INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY, COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE BALTIMORE & OHIO RAILROAD NEAR QUAKER CITY, OHIO, ON FEBRUARY 20, 1917

August 20, 1917.

To the Commission:

On February 20, 1917, there was a derailment of a passenger train on the Baltimore & Ohio Railroad near Quaker City, Ohio, which resulted in the death of one employee and the injury of two passengers, two railway-mail clerks, one express messenger, 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. 38, consisting of one combination mail and express car, one combination baggage car and coach, one coach, one combination coach and café car, and Pullman chair car Adelaide, all of steel construction, hauled by locomotive 2117, and was in charge of Conductor Faust and Engineman Floyd. It passed Schick, Ohio, at 10:31 a.m., 4 minutes late, passed Eldon, Ohio, at 11:37 a.m., 7 minutes late, and at about 11:39 a.m. was derailed at a point 1,650 feet east of Quaker City, which station is 1.6 miles west of Eldon, while traveling at a speed of about 43 miles an hour.

After derailment the engine ran on the roadbed about 100 feet, turned over to the south, and came to rest on its left side at an angle of about 45 degrees with the track, with its front end on the roadbed. The tender remained coupled to the engine and came to rest on its right side at right angles with the track, with the rear end farthest from the track. The combination mail and express car came to rest on its left side parallel with and about 50 feet from the track, the forward end being at the rear of the tender. The combination baggage car and coach remained on its trucks and came to rest with its front end about 45 feet from the track and against the preceding car, and its rear end about 12 feet from the track. The coach remained upright on its trucks with its forward end down the embankment against the combination baggage car and coach; its rear end remained attached to the combination coach and café car, which car was derailed but remained upright on the roadbed. Pullman chair car Adelaide remained upright with its rear end still on the track. None of the equipment sustained severe damage. The track was torn up for a distance of 388 feet.

A view of the derailed engine as it appeared from the foot of the embankment is shown by figure No. 1.

The subdivision on which this derailment occurred is a single-track line extending from Schick to Newark, Ohio, a distance of 102.2 miles. Train movements are governed by time-table and train orders, supplemented by a manual block system. Approaching the scene of accident from the east the track is tangent for a distance of 1½ miles, followed by a curve to the right of 3 degrees 50 minutes, 950 feet in length, where there is a slight grade descending westward. The derailment occurred on this curve about 135 feet from its western end. The track is laid with 85-pound rails 33 feet in length, on a fill varying from 12 to 15 feet in height. The rails are single spiked to about 18 oak ties to the rail, tie-plates, Weber 4-hole rail joints and common 4-hole angle bars are used, and the ballast consists of about 7 inches of granulated slag on top of 4 or 5 inches of gravel. The superelevation on the curve on which the accident occurred varied from 2½ inches to 4 inches, the gauge varied from 4 feet 8½ inches to 4 feet 9 inches, and the curvature varied from 3 to 5 degrees. The maximum permissible speed for passenger and express trains over this track is 45 miles an hour. The weather was clear.

The engineman was killed in the accident. A careful examination of the engine failed to reveal any mechanical or other defect that might have contributed to the derailment. An examination of the track on the outside rail of the curve was made beginning at the point of derailment and proceeding eastward; it was found that the gauge side of the head of practically all the rails was flange worn from 30 to 50 per cent. Many of the rails were tilted outward, and in some of these the head of the rail was sprung outward near the middle of the length of the rail. The tie-plates on the inside of the rails were barely down on the surface of the tie, but on the outside they were pressed down into the ties until the top of the plate was below the surface of the tie, or the part of the plate outside of the base of the rail was bent upward. An average of four ties per rail had been marked for renewal, and in two instances the ties under rail joints were found to be broken. At the joints the surface of the ties was from ¼ to 1 inch below the base of the rail. The spikes at other parts of the rails were found to be raised from ½ to ¾ inch, and at the joints they were so loose that in some instances it was possible to remove them by hand

Conductor Faust who was riding in the chair car at the time stated that his first intimation of the derailment was when he felt a sudden application of the air brakes, that his impression was that someone had been struck by his train and that he did not realize that the train was derailed until after he had gotten out of the car in which he was riding Fireman Scott stated that the engine was the first to be derailed that the speed of his train was about 10 miles an hour at the time of the accident and that the engineman was working little or no steam and made an emergency application of the brakes

Division Engineer Tordella stated that he made an examination of the rails involved in this accident and found that in the web of a rail on the outside of the curve there was an old defect, which so weakened the head of the rail as to permit it to kink the rail kinked about 2½ inches and the length of the kink was about 5 feet He stated that in his opinion the derailment was due to this defective rail and that the first part of the train to be derailed was the rear driver of the engine or the tank or possibly the first trucks of the mail car He further stated that while the gauge side of the head of the rail was flange worn approximately 33 per cent, he did not consider that sufficient to cause derailment and that he was of the opinion that the rail did not turn over until after it had failed Division Engineer Tordella stated that under that particular rail only four ties had this year been marked for renewing, and at the exact point of derailment none had been marked He also said that he rode over this track on February 13 and thought then that the curve rode very well considering the season of the year Track Supervisor Frers stated that he considered the track on the curve where the derailment occurred good for a speed of 15 miles an hour Track Foreman Brill stated that he went over this track on a hand car on the Saturday preceding the date of the accident found the track in good condition, and did not think the rails were worn to the danger point

