INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT ON THE CHICAGO, ST PAUL, MINNEAPOLIS & OMAHA RAILWAY NEAR BIGELOW, MINN, ON FEBRUARY 9, 1914

NOVEMBER 5, 1914

TO THE COMMISSION

On February 9, 1914, there was a derailment of a passenger train on the Chicago, St Paul, Minneapolis & Omaha Railway near Bigelow, Minn, resulting in the death of 1 passenger and 1 express messenger and the injury of 11 passengers, 2 mail clerks, 2 porters, and 2 conductors After investigation as to the nature and cause of this accident, I beg to submit the following report

The derailed train was eastbound train No 2, known as the "Twin City Limited," running from Omaha, Nebr, to Minneapolis, Minn It consisted of 1 mail car, 1 express car, 1 buffet car, 2 wooden Pullman sleeping cars, 1 chair car, and 1 smoking car, all of wooden construction, excepting the mail and chair cars, which were of steel construction This train was hauled by locomotive No 371 and was in charge of Conductor Hay and Engineman Hammer Train No 2 passed Bigelow at 2 40 a m, 11 minutes late, and at about 2 45 a m was derailed at a point about 2½ miles east of Bigelow, while running at a speed estimated to have been about 45 miles per hour

The locomotive broke away from the cars and came to a stop at a point about 1,650 feet beyond the point of derailment, the forward pair of engine truck wheels and the rear pair of tender truck wheels being derailed All of the cars in the train were derailed, and with the exception of the express and smoking cars all came to rest on their sides The express car was bottom up and damaged to such an extent that it was afterwards burned, while the smoking car remained upright Illustration No 1 is a view looking in a westerly direction The remains of the express car can be seen at the right of the mail car, which is shown on the extreme left

No 1 General view of the derailment, looking west

This part of the Chicago, St Paul, Minneapolis & Omaha Railway is a single-track line Trains are operated by train orders and time-card rights, their movements being governed by the manual block-signal system The track is on a tangent extending for more than 1 mile in each direction, while the grade is 1 per cent descending for eastbound trains The track is laid with 80-pound steel rails, 30 feet in length, with about 18 oak and cedar ties under each rail Tie plates are used on the cedar ties The ballast is of gravel, about 18 inches in depth The weather was clear

A careful examination was made of locomotive No 371, but nothing was found which in any way could have contributed to the accident Examination of the track approaching the accident from the west showed that the first indication of derailment consisted of a broken rail on the south side of the track nearly 300 feet west of the rear car of the derailed train East of this broken rail the track was more or less damaged by the derailed wheels

Engineman Hammer stated that at the point of derailment the locomotive seemed to drop down and then to rise up He saw fire flying from the engine truck wheels and at once applied the emergency air brakes He did not know that the locomotive had broken away from the cars until it had come to a stop His statements were corroborated by the fireman

The crew of eastbound train No 1, which passed over this section of the track at about 1 55 a m , stated that they felt no unevenness of any kind, there being no indication whatever of a broken rail

This accident was caused by a broken rail, the fragments of which were sent to the Bureau of Standards for examination and test The report of the bureau on the results of its examination is as follows

Report of the Bureau of Standards

The fractured rail was 30 feet long, weighed 80 pounds per yard, and was rolled by the Carnegie Steel Co in September, 1899 Assuming it to have been laid in the track shortly after having been rolled, its total term of service in the track was about 13 years and 5 months

The rail was broken into a large number of pieces, 74 of which were recovered Plate A shows the fractured portion of the rail, near its west end, with pieces of the head placed near the base of the rail

To ascertain the probable cause of the failure of this rail, the following examinations were made

1 Physical tests
2 Metallographic examination
3 Chemical analysis

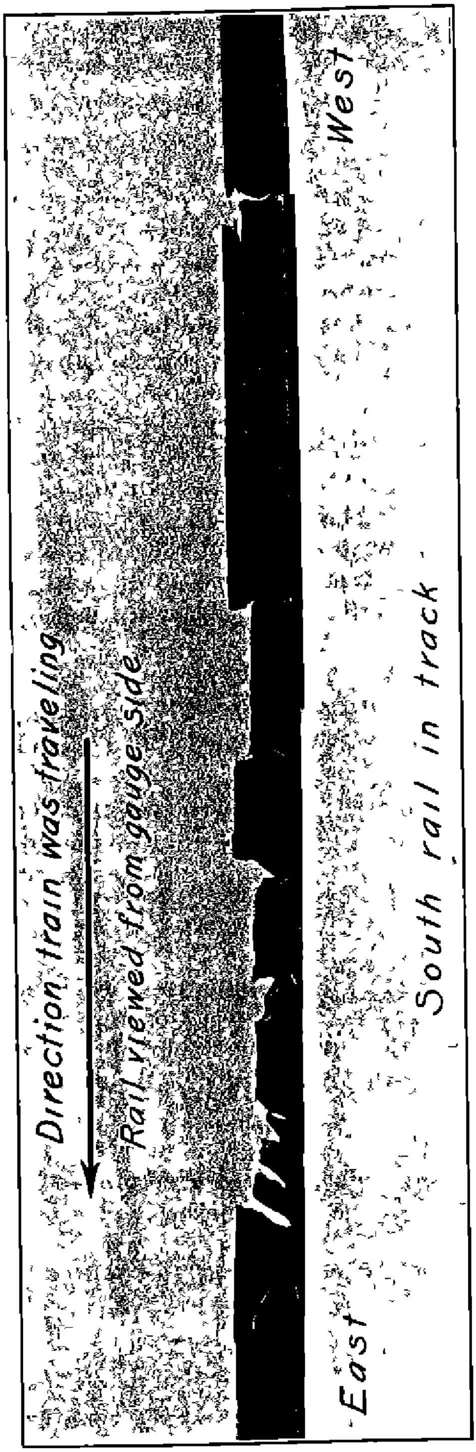


PLATE 4 —South rail in track

PHYSICAL TESTS

A résumé of the physical tests, comprising tensile and hardness tests, is given.

The tests show the material of the rail to be far from homogeneous, the mean tensile strength being 99,900 pounds per square inch and its extreme variation being 28.4 per cent of the mean value. While the gauge side of the head at the east end of the rail shows a reduction of area of 29.5 per cent and an elongation of 20 per cent for a 2-inch specimen, the percentages of the reduction of area and of the elongation are strikingly small for the specimen taken from the base of the rail at a point 6 feet from the west end, these percentages being only 1.5 and 2.5, respectively. There is also a considerable range in the hardness of the rail, the mean hardness numeral for the head of the rail being 783, that of the base 675, and the mean of all determinations 749. The extreme variation of the hardness numeral is 38.3 per cent of its mean value.

Tensile tests

Position of specimen in rail	Modulus of elasticity, per square inch	Proportional limit, per square inch	Ultimate strength, per square inch	Reduction of area	Elongation	Character of fracture
	Pounds	*Pounds*	*Pounds*	*Per cent*	*Per cent*	
Outside of head, west end	30,000,000	45,000	107,800	8.5	9.0	Bright granular
Gauge side of head, west end	28,400,000	37,000	99,900	4.0	5.5	Do
Outside of head, 6 feet from west end	28,000,000	37,000	111,500	7.5	15.0	Do
Gauge side of head, 6 feet from west end	29,000,000	41,000	112,000	11.0	10.5	Do
Gauge side of head, east end	29,300,000	39,000	99,000	29.5	20.0	50 per cent bright granular, 50 per cent fibrous
Outside of head, east end	29,800,000	36,000	83,600	4.0	4.0	Bright granular
Base, west end	27,000,000	40,000	107,100	7.0	9.5	Do
Base, 6 feet from west end	28,000,000	43,000	89,000	1.5	2.5	Do
Base, east end	28,200,000	45,000	89,500	4.5	6.0	Do

Brinell hardness tests

	Hardness numeral in kilograms required for a 0.1 millimeter indentation (10 millimeters diameter ball), for positions						
	1	2	3	4	5	6	7
East end	749	772	834	931	644	672	658
West end	755	768	818	814	672	724	680

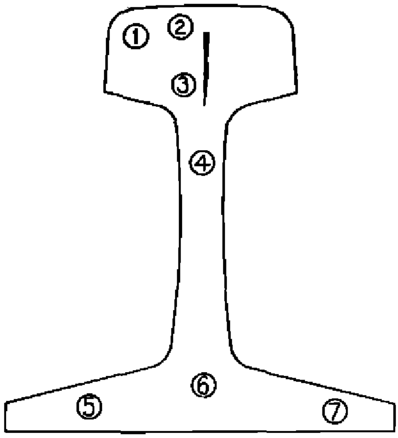


Diagram showing places on the cross section of the rail where hardness tests were made

A material as inhomogeneous as that just described would not be tolerated in any other type of engineering structure

METALLOGRAPHIC EXAMINATION

Macroscopic—Cross sections were taken at the following points Twelve inches from the west end (section W), 24 inches from the east end (section E), and from one of the intermediate unidentified pieces (section X) These, after polishing, were etched with ammonium-copper chloride solution to indicate the character of the metal and are represented in Plates B and C These three sections which represent the ends and center of the rail, have practically the same characteristic features They show that the split in the head extends from the west end to within at least 24 inches of the east end, though it does not show on the outside at the east end The appearance of the sections after etching indicates rather poor material, especially in the web, which is badly streaked and laminated The head and base, while not so bad, show distinct evidence of inhomogeneity of the material The metal of the head has flowed somewhat under the wheel pressure, indicating that it is rather soft and weak for the service to which it has been subjected The general appearance of the section suggests that this is an A rail or one from the upper part of the ingot

Microscopic—For the examination of the microstructure, samples were cut from one-half inch sections taken at the following points Twelve inches from west end (section W), 6 feet from west end (section W6), and 18 inches from the east end (section E)

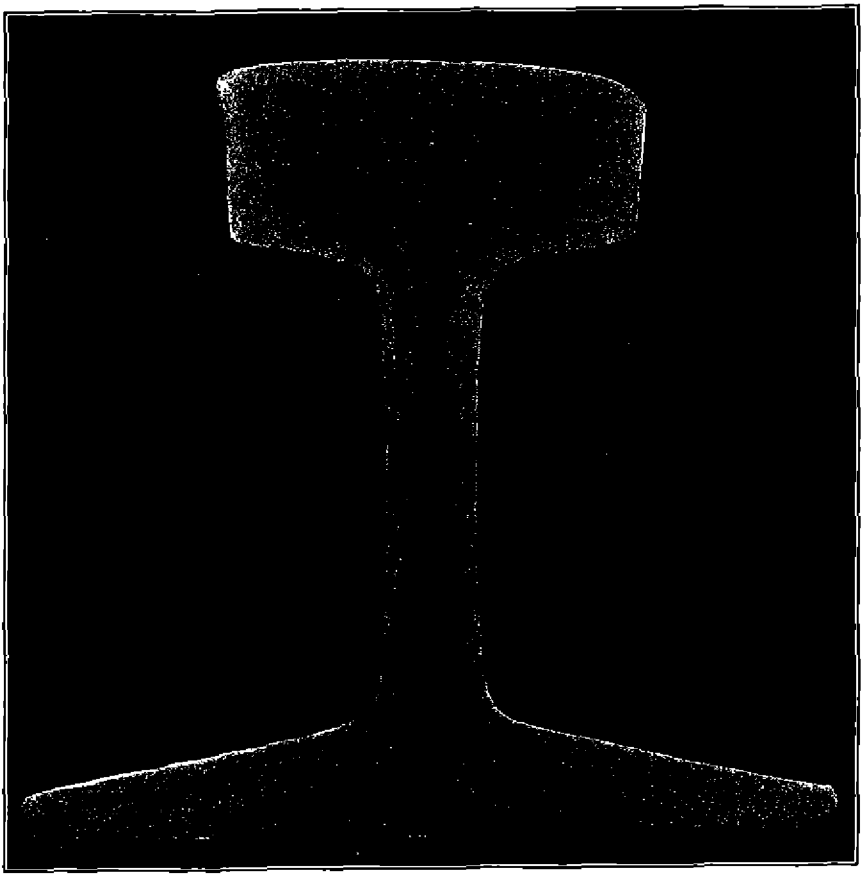


PLATE B.—Section W, 12 inches from the west end of the rail. Etched with ammonium chloride solution.

