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EXAMINATION OF QUEBEC NORTH SHORE AND LABRADOR RAIL STEEL SERVICE AND TEST RAIL SECTIONS

by

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SUMMARY OF RESULTS

The mechanical and metallurgical properties of Quebec North Shore and Labrador Railway Company carbon steel rails rolled in the years 1951 to 1962 were compared to determine if any relation could be detected between steel properties, date of manufacture and rail wear. In addition to this comparative examination, one carbon steel rail from the Quebec Cartier Mining Company Railway and one from the Lackawanna Railway were examined. The investigation also included one Dominion Steel and Coal Company manganese-vanadium alloy steel rail and one Bethlehem Steel Company quenched and tempered steel rail.

From the metallurgical viewpoint, the properties of the manganese-vanadium alloy steel rail and of the quenched and tempered carbon steel rail appeared to be superior, although the Charpy V-notch impact strength of the alloy steel was low. The fatigue properties of this alloy steel, however, were higher than those obtained with standard carbon steels.

Comparison of the QNS and L carbon steel rail samples indicated that the samples rolled in the years 1951 and 1952 appeared to have slightly higher ultimate and 0.1% proof strengths and less surface decarburization than the samples rolled in 1953, 1957, 1961 and 1962.

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Despite metallurgical differences in the 1952 and 1953 rail samples, both samples were stated to represent batches that gave superior service, of the order of 230 million gross tons of ore hauled. The similarity of service, despite metallurgical differences, suggests that service life is at least partly controlled by non-metallurgical factors-for example, by wheel loads, winter roadbed conditions, by track elevation and curvature in relation to contact area, by train speed, and by inspection or maintenance conditions.

The surface of the 1951 and 1952 QNS and L and of the Quebec Cartier rail appeared superior with respect to surface hardness and absence of decarburization in comparison with QNS and L rail of later manufacture. Rail samples for 1957 were less clean than average, and samples rolled in the years 1953 to 1962 inclusive, appeared to contain more surface decarburization, for a depth of about 1/16in. at the top centre position, than rail rolled in 1951 or 1952. Highest Charpy V-notch impact strength in standard carbon steel rails was obtained in 1962 QNS and L samples and in the Lackawanna rail sample. The heat treated carbon steel rail gave the highest tensile and impact results of any of the samples tested. The alloy steel rail gave higher fatigue results than standard carbon steel; however, no fatigue tests were made on the heat treated carbon steel.

The ultimate tensile strength of standard carbon steel rail varied between 110 and 148 kpsi, and the per cent reduction in area varied between 4.0% and 25.0%. All rail had been control-cooled to avoid hazard of hydrogen-thermal flakes.

The results of tensile, Charpy and fatigue tests done in the longitudinal and transverse directions at seven points representing the 39 ft length of one rail from each of the years 1951 to 1962 inclusive, and of a length of manganese-vanadium alloy steel rail are included. Comparison of the 1953, 1957 and 1962 samples did not reveal any statistically significant difference in mechanical properties throughout the length of individual rails. The data for the full-length rail tests are listed and discussed in Appendix A.

INTRODUCTION

A comparison of the metallurgical and mechanical properties of rail samples, representing rail rolled by Dominion Steel and Coal Company (DOSCO) in the years 1951, 1952, 1953, 1957, 1961, 1962 and 1963, has been carried out by the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, at the request of Dr. Hugues Marquis, Research Engineer, Quebec North Shore and Labrador Railway Company (QNS and L) Sept Iles, P. Q.

The rails and rail sections were new or slightly used and were lengths remaining from batches of rail rolled between 1951 and 1963. The rail, represented by the samples, was used in service in the QNS and L Railway in the years 1954 to 1963.

OBJECT AND SCOPE OF INVESTIGATION

One object of the investigation was to detect any metallurgical or mechanical property of the steel rail that could be related to the service life obtained. (At this time, no attempt was made to associate wear life of rail with operating variables, such as wheel loading, extent of winter operation, roadbed condition, or inspection standard. However, complete records of rail service with respect to manufacture, position in the line, curvature of track, incidence of service defects and total tonnage carried is available for the rail represented by the samples).

A second object of the tests was to obtain metallurgical information concerning test lengths cut from a DOSCO, manganese-vanadium alloy steel rail and from a liquid-quenched, tempered, carbon steel rail for comparison with standard high carbon rail steel manufactured by DOSCO, U. S. Steel, or Bethlehem Steel Company. The information obtained, supplemented by operations data on test sections installed in the QNS and L Railway, is intended to assist in making decisions about the suitability of carbon, alloy, or heat treated rail steel for heavily loaded Labrador iron ore train service.

IDENTIFICATION OF SAMPLES

The samples examined are identified by the letters A to U throughout this report and are listed in Table 1. Rail samples from each of three heats were examined for each year of fabrication, except 1953, when only two samples were submitted. Two of the samples (from each year) were 6 in. in length and were cut adjacent to one end of each rail. The third set of samples was cut at intervals from 39 ft rail lengths and, in addition to metallurgical tests (at one position) these rails were sectioned and test bars were obtained for tensile, impact and fatigue tests in the longitudinal and transverse directions at seven positions along the length of the rail. Thus, the investigation included three replicates with respect to melts and one complete length of rail from each year of fabrication together with the history of each rail with respect to furnace practice, ingot number, or rail position within the ingot. The code relating ingot and rail number to the samples is shown in Table 1. The rail samples submitted for investigation are illustrated in Figure 1.

Throughout this report the rail samples are identified by use of the code letters A to U inclusive or by letter and position whenever mechanical tests were carried out along the 39 ft length.

PROCEDURE

Metallurgical examination and mechanical testing of the rail samples were carried out as follows:

(1) Chemical Analysis - samples A to U inclusive (Table 2).

(2) Macroexamination - illustrates the quantity of surface seams observed on the head and flange surfaces of the rails (Figures 2 and 3, Table 11).

(3) Deep Etch - ground transverse sections (Figure 4).

(4) Sulphur Prints - ground transverse sections (Figure 5).

(5) Hardness Tests - Tukon hardness, measured at the top centre position of the transverse rail section (Table 3). Rockwell hardness, core hardness (Table 4).

(6) Cleanness Examination - inclusion count (Table 5).

(7) Grain Size Count - (Table 6).

(8) Ferrite Area Quantity at Surface - surface decarburization and grain boundary ferrite (Table 7, Figure 8).

(9) Pearlite, Lamellar Spacing - metallography "crown" area (Figure 9).

(10) Mechanical Tests, 6 in. Samples - tensile and Charpy V-notch impact strength - samples A to U (Tables 8, 9, 10, 11).

(11) Mechanical Tests, 39 ft Rails-(Appendix A). Samples C, F, H, K, N and Q. tensile, Charpy V-notch and Krouse fatigue tests at seven positions spaced along the 39 ft lengths of rail.

(12) Summary of Results -(Tables 10 and 11). Residual Gas contents (H_2, O_2, N_2)-Table 12.

TABLE 1.

Identification of Rail Samples

Type RE, 132 lb/yd, Control-Cooled Rail

Code	Year of Mfg.	Mfger's. Serial No.	Full length (39 ft) Sample Examined	Description	Ingot No. & Rail Position	Service
A	1951	G848-8E	--	DOSCO-CC-132lb/yd RE	Ingot 8,Rail E	Light
B	"	E181-15E	--	" " " "	" 15, " E	"
C	"	C566-10B	51-1/51-9	" " " "	" 10, " B	"
D	1952	E849-12E	--	" " " "		"
E	"	C336-17E	--	" " " "		"
F	"	E994-17E	52-1/52-9	" " " "		"
G	1953	A196-2D	--	" " " "		"
H	"	C217-1D	53-1/53-9	" " " "		New
I	1957	B489-14D	--	" " " "		"
J	"	B493-17D	--	" " " "		"
K	"	C577-11E	57-1/57-9	" " " "		"
L	1961	4406-23E	--	" " " "		"
M	"	2874-28D	--	" " " "		"
N	"	4235-14E	61-1/61-9	" " " "		"
O	1962	5162-23E	--	" " " "		"
P	"	5167-19F	--	" " " "		"
Q	"	5163-9F	62-1/62-9	" " " "		"
R	1963	EA824-1D	EA1/EA9	DOSCO Mn-V Alloy Steel		"
S	--	739295-B26	--	U.S.S., Que. Cartier		Used
T	1963	29355-F7	--	Bethlehem Lackawanna		New
U	1962	Bethlehem	--	Bethlehem-Heat Treated		"

Full Length Rails Tested - Samples:- C, F, H, K, N, Q and (Alloy) R.

(1) Chemical Analysis

The results of chemical analysis of the samples A to U are shown in Table 2.

The QNS and L specification for 132 lb RE rail requires that, "the average mill carbon content shall be not less than 0.755% and that, the number of heats having a carbon exceeding 0.755% shall be at least equal to the number of heats having a carbon content of less than 0.755%.

Rails rolled from heats having a carbon content of 0.78% or more and a manganese content of 0.85% or more, shall be classed as high carbon rails.

Rails rolled from heats having a carbon content of less than 0.78% and a manganese content of less than 0.85%, shall be classed as low carbon rails".

(2) Macroexamination

A one-inch section from each of the rail samples was surface ground, deep etched and examined to observe the quantity of seams visible on the head and flange surfaces. The appearance of the head and flange sections, Samples A to U inclusive, is shown in Figures 1, 2 and 3. - (The Samples were ranked 1 to 4, the quantity of seams increasing to a maximum at No. 4. - Tables 10 and 11).

(3) Deep Etch, Transverse Sections

The appearance of transverse sections, etched 20 min in hot 50% HCl, 50% water at 160-180°F is illustrated in Figure 4. (A to U). (See also inclusion count, Table 5).

(4) Sulphur Print

Transverse sections were ground and sulphur prints were obtained to show any segregation of sulphur with respect to the working surfaces of the rail head. The appearance of these prints is illustrated in Figure 5. (A to U).

(The sections were ranked 1 to 4 in order of increasing quantity of sulphide inclusions, rating No. 4 indicating the maximum concentration of sulphides, Tables 10 and 11).

TABLE 2.

Chemical Analysis Samples A to U Inclusive

Sample and year of Mfg.	Element - (Per Cent)												
	C	Mn	Si	S	P	N	Soluble Al	Cr	V	Ni	Mo	Cu	Sn
1951-A	0.81	0.89	0.14	0.023	0.033	0.003	0.002	0.02	--	0.01	<0.01	0.02	<0.01
" B	0.75	0.85	0.13	0.030	0.037	0.003	0.002	0.02	--	0.02	<0.01	0.05	0.01
" C	0.82	1.00	0.13	0.030	0.038	0.007	<0.002	0.02	--	0.02	<0.01	0.03	<0.01
1952-D	0.75	1.15	0.19	0.016	0.023	0.003	0.002	0.02	--	0.02	<0.01	0.06	<0.01
" E	0.67	1.06	0.12	0.036	0.029	0.008	0.003	0.02	--	0.02	<0.01	0.09	0.01
" F	0.80	1.12	0.14	0.028	0.033	0.006	0.003	0.01	--	0.02	<0.01	0.04	<0.01
1953-G	0.67	0.85	0.08	0.015	0.033	0.004	0.002	0.02	--	0.02	<0.01	0.03	0.01
" H	0.72	0.72	0.17	0.021	0.026	0.005	0.003	0.02	--	0.02	<0.01	0.03	<0.01
1957-I	0.77	0.94	0.15	0.033	0.025	0.005	0.003	0.02	--	0.02	<0.01	0.09	0.01
" J	0.72	0.79	0.15	0.029	0.026	0.004	0.004	0.03	--	0.02	0.01	0.10	0.01
" K	0.70	0.72	0.14	0.029	0.016	0.005	<0.002	0.04	--	0.02	0.02	0.04	<0.01
1961-L	0.74	0.86	0.12	0.028	0.014	0.003	<0.002	0.02	--	0.01	<0.01	0.03	<0.01
" M	0.78	0.90	0.12	0.025	0.031	0.002	0.002	0.02	--	0.02	<0.01	0.09	0.01
" N	0.72	0.97	0.13	0.022	0.020	0.002	<0.002	0.02	--	0.01	<0.01	0.02	<0.01
1962-O	0.73	0.80	0.12	0.029	0.009	0.003	0.007	0.03	--	0.02	<0.01	0.09	<0.01
" P	0.77	0.87	0.13	0.029	0.009	0.003	0.004	0.03	--	0.03	<0.01	0.11	<0.01
" Q	0.73	0.76	0.15	0.029	0.009	0.003	<0.002	0.04	--	0.04	0.02	0.12	0.01
1963-R	0.60	1.64	0.32	0.026	0.010	0.005	0.004	0.33	0.10	0.03	0.01	0.06	<0.01
" S	0.78	0.84	0.17	0.035	0.023	0.003	0.003	0.03	--	0.01	<0.01	0.03	<0.01
" T	0.76	0.97	0.17	0.030	0.007	0.004	0.004	0.04	--	0.01	<0.01	0.02	<0.01
" U	0.74	0.78	0.19	0.042	0.013	0.003	0.003	0.06	--	0.04	0.01	0.13	0.02
QNS&L Spec. C.Steel Rails	0.68 0.83	0.70 1.00	0.10 0.20	0.055 max.	0.040 max.								

Note the high manganese level in 1951 and 1952 samples C, D, E, F.

Average carbon level of samples 0.744% (DOSCO samples A to O inclusive)..
No. of samples having carbon higher than 0.755% = 6 samples.
No. of samples having carbon lower than 0.755% = 9 samples.

High carbon, 132 lb RE rails (>.78%C, >.85%Mn) - A, C, F, I, M, P,-S
Low carbon, 132 lb RE rails (<.78%C, <.85%Mn)-B, D, E, G, H, J, K, L, N, O, Q,-T, U
Manganese content 0.85% on above - A, B, C, D, E, F, G, I, L, M, N, P, - R, T.
Manganese content 1.00% on above C, D, E, F.

(5) Hardness Surveys

Tukon hardness surveys were taken inwards from the centre of the head (crown) surface. The amount of surface decarburization is illustrated in Figure 8. The results of Tukon hardness measurements made for a depth of about 1/16 in. are listed in Table 3.

Rockwell C hardness tests were made on a ground transverse section through each of the Samples A to U according to the plan shown in Figure 6. The Rockwell hardness values are listed in Table 4.

(6) Inclusion Counts

Inclusions were counted at the centre surface of the head, $\frac{1}{4}$ in. beneath the surface and $1\frac{1}{4}$ in. from the contact point. Counts of the total number of inclusions observed in ten random areas of 0.0054 in.^{2}, located at the crown of the rail head, $\frac{1}{4}$ in. from the crown and $1\frac{1}{4}$ in. from the crown were obtained using a quantitative television microscope (Q.T.M.) at maximum sensitivity. Part of the area rated for cleanness is shown in Figure 8. The results of inclusion counts are listed in Table 5.

(7) Grain Size

The austenite grain size was measured in transverse microspecimens, taken at the head surface, $\frac{1}{4}$ in. from the surface and $1\frac{1}{4}$ in. from the surface, using polarized light and an ASTM, McQuaid-Ehn eyepiece. The samples were viewed after etching in 2% nital solution. The grain size results are listed in Table 6.

(8) Ferrite Area Measurement

The area of ferrite observed at the decarburized head surfaces or as grain boundary ferrite was determined using the Q.T.M. instrument. The location of the tests and the results are shown in Table 7.

(9) Pearlite Lamellae Spacing

The interlamellar spacing and appearance of the pearlite observed in the rail samples is illustrated in Figure 9. The appearance of pearlite observed in the four test sections R, S, T and U is also shown in Figure 9.

(10) Mechanical Tests - (8 in. lengths of rail)

The location of Hounsfield tensile and Charpy V-notch impact test specimens, taken from Samples A to U inclusive, is shown in Figure 7. The results of tensile tests (3 bars per sample) and of impact tests made at 300°F, 212°F, and 75°F are listed in Tables 8, 9 and 10. Averaged results are reported in Table 11.

(11) Mechanical Tests - 39 ft. lengths of rail)

Longitudinal and transverse, tensile, Charpy V-notch and Krouse fatigue tests were carried out at several intervals along the length of one 39 ft rail sample from each group viz:- 1951, 1952, 1953, 1957, 1961, 1962 and from the Mn-V alloy steel rail. These tests are described and the results are listed in Appendix A.

(12) Summary of Results

The results, exclusive of those shown in Appendix A, are summarized and shown as averages for each year of fabrication in Tables 10 and 11.

Table 12 lists the results of determinations for residual hydrogen, nitrogen and oxygen in metal cut from the rail samples.

OBSERVATIONS

(1) Variation of carbon content between 0.67% (Samples E and G) and 0.82% (Sample C - 1951) was noted. Considerable variation in manganese to carbon ratio 0.91 to 1.50 and in total alloy content was noted and was reflected in the ultimate strength values. The sixth column, Table 11, lists the total per cent alloy obtained by summing the C, Mn, Si, Ni, Cr, Mo, Cu, Sn content of each sample.

(2) The highest ultimate tensile strength and 0.1% proof strength for standard carbon steel rail were obtained in the DOSCO 1951/1952 samples and in the Quebec Cartier Sample (S), as shown in Table 11.

These samples were characterized by having a section hardness of at least Rockwell C 27 and by showing practically no decarburization at the centre contact surface. These samples also showed some work-hardening of the contact surface. The Charpy V-notch impact strength of these samples was lower than the 1962 group.

(3) Sample G (1953) contained only 0.67%C and was decarburized for a depth of about 1/16 in. This sample did not appear to have work-hardened to the extent noted in the 1951/1952 samples.

(4) The 1957 Samples (I, J, K) had considerably higher inclusion contents than any of the other groups and were also decarburized at the centre contact surface.

(5) Rail samples produced in 1961 and 1962, were stated to have given only 90 million and 53 million tons service respectively. These samples tended to have intermediate carbon and alloy contents. This rail, unlike the 1951 and 1952 rail, was characterized by the presence of surface decarburization, (Table 11). The tensile and yield strengths were lower than the 1951 and 1952 samples but were higher than the 1953 and 1957 samples. Except for surface decarburization and lower tensile strength, rail fabricated in 1961 and 1962 appeared to compare favourably with 1951/1952 production in inclusion content and evidence of macrosegregation.

(6) The tensile strength, yield strength, tensile ductility and Charpy V-notch impact results obtained on the heat treated carbon steel Sample (U) were considerably higher than any of the other carbon steel samples and were slightly higher than the manganese-vanadium alloy steel rail Sample (R).

(7) The alloy steel rail Sample (R) had higher ultimate tensile, yield strength and tensile ductility than carbon steel rails at the same hardness. The Charpy V-notch impact strength was the same as that of the carbon steel rails having higher carbon and alloy content but was lower than the averaged result for 1962 carbon steel rails. (Improved fatigue life was obtained - see Appendix A).

(8) The results of mechanical tests made along the length of one rail sample from each year of fabrication are discussed in Appendix A.

(9) None of the samples had been deoxidized by use of aluminum. However, an ASTM grain size of 6 was observed in the manganese-vanadium alloy steel rail containing 0.10% V. The heat treated Sample (U) was fine grained due to recrystallization during heat treatment and had a grain size of ASTM 7. The silicon content of all samples varied between 0.12% and 0.19%, excepting Sample G (1953) having 0.08% Si, and the manganese-vanadium alloy steel rail Sample R having 0.32% Si.

(10) The phosphorus content of the 1962 rails at 0.009% was lower than that observed in the other groups.

DISCUSSION

Separation of metallurgical and operating variables is difficult, for example, the extent to which "slight service" has affected the surface of the 1951 and 1952 samples is unknown. In these samples there is definite evidence of cold working of the surface, whereas "slight service" in Sample G appears to have caused no change. The latter resembles Sample H, which was never used in service. Evaluation of the results also presumes that the samples submitted are typical of and accurately represent the batches of rail that actually gave service variation between 235 and 50 million gross tons.

The 1951/52 rail samples and the Quebec Cartier rail sample appear superior with respect to surface decarburization, tensile strength and hardness. These samples have work hardened and have higher than average 0.1% proof stress. This rail represented rail having a service life of 230 million gross tons.

However, rail rolled in 1953, represented by Samples G and H, was also reported to give similar service, despite the fact that its chemical composition and mechanical properties were at the extreme low side of the specification, opposite to the 1951-52 samples.

The 1953 rail samples contained lower than average quantities of carbon, manganese, and other alloy content, had minimum tensile strength, hardness, and were decarburized for a depth of 1/16 in., at the contact surface.

Rail from the 1957 group appeared to be dirtier than that from the other groups and, while tonnage records were not provided for this group, the high inclusion content might infer poor service with this group if service life is responsive to inclusion content. (Al_2O_3 inclusions of the galaxy or cluster type were not observed in any of these, silicon-killed steels).

