.

(2) Development of an ice and snow formation precursor sensor system.

(3) Improvement of the RF inductive heating concept through system redesign to reduce size and increase efficiency.

(4) Continued investigation of ice/substrate physics.

Vought is responsible to Notre Dame for the development of the engineering applications and their performance. These tasks are as follows:

(1) Evaluation of a pneumatic bus wheel housing deicer system.

(2) Design and evaluation of a rail transit vehicle traction motor winterization system.

(3) Design and evaluation of improved third rail deicing systems.

(4) Evaluation of track switch deicing systems.

(5) Investigation of the rail heater reliability problems.

(6) Investigation of a rail pull apart problem.

The results of these efforts will be published in a series of reports through UMTA. The anticipated total list of reports is given below.

LIST OF REPORTS

REPORT NUMBER	TITLE
UMTA-IN-06-0009-83-1	Executive Summary
-2	Transit System Survey
-3	Investigation of the High Incidence of Rail Pull Aparts on Continuous Welded Rail
-4	Investigation of Rail Heater Reliability
-5	Third Rail Deicing System Research
-6	Winterization of Self-Ventilated Traction Motors on Rail Transit Vehicles
-7	Track Switch Deicing System Research
-8	Bus Wheel Housing Deicing Project
-9	Ice Formation Precursor Research
-10	Composite Rail and Associated Surface Phenomenon
-11	Prediction of Ice Formation
-12	Study of Laser Deicing
-13	Microwave Coupling to Ice/Metal Structures
-14	RF Coupling to Complex Geometric Shapes
-15	Modeling and Analyses of Thermal Conduction in Several Ice Melting Problems
-16	Modeling of Ice Fracture
UMTA-IN-06-0009-83-17	(Reserved)

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COLD WEATHER TRANSIT TECHNOLOGY PROGRAM

INVESTIGATION OF THE HIGH INCIDENCE OF RAIL PULL APARTS ON CONTINUOUS WELDED RAIL

1.0 INTRODUCTION

The Vought Corporation undertook as part of the Cold Weather Transit Technology Program the task of conducting an engineering investigation into the increased rate of rail pull apart failures on continuous welded rail experienced by the Massachusetts Bay Transportation Authority (MBTA) during the period from September 1981 to May 1982. The objectives of the investigation were to determine the probable cause for the increased failure rate and to recommend corrective actions to prevent recurrence.

The investigation was conducted in three phases. The first phase included site, literature and industry surveys to collect pertinent data. The second phase consisted of a laboratory evaluation of representative failure samples to determine the probable cause of failure. In the third phase, a series of test welds were made. The results were evaluated to confirm the conclusions reached during the second phase and to define process and/or operational limits required for corrective actions.

2.0 SITE, LITERATURE AND INDUSTRY SURVEYS

This section of the report discusses the various data gathering surveys performed as part of the investigation.

2.1 Site Survey

Initial visits were made to the MBTA to collect data and to observe their shop and field welding practices during normal operating conditions. The data collected is presented in Appendix A, and the results of the observed welding operations are discussed in subsequent paragraphs.

Table 2.1-1 summarizes the data relative to fracture location. Since the requirement for detailed reporting was not initiated until the increased failure rate had become evident, the exact fracture location for early failures was not known except where the failed rail samples were still available. Discussions with cognizant maintenance and engineering personnel indicated that the distribution of fracture location for the unknown cases would be similar to the distribution for the known cases. For the purpose of study, this was assumed to be the case. Since continuously welded rail was being employed only on the system lines that use 115 pound/yard chrome rail, the fact that all but one of the weld related failures occurred on this type of rail is understandable. The significant factor to note is that during this reporting period, more weld related failures (26) occurred than for all other factors combined (17).

Table 2.1-2 summarizes the data relative to load magnitude and frequency. Several simplifying assumptions were made in order to prepare this table - first, that the trains always operated on schedule and with the scheduled number of cars; second, that the weight of the cars was always equal to the average of the maximum weight of a fully loaded car and the weight of the empty car; and third, that the load was equally distributed to each axle. Based on these assumptions, a qualitative comparison can be made even though the quantitative values themselves are not exact. Evaluation of these data did not reveal any obvious correlation between the failures and load frequency or magnitude.

Table 2.1-3 summarizes the data relative to the time in service prior to failure. These data show that almost without exception, the weld related failures were occurring in the first year of serivce whereas the non-weld related failures were not occurring until after five or more years of service. From these data, it is readily apparent that the increased rate must be related in some manner with the weld quality or welding process used.

Discussions with the cognizant maintenance and engineering personnel revealed that two significant changes had been recently introduced into the MBTA system. First, chrome rail was introduced for improved wear resistance, and second, a new weld kit supplier was introduced for economic reasons. Without a doubt, some of the weld failures were the result of the learning curve characteristic that is associated with the introduction of any new process. Likewise, some of the non-weld failures had probably occurred prior to the reporting period but had gone unnoticed and/or unreported until this time period.

In any case, based on the evaluation of the preceding data and the fact that the MBTA was committed to the use of chrome rail and the thermite field welding process, it was decided to concentrate the subsequent investigation on these parameters.

TABLE 2.1-1

SUMMARY OF MBTA RAIL PULL APART FAILURES REPORTED BETWEEN SEPTEMBER 1981 AND MAY 1982

			LOCATION OF FRACTURE				
RAIL SIZE	MATERIAL(1)	NO. OF FAILURES	BOLT HOLE	CABLE BOND	FIELD WELD(3)	SHOP WELD(3)	UNKNOWN
115 lb/yd.	Chrome (2)	29	-	1	19(4)	6(4)	3
85 lb/yd.	Control Cooled	25	5	4	1	-	15
100 lb/yd.	Control Cooled	8	5	2	-	-	1
TOTAL		62	10	7	20	6	19

NOTES:

(1) See Appendix A for material composition.

(2) All but one of the 115 lb/yd. weld failures identified involved a chrome to chrome or a chrome to control cooled rail joint.

(3) The failure was classified as weld related whenever the fracture occurred in the weld or the heat affected zone.

(4) Three weld related failures did not identify whether they were field or shop welds, so based on distribution of known cases, two were added to the field weld column and one to the shop weld column.

TABLE 2.1-2

SUMMARY OF MBTA LOAD/FREQUENCY DATA
SEPTEMBER 1981 THROUGH MAY 1982

LINE	TRAINS PER WEEK	LOAD CYCLES PER WEEK	AXLE LOAD LB.	TOT. NO. OF FAILURES	WELD FAILURES	NON-WELD FAILURES	TYPE UNKNOW
RED 1	1,684	21,952	22,109	11	4	4	3
2	842	10,976	23,306	7	4	1	2
3	842	10,976	19,614	0	0	0	0
4	1,046	4,184	12,323	18	17	0	1
ORANGE	924	12,432	20,905	15	1	7	7
BLUE	1,100	14,328	18,900	2	0	1	1
GREEN 1	1,173	7,038	14,250	2	0	1	1
2	1,026	6,156	14,250	0	0	0	0
3	911	5,466	14,250	1	0	0	1
4	994	4,516	12,324	0	0	0	0
5	3,110	18,660	14,250	0	0	0	0
6	4,104	23,176	13,875	4	0	1	3
7	3,110	18,600	14,250	2	0	2	0
8	2,199	13,194	14,250	0	0	0	0

NOTES:

1. See discussion in Section 2.0 for definitions and assumptions.
2. See route map in Appendix A for route definitions.

TABLE 2.1-3

SERVICE TIME PRIOR TO FAILURE

RAIL SIZE	NO. OF WELD FAILURES	NO. OF NON-WELD FAILURES	SERVICE TIME (YEARS)				
			0 - 1/2	1/2 - 1	1-2	2-5	5 OR MORE
115	25		10	14	1	-	-
100	0		-	-	-	-	-
85	1		-	-	-	-	1
115		4	2	2	-	-	-
100		8	-	1	-	2	5
85		24	2	1	-	-	22

2.2 Literature Survey

The first part of the survey consisted of obtaining data and recommended practices from the rail supplier and the two weld kit suppliers. References 1 through 4 and item 7 of Appendix A summarize these data. Discussions with other rail properties and observation of their practices combined with the above data led to the conclusion that the observed MBTA welding operations and procedures were in accord with generally accepted practices and in compliance with supplier recommendations. However, it was readily evident that significant variations in the process variables can and do occur. These variations not only exist between transit properties but also between different work crews within a given transit property. Many of these variations result from the environmental conditions, and the revenue operating pressures over which the work crew has little or no control. The effects, if any, of these variations on rail/weld performances is not known. At the present, experience has established procedures and/or practices that produce "acceptable performance without having a quantitative criteria for evaluation or inspection."

The second part of the survey consisted of a literature search for a practical criteria that could be used to distinguish between acceptable and unacceptable welds. A wealth of test data is available. The majority of which is contained in the AREA Proceedings beginning with volume 44 and extending to the present. References 5 and 6 provide a significant bibliography on this subject. References 8, 9 and 10 contain specific results obtained using rail and weld kits supplied by the MBTA suppliers and/or subcontractors. With few exceptions, these data report test results without providing comparable data for unwelded rail such that a quantitative criteria for evaluating the welds could be derived.

Tables 2.2-1 and 2.2-2 prepared from the data in reference 7 represents a typical set of results for the limited number of cases where comparative data is provided. These data reflect the fact that welds for a given rail material will have different strengths depending on the weld kit supplier. Also, the impact relative to the rail material strength will vary as the rail material changes. It appears that the weld metal composition is the significant factor even though such variables as preheat time, temperature and cooling rate will also affect the results. Although the statistical validity of these conclusions can be questioned, the trends noted were duplicated to some extent in all cases where the required data was available.

In summary, there is no generally accepted mechanical property type criteria that can be used to differentiate between acceptable and unacceptable welds. Values for weld strength and ductility vary significantly from one weld kit supplier to another even when the same weld process is used. Also, the values relative to the rail strength will vary from one rail material to the next even when the same weld kit supplier is used. It appears that a weld kit composition certification needs to be established and required by the transit properties as they currently require for the rail material when purchasing rails. This would not guarantee acceptable welds, but it would control one major variable that is not currently controlled.

The third part of this survey consisted of a literature search for a non-destructive inspection technique that could be used to distinguish between acceptable and non-acceptable welds. Considerable work has been done utilizing both radiographic and ultrasonic techniques with varying degrees of success. The basic goals for any of the methods are: (a) to establish a set of standards which correlates with weld performance and (b) to develop a reliable and economically feasible method to inspect field welds. Even in the cases where the transit property finds it economically feasible to grind the weld smooth with the rail, the geometric variables and site restrictions present a formidable challenge. Based on the information to date, the ultrasonic inspection technique seems to offer the best chance of evolving into a practical and reliable inspection method. References 11, 12 and 13 present three recent efforts on this subject. Based on these data, a simplified technique was used in this study and the results are discussed in a subsequent section of this report.

TABLE 2.2-1

TENSILE PROPERTIES - TWO TYPES OF THERMITE WELDS IN TWO DIFFERENT RAIL MATERIALS

RAIL MATERIAL(1)	WELD TYPE(1)	F_{TU} KSI	ELONG. %
SCC	-	131.5	12.0
	A	112.6(2)	2.0(2)
	B	121.7(2)	2.5(2)
HiS	-	143.0	13.0
	A	112.5(3)	1.0(3)
	B	121.8(4)	2.2(4)

NOTES:

(1) See Table 2.2-2 for rail and weld material composition.

(2) Average of 3 tests.

(3) Average of 6 tests.

(4) Single test result.

TABLE 2.2-2

CHEMICAL COMPOSITION - TWO TYPES OF THERMITE WELDS AND THE TWO RAIL MATERIALS

				COMPOSITION	%		
SAMPLE	CARBON	MANGANESE	SILICON	NICKEL	CHROMIUM	MOLYBENUM	ALUMINUM
SCC RAIL(1) 0.014	0.75-0.76	0.80-0.84		0.17	0.07-0.08	0.02-0.03	0.01-0.04
HiS. RAIL(2) 0.007		0.75	0.90-0.93	0.68-0.74	0.06-0.08	0.02-0.03	0.01-0.04
TYPE A Weld(3) 0.34-0.68		0.48-0.59	1.10-1.40	0.35-0.50	0.04-0.05	0.01-0.03	0.08-0.10
TYPE B WELD(2) 1.07-1.25		0.47-0.49	1.26-1.33	1.09-1.49	0.12-0.13	0.12-0.13	0.04-0.05

NOTES:

(1) Range for 5 samples.

(2) Maximum/minimum 2 samples.

(3) Range for 4 samples.

2.3 Industry Survey

To assist in this investigation, a questionnaire, item 8 of Appendix A, was prepared and distributed to selected transit properties and railroads. Selection was made to insure inclusion of systems using the rail materials and welding processes employed by the MBTA. In addition, systems were also selected to include as wide a range of environmental operating conditions, requirements and philosophies as possible. In general, telephone contact was made and the questionnaire forwarded and returned as confirmation of the telephone discussions.

The results obtained are summarized in Table 2.3-1. In short, no recent increases in rail pull apart failure rate were reported nor had there been any indications of specific problems with either rail material or weld kits employed. Selection of one field weld process or another appears to depend on past experience of the company and/or personnel involved. Changes are sometimes made due to "poor" results with a given process and "better" results with another.

Generally speaking, it is apparent that welding practices are widely diverse as is the criteria for acceptability of the welds. The significant factor to note is that a nominal failure rate is accepted as normal, even though all use some sort of inspection ranging from visual to periodic use of a Sperry Rail Service Car. In summary, these data did not indicate that the rail pull apart problem was directly related to either the rail material used or the weld process employed.

The time and effort spent and the information forwarded by the personnel of the transit properties and railroads listed in item 9 of Appendix A is gratefully acknowledged.

TABLE 2.3-1

SUMMARY OF INDUSTRY SURVEY RESULTS

Questionnaires(1) sent out	- 9 (5 Transit; 4 RR)
Replies received	- 6 (4 Transit; 2 RR)
Properties using no welded joints	- 1
Rate of pull apart failures considered normal	- 2 to 4 per month
Rail pull apart problems	- 0
Properties requiring special training for welders	- 2
Properaties requiring certification	- 1
Inspection: Visual - all	- 6
Sperry - 1 to 3 times per year	- 4
Preferences for weld supplier A over B(2)	- 2
Preferences for weld supplier B over A(2)	- 1
Properties using chrome rail	- 1

NOTES

1. See item 8 of Appendix A for questionnaire content.
2. Weld supplier A and B to distinguish between the two thermite type weld kit suppliers listed in References 1 through 4.

3.0 LABORATORY INVESTIGATION OF MBTA RAIL PULL APART FAILURES

This section of the report discusses the various laboratory and metallurgical tests conducted on the failure samples collected during the site survey at the MBTA. Support and assistance was provided by cognizant MBTA engineering and maintenance personnel as well as representatives from the Transportation Systems Center in Cambridge, Massachusetts.

3.1 Objectives

To determine the failure mode and the probable cause of failure in order to establish a rational test plan for the next phase of the investigation.

3.2 Procedure

The eleven (11) representative failure samples were examined visually and classified by type of failure. Representative specimens were then cross-sectioned and subjected to both metallurgical and hardness tests.

3.3 Results

Visual examination revealed that eight of the failures occurred at weld joints, and the remaining three occurred at bus wire bond points. Table 3.3-1 summarizes the results of the visual examination. These results show that the majority of the weld failures occured in field welded joints on chrome rail using calorite kits.

The reason that the majority of the failure samples involved this alloy and weld kit was discussed in Section 2. The significant factor is that the same failure characteristics were present regardless of rail alloy or weld kit supplier.

Figures 3.3-1 through 3.3-9 show two examples of weld joint failures. Specimen #1 (Figures 3.3-1 through 3.3-5) broke from the bottom flange up through the head. THe crack deviated to one side from about the center of the web up. Figures 3.3-1 and 3.3-2 show that the bottom half of the rail did not fuse together while the top did fuse. The lack of fusion is indicated by

TABLE 3.3-1

SUMMARY - RESULTS OF VISUAL EXAMINATION OF FAILED SAMPLES

		Composition		Failure Location				
Specimen	Rail Type	A	B	Weld	Bus Bond	Other	Weld Type	Cause of Failure
B-1	115	CR	CR	X			C	Lack of fusion (30%)
B-2	85	CC	CC	X			Unk	Slag/brittle (10%)
B-3	115	CR	CC	X			C	Lack of fusion (80%)
B-4	115	CR	CC	X			C	Lack of fusion (75%)
B-5	115	CC	CC			X	T	Slag/runout (head)
B-6	115	CC	CC		X		-	Overheated bond
B-7	115	CC	CC		X		-	Overheated bond
B-8	115	CC	CC		X		-	Overheated bond
B-9	115	CR	-	X			C	Lack of fusion (30%)
B-10	115	CC	-	X			C	Lack of fusion (40%)
B-11	115	CC	-	X			C	Lack of fusion (30%)

A, B	Used to designate each side of broken sample (Columns 3 and 4)
CR	Designates chrome rail (Columns 3 and 4)
CC	Designates control cooled rail (Columns 3 and 4)
115	Designates 115 pound/yard rail, 85 designates 85 pound/yard rail (Column 2)
C	Used to designate Calorite weld (Column 8)
T	Used to designate US Thermit weld (Column 8)

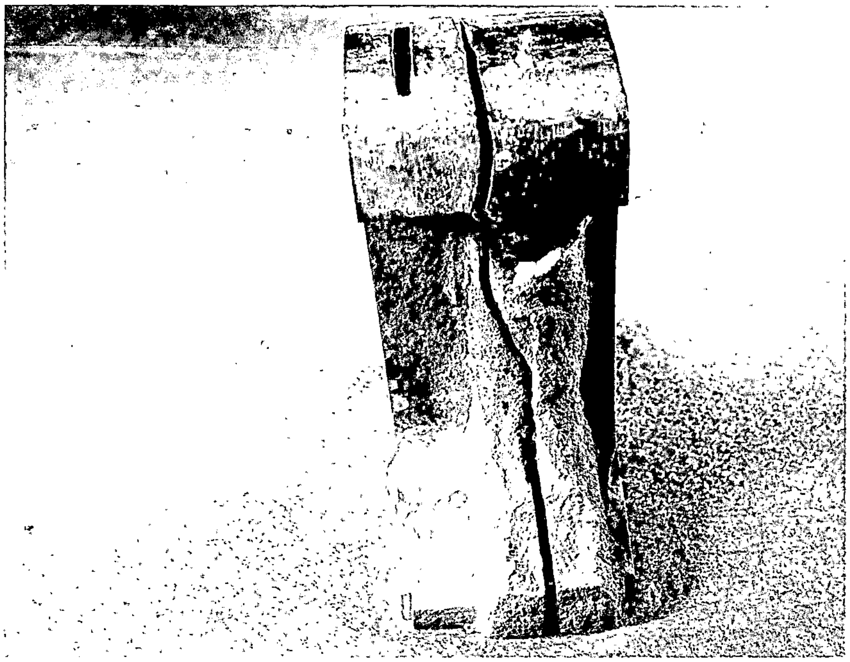


Figure 3.3-1 Side View of the crack in failure specimen #1.

Figure 3.3-2 Failure specimen #1 opened to show the fracture surface.

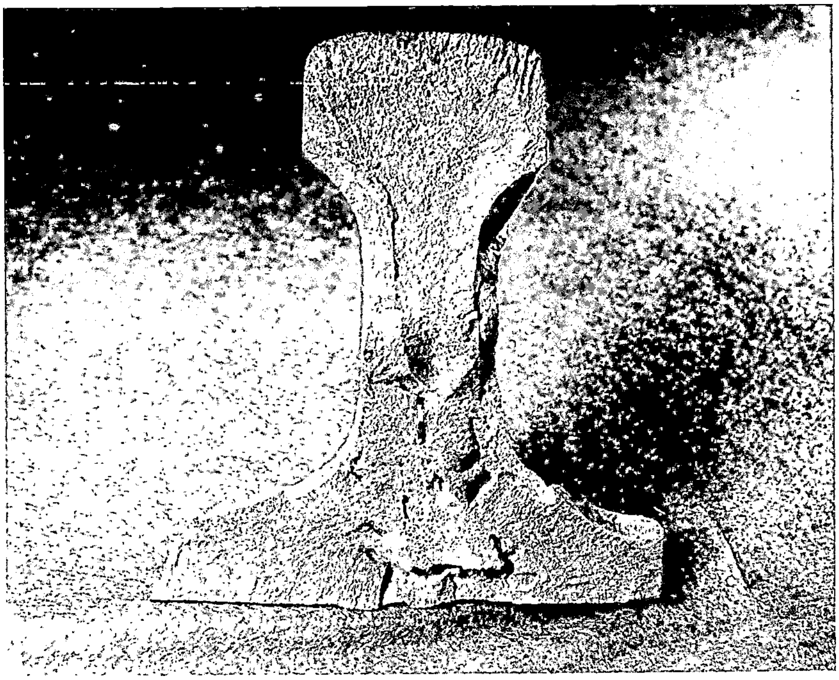


Figure 3.3-3 Fracture surface of #1 showing lack of fusion in the bottom half of the weld.

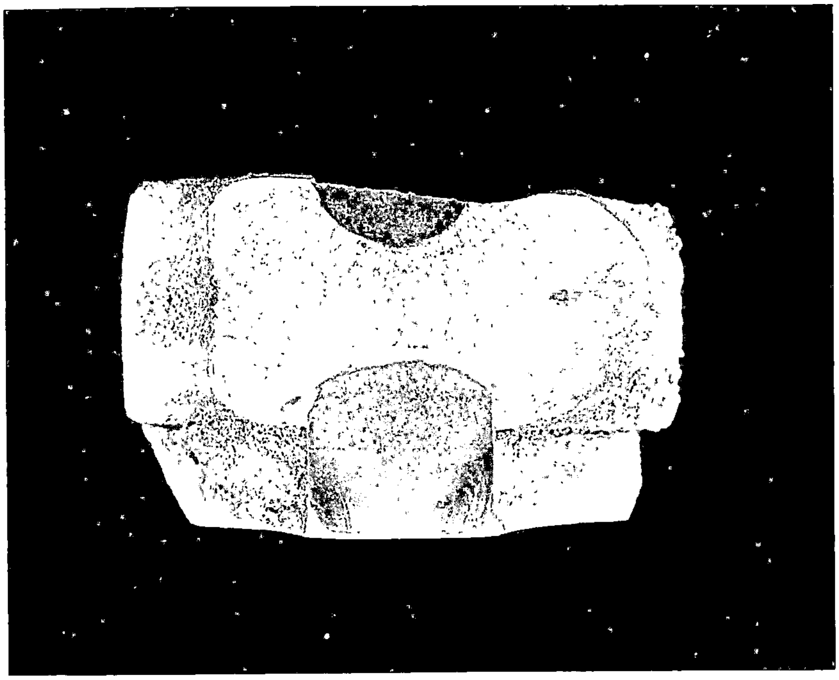


Figure 3.3-4 Section taken from the top of #1, showing fusion in the top half.

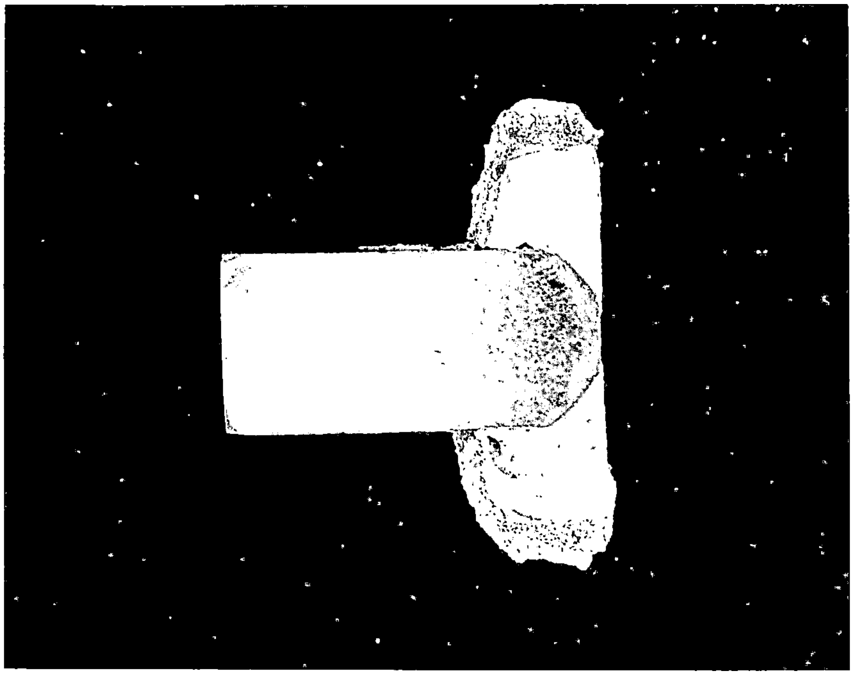


Figure 3.3-5 Section taken from the bottom of #1, showing lack of fusion in the bottom half.

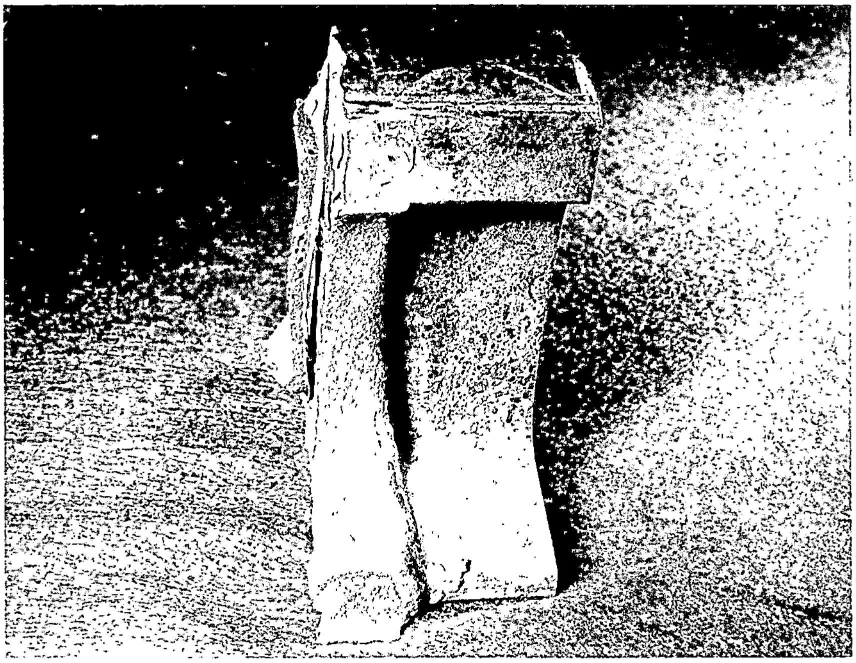


Figure 3.3-6 Side view of specimen #3 showing crack along the weld interface.

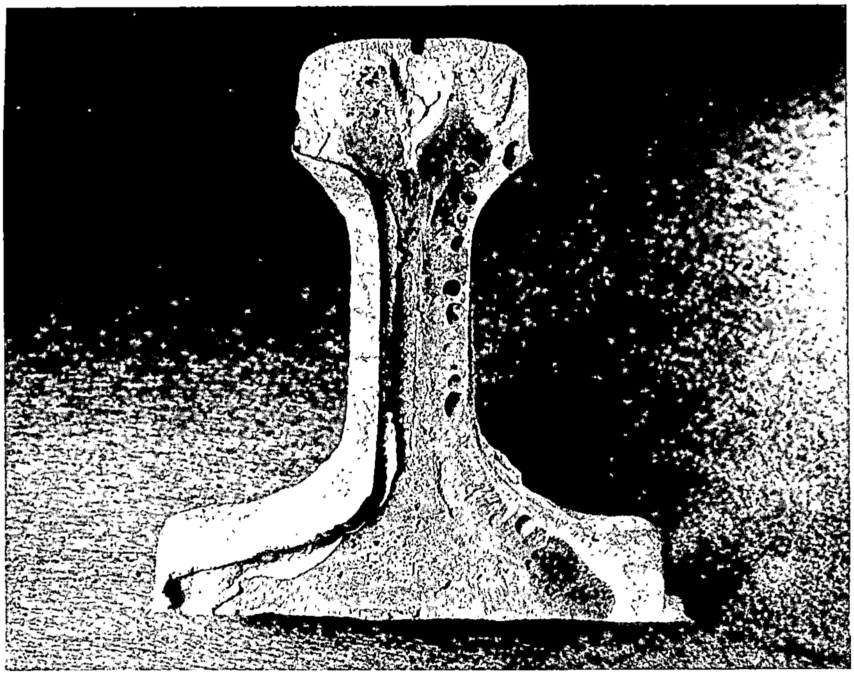


Figure 3.3-7 Fracture surface of #3 showing lack of fusion (dark area) throughout the weld zone.

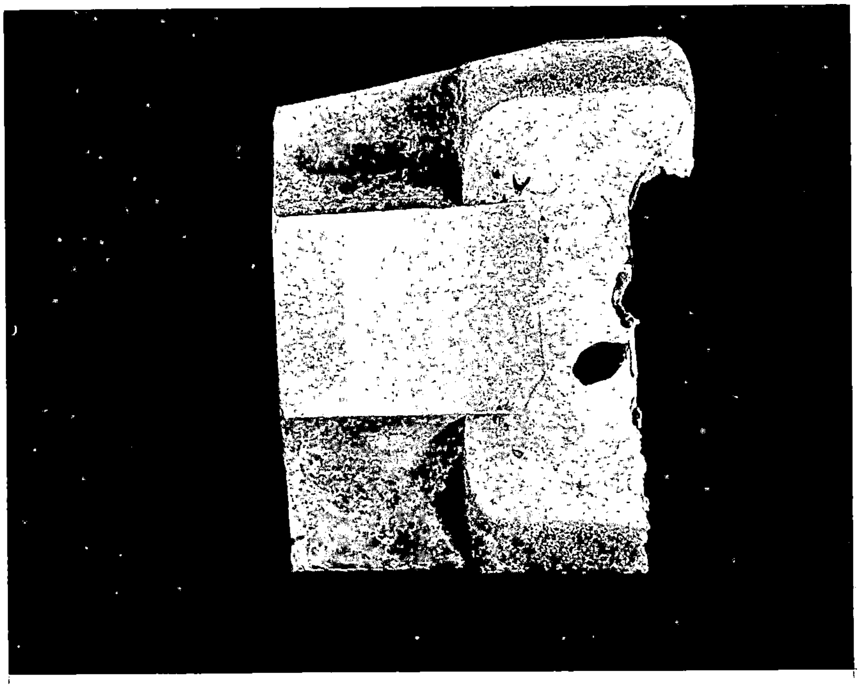


Figure 3.3-8 Section of #3 showing almost no melting of the rail.

sponge porosity and a flat oxidized surface showing little or no tensile fracture. Figures 3.3-4 and 3.3-5 are sections taken from the top and bottom, respectively. The lack of fusion in the bottom (Figure 3.3-5) is evidenced by the lack of melting of the rail ends in contrast to Figure 3.3-4, which indicates good fusion in the head of the rail. The variation of fusion from top to bottom shows that the top half of the rail was preheated more than the bottom half.

Specimen #3 (Figures 3.3-6 through 3.3-9) is an example of a weld in which no fusion was achieved. The crack runs straight up the side of the weld along the interface between the weld metal and the rail (Figure 3.3-6). The lack of fusion is evidenced in Figure 3.3-7 by the flat, oxidized (dark colored) appearance of the fracture. Figure 3.3-8 shows that one corner of the rail had begun to melt, otherwise no fusion had occurred. The photomicrograph in Figure 3.3-9 shows complete lack of fusion along the interface between the weld metal and the rail.

An example of a bus bond failure is shown in Figures 3.3-10 through 3.3-13. In this type of failure, cracking developed from the point where the copper bus wire was welded to the rail (Figure 3.3-10). Figure 3.3-11 is a section through the bond site showing the copper penetrating into the rail. Figure 3.3-12 is a photomicrograph at 100X showing a hard layer of untempered martensite which formed at the interface of the copper bus and the rail. This layer, shown in more detail in Figure 3.3-13, was made up of martensite with a hardness as high as RC 57. Intergranular cracking and copper penetration are evident in the photograph.

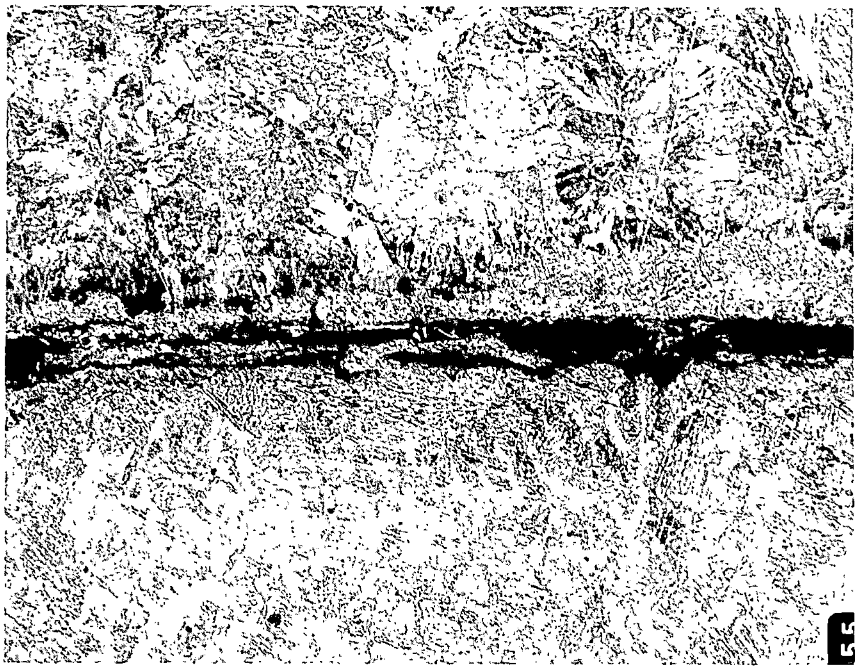


Figure 3.3-9 Photomicrograph showing lack of fusion along the weld interface of #3. Nital Etch. (100x)

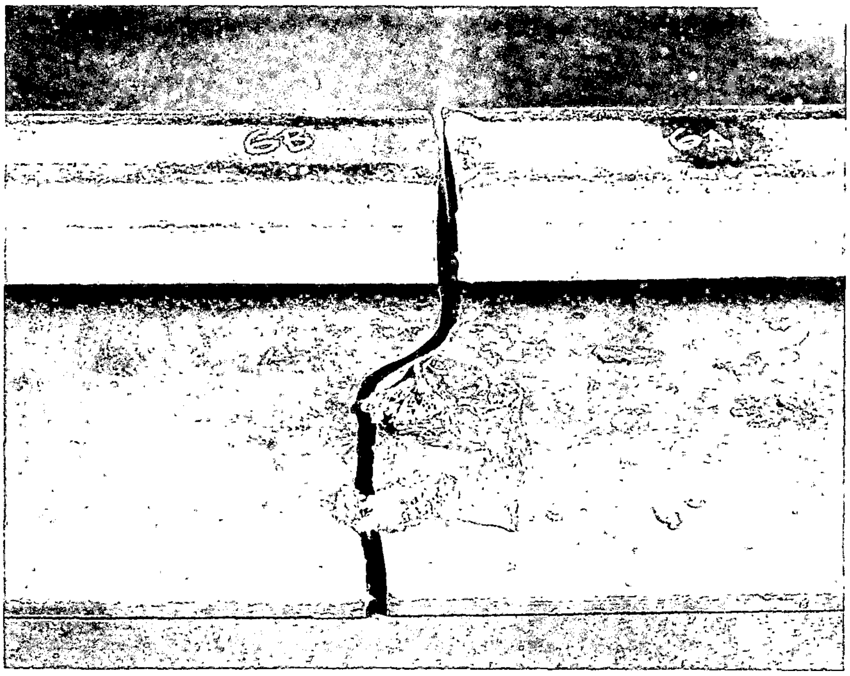


Figure 3.3-10 Failure specimen #6 showing typical bus bond type failure.

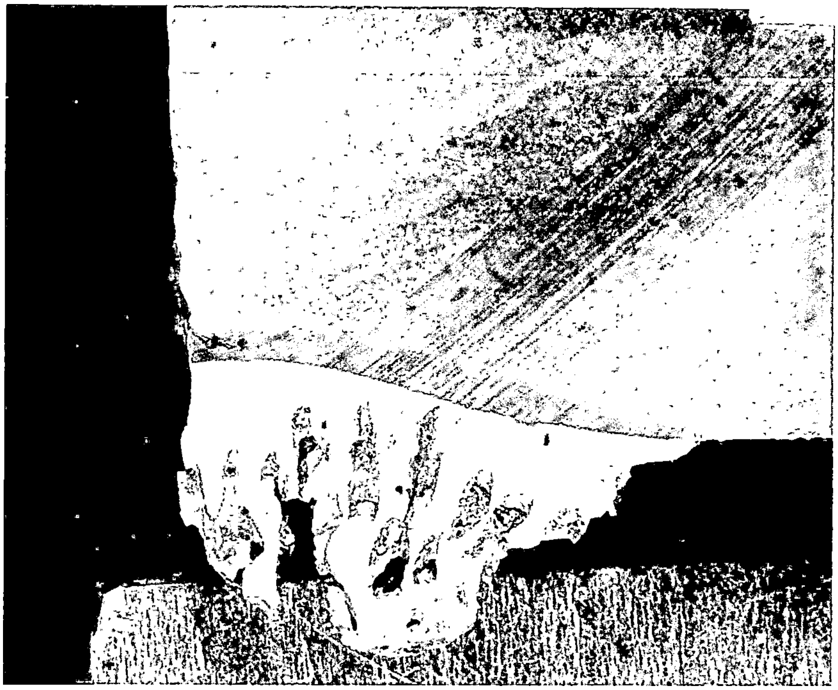


Figure 3.3-11 Cross section of a bus bond showing penetration of the copper into the rail. (10x)

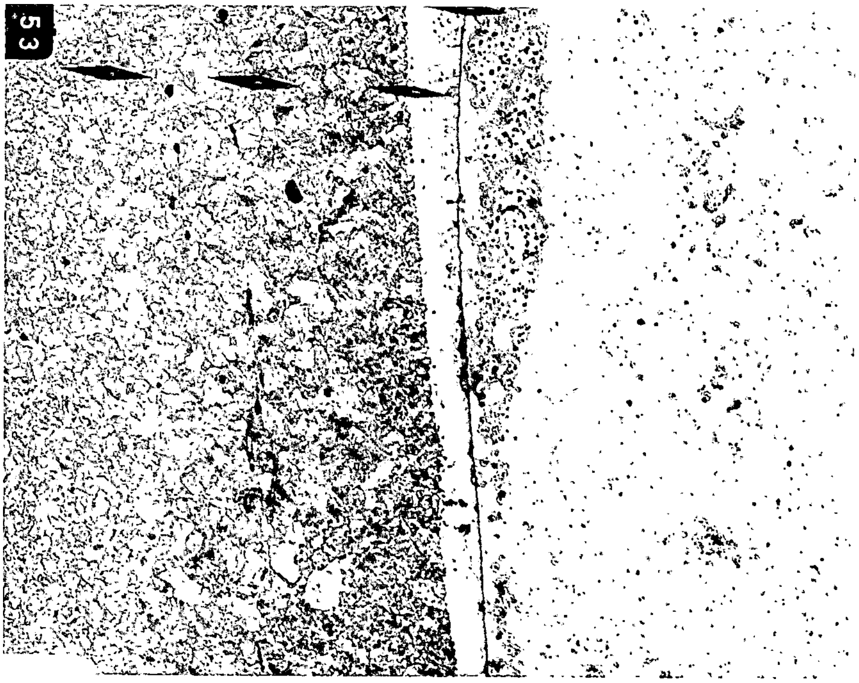


Figure 3.3-12 Photomicrograph showing hard (RC 57) untempered martensite layer which formed between the copper bus and the rail. Nital Etch. (100x)

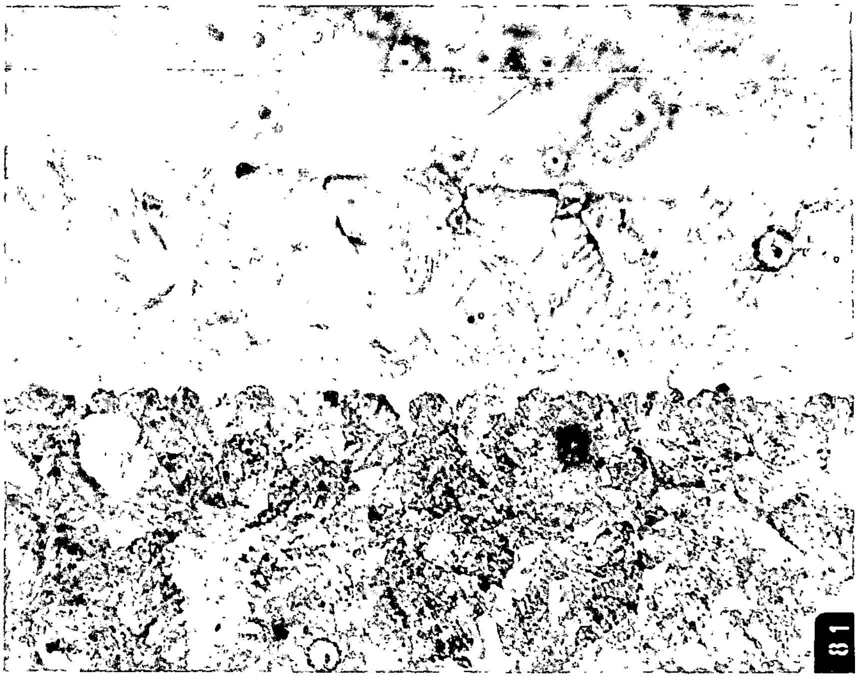


Figure 3.3-13 High magnification view of the layer in Figure 3.3-12. Note intergranular cracking associated with copper penetration into the steel. Nital Etch. (500x)

3.4 Findings

Based on the results in paragraph 3.3, two failure modes were identified:

- Failure at the thermite welded joints
- Failure of the rail at bus wire bonding joints.

The weld joint failures were characterized by poor fusion up to and including complete lack of fusion over significant areas of the joint. The probable causes of the poor fusion were insufficient and/or uneven preheating of the joint prior to welding.

The failures associated with the bus wire bonding joints were characterized by a fully rehardened zone in the rail accompanied by intergranular penetration of copper into the steel. These features indicated an excessive heat input during the bond operation and failure to temper the steel after completion of the bond.

4.0 METALLURGICAL EVALUATION OF TEST WELDS MADE UNDER CONTROLLED CONDITIONS

Based on the results reported in the prior section, a series of test welds were made to determine the operational limits for the welding processes used by the MBTA. All of the subsequent work was conducted using 115 pound/-yard standard control cooled or chrome rail.

4.1 Objectives

To evaluate 1) the effects of outside temperature, 2) the effects of preheat temperature, 3) the effects of rail and weld kit chemistry, and 4) to compare the two weld processes used by the MBTA.

4.2 Procedures

Two test welds (one each by the two vendor representatives) were made, ultrasonically inspected and then subjected to a typical slow bend test. (See Figure 4.2-1 for the test setup). The ambient temperature when these welds were made was 95^{0}F. The primary purpose for these welds was to insure that vendor recommended procedures were used, to serve as a training exercise for the laboratory personnel who were to make the subsequent test welds and to compare the bend test results with industry norms.

Figures 4.2-2 and 4.2-3 illustrate typical test weld setups for ambient temperature conditions and for controlled temperature conditions respectively. The temperature was controlled by using a Thermotron to circulate CO_2 through a chamber built around the rail joint that was to be welded.

A series of test welds were made using Calorite chrome weld kits on standard control cooled rail and/or chrome rail. Ambient temperatures were adjusted to 50^{0}F, 30^{0}F and 10^{0}F while preheat temperature was adjusted to various points in the range 1200^{0}F to 2000^{0}F. Each test weld was instrumented as shown in Figure 4.2-4.

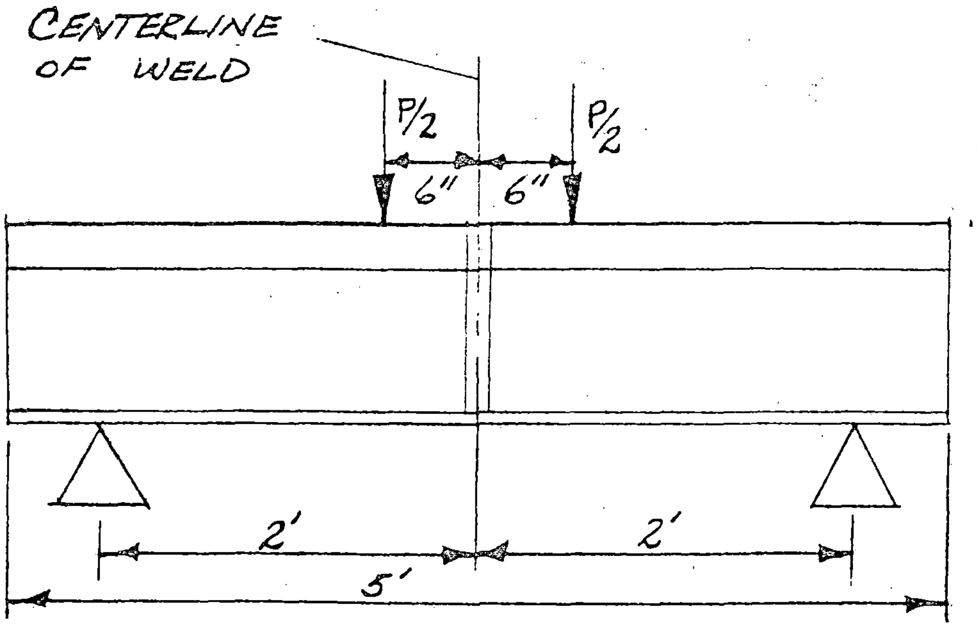


Figure 4.2-1 Slow Bend Test Setup

Figure 4.4-2 Typical Test Weld Setup, Ambient Temperature Conditions

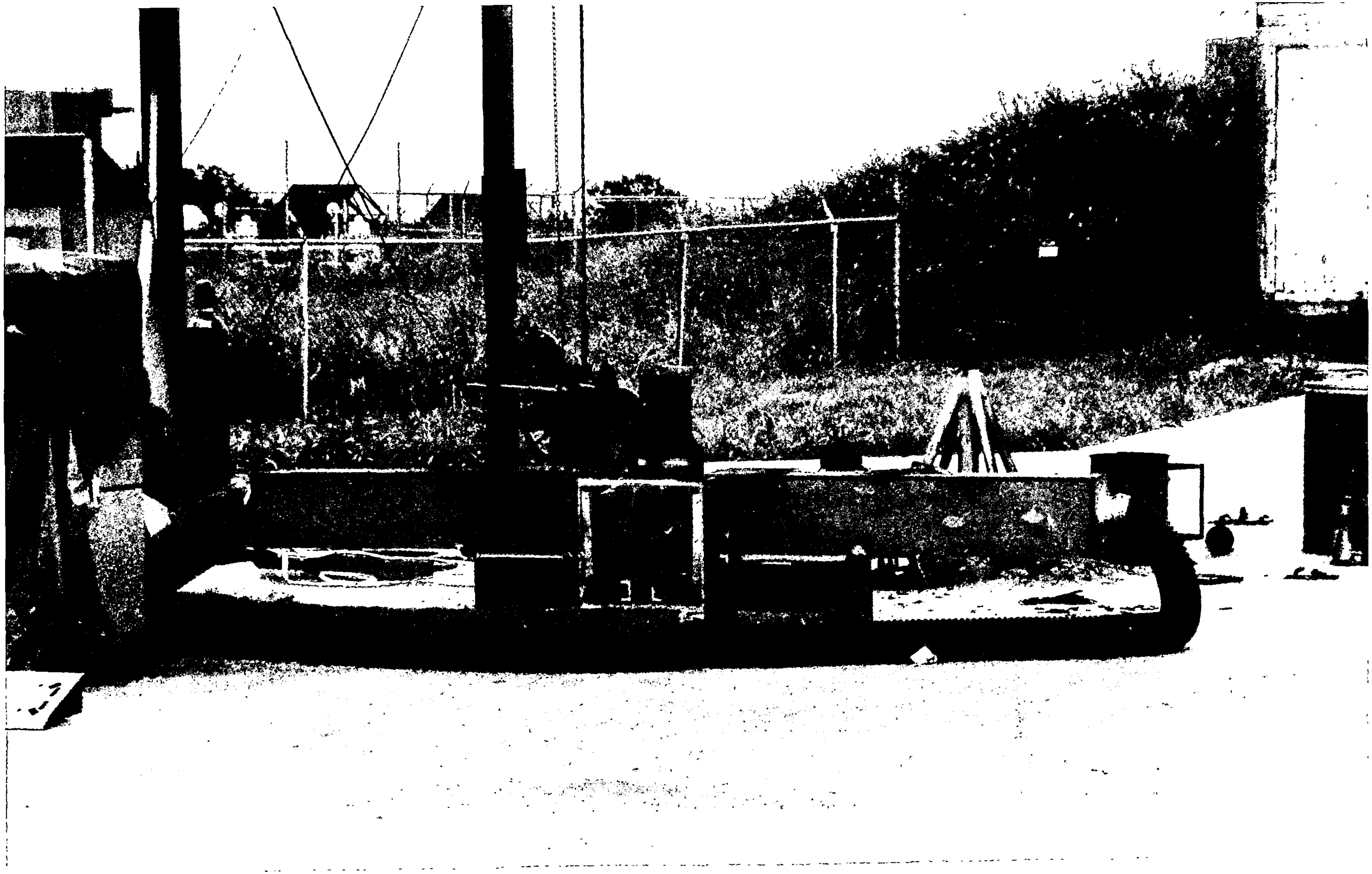


Figure 4.2-3 Typical Test Weld Setup, Controlled Temperature Conditions

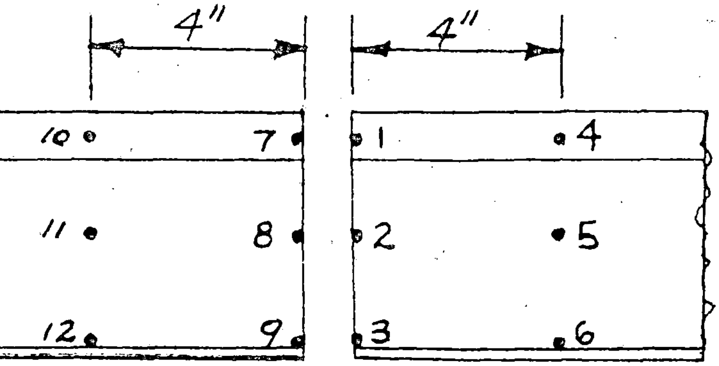


Figure 4.2-4 Thermocouple Locations

Three test welds were made using U.S. Thermit kits. Two of the welds (T-1 and T-2) were made in control cooled rail, and the third (T-3) was in chrome rail. The welds were made at ambient temperatures in the range of 95°F, 50°F and 10°F.

