INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE BUREAU OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE LONG ISLAND RAILROAD NEAR CENTRAL ISLIP, N. Y., ON APRIL 15, 1918

August 5, 1918.

To the Commission

On April 15, 1918, there was a derailment of a troop train on the Long Island Railroad near Central Islip, N. Y., which resulted in the death of 3 soldiers and the injury of 36 soldiers. After investigation I beg to submit the following report.

That part of the Long Island Railroad on which this accident occurred is a single-track line over which train movements are governed by time-table, train orders, and a manual block system. From Ronkonkoma to the point of derailment, a distance of about 2.5 miles, the track is straight and on a grade descending in the direction the train was moving, varying from 0.06 percent at Ronkonkoma to 0.84 percent, but ending with a short piece of 0.15 percent. The derailment took place on a short piece of level track about 500 feet east of the foot of the grade. The track was laid with 80-pound steel rails, 30 feet in length, and with 17 or 18 oak ties under each rail, but no tie plates were used. The ballast was gravel and cinders Anti-creepers were used.

The train involved in this accident was a westbound passenger train, consisting of locomotive 89 and 12 steel coaches, and was in charge of Conductor Johnston and Engineman Foy It left Camp Upton at about 3.15 a. m , passed Ronkonkoma, 2.5 miles east of the point of accident, at 3.50 a. m., and was derailed at a point about 2.3 miles east of Central Islip at about 4 a. m., while running at a speed estimated to have been about 30 miles an hour.

The locomotive and four cars separated from the rest of the train and were brought to a stop, with the rear trucks of the fourth car derailed, by an automatic application of the air brakes after having run about 650 feet. The next four cars lay on their sides on the slope of the embankment and almost parallel with the track, and about 500 feet behind the head section of the train. The next four cars were derailed, with the exception of the rear trucks of the rear car of the train, but remained in an upright position. The first car of the rear section of the train had its roof crushed in and there was damage to the floors of all the derailed cars owing to the car bodies sliding over the trucks Many of the journal boxes and pedestals were broken, but there were no broken or loose wheels About 250 feet of track immediately west of the initial point of derailment was practically destroyed, while the next 200 feet of track was so damaged as to require a large number of new ties in repairing it. The weather at the time was clear.

The coaches in this train were what is known as the T-54 class, and were of light steel construction, 65 feet in length over all, with four-wheel trucks, and weighing about 64,000 pounds. The locomotive was an eight-wheel type, having a total weight of 138,000 pounds when in working order, with axle loads of 51,000 and 50,000 pounds on the rear and forward wheels, respectively.

(This was a printed report, all figures have been removed)

Figure No. 1 is a general view of the derailed train, looking east. The bunching of the trucks under the rear end of car No. 970 is shown by figure No. 2 There was damage done the flooring of the cars by the displaced trucks, which is shown by figures Nos. 3 and 4.

Engineman Foy stated that the train was proceeding at a speed not in excess of 30 miles an hour when the air brakes applied automatically, and he then placed the brake valve in lap position and it remained in that position until the locomotive stopped. Prior to the application of the brakes he had noticed no unusual jar and had not noticed anything wrong with the track on previous trips over it.

Road Foreman of Engines Ward stated that he was riding on the locomotive when the air brakes applied, and when the speed was reduced to about 5 miles an hour he got off, found the rear trucks of the fourth car derailed, and the balance of the train missing. In company with the conductor he went back and found the next four cars turned over on their sides, about 500 feet from the rear of the head part of the train and lying on the north side of the track. He thought the speed of the train at the time of derailment might have been 31 or 32 miles an hour.

Conductor Johnston said he was riding in the rear end of the head coach of the train when the derailment occurred, looked at his watch shortly after the derailment and it was then 4 a. m. he estimated the speed of the train to have been 20 or 25 miles an hour, and a few seconds before the brakes were applied he felt a little motion in the car similar to that caused by going over a switch.

Chief Train Dispatcher Magee stated that extra 89 left W.C. cabin at 3.22 a. m. and passed Ronkonkoma, the last reporting station before reaching the point of derailment, at 3.50 a. m. The distance from W.C. cabin to point of accident is 16.9 miles, and as extra 89 traveled that distance in 38 minutes, its average rate of speed between those points was 27 miles an hour. He said that the last westbound train over this section of track was one that left Ronkonkoma at 3.12 a. m. and previous to that there had been five eastbound trains.

Assistant Engineer Maintenance of Way Williams stated that he reached the scene of accident at about 7.45 a. m. and made an inspection of the track. The first break in the rail was about 4 feet 2 inches west of a rail joint, and this rail was broken into 14 parts, 7 of the fractures showing transverse fissures. One other broken rail west of the first broken rail had transverse fissures.

Investigation definitely developed the fact that the cause of the accident was due to the failure of two rails in which a number of transverse fissures were present. The investigation of these rails and other relevant matters was conducted by Mr. James E. Howard, engineer-physicist, whose report follows.

Acknowledgement is made of the cooperation of Mr. L. V. Morris, chief engineer, and Mr. E. H. Weaver, engineer, maintenance of way, and others of the Long Island Railroad, Mr. A. C. Shand, chief engineer, and others of the Pennsylvania Railroad, Mr. J. R. Onderdonk, engineer of tests, Baltimore & Ohio Railroad, Dr. G. B. Waterhouse, metallurgist of the Lackawanna Steel Co.; Dr. P. H. Dudley, consulting engineer, New York Central Lines, Prof. H. W. Hayward, of the Massachusetts Institute of Technology, and Mr. Paul E. McKinney, chemist of the Washington Navy Yard, in the investigation of the material and aid extended in acquiring the data here presented.

REPORT OF THE ENGINEER-PHYSICIST

Two rails failed on the Long Island Railroad, April 15, 1918, derailing a troop train, bound from Camp Upton to point of embarkation, at a point about 2-1/2 miles east of Central Islip. The rails were located on the north side of the track, the fractures of which, together with other rails which were forced from the ties at that time, caused an opening to be made through which portions of the train left the track and roadbed.

The rails were 80 pounds weight, A. S. C. E. section, Bessemer steel, rolled by the Lackawanna Iron and Steel Co., at Scranton, Pa., the brands upon which were "L. I. & S. Co., S. W. Scranton, 3.98." Rail designated as No. 1 was the easterly of the two and is believed to have been the one first fractured. Its heat number was incomplete and obscure. The heat number of rail No. 2 was 2814.

Each rail displayed a number of transverse fissures. Seven were displayed by rail No. 1, and six by rail No. 2 A seventh fissure was subsequently found in the latter when the rail was nicked with a chisel and broken apart for convenience in handling. The nicking chanced to be done in the vicinity of an unknown transverse fissure which had not reached the periphery of the head Upon breaking the rail the line of rupture was diverted from its direct course, passed through the plane of andrevealed the seventh transverse fissure in this rail. In the examination which followed eight additional transverse fissures were found in two other rails, four in each, rails which came from other parts of the railroad, making 22 transverse fissures in all which were examined.

The cause of the derailment was clearly due to the presence of transverse fissures in rails Nos. 1 and 2, which occupied positions adjacent to each other in the track. These two and other 80-pound rails rolled by the Lackawanna Iron & Steel Co., in the year 1898, were made the subject of examination, which included tests on the physical properties of the steel, on the state of internal strains in the rails, chemical analyses, and etchings showing the structural state of the metal. The results showed the rails to be exceptionally deficient in structural uniformity.

Figure No. 5 is a diagram of rails Nos. 1 and 2 viewed from their gauge sides, showing the lines of rupture made at the time of derailment, indicating those which displayed transverse fissures and giving their dimensions The line of rupture between sections E1 and E2, rail No. 2, shows the position of the transverse fissure disclosed when this rail was nicked and broken.

At the time of derailment it is believed that the line of rupture first developed was that next the receiving end of rail No. 1, followed in succession by the other lines of rupture in the direction in which the train traveled, the last fracture made being the one nearest the leaving end of rail No. 2. Beyond this point the rails involved in the derailment were stripped from the ties and bent, but none were broken.

The appearance of four of the transverse fissures displayed by rail No. 1 is shown by figure No. 6. Two of the larger fissures had increased in size to such an extent that they had reached the periphery of the head on the gauge side. They presented dark-colored surfaces, as usual with fissures which have reached the surface of the head. Two smaller fissures are shown on this cut. Their surfaces had a silvery luster, not having become darkened by exposure to the air. No. 6a represents the transverse fissure located 4 feet from the receiving end of rail No. 1, and believed to be the initial break in the rail, No. 6b, the fissure 6 feet 6 inches from the receiving end; No. 6c, the fissure 10 feet 8 inches from the receiving end, and No. 6d, the fissure 11 feet 3 inches from the receiving end. These and other fissures witnessed in these rails had their nuclei located on the gauge side of the head.