While the division engineer was of the opinion that the accident was caused by a broken rail this investigation disclosed that the first marks of derailment were located on the third tie from the west or leaving end of a rail on the outside of the curve, which rail was the one preceding that which the division engineer mentioned as having developed a kink in the head, because of a defect in the web and having caused the derailment The west end of the rail at the point of derailment was twisted outward at an angle of about 30 degrees Figure No 2 shows a view of this rail the head of which was bent outward at the leaving end

The next rail showed flange marks on the inside face of the web over the greater part of its length the web being fractured a short distance beyond its receiving end The rails on the outside of the curve were turned over for a distance of 50 feet beyond the point of derailment, where the train overturned and went down the embankment on the outside of the curve

On account of the bad track conditions low joints loose spikes sprung and badly flange-worn rails it is believed that the rails overturned by reason of there being insufficient security against flange pressures to prevent them doing so and that the web fracture was a consequence of the derailment and not its cause The second or westerly rail, in which this web fracture occurred was an [illegible]-pound Carnegie steel rail rolled in September, 1902 and laid in the track in the fall of that year This rail was submitted for examination to Mr James E Howard engineer-physicist whose report upon it accompanied by data upon some additional rail sections follows

Acknowledgment is made of the cooperation of Mr J R Onderdonk, engineer of tests and other officials of the Baltimore & Ohio Railroad in the investigation of this rail

REPORT OF THE ENGINEER-PHYSICIST

Two rails were involved in this derailment one of which was partially turned over and twisted through an angle of about 30 degrees while the other was turned completely on its side having been rotated as a whole through an angle of 90 degrees The heads of the rails were turned outward The derailment resulted from the displacement of these rails which were located on the outside of a curve of 3 degrees 30 minutes

The easterly rail of the two first mentioned above showed marks on the inside face of the web near its leaving end made apparently by the flanges of the wheels of the derailed train The westerly rail showed more pronounced marks of the same character extending along the greater part of the length of the rail and likewise on the inside face of the web The web of this rail was forced outward and slightly hollowed by the wheel flanges, and a line of rupture developed 3½ feet long beginning 3 feet from the receiving end The web was forced outward one fourth inch where the line of rupture approached the junction of the head and the web Other short longitudinal lines of rupture were displayed in the web near the leaving end of the rail There was a noticeable bend in the rail normal to the plane of the web 3½ feet from its receiving end a bend attributed to the wheels of the train when the rail was on its side