During each test, the temperature was monitored from the beginning of the cool down until approximately 20 minutes after completion of the weld.

For each weld, the following procedure was followed:

- Place rail in cold chamber and cool to desired ambient.
- Calorite welds - install molds and preheat to desired temperature. Place plug in mold, swing crucible into place and light the charge. Upon completion of the pour, remove crucible and slag tray.
- U.S. Thermit - Dry rail ends and then install the molds. Place tapping discs in the mold, pour in the charge and then light the charge.
- Upon completion of the welds, allow the welds to cool for 20 minutes with the molds in place.
- After the twenty minute cool down period, remove the mold and then remove the welded rail from the cold chamber.
- Excess weld metal on the top of head and the field side of the head was removed by grinding and then each weld was ultrasonically inspected.
- Following the inspection, the weld zone was cut out and the remaining rail was used for further welding.

Each weld sample was then subjected to metallurgical tests as follows:

- Cross sections were made at the top, center and bottom of the web.
- Hardness transverses were made from the weld centerline to the basic rail at 1/8" increments.

- In cases where ultrasonic indications of defects were noted, sections were made to determine the nature of the NDI indication.
- Photomicrographs were made of representative samples showing the material microstructure and typical defects found.
- Photomicrographs were made to depict various stages of fusion in the weld zones.
- Chemical analyses using atomic absorption techniques were performed on selected specimens.
- Following the initial weld series, three welds were made using Calorite kits and chrome rail. The purpose of these welds was to verify that 1500°F preheat was also acceptable for use with chrome rail at temperatures down to 10°F. These welds were subjected to the same examination and tests as the previous welds except that ultrasonic inspection was not carried out.

4.3 Results

4.3.1 Bend Tests

Figures 4.3.1-1 and 4.3.1-2 show the failures in the bend test specimens. The two failures followed similar paths. Cracking initiated in the bottom flange at the weld/rail interface. After reaching the mid-height of the rail, the crack propagated in two directions, as evident in the figures.

The Calorite weld (#C-1) failed at a maximum load of 245,000 pounds with a maximum deflection of 0.91 inches. The U.S. Thermit weld (#T-1) failed at 226,000 pounds with a maximum deflection of 0.66 inches. Figure 4.3.1-3 shows the load vs. deflection curves of the two specimens superimposed.

The lower strength of specimen T-1 resulted from porosity in the weld interface in the bottom flange. Figures 4.3.1-4 and 4.3.1-5 show ultrasonic inspection results on the two bend test specimens. After the test, metallographic examination revealed that the indication observed in T-1 was due to microscopic gas porosity distributed along the weld interface.

As discussed earlier, no generally accepted values were available to distinguish acceptable from unacceptable welds. Results from the data reviewed gave ultimate load values for this rail ranging from a low of 190,000 pounds to a high of 318,548 pounds and maximum deflections ranging from 0.4 inches to 1.45 inches. In most cases, examination after failure would indicate metallurgical flaws and/or lack of fusion. These defects could possibly correlate with the results, but there was no indication of whether the results were considered acceptable or unacceptable. The important fact here is that the welds produced using the best procedures possible resulted in strengths well above the minimum based on the available data.

The fracture pattern was similar to that noted for several other industry test samples when the ductility of the weld was low as determined by maximum deflection measurement.

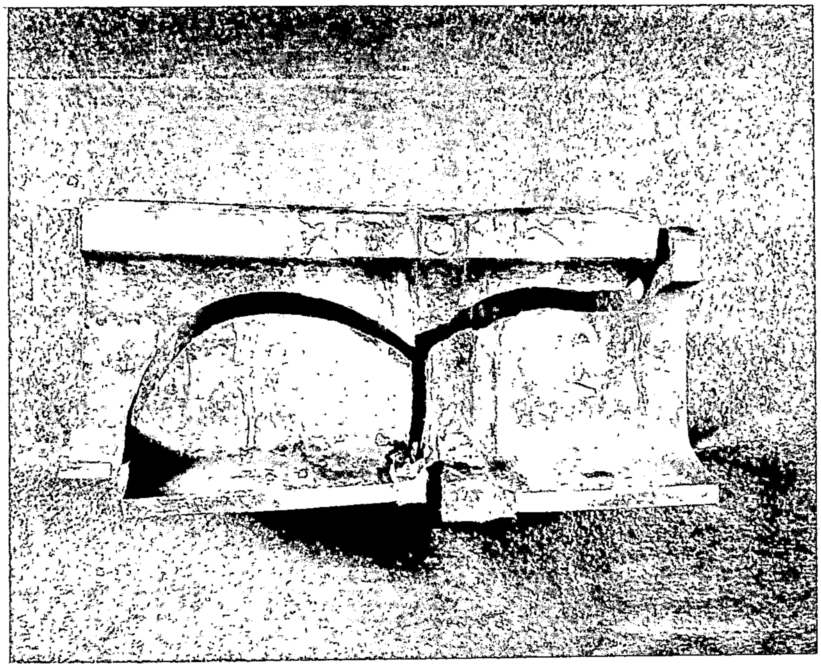


Figure 4.3.1-1 Calorite weld specimen #C-1 after bend test.

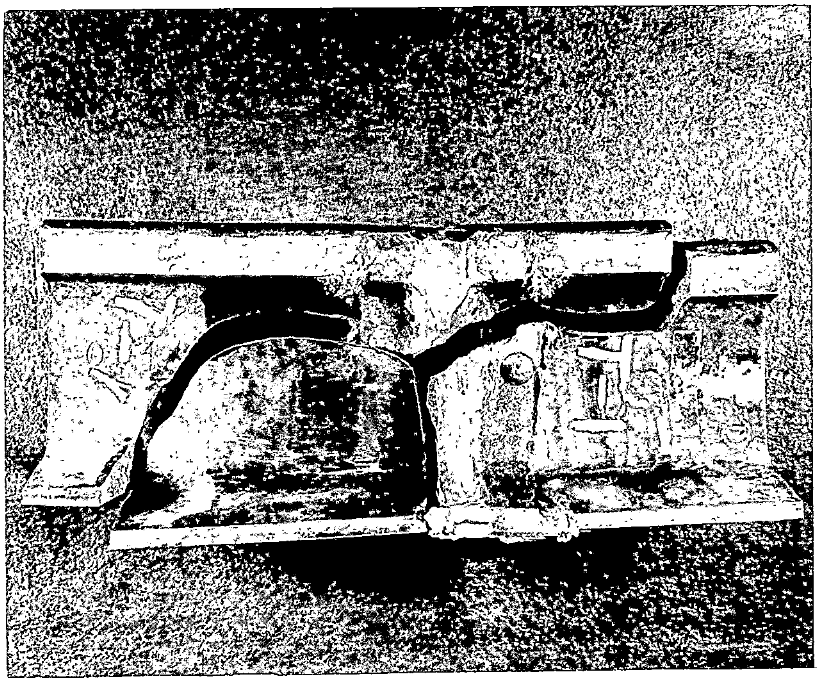


Figure 4.3.1-2 US Thermit weld specimen #t-1 after bend test.

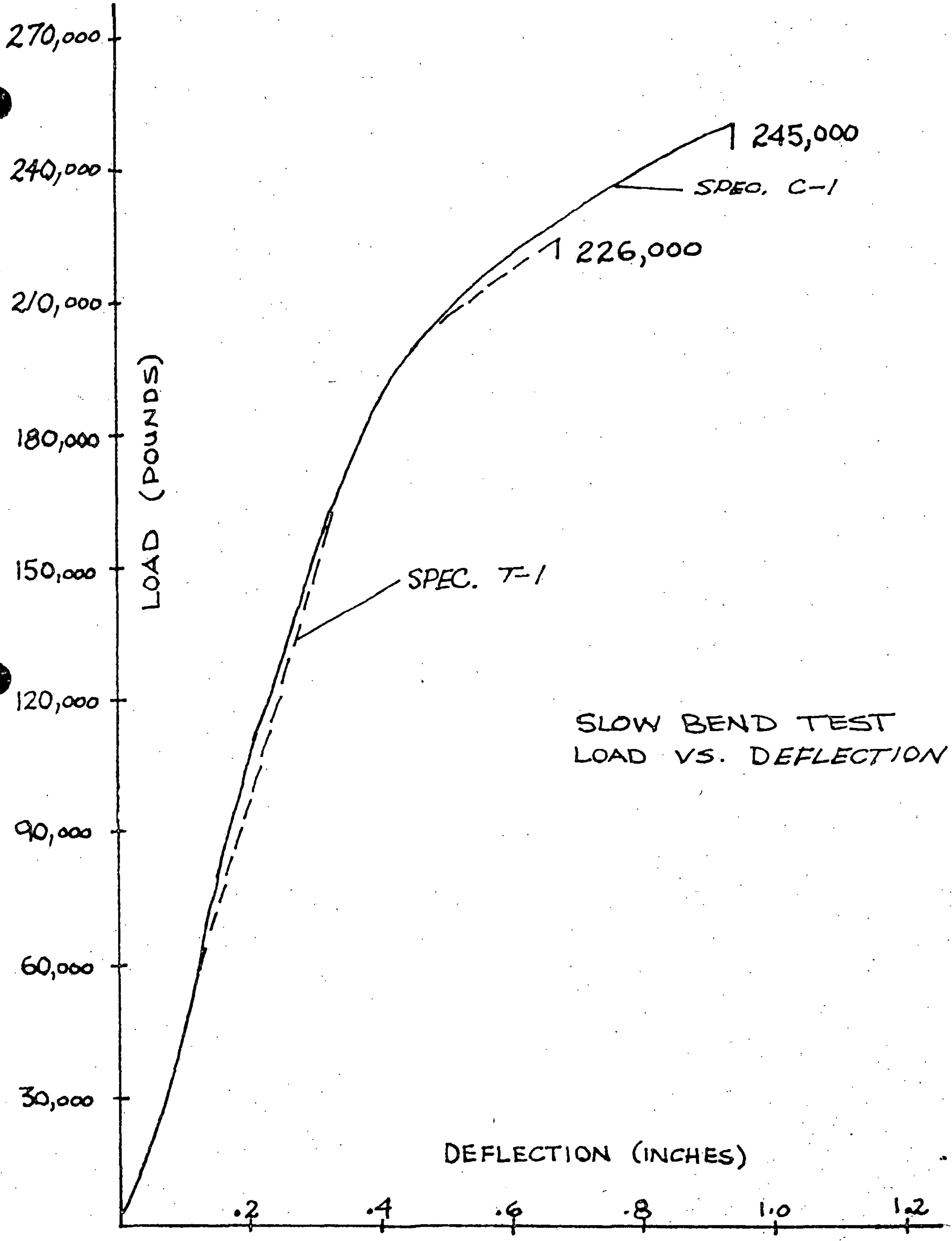


Figure 4.3.1-3 Load Vs. Deflection Curves

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

26 JULY 1982
DATE

ONE (C-1)
Part No.

RESULT

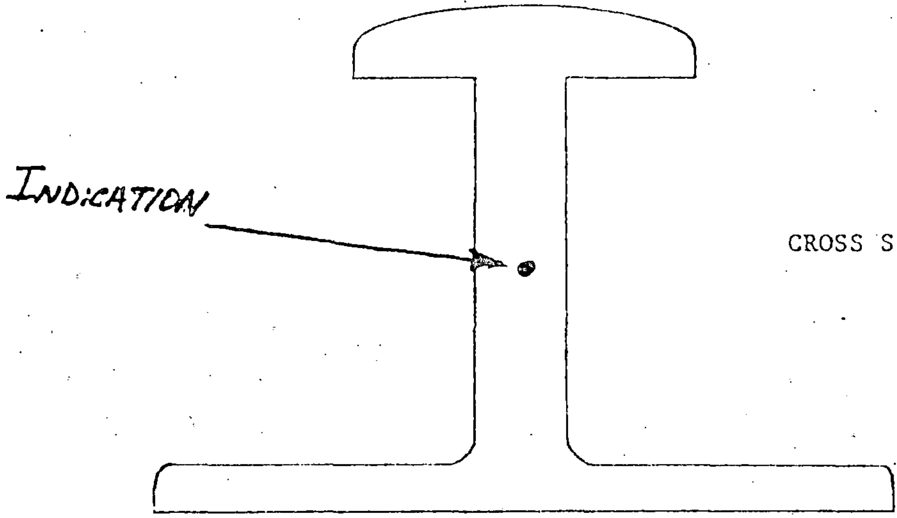
Calorite # 1
~75°F AMBIENT
~ 1800°F PREHEAT
(Weld By J. Dolce)
(BEND TEST Specimen)

NO. OF INDICATION: ONE

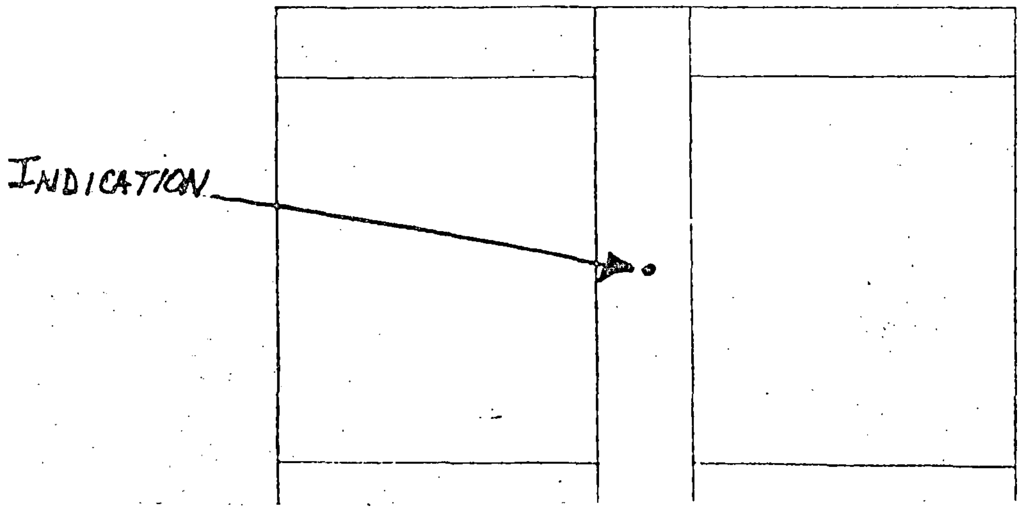
INDICATION TYPE: POSSIBLY POROSITY OR FLAW

INDICATION SIZE: APPROXIMATELY 0.047"

LOCATION: SEE BELOW



CROSS SECTION VIEW



SIDE VIEW

Figure 4.3.1-4 Ultrasonic inspection report on specimen #C-1

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

6 Aug 1982
DATE

Four (T1)
Part No.

RESULT

NO. OF INDICATION: Two

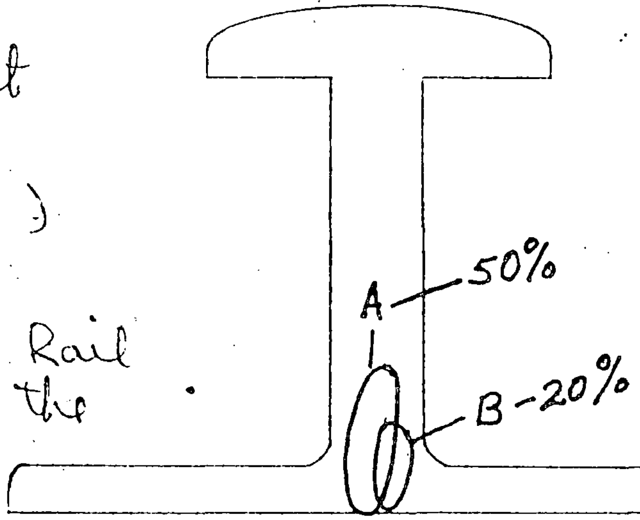
INDICATION TYPE: Porosity, grain, flaw

INDICATION SIZE: 1"(B), 2"(A)

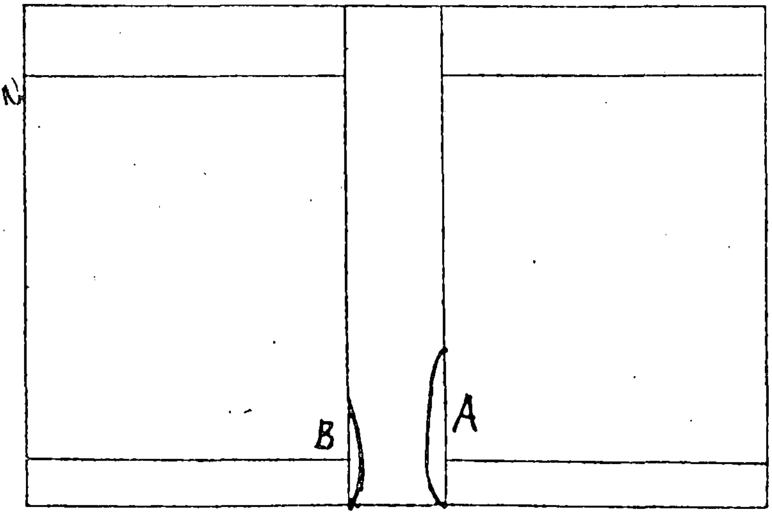
LOCATION: SEE BELOW

US Thermit
at 95°F ambient
No-Preheat
(weld by T. Allen)

Cross Sections of Rail Base show that the UT INDICATIONS ORIGINATED FROM AREAS of SPONGE LIKE POROSITY — A CONCENTRATION of VOIDS WAS NOTED AT the fusion LINE — this could have given a crack like appearance —



CROSS SECTION VIEW



SIDE VIEW

Figure 4.3.1-5 Ultrasonic inspection report on specimen #T-1

4.3.2 Test Weld Series

Table 4.3.2-1 gives a summary of the welding conditions for each of the test welds. Also included is a comment column indicating problems that were experienced. Table 4.3.2-2 summarizes the results of the metallurgical and non-destructive inspections. Detailed data from which these tables were constructed may be seen in Appendix B.

Figure 4.3.2-1 shows a typical as welded joint after removal of the risers and excess metal from the rail head. The weld beads were approximately one inch wide and were encrusted with a layer of ceramic material from the mold. The lines drawn on the figure show locations where the weld sections were cut.

Figures 4.3.2-2 through 4.3.2-4 show a comparison between a weld with good fusion and one which has not completely fused. Figure 4.3.2-2 shows complete fusion achieved in #C-12 using a 1500°F preheat temperature. Partial fusion obtained in #C-5 (Figure 4.3.2-3) resulted when the initial preheat temperature of 1800°F dropped to 1300°F while the welder was having trouble igniting the charge. An extreme case in which almost no fusion was obtained is illustrated by #C-3 shown in Figure 4.3.2-4. Here the initial 2000°F preheat had dropped to 900°F in the 4.5 minutes it took to get the charge ignited.

The importance of preheating evenly is illustrated by #C-13 (Figure 4.3.2-5) in which complete fusion was obtained on one side while no fusion was obtained on the opposite side.

TABLE 4.3.2-1

TIME-TEMPERATURE DATA SUMMARY

Specimen	Ambient Temp-°F	Preheat Time-Min	Preheat Temp-°F	Tap Time Min	Tap Temp °F Top	Tap Temp °F Bottom	Remarks
C-1	95	20	1800	0.5	-	-	Vendor Rep., Bend Test
C-2	95	20	1800	0.7	-	-	Vendor Rep.
C-3	50	38	2000	4.2	1200	900	Trouble Igniting
C-4	50	28	2000	0.5	1900	1200	
C-5	50	20	1800	1.5	1600	1300	Trouble Igniting
C-12	50	24	1500	1.2	1500	1300	Trouble Igniting, CR Rail
C-13	50	35	1000	1.8	1100	1000	CR Rail/Mold Broke
C-6	30	32	2000	1.8	1600	1300	Trouble Igniting
C-7	30	36	2000	2.5	1600	1300	Trouble Igniting
C-8	30	26	2000	0.8	1900	1500	
C-10	30	16	1200	4.8	900	700	Trouble Igniting
C-9	10	21	2000	0.7	1800	1600	
C-11	10	38	1200	1.8	-	1100	Trouble Igniting
C-14	10	38	1500	3.8	1200	1000	Mold Leaked, CR Rail
T-1	95	-	-	-	-	-	Vendor, Bend Test
T-2	30	-	-	-	-	-	
T-3	10	-	-	-	-	-	CR Rail

TABLE 4.3.2-2

SUMMARY
NON-DESTRUCTIVE INSPECTION AND METALLURGICAL TEST RESULTS

Specimen	NDI(1)	Met. Section(2)	% Penetration Top/Bottom	Hardness-RC Top	Hardness-RC Bottom	Tap Temp-°F Top	Tap Temp-°F Bottom
C-1	P/I	-	100	51	36	-	-
C-2	P/I	-	100	35	34	-	-
C-3	F/P	LOF	100/30	31	31	1200	900
C-4	P	None	100/100	33	35	1900	1200
C-5	F	LOF	100/40	33	33	1600	1300
C-6	P	-	100/100	43	39	1600	1300
C-7	P	-	100/100	32	36	1600	1300
C-8	P/F	None	100/100	33	34	1900	1500
C-9	P	-	100/100	43	40	1800	1600
C-10	-	LOF	50/12	33	35	900	700
C-11	F	Crack	60/100	53	52	-	1100
C-12	-	Incl.	100/100	38	36	1500	1300
C-13	-	LOF/CK	15/62	57	57	1100	1000
C-14	-	LOF	100/94	37	36	1200	1000
T-1	P/F	P	100/100	28	28	-	-
T-2	P/F	None	100/100	27	30	-	-
T-3	-	None	100/100	29	30	-	-
B-1	-	-	-	37			
B-12	-	-	-	51			
B-10	-	-	-	30			
B-3	-	LOF	0/18	31	32		

(1)P = Porosity I = Inclusion
F = Flaw (crack like indication)
(2)LOF = Lack of Fusion
Incl = Inclusion
Ck = Crack

Specimen Designation:
C = Calorite
T = US Thermit
B = Boston field failure

NOTE: Specimens C20, 12, 13 and 14 were not ultrasonically inspected.

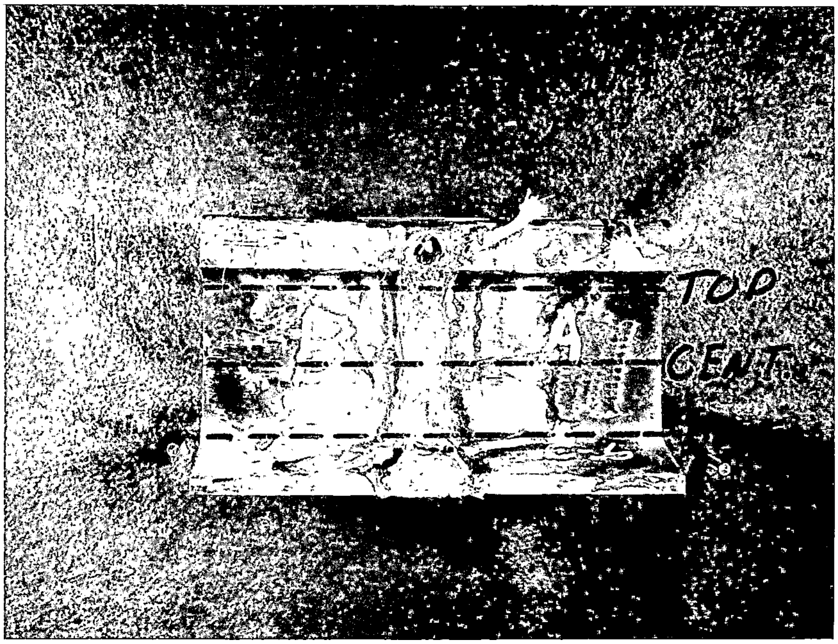


Figure 4.3.2-1 Typical Calorite test weld "as welded".

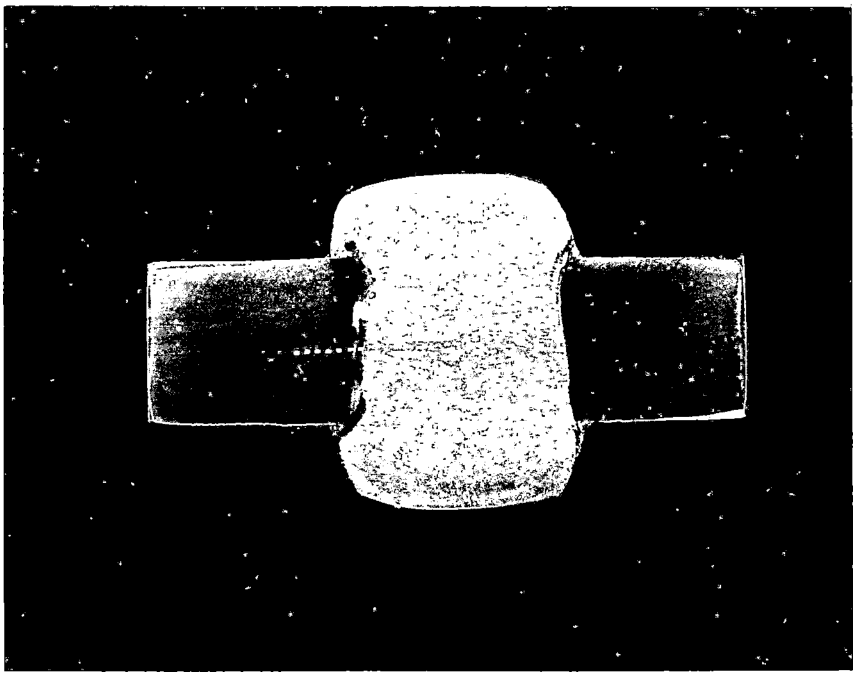


Figure 4.3.2-2 Complete fusion in specimen #C-12 at 1500°F preheat.

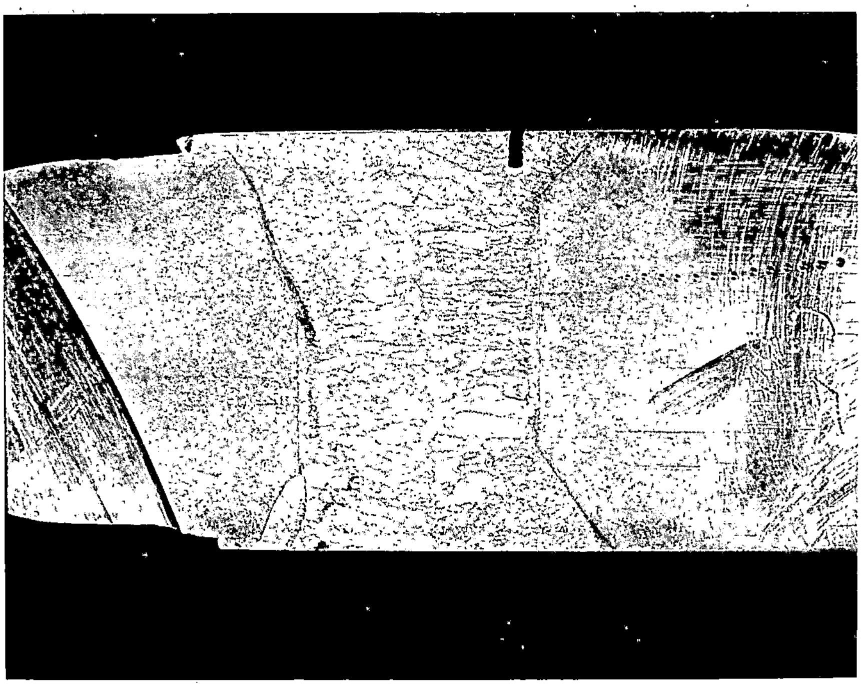


Figure 4.3.2-3 Incomplete fusion in specimen #C-5 at 1300°F preheat (2x).

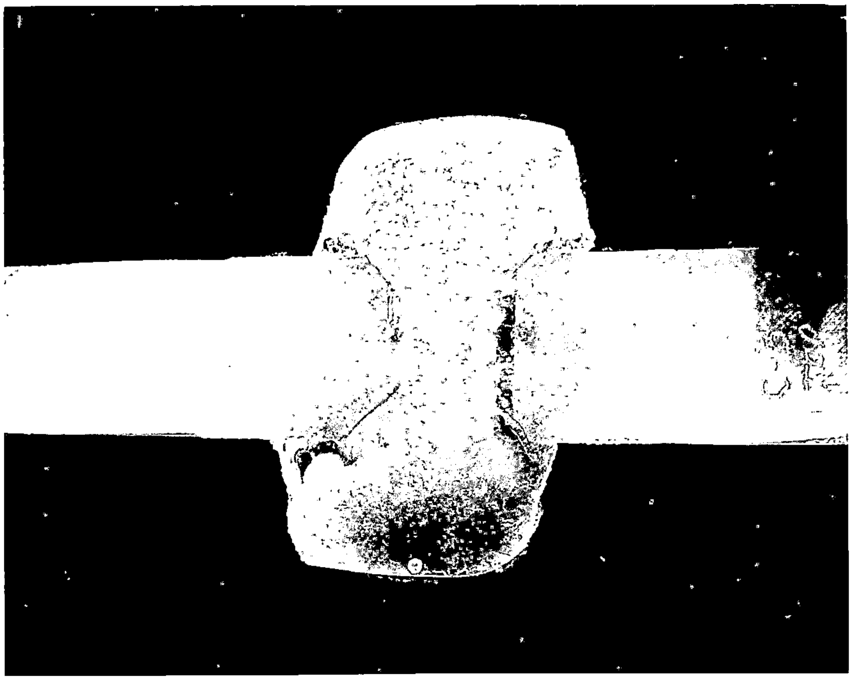


Figure 4.3.2-4 Almost no fusion in specimen #C-3 at 900°F preheat.

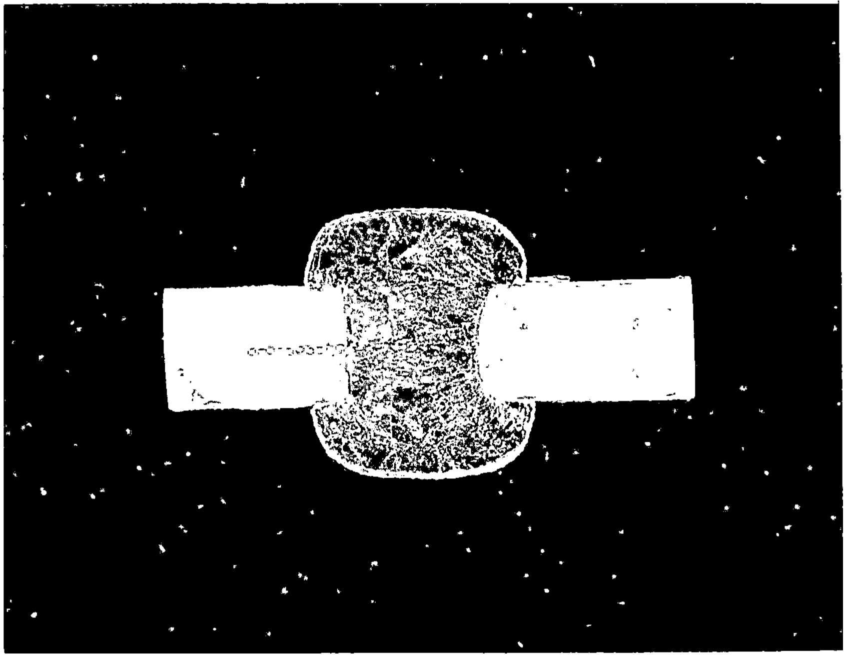


Figure 4.3.2-5 Uneven fusion in specimen #C-13 resulting from uneven preheating. (1000°F nominal preheat.

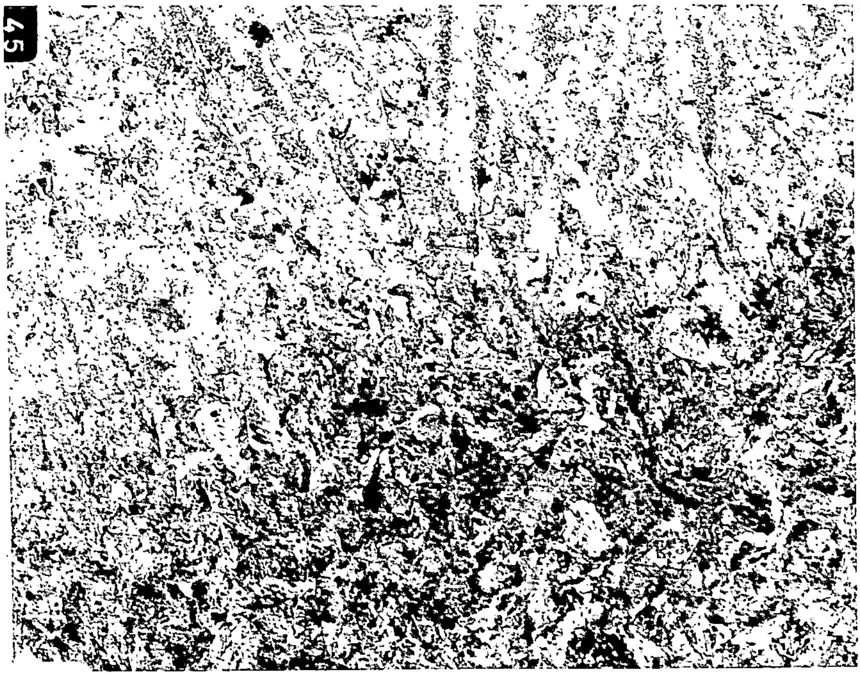


Figure 4.3.2-6 Weld interface - complete fusion - specimen #C-4 (1900°F preheat). Nital Etch. (100x)

Figures 4.3.2-6 through 4.3.2-9 illustrate microscopic conditions observed in the weld joints. A normal completely fused joint is illustrated by #C-4 (Figure 4.3.2-6) welded at 1900°F preheat. Lack of fusion is illustrated by #C-3 (Figure 4.3.2-7) welded at 900°F preheat. Specimen #C-12 (Figure 4.3.2-8) shows a case in which complete fusion was achieved at 1500°F preheat, but a large inclusion was retained in the weld. Specimen #C-11 (Figure 4.3.2- 9) is an example of cracking which developed in a weld which was too hard (RC 52-53).

A wide range (RC 57-31) of hardness was observed in the Calorite weld joints. Figures 4.3.2-10 through 4.3.2-12 illustrate the microstructure changes observed over the hardness range. Specimen #C-1 (Figure 4.3.2-10) contained hard untempered martensite combined with upper banite resulting in high (RC 51) hardness. Specimen #C-6 (Figure 4.3.2-11) had a hardness of RC 43, and the microstructure consisted of banite and approximately 40% martensite. Specimen #C-7 (Figure 4.3.2-12) had hardness of RC 36-32 with microstructure containing approximately 5% martensite.

Curves of temperature versus time (see Appendix B) show that the head of the rail chilled the weld metal more rapidly than did the thin sections in the web and bottom flange. An inspection of Table 4.3.2-2 shows that the highest hardness generally occurred in the head of the rail where the quench rates were the highest.

US Thermit welds do not require preheating because they employ excess metal flowing through the joint to raise the temperature. Figure 4.3.2-13 is a section from specimen #T-2 showing complete fusion in the joint. This appearance was typical of all three welds examined. The hardness of the

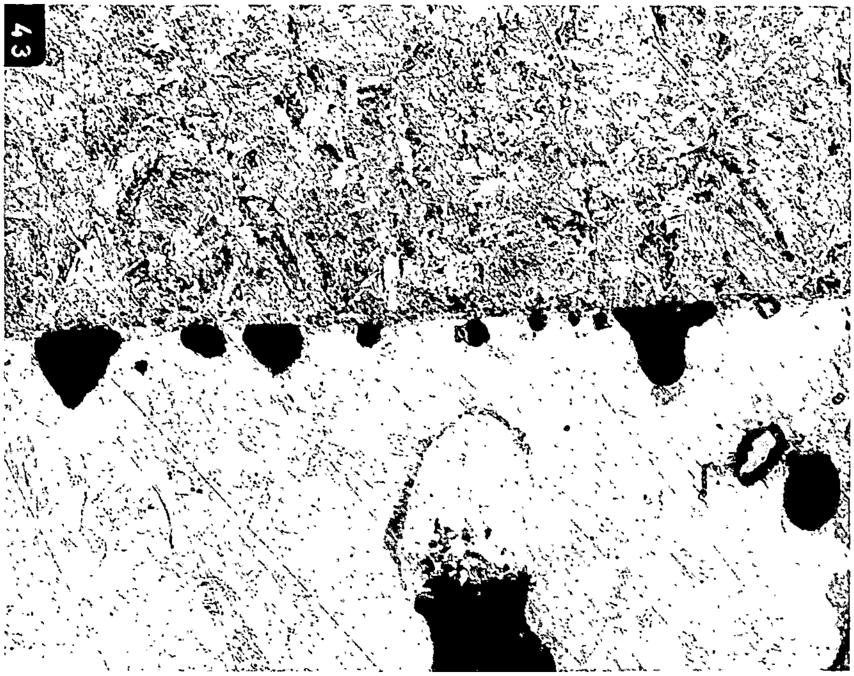


Figure 4.3.2-7 Lack of fusion and gas porosity - specimen #C-3 (900°F preheat). Nital Etch. (100x)

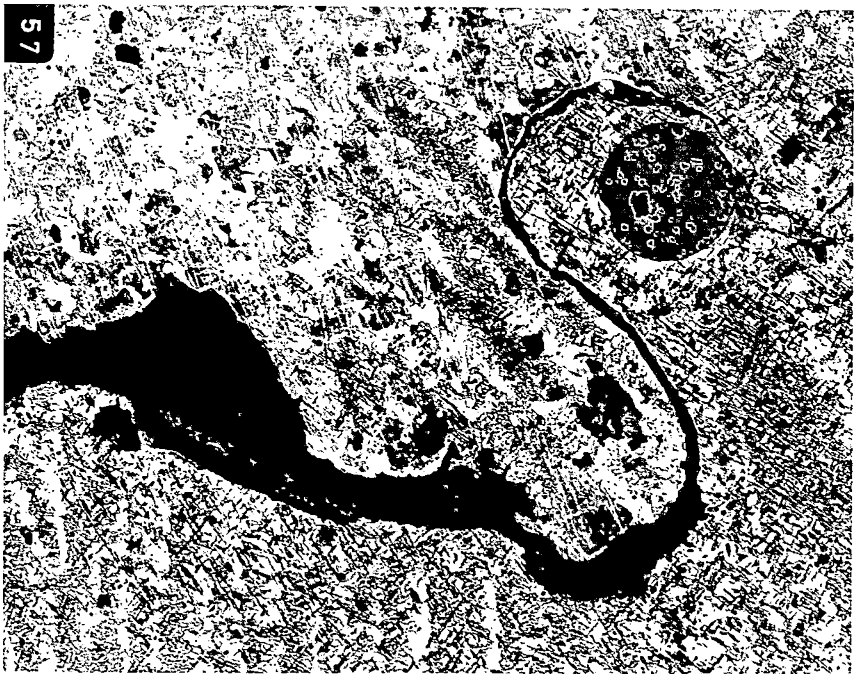


Figure 4.3.2-8 Large inclusion and gas void - specimen C-12 (1500°F preheat). Nital Etch. (100x)

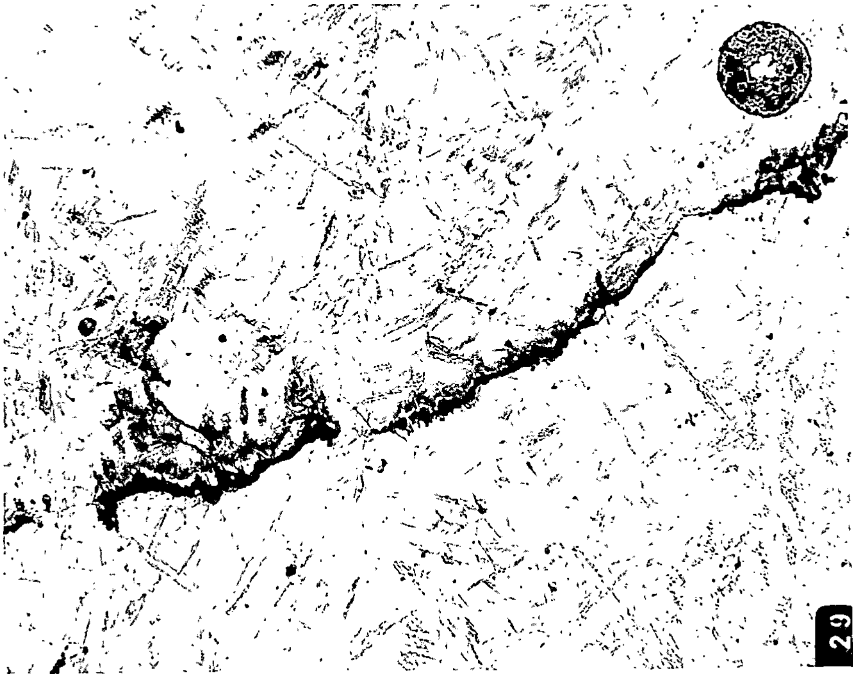


Figure 4.3.2-9 Cracking resulting from excessive weld hardening (RC 52-53) in specimen #C-11 (1100°F) preheat). Nital Etch. (100x)

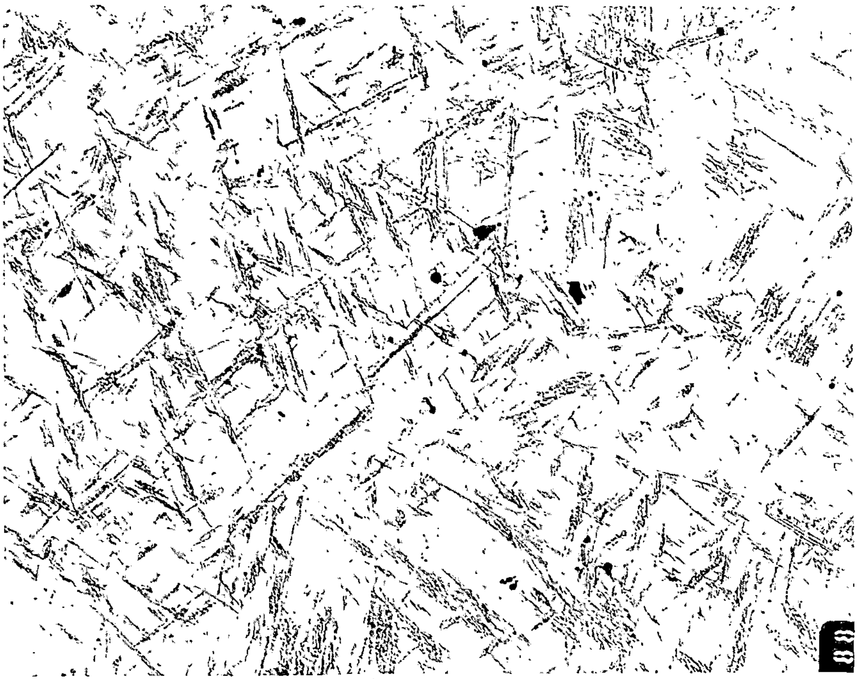


Figure 4.3.2-10 Photomicrograph - specimen #C-1 showing hard (RC 51) weld containing martensite and upper banite. Nital Etch. (100x)

Figure 4.3.2-11 Photomicrograph - specimen #C-6 showing a hard (RC 43) weld containing banite and martensite. Nital Etch. (100x)

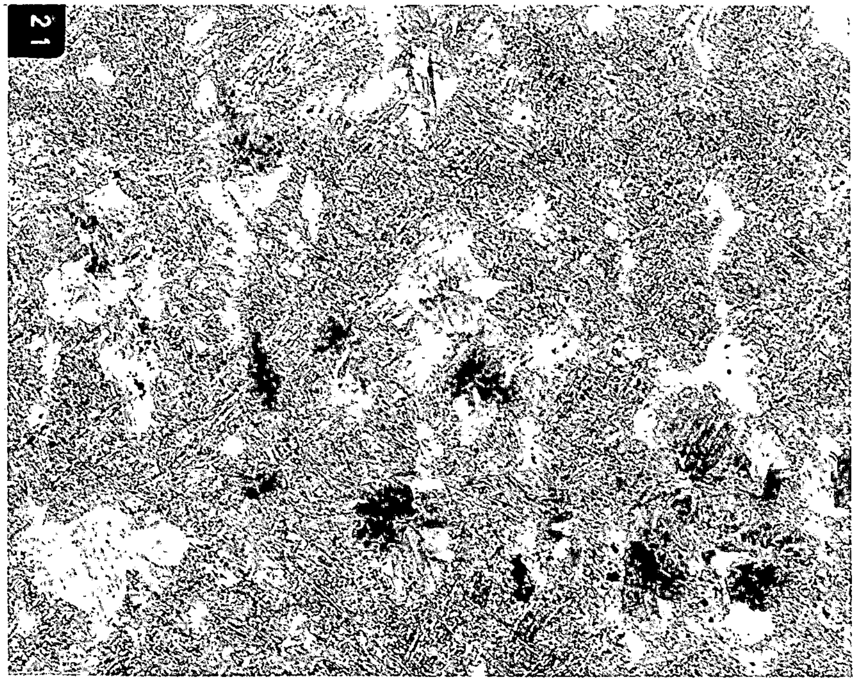


Figure 4.3.2-12 Photomicrograph of specimen #C-7 showing normal hardness (RC 32-36) weld containing fine pearlite and widmanstatten structure with approximately 5% martensite. Nital Etch. (100x)

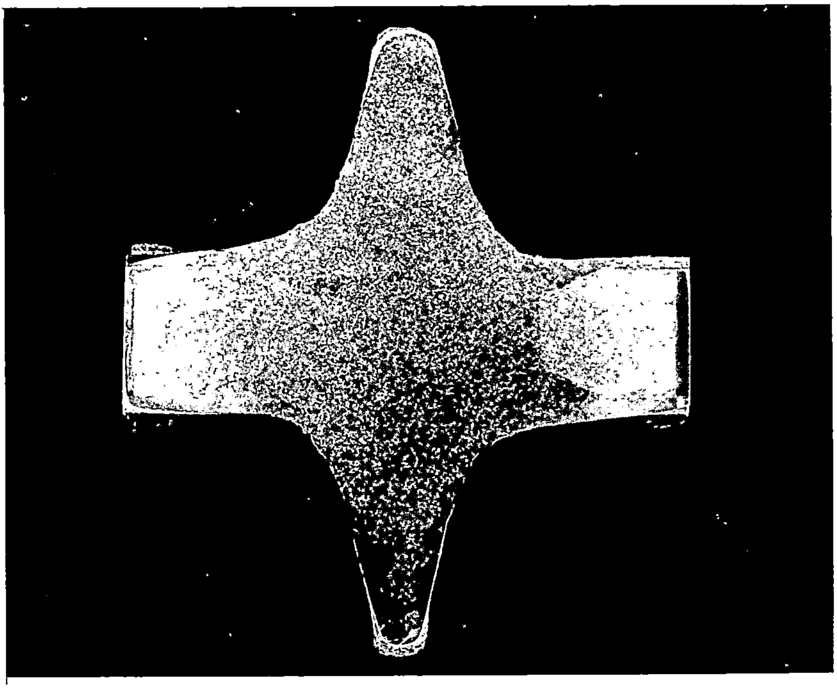


Figure 4.3.2-13 Section from weld #T-1 showing complete fusion - typical of U. S. Thermit welds.

