INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE GALVESTON, HARRISBURG & SAN ANTONIO RAILWAY NEAR ISER, TEX , JANUARY 31, 1916

FEBRUARY 12, 1917

To the Commission'

On January 31, 1916, there was a derailment of a passenger train on the Galveston, Harrisburg & San Antonio Railway near Iser, Tex , which resulted in the injury of five passengers and one employee After investigation as to the nature and cause of this accident, I beg to submit the following report

The train involved in this accident was westbound passenger train No 101, in charge of Conductor Brahm and Engineman Lees, en route from New Orleans, La , to San Francisco, Cal , and it consisted of seven cars hauled by locomotive 926 It was derailed at about 10 41 p m at a point one-half mile west of Iser while traveling at a speed estimated to have been about 40 miles an hour

The locomotive and the baggage car were not derailed, the next three cars, which were two sleeping cars and a dining car, were derailed and turned over on their sides clear of the track, the next sleeping car was derailed and partially overturned, while the forward trucks of the following sleeping car were derailed, the rear car was not derailed or damaged in any way, and no serious damage was sustained by the bodies of any of the cars

This part of the Galveston, Harrisburg & San Antonio Railway is a single-track line No block-signal system is in use, trains being operated by time table and train orders At the point of accident the track is tangent, with a slight ascending grade The track is laid with 80 pound rails, 33 feet in length, rolled in 1904, and laid in February, 1905, with about 20 pine ties under each rail, ballasted with about 15 inches of slag

The statements of the employees on the train indicated that their first knowledge of the derailment was when the emergency brakes were applied, presumably by the breaking of the air-brake connections Examination of the equipment did not develop anything which could have been the cause of the accident Examination of the track showed that it was in good surface, gauge, and alignment The first marks of derailment were found at a broken rail on the left side of the track The initial break was about 2 feet from the end of the rail The opposite end was intact for a distance of 18 feet 6 inches, while the intermediate section of about 12 feet 6 inches was broken into 8 principal pieces and 3 smaller ones, or a total for the entire rail of 11 pieces The broken rail showed transverse fissures at each of the principal breaks, and the investigation clearly indicated that this accident was caused by a broken rail Acknowledgment is made of the cooperation in this investigation of Mr J D Isaacs, representing the Southern Pacific Railway, and Dr J R Harris, chief chemist of the Tennessee Coal, Iron & Railroad Co The examination of the rail for the purpose of determining the reason for its failure was conducted by Mr James E Howard, engineer-physicist, whose report immediately follows

REPORT OF THE ENGINEER-PHYSICIST

The broken rail which caused the derailment of Southern Pacific train No 101 near Iser, Tex, was an 80-pound rail, A S C E section, made by the Tennessee Coal, Iron & Railroad Co, and branded "T C I Co 80 IIIIIIIIII A S 04" It was laid in the track February, 1905, and broke January 31, 1916, its length of time in service, therefore, having been 11 years

At the time of derailment the receiving end of the rail broke at 8 places, at each of which there was displayed a transverse fissure The leaving end, comprising about half the length of the rail, was torn from the ties and somewhat bent In the subsequent examination of the rail 7 additional transverse fissures were revealed, making 15 in all The fissures ranged in size from 0 30 inch in diameter to 1½ by 1 inch Thirteen were on the gauge side of the head, or central over the web, and two were in the outer half of the head

Figure No 1, a view of the rail from the gauge side, shows the location of the fractures made at the time of derailment and the places where additional transverse fissures were found in the subsequent examination of the rail One fissure was located beyond the section shown on the diagram The dimensions of the transverse fissures are entered thereupon Fragment marked No 3 was detached by a semicircular line of rupture, which had its origin at a transverse fissure 0 30 inch in diameter at its leaving end, extending thence through the web and, in reverse direction to the movement of the train, up through the head to the receiving end Pieces of the base were detached at this place Fragment No 5 was split lengthwise along the middle of the web

Figure No 2 shows the appearance of four transverse fissures on fractured surfaces made at the time of derailment The nucleus of the transverse fissure on the leaving end of fragment No 7 was over the outside edge of the web, the nuclei of the other transverse fissures were over the web or on the gauge side of the head The surfaces of these transverse fissures presented the usual appearance of this type of fracture The nucleus of the fissure commonly has a silky surface, while the balance of the fracture has a burnished appearance with a silvery luster when it is first exposed to the air It is not uncommon to find fissures in their very early stages of development in which the silky nuclei have about them silvery, crescent-shaped sections The silky portions resemble silky fractures witnessed in certain tensile-test pieces, and there looked upon with favor The absence of any structural inequality or abnormality in chemical composition at or in the vicinity of the nuclei of transverse fissures, as they are found in the greater number of instances, makes the resemblance a closer one in comparing their nuclei with the ap-

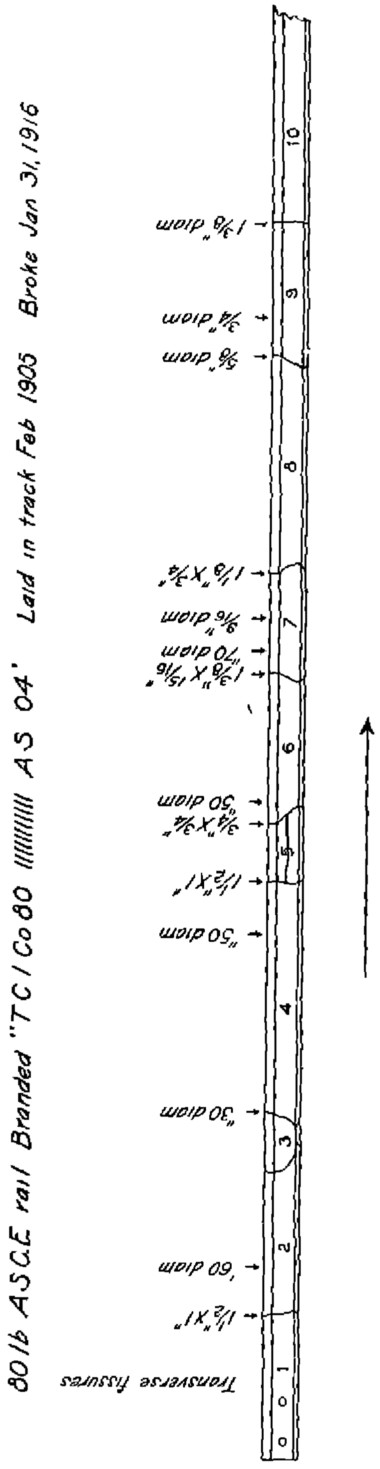


FIG 1.—View of receiving end of rail, showing lines of rupture made at time of derailment, and dimensions of transverse fissures at those places, also positions and dimensions of transverse fissures revealed in the subsequent examination of the rail

pearance of tensile-test pieces As the transverse fissure progressively extends in size the proportion of the surface having a silvery luster to the silky nucleus increases Eventually the nucleus may be surrounded almost evenly by metal of a silvery luster, but generally retaining an eccentric place on the fractured surface

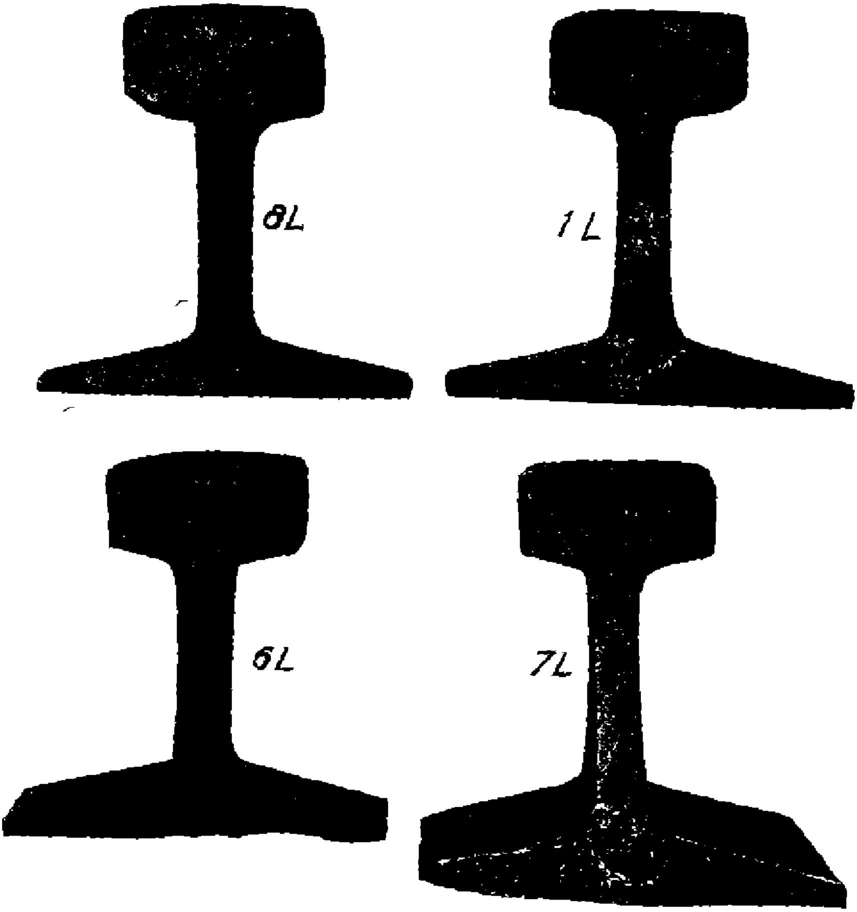


Fig 2 —Transverse fissures in leaving ends of fragments Nos 1, 6, 7, and 8 Gauge side of the rail on the left

Figure No 3 shows the appearance of three incipient fissures which were revealed in the subsequent examination of the rail The metal was planed off one side of the head, revealing the presence of these fissures, which appeared as fine vertical lines on the longitudinal section of the head Favorable conditions are required for the detection of certain transverse fissures when viewed on edge

The opposite faces may be in such close contact as to obscure their presence either under macroscopic or microscopic examination The fissure shown on the right hand of this group was obscure at certain stages of the examination A panoramic view, however, was obtained of this fissure, taken on edge, at 100 diameters magnification, the several sections of which furnished a continuous micrograph 4 feet long in its magnified image The fissure passed through the grains of the steel without any apparent tendency to follow their boundaries

The lower part of the fissure was the incipient portion The microstructure of the rail in that part of its course or elsewhere did not show any abnormality which could be ascribed as a cause for the development of a transverse fissure in that vicinity

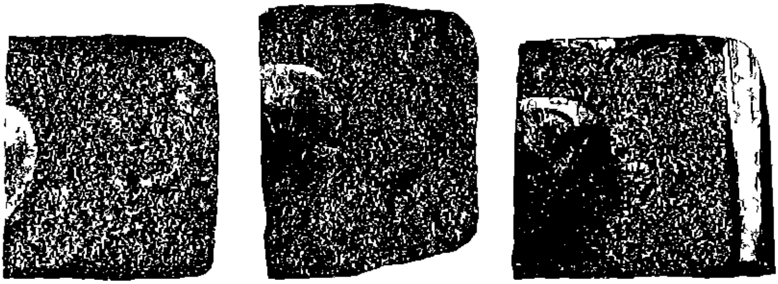


FIG 3 —Incipient transverse fissures revealed during the subsequent examination of the fragments of the rail, after the derailment

The piece of the head of the rail in which this fissure was located was planed down to cubical form, for convenience of handling at the microscope, measuring 1⅛ inches on a side, the fissure occupying a place on the middle of one face This piece was broken into halves, by resorting to peening its top, the running surface of the rail After peening the surface for a time there was a visible growth in the length of the fissure, which soon thereafter resulted in the complete separation of the cube Internal strains were thus added to those which previously existed, increasing the strains at the top of the head in sufficient degree to complete the rupture of this cubical piece In doing this the action of the peening hammer assimilated to that of wheel loads in the cold rolling of the heads of rails in the track The growth of this transverse fissure was similar to those in the track but accelerated in degree By reason of the absence of bending stresses to cause burnishing of the opposite faces, the fracture was completed without further enlargement of the silvery oval

The state of internal strain of the rail was made the subject investigation, observations being directed to sections from both receiving and the leaving halves The shorter fragments of receiving end were broken off with less distortion in shape than t bent portions of the leaving half, in that respect leaving the fr ments more nearly in the state in which the rail existed precedi the time of derailment A record is left in the rail whenever a permanent set is given the steel The complicated form of the cr section and preexisting initial strains not infrequently renders so of the changes in the internal strains difficult of complete interpret tion With more available data collected upon the combinations a relations of internal strains, the vicissitudes through which ra pass after they leave the rail mill will become more clearly appare in later examinations of the steel It is expected that more extend investigation of this subject will add materially to the meager b much-needed information upon the durability of materials und those varying conditions which are experienced in the service rails

Figure No 4 presents some cross sections on which are show the internal stresses, corresponding to the measured strains in fragments Nos 4 and 10, two sections from each Fragment No 4, a a whole, was not materially deformed when the rail was broken Transverse fissures at each end of this fragment permitted its detachment from adjacent parts without sensible change in shape The leaving end of the rail, of which fragment No 10 was a part received permanent bends at the time of derailment