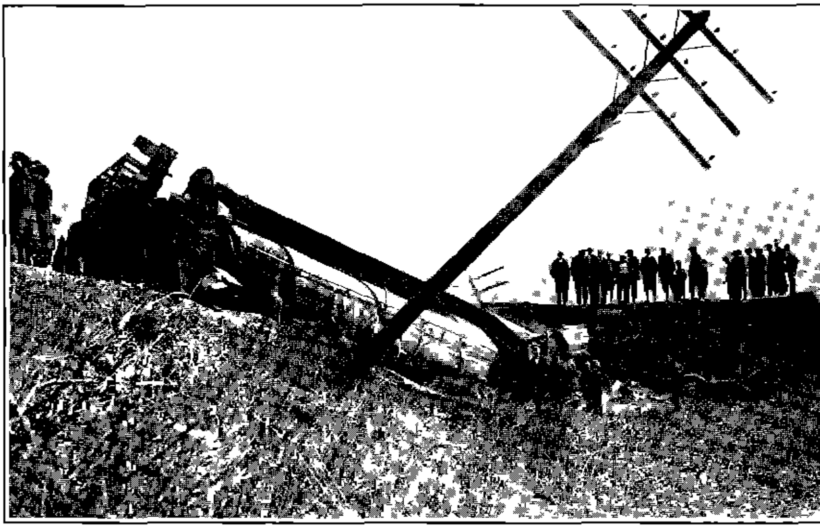

Figure No 1 —View of derailed engine

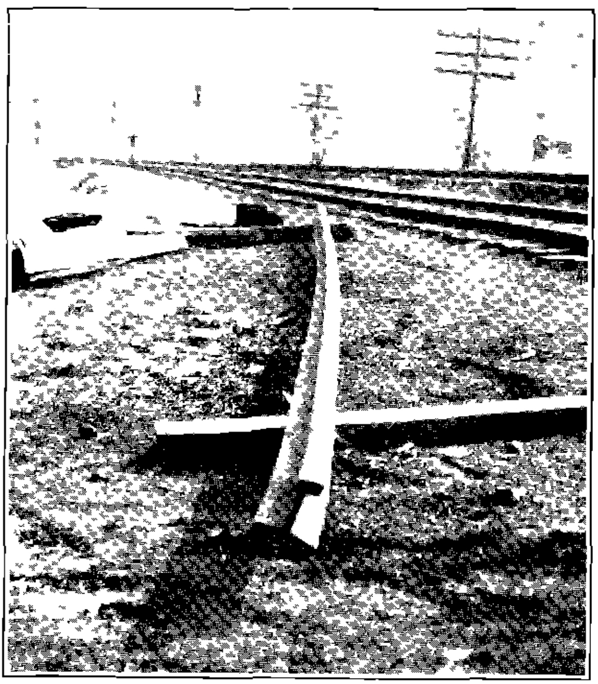

Figure No 2 —View of outer rail of curve Head at end bent outward and rail twisted about 30 degrees

Each rail, on the outside face of its web, exhibited short seamy lines, a condition attaching to their fabrication. The surface metal was folded over, causing laps of shallow depth. At one place, in the plane of rupture of the web of the westerly rail, it was thought that an incipient crack had been developed, representing an extension of a surface lap. In other places the primitive condition of the laps appeared undisturbed. The presence of these seamy laps clearly had no influence upon the causes which led to the derailment, which was due to the overturning of the rails from insecurity of attachment to the ties.

An inquiry was made into the state of internal strains of the westerly rail, and to those results are appended the results of measured strains of other rails, those which had not been in service, representing normal and accelerated rates of cooling. The benefits which may result from inquiries into the causes of rail failures depend in a measure upon the scope of the work done in individual cases, but such work is aided by accumulated data derived from the examination of other rails upon the phases through which steel passes from its primitive state until rupture ensues. The consideration of internal strains in rails, which not infrequently attain a magnitude equal to or exceeding the direct stresses from wheel loads, is a matter which has been neglected. This fact emphasizes the need of acquiring and recording as much information as may be gathered upon this important matter, and supplemental data covering such observations are submitted in this report.

The rails involved in the present derailment were of 85 pounds weight, A. S. C. E. section, and were branded "Carnegie 1902 E T IIIIIIIII." The chemical analysis of the rail, the web of which was fractured, was as follows, the analysis showing the composition of the metal at the outside upper corner of the head and at the middle of the head near its junction with the web:

Location	Chemical composition				
	Carbon	Manganese	Silicon	Sulphur	Phosphorus
Outside	0.498	0.84	0.058	0.049	0.074
Middle	.432	.85	.058	.048	.074

The internal stresses corresponding to the measured strains in a section of this rail at its receiving end are shown on figure No. 3.

The internal stresses at the periphery of the head, all of which were of compression, were of moderate degree for rails which have been in the track and subjected to the cold rolling effects of the wheels. They were higher, however, than the cooling strains of fabrication are expected to be in rails of this weight under normal conditions of cooling, and therefore had doubtless been increased by service conditions.

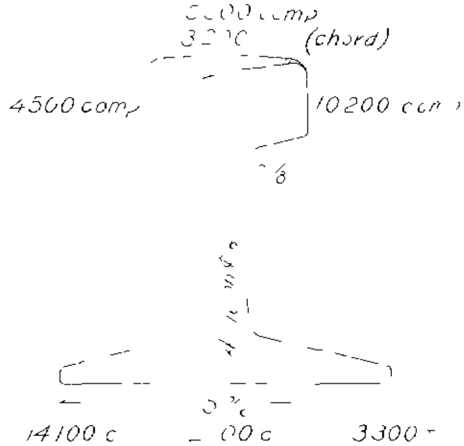

FIGURE No. [illegible]—Cross-section of [illegible] rail of curve which was [illegible] fractured. Shaded part of diagram shows area of metal worn away. Figures on diagram show the state of internal stress in rail.

The lowest stresses observed in the head were on the gauge side where flange wear had removed considerable metal. Two values are given for the compressive stresses at the top of the head. The lower value in magnitude represents the mean compressive stress in the strip 0.15 inch deep, which was detached from the rail at this place. The higher value more closely represents the maximum stress in this part of the rail. The internal stresses progressively varied according to the distance below the running surface. This was shown by the detached strip assuming a curved shape, convex on the upper side. Securing the strip in a straightened position, its expansion was 0.0031 inch on a gauged length of 10 inches, which corresponds to a compressive stress of 9,300 pounds per square inch. When the strip was in a free state the chord measurement showed an expansion of 0.0044 inch, which represents a compressive stress of 13,200 pounds per square inch.

Since the arc would measure more than its chord, it is evident that the higher value more nearly represents the actual stress at the immediate top of the head than the lower value. In order to balance the compressive stresses in the metal at the periphery, the interior of the head must have been in a state of tension. It will be recognized that this state of tension constitutes the reason for and furnishes the explanation of the interior origins of transverse fissures.