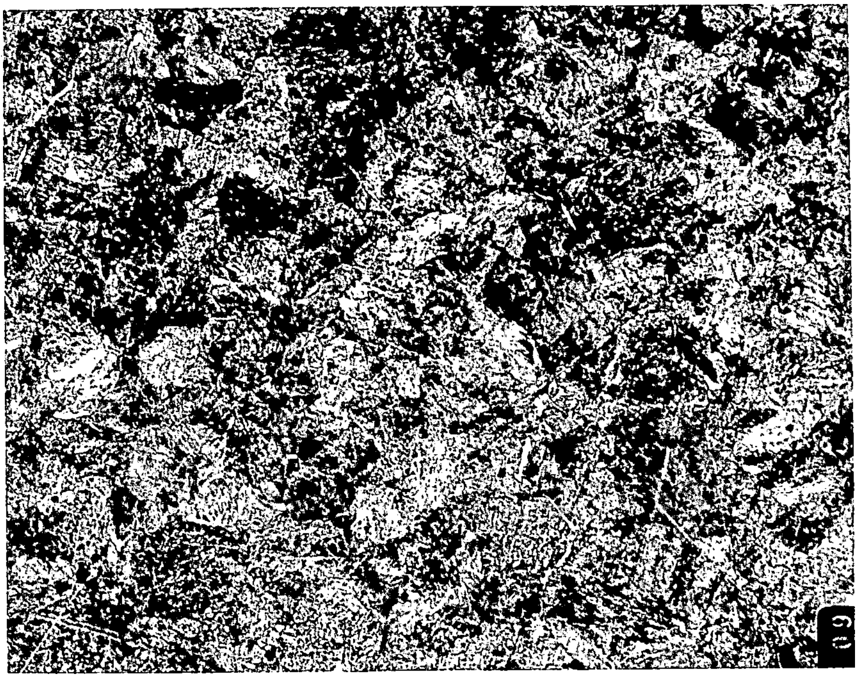


Figure 4.3.2-14 Photomicrograph from specimen #T-3 showing soft (RC 28) weld containing fine pearlite. Nital Etch. (100x)

US Thermit welds (RC 28) was substantially lower than the Calorite welds. This was due to the lack of alloying elements in the US Thermit weld metal, which results in a completely pearlitic microstructure, Figure 4.3.2-14. Hardness in the US Thermit welds was approximately the same as that of control cooled rail. Therefore, in the chrome rail, the weld was softer (RC 28) than the rail (RC 32-35).

Table 4.3.2-3 contains results of chemical analyses of the weld metal and both types of rail. The hardenability of the Calorite weld metal results primarily from the additions of chromium, nickel and molybedenum.

TABLE 4.3.2-3

CHEMICAL ANALYSIS RESULTS

SPECIMEN	Si	Cr	Mn	Ni	Mo	Al
C-1	0.20	0.40	0.90	0.20	0.40	1.10
C-2	0.60	0.40	0.90	0.20	0.40	0.80
C-3	0.20	0.15	1.10	0.25	0.15	0.39
C-5	0.80	0.50	0.90	0.20	0.30	1.10
C-6	0.40	0.40	1.20	0.20	0.40	1.40
C-7	0.40	0.40	0.90	0.20	0.30	0.90
C-8	1.0	0.30	2.00	0.20	0.30	0.80
B-10	0.20	0.20	0.65	0.25	0.32	0.15
CC Rail	0.2-0.4	0.01-0.02	0.35-0.49			
CR Rail	0.02-.03	1.01-1.25	0.96-1.20			

4.4 Findings

4.4.1 Calorite Welded Joints

Variations in the preheat temperature produced weld joints with fusion characteristics similar to the MBTA failures.

- Preheating in the range of 1500°F to 2000°F produced complete fusion in the joints.
- Preheating below 1200°F consistently produced welds with poor fusion.
- Preheating in the range of 1200°F to 1500°F produced mixed results.

Different cooling rates were observed between welds and between the top, center and bottom of a given weld joint. This variation in cooling rates contributes to the mixed results for the temperature range quoted above.

Welds with complete fusion can be achieved at ambient temperatures as low as 10°F provided that proper preheating conditions are achieved. However, complete fusion becomes more and more difficult to achieve at low ambient temperatures.

The inability to easily ignite the Calorite charge was found to be a problem with the weld kits used for these tests. This problem was a direct cause of several bad welds due to loss of rail preheat temperature while attempting to light the charge.

The hardness of the Calorite weld metal was strongly influenced by the cooling rate of the weld joint. This characteristic disclosed an additional problem. The observed hardness range, RC 33 to RC 57, exeeded the normal range, RC 31 to RC 41, for the chrome rail material. Welds with a hardness exceeding RC 50 may experience delayed internal cracking due to residual stresses. Welds with hardness as low as RC 35 still contained as much as 5 to 10% untempered martensite which is undesirable. Avoiding these high hardness results conditions with the present kit will required extra measures such as insulating blankets and post weld tempering.

Correspondence from the Calorite weld kit supplier confirmed that an error had been made in the amount of alloying elements added to the weld kit and indicated corrective action would be taken. Recent discussions with Calorite indicate that this was accomplished and that the desired lower weld hardnesses and improved metalurgical formations were achieved.

4.4.2 U. S. Thermit Welded Joints

The three weld joints made using the U. S. Thermit process produced complete fusion within the ambient temperature range of these tests. The lack of a higher chrome alloy content in the U. S. Thermit rail metal used in this investigation resulted in welds which were substantially softer than the chrome rail but compatible with the hardness of control-cooled rail. Welding control-cooled rail to chrome rail with these kits will cause no degradation in performance since the result is only a shift in the hardness transition location. When this weld kit is used to weld chrome rail to chrome rail, the effect of the soft (RC 28) weld metal between the hard (RC 35) chrome rail may result in some long term performance degradation. However, no evidence was found in the literature to indicate that this hardness combination has been a significant problem. In any case, an increase in alloying elements in weld kits for joining chrome rail would be prudent. Recent correspondence with U. S. Thermite, Inc. has confirmed that higher chrome alloy weld kits can be supplied if specified by the user.

4.4.3 Ultrasonic Inspection

Ultrasonic inspection techniques were successful in locating internal (non-visual) flaws in the weld joints. A preliminary procedure for these inspections is contained in Appendix C. However, in order to utilize this procedure, a reliable rejection criteria needs to be developed.

From the data observed, it is evident that it would be possible to establish an accept/reject standard through a correlation between flaw size and weld strength. This could only be done by creating a series of weld joint specimens with various types of flaws and flaw sizes and obtaining an ultrasonic inspection measurement for each. The specimens would then be tested to failure. By defining the maximum strength degradation that would be acceptable, the ultrasonic measurement corresponding to this limit would then be used as the accept/reject standard for weld inspection.

It is probable that accept/reject standards would require tailoring for each transit system since each system will have different operating requirements and conditions and different rail sizes and materials.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Under normal conditions and by following the weld kit suppliers' instructions satisfactory welds can be obtained.

The most critical variable is the control of the preheat. That is, complete fusion is only possible when the rail is at the proper preheat temperature prior to and during the welding process.

The ambient temperature, between 95^{0}F and 10^{0}F does not appear to affect weld quality. However, as the ambient temperature drops below 30^{0}F, the ability of the weld crew to control all of the other processes deteriorates significantly.

Acceptable welds can be made even when the weld kit material and rail material differ. However, this will generally exaggerate the hardness variation across the joint which can lead to problems with brinnelling at the joint when the weld is "softer" than the rail or vice versa. This can be significant since the area impacted can be as wide as 2 1/2 to 3 inches (see hardness plots in Appendix B).

5.2 Recommendations

Qualify and certify welders and weld processes before putting them in the field. Include periodic recertification requirements for the field crews.

Require tighter limits and extra precautions for welding chrome rail than is normal for control-cooled rail.

Utilize some means such as Tempil stick or an optical pyrometer to establish a minimum preheat and/or a uniform preheat.

Develop a critical flaw size for ultrasonic inspection of weld quality so that a cost effective accept/reject criteria can be established. This investigation indicated that the critical rail flaw size depends on the type of flaw and is in the 1/2 to 1 inch range.

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9. Slow Bend Test 115 Lb. Welded Rails by J. F. White Construction Co.: R. H. Hawley, Ltr. Rept. to Calorite, Inc.; Swansea, MA; August 1980.

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12. Ultrasonic Rail Flaw Imaging System; H. Cellon; FRA Directed Research Project by TSC; 1978.

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APPENDIX A

SYSTEM INFORMATION GATHERED DURING THE SURVEY PHASE OF THE INVESTIGATION

SUMMARY OF FAILURES
CONTROL COOLED RAIL

			RAIL				
NO.	DATE	LOCATION (1)	SIZE (2)	TYPE (3)	TEMP ^{o}-F	YEARS IN SERVICE	FRACTURE LOCATION (4)
1	1-7-82	West of Kenmore, EB	85	ASCE	30's	30	-
2	1-7-82	East of Arlington, W.B.	85	ASCE	20's	15	C
3	1-20-82	Barlet St., SB	85	ASCe	Teen's	15	B
4	1-20-82	No. of Kendall, N.B.	85	ARAB	40's	10	C
5	1-21-82	Cedar STret, S.B.	100	AREB	20's	15	B
6	1-19-82	So. of Dover, S.B.	85	ASCE	20's	12	B
7	1-15-82	No. of Egelston, N.B.	85	ASCe	20's	15	B
8	1-16-82	Boylston, N.B.	100	ASCE	40's	1	-
9	1-17-82	So. of Wash., N.B.	85	ASCE	30's	20	-
10	1-28-82	So. of Dudley, N.B.	100	AREB	20's	5	B
11	1-29-82	East of Airport, E.B.	100	AREB	Teen's	20	B
12	1-29-82	Kenmore, E.B.	85	ASCE	40's	20	-
13	2-5-82	So. of Oak Grove, N.B.	100	AREB	20's	5	B
14	2-5-82	No. of ForestHills, N.B.	85	ASCE	20's	20	F
15	2-8-82	Forest Hills, N.B.	85	ASCE	20's	20	B
16	2-9-82	No. of Dover, S.B.	100	AREB	20's	12	B
17	2-18-82	No. of Oak St., N.B.	85	ASCE	20's	15	-
18	2-19-82	Park St., S.B.	85	ASCE	20's	18	B
19	2-21-82	No. of Green St., S.B.	85	ASCE	30's	15	-
20	2-25-82	So. of Harvard, S.B.	100	ARAB	30's	20	C
21	2-26-82	So. of Haymarket, S.B.	85	ASCE	20's	20	-
22	2-26-82	East of Arlington, W.B.	85	ASCE	20's	15	-

SUMMARY OF FAILURES CONTROL COOLED RAIL (Continued)

NO.	DATE	LOCATION (1)	SIZE (2)	RAIL TYPE (3)	TEMP °-F	YEARS IN SERVICE	FRACTURE LOCATION (4)
23	3-5-82	No. of Kendall, N.B.	85	ASCE	2's	1/8	C
24	3-5-82	No. of Green St., N.B.	85	ASCE	20's	12	-
25	3-10-82	East of Copley, E.B.	85	ASCE	20's	20	-
26	3-12-82	So. of Egleston, S.B.	85	ASCE	40's	1/12	-
27	3-16-82	So. of Broadway, S.B.	85	ASCE	30's	-	-
28	3-16-82	No. of South Sta., S.B.	100	ARAB	40's	-	C
29	3-23-82	So. of Charles Portal, S.B.	85	ASCE	40's	17	-
30	3-31-82	No. of Park Sta., S.B.	85	ASCE	40's	20	C
31	3-26-82	Codman Yard	85	ASCE	40's	25	-
32	4-9-82	No. of Northampton	85	ASCE	50's	20	-
33	4-10-82	East of Aquarium	85	ASCE	40's	15	-

NOTES:

1. See system map.
2. Rail size in lb./yd.
3. Rail was procured to AREA material specification for steel rails.
4. B - Failure thru bolt hole; C - failure thru cable bond;
   F - failure thru field weld.

NO.	DATE	LOCATION (2)
1	9/81	DRTX
2	9/81	DRTX
3	10/81	DRTX
4	10/81	DRTX
5	11/81	DRTX
6	1/82	DRTX
7	10/81	DRTX
8	9/81	DRTX
9	12/81	DRTX
10	-	Hi-Speed
11	-	
12	-	
13	-	
14	-	
15	-	
16	-	
17	-	
18	-	
19	-	
20	-	
21	-	
22	-	Hi-Speed

SUMMARY OF FAILURES
CHROME[1] RAIL

SIZE [3]	RAIL TYPE[4]	MONTHS IN SERVICE	FRACTURE LOCATION[5]
115	AREA	2	F
		2	F
		3	S
		3	-
		4	F
		6	F
		3	-
		2	-
		4	-
		5/6	F
			F
			S
			-
			F
			F
			S
			F
			F
			F
			S
			S
115	AREA	5/6	F

SUMMARY OF FAILURES - CHROME (1) RAIL (Continued)

23	4-16-82	Hi-Speed	115	AREA	3	F
24	4-11-82				3	F
25	4-11-82				3	S
26	4-13-82				4	F
27	5-3-82	Hi-Speed				-
28	6-12-82	DRTX			1/2	F
29	3-4-82	DRTX	115	AREA	2 1/2	C

NOTES:

1. Failures involved chrome rail to chrome rail weld, chrome to control cooled rail weld or a failure in a chrome rail section.

2. See system map, DRTX (Ashmore to Cambridge), Hi-Speed (Matapan to Ashmont).

3. Rail size in lb./yd.

4. Chrome rail procured to British Steel Corp. specification - Item 7 of Appendix A.

5. C - Failure thru cable bond; F - Failure thru field weld; S - Failure thru shop weld.

MBTA VEHICLE INFORMATION

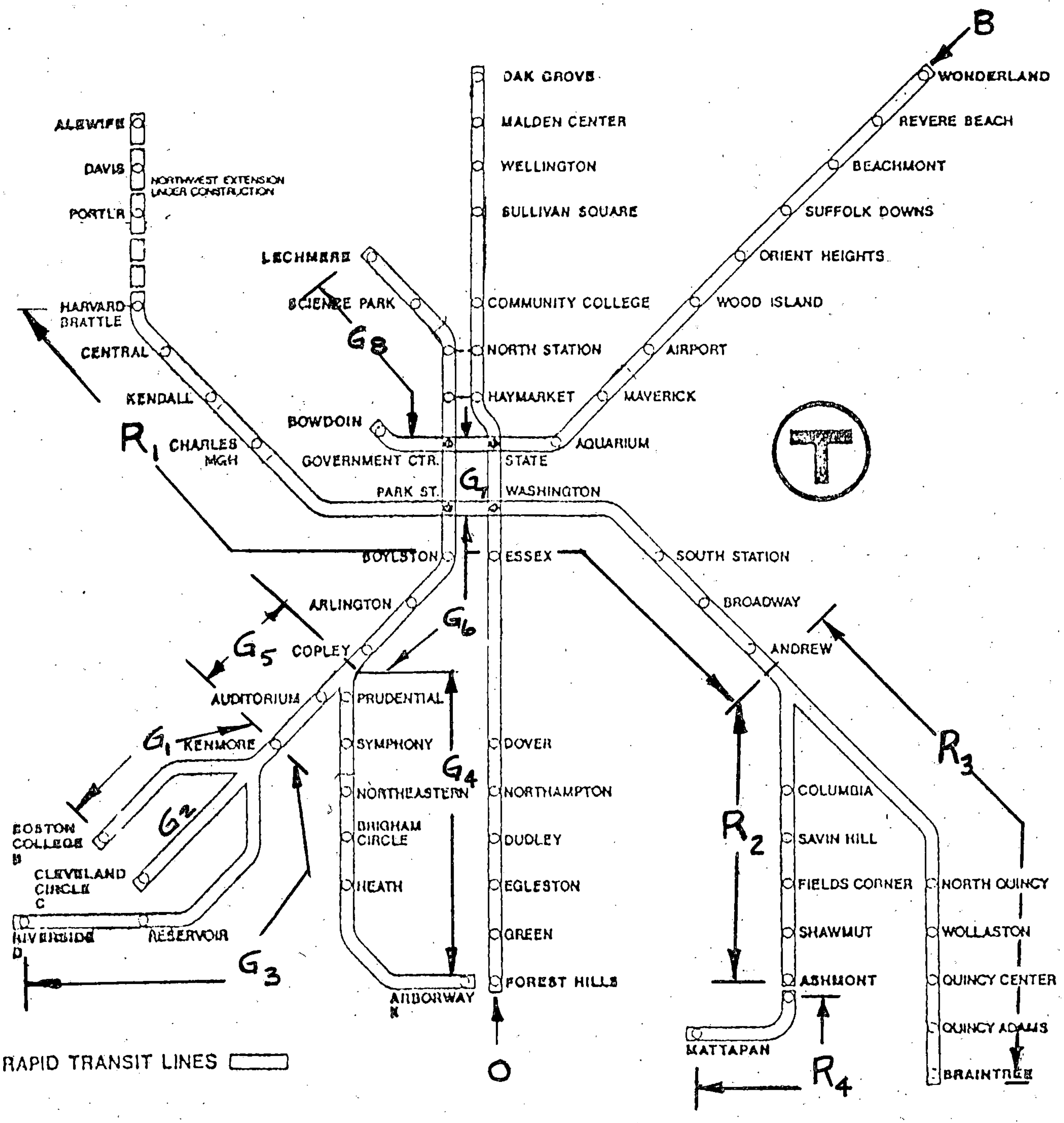
LINE	ROUTE	VEHICLE WEIGHT LB. MAXIMUM	VEHICLE WEIGHT LB. EMPTY	NO. OF CARS TYPICAL RUSH	NO. OF CARS TYPICAL DAY	NO. OF CARS TYPICAL NITE	NO. OF CARS TYPICAL SAT	NO. OF CARS TYPICAL SUN	NO. OF AXLES
Orange	-	98,472	68,772	4	4	2	4	2	4
Blue	-	90,452	60,752	4	4	2	4	2	4
Red	H/A	115,150	71,300	4	4	2	4	2	4
	H/Q	95,188	61,728	4	4	2	4	2	4
	M/A	58,395	40,195	1	1	1	1	1	4
Green	BC/L	104,000	67,000	1	1	1	1	1	6
	CC/L	104,000	67,000	1	1	1	1	1	6
	R/NS	104,000	67,000	1	1	1	1	1	6
	A/PS	58,395	40,195	2	1	1	1	1	4

NOTE: See schedule information for route definition.

MBTA SCHEDULE INFORMATION

APPROXIMATE FREQUENCY - MINUTES

	RUSH HOURS	DAY	NIGHT	SAT	SUN
ORANGE LINE	5	8	15	8/9	15
BLUE LINE	4/5	7/8	11	7 1/2/9	7 1/2/12
RED LINE					
Harvard - Ashmont	6	10	10/15	8/15	15
Harvard - Quincy	6	10	10/15	8/15	15
Mattapan - Ashmont	3	8	15	8/15	15/30
GREEN LINE					
Boston College - Lechmere	5/6	7	8	7	8
Cleveland Circle - Lechmere	7	7	10	7	10
Riverside - North Station	7/8	10	10	7	10
Arborway - Park Street	9	7	10	9	7



NOTE: 0, B, R --- G, ---- G_8 = SECTIONS OF SYSTEM LINES USED IN TABLE 2.1-1

MBTA ROUTE MAP

TYPICAL MBTA PROCUREMENT DATA PACKAGE

NOTE: Actual contract required to completely define supplier/ subcontractor requirements.

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
MATERIALS DEPARTMENT
80 Broadway, Everett, MA 02149

PAGE 2

REQUEST FOR PROPOSAL
No. CAP - 292-80

Item No.	Quantity	MATERIAL (Fully Described)	Delivery in Days	Price per Unit	Item Total
			ENCL. 2 ITEM 5 15 PAGES		

FOR HEAT TREATED RAILS:

Chapter 4, Part 2, pp. 4-2-1 through 4-2-6.4;
pp. 4-2-6.7 through 4-5-6.9; and
pp. 4-M-5 through 4-M-8.

FOR ALLOY HIGH STRENGTH RAILS:

Chapter 4, Part 2, pp. 4-2-1 through 4-2-6.4; and
pp. 4-2-6.7 through 4-5-6.9.

In addition alloy high strength rails must be successfully weldable by any of the above process without the development of an undesirable percentage of martensite or bainite. Weldment criteria must be met as follows:

- Martensite or bainite level must not exceed 5% in any field of view at 50x magnification;
- In heat affected zone, the minimum hardness must be no lower than 300 Brinell Hardness; and
- The distance between heat affected zones shall not exceed 1½ inches to 2 inches.

Bidder shall submit chemical composition limits with bid proposal.

Also, rails must have been successfully butt welded in the United States by both the electric-flash and thermite welding processes. Written confirmation of satisfactory performance in-track, including location and service period, shall be submitted with the bid proposal.

Approximately 1413 net tons.

Please quote firm fixed prices F.O.B. destination including all transportation charges. The Authority prefers firm fixed prices. However, the Authority will accept a price escalation provision with a ceiling (usually expressed in terms of a maximum percentage increase) above which the price will not escalate.

6. Construction of the following new special trackwork items, complete with switch timber on the Dorchester Rapid Transit Extension:

   a. Three - 150 foot radius turnouts.

   b. Two - No. 6 Turnouts.

   c. One - No. 6 Double Crossover.

   d. Three - No. 6 Crossovers.

7. Replacement and modification of wood platforms and walkways north of Codman Yard entrance.

8. Make necessary steel and/or concrete repairs, patch-paint, and waterproof as required on the floor systems of 13 ballasted-deck track bridges.

9. Application of a soil sterilant and contact herbicide as indicated.

1.02 SUBMITTALS

D. Welding

1. Submit, prior to initiation of welding, a detail specification of proposed method and procedure for welding running, restraining, and contact rails. Include name of manufacturer and manufacturer's requirements and details for the following:

   a. Rail preparation;

   b. Rail spacing and tolerances;

   c. Rail alignment;

   d. Placing and bolting of molds;

   e. Preheating rail, including temperature, method, and time;

   f. Crucible tapping procedures, including duration of weld and cooling time; and

   g. Trimming and grinding of weld at red heat.

2. Submit welders' qualification certifications and certified laboratory test results for welding tests specified under Article 1.03 herein.

5. Submit weld record of all welds, as specified under Article 3.04.C.4.

G. Submit to the Authority for approval an order list of tabulated lengths of continuous welded rail to be supplied to the project prior to the initiation of welding.

J. The Contractor shall submit manufacturer's drawings, material specifications, installation procedure, locations of previous installation, length of time in service, guarantee period, and other pertinent data relating to the prefabricated concrete panels specified herein.

K. Samples of filter fabric and physical properties relating to high strength and toughness, puncture resistance, chemical resistance, soil stabilization and methods of installation shall also be sumitted for review and approval for use on the project.

1.03 QUALITY CONTROL

C. Qualification Thermite and Electric-Flash or Shop Butt Welding

1. Prepare, in accordance with method specifications described under Article 1.02.D herein, not less than three sample thermite and electric-flash or shop butt welds for each type of rail to be used in the work (heat-treated and control-cooled).

3. Slow Bend Test

   b. Acceptance criteria: minimum of one inch deflection or 100,000 psi modulus of rupture.

5. Ultrasonic Testing

   a. All welds shall be inspected ultrasonically for internal discontinuities. Five percent of all welds that have passed the ultrasonic test shall be selected at random by the Authority's Engineer for radiographic testing. (Those welds selected shall have the excess weld metal on the web and head removed and finished to minimal requirements.) All welds replacing those not passing the original tests shall be inspected ultrasonically and five percent of the replacement welds passing the ultrasonic test shall also be tested radiographically. Testing shall be performed prior to final track inspection.

   b. Record of Welds. Each qualified welder will have an alphanumeric symbol assigned to him. The symbol will be used to mark and identify his work. This symbol shall not have been used before by any other welder. The Contractor will maintain a list of welder identifying marks and the welders to which they are assigned which shall be used in the compilation of testing reports and for the record of welds as specified.

6. Radiographic Testing

   a. Radiographic tests shall be conducted in accordance with ASTM E142 - "Controlling Quality of Radiographic Testing" and ASTM E-94 - "Recommended Practices for Radiographic Testing." Those tests shall detect flaws in the welds with sufficient detail to indicate any existence of incomplete fusion and the size of any defects found in the head, web, or base of rail. The testing laboratory shall furnish a radiographic examination form for each sample weld examined. The form shall include the welder's identity, the number of the weld, the number of the welding machine or thermite process, and shall identify the film and the laboratory specialist performing the examination.

   b. Nondestructive examination of metal welds by radiographic use of nuclear by-product materials shall be conducted by a laboratory authorized and licensed by the U.S. Nuclear Regulatory Commission, and shall comply with all prescribed rules and regulations required for such examinations.

F. Testing

1. Third Rail

   d. Joints

      4) All third rail joints shall be tested both mechanically and electrically.

      5) Mechanical Testing

      When cooled to normal temperature, the rail joint shall withstand jacking or lifting to 5 inches above its normal position. Where rail strings are sitting on the ties, this shall mean lifting 5 inches from the tie position. Where the rail strings are already on insulators, this shall mean lifting 5 inches above the normal level the rail would have on the insulators. The lifting may be accomplished by a jack placed under the weld or by lifting cable around the weld and the suitable hoisting device.

6) Resistance Testing

a) Electrical resistance of the finished joint shall be measured using a 36 inch gauge length. The gauge shall be applied so that the weld is at the center on 18 inch point. The resistance measured across a weld shall be a maximum of 110 percent of the resistance of 36 inches of rail without a joint. The checks of the 36 inch rail should be made on either side of the joint and on both rails as there may be variations on the resistivity of individual rail sections.

b) Instruments: Instrumentation for the electrical resistance test shall be either a direct reading low resistance ohm-meter using at least a 100 amp dc power supply, or a suitable arrangement of ammeter and milli-volt meter with a dc power supply. Should milli-volt meter, ammeter system be used, simultaneous readings of ammeter and milli-volt meter should be taken to assure that any fluctuation in current will not adversely affect the accuracy of the milli-volt meter readings. A dc welding generator is a recommended power supply.

PART 2 - PRODUCTS

2.01 MATERIALS

A. Soil sterilant and contact herbicide approved by the Authority and the Massachusetts State Pesticide Board.

B. Crushed stone shall conform to A.R.E.A. Specifications, Chapter 1, Part 2, Pages 1-2-1 through 1-2-4. Gradation: A.R.E.A. Size No. 4 for track construction and Size No. 5 for small stone under prefabricated concrete crossing edge beams.

C. Timber Ties

1. Ties shall be manufactured from mixed hardwoods as shown in the A.R.E.A. Specifications, Chapter 3, Part 1, Article 1.1.6.4., Group Ta.

2. Dimensions

a. Standard cross ties: seven inches deep, nine inches wide and eight feet, six inches long and eight feet, zero inches long.

S2.1.1 Heat-treated rails may be hot stamped with letters CT in the web ahead of the heat number.

S2.1.2 All heat-treated rails shall be paint-marked orange.

S3. Standard Length Variations

S3.1 Rails may be furnished in miscellaneous lengths between the 1 ft increments established in 10.2. Rails may be applied in the maximum length at which ends can be properly prepared.

S3.2 Under the arrangement of S3.1 the provisions of 10.3 shall be waived for other than the 39-ft lengths. Lengths 38 ft and under shall be considered as shorts and subject to the specified limitations.

[1]SPECIFICATIONS FOR FABRICATION OF CONTINUOUS WELDED RAIL

1967

(Adopted 1967)

Scope. The requirements recommended herein are intended for use only in the fabrication of continuous welded rail and are not intended for use in the acceptance or rejection of rails from the mills. New rail shall be in accordance with the latest issue of the AREA Specifications for Steel Rails, Part 2, this Chapter.

1. All rail delivered to the welding plant should be examined prior to welding. Rails having vertical or horizontal misalinement in the last 4 ft of the rail in excess of 0.030 in per ft tangential deviation measured with a straightedge should be rejected. (Figures 1, 2 and 3)
2. Alinement of rail *in the welding machine* should be done on the head of the rail.
   (a) Vertical alinement should provide for a flat running surface. Any difference of height of the rails should be in the base.
   (b) Horizontal alinement should be done in such a manner that any difference in the width of heads of rails should be divided equally on both sides of the head. Where the difference when divided exceeds 0.040 in and the gage side is predetermined, it may be desirable to aline this side of the head, allowing any difference in the width of heads to occur on the field side.
   (c) Horizontal offsets should not exceed 0.040 in. in the head and/or 0.125 in. in the base.
3. Surface Misalinement Tolerance (Figures 4 and 5):
   (a) Combined Vertical Offset and Crown Camber should not exceed 0.040 in/ft at 600 deg F or less.
   (b) Combined Vertical Offset and Dip Camber should not exceed 0.010 in/ft at 600 deg F or less.
4. Gage Misalinement Tolerance (Fig. 6):
   (a) Combined Horizontal Offset and Horizontal Kink Camber should not exceed 0.040 in/ft at 600 deg F or less.

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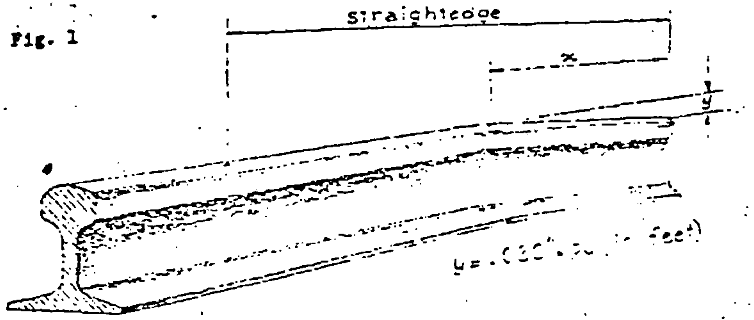
[1] References, Vol. 68, 1967, p. 368.

[1] *Latest page consist; 6.1 to 6.4, incl., (1967).*

5. A finishing deviation of not more than plus or minus 0.005 in of the parent section of the rail head surface should be allowed.
6. The sides of the rail head should be finished to plus or minus 0.010 in of the parent section. The bottom of rail base should be finished to within 0.010 in of the lowest rail.
7. The web zone (underside of head, web, top of base, both fillets each side), shall be finished to within ⅛ in of parent contour or closer but should not be deeper than parent section. Finishing should eliminate all cracks.
8. All notches created by offset conditions or twisted rails should be eliminated by grinding to blend the variations.
9. All fins on the weld due to grinding drag should be removed prior to final inspection.
10. All welds giving fault indication in magnetic particle inspection shall be cut out, repaired, or protected by joint bars.
11. All rails used for electric-flash butt welds should have the scale removed down to bright metal in those end zones, top and bottom of the rails, where the welding current-carrying electrodes contact on head and base of rail. The weld and adjacent rail for a distance clearing the electrodes should be rejected if in the areas of electrode contact there is not more than 95 percent of the mill scale removed.
12. All electric-flash butt welds should be forged to point of refusal to further plastic deformation and have a minimum upset of ½ in, with ⅝ in as standard.
13. If flashing on electric-flash butt welds is interrupted because of malfunction or external reason, with less than ½ in of flashing distance remaining before upsetting, rails should be reclamped in machine and flashing initiated again.
14. Whenever the finishing process involves heavy grinding which is done immediately following welding to prevent metallurgical damage, this heavy grinding should always be completed at the normally high temperature whenever a production line is interrupted for any reason.
15. Where jagged, notched or badly mismatched cuts are made by cutting torch on rails for electric-flash butt welding, the mismatched end faces should be pre-flashed to an even or mated condition before setting up rails for preheating and final flashing to assure that the entire surfaces of rail ends are uniformly flashing immediately preceding upsetting.
16. It is recommended that a straightening press be included in a welding production line to help achieve or improve upon the alinement tolerances of items 2, 3 and 4.

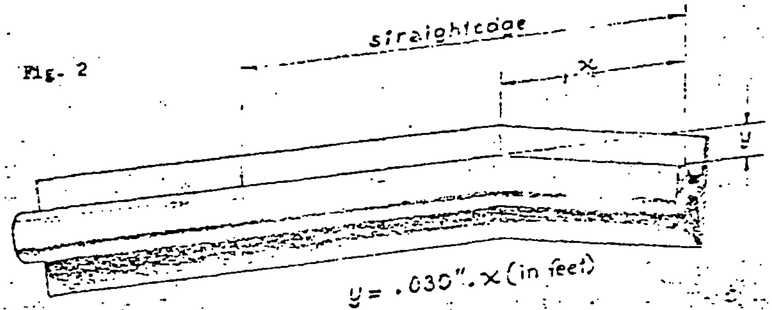
TOLERANCES FOR INSPECTION OF RAIL FOR WELDING—NEW AND MAIN LINE RELAYER RAIL

Fig. 1



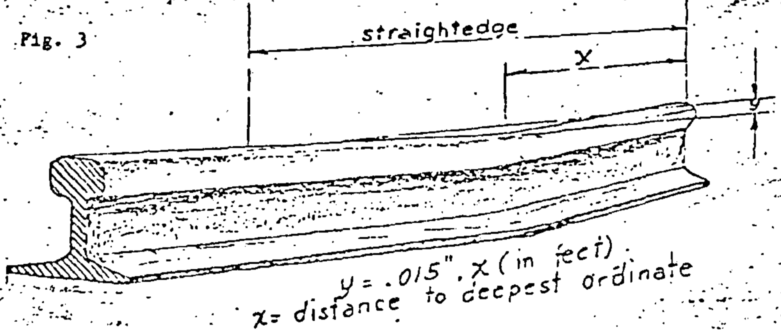
Elevation of rail showing tolerance of surface end bent condition.

Fig. 2



Plan view of rail showing tolerance of side bent condition.

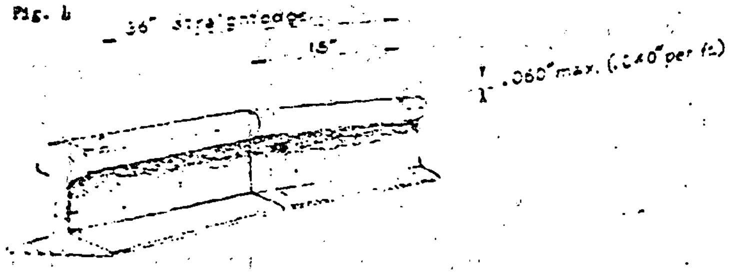
Fig. 3



Elevation of rail showing tolerance of surface end bent condition.

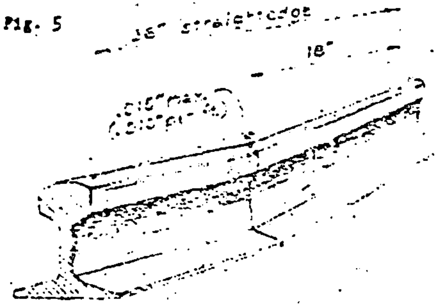
TOLERANCES FOR INSPECTION OF WELDED RAIL—NEW AND MAIN LINE RELAYER RAIL

Fig. 4



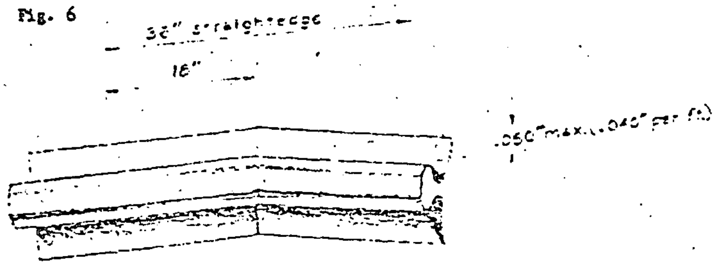
Elevation of rail showing weld misalinement tolerance in vertical alinement.

Fig. 5



Elevation of rail showing weld misalinement tolerance in vertical alinement.

Fig. 6



Plan view of rail showing weld misalinement tolerance in horizontal alinement.

NOTE: These tolerances apply at the inspection point where rail temperature at weld is approximately 600° F.

[1]INSPECTION AND CLASSIFICATION OF SECONDHAND RAIL FOR WELDING

1969

(Adopted 1969)

A field inspection should be made while the rail is in service, and all rails containing severe engine driver burns, anchor nicks, excessive wear on the rail base or other visible flaws should be rejected for welding. It is recommended that a rail flaw detector car inspect the rail immediately preceding the rail recovery, with no more than 60 days maximum intervening.

Some railroads may choose to pick up rail out-of-face, while others may choose to pick it up in two or more phases. It is recommended that the rail selected for welding be picked up in such a manner that the rail wear pattern in the CWR string will remain approximately the same as it was in original service. One method to keep the rails in an orderly manner with respect to their wear patterns is to mark the north or west rail 2-4-6 etc., and the opposite rail 1-3-5 etc.

Some railroads remove jointed rail in quarter mile sections, then upon arrival at the welding plant the joint bars are removed. Joint bars, bolts and washers may be salvaged as repair material or the rail may be cropped without removing the joint bars. In the latter case, the two short pieces of rail, bars, bolts and washers are scrapped as a unit. The rail is carefully inspected after cropping, and rail not suitable for welding is removed. However, some engine driver burns are oxyacetylene welded to upgrade the rail.

When the rail arrives at the welding site, a qualified rail inspector should carefully inspect the rail for head wear, corrosion, base wear, sweeps, kinks or any other defect that may have escaped detection in the previous inspection. Rail for each CWR string must be matched to have the same height and width of head within 1/16 in.

It is recommended that the rail be stored straight and level on a firm base and each tier stripped in four places.

The following restrictions are recommended:

1. Minimum rail length should be 27 ft after cropping
2. Excess oils, grease, tars, etc., must be removed from the rail before welding.
3. Non-control-cooled and control-cooled rail should be welded separately.
4. Maximum head flow should be ¼ in on each side of the rail if shears are used to remove the upset metal.
5. Grade crossing rails must be free of corrosion or rejected for welding except for yards or similar tracks.
6. Bolt holes and bond holes must be eliminated by cropping.
7. After cropping, both ends of the rail should be inspected for piped condition.

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[1] References, Vol. 70, 1969, p. 437.

RECOMMENDED RAIL GRADING CLASSIFICATIONS

Rail Weight	Maximum Rail Wear-Inches Top	Gage	General Rail Use & Rail Condition
Class I			
140	1/4	1/2	Main Line use - Very minor engine burns and corrugation.
132-131	3/16	1/2	
122	5/32	7/16	
115	1/8	3/8	
112	1/8	1/4	
100	1/8	1/8	
90	1/8	1/8	
Class II			
140	3/8	3/4	Branch Lines - Small engine burns and corrugation.
132-131	5/16	3/4	
122	5/16	3/4	
115	5/16	3/4	
112	5/16	1/2	
100	3/16	1/4	
90	1/4	3/16	
Class III			
140	5/8	7/8	
132-131	7/16	7/8	
122	1/2	7/8	Light Branch Lines - Medium engine burns and corrugation, may be pitted and show some oxidation.
115	3/8	3/4	
112	3/8	3/4	
100	1/4	1/4	
90	5/16	5/16	
Class IV			
140	3/4	1	Yards.
132-131	9/16	1	
122	11/16	1	Any burns not mashed or fractured.
115	1/2	7/8	
112	1/2	7/8	
100	7/16	7/8	
90	3/8	3/8	

[1]THERMITE WELDING—RAIL JOINTS

1971

(Adopted 1971)

GENERAL

The ASM Handbook and Webster define thermite, thermite reaction and thermite welding as follows:

THERMITE—A mixture of finely divided aluminum with an oxide of iron or other metal.

THERMITE REACTION—Strongly exothermic self-propagating reaction where finely divided aluminum reacts with a metal oxide. A proper mixture of aluminum and iron oxide produces sufficient heat to weld steel.

THERMITE WELDING—Welding with heat produced by the reaction of aluminum with a metal oxide. Filler metal is obtained from the reduction of the appropriate oxide.

When ignited, the reaction within the thermite mixture develops a temperature approaching 5000 F and produces a filler metal of about 3500 F which, when introduced into a gap between the rails, welds or fuses the ends together. The reaction metal is generally iron which has been enriched with alloys to produce a filler metal assimilating the characteristics of the rail steel being welded.

In all aluminothermic or thermite welding processes, the reaction takes place in a separate crucible or in a reaction chamber integral with the mold. When complete, the resultant metal is tapped, either manually as in the European processes, or is self-tapping as in the United States processes, into disposable prefabricated molds properly placed over the opening between the rail ends previously prepared for the butt welding.

Preheating, an important part of thermite welding, is applied differently by the various rail welding processes available today. Separate preheating equipment, operated independent of the reaction crucible, along with accessory clamps, etc., is common to the foreign developed systems, while United States processes employ shell molds, in one case provided with an exothermic binder in the mold to be consumed as the preheater, while in another case the preheat is supplied by an initial portion of the filler metal washing the rail end faces as it passes through the joint gap to a sump provided in the mold beneath the base of the rails to be welded.

Small hand tools, luting material, and cutting and grinding equipment are required with all processes.

WELDING

The basic requirements for thermite welds are:

1. Remove moisture and all foreign substances such as dirt, grease, loose oxide, slag, etc., from the weld area.

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[1] References, Vol. 72, 1971, p. 157.

[2] *Latest page consist: 6.7 to 6.9, incl., (1971).*

2. Align rail ends properly. Joint gap and lateral and vertical positioning of the ends are very important.
3. Apply mold in exact location over rail gap and properly seal.
4. Follow detailed instructions of the qualified thermite process without deviation.
5. It is assumed that flotation of impurities in the crucible and the mold, and proper gating and feeding, are provided for in the equipment and instructions supplied with the thermite package.

Following are minimum requirements for quality welds, good track alignment through the weld, and satisfactory riding characteristics over the welded joint:

1. The rail end faces should be square to the running surface of the rail. In order to obtain this condition, the rail should be properly aligned first if the gap is to be cut in track, or pre-cut square rail ends should be properly aligned and spaced.
2. The gap between the rail end faces should be between ⅝ inch and 1 inch, depending on the welding process and rail section involved.
3. The joint gap may be either flame, saw, or abrasive-disc cut. Flame cuts should be reasonably smooth. A precaution should be observed in the case of flame cutting in that the weld should be made within an hour in order to prevent deep thermal cracks from forming on the flame-cut rail end faces.
4. All burrs should be removed from the cut rail ends at the joint gap, all fins and head metal flow in relayer rail ground away, and loose oxides and foreign material removed from the weld area surfaces for at least 5 inches back from the ends of the rails. This permits close fitting of the molds and reduces contamination of the weld.
5. Sufficient preheat to promote good fusion is desirable. Preheating strictly to prescribed times is desirable. Preheating may be accomplished with a propane-oxygen flame, a generated gas flame, a higher temperature filler metal, or by the initial filler metal passing over the rail end faces into a sump.
6. The prefabricated molds used in any of the processes should be centered exactly with the center of the rail gap.
7. The luting or sealing of the molds to the rail should be performed with care so that the luting material is not introduced into the weld chamber. It has been found practical and economical to use car and locomotive sand mixed with western bentonite at a proportion of 4:1 with a minimum of moisture in the mixture. The sand specification is AAR M-916-51.
8. The crucible or reaction chamber should be dry and clean at all times.
9. In the case of the processes in which the filler material is tapped manually, it is desirable that the metal should not be tapped until the reaction is completed and the slag has separated from the filler metal.
10. After the molds have been removed, the excess weld metal should be chiseled off and ground to match the rail contour, at least on the top

and sides of the head. At no time is it permissible to use a cutting torch to perform the above operation.

11. The use of X-ray or ultrasonic equipment to evaluate the quality and soundness of the completed weld is recommended.

In order to cope with all possible conditions which may be encountered when welding joints in connection with rail laying operations, the use of a hydraulic jack is recommended. The jack is installed after the rail is aligned and before a gap is cut, if necessary. The jack will protect the weld against sudden atmospheric changes and hold the gap in rail which may have been heated to provide a median rail laying temperature. The jack tension rods should be protected against higher ambient temperatures caused by the preheating or crucible reaction.

[1]RECOMMENDED FIELD REPAIRS TO PRESSURE BUTT WELD FAILURES

1973

(Adopted 1973)

The following procedure is based on providing a proper rail temperature adjustment in accordance with local established requirements.

1. Repair by cutting in a short section of rail with the application of standard joint bars:

(a) Determine if a CWR temperature adjustment is necessary by consulting rail laying temperature records and other track condition data that may be available as a result of past track inspections or experiences.

(b) If necessary, proceed with the adjustment in accordance with standard practice.

(c) Promptly secure the CWR ends to prevent further movement. It is recommended that additional rail anchors be applied to the CWR ends for a sufficient distance to protect against rail-end movement in either direction.