Figure No. 7 illustrates two of the transverse fissures displayed by rail No. 2. The larger one was slightly darkened, having probably just reached the periphery of the head. The other fissure presented a silvery luster. No. 7a was located 6 feet from the receiving end, and No. 7b, 3 feet from the receiving end of rail No. 2.

Tests were made upon four full-length rails and five partial-length rails. The former represented those which were located in the track next beyond those which ruptured at the time of derailment, displaying transverse fissures. They were bent sidewise at the time of derailment, but not broken. The short-length rails were collected from different parts of the railroad, each of which had displayed a transverse fissure in service. Six heats at least were represented in these rails, all of which were rolled by the Lackawanna Iron & Steel Co. in the months of February and March, 1898

Bending tests were made under a steam hammer, the rails resting upon a V-shaped block and bending them with their heads on the tension side. The appearance of these rails after testing is shown by figure No. 8. The full-length rails displayed good bending properties, one of which deflected 3 feet without rupture. The short-length rails were brittle. In two of these the eight additional transverse fissures were disclosed. Five of these additional fissures are illustrated in figure No. 9, the sixth fissure, in the upper left-hand corner of the cut, representing one which occurred in the track.

Rails Nos. 1 and 2, when polished and etched, were shown to be structurally very unsound. This decided lack in uniformity had also been observed in machining the rail sections. Portions of the cross section were spongy, other parts were hard and machined with difficulty. The flange of one section displayed irregular shaped voids along a part of its length. The interior sponginess surrounded a central core in the head with streaked metal in the web and upper part of the base

From information acquired, it appears that the Lackawanna Iron and Steel Co., at the time these rails were rolled, used horizontal heating furnaces at the South mill at Scranton, new soaking pits having been introduced later in the year 1898. This practice would lead to such indications as were witnessed in these cross sections.

Figures Nos. 10a and 10b represent cross sections of rail No. 1. No. 10a shows a section which was polished and etched with tincture of iodine, It appears foreshortened in this cut. No. 10b is a reproduction of a sulphur print.

Figures Nos. 11a and 11b represent cross sections of one of the short length rails on which bending tests were made under the hammer. An iodine etched section and a sulphur print, respectively, are shown in these two figures. A light chip had been taken off the top of the head of this rail, in a shaper, before these sections were polished.

The chemical composition of these rails is shown on table No. 1, as follows:

Table No. 1.- Chemical analysis of rail No. 1 and short length rail used in bending test

Description	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Copper
Rail No 1:						
Corner of head. . .	0.63	124	0.053	0.121	0.183	0.735
Center of head near web... . .	.41	114	.021	.041	157	.703
Short length rail.						
Corner of head......	.61	139	.040	.127	.157	.721
Center of head near web. . .	.60	137	.043	.143	.149	.696
Rail No. 1:						
Near periphery of head and base.. .	.62	120	.044	.083	. ..	....
From center core of head	.41	100	.020	.044	. .	....

The results of tensile tests of longitudinal specimens from the head of rail No. 1 are shown on Table No. 2

Table No. 2.-Tensile tests of specimens from head of rail No. 1.
(Diameter of stem, 0.505 inch; length, 2 inches)

Location	Approximate elastic limit per square inch	Tensile strength per sq. inch	Elongation	Contraction of area	Appearance of fracture
	Pounds	Pounds	Percent	Percent	
Inside	77,000	85,000	1.5	5.7	Granular
Do. . ..	75,500	100,000	5.0	5.7	Do
Middle of head. ..	67,000	116,000	10.5	13.3	Do
Do... . .	67,000	102,000	4.0	5.7	Do
Outside	69,500	72,000	2.5	5.7	Do
Do	73,500	102,500	4.0	5.7	Do

A drill 9/16 inch in diameter was used in getting the chips for the analysis given on the first four lines of the above table. The results on the fifth line represent the metal near the running surface of the head and lower part of the base of rail No. 1, mixed together. The results on the sixth line represent the metal in the lower part of the head and along the middle of the web of the same rail. Chips for these results were taken out with a small drill The negative segregation of the metal in rail No. 1 will be noted.

The tensile tests showed brittle metal In machining some parts of the rail showed toughness, while other parts were weak and brittle Rail No. 1, as a whole, was irregular in chemical composition and physical state.

The internal strains in rails Nos. 1 and 2 were measured. Figures Nos. 12 to 17, inclusive, show the results on rail No. 1; figures 18 and 19 the results on rail No. 2 The stresses in the head and the base of rail No. 1, at a distance of 3 feet from its receiving end, are shown on figure No. 12. The shaded portions of this cut and succeeding ones indicate the cross sections of the strips on which the stresses were determined. Each of these strips expanded in length when detached from the remaining portions of the rail, showing the metal along them had been in a state of compression when the rail was intact. The stresses reported are based upon a value of 30,000,000 pounds per square inch for the modulus of elasticity, the strains being measured on gauged lengths of 10 inches each

Figure No. 13 shows the strains which were displayed by the metal of the head and the values of the stresses in the base on a section of the rail 2 feet from its receiving end. The strains in the head are not converted into their corresponding stresses. Those entered on the diagram represent the strains which were displayed when the head was turned down to a diameter of 1/2 by 9 inches long. They were the changes in length which occurred after the head had been detached from the web and base. It will be noted that a contraction in length occurred on the top of the head and along the gauge side, while the measurements on the outside of the head and next the web showed an expansion in length.

The disposition of the strains in the interior of the head were indicated by these measurements. The relief of internal strains of tension occurred on the gauge side and upper part of the head, with strains of compression released on the outside of the head and next the web. The maximum tension in the head, when the rail was intact, was therefore at some place on a diagonal line leading from the center of the head to the upper corner on the gauge side, crossing the locality in which many transverse fissures have their nuclei.

There was a change in the dimensions of the head when it was detached from the web, most pronounced along the top of the rail. The gauged length on the top of the head showed an extension of 0.0029 inch.

Figure No. 14 shows the stresses in a strip from the middle of the head, also the stresses in the flanges. The stresses in the head were in tension, those in the flanges were in compression. There is difficulty in ascertaining the state of strain in the interior of the head, owing to the readjustment which occurs in the metal whenever any part of the cross section is removed. It is probable that the values reported are in most cases conservative ones, the intensity of the stresses locally exceeding the reported values.

Figure No. 15 shows the stresses in a section of the rail at its receiving end. Measurements on one of the strips from the head were lost on account of an accident in machining. The stresses in the flanges exceeded those witnessed in the flanges in other parts of the rail. The fishing surfaces in this vicinity had been hammered by contact with the splice bars. To this peining action the higher values exhibited by this section of the rail are ascribed.

Figure No. 16 shows the strains released in the head of the rail when detached from the base, taken on a section located 5-1/2 feet from the receiving end. The upper element expanded 0.0030 inch while the under side of the head contracted 0.0024 inch on each gauged length in the fillets. The gauged lengths on the sides of the head were just above its neutral plane, each expanding one-thousandth of an inch. These measurements represent the first stage in the examination of this section. They were followed by the determination of the internal strains in the strip of metal from the middle of the head, shown by the shaded section of figure No. 17. The metal in this part of the head was in an initial state of tension, excepting the outside edge of the strip. The tension was greatest at the edge on the gauge side of the head, while in the vicinity of the nuclei of transverse fissures it reached a value of 7,660 pounds per square inch.

Two sections of rail No. 2 were examined for internal strains, the results of which are shown on figures Nos. 18 and 19. The stresses on a section 9 feet from the receiving end appear on figure No 18, the results on a section 8 feet from the receiving end appearing on figure No. 19. The examination of the latter section was carried out in substanially the same manner as the corresponding section from rail No. 1, shown by figure No. 13. These internal strain determinations completed the examination of rails Nos. 1 and 2.

It was clearly established that the derailment of the troop train was caused by the failure of these rails, and that their failure was due to the presence of transverse fissures which weakened their resistance, resulting in the rupture under the weight of the derailed train.

The rails had been in service for a period of 20 years. To outward appearances they were good-looking rails, little wear had taken place. The shapes of the heads showed but little distortion, yet within them destructive transverse fissures had developed. Over what interval of time these transverse fissures had been in existence, or the rate of their development, is not known. In the laboratory the failure of bars under repeated stresses, working under constant loads, progresses very rapidly after the first symptoms of rupture appear, and bars which have endured lesser loads for a long time fail very promptly when higher loads of sufficient magnitude are applied.

These rails had carried the lighter traffic of the railroad for a period of time without known examples of transverse fissures having appeared. War activities increased the traffic some seven to ten fold in the amount of tonnage currently passing over them, with a considerable increase in the weight of the equipment, conditions which not unlikely contributed toward the formation of transverse fissures and accelerated their development.

While the interval of time between the inception of a transverse fissure and its final development can not be stated, one of the components which is held to lead to this type of rupture may be of long duration. The internal strains in these rails were doubtless of long standing. Cold rolling strains are acquired very promptly when rails are put into service. They are permanent in their character, remaining in the rails, whence they can not be dislodged, although they admit of change of position and magnitude.