The values of the normal cooling strains in some rail sections hav been fairly well established, and also those which result from whee pressures in the track In these four sections normal strains appeared in some of the flanges Compressive stresses having values in the vicinity of 10,000 to 12,000 pounds per square inch indicate a normal state of the metal for this type of rail The lesser stresses in the flanges of section No 10A′ are taken to mean that those flanges received a permanent set at the time of derailment, and that the web was similarly affected

The cold-rolled surface of the head, Nos 4′ and 10A′, showed stresses of compression ranging from 12,000 to 15,600 pounds per square inch The stress on the outside half of the head, No 4′, was somewhat higher than that of the gauge side This result is in harmony with the display of transverse fissures on that side of the head The internal strains introduced by the wheel loads are held to be one of the chief causes which lead to the development of transverse fissures, it follows that the location of the fissures in the head of the rail will be modified in position in accordance with the maximum effects of those pressures In section No 4, adjacent to No. 4′, incipient transverse fissures were found in the small square bar taken from the center of the head and in those of the outer half The results of some special tests will be referred to in a later part of this report, where it will be shown that the position of the nucleus of a transverse fissure may be located at will in the middle of the width of the head, or on the right-hand or the left-hand side, according to the place where the load is applied This control over the

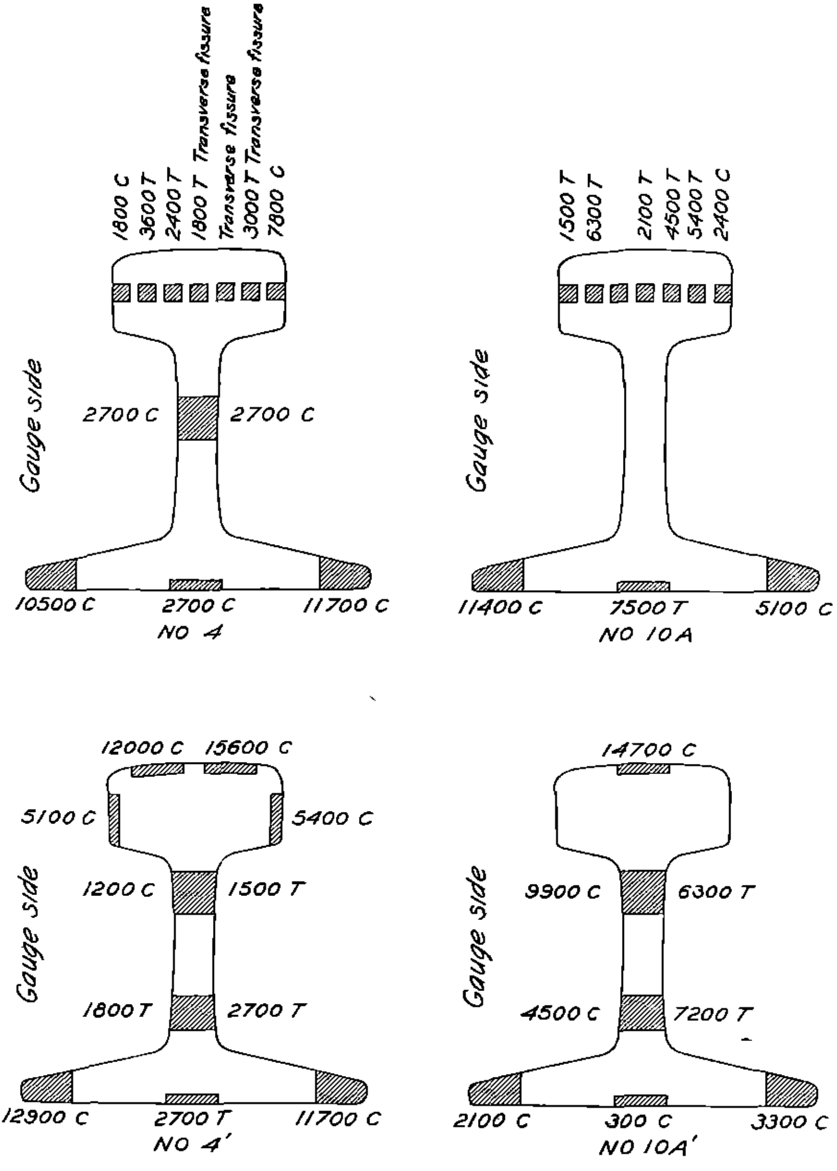


FIG 4—Internal stresses which were found in fragments Nos 4 and 10 Shaded parts of the cross sections of the rail indicate the parts on which the internal strains were measured

development of the transverse fissure in respect to position is confirmatory evidence of the explanation which has been offered in these reports that the cause of the formation of transverse fissures in rails pertains to track stresses and conditions of service

In addition to the usual strips, taken from the periphery of the head in the determination of initial strains, there were small rectangular bars taken from slices at the middle of the depth of the head, shown in the upper two cross sections of figure No 4 Strains of tension were found in the interior of the head, reaching a maximum of 6,300 pounds per square inch With metal at the top of the head in a state of compression and in the interior of the head in a state of tension, a favorable condition exists for the formation of an interior fracture under repeated wheel loads

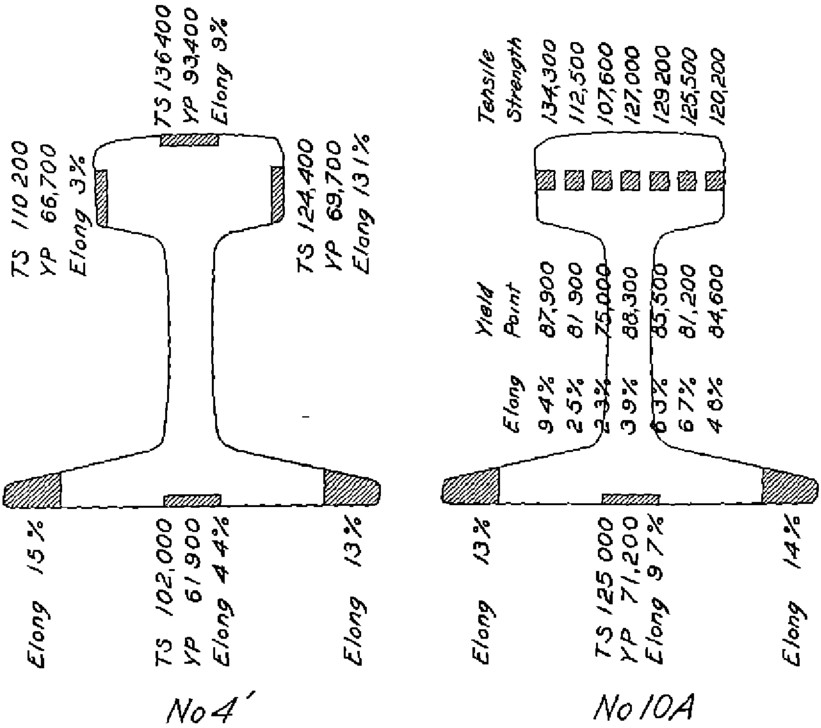


FIG 5 —Tensile and bending tests of the metal of the rail, using strips on which internal strains were measured Strips from flanges used for bending tests only

The results of tensile and bending tests are entered on two cross sections of the rail and shown on figure No 5 The tensile strength was found to range from 102,000 to 134,000 pounds per square inch The maximum strength was displayed by the strip from the top of the head The minimum strength was in the metal at the middle of the bottom of the base Tests of the metal from the interior of the head showed intermediate results

The yield points, which may be taken as values somewhat above the elastic limit of the steel, ranged from 61,900 to 93,400 pounds per square inch The cold rolling of the metal at the top of the head gave increased rigidity to the steel, as it had also affected the tensile strength, and the highest yield point was recorded in that part of the rail It is not held that the usual tests defining the yield point suffice to indicate the real condition of the metal affected by cold rolling, or the effect of repeated alternate stresses which the rail had endured Tests of greater refinement than the usual laboratory tests are necessary for such a purpose The metal of the rail would be expected to fail ultimately under stresses of much lower magnitude than the yield points recorded in these tests, although these values represent loads at which decided permanent sets were first observed

The elongation of the tensile specimens ranged from 2 3 to 13 1 per cent, the minimum amount displayed being shown by the specimens from the interior of the head All fractures were granular in appearance without local contraction of the steel at the place of rupture The metal displayed low ductility and probably was so at the time the rail was rolled While it is commonly desired to employ steel which in its primitive state possesses greater ductility than here witnessed, still the fact will be borne in mind that it has not been shown what direct influence primitive ductility has on the endurance of the rail to repeated stresses, where rupture is reached without appreciable display of the ductility which the primitive tests displayed Nevertheless there are other considerations which lead to the choice of steel having ductile properties in its original state, and steel of a ductile nature is preferred for rails

Bending tests which were made with the strips from the flanges of the rail showed an elongation on their tension sides of 15 per cent without reaching the limit of rupture The chemical analysis of this rail showed a high phosphorus content, notwithstanding which the bending tests of the steel in parts of the rail remote from the zone in which transverse fissures were displayed gave favorable results Bending tests of the metal, using one-half of the head, and those made with the web of the rail, showed limited ductility, conforming to the results of the tensile specimens from the interior of the head

Drillings for chemical analyses were taken in three places—from the top of the head, from the location of the nuclei of the transverse fissures, and at the junction of the head and the web Four sets of determinations were made—one representing the metal at the receiving end of the rail, two at intermediate places along its length and one from the leaving end The results of the chemical analyses are shown in Table No 1

TABLE No 1—*Chemical analyses of rail in different parts of its cross section and length*

Marks	Location	Carbon	Sulphur	Phosphorus	Manganese	Silicon
1-L	Top of head	0 67	0 027	0 113	0 76	0 004
	Fissure location	77	030	127	77	003
	Junction of web and head	70	031	131	80	004
6-L	Top of head	67	029	113	77	003
	Fissure location	74	031	136	80	003
	Junction of web and head	73	030	135	78	003
10-A	Top of head	68	029	113	77	003
	Fissure location	75	030	127	77	004
	Junction of web and head	69	030	112	78	002
10-L	Top of head	67	028	108	75	004
	Fissure location	73	030	128	78	004
	Junction of web and head	68	025	109	74	003

Neither the chemical analyses nor the microscopic examination showed any specific cause for the development of transverse fissures Two photomicrographs appear later in the report, showing the general structure of the interior of the head, and also the distortion of the grain of the steel at the immediate surface of the head, the latter caused by the flow of the metal under the wheel pressures The surface flow was equally pronounced across the top of the head, and not confined to the gauge side The rail showed a very limited amount of wear, but wheel loads had clearly been received over a width of 2 inches, or out to about one-half an inch from the outside of the head

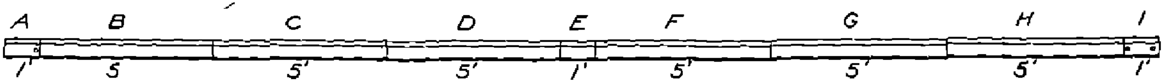
The direct examination of the rail, excepting some metallographic work, was completed with these tests and observations The subject of transverse fissures in rails is one of such importance that supplementary data were acquired from other rails, it being necessary to acquire information upon the successive stages through which the metal passes from the time of fabrication until rupture is reached

The supplementary tests made in connection with the present rail next follow

The effects of wheel loads on the running surface of a new 100-pound rail were determined by subjecting different sections of its length to wheel loads of 35,000, 25,000, and 15,000 pounds, respectively Sections 5 feet long each were subjected to wheel loads in a reciprocating machine, a chilled cast-iron wheel, 33 inches in diameter, being used for the purpose of applying the loads The rail sections passed under the loaded wheel with a reciprocating motion, a trip forward and back counting as one reciprocation The number of reciprocations on each section and the wheel loads are shown on figure No 6, which also shows the strains developed in the rail by this cold rolling and the stresses corresponding to the strains which were released when individual strips were detached from the rail

New 100-lb rail ARA-B type

Sections exposed to different wheel pressures in reciprocating machine



	A	B	C	D	E	F	G	H	I
Wheel loads	0	35,000	25000	15,000	0	15000 both edges	15,000 both edges 35,000 one edge	25000	0
Number of reciprocations		2000	2000	2000		2000 & 2000	2000 & 2000 1000	10000	
Strains developed, in intact sections, by reciprocating machine — Head, sides and top		+"0003	+"0008	+"0003		+"0005	+"0006	+"0009	
		+"0004	+'0005	+"0002		+"0012	+"0006		
		-"0002	+"0004	+"0001		+"0003	+"0006	+"0006	
Base, middle of		-"0003	0	+"0001		+"0001	+"0001	-"0001	
Stresses in top of head, measured on parts of sections exposed to wheel loads		6000 c	9900 c	16500 c		14100 c 15900 c	15000 c 9000 c	12600 c	

FIG 6.—New 100 pound rail, A R A -B type, subjected to different wheel loads in reciprocating machine Wheel loads applied, number of reciprocations, strains developed in the rail by these loads, and stresses corresponding to the strains released when individual strips were detached

Comparison sections, 1 foot in length each, were cut from the rail and designated by the letters A, E, and I

Chemical analysis of 100-pound rail used in reciprocating test, type A R A–B, open-hearth steel

	C	Mm.	P	S	Si	Cr	Ni
Mold test	0 628	0 76	0 014	0 048	0 085	0 35	0 75

By reason of the coning of the tread of the chilled iron wheel, only one edge of the top of the head was directly affected by contact with the wheel The outer half of the head was but little affected when the loads were applied to the rail in one position only in the reciprocating machine

