INTERSTATE COMMERCE COMMISSION.

REPORT OF THE CHIEF OF THE DIVISION OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE WESTERN MARYLAND RAILWAY NEAR YORK ROAD, PA, ON JANUARY 7, 1916

JUNE 19, 1916

To the Commission

On January 7, 1916, there was a derailment of a passenger train on the Western Maryland Railway near York Road, Pa, which resulted in the injury of 1 employee and 2 passengers   After investigation as to the nature and cause of this accident, I beg to submit the following report

Westbound passenger train No 7 consisted of 2 express cars, 1 combination car, 1 coach, and 2 sleeping cars, hauled by locomotive 201, and was in charge of Conductor Fauver and Engineman Gutshall   It was en route from Baltimore, Md, to Pittsburgh, Pa, when it was derailed near York road at 10 47 p m while traveling at a speed estimated to have been about 40 miles an hour   The entire train was derailed, with the exception of the locomotive and the rear truck of the rear sleeping car, but none of the equipment was seriously damaged, while the track was torn up for a distance of about 350 feet

This part of the Western Maryland Railway is a single-track line. No block-signal system is in use, trains being operated by time-table and train orders   The accident occurred on tangent track at a point nearly 300 feet beyond the western end of a curve of 1° to the right, this curve being about 1,300 feet in length   The track is laid with 90-pound rails, 33 feet in length, single spiked to about 18 oak ties under each rail, ballasted with stone   No tie plates or rail braces were in use at the point of accident   The weather was clear

An examination of the track showed that the derailment was due to a broken rail located on the north side of the track This rail, which was a 90-pound rail, 33 feet in length, manufactured by the Maryland Steel Co, was rolled in December, 1905, and was originally laid in tangent main track in 1906 In September, 1915, it was removed and on account of showing little wear was shipped to Hanover, Pa for use as a second-hand rail and about December 20, 1915, it was placed in the track at the point where it broke on the day of the accident

A portion of the receiving end of the rail about 11 feet in length was broken into many pieces, of which 56 were recovered There was an old split extending nearly through the head of the rail, and the head was split loose from the web at the receiving end The last fracture did not show any evidence of a split Several small pieces of the broken head also showed evidence of a split, this split being near the outside of the head At a point about 3 feet 6 inches beyond the break the rail was cut in two and the metal at this point appeared to be sound
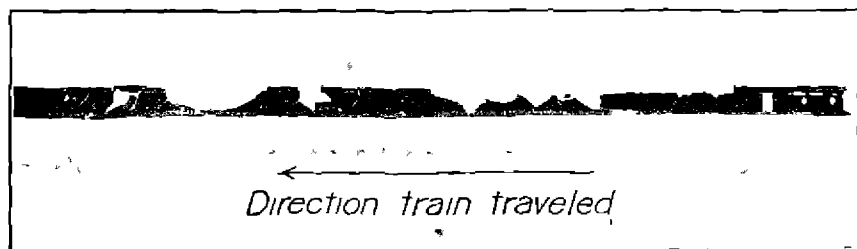

Fig No 1 —General view of fractured rail

Locomotive 201 is a Pacific type locomotive, with a weight of 156,-000 pounds on the driving wheels The engineman in charge stated that he had not noticed anything wrong with the track as the locomotive passed over it, while nothing wrong was noticed when the last train previous to train No 7 passed over the track The preceding train was an eastbound freight train, which passed at about 9 35 p m

The examination of this rail for the purpose of determining the reason for its failure was conducted by Mr James E Howard, engineer-physicist, tests being made at Sparrows Point, Md , in conjunction with representatives of the Western Maryland Railway and the Maryland Steel Co , the manufacturers of this rail The report covering the results of this investigation is as follows

REPORT OF ENGINEER-PHYSICIST

The derailment of train No 7 was caused by the fracture of a rail of 90 pounds weight, A S C E section, rolled by the Maryland Steel Co in December, 1905   It was an " A " rail, as regard its ingot position, from heat No 15694   The receiving end broke into a large number of fragments, of which 56 were recovered

The primary cause of failure was the presence of a split head, which had reached an advanced stage of development prior to its complete fracture under this train   Secondary lines of rupture were developed at the time of derailment, the latter separating the metal of the web and the base at a considerable number of places Short pieces of the head, web, and base were broken off in succession by the wheels of the train, after the initial break was made by the forward part of the train, and presumably by the engine
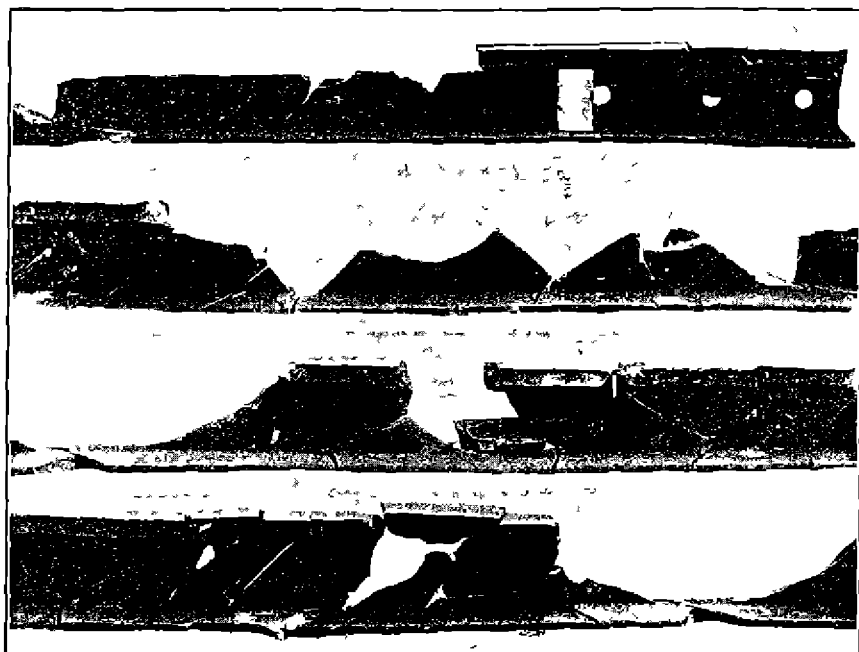