(d) Saw cut the CWR, or flame cut if approved, on each side of the failed weld to obtain an opening for a short section of rail. It is recommended that the short rail be one-half the standard rail length to 36 ft long or at least 3 ft shorter than the standard length. If flame cut, the cut should be reasonably smooth. Smooth by polish grinding if necessary.

(e) Cut a rail to the desired length.

(f) Bevel all cut rail ends.

(g) Promptly place the short rail into the opening and spike it in place.

(h) Drill bolt holes of standard size. It is recommended that a templet be used to inscribe the bolt hole locations. Drilling through the joint bar holes is not recommended.

(i) Dress the edges of the bolt holes in accordance with standard practice.

(j) Install standard joint bars fully bolted.

(k) Adjust the rail anchor pattern to conform with standard practice.

(l) If in track circuit territory, install any necessary bond or connection wires.

(m) In a stretch of new rail, if the rail surface has not been sufficiently work hardened, it is recommended that all cut rail ends be end hardened at this time.

2. Repair by cutting in a short section of rail and thermite welding the rail ends:

(a) Proceed as outlined in paragraphs (a) through (e) above, except it is recommended that the short rail be at least 10 ft long or longer, preferably one-half the standard rail length.

(b) Promptly place the short rail into the opening, spiking it in place.

(c) Line up the rail ends to match, and block or wedge rail ends on each side of the joint sufficiently to maintain a good match for thermite welding.

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[1] References, Vol. 74, 1973, p. 148.

[1] *Latest page consist: 6.10 and 6.11 (1973).*

(d) Proceed with thermite welding in accordance with standard practice. (See Thermite Welding—Rail Joints, Chapter 4 of the Manual, covering minimum requirements for making quality welds, good track alignment through the weld and satisfactory riding characteristics for thermite welded joints.)

(e) In cutting the opening for the short rail, the rail ends (joints) should fall in the center of a tie crib and/or ties moved as necessary for the free unobstructed application of the thermite weld mold.

(f) Adjust the rail anchor pattern to conform with standard practice.

(g) If in track circuit territory, install any necessary connection wires.

(h) If a CWR adjustment has been made or is not necessary but conditions do not permit thermite welding at the time, then drill the rail ends for the temporary use of standard joint bars with the exception of the first bolt holes of the rail ends. Omitting these holes will permit thermite welding later without further rail change. Adjust the rail anchor pattern to conform with standard practice for buffer rail. Follow with thermite welding as promptly as conditions permit.

If a CWR adjustment is necessary but conditions do not permit it at the time, it is recommended that thermite welding be postponed. Cut in a short plug rail of approved length. Drill all rail ends for the application of fully bolted standard joint bars. Adjust the rail anchor pattern to conform with standard practice for buffer rail. Follow with CWR adjustment and thermite welding as promptly as conditions permit.

General

(a) Before proceeding with repairs, thoroughly inspect the CWR and track condition for a sufficient distance to determine general track and rail condition, rail anchor performance, ballast condition, track alignment, rail tension or compression, etc. Any condition found warranting correction should be corrected at that time or the necessary safeguards taken to provide for the safe movement of trains until it is corrected.

BRITISH STEEL CORPORATION

MATERIAL CERTIFICATION

c.c. V.F. White
T.K. Dyer
T. Connolly
Field

TF.

British Steel Corporation Inc.
Dresser Tower
601 Jefferson
Houston, Texas 77002

Telephone: 713-659-1000
Domestic Telex—775 298

30 April 1981

Mr. Ed Tumulty
Manager, Capital Procurement
Massachusetts Bay Transportation Authority
Materials Department
80 Broadway
Everett, MA 02149

RE: Formal Contract No. 180-UMTA
Project No. MA-03-0057
BSC Order No. 73874 CF

Gentlemen,

We would draw your attention to the above mentioned contract.

The mill advise that the vessel, "The Melton Challenger" sailed on Friday, the 24th of April. They also advise that the vessel will call at Five Islands, Nova Scotia, Canada, before sailing for Boston. The vessel is due into Five Islands on the 5th of May which would indicate that arrival in Boston will probably be either the 8th or 9th of May. We will, of course, keep you fully informed on the vessel's progress.

Please find enclosed a copy of the test certificates covering the entire shipment. We trust that this meets with your approval, however, should there be any questions please do not hesitate to contact us.

Yours sincerely,

BRITISH STEEL CORPORATION INC.

Alan Briggs

Alan Briggs
Product Manager, Rail & Track Products

AB/lam
Enclosures

cc: Mr. T. J. Murray

RECEIVED
-5 1981
TRACK IMPROVEMENT PROGRAM

s Bay, Workington, Cumbria, CA14 5AE
ephone 0900 - 4321 Telex 64147

TEST CERTIFICATE

E FOR BSC INC (MBTA) ON 115 RE FB RAILS 1% CHROMIUM QUALITY O/NO. 73874 CF
CONTROLLED COOLING APPLIED

DATE 22 April 1981

ANALYSIS								FALLING WEIGHT TEST			TENSILE TEST					REMARK
								Wt. Tonnes		Bearer						
C.	Si.	S.	P.	Mn.	Cr		BHN	1st m Def in mm.	2nd m Def. in mm.	3rd m Def. in mm.	Test Piece	Yield N/mm²	Max. Stress N/mm²	Elong %	Red. of Area %	
.68	.50	.040	.030	.90	.95		311									45K
.78	max.	max.	max.	1.20	1.25		388									62K
.735	.35	.030	.025	1.20	1.16		331									52K
.710	.32	.024	.030	1.20	1.04		331									
.735	.32	.032	.013	1.10	1.05		331									
.755	.26	.027	.028	1.07	1.14		341									59K
.725	.30	.031	.016	1.03	1.06		331									
.755	.33	.030	.016	1.09	1.05		331									
.735	.25	.030	.010	.98	1.01		321									51K
.710	.33	.030	.024	.96	1.06		331									
.755	.29	.025	.021	1.12	1.25		331									
.715	.26	.026	.021	1.03	1.09		321									
.720	.33	.025	.024	1.11	1.11		321									
.725	.31	.030	.023	1.10	1.10		331									
.725	.29	.026	.023	1.10	1.15		321									
.740	.37	.034	.023	.99	1.09		341									

ALL RAILS ULTRASONICALLY TESTED

REPRESENTING 1278.662 TONNES

lied by F Jackson (Chief Chemist)   Tested on behalf of the above by   In the presence of

QUESTIONNAIRE

RAIL PULL APART INVESTIGATION

1. Have you experienced a recent increase in the rate of pull apart failures?

2. If yes, what has been the rate increase and describe any predominant factor associated with the failures?

3. If no, what rate is considered typical, and is there a predominant characteristic, and what is it?

4. What type of rail material/supplier do you use?

5. What sizes and specifications do you use to procure the rail?

6. What shop weld and/or field weld processes and suppliers do you use?

7. What specifications, requirements, or quality control procedures for incoming materials so you use?

8. Do you use the same processes for welding high chrome to high chrome, high chrome to controlled cooled and controlled cooled to controlled cooled? If no, what are the differences?

9. What cable attachment method and suppliers do you use?

10. Is the location of cable with respect to the rail controlled? If yes, where on the rail is it attached.

11. What process controls or procedures do you use for field welding?

12. What crew certification or training reqirements do you use?

13. What weld factors do you consider critical?

14. What inspection requirements do you use?

15. Do you use any periodic inspection procedure? If yes, what do yo use and how often?

NOTE: Please use additional space for replies as necessary for a complete answer.

LIST OF TRANSIT PROPERTIES AND RAILROADS CONTACTED DURING THE RAIL PULL APART INVESTIGATION

1. Chicago Transit Authority
   Mr. T. L. Wolgemuth
   Manager, Facilities Engineering and Maintenance
   Engineering Department
   P. O. Box 3555
   Chicago, IL 60654

2. Greater Cleveland Regional Transit Authority
   Mr. C. S. Cross
   Superintendent of Rail Operations
   615 Superior Avenue, NW
   Cleveland, OH 44113

3. New York City Transit Authority
   Mr. C. Kalkhof
   Vice President and General Manager, Rapid Transit
   370 Jay Street
   Brooklyn, NY 11201

4. Port Authority of Allegheny County
   Mr. E. A. Totin, Jr.
   Facilities Engineer
   Maintenance Department
   Beaver and Island Avenues
   Pittsburgh, PA 15233

5. Southeast Pennsylvania Transportation Authority
   Mr. C. L. Stanford
   Chief Engineer - CTD
   200 Wyoming Avenue
   Philadelphia, PA 19140

6. Boston and Maine Corporation
   Mr. V. R. Terrill
   Vice President, Engineering
   No. Billerica, MA 01862

7. Canadian Pacific, Ltd.
   Mr. J. Fox
   Chief Engineer
   P. O. Box 6042, Sta. A
   Montreal, PQ H3C 3E4 Canada

8. Quebec North Shore and Labrador Railway Company
   Mr. T. McElroy
   Superintendent, Maintenance of Way
   P. O. Box 1000
   Sept. Iles PQ GAR 4L5 Canada

9. San Manuel Arizona R. R. Company
Mr. M. R. Elliot
Superintendent
P. O. Box M
San Manuel, AZ 85631

APPENDIX B

TEST DATA OBTAINED DURING LABORATORY PHASE OF THE INVESTIGATION

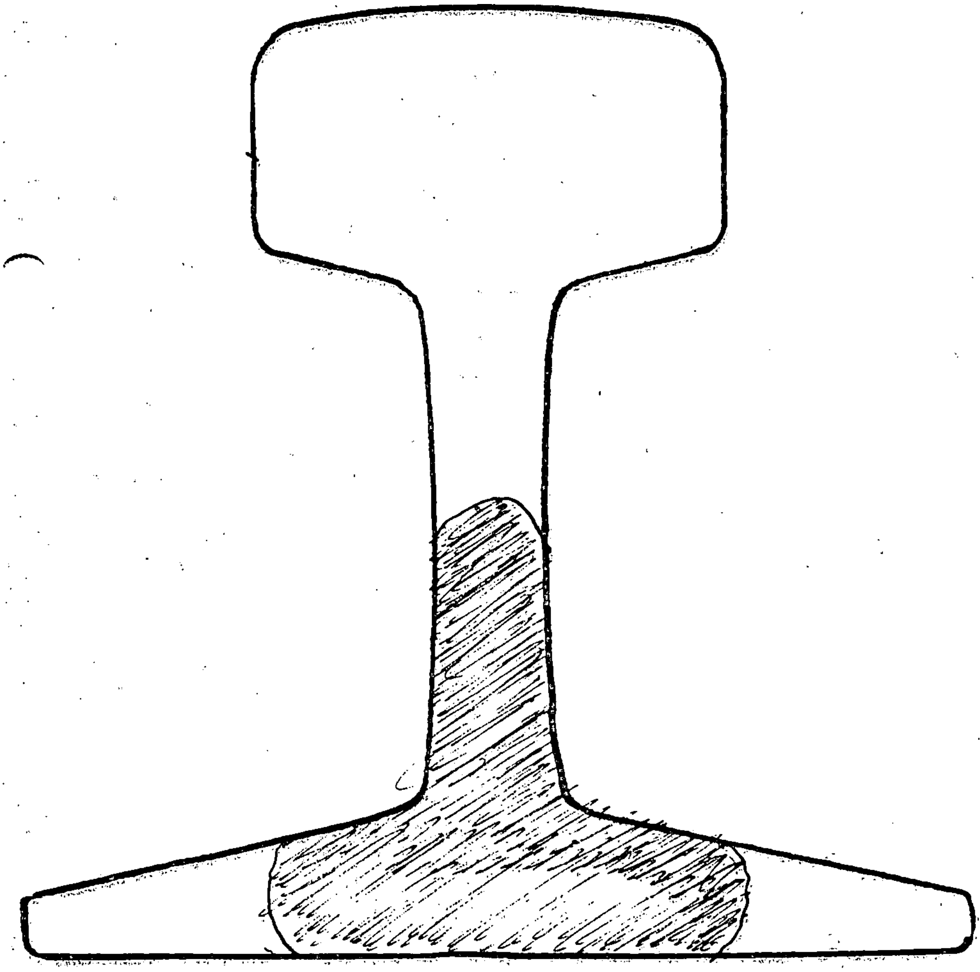
PAGE NO.

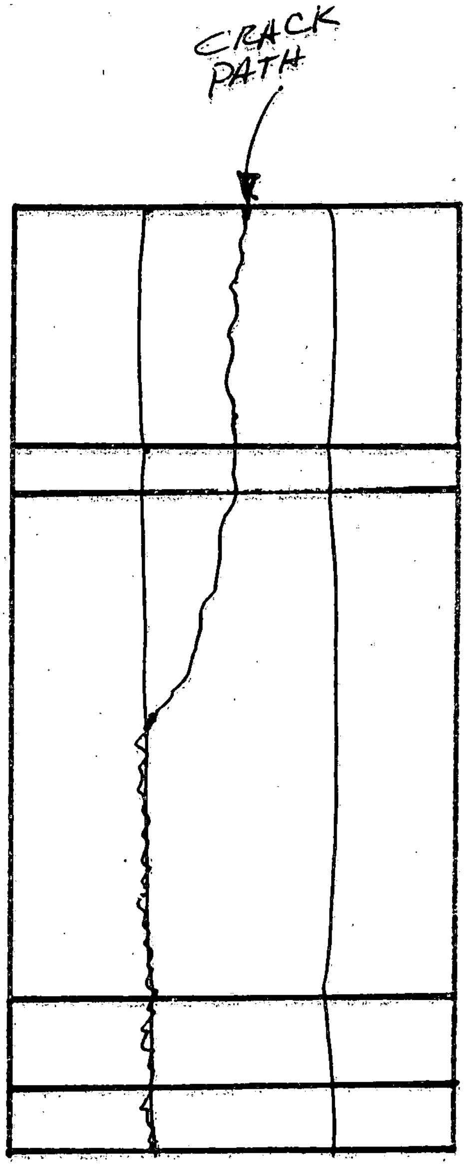
RESULTS OF VISUAL EXAMINATION OF FAILED RAIL SAMPLES

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #1 A,B
RAIL TYPE 115#

FRACTURE APPEARANCE





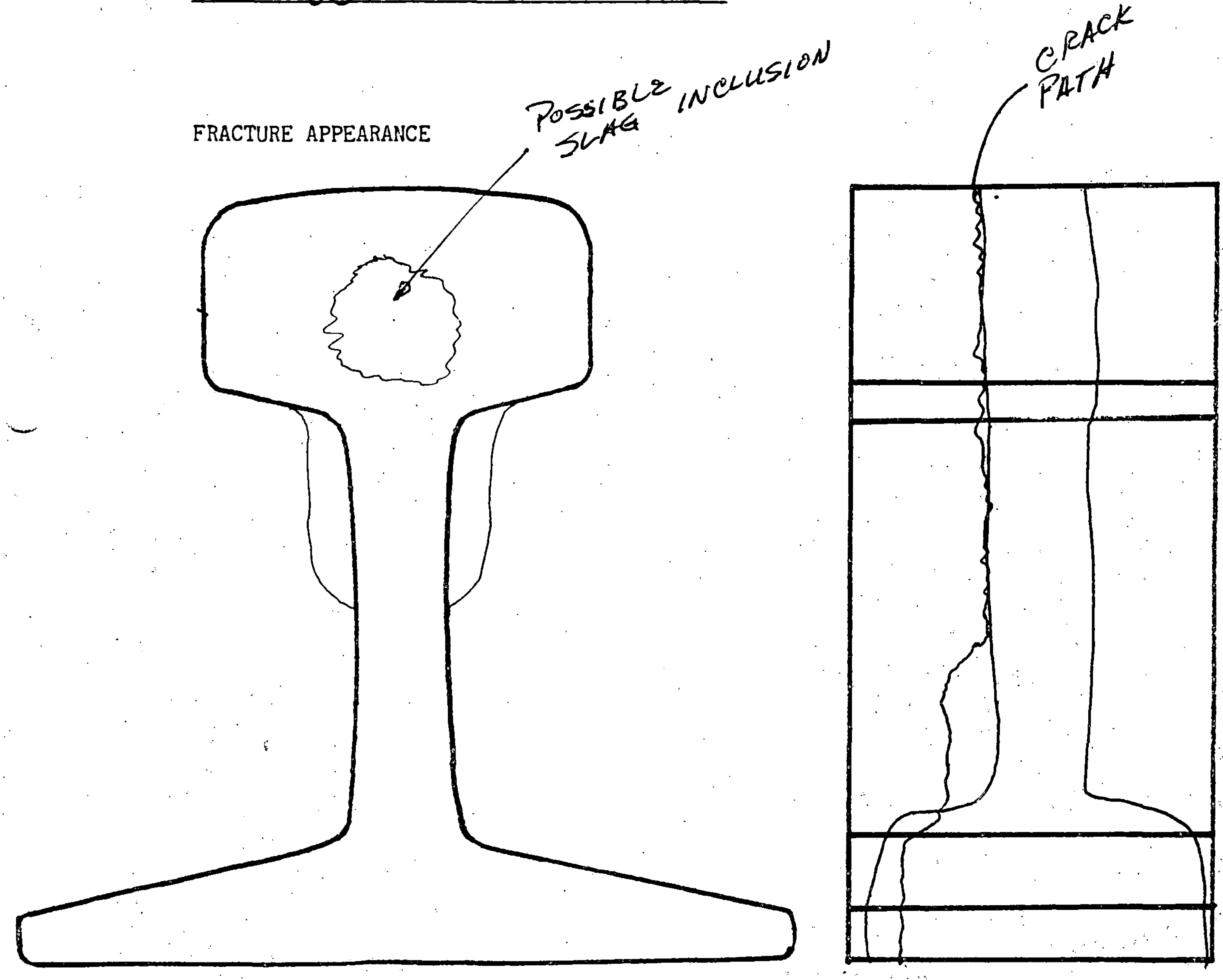
FAILURE LOCATION WELD
TYPE OF WELD CALORITE GAP USED
% UNFUSED METAL 30%
PROBABLE CAUSE OF FAILURE LACK OF FUSION AT BOTTOM OF WEB.
COMMENTS:

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #2 A,B

RAIL TYPE 85#

FRACTURE APPEARANCE



FAILURE LOCATION WELD (HAZ)

TYPE OF WELD UNKNOWN GAP USED

% UNFUSED METAL 10%

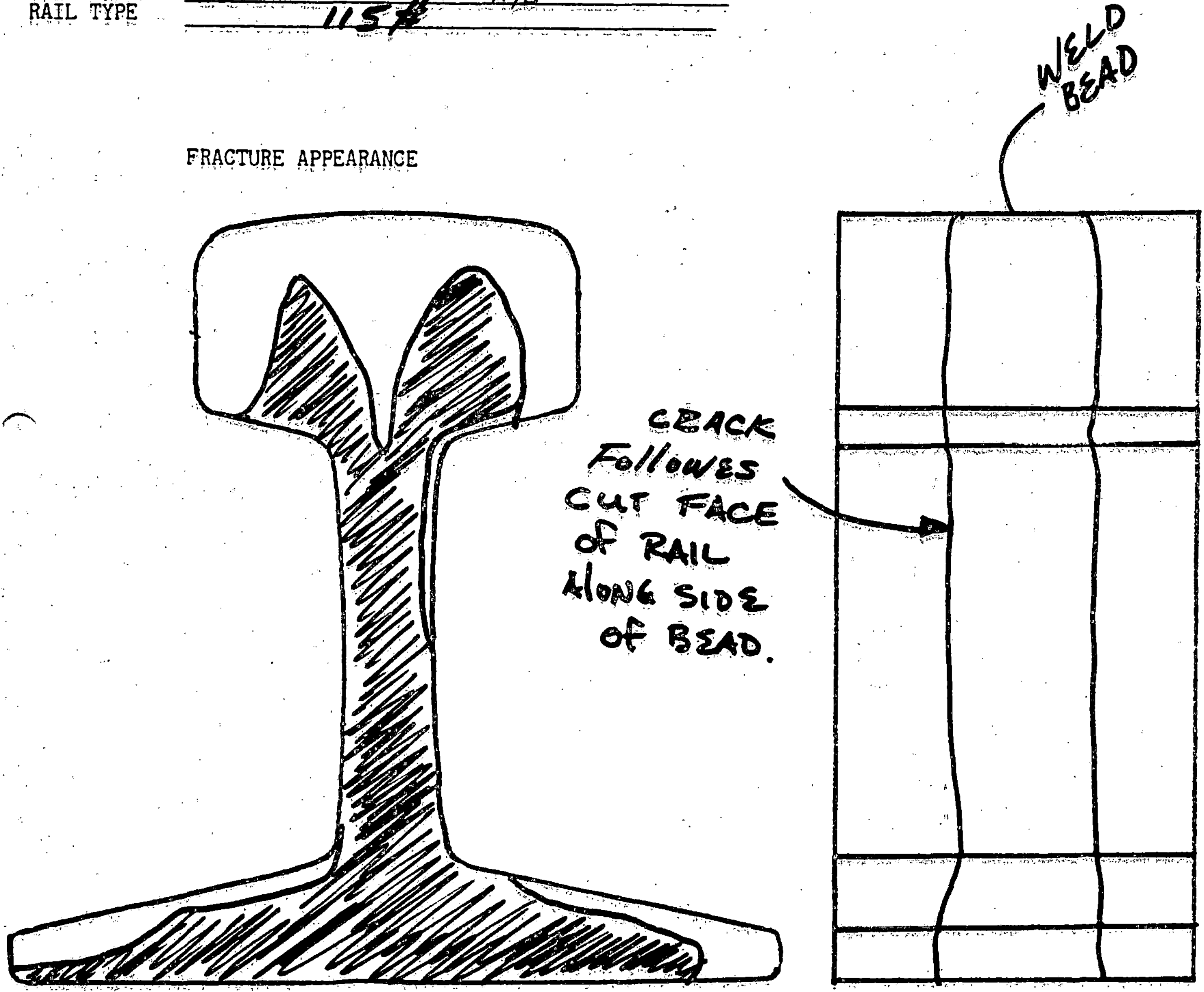
PROBABLE CAUSE OF FAILURE SLAG INCLUSION / BRITTLE HEAT AFFECTED ZONE,

COMMENTS:

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. 3A A,B
RAIL TYPE 115#

FRACTURE APPEARANCE

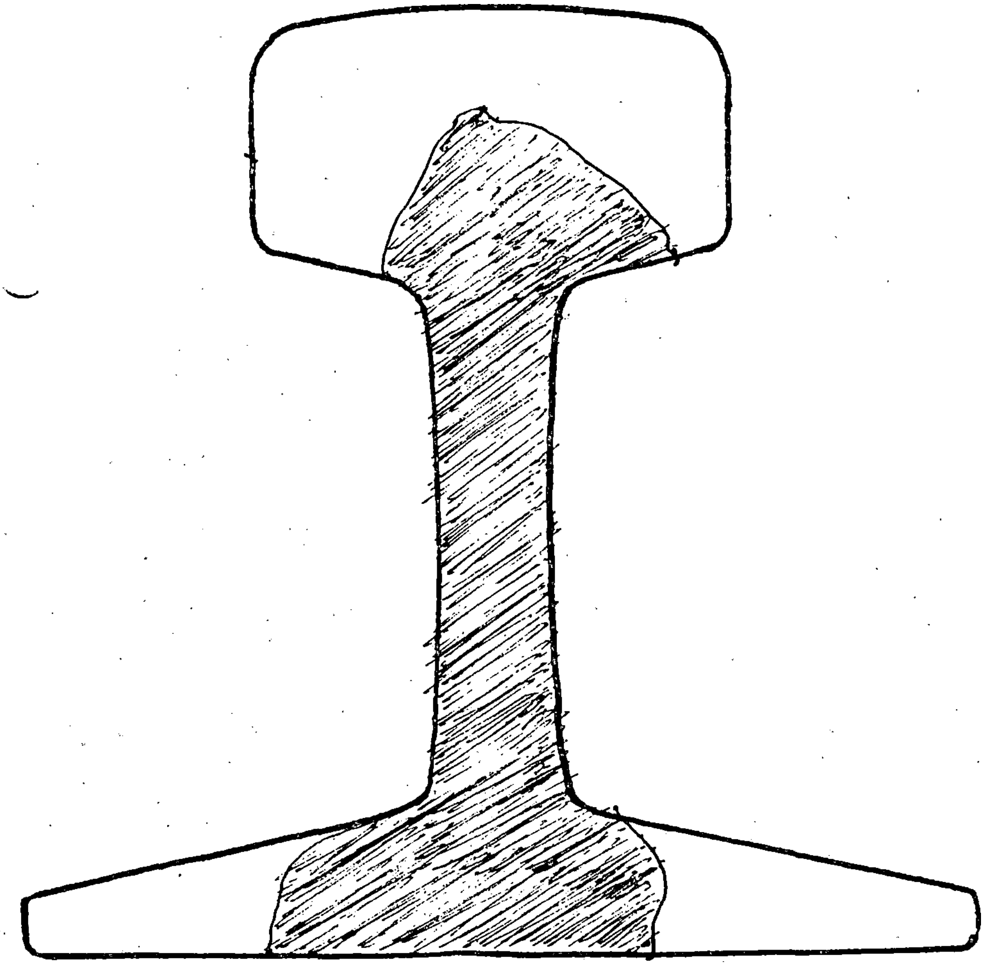


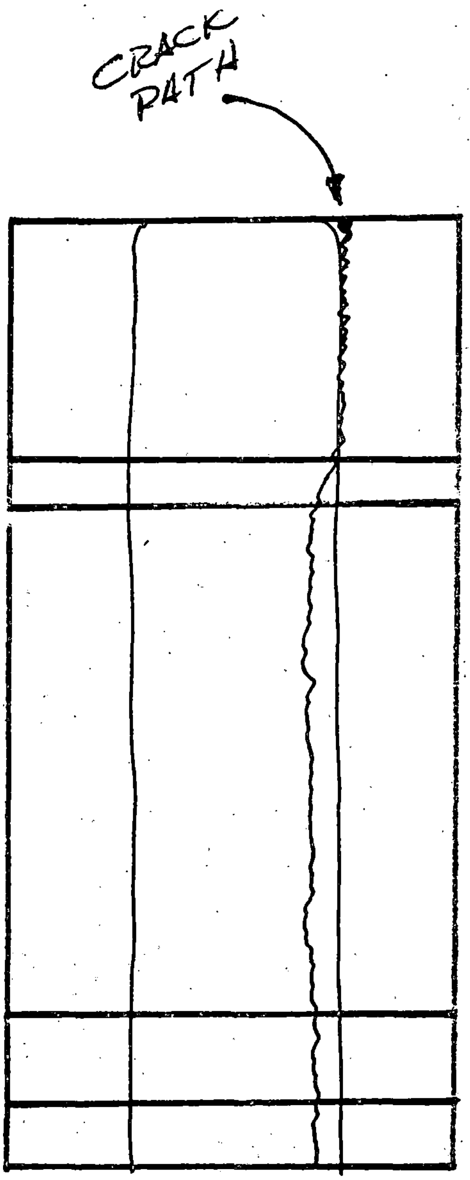
AILURE LOCATION WELD
TYPE OF WELD CALORITE GAP USED ~ .45"
% UNFUSED METAL 80 - 90 %
PROBABLE CAUSE OF FAILURE LACK OF FUSION DUE TO INADEQUATE PRE HEAT.
COMMENTS:

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #4 A,B
RAIL TYPE 115#

FRACTURE APPEARANCE



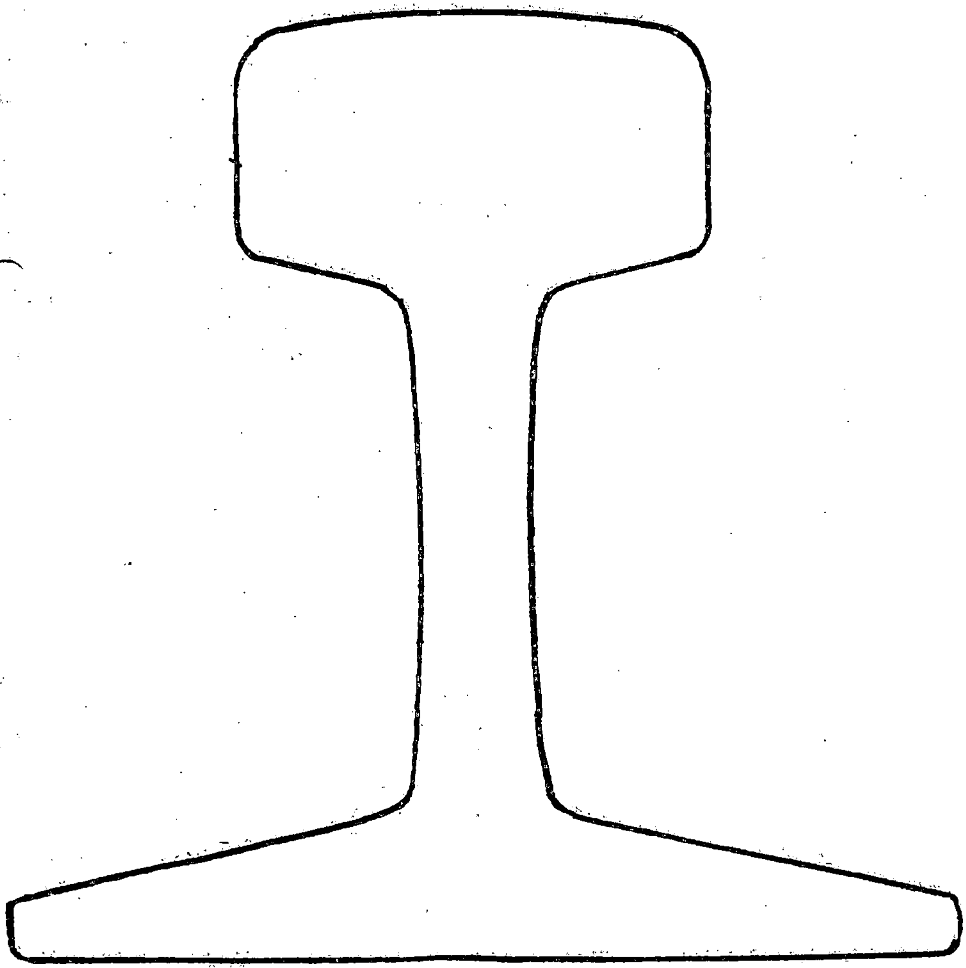


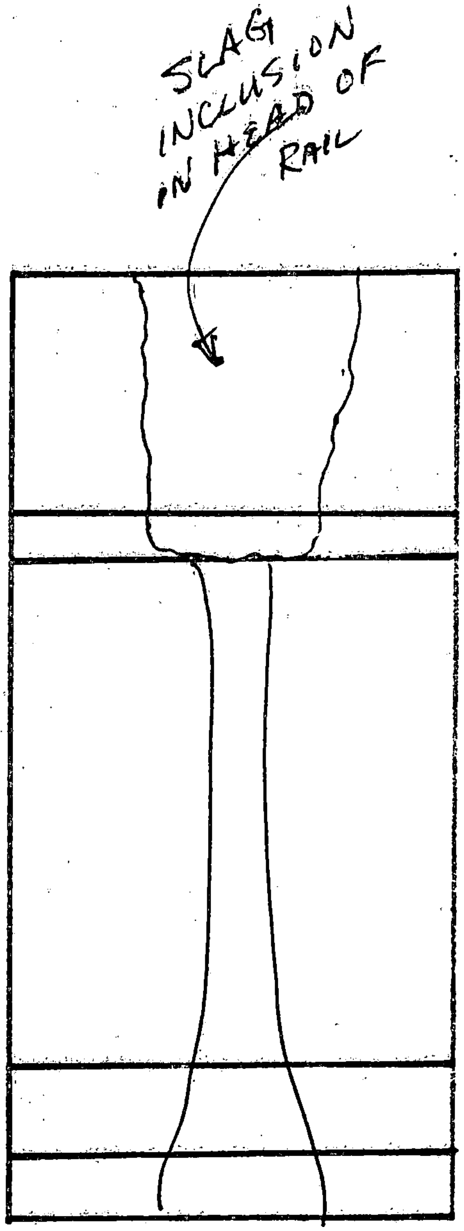
FAILURE LOCATION WELD
TYPE OF WELD CALORITE
GAP USED
% UNFUSED METAL 75-80%
PROBABLE CAUSE OF FAILURE LACK OF FUSION
COMMENTS: Top of RAIL INDICATES POSSIBLE BRITTLE HAZ.

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #5 A,B
RAIL TYPE 115#

FRACTURE APPEARANCE
NOT BROKEN



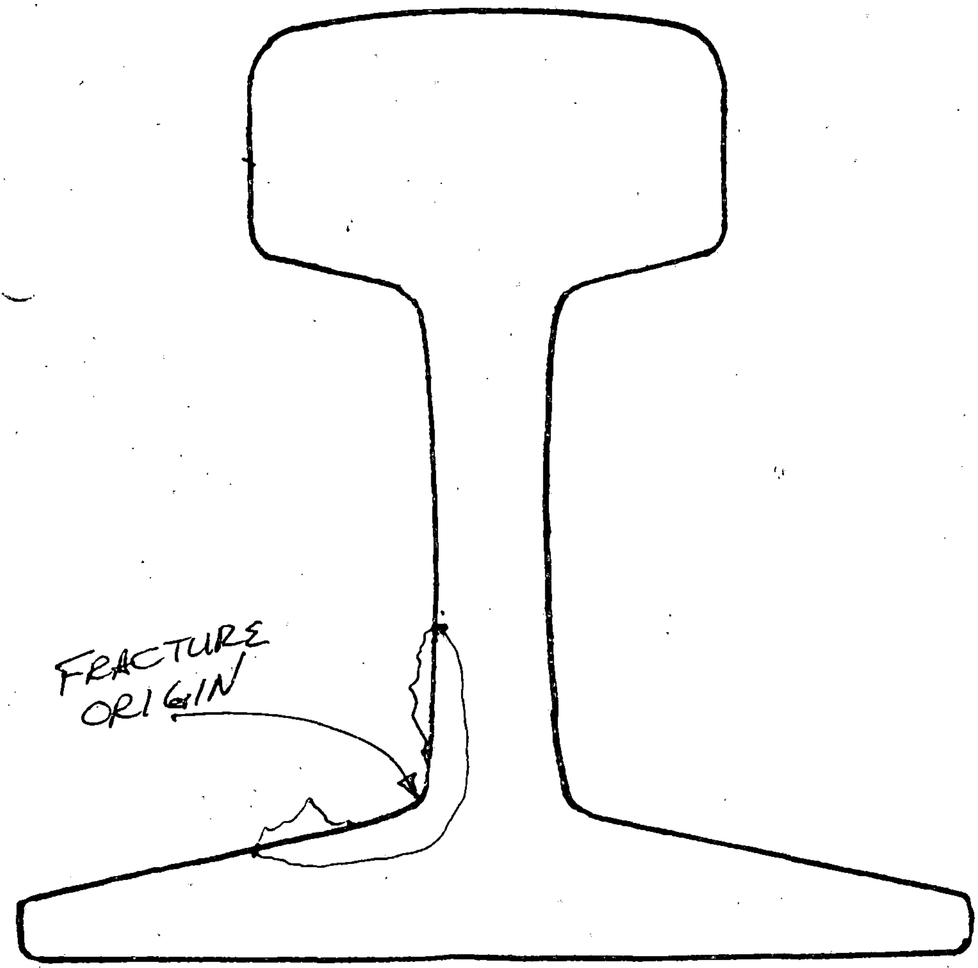


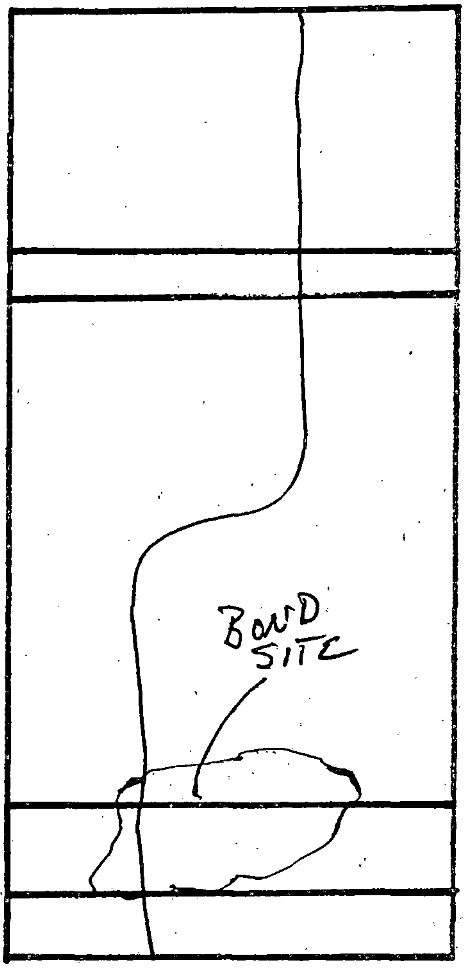
FAILURE LOCATION WELD
TYPE OF WELD US THERMIT GAP USED
% UNFUSED METAL 30%
PROBABLE CAUSE OF FAILURE WELD METAL RUN OUT
COMMENTS: POSSIBLE IMPROPER SEALING OF MOLD AT BOTTOM,

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #6 A,B
RAIL TYPE 115#

FRACTURE APPEARANCE



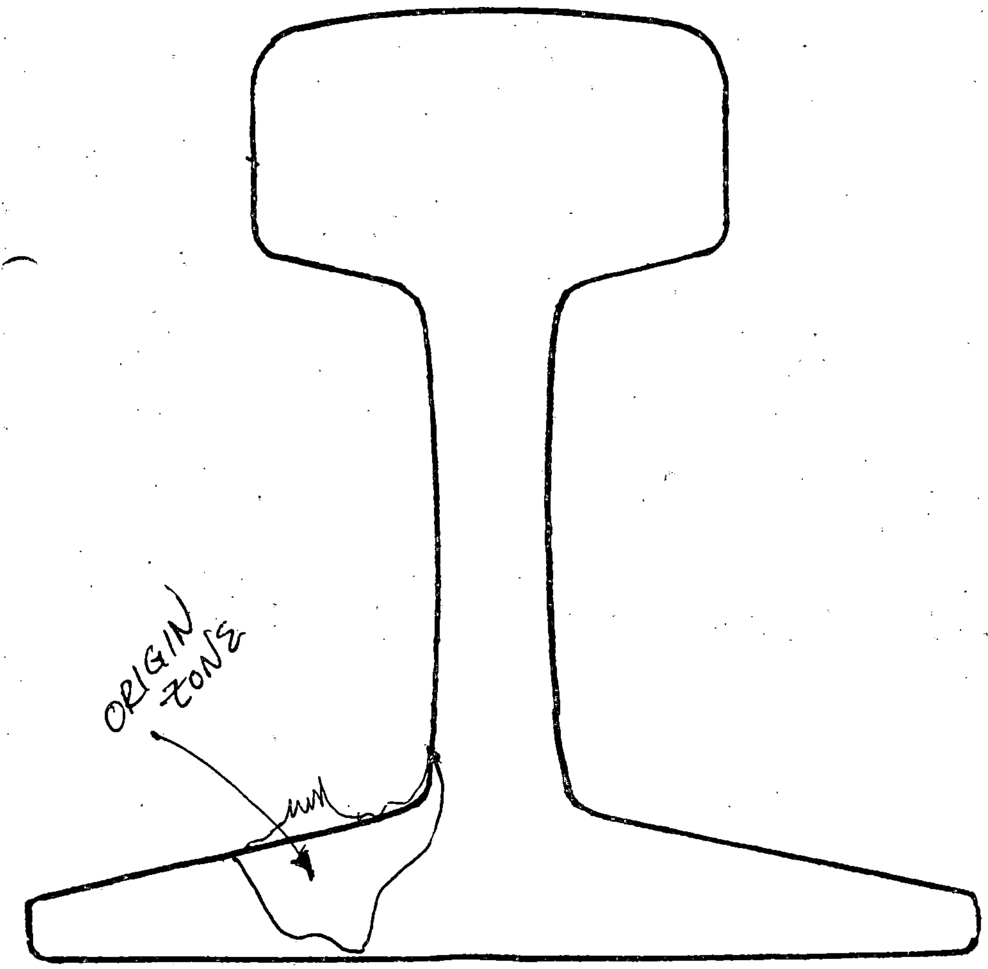


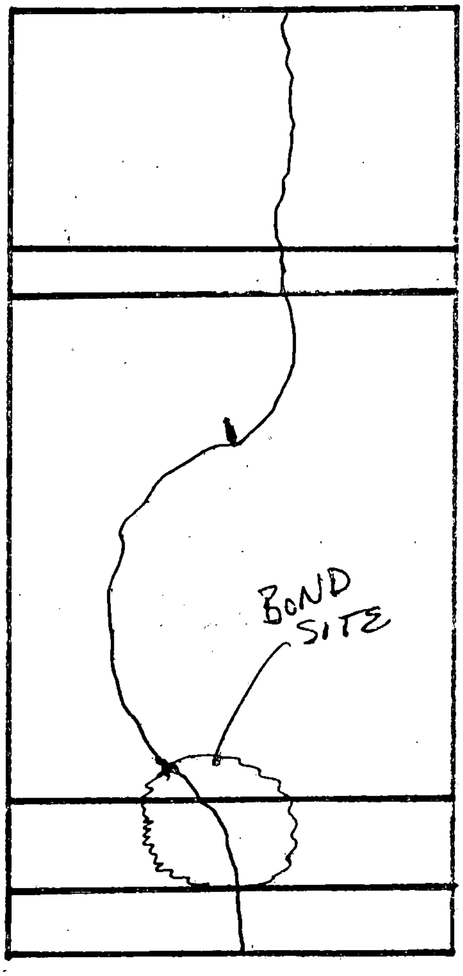
FAILURE LOCATION Bus Bar Bond
TYPE OF WELD
GAP USED
% UNFUSED METAL
PROBABLE CAUSE OF FAILURE OVERHEATING OF BOND
COMMENTS: [redacted]

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. # 7 A,B
RAIL TYPE

FRACTURE APPEARANCE





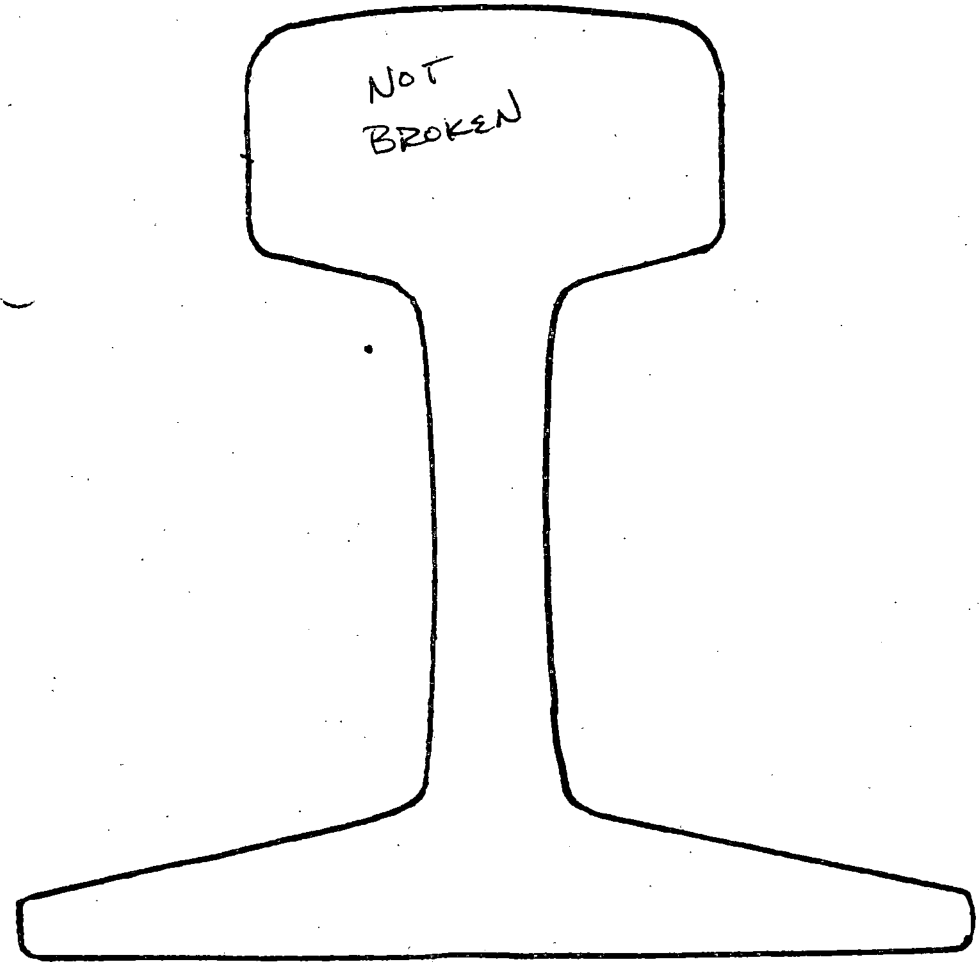
FAILURE LOCATION Bus Bar Bond
TYPE OF WELD GAP USED
% UNFUSED METAL
PROBABLE CAUSE OF FAILURE OVER HEATING OF BOND -
COMMENTS: [redacted]

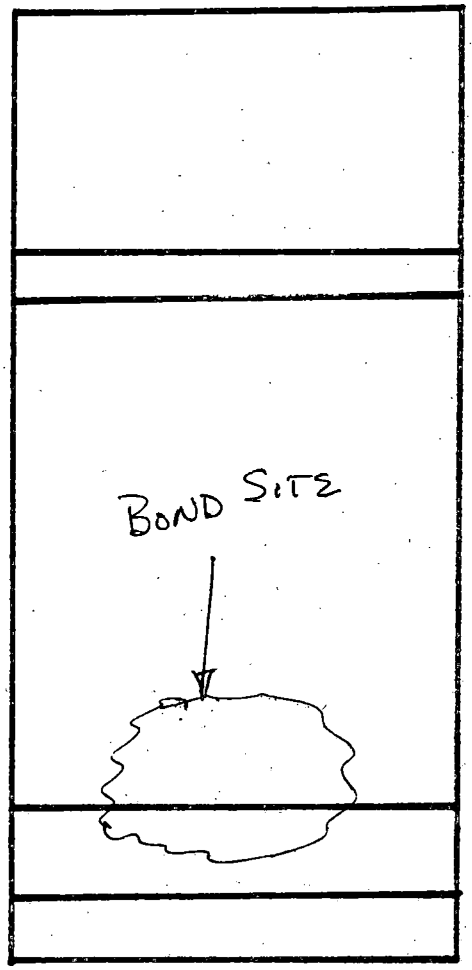
MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #8 A,B

RAIL TYPE 115#

FRACTURE APPEARANCE





FAILURE LOCATION Bus Bar Bond

TYPE OF WELD

GAP USED

% UNFUSED METAL

PROBABLE CAUSE OF FAILURE

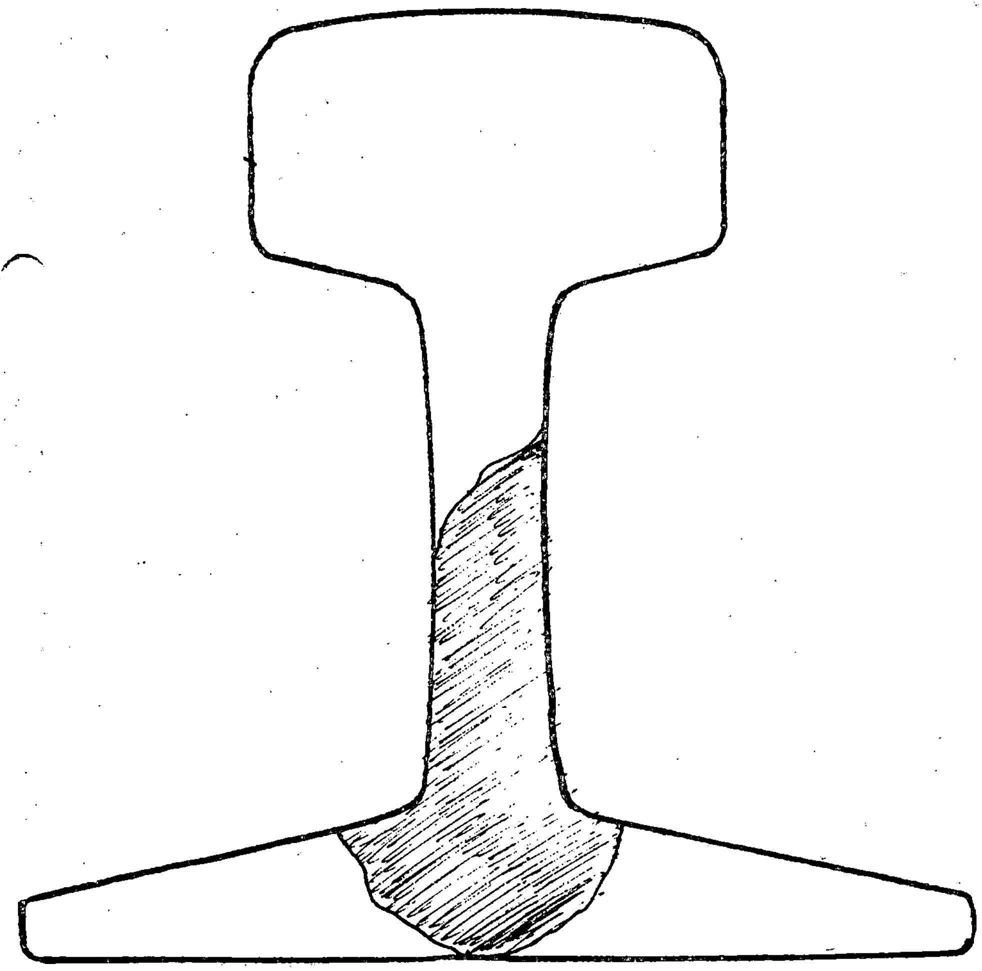
COMMENTS: POOR BOND OF BUS BAR TO RAIL / RAIL DID NOT BREAK - BUS PULLED OFF.

