INTERSTATE COMMERCE COMMISSION

REPORT OF THE CHIEF OF THE BUREAU OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE CLEVELAND, CINCINNATI, CHICAGO & ST. LOUIS RAILWAY NEAR CLEVES, OHIO, ON MARCH 30, 1917.

December 28, 1917.

To the Commission:

On March 30, 1917, there was a derailment of a passenger train on the Cleveland, Cincinnati, Chicago & St. Louis Railway near Cleves, Ohio, which resulted in the injury of seven passengers and two employees. 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 passenger train No. 31, known as the Royal Palm, en route from Jacksonville, Fla., to Chicago, Ill. It consisted of locomotive 6950, 1 steel underframe baggage car, 1 steel underframe combination car, 1 steel chair car, 3 Pullman sleeping cars of steel construction, 1 Pullman sleeping car with steel underframe and vestibules, and 1 Pullman library observation car of steel construction, in charge of Conductor Monger and Engineman Murphy. This train left Cincinnati, westbound, at 1.23 a. m., 3 hours and 23 minutes late, with orders to run on the eastbound track from Riverside, 4.2 miles west of Cincinnati, to Valley Junction, 17.7 miles west of Cincinnati, and then cross over to the westbound track, with rights over all trains. It passed Fernbank, 12 miles west of Cincinnati, at 1.48 a. m., and was derailed at a point about 5 miles west of Fernbank, or nearly a mile west of Cleves, at about 1.55 a. m., while running at a speed of about 50 miles an hour.

The front wheels of the engine trucks and the rear trucks of the tender were derailed. The locomotive and baggage car separated from the combination car about 20 feet, the locomotive running about 648 feet before coming to a stop. The combination car was separated from the remainder of the train about 30 feet. Both trucks of the baggage car were derailed on the inside of the curve, the body of the combination car was thrown from its trucks and stood upright beside the track, the chair car and 3 Pullman sleeping cars were derailed and came to rest at an angle of about 30°, and the front trucks of the other Pullman sleeping car were derailed. Practically all the damage to the cars was done to their trucks. Figure No. 1 shows a view of the derailed train.

This part of the Cleveland, Cincinnati, Chicago & St. Louis Railway is a double-track line over which train movements are governed by time-table, train orders, and a manual block system. The track consists of 90-pound steel rails, 33 feet in length, with 19 or 20 ties under each rail, tie-plated and single-spiked and is ballasted with about 3 feet of gravel. The derailment occurred on a 2° curve and on practically level track. The weather at the time was clear.

Engineman Murphy stated that his train left Cincinnati at 1.23 a. m., and was running at a speed of about 55 miles an hour when he felt the engine jar and the gravel began flying, at which time he applied the air brakes in emergency, thinking the pilot may have fallen down. The front trucks of the locomotive were the first to be derailed, and when the train stopped he looked back and saw that the cars were derailed and partially tipped over. At the time of the derailment he was sitting on the engineman's seat box, looking straight ahead. The headlight was burning brightly and illuminated the track plainly at least 800 feet in advance of the locomotive. After the derailment he inspected the wheels, flanges, and axles of the locomotive, but did not find anything wrong with them. Upon examining the track he found a broken rail, which in his opinion was the cause of the derailment.

Conductor Monger stated that after the accident he examined the track for the purpose of ascertaining the cause of the derailment and found a piece of the broken rail about 23 inches long lying in the ballast of the westbound track at a point about 200 feet from where it had originally been in the track. All of the breaks in the rail appeared to be new breaks and no flaws of any kind were visible.

Master Mechanic Bauer stated that after the accident he examined the running gear of locomotive 6950 and found the wheels, flanges, axles, etc., in good condition, and nothing was discovered that could have caused the derailment.

Supervisor of Track Folks stated that he reached the scene of accident about 3.30 a. m. and made an examination of the track. He found two broken rails, the east rail being broken into six pieces. He could find no flaws or defects in the rails, and so far as he could determine the rails were in good condition prior to the derailment. He said that this section of track had been inspected by trackmen on two different occasions on the day before the accident and he had passed over it the same day on train No. 15, and the track apparently was all right. By his inspection after the accident he could find nothing that should have caused the derailment other than the broken rails.