The internal stress in the edge of the flange on the gauge side of the base was substantially that which might result from normal cooling. The rail had been subjected to an outward overturning force in service in the track and no wear was shown on the undersurface of the inside flange. The undersurface of the outer flange, however, had been worn smooth. This flange showed a state of internal tension amounting to 3,300 pounds per square inch. The normal stresses in the flanges being of compression, it is inferred that service conditions or those attending the derailment were responsible for the reversal from compression to tension. It has been shown that gagging may reverse the normal strains of cooling. If gagged upon the base both flanges would be similarly affected, or if upon the side of the rail a similar disturbance would be expected in both the head and the flange of the same side, a modification not witnessed in the present instance, since the outside of the head remained in compression. Under normal conditions the metal along the middle of the width of the base is in an initial state of tension, where this rail displayed a compressive stress of 2,100 pounds per square inch.

Photomicrographs were taken of the structure at different parts of the rail. Figure No. 4 shows the average structure, in cross section, at the center of the head at a magnification of 100 diameters. Figure No. 5 represents the flattened grains of the metal next the running surface of the head, the result of flow under the cold rolling action of the wheel pressures, under the same magnification as above stated, and also shown in cross section. Impaired ductility under tensile stresses is characteristic of the metal thus affected. Early observations have shown a restoration in ductility is accomplished by annealing the steel. A restoration in the shape of the grains also attend exposure to annealing temperatures.

Figure No. 6 shows the appearance of the structure at the side of the head which had been exposed to flange wear. The metal was worn away without disturbing the shape of the grains immediately below the abraded surface. Metal next below that which is worn away in this manner is commonly less affected by internal strains than that which is exposed to cold rolling without material loss by abrasion or without the relief which comes from lateral flow.

Three features are associated in connection with the effect of wheel pressures on the top of the head, namely, the depth at which the grains in the microstructure of the steel are distorted by the cold rolling of the wheel, the depth at which the character of the fractured surface generally exhibits a change from an oblique shearing fracture to a granular one, when the head is on the tension side of a rail tested to destruction, and the depth of penetration of the internal strains of compression. Each of these zones at times appears to have different depths, without apparent fixed relations to each other. The presence of internal strains does not necessarily manifest itself in the appearance of a fractured surface, nor does the microstructure appear to furnish indications of the presence of internal strains or show distinctive differences in metal in which the internal strains are of tension or of compression.

Figures Nos. 7 and 8 show the microstructure of the flanges of the present rail in longitudinal section. The internal strains in the flange represented by figure No. 7 were of compression, equivalent to a stress of 14,100 pounds per square inch, while those in the flange represented by figure No. 8 were of tension, equivalent to 3,300 pounds per square inch. The determination of the presence of internal strains, their direction and magnitude, appears to be restricted to the method of strain gauge measurements.

The rate of cooling may be artificially regulated, causing decided modifications in the internal strains over those which are normal to a given section of rail. Some results will be introduced illustrating the effects of accelerated cooling in comparison with the same rail section cooled under normal conditions, in each case air being the cooling medium.

Figure No. 9 shows the stresses in a 100-pound rail, A. R. A. B. type, after normal cooling. The metal at the top of the head and in the flanges of the base was in a state of internal compression. There is a progressive change in the strains from the edges of the flanges to the middle of the base, where they are commonly reversed and become strains of tension. Local strains of considerable intensity in tension are not uncommon at the junction of the web with both the head and the base, as illustrated in this rail.

Figure No. 10 shows the stresses present in a rail of the same weight and type as above after accelerated cooling by means of an air blast. The results show most marked differences at the edges of the flanges. In the strips taken from the sides of the head there was a gradual reduction of the compressive stresses from the upper toward the lower edges, on one side of the head even reversing to a state of tension. Four gauged lengths were established on each of these strips at different distances from the plane of the neutral axis, furnishing the several values of the internal stresses here recorded.

Figure No. 11 shows the internal stresses in a rail of 92.7 pounds weight per yard. This section was cooled at a normal rate in the air. The higher values of the compressive stresses in the flanges over the preceding section of corresponding treatment will be noted, a characteristic difference between thick and thin flanged rails.

Figure No. 12 shows the state of internal stresses in the companion rail of No. 11 after accelerated cooling with an air blast. The stresses in this section are the highest that have yet been measured in air-cooled rails. The total range from tension to compression reached 59,400 pounds per square inch. The magnitude of these internal strains will be realized when compared with stresses usual in permanent engineering structures, where the values commonly

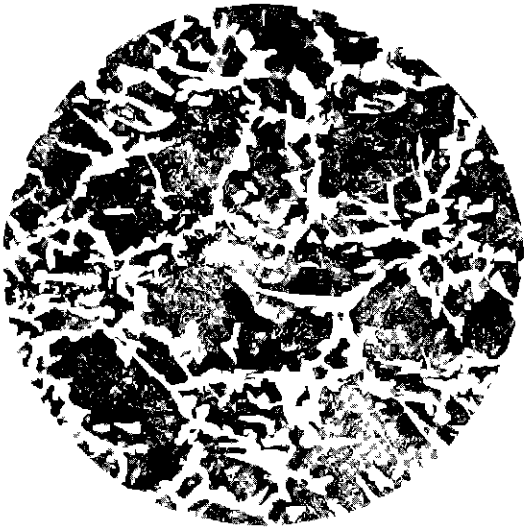

Figure No 4 — Microstructure of rail shown in Figure No 3 at center of head Cross section magnification 100 diameters