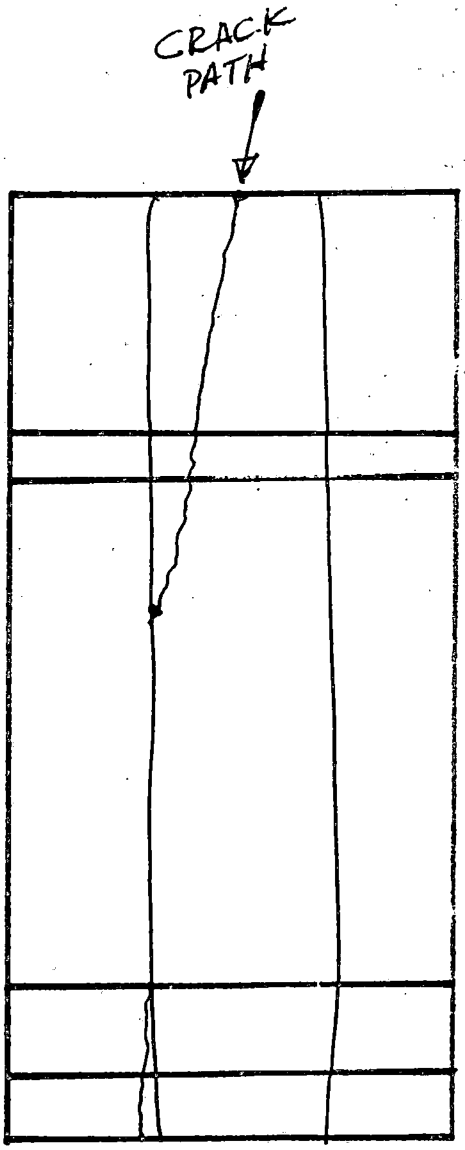
MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #9

RAIL TYPE 115#

FRACTURE APPEARANCE





FAILURE LOCATION WELD

TYPE OF WELD CALORITE GAP USED

% UNFUSED METAL 30 %

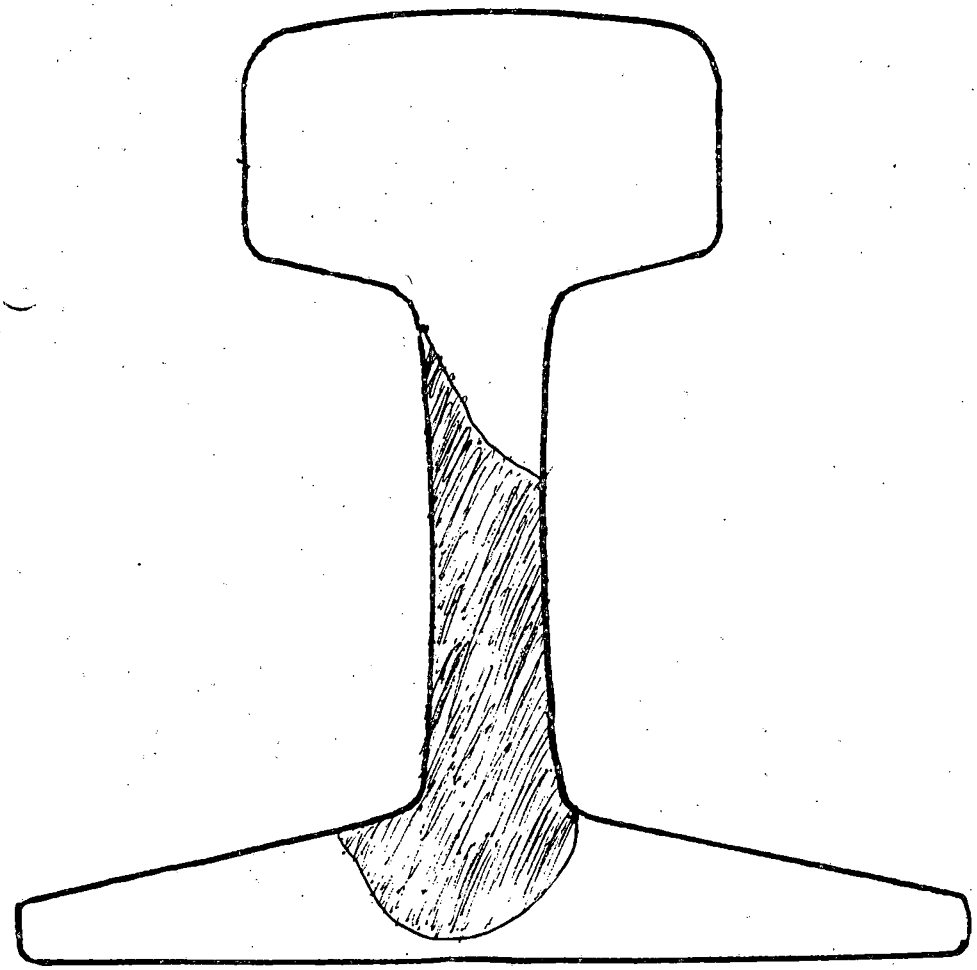
PROBABLE CAUSE OF FAILURE LACK OF FUSION IN WEB

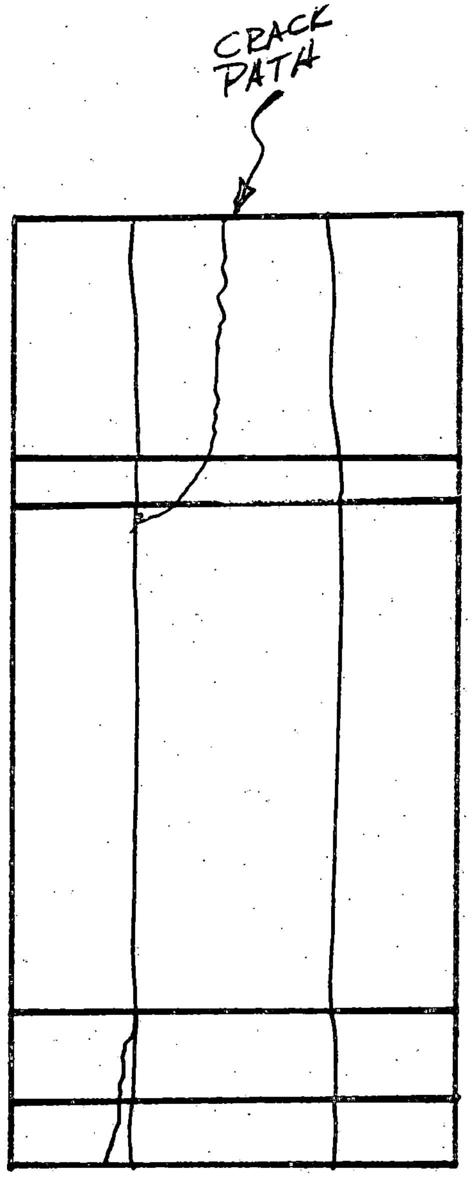
COMMENTS:

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. #10
RAIL TYPE 115#

FRACTURE APPEARANCE



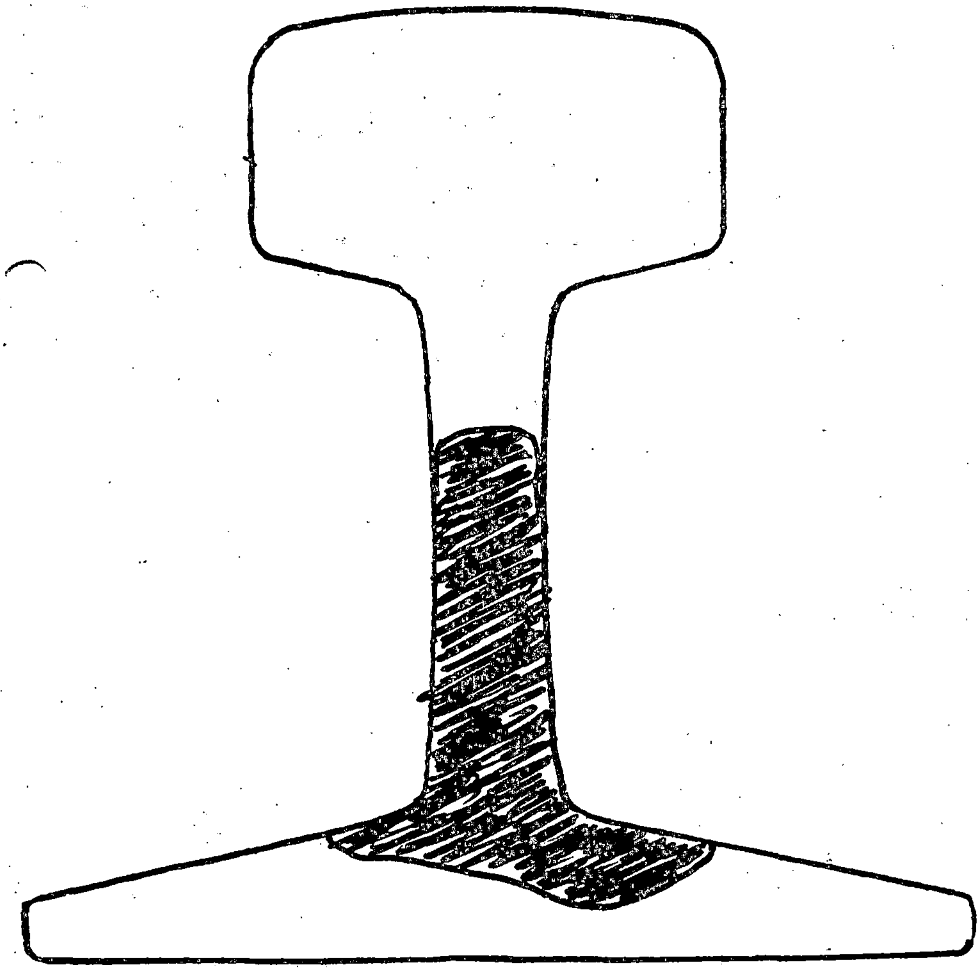


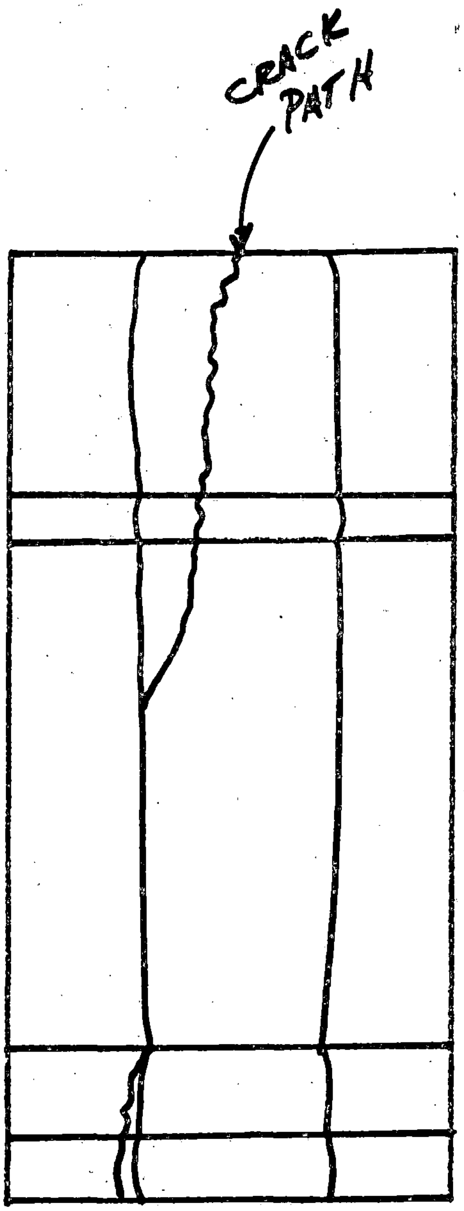
FAILURE LOCATION WELD
TYPE OF WELD CALORITE
GAP USED
% UNFUSED METAL 40 %
PROBABLE CAUSE OF FAILURE LACK OF FUSION IN CENTRAL ~~B~~ WEB.
COMMENTS: POSSIBLE TORCH MISALIGNMENT DURING PRE HEAT.

MBTA RAIL FAILURE INVESTIGATION

SPECIMEN NO. # 11 A
RAIL TYPE 115 #

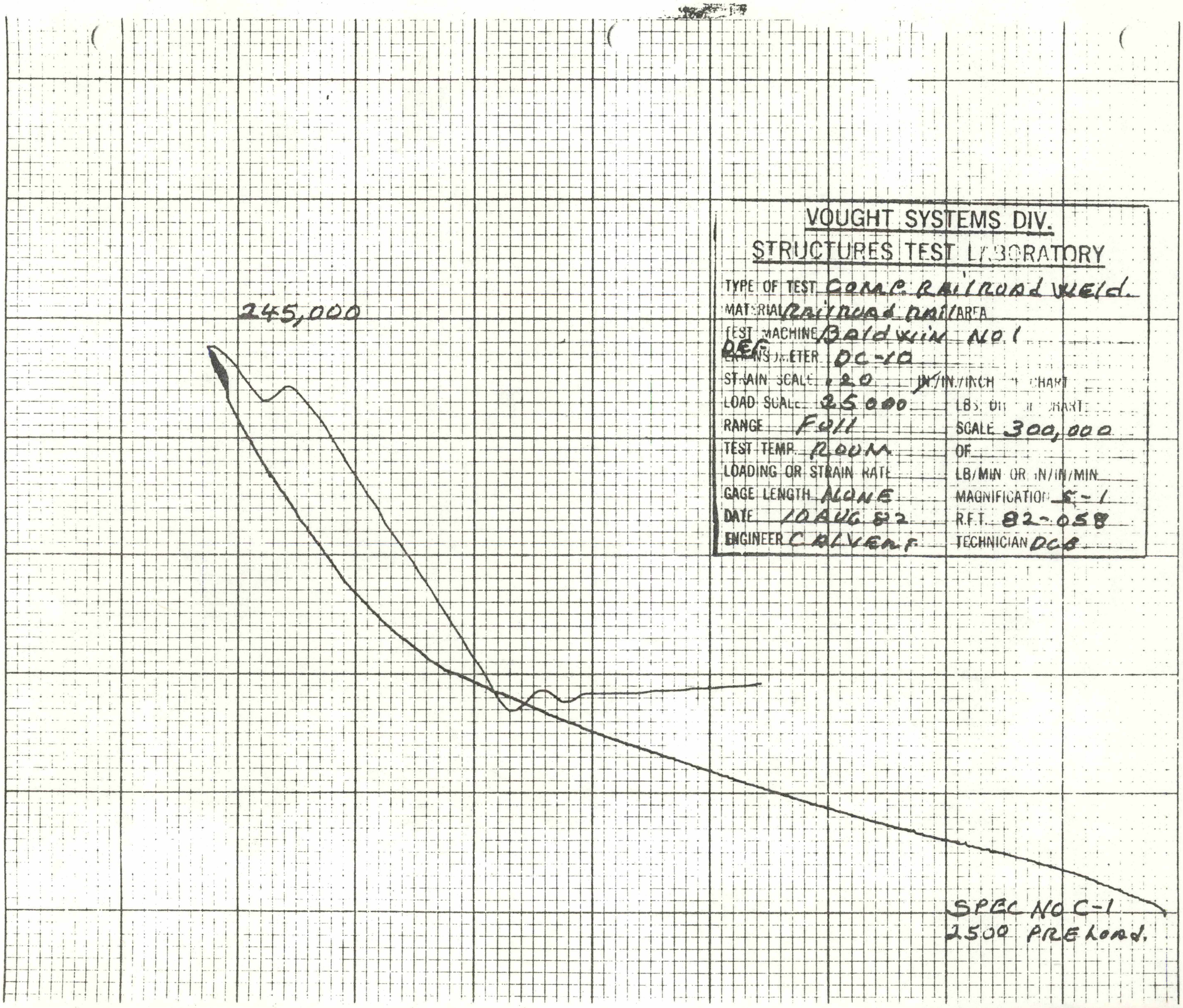
FRACTURE APPEARANCE





FAILURE LOCATION WELD
TYPE OF WELD CALORITE GAP USED
% UNFUSED METAL 30 %
PROBABLE CAUSE OF FAILURE LACK OF FUSION NEAR BOTTOM OF WEB.
COMMENTS: POSSIBLE MISALIGNMENT OF TORCH FOR PRE HEAT.

LOAD-DEFLECTION CURVES
SLOW BEND TESTS



VOUGHT SYSTEMS DIV.

STRUCTURES TEST LABORATORY

TYPE OF TEST COMP. RAILROAD WELD.

MATERIAL RAILROAD RAIL AREA

TEST MACHINE BALDWIN NO. 1

DEF ~~EXT~~ENSOMETER DC-10

STRAIN SCALE .20 ~~IN~~/IN./INCH OF CHART

LOAD SCALE 25000 LBS. DIV. OF CHART

RANGE Full SCALE 300,000

TEST TEMP. ROOM OF

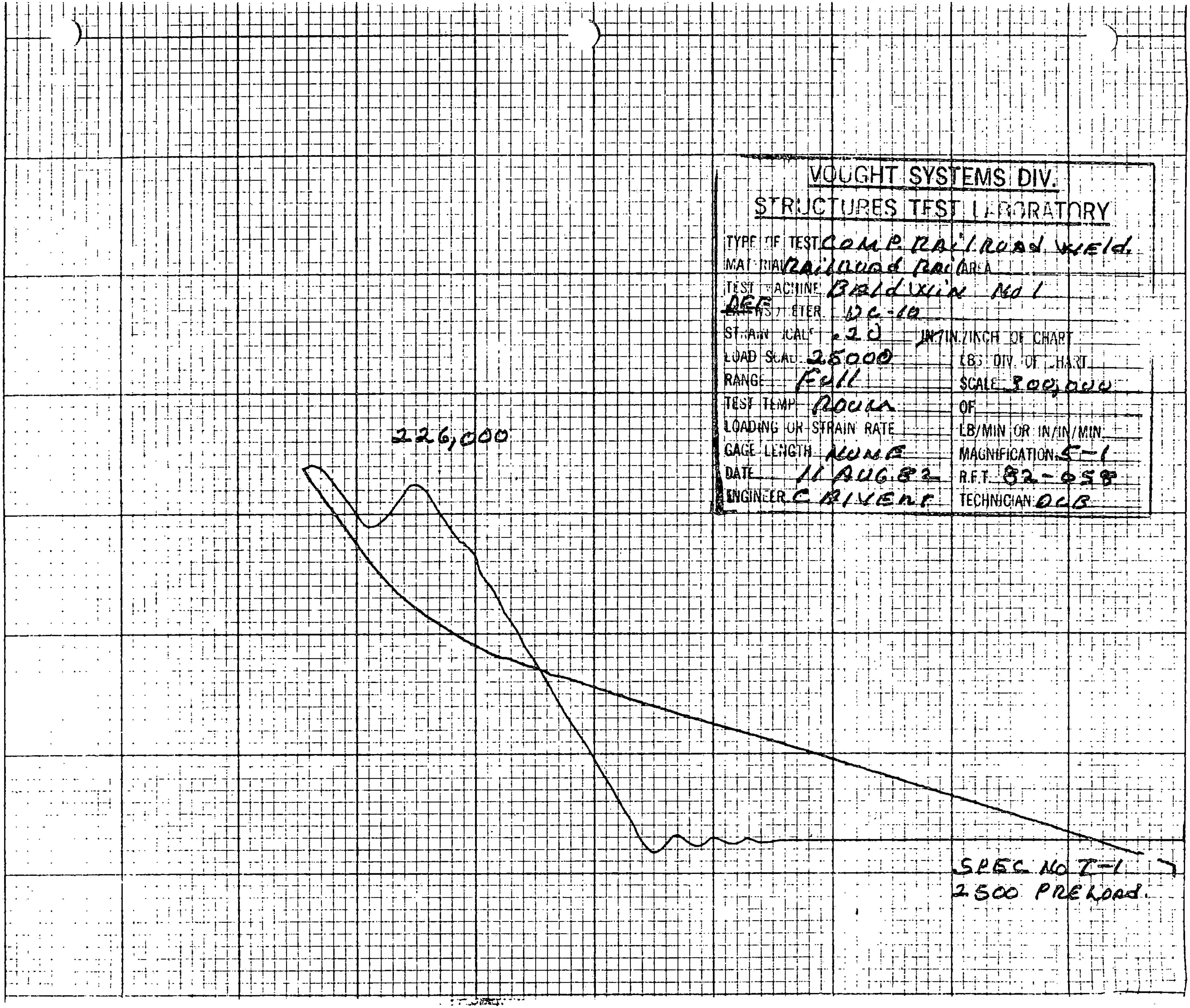
LOADING OR STRAIN RATE LB/MIN OR IN/IN/MIN.

GAGE LENGTH NONE MAGNIFICATION 5-1

DATE 10 AUG 82 R.F.T. 82-058

ENGINEER CALVERT TECHNICIAN DCB

CHART NO. 1010 SATEC Systems, Inc., Grove City, Pa. 16127 Printed in U.S.A.



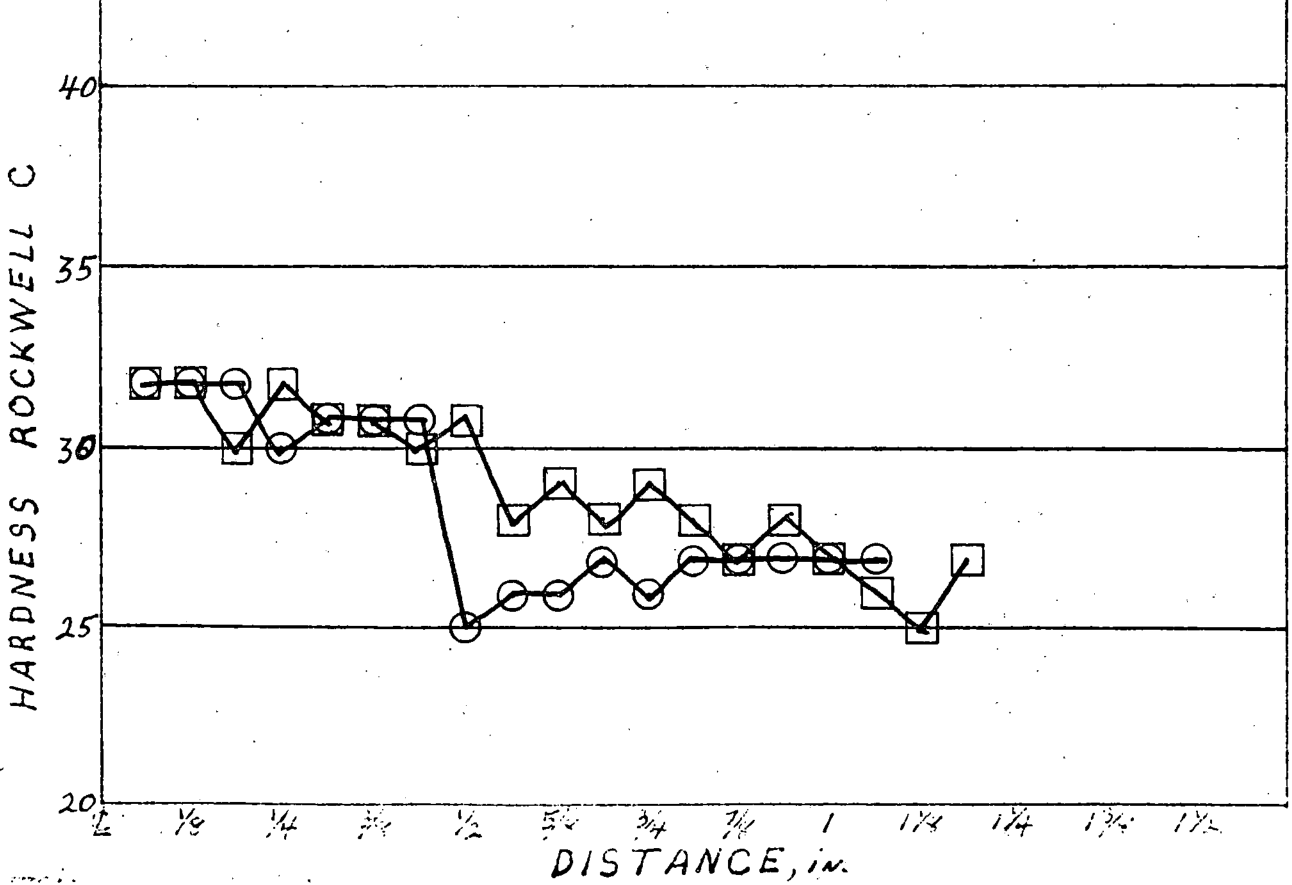
SPEC NO T-1
2500 PRELOAD.

VOUGHT SYSTEMS DIV.
STRUCTURES TEST LABORATORY

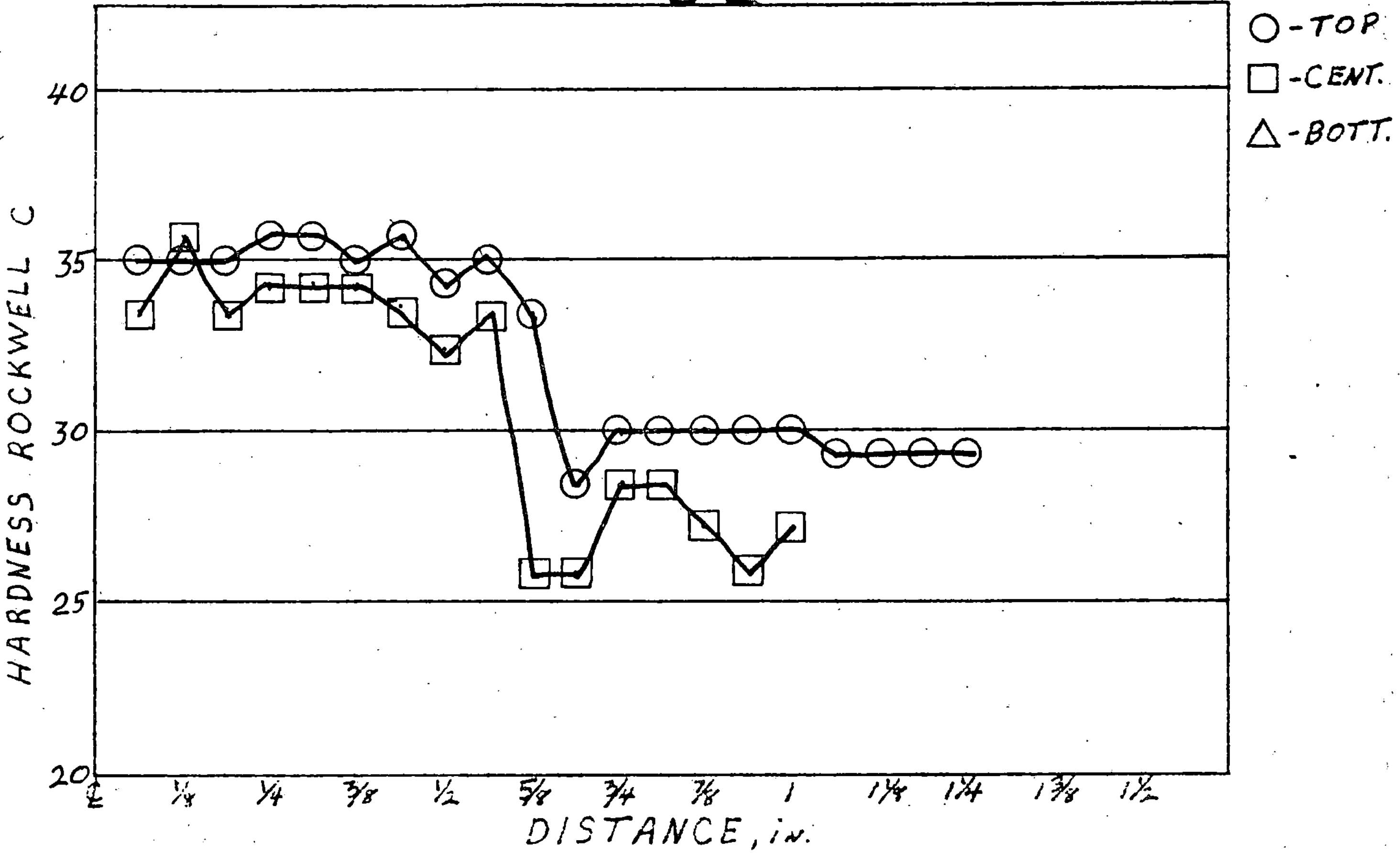
TYPE OF TEST COMP. RAILROAD WELD.
MATERIAL Railroad Rail AREA
TEST MACHINE Baldwin No 1
DEF~~EXT~~ENSOMETER DC-10
STRAIN SCALE .20 ~~IN~~/IN./INCH OF CHART
LOAD SCALE 25000 LBS DIV. OF CHART
RANGE Full SCALE 300,000
TEST TEMP Room OF
LOADING OR STRAIN RATE LB/MIN OR IN/IN/MIN
GAGE LENGTH None MAGNIFICATION 5-1
DATE 11 AUG 82 R.F.T. 82-058
ENGINEER C RIVENE TECHNICIAN OCB

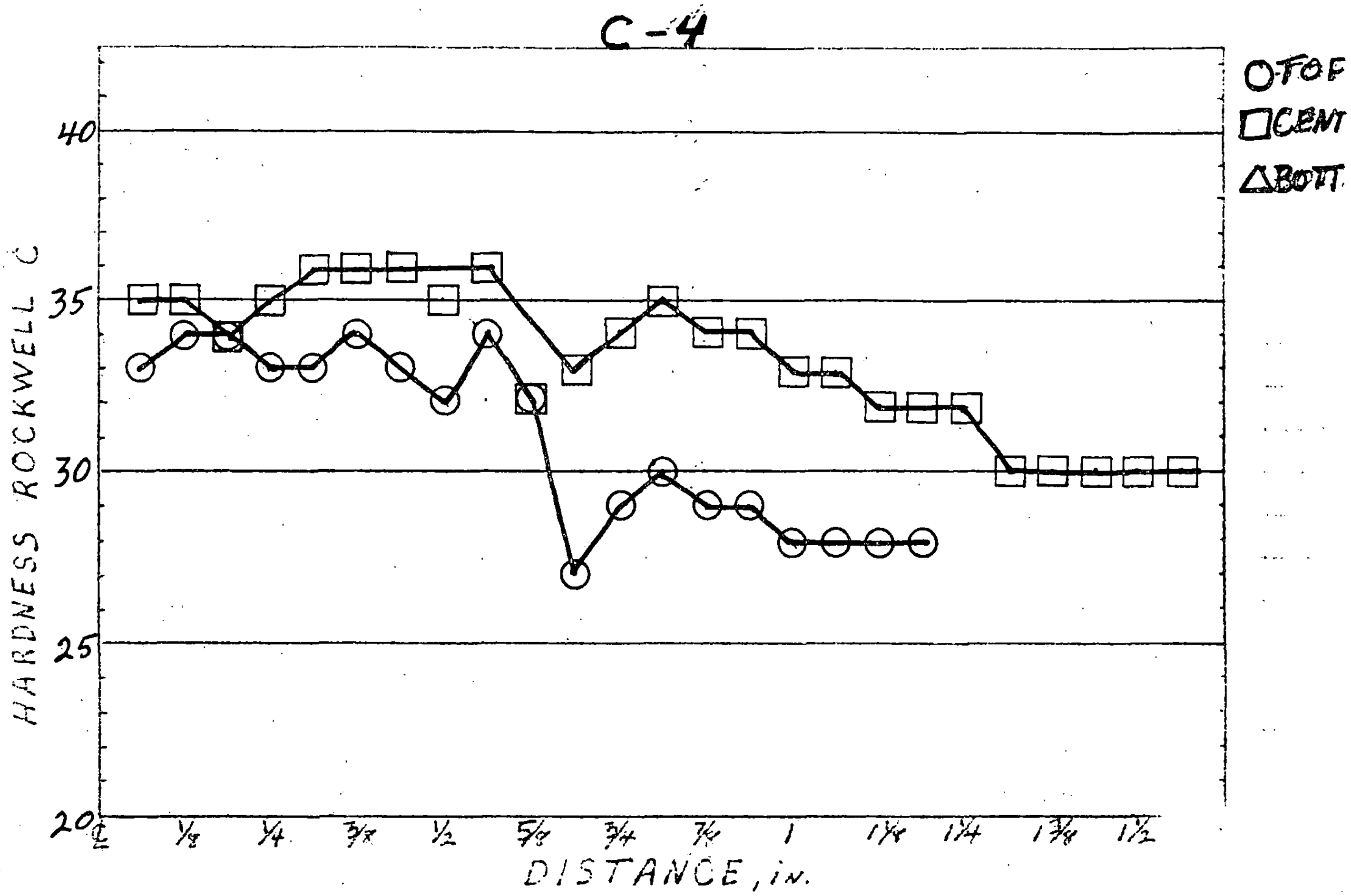
HARDNESS DATA FROM TEST WELDS

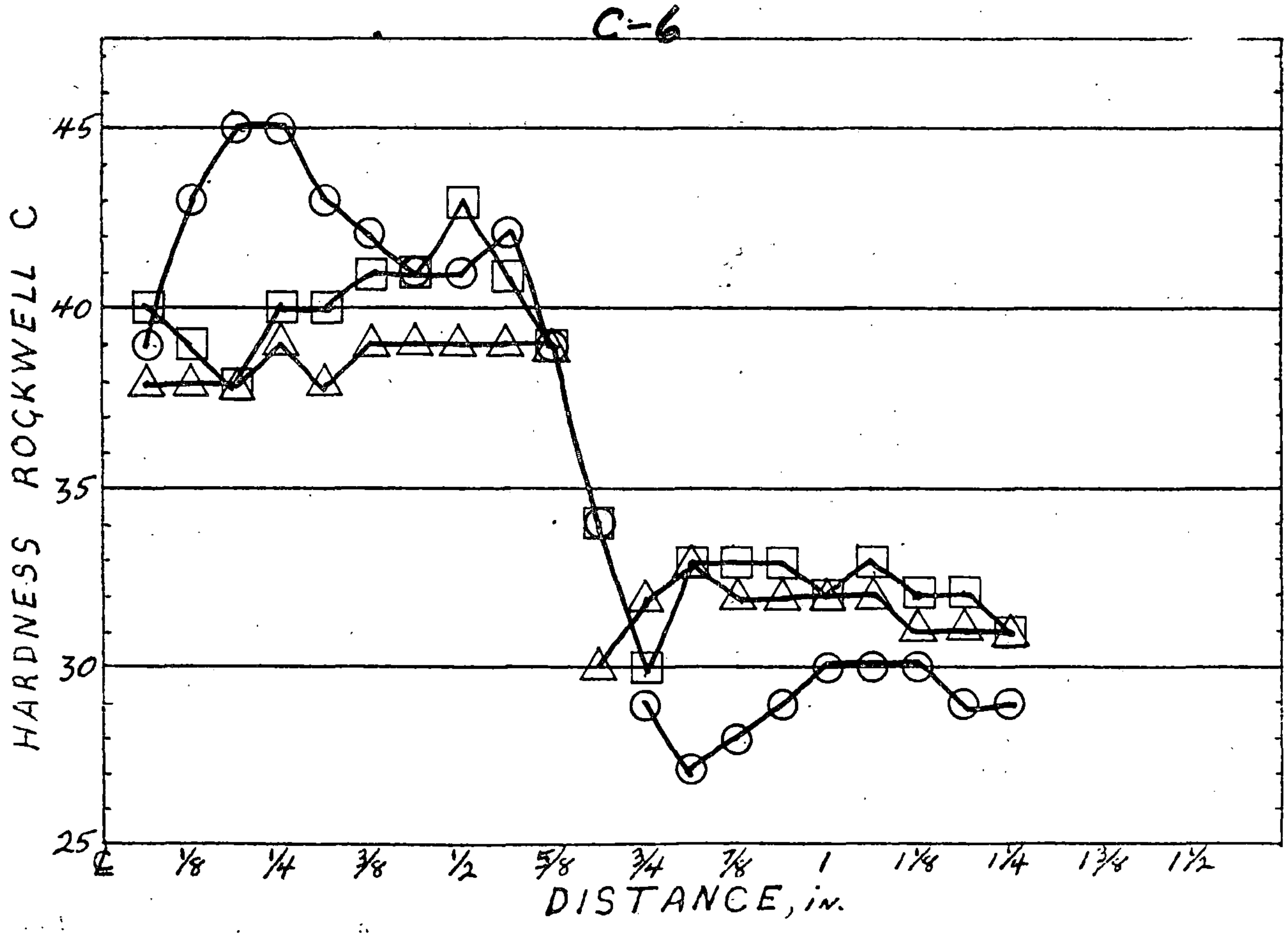
C-3

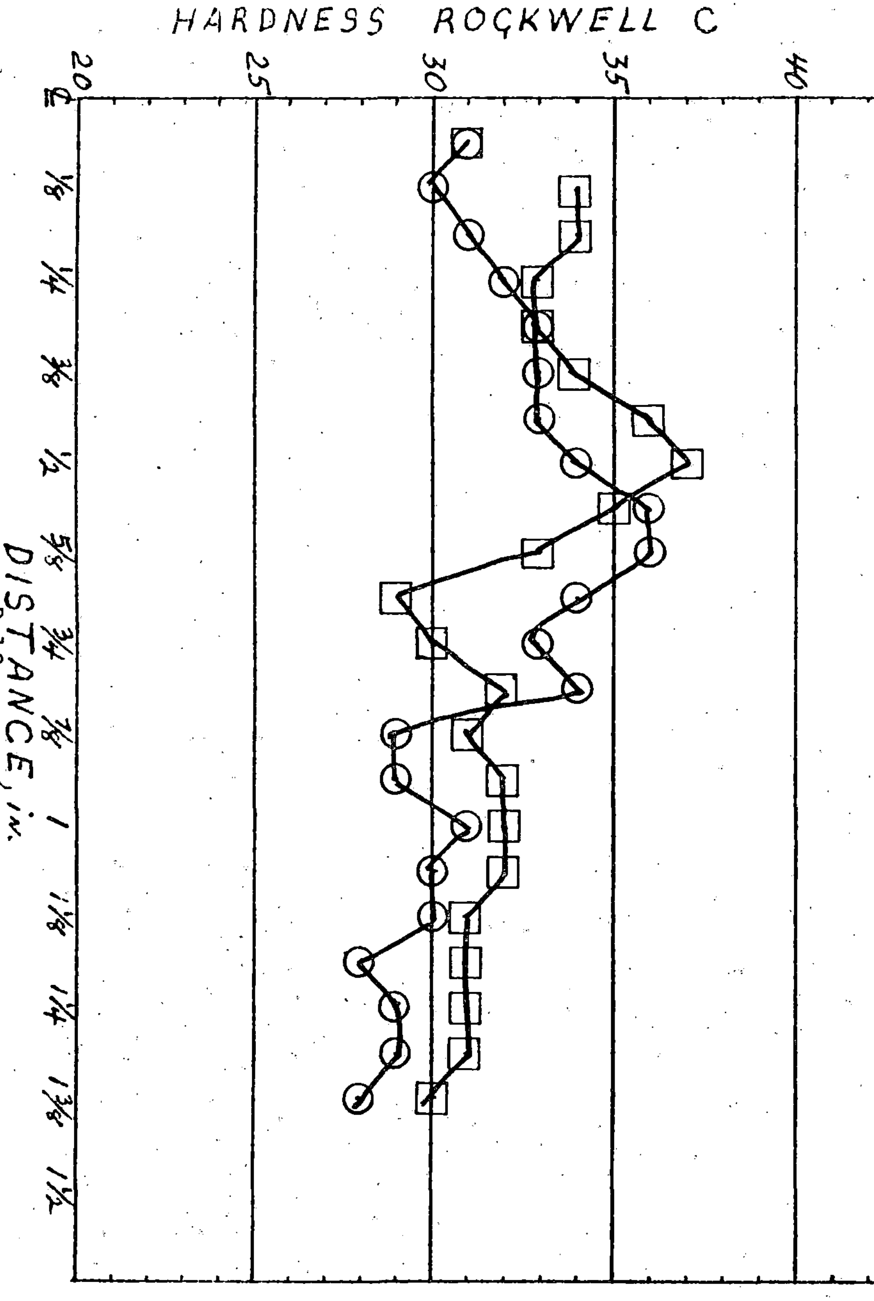

HARDNESS ROCKWELL C
40
35
30
25
20
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

C-2

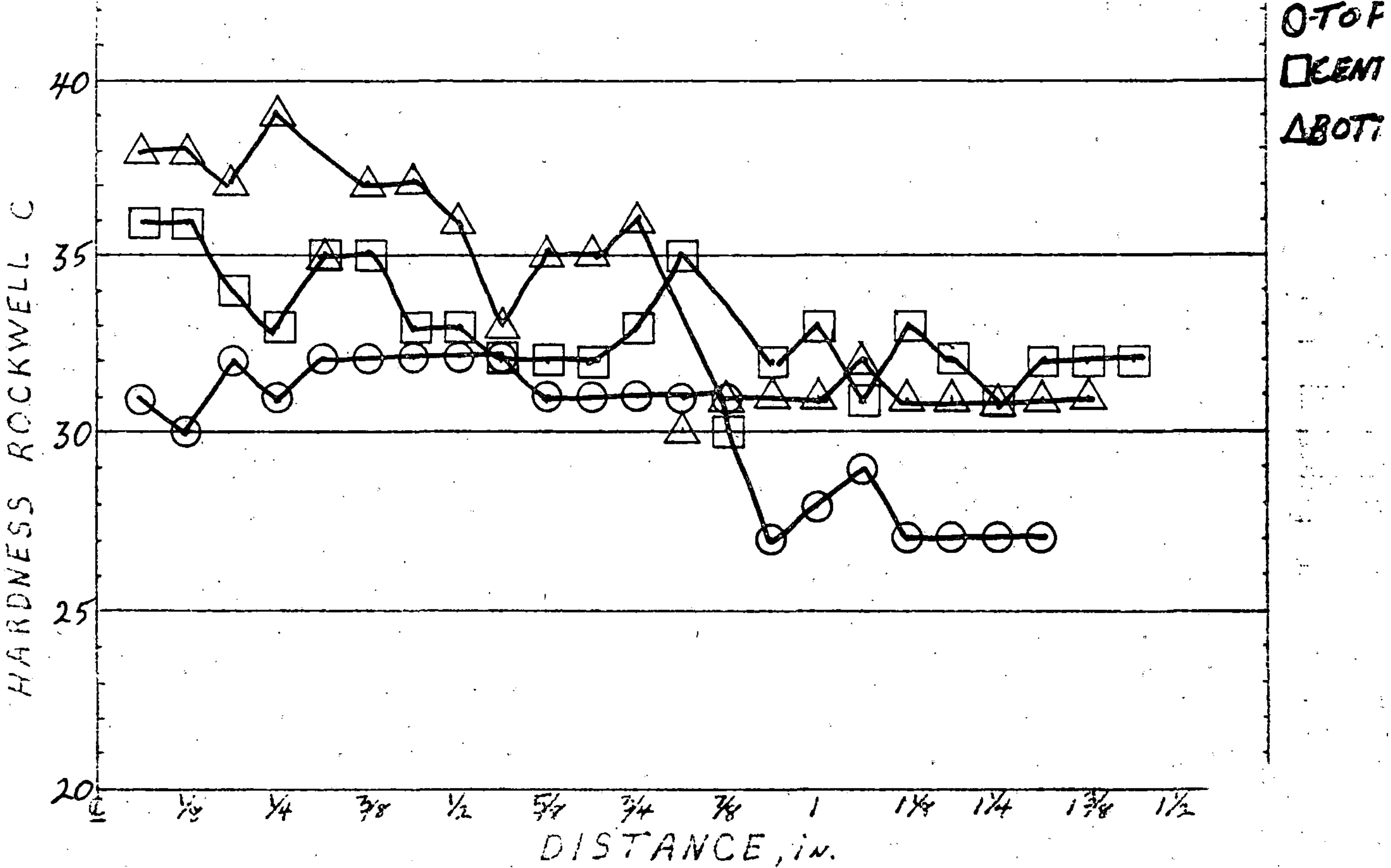

HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.
○ -TOP
□ -CENT.
△ -BOTT.