The last train to pass over this track prior to the derailment was eastbound freight train No. 80 which passed about three hours before train No. 31 was derailed, and the crew of that train stated that they did not notice any unusual roughness of the track or anything that would indicate that it was not in good condition.

The derailment was clearly the result of an opening having been made in the track by the breaking of portions of two adjacent rails on either side of the joint which connected them. While this fact is well established, there is a diversity of opinions as to what part of the track was the first to fracture. Different theories have been offered as to the immediate cause of the derailment by those who participated in the examination of the track and the fragments of the rails.

Officials of the railway, who were the first to reach the scene of derailment, in describing the appearance of fracture B, as shown by figure No. 2, state that it had the indications of having worked up and down and was slightly worn, but the break was a very recent one; that all other fractures were absolutely new ones. In this connection it is to be noted that the opposite surfaces of fracture B do not fit together well, showing that they were bruised by different objects striking them.

Dr. P. H. Dudley, consulting engineer, New York Central Lines, in reporting upon these rails, considered that the first break occurred at B, between fragments 2 and 3, probably before the numerous breaks in the two rails, and was of the opinion that this break was caused by some preceding train. He pointed out that the bearing surface on the inside showed that the drivers had been slipping extensively and had hardened the metal; furthermore that the primary cause of the fracture in his opinion, was the hardened layers, caused by slipping on the bearing surface of the rails, thus inducing transverse cracks, which he found in all of the head fractures; and that the negative segregation of carbon and phosphorus in the analyses which he made, indicated that it was a rail from the lower part of the ingot.

An inspecting bureau reported that this rail showed on its etched surface a kind of porous structure, generally indicative of a location near the top of the ingot, and that neither rail showed any marked indications of segregation. Referring to fracture A, it was stated it had indications of being a progressive fracture and that some of the cross section was evidently broken a considerable time prior to ultimate failure.

Divergent views were thus expressed concerning the circumstances which resulted in the derailment of this train. The two rails and their connecting splice bars were submitted to Mr. James E. Howard, engineer physicist, for examination, who makes the following report, accompanied by data upon some additional rail sections.

Acknowledgment is made of the cooperation of Dr. Dudley and officials of the Cleveland, Cincinnati, Chicago & St. Louis Railway in the investigation of these members.

REPORT OF THE ENGINEER PHYSICIST.

Two rails were fractured at the derailment of train No. 31, on the Cleveland, Cincinnati, Chicago & St. Louis Railway, near Cleves, Ohio, March 30, 1917, namely, the leaving end of one rail and the receiving end of the other. An opening was made in the track by these fractures about 18 feet long, symmetrical with the joint between the two rails, through which the derailed cars of the train passed.

These rails were of 90 pounds weight per yard, American Society Civil Engineers section. The easterly one was a Bessemer rail rolled by the Carnegie Steel Co., and branded "Carnegie O. W. 90A 1905 IIIIIIIII"; the westerly one was an open-hearth rail rolled by the Illinois Steel Co., and branded "O.H. 9002 I S Co. Gary Wks. IIII 1911." The brand mark on the outer splice bar, which connected these rails, showed that it was made at Joliet, Ill., in 1908.

The length of time which these rails were in the track at the place of derailment is not known. Most of the track in that vicinity was laid in 1906 with new 90-pound rails rolled by the Illinois Steel Co. From this it would appear that these particular rails had been used to replace others which had been removed from the track. It is probable that each one had been used elsewhere, following the usual practice of replacing individual rails with those which had been in service and worn to about the same shape of head as those which they replace.

About 9 feet in length of each rail was fractured. In the Bessemer rail there were five lines of rupture through the head; in the open-hearth rail there were six lines of rupture in the fragments of the head which were recovered, some of which were lost. An examination of the fractured surfaces showed that each line of rupture had its origin at the upper corner of the head, on the gauge side of the rail. From its initial point each fracture extended downward through the web and the base, taking direct or oblique courses through the latter portions of the cross section.

The rails broke into relatively small pieces in the sections which were near the joint, with longer fragments in the more remote portions. The parts of the rails covered by the splice bars, due to such reinforcement, remained intact. The fractures in the heads of each were brittle ones, a very limited degree of ductility being displayed in the breaks which were made at the time of the derailment.