The physical examination showed these rails to be very unsound. Seldom is metal so defective witnessed in rails. Whether this circumstance accelerated the formation of the transverse fissures or retarded their progress of development, or was a negligible factor can not be definitely stated.

The metal was no doubt defective at the time the rails were rolled. The rails having been in service for a period of 20 years before displaying these transverse fissures would lead to the inference that the defective state of the metal had had slight influence, if any, on the development of the fissures, and that they had developed when traffic over them increased and for that reason.

The structural unsoundness of the metal unquestionably detracted from its strength in a crosswise direction, and variations in strength in the direction of its length lowered its tensile strength. There was a considerable margin, however, between the elastic limit of the steel, and the sum of the internal stresses and the direct bending stresses under train loads, as the latter are understood to be. The margin between the working stresses and the elastic limit of the steel is the factor which has most to do with retaining the integrity of the metal unimpaired. What advantages accrue from high tensile strength and ability to display a given elongation or contraction of area in the tensile test when referred to the endurance of rails under service conditions, are yet obscure matters.

The present rails affording such pronounced examples of defective steel, at the same time being coupled with a long term of service before displaying transverse fissures, gives emphasis to the query what influence the structural unsoundness may have had in accelerating or retarding the inception and rate of development of these transverse fissures. Judging from the present exhibit, the lesser number of transverse fissures recorded as having occurred in Bessemer rails over those made of open hearth steel, can not owe their comparative immunity to the excellence of the earlier product of the Bessemer process, nor more specifically to the casting conditions then in vogue. It may be possible that a certain looseness of structure in the zone of transverse fissures will permit the metal to respond to internal strains without starting an incipient fracture. The prevalence of transverse fissures in steel structurally sound and of satisfactory chemical composition removes from consideration the suggestion that essentially unsound steel must be present in order that a transverse fissure may be developed.

Correlated data will be introduced, presenting results bearing upon the display of transverse fissures together with illustrations of features associated with the intermediate phases through which steel passes, under service conditions, from the time of its fabrication until rupture ensues when such an event occurs, followed by remarks reviewing the general subject of transverse fissures.

An examination was made of a 100-pound Bessemer rail which fractured after a term of service of 18 years in the track, displaying a transverse fissure. The internal stresses in this rail are shown by figures Nos. 20 and 21. Referring to the results presented on figure No. 20 three gauged lengths were established on each side of the head, as indicated by the witness marks. The internal stresses in the strip from the outside of the head ranged from 3,900 pounds per square inch at the lower corner to a maximum of 17,700 pounds per square inch at the upper corner of the head at the outside of the rail. A cumulative effect in the strains introduced, resulted during the formation of the fin along the upper corner of the head on the outside of the rail. Examples have been met in which lower internal strains were displayed in this part of the head than found in the opposite corner. The results are influenced, without doubt, by the manner in which the wheel pressures cause the flow of the metal to take place.

Figure No. 21 shows the stresses found in a strip taken across the middle of the head, in which strains of tension were displayed.

Since the internal strains shown by the strips from the sides of the head in the preceding figure, abreast the places which here show tension, were of compression, it is evident that residual strains were left in the strips in one or in both cases. The maximum value here shown, 3,600 pounds per square inch tension, is probably a diminished one having become so under the influence of the surface metal at the sides of the head.

Figures Nos. 22 and 23 represent cross sections of this rail. Figure No. 22 is a foreshortened view of a section of the rail which was polished and etched with tincture of iodine. Figure No. 23 is a reproduction from a sulphur print. The state of structural unsoundness of the metal is shown in each of these illustrations.

For a direct determination of the internal strains introduced by wheel pressures, observations were made on a 100-pound rail, A. R. A.-B section. The original length of the rail was 33 feet. A 3-foot section was cut off for preliminary tests, the remaining part being cut into two 15-foot lengths, and those lengths were laid in the track of the Baltimore & Ohio Railroad on the Magnolia Cut-off. One 15-foot section was laid on bridge No. 390, where it rested upon 13 oak ties, of 8-inch faces each. The other 15-foot length was laid on stone-ballasted roadbed, resting upon eight oak ties with tie plates. They were on the north side of the westbound track, within a short distance of each other. They were laid in the track August 23, 1916, and removed June 12, 1917, after an interval of nearly ten months. During this period the tonnage passing over them amounted to 23,653,000 tons. This was a C rail, the mold analysis of which heat showed the following composition. Si. .104

C. 645 Mn. .66 P. .030 S. .0[illegible] / Cr. .33 Ni. .60

The results of the measurements of the primitive internal strains in this rail, upon pieces of the 3-foot length, were incorporated in the report under date of February 12, 1917, pertaining to an accident which occurred on the Galveston, Harrisburg & San Antonio Railway near Iser, Texas. Figures Nos. 24 and 25 are reproduced from that report showing the primitive stresses which were in the rail. These represented the cooling strains of fabrication.

Figure No. 26 shows the manner in which the two 15-foot lengths were cut up for examination after their removal from the track. In addition to the determination of the internal strains acquired in the track other tests were conducted, forming a part of the general inquiry into the physical changes which take place in railway materials and which may imperil their safety in service.

Figures Nos. 27 to 36, inclusive, refer to results obtained upon the 15-foot length which was laid on bridge 390. Figure No. 27 shows the stresses which were found in the section marked 3 of figure No. 26. From a neutral state, in the primitive tests, the metal at the top of the head had acquired stresses of compression of 9,000 and 10,200 pounds per square inch, respectively. The stresses in the base which generally retain their primitive values were not modified in an unusual degree by service conditions.

The usual manner of detaching the strips on which the strains were measured was modified in section marked 4 on the diagram, the final results of which appear on figure No. 28. The sides of the head were planed off of this section, the flanges of the base were detached, and that part also planed off in width, after which the web was cut apart, followed by planing away the metal from the strips representing the top of the head and the lower side of the base. Changes in the lengths of the strips at the head and the base attended each reduction in the cross sections of these parts. At an intermediate stage the strains in the base represented 4,500 pounds per square inch tension, the final results on the strip showing 2,100 pounds per square inch compression. The intermediate changes showed the relations which existed from stage to stage between the interior metal and that of the surface on which the gauged length is established Information upon the location of the zones in which strains of tension and compression respectively reside, may be acquired in this manner, and an approximate idea formed of the magnitude of the internal strains in different parts of the cross section

A progressive change in the magnitude of the strains occurs in passing from one part of the cross section to another. Normal cooling would be expected to facilitate a symmetrical arrangement of the internal strains taken about a given axis, which service conditions, in all probability, disturb

Two values for the stresses in the strip from the head of this section are entered on diagram No. 28. This strip assumed a convex shape when the metal below it had been planed away. Chord measurement on the strip in a free state indicated a stress of 17,700 pounds per square inch compression. When forcibly held straight, the strip showed a value of 14,700 pounds per square inch compression. The chord measurement is believed more closely the actual stress in this part of the rail.

The section of the rail marked 5 was subjected to endwise compression. A total load of 600,000 pounds was applied, in two stages of 300,000 each, in succession on the head and upper part of the web, and the lower half of the rail. This endwise compression amounted approximately to 61,000 pounds per square inch. It exceeded the elastic limit of the steel and effected a shortening of the gauged lengths, excepting those on the lower surface of the base, each of which showed a slight increase in length. These permanent sets are entered on figure No. 29

The internal stresses found in this section after endwise compression are entered on figure No. 30 No decided modification in their magnitude or relations resulted from this treatment. It will be recognized that the problem is a different one when the entire cross section or the greater part of it is overstrained than when local overstraining forces are applied. Data upon this feature are incomplete. Local overstraining by tension or by compression introduces internal strains or modifies preexisting ones.

Section marked 6, a 5-foot length, was subjected to transverse loads. It was supported on blocks 4 feet apart and loaded at the middle. Twelve gauged lengths of 10 inches each were established on different elements of the head, web, and base on which permanent sets were observed after increments of load were applied and released. Loads were applied in increments of 10,000 pounds per square inch fiber stress and advanced to a maximum of 130,000 pounds fiber stress with the head of the rail on the tension side. The rail was then reversed and loaded with the head on the compression side. The same increments of load were applied as before, discontinuing the test, in this position, at 40,000 pounds per square inch fiber stress. The fiber stresses mentioned refer to the metal in the head of the rail.

The results at four stages of the test are presented. Diagrams Nos. 31 to 34, inclusive, show the permanent sets after loads of 60,000, 90,000, and 130,000 pounds per square inch, respectively, the head of the rail being on the tension side, and on the last diagram of this group, the sets which occurred with the rail in reversed position with the head on the compression side, after a load of 20,000 pounds per square inch had been applied. The elastic limit of the rail in the first position was in the vicinity of 60 000 pounds per square inch. Permanent sets began to appear at this load and gradually increased under higher increments of stress. Attention is called to the permanent sets displayed on the two gauged lengths at the top of the head after a load of 60,000 pounds, their increased values after 90,000 pounds had been applied, and their values after 20,000 pounds per square inch fiber stress had been applied in reversed position, a maximum stress of 130,000 pounds having been applied in the meantime. In reversed position the permanent sets after 20,000 pounds were applied reached substantially the same amounts as at 60,000 pounds at the time first loaded.