FIG No 2 —Fragments of rail, detailed views

Figure No 1 is a general view of the fractured portion of the rail, taken from the gauge side   The fragments, on a less reduced scale, are also shown by the group of figures in illustration No 2 Such of the fragments as admitted of being assembled in their relative positions are shown in these two illustrations

The fracture of the rail occurred at its receiving end   The splice bars held the fragments at the extreme end in place, beyond which the fracture of the rail was complete   An opening was here made in the track, through which the derailed portion of the train passed   The section fractured was 11 feet long, of which length 8 feet showed the presence of a steam in the head   The shape of the fragments, in cross section, indicated that the origin of the split was in the upper part of the head, a short distance below the running surface   Individual fragments indicated that the split had been a progressive one, extending downward toward the web, and traveling lengthwise the rail from some definite although unidentified starting point   The recovered fragments were insufficient to admit of recognition of the incipient place of rupture

A polished and etched cross section of the rail displayed markings characteristic of seamy steel, that is, acicular lines of structural unsoundness when viewed on end   Such seaminess is recognized as a common cause, leading to incipient separation of the metal, and eventually resulting in split heads and certain base fractures   These acicular lines are disposed parallel to the length of the rail   Some have considerable length, while others are short but associated with each other in such close proximity as to appear as continuous streaks, which at times are several feet in length   Their presence does not impair the ductility of steel, when strained in the direction of their length, but against deformations in a crosswise direction they have a decided influence in lowering the ductility of the steel

By reason of structural weakness and loss in ductility crosswise such streaks, opportunity is afforded for the starting of longitudinal fractures when lateral flow of the head of the rail occurs under the action of wheel pressures   Fractures of this kind have been found in an incipient stage in planing away the metal of the heads of rails, at a period of development much earlier than would admit of detection from surface indications   This evidence, acquired from the metal of the interior of the rail, confirms the conclusion that streaks of structurally weak steel are contributory causes to split heads and certain base fractures   The zone in which these streaks are present is located a short distance below the surface and parallel to the periphery of the rail   Streaks are found in the head, web, and base   Their symmetrical arrangement suggests a common origin which is attributed to ingot conditions, an inference which is supported by the results of the examinations of ingots and derivative shapes   Small blowholes in the ingot, with or without the presence of slag inclusions, suggest themselves as primarily responsible for the structural state witnessed in this rail

Interior seams, as well as surface defects, are of more serious import in hard steels than in mild grades of metal   Steel enriched in carbon and other elements—that is, segregated metal—is not held directly responsible for the formation of longitudinal seams, the origins of which are traceable to the presence of lines of structural weakness, although structural weakness, whether in acicular lines or planes of appreciable width, associated with hard steel, is regarded as an unfavorable combination   Minor defects in structure which are negligible in soft steel become a menace in hard steel   The conditions of service have much to do in defining what constitutes a serious defect in the metal, the need of structural soundness increasing as the stresses in the rails increase in magnitude and in the number of times the loads are repeated   The relations between structural defects and the grade of steel increase in importance as harder steels are used

The period in the process of steel making during which streaks have their origin, being confined to the ingot, as it is supposed, their elimination, partial or complete, is a metallurgical problem   Whatever difficulties interpose, streaks of this kind should not find their way into finished rails in greater degree than the state of the art renders unavoidable   Specific information on the condition of the steel before it is rolled, and in the early stages of rolling, before these acicular lines are developed by the reductions of the rail mill, constitutes information which is demanded   A physical state is displayed by the metal in the finished rail which is recognized as a common cause in many failures

Concerning the detection of rails in the track in which split heads are in process of development, they admit of recognition but at a late period   A general increase in the width of the head is one of the indications of a split head   The width of opening of an interior seam is closely represented by the gain in width of the head   The depth of the seam is many times its width   The head may be far advanced toward separation when its increase in width is first noticed   The formation of a fin along the edge of the head, from the lateral flow of the metal at the immediate surface, will not be mistaken for evidence of a split head, the general width of the head remaining unchanged   Other indications of split-head fractures consist of a slight depression along the middle of the top of the head, or the presence of a dark streak at that place, also local sags in the head, as seen from the side of the rail

Figure No 3 shows the appearance of the top of the head of the present rail at a place just beyond the splice plates, at the receiving end   The recovered fragments from this part of the rail included both sides of the head   This permitted the placing of the fragments

together and photographing them in approximately the relative positions they occupied before rupture was complete   There was a dark streak along the middle of the running surface about 0 60 inch in width   The general increase in the width of the head was 0 13 inch   Unruptured metal, about $\frac{1}{16}$ inch in depth, between the running surface and the seam appeared to have existed prior to the time of derailment   Evidence was to the effect that surface indications of a split head were visible preceding the time of derailment
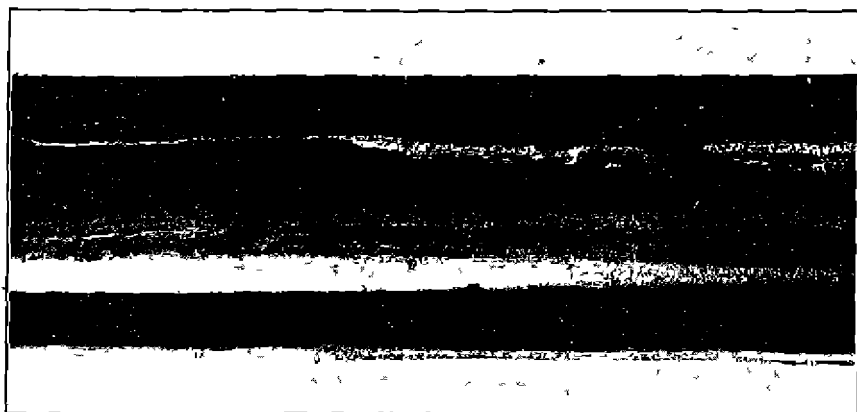