The inner splice bar was found broken at the first bolt hole, from the joint, in the end which engaged with the Bessemer rail, the line of rupture having its origin at the sides of the hole. Evidence presented by the fishing surface under the head of the Bessemer rail led to the belief that the fracture of this bar was one of long standing.

The outer splice bar was fractured across the middle of its length, opposite the joint at the rail ends. The origin of this fracture was at the upper edge of the bar. Its full development appeared to have taken place at the time of the derailment. It is believed that the fracture of this bar precipitated the derailment. In addition to these fractures there were two others in process of development in the outer bar, one starting from each of the two spike slots in its flange. Of the four lines of rupture displayed by these two splice bars, two of which were in a partial state of development and two of which were complete lines of rupture, three are believed to have reached substantially the state of development in which they were found prior to the derailment, the fourth line of rupture, located at the middle of the length of the outer splice bar, alone being entirely accomplished at the time of the derailment.

The proximate cause of the derailment is ascribed to the fracture of the outer splice bar at the middle of its length, the lines of rupture in the rails being regarded as secondary incidents and successively developed in each direction, east and west, from the joint.

The fractured splice bars were attached to the fragment of the leaving end of the Bessemer rail when this examination began. The fishing surface under the head, on the inside of this rail, was worn smooth for a length of 2-3/4 inches from the end of the rail to the fractured end of the inner splice bar. The overlapping end of the longer fragment of this bar, which in service was attached to the open-hearth rail, was held responsible for this smooth spot, and occasioned by the forward and backward movements of the rail ends during the passage of trains. This worn spot is evidence of the earlier formation of the fracture of the inner splice bar.

Two sizes of track bolts were used in securing the splice bars to the Bessemer rail, having diameters of thirteen-sixteenths and fifteen-sixteenths of an inch, respectively. The bolt used in the end hole of the rail had the smaller diameter. The bodies of these bolts were reduced in diameters by corrosion, rust having reduced the thirteen-sixteenths inch bolt to a minimum diameter of 0.70 inch. A heavy rust had accumulated between the splice bars and the web of the rail.

The tops of the heads of the rails showed roughened surfaces, due to the slipping of driving wheels of engines. The surface metal was dragged or forced backward against the direction of the current of traffic by the slipping of wheels in starting trains. The point of derailment and location of these rails was just beyond a water plug.

By reason of the mechanical work done on the heads of the rails and the heat developed by the slipping of the wheels the running surfaces of each rail had acquired a state of extreme hardness. Hardness and brittleness in steel are features which accompany each other, and brittleness of the surface metal was doubtless a contributory cause in the breaking up of these rails into small fragments. The fractures developed at the time of the derailment in each rail were practically devoid of ductility.

New 90-pound rails, rolled in 1916, were used in repairing the track. An examination was made of the condition of these rails after they had been in service a period of eight months, also noting in this subsequent inspection the condition of the splice bars in that vicinity.

The running surfaces of the new rails had acquired substantially the same roughened state as the rails which broke; a condition not unlike that of other rails in the vicinity on both the eastbound and the westbound tracks. Many illustrations, however, are met in which driving wheels have slipped in starting trains, at stations and water plugs, on grades and elsewhere. There is probably no railroad which is exempt from such examples.

Track inspection showed the presence of incipient cracks or complete lines of rupture in many of the splice bars of the type involved in the derailment. On the curve, east and west of the point of derailment, in the track on which it occurred, there were 25 splice bars having incipient cracks in different stages of development or which displayed complete lines of rupture. These had their origins at the spike slots, extending thence upward to the nearest bolt hole or completely separating the bar. No joint was found, however, which had more than one crack, whether incipient or complete line of rupture. Two splice bars, one on the eastbound and one on the westbound track, displayed incipient cracks, each of which had its origin at the upper edge of the bar opposite the joint between the rails.

The state of internal strains in the rails was determined in a series of observations made on certain of the fragments, followed by bending tests of the detached heads, and sections comprising the web and the base. Transverse tests were made on 5-foot lengths of each rail taken from the unbroken ends, one test of each being made with the head on the tension side and one with the head on the compression side. The results are presented in a later part of the report together with those on the state of strain in some new rails of 90-pound weight, in which transverse fissures had been experimentally developed by means of progressive gagging, also results on the internal strains in a segregated rail.