C-4
○ TOP
□ CENT
△ BOTT
HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

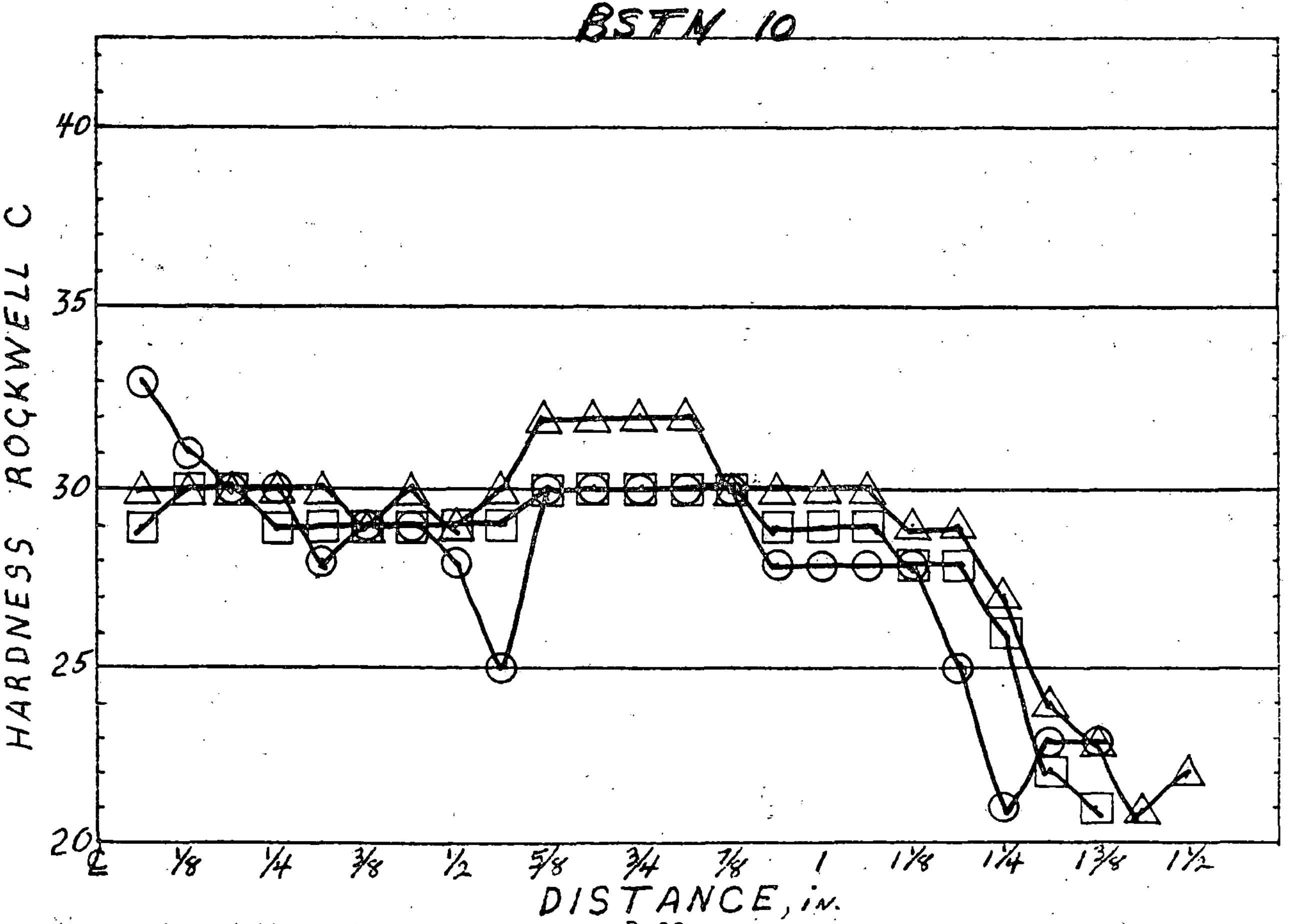

C-6
HARDNESS ROCKWELL C
45
40
35
30
25
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

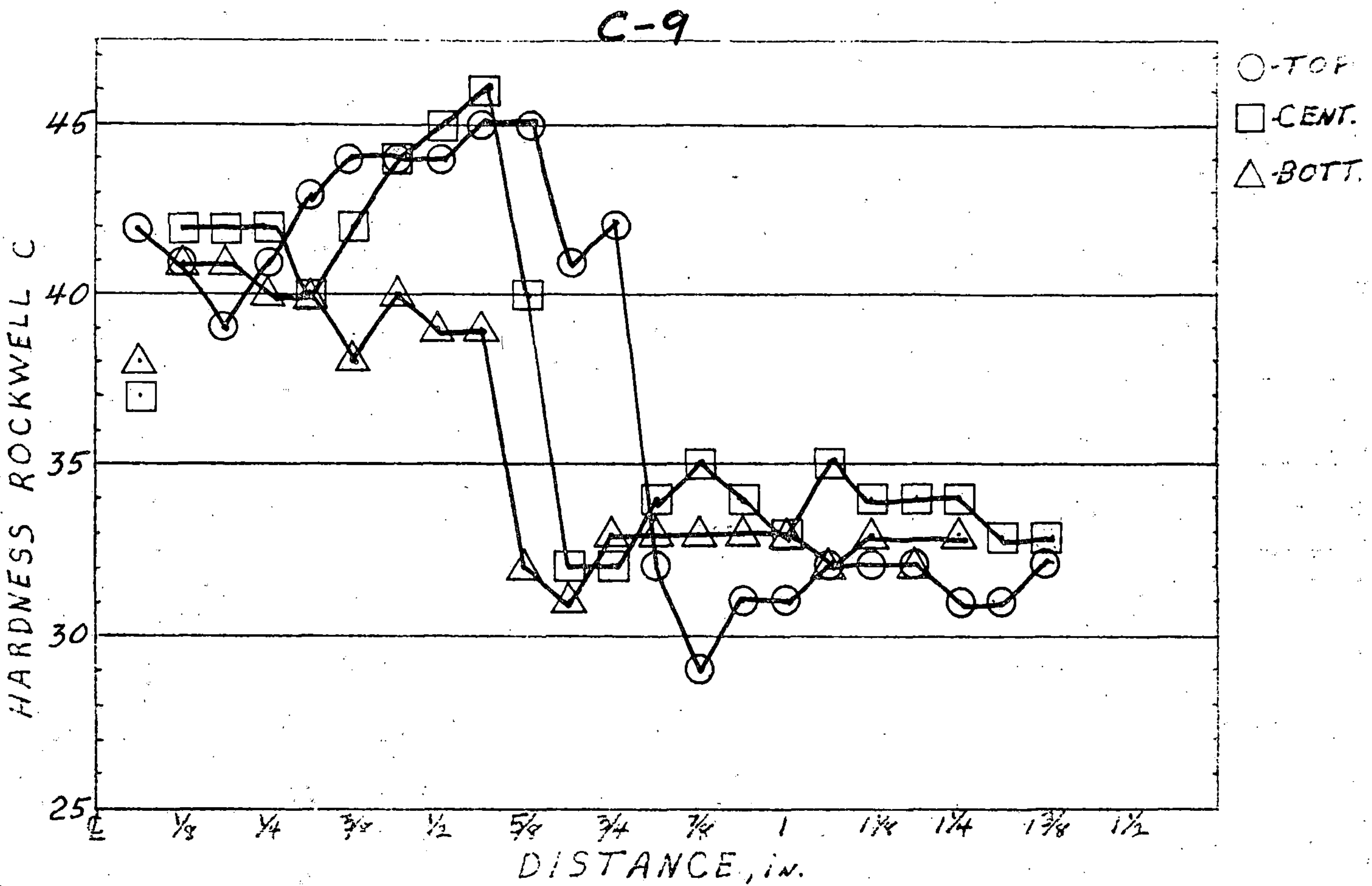

HARDNESS ROCKWELL C
20
25
30
35
40
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

C-7

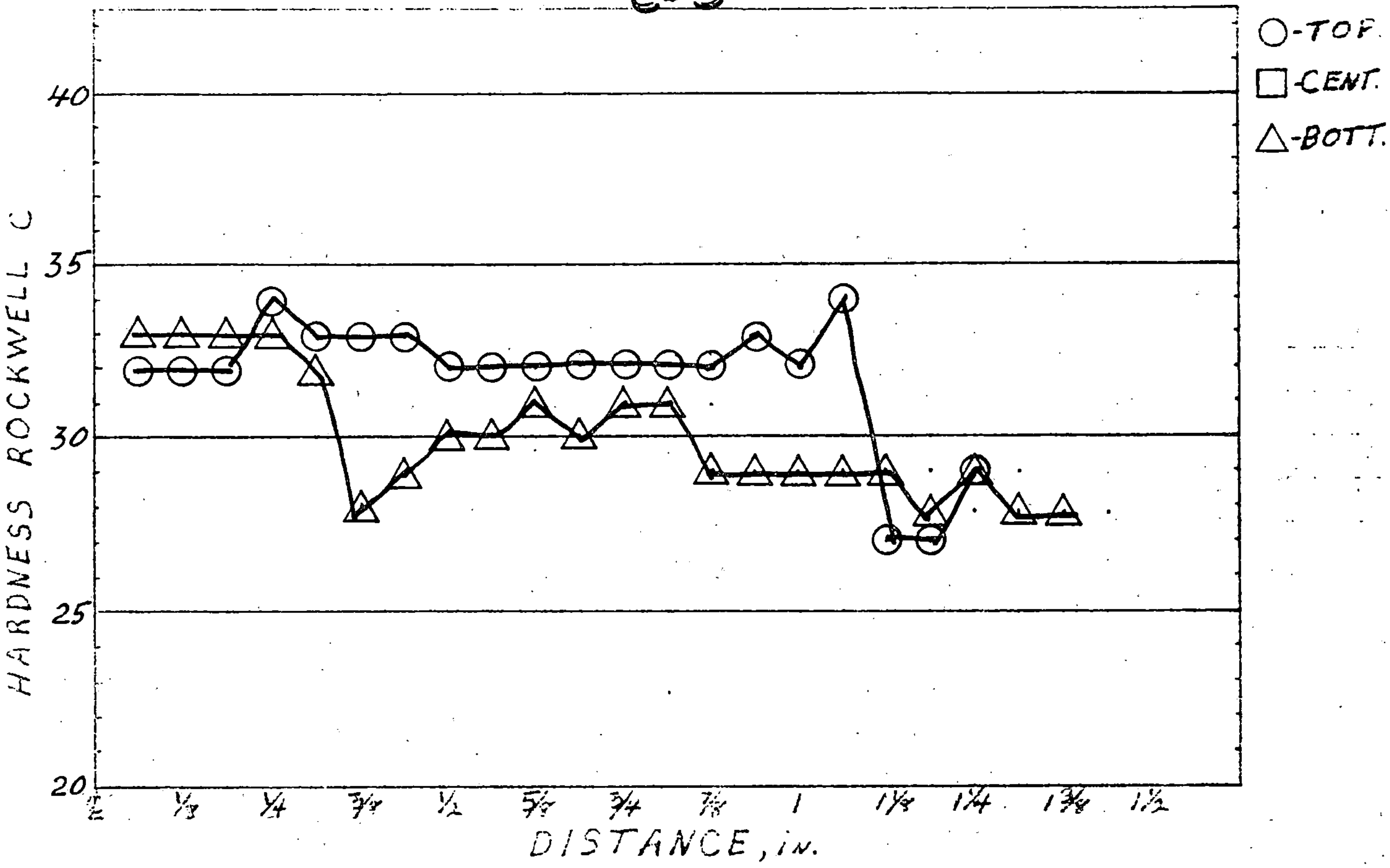

HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.
○-TOF
□CENT
ΔBOTI

C-8

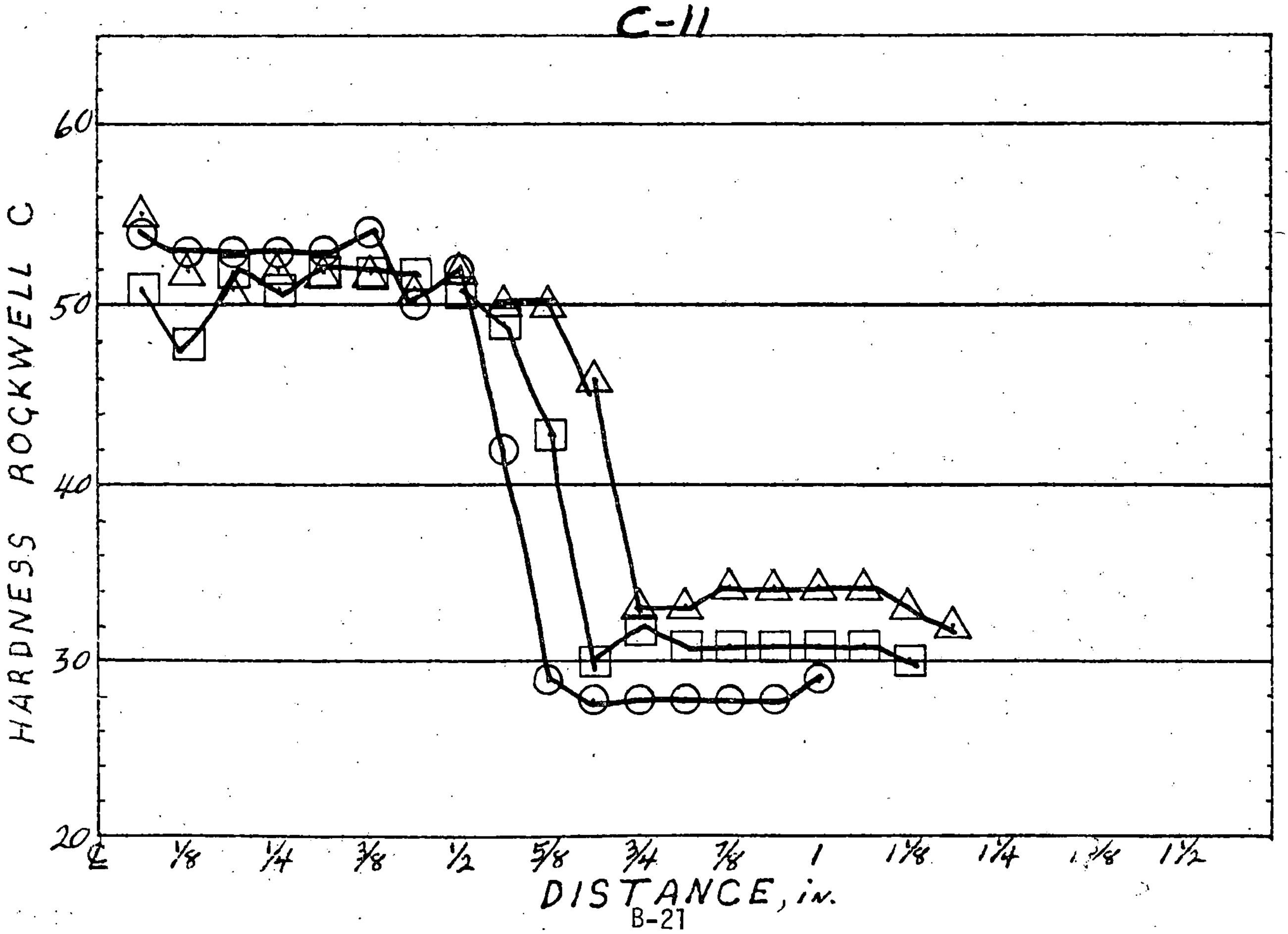

BSTN 10
HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.


C-9
HARDNESS ROCKWELL C
25
30
35
40
45
DISTANCE, in.
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
○-TOP
□-CENT.
△-BOTT.

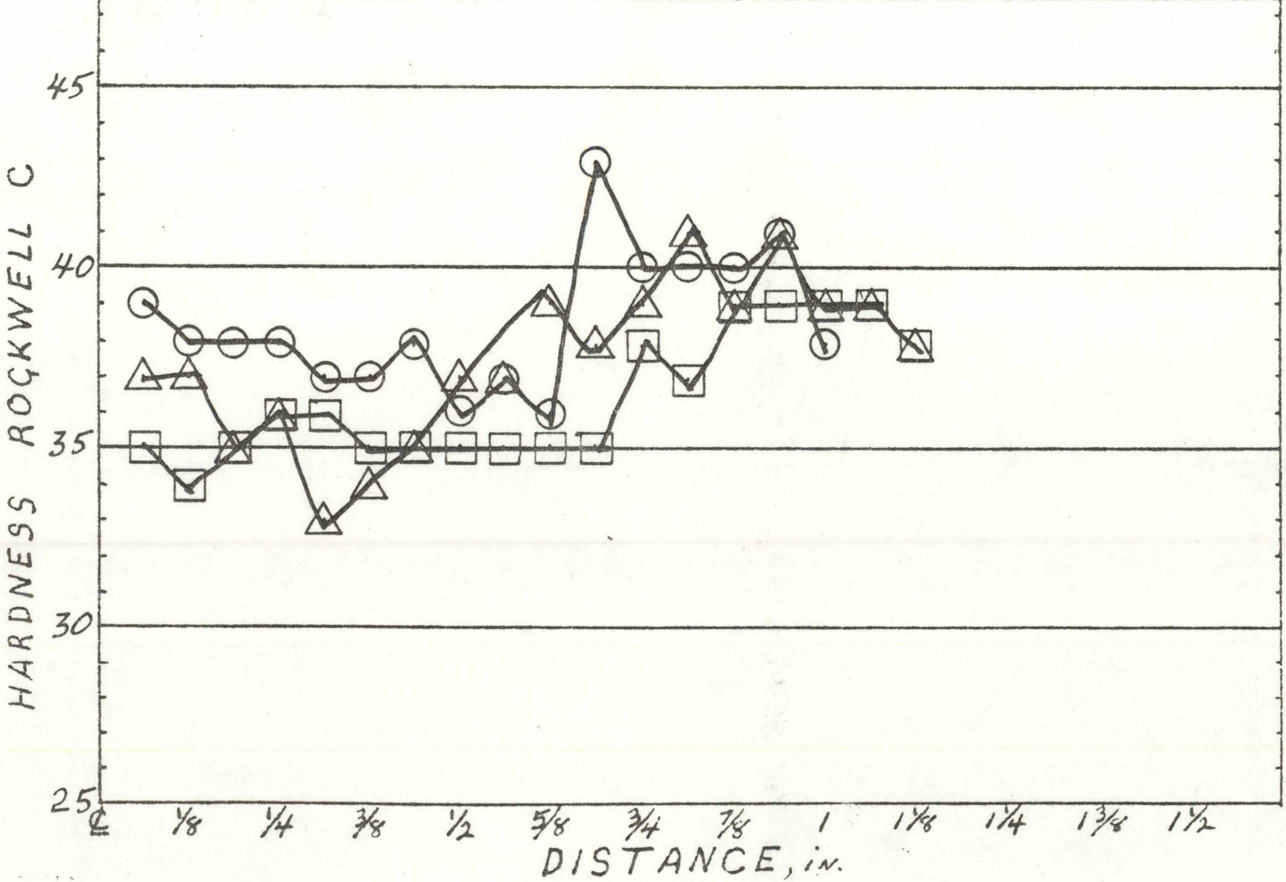
C-5

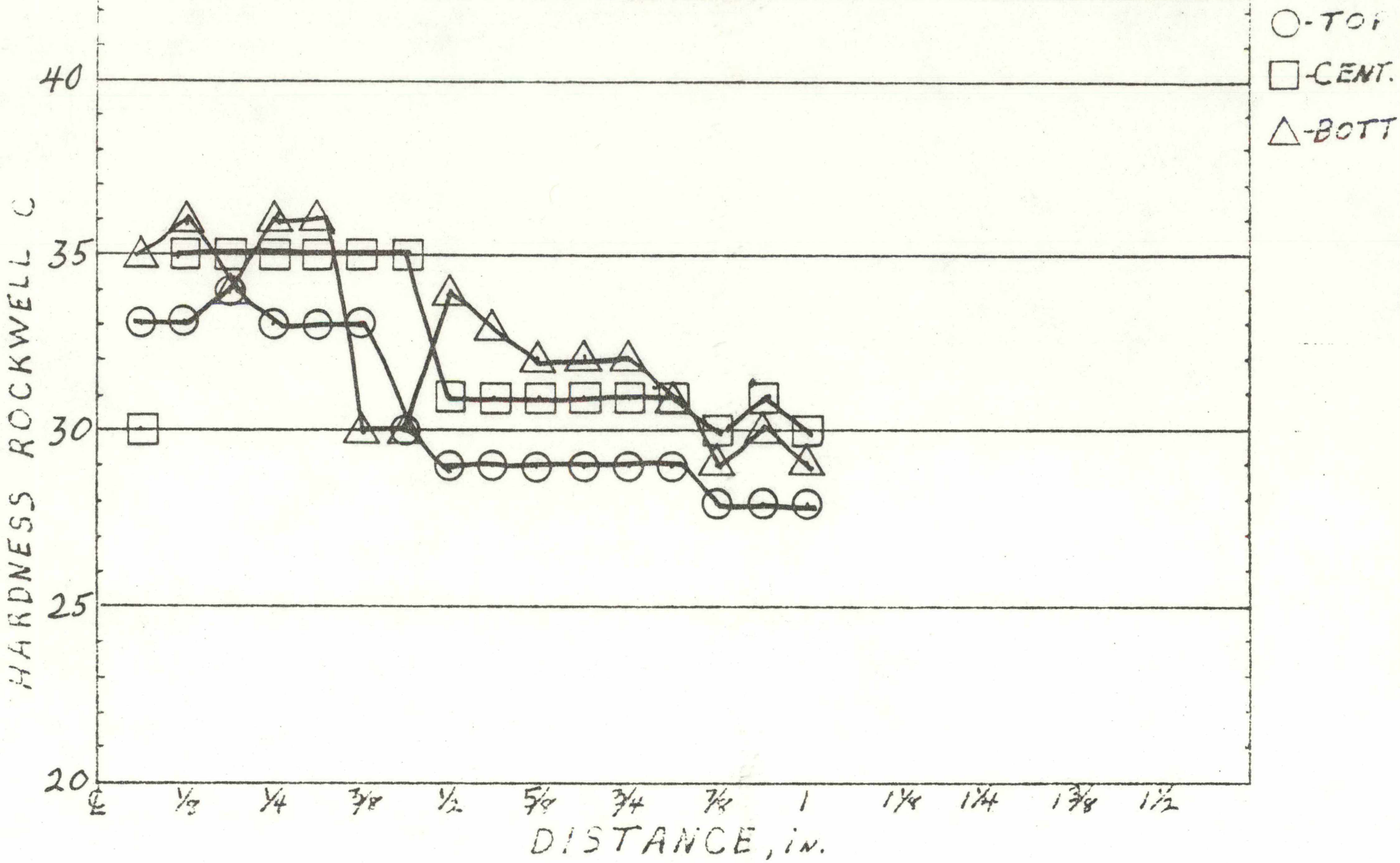

○-TOP
□-CENT.
△-BOTT.
HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

C-11


HARDNESS ROCKWELL C
60
50
40
30
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

C-12

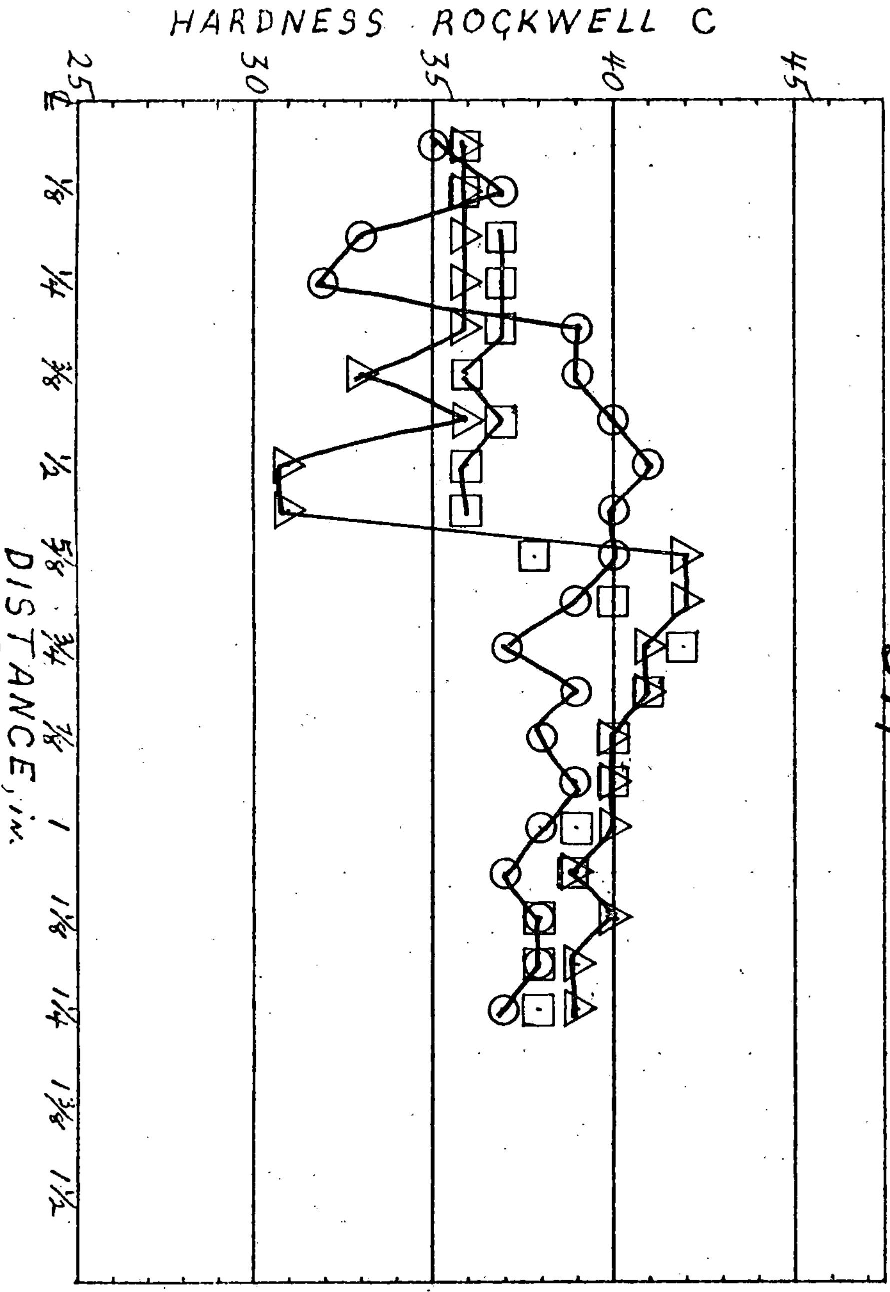

HARDNESS ROCKWELL C
45
40
35
30
25
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

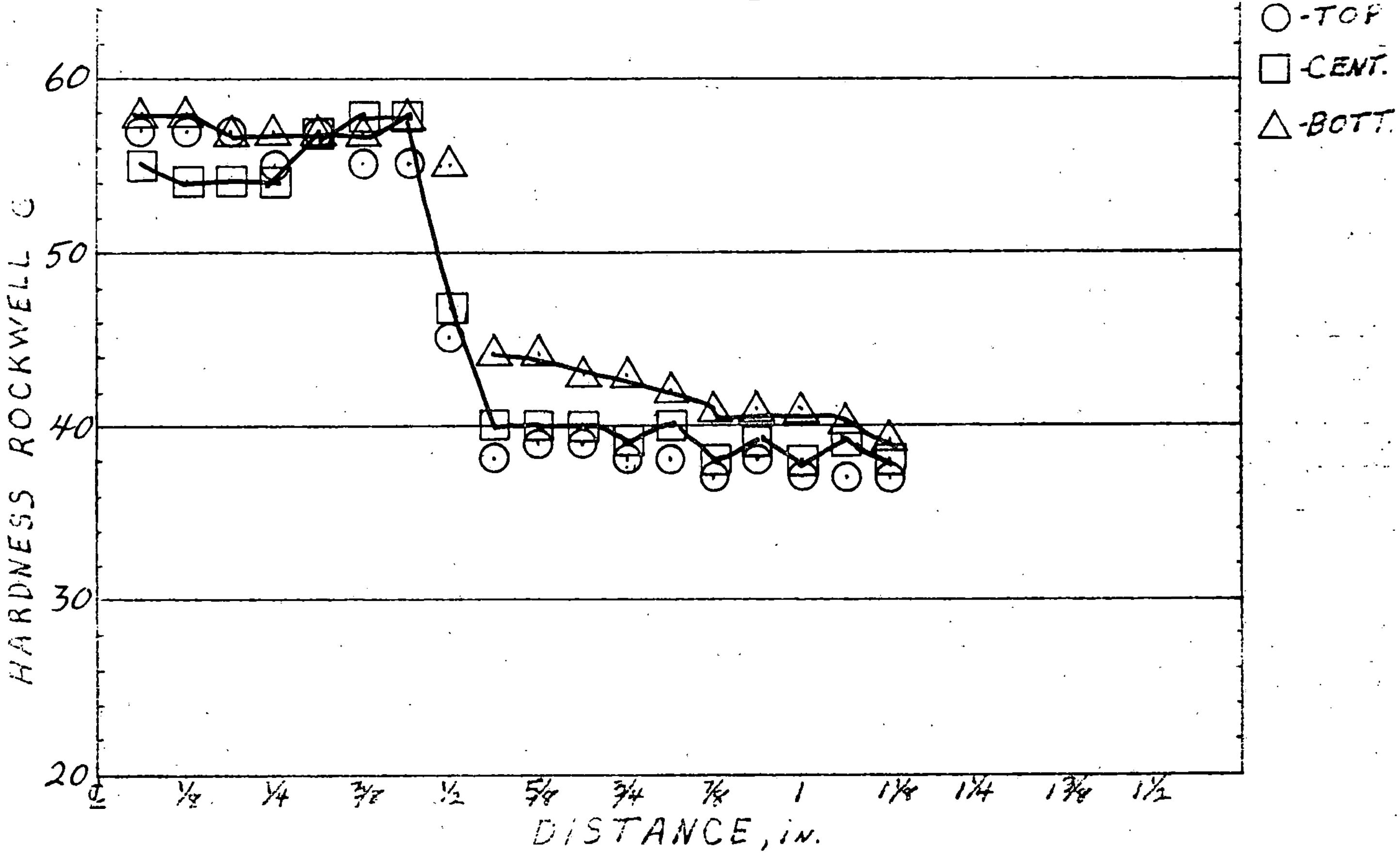


C-10

HARDNESS ROCKWELL C
20
25
30
35
40
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.
○-TOP
□-CENT.
△-BOTT

C-14

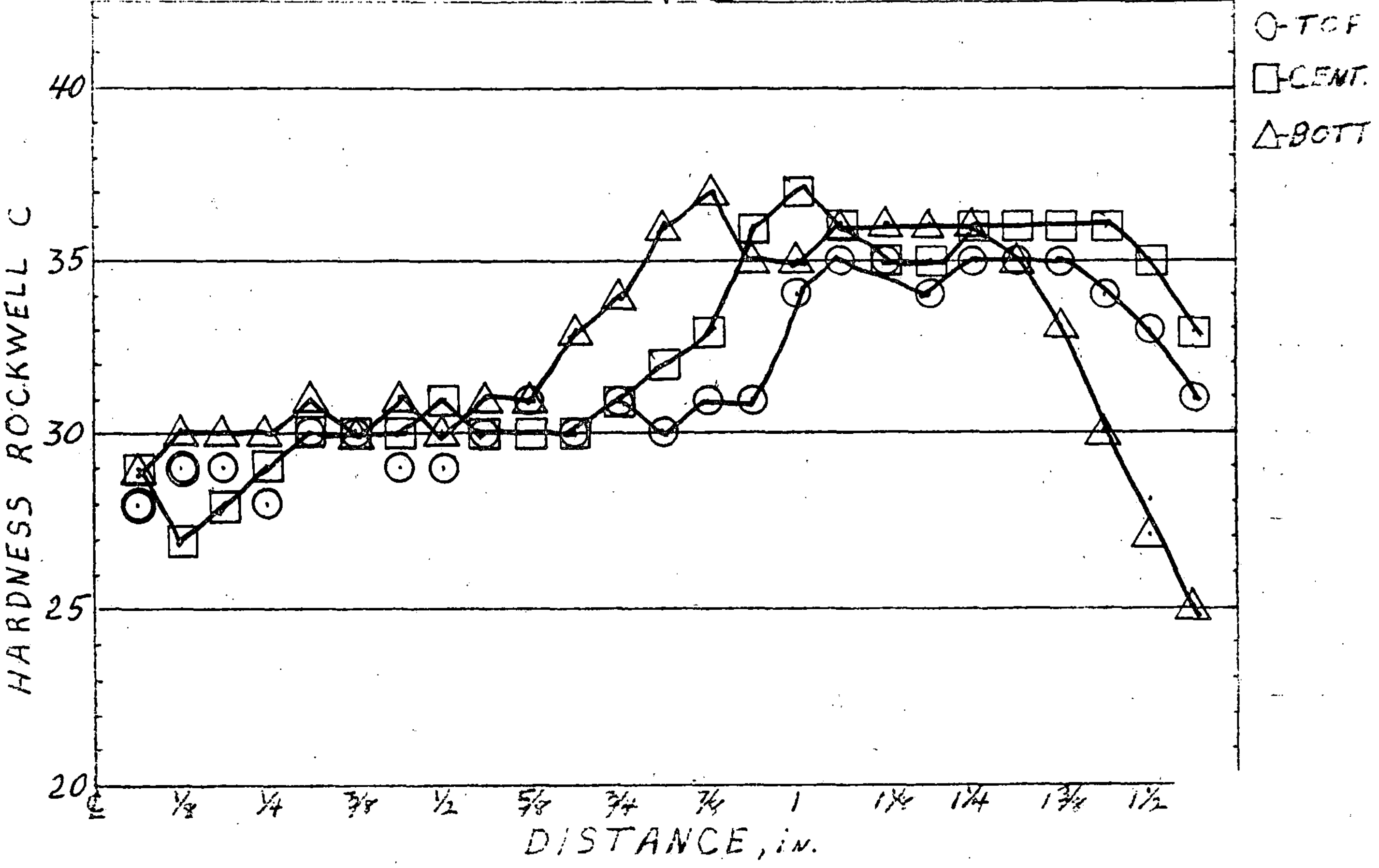

HARDNESS ROCKWELL C
25
30
35
40
45
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.



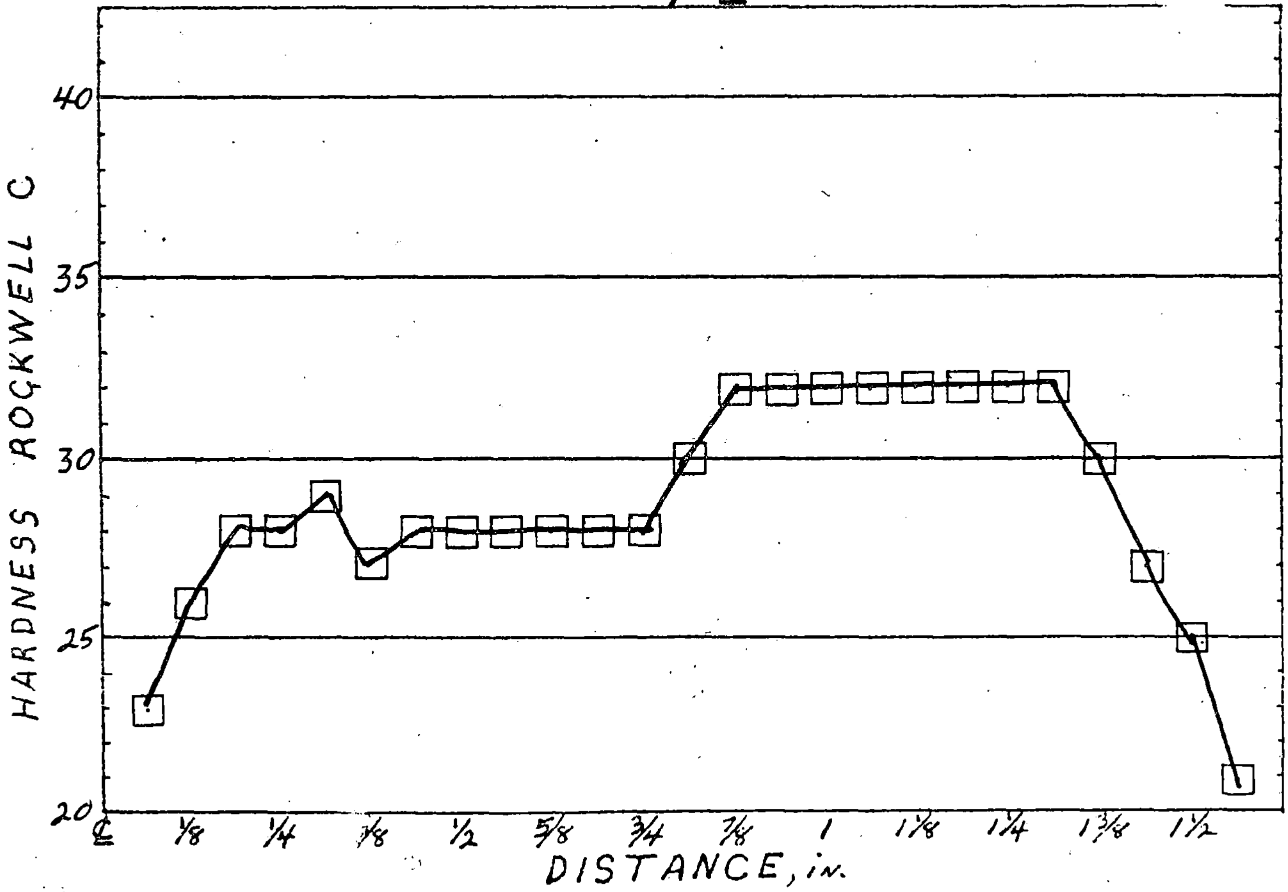
C-13

○ -TOP
□ -CENT.
△ -BOTT.
HARDNESS ROCKWELL C
60
50
40
30
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, IN.

T-3

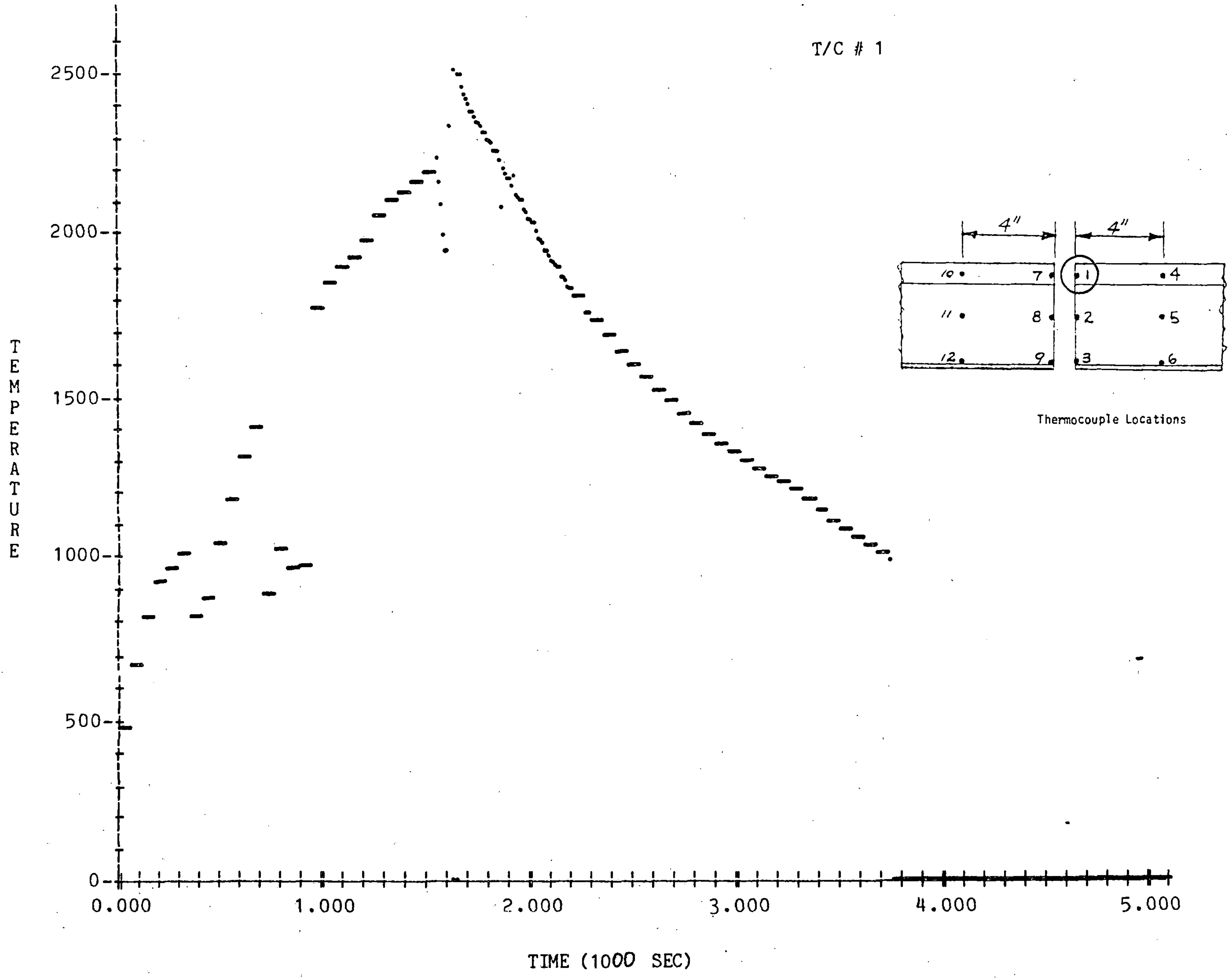

○-TOP
□-CENT.
△-BOTT
HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

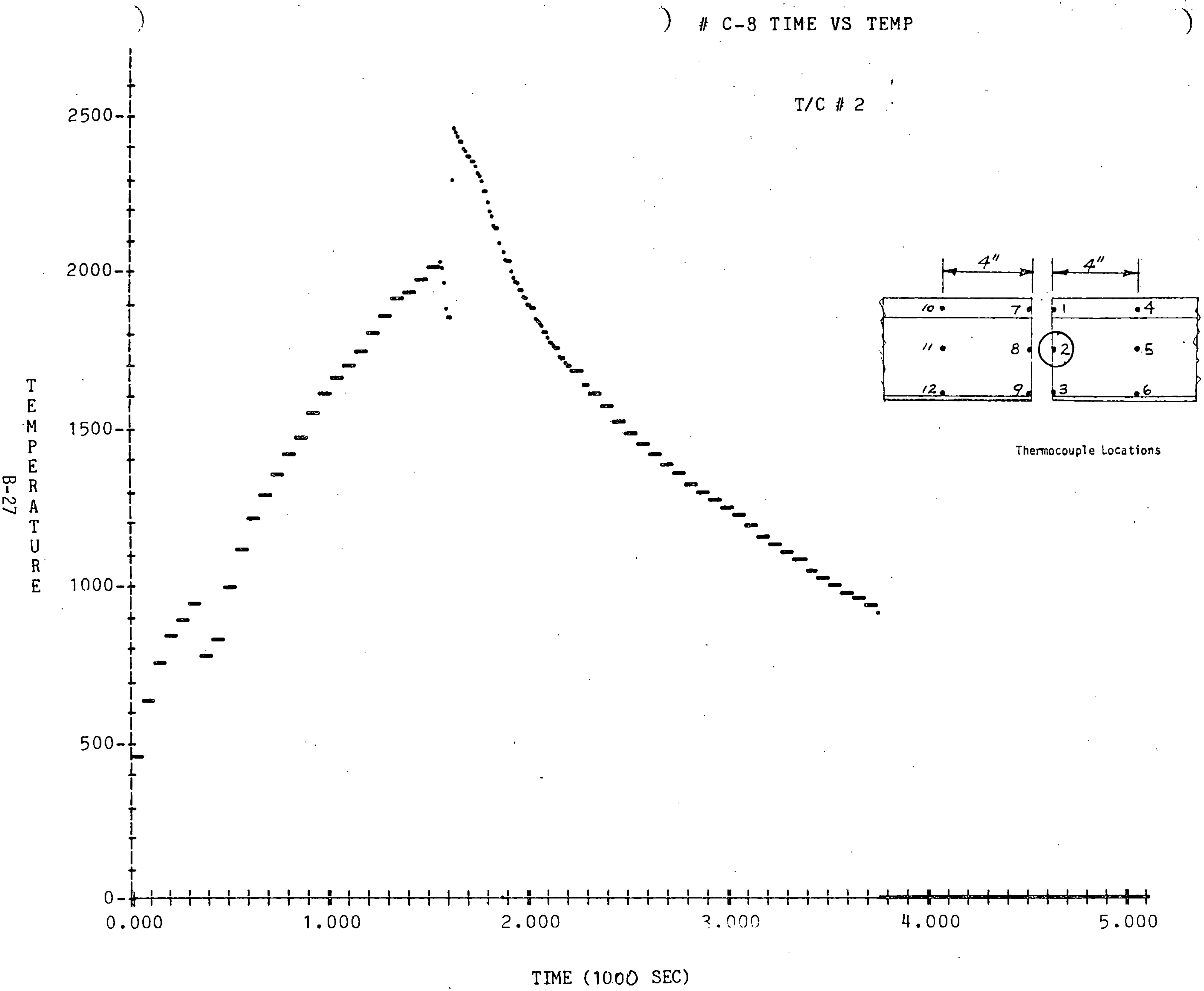
T-1


HARDNESS ROCKWELL C
40
35
30
25
20
℄
1/8
1/4
3/8
1/2
5/8
3/4
7/8
1
1 1/8
1 1/4
1 3/8
1 1/2
DISTANCE, in.