Rail from the 1961 and 1962 rolling appeared to be intermediate between the 1951-52 and the 1953 groups with respect to decarburization, tensile strength, hardness and total alloy content. The 1962 rail appeared superior with respect to cleanness, etched sections (macrosegregation) and phosphorus content, yet was reported to have given only 50 million gross tons' service. These rails gave the highest Charpy V-notch impact results of any of the standard carbon steel rails, but did have slightly lower 0.1% proof stress than the 1951-52 and Quebec Cartier (S) rail samples.

Examination of the metallurgical data would indicate that the DOSCO alloy rail steel and the heat treated carbon steel rail, of those tested, should have the best chance of demonstrating improved service in the test installations, (2) (11) (15) (17) (19). The Charpy V-notch impact properties of the heat treated carbon steel were considerably higher than those of the alloy steel section examined.

Data are published [10] for a similar eutectoid steel composition, which shows that, in small, 5/8 in. x 5/8 in. aluminum-killed sections heat treated by quenching and isothermal transformation at 1000°F, ultimate tensile strength of 174 kpsi, 15% elongation and 46% reduction in area were developed at a BHN of 329.. (Use of this type of heat treatment for rail steel would require alloying to make the quench possible but in the past has been precluded by the necessity for slow "control-cooling" to avoid hydrogen defects. Possibly in the future control of hydrogen content may offer the possibility of direct quenching after hot rolling) [12,38].

No investigation was made of induction-hardened rail at this time.

CONCLUSIONS

(1) The combination of metallurgical and mechanical properties, observed in the liquid quenched and tempered Sample U and in the DOSCO manganese-vanadium alloy steel rail would be expected to offer some increase of service life in comparison with standard carbon steel rail. (Results from the rail test bed will tend to confirm or disprove this possibility). The Charpy V-notch impact strength of the quenched and tempered carbon steel rail appeared to be considerably higher than that of the alloy steel rail sample.

(2) The DOSCO 1951-52 rail samples and the Quebec Cartier rail sample appeared to be superior with respect to absence of surface decarburization and also had higher than average section hardness [17].

(3) The rail samples representing 1957 fabrication gave higher inclusion counts than other groups.

(4) The Samples, 1952 (D,E,F) and 1953 (G,H), appeared to represent the two extremes of composition within the specification but, despite this, had afforded equivalent service, possibly indicative that service life of standard carbon steel rails was controlled by non-metallurgical factors. (This may not be true at the higher strength levels represented by Samples R and U).

(5) No conclusion is possible concerning service factors, known to influence rail wear since the scope of this work has been limited to metallurgical and mechanical testing.

(6) Residual hydrogen content obtained after cutting $\frac{1}{4}x\frac{1}{4}x\frac{1}{4}$ in. cubes from the head section of the rail samples varied between 0.00001 and 0.00013% by weight. Residual oxygen varied between 0.0009 and 0.0106%. The nitrogen level varied between 0.002 and 0.008%.

RECOMMENDATION

Observe if data from the test bed indicate improved life for the manganese-vanadium alloy steel and the heat treated steel samples.

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7. Data, Electric Arc Alloy Steel, Mn-V, Melt E824 Sample "R" Report - High Strength Rail Steel; Test Data on Trial Lot - DOSCO 11501 Rail Dominion Steel and Coal Corporation, Limited, Sydney Works (May 30, 1963). Letter - Mr. L.C. Johnston, Chief Metallurgist, Sydney Works, Dominion Steel and Coal Corporation, Limited to Mr. K.R. Kilburn, Research Engineer, Quebec North Shore and Labrador Railway. Heats No. EA-823; EA-824; EA-825; EA-826; EA-827.

8. Visit to Sept Iles, P. Q., to Study Quebec North Shore and Labrador Railway Company Operations and to Labrador City, Labrador to observe Iron Ore Company of Canada (IOC) Operation, January 11 to 14, 1965, by E.G. Eeles and D.E. Parsons, Physical Metallurgy Division Internal Report PM-V-65-3 (February 18, 1965).

9. "Rail Defect Manual". Sperry Rail Service (published 1964).

10. "The Effect of Pearlite Spacing on Transition Temperature of Steel at Four Carbon Levels", by John Rinebolt, Trans. ASM 46, pp. 1527-1537 (1954).

Papers and J.I.S.I. Abstracts

11. "Investigation of Fatigue in Control-Cooled Rails", by R.E. Cramer, Univ. Illinois Eng. Exp. Station, Reprint No. 63, 16pp. (1962). High-Si Cr-V rails have given extremely high rolling load tests of almost 12×10^6 cycles; basic-oxygen standard steel rails gave an average of 3,106,500 cycles in six tests while another series containing Nb ran 2,458,100 cycles.

Rolling load tests on six flame-hardened rails, which were produced by the Union Pacific process; these ran from 11×10^6 to 3×10^6 cycles. End-quench hardenability curves are given for four rail steels to give data on the quenching characteristics of low-alloy rail steels.

12. Development, production and properties of wear-resistant rails of natural hardness, Janiche, W. von Hye, H., Stahl u. Eisen 81, 1253-1263 (Sept. 14, 1961).

There are three main types of railway rails: The wear resistant or "natural-hardness" rails in which the wear-resistance is achieved by chemical composition, the compound rail and the heat-treated rail. In Germany, the rail having a natural hardness is the most common and most of the experience accumulated in production and service concerns this type. The authors discuss deviations from the nominal composition, they argue that the carbon limit of 0.65% is too low, 0.70% should be allowed in order to attain the required strength values with certainty. H_2 has a marked effect on the strength, it is recommended to hold test pieces for a short time at an elevated temperature. Defects in rails are briefly mentioned. Joining the rails by welding is superior to mechanical joining by means of fishplates (23 references).

13. Investigation of Failure in Control-Cooled Rails - Cramer R.E., Univ. Illinois Eng. Exp. Station 1962, Reprint Series 64, 1963, 16pp., April 10-18; Proc. Amer. Railway Eng. Assoc., 64 (1963).

Reports on 16 control-cooled rails sent to the laboratory as failed rails are reviewed and a variety of causes are presented and discussed.

14. Shelly Rail Studies at the Univ. Illinois, R.E. Cramer, Illinois Univ. Eng. Exp. Station Reprint Series, 64, 13-26, (1963) or from Proc. Amer. Railway Eng. Assoc. p.64 (1963).

Rolling-load tests to produce shelling on S-64-KG (132 lb) abrasion resistant Krupp rails; on basic-oxygen Colorado steel and high-silicon steel rails; on standard carbon-steel rails, flame-hardened Union Pacific Railroad rails, and continuous-cast French-German rails (German-rolled from French ingots) are reported. Mechanical tests are also reported of two Japanese induction-hardened 119 lb rails. The results of the Stations' investigations are available to the public.

15. High-Frequency Induction Heat-Treated Rails. Gohda, S; Kimura, I; Hamahashi, H; Ito, A; Kanoh, S; Takeyama, T. (Yawata Tech. Rep. No.244, 4496-4503) (Sept. 1963).

The authors describe the facilities at Yawata Iron and Steel Co. Ltd. for the high-frequency induction heat treatment of rails. The metallurgical structure, wear resistance, fatigue resistance, and profile of the hardened layers are described and compared with those of ordinary rails.

16. Results of various tests on high-frequency pressure-weld rails. Morita, S; Ito, T; Moriyama, K; Toyofuku, K. (Yawata Tech. Rep. No.244, 4504-4510) (Sept. 1963).

The authors describe the process used at Yawata Iron and Steel Co. Ltd. for high-frequency pressure-welding of steel rails. They also outline the results of a number of tests carried out on welded rails; these include magnetic flux inspection, full size bending test, falling weight test, determination of fatigue resistance, and determination of mechanical properties.

17. A study on High Carbon Medium-Manganese Steel Rails. Kimura, L; Hamahashi, H; Ito, A. (Yawata Tech. Rep. No.244, 4489-4495) (Sept. 1963) (in English).

The authors have studied the properties of rails made from 0.6-0.75%C, 1.0-1.3%Mn and 0.6-0.75%C, 1.3-1.6%Mn steels. They observed excellent resistance to wear and fatigue, and higher ductility than normal rails. Controlled cooling after rolling eliminated hair-line cracking. Upper composition limits are to be set at 0.72%C and 1.60%Mn.

18. Improving the strength and ductility of chromium-nickel-steel rails. (Stal', 1963, (5), 459-460). Plekhanov, P.S.

A composition of 0.5-0.6%C, 0.6-0.9%Mn, 0.18-0.3Si and <0.04P and S, 0.6-1.0%Cr and 0.6-1%Ni is recommended for rails carrying heavy traffic and on curves of small radius. A naturally alloyed steel from Orsk Khalilovo is used.

19. Alloy Rails, Grdina, Yu V; Govorov, A.A; Nesterov, N.A; Grigorkin, V.I. (Izvest VUZ. Chern, Met., 1963 (10), 120-124).

The mechanical properties of rail steel containing 1% chromium are considerably better than those of ordinary carbon steel rail. The UTS is 10% higher, the elongation 20% and the wear in samples tested under practical conditions about half. These figures would probably be improved after heat treatment. Steels containing 2%Cr are less useful, and those containing 3%Cr cannot be recommended, even after adding 0.2%V.

20. Properties of Rails made from 3% Chromium Steel (same authors as above) (Izvest. VUZ. Chern. Met., 1962, (2) 125-130).

Results are presented of an investigation into rails made from 3% chromium steel and recommendations are made concerning certain aspects of their production and heat treatment. When it contains 0.3-0.4%C this steel can benefit considerably from heat-treatment and on cooling in air its yield-point is 100-120 kgm/mm^2 and tensile strength 120-140kg/mm^2. (note by same authors in 1963 does not recommend 2% or 3%Cr steel for rail use).

21. Possibilities of the quality enhancement of railway rails, Horejs, S; (Hutn. Listy 16, 533-539) (Aug. 1961)

To improve wear and eliminate faults several precautions are recommended, e.g. to increase carbon content and other alloying elements and to control the cooling rate and hydrogen included, except where the LD process has been used.

22. Investigation of the contact strength of steels for railway rails, by Makukhin, S.I.; Kazaronovskii, D.S.; Navrotskii, I.V. (Stal', 1962, (9), 838-842).

Model experiments on the appearance of black spots and cavities on heavy rails caused by metal flow at contact have given conclusions, later confirmed on full scale trials, that large tangential force components are responsible and that use of a harder Cr-containing steel without heat treatment and reduction of the normal component of the load prevents these defects.

23. Influence of the temperature at the end of rolling on the grain size and mechanical properties of rail steel, by Govorov, A.A.; Koshkin, V.A.; Gordin, O.V.; Tuzovskii, A.I.; Sakharova, N.A.; Lymar, A.I. (Izvest. VUZ Chern. Met., 1963, (8), 137-140).

Raising the end temperature above 980-1000°C severely coarsens the austenite grain, and for satisfactory results the end temperature should be less than this. The tensile strength is not greatly affected by the end temperature, but the plastic properties worsen with increasing grain size. The best mechanical properties are obtained for an end temperature of 850°, but this is accompanied by greater wear on the rollers and increased net cost of the rails. To obtain small grains at the higher temperature, modification of the steel is required.

24. Effects of self-tempering and furnace tempering on the mechanical properties of rails hardened along their whole length by high frequency current heating by Zannes, A.N.; Sapelkina, O.R.; Zubarev, V.F.; Demakova, A.V.; Pereverzeva, E.G. (Izvest. VUZ. Chern. Met., 1964, (2) 118-123).

A technique for hardening the surfaces of rails by high frequency heating has been developed and successfully applied. The rails can either be self tempered or submitted to subsequent furnace tempering. The mechanical properties of rails subjected to the two processes were compared, and it was found that in general the furnace tempering was unnecessary, as it did nothing to increase the technical properties of the rails.

25. Modifying rail steel. Grdina, Yu V.; Koshkin, V.A.; Gordin, O.V.; Sakharova, N.A.; (Izvest. VUZ. Chern. Met., 1963 (10), 129-133).

In general, small additions of alloying elements reduce austenite grain size for final rolling temperature 950-1070°C; Ce, however, increases grain size. Strength is generally improved by modification, but ductility is lowered. Te and Ce leave tensile strength unchanged but raise impact strength. The best hardenability is obtained by adding Ti, V, and B which give good surfaces and low roll wear, and require less rolling-power than unmodified steel. The long-term stability of the modified steels, however, remains to be investigated.

26. Change of mechanical properties of rail steels due to hydrogen effusion, (Stahl Eisen, 1963, 83, Jan. 31, 145-154).

Changes of the content during heat treatment, tensile testing, fatigue and impact are measured and related to physical properties.

27. Volume quenching in oil of an industrial batch of rails. (Izvest. VUZ. Chern. Met., 1962 (8) 111-118 Grdina, Yu V.; Govorov, A.A.; Nesterov, N.A.; Grigorkin, V.I.

After volume quenching in oil of an industrial batch of 1250 tons of rails the proportion of top grade was 89.6% which is very satisfactory considering that the operation was carried out with primitive equipment. Rails with less than 0.65%C should be so treated as this increases yield strength and UTS by 20-25% and doubles the reduction of area. With higher carbon contents even better mechanical properties may be expected.

28. The effect of full-hardening on the resistance of R-50 type rails to erosion. (Stal', 1962, (6), 551-553), by Kontorshichikov, P.V.

Carbon steel rails quenched from 900-940° and tempered at 400-450°C showed increased strength and ductility and resistance to erosion.

29. Volume quenching in oil of an industrial batch of rails. (Izvest. VUZ. Chern. Met., 1962, (8) 111-118). Grdina, Yu. V.; Govorov, A.A.; Nesterov, N.A.; Grigorkin, V.I.

After volume quenching in oil of an industrial batch of 1250 tons of rails the proportion of top grade was 89.6% which is very satisfactory considering that the operation was carried out with primitive equipment. Rails with less than 0.65%C should be so treated as this increases yield strength and UTS by 20-25% and doubles the reduction of area. With higher carbon contents even better mechanical properties may be expected.

30. The influence of blowing with O_2 on the vault of the basic OH furnace during the refining period on the quality of KR 45 steel for rails, by G. Botto (Met. Ital., 1963, 55, Nov., 585-592).

After a quick description of the process of making rail steel, the making of steel for rails in the basic OH with or without use of O_2 by a water-cooled lance during the refining period is examined for quality. The comparison is made by taking the two processes of manufacture with results of tests both microscopical and superficial.

31. Rolling Contact Phenomena. Symposium held at General Motors Research Laboratories, Warren, Mich., October 1960. $9\frac{1}{2}$ x $6\frac{1}{2}$in., pp. viii & 438. Illustrated J.B.Bidwell (Editor). Amsterdam, 1962 Elsevier (Price D.Fl.50).

32. Proceedings of the Symposium on Fatigue in Rolling Contact. Institution of Mechanical Engineers, London, 28th March, 1963. 11 x $8\frac{1}{2}$in., pp. 162. Illustrated London 1964. (IME) Price (£4).

33. Railroad materials and facilities research. American Society for Testing Materials. S.T.P. No. 354. 9 x 6in., pp. v & 62. Illustrated Philadelphia, 1962, The Society (ASTM) Price ($3.00).

34. Furnace for the heating of rails before hardening Met. 1961, (6), 26-29 by G.N. Kryukov; I.I. Kharybin.

A furnace at the Dzerzhinsku works is described which is used for the heating of rails type R-43 and R-50 each 12.5in. in length to 820-840° before hardening of the head to bainite on a hardening machine. The layout of the furnace for the normalization of rails and of its auxiliary equipment is shown.

35. The effect of heat treatment after rolling, on the mechanical properties of mine rails. (Izvest. VUZ Chern. Met., 1960, (4), 145-160), by Tovpenets, E.S.; Zaruev, V.M.; Goncharenko, N.I.; Babii, A.S.

The bainitization of rail heads increases appreciably their mechanical properties, but one bainitization alone or a bainitization and a tempering below 600°C does not impart ductile properties to the metal and cannot be recommended.

Direct bainitization after rolling and subsequent high heat tempering at 600-650°C improves the quality of the metal, its strength indices, ductility, the appearance of the fractures and almost completely eliminates the stresses originating with bainitization.

36. Upper structure of the track under special heavy rolling stock in iron and steelworks on sectional reinforced concrete slabs (without sleepers and ballast). (Stal', 1964, (3), 284-286), by Yanchuk, I.K.

A special track for cars with heavy axle loading was laid at Cherepavets. The cost was 20-30% higher but maintenance per km was only 1000 reubles in the first year and 307 in the second, compared with 6000-7200 for ordinary track.

37. On quenched hard-head rails. (Tech. Rep. of the Fuji Iron and Steel Co., 1962, 11, June, 139-150), by Shoya, T.; Ohnuma, Y.; Ohnuki, T.

38. Tempering of cold-worked rail steel. (Izvest. VUZ Chern. Met., 1963, (8), 132-135). Grdina, Yu V.; Kotov) Tempering at 550 or 600°C with or without soaking for 30-40 seconds, leads to the formation of an evenly distributed, finely dispersed structure with a Vickers hardness of 320-300.

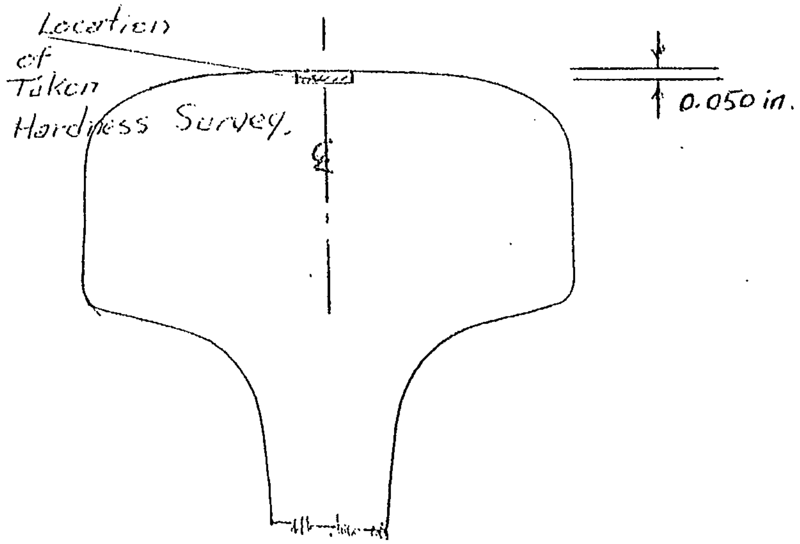
TABLE 3.

Tukon Hardness Survey Taken At The Centre Of The Head Section - Converted to Rockwell C.

Depth below head surface (inches).

Surface	002	004	006	008	010	012	014	016	018	020	030	040	050	Remarks
* A	53	34	32	32	28	30	31	38	31	31	35	26	30	1951
B	30	30	30	30	32	33	33	33	30	33	32	30	32	"
* C	57	38	33	35	35	34	34	32	33	33	34	29	33	"
* D	38	40	40	35	35	35	34	34	34	33	34	32	32	1952
E	29	29	29	29	29	29	29	29	29	29	29	29	32	"
F	27	34	34	34	32	33	33	32	33	33	33	34	34	"
G	58B	62B	74B	71B	74B	76B	76B	76B	79B	85B	90B	92B	98B	1953
H	69B	80B	84B	84B	84B	89B	89B	94B	94B	94B	23C	23C	96B	
I	79B	84B	88B	92B	90B	92B	96B	99B	99B	99B	25C	25C	25C	1957
J	99B	99B	96B	21C	96B	92B	92B	92B	92B	99B	99B	21C	20C	"
K	76B	92B	92B	97B	98B	97B	99B	97B	99B	99B	99B	78B	99B	"
L	21	25	25	22	22	25	25	25	27	27	27	23	23	1961
M	98B	25	27	27	29	26	26	26	26	26	32	24	29	"
N	92B	97B	99B	99B	86B	21	99B	22	21	21	23	21	25	"
O	92B	92B	92B	92B	92B	94B	98B	98B	99B	21	26	26	26	1962
P	80B	88B	88B	91B	94B	92B	97B	23	21	21	21	25	26	"
Q	20	24	96B	27	23	29	25	25	25	27	27	25	25	"
R	21	23	25	23	27	26	28	27	30	31	32	35	34	DOSCO-Mn - V.
S	35	21	25	22	23	23	27	27	27	27	27	27	27	Que. Cartier.
T	82B	92B	96B	96B	97B	97B	20	23	25	25	25	27	27	Lackawanna
U	29	32	32	32	32	32	32	32	32	32	38	32	35	Beth. Quench&Temper.