A tabular statement is given of the chemical composition of the two rails involved in the derailment, comprising determinations made by the officials of the railway, those by an inspecting bureau, and check analyses of each rail.

Table No. 1. - Chemical analyses of Bessemer and open-hearth rails involved in the derailment of train No. 31

Description	Carbon	Manganese	Phosphorus	Sulphur	Silicon
Bessemer rail:					
Analyses furnished by officials of railway (O	0.620	0.91	0.068	0.026	0.090
company.................(M	.526	.92	.076	.026	.103
Analyses by inspection (O	.54	.93	.066	.026	.08
bureau................ (M	.52	.94	.066	.024	.03
Check analyses........ (O	.61	.89	.097	.029	.092
(M	.55	.88	.088	.028	.094
Open-hearth rail:					
Analyses furnished by officials of railway (O	.68	.85	.023	.039	.135
company .... (M	.656	.88	.019	.038	.141
Analyses by inspection (O	.68	.90	.018	.041	.05
bureau................ (M	.65	.89	.017	.041	.05
Check analyses.........(O	.74	.84	.014	.052	.11
(M	.71	.84	.016	.052	.11
Rail in which transverse fissure was experimentally developed, after 1,483 reversals of load, 90,000 gagging blows per rail length....................	.74	.73	.026	.035	.12
Rail in which transverse fissure was experimentally developed, after 1,645 reversals of load: 109,000 gagging blows per rail length......................	.74	.80	.024	.035	.16
Segregated rail, center of head......................	.74	.66	.017	.053	.150
Junction head and web......			.021	.072	
Middle of web...............			.088	.067	

The evidence upon which the belief is founded that the line of rupture which precipitated the derailment was that of the outer splice bar is in a measure presumptive in its character. The fractured ends do not in themselves definitely show which was the first fracture to be developed, nor do they indicate the sequence in which they occurred. Upon one feature the evidence is conclusive, namely, that all fractures through the heads of the rails had their origins at the running surfaces; furthermore, that they started at the corner of the head on the gauge side. In one line of rupture the battered condition of the surfaces obscured the exact point. The fracture of the outer splice bar, as previously remarked, had its origin at its upper edge.

Under these circumstances, all of the fractures having started at the top and extended downward, it would be inferred that the initial line of rupture would take place at a point where the track normally is the weakest - that is, at the joint between the rails. This track already having a broken inner splice bar, the strength at the joint would be that of the outer bar only. The section modulus of the bar was much below that of the rail, therefore the weakest place in the track normally would be at the joint. An initial line of rupture elsewhere would call for a decided loss in the strength of the rail, or an exceptional stress upon the rail not transmitted to the joint.

Two splice bars in the track in that vicinity, displaying incipient cracks starting from the top, furnished examples of this manner of failure and showed the probability of failure at a joint, in the manner witnessed in the outer splice bar. Furthermore, the results of the transverse tests on the two rails showed greater strength than the weight of the engine would be expected to put upon them. No accessory influence was found which would adequately account for the initial failure at the time of derailment occurring in either rail.

In other instances wheel burns have been witnessed which have induced the formation of thermal cracks penetrating the metal of the head a sufficient depth to seriously impair the strength of the rail. Such depth of penetration was not reached in these rails. It was not clear that any crack had extended beyond the zone of hardened surface metal in the fractures which were made at the time of the derailment. In the subsequent examination two fractures were developed in which the cracks had extended into the normal metal below the hardened surface, reaching a maximum depth of about one-eighth inch.

It would present very disquieting conditions if sole responsibility for the derailment should attach to the state of the rail due to the slipping of the driving wheels. There are many rails in the track, not referring to any particular railroad, in a condition closely resembling those which broke under train No. 31. The short interval of time in which the rails of 1916 rolling, used in making repairs to the track, have acquired substantially the outward appearance of the rails which broke would add to the anxiety attaching to all such rails if this responsibility was established.