Figure No 5 —Microstructure of rail shown on Figure No 3 next running surface of head showing flattening of the grains Cross section magnification 100 diameters

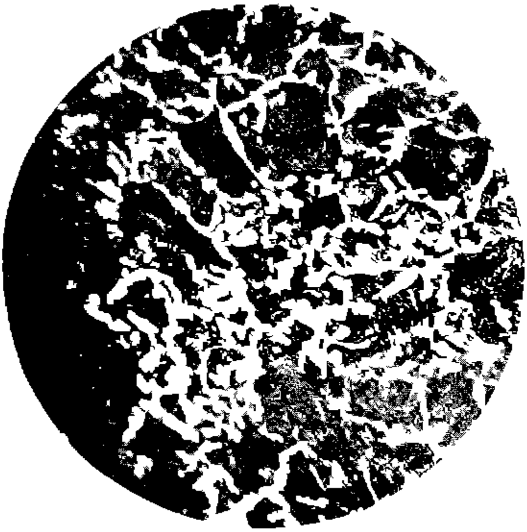

Figure No. 6.—Microstructure o[illegible] Figure N[illegible] flange side of [illegible]ead[illegible] gra[illegible] [illegible]surface. Cross section, magnification 100 [illegible]

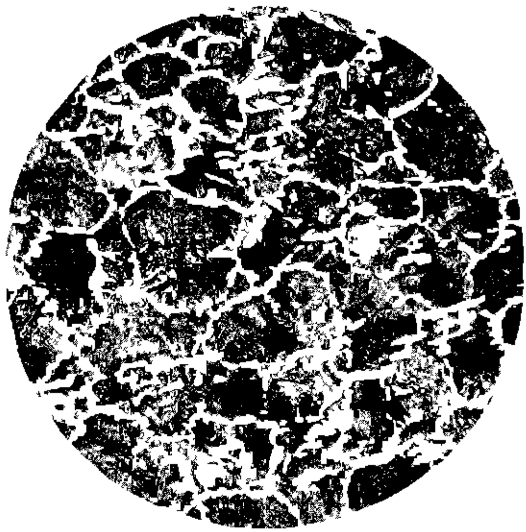

Figure No 7 Microstructure of rail shown on Figure No 3 Longitudinal section of flange which was in a state of initial compression of 14 100 pounds per square inch Magnification 100 diameters

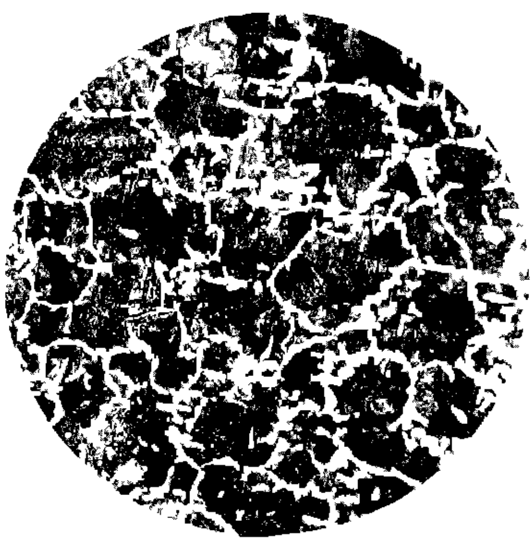

Figure No 8 —Microstructure of rail shown on Figure No 3 Longitudinal section of flange which was in a state of initial tension of 3 300 pounds per square inch Magnification 100 diameters range from 12,000 to 16,000 pounds per square inch. The magnitude of the internal stresses of this rail are not expected to be reached in ordinary cases. They illustrate, however, a range in values which it is possible to acquire in steel cooled by a less energetic medium than frequently employed, referring to the practice of cooling certain overheated members by means of water.

Internal strains in one part of the cross section of the rail react upon other parts in the same manner as in the application of external loads. A zone of metal in one part in a state of compression is met and resisted by another part by metal in a state of tension. This is another way of stating a well-known axiom concerning the relations between action and reaction. Any change in the state of strain in one part, therefore, causes a readjustment of the strains in other parts. Diagrams Nos. 13 and 14 show the successive stages passed through by two rail sections during changes in dimensions occasioned by the removal of parts of the cross section. Strips were successively detached on which reference lengths had been established and effects measured at each stage as indicated by the progression of figures in these two diagrams.