Section F was reversed in position after 2,000 reciprocations, and the opposite side of the rail then became the gauge side, thus exposing both sides to the action of the chilled iron wheel Section G was exposed to 2,000 reciprocations on one side of the head, then reversed in position and loaded 2,000 times on the other side, followed by an increase of the wheel load to 35,000 pounds on the second side Reference lengths of 10 inches each were established on the head and base of each section prior to loading The changes in the gauged lengths, due to the wheel loads, are shown on the diagram Along the center of the top of the head the maximum strain was 0 0012 inch

These changes in lengths, measured on the intact section of the rail, do not stand in direct relation to the internal strains which were introduced by the wheel loads There is a certain response in the metal to the strains which are being introduced by the wheel loads, but this response is the resultant effect of the strains which are in the metal at the running surface of the head, and those strains which represent the reaction of contiguous metal next below Differences in the respective volumes of metal directly affected, and the volume of contiguous parts, will modify the results

Each of the wheel loads employed introduced initial strains on the gauge side of the head, and it was further shown that the internal strains in the sections rolled with 15,000 pounds wheel load were greater than those of the higher wheel loads Still further, it appeared that the highest wheel load employed had the effect of reducing the initial strains which were introduced by the lowest wheel load This result appears in the test of section G, which was rolled on each edge with 15,000 pounds, followed by a load of 35,000 pounds on the second edge The effect of 10,000 reciprocations at 25,000 pounds on section H was greater than that due to 2,000 reciprocations of the same load in section C

The maximum value reached in these stresses was 15,900 pounds per square inch, a high value, but one which has been exceeded by rails in the track The internal strains which were found in the metal on the gauge sides of the rail were so much above those found in the outer side of the head, which latter were almost negligible, and also so much above those which were present in the companion 1-foot lengths not cold rolled, as to leave no doubts concerning the augmentation of internal strains in the top of the rail by wheel pressures

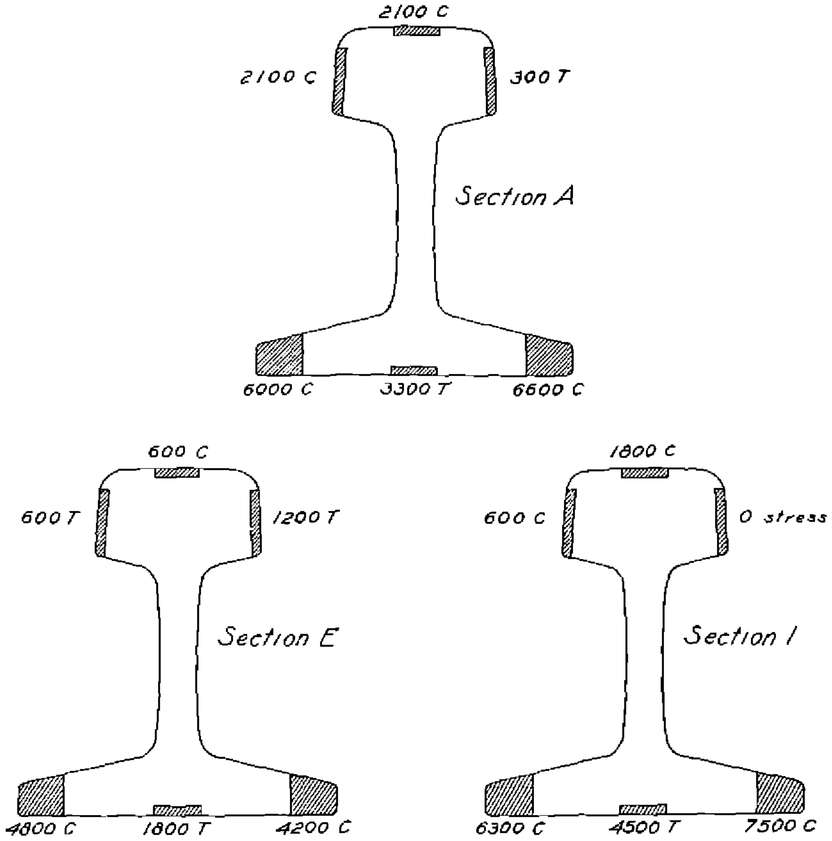


FIG 7—Initial stresses in sections of new 100 pound rail, which had not been subjected to wheel loads in reciprocating machine

Figures Nos 7 and 8 show the internal strains which were present, respectively, in the 1-foot sections and those of the 5-foot sections which were cold rolled There was a fairly uniform state of initial strains throughout the base, indicating that the cooling strains are substantially the same in different parts of the length of the rail The greatest departure from uniformity was found in the 1-foot pieces particularly in section E, taken from the middle of the length of the rail It is believed that the internal strains were here modified by the cold sawing of the rails into short lengths for testing, that the cold sawing, which left the ends very hard, changed the state of strains in the vicinity of each sawed end This effect, if it prevailed, would be most felt in section E, and here the greatest departure from the average results was observed in the flanges and middle of the base The results on strips from the head necessarily are not comparable between the rolled and the unrolled sections

The reported results represent the mean strains and stresses in the several detached strips These strips must have such dimensions as permit being machined, and in their cross section the internal strains may vary The results are conservative statements of the magnitude of the internal strains, which no doubt locally exceed the reported values

In order to acquire data upon the depth of penetration of the effects of the wheel loads on the rail sections from the reciprocating machine, sections of the head were examined adjacent to those on which the initial strains in the strips were measured The heads from these adjacent sections were turned down in successive stages and the strains displayed by the central core were measured at each stage The results are shown on figure No 9, together with a section of a new 100-pound rail The cold-rolling strains in the sections from the reciprocating machine did not penetrate deeply into the metal of the head Internal strains greater than those observed in these sections may be put into the rail by peining with a light hand hammer, but they also are superficial and do not penetrate deeply into the interior of the head On the other hand, loads in the reciprocating machine, which were much greater than those here used, and wheel loads on rails in the track have shown effects penetrating to the center of the head Many of the phenomena attending the introduction of initial strains have not been investigated The paradoxical effects apparently shown by the lower wheel pressures in introducing greater internal strains than higher wheel loads, and even reducing those of the lower loads, will probably be explained when more complete data shall have been acquired upon the volumes of the affected metal, the varying intensities of the internal strains in the affected zones and the influence which such disturbing conditions have upon the elastic limits of the steel in tension and in compression

Steel rails furnish a convenient opportunity and source whence information may be derived concerning the effects of service conditions on the endurance of the metal to different combinations of stresses, and stresses of different magnitude Evidence of the introduction of internal strains in the rails after they reach the track carries with it proof that service stresses locally or otherwise have exceeded the elastic limit of the steel No permanent change in the state of the cooling strains would be expected unless the elastic limit of the metal had been exceeded in some part of the cross section of the rail

To provide for a direct measure of the internal strains which are introduced in the track, a new 100-pound rail was selected from a lot which was being laid The chemical analysis of this rail was as follows

Chemical analysis of 100-pound rail used in experiments on the introduction of internal strains in rails in the track, C rail, A R A -B, open-hearth steel

	C	Mn	P	S	Si	Cr	Ni
Mold test	0 645	0 68	0 030	0 043	0 104	0 33	0 60

Three feet in length was cut from one end of the rail, and the remaining portion was cut into halves, one part being laid on gravel ballast and the other near by on a bridge The internal strains in these two sections of 15 feet each will be ascertained after they have received a certain amount of track service The 3-foot length was cut into three parts and each part separately examined, two representing the rail in its primitive state, while the third piece was specially treated, the results of which are shown on figure No 10 Strips from the periphery of the sections in the primitive state of the rail showed internal strains which were judged to be normal to this weight of rail, type A R A -B The strains in the flanges were of compression, as usual, and those along the middle of the base were in tension The strains in the periphery of the head were much less than those of the base, conforming to the general results found in rails of this weight Rails in general show higher primitive internal strains in the base than in the head, which are reversed in their order after the rail reaches the track, by increase of the strains in the head

The initial strains in the center of the head of this rail were practically zero There was only 330 pounds compression at the center of the head, a negligible quantity

The third 1-foot piece was annealed, and a strip then detached from one flange The rail was then heated to about 900° F and quenched in water at a little above 100° F The annealing was efficient, the strip from the flange showing only 1,800 pounds compression Annealing will not efface all internal strains, but reduce their magnitude to about the elastic limit which the steel has at the annealing temperature

The subsequent heating and quenching of this section of the rail resulted in the introduction of internal strains differing radically from those which occur from normal cooling in air The strains in the quenched rail were greater in the head than in the base A maximum of 23,100 pounds compression was found on one side of the head A strain of compression along the middle of the base, amounting to 13,800 pounds per square inch, was substituted for the usual state of tension The remaining flange left on the section showed strains higher than normal for an air-cooled rail, but less than the strains of the thicker parts of the rail

These results illustrate the differences occasioned by changes in the rate of cooling and the influence of the dimensions of the cross section of the rail During the period of rapid cooling the internal strains temporarily have opposite signs to those of their final state Thus the periphery of the head is momentarily put into a state of tension at the time of quenching, the interior still being hot As the

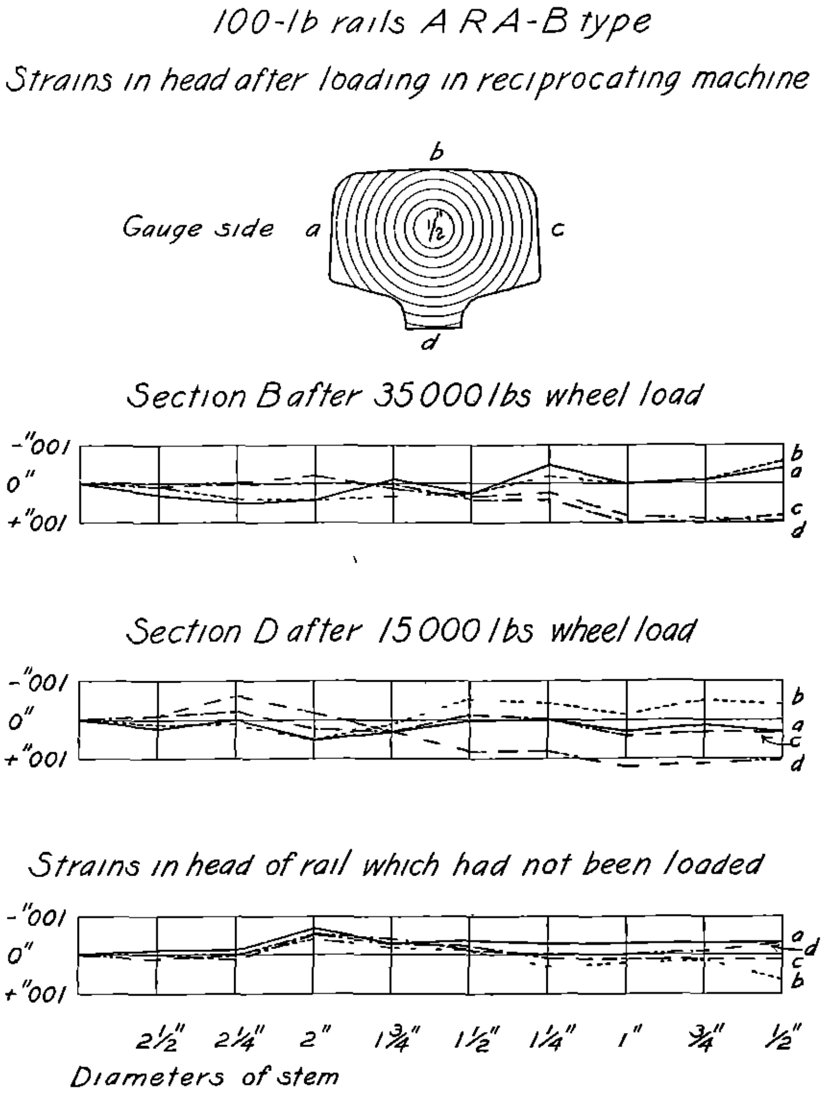


FIG 9—Internal strains in central part of head of rail after loading in reciprocating machine, and strains in rail which had not been loaded Curves show strains released at different diameters of stem

interior metal cools, the temporary strains of tension set up at the periphery are reduced to zero and then pass into a final state of compression According to the mass of the metal and the suddenness of cooling these reversed strains assume greater or less magnitude In air cooling the greater mass of the metal in the head tends to ameliorate the final state of internal strain, in sudden quenching the opposite result is reached and internal strains are greater in the periphery of the head than in the thinner parts of the rail The difference in temperature of different layers as they simultaneously exist, is a factor in the case