Wheel pressures effect a change in the physical properties of the metal at the top of the rail, causing brittleness to be shown when the rail is tested to destruction, whether or not wheel burns are made. These influences tend toward ultimate rupture of the steel, but it would be a serious matter if the margin in strength above usual working loads was found to be immediately destroyed by such means. Efforts to establish the gravity of the effects of wheels which have slipped, in the absence of direct tests, becomes a matter of judgment involving the discrimination between the different phases of a common source of injury to which rails are exposed. It would be desirable to avoid the slipping of wheels altogether if it were possible to do so, but it seems impracticable to prevent such occurrences.

A distinction may be made between the slipping of a wheel on one spot, without advance movement, and slipping which takes place when the train is in motion, but when the peripheral speed of the wheel is greater than its rate of advance. The slipping which occurred on the present rails took place, for the most part, when the trains were in motion. The slipping was general along the entire length of each rail. Trains rounding curves present examples of wheel slipping, owing to the difference in the aggregate length of the two sides of the track. In a strict sense, each of the longitudinal elements on the running surface of the head is exposed to slight effects of this kind, the relations between the head of the rail and the treads of the wheels being such as they are.

The last remark takes the subject matter quite a distance apparently from the examples furnished in the present rails. However, the effects of wheel pressures whether resulting in wheel burns, dragging of the surface metal, effecting a general hardness of the steel in a zone next the running surface by mechanical means along or together with thermal changes, and the introduction of internal strains, all belong to the same class of phenomenon. There may be differences in degree in each example, but with one common tendency in all--that is, a destructive influence on the integrity of the rail. If not the prime cause of rupture in any given rail they may be contributory to its failure, and introduce conditions causing greater destructiveness of track and equipment when a derailment does take place.

Referring to the examination of the two rails, figure No. 2 shows the appearance of the fractured portions of the Bessemer and the open-hearth rails assembled and photographed after the derailment. The cut shows the rails viewed from the outside. The fragments were numbered from 1 to 20, inclusive, in the direction the train was moving. Fragments Nos. 1 to 10, inclusive, represent the ruptured parts of the Bessemer rail; Nos. 11 to 20, inclusive, those of the open-hearth rail. Fragments of the latter which were not recovered occupied the open space between fragments 12 and 13, covering a length of rail of about 2 feet.

Twenty-three feet and 11 inches of the receiving end of the Bessemer rail remained intact, and 24 feet and 3 inches of the leaving end of the open-hearth rail remained unbroken. Each displayed brittle fractures without appreciable development of ductility. Arrows show the directions taken by the several lines of rupture through the heads of the rails, all of which started from the top of the head on the gauge side. The receiving ends of the several fragments were battered at the corners of the running surface. The heads of pieces 2 and 3, at line of rupture marked B, were battered endwise. In addition, the web of piece No. 3 was upset by some end blow which it received. These battered surfaces did not fit together well, showing the effects of independent blows upon them. The bases were not disturbed in that manner, and fitted together well.

The outer splice bar fractured from the top, opposite the joint marked with the letter F. An incipient crack is shown in the flange between the spike slot and the middle bolt. There was a crack also in the other half of this splice bar, beginning at the spike slot and extending through the flange. The inner splice bar was found ruptured across the first bolt hole, at the left of the letter E.

The line of rupture of the outer splice bar, located under the letter F of the cut, is that which is believed to have been the initial line of rupture which precipitated this derailment, the inner splice bar having been ruptured prior thereto. These bars are used in suspended joints.

Figure No. 3 is a view of the leaving end of the Bessemer rail, taken from the inside, with the fractured half of the inside splice bar in position, but with the bolts removed. The fishing surface under the head was worn smooth, between the end of the rail and the fractured end of the splice bar, a length of 2 3/4 inches. Figure No. 4 is a view of the same fragment with the splice bar removed, showing the well-defined limits of the worn surface under the head of the rail. The overlapping end of this bar, attached to the open-hearth rail, was doubtless responsible for the appearance of this smooth area, which represented the effect of a longitudinal rubbing movement of these parts against each other.

The appearance of the three bolts removed from this end of the joint is shown in figure No. 5. The original diameter of the end bolt was thirteen-sixteenths of an inch, which was reduced to 0.70 inch diameter at the middle of the length of its body. The other bolts were fifteen-sixteenths of an inch in diameter. Rust had reduced their bodies to a lesser degree.