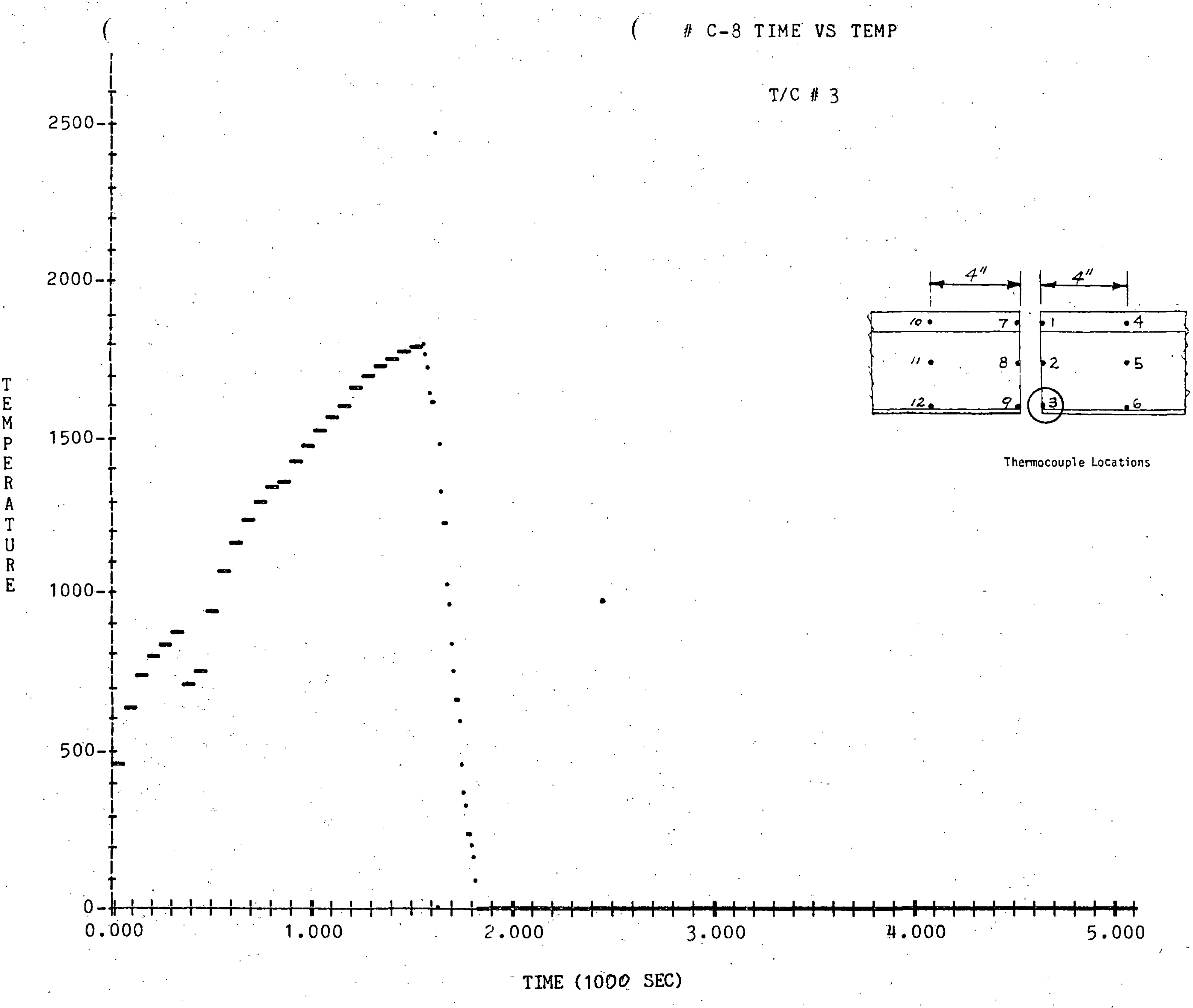
TYPICAL TEMPERATURE DECAY
OF TEST WELDS

C-8 TIME VS TEMP





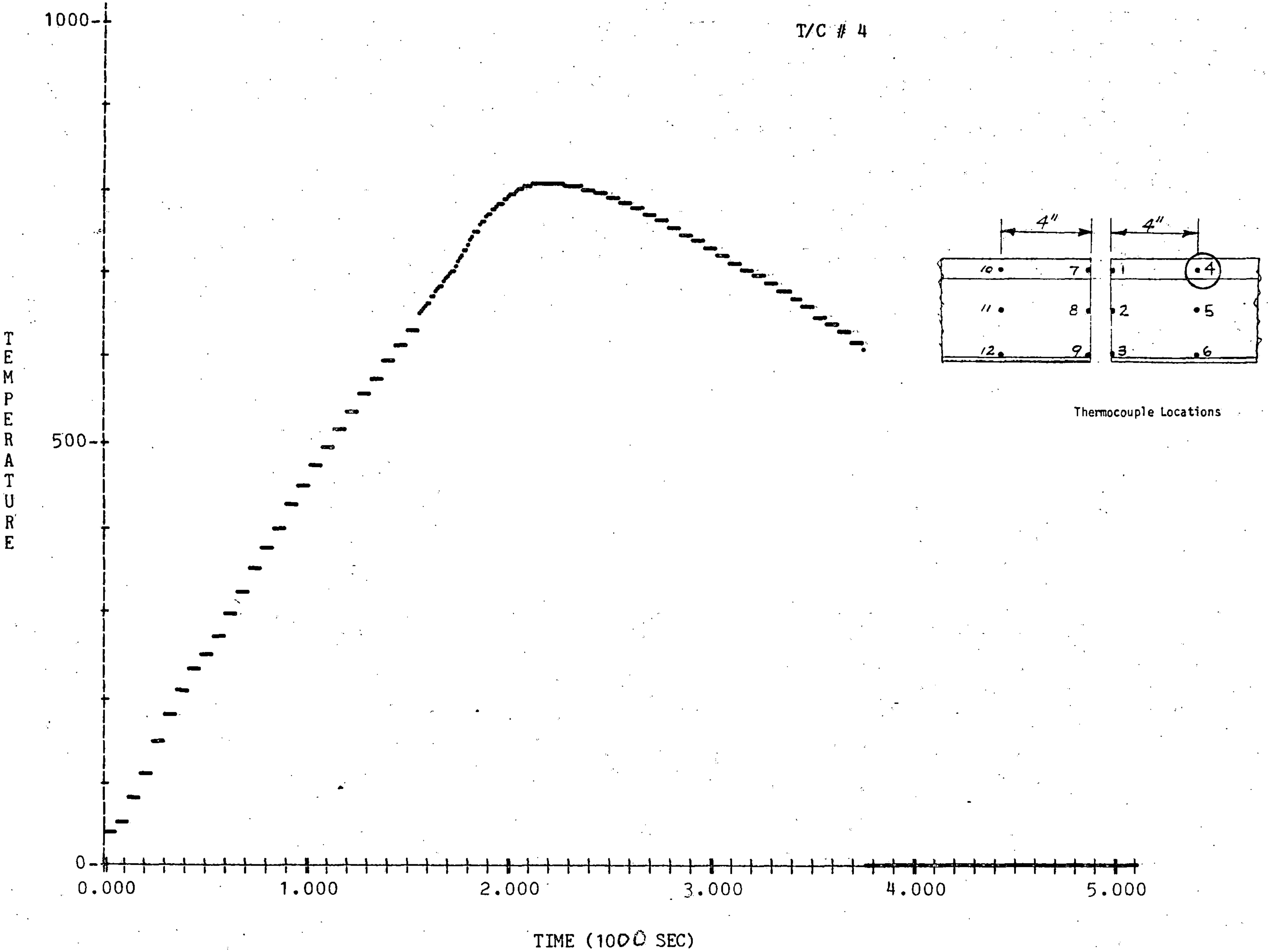
C-8 TIME VS TEMP
T/C # 2
TEMPERATURE
2500
2000
1500
1000
500
0
0.000
1.000
2.000
3.000
4.000
5.000
TIME (1000 SEC)
4"
4"
10
7
1
4
11
8
2
5
12
9
3
6
Thermocouple Locations



C-8 TIME VS TEMP
T/C # 3
TEMPERATURE
2500
2000
1500
1000
500
0
0.000
1.000
2.000
3.000
4.000
5.000
TIME (1000 SEC)
4″
4″
10
7
1
4
11
8
2
5
12
9
3
6
Thermocouple Locations

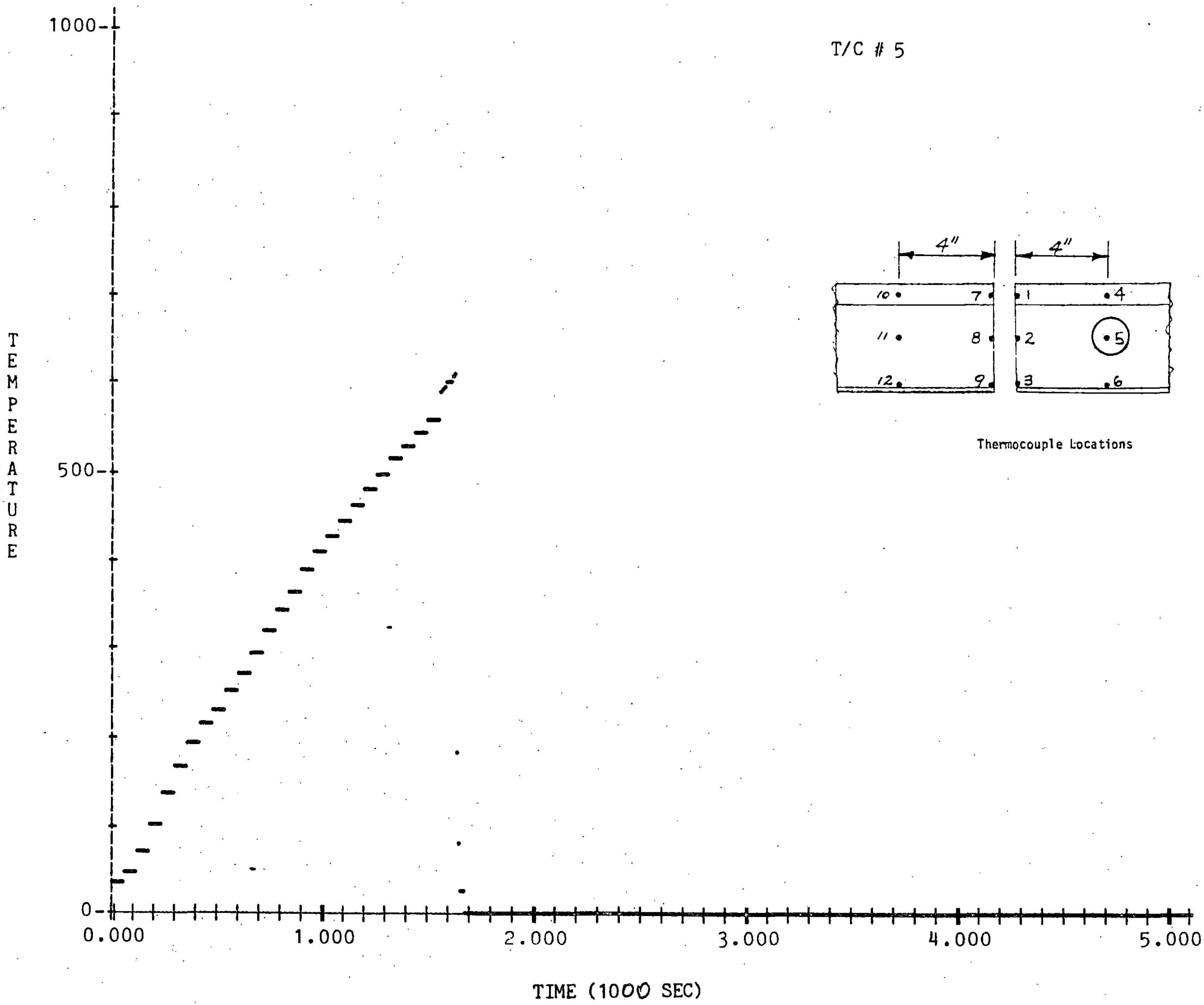
C-8 TIME VS TEMP

T/C # 4

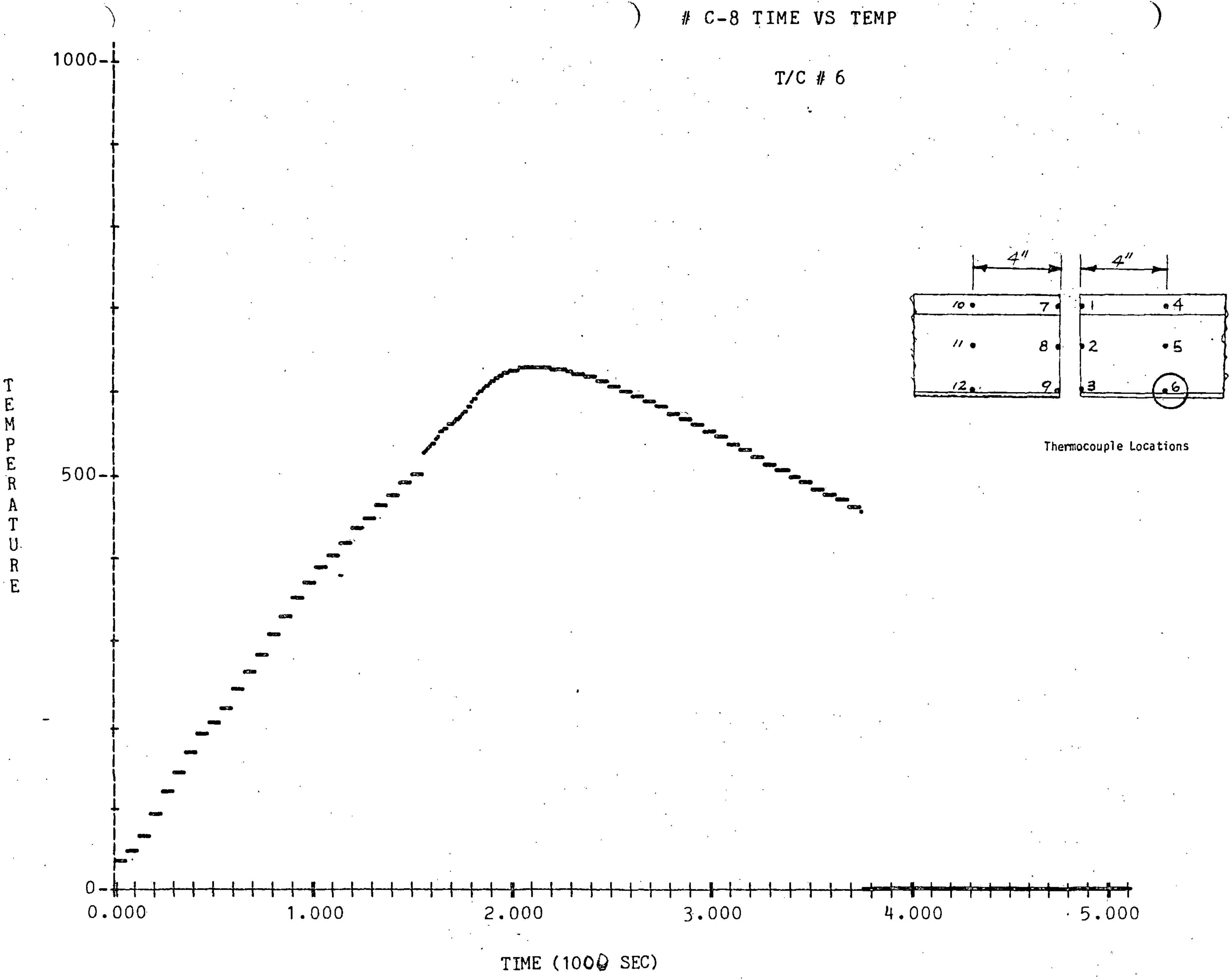


C-8 TIME VS TEMP

T/C # 5



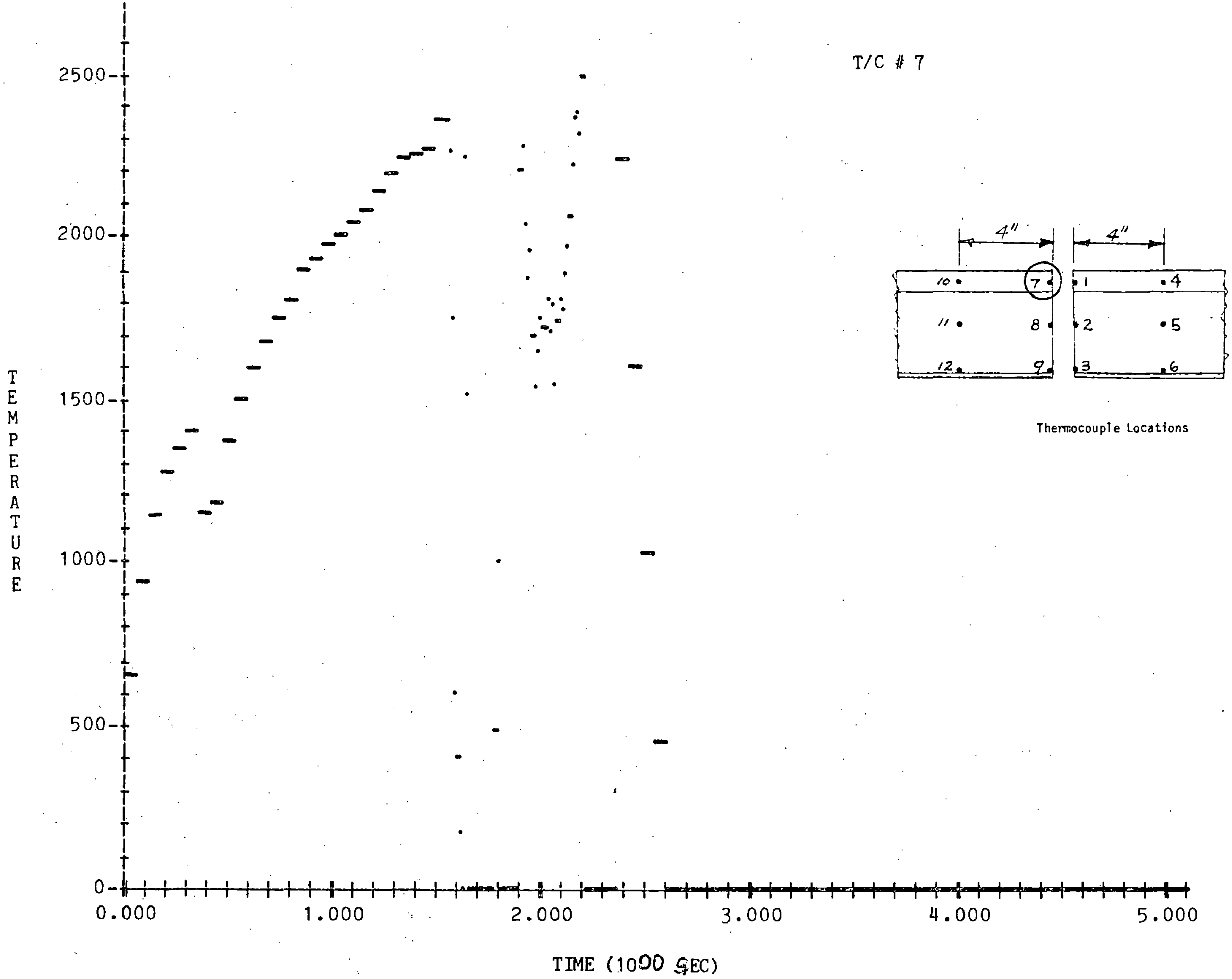
Thermocouple Locations



C-8 TIME VS TEMP

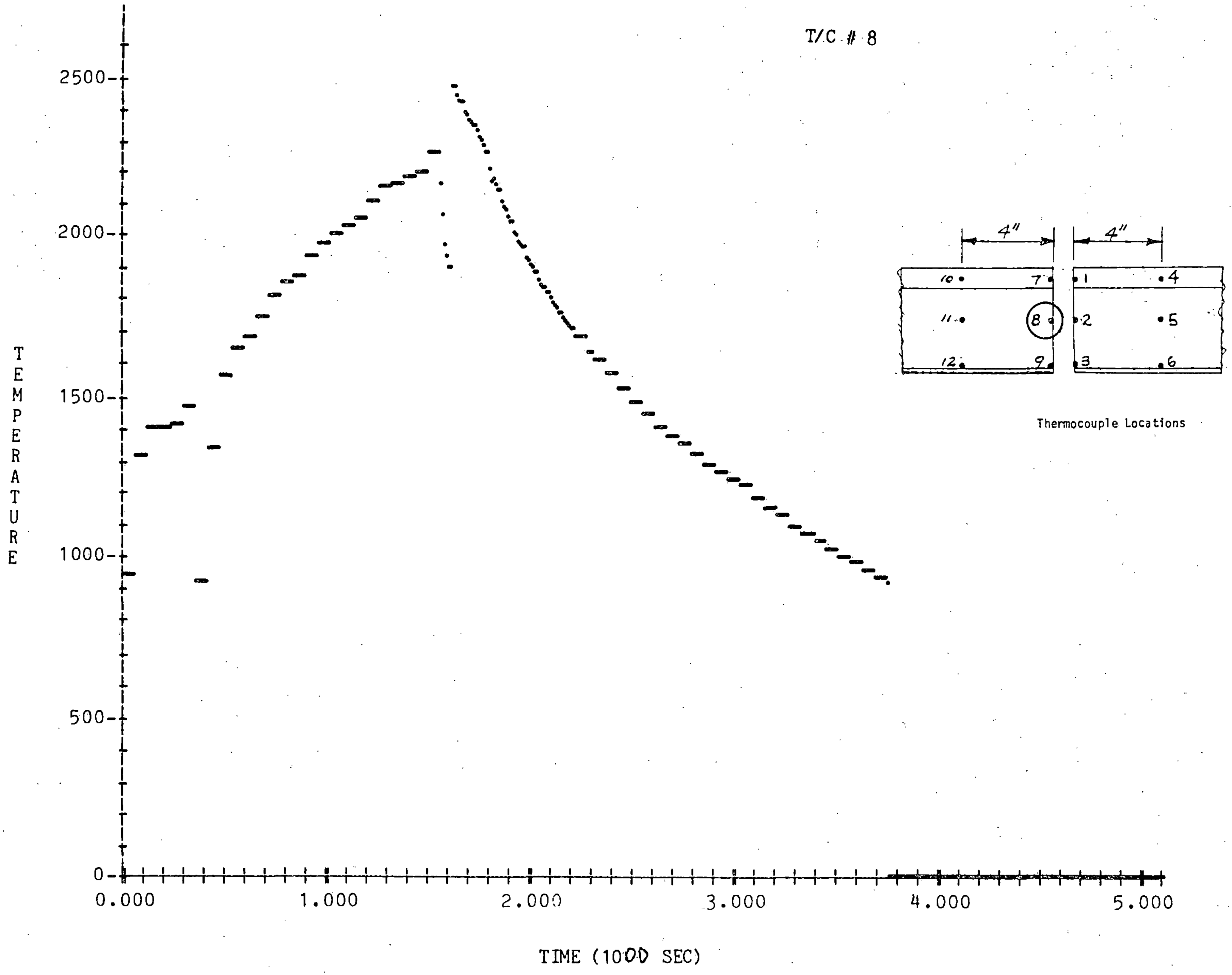
T/C # 6

C-8 TIME VS TEMP



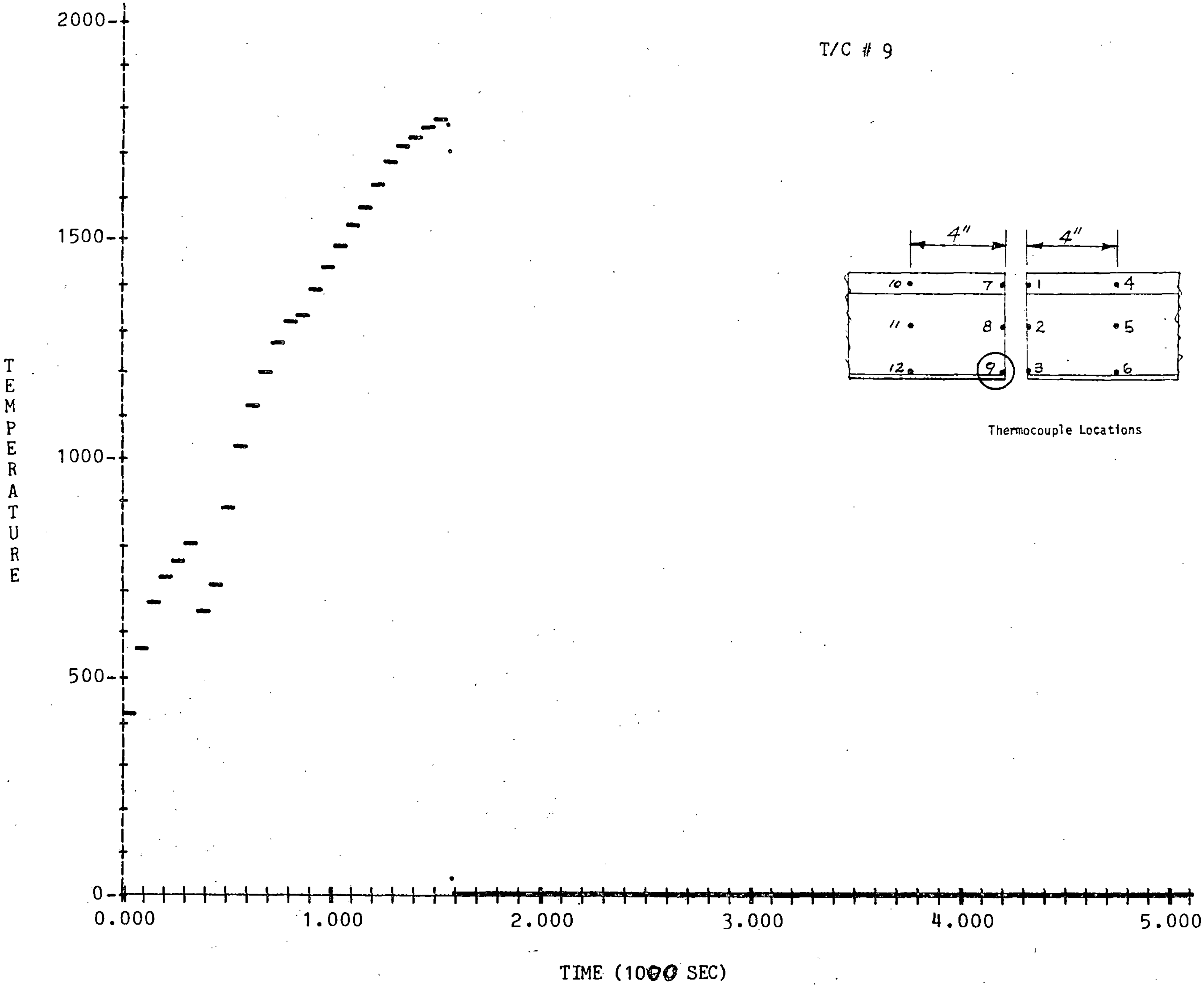
C-8 TIME VS TEMP

T/C # 8



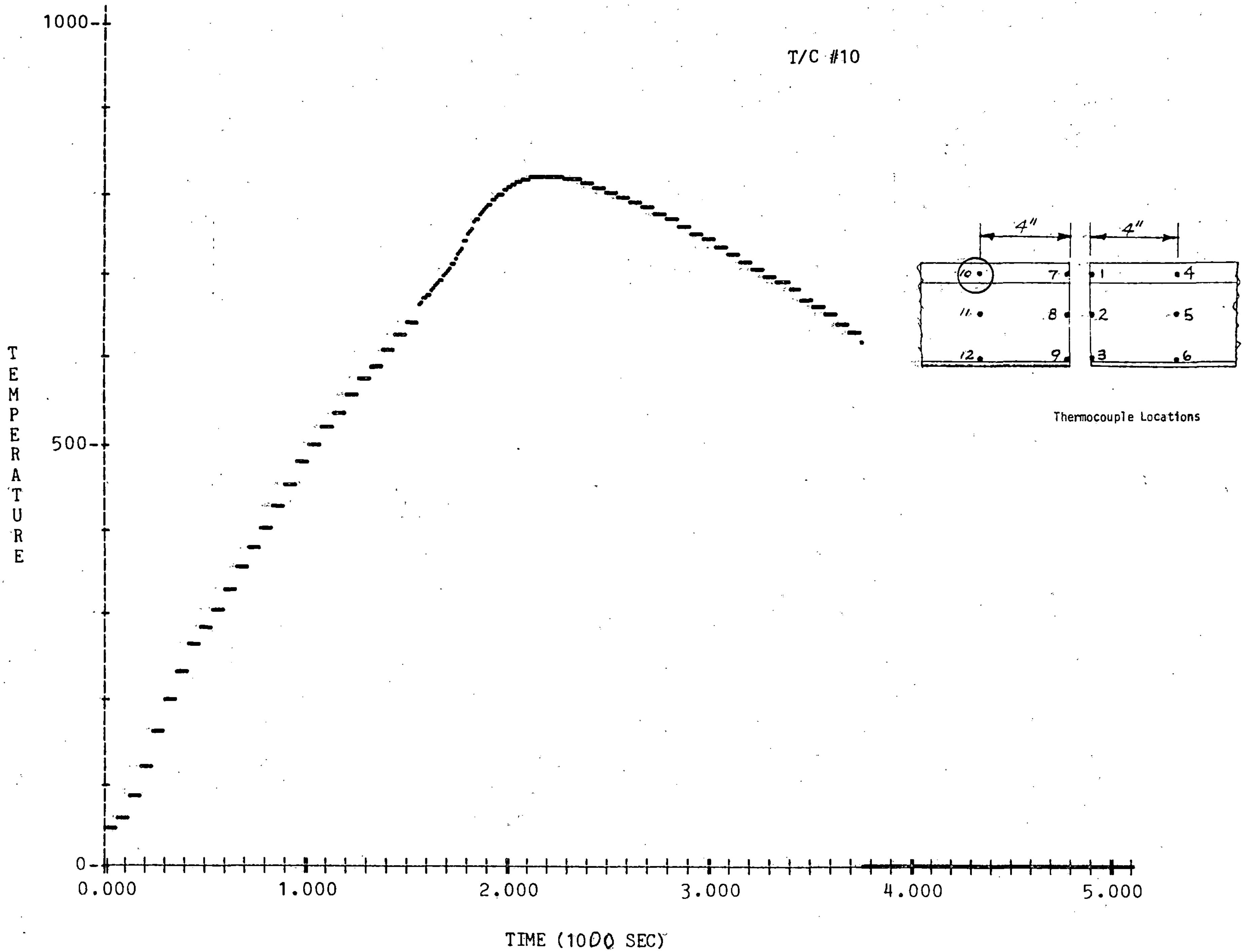
C-8 TIME VS TEMP

T/C # 9



C-8 TIME VS TEMP

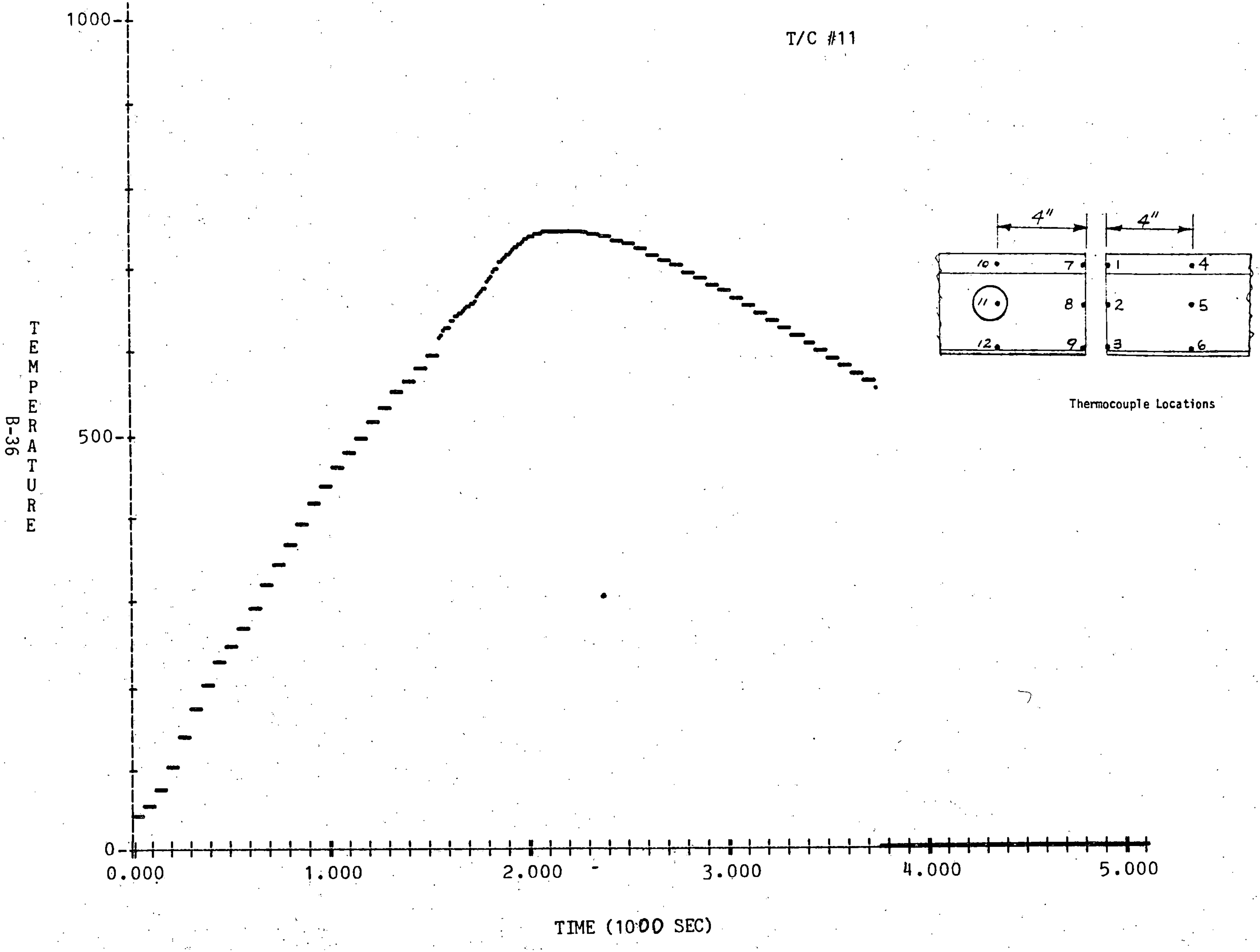
T/C #10



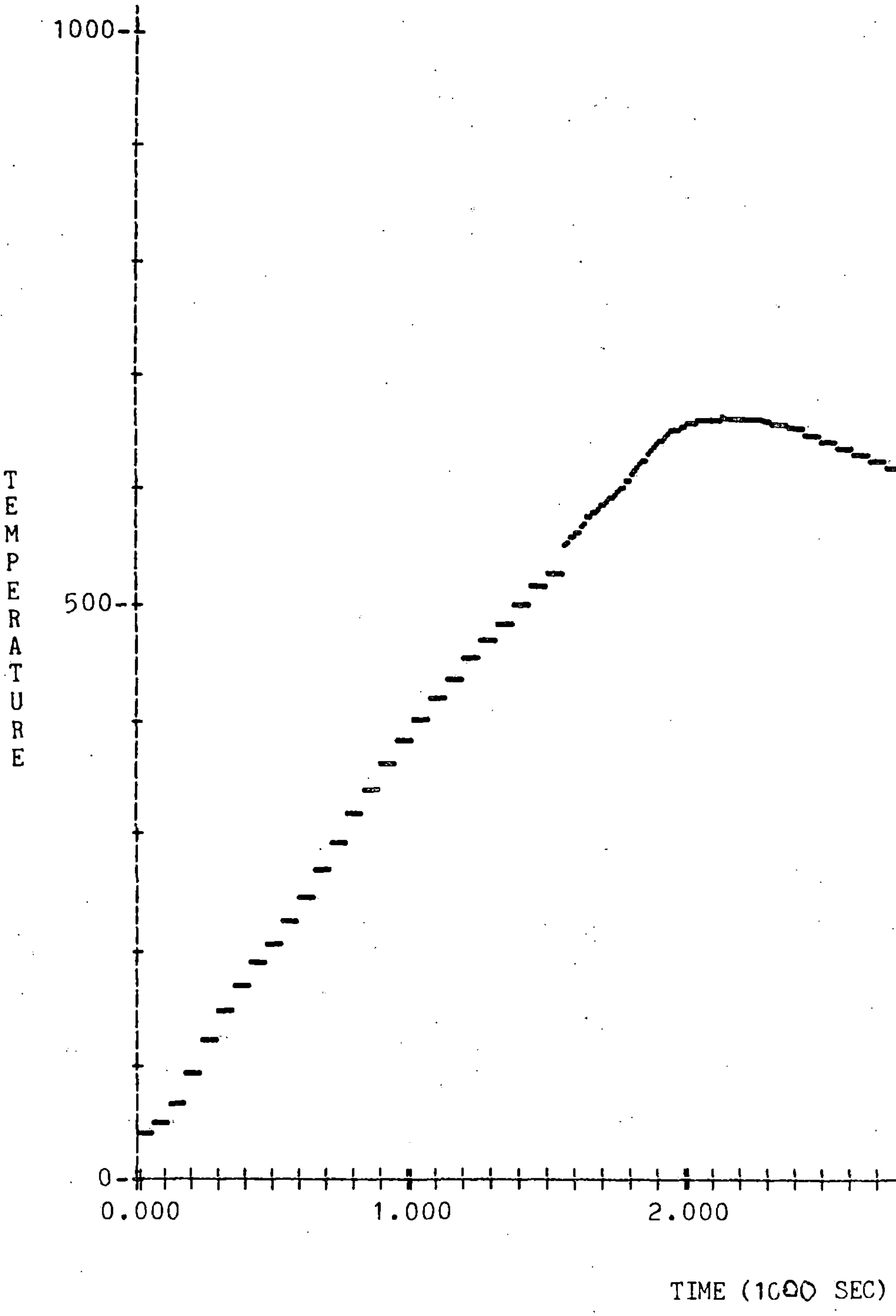
Thermocouple Locations

C-8 TIME VS TEMP

T/C #11

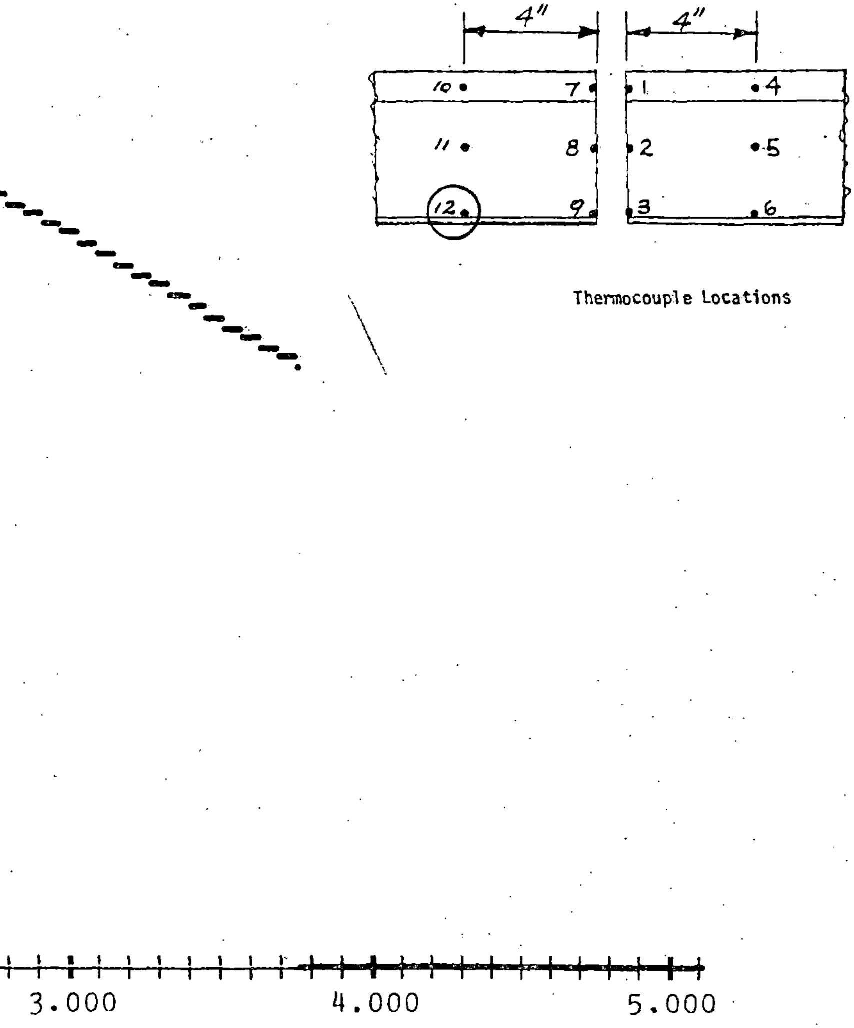


Thermocouple Locations


1000
500
0
TEMPERATURE
0.000
1.000
2.000
TIME (1000 SEC)

C-8 TIME VS TEMP

T/C #12

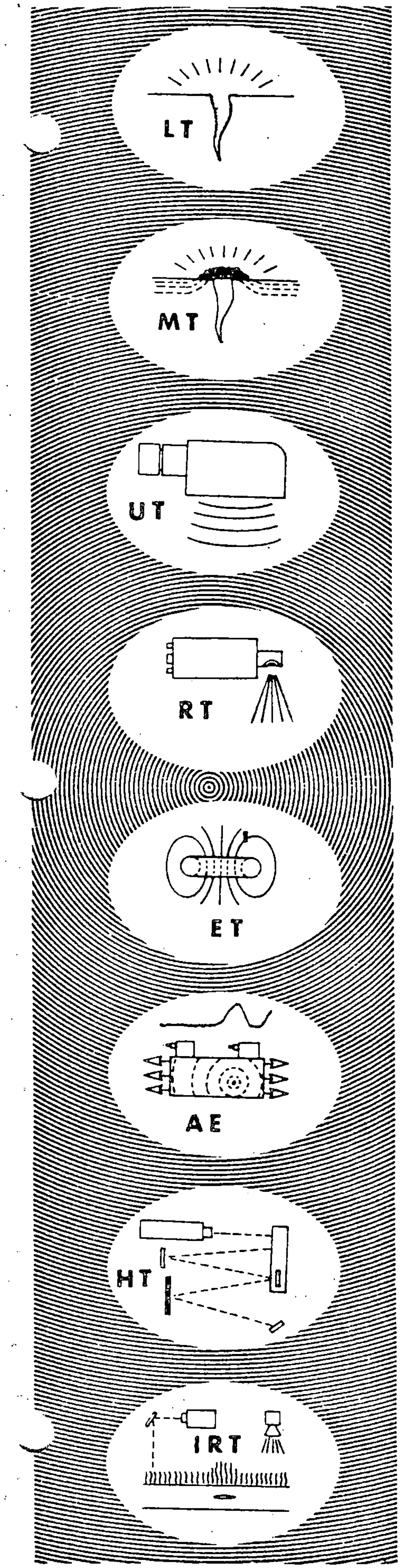


Thermocouple Locations

APPENDIX C

NON-DESTRUCTIVE ULTRASONIC INSPECTION

PROCEDURE AND RESULTS



NON DESTRUCTIVE TESTING

ULTRASONIC NDI PROCEDURE

BOSTON RAPID TRANSIT SYSTEM RAILROAD RAIL INVESTIGATION

INSPECTION OF RAILROAD WELDS

16 October 1982

BY

VOUGHT CORPORATION
Post Office Box 225907 • Dallas, Texas 75265
an LTV company

ULTRASONIC NDI PROCEDURE

BOSTON RAPID TRANSIT SYSTEM RAILROAD RAIL INVESTIGATION

INSPECTION OF RAILROAD RAIL WELDS

Summary

An NDI method was required to determine the material integrity of the Calorite and Thermite weldments in railroad rails. A contact ultrasonic anglebeam/shearwave inspection technique was developed to meet this requirement for in-house inspections. The technique requires off-the-shelf ultrasonic test equipment and a transducer with a 45° plexiglas refracting wedge. For calibration purposes a reference standard was developed with the reference flaw having dimensions of 0.5" long x 0.050" wide x 0.125" deep (Figure 2).

The attached procedure describes the technique with an enclosed table (Table 1) showing results determined from the inspections performed on test welds. A data sheet (Figure 3) was also used to record results of each inspection.

PREPARED BY: L. J. Marshall

APPROVED BY: John D. Fenton

1.0 INTRODUCTION

The Boston Rapid Transit System's tracks are formed by welding sections of railroad rails together. Seasonal temperature changes cause the tracks to expand and contract. This constant expansion and contraction induces stresses into the weldments of the rails. Initial designs compensated for the stresses involved. Vought Engineering has been awarded a contract to investigate the problem and develop welding procedures that are applicable to both hot and cold weather. The investigation is being conducted with sections of standard rails using standard field welding techniques.

To date several rails have been welded, with each weld having individual processing characteristics. After each weld had been fabricated and scale removed, the NDT Lab was then requested to provide ultrasonic data in an effort to determine the integrity of the weld. Each rail was then subjected to destructive tests to determine weld strength.

2.0 EQUIPMENT AND STANDARDS

A Krautkramer-Branson USL 38 ultrasonic instrument with a 0.5" x 0.5" 2.25 MHZ 45° anglebeam transducer was employed in the inspection of the welded rails. Engineering furnished the NDT Lab with a section of rail containing a reference flaw having dimensions of 0.5" long x 0.050" wide x 0.125" (Figure 2).

3.0 PROCEDURE

An inspection technique was developed using a contact anglebeam/shearwave ultrasonic method. The ultrasonic instrument was calibrated to obtain a full screen (100% vertical scale) reflection from the end of the rail. The time delay was adjusted to position the received signal at the tenth division of the horizontal scale (Figure 1). The instrument was then calibrated to obtain an 80% vertical scale reflection from the reference flaw.

The rails were then inspected from both sides of the weld and results recorded on a data sheet (Figure 3). Ultrasonic results on all inspected welds have been compiled and are shown in Table 1. After ultrasonic inspections were completed, each welded rail was subjected to destructive tests. Visual examinations were conducted on the welds after destructive tests, good correlation was evident between the visual and ultrasonic inspection results.

4.0 CONCLUSION

Through the correleation of data made from visual and ultrasonic inspections, the contact ultrasonic shearwave method has been shown to be an acceptable as well as practical nondestructive inspection technique that is readily available.

VOUGHT CORPORATION
systems division

QUALITY ASSURANCE

NDI SPECIAL TECHNIQUE

PROGRAM: RAILROAD RAIL INVESTIGATION		NDT METHOD: ULTRASONIC
PART NAME: RAIL WELDS	PART NUMBER:	TYPE:

REFERENCE DOCUMENTS: Test Request WP No. T46N

1.0 PURPOSE

To inspect subject rail welds for discontinuities.

2.0 SCOPE

All Boston Rapid Transit Rail Systems

3.0 REFERENCED DOCUMENTS

3.1 Test Request WP No. T46N "Rail Pull Apart Investigation"

4.0 EQUIPMENT REQUIREMENTS

4.1 The following equipment and accessories are necessary to perform the aforementioned inspection:

4.1.1 Krautkramer-Branson Model USL 38 Ultrasonic Flaw Detector Unit or equivalent.

4.1.2 Harisonic 2.25 MHz, 45° ST shear, 0.500" X 0.500", Type ABM0208 Transducer or equivalent.

4.1.3 Ultrasonic couplant (Echo Lab Sonotrace 30 or equivalent).

5.0 ENCLOSURE

5.1 Figure 1, Calibration setup.

6.0 INSTRUCTIONS

6.1 Calibrate ultrasonic flaw detector unit on reference standard provided.

APPROVED:	DATE:

6.1.1 Place transducer on standard as shown in Figure 1 for position 1.

6.1.2 Position the leading edge of the indication from bottom of standard at approximately 100% of the horizontal scale as shown in Figure 1, Display A.

6.1.3 Place transduer on standard as shown in Figure 1 for position 2.

6.1.4 Adjust ultrasonic unit REJECT or DAMP control for minimum amount required for fairly clean baseline.

6.1.5 Adjust ultrasonic unit for reference indication (flaw) of approximately 80% of vertical scale as shown in Figure 1, Display B.