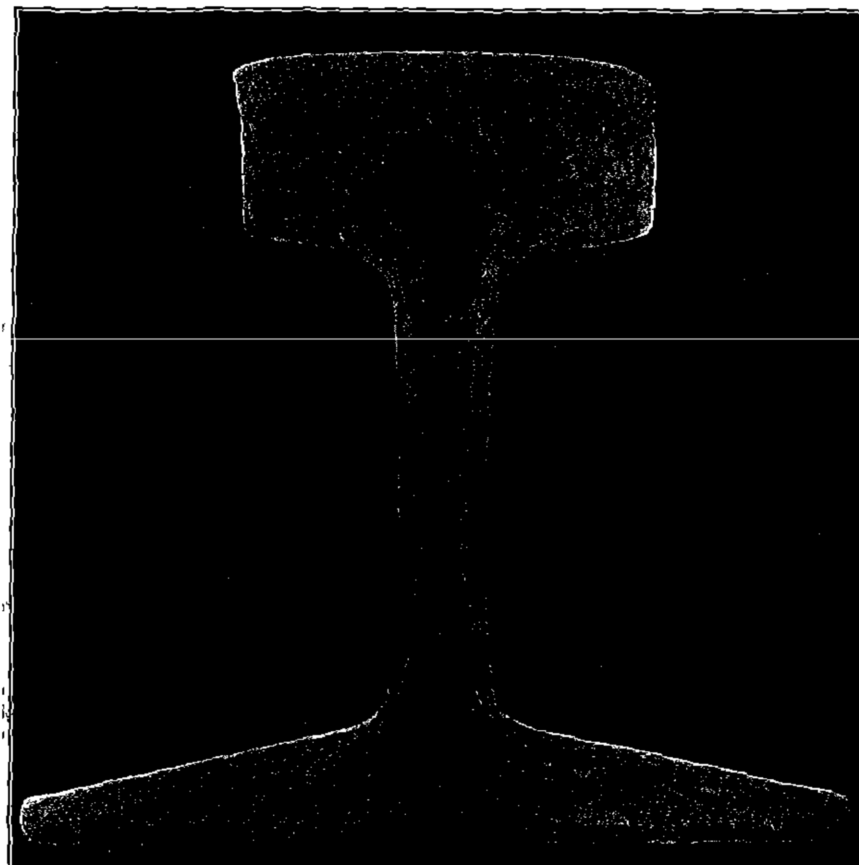


PLATE B.—Section E, 24 inches from the east end of the rail. Etched with ammonium-chloride solution.

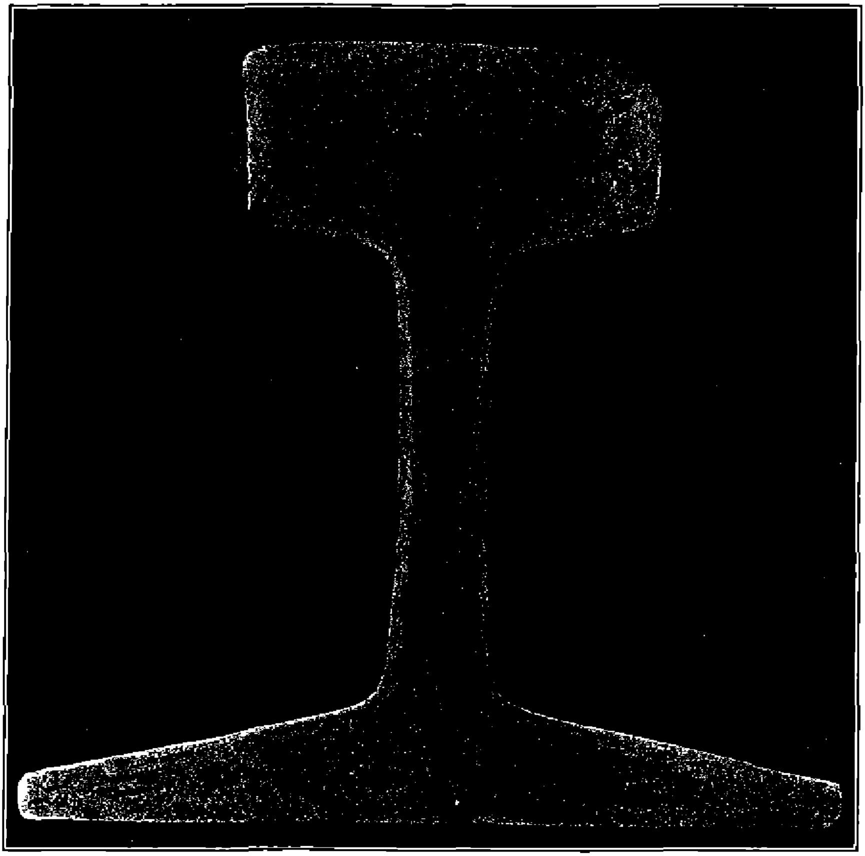
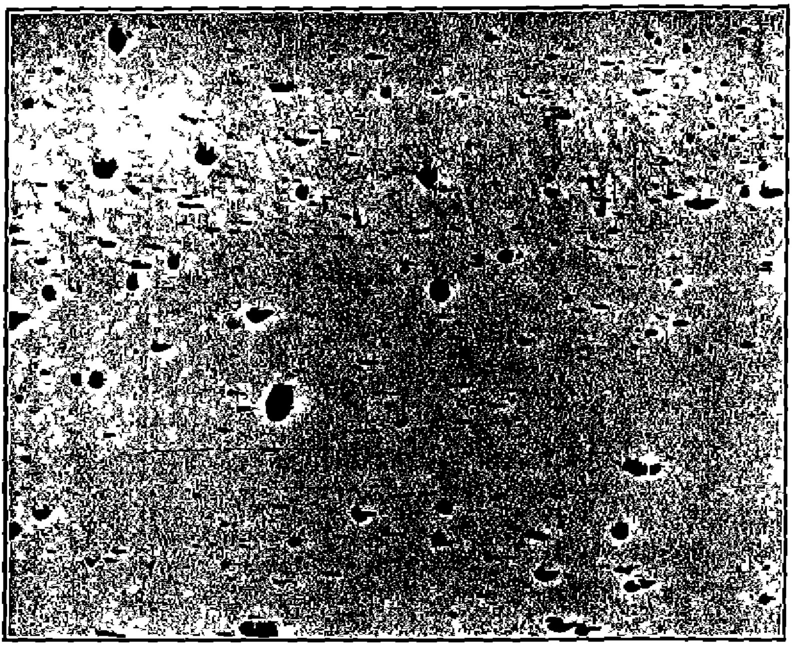


PLATE C.—Section X, from one of the unidentified pieces from the central part of the rail. Etched with ammonium chloride solution.

Sections E and W were examined at two spots in the head, directly adjacent to the split and near the center of the remaining portion of the head In section W6 horizontal longitudinal sections of the web and central portion of the base were examined in addition The accompanying diagram shows where the samples were chosen

Preliminary low-power examinations were made of the four samples from section W6 before etching in order to estimate amount and number of foreign inclusions present (Plates D and E) As a result of the polishing process microscopic pits and grooves are formed around each inclusion and the size of each inclosed particle of foreign matter appears considerably larger than it is The metal of the center of the head adjacent to the pipe is fairly clean and contains only minute particles, while in the other portions of the head there is considerably more included matter The web shows well-defined streaks throughout its entire width In the base are found some very prominent streaks in which the metal is badly fissured and apparently contains considerable "slag" One such streak is shown in Plate E, examination at higher magnification shows that the transverse black markings in these streaks are fissures and pores rather than "slag" inclusions The metal in the greater part of the base is of about the same grade (so far as these inclusions are concerned) as that of the outer portions of the head

Plates F and G show the microstructure of the rail at the different points examined at a linear magnification of 100 diameters after etching the polished samples with dilute nitric acid This method of etching darkens the pearlite The structure indicates a medium carbon steel of very coarse structure The ferrite boundaries of the pearlite grains are thick and heavy and in many cases the entire grain has been broken up by precipitation of the ferrite in the cleavage planes of the pearlite crystal A comparison of the structure at the different sections shows that in general the center of the rail is higher in carbon, as shown by the greater amount of pearlite, and the amount of ferrite increases considerably as the outer portion of the rail is approached This is very pronounced in the web at section W6 The segregation of carbon, however, is not excessive, as the metal is still considerably below the eutectoid composition (0 85 per cent approximate) and free ferrite is still present Ferrite has the properties of pure iron, and hence steel in which this constituent predominates approaches soft iron more and more in its properties The metal in the outer portions of the head contains enough ferrite to cause it to "flow" under the heavy wheel pressure to which it has been subjected



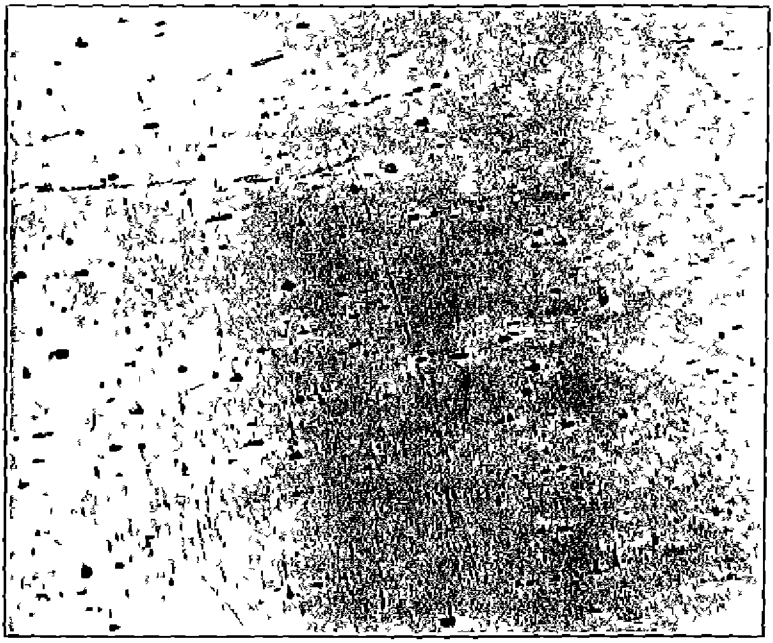
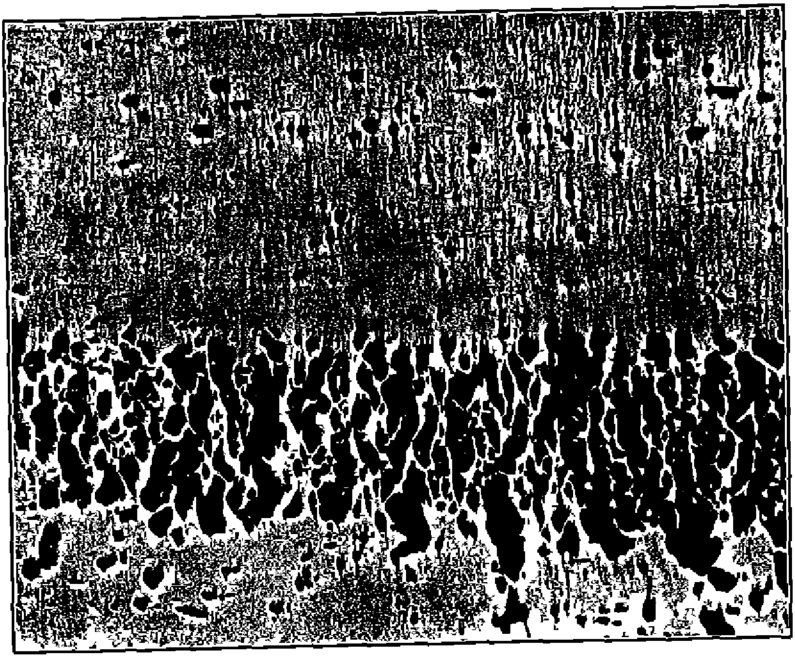