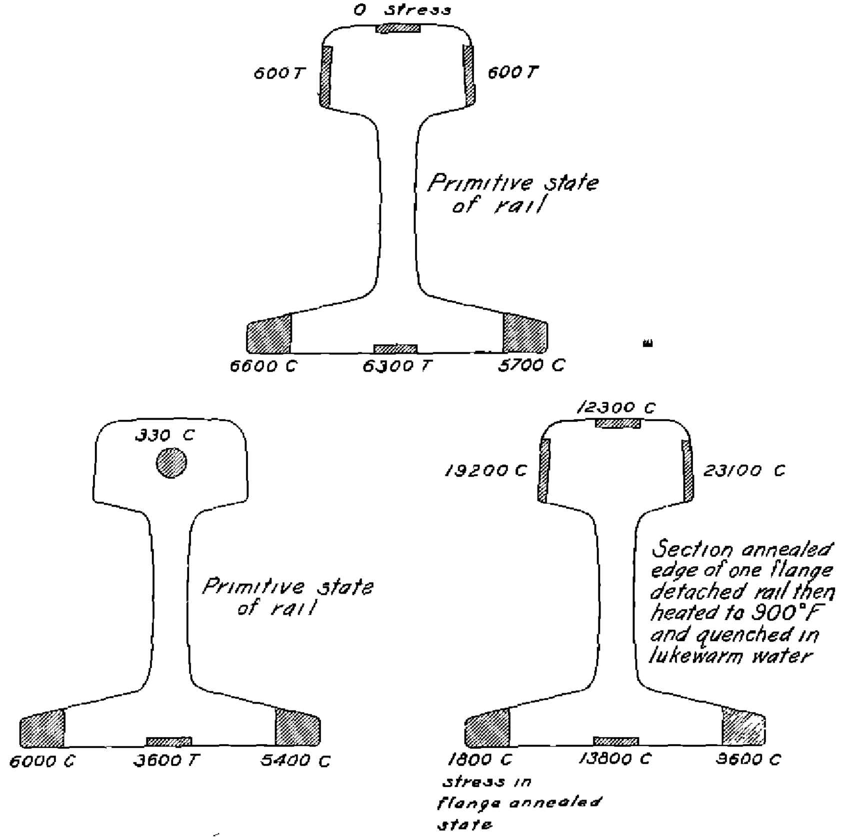


FIG 10 —Internal stresses in new 100-pound rail, type A R A –B in primitive state also stress in flange of an annealed section, and stresses introduced by quenching the annealed section from a temperature of 900° F

The temperature to which this rail section was raised at the time of quenching was much below the zone of critical temperature Transformations at the recalescent periods of temperature are not involved in the introduction of these strains They were introduced by sudden cooling from a temperature several hundred degrees below the critical points In other examples it has also been found that rapid cooling from temperatures in the vicinity of 900° F will bring about a state of internal strain represented by stresses of 30,000 pounds per square inch, or more The peripheral metal is from its exposed position susceptible to the more radical changes due to heating and cooling Hence the cooling strains are greatest in those parts which are directly exposed to the quenching medium, and, conversely, the interior metal from its protected position is less affected, or indirectly affected by the cooling medium The region in the interior of the head, in which the nuclei of transverse fissures are located, places it beyond the direct influence of cooling during fabrication, in respect to arresting transformations which rapid passing over the critical range in temperature effects

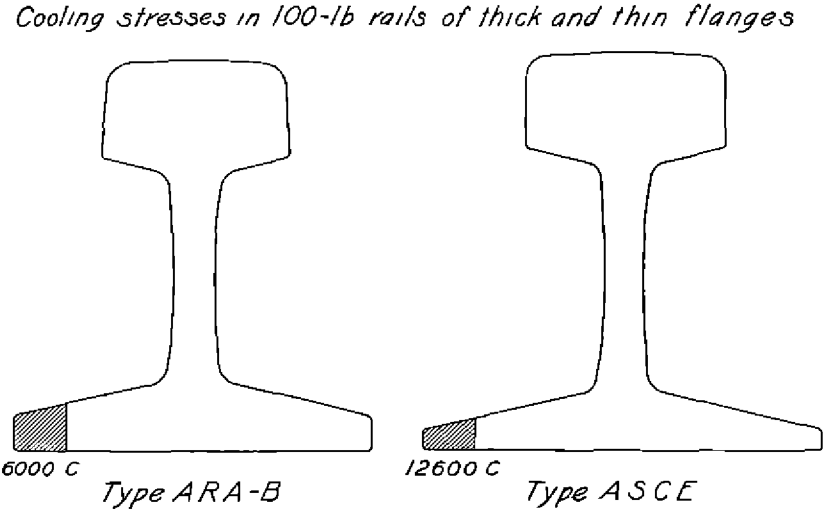


FIG 11 —Internal stresses in two 100 pound rails, cooled normally, showing increased stress in the thin flanged rail

Figure No 11 illustrates the difference in the cooling stresses in two rails of 100-pound section, each cooled normally The initial stresses in the flange of the thin-flanged section were twice those of the thick-flanged section The A. S C E type of rail here shown does not represent an extreme example of a thin-flanged rail Other observations have shown stresses of 18,000 pounds per square inch compression in a thin-flanged rail, cooled normally

It has been ascertained that the introduction of cooling strains takes place chiefly after the rails have left the last pass of the rail mill At recalescent temperatures the steel is somewhat plastic and internal strains are not believed to be physically possible in values above the elastic limit of the steel at any given temperature, and which approaches zero value at plastic temperatures The capacity for receiving and retaining initial strains appears axiomatically to depend upon the elastic limit of the steel at a given temperature

Gagging will introduce internal strains, cause the rearrangement of preexisting strains, and even locally efface severe cooling strains in certain parts of the rail—such action not eliminating the internal strains as a whole, but shifting their positions—nevertheless it does not follow that gagging will cause a perceptible change in the microstructure of the steel A series of observations were made upon 100-pound rails of two grades of steel, a high-carbon and a low-carbon series, touching upon this feature

Chemical analyses of steel in high-carbon and low carbon series of gagging and drop tests

	C	Mn	P	S	Si	Cr	Ni
High-carbon series	0 669	0 72	0 032	0 055	0 244	0 29	0 40
Low-carbon series	492	63	038	079	067	25	34

Rails of each grade were subjected to mechanical treatment, as follows

Gagging upon the head, normal
Gagging upon the base, normal
Gagging upon the head, excessive
Gagging upon the base, excessive
Drop test, 10 feet, on head
Drop test, 10 feet on base

Cross sections of these rails were taken out after the above treatment and examined with reference to the microstructure of the head in the region where transverse fissures have their origins The sections were also tested to ascertain whether the physical properties of the rail were affected in an appreciable manner by the normal and excessive gagging on the head or on the base, or whether an accentuation of gagging pressures, such as experienced by the rail in the drop tests, affected the strength of the steel It was recognized that the detection of a change in microstructure would be more difficult in the high-carbon series than in steel of lower carbon content, hence two grades of metal were used the more pronounced cellular structure of the lower carbon metal making that grade the more favorable one for this purpose, although the high-carbon series represented metal of the composition called for in current rail specifications

The microstructure of the rail heads was carefully examined and photomicrographs taken representing the average structure at the top and at the center of the cross sections, etching the specimens with picric acid and photographing them at a magnification of 100 diameters The photomicrographs shown by figures Nos. 12 and 13 represent the appearance of a number of these etched sections The metal at the immediate surface of the head is shown to be decarburized in each series, most noticeable in the low carbon series Concerning the metal at the interior of the head, in the region of transverse fissures or elsewhere, no peculiarities of structure were found indicative of the effects of gagging or the drop tests which had been given, either on the head or on the base In other words, neither the gagging in normal or excessive amount on the head or base nor the more severe ordeal of the drop test had appreciably affected the microstructure, these remarks applying to each grade of steel It is not necessary to state that no effect of the gagging or the drop test was visible macroscopically Companion pieces of the rail, which had not been treated, were examined for the purpose of comparison, in conjunction with those which had received mechanical treatment

Distortion of the metal may be of such degree as to be plainly visible on polished and etched sections Such examples have shown distortion, but it was confined to the immediate zone of metal next the part acted upon The dissipation of the effect was such that traces of its action were lost before reaching the zone within which transverse fissures are formed The present results were negative in respect to connecting the effects of gagging and the drop test with any change in structure having to do with the formation of transverse fissures

Gagging may, however, be conducted after the manner of fatigue tests and ultimately cause the rupture of the rail In order to do this a large number of repetitions are necessary Interior transverse fissures may in this manner be developed at will in rails, instead of the common type of fatigue fracture in which rupture has its origin at the surface of the member To produce an interior fissure by means of repeated gagging it has been found necessary to apply the gag progressively over the entire length of the rail, bending it alternately convex and concave, and repeating this operation for a considerable number of times When the gagging is confined to one place, applied alternately on the head and the base, the common type of fatigue fracture of exterior origin results

By means of progressive gagging interior transverse fissures have been developed in 24 new rails The task of making these fractures was rather colossal Half-rail lengths were used for convenience, the number of blows upon which in the aggregate amounted to nearly one and one-half millions Each blow of the gag caused a permanent set in the rail The number of blows delivered at any one point on a rail ranged from 800 to 4,000 During the progress of gagging the stroke of the press was increased from time to time over the

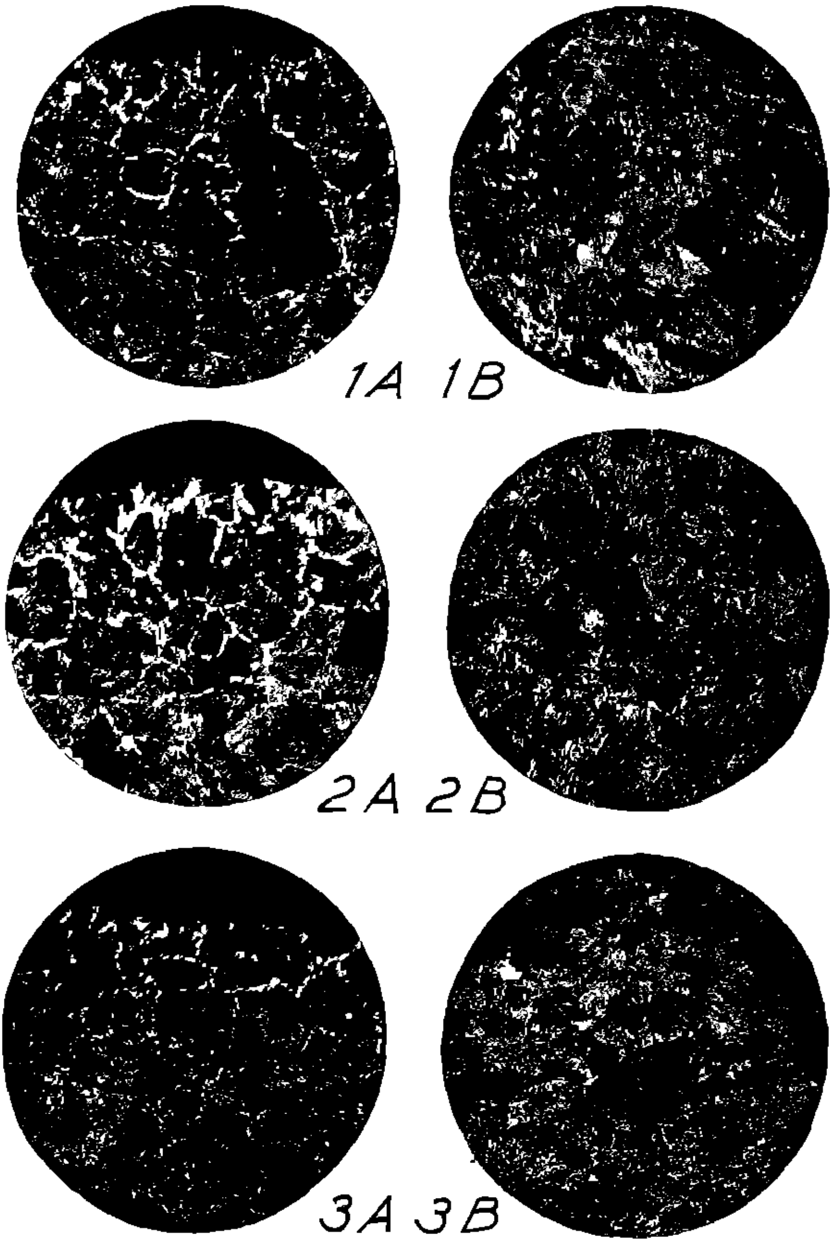


FIG 12 —Microstructure of rail sections, high carbon series, at top of and at center of base 3 A, 3 B, rail not gagged Figures marked 'A" show structure at edge of top,
base 3 A, 3 B, rail not gagged Figures marked A show structure at edge of top,
those marked B show structure at center of head Magnification, 100 diameters

