INTERSTATE COMMERCE COMMISSION.

REPORT OF THE CHIEF OF THE BUREAU OF SAFETY COVERING INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE CHICAGO & NORTH WESTERN RAILWAY NEAR LEBANON, WIS., FEBRUARY 25, 1918.

DECEMBER 30, 1919

To THE COMMISSION:

On February 25, 1918, there was a derailment of a passenger train on the Chicago & North Western Railway near Lebanon, Wis There were no casualties as a result of this accident After investigation I respectfully submit the following report:

The train involved was northbound passenger train No. 405. known as the "Northwestern Limited," consisting of nine cars, hauled by engine 1612. Train No. 405 was traveling at a speed of about 25 miles an hour when it was derailed by a broken rail at a point about 2¼ miles from Lebanon. Six sleeping cars were derailed but remained upright on the roadbed and sustained only a slight damage to their trucks.

On account of the fact that there were no deaths as a result of this accident no report of it was made to the Commission and no investigation was made by the Commission's inspectors, but on account of the very large number of rail failures of this particular type which occurred on the Chicago & North Western Railway at about that time the matter was brought to the Commission's attention and an investigation as to the reason for the failure of these rails was conducted by Mr. James E Howard, engineer-physicist, whose report is as follows:

REPORT OF THE ENGINEER-PHYSICIST

The rail which failed and caused the derailment of train No. 405, on the Chicago & North Western Railroad near Lebanon, Wis, was a Bessemer rail, 90 pounds weight per yard, type ARA–B, ingot position D, rolled by the Illinois Steel Co. in the year 1912 The brand marks were, "9030 Illinois Steel Co. South Works IV 1912."

A fracture of the base of the rail occurred, a partially developed crescent-shaped break, of the class of breaks commonly called half-moon fractures The origin of the fracture was at a longitudinal seam on the undersurface of the base about midway its width. The line of rupture followed the seam a short distance, then separated into three branches, two of which curved outward and extended to the edges of the flanges, while the third passed upward through the web and the head, thus completely separating the rail. At a distance of 4 feet beyond this point a group of secondary fractures were formed, covering a length of 2 feet. Here the rail was broken into six or eight small fragments. An opening in the track was made by the dispersion of these fragments, directly resulting in the derailment of the train.

Track conditions at the place of derailment were not unfavorable for an occurrence of this kind, the passengers escaping without serious injuries while the damage to the track and equipment was comparatively slight. The type of rupture, however, was one of which there have been many examples, presenting an economic feature of importance, in addition to that of safety of travel. There have been periods in the past in which fractures of this kind seemed epidemic. so many failures having been reported within short intervals of time.

Seaminess of the metal in the base of the rail has been responsible for all or nearly all half-moon fractures. Rails are affected by seaminess of the metal, both exterior and interior, and while the present derailment was the result of exterior seaminess, this report will touch upon both classes of seams, or streaks, as they are sometimes called. Interior seams or streaks are contributory chiefly to fractures of the head of the rail; exterior seaminess to those of the base.

Interior streaks are believed to have their origin in the ingot. Upon this point most opinions are in accord. Divergent views are held in respect to the origin of exterior seaminess, some of which attach responsibility to the surface condition of the ingot; others attribute the cause to some stage in the process of manufacture.

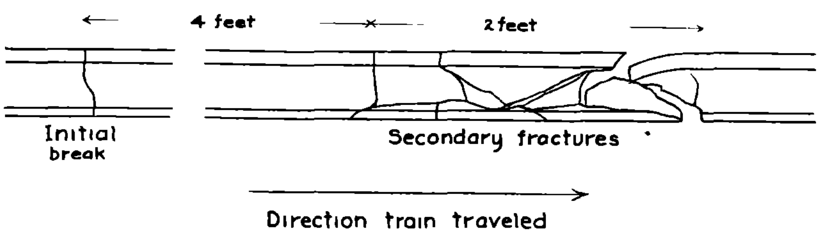

FIG 1—Diagram showing lines of rupture of broken rail

Figure No. 1 is a diagram showing the lines of rupture in the present rail. The initial break, which was a brittle one, and which developed as above described. weakened the rail and led to the formation of the secondary lines of rupture. These are more fully shown by the photographic print reproduced in Figure No 2. The rail displayed toughness in these secondary fractures, illustrating the fact that brittleness and toughness may each be shown by the same rail, depending upon the manner in which rupture is reached