Fig No 3 —View of head of fractured rail, showing dark streak along the middle of the running surface

Two features are brought into prominence in considering the primary cause of the derailment and the circumstances attending it, first, the need of eliminating interior structural defects in the steel, and, second, employing close scrutiny in detecting early indications of defective rails in the track

In the investigation of rail failures, it is essential to inquire into conditions associated with those which have led to specific failures During the present examination supplementary data were acquired upon the state of internal strains and stresses which affect rails and which must be taken into consideration in judging of the total stresses which rails are being called upon to endure while in the track   These initial strains, markedly pronounced in steel in the form of rails under current methods of fabrication, are to all appearances just as real as the direct strains which attend the passage of a locomotive over the rails   The total stress in the steel is the sum of these strains which include the cooling strains of fabrication, the cold rolling strains in the head resulting from successive wheel pressures on the running surface, and the direct bending loads which are present when the locomotive and train are supported by the rail The magnitude of the stress is the algebraic sum of these several components, since the direct loads of the equipment cause reversed

stresses of tension and compression, according to the position of the
wheels, with reference to any given place on the rail

The state of the initial strains in the present rail was ascertained
in a section taken from the receiving end, just beyond the last frac-
ture made at the time of the derailment, also in a section from the
leaving end of the rail, each section being examined in the condition
it was left by the derailment   A duplicate section was taken from
the receiving end, which was annealed before its examination   In
addition, pieces of new rails were examined for the purpose of
ascertaining the primitive strains acquired during fabrication, those
resulting from accelerated and from retarded rates of cooling, the
residual strains after annealing, also measuring the modified strains
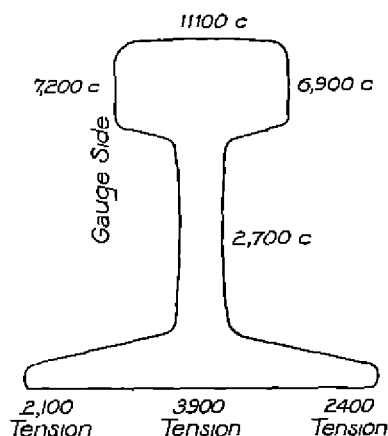in sections which had been gagged   A few observations were made,

FIGURE No 4 —Cross section of 90 pound rail   Stresses corresponding to the initial
strains in section of rail near its fractured receiving end

illustrating the manner in which exposure of the base of the rail to
heat affects the head, the expansion of the base by rapid heating,
momentarily causing contraction of the upper elements of the head

Referring to the rail which caused the present derailment, the
stresses corresponding to the strains which were present in the rail
near its fractured receiving end are shown on figure No 4   There
was a maximum stress of compression of 11,100 pounds per square
inch at the top of the head   The sides of the head and the web were
each in a state of compression   It will be noticed, however, that the
edges of the flanges were in a state of tension, an unusual circum-
stance, which requires explanation, since the flanges are also expected
to be in compression when normal cooling strains of fabrication alone
are present

At the time of derailment the receiving end of this rail was subjected to bending stresses of unusual degree. Pieces were broken off in succession by the hammering of the wheels of the train after an opening had been made in the track. In consequence of this the overhanging end was bent downward, overstraining the rail and resulting in the reversal of the strains in the flanges from a primitive state of compression to a final state of tension. It has been previously shown that in bars similarly bent the final initial strains in the outside fibers are the reverse of those present while the bending load is acting, that is, strains of tension are left on the concave side of the bent bar and those of compression on the convex side. The understrained metal, lying near the neutral axis, remains unchanged, that is, with compression on the concave side and tension on the convex side of the bend. This modified state of initial strains in bent
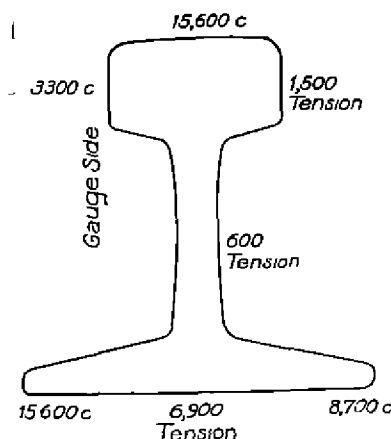

FIGURE No 5 —Cross section of 90 pound rail   Stresses corresponding to the initial strains in section of rail near its leaving end

bars is again referred to, since the apparent anomaly of strains of tension being on the inside of a bent bar, and compression on the outside, is a matter at times misinterpreted

The final state of strain existing in this part of the length of the rail is taken to be a reliable record of the vicissitudes through which it passed at the time of the derailment. The tensile stresses in the flanges are consistent with the conditions which attended its fracture

Figure No 5 shows the stresses which were present in the section taken from the leaving end of the rail. In this section the initial strains were more nearly normal to rails which have been exposed only to usual track conditions. It is believed, however, that this portion of the rail was subjected to an unusual load at the time of derailment but of lesser degree than the receiving end. Records

of initial strains furnish reliable evidence of a permanent character upon some of the conditions attending the previous treatment of the steel   The complex conditions which affect rails frequently render their interpretation difficult, and, with present knowledge, at times impracticable