PLATE D —Unetched specimens, magnification 25 diameters
Section W6 (at top), 6 feet from the west end center of the sound portion of the head
Section W6 (at bottom) 6 feet from the west end directly adjacent to the split in the head



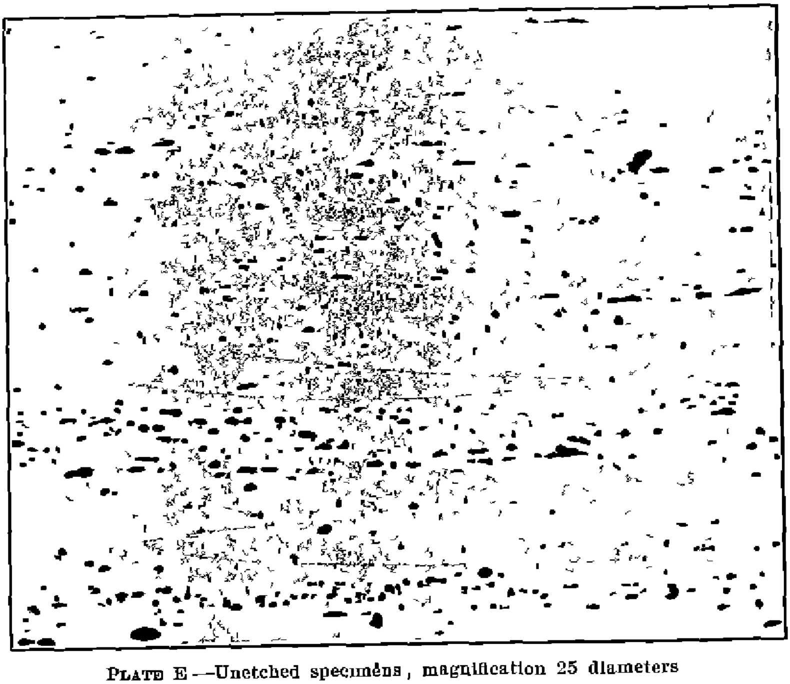


PLATE E.—Unetched specimens, magnification 25 diameters

Section W6 (at top) 6 feet from the west end view of the center of the base of the section, showing one of the bad streaks in the metal

Section W6 (at bottom), 6 feet from the west end view of the metal of the web

A determination of the grain size was made for the three sections with the following results

Section	Specimen	Grains per square inch	Averages
W	Head	16,250	Average for head, 12 100
	Head adjacent to split	12,000	
W6	Head	14,250	Average for head, 12,900
	Head adjacent to split	11,500	Average for section, 13,500 [1]
	Web	13,250	
	Base	14,250	
E	Head	[2]	Average for head somewhat more than 10,000
	Head adjacent to split	10,250	

[1] To compute the section average weights of 2, 1, 2 were used for head, web, and base, respectively, since these numbers represent the relative areas approximately

[2] No count could be made, ferrite too much broken up

A "grain size" of 45,000 per square inch may be regarded as medium fine In comparison with this standard, the rail should be classed as very coarse grained

SUMMARY

1 The type of failure is a "split head," the split extending the entire length of the rail

2 The macroscopic examination shows the metal to be decidedly inhomogeneous throughout the entire web, the head and base are of a better quality

3 There is no excessive segregation surrounding the split in the center of the head

4 The microstructure is that of a medium carbon steel and is very coarse grained The outer portions of the web are rich in ferrite, and hence relatively soft and rather ductile

Chemical analysis

Designation of cross section	Position in rail	Position of sample in cross section (see diagram)	Analysis C	Si	Mn	P	S
W	18 inches from west end	1	0 53	0 058	0 67	0 117	0 044
		2	44	057	66	101	051
W6′	6 feet (approximately) from west end	1	54	055	68	140	057
		2	43	055	66	100	056
		3	57	055	66	144	061
		4	44	061	64	079	044
E	24 inches from east end	1	49	060	68	127	047
		2	37	058	66	088	051

A

B

C

D

PLATE F.—Magnification 100 diameters

A and B represent the structure of the head of the rail at section E. A shows the structure directly adjacent to the split, while B is the center of the remaining part of the head. Though there is some segregation near the center of the head as shown in A by the increased amount of pearlite (the dark constituent) still the carbon content is considerably below the eutectoid composition (i. e. .85) as indicated by the ferrite which forms the boundaries for the large crystals of pearlite.

C and D represent the structure of the head of the rail at section W adjacent to the split and near the center of the remaining portion respectively. There has been but little, if any, segregation of carbon here as shown by the relative amounts of pearlite in the two cases.

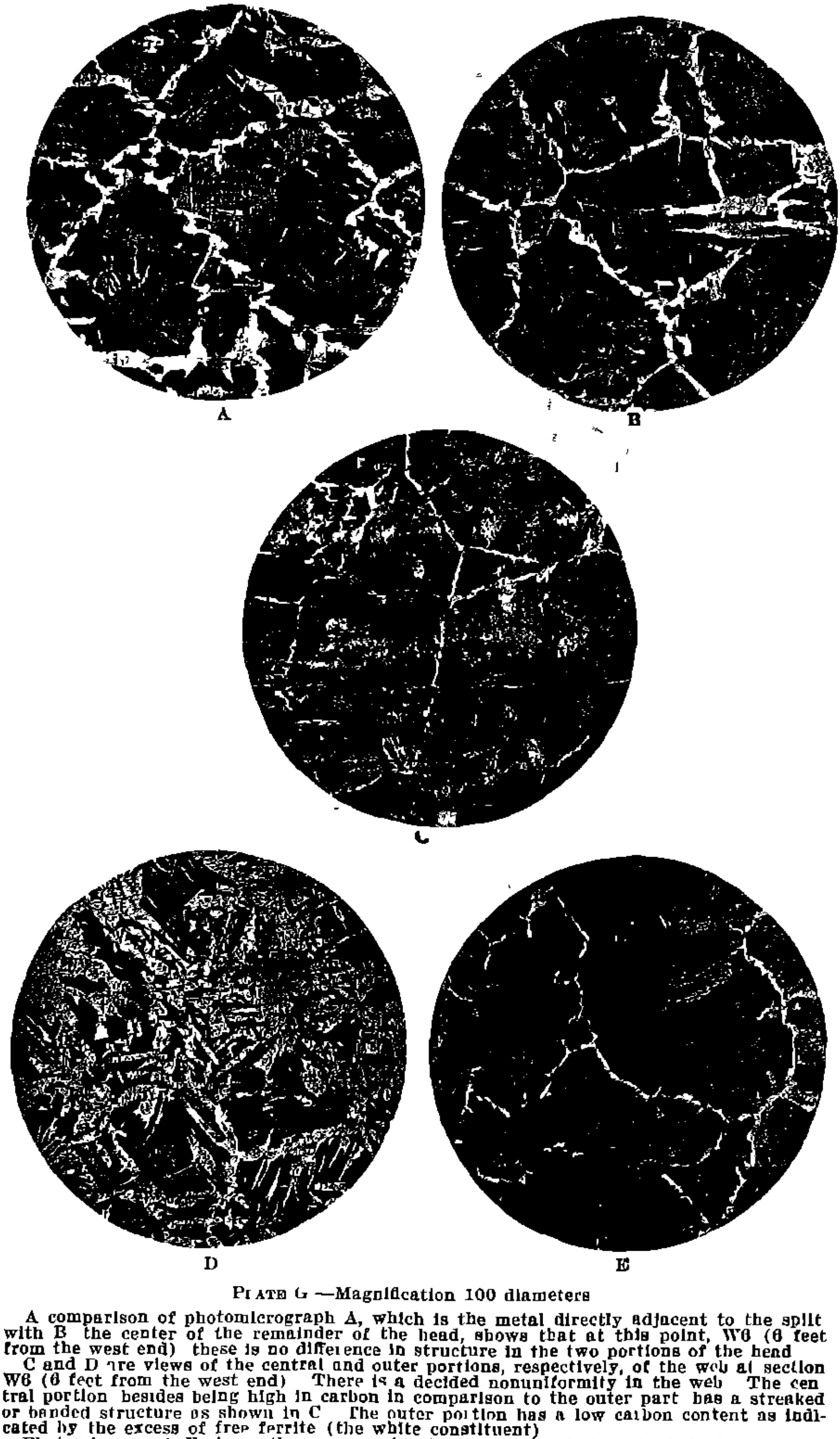


PLATE G.—Magnification 100 diameters

A comparison of photomicrograph A, which is the metal directly adjacent to the split with B, the center of the remainder of the head, shows that at this point, W6 (6 feet from the west end) these is no difference in structure in the two portions of the head.

C and D are views of the central and outer portions, respectively, of the web at section W6 (6 feet from the west end). There is a decided nonuniformity in the web. The central portion, besides being high in carbon in comparison to the outer part, has a streaked or banded structure as shown in C. The outer portion has a low carbon content as indicated by the excess of free ferrite (the white constituent).

Photomicrograph E shows the average structure of the central part of the base at section W6. The lower half of the figure shows part of one of the streaks shown in Plate E. The dark indefinite spots indicate cracks and fissures in this streak.