6.2 Position transducer on subject rail to be inspected.

6.3 Scan subject rail weld from both directions.

6.4 Record any discontinuity indications (if any) for size and location on the NDT R & D data sheet.

6.5 Any indications of discontinuity sizes greater than __% of vertical scale are considered rejectable.

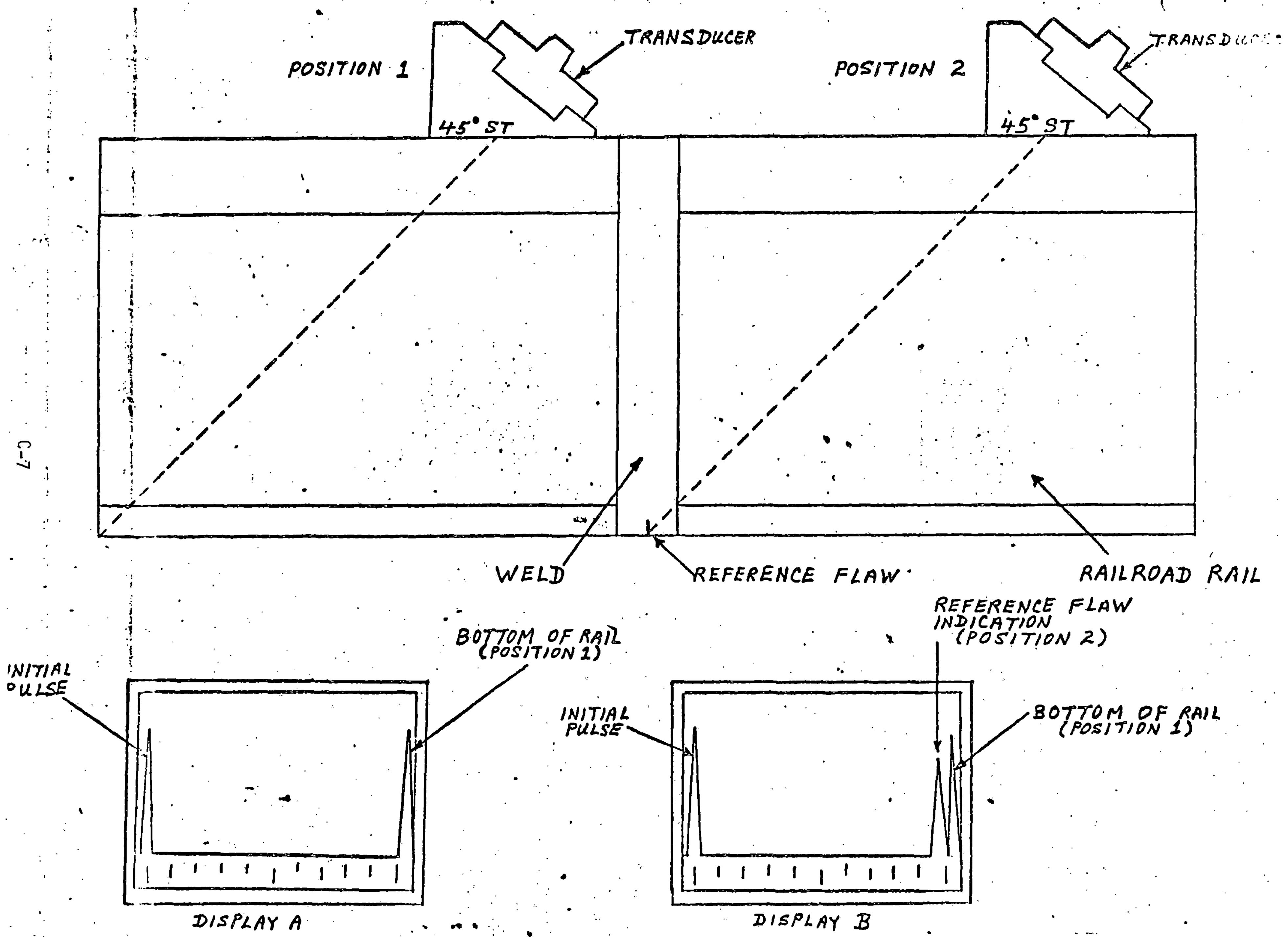


FIGURE 1 CALIBRATION SETUP

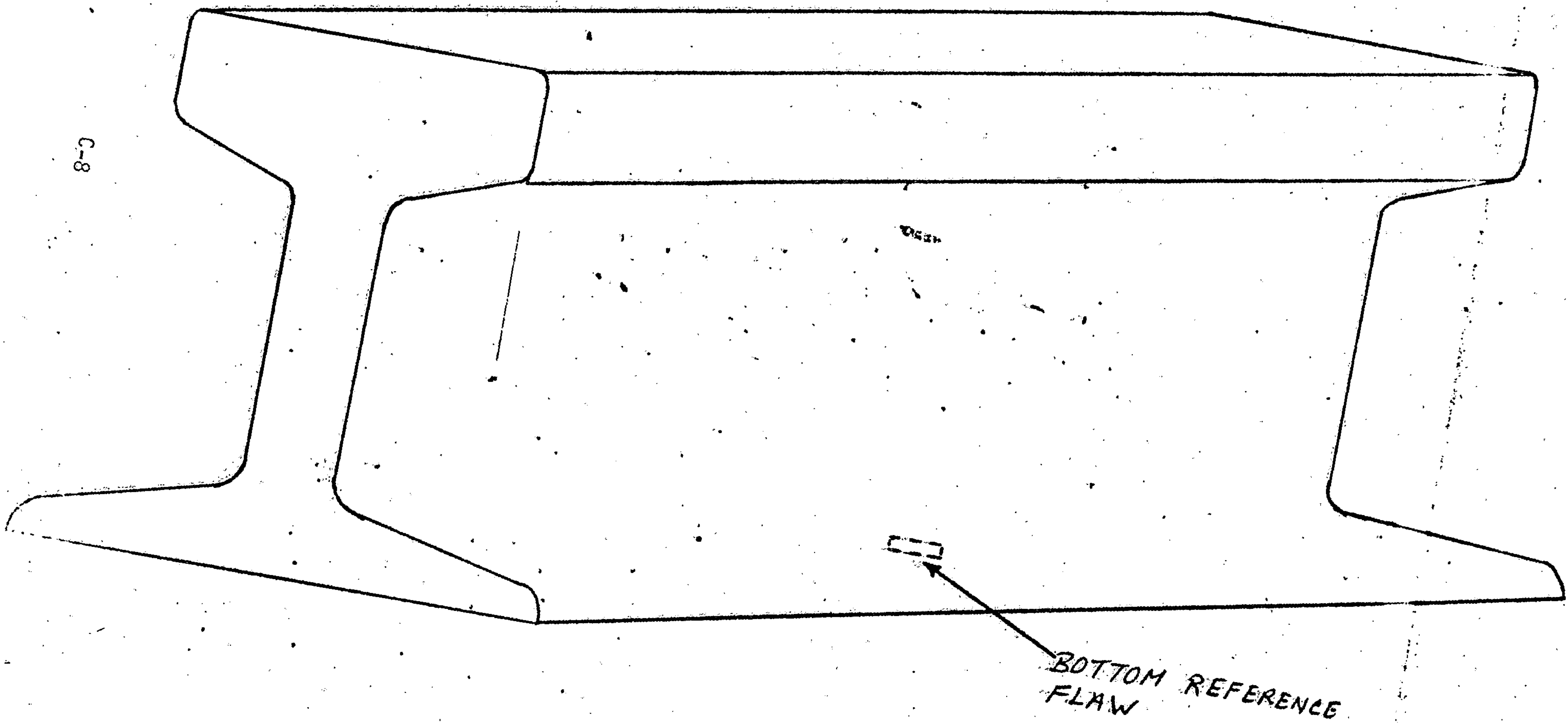


FIGURE 2. REFERENCE RAIL STANDARD

VOUGHT
CORPORATION

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA

2-42200 R1

DATE ________________ Part No. ________________

RESULT

NO. OF INDICATION: ____________________

INDICATION TYPE: ____________________

INDICATION SIZE: ____________________

LOCATION: ____________________

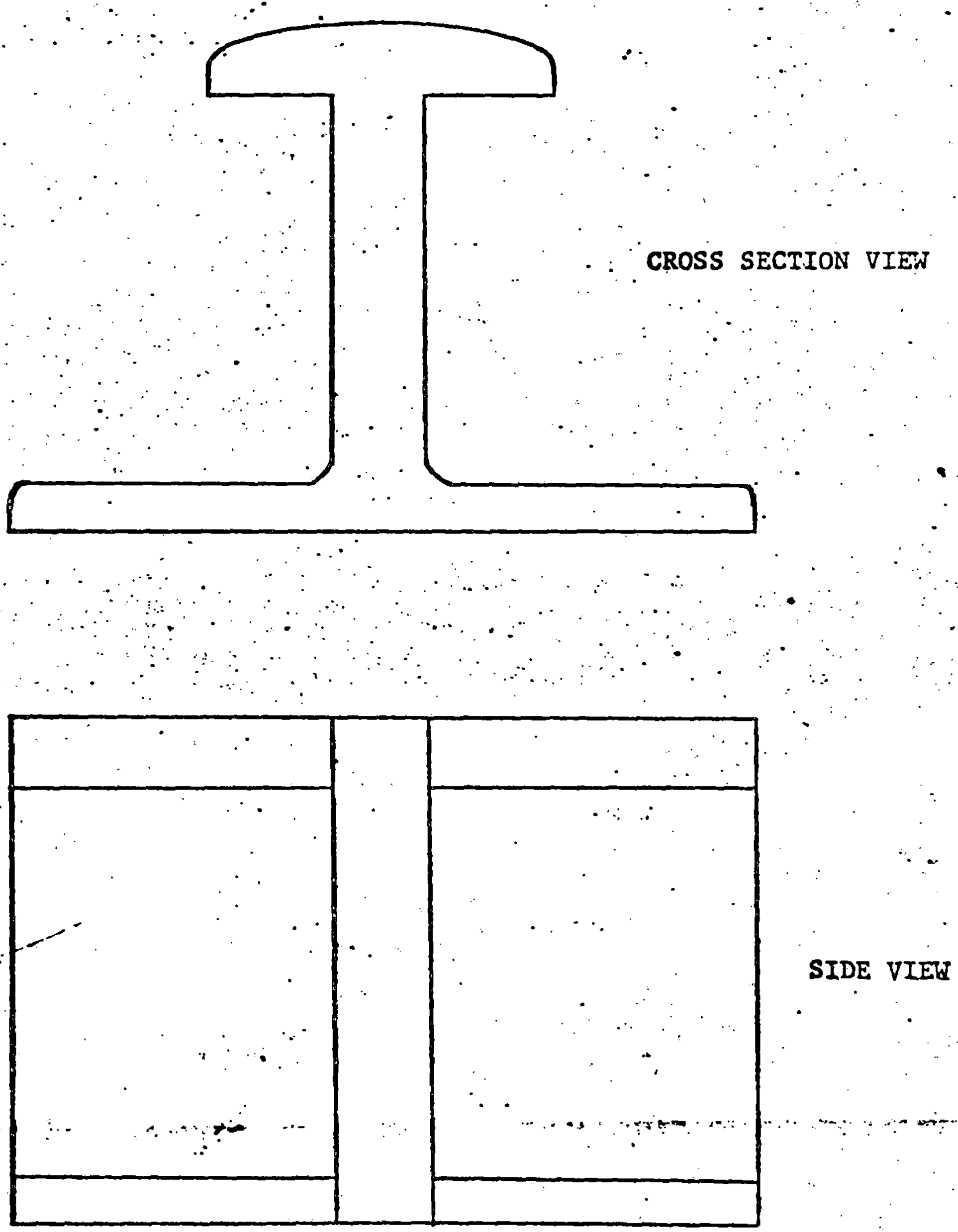


FIGURE 3.

	Number Of Indications	Type	Size	Location Of Weld	% Screen Height
C-1	1	Porosity or Inclusion	0.050"	Middle	Unavailable
C-2	2	Porosity or Inclusion	Not Determined	Middle	Unavailable
C-3	1	Flaw, Porosity	5.0"	Length	90%
C-4	2	Porosity	3.0"	Bottom	20% - 50%
C-5	2	Flaws	3.0"	Bottom	40% - 70%
C-6	6	Porosity	0.050"	Top, Middle, Bottom	30% - 100%
C-7	4	Porosity	0.050"	Middle, Bottom	20% - 40%
C-8	6	Porosity, Flaw	2.0", 1.0"	Top, Middle, Bottom	20% - 90%
C-9	1	Porosity	Not Determined	Bottom	10%
C-10					
C-11	2	Flaws	3.0"	Top	80% - 100%
T-1	2	Porosity, Flaw	2.0"	Bottom	20% - 50%
T-2	3	Porosity, Flaw	1.0"	Top, Middle	50% - 100%

ULTRASONIC RESULTS OF RAIL WELDS

TABLE 1

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

26 JULY 1982
DATE

ONE (C-1)
Part No.

RESULT

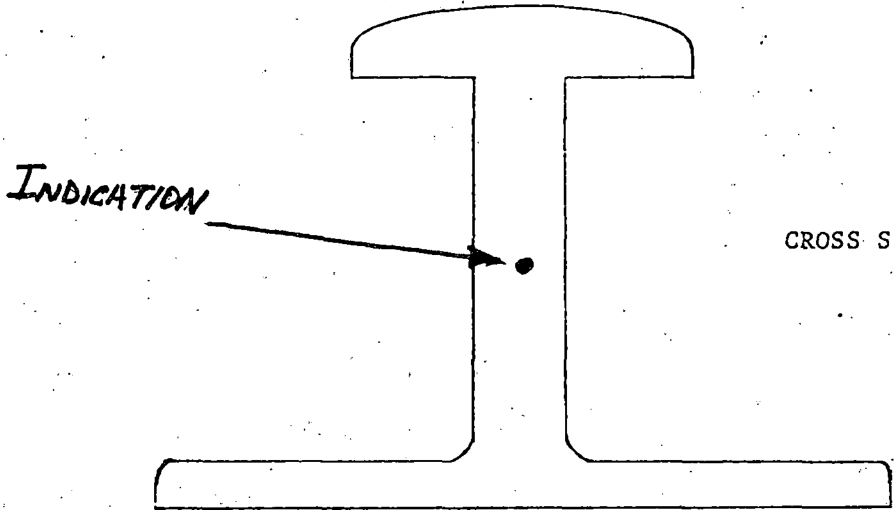
Calorite # 1
95°F AMBIENT
~ 1800°F PREHEAT
(Weld By J. Dolce)
(BEND TEST Specimen)

NO. OF INDICATION: ONE

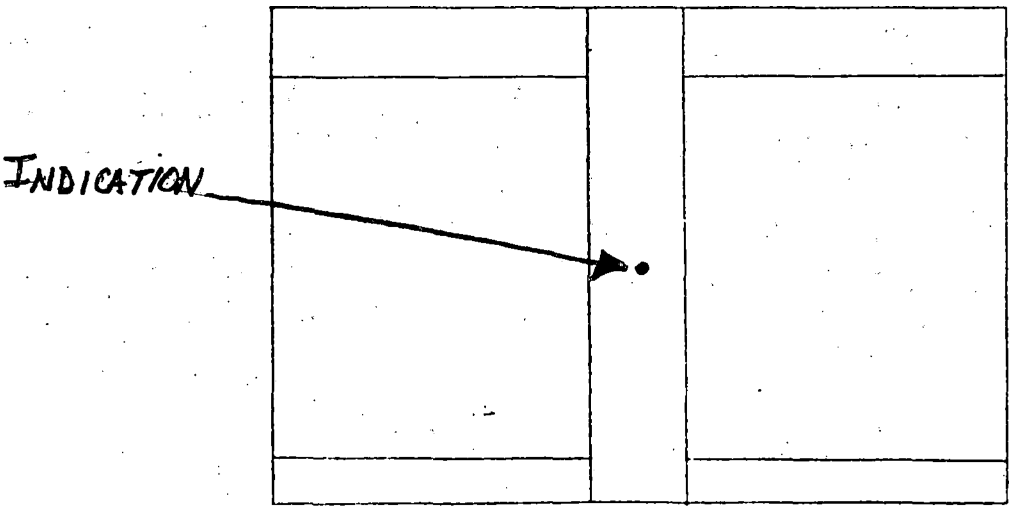
INDICATION TYPE: POSSIBLY POROSITY OR FLAW

INDICATION SIZE: APPROXIMATELY 0.047"

LOCATION: SEE BELOW



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

26 JULY
DATE

TWO(C-2)
Part No.

Calorite #2
95°F Ambient
~ 1800°F Preheat
(Weld by J Dolce)

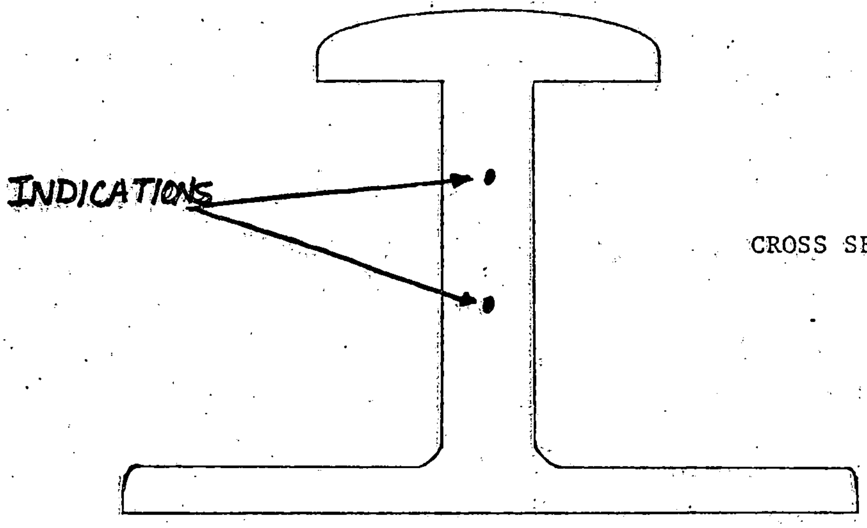
RESULT

NO. OF INDICATION: TWO

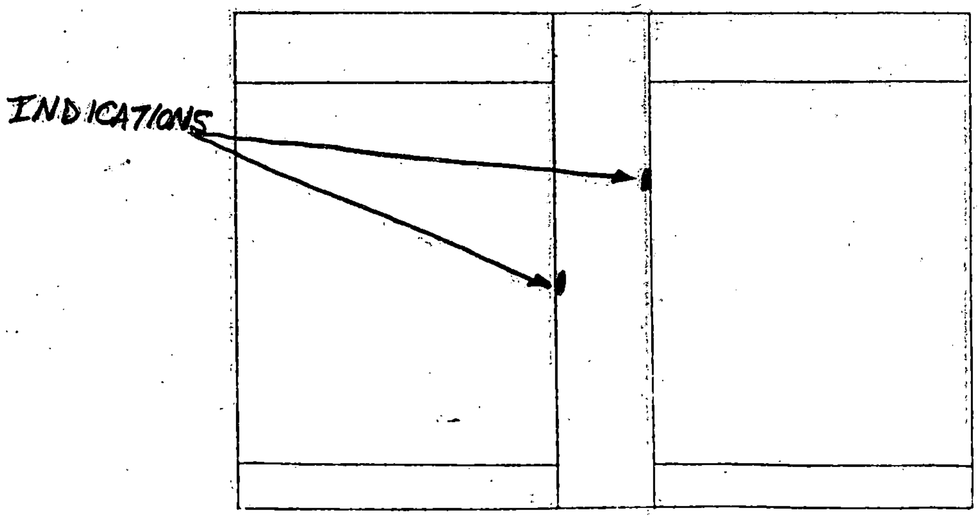
INDICATION TYPE: POSSIBLY POROSITY OR FLAW

INDICATION SIZE: UNABLE TO DETERMINE

LOCATION: SEE BELOW



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing
RESEARCH AND DEVELOPMENT DATA
2-42200 R1

DATE: 6 AUG 1982

Part No.: THREE (C-3)

RESULT

NO. OF INDICATION: ONE (90% OF VERTICAL-BOTTOM TO TOP)

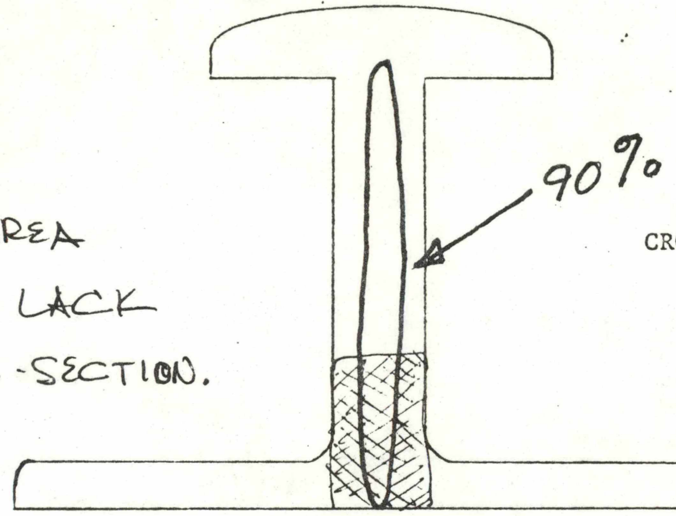
INDICATION TYPE: FLAW SOME POROSITY AND GRAIN

INDICATION SIZE: VERY LARGE

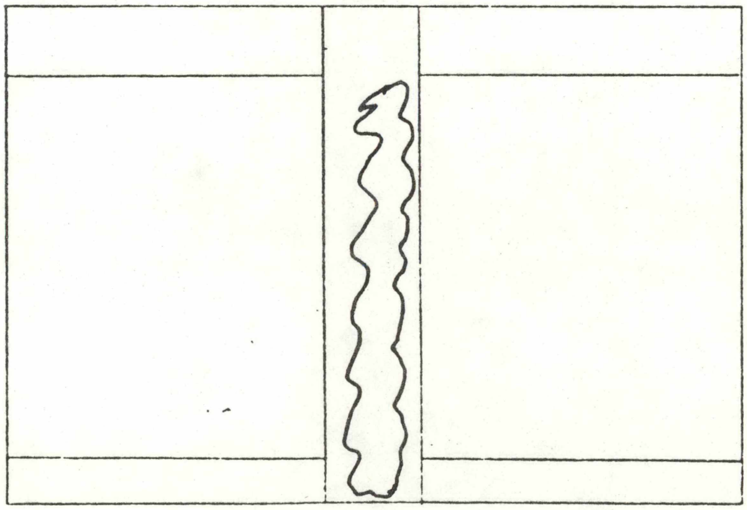
LOCATION: SEE BELOW (DIRECTION FROM A AND/OR B)

Calorite #3
50°F ambient
~1300°F Preheat

CROSS HATCHED AREA SHOWED complete LACK OF FUSION IN C-SECTION.



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 -R1

6 AUG 1982
DATE

FOUR (T1)
Part No.

RESULT

NO. OF INDICATION: TWO

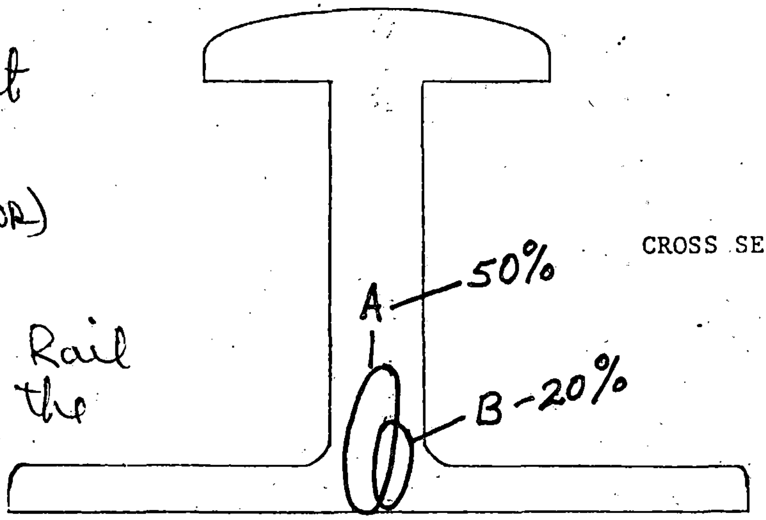
INDICATION TYPE: POROSITY, GRAIN, FLAW

INDICATION SIZE: 1"(B), 2"(A)

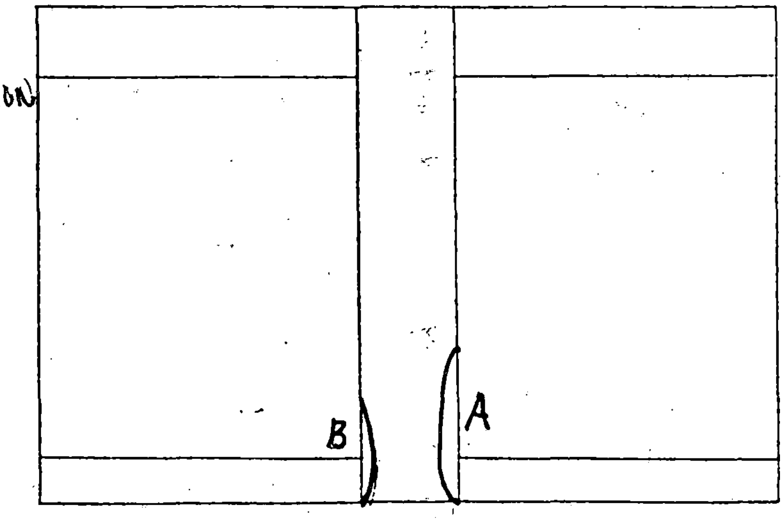
LOCATION: SEE BELOW

US THERMIT
at 95°F ambient
NO-PREHEAT
(PERFORMED By VENDOR)

Cross Sections of Rail Base show that the NDI INDICATIONS ORIGINATED FROM AREAS of SPONGE LIKE POROSITY — A CONCENTRATION of VOIDS WAS NOTED AT the fusion LINE — this could have given a Crack like appearance —



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

6 AUG 1982
DATE

FIVE (C-4)
Part No.

RESULT

NO. OF INDICATION: TWO

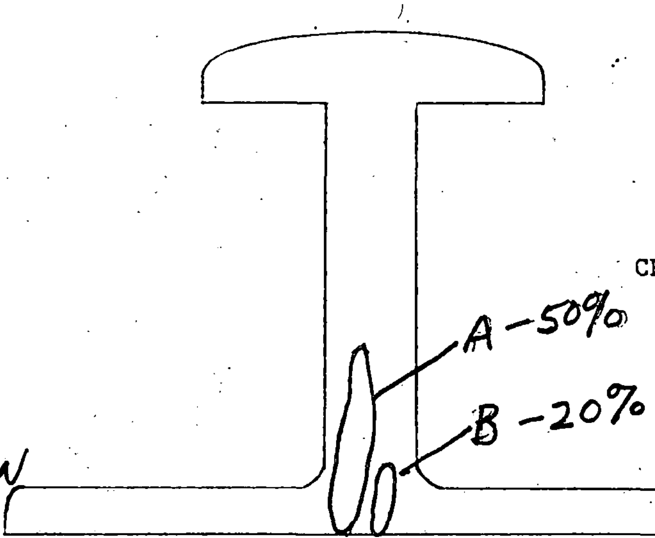
INDICATION TYPE: POROSITY, GRAIN, FLAW

INDICATION SIZE: 3"(A), 1"(B)

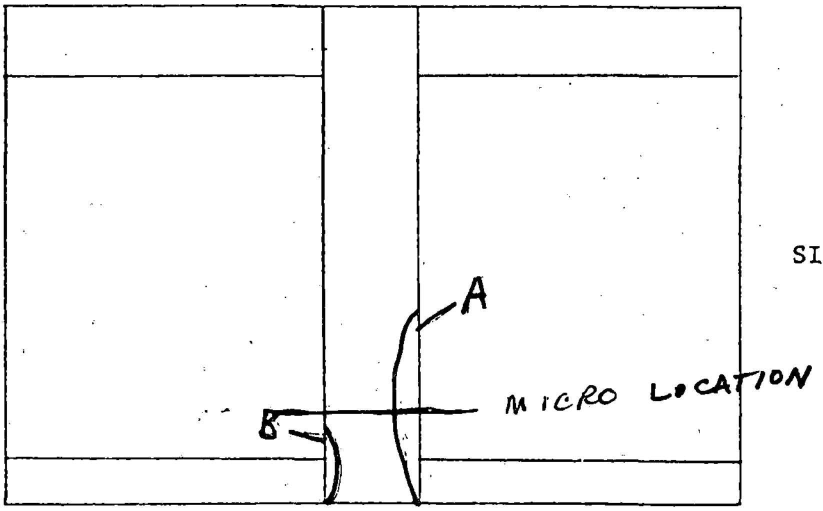
LOCATION: SEE BELOW

Calorite #4
50°F Ambient
2000°F Preheat

NOTHING FOUND ON MICRO SECTION



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

DATE: 8/6/82

Part No.: Six (C-5)

RESULT

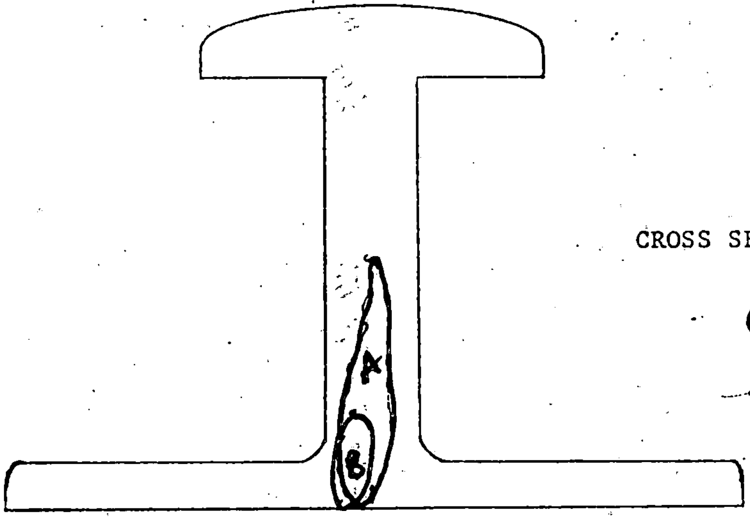
NO. OF INDICATION: 2

INDICATION TYPE: Definite flaws

INDICATION SIZE: (A) - 3", (B) - 1"

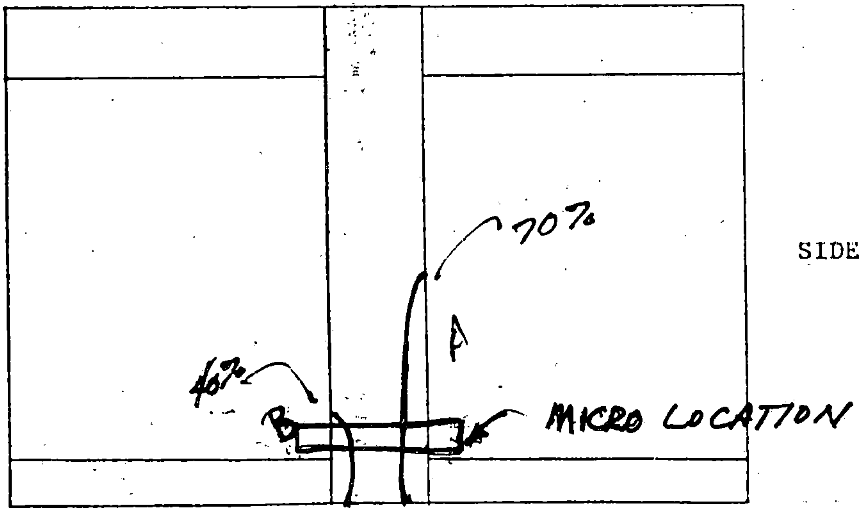
LOCATION: Below

Calorite # 5
50°F ambient
1600°F Preheat



CROSS SECTION VIEW

C-Sect shows
Lack of
Fusion



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

DATE: 8/11/82

Part No.: SEVEN (C-6)

RESULT

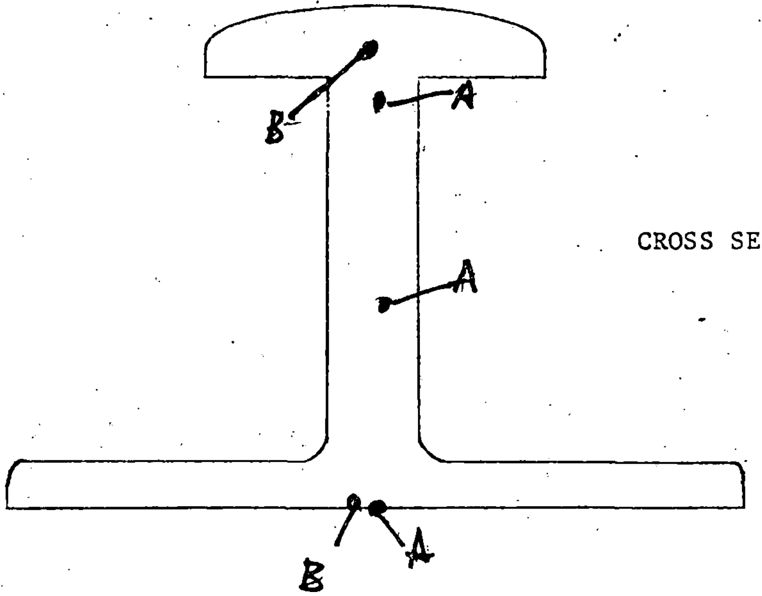
NO. OF INDICATION:

INDICATION TYPE: POROSITY & FLAW

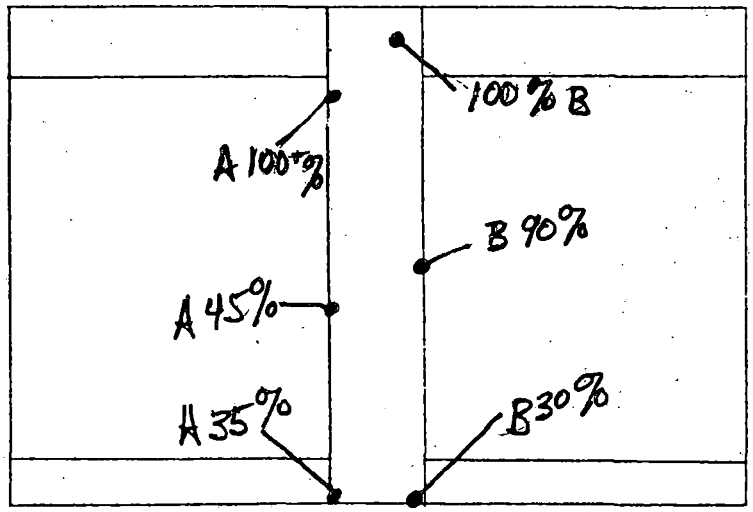
INDICATION SIZE: A - 35%, 45% 100+%, B - 30%, 90%, 100+%

LOCATION: SEE BELOW

Calorite #6
50 °F ambient



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

8/11/82
DATE

EIGHT (C-7)
Part No.

RESULT

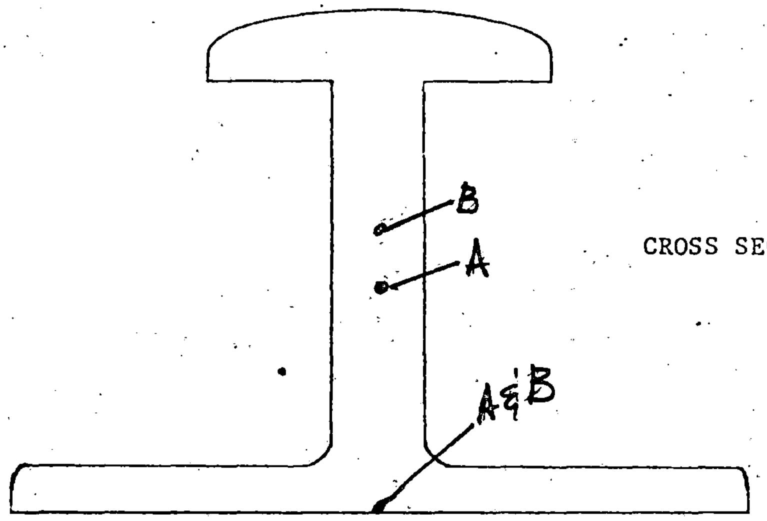
NO. OF INDICATION: FOUR

INDICATION TYPE: POROSITY

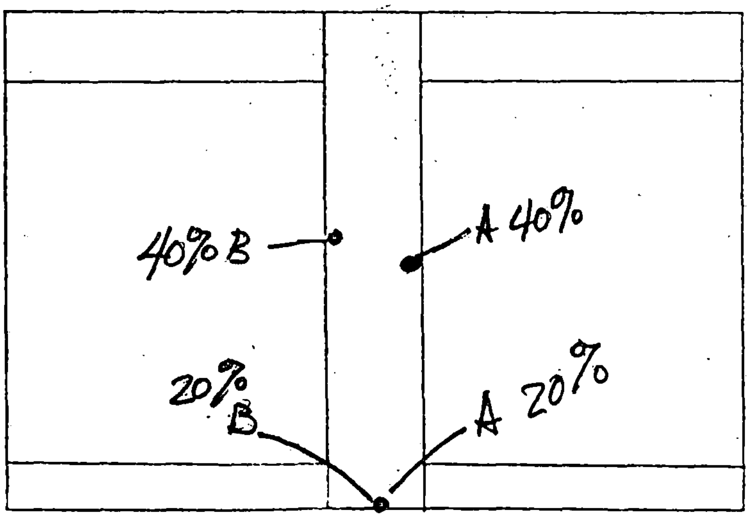
INDICATION SIZE: A 20% 40% B-20%, 40%

LOCATION: SEE BELOW

Calorite # 7
30°F ambient
1400°F Preheat



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

8/13/82
DATE

NINE (C-8)
Part No.

RESULT

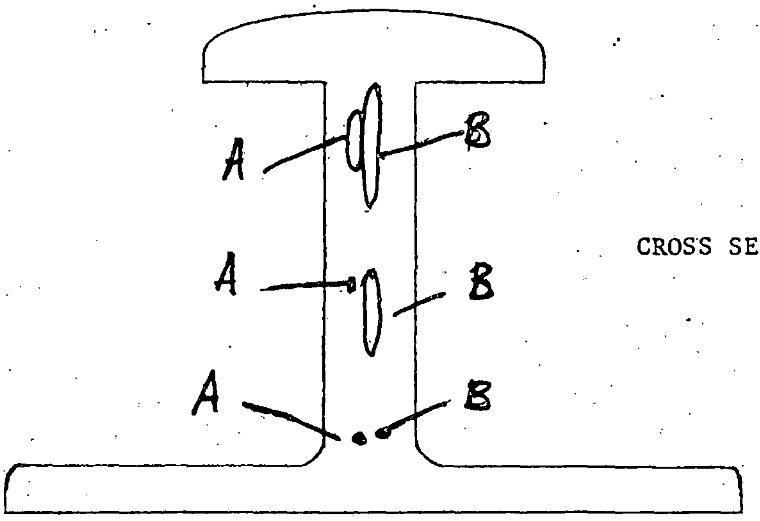
NO. OF INDICATION: SIX

INDICATION TYPE: POROSITY, FLAW

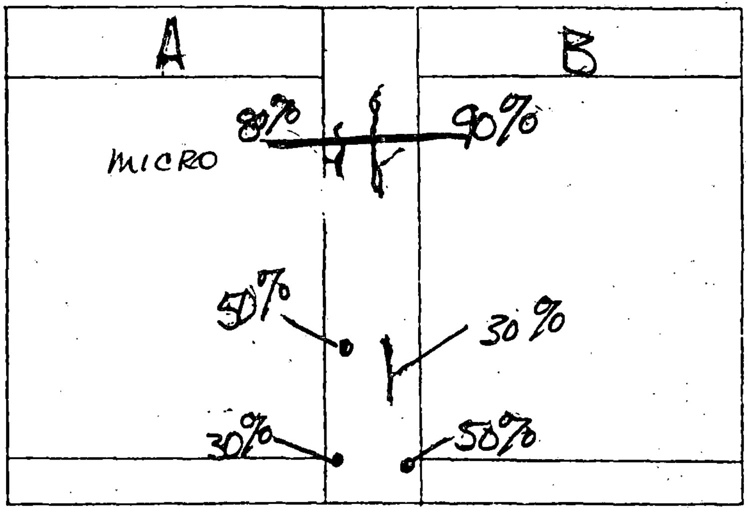
INDICATION SIZE: A- 20%, 50%, 80% B -50%, 30%, 90%

LOCATION: SEE BELOW

MICRO SECTION FAILED TO SHOW DEFECT



CROSS SECTION VIEW



SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

8/20/82
DATE

TEN (C-9)
Part No.

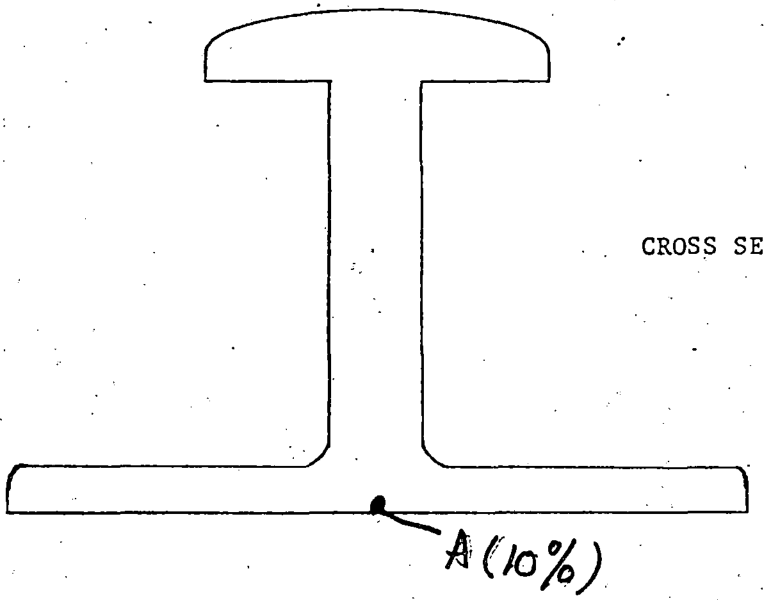
RESULT

NO. OF INDICATION: ONE

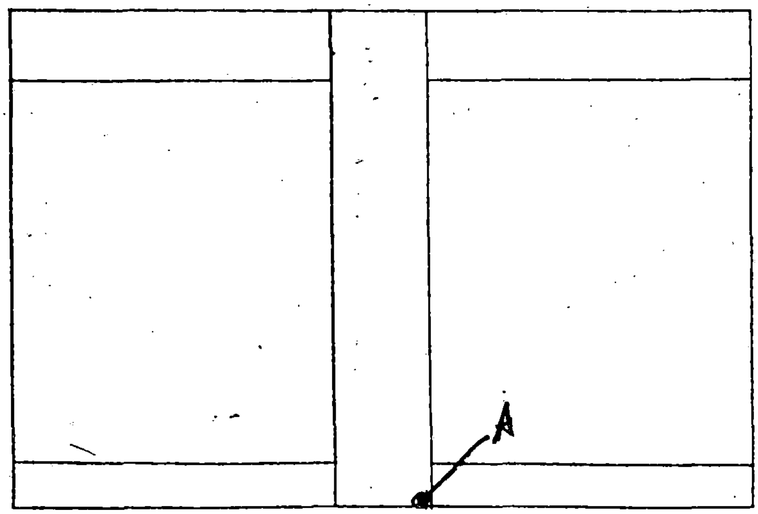
INDICATION TYPE: POROSITY

INDICATION SIZE: 10%

LOCATION: SEE BELOW



CROSS SECTION VIEW



SIDE VIEW

PAGE ______ of ______

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

DATE

C-11
Part No.

RESULT

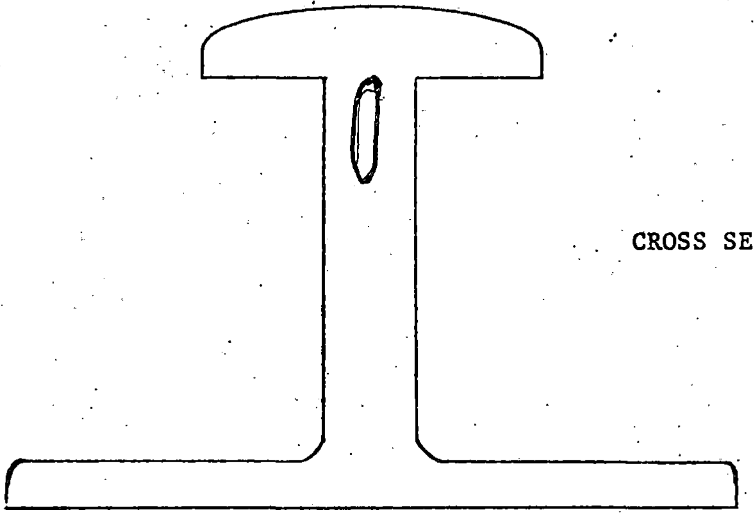
NO. OF INDICATION: ONE

INDICATION TYPE: FLAW

INDICATION SIZE: A - 1½" (80%-100%); B-3" (100%)

LOCATION: Top of WEld

MICRO SHOWED
CRACH THRU
CENTER OF
WELD



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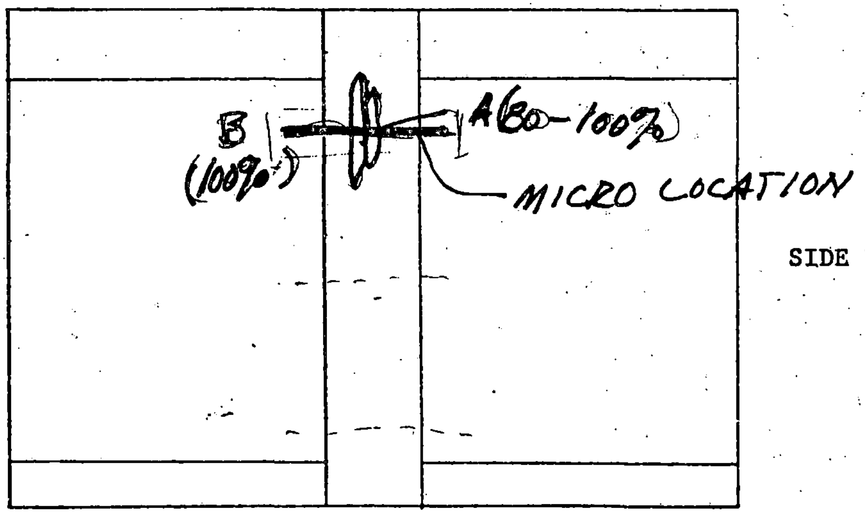


SIDE VIEW

VOUGHT CORPORATION

QUALITY ASSURANCE
NDT LABORATORY

NonDestructive Testing

RESEARCH AND DEVELOPMENT DATA
2-42200 R1

8/20/82
DATE

ELEVEN (T-2)
Part No.

RESULT

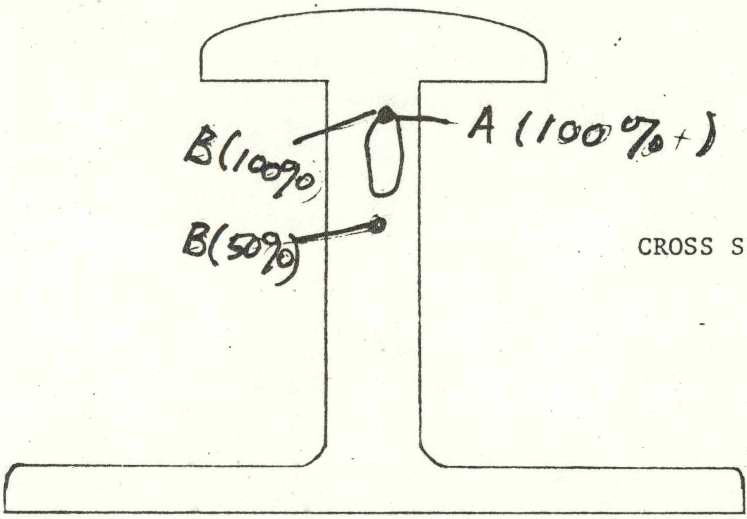
30°F AMBIENT

NO. OF INDICATION: THREE

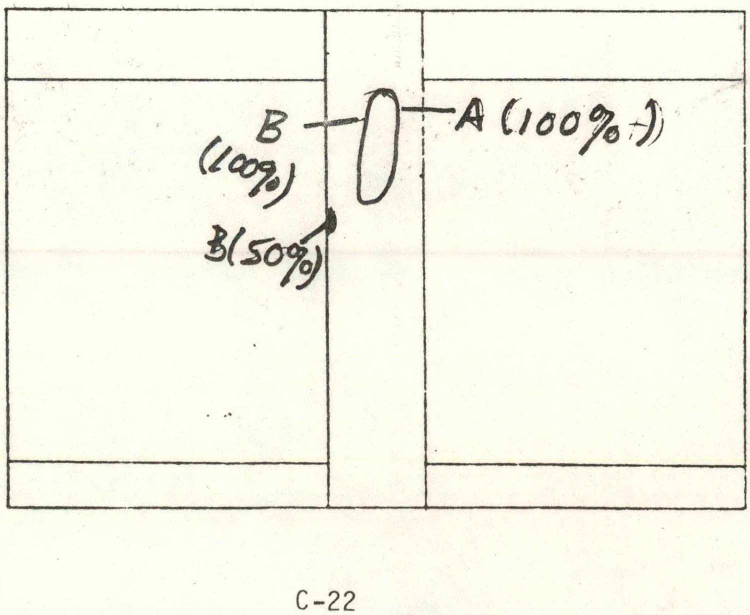
INDICATION TYPE: POROSITY, FLAW

INDICATION SIZE: A - 1"(100%-)

LOCATION: SEE BELOW



CROSS SECTION VIEW



SIDE VIEW