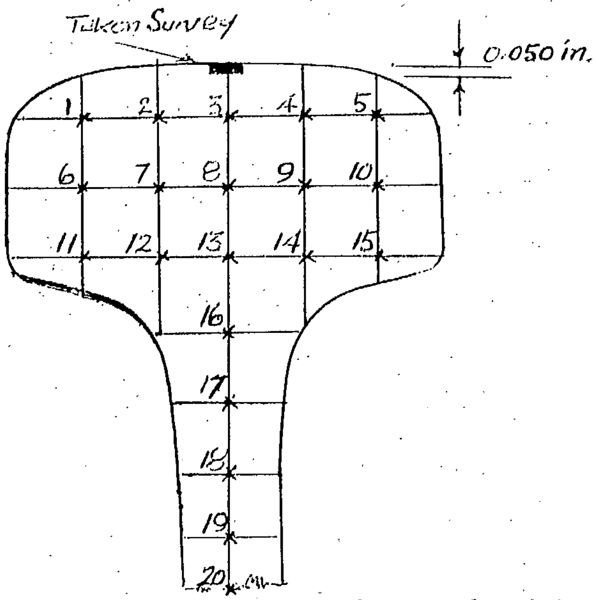
* Samples A, C and D have work-hardened for a depth of about 0.002 in.



Note:-
Samples A, C, D & S show evidence of surface hardening at the ℄ head surface.
Samples B, E, F, L, Q, R, U. have hardness of R_C 21 to R_C 30 at the head surface.
Samples G, H, I, J, K, M, N, O, P, T are soft, having hardness 58/98 Rockwell B.

TABLE 4.

Hardness, Rockwell C, Head and Web (Area shown in Sketch).



Head and Web, Positions 1 to 20, Samples A to U.

Sketch	1951			1952			1953		1957			1961			1962			Mn-V	USS	Beth.	Beth. QT
Position	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	31	24	22	41	29	27	26	25	26	28	24	25	32	26	24	26	25	34	38/28	25	39/38
2	29	27	37	27	22	28	20	22	29	24	24	25	28	26	25	25	25	32	38/28	25	38
3	27	27	37	25	21	27	21	22	27	28	24	25	28	26	25	26	23	32	26	24	38
4	29	26	28	27	25	28	22	22	27	22	24	24	30	27	25	26	23	32	24	24	35
5	28	25	29	30	26	31	24	24	28	26	25	25	31	26	25	27	26	33	28	27	38
6	24	20	27	25	23	27	22	18/20	29	26	26	25	32	26	25	26	24	30	26	40/27	38
7	28	25	26	25	19	22	23	18	29	26	21	25	29	25	25	24	25	30	26	26	35
8	24	36	23	26	20	24	20	18	29	26	25	24	27	26	24	25	23	35/30	21/25	26	34
9	24	27	29	26	20	24	20	18	28	26	21	24	29	28	26	25	23	28	24	26	35
10	26	25	28	29	22	25	21	19	29	27	32/24	25	30	35	26	25	24	30	24	21/26	37
11	26	24	29	28	25	29	21	21	29	25	24	23	30	27	26	27	25	33	27	26	35
12	23	39	37	29	22	27	21	19	28	27	24	24	28	30	24	25	23	29	23	25	32/35
13	28	29	28	28	21	25	20	18	28	26	22	22	27	27	26	25	23	28	28	27	35
14	25	28	28	28	22	25	22	18	28	27	22	24	29	30	23	25	22	29	27	24	35
15	30	24	29	21	25	28	22	21	28	26	24	26	29	26	25	28	25	31	28	27	38
16	20	39	27	28	21	34/27	20	19	28	24	19/21	23	25	31	24	27	21	27	36/27	24	35
17	20	31	28	26	21	26	21	21	27	25	24	25	25	29	24	28	21	30	27	21/26	35
18	21	30	30	20	20	27	22	20	30	26	23	25	25	27	24	27	23	32	27	24	35
19	21	32	28	30	21	26	21	21	28	24	24	24	26	32	24	27	22	32	26	26	35
20	22	31	28	17	21	26	21	21	28	25	22	24	27	25	23	26	22	32	24	25	36

(cont'd)

TABLE 4 (concl'd)

Hardness, Rockwell C, Web and Flange (Area shown in Sketch). Web and Flange, Positions 21 to 44, Samples A to U.

Sketch Position	1951 A B C	1952 D E F	1953 G H	1957 I J K	1961 L M N	1962 O P Q	Mn-V R	USS S	Beth. T	Beth.QT U
21	22 29 29	27 21 33/26	21 20	25 24 22	24 26 30	24 25 21	32	23	25	36
22	21 30 24	28 20 25	20 20	28 21/24 22	24 27 26	23 26 21	31	23	25	36
23	24 25 25	26 20 25	20 18/21	28 26 21	23 28 27	24 26 22	30	26	26	36
24	26 22 24	33 27 24	20 18	28 29 18/19	25 27 24	24 25 22	29	25	26	38
25	21 28 30	31 22 23	21 19	28 20/25 23	24 24 28	24 26 22	29	28	25	36
26	27 27 30	28 21 25	20 19	28 24 23	24 26 26	23 25 23	40/32	26	27	37
27	27 26 31	29 25 26	31/22 23	42/30 28 24	25 31 30	27 35/28 26	31	28	27	45/38
28	23 24 30	27 23 27	22 21	29 27 21	27 30 27	28 26 24	31	28	28	39
29	27 29 30	26 22 29	23 21	29 25 23	25 27 26	24 26 23	30	26	23	38
30	25 25 26	32 23 30	22 22	28 26 25	25 29 34	25 26 24	32	28	27	34
31	29 27 30	30 23 26	20 22	28 28 23	25 27 27	23 25 23	35	27	26	35
32	29 28 31	38/30 27 27	22 22	29 27 26	26 30 28	23 26 24	35	28	28	36
33	25 28 31	31 27 30	24 23	30 28 25	27 32 28	25 28 26	35	28	28	38
34	28 29 32	28 28 30	24 26	30 28 26	27 31 31	28/29 28 27	35	29	30	34
35	30 30 33	38/30 28 30	25 24	29 26 24	28 31 29	29 30 28	34	29	28	37
36	29 32 35	31 34/28 29	24 27	30 27 22	26 31 27	27 28 27	34	29	29	37
37	28 28 45	29 22 29	23 23	32/30 28 18/19	26 30 28	27 28 25	34	28	29	38
38	28 26 29	28 27 34/30	24 24	28 26 20	23 29 26	25 27 24	34	28	27	38
39	28 21 29	28 29 35/30	23 23	28 30 23	25 28 21	25 27 23	36/34	27	27	36
40	29 24 37	29 25 27	23 24	28 27 23	26 28 28	25 26 25	35/36	27	28	38
41	30 31 28	27 27 30	23 22	29 27 26	28 30 30	26 26 26	34/35	28	28	37
42	30 36 32	31 24 27	23 25	30 29 26	26 31 29	26 28 27	36	29	29	35
43	29 28 32	31 24 26	25 24	30 29 27	27 33/32 30	27 29 28	35	33/29	29	36
44	28 29 32	33 30 35/33	28 31/27	31 29 27	28 34/33 30	29 31/30 28	40/36	29	30	37

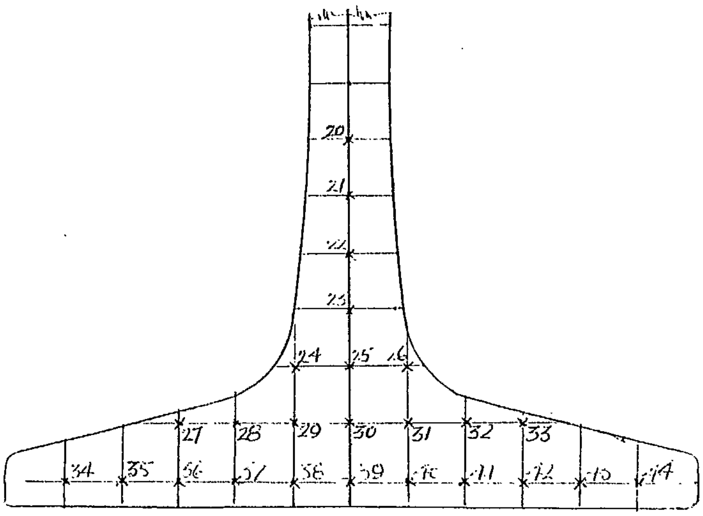
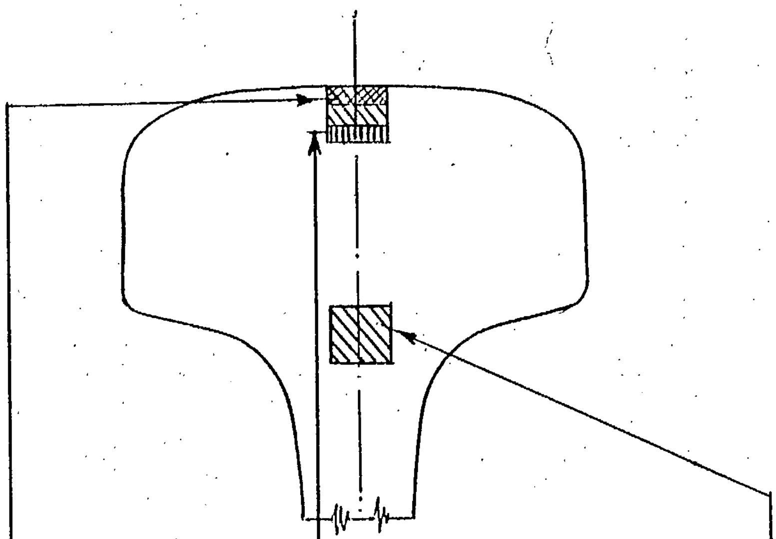


TABLE 5.

Inclusion Count (QTM) Number of Inclusions in 0.0054 in.^{2} Area.



Inclusions (Total Number in 0.0054 in.^{2} Area).

Sample		Crown Surface		Area $\frac{1}{4}$ in. Below Surface		Area $1\frac{1}{2}$ in. Below Surface		
		Range	Number (Ave.)	Range	Number (Ave.)	Range	Number (Ave.)	Ave.
1951	A	8/26	18	6/60	21	8/28	19	19
	B	6/21	13	3/15	10	6/22	14	12
	C	8/31	16	6/18	10	4/24	10	12
1952	D	3/18	8	2/10	7	4/20	10	8
	E	8/22	12	8/28	15	12/53	24	17
	F	6/17	12	6/24	15	6/22	14	14
1953	G	6/16	9	5/22	12	4/12	8	10
	H	2/14	7	4/12	9	7/14	11	9
1957	I	4/18	13	6/38	17	22/88	47	26
	J	24/48	35	10/48	28	20/48	35	33
	K	30/84	49	30/64	44	38/82	58	50
1961	L	8/28	20	18/56	34	6/26	15	23
	M	10/17	14	16/24	18	8/20	14	15
	N	4/24	14	2/13	7	5/22	11	11
1962	O	8/18	12	4/14	8	2/22	10	10
	P	3/26	13	4/31	12	6/22	14	13
	Q	4/16	10	3/16	11	8/22	16	12
Mn-V	R	4/20	13	2/18	10	6/24	11	11
(USS)	S	4/28	13	6/26	14	2/15	9	12
(Beth)	T	14/24	20	10/24	20	3/24	11	17
(Beth) (QT)	U	14/20	17	6/24	13	6/18	13	14

Range & Averages Each, Represent 10 Area Counts.
Q.T.M.-Quantitative Television Microscope.
Mn-V. DOSCO Alloy Steel; USS-Quebec Cartier; Beth:-Bethlehem Standard Rail.
Beth. Q.T.-Bethlehem-Liquid Quenched and Tempered Rail.

TABLE 6.

ASTM Austenite Grain Size.

Measured at X100-viewed in polarized light-etched 2% nital.

(areas examined same as for inclusion count).

Sample	Crown Surface		$\frac{1}{4}$ in. Below Surface		$1\frac{1}{2}$ in. Below Surface		Grain Size
	Range	Size	Range	Size	Range	Size	Average
A	2/3	3	1/3	3	1/4	1	2
B	1/2	2	1/2	2	1/2	1	1
C	1/4	3	1/6	4	2/4	3	3
D	2/3	2	2	2	2/4	4	3
E	1/4	2	1/5	1	2/3	2	2
F	3	3	3	3	2/4	3	3
G	2/3	2	1	1	1/3	2	2
H	2/5	3	2	2	4	4	3
I	1/3	1	1/3	2	1+/3	1	1
J	1+	1+	1	1	--	1+	1+
K	1+	1+	1+	1+	1+	1+	1+
L	1/3	1	1/2	2	1/3	2-	2
M	1+/3	1+	1+	1+	1/4	1+	1+
N	2/3	2-	1/3	2-	2/3	3-	2
O	2/3	2	1/2	2	2	2	2
P	2	2	1/2	1	1/2	2	2
Q	1+	1+	1	1	1+/4	1+	1+
* R	4/6	6-	6	6	4/8	6-	6
S	1	1	1	1	1/4	2	1
T	1	1+	1	1+	1/2	1	1+
U	5/10	7-	5/10	7-	5/10	8	7

* fine grained, V-deoxidized, fully killed, alloy steel (no aluminum).

TABLE 7.

Ferrite-Per Cent of Area in Etched Microsections

Samples A to U; Same Areas as for Inclusion Counts

Sample	(Decarb). Crown Surface	"X" $\frac{1}{4}$in. Below Surface	"Y" $1\frac{1}{2}$in. Below Surface	Ave. X.Y.
A	.06	.1	⊗ .12/.4	.26
B	.06/.2	.8/1.9	.01/.13	.07
C	.005/.02	.008/.1	.02/.21	.12
D	.02	.002/.06	.06/.2	.13
E	⊙ ⊗ .8/3.0	0/.04	⊗ .64/1.2	.92
F	0/.06	0/.04	0/.08	.04
G	⊙ ⊗ 3./22.	.2/.55	⊗ .7/1.2	.95
H	⊙ ⊗ 8.0	.01	⊙ .12/.4	.26
I	⊙ ⊗ 2.0	0	0	0
J	⊙ ⊗ 2.6	0	0	0
K	⊙ ⊗ 5.0	0/.07	0	0
L	⊙ ⊗ 8.0	.1	0	0
M	⊙ ⊗ 9.0	.6	.1	.1
N	⊙ ⊗ 68.0	1.5	.01	.01
O	⊙ ⊗ 50.0	---	.01	.01
P	⊙ ⊗ 35./52	---	.01/.1	.05
Q	⊙ ⊗ 30./52	---	⊙ .5/1.0	.7
R	⊙ ⊗ 1./3.	---	⊙ .5/1.0	.7
S	.01	---	.1	.1
T	⊙ ⊗ 10./15.	---	⊙ 1.9/2.0	2.
U	.01	---	.1	.1

⊙ - blocky ferrite.

⊗ - grain boundary ferrite.

Ave-indicates per cent ferrite sub surface, does not include 1st column.

Decarb column - indicates extent of surface decarburization.

TABLE 8.

Tensile and Charpy V-notch Impact Results (Short Lengths).

Sample	Tensile Results UTS kpsi	1%P.S. kpsi	Elong %	RA %	Year of Mfg.	Charpy V-notch impact ft-lb Bar No.	300°F	Bar No.	212°F	Bar No.	75°F	
A-11	119.7	61.0	17.0	20.0	1951	A-5	11.	A-3	4.3	A-1	3.0	
A-12	122.8	63.8	14.0	17.0	"	A-6	17.5	A-4	15.5	A-2	1.5	
A-13	127.3	64.6	13.0	15.0	"		14.3		9.9		2.3	Ave. Charpy Result
B-11	138.7	75.7	10.0	9.0	"	B-5	12.0	B-3	6.3	B-1	2.5	
B-12	139.3	72.7	9.0	9.0	"	B-6	19.0	B-4	15.0	B-2	3.3	
B-13	146.2	79.5	10.0	10.0	"		15.5		10.7		2.9	Ave. " "
C-11	141.7	73.2	11.0	11.0	"	C-5	6.0	C-3	4.2	C-1	5.3	
C-12	143.8	73.2	9.0	9.0	"	C-6	15.0	C-4	14.5	C-2	6.2	
C-13	138.8	71.4	12.0	16.0	"		10.5		9.4		5.8	Ave. " "
D-11	145.7	76.3	11.0	11.0	1952	D-5	12.	D-3	15.8	D-1	1.8	
D-12	145.8	75.8	11.0	10.0	"	D-6	17.3	D-4	15.0	D-2	2.3	
D-13	145.0	78.2	17.0	12.0	"		14.7		15.4		2.0	Ave. " "
E-11	118.9	59.8	20.0	26.0	"	E-5	12.	E-3	5.8	E-1	3.0	
E-12	119.3	57.5	18.0	27.0	"	E-6	16.8	E-4	4.5	E-2	4.2	
E-13	117.3	58.1	19.0	27.0	"		14.4		5.2		3.6	Ave. " "
F-11	128.2	65.4	17.0	18.0	"	F-5	8.	F-3	4.0	F-1	2.8	
F-12	129.0	65.0	15.0	18.0	"	F-6	15.3	F-4	17.5	F-2	2.8	
F-13	130.5	67.5	16.0	20.0	"		11.7		10.8		2.8	Ave. " "
G-11	113.2	52.6	15.0	17.0	1953	G-5	16.	G-3	21.8	G-1	5.5	
G-12	112.6	55.7	17.0	20.0	"	G-6	19.2	G-4	27.8	G-2	9.7	
G-13	114.1	58.0	17.0	20.0	"		17.6		24.8		7.6	Ave. " "
H-11	116.3	54.2	16.0	21.0	"	H-5	11.	H-3	15.7	H-1	1.8	
H-12	118.0	57.9	15.0	20.0	"	H-6	22.5	H-4	5.7	H-2	2.5	
H-13	117.3	54.3	15.0	20.0	"		16.8		10.7		2.2	Ave. " "
I-11	130.9	69.6	12.0	11.0	1957	I-5	8.	I-3	15.7	I-1	3.0	
I-12	130.5	69.5	11.0	11.0	"	I-6	18.8	I-4	15.3	I-2	4.0	
I-13	127.7	67.5	13.0	15.0	"		13.4		15.5		3.5	Ave. " "
J-11	128.5	66.7	10.0	9.0	"	J-5	14.	J-3	15.5	J-1	3.0	
J-12	129.7	68.7	10.0	11.0	"	J-6	21.0	J-4	16.3	J-2	3.2	
J-13	125.8	63.9	14.0	17.0	"		17.5		15.9		3.1	Ave. " "
K-11	116.4	59.4	15.0	20.0	"	K-5	14.	K-3	6.0	K-1	3.8	
K-12	118.1	59.4	14.0	16.0	"	K-6	21.5	K-4	16.2	K-2	4.2	
K-13	118.5	61.2	15.0	18.0	"		17.8		11.1		4.0	Ave. " "

Longitudinal Test Bars.