After this rail had been given decided permanent sets with the head on the tension side its elastic limit in the opposite direction was very much affected. It was lowered and permanent sets introduced by 20,000 pounds fiber stress of substantially the same amounts as the sets after 90,000 pounds per square inch fiber stress in the first position.

These tests illustrate the effects of overloads on the elastic limit of the steel when strained in reversed directions. After this rail had received decided permanent sets with the head in tension its elastic limit in the opposite direction was reduced to a low value, nearly eliminated Earlier laboratory test have shown this to be the usual result of overstraining steel. This feature affects that part of the rail which is overstrained by the impinging pressures of the wheels on the running surface of the head.

Figure No. 35 shows certain of the stresses which were in section marked 7 At intermediate stages the strains in the strip from the middle of the base were reversed from tension to compression, covering in this reversal a range of stress of 8,100 pounds per square,

On figure No. 36 are entered the stresses found in five elements along the running surface of the head, section marked 8, also those measured on the base. A maximum value of 17,700 pounds per square inch compression was displayed by this section of the rail which was laid on bridge 390, this value being identical with the corresponding element of section marked 4 of the same rail length

The measurements made on the first 15-foot length were, for the most part, duplicated on the other half of the rail which was laid on stone-ballasted track, the results of the latter being shown on figures Nos. 37 to 47 inclusive.

The stresses in section marked 13 are entered on figure No 37 At the top of the head stresses of 13,500 and 18,000 pounds per square inch were found, values which are seen to be higher than the corresponding stresses in the half of the rail laid on bridge 390.

The results entered on figure No. 38 refer to section marked 14, and correspond to those of figure No. 28. The stress at the top of the head again exceeded that of the other rail length.

The treatment of section marked 15 differed from that of the corresponding section in the other 15-foot length. This section was successively annealed five times at a temperature of 1,400° F., with a sixth annealing at 1,450° F. The heating and cooling was done slowly, in a closed box. The aggregate time of exposure to maximum temperatures was approximately 20 to 24 hours.

A progressive shortening of the rail resulted from each period of annealing, which ultimately reached a maximum of 0.0302 inch on one gauged length. The results on each of the 11 gauged lengths are entered on figure No. 39. Detached strips from sections marked 3, 4, 7, 8, 13, and 14 were annealed in the same box with the full section The strips contracted, but less in amount than the full section. Five of the detached strips were in a state of initial compression and one in a state of initial tension when they were integral parts of the rail. It appeared from their subsequent behavior that the primitive state of strain did not control the tendency to contract in length which each displayed when exposed to annealing temperatures.

The amount shortened by the annealing, 0.0302 inch on a gauged length of 10 inches, would if it were an elastic movement represent a compressive stress of 90,600 pounds per square inch If regarded as a permanent set, caused by endwise compression, it exceeded several times the set caused by a load of 60,000 pounds per square inch Referred to a full rail length of 33 feet, this contraction represents a total shortening of 1.2 inches. Notwithstanding these relations, illustrating the significance of such a change in length, if accomplished by other means, the result was a relief to the internal strains. They were reduced to negligible values. The elimination of internal strains was practically accomplished by the annealing operations, although attended with a decided reduction in length. The values of the residual stresses in this section of rail are entered on figure No. 40

A group of four diagrams, figures Nos. 41 to 44, inclusive, show permanent sets, the results of transverse tests made on section marked 16 The tests were carried out in the same manner as those on section marked 6, the results being practically the same as before witnessed. The effect of overloading the rail in the one direction nearly or quite destroyed the elastic limit of the metal in the opposite direction, as previously stated. This change in state is doubtless confined to the outside fibers, that is, to those which are near the top and the bottom of the rail. Those nearer the neutral axis, not overstrained, are expected to remain with their original properties undisturbed.

Figure No. 45 shows certain of the stresses which were in section marked 17, corresponding to the results obtained on section marked 7. During the period of cutting up this section the stresses in the web reversed from tension to compression, while those at the middle of the base were higher in tension at an intermediate stage than in the final strip.

Figure No. 46 shows the stresses on five elements along the running surface of the head of section marked 18. The maximum value displayed by this section, 21,600 pounds per square inch compression, chanced to be identical with that of section marked 14 of the same rail length, as those were identical in sections marked 4 and 8 respectively but with a higher value in this section.

Figure No. 47 shows the stresses in a strip across the middle of the head, also those in the flanges The stresses in the head were all of tension. As previously remarked, local strains in the intact section of the rail doubtless exceed the values reported. Nevertheless, these measured strains represent a range occurring in the upper part of the head from tension to compression of 25,700 pounds per square inch within a zone of metal less than 1 inch deep.

It will be noted that the internal stresses in the section of rail from the ballasted track where higher than those in the section of rail that was laid on the bridge. These two half-rail lengths occupied positions in the track close to each other. Each was exposed to the same weight of equipment, to the same speeds, and the same tonnage. They are the first rail lengths which have furnished opportunity for comparing the effects of traffic on a bridge with that on ballasted track It is expected that other determinations of this kind will follow.

Since the internal strains are components of the total strains to which the rails are subjected, more complete determinations of their values are matters of interest. The information thus far acquired appears to show that rails are strained higher than other classes of engineering materials. It is important to ascertain how intimately this feature is associated with or has a vital influence upon the annual number of broken rails.

In conjunction with the annealing tests on section marked 15 auxiliary tests were made on a number of hot forged bars of rail steel and other grades, the chemical analysis of which were as follows:

Description	Carbon	Manganese	Phosphorous	Sulphur	Silicon	Chromium	Nickel
Rail steel bars	0.635	0.67	0.021	0.080	0.095	0.35	0.67
Low-carbon bars	.27	.34	.028	.015	.15	. . .	. . .
Chrome-nickel bars	.43	.35	.030	.014	.10	.88	1.92

The rail steel bars were forged down from a 7-1/2-inch bloom, taken from the middle of the length of the ingot. Six bars, 1 inch square each by 12 inches long, were treated as follows. The first bar was finished at a high forging temperature, the second at a low forging temperature, the third was finished when nearly black hot. These three were allowed to cool naturally in the air. Three other bars were drawn down at ordinary forging temperatures, one of which was cooled by an air blast, another by quenching in oil, and the other by quenching in water.

The bars of this group were annealed in succession, at 550°, 1,000°, and 1,450° F., respectively. They were measured after each period of annealing on each of their four faces. In respect to the effects of the lower temperatures, the bars resolved themselves into two groups. Those which were finished at different forging temperatures and cooled normally in the air and the bar which was cooled with an air blast remained practically unchanged in length after exposure to the two lower annealing temperatures. The bars which were quenched in oil and water, respectively, were, on the other hand, affected by each of these temperatures. They were appreciably shortened in length after drawing at 550° F., and were still shorter after exposure to 1,000° F. All were shortened by the highest annealing temperature. The diminution in length between 1,000° and 1,450° F., was about the same in each bar, the total diminution being greatest for the oil and water quenched bars since they had lost in length by earlier exposure to the two lower annealing temperatures. It will be noted that the oil and water quenched bars were affected by temperatures below the recalescence periods.

Two cubes marked A and B respectively, from the same bloom as the above bars, were drawn down under a forging press and finished 4 inches full on a side. They were subjected to annealing and quenching operations, the changes in dimensions resulting therefrom being observed on 28 gauged lengths of 4 inches each, established on the several faces of the cubes.

Cube marked A was annealed at 1,450° F. This resulted in a decided contraction in dimensions, opposite to that in which the metal had been forged. Lengthwise the mean shortening was 0.0022 inch, crosswise 0.0003 inch. That is, against the direction of forging the contraction was over seven times that which took place in crosswise or girth dimensions, these measurements being taken across the middle of the faces. The gauged lengths at the corners were affected less than those along the middle of the faces, while one end showed several ten-thousandths of an inch expansion.

The cube was next heated to 1,450° F. and quenched in oil, whereupon an increase on each of the gauged lengths occurred, but without special reference to the direction of forging. The previous shortening which attended the annealing operation was overcome, leaving the cube with larger dimensions on each gauged length than in its original forged condition. Concerning the change in volume a definite statement does not admit of being made, based upon these measurements, since the several faces of the cube did not remain plane surfaces, each was concave at the termination of these tests.

Cube B was quenched in oil from a temperature of 1,450° F., resulting in a decided increase in dimensions on certain of the gauged lengths, with a limited decrease on others. The corners showed greater changes in lengths than along the middle of the faces. The range was from 0.0066 inch expansion to 0.0013 inch contraction, on 4-inch gauged lengths. This cube was again heated to 1,450° F. and quenched in water, resulting in further changes in dimensions. Referred to its original forged dimensions the maximum expansion was 0.0149 inch, the maximum contraction 0.0060 inch.