The diagram indicates the position of the sample analyzed in the cross section of the rail

Though the percentage of carbon varies noticeably in the central and outer portions of the rail, the variation does not differ much from that allowed by most standard specifications for Bessemer rails of this weight The phosphorus content of the inner portions of the rail is considerably above the maximum specified for rails of this type and weight (0 10)

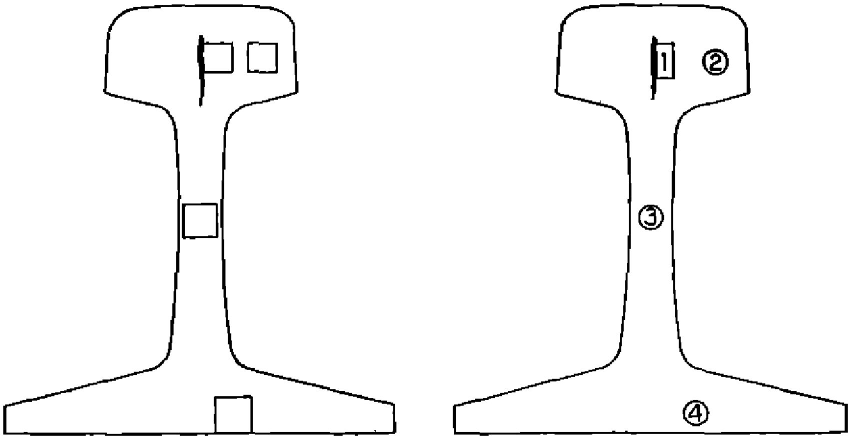


Diagram on the left indicates position of specimens for microscopic examination, that on the right side the position of samples used in the chemical analysis of the metal

CONCLUSIONS

The type of failure of this rail is very probably a "split head," the split having developed during service and not during fabrication

The chemical, metallurgical, and physical examinations have shown the rail to have the following characteristic properties

The steel is a very coarse-grained Bessemer steel of about normal carbon content and without excessive segregation about the split, but the inner portion has a phosphorus content considerably above the maximum specified for rails of this type and weight

The metal is decidedly inhomogeneous, badly streaked, and laminated, especially in the web, and contains microscopic fissures The outer portions of the rail are rich in ferrite, and consequently soft and ductile, as is shown by the flow of the metal in the head under wheel loads

As this flow of the metal in the head of the rail indicates that the metal was subjected to stresses beyond its elastic limit, it seems very probable that the split was caused by repeated applications of excessive stresses to a poor quality of rail material

Although there is no excessive segregation surrounding the split, the possibility of a piped rail must not be excluded, as it may be that the rail was rolled from the part of the ingot containing the lowest portion of a pipe, caused by contraction of the metal while cooling, where there is little or no segregation

If there was any inspection before the railroad company's acceptance of the rail lot, of which this rail was one, it is evident that it either failed to discover the poor quality of the steel of this rail or the rail was accepted in spite of its quality If the character of the inspection was such that the inhomogeneity of the rail could not be detected by it, then methods different from the ordinary ones ought to be resorted to—e g , tensile tests of a certain number of rails of each lot might be made in addition to the usual chemical and drop tests Since, however, even with the best inspection at the mills, rails of poor material might enter into a track, it is clear that a continual and careful inspection of the rails ought to be made while they are in service, and if any flow of the metal as is shown at the outside of the head in Plate B manifests itself in any of them, these should at once be removed from the track, since such flow of metal indicates that the material is being stressed beyond its elastic limit, a condition which is dangerous in any structure

S W. STRATTON, *Director*

The failure of the rail which caused this derailment represents a type of fracture of which many examples annually occur in the track The scope of the present inquiry was extended, therefore, for the purpose of ascertaining the conditions which at times exist in the steel and which are believed to be common causes leading to failures of this kind Data were collected upon a number of rails having split heads, also upon base fractures having features of a similar nature, and incidentally acquiring data upon another distinct class of fractures, namely, those which take place in the web across the bolt holes

These data, together with remarks upon the present rail, are found in the report of Mr James E Howard, engineer-physicist, whose report immediately follows

Report of Engineer-Physicist

The fractured rail concerned in the present derailment was an 80-pound section, 30 feet long, rolled by the Carnegie Steel Co, and branded "Carnegie 1899 E T IIIIIIII" It had the following dimensions

	Inches
Height	4 86
Width of base	5 05
Width of head	2 52
Thickness of web	9/16

The rail was first laid in 1900, in the track between Solon Springs and Gordon, Wis, where it remained until July, 1908 It was then removed from this section at a time when about 2 miles of track were taken up to provide a supply of 30-foot rails for renewals The new rails available at that time were in 33-foot lengths With others it was shipped to the St James material yard, and from there requisitioned to replace an injured rail at the place where it subsequently failed under train No 2

The rails between Worthington and Bigelow, Minn, were 80-pound sections of the Illinois Steel Co's manufacture, and were laid in 1902 On April 15, 1908, one of these rails, located 630 feet west of milepost 185, was found with a crescent-shaped break in its base, the length of the fracture being 10 inches This rail remained in the track until the following November, when it was replaced on the 16th of that month by the Carnegie rail

The track at the place of derailment was inspected on Sunday, February 8, about 14½ hours before the time of the accident to train No 2 A southbound train passed over the track about 1 55 a m, the morning of the 9th, or some 50 minutes before the derailment of train No 2 Nothing unusual about the track was noticed by those on the preceding train, nor did the inspection of the day before show anything out of order The rail was undoubtedly defective, however, at the time train No 2 came upon it, and probably had been in such a state for a considerable length of time previous thereto, still the continuity of the head in a lengthwise direction remained intact until fractured by train No 2 at 2 45 a m, the morning of the 9th of February, 1914

The fractured portion of the rail included some 19 feet of its length The most westerly fracture was 2 feet 8 inches from the receiving end of the rail, the most easterly one 8 feet 8 inches from the trailing end

There was a split in the head, which was the cause of the fracture of the rail and the derailment of the train Along a portion of the fractured section the head separated into halves and these were detached from the web Other lines of rupture were developed in the web and base An opening was thus made in the track through which the train drifted The split in the head extended lengthwise into the end fragments, but did not appear at the extreme ends of the rail

Plate A is a view of the fractured rail as it appeared from the gauge side and near the west end

The seam or split had its origin, apparently, in the upper part of the head, gradually extending downward toward the web When it had reached a place opposite the upper edge of the web the seam bifurcated, the branches leading each way toward the sides of the web This change in direction of the split in the head naturally took place when the web was reached The leverage of the wheel loads on the halves of the head tend to bend the sides inward and outward, respectively, and unless there is decided seaminess in the web the fragments of the head are detached when the web is reached, without further extension of the split

In this rail the main seam was about 20 feet in length by 1 inch or more in depth, in its final dimensions It apparently had its origin at a place 7 feet from the receiving end of the rail, extending longitudinally in each direction There were places in which short, disconnected lines of fracture were present These were of a minor order, in their stage of development at the time when the rail as a whole failed

Etched cross sections showed the rail to be very streaked The formation and development of the split head is attributed to this streaked state of the steel, a condition which must have prevailed when the metal left the rolls of the rail mill There were, therefore, inherent lines of weakness present in the rail during its full term of service in the track Conjecturally, a progressive increase in the extent of the seams or splits succeeded the time when development first began Seams 20 feet long are not likely to exist in rails during a period of service of 13 years Evidence seems to indicate that they have in general small beginnings, increasing with lapse of time in service

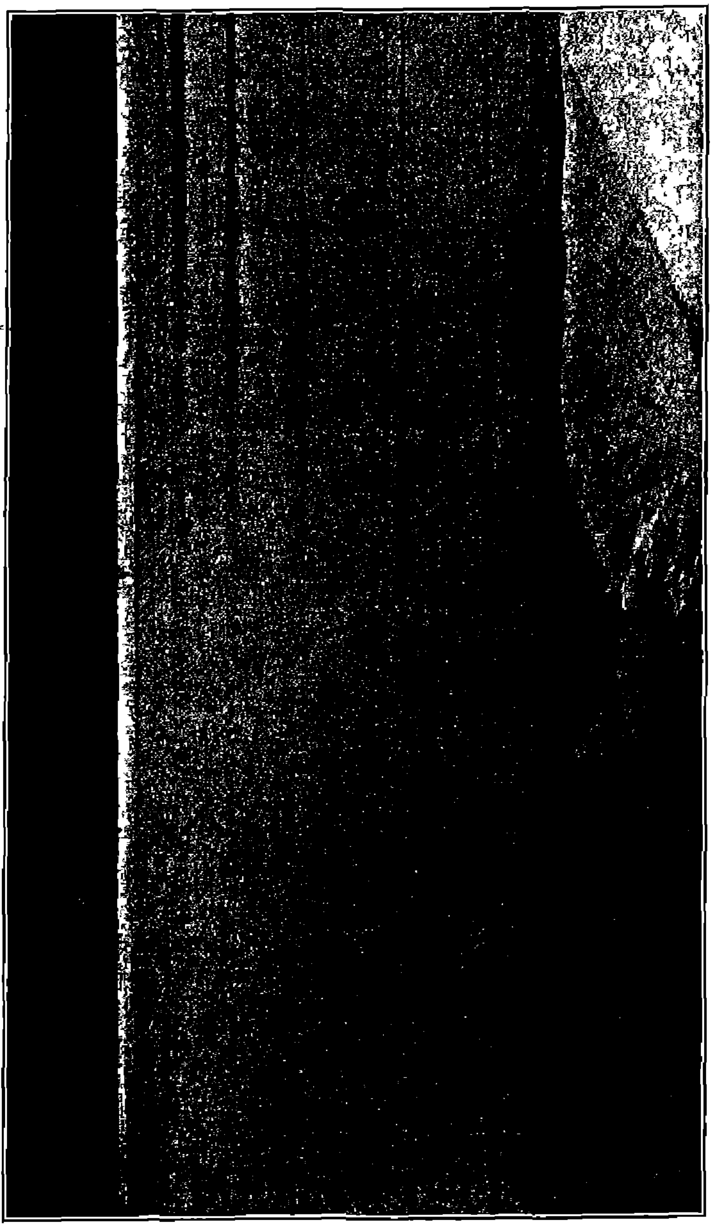
The surface of this rail was low in carbon—a soft steel Carbon determinations on a cross section from the middle part of the fractured portion of the length of this rail showed 0 35 C immediately below the running surface of the head, 0 61 C at the middle of the web, and only 0 28 C near the lower surface of the base, a range of 0 33 per cent

Since this rail had lost some of the metal from the top of the head during its term of service in the track, it seems not improbable that softer metal originally was present at the running surface, corresponding to that of the base These results assist in explaining the cause of the formation of the split head, in accounting for the softness of the steel and its attendant low resistance against transverse flow It flowed readily, in a lateral direction, under the wheel loads, and in so doing necessarily exerted a splitting influence on the metal of the head below the running surface When this zone of affected metal penetrated a sufficient depth and encountered a streak in the steel, the conditions were favorable for the starting of a longitudinal seam or split in the head The split would naturally have its origin in the upper part of the head, and thence extend downward toward the web The manner of development witnessed in split heads in general follows this description

In their early stages the seams are not necessarily continuous, but may consist of short parallel streaks lying more or less closely contiguous, which eventually merge and form a common seam many feet in length These remarks refer to a class of split heads which owe their origin to defects in the ingot of a minor order in respect to their magnitude, but not in their importance, and not to such as result from the presence of a large central pipe In each case the underlying cause is found in the state of the metal in the ingot

A recent examination of 100-pound rails, in connection with this derailment, furnishes supplementary data in respect to the present rail and gives further confirmation to some earlier work on rails from the track Photographic print (fig No 2) is reproduced from an examination of earlier date, showing an incipient split in the head of a rail This streak was located at a depth of about one-fourth inch below the running surface There were no surface indications of the presence of this short seam, which had began to open along the line of a streak in the steel This example is believed to illustrate the manner of development of certain split heads which in their subsequent stages show the characteristic dark lines on the running surface of the head, and which are then accompanied by a material increase in the width of this part of the rail