Diagram No. 13 shows the successive stages passed through by a rail of 92.7 pounds weight which cooled normally. The first machine cut which was made detached the head and the upper part of the web from the base. A general expansion occurred on each reference length on the underside of the base. In the upper portion of the rail the top of the head expanded while the web contracted in length. The readjustments which subsequently took place as the machine cuts were made for detaching the strips may be followed on the diagram. The shaded areas represent the state of the rail at each stage of its disseverance. The final results showed the rail to have been in an initial state of compression at the top of the head and immediate vicinity. The flanges were also in a state of compression but merging into tension at the middle of the base. The sides and the lower part of the interior of the head was in tension, and likewise the metal of the web at the middle of its depth and at its junction with the head. The results on this rail are fairly representative of the strains which are present in new rails of similar dimensions.

Diagram No. 14 shows the results of the examination of a companion rail of the same weight as before, after accelerated cooling, accomplished by means of an air blast directed upon the head. The cooling was done immediately after the last pass in the rail mill. The manner of disseverance was nearly the same as in the previous example, measurements being taken at each stage. Accelerated cooling caused the introduction of higher strains throughout the cross section than witnessed in the section of normal rate of cooling. The respective zones occupied by the metal in tension and in compression however remained substantially unchanged in their positions

Internal strains in rails may very properly be considered as analogous to the dead-load stresses in other engineering structures. Obviously no engineering design of a bridge of large span would be entertained which omitted the consideration of the dead-load stresses

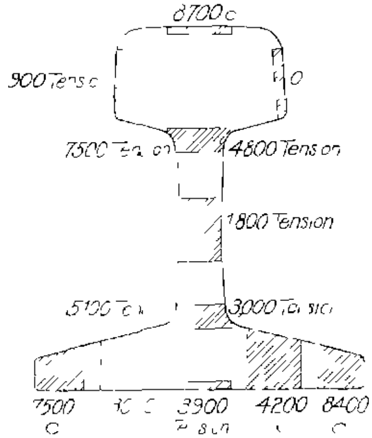

FIGURE NO 9 —Cross section of ... 100 pound rail ...

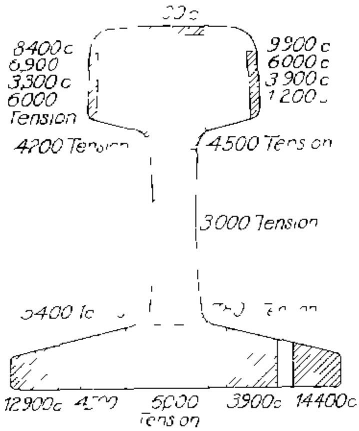

FIGURE NO 10 —Cross section of new 100 pound rail Internal ... cooling with air blast

nor should they be omitted in the consideration of the stresses in rails The dead loads not infrequently exceed the live loads The sum of the two represent the actual loads which the bridge members must sustain Bridge members themselves are also affected by internal strains but in a lesser degree doubtless, than rails Internal strains equivalent to stresses of 15,000 to 20,000 pounds per square inch are not uncommon in the heads of rails which have been in service for a time. To these should be added algebraically, the live loads to express the magnitude of the total stresses in the rails.

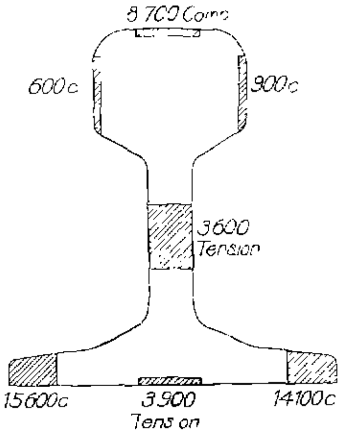

FIGURE No. 11.—Cross section of a new 92.7 pound rail. Internal stresses after normal cooling in air.

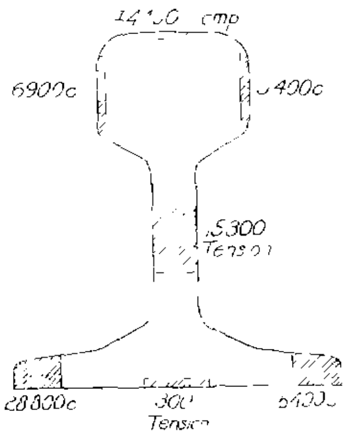

FIGURE No. 12.—Cross section of a new 92.7 pound rail. Internal stresses after accelerated cooling with air blast.

In judging of the effects of these combined stresses it is important that the distinction be made between the effects of loads once applied, as they are applied in the usual determination of the physical properties for the purpose of acceptance, and the effects of the loads which are received by the rails in service. The latter are repeated a considerable number of times. The relations between the primitive properties shown in the acceptance tests, or such property as may have such a relation, and the loads which may safely be applied and repeated without causing rupture of the rail, have not been satisfactorily investigated or defined.

Present information, developed in the laboratory on carefully prepared bars, goes no further than to establish the fact that repeated alternate stresses must not approach too closely to the elastic limit of the steel for long endurance of the metal. What shall be taken as the elastic limit of a rail in view of the presence of these opposing internal strains of tension and compression is a subject which claims early attention. The prevention of rail failures will be advanced by the acquisition of definite knowledge concerning the resistance of rails in full section against the kind and degree of stresses which are encountered in the track, and this necessarily requires that definition shall be made of what the track stresses themselves are.