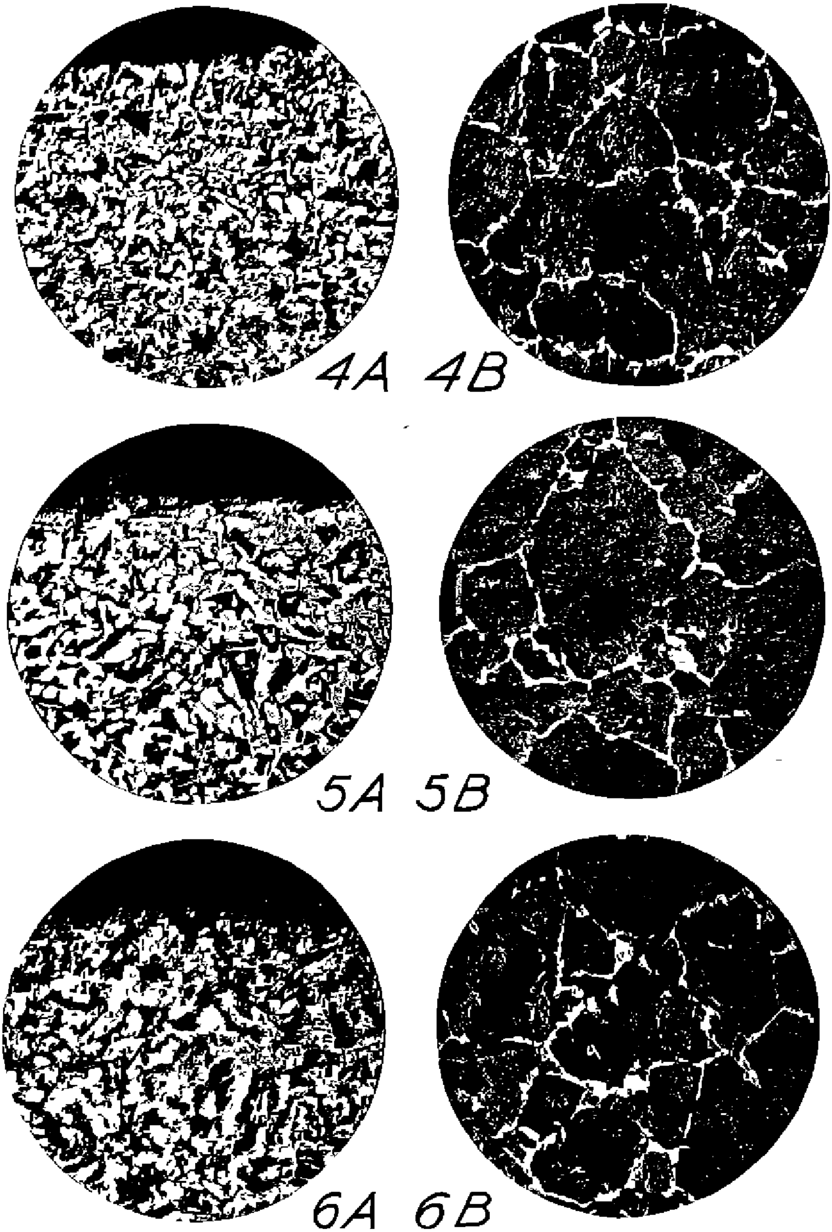


FIG 13—Microstructure of rail sections, low carbon series, at top of and at center of head 4 A 4 B, after normal gagging on the head 5 A, 5 B, after one blow of 2,000 pound tup on head, 10 feet drop 6 A 6 B, rail not gagged Figures marked "A" show structure at edge of top, those marked "B" show structure at center of head Magnification, 100 diameters

original amount in order to compensate for the changes in resilience which resulted from repeated reversals of loads A decided permanent set was given the rail by each blow and maintained throughout the test

Not only was it possible to produce interior transverse fissures by means of progressive gagging in new rails as above described, but it was also demonstrated that control could be exercised over the position of the nucleus of the transverse fissure within the head of the rail Central, vertical loading produced a transverse fissure in the middle of the width of the head By inclining the rail and applying the load on one side of the head, a transverse fissure was produced on the side of the head which was loaded, and on either the right or the left side of the head, according to the side on which the load was applied

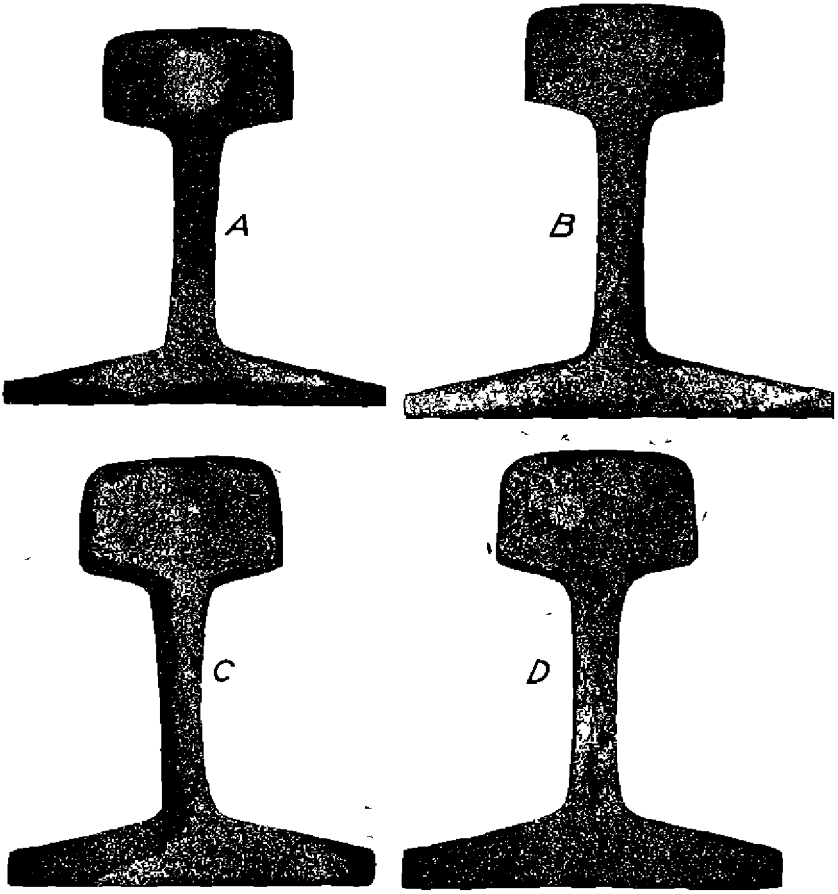


FIG 14—Four transverse fissures developed in new rails by progressive gagging Sections marked 'A' and 'B'' were 85 pound rails Section A was loaded over center of head Section B was loaded on right side of head Sections C and D were 100 pound rails Section C was loaded over center of head Section D was loaded on left side of head

Views of the fractured surfaces of four rails are shown on figure No 14, representing transverse fissures developed in rails of 85 and 100 pounds section One rail of each weight shows a central transverse fissure, and one eccentric fracture on the right side and one on the left side of their respective weights The eccentric transverse fissures were developed on the sides of the heads on which the loads were applied

The transverse fissures of this series were smaller than those which are reached in rails in the track The rupture of the rail was completed before the transverse fissure had reached that stage of development which is frequently witnessed in the track The burnishing effects of the opposite faces of the fissure, on each other, were less pronounced than in rails from the track These features appear consistent with the method of loading, in which high bending stresses were maintained throughout each test

The details of the tests of these four gagged rails are shown in Table No 2 The column headed "Reversals" states the number of times the half-length rail passed through the gagging press, first with the head up and then the base up Gagging blows were delivered at intervals of about 6 inches each The column headed "Loads per 33 feet" gives the equivalent number of blows referred to a full-length rail In the complete series of tests there were rails which were reversed in position over 4,000 times, the equivalent number of blows per 33-foot rail exceeding 250,000

TABLE No 2—*Transverse fissures developed in new rails by progressive gagging*

Test	Section	Loads per 33 feet	Reversals	Heat No	C	Mn	P	S	Si
A	85 pounds	94,000	1,429	54,194	0 69	0 77	0 020	0 040	0 14
B	85 pounds	170,000	2,581	54,194	69	77	020	040	14
C	100 pounds	145,000	2,189	33,123	75	80	020	044	16
D	100 pounds	254,000	3,855	53,021	62	72	020	035	21

Test	Section	Loads applied	Position of traverse fissures
A	85 pounds	Central	Central
B	85 pounds	Off center on right side	Off center on right side
C	100 pounds	Central	Central
D	100 pounds	Off center on left side	Off center on left side

Concerning the state of internal strain set up by progressive gagging, figures Nos 15 and 16 illustrate the results found in the examination of two sections of 90-pound rails after transverse fissures had been developed The internal strains in the section shown by figure No 15 were those which were measured after the final bend in the gagging press had been reversed and a permanent set given the rail in the opposite direction The examination of the metal in the center of the head of the section, shown by figure No 16, shows the internal strains as they were left at the termination of the gagging test

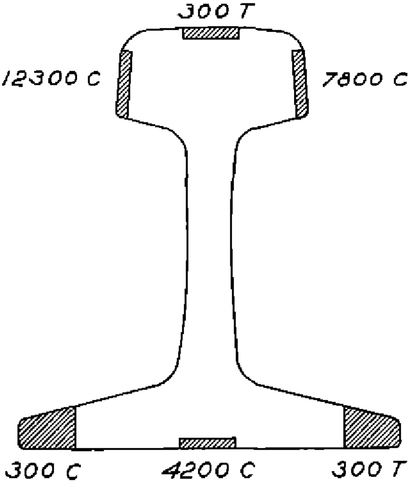


FIG 15—Internal stresses in section of a 90 pound rail, after a transverse fissure had been developed by progressive gagging

The initial stresses measured on the strips from the section illustrated by figure No 15 show a radical modification over those which are normally present in new rails The usual state of compression of several thousand pounds per square inch in the flanges had been reduced to a negligible amount In one flange there was compressive resilience, in the other, tensile resilience, each amounting to only one ten-thousandth of an inch This is the limiting value in the manipulation of the strain gauge and is not regarded as having any practical significance There was only one ten-thousandth of an inch change in the strip from the top of the head On the sides, however, the stresses attained values of importance, being 12,300 and 7,800 pounds, respectively, each of compression, and the usual state of tension along the center of the base was reversed and a strain of compression of 4,200 pounds per square inch was there present Necessarily, the interior of the head was in a state of tension in order to balance the external strains of compression

In the examination of the head of the rail, it was demonstrated that initial strains were present in the center and were displayed when the stem was turned down to diameters less than 1½ inches

In connection with the laboratory development of transverse fissures, and the control which was exercised over their positions in the heads of the rail, the results of rails which developed transverse fissures in the track will be presented In a group of 663 rails, which displayed transverse fissures, a large preponderance of the fractures were on the gauge side of the head, a lesser number were centrally located, and none were on the outside of the head These fissures were in rails of different chemical composition, of different weights of sections, of Bessemer and open-hearth steel and failed after different periods of time in service Figure No 17 illustrates the results, showing the number of transverse fissures in different parts of the heads of the rails, and the ingot positions of the rails There were 535 transverse fissures on the gauge side of the head, 128 were centrally located, and none on the outside of the head

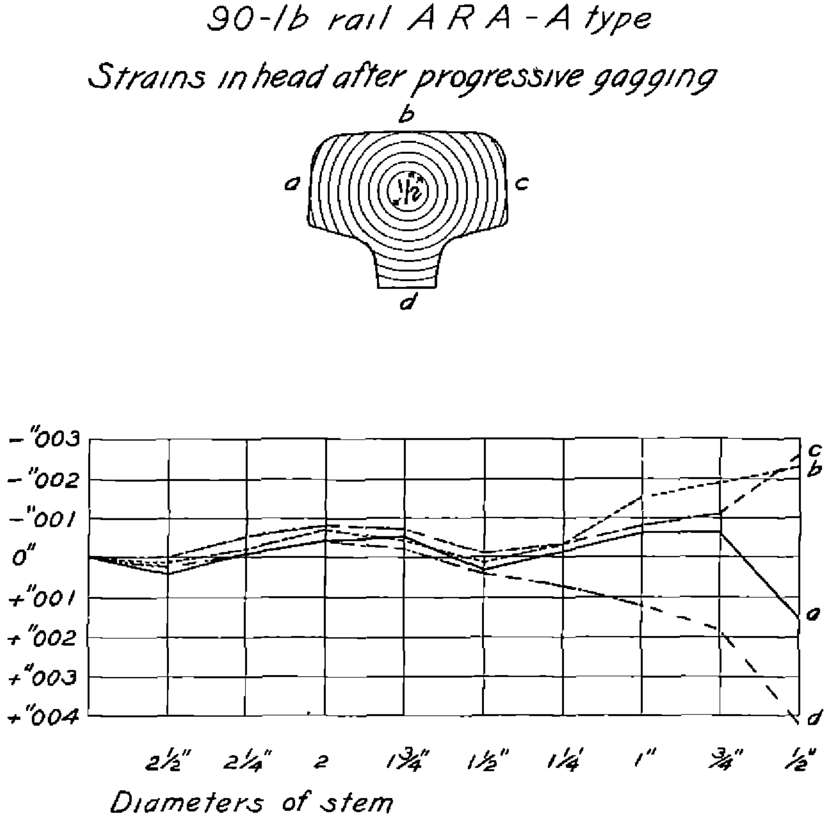


FIG 16 —Internal strains in section of a 90 pound rail, after a transverse fissure had been developed by progressive gagging Strains measured on the four sides of the head, as stem was successively turned down in diameter

The fissures were generally distributed among those designated as A, B, C, and D rails The lesser number of transverse fissures developed in the E to H rails is accounted for by the fact that comparatively few ingots furnish rails of these letters

The time interval of a rail in the track is not per se the controlling factor in the development of transverse fissures Fractures of this type have been displayed in rails after a few months in the track, and in others which have been in service from 10 to 20 years The life of steel under repeated stresses is not measured by lapse of time but in terms of the maximum stresses and the number of times which