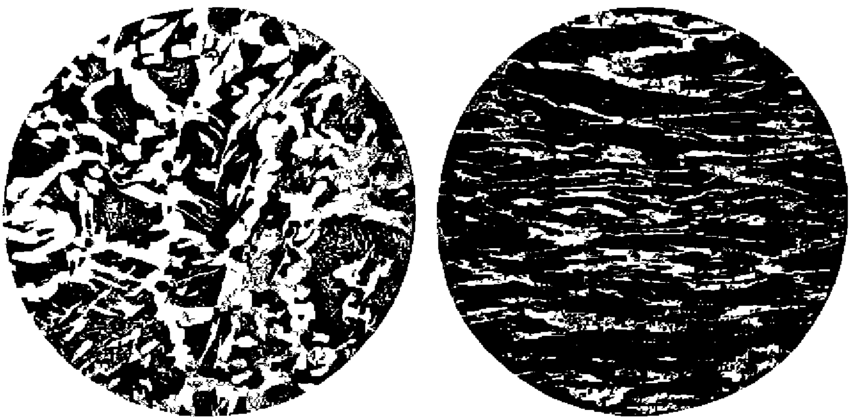
Photomicrographs Nos 3a and 3b show the normal structure of a rail and the structure immediately below the running surface of the head where the metal had been affected by the wheel loads, causing a flattening of the grain The appearance of the metal on the gauge side of the head of this rail was the same as that immediately below the running surface Distortion of the metal, such as shown by this photomicrograph, or even of a lesser degree, would menace the integrity of the steel when the cold-rolled metal reached that part of the head in which streaks were prevalent



No 2 Longitudinal streaks in head of rail, showing an incipient fracture at a streak, natural size

This type of failure is one of such consequence that it led to the steps which were taken to inquire more at length into cases of its display, examining a number of rails in which split heads were represented The rails in this supplementary series were those which had been removed from the track, having given evidence of the presence of defects, although none had caused derailments

Certain base fractures owe their origins to causes similar to those of split heads They also are due to the presence of seams or streaks in the steel, some at or near the surface and others which are interior seams Rails of this class are included in the supplementary examination Incidentally, another type of failure was examined namely, those which occur in the web across the bolt holes



3a 3b

No 3 Microstructure of head of a rail, cross section, magnification 110 diameters

3a Normal structure

3b Structure immediately below running surface of the head showing flattening of the grain due to wheel pressures

This inquiry was made upon a group of 121 rails of 100-pound weight which had recently been removed from the track, to which was added 1 new rail which had not been in service They represented rails chiefly from the South Chicago and Gary plants of the Illinois Steel Co, with a few from the Cambria Steel Co, Johnstown, Pa They were rolled during the five years of 1909 to 1913, inclusive

The rails came from different divisions of high-speed passenger track and from ore-carrying divisions The majority were removed from the track during the period covered by the last week of January, the month of February, and the first week of March of the present year

By reason of the careful inspection which the railroad gave its track the group of rails collected furnished examples which showed the progressive character of certain types of failure, illustrating the successive stages and furnishing important information in judging of the causes which led to the development of these types

Rails with split heads in different stages of development were removed from the track, some before the splits had reached the running surface and others showing a separation of the metal, the latter fractures representing a more advanced stage Similarly base fractures were illustrated by examples, in some of which there was only the usual crescent-shaped fragment detached from the flange, or even before the line of rupture had departed from the initial longitudinal seam in the base Then, again, others in which the crescent-shaped break was complete and another stage of rupture passed, the fracture having separated the metal of the web and entered the lower part of the head Finally there were rails in which the break was complete, the metal of the head entirely separated, thus completing the fracture of the rail Fractures of the last group are currently reported as square breaks, although they have their origins as base fractures

Each of the 121 rails was examined in detail and its condition noted This was followed by the selection of 22 of the series for special examination and test These selected rails represented the product of the three mills, of different year's rolling, and different types of failures They were cut up for examination in the machine shops of the railroad company, the work being done in an exceptionally expeditious manner Longitudinal and cross sections were taken the surface of the head, web, and base, respectively, being planed off, polished, and etched to show the structural state of the steel, and photographic records taken of typical cases

Concerning the types of fractures represented in these rails, they are described as follows

	Rails
Of split heads, mashed ends, and piped rails, so called, there were	30
Split webs	2
Bolt-hole fractures	22
Base fractures, crescent shaped	59

Parts of two rails were sent in from which the fractured ends had been cut off, and, therefore, can not be classified

In respect to position in the ingot, for the different year's rollings, they were distributed as follows

Year rolled	Position in the ingot						
	A	B	C	D	E	F	Not known
1909	5	4	5			1	1
1910	13	8	14	1		1	1
1911	9	4	21	1		1	2
1912	16	3	2				
1913			3	2	2	1	

The types of fractures for these several years' rollings were as follows

Year rolled	Split heads	Split webs	Bolt-hole fractures	Base fractures	Not known.
1909	4		8	5	
1910	13	1	5	19	
1911	7	1	2	25	2
1912	12		7	2	
1913				8	
Total	36	2	22	59	2

The ingot positions of the different types of failures, so far as they were known, were

	A	B	C	D	E	F
Split heads	23	6	2			
Split webs	2			1		
Bolt-hole fractures	13	8	1			
Base fractures	4	7	41	2	2	

The number of fractured rails represented in each of the several years' rollings were as follows

1909	1910	1911	1912	1913
17	38	37	21	8

Remarking upon the general results of the examination before describing in detail the work done with the 22 selected rails which were cut up for examination, it is seen that the years 1910 and 1911 furnished the largest number of failed rails, in the aggregate, of this series From this it is inferred that rails which eventually fail in the track are not culled out by natural causes of elimination during the early periods in which the rails are in service From the stand-point of safety the question is an important one as to which particular year's service, in the ordinary life of a rail or group of rails, the maximum number of failures occur, or of such kind as would lead to derailments. Furthermore, what types of failure are most common at different periods in the life of the rails. These questions refer to rails defective in a mill sense.

Rails which are structurally sound should ordinarily be exempt from failure until worn out or until there is an approach to that limit. The question of fractured rails in general, however, does not present itself in that form. We are here centering attention upon the endurance of rails which are expected to fail prematurely by reason of structural defects, the presence of which we are cognizant. It will not be overlooked, however, that information of this kind is retrospective and subordinate to the principal question which deals with the causes and their elimination.

When it is found, as in the present case, that rails display split heads after a term of three or more years in service, and that they presumably remained unfractured during a part of the interval, it leads to the conclusion that rails containing inherent defects of a certain kind may exist in the track in an undeveloped state for a considerable period of time. In a way this is a disquieting thought since it follows that in course of time additional defects may make their presence manifest. A split-head fracture is of such a character as to permit of gradual development, and no inconsistency appears which would be a barrier to slow formation at times. The appearance of split heads periodically in a given lot of rails, year after year in the track, offers no definite assurance when such types of fractures will cease to display themselves.

The development of base fractures is probably a matter of shorter duration than those of head splits. That is, the interval of time between the starting of a seam in the base and when it becomes a fully developed fracture is probably a brief period. Since little or no display of ductility in the base is shown by those rails which have ruptured, it follows that no warning will precede the fracture of the rail in the formation of a base fracture. A base fracture has to travel but a short distance vertically before it separates the base from the web.

It is evident from the presence of longitudinal seams which invariably accompanied the development of these base fractures that the rails had been at all times in a critical condition, and liable to display such fractures. The seams were there and only the necessary force remained to be applied to cause rupture, whether through transverse bending of the flanges of the rail or in the transmission of vibratory waves, which intensified the strains at places where there was a lack in the continuity of the metal A streak or seam is a menace to the integrity of a rail, regardless of the means by which final rupture is accomplished, and must be considered as one of the prime causes in the development of many fractures

Notwithstanding the considerable number of rails on which this report rests, there still remains data to be acquired before many questions admit of answer—questions of deep interest Some refer to the position of the rails in the ingot and the relative length of time in the track of rails from the different parts of the ingot before they yield to disrupting influences, others to establish at what period the rate of failure increases or decreases Such information would aid in determining questions of the relative safety of the track at different periods in the life of the rails and the relative gravity of defects from the different parts of the ingot

It will be noticed that of the 1913 rails which failed in the track all were base failures These failures again direct attention to the probable periods of greatest number of failures of any given type, according to age of the rails in the track Rails first to fail are naturally those in which there resides the least margin in strength between working stresses and the ultimate resistance of the metal The order in which the greatest number of each type of failure occurs is in a way an index of the relative safety of the rails as regards metallurgical questions of manufacture, as well as in respect to details in the design of the rails Exposure to unusual conditions of track or rolling stock may obscure this feature of the case at times, but, in general, the frequency and order of development of different types of failures will stand as an index of the relative safety of the track in respect to different rail failures

Split-head fractures and base fractures have their origin generally from some metallurgical defect, in which the matter of streaks of structural weakness are prominent factors The above remarks have been directed chiefly to the metallurgical side of the subject, but metallurgical questions can not be considered apart from mechanical strains caused by the wheel loads in the light of complete data on rail failures

In addition to the fractures above referred to there were witnessed in the present series those of another type, namely, bolt-hole fractures, the origins of which seem referable to track conditions, or at least track conditions seem to precipitate these fractures in such a manner that the primary cause may be attributed, with probable justness, to track conditions Surfaces of this class which have been examined, whether recent or early ones, have shown that such fractures had their origins at the sides of the holes They started at the bolt holes in the web and extended in each direction toward the head and base, respectively The manner of failure is suggestive of a force acting against the sides of the hole

In attributing failures across the bolt holes to the presence of forces acting against the sides of the holes it becomes necessary to inquire as to the manner in which such forces can be received Splice bars permit their bolts to come into contact with the sides of the holes in the webs of the rails only when the ends of the rails are wide apart, since joints are so made that there is clearance when the rail ends are in contact with each other The creep of one rail in advance of the adjacent rail will bring the bolts into a state of shear and concentrate loads against the web

Repeated stresses coming upon bolts wear them, and bent bolts are not of infrequent occurrence, showing their stressed condition A reciprocal effect must come upon the webs of the rails In this statement of the case forces are recognized which act in a manner suitable to account for the types of failures witnessed at bolt holes So far as information is now available, the causes of bolt fractures appear due to the shearing and compressive stresses on the web of the rail incident to the exhaustion of clearance on one side of the bolt

Reference has not been made to track conditions, low joints, imperfectly tamped ties, or improper bearings on ties as causes for the rail failures exhibited The rails of this series represented the heaviest sections used on the railway from whence taken, and were taken generally from high-speed sections of the road They came from divisions on which high standards of track were maintained Attributing unsatisfactory maintenance as a proximate cause of failure for these rails is, therefore, not to be considered

Except in the matter of bolt-hole fractures, which, it is believed, may be induced in sound steel by conditions of service, the fractures here exhibited were those which were due to a primitive state of structural unsoundness in the rails themselves

Rolling at too high or too low a temperature, too rapid reductions in the rolls, improper finishing temperature, cold straightening or gagging, segregation of chemical constituents, microstructure, whether the rails did or did not fulfill specifications as to composition or the drop test prescribed, are features which were not entered into It was not evident that they needed to be, but on the other hand, since the causes of the failures obviously lay in other directions, it would tend to obscure the real issues were such features entered upon at length

The prime cause, in respect to the base fractures and for certain of the head fractures, was referable to the ingot or to conditions which existed during the casting period The metal of these rails was streaked and seamy, and to that condition was due much of the trouble with them