The fluctuations in dimensions after oil quenching were less than those experienced by quenching in water. It is obviously impracticable to simultaneously quench the six faces of a cube, and however brief the interval of time of immersion may be, some parts will be quenched in advance of others. The corners and edges naturally cool earlier than the middle of the faces. These considerations account for some of the differences in the results which were witnessed. There have been suggestions of heating and quenching rails as a manufacturing operation. The data here presented show some of the effects which attend such operations.

The tests on the low carbon and the chrome-nickel steel furnished results of a paradoxical nature. The chrome-nickel bars conformed in behavior to the rail steel, while the low carbon steel displayed opposite characteristics. The latter contracted in length when heated and quenched, whether in oil or in water as the quenching medium. The several bars were heated side by side and quenched in the same medium, yet one kind of steel expanded and the other contracted in length. In the forging operations, the bars were reported as having been treated alike. In behavior the bars stand in opposition to each other, the explanation for which attaches to differences in chemical composition or to some antecedent influence not known.

One of the chrome-nickel bars was heated and quenched three times, with periods of annealing between the first and second quenchings. The first quenching was in an oil and water emulsion, the second in plain water, the third in brine, each quenching being from a temperature of 1,450° F. This treatment was attended with a progressive gain in length, not effaced by intermediate periods of annealing, which finally resulted in an expansion in length of 0.076 inch in 10 inches. The bar remained intact, without cracking. To return this bar temporarily to its primitive length, provided it had so high an elastic limit, would require a load of compression exceeding 200,000 pounds per square inch. Expressed in thousandths of an inch, some of the observed changes in length seem of minor importance, yet they stand for many thousand pounds per square inch when converted into their corresponding stresses.

Additional examples of transverse fissures displayed by Bessemer rails of 100 pounds weight are shown by figures Nos. 48, 49, and 50, the chemical analysis, representing the metal in the upper corners the heads, of which were as follows:

Description	C	Mn	P	S	Si	Cr	Ni
No. 48, Maryland steel	0.50	0.97	0.058	0.051	0.089	0.37	0.47
No. 49, Cambria steel	.55	1.05	.092	.046	.061	....	....
No. 50, Cambria steel	.39	.73	.077	.020	.056	....	....

Tensile tests of the metal from the centers of the heads gave the following results:

Description	Elastic limit per sq. inch	Tensile strength per sq. inch	Elongation	Contraction of area
	Pounds	Pounds	Percent	Percent
No. 48	63,880	122,900	17	33.2
No. 49	64,750	128,400	15	22.4
No. 50	48,590	103,150	12	14.7

These rails were removed from the track, no derailment having been caused by the transverse fissures. Each represents different track conditions. One was laid on a bridge, one on stone ballast, and one on cinder ballast.

Figures Nos. 48a to 48d, inclusive, represent the appearance of the Maryland rail. Figure No. 48a is a view of the transverse fissure, which nearly separated the cross section of the head.

Figure No. 48b is reproduced from a sulphur print. The photomicrographs Nos. 48c and 48d were taken from the upper corner of the head, gauge side, and from the upper part of the web, respectively. The sulphur print shows good metal with no structural inequality in the vicinity of the transverse fissure. This rail was laid on a bridge, on oak ties with tie plates. Its age when removed from the track was 3 years 9 months.

Figures Nos. 49a to 49d, inclusive, represent the first Cambria rail. No. 49a is a view of the transverse fissure which separated the head on the gauge side and a considerable part of the outer half. No. 49b represents a deep etched section of the rail. Photomicrographs Nos. 49c and 49d were taken near the upper corner of the head, gauge side, and from the center of the head, respectively. The etching shows structural uniformity in the steel. This rail was laid on stone ballast, on oak ties with tie plates. Its age when removed from the track was 8 years.

Figures Nos. 50a to 50d, inclusive, represent the appearance of the second Cambria rail. Figure No. 50a is a view of the transverse fissure, located near the gauge side of the head, covering a portion only of the area. A deep etching is represented by figure No. 50b, showing the metal decidedly lacking in uniformity of structure. Photomicrographs Nos. 50c and 50d were taken near the upper corner of the head, gauge side and center of the head, respectively. It was laid on cinder ballast, on oak ties with tie plates. Its age was 13 years. It was a badly segregated rail, shown both by the etched section and the chemical analysis of the steel. The metal at the middle of the web had a carbon content of 0.53, phosphorus 0.136, sulphur 0.043. Notwithstanding its lack of uniformity it remained in the track the longest of these three Bessemer rails. Its unfavorable structural state clearly did not result in the early display of a transverse fissure, if indeed its structural state had an influence upon this development.

Figures Nos. 51a and 51b show the appearance of a transverse fissure and sulphur print displayed by an 85-pound rail rolled by the Illinois Steel Co.

This rail had been in service about 5 years. It shows little wear, and is structurally uniform. The carbon content in this rail was 0.77, the manganese 0.76.

Figures Nos. 52a and 52b refer to a 100-pound rail, also rolled by the Illinois Steel Co., which displayed a transverse fissure after seven years in the track. The carbon content was 0.79, the manganese 0.68. The sulphur print shows the metal lacking in structural uniformity. The rail retained its shape, however, and showed little wear. No suspicion would attach to this rail from its outward appearance.

These illustrations and succeeding ones show rails in which transverse fissures were displayed in metal strictly uniform as indiated by the sulphur prints, and also rails which, according to the same evidence, were deficient in structural soundness and uniformity. Some fissures had their nuclei at the junction of the interior and exterior metal which showed different characteristics, while others had their origins where uniform metal prevailed, or which displayed a uniform structure throughout.

Figures Nos. 53a and 53b represent another 100-pound rail rolled by the Illinois Steel Co. This rail displayed a transverse fissure after seven years in the track. It shows very little wear, retaining its shape practically unchanged. The lack of uniformity in its structure was confined to the metal of the web and the lower part of the head. The nucleus of the transverse fissure was located in the sounder part of its cross section. The carbon content of the rail was 0.74, manganese 0.83.

Figures Nos. 54a and 54b represent still another 100-pound rail rolled by the Illinois Steel Co., which displayed a transverse fissure after six years in the track. The composition of the metal showed carbon 0.71, manganese 0.73. There was a decided lack of uniformity in this rail, most pronounced in the lower part of the head and the upper part of the web. A general spotted appearance prevailed in the head. Not unlikely the nucleus of the transverse fissure was located in the vicinity of some of these markings, it could hardly be otherwise. The nuclei of transverse fissures are located at fairly definite depths below the running surface of the head, but whether a change of position is effected by the structural state of the steel is not clearly apparent.

Figures Nos. 55a and 55b illustrate a transverse fissure rail of unusual degree of structural uniformity. This was a 125-pound rail rolled by the Cambria Steel Co., the carbon content of which was 0.78, the manganese 0.65. It displayed a transverse fissure in less than two years in the track. No structural state or condition of the metal was revealed which could have influenced the location of the transverse fissure.

Figures Nos. 56a, 56b, and 56c, representing one rail, and figures Nos. 57a, 57b, and 57c, representing another rail, show photographs of transverse fissures and sulphur prints of two heat-treated rails of 121 pounds weight, which displayed transverse fissures in less than one year in service. The sulphur print of one shows a uniform structure, in the other a variation in the metal of the web, but uniform in the vicinity of the nucleus of the transverse fissure. The nuclei of the fissure in these two rails are located nearer the running surface than usual. The following table shows the chemical composition of these rails:

Description	C	Mn	P	S	Si	Cr	Ni
No. 56.	0.41	0.50	0.017	0.026	0.214	0.53	1.30
No. 57..........	.37	.52	.017	.026	.047	.52	1.30

Figures Nos. 58 and 59 represent two ferrotitanium rails which displayed transverse fissures. The fissure in rail No. 58, a 100-pound section, was located on the gauge side of the head near the nebulous core. In rail No. 59, a 105-pound section, the fissure developed in the uniform metal of the head. The nuclei of the fissures were located within the limits of their customary zones.

A group of six transverse fissured rails are illustrated by figures Nos. 60 to 65, inclusive. These rails displayed transverse fissures after periods of time in service ranging from 5 months to 6 years, 6 months. The following table describes these rails and states the time they were in service when transverse fissures were found:

Description	Length of time in service		
	Years	Months	Days
No. 60, 85-pound P.S.,O.H.	6	6	..
No. 61, 100-pound P.S.	..	10	..
No. 62, 100 P.S.O.H. Vanadium	1	..	20
No. 63, 121-pound heat treated Mayari	.	5	..
No. 64, 125-pound P.S.	..	7	..
No. 65, 125-pound P.S.	1	3	.