Figure No. 6 shows end views of the fractured splice bars. The first figure on the left represents the inner splice bar, which had its line of rupture across the first bolt hole. The next figure in the cut shows the fracture of the outer splice bar, in the half which was on the open-hearth rail. A crack of long standing existed in the flange of this half of the bar, shown by the darker portion of the cross section. The lighter portion of the fractured surface represents the fresh portion made at the time of its examination. The third figure of the cut shows the appearance of the outer splice bar which fractured at the middle of its length. The full cross section of the bar at this place was fractured at the time of the derailment. The fourth figure of the cut represents the incipient fracture shown at the spike slot in figure No. 2, completed at the time of its examination.

Figure No. 7 is a view of the running surfaces of the two rails. The shorter fragment represents the top of the head of the Bessemer rail, the longer fragment the open-hearth rail. The appearance of the running surface of each varied from place to place. In general, the Bessemer rail showed the more decided surface disturbance of the metal. The change in shape of the cross section also was more pronounced in this rail than in the open-hearth rail. A fin had been formed along the outer edge of the head of each rail, representing lateral flow of the metal under the action of the wheel loads. Other rails in the track in this vicinity, remaining intact, showed the formation of fins along the outer corners of their heads; some of which were more pronounced than those witnessed in the fractured rails.

Figure No. 8 is a view of pieces of the Bessemer rail and section of the outer splice bar after bending tests were made upon them. Bending tests of the head, detached from the web and with the running surface on the tension side, showed great brittleness. Upon heating the metal to a low red heat a portion of its toughness was restored. The base and web, and a detached strip from one of the flanges, displayed good bending properties. The metal of the splice bar was shown to possess toughness where service conditions had not induced a brittle fracture.

Figure No. 9 is a view of parts of the open-hearth rail. The test of the detached head was discontinued before reaching its limit of rupture. The web and base showed good bending properties.

Figure No. 10 shows the appearance of the top of the head of the open-hearth rail, magnified 3 diamters. The dark groove across the figure represents a saw cut made in the sample lengthwise the rail. The roughened metal near the corner of the head, on the gauge side, is shown on the right side of the illustration.

Figure No. 11 is an enlarged view of a part of the head shown in illustration No. 10 after giving the surface a slight polish. The magnification of this illustration is 10 diameters. Numerous thermal cracks are shown due to the slipping of the wheels. The metal superficially reached a temperature which resulted in the hardening of the steel through the conductivity of the metal below the surface. These thermal cracks penetrated the top of the rail in varying depths, seldom exceeding one-sixteenth of an inch, and generally confined to the hardened zone of steel.

Figure No. 12 is a photomicrograph of a section just below the running surface, having a magnification of 100 diameters. The upper zone, nearly white in the cut, represents the zone of glass hard steel immediately below the surface of the head. The line scratched across the normal metal was made with the point of a needle, which would not scratch the hardened metal.

Figure No. 13, photomicrographs A and B, shows the structure of metal in one of the rails which were subjected to progressive gagging, in which a transverse fissure was experimentally developed. There were 1,488 reversals of this rail in the gagging press, equivalent to 90,000 blows on a full rail length of 33 feet. The gagging was more severe than required in the usual straightening of rails for service. No evidence of a change in the microstructure due to the gagging was discovered in the cross section of this rail.

The state of internal strains in the metal next the running surfaces of the Bessemer and the open-hearth rails was determined, the results of which appear on figures Nos. 14 and 15. The results entered on figure No. 16 show the internal strains in the flanges of these rails, each series of results being converted into their equivalent stresses in pounds per square inch. Gauged lengths were established on the rails when their sections were intact and again observed when the individual strips were detached. Measurements of the gauged lengths established on the heads were successively observed as portions of the cross section were planed away.

The internal strains, or stresses as they are reported, represent the changes in lengths which took place along the particular elements on which the gauged lengths were located. When the detached strips were reduced to a minimum thickness the strains released represented substantially the state of internal strain which existed in the intact rail at its periphery along those elements. There is a progressive variation in the magnitude of the internal strains in different parts of the cross section, from element to element. The strains commonly vary in some degree in the thin strips which are detached, whence it follows that the reported results are seldom maximum values, but represent approximately mean values. They understate rather than overstate the maximum intensities of the strains.