(cont'd)

TABLE 8 (concl'd)

Sample	Tensile Results			RA	Year	Charpy V-notch impact ft-lb						
	UTS kpsi	.1%P.S. kpsi	Elong %	%	of Mfg	Bar No	300°F	Bar No	212°F	Bar No	75°F	
L-11	122.4	61.1	13.0	15.0	1961	L-5	12.0	L-3	6.8	L-1	2.0	
L-12	118.5	59.0	15.0	17.0	"	L-6	20.0	L-4	18.8	L-2	10.5	
L-13	119.7	60.2	14.0	17.0	"		16.0		12.8		6.3	Ave. Charpy Result
M-11	129.2	67.5	12.0	12.0	"	M-5	16.0	M-3	14.2	M-1	2.8	
M-12	128.9	65.8	12.0	11.0	"	M-6	16.5	M-4	4.5	M-2	2.8	
M-13	123.7	64.2	14.0	17.0	"		16.3		9.4		2.8	Ave. " "
N-11	133.7	70.3	11.0	12.0	"	N-5	19.5	N-3	16.3	N-1	2.5	
N-12	134.5	70.3	11.0	11.0	"	N-6	18.5	N-4	20.2	N-2	2.5	
N-13	141.5	75.2	10.0	10.0	"		19.0		18.3		2.5	Ave. " "
O-11	118.5	59.8	16.0	20.0	1962	O-5	21.8	O-3	17.0	O-1	2.7	
O-12	118.5	59.0	16.0	20.0	"	O-6	23.0	O-4	18.5	O-2	3.3	
O-13	118.5	61.8	17.0	20.0	"		22.4		17.8		3.0	Ave. " "
P-11	125.3	66.2	14.0	18.0	"	P-5	20.0	P-3	23.0	P-1	7.2	
P-12	125.7	65.9	14.0	17.0	"	P-6	23.5	P-4	22.8	P-2	11.7	
P-13	128.9	69.0	14.0	17.0	"		21.8		22.9		9.5	Ave. " "
Q-11	123.7	59.8	16.0	22.0	"	Q-5	20.0	Q-3	19.0	Q-1	4.0	
Q-12	121.4	59.4	17.0	22.0	"	Q-6	20.6	Q-4	19.8	Q-2	12.2	
Q-13	122.2	61.4	16.0	22.0	"		20.3		19.4		8.1	Ave. " "
R-11	151.4	93.6	17.0	31.0	Test	R-5	18.3	R-3	16.5	R-1	3.5	
R-12	148.9	93.2	15.0	30.0	"	R-6	20.0	R-4	5.5	R-2	2.0	
R-13	151.4	96.8	16.0	32.0	"		19.2		11.0		2.8	Ave. " "
S-11	139.2	73.3	12.0	11.0	"	S-5	18.0	S-3	18.2	S-1	2.7	
S-12	133.8	69.5	12.0	14.0	"	S-6	21.5	S-4	18.3	S-2	4.5	
S-13	137.0	70.2	12.0	14.0	"		19.8		18.3		3.6	Ave. " "
T-11	129.7	68.2	15.0	18.0	"	T-5	19.0	T-3	19.0	T-1	4.8	
T-12	129.2	68.2	14.0	18.0	"	T-6	20.5	T-4	21.0	T-2	12.8	
T-13	130.4	68.2	14.0	20.0	"		19.8		20.0		8.8	Ave. " "
U-11	161.5	104.4	16.0	39.0	"	U-5	20.7	U-3	29.0	U-1	9.7	
U-12	163.4	104.4	16.0	37.0	"	U-6	25.3	U-4	33.0	U-2	15.8	
U-13	162.5	104.7	16.0	38.0	"		23.0		31.0		12.8	Ave. " "

Longitudinal Test Bars

TABLE 9.

Tensile Results Averaged. (Short Lengths).

Sample	Average of 3 Bars per Sample UTS kpsi	.1%P.S. kpsi	% Elong.	% RA	Average for Year of Rolling UTS kpsi	.1% P.S. kpsi	% Elong.	% RA	Year Rail Rolled
A	123.3	63.1	14.7	17.3					
B	141.4	76.0	9.7	9.3	135.4	70.5	11.7	12.9	1951
C	141.4	72.3	10.7	12.0					
D	145.5	76.8	13.0	11.0					
E	118.5	58.5	19.0	26.7	131.1	67.1	16.0	18.8	1952
F	129.2	66.0	16.0	18.7					
G	113.3	55.4	16.3	19.0	115.2	55.5	15.8	19.7	1953
H	117.2	55.5	15.3	20.3					
I	129.7	68.9	12.0	12.3					
J	128.0	66.4	11.3	12.3	125.1	65.1	12.7	14.2	1957
K	117.7	60.0	14.7	18.0					
L	120.2	60.1	14.0	16.3					
M	127.3	65.8	12.7	13.3	128.0	65.9	12.5	13.5	1961
N	136.6	71.9	10.7	11.0					
O	118.5	60.2	16.3	20.0					
P	126.6	67.0	14.0	17.3	122.7	62.5	15.5	19.8	1962
Q	122.4	60.2	16.3	22.0					
● R	150.6	94.5	16.0	31.0	150.6	94.5	16.0	31.0	Mn-V 1963
X S	136.6	71.0	12.0	13.0					
⊗ T	129.8	68.2	14.3	18.7					
⊙ U	162.5	104.5	16.0	38.0	162.5	104.5	16.0	38.0	1963Beth.Q.T.

● - DOSCO Mn-V alloy steel rail sample.

X - Quebec Cartier Railway. USS standard rail.

⊗ - Lackawanna Railway. Bethlehem Steel Co. standard rail.

⊙ - Bethlehem liquid quenched and tempered rail.

TABLE 10

Summary of Results

Year of Rolling & Identity	% C	% Mn	% C+ Mn+ Si	Ni+ Cr+ Mo+ Cu+ Sn	New or Used	% Total Cols. 3&4	% V	Mech. Props. (Long.) Rail Heads: UTS kpsi	.1%P.S. kpsi	Elong. %	RA %	Surf. Incl. Count	Ave. Incl. Count	Hardness: Surf. Rc	Sub Surf. Rc.	Centre Rc.	Ferrite: Grain Size X100	Decarb. % Surf.	% Centre
1951-A	.81	.89	1.84	.06	Used	1.90		123.3	63.1	14.7	17.3	18	19	53	27	28	2	.06	(*).26
" -B	.75	.85	1.73	.11	"	1.84		141.4	76.0	9.7	9.3	13	12	30	27	29	1	.13	.07
" -C	.82	1.00	1.95	.08	"	2.03		141.4	72.3	10.7	12.0	16	12	57	37	28	3	.01	.12
1952-D	.75	1.15	2.09	.11	"	2.20		145.5	76.8	13.0	11.0	8	8	38	25	28	3	.02	.13
" -E	.67	1.06	1.85	.15	"	2.00		118.5	58.5	19.0	26.7	12	17	29	21	21	2	1.9	(*).92
" -F	.80	1.12	2.06	.09	"	2.15		129.2	66.0	16.0	18.7	12	14	27	27	25	3	.03	.04
1953-G	.67	.85	1.60	.09	"	1.69		113.3	55.4	16.3	19.0	9	10	58B	21	20	2	12.0	(*).95
" -H	.72	.72	1.61	.08	New	1.69		117.2	55.5	15.3	20.3	7	9	69B	22	18	3	8.0	.26
1957-I	.77	.94	1.86	.15	"	2.01		129.7	68.9	12.0	12.3	13	26	79B	27	28	1	2.0	0
" -J	.72	.79	1.66	.17	"	1.83		128.0	66.4	11.3	12.3	35	33	99B	28	26	<1	2.6	0
" -K	.70	.72	1.56	.13	"	1.69		117.7	60.0	14.7	18.0	49	50	76B	24	22	<1	5.0	0
1961-L	.74	.86	1.72	.07	"	1.79		120.2	60.1	14.0	16.3	20	23	21	25	22	2	8.0	0
" -M	.78	.90	1.80	.15	"	1.95		127.3	65.8	12.7	13.3	14	15	98B	28	27	<1	9.0	.10
" -N	.72	.97	1.82	.06	"	1.88		136.6	71.9	10.7	11.0	14	11	92B	26	27	2	70.0	.01
1962-O	.73	.80	1.65	.15	"	1.80		118.5	60.2	16.3	20.0	12	10	92B	25	26	2	50.0	.01
" -P	.77	.87	1.77	.18	"	1.95		126.6	67.0	14.0	17.3	13	13	80B	26	25	2	43.0	.05
" -Q	.73	.76	1.64	.23	"	1.87		122.4	60.2	16.3	22.0	10	12	20	23	23	<1	41.0	.70
** R	.60	1.64	2.56	.43	"	3.00	.10	150.6	94.5	16.0	31.0	13	11	21	32	28	6	2.0	.70
S	.78	.84	1.79	.08	Used	1.87		136.6	71.0	12.0	13.0	13	12	35	26	28	1	.01	.10
T	.76	.97	1.90	.08	New	1.98		129.8	68.2	14.3	18.7	20	17	82B	24	27	<1	12.0	2.0
U	.74	.78	1.71	.26	"	1.97		162.5	104.5	16.0	38.0	17	14	29	38	35	7	.01	.10

Year of Rolling & Identity	Tonnage Million Gross Tons	Seams 1-good 4-bad	S. Seg. S Print	S %	P %	N %	Deoxidation: Al	Si	Position: Ingot No.	Rail Posit.	Charpy V-notch Impact: 300°F ft-lb	212°F ft-lb	75°F ft-lb
1951-A	230	1	3	.023	.033	.003	.002	.14	8	E	14.3	9.9	2.3
" -B	230	1	4	.030	.037	.003	.002	.13	15	E	15.5	10.7	2.9
" -C	230	2	3	.030	.038	.007	<.002	.13	10	B	10.5	9.4	5.8
1952-D	235	3	2	.016	.023	.003	.002	.19	12	E	14.7	15.4	2.0
" -E	235	1	4	.036	.029	.008	.003	.12	17	E	14.4	5.2	3.6
" -F	235	4	3	.028	.033	.006	.003	.14	17	E	11.7	10.8	2.8
1953-G	230	4	1	.015	.033	.004	.002	.08	2	D	17.6	24.8	7.6
" -H	235	2	2	.021	.026	.005	.003	.17	1	D	16.8	10.7	2.2
1957-I	---	2	3	.033	.025	.005	.003	.15	14	D	13.4	15.5	3.5
" -J	---	2	4	.029	.026	.004	.004	.15	17	D	17.5	15.9	3.1
" -K	---	1	4	.029	.016	.005	<.002	.14	11	E	17.8	11.1	4.0
1961-L	90	1	4	.028	.014	.003	.002	.12	23	E	16.0	12.8	6.3
" -M	90	1	3	.025	.031	.002	.002	.12	28	D	16.3	9.4	2.8
" -N	90	4	3	.022	.020	.002	.002	.13	14	E	19.0	18.3	2.5
1962-O	53	1	3	.029	.009	.003	.007	.12	23	E	22.4	17.8	3.0
" -P	53	1	4	.029	.009	.003	.004	.13	19	F	21.8	22.9	9.5
" -Q	53	2	2	.029	.009	.003	.002	.15	9	F	20.3	19.4	8.1
** R	Test	3	2	.026	.010	.005	.004	.32	1	D	19.2	11.0	2.8
S	Test	2	4	.035	.023	.003	.003	.17	26	B	19.8	18.3	3.6
T	Test	3	3	.030	.007	.004	.004	.17	7	F	19.8	20.0	8.8
U	Test	3	4	.042	.013	.003	.003	.19	—	—	23.0	31.0	12.8

(*) - grain boundary ferrite.

longitudinal test bars.

**- Sample R contains 0.10%V.

TABLE 11.

Summary of Results, Averaged with Respect to Year of Rolling & Comparative Data.

Year of Rolling	Element %			% C+Mn+Si	Ni+Cr+Mo+Cu+Sn	Total % Alloy	Ratio Mn/C	% V	Tensile Results				Inclusion Counts No/0.0054in.2		Hardness Rockwell			Grain Size ASTM	Ferrite %		Tonnage Million Gross Tons	Seams 1-bad 4-good	S Seg. 1-bad 4-good	Element %			% Al Acid Sol.	Charpy V-notch Impact		
	C	Mn	Si						UTS kpsi	1%PS kpsi	Elong. %	RA %	Surf.	Average	Surf.	Sub Surf.	Centre		Surf.	Centre				S	P	N		ft-lb 300°F	ft-lb 212°F	ft-lb 75°F
1951	.79	.91	.13	183	.08	1.91	1.15		135.4	70.5	11.7	12.9	16	14	47	30	28	2	.07	.15	230	1	3	.028	.036	.004	<.002	13.4	10.0	3.7
1952	.74	1.11	.15	200	.12	2.12	1.50		131.1	67.1	16.0	18.8	11	13	31	24	25	3	.65	.36	235	3	3	.027	.028	.006	.003	13.6	10.5	2.8
1953	.70	.79	.12	161	.09	1.70	1.13		115.3	55.5	15.8	19.6	8	9	63B	21	19	2	10.0	.60	232	3	2	.018	.029	.004	<.003	11.5	11.8	3.3
1957	.73	.80	.15	168	.15	1.83	1.10		125.1	65.1	12.7	14.2	32	36	85B	26	25	<1	3.2	0	---	2	4	.030	.022	.005	<.003	16.2	14.2	3.5
1961	.75	.91	.12	178	.09	1.87	1.21		128.0	65.9	12.5	13.5	16	17	98B	26	25	<2	29.0	.04	90	2	3	.025	.022	.002	<.002	17.1	13.5	3.9
1962	.74	.81	.10	165	.19	1.84	.91		123.0	62.5	15.5	19.8	12	12	91B	25	25	<2	45.0	.25	53	1	3	.029	.009	.003	.004	21.5	20.0	6.9
"R"	.60	1.64	.32	256	.43	2.99	2.74	.10	150.1	94.5	16.0	31.0	13	11	21	32	28	6	2.0	.70	Test	3	2	.026	.010	.005	.004	19.2	11.0	2.8
"S"	.78	.84	.17	179	.08	1.87	1.08		136.6	71.0	12.0	13.0	13	12	35	26	28	1	.01	.10	Test	2	4	.035	.023	.003	.003	19.8	18.3	3.6
"T"	.76	.97	.17	190	.08	1.98	1.27		129.8	68.2	14.3	18.7	20	17	82B	24	27	<1	12.0	2.0	Test	3	3	.030	.007	.004	.004	19.8	20.0	8.8
"U"	.74	.78	.19	171	.26	1.97	1.05		162.5	104.5	16.0	38.0	17	14	29	38	35	7	.01	.10	Test	3	4	.042	.013	.003	.003	23.0	31.0	12.8

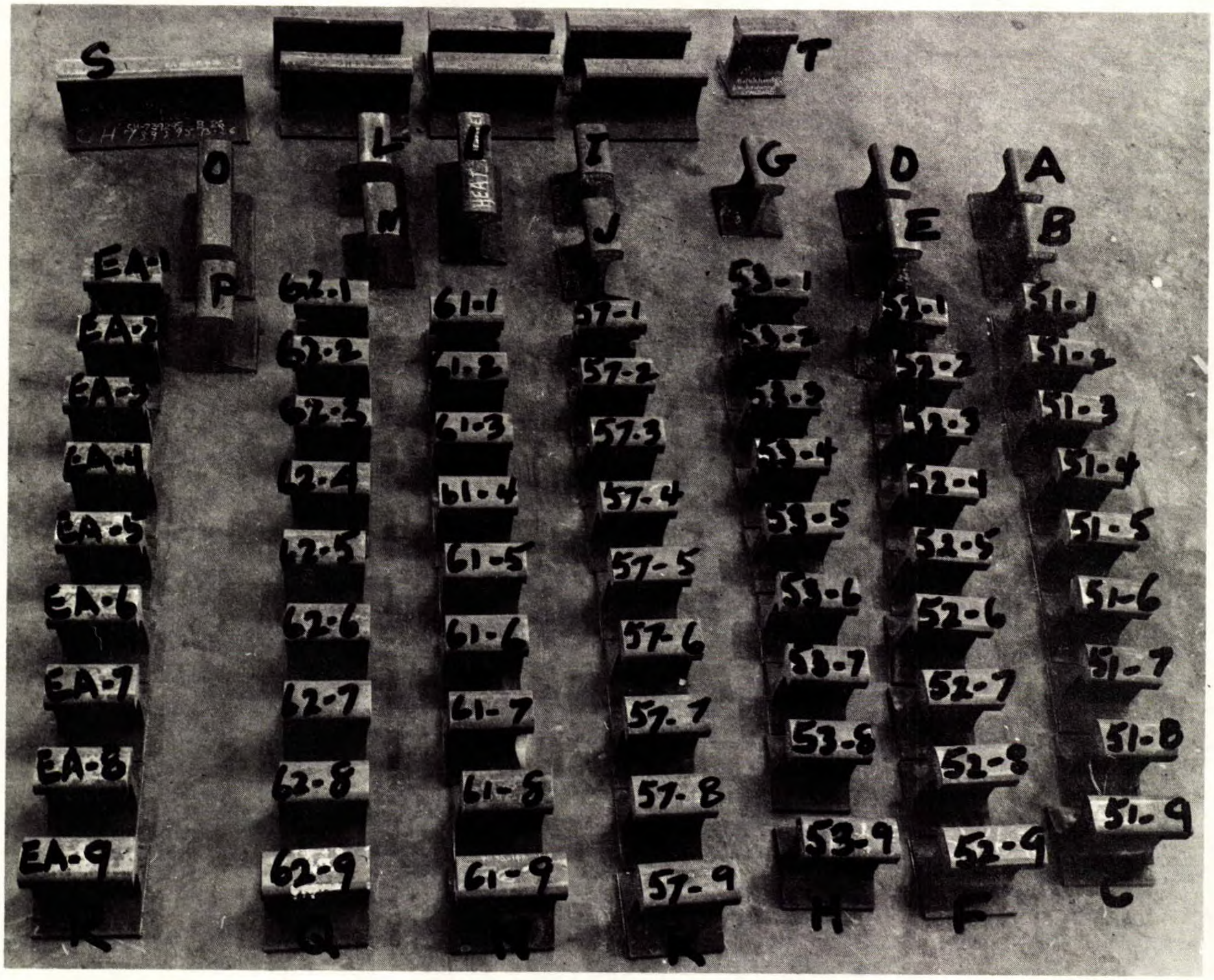
TABLE 12.

Results of Analyses For
Hydrogen, Oxygen, and Nitrogen Made
On Triplicate $\frac{1}{4}$x$\frac{1}{4}$x$\frac{1}{4}$in. Pieces Cut From The Rail Samples

Sample	Hot Extraction Residual Hydrogen	* (V.F.) Oxygen		* (V.F.) Nitrogen		**Kjeldahl N2
A	0.00002	0.0024	0.003	0.00327		0.003
B	0.00005	0.0029	0.003	0.00029		0.003
		0.0026	0.0023	0.0036	0.0019	
C	0.00009	0.0009	0.0030	0.0102	0.0048	0.007
			0.003			
D	0.00003	0.0043	0.004	0.00219		
		0.0014	0.00865	0.0019	0.0034	0.003
E	0.00003	0.0035	0.0106	0.0102	0.0056	0.008
			0.01			
F	0.00007	0.0057	0.01	0.0046		0.006
G	<0.00002	0.0040	0.0050	0.0036	0.0027	0.004
			0.006			
H	0.00003	0.0080	0.006	0.0022		0.005
I	0.00004		0.002			0.005
J	<0.00002	0.0034	0.003	0.0011		0.004
K	<0.00002	0.0034	0.003	0.00039		0.005
L	0.00002		0.003			0.003
M	<0.00002		0.003			0.002
N	<0.00002	0.0009	0.003	0.0044		0.002
O	<0.00002		0.005			0.003
P	<0.00002		0.005			0.003
Q	0.00002		0.004			0.003
R	0.00004		0.003			0.005
S	<0.0002	0.0028	0.002	0.0015		0.003
T	<0.0002		0.002			0.004
U	<0.0002		0.004			0.003
		Duplicate Analyses		Duplicate Analyses		

* Vacuum Fusion Analysis.
** Kjeldahl wet analysis for nitrogen.
< Less than

<u>Note</u>: Hydrogen results obtained by hot extraction.
Sample C has highest residual hydrogen.
Samples D F G H have higher than average oxygen contents.

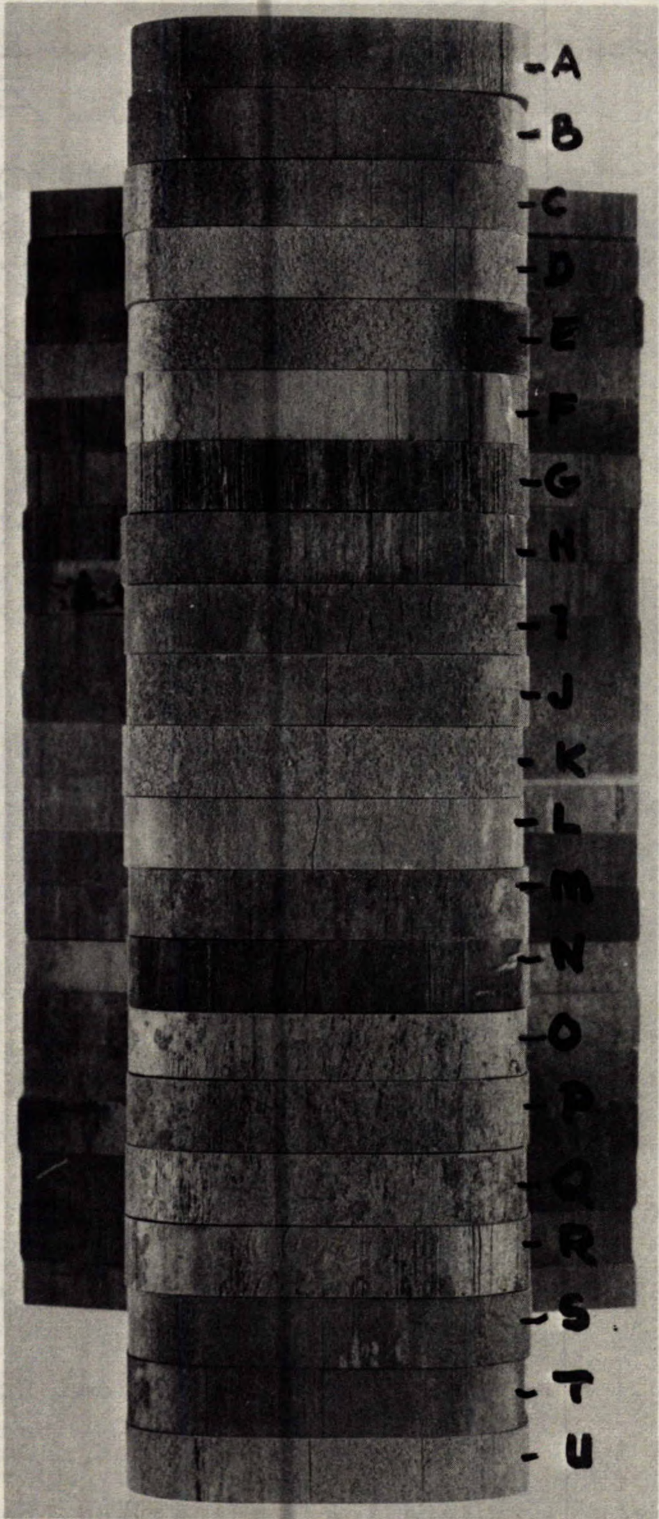


1963 Mn-V   1962   1961   1957   1953   1952   1951

Figure 1. Samples Received For Metallurgical Examination.