Transverse fissures have been displayed in carbon steel rails of different grades of hardness, from mild steels up to those above the saturation point of carbon. Examples have been given herein of alloy steels and heat-treated rails which have displayed fissures. These illustrations show fissures to have occurred in ferro-titanium, in vanadium-treated rails, and in heat-treated rails of Mayari ore. High chromium rails are reported to have displayed transverse fissures, but no photographs of them were available. It would seem that a comprehensive trial had been made of the different grades of carbon steel, alloy steels, and a heat-treated rail, none of which have proved immune from this type of fracture.

Manganese steel has been, so far as known, an exception, furnishing no examples of transverse fissures. It has, however, furnished a type closely resembling a transverse fissure, which is illustrated by figure No. 66. This figure represents a fracture in the head and upper part of the web of a 100-pound manganese steel rail rolled by the Illinois Steel Co., in June, 1912, and removed from the track during the present year, after about 6 years in service.

Three fractures were displayed by this rail They presented smooth surfaces, in a plane normal to the length of the rail, having their origins apparently at the intermediate running surface of the head, whence they progressively extended through the head into the web They were discovered at this stage of development and the rail removed from service.

Subsequent tests showed the almost total exhaustion of toughness of the metal where the cold rolling action of the wheels had taken place on top of the rail. When the head was strained in tension fine surface cracks immediately appeared on the running surface in parallel lines, 1 inch or less apart. It was a peculiarity of this rail that its inherent toughness resisted the extension of the deep cracks which had developed in service. The completion of these fractures was accomplished with difficulty, whether under the drop testing machine or by the use of a heavy maul. If such residual toughness should be found a reliable factor in the track, it would present an important safeguard against the display of brittleness characteristic of carbon steels under like conditions of partial rupture of the rail.

Observations were made upon the effects of gagging. Two grades of steel were used, the product of the Sparrows Point rail mill of the Bethlehem Steel Co., one of which was rolled to meet current specifications for domestic rails, the other a grade of steel for rails to meet the specifications of the French Government. Their analyses were as follows:

Description	C	Mn	P	S	Si	Cr	Ni
100-pound domestic rail.	0.667	0.72	0.032	0.055	0.244	0.29	0.40
100-pound French composition.	.492	.63	.038	.079	.067	.25	.34

The rails of each composition were rolled into 100-pound A.R.A.-B shapes. One of the high-carbon rails was a high rail, the other a low rail, in the rail mill sense of the term, referring to their curvature after cooling on the hotbed. The gagging of the high rail resulted in shortening an element along the top of the head 0.0133 inch on a gauged length of 10 inches. The effect of gagging was measurable at the middle of the web, where a shortening of 0.0007 inch occurred. On the lower surface of the base the metal was extended 0.0061 inch on one flange, 0.0103 inch on the other flange, and 0.0088 inch along the middle of its width. These figures represent permanent sets. The mill scale was disturbed in the vicinity of the gagging blows, as usual.

The low rail, of the same composition, gagged on the base, gave the following results: The element along the top of the head was extended 0.0013 inch. The web was extended 0.0008 inch. One flange was shortened 0.0010 inch, the other 0.0013 inch. Along the middle of the base the shortening was 0.0011 inch.

The low-carbon rail was a high rail, and therefore was gagged on the head. The element along the top of the head was shortened 0.0443 inch. Along the middle of the web the metal was extended 0.0029 inch. One flange was extended 0.0283 inch, the other 0.0459 inch. Along the middle of the base the metal was extended 0.0388 inch.

The gagging of the high rails was more severe than conditions usually require in the process of straightening. It will be noted in the hard rails that the change in length of the web partook of the movement of the head, while in the soft rail it followed that of the base. The subject of distribution of strains, shown here in rails of different composition, is referred to, since it has presented itself in rails of different weights. In drop tests of 125-pound rails it has been witnessed that rupture did not begin on the tension side of the rail, but had its origin under the head at the junction of the head and the web. The metal at the top of the head under these circumstances did not have opportunity to display its ability to elongate, as contemplated in specifications, which have an elongation clause. The design of the rail, rather than the inherent properties of the steel, controlled the manner of its fracture.

Concerning the ordinary effects of gagging, they are confined to surface indications. The mill scale is disturbed and the rail slightly indented. In respect to the metal in the interior of the section, neither macroscopically nor microscopically has evidence been found of the effects of gagging. Strain gauge measurements are adequate to show the modifications in internal strains resulting from gagging.

When a sufficient number of gagging blows have been applied to a rail in one place, first on the head and then on the base, rupture occurs by a fracture which has an exterior origin. Such were the results in a series of 62 tests. On the other hand, by progressive gagging it has been found possible to develop fractures with interior origins, that is, transverse fissures have been made in this manner. The continuous gagging from end to end of the rail, at short distances between blows in progressive gagging, has an effect akin to the cold-rolling action of the wheels, and in this manner has been the means of producing transverse fissures. A large number of gagging blows were required. Per rail length of 33 feet the number has ranged from 52,000 to 254,000 gagging blows. It was found that the position of the nucleus of the experimental transverse fissure could be located at will on the right or the left side of the head, according to the manner of applying the gagging blows. This was accomplished by directing the blows on the side of the head on which it was prearranged the fissure should be located. Carbon steel rails were used in these gagging tests, one titanium-treated rail being included in the series. The weights of the rails were from 80-pounds to 100 pounds; in composition the carbon contents ranged from 0.62 to 0.85.

Figure No. 67 shows the appearance of a transverse fissure developed in an 85-pound rail by progressive gagging. The load was applied off center for the purpose of locating the fissure on the side of the head. The number of gagging blows per rail length of 33 feet required to cause the development of this fissure was 170,000. The test was made on a half-rail length; the number of blows actually delivered, therefore, was one-half the above number.

The development of transverse fissures in service in the track causes a progressive loss in strength of rails under bending stresses when the head is in tension, which becomes serious before the fissures reach the periphery of the rail. The results of some bending tests in which automatic records were taken showed the residual strength in 100-pound rails, which displayed transverse fissures, when finally broken as follows:

B rail............17,157 pounds per square inch fiber stress.
B rail.............34,314 pounds per square inch fiber stress.
F rail............. 28,075 pounds per square inch fiber stress.

These results were obtained with high-carbon rails taken from the track, which had displayed transverse fissures in service. The average composition of the steel was—carbon, 0.876; manganese, 0.75. These rails in their primitive condition would be expected to possess an ultimate strength under bending stresses of not less than 150,000 pounds per square inch fiber stress

It has long been known that all grades of steel may be ruptured by repeated alternate stresses, none of which in magnitude approach the elastic limit of the metal. Some results will be presented, compiled from earlier tests, showing the endurance of certain bars of steel under different fiber stresses. The chemical composition of the steel was C .55, Mn. .75, P. .034, S. .050, Si. .138. The test bars were 1 inch in diameter by 33 inches long, loaded on a double bearing, and rotated at a speed of 500 rotations per minute. The highest fiber stress of the series was 60,000 pounds per square inch, which slightly exceeded the tensile elastic limit. The lowest fiber stress was 50.8 per cent of the elastic limit, or substantially one-half of its value.

Figure No. 68 graphically illustrates the relative endurance of this grade of steel to repeated alternate stresses. Figures entered on the diagram state the number of repeated stresses required to rupture the steel under different fiber stresses, the percentage of the loads in terms of the elastic limit, and the relative endurance in terms of the bar when loaded with 60,000 pounds per square inch taken as unity.

The lowest fiber stress employed 30,000 pounds per square inch, did not rupture the bar with 76,326,240 rotations. After enduring this number of repeated stresses, the load was increased to 60,000 pounds per square inch, rupture ensuing after 8,100 rotations. The life of the steel at 30,000 pounds fiber stress was more than 6,111 times that at 60,000 pounds. In many situations the durability of the steel under the lower fiber stress would be considered as indefinite. There is a zone of demarkation, above which the life of steel is comparatively short, below which it is of long duration. With a proper limitation of the maximum stress the life of steel may be so prolonged that failure in service would not be looked for. This statement is true of all grades of steel, the limiting stresses being different in different grades, but a danger zone exists in all.

The danger zone in rails of a given composition is probably lower than carefully prepared laboratory bars would show for that grade of metal. Repeated bending tests on full rail sections, none of which caused a permanent set, have resulted in early rupture, leading to the inference that the shape of the rail, together with the state of strains which are set up within it, detract from its ability to endure repeated stresses.

Considering the ability of the metal to perform mechanical work under different fiber stresses is another way in which these results may be examined. The original tensile test of the steel which furnished the repeated stress tests of figure No. 68, showed an elastic limit of 59,000 pounds per square inch; tensile strength, 109,600 pounds per square inch, with an elongation of 16.2 per cent; and a contraction of area of 20.8 per cent. The mechanical work necessary to strain this steel from zero stress to its elastic limit, was 5-foot pounds per cubic inch of metal. To rupture the steel by tension required 1,047 foot-pounds of work per cubic inch. In the table which follows, the number of foot-pounds work done under different fiber stresses is stated in terms of the work required to strain the steel to its elastic limit and also to effect rupture by tension. Under repeated alternate stresses at 60,000 pounds per square inch fiber stress this steel performed 12,490 times the amount of work which was required to strain it to its elastic limit. Under the lowest load of the repeated stress test, the steel performed over 19 millon times the work required to strain it to its elastic limit, illustrating the enormous capacity of steel for doing work, provided the stresses are carefully regulated.