Average values are not sought in these determinations, but incidentally they are unavoidably obtained, since the detached strips must have certain minimum dimensions to admit of proper machining and the internal strains may vary within the limits of their cross sections. The internal strains of tension and compression balance each other in the full cross section of the rail, hence the average value for an entire rail is zero.

The successive changes which take place as the cross section of the metal is reduced are indexical of the varying values of the internal strains which were in that part of the rail. These changes were observed in detaching the heads and the upper parts of the webs from the bases of the two rails involved in the derailment. The results entered on the several sections of figure No. 14 show the values of the strains which were released at intermediate stages and in the final state of the examination of the Bessemer rail. The first remeasurement was made when the rail was cut apart along the web, near the neutral axis. At this stage, there was a slight increase on each gauged length. Each subsequent reduction in depth of the head resulted in the release of additional increments of length. Eventually the strains were equivalent to a stress of compression of 19,800 pounds per square inch, the strip then having been reduced to a thickness of about one-fourth inch. The final results are entered on the full cross section of the rail, the shaded portions representing the areas of the strip from the head and those of the flanges on which the measurements were made.

Similar measurements were made on the head of the open-hearth rail, the results of which are entered on figure No. 15. This rail in its head had not acquired strains of so high a value as the Bessemer rail. The maximum value displayed was 10,800 pounds per square inch compression.

On figure No. 16 are shown the internal stresses in the flanges of these two rails, taken at places over the ties and between them. The results showed widely divergent states of strain. In the Bessemer rail a maximum value of 19,500 pounds per square inch compression was found, while in the open-hearth rail the highest stress of the present series was displayed, amounting to 31,500 pounds per square inch compression. These values were present in the portions of the flanges which rested on ties. Minimum values pertained to the strips taken from the flanges between ties. In the open-hearth rail the usual state of compression in the flange was reversed to a state of tension in a portion of the rail located between ties.

Two influences are responsible for a modification of the state of strain in the bases of these rails. The rails presented smooth surfaces where they rested upon the tie-plates, while the flanges were bent upward at these places. The smooth hammering of the base would tend to modify the initial state of strain, while permanent bends received by the flanges would likewise disturb preexisting strains. If the smoothness of the base was acquired through abrasive action and not by hammering, a difference in the results would be looked for.

The sections of these rails available at the time of the examination were insufficient to make further observations on the relations between the portions of the flanges over ties and between them. The parts examined were in bad order, in consequence either of permanent bends received at the time of the derailment or previously acquired during service conditions. The long ends of each rail, subsequently inspected, showed similar surfaces and flanges which were bent, but the flanges showed less distortion than witnessed in the fragments which were examined.

The Bessemer rail displayed the higher internal strains in the head, the open-hearth rail the higher internal strains in the base. The influence of unknown antecedent conditions renders it unwarrantable to attempt extended deductions from these few results. It is apparent, however, that internal strains attain values of great magnitude in different parts of the lengths of steel rails; that wide variations may characterize those values in the same parts of the rail in different parts of its cross section; that service conditions influence these results and are responsible for certain erratic results not prevalent in new rails; and, furthermore, it is believed that these phenomena bear definite relations to or are precursors to ultimate rupture of the metal.

Two pieces 5 feet long each were cut from the unbroken ends of the Bessemer and the open-hearth rails and subjected to transverse tests. The rails were placed on supports 24 inches apart and loaded at the middle of the span. One end of each piece was loaded on the head up to the capacity of the testing machine, 100,000 pounds. The rails were then reversed and loaded on the other end, applying a load of 100,000 pounds on the base. The rails endured these tests without rupture. Each piece acquired a permanent set, ranging from 0.04 to 0.08 inch.

The total weight on the drivers of engine No. 6950, which was of the 4-4-2 type, was 103,500 pounds. Evenly distributed this gives a wheel load of 25,875 pounds. The diameters of the driving wheels were 79 inches. From the above results it appears that each rail sustained without fracture a concentrated load nearly four times the wheel load of the engine involved in the derailment.