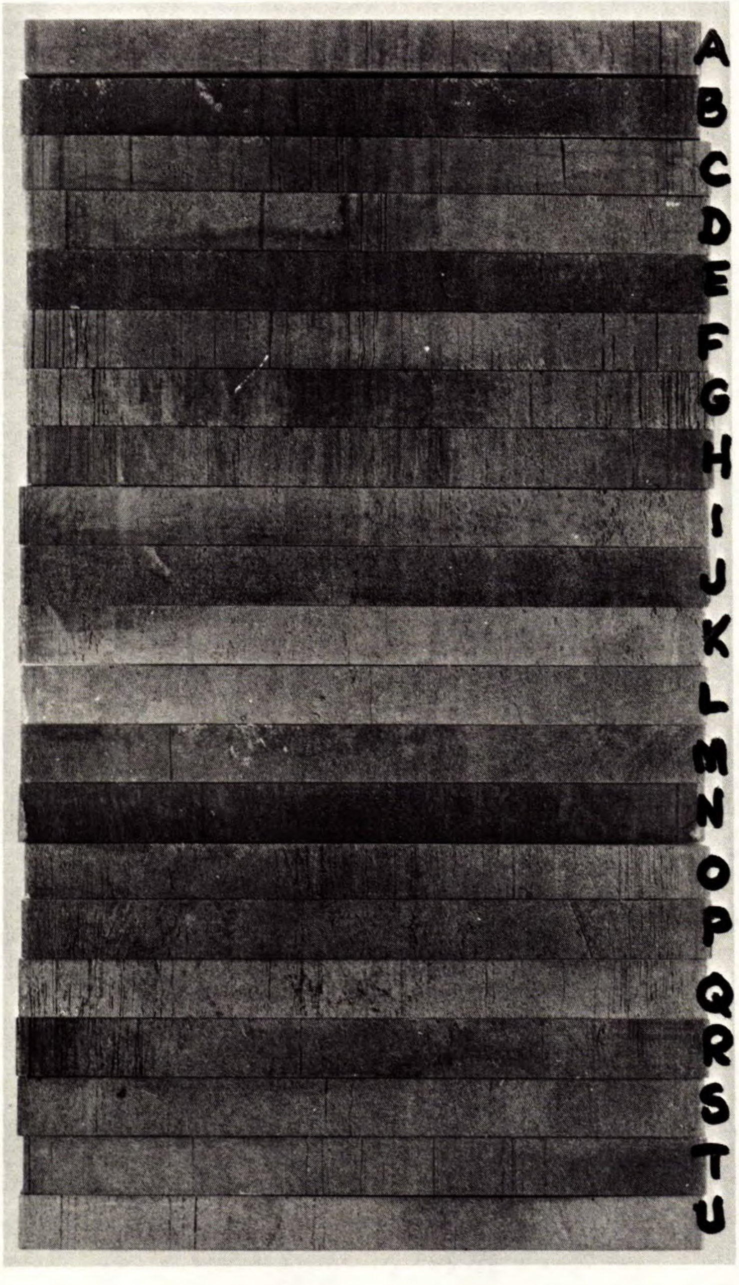
Samples A to U inclusive were examined. One sample from each of the 39 ft rails was examined - EA9; 62-9; 61-9; 57-9; 53-9;52-9; and 51-9; however, complete longitudinal and transverse, tensile, impact and fatigue tests were made at each of the nine positions along each rail. Samples O, P; L, M; I, J; G; D, E and A, B were replicates for each of the years of rolling.

Samples R, S, T and U were lengths representing test rails installed in the railway for test purposes. Detailed identification with respect to code letter, year of rolling and heat number is shown in Table 1.



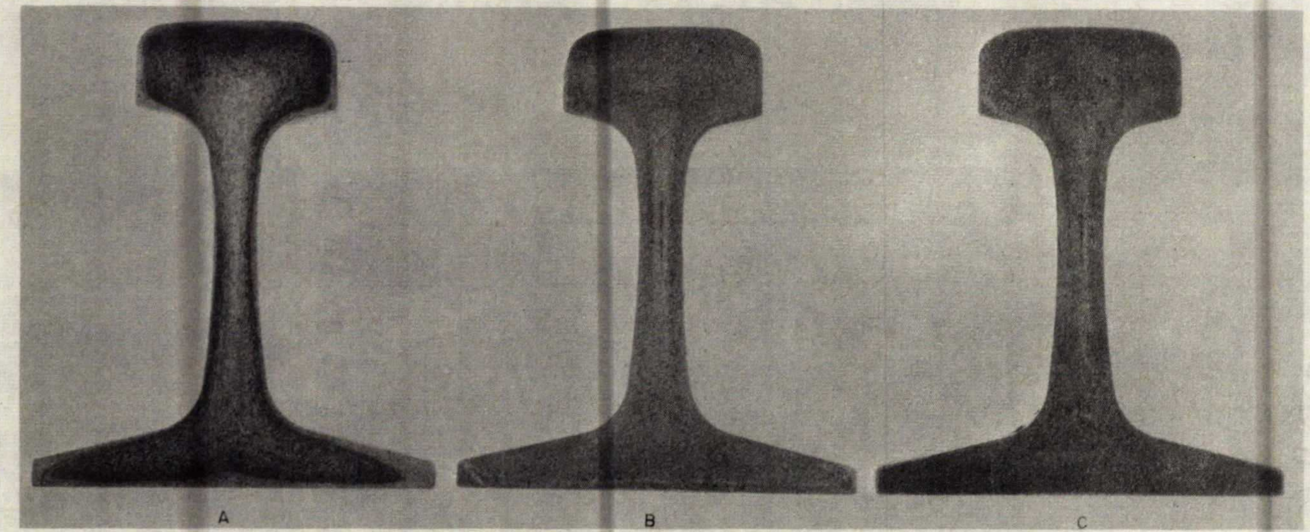
X 2/3 approx.

Figure 2. Illustrates the Surface of the Rail Heads, after Etching 20 minutes in 1:1 HCl water at 170°F.

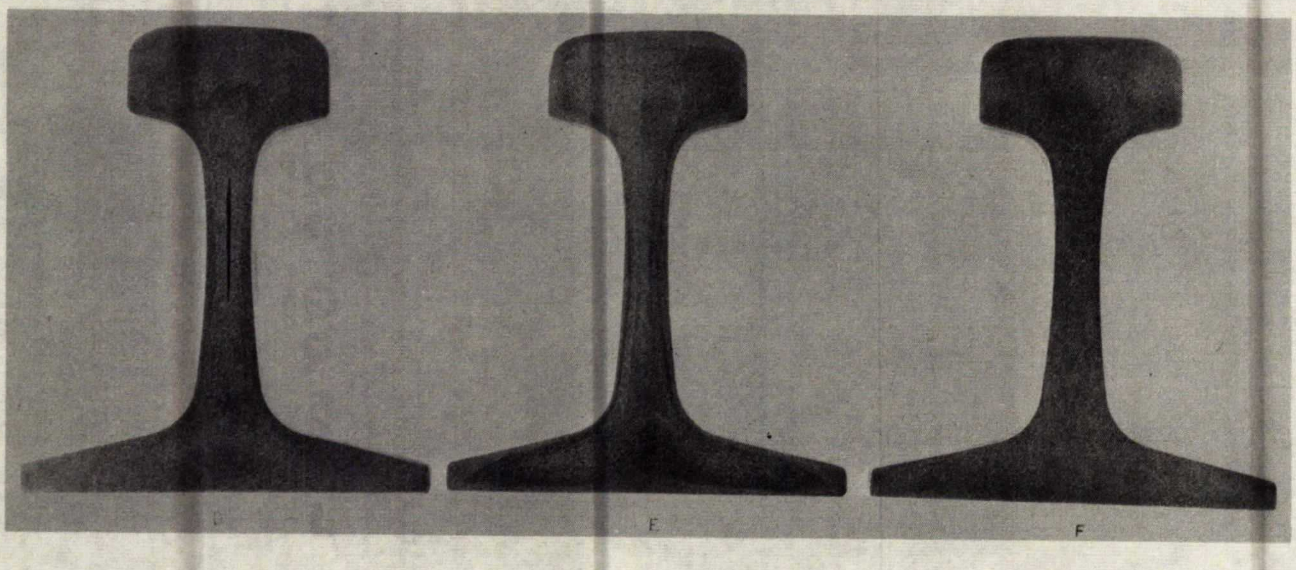


X$\frac{1}{2}$ approx.

Figure 3. Illustrates the Appearance of the Rail Flanges after Deep Etching.



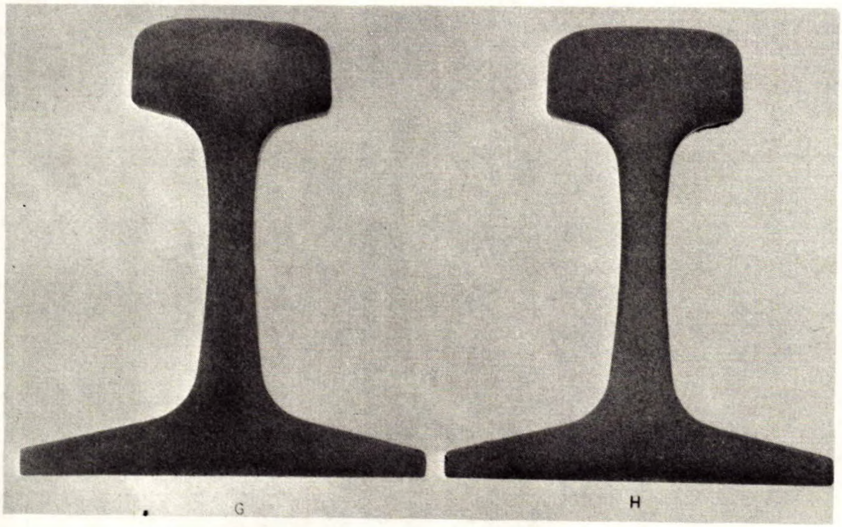
(A) (B) (C)



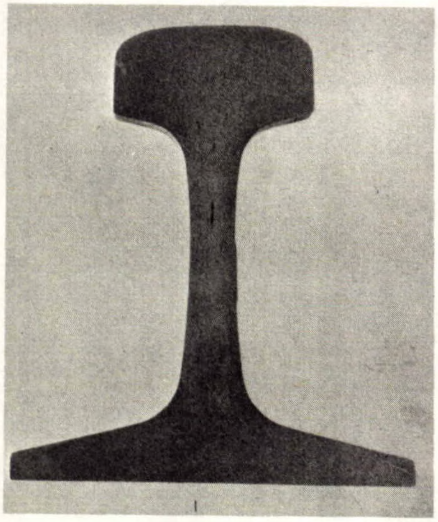
(D) (E) (F)

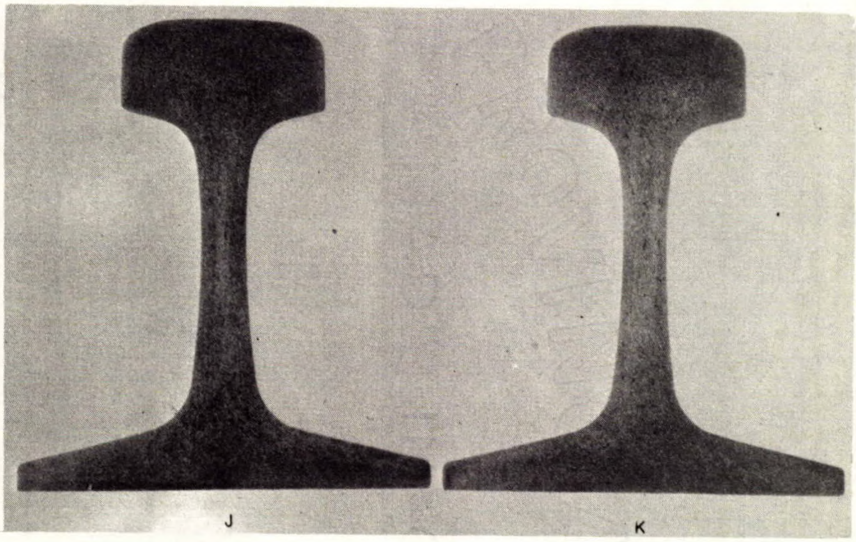
Figure 4.

(cont'd)



(G) (H)

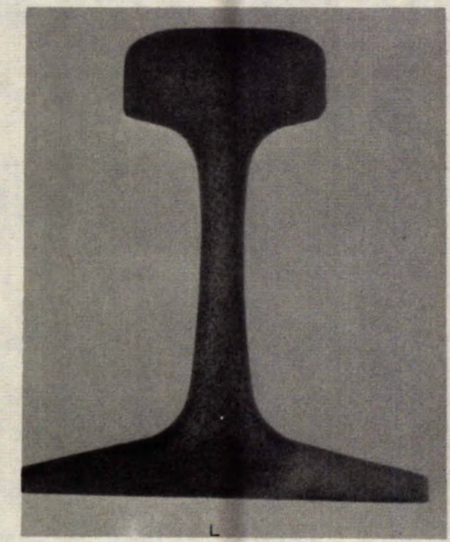




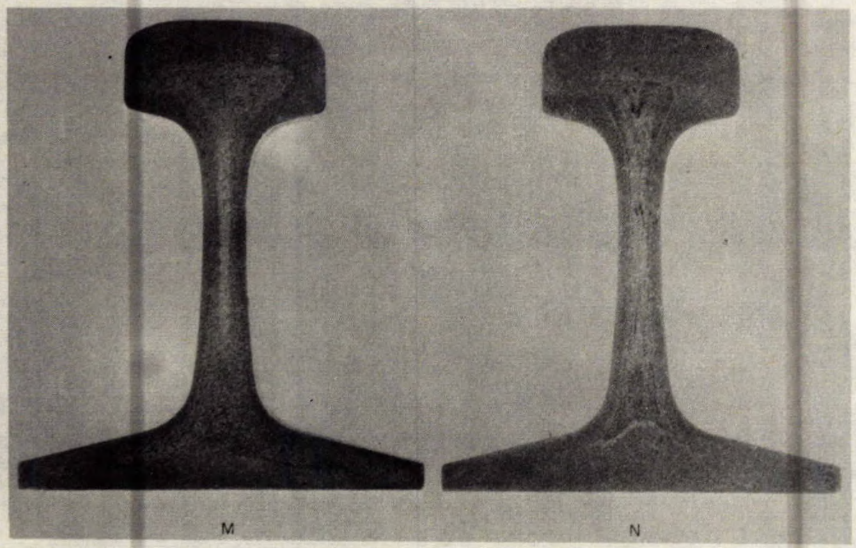
(I) (J) (K)

Figure 4.

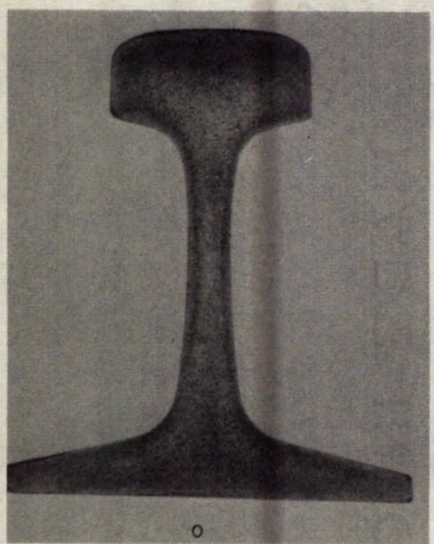
(cont'd)



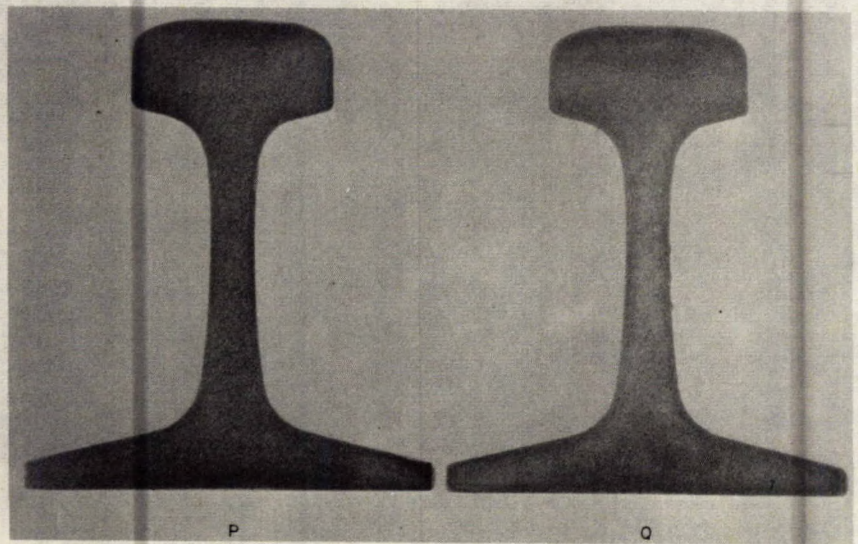
(L)



(M) (N)



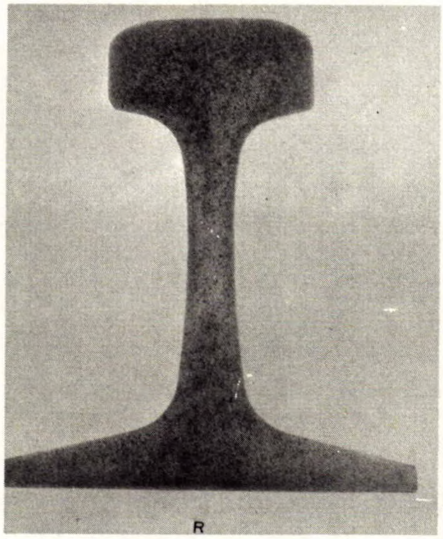
(O)



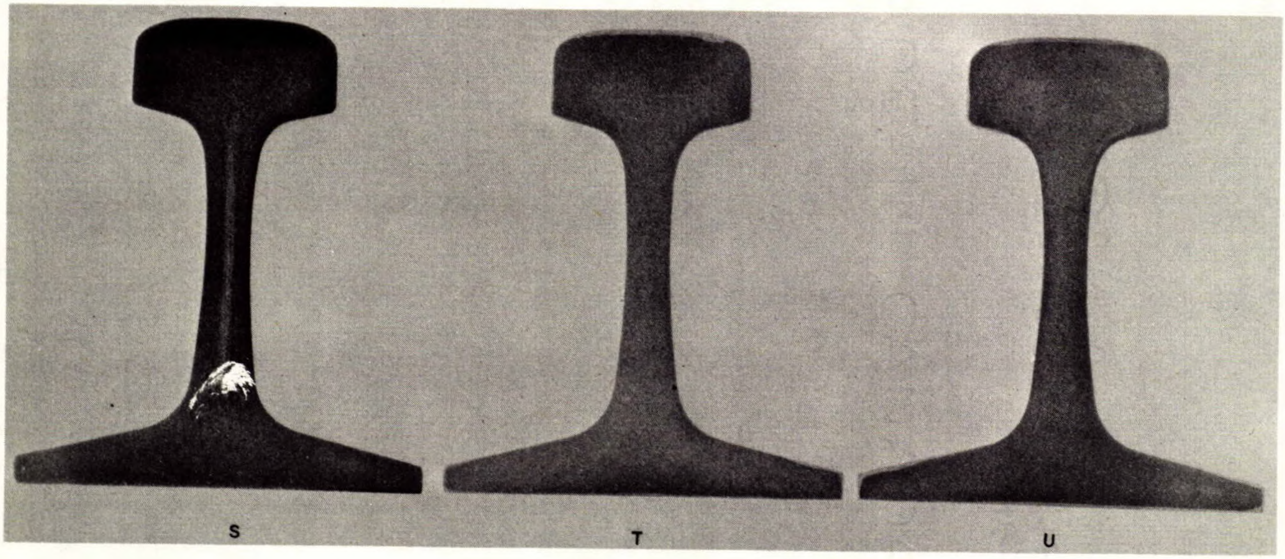
(P) (Q)

Figure 4.