Table No. 3 shows the mechanical work done in the repeated stress tests of the .55 carbon steel, graphically represented on figure No. 68. In this table the work done in the repeated stress tests is expressed in te[illegible] of that which was done in the primitive tensile test at the elastic limit and at the tensile strength.
Table No. 3.-Mechanical work done in repeated stress tests in terms of primitive tensile properties.

Fiber stress	Per cent of elastic limit	Work per cubic inch in terms of that of the tensile test at the Elastic limit	Tensile strength
30,000	50.8	19,081,560	91,125
35,000	59.3	306,641	1,464
40,000	67.8	[illegible]02,202	965
45,000	76.3	93,510	447
50,000	84.7	64,690	309
60,000	101.7	12,490	60

The work done on the outside fibers is that which is referred to in the table.

Original tensile test.

Elastic limit:
- Pounds per sq. inch.. 59,000
- Mechanical work... .. . .ft.-lbs. 5

Tensile strength:
- Pounds per sq. inch 109,600
- Mechanical work. .. ..ft.-lbs. 1,047

Elongation .... percent. 16.2
Contraction of area. . ... ,percent. 20.8

Table No. 4 shows the results of earlier tests on the tensile properties of six grades of steel, including the amount of mechanical work done in straining the steels to their elastic limits and their tensile strengths.

Table No. 4.-Tensile properties and mechanical work required to produce rupture in different steels.
(From early reports of Tests of Metals)

Carbon content	Tensile tests				Mechanical work per cubic inch at	
	Elastic limit per sq. inch	Tensile strength per sq. inch	Elongation	Contraction of area	Elastic limit	Tensile strength
	Pounds	Pounds	Percent	Percent	Ft.-lbs.	Ft.-lbs.
0.17C	51,000	68,000	33.5	51.9	3.6	982
.34C	54,000	85,000	26.7	54.2	4.3	993
.55C	59,000	10[illegible].600	16.2	20.8	5.0	1,047
.73C	64,000	140,200	10.0	11.6	6.2	1,003
.82C	63,000	142,250	8.5	6.5	5.9	688
1.09C	77,000	132,800	8.7	9.2	8.5	892

Repeated stress tests were made on these six grades of steel. One bar endured over 200 millon repetitions of stresses, performing 76 millon times the amount of mechanical work required to strain the steel to its elastic limit. The bar remained unruptured after performing this amount of work. There is no fixed relation between the primitive tensile properties and the useful work which steel can perform. If the working stresses are of moderate degree, the life of the steel will be practically unlimited. If, on the other hand, the loads applied are excessive, the life of the steel will be very short.

Referring briefly to track stresses: The results of early measured strains in the track on different weights of rails resting on different kinds of ballast and under different wheel loads showed stresses under static conditions of loading, which, while not generally excessive, were nevertheless as high as engineering practice sanctions for structures intended to be permanent. Lower wheel loads prevailed at the time of those tests than those of present equipment. There has been a gradual increase in wheel loads until a maximum of over 17 tons has been reached. To the direct bending stresses should be added the internal stresses in order to get an expression which shall represent the total fiber stress on the rail.

In the track many rails show permanent downward bends at their ends. Low joints in the heavier rail sections are frequently seen. The combined effects of wheel loads and internal strains is thus shown to have exceeded the elastic limit of the rail, which, in steels now used, calls for a fiber stress of 50,000 or perhaps 60,000 pounds per square inch. These sets which are permanent records of high stresses, furnished by the rails themselves, must be accepted as reliable indications of what has occurred in the track.

Seven years have elapsed since the first accident report was issued by the Interstate Commerce Commission upon this type of fracture, to which the term "transverse fissure" was applied. Since the date of that report——August, 1911——other accidents have occurred due to this cause. The number of individual examples of transverse fissures has reached into thousands. Their numbers continue to increase.

On the occasion of the first report an explanation was offered of the cause of this type of fracture. It was recognized as a modified type of fatigue fracture, its interior origin being due to the presence of internal strains of compression along the upper zone of metal in the head of the rail. In order to distinguish this type of fracture from the more common fatigue fracture in which this compressive component is absent the term "transverse fissure" was used. This fracture is progressive in its character, starting from a small nucleus and extending until the entire cross section of the head is ruptured.

Transverse fissures predominate in the gauge side of the head of the rail, establishing the relations between them and wheel pressures. No structural nor chemical cause has been found to which their formation can be ascribed.

A distinction may properly be made between the proximate cause of the formation of transverse fissures and features which may promote or retard their inception and progress. A study has been made of features connected with the process of fabrication from the ingot to the finished rail, and thence to conditions which are experienced in the track. Rails from all parts of the ingot display transverse fissures, hence there is no peculiar condition in one part over another which is responsible for their inception.

Steels of different compositions display transverse fissures. Their presence is not peculiar to any definite chemical composition, either in carbon steels or in alloy steels, so far as yet traced. Appearing, as they do, in rails of different weights and shapes, in rails from different mills, where different numbers of passes are used, where rails are rolled direct from the ingot and where they are rolled from reheated blooms, no specific or common cause for the formation connects with mill practice. They occur in both Bessemer and in open-hearth rails. The larger number of transverse fissures have occurred in the latter. No inherent reason has been presented why any essential difference should be found in rails made from either process All rails are gagged for the purpose of straightening them. No transverse fissures in rails in the track have been witnessed which were traceable to the effects of gagging. If the effects of gagging were serious on certain steels, there would be no justification in using such grades of metal for rails. If the thought that gagging was seriously detrimental and carried conviction that such rails were unsafe, it would constitute self-condemnation that unsafe steel was being used, demanding the immediate change to a grade of steel which would endure a detail in the process of fabrication to which practically all rails are subjected.

Repeated stresses are competent to rupture any grade of steel. To this statement there are no exceptions. None can be, since it would mean the production of a nonbreakable steel. Among those who do not recognize the influence of repeated stresses and the presence of internal strains as proximate causes in this type of rail failures, the argument is put forward that mill conditions, and not track conditions are responsible for the formation of transverse fissures. It is not clear through what process of reasoning this result is arrived at. On the contrary, the evidence places the responsibility for this preticular type of fracture upon the conditions to which the rails are exposed in the track. The direct bending stresses and the shearing stresses due to the wheel loads, together with the internal strains introduced by the cold rolling action of the wheels, constitute these conditions. The combined stresses should be kept below certain fiber stresses in order to avoid rupture and maintain a reasonable margin of safety.

In order to graphically illustrate this feature, diagram Figure No. 69 has been prepared, again using the data exhibited on diagram No. 68. In this particular grade of steel the limit of indefinite endurance is in the vicinity of 30,000 pounds per square inch. Working loads should be less than this amount. A dotted line marked A is drawn on the diagram representing an assumed safe load. The distance between this dotted line and line B represents the margin in safety in the use of this grade of steel.

There are practical difficulties, however, which present themselves in the effort to establish the positions of either lines A or B in the case of rails. Tests on the rail in its primitive state will not indicate the position of line B, since only the internal strains of fabrication are then present. The cold-rolling strains from the wheel pressures must be present in the rail. Again, there is difficulty in deciding at what period the rail should be regarded as having acquired the internal strains necessary to prepare the rail for a proper basis of comparison. When two components are involved, each of which exerts a progressive and cumulative tendency, ending in rupture, the consequence may be that line B may not have a fixed position. The early display of transverse fissures, a minimum interval of time being taken at five months, suggests the prompt lowering of this line.

The direct bending stresses received by the rails, as track measurements have shown them, are of such a degree that a much longer life of the rails would be expected, provided the bending stresses alone were present. Responsibility, therefore, attaches to the cold-rolling strains introduced by the wheel pressures—the only other component. Evidences places a large share of the responsibility for the formation of transverse fissures on the use of high wheel loads, the explanation which was offered in the report on the failure of the rail which caused the disastrous wreck on the Lehigh Valley Railroad at Manchester, N. Y., August 25, 1911.

The early failure of rails would not be expected from the bending stresses alone, nor would the origins of the fractures be interior ones, neither would the cold-rolling strains unattended with bending stresses produce this result, but the combination of bending stresses and internal strains appear competent to cause the early rupture of the rails.

Experimental research on the endurance of rails of full cross section suggests itself as the means of acquiring definite information, in order to establish the primitive position of line B, and furnish data upon its migration while the rails are in service. Lines A and B should be separated a reasonable distance and so remain, without merging. If they are not found to do so, it is obvious that the severity of track conditions should be reduced or the rails removed from service before their margin in strength is exhausted.