SUMMARY

The investigation of the rails involved in this accident showed that the outer rails of this curve displayed considerable flange wear, and that the base of the rail which was overturned was worn smooth under the outer flange, while under the inner flange there was no evidence of wear. The overturning tendency which had been resisted by this rail was indicated by the worn surface of the base. In addition to these badly flange-worn rails, there were low joints and loose spikes in the track in the vicinity of the accident, and these conditions are believed to have been the cause of the derailment.

One of the rails which overturned showed flange marks of wheels on the inside surface of the web practically its full length, and at places the web was fractured. These lines of rupture were clearly the result of the derailment, as they were located on the web at a place inaccessible and immune from such effects when the rail is in upright position.

Each of the two rails showed short seamy lines on the outside surfaces of their webs which appeared as lap marks made in the fabrication of the rails. One of these which was in the plane of the fracture of the ruptured web was believed to have extended and formed an incipient crack in the web. It was incidental that it chanced to be located in the course of the line of rupture developed by the wheel flanges, and could not be regarded as a contributory cause in the derailment.

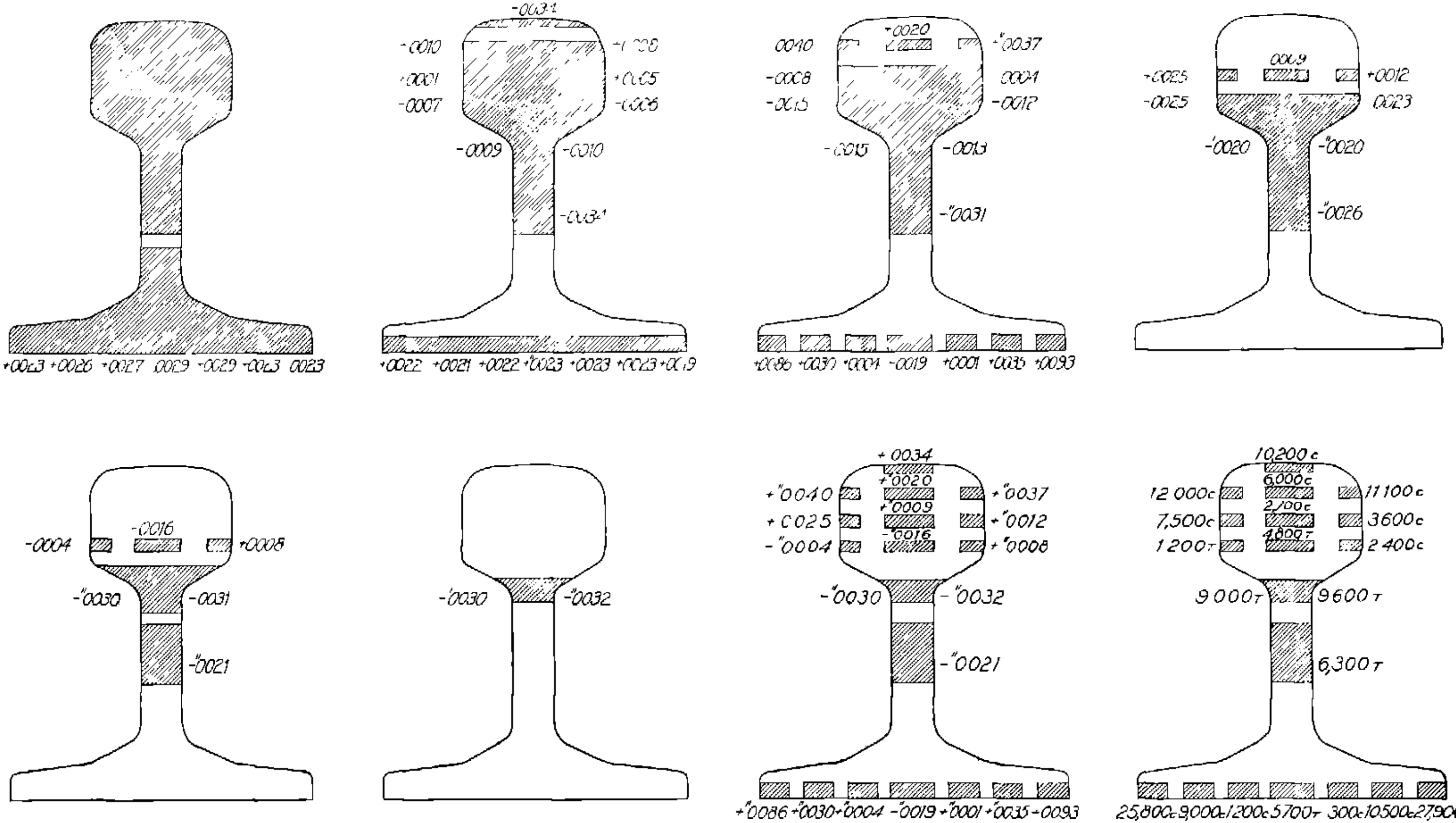

Diagram No 14 —Cross section of a new 92 7 pound rail Internal strains and stresses after accelerated cooling with air blast on head Strains progressively displayed as section of rail was dissevered, with stresses corresponding to total strains released