The third section from the fractured rail was annealed   The results appear on figure No 6   The initial strains throughout were of moderate degree. showing a decided reduction below those witnessed in the other two sections and below those generally in rails of similar dimensions and weight   The effect of annealing is to efface initial strains, the magnitude of the primitive strains and the annealing temperatures being factors which influence the results

Observations were continued upon a series of seven sections of 85-pound rails, those having rather thin flanges, of the type known
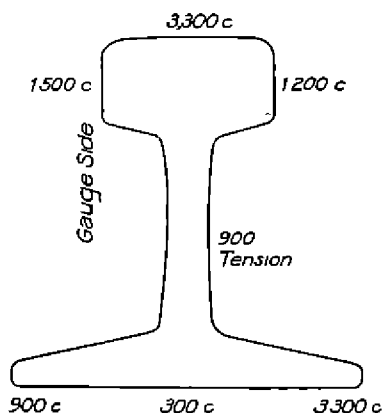

FIGURE No 6 —Cross section of 90 pound rail   Stresses corresponding to initial strains in section of rail near its receiving end after annealing

as the Dudley section   New rails were used in which the strains were measured due to cooling under normal conditions, those resulting from an accelerated rate of cooling, and those from a retarded rate of cooling, also strains which remained in the rail after annealing and the strains as they were modified by the operation of gagging

The section which represented the normal rate of cooling was taken from the end of a rail which cooled in the usual manner on the hot bed of the rail mill   The section of accelerated rate of cooling was cooled rapidly by a blast of air directed upon it by a hose, the air being applied immediately after the section came from the hot saw, and continued until the section was cool enough to handle. The section of retarded rate of cooling was buried in dry ashes, in

company with two other sections, each taken immediately after hot sawing   The two additional sections were placed in the ashes in order that the increased volume of metal might aid in accomplishing a slow rate of cooling

The gagged sections were taken from a rail which cooled normally on the hot bed

Diagrams are inserted showing the stresses which corresponded to the initial strains observed   Figures Nos 7 to 13, inclusive, on diagram A, show the final results on the 85-pound rails   Figures 7, 8, and 9, lettered " a " to " d," on diagram B show the strains in three of the sections at each of the intermediate stages of the examination

Under the normal rate of cooling, as shown by figure No 7, the stresses of compression in the flanges were found to be 16,800 and 18,300 pounds per square inch, respectively, with a tensile stress of 4 800 pounds in the elements along the middle of the width of the base   Lower stresses prevailed in the head, the maximum compression there being 6,900 pounds per square inch   The thinner metal of the flanges permitting a more rapid rate of cooling accounts for the difference in the initial strains in the head and the base   The total range in stresses in the base, those of tension plus those of compression, were 23,100 pounds per square inch

Under the conditions of accelerated cooling, as shown by figure No 8, the initial strains were much increased, particularly in the thinner parts of the web and the base   The maximum compression in the flanges rose to 33,300 pounds per square inch, with tension along the middle of the base of 19,200 pounds per square inch   The total range in stresses in the base was therefore 52,500 pounds per square inch   The metal at the middle of the web showed a compressive stress of 11,400 pounds   Less pronounced effects were found in the metal of the head, each gauged length of which, however, showed higher results than in the normally cooled section

The section of retarded rate of cooling, figure No 9, showed moderate initial stresses along each of the elements examined which did not materially differ in magnitude from those of the annealed section, figure No 10   The results upon this section furnish data concerning the period in the fabrication of the rail when the initial strains are acquired   It appears that initial strains are chiefly acquired during the period of cooling, succeeding the last pass in the rail mill   The reductions in the rolls, occurring at a time when the metal is plastic, do not appear accountable for the final strains which are in the rails   The difference in the rate of cooling of the thick and thin sections of the rail chiefly influences the results   Sections having thin flanges may be expected to display greater initial strains than those with heavier bases

Steel is susceptible of acquiring initial strains by rapid cooling from higher temperatures, which slow cooling ameliorates   A state of complete repose, in which initial strains are entirely absent, is not practical to reach in rolled and forged shapes   The shape of a steel rail is one that readily acquires internal strains, which weight and dimensions of section modify

The effects of gagging are shown by figures Nos 11, 12, and 13 It has been remarked that initial strains of tension or of compression may be introduced at will on one side or the other of a bar, according to the direction of the bending load   It follows that a modification of the initial strains in a rail may be effected in a similar manner by cold bending   The strains introduced during cooling admit of being disturbed and even reversed by gagging

The reversal of the strains in the top of the head from a state of compression to that of tension is shown in the results entered on the diagram, figure No 11   It also appears that a state of reduced strain was effected in the metal of the base   Stresses of 1,200 pounds tension and compression, respectively, were displayed by the flanges of the section that was gagged in two directions, figure No 13, against a maximum compression of 18,300 pounds per square inch in the section normally cooled

The initial strains pertaining to the sides of the head of the rail represent the mean effect on strips of the full depth of the sides The influence of position of the metal with reference to its distance from the neutral axis is a factor to be considered in judging of the effects of gagging   The results on these strips, the sides of which were at varying distances from the neutral axis, will therefore be taken as representing mean stresses   The opposite edges of the strips were doubtless affected by strains of different degrees of intensity

These gagged sections were found to have strains present of diminished magnitude over those in the section of the rail which cooled normally   The operation of gagging, in so far as it related to these sections, was therefore an ameliorating process rather than one which increased the intensity of the strains in the surface metal of the rail   The rate of change in the intensity of the initial strains, in passing from the periphery of the rail toward the center of the section, probably differs according to the volume of the rail and its rate of cooling, differing also in rails which are gagged and in the cold-rolled metal of the head