The position of the critical zone of metal in the head of the rail is illustrated by figure No. 70. Within this zone the direct effects of the wheel pressure are felt. The elastic limit of the steel is exceeded in this zone, the relations of the elastic limits in tension and compression and their values are disturbed, internal strains are introduced; and, from laboratory tests, it is found that the value of the modulus of elasticity is at least temporarily lowered by overstraining loads. These are features which affect the zone of metal at the top of the head of a rail.

Different conditions prevail on different divisions of a road which are met by the use of heavier rails and improvements in maintenance of way: The differences in traffic conditions have manifested themselves in the display of transverse fissures which have been found of more frequent occurrence on divisions where the traffic is heaviest. The results of such failures examined more in detail have also shown the more frequent display of fissures in the low rails than in the high rails of a curve. The normal interval of time intervening between the laying of the rails and when transverse fissures make their appearance has been noted on some roads. Transverse fissures, which thus appear on schedule time, clearly connect their appearance with service conditions.

The subject of transverse fissures has been discussed at length on account of the dangerous character of this type of fracture, and for the additional reason that no steps have been taken which have afforded relief from their development. Steels of different degrees of hardness have been tried, carbon steels and alloy steels, some of which have displayed good wearing qualities, but transverse fissures have formed in them and they have failed without warning. Heavier rails have been introduced. The experience thus far has been that transverse fissures have developed in them and within short intervals of time. It is conjectural whether further increase in weight will prevent their formation. The reinforcement of the affected zone of metal at the top of the head would not seem very great against the impinging pressures of the wheels with any reasonable increase in the weight of the rail. A narrow zone of metal on the running surface sustains individual wheel loads, which shifts to new zones under different shaped wheel treads.

Many and varied features have been discussed in this report, but all have their relation to the physical state of the rails or refer to the phases through which rails pass from the time of fabrication until they have completed their terms of service in the track. Rails are undoubtedly subjected to severe stresses, no other engineering structures furnishing parallel examples. The action of the wheels on the critical zone of metal next the running surface of the head tends toward ultimate rupture in all rails. It is a matter of severity of stresses, stresses beyond the ability of the steel to endure, and their continuance, when rupture will ensue in any rail. The present problem is to judge whether service stresses have reached such a limit that the margin in strength which resides in a new rail is not being rapidly exhausted. High wheel loads and bending stresses are the destructive agents involved in the case. There is a limit of stress beyond which steel will not endure. The frequent display of transverse fissures raises the query whether the limit of endurance is being too closely approached or whether it has not already been reached.

The alternative methods for insuring safety against the formation of transverse fissures appear to lie in the direction of greatly increased rail sections, or in reduced wheel loads, or in the removal of the rails from the track before their margin in strength and endurance is exhausted.

SUMMARY

The following is a summary of the results of the investigations conducted by the Engineer-Physicist:

This derailment again forcefully calls attention to the dangers resulting from transverse fissures in rails. The testimony of those who were present at the time of the derailment of the troop train on the Long Island Railroad, and evidence since then acquired from examination and test of the materials of the track, fully establishes the cause of this accident as the failure of two rails, in these rails there were 14 transverse fissures, of which 13 were disclosed at the time of the derailment and one other in the subsequent examination of the rails. In two other rails which were also examined at the time 8 transverse fissures were found, making 22 fissures in all.

The data acquired in this investigation, as well as the investigations of previous accidents resulting from rail failures due to the presence of transverse fissures shows this to be a progressive type of fracture. It is commonly located on the gauge side of the head, starting from some point in the interior of the rail External appearances of the rails do not give any indication of the presence of transverse fissures, they may remain unknown and without possibility of detection until they have extended to the surface of the rail or until the rail breaks. Even when a transverse fissure has reached the surface of the rail the opportunity for discovering it is very slight as only a fine crack is visible, although practically the entire cross section of the head may then be fractured.

A rail is much weakened by the presence of transverse fissures even in their earlier stages of development, and ultimately the fracture of the rail is sudden and without any display of ductility which might lead to its detection in time to avert disaster. Transverse fissures may be formed, as in the present case, at a number of places along the length of the same rail. The complete rupture of the rail at one place is not infrequently followed by other fractures almost simultaneously, causing an opening to be made in the track. Under these circumstances the only means left for maintaining security and continuity of the track is the spiking, which is very severely taxed when the rail is broken into one or more short pieces. The urgent need of eliminating this dangerous type of rail fracture is apparent.

Several years have now elapsed since this type of rupture was first brought to notice in these accident reports, and no remedy has been applied which has checked their formation. Practically all grades of steel have been tried, both carbon and alloy steels, and transverse fissures have been found in each. Investigations have shown that transverse fissures occur in steel which is structurally sound and chemically satisfactory, as well as in rails having defective metal. The earliest display of transverse fissures in point of time has occurred in rails which exhibited the best physical properties in respect to structural soundness and uniformity.

The study of transverse fissures has been directed to the state of the metal at and in the vicinity of their nuclei, where defects influencing such failures, if they existed, would be looked for. But even among rails exhibiting defective metal there has been found no common defect to which the formation of transverse fissures could in those cases be attributed, and the investigations have shown conclusively that neither defective metal nor any physical property or characteristic of the rail structure can be assigned as the cause of the formation of transverse fissures

Investigations, in the quest of a proximate cause for the development of transverse fissures, have been directed particularly to the condition of the metal in the rail after it has been in service for a time. It is found that the metal at the top of the head is charged with internal strains of great magnitude, these strains being acquired chiefly after the rail has reached the track. The cold rolling of the metal of the running surface by the wheel pressures causes these internal strains. They amount to thousands of pounds per square inch. There are also certain cooling strains in the rails which are acquired during their fabrication, but these are much lower than the strains which result from the wheel pressures.

The total stresses which rails are required to endure in the track are the internal strains plus the direct bending loads when trains are on them. The rupture of rails is brought about by these two factors, the internal strains and the external loads. This is true whether the rail is sound or unsound. Provided no physical or chemical defect exists, the direct responsibility for rail failures must necessarily be attributed to the track stresses.

Many influences which affect rails have been referred to in the body of this report. A certain area of the metal next the running surface of the head, upon which these influences center, constitutes the critical zone to which attention must be directed. Careful consideration of the features which have been enumerated, tending in their action to cause the ultimate failure of the rail, may bring about an amelioration of existing conditions and remove this very prevalent source of danger.

All steels have the ability to endure certain stresses of low magnitude extending over periods of time which may be regarded as indefinite, but different grades of metal posses differences in the degree of their ability to endure loads. Questions of endurance depend fundamentally upon the magnitude of the loads which the rails are required to sustain.

The continued display of transverse fissures in rails demands action should be taken for their prevention. If present equipment has reached that stage when increase in wheel loads is no longer permissible, this feature should be taken into account in the design of new equipment. This idea calls for a suspension of the trend which has marked the design and construction of new rolling stock, and which, in the immediate past, has been in the direction of both heavier motive power and rolling stock.

If the prevalence of this type of fracture is accepted as evidence that wheel loads are too high, the correction can not be made at once. The equipment, such as it is, must be used, and can be replaced only by the gradual process of renewal. For the time being reliance must be placed on superior maintenance of way and vigilance in track inspection to obtain immunity from the dangers which attend broken rails.

There are no remedial measures, as such, for the restoration of overstrained steel. The safety feature is in no way changed, whether the overloading is done on sound or unsound steel. Loads must be regulated according to the properties of the materials which are obtainable, but this will not be considered an excuse for the manufacture or use of steel if it can be improved in what is so vaguely designated as its quality.

It has been held on the part of some that the responsibility for the formation of transverse fissures rested upon the steel mills, although it has not been made clear what detail of manufacture was under consideration in attaching responsibility to the properties of the steel. Importance has been placed upon the facts that certain heats of steel developed transverse fissures, while other heats did not. In the preparation of these accident reports efforts have been made to acquire data upon the conditions of manufacture, investigating all tangible suggestions which have come to notice having to do with mill practice. The results of these efforts have not confirmed the views of those who regard the cause of transverse fissures as being due to mill practice. The discovery of a mill defect and its correction would put the matter of transverse fissures on a much less disquieting basis than the results of the investigations have led to. They tend to indicate that rails are being strained beyond the ability of steel to permanently endure the service stresses, which is a very serious situation to meet. The installation of rails of far greater sections than those which are now being rolled, in itself not yet found promising, would seem to exhaust the efforts which have been made in providing for present equipment and speeds on track as now constructed.

Opportunity is open to acquire more exact data from the track than are now available concerning the conditions which attend the formation of transverse fissures. The limit of rolling loads on wrought iron rails was very early reached and it has already been passed on rails of low carbon. The hardest rails, as well known, display transverse fissures and fail without warning. An appreciation of the conditions which prevail in the track should lead, without delay, to concerted action toward the elimination of this dangerous type of rail fracture.

Respectfully submitted,

W. P. BORLAND,

Chief, Bureau of Safety.

Note. This was a printed report, all figures have been removed.