(cont'd)



(R)

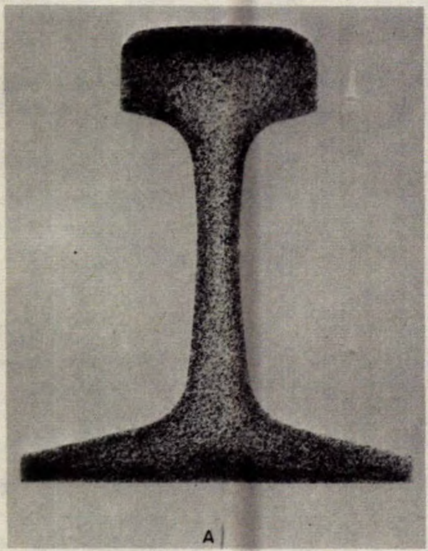


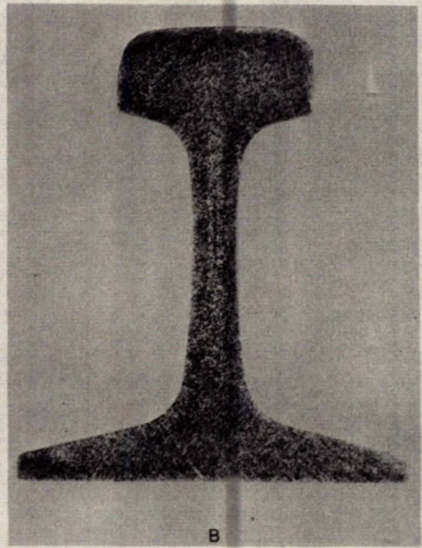
(S) (T) (U)

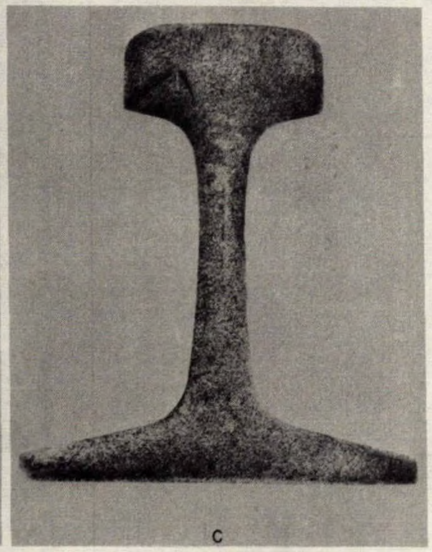
X 1/3 approx.

Figure 4. Deep Etched Transverse Sections Through Rail Samples A to U Inclusive. - i.e., Figure 4-A to U inclusive.

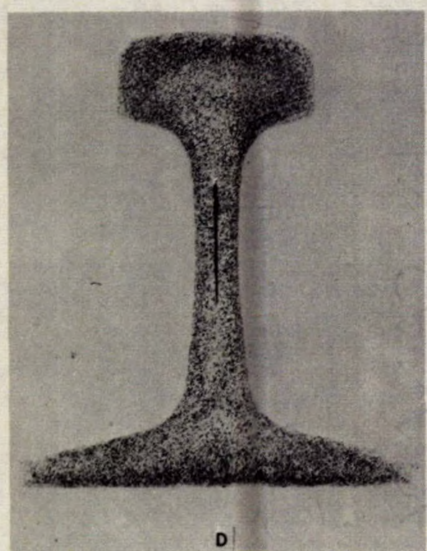
(concl'd)

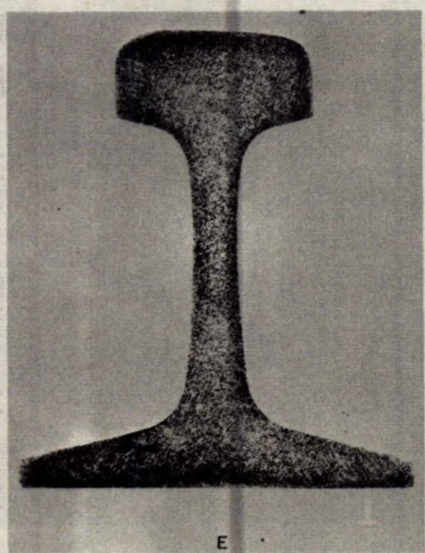


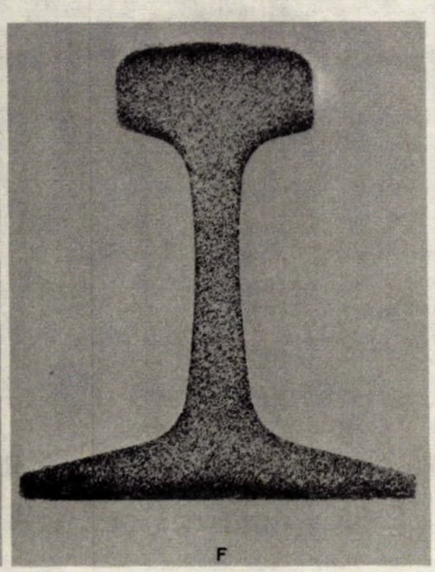




(A) (B) (C)



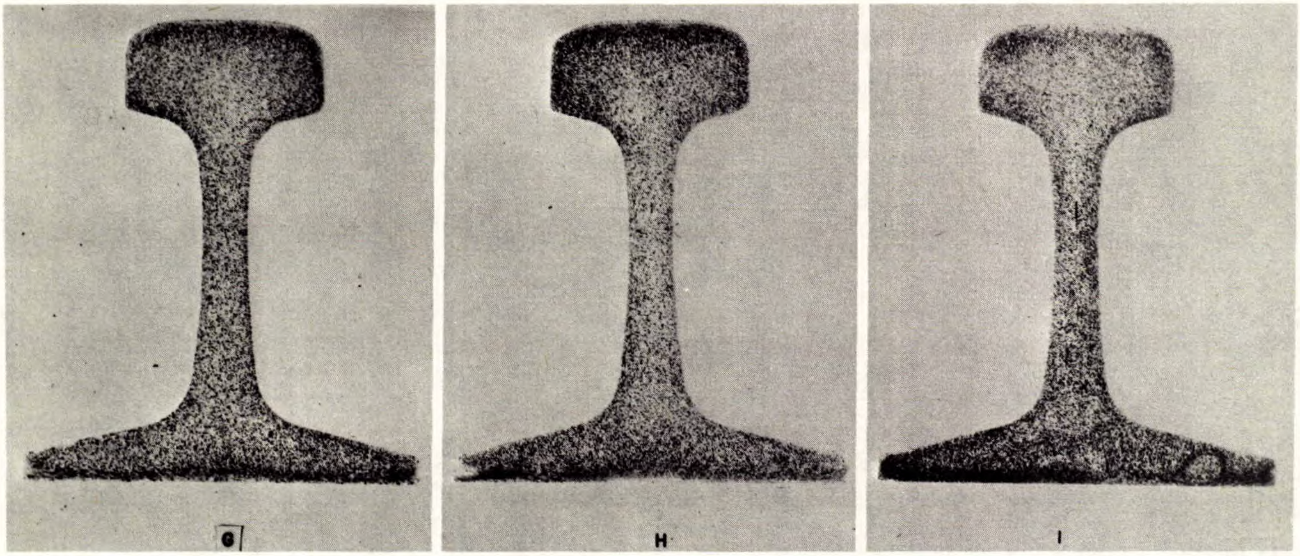




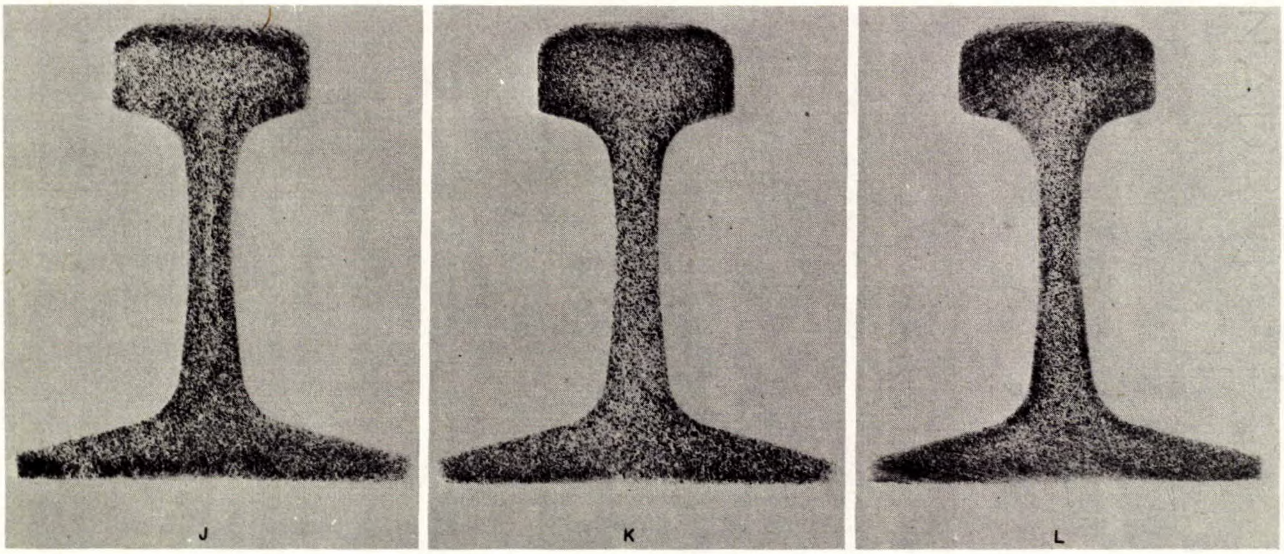
(D) (E) (F)

Figure 5.

(cont'd)



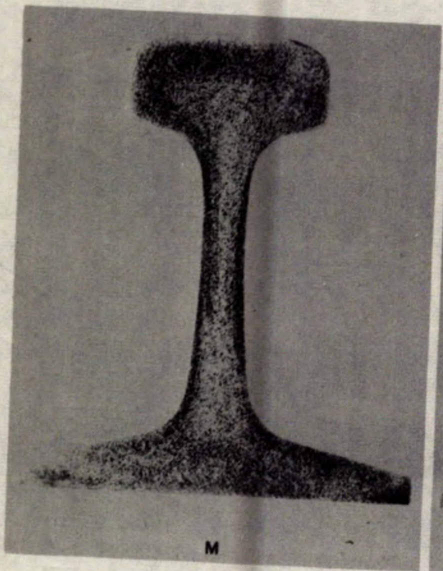
(G) (H) (I)



(J) (K) (L)

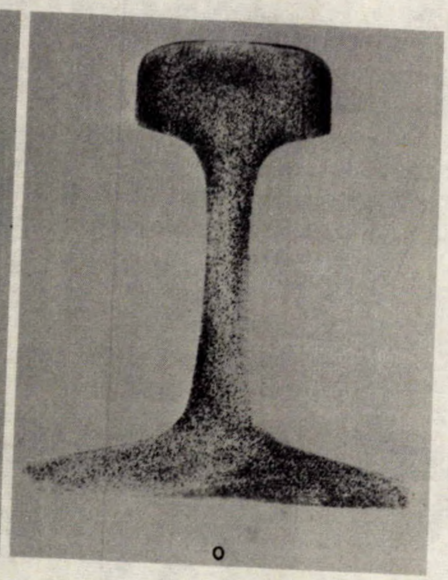
Figure 5.

(cont'd)

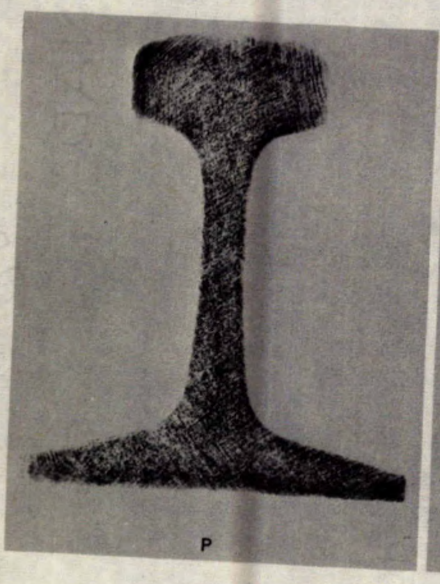


(M)

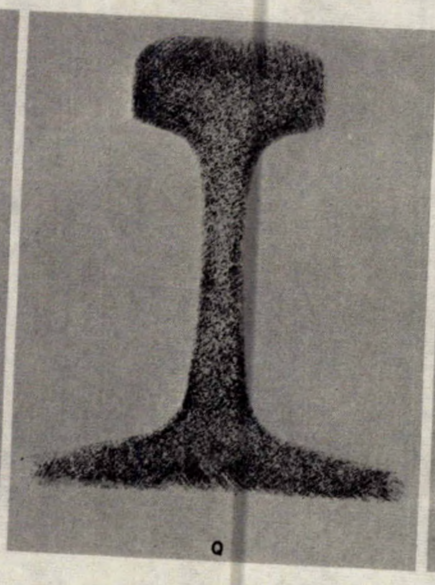
(N)



(O)



(P)

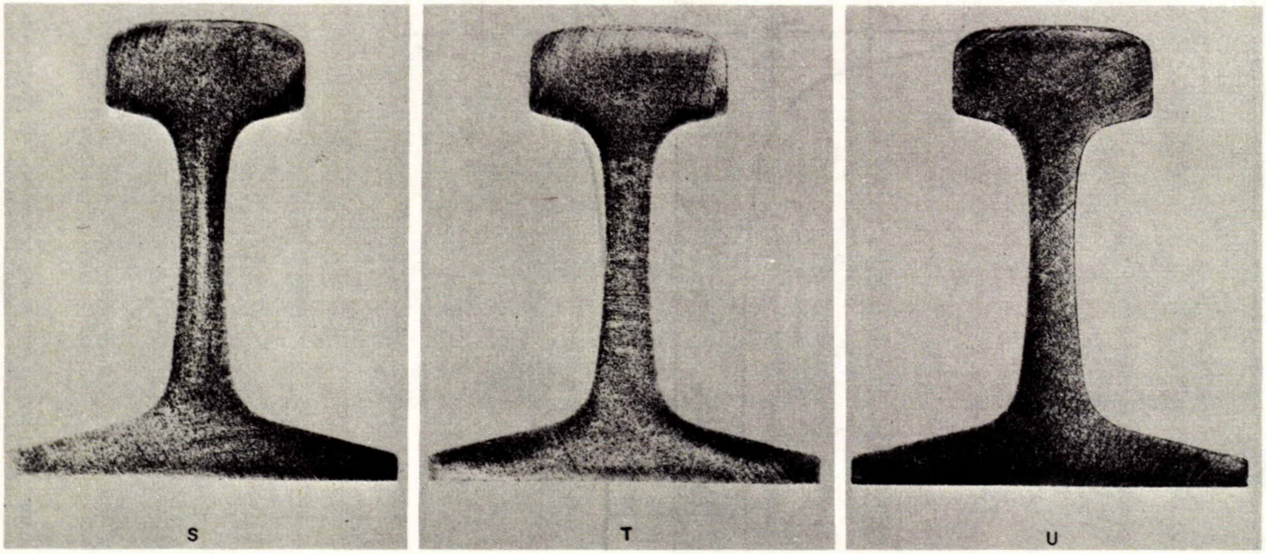


(Q)

(R)

Figure 5.

(cont'd)



(S) (T) (U)

Figure 5. Photograph of Sulphur Prints, Transverse Sections, Samples A to U inclusive.

The sections were rated 1 to 4 with respect to quantity of sulphide inclusion observed in the sulphur print:- rating 1= minimum quantity of sulphide; 4= maximum quantity of sulphide.

(Concl'd)