Each change in cross-section dimensions, occasioned by detaching individual strips, was attended with a rearrangement of the initial strains in the remaining portions of the rail   The removal

of a strip of metal from one portion disturbs the state of equilibrium previously existing and causes measurable changes in the adjacent parts of the rail, and in many cases changes that are measurable in each of the remaining parts of the section   The rails were examined at each of the intermediate stages, during which the several strips were being detached   The results obtained on three of the sections are introduced in this report, on diagram B

Figures 7a–d show the strains released when the section, which was cooled normally, was cut up for examination   The shaded parts indicate the cross section of the rail at successive stages, while the figures affixed show the total strains which were released at each of those stages   Referring to these results, it was found that when the side strips were detached from the head of the rail they expanded 0 0015 inch and 0 0017 inch, respectively   The removal of metal in a state of compression permitted the strains in the remaining part of the cross section to readjust themselves, in consequence of which the metal along the top of the head contracted, the strain there displayed being 0 0011 inch   All measurements refer to original gauged lengths of 10 inches each   When the strips from the flanges were detached they expanded 0 0056 inch and 0 0061 inch, respectively   The metal along the middle of the base at this stage showed a contraction of 0 0010 inch   Upon a further reduction of the width of the base to 1 inch the total contraction increased to 0 0031 inch   The maximum observed contraction at the middle of the base was displayed before the thin strip 1 inch wide was detached from the lower surface   There was a recovery of 0 0015 inch, leaving a final contraction of 0 0016 inch in the detached strip   This result indicated that a higher state of tension existed in the interior portion of the rail at the junction of the web and base than pertained to the surface metal   Indications of this kind enable the presence of strains in other parts of the rail to be recognized, of greater intensity than those in the particular parts included in the measured strips

In the metal of the head a reversed movement occurred which reduced the first measured change of minus 0 0011 inch to minus 0 0009 inch and then to minus 0.0005 inch   Finally, the strip from the head expanded to 0 0023 inch above its primitive length Changes in the web also occurred during these reductions in cross-section dimensions, which are shown on the diagram

In the section of accelerated rate of cooling, the initial strains were greater, and their changes during readjustment were more pronounced than in the section of normal rate of cooling   At the top of the head the successive strains were contractions of 0 0016 inch, 0 0010 inch and 0 0008 inch, respectively, with a final movement of

expansion of 0 0024 inch when the strip was detached, thus display-
ing a total range in plus and minus directions of 0 0040 inch   This
range is equivalent to a stress of 12,000 pounds per square inch

In the thinner parts of the base, where the initial strains greatly
exceeded those of the head, the successive changes were greater, and
the total range in the stresses was also greater than in other parts of
the cross section   In plus and minus directions the range in stresses
in the base amounted to 52 500 pounds per square inch

The progressive and total strains displayed by the section of
retarded rate of cooling were of moderate extent   The latter sec-
tion furnished an example, illustrating common knowledge, that steel
slowly cooled does not acquire high initial strains

Strains may be eliminated, or at least partially, by annealing,
effacing in part those which had been acquired, and also, by slow
cooling from the temperature of rolling, they may in part be pre-
vented from forming   While the steel is in its plastic state, at rolling
temperatures, initial strains can hardly exist of substantial amount
The period when they are acquired is at lower temperature, after the
metal has reached a state of partial rigidity   The capacity for re-
taining initial strains is apparently controlled by the elastic limit
of the steel   If the metal is allowed to cool after any of the passes
in the blooming or rail mill it would then acquire initial strains
These earlier shapes have displayed initial strains when cold, but
of lesser degree than witnessed in the finished rails

A distinction must be made between the amount of extension or
compression which may be given the rail by the process of gagging,
and the initial strains which result therefrom   The capacity for
initial strains is necessarily limited to the elastic limit of the metal—
that is, the initial strains in an ordinary rail can hardly be greater
than represented by two-thousandths of its length, the strain cor-
responding to an assumed elastic limit of 60,000 pounds per square
inch, whereas the total extension or compression from gagging may
be any reasonable amount—several times the amount of the initial
strain which results therefrom   In respect to the amount of exten-
sion or compression given the rail, gagging is not the same as peining
the surface, nor the same as the cold rolling effects of wheel pres-
sures, each have their own characteristics

It is necessary to refer to these matters at length in order that at
least some of the governing principles may be made clear   They do
not admit of brief mention, and yet a discussion covering only the
main features might seem prolix   It is believed, however, that the
importance of the subject is such as to justify presenting the details
at considerable length

The normal stresses which affect rails—that is, the direct bending stresses from wheel loads—cause unit stresses considerably higher than engineering practice prescribes for use in permanent structures, and to these direct stresses the initial strains must be added to show the total strains and stresses in the rails   Initial strains have not generally been given due consideration   They have not even been measured in many instances   The present determinations and those of earlier reports show the initial strains to be of magnitude approaching or even exceeding at times the direct bending stresses of the train loads

The susceptibility of steel to receive initial strains, long known to be a fact, is clearly shown in the present examination and those of earlier date   It has been shown by many tests that steels may be ruptured by repeated stresses, unaccompanied by the display of ductility, and that fewer repetitions are necessary to accomplish rupture in proportion as the loads are increased, furthermore, that the characteristics of initial strains are the same as those due to external loads   These considerations make it necessary to take into account the magnitude of the initial strains as having an influence upon the ability of the steel to endure repeated loads with safety Internal strains from cooling at time of fabrication and those from cold rolling in the track are not negligible factors