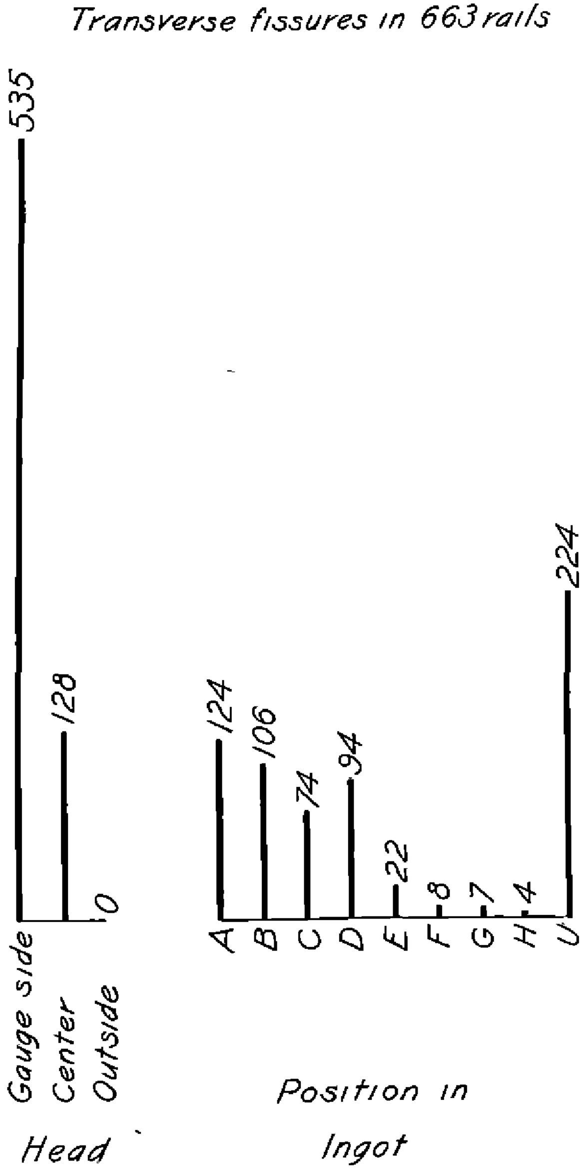


FIG 17.—Transverse fissures in 663 rails Location of fissures in the heads of the rails and ingot positions of the rails

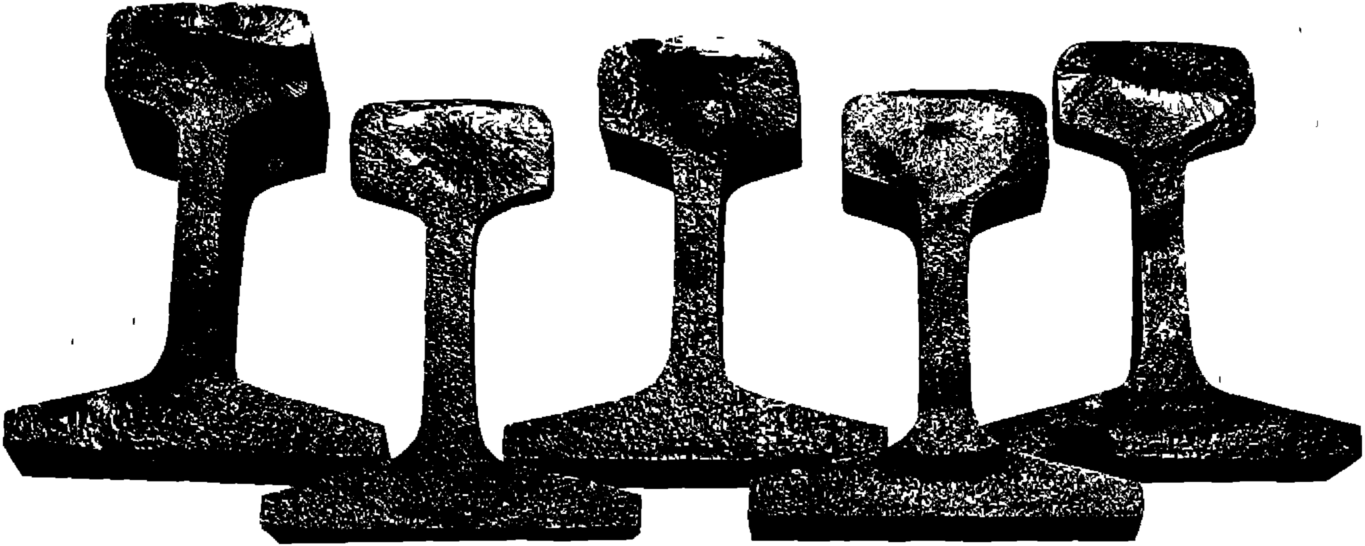


FIG 18 —Transverse fissures displayed by rails of 125 pounds weight, after a comparatively short period of service in the track Rails rolled from reheated blooms the stresses are applied According to the weight of equipment and the density of traffic, this may be accomplished in rails within a few months, or it may require a term of years

Figure No 18 shows the appearance of five transverse fissures which developed in rails of 125-pound section, after a comparatively short term of service in the track Figure No 19 is the reproduction of a sulphur print taken immediately behind one of the transverse fissures The uniformity in structure of the rail will be noted

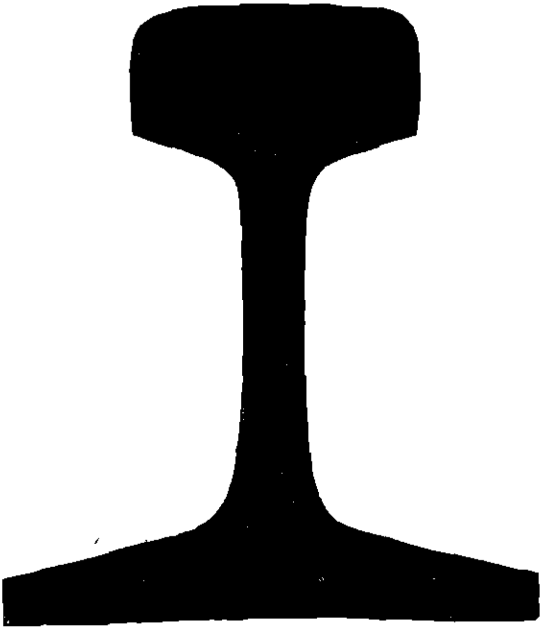


FIG 19 —Sulphur print of 125 pound rail which displayed a transverse fissure Print taken on cross section of rail immediately adjacent to the transverse fissure

The early appearance of transverse fissures in sections of this weight of rail gives emphasis to the need of investigating the individual components which contribute to their formation These rails were made from reheated blooms The reheating of the blooms presents a feature which has advantages from a manufacturing point of view, but it is not clear that reheating should be expected to restrain the metal from the development of transverse fissures

Different types of failure occasionally appear in the same rail Service conditions which affect the head of the rail render this part liable to display one or more types of rupture, singly or jointly The cold-rolling action of the wheels causes the metal of the head to flow in a crosswise direction The formation of a fin along the side of the head is evidence of such lateral flow having taken place, of the metal having responded to the shearing stresses from the wheels Split heads are formed in this manner

The term "split head" is applied when the plane of rupture follows a vertical, longitudinal course The term "mashed head" is applied when lateral flow occurs, either unaccompanied or accompanied by an actual shearing fracture developing in an oblique or horizontal longitudinal plane

Steel is capable of displaying great malleability under favorable cold-rolling or cold-swaging influences Hard steels have less malleability than the softer grades The softer rails, in some instances, have shown fins of one-half an inch or more in width But whenever the ability of the steel to display ductility has been exhausted, rupture will necessarily ensue

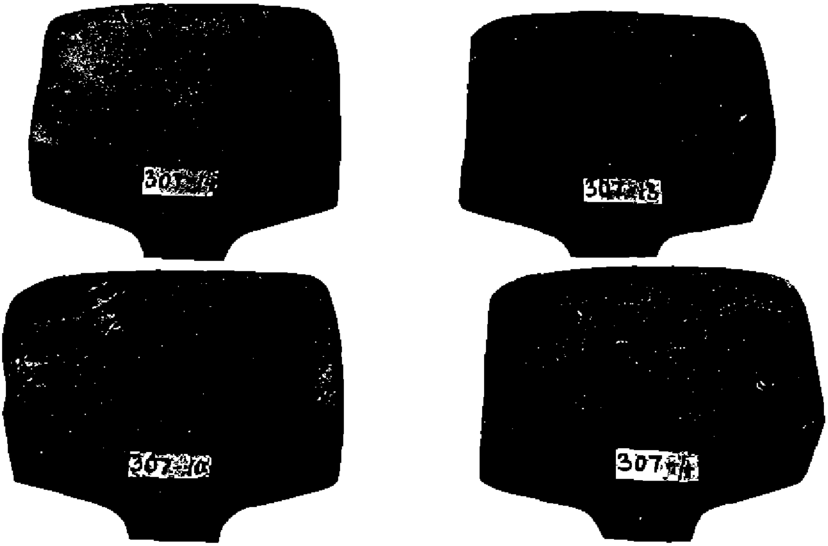


FIG 20—A type of shearing fracture in the head of a rail, illustrating its development at four places of its length

Figure No 20 illustrates a common type of shearing fracture in the head of a rail The fracture is shown at four places of its length This fracture had reached an advanced state of development when the rail was cut into short sections and photographed

Very frequently the incipient point of such a fracture is at a longitudinal streak in the rail, at a slag needle or partially welded blow hole, which affected the normal display of shearing ductility A progressive enlargement of the fracture next follows, starting from the seam as a nucleus, developing into a plane surface, and extending thence both in width and in length

Fractures of this type are, at times, associated with transverse fissures The cold-rolling action of the wheels plays a common part in the development of each kind of fracture, causing the introduction of longitudinal internal strains in one case, and lateral flow of the metal in the other The difference in the manner of failure will be borne in mind, to avoid confusion when considering these two distinct types of fracture, either of which may be developed independently of the other, or both may appear in the same rail

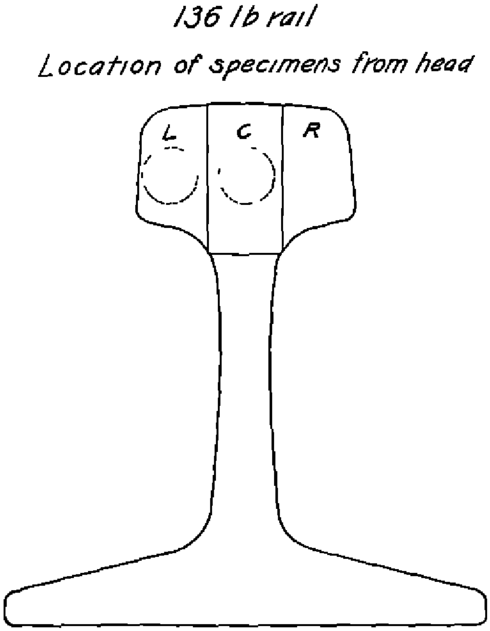


FIG 21—136 pound rail, showing location in head whence specimens were taken Tensile test pieces taken from sections L and C, microscopic and hardness determinations made on section R

Tests were made on sections of a rail of 136 pounds weight, in which the effects of different rates of cooling on the properties of the steel at the interior of the head were ascertained, including also tests upon the effects of severe blows in the drop test In the latter there was pronounced indentation of the metal on the top of the head A companion section of the rail represented the steel after normal rate of cooling Three sections were each heated to 1,450° F, one of which was allowed to cool naturally in the open air, one was cooled rapidly by means of an air blast, and one was buried in hot lime The section which cooled in the open air lost its heat and the head became black in 18 minutes after drawing from the furnace

The section cooled with the air blast lost its color in 3 minutes, the blast being continued for a period of 8 minutes The section buried in hot lime retained its heat, and was too hot to bear the hand upon when withdrawn from the lime 17 hours after it was buried The above sections were 12 inches long each

Two pieces, 5 feet long each, were struck on the head with a 2,000-pound tup, dropped from a height of 20 feet The section was supported by a rigid block directly beneath the tup Tensile specimens were taken out longitudinally from the center and from one side of the head of each section treated as above, while the other side of the head was used for microscopic examination and Brinell hardness determination The manner of taking out these specimens is shown by figure No 21 The results of the tensile tests and Brinell hardness are shown in Table No 3

TABLE No 3—*Tensile tests and hardness determinations on longitudinal specimens from head of 136-pound rail*

NOT TREATED

No of specimen	Elastic limit, per sq in	Tensile strength, per sq in	Elongation	Contraction of area	Appearance of fracture	Brinell hardness
	Pounds	*Pounds*	*Per cent*	*Per cent*		
1AC	63,000	123 000	11 0	17 02	C S spot	
1AL	68,000	127,500	13 0	17 02	do	241
1BC	69,000	127,000	10 5	17 02	C S center	
1BL	68 000	127,500	11 5	17 02	do	245
HEATED TO 1,450° F—COOLED NATURALLY IN AIR						
2AC	68,000	127,000	12.0	17 02	C S center	
2AL	70,000	130,000	15 0	18 8	do	244
2BC	63,000	127,500	12 5	15 83	do	
2BL	63,000	128,000	14 5	17 73	C S spot	239
HEATED TO 1,450° F—COOLED BY AIR BLAST						
3AC	88,000	149,000	12 0	22 33	C S center	
3AL	99,000	155,000	13 0	24 76	do	286
3BC	92,000	150,000	12 0	21 98	do	
3BL	100,000	154 000	12.5	24 08	do	281
HEATED TO 1,450° F—COOLED IN HOT LIME						
4AC	53,060	113 000	11 0	14 53	C S	
4AL	60,000	113,000	13 5	17 02	do	212
4BC[1]						
4BL	54,000	106,500	14 0	18 8	C S	215
STRUCK TWO BLOWS WITH DROP FROM HEIGHT OF 20 FEET						
5C	70,000	128,000	12.0	13 38	C S	
5L	62,600	122,000	12 0	18 98	C S center	241
8C	69,000	129,000	8 5	11 51	C S spot	
8L	76,000	130,000	10 5	15 02	do	245