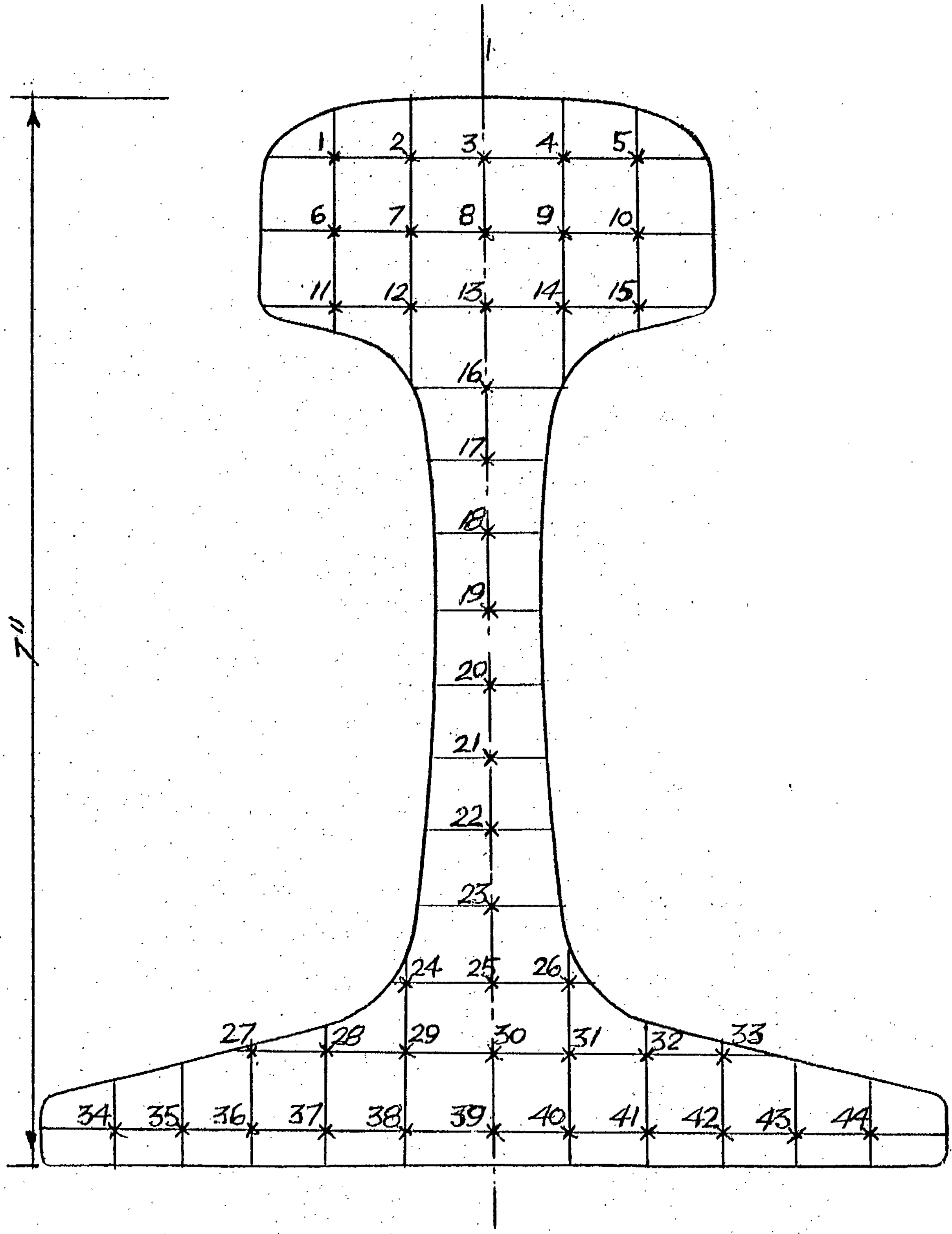
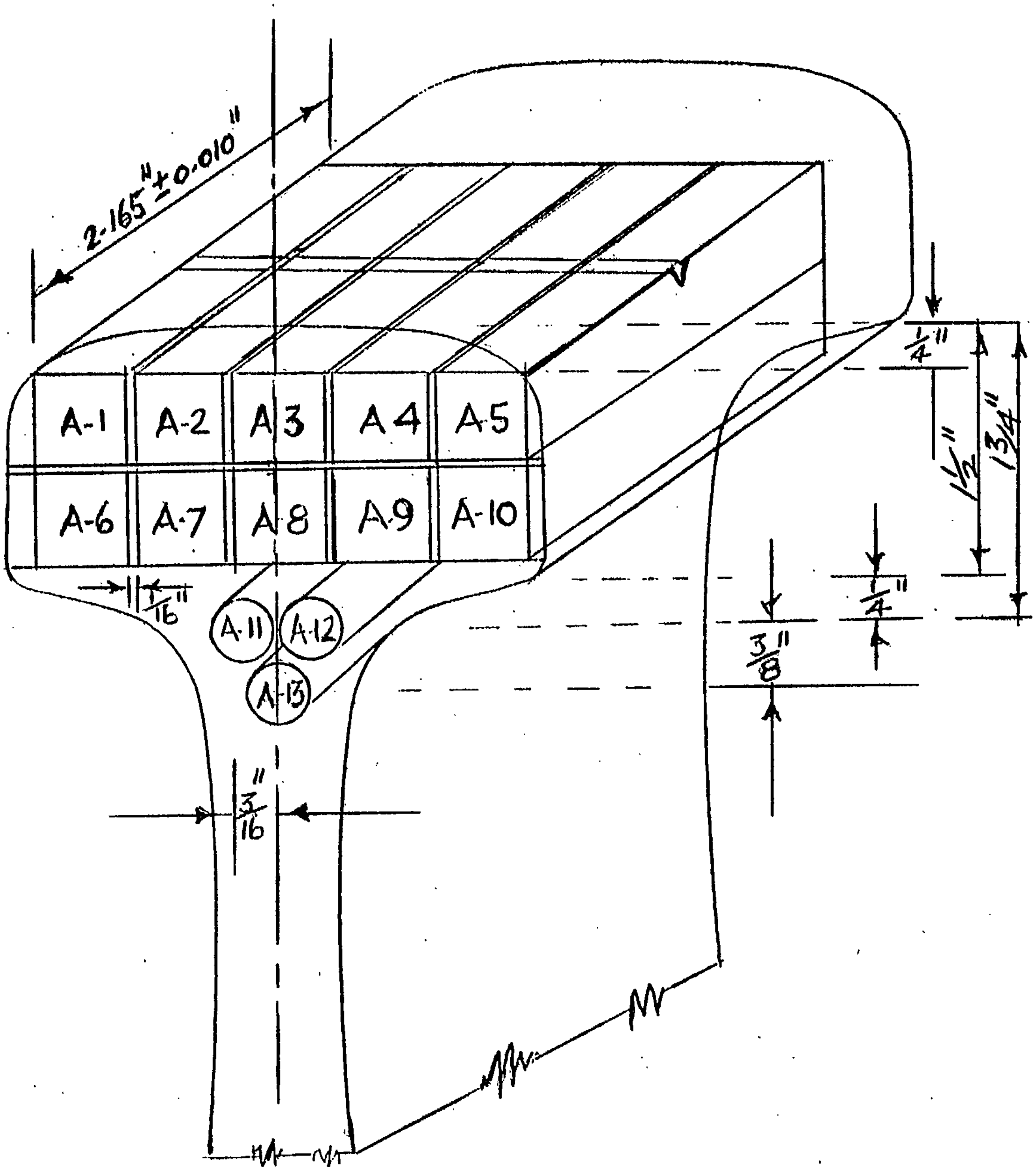
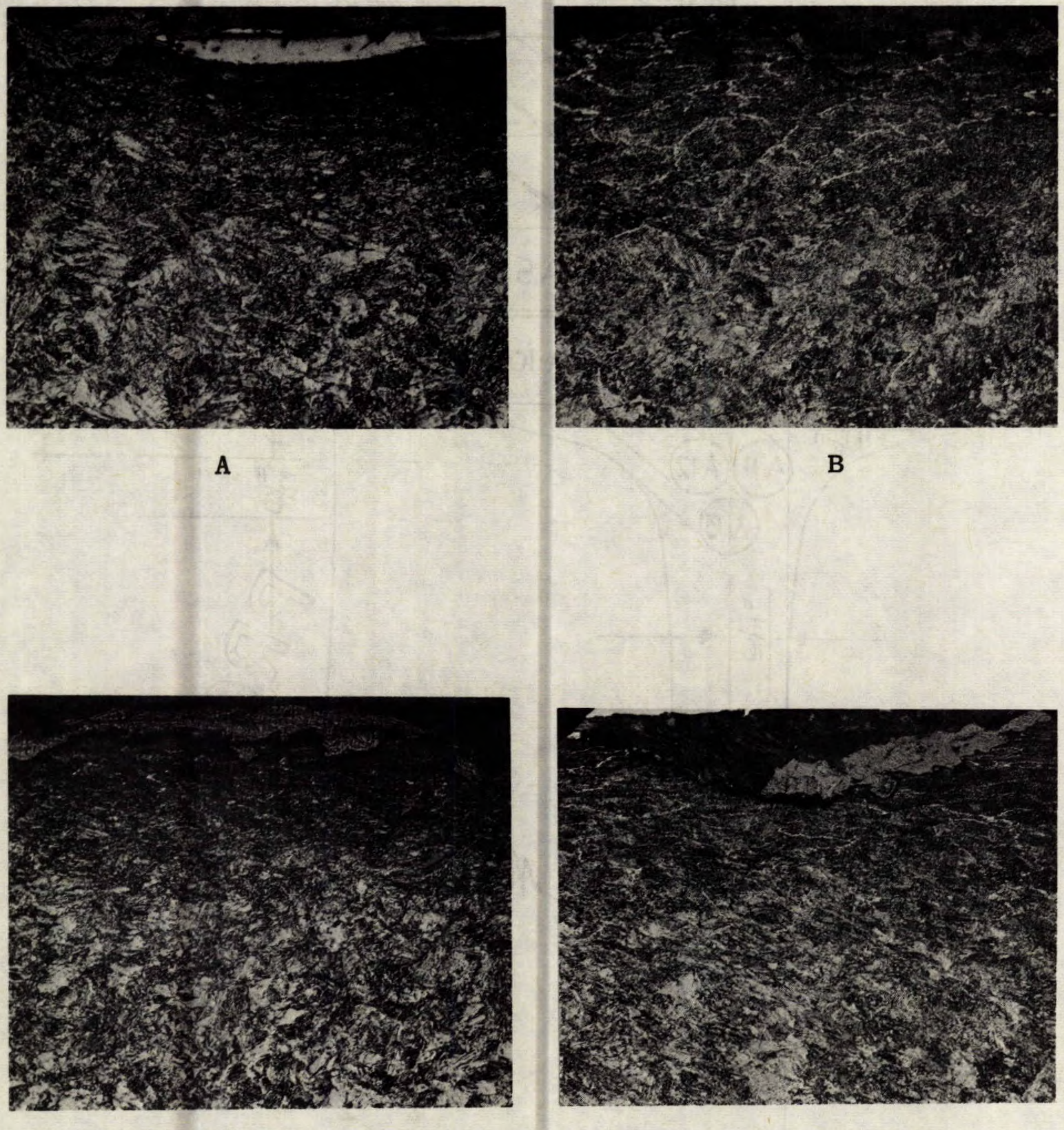


Figure 6. Position of Rockwell C Hardness Survey Readings.



Actual Size

Figure 7. Location of Hounsfield Tensile and Charpy V-Notch Impact Bars Obtained from 8 in. Samples. The test bars were machined in the longitudinal direction. Notches were cut at the top surface, transverse to the rolling direction.

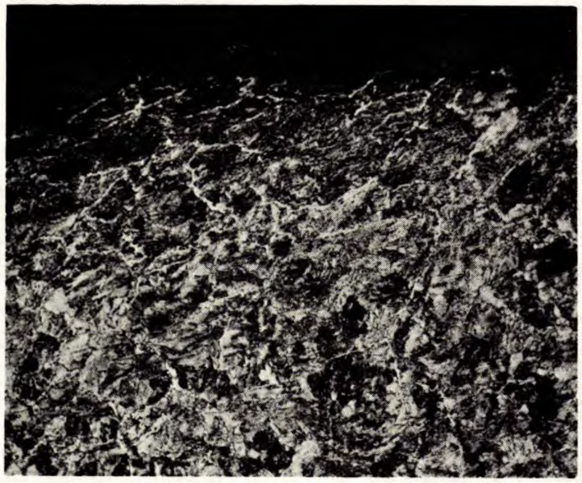


A B

C D

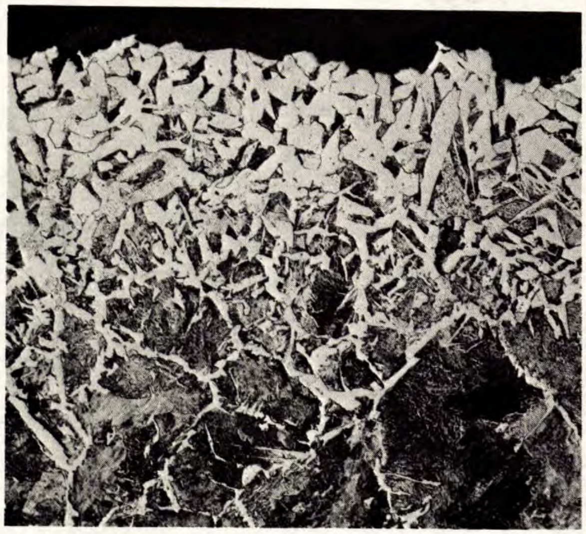
Figure 8. X100

(cont'd)

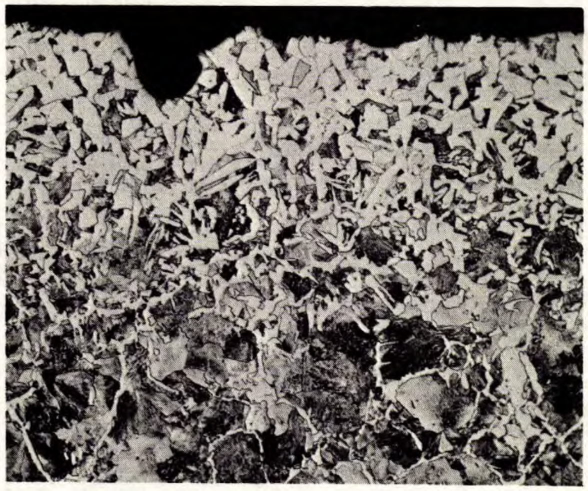


E

F



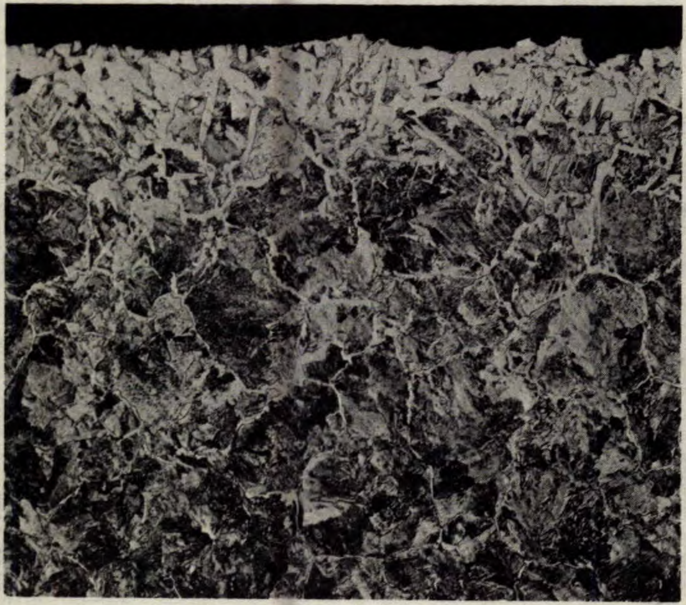
G



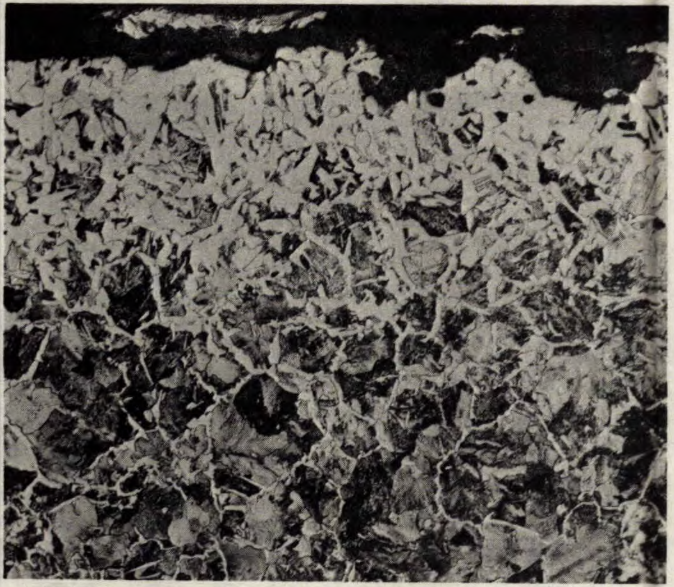
H

Figure 8. X100

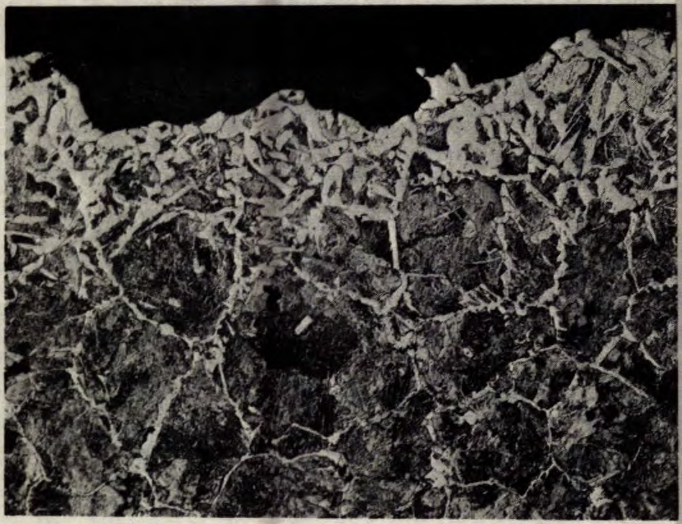
(cont'd)



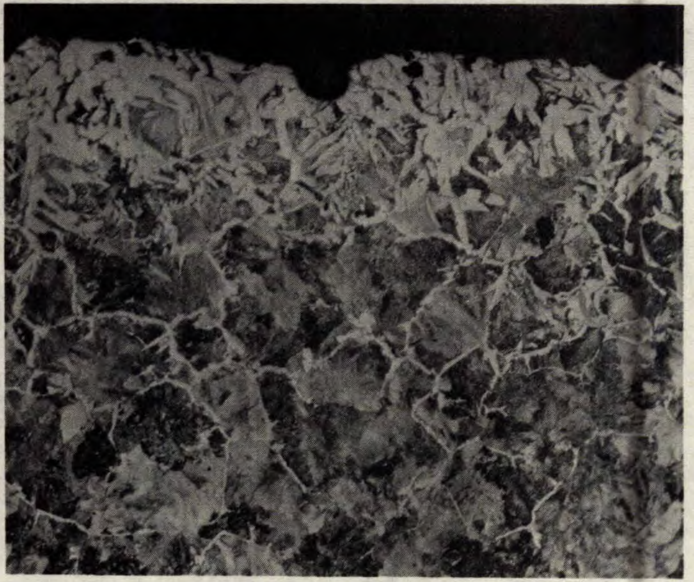
I



J



K

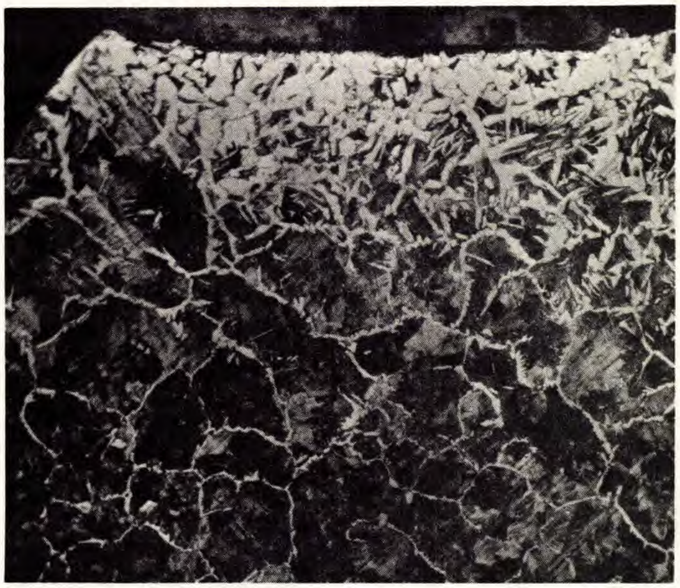


L

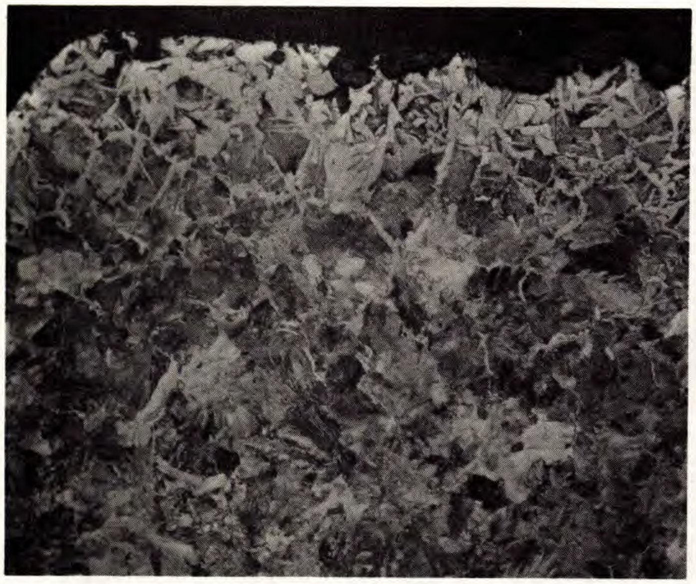
Figure 8. X100

(cont'd)

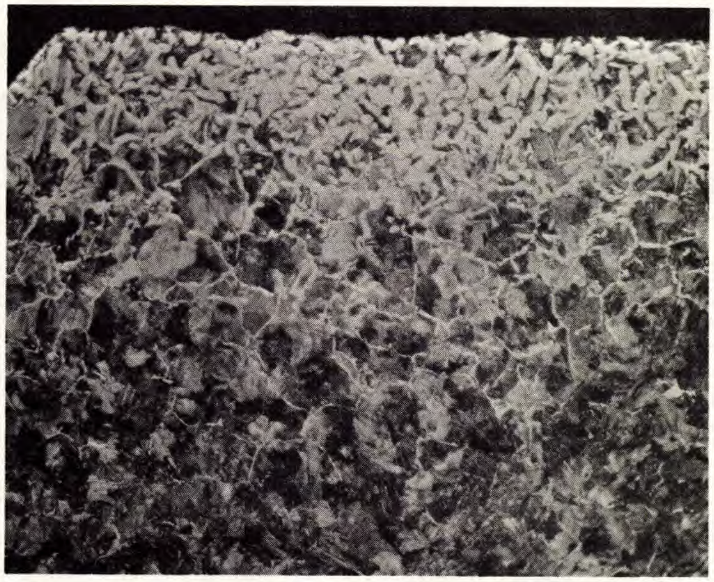
M



N



O

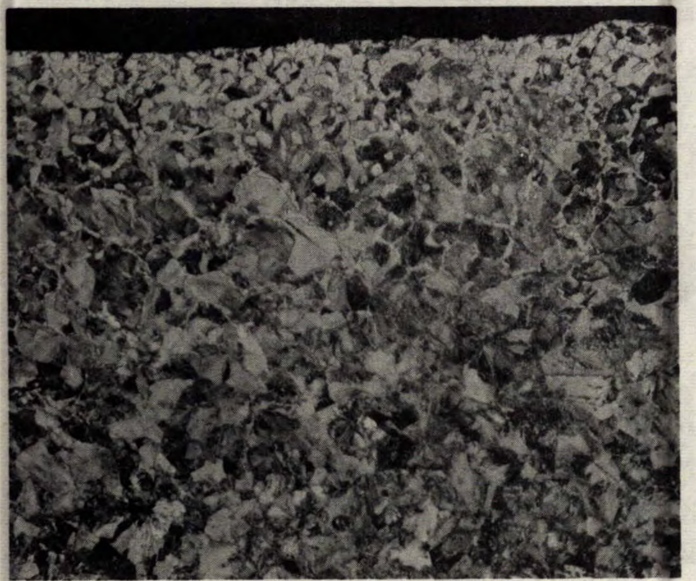


P

Figure 8. X100

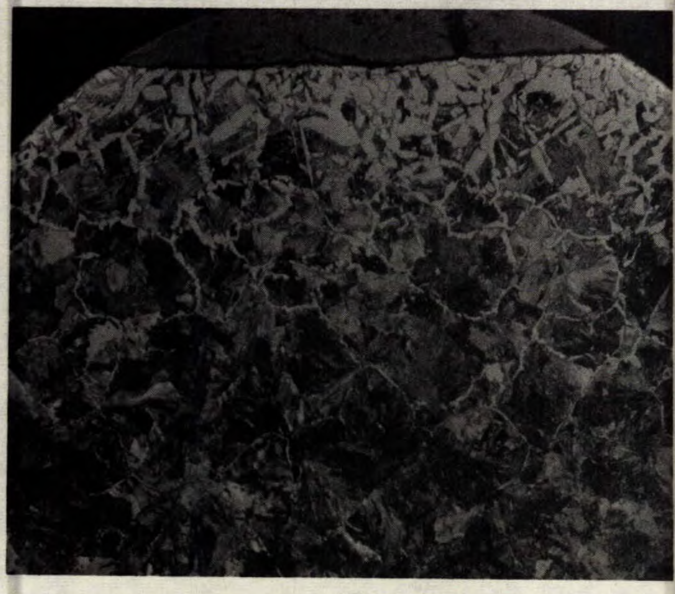
(cont'd)

Q



R
DOSCO Alloy Mn-V Steel

S
(note, fine pearlite, no decarburization) Quebec Cartier Rail



T
Bethlehem Std. Carbon Steel

Figure 8. X100

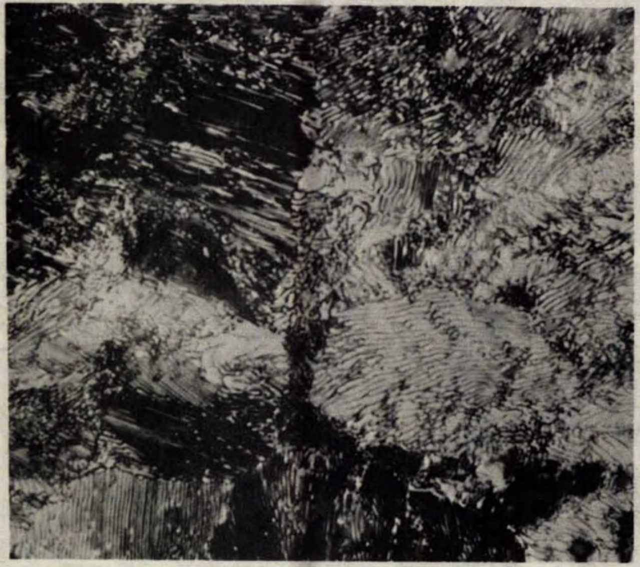
(cont'd)

U
Etched 2% Metal. (Grain Size=7)
Bethlehem Quenched & Tempered.
X100

Figure 8. Illustrates the Microstructure of Samples A to U inclusive viewed on a transverse section at the centre of the head crown surface, corresponding to the loaded high point at the centre of the rail head.