Referring to the measurements which were made on pieces of rails when gagged the results of which appear on diagram C Rails of 100 pounds weight, A R A –B section, were employed Rail A figures Nos 14a–d, was first gagged on the head, causing a permanent set of compression on the top of the head of 0 0081″, with an attending set of extension on the base of 0 0041″   The rail was reversed and gagged on the base   The permanent sets were accordingly reversed, the head now being extended and the base shortened   This was followed by regagging on the head   The amount of gagging was about the same as that normally given in the regular work of rail straightening   Repeated gagging is believed to be accomplished with less mechanical work than that required on the first occasion   This impression is held by those at the gagging press and is consistent with the known reduction in the elastic limits caused by overstraining the steel and consistent also with observations which have been made on the power required to drive shafting, rotated under overstraining loads. Progressive fractures are not started necessarily at this stage, the reduction in resistence to gagging being attributable to the lowering of the elastic limits of tension and compression and the slight attendant reduction in the value of the modulus of elasticity   The portion of the cross section of the rail near the neutral axis is not overstrained by gagging, hence it is

the behavior of the fibers which are remote from the neutral axis that accounts for the reduction in the amount of bending force required in the case of repeated gagging

In both of the gagged rails, A and B, it will be noted that the permananet sets in the head were greater than those of the base This result occurred regardless of whether the sets were of extension or compression   Differences in the physical properties of the thick and the thin sections of the rail, and in the primitive initial strains from cooling doubtless influence the relative display of sets in the head and the base   The measured extensions and compressions of the metal upon reversal of gagging operations furnishes evidence that the length of the rail over all does not undergo any decided change in length in consequence of gagging   Gagging beyond the gauged length, on each end, was done without causing measurable change within the gauged length

The longitudinal effects of gagging are, of course, greatest in the outside fibers of the rail   The interior fibers are strained in a lesser degree than those at the top of the head, or along the lower surface of the base   While any straining beyond the elastic limit of the steel may be considered as having a detrimental tendency, and if long continued would eventually end in rupture, nevertheless the overstraining of rails for the purpose of straightening them, by loads once applied, and of a magnitude causing permanent extension amounting to only one-tenth of 1 per cent, should not seriously affect a grade of steel which is suitable for rails

In a crosswise direction, the effect of the plunger of the gagging press, according to the testimony of those in position to make frequent observations does not cause material visible deformation

Rails are at times subjected to rapid heating by the slipping of wheels, resulting in "wheel burns," so-called   Momentarily a state of strain is set up which is modified as soon as the transmission of the heat wave has time to take place   There is a wide difference in the rate of transmission of such heat waves and the transmission of the strains which are caused by the sudden application of heat to the surface of the rail   The treads of wheels and brake shoes are affected in this manner more frequently and with greater severity than in the case of rails

The display of elastic extension or compression takes place with rapidly applied loads without noticeable lag, when the stresses do not exceed the elastic limit of the steel   Observations on this feature have been made with speeds of loading up to about one hundred and fiftieth of a second, and from zero load to a maximum tension or maximum compression of 40,000 pounds per square inch   The transmission of heat waves, on the other hand, is very sluggish, in a

compaiative sense Heat suddenly applied to one surface of a iail will momentarily cause a reveised strain in the opposite face, before equalization of temperature occurs Heating the base of the rail and extending the metal on that side will momentarily cause a shortening of the rail along the top of the head and this will be maintained until the heat wave is transmitted and the temperature of the iail is approximately equalized after which the top of the head will, of couise, lengthen

The results entered on the diagram herewith show the contractile movements observed when a rail of 100 pounds A R A -B section was placed upon a hot billet The first observation showed a contraction of 0 0003 inch, the second a contraction of 0 0005 inch, and the third a contraction of 0 0006 inch, the rail remaining on the hot billet different inteivals of time Between each obseivation the rail was cooled The maximum contraction mentioned corresponds to a stress of 1,800 pounds per square inch When the heat wave reached the top of the rail an expansion necessarily took place The final observation was made after the rail had rested on the hot billet for a period of 15 minutes The expansion at this time was 0 0125 inch, which increased to 0 0155 inch five minutes later, the rail in the meantime having been iemoved fiom the source of heat During a portion of the time of these observations the metal at the running suiface of the head was in a state of compiession Accoiding to the shape of the section, or the point of application of the heat, the adjacent paits of the rail might temporarily be put into eithei tension or compression Rails, wheels, and brake shoes pass through thermal changes of this kind, which contribute their share in augmenting the direct strains of service.

A general summary of the results of the measured strains which were found in the several sections is shown on Table No 1

TABLE No 1 —*Initial strains in steel rails*

[Stresses pounds per square inch, corresponding to measured strains Compressive stresses in ordinary faced type Tensile stresses in heavy faced type]

Description	Head			Web	Base		
	Side	Top	Side		Flange	Middle of width	Flange
90-pound rail, Western Maryland							
Fractured end	7 200	11,100	8,900	2,700	**2,100**	3 900	**2,400**
Leaving end	3 300	15,600	**1 500**	600	15 600	**6,900**	8,700
Fractured end, annealed	1,500	3,300	1,200	**900**	900	300	**3,300**
85-pound rail, new							
Normal cooling	4,500	6,900	**5 100**	1,600	16 800	**4 800**	18,300
Accelerated cooling	8 400	7 200	**8 100**	11 400	33,300	**19 200**	31,800
Retarded cooling	3 300	1 500	2,100	**1 800**	300	3 600	300
Annealed	1,500	3 900	1 200	**600**	2,400	4 200	1,200
Gagged on head	5 700	**3 600**	5 400	600	9 900	**1 200**	9,600
Gagged on base	3 000	6 900	**3 600**	10 500	8 400	**3,600**	6,000
Gagged on base then on head	8 400	6 000	**8 400**	4 800	1 200		1,200