Seamy steel, whether occasioned by the presence of slag inclusions drawn out into acicular form in the reduction of the ingot to the section of the finished rail or to the presence of imperfectly welded blowholes in the steel, is a source of weakness where working stresses are received crosswise the direction of the rolling Such are some of the stresses in the track, as is well known

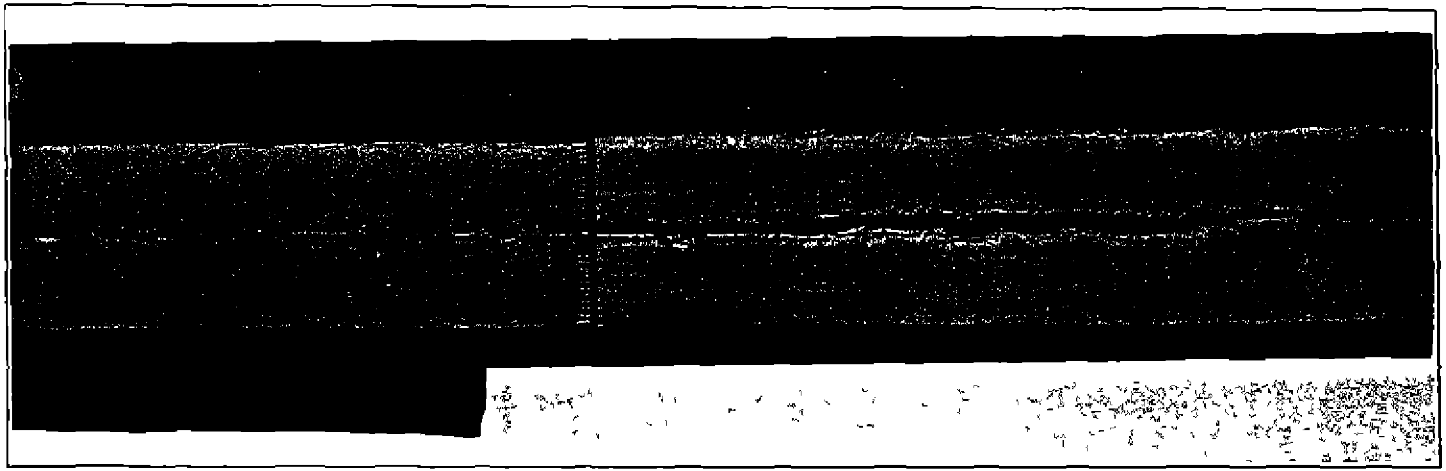
It would be of interest to ascertain the relative importance played by the presence of slag inclusions in the ingot and from blowholes and piping Two distinct questions are involved in this aspect of the case, one pertains to getting sound ingots, as regards freedom from piping and blowholes, while the other involves the elimination of slag inclusions

Concerning the elimination of interior streaks, such as lead to rail failures under present conditions, the mills do not hold out encouragement that such a result will be accomplished If such is the case respecting the manufacture of steel by the processes necessarily used in rail making, it follows that the magnitude of service stresses in the track has practically been reached

The products of different mills admit of comparison, and a sufficient number of ingots could readily be examined to demonstrate whether they are substantially the same from each source If the structural condition of the steel is found to be alike throughout and improvements in product are not feasible, then the avoidance of accidents will obviously be accomplished only by the lowering of the service stresses

The examination of rails from different mills for streaked metal of different years rolling, and of ingots in sufficient numbers to establish the character of the product and aid in the settlement of this fundamental question, is one which involves comparatively little expense and would not disturb mill conditions If structurally sound steel is being made in any mill, the fact should be known If the output of any one mill is superior to that of others, it should be known and the reason thereof established If either of the two great processes of steel making is superior to the other in the production of rail steel, the fact should be demonstrated beyond peradventure If the formation of slag inclusions is an incident to the reactions in the molten bath of steel, and only gravity separation is feasible to clear the bath, and no hope can reasonably be entertained of obtaining steel free from such inclusions, then such fact should be well established and reckoned with

Illustrations Nos 4 to 11, inclusive, illustrate features brought out in the examination of the group of 100-pound sections Figure No 4 shows the split in the head of a rail which had been in service for a



No 4 Rail with split head Running surface planed off at different depths, showing width of split end disclosing streaked metal Branded " Cambria 100 lbs 1911 VII," D rail, heat Number 20746 In service 2 years 5 months, removed on account of split head

period of two years and five months This was a D rail in respect to its position in the ingot The metal had not separated at the running surface, although the head of the rail had shown an increase in width of one-fourth inch, covering a length of 3 feet There was also a longitudinal seam in the web, directly under the head, at one end of the rail, extending a length of 17½ inches The metal of the head was planed off different depths, displaying the length and width of the split, and showing the presence of streaked metal in general

Figure No 5 shows three cross sections, after having been polished and etched with tincture of iodine The middle section of the figure represents the rail illustrated in figure No 4 At the place where this cross section was taken the split in the head was in an early stage of development The section on the left side of the cut represents an A rail removed from the track after a term of service of four years The steel was streaked

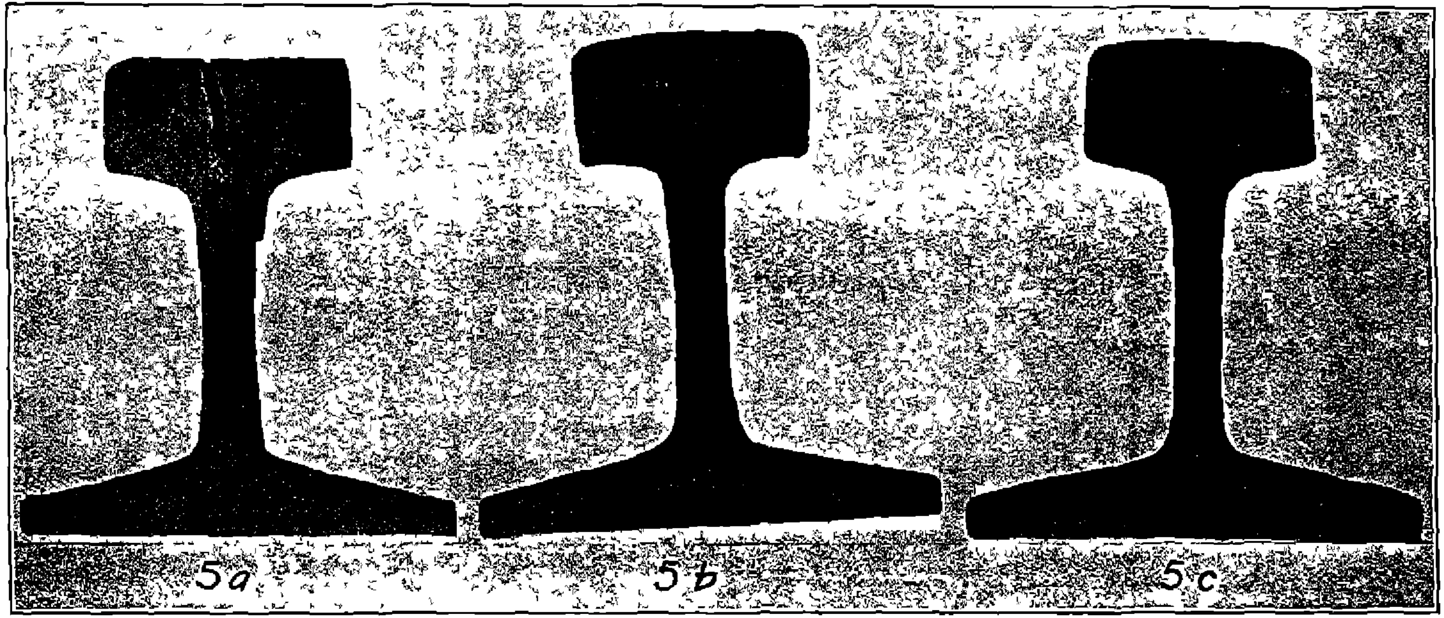
The section on the right side of the cut also was an A rail, which was removed from the track after a period of three years and six months This rail had a split head The fracture reached into the web and there caused a seam 18½ inches long, crosswise, the thickness of the web This was a dangerous fracture, owing to the possibility of an opening being made in the track by the detachment of a piece of the head and web The metal beyond the split, where etched and photographed, was not characterized by unusual markings

Figure No 6 represents a rail removed from the track after one year and three months on account of evidence of the formation of a split head The evidence was very slight before the rail was cut up for examination, and it is somewhat remarkable that this rail when in the track was adjudged as having the defect which subsequent examination proved to be present

The split was revealed when the top of the head had been planed off to a depth of five-sixteenths inch The split was an interrupted one, made up of short independent seams located in different planes An undercut of the head was made in a planer, cutting away the under side until a strip one-half inch in depth remained This strip was broken off with a hammer, revealing the short lamellar streaks, some of which were photographed and shown in figure No 7

The surfaces of these seams were bright and lustrous In appearance they were similar to those which have been found in the heads and bases of other rails where the metal had not been subject to oxidization

Longitudinal specimens were taken from the head of this rail for tensile and repeated stress tests The results of the tensile test on a specimen having a stem 10 inches long by 1 1129 inches diameter were as follows



No 5 Cross sections of rails which had developed split heads, surfaces polished and *etched with tincture of iodine.*

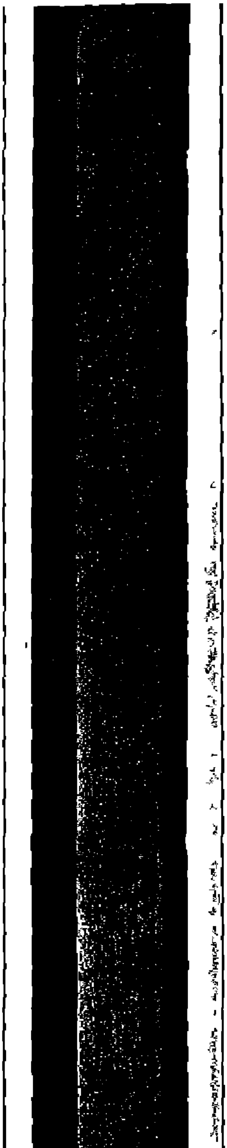
5a Branded " 10030 Illinois Steel Co South Wks III 1910," A rail, heat number 16296, in service 4 years, removed on account of split head

5b Branded " Cambria 100 lbs 1911 VII " D rail, heat number 20746, same rail as shown in Figure No 4, cross section where split in the head was in early stage of development, split shown by dark line at center of head

5c Branded " OH 10030 I S Co Gary VI 1910," A rail, heat number 32703, in service 3 years and 6 months, removed on account of split head and fracture in web 18¾ *inches long*

Elastic limit, pounds per square inch	53,000
Tensile strength, pounds per square inch	111,970
Elongation, per cent	14
Contraction of area, per cent	24

Appearance, fine granular, radiating from a point near the center of the cross section Fracture occurred at the middle of the length of the stem