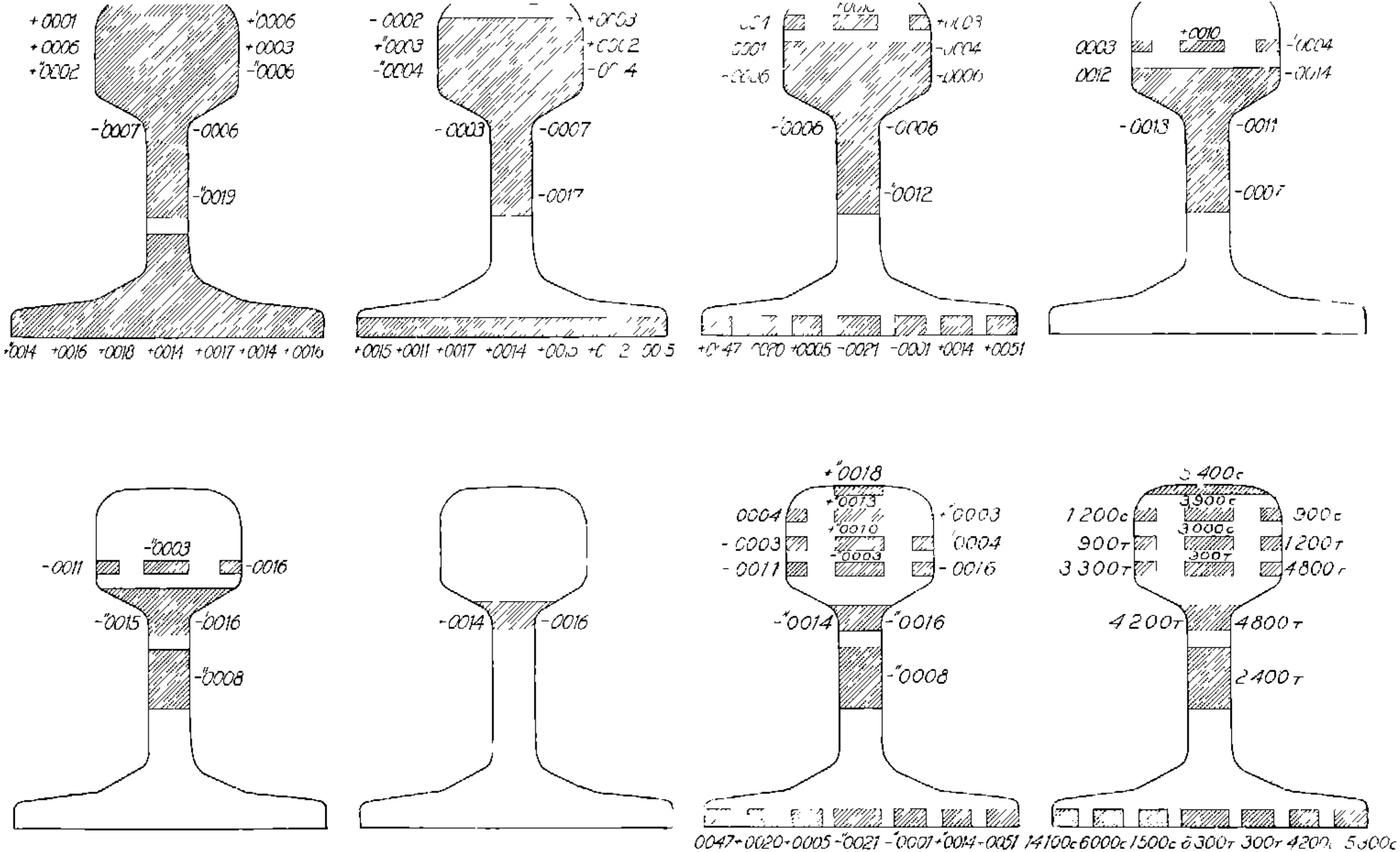

Diagram No. 13.—Cross section of a new 92.7 pound rail. Internal strains and stresses after normal cooling in air. Strains progressively displayed as section of rail was dissevered, with stresses corresponding to total strains released.

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The examination of the rail which had the fractured web showed structural soundness in other parts while its state of internal strain disclosed no feature which could be held responsible for the derailment The relation which the fractured web bore to the head of the rail clearly indicated that the fracture occurred after the rail was turned on its side The twisted rail next preceding this rail in the track was bent outward all of which consistently indicates that the accident was due to insecurity of the track structure which permitted the rails to be overturned

Respectfully submitted

H W BELNAP,
Chief, Division of Safety