Figure No. 3 represents a vertical, longitudinal section of the head, from the secondary group of fragments, where the rail was bent downward at the time of derailment. The surface photographed was pickled in hot hydrochloric acid developing a fibrous, woody appearance due to interior seaminess of the steel Seamy lines parallel to the axis of the rail appear as curved lines on this figure, corresponding to the bent shape of the fragment. The pickling was done in connection with another accident investigation in which a shattered state of the metal had been found in certain parts of some rails. The affected zones in those rails were along the central parts of the heads and at the junctions of the webs and bases. No evidence, however, of shattered metal was found in this rail.

Figure No. 4 shows a portion of the central seam of the present rail, as disclosed by a test of the flanges. The seam ranged in depth from 0.03 to 0.05 inch. This fracture of the base, under crosswise bending, was brittle, with no display of toughness. The presence of the seam in this part of the rail was not apparent until the test of the flanges was made.

Figure No. 5 represents a companion rail which failed in service, displaying seams in five places along its length. At the place photographed, the seam was visible on the rolled surface for a length of 8 inches. Sections of the base were planed off a few hundredths of an inch in depth, revealing the crack 18 inches long. Cracks are not infrequently of greater length than an inspection of the surface indicates. They may extend a number of inches without appreciable width of opening between their sides. Furthermore, incipient cracks on the underside of the base, due to position, remain unknown until they have reached an advanced stage, until a half-moon fragment is about to be detached or complete rupture of the rail has taken place.

Figure No. 6 is a diagram illustrating the different stages of development of a base fracture. The first stage of development is the formation of a longitudinal crack, shown at figure *a* on the cut. This usually begins at a surface seam. There are few, if any, exceptions to this rule. The seams in some rails may be obscure but nevertheless present Figure *b* of the cut represents a complete half-moon break The central crack is diverted from its course, curves and extends to the edge of the flange. The line of rupture travels from the central seam toward the edge of the flange, never in reverse direction The distance the line of rupture may follow a base seam ranges from less than 1 inch to 2 feet or more Half-moon fragments may be detached from either flange of the base, from the gauge side or from the outside of the rail.

Figure *c* illustrates the type shown at the initial break of the present rail. Lines of rupture branched from the central seam and separated the base These were followed by an upward line of rupture which separated the web and the head. Many breaks of this kind are classified as square breaks in rail failure reports. The cause of rupture is not indicated by such terminology. All rail failures have definite causes, and classifications in rail failure reports are most useful which, in each instance, impart information upon the specific cause of failure.

Other modifications of base fractures are shown by figures *d*, *e*, and *f*. Modification *d* is not unusual; the latter two are less commonly witnessed. Local injury to the edges of the flanges, indentations from hand-car wheels, or abrasion against the shank of a spike lead to square breaks having their origins at the edge of a flange. Such fractures are entirely dissociated from those which are caused by seaminess of the metal.

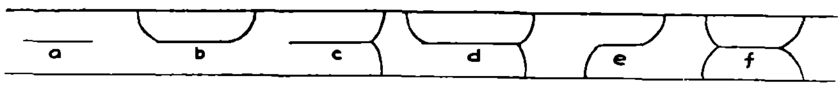

FIG 6—Diagram illustrating the progressive stages of base fractures and modified forms of half-moon breaks

Under normal conditions the incipient portion of a base fracture will form over a tie. Rails are unsymmetrically strained. The coning of the wheels throws the weight on the gauge side of the head, which is transmitted to the inner flange of the base. On the other hand, flange thrusts from the wheels stress the outer flange of the rail. Each flange of the base curls up slightly when the rail is deflected. This local movement in the flanges is probably responsible for rails deflecting a little more under bending stresses than their section moduli call for.