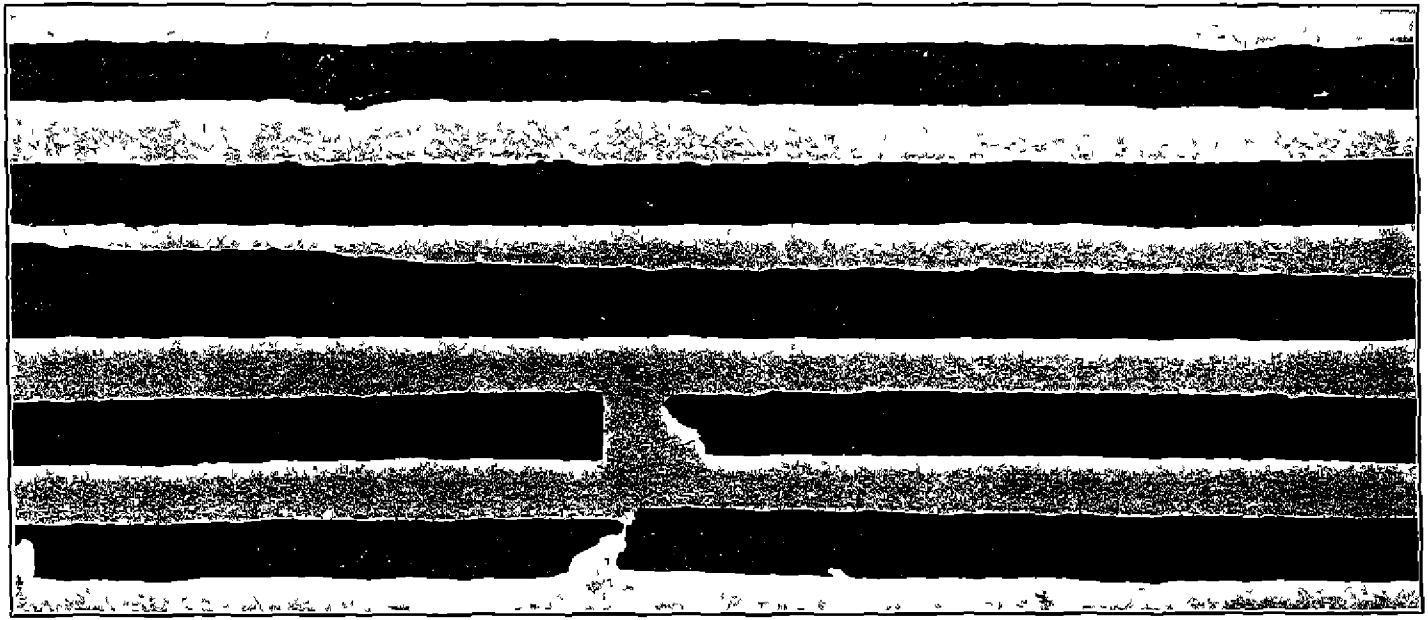
No 6 View of head of rail, five sixteenths inch planed off running surface, showing split, of short independent seams seams were wholly interior ones, and did not reach the running surface, branded ' 10035 I S Co South XI 1912 ,' A rail, heat number 45206, in service 1 year, 3 months, removed on account of indications of split head

The bar for repeated stress test was 1 inch diameter by 33 inches long It was loaded at the middle on double bearings in order to have a uniform bending stress over 4 inches of its length The bar was loaded transversely and run at 500 rotations per minute

Loads were applied in increments of 10,000 pounds per square inch each, 1,000 rotations being made under each increment, until 40,000 pounds fiber stress was reached Under the latter load the bar was run until it ruptured

No permanent sets were displayed until the load reached 40,000 pounds The deflection sets on a chord of 10 inches then ranged from 0 0002 to 0 0005 inch each The bar endured 993,000 rotations before rupture, of which total number 990,000 rotations were under the maximum fiber stress of 40,000 pounds per square inch

This test appears to demonstrate that a larger number of repetitions of alternate stresses of tension and compression of 40,000 pounds per square inch can be endured by steel of this grade than would be expected to come upon a rail in its ordinary life in the track It, therefore, follows if rails of this grade of steel rupture in the track as a result of longitudinal tension, that the magnitude of such stresses virtually exceeds 40,000 pounds per square inch This in an indirect method of judging of the magnitude of the stresses in the track through the results of tests of the metal



No 7 Strips from head of rail shown in Fig No 6, showing the presence of seams and streaks in the metal, surface of seams bright, lustrous, with a fine granular structure incipient splits have been found as such lamellar streaks

The following rails were examined for streaks in the metal of the head and the base

	Heat
A rail 10035, I S Co, South Works, X 1912	40547
B rail O H 10030, I C Co, Gary, IIIIII 1910	53270
C rail 10030, I S Co, South Works, III 1910	16384
D rail O H 10030, I S Co, Gary Works, IIIIII 1910	53270
E rail O H 10035, I S Co, IIIII 1913	43206
F rail O H 10035, I S Co, Gary, IIIII 1913	51285

The A rail was removed from the track after one year and one month in service There were 47 seams displayed in the metal of the head and base ranging in length from one-half inch to 7½ inches each There were also groups, in both the head and the base, 12 inches long, composed of short seams In the head the seams were prevalent at depths of one-fourth to three-eighths inch, while in the base they were found at the surface and at varying depths up to three-eighths inch

In the B rail no seams were disclosed by the examination, the metal being structurally sound throughout, so far as covered by the inquiry

No interior seams were disclosed in the C rail A number of longitudinal surface seams were found in the base One had a length of 12 inches and had penetrated to a depth of 0 45 inch, of which the metal was darkened to a depth of three-eighths inch Another seam had a length of 15½ inches

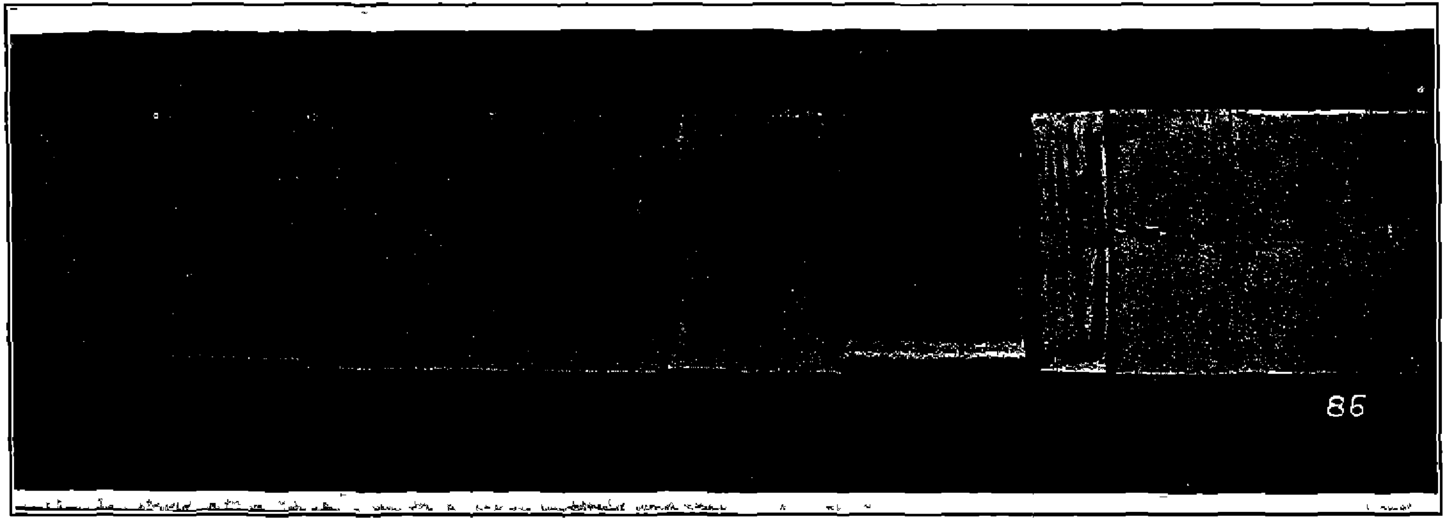
The D rail was practically free from interior seams, traces being found in two places only A few small surface seams were in the base

The E rail was free from seams in the head In the base there were a few interior seams, but generally confined to the surface One seam was 9½ inches long by 0 06 inch wide Along a distance of about 7 feet, and 2½ inches from the edge of the flange, there was a seam practically continuous

The F rail appeared entirely free from seaminess

It was evident from the results of this examination that in certain rails, at least, the structural state of the steel was sound and satisfactory, and this gives promise that steel may be produced of the desired freedom from streaks

Figure No 8 represents a portion of a split present in the head of rail branded 10035 I S Co, South Works, X 1912 This was a B rail, and removed from the track on account of a split head after a term of service of one year and one month The line of rupture had broken through the running surface of the head at one place The metal of the head was planed off to different depths, at each of which streaked metal was displayed When the split was reached



No 8 View of running surface of head, planed off, different depths, exposing split which extended beyond the part of the rail at which it had reached the surface, interrupted lines of fracture displayed, streaks shown in the metal on each planed section, split nearly full depth of head disclosed, surfaces of split bright, lustrous, and fine granular Branded "10035 I S Co South X 1912," B rail, heat number 40519, in service, 1 year 1 month, removed from track on account of split head

it appeared as interrupted lines of rupture In general, the surface of the split was bright, lustrous, and fine granular

A group of four rails having bolt-hole fractures are shown by figure No 9 These fractures occurred without the display of appreciable enlargement of the holes, conforming in this respect to service fractures in general which take place without the display of ductility in the metal

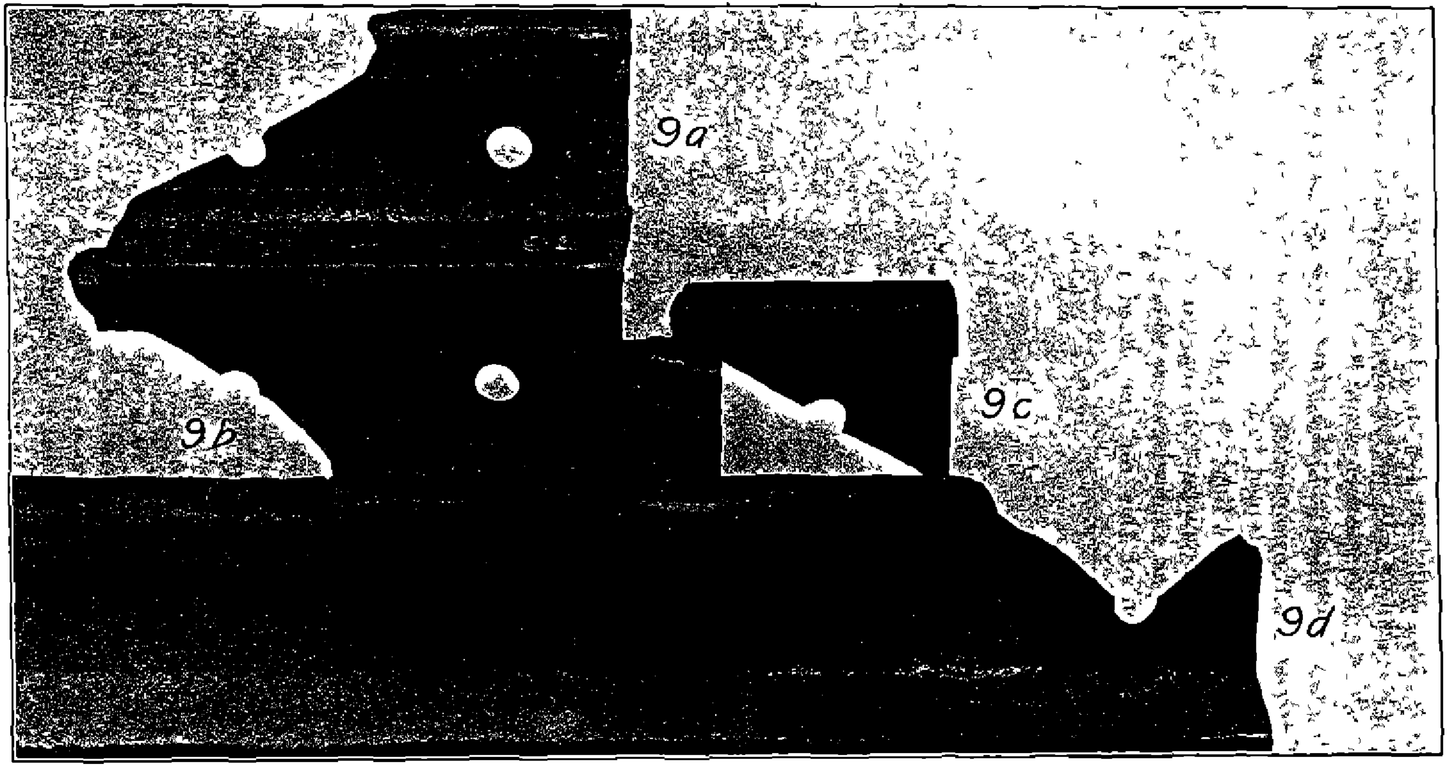
A drifting test was made of the second bolt hole in the rail shown by the upper figure of the cut This hole was drifted from its original diameter, $1\frac{1}{16}$ to $1\frac{1}{4}$ inches, without rupture Other drifting tests were made, in each of which the metal about the bolt holes displayed considerable extension