[1] Bar lost

The heat analysis of the 136-pound rail was

C	Mn	P	S	Si
0 760	0 63	0 041	0 046	0 175

The check analysis of the D rail, used in these tests was

C	Mn	P	S	Si
0 710	0 65	0 045	0 048	0 171

The heating of the three 12-inch sections was carried to a temperature above the critical point, thereby enabling the cooling to be done over the recalescence period at different rates of speed The air blast gave an accelerated rate over that which would be experienced in mill practice, while cooling in hot lime took place at a retarded rate Exaggerated conditions of cooling were therefore given the rail sections over those which would be experienced in rail fabrication

The modifications in physical properties, due to the different methods of cooling or to the blows of the drop test, were consistent with common understanding of such influences The section which was reheated to 1,450° F and cooled in the open air gave substantially the same results as the untreated section, while accelerated cooling by means of the air blast raised both the elastic limit and tensile strength Cooling in hot lime had an annealing effect and lowered the elastic limit and tensile strength The drop test did not materially impair the primitive ductility of the steel, only one specimen of which fell below the mean elongation of the series Specimens from the section cooled by the air blast gave greater contraction of area than displayed by the other samples

Four features are usually mentioned in current specifications—elastic limit, tensile strength, elongation, and contraction of area, each representing primitive properties of the steel in the state when fabrication is complete These properties do not admit of being used up to their maximum limits in actual construction Under the general conditions of service, failures occur without the full display of any of them The possession of properties recognized as desirable in the primitive condition of the steel does not constitute a safeguard against failure A vital link is missing which connects the utilization of the primitive properties with the endurance of the steel under long-continued use Those neglected factors which impair the properties of the material after it has been put into service must not be overlooked, and such use made of steel that, whatever grade may be selected, it shall be so used that its integrity will not be destroyed

In the sections of 136-pound rail which were subjected to the drop test, surface indentations were made at the places where the tup struck the head of the rail The maximum indentation was a little over one-eighth of an inch, but this depth of indentation did not introduce evidence of distortion in the microstructure of the steel Figure No 22, 7–A, shows the microstructure at the head of the section where struck by the tup, 7–B, the general structure at the center of the head The decarburization at the surface appears in the first of these photomicrographs, representing usual decarburization witnessed at the surface of rolled shapes The effect of gagging and the indentation by the tup of the drop test each produces a surface effect in which the mill scale is disturbed, and causes a measurable change in the state of initial strains The present examination, however, did not reveal a change in the microstructure, viewing the rail sectionally No evidence of the imprint of the gag or of the tup of the drop test reached the interior of the head The intensity of the pressure of the gag or tup would be dissipated in the more remote parts of the head of the rail, and influences not perceptible at the surface would not be expected to be visible in the center of the head or where they were upon the point of vanishing

FIG 22 —Microstructure of head of 136 pound rail after it had received two blows of a 2,000 pound tup, dropped from a height of 20 feet, cross sections 7 A shows average structure at top of head 7 B shows average structure at center of head Magnification, 100 diameters

Rolling loads on the head of the rail cause surface distortion of the grain Rails from the track, in general, show distortion of the grain from wheel loads Figure No 23 illustrates the microstructure of the head of the rail which caused the present derailment Photomicrograph 8–A shows the distortion of the grain of the steel at the top of the head, 8–B, the average structure at the center of the head, each taken on cross sections of the rail Photomicrograph 8-A was taken on the outside half of the head, the same distortion, however, extended across the top from the gauge side for a width of about 2 inches During the 11 years of service in the track each of the top elements had been directly loaded by wheels of different contours of treads

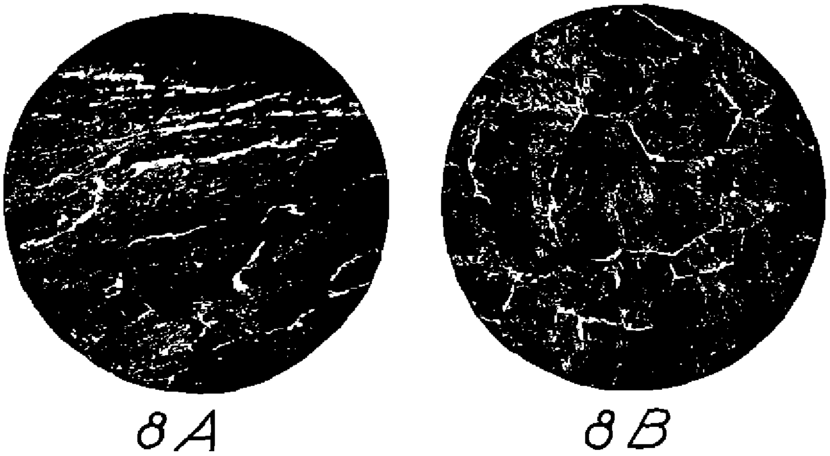


Fig 23—Microstructure of head of 80 pound rail, which caused the present derailment, cross sections 8 A, taken at edge of top of head outside half, showing distortion of grain from wheel loads 8 B microstructure at the center of the head Magnification 100 diameters

In considering the relations between the elements of the head which have been affected by the wheels with the internal strains which have been introduced, and the location of the nuclei of transverse fissures in the rail, it will be noted that this rail, which exhibited two transverse fissures in the outside of the head, showed the effects of wheel loads across the full width of the head, and that the strip from the outside half displayed initial stresses of compression a little higher than that of the strip from the gauge side

Additional data upon the appearance of the metal in the region of a transverse fissure were acquired, and illustrated by figure No 24 The region of an incipient transverse fissure was polished and etched with picric acid The photomicrographs shown in this cut were taken across the plane of the fissure No trace of the fissure was detectable under the microscope with this polishing and etching, as may be noted by inspection of photomicrograph 9-A This area was repolished, removing traces of the structure of the steel which the picric acid had brought to view Again there was no evidence of the presence of the transverse fissure The specimen was next treated in a boiling solution of ammonium oxalate and then etched with picric acid, whereupon the presence of the fissure was manifest, as illustrated in photomicrograph 9-B The opposite faces of the fissure were in such close contact that the slight folding effect of polishing the metal hid the fissure from view against the mild effects of picric acid, its presence being revealed by the more energetic action of the ammonium oxalate

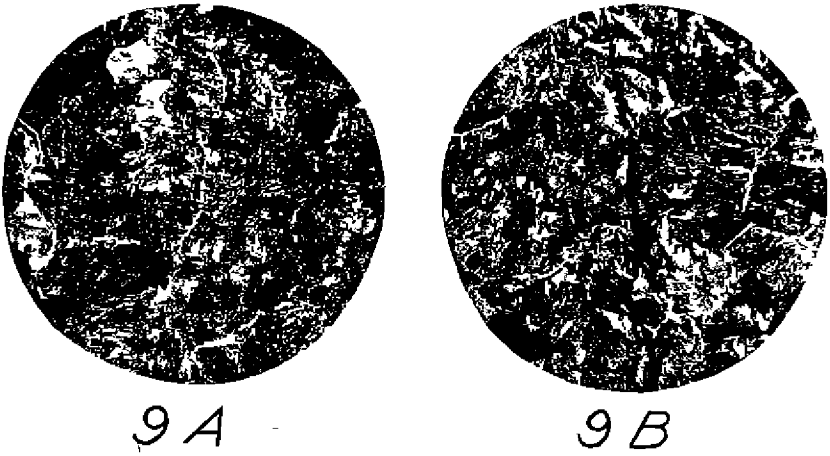


FIG 24 —Microstructure, at an incipient transverse fissure, of rail which caused present derailment, longitudinal section 9 A, area containing transverse fissure but not revealed by polishing and etching with picric acid 9 B, area containing transverse fissure the presence of which and its location being revealed by treating polished section in boiling solution of ammonium oxalite Magnification, 100 diameters

Still further information was acquired upon the microstructure of this rail at another incipient transverse fissure, one which also showed the opposite faces of the fissure to be in close proximity to each other, and illustrated by figure No 25 The location of the fissure having been predetermined, the specimen was polished and etched with picric acid No trace of the transverse fissure appeared on the etched surface, as indicated by photomicrograph 10–A The metal was repolished, removing the structural shapes which the picric acid had brought into view, the fissure still remaining unrevealed, as indicated by photomicrograph 10–B

The specimen was then treated with a boiling solution of ammonium oxalate, which brought into view the transverse fissure, as shown by photomicrograph 11–A The location of the fissure remained visible when again repolished, as shown by 11–B Photomicrograph 10–C, not here reproduced, was taken at 300 diameters magnification, the results being the same as with the lower magnification

There is a zone for each grade of steel within which loads may be repeated without rupture, practically, for an indefinite number of times When loads exceed this zone all grades of steel are soon ruptured From the period of successfully enduring loads, which may be repeated hundreds of millions of times, the endurance of the steel suddenly drops to a few thousand or hundred thousand repetitions Herein is recognized a danger zone, on one side of which steel has nearly unlimited life, on the other side of which early failure will certainly take place These remarks state an inexorable law in the physics of steel, from which there is no escape

Laboratory tests have established the general limits of these danger zones for different grades of steel, as applied to carefully prepared specimens on which basic results have been obtained Very few tests, however, have been made on the endurance of full-sized rails to repeated alternate stresses The influence of form, dimensions, initial strains of cooling and of cold rolling, all of which pertain to rails, have not been fully ascertained The limiting stresses, or the life of a rail under repeated loads, is unknown, a deficiency which constitutes an adverse comment upon engineering progress in this important use of steel

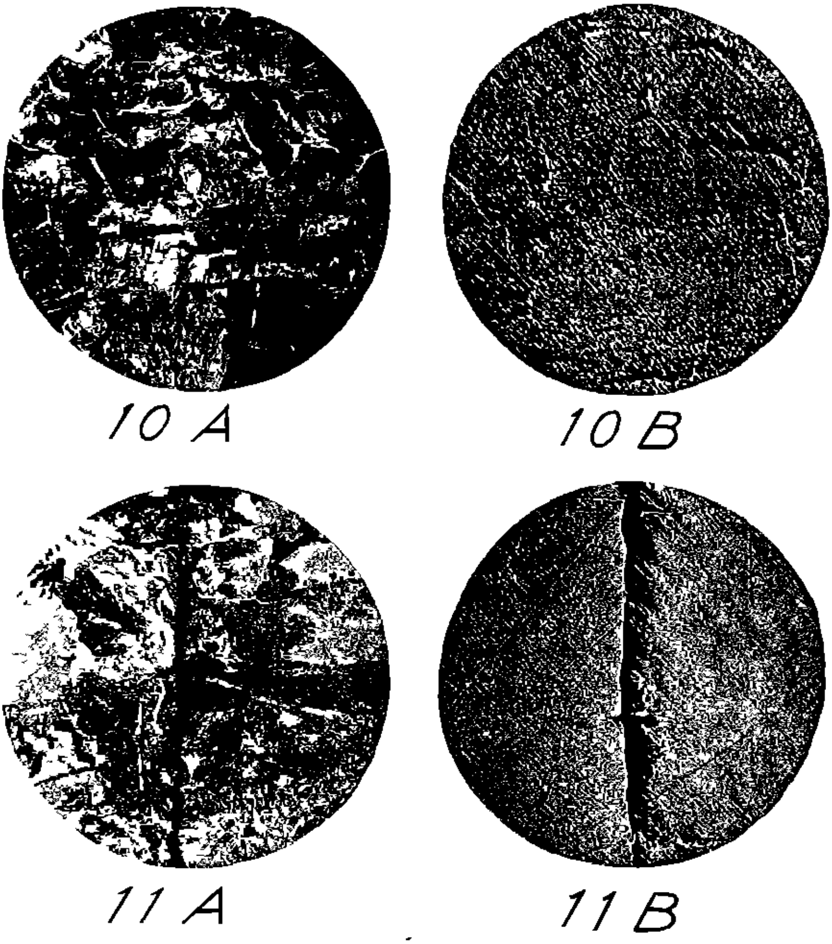


FIG 25 —Microstructure, at an incipient transverse fissure, of rail which caused present derailment longitudinal section 10 A, area containing transverse fissure, but not revealed by polishing and etching with picric acid 10 B, same area repolished 11 A, same area treated with ammonium oxalate, revealing the presence of the transverse fissure 11 B same area repolished after treatment with ammonium oxalate Magnification, 100 diameters

Two grades of steel have been selected for illustrating their endurance in laboratory tests, the results of which are shown on figure No. 26. Steel of 0.55 carbon content endured 76,000,000 repetitions of 30,000 pounds per square inch, alternate tension and compression, without rupture. The load was increased 5,000 pounds per square inch, on a companion bar, whereupon rupture ensued at 900,720 repetitions. The fracture of a third bar, tested under an additional increment of load of 5,000 pounds per square inch was reached at 455,350 repetitions. Similar results were shown by the 0.82 carbon steel. Two hundred million repetitions of 40,000 pounds load were endured without rupture, while under 45,000 pounds load the steel failed at 605,460 repetitions, and under 50,000 pounds load it failed at 213,150 repetitions. In another grade of steel, its endurance under fiber stresses of 45,000, 40,000, and 35,000 pounds per square inch, respectively, stood as the numbers, 1 to 2½ to 947; that is, the steel under a load of 35,000 pounds per square inch had a life 947 times longer than the same grade of steel under stresses of 45,000 pounds per square inch. The danger zones against long-continued alternate stresses for each of these grades of steel were clearly indicated in the laboratory results. It would be a case of temerity to load these steels above the limits there shown.