The individual strips on which the initial strains were measured were annealed, the results of which appear on Table No 2   They were box annealed at an estimated temperature of 1,400° F   The temperature of the furnace was gradually raised and maintained at the maximum for an interval of 1 hour, after which it slowly cooled, the strips remaining in and cooling with the furnace   The general result of the annealing was a shortening of the strips

TABLE No 2 —*Strips annealed at 1,400° F*

[Contractions on gauged lengths of 10 inches each]

Description	Head			Web	Base		
	Side	Top	Side		Flange	Middle	Flange
	Inch	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
90-pound rail, Western Maryland							
Receiving end (fractured)	0 0027	0 0042	0 0040	0 0019	0 0030	0 0012	0 0057
Leaving end	0069	0059	0089	008ɔ	0043	0047	0038
Receiving end (annealed)	0070	0063	0106	0091	0088	0088	0126
85-pound rail, Maryland Steel Co							
Normal cooling	00ɔ3	0040	0048	00ɔ0	0018	1 0004	0016
Accelerated cooling	0046	0034	0040	0043	0033	001ɔ	0019
Retarded cooling	0030	0030	0035	0037	0037	0015	0028
Annealed	0002	1 0015	0016	000ɔ	0025	1 0008	0021
Gagged on head	0031	0014		003ɔ	0	0	0018
Gagged on base	0009	0022	0014	0036	0021	0025	0022
Gagged on base, then on head	0033	0024	0019	0032	1 0009	0010	0012

1 Increase in gauged length

Certain of the strips were reannealed at an estimated temperature of 1,450° F   The strips were kept in the furnace for a period of 3 days, during which interval the maximum temperature was maintained for a period of about 3 hours each day   Each strip, when cooled, showed additional contraction in length   These strips were again annealed, for a third time, being kept in the furnace for a period of 6 days, raised to and maintained at an estimated temperature of 1,450° F for a period of about 4 hours each day   The strips continued to contract in length, as shown by the measurements taken when they were cold

Table No 3 shows the amount of the shortening of each strip on gauged lengths of 10 inches each, caused by each annealing, and the total amount resulting from the three annealings

TABLE No 3—*Contractions of strips on gauged lengths of 10 inches each, caused by each of 3 annealings, and total contractions resulting therefrom*

Description	Head			Web	Base		
	Side	Top	Side		Flange	Middle	Flange
90-pound rail, Western Maryland, leaving end	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
First annealing	0 0069	0 0059	0 0089	0 0085	0 0043	0 0047	0 0038
Second annealing	0163	0111	0138	0114	0092	0149	0106
Third annealing	0167	0179	0177	0164	0139	0197	0140
Total	0399	0349	0404	0363	0274	0303	0284
85-pound new rail, normal cooling							
First annealing	0023	0040	0048	0050	0018	1 0004	0016
Second annealing	0075	0070	0075	0043	0032	0063	0025
Third annealing	0109	0129	0142	0151	0085	0105	0084
Total	0207	0239	0265	0244	0135	0164	0125
85-pound new rail, accelerated cooling							
First annealing	0046	0034	0040	0038	0033	0015	0019
Second annealing	0107	0087	0077	0058	0045	0073	0048
Third annealing	0121	0126	0113	0117	0071	0102	0062
Total	0274	0247	0230	0213	0149	0190	0129
85-pound new rail, gagged on head							
First annealing	0031	0014		0035	0	0	0018
Second annealing	0062		0068	0052	0030		0020
Third annealing	0111		0127	0125	0069		0057
Total	0204			0212	0099		0104

1 Increase in gauged length

It is seen that repeated annealing of the strips resulted in successively shortening their lengths in amounts which eventually ranged from about one hundredth of an inch to four hundredths of an inch on gauged lengths of 10 inches each   Thus a very material change in this dimension was effected without evidence that the maximum amount had been reached

In order to further illustrate the physical changes to which steel is susceptible a few of the strips were subjected to other treatment for the purpose of reversing the contractible movement of annealing and causing an expansion in their lengths   These strips were heated to a temperature of approximately 1,000° F and quenched in water   The expansions displayed by these strips are shown in the accompanying table, No 4

TABLE No 4—*Expansion of strips, on gauged lengths of 10 inches each, by quenching from a temperature of approximately 1,000° F*

Description	Location of strip	
	Side of head	Edge of flange
	Inch	*Inch*
90-pound rail, Western Maryland, leaving end	0 0018	0 0014
85-pound rail, new, normal cooling	0012	0013
85-pound rail, new, accelerated cooling	0007	0015

The above expansions correspond to stresses ranging from 2,100 to 5,400 pounds per square inch   The equivalent values in stresses which are brought about by such means, modifying the rate of cooling at the time of fabrication of the rail, influenced by the thinness of different parts of the rail section, by heating followed by slow or rapid cooling in the finished rail, or by the cold rolling effects of wheel pressures, emphasize how much should be taken under consideration in addition to the direct stresses of the wheel loads on the rails in the track

Bending tests were finally made on a number of the strips, on those which had been annealed only, and on others which were quenched after annealing   The thinner strips from the head and base were bent cold, through an angle of 180° and closed down without fracture   Strips from the edges of the flanges having the full depth of the base at that place were bent 180° to a radius of curvature of three-fourths inch, also without fracture

The elongation of the metal on the tension side of the curved portions of the flange strips ranged from 12 to 17 per cent in the different rail sections, this extension not exhausting the amount which the steel was capable of displaying

The chemical composition of the rails examined and herein reported upon is shown on Table No 5

TABLE No 5—*Chemical analyses of rails*

Description	C	Mn	P	S	Si	Cr	Ni & Co
90-pound rail from derailment near York Road, Pa							
Top of head	0 596	1 13	0 072	0 057	0 065		
Lower center of head	694	1 15	080	063	068		
Corner of flange	556	1 11	073	061	063		
Mold test	55	1 19	067	069	075		
85-pound new rails, examined for initial strains	653	67	010	048	121	0 33	0 59
100-pound A R A –D new rail, gagging tests	677	69	015	030	125	27	85