Attention is directed to this feature, since it is not infrequently assumed that ductility displayed in the laboratory tests may be relied upon when the metal is exposed to service conditions Experience has shown that service failures must be considered as the result of combined and repeated stresses in which the display of ductility may not be, and rarely is, realized

Figure No 10 shows a web fracture of an unusual kind It was caused by an identation in the surface of the web by the dog which carried the heat-number figures This marking is done immediately after the rail leaves the hot saws A deep furrow was made in the metal of the web, at which place the line of rupture had its origin The fracture extended in each direction therefrom, in all, a distance of 16 inches along the web It then branched upward and extended through the metal of the head A fracture of this kind introduces a dangerous condition, leading to the detachment of a portion of the head and destroying the continuity of the track This rail had been in service two years and four months

Figure No 11 shows different stages in the fracture of rails having their origins as crescent-shaped base fractures The lower figure in the cut represents a rail, viewed from the base, in which a short crescent shaped fragment had been detached—a rail in the first stage of rupture The section viewed on end shows a fracture which had extended through the base and web and into the head About three-fourths of the head remained unfractured at the time this rail was removed from the track The final stage of fracture is shown by the figure on the right of the cut This had a longitudinal split in the base, from which the line of rupture started, passing through the web, and then extending through the head, completing the fracture of the rail

A new A rail was taken from stock and examined for streaks and seams This rail was branded "O H 10030, Illinois Steel Co, Gary IIIIIIIII 1913, heat number 40466"

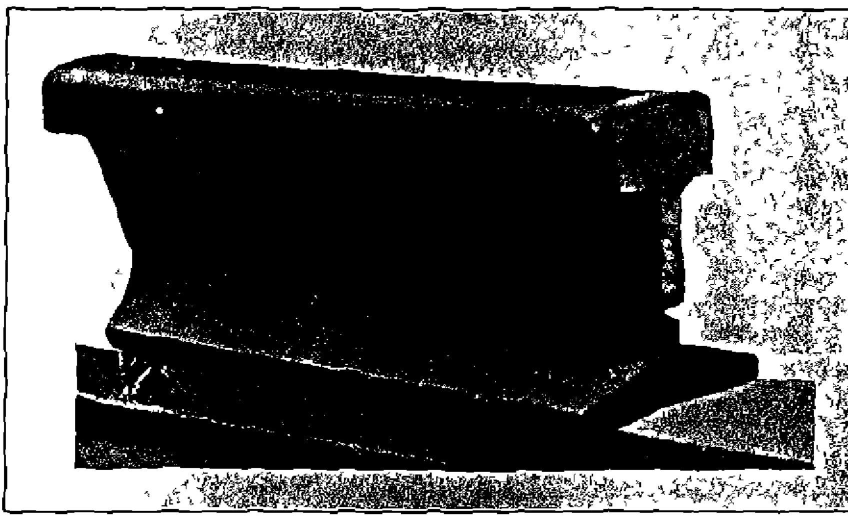


No 9 Group of rails which fractured in webs at bolt holes Fractures, in each case, had their origins at sides of holes, extending thence toward heads and bases of rails Fractures took place without appreciable enlargement of bolt holes

9a. Branded "10035 I S Co South IX 1912," A rail, heat number 35279, in service 9 months
9b Branded "*10030 Illinois Steel Co South Wks VII 1910*," A rail, heat number 39551, in service 5 years, 6 months
9c Branded "10035 I S Co South X 1912," A rail, heat number 38193, in service 8 months
9d Branded "10030, Illinois Steel Co South Wks V 1909,' in service 3 years, 5 months

A fractured surface revealed the presence of a vertical seamy line in the center of the head three-fourths of an inch in extent The sides were in close contact In appearance it suggested the location of a place at which service stresses would lead to the development of a split head The limited extent of surface presented to view was bright granular

The same appearance pertained to the surfaces of streaks, which were disclosed in the metal of the base Cross sections, polished and etched, showed more pronounced markings in the vicinity of the incipient split in the head than elsewhere along the length of the rail The examination of this rail completed the supplementary tests



No 10 Fracture of web caused by indentation in surface made by dog carrying heat number figures Furrow made in hot metal was origin of web fracture 16 inches long Dangerous type of failure. Branded "10030 Illinois Steel Co South Wks V 1911," A rail, heat number 28198, in service 2 years, 4 months

In conclusion, it appears that the derailment of train No 2 was caused by a rail having a split head

That the metal of the head of the rail was detached from the web at the time of derailment, and that other fractures separating the metal of the web and the base occurred immediately thereafter, causing an opening in the track through which the train left the roadbed

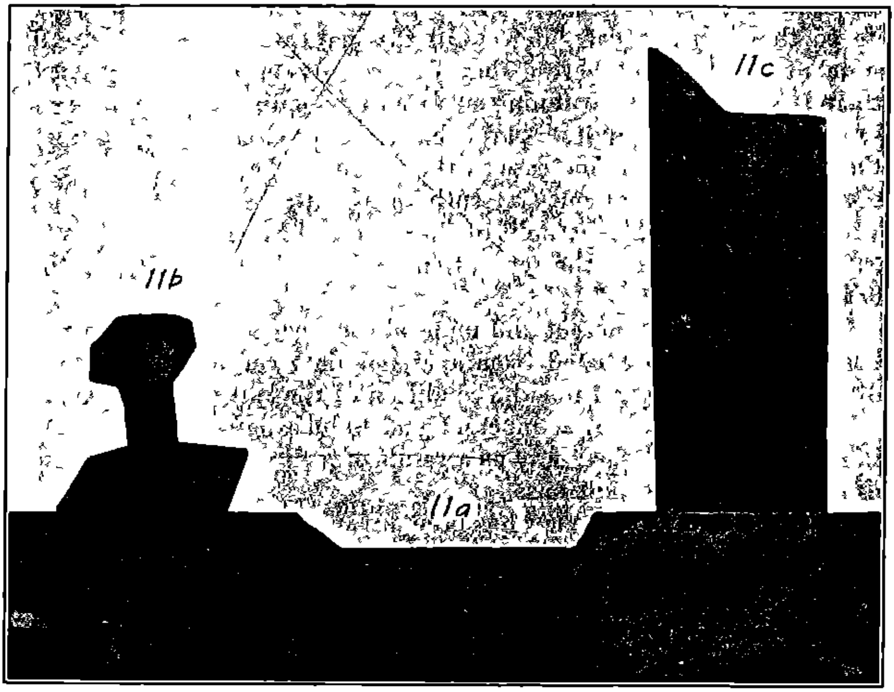
That the cause of the split head was referable to the primitive state of the metal of the rail

That a common cause in certain rails which develop split heads in service is found in the primitive streaked condition of the steel

That cases of split heads occur due to the presence of short seams or streaks in the steel, lines of rupture which progressively develop and at times merge, forming a common seam of considerable length

That the elimination of the causes of this class of split heads will be accomplished by modifications in rail-mill conditions

Conditions which introduce streaks into the finished rails remaining uncorrected, the elimination of failing rails will be reached by a reduction in wheel loads, since it follows that either structural soundness of the steel must be attained or a reduction effected in the working stresses to avoid the development of inherent defects



No 11 Different stages in the fracture of rails having their origins at seamy metal in base

11a First stage of rupture Crescent shaped piece detached from base due to presence of a longitudinal seam

11b Fracture extended from crescent shaped fragment detached from base Metal of remaining part of base and web fractured and part of the head Portion of head unfractured when rail was removed from the track

11c Fracture of rail completed

11a, branded "10030 Illinois Steel Company South Wks III 1911," C rail heat number 4569 in service 2 years, 7 months 11b branded "O H 10035 I S Co Gary Works IIIIII 1913 F rail heat number 51285, in service 6 months 11c, branded "O H 10030 I S Co Gary Works VII 1910," F rail, heat number 50270 in service 3 years 7 months

That the weakness of partially decarburized surface metal in conjunction with streaked steel is a contributory cause in the development of split heads under the action of wheel loads

Summary

The pieces of the broken rail which were recovered after the accident did not afford sufficient evidence to determine the condition of the rail immediately preceding its failure, and while it seems inevitable that with a split approximately 20 feet long in the head of the rail there would be some surface indications of the defect, it is impossible to say positively whether or not in this case the rail head was materially deformed

It is apparent that splits in rail heads have small beginnings and that in the early stages of their development they furnish little, if any, indication or evidence of their presence Furthermore, it is believed that in many cases defects of this nature reach an advanced state of development before they can readily be detected When there is evidence on the running surface that a split head is in process of development it is quite certain that a seam exists of substantially the same width as the increase in the width of the head of the rail, that is, an increase of one-sixteenth inch in the width of the head would indicate an interior split of the same width, which would be of sufficient size to cause the separation of a considerable part of the head

The presence of inherent and undeveloped seams and splits in rail heads can not be predicted from available data concerning the state of the steel in the ingot nor the condition of the rail when it reaches the track Assurance that inherent and hidden defects do not exist in rails can be furnished only as a result of a thorough investigation of ingot and mill conditions

In some instances the view has been advanced that split heads give warning of the defective condition of the rails in ample time to permit their removal before the occurrence of accidents, and for that reason rails with split heads have been regarded with little or no apprehension But, under modern conditions, with heavy wheel loads and high speeds, structurally sound track material is required, it is manifestly unsafe to have rails in the track which are in a progressive state of rupture Rigorous and vigilant track inspection is the only safeguard which can at present be relied upon for the detection of rail defects of this type The large number of rail failures due to split heads points to the necessity of exercising greater care in track inspection to discover split heads as early as possible in their course of development, and when discovered remove such rails from the track

Respectfully submitted

H W Belnap,
Chief Division of Safety

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