Figures Nos. 17, 18, and 19 show the stresses corresponding to the strains in three rails which were progressively gagged and by such means developed transverse fissures. Photomicrographs appearing in another part of this report refer to one of these rails, which was reversed 1,483 times in the gagging press. The second rail was reversed 1,845 times, the total number of blows struck per full rail length being 109,000. The third rail was subjected to the same process of gagging, the exact number of blows not being known, but approximately the same as in the other two. Arrows on the cross sections indicate the directions in which the rails were last bent, prior to this examination.

The internal strains varied according to the distance of the elements from the neutral axis, shown by the detached strips assuming curved shapes. Two values of the strains are entered on the cuts for some of the strips. The higher values refer to chord measurements, the lower values when the strips were forcibly held straight. The results on the chord measurements more nearly represent the internal strains of the surface metal than those based upon the straightened strips.

It will be noted that the internal strains in the strips taken from the tops of the heads of the first and second rails were of tension; that is, opposite in direction to the last overstraining load. The resilience of the rail when the overstraining load is removed causes this reversal of strains in the outside fibers. The fibers on the compression side of the rail acquire a state of internal tension, while those on the tension side acquire a state of compression. The fibers nearer the neutral axis, which are not overloaded, maintain the state they were in while the bending load was acting on the rail. This explains the apparent paradox of fibers at the surface on the compression side of a bent bar displaying internal strains of tension and those on the tension side a state of compression. When such strips are detached they do not tend to straighten themselves, but increase their curvature.

The internal strains in the segregated rail, after normal cooling on the hot bed, are given in their equivalent stresses on figure No. 20. The strains were not of unusual magnitude, showing substantially the range which is expected in rails of normal composition, of this weight and section.

SUMMARY

The initial point of rupture in the track was not regarded as being definitely indicated by the circumstances attending the derailment, nor displayed on the fractured surfaces of the broken rails. The initial points of the individual lines of rupture were clearly shown, but without establishing their order of sequence.

It is believed, however, that the track failed first at the joint between the two rails, structurally the weakest place under normal conditions, and which in this case was below normal strength. Evidence on the fishing surface of the Bessemer rail proved that the inner splice bar was broken prior to the derailment, leaving the joint with only the strength of the outer bar, while the outer bar itself had two independent cracks in it prior to this occurrence.

Subsequent inspection revealed 25 cracked splice bars in the track in this vicinity, representing incipient or complete lines of rupture having their origins at the spike slots, and two cracked bars, one in the eastbound and one in the westbound tracks, having cracks starting at their upper edges opposite the rail ends. Figure No. 21 shows the appearance of the halves of the outer and inner bars which were over the Bessemer rail. The location of a spike slot in close proximity to a bolt hole undoubtedly makes a line of weakness at that place, and the general display of cracked splice bars in the track is significant of less strength at the joints than service conditions call for.

The investigation further developed that the running surfaces of these ~~rails were~~ in a disturbed condition. Each showed the effects of the slipping of driving wheels upon it, this slipping causing sufficient heat to result in the formation of a zone of hardened steel on the top of the head of each rail. Fine thermal cracks divided this hardened metal into small areas, which did not, however, penetrate the rail deeper than the hardened zone, in the fractures which were developed at the time of the derailment, nor in the subsequent examination except in two cases of about one-eighth inch each. While this depth of penetration was not sufficient to weaken the rail below the strength required to support the train loads, the extension of these thermal cracks would undoubtedly cause such a reduction in the strength of the rail that failure from this cause would ultimately result under normal conditions of traffic. That it did not do so on this occasion does not lessen the danger which attends the formation of thermal cracks in rails.

Tests were made upon the remaining portions of these rails, in which they were loaded with 100,000 pounds each on a 24 inch span and which they successfully sustained, with only a slight permanent set. This concentrated load was nearly four times the weight per driving wheel of the engine which was involved in this accident.

The general weakness of the joints and the preponderance in strength of the rails, as shown in the testing machine, justifies the conclusion that the immediate cause of the derailment was the weakness of the splice bars at the joint between the two rails, and the fractures of the rails occurred later and were incidental to the initial break at the joint.

The numerous rails at the present time in railroad track which have the outward appearance presented by these rails would make the question of safety one of very grave concern, if the margin in strength of a rail is immediately lowered to the danger limit by the slipping of wheels upon it. This matter is one of such importance that further inquiry should be made into this common defect acquired by rails in the track.

Respectfully submitted,

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