From the small number of tests which have been made on full-sized rails, the results of two will be presented, furnishing examples of rupture by repeated, alternate, bending loads, none of which caused appreciable permanent sets. These tests were made in a vibratory machine on rails which had been in service in the track. Their composition and physical properties are shown in Table No. 4.

TABLE NO. 4.—*Rails fractured by repeated, alternate, bending in vibratory machine. Tests of 90-pound rails taken from the track.*

No.	Rolled	Ingot position	C	Mn	P	S	Si	Number of vibrations causing rupture	Manner of failure
1	9–1911		0.73	0.69	0.027	0.034	0.10	145,086	Fatigue fracture in head.
2	5–1912	C	.88	.80	.028	.029	.13	289,557	Fatigue fracture in base.

TENSILE TESTS

No.	Elastic limit	Tensile strength	Elongation	Contraction of area	Appearance of fracture
			Per cent	*Per cent*	
1	75,360	118,400	16.0	25.6	60 per cent crystalline.
2	86,800	138,500	11.0	16.2	Crystalline.

Figure No 27 shows the appearance of the fractured ends of the rails which were broken in the vibratory machine The rails were ruptured after a small number of vibrations, a significant feature bringing *into prominence questions upon the life of rails Millions* of repetitions of loads are expected to be successfully endured by rails in the track In the vibratory machine rupture was reached after a few hundred thousand repetitions

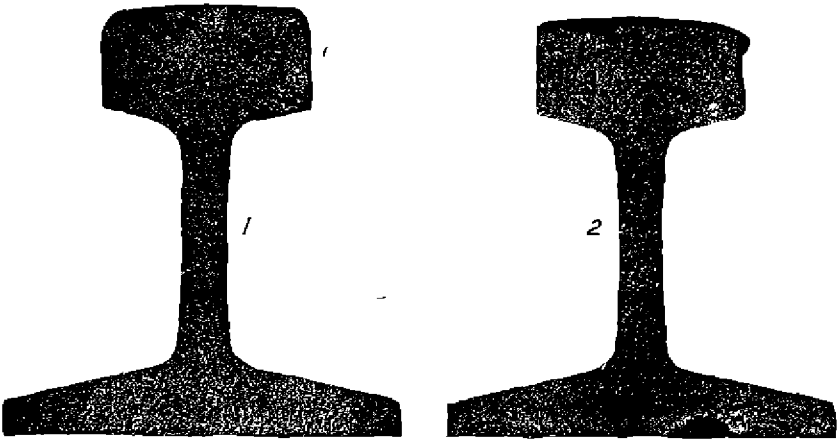


FIG 27 —Fatigue fractures developed in vibratory test of two 90 pound rails tested after a term of service in the track

This report would not call for the discussion of contributory causes which effect changes in the physical properties of rails, presenting the subject in such detail, were it not for the fact that the development of transverse fissures in large numbers precipitates the basic question whether rails which display this type of fracture were or were not overloaded in the track The actual stresses in the track are not known The resistance of the rails against repeated stresses is not known Therefore, the essential data upon which the use of rails should rest are unknown The barrenness of information necessary to formulate a reply to this query could hardly be more complete The information furnished by the rails themselves, in their manner of failure, possesses more definiteness in respect to this fundamental question than data which have been obtained from other sources

The development of a transverse fissure presents a type of failure which has the characteristics of a fatigue fracture A fatigue fracture is one which results from the repetition of loads too great for the steel to long endure It is a progressive fracture in its usual development, one to which the name "detail fracture" is often applied It is gradual in its development chiefly when the loads which cause it are variable It is a tension fracture, and occurs where the tensile stresses reach a maximum

In a rail, the greatest tension in the head is along certain interior elements by reason of the initial strains of compression set up at the running surface by the cold rolling by the wheels The location of the metal in maximum tension accounts for the interior origin of transverse fissures Its interior formation is a distinguishing feature over other fatigue fractures where the compressive component is not present

Incipient fissures are found at frequent intervals along the interior elements of the head in rails which have failed in this manner The same is true in fatigue fractures made in the laboratory The integrity of the steel is destroyed locally, and fine checks appear on the surface of the bars when they are subjected to direct tensile stresses, after failure under repeated loads

Experimentally, transverse fissures have been made in new rails, where control over their location in the head has been demonstrated They were located at will, centrally over the web, and on the right side or the left side of the head, according to that on which the load was applied

Neither chemical analyses nor microscopic examinations have shown a definite cause for the development of transverse fissures They have occurred in rails of different weights, in those of different ingot positions, in the product of each of the two great methods of steel making, Bessemer and open-hearth, in direct-rolled rails and in those from reheated blooms, in rails laid on curves and in those on tanget track, over ties and between them, they have made their appearance in the different seasons of the year, and in rails rolled in the different seasons, they occur where, according to chance, the rails may have been gagged and from the number and proximity of the fissures, where they probably were not gagged, they have displayed themselves singly, and independent of other types of rupture, and also associated with shearing fractures or seams which have developed in planes at right angles to the fissures, they are found in the head and not in the base of the rail, they appear in rails which show very little wear, they are not confined to any one rail mill, nor to northern or southern mills, nor to any one year's rolling, but have been displayed by rails rolled at periods of time separated by not less than two decades The latter fact should remove doubts concerning any peculiar conditions having found their way into modern mill practice influencing this type of failure

On the other hand, traffic has increased, wheel loads have increased, and speeds have increased, and transverse fissures are in general found where these conditions are well advanced The girder strength of the rails has been increased, while the impinging pressures of the wheels still remain without amelioration It is a disquieting matter that rails of the heavier sections recently laid have displayed transverse fissures Mere increase in weight of section has not brought with it immunity from failure in this manner It gives emphasis to the need of acquiring further data upon the features which have been discussed in this report

The conclusion seems well founded that transverse fissures are fatigue fractures, and that they develop in rails which are structurally and chemically free from any known defect It is a modified type of fatigue fracture in which there is a compressive component in the rail next the running surface of the head The presence of this compressive component accounts for the interior origin of the transverse fissure It constitutes the difference which the introduction of the term "transverse fissure" was intended to emphasize over the common type of fatigue fracture in which this component is absent and which in consequence thereof has an exterior origin

The compressive component represents the state of internal strain caused by the cold rolling of the wheels on the top of the head after the rail has reached the track A preponderance of transverse fissures is on the gauge side of the head, the side on which the wheels have the greatest effect Transverse fissures experimentally formed in new rails are located at will on the right side or the left side of the head, or centrally, according to the place where the loads are applied

The general law enunciated some 50 years ago in respect to the invariable result of repeated stresses in causing rupture in sound steel, and without display of ductility, applies to this type of fracture of rails To this law there are no exceptions

The continued use of rails without exact knowledge upon their resistance to repeated alternate stresses, which constitutes their regular function in service, and without exact knowledge upon the magnitude of the track stresses which they daily receive, presents an engineering anomaly which has extended far beyond its proper limits of time The continued use of steel rails without this fundamental information is unjustifiable Data upon the stresses which the rails receive admit of determination only by recourse to track observations The form of a rail is such that data are required upon the full rail section in order to satisfactorily determine its resistance to repeated alternate stresses Information of this kind would aid in putting rails upon a sounder basis of use, and in conformity with that which should be experienced by steel in all engineering structures

In conclusion, the direct investigation of the rail which ruptured attaches the cause of its failure to the development of transverse fissures in different parts of its length Transverse fissures are held to represent a modified type of fatigue fracture, the formation of which is due to repeated alternate stresses received in the track

It is a modified type of fatigue fracture by reason of the initial strains introduced in the head of the rail by the cold-rolling action of the wheels of the equipment, causing the metal below the running surface to acquire a state of initial tension, and thus accounting for its interior formation

Data are needed upon the magnitude of the track stresses, and upon the limit of endurance of rails to such repeated stresses The magnitude of the loads received and the number of repetitions are factors which determine the life of the rail against fatigue fractures The satisfactory use of rails requires the determination of this information, with such limitation placed upon the number of repetitions of loads that a proper margin in residual strength shall be maintained

SUMMARY

The investigation clearly shows that this accident was caused by a broken rail, the rail displaying a considerable number of transverse fissures, one at each of the main lines of rupture, while additional fissures were discovered in the subsequent examination of the rail, making in all a total number of 15 They were in different stages of development, ranging in size from 0 30 inch in diameter to 1½ by 1 inch The report of the engineer-physicist dealing with this fractured rail enters upon a discussion of the type of fracture to which a transverse fissure belongs, and the evidence which leads to the belief that it is caused by overloads in the track The correlated influences which affect rails in service, together with the earlier state of the steel as it is left by the rail mill, are presented and analyzed

Obviously, no rail could be rolled with fissures of such magnitude as here exhibited, nor is it reasonable to suppose that fissures, occupying a plane at right angles to the direction in which the rail is extended, admit of being formed at the time of rolling Blowholes or slag inclusions in the ingot are extended in the direction of the length of the rail and finally appear as acicular lines or streaks Transverse fissures eventually attain dimensions which cover the entire head of the rail They are undoubtedly of progressive development, and in their incipient stages are small fissures which eventually extend under the influence of track conditions

Questions arise in this connection, relating to the manner in which incipient fissures extend during the term of service of the rail Assume the existence of a minute fissure in the center of the head of the rail, it must follow that stresses in service are adequate to so strain the rail that extension takes place The manner of failure indicates a tension fracture, hence the track stresses must cause the necessary tensile stress The range in stresses will be greatest at the most remote fibers from the neutral axis, according to the laws of mechanics, but transverse fissures are interior fissures and do not form at the most remote fibers from the neutral axis It therefore becomes necessary to find a reason for their interior formation Tests upon initial strains show that the interior of the head of the rail, after it has been in service, is ordinarily in a state of tension, and that the top of the head is in a state of initial compression, chiefly the result of the wheel loads A bending stress in the track must be sufficient in degree to overcome the initial state of compression at the immediate surface of the head and reverse the strain before an exterior tension fracture can physically take place While this reversal is being accomplished the greatest tensile strain, according to measurements, is in the interior of the head, in the region where transverse fissures have their origin This is prima facie evidence of a state of tension which accounts for the interior extension of the transverse fissure once it has formed It is believed that the incipient stage is reached in the same manner by reason of metal in the interior of the head being exposed to tension of greater magnitude than at the surface, and for that reason there appears no inconsistency in the initial formation and progressive development of an incipient transverse fissure in the interior of the head of a rail

It has been demonstrated in a large number of cases that rupture may be accomplished by repeated alternate stresses, and in all grades of steel, without the display of appreciable ductility These fundamental tests have well established what results will follow repeated stresses when applied a sufficient number of times and of suitable magnitude There is fundamentally no metallurgical reason why a rail could not be ruptured in the same manner by repeated alternate stresses as laboratory bars are ruptured In fact, tests which the engineer-physicist presents show that rails of full section have been ruptured in this manner While the tests introduced were made on rails which were taken from the track, there is no reason why new rails should not display the same traits under repeated bending loads

The examination of new rails has not shown the presence of transverse fissures Diligent inquiry has been made extending over a period of years, participated in by a number of experimenters, which has not shown an incipient condition in the steel accounting for the development of these fissures In the absence of data connecting the formation of a transverse fissure with the primitive state of the metal of the rail, there are left, by the process of elimination, only service conditions to account for their development

Basically, the display of a fatigue fracture is established upon one of the fundamental laws of the physics of steel and upon this basis rests the evidence that tracks conditions may accomplish such a result as witnessed in the formation of transverse fissures

Too much weight can not be given the remarks in this report upon the need of acquiring complete data upon the actual resistance the rails in full cross section will endure without loss of integrity A finished rail is subjected to internal strains of tension and compression, respectively, and its form is so dissimilar from that of a plain cylindrical bar that the endurance of the rail to repeated alternate stresses may not be safely judged of from laboratory tests on carefully prepared cylindrical bars

The presence of transverse fissures in the track presents a serious matter Their formation goes on without knowledge of their presence, and attains such a degree of development that the first indication of a fissure is not infrequently found when the fracture of the rail is complete The presence of several transverse fissures in the same rail constitutes a grave danger, since there is not only the danger of the rail failing, but also the added danger of the rail breaking in so many places that the continuity of the track will be destroyed Diligent inspection does not furnish immunity from danger The rail may in appearance be as good as when it was first laid, but such an appearance does not afford evidence of the absence of danger in the formation of transverse fissures Fatigue fractures take place without perceptible distortion of the rail The controlling factors in the formation of fatigue fractures are the magnitude of the stresses applied and the number of repetitions of them

Earlier reports dealing with accidents have embraced those in which rails have fractured and caused derailments by reason of the presence of transverse fissures The examinations which were made yielded data along the same lines and led to the same conclusions that are reached in the present report; namely, that a transverse fissure is a modified type of fatigue fracture in which service conditions appear to be controlling factors

The elimination of such failures will be accomplished or facilitated by information upon the actual fiber stresses endured by the rails in the track, and data upon the limiting number of repetitions of alternate stresses which a rail is capable of enduring, then restricting the rail in the track to such stresses and to such a number of repetitions as may be needed to maintain a proper margin of safety

Respectfully submitted

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Chief, Division of Safety

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