(concl'd)

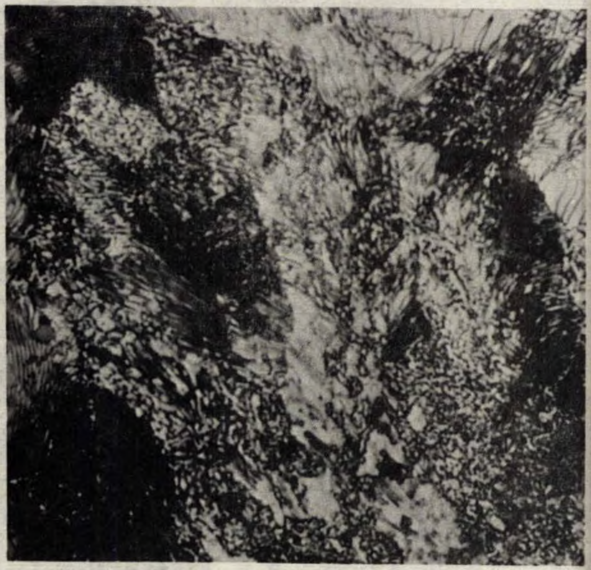
Pearlite Lamellae Spacing Etched 2% Metal



C

1951

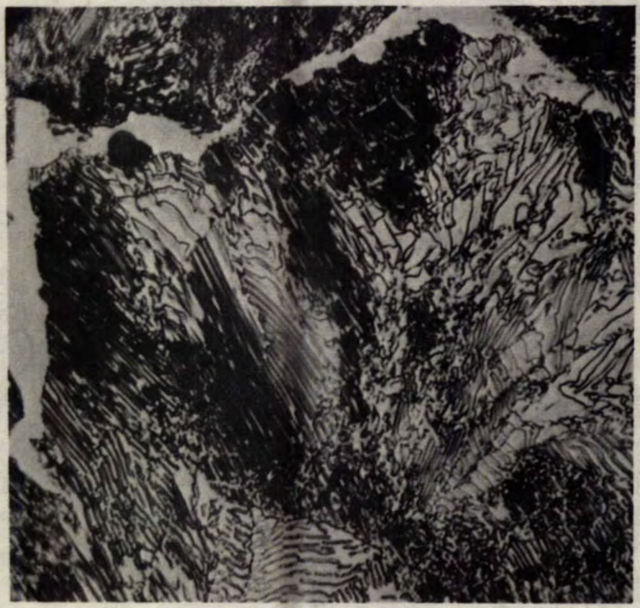
¼ in. from crown head surface



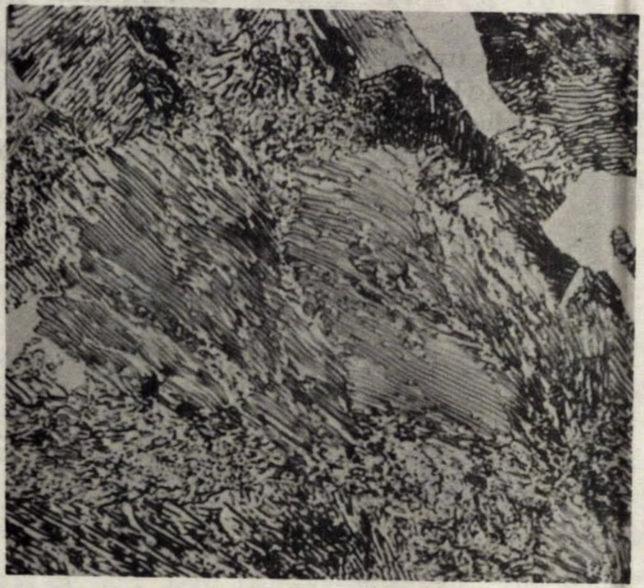
D

1952

¼ in. from crown head surface



H



I

1953

¼ in. from crown head surface

* Note: lamellae spacing is considerably finer in 1951, 1952 samples than in 1953 or 1957 samples

Figure 9. X1500

(cont'd)

M

1961

$\frac{1}{4}$ in. from crown head surface

N

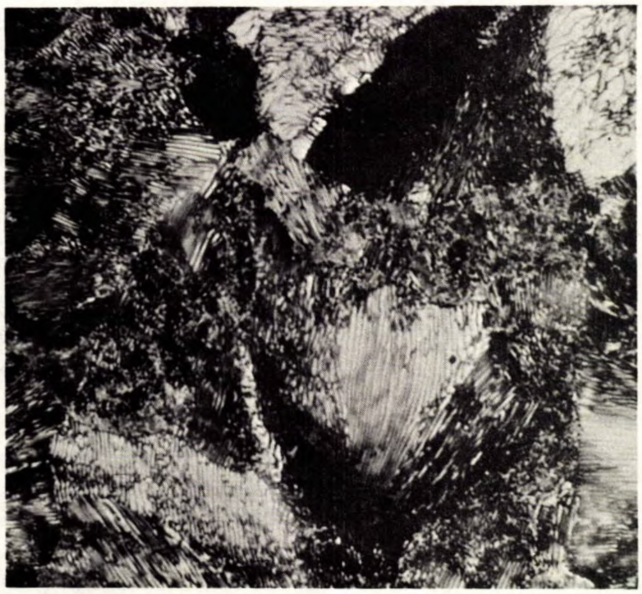
1961

$\frac{1}{4}$ in. from crown head surface

P

1962

$\frac{1}{4}$ in. from crown head surface



R

Mn-V. alloy steel

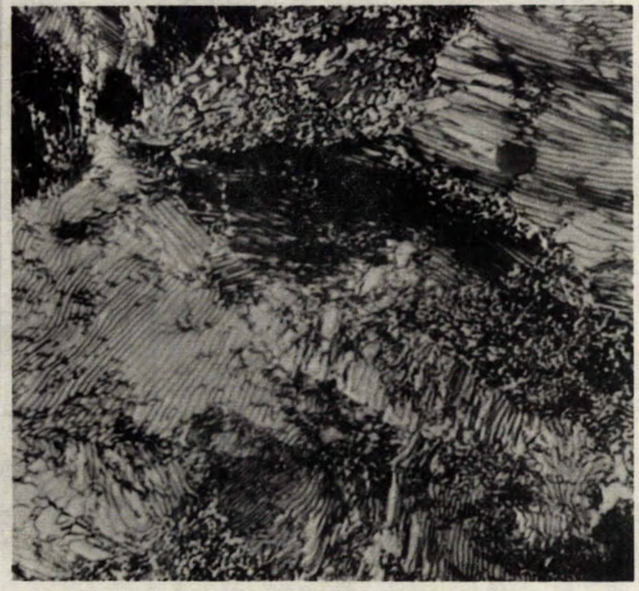
$\frac{1}{4}$ in. from crown head surface

Figure 9. X1500

(cont'd)

S

Quebec Cartier, Rlwy. USS Standard Carbon Steel Rail - ¼ in. from crown head surface



T

Lackawanna Rlwy. Bethlehem Steel Co., Standard Carbon Steel Rail, ¼ in. from crown head surface

U

Bethlehem Steel Co., Quenched and Tempered Rail ¼ in. from crown head surface

Figure 9. Illustrates the pearlite lamellae spacing at X1500 after etching in 2% metal solution.

(concl'd)

APPENDIX A

Mechanical Tests (E. G. Eeles, Engineering Physics Section).

The bulk mechanical properties of one rail each from 1951, 1952, 1953, 1957, 1961 and 1962 were measured from samples taken from various positions in each rail. In addition, a rail manufactured from low alloy steel (R) was tested. Nine sampling positions were taken from each rail, these comprised the two ends and seven equi-spaced intermediate positions. At each position six longitudinal and three transverse 3/4 in. x 3/4 in. x 3/4 in. sample blanks were cut. In general, only seven tests were made in each rail, positions 2 and 8 being retained for any further testing required.

The mechanical tests carried out were tensile, Charpy impact and Krouse rotating bending fatigue, in each instance using the largest standard test piece obtainable from the blanks.

The results of the tests are given in Tables 1, 2 and 3 as mean values for the tensile and impact tests and as antilog log mean and median rank endurance values for the fatigue tests.

In addition to the impact values given in Table 2, some elevated temperature Charpy tests were carried out to determine the nature of the energy versus temperature curve. As would be expected for a material of this type, no sharp brittle to ductile transition was found and, at the highest temperature used, 300°F, the energy absorbed was less than 20 ft-lb.

Examination of the individual test data showed that, in some instances, the distribution of values around the mean was irregular and it was therefore considered that no justification existed for application of Gaussian distribution statistics. It is possible that, had a larger number of tests been performed, one or other of the various extreme value distribution functions could be applied. In the absence of confirmatory evidence for this, direct rank testing was used to establish the differences between the various years. The results of these comparisons are shown in Tables 4A to 4G. The alloy steel rail (R) is not included.

These tables show that, although differences exist between the mean values given in Tables 1, 2 and 3, 5% significance is not found throughout. In general, 1951 and 1961 rails have similar properties while 1953, 1957 and 1962 have comparable properties. As indicated in the Tables, χ^2 significance tests show that these latter years are indistinguishable for tensile properties, except reduction of areas.

The general conclusion to be reached is that, although some differences were found, no significant pattern was established and, therefore, no conclusions can be reached as to possible service life.

TABLE 1.

Results of Tensile Tests-Mean Values

Year	Longitudinal	Transverse
a) Ultimate Tensile Strength (kpsi)		
1951	148.4	128.1
1952	136.9	124.9
1953	128.6	123.3
1957	127.9	124.4
1961	142.8	137.7
1962	131.5	125.2
R	154.8	149.6
b) 0.2% Offset Stress (kpsi)		
1951	77.9	81.1
1952	73.9	70.8
1953	66.9	69.5
1957	64.7	62.5
1961	79.9	77.5
1962	70.9	65.4
R	98.5	95.5
c) 0.01% Offset Stress (kpsi)		
1951	63.6	62.3
1952	59.8	58.1
1953	57.0	51.7
1957	55.1	49.2
1961	64.3	58.9
1962	55.7	51.8
R	80.8	76.4
d) Elongation (% on 4XD)		
1951	10.1	3.9
1952	16.1	5.3
1953	14.6	10.6
1957	14.1	9.4
1961	12.1	6.2
1962	14.3	8.5
R	12.0	9.6
e) Reduction of Area (%)		
1951	13.6	5.8
1952	16.1	4.6
1953	21.5	10.6
1957	19.7	9.4
1961	15.7	7.0
1962	25.1	7.5
R	33.0	15.1

TABLE 2.

Results of Charpy Impact Test (ft-lb).

Year	Longitudinal	Transverse
1951	2.8	3.1
1952	2.3	2.3
1953	3.3	3.6
1957	4.0	3.7
1961	4.2	4.2
1962	8.3	5.1
R	2.6	3.8

TABLE 3.

Results of Krouse Rotating Bending Fatigue Tests ($X10^3$ cycles).

Year	Longitudinal		Transverse	
	Mean	Median	Mean	Median
1951	10^4+	10^4+	30	31
1952	252	241	22	26
1953	133	117	15	17
1957	87	89	31	24
1961	2,720	10^4+	48	49
1962	323	185	25	24
R	10^4+	10^4+	206	192

Stress 60,000 psi

TABLE 4A.

Comparison of Ultimate Tensile Strengths
(5% Significance).

	1952	1953	1957	1961	1962
1951	+ =	+ =	+ =	+ -	+ =
1952		+ =	+ =	- -	= =
1953			= =	- -	= =
1957				- -	= =
1961					+ +

χ^2 test shows no significant difference between 1953, 1957 and 1962.

TABLES 4

Symbols represent relation of year with year given at head of column. First symbol is for longitudinal property, second is for transverse, + larger than, = same as, - smaller than.

TABLE 4B

Comparison of 0.2% Proof Stress

(5% Significance).

	1952	1953	1957	1961	1962
1951	+ +	+ =	+ +	= =	= +
1952		+ =	+ +	= -	= +
1953			= =	- =	= =
1957				- -	= =
1961					+ +

χ^2 test shows no significant difference between 1953, 1957 and 1962.

TABLE 4C

Comparison of 0.01% Proof Stress

(5% Significance).

	1952	1953	1957	1961	1962
1951	= =	= +	+ +	= +	= +
1952		= +	= =	= =	= +
1953			= =	= -	= =
1957				- -	= =
1961					= +

χ^2 test shows no significant difference between 1953, 1957 and 1962.

TABLE 4D

Comparison of Elongation
(5% Significance)

	1952	1953	1957	1961	1962
1951	– =	– –	– –	– –	– =
1952		– –	= –	= –	= =
1953			– =	+ +	– –
1957				= +	= =
1961					= –

χ^2 test shows no significant difference between 1953, 1957 and 1962.

TABLE 4E

Comparison of Reduction of Area
(5% Significance).

	1952	1953	1957	1961	1962
1951	– =	– =	– =	– =	– =
1952		– =	= =	= =	– =
1953			= =	+ +	– =
1957				+ +	– =
1961					– =

TABLE 4F

Comparison of Charpy Impact Values

(5% Significance).

	1952	1953	1957	1961	1962
1951	= =	= =	+ =	= =	- -
1952		= -	- -	- -	- -
1953			= =	= =	- -
1957				= =	- =
1961					- =

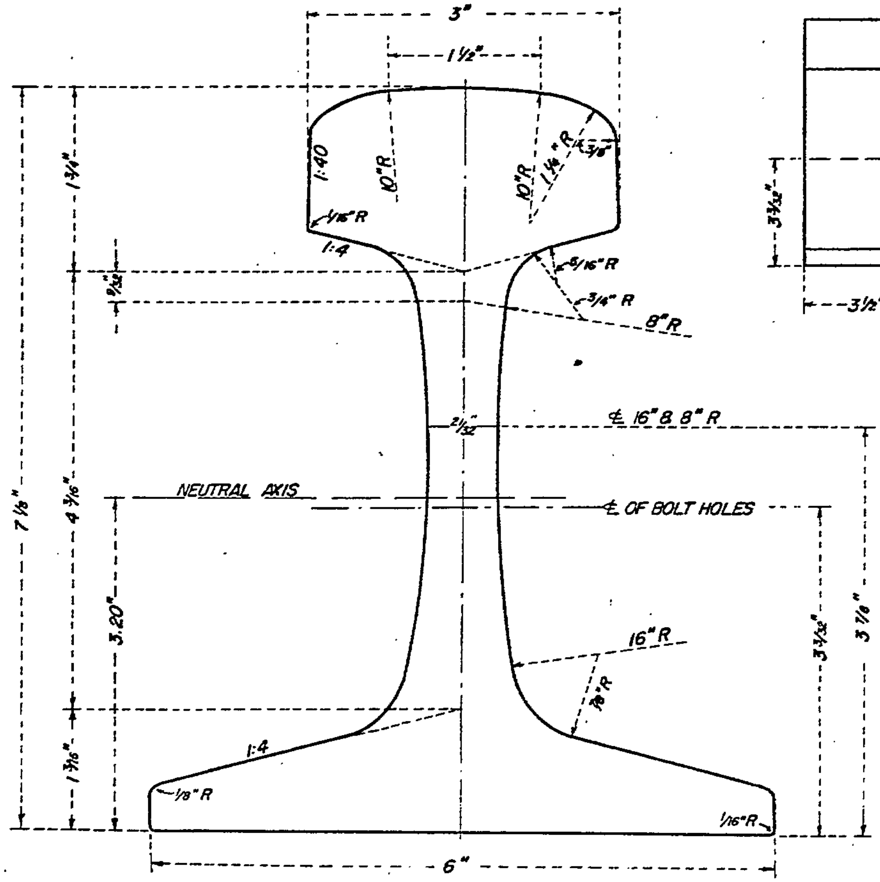
TABLE 4G

Comparison of Krouse Fatigue Values

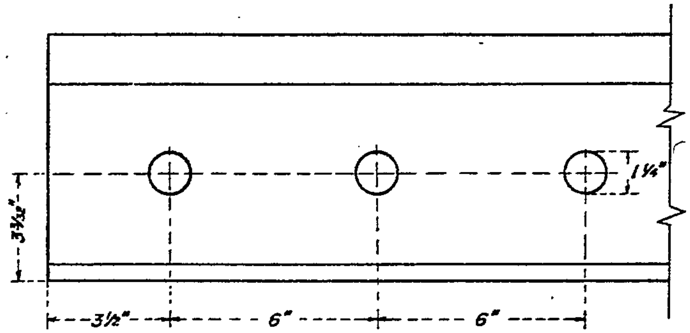
(5% Significance).

	1952	1953	1957	1961	1962
1951	+ =	+ +	+ =	+ -	+ =
1952		- =	+ =	- -	= =
1953			= -	- -	= -
1957				- -	- =
1961					= +

APPENDIX B



FULL SIZE



SCALE: 4" = 1'0"

MATHEMATICAL PROPERTIES

MOMENT OF INERTIA	88.2
SECTION MODULUS, HEAD	22.5
SECTION MODULUS, BASE	27.6
RATIO M. I. TO AREA	6.81
RATIO S. M. HEAD TO AREA	1.74
RATIO HEIGHT TO BASE	1.19
CALCULATED WEIGHT, LB. PER YD.	132.1

	AREA — SQ. IN.	PERCENT
HEAD	4.42	34.1
WEB	3.66	28.3
BASE	4.87	37.6
TOTAL	12.95	100.0

QUEBEC NORTH SHORE & LABRADOR RAILWAY

STANDARD

132 LB RE RAIL

SCALE: AS SHOWN
DATE: SEPT. 28, 1954
DRAWN:

CHIEF ENGINEER

REDUCED 32% PLAN No. S-2-3