In conclusion, it appears that the cause of the failure of the rail, which resulted in the derailment of train No 7, was a split head This was induced by the presence of seamy, acicular metal which was located in a zone a short distance within the periphery of the rail   The seamy metal below the running surface of the head was exposed to lateral flow, the usual effect of wheel pressures   The absence of or impairment of, ductility in the steel, crosswise these seamy lines, led to the formation of incipient cracks, it is believed, which gradually extended until a split head resulted

The presence of seaminess is a structural defect which has its origin in the ingot, the elimination of which is a metallurgical and

mill question   The elimination of seamy steel, complete or partial, will effect an improvement in rails and remove the common cause of many rail failures

The presence of the split in the head of this rail, it is believed, admitted of detection prior to the derailment   The increase in width and the presence of a dark streak along the middle of the running surface were each the usual indications of a split head

SUMMARY

The result of this investigation shows that the failure of the rail which caused the derailment of train No 7 was due to a split head Rail failures of this kind are not of infrequent occurrence, since lateral flow of the metal of the head, the result of wheel pressure leads to this type of fracture   The immediate cause of the disturbance of the metal of the head is therefore the wheel pressures, but back of this is the matter of structural soundness of the steel, which is the vital feature in many instances and is the important one in the present rail   Sound steel will display a certain amount of ductility when tested by tension, and will display a greater amount when cold swaged, cold drawn, or cold rolled—that is, when its own strength is not called upon to cause the extension

In rails of medium hardness fins form along the sides of the head, illustrating the primitive ductility of the steel, the metal which forms these fins coming chiefly from the top of the head   Seaminess of the steel detracts from this ability to flow in a lateral direction hence when the rail contains seamy metal in the head there is a tendency, when strained laterally, to develop incipient cracks which ultimately extend and finally result in split heads   If the surface metal is softer than that of the interior of the head, then such a condition in conjunction with seaminess increases the tendency to form split heads   The real danger, it would appear, has to do with seaminess rather than segregation

The symmetrical arrangement of those marks which appear on the cross section of etched rails and represent seaminess place the responsibility for their presence on the state of the metal in the ingot Investigation has shown that seaminess in the base has the same character as that which is found in the head, and certain base fractures are attributable to such seaminess   In the web, however, less trouble is experienced from this cause   An improvement in ingot conditions should effect an improvement in both the metal of the head and the base, and definite information should be acquired on the structural state of the metal in the ingot in a sufficient number of examinations to fully demonstrate the extent to which the causes of seaminess prevail as well as what remedial measures can be adopted to prevent their recurrence

It is important, as a mill question, to remove the causes of seaminess, while in reference to track maintenance it is necessary to exercise diligent scrutiny in the detection of rails which are failing, and which present evidence of the same by surface indications   This rail apparently displayed evidence of a split head on the running surface prior to its complete failure, in showing a general increase in width, and also in exhibiting a dark line along the middle of the head, the latter being a feature which is commonly recognized as the visible indication of a split head   It so chanced that this was a relaid rail, but that circumstance is believed to have no direct bearing upon its failure

Briefly summarized, it is a desideratum that the causes of seaminess be eliminated from the ingot or elsewhere, if not confined to ingot conditions, but until there is assurance of the elimination of the causes of seams, reliance must be placed on track inspection for the detection and removal of rails having split heads   Since the depth of the seam in the head of a rail is many times its width, the detection of a split head is confined to evidence which is furnished by the lesser dimension of the seam and such inspection becomes essentially, a rigorous matter

This report contains further data upon the state of initial strains which affect rails   Rails are exposed to repeated alternate stresses and it has been shown by laboratory tests that an increase in the fiber stresses of steel exposed to repeated stresses lowers its limit of endurance, which diminishes very rapidly when the loads attain certain limits, that is, when the fiber stresses approach the elastic limit of the metal   It is further known that the direct bending stresses of rails in the track are very high in comparison with the unit stresses which are deemed prudent to use in other engineering structures   The presence of initial strains from cooling during fabrication and those due to the cold rolling action of the wheels on the running surface of the head increase the total stresses of the rails when the wheels are in certain positions   Necessarily, these initial strains should be taken into consideration in judging of the strength and ability of the rails to endure the loads which are imposed upon them in the track   It does not appear, however, that such consideration has been given the subject

The present report also contains measurements on the initial strains in rails under normal conditions of cooling, when the rate of cooling was accelerated, when it was retarded, and strains present in annealed sections   The effects of gagging are also shown   The subject of gagging throughout the history of rail making has been a discursive theme, without attaining definite ends   In respect to the present results the magnitudes of the initial strains in the gagged

sections were found to be lower than those in the corresponding section which cooled normally   In the head, the normal condition of a state of compression was reversed and initial strains of tension were introduced   Laboratory tests of an early date showed such a reversal of strains would be expected as a result of gagging

The report invites attention to the distinction which should be made between the permanent sets of tension or compression which are given the rail by the process of gagging and the initial strains which result therefrom   A few observations were made on the transmission of stresses by heating one part of the rail, the head being shortened by rapidly heating the base   This temporary contraction of the metal of the head was, of course, lost when the temperature of the rail was equalized   The effects of sudden heating have a bearing upon the strains momentarily introduced in rails when "wheel-burns" occur, as well as influencing the strains in brake shoes and the rims and plates of wheels   The transmission of strains occurs immediately, while a slower action attends the equalization of temperature

Respectfully submitted

H W BELNAP,
Chief Division of Safety