It is not necessary that rails should rest unevenly on the ties in order to induce base fractures. The contention that a crescent-shaped break is prima facie evidence of uneven bearing on the tie is not well supported by observation. The bases of rails are exposed to repeated stresses in crosswise direction as well as longitudinally, tending to result in progressive fractures under stresses below the primitive strength of the flanges.

The presence of a seam of any degree on the surface of the base is a source of weakness, and follows the usual law of being more serious in hard steels than in the softer grades of metal. It is disquieting to note how slight a surface defect may culminate in a half-moon break in current grades of rail steel. The doubt is raised whether they are all of a remediable order. Prolonging the life of the rail by increased depth of metal in the base, a reinforcing measure, suggests itself from an engineering point of view. Metallurgical or fabricating requirements may be compensated for in some cases, but failures of recent occurrence show this would not be a satisfactory method of obscuring such defects. The elimination of surface seaminess should be accomplished, so far as it is practicable.

Base fractures of recent occurrence are numerous. In connection with the present investigation 748 rails were inspected which failed in this manner. Among this number was a group of 224, companion rails of the one which caused the present derailment. Surface seaminess on the base was a factor common to all which were critically examined

These failed rails represented the product of six mills, and had been in service on different divisions of seven railroads. Their weights ranged from 75 pounds per yard to 107 pounds. The periods of time in the track were from 4 months to 13 years. The progressive character of the fractures was equally apparent on those which failed in four months' time as on those of the longest duration in the track

Figure No 7 shows two progressive fractures in the base of a 75-pound rail which occurred over adjacent ties. The fractures were on the same longitudinal seam which extended from tie to tie This strip from the base, 4 feet long, did not include all of the seam Its depth of penetration was about one-tenth of an inch, and of the same depth between the ties as over them The rail had been in the track 12 years

Figure No 8 represents a progressive fracture in the base of a 100-pound rail. This rail had been in the track four months. The fracture started at a surface seam, located near the center line of the base Seams were displayed by companion rails of the same age.

The characteristics of other base fractures inspected were practically the same as those which are here illustrated. Multiplication of examples would serve no other purpose than emphasizing the importance of inaugurating measures to aid in their prevention and reduce their number The elimination of surface seaminess is the ultimate result to be attained.

According to the extent of the seaminess and also influenced by traffic conditions, half-moon breaks occur early or are deferred for a term of years This also is the general history of progressive, fatigue, or repeated stress fractures, by whichever name they may be designated. Lowering the fiber stress invariably tends to prolong the life of steel, regardless of its manner of failure. Increase of section, previously referred to, although not a corrective measure metallurgically, has the advantage of being positive in its character. Still, without resorting to this expedient the variable extent of seaminess witnessed in different rails encourages the belief that substantial improvements in fabrication are attainable.

The cause or causes which lead to surface seaminess is a somewhat mooted affair This defect has been variously ascribed to the original surface condition of the ingot, to the effects of breaking down passes of the blooming mill, to ragging of the rolls, and to an intermediate pass of the rail mill. Testimony has been to the effect that a modification in shape at one of the intermediate passes was attended with a favorable result. Laps in the base of the rail were traced to this particular pass and corrected by diminution of the depth of the concavity in the rolled shape, which in the finished rail had to be filled out to a flat surface.

The sides of seams are frequently blue-black in color, showing their formation occurred during brief exposure to the air when the steel was at an oxidizing temperature Some seams present only slightly oxidized walls, but are lined with the microconstituent ferrite, suggesting the explanation that the walls of the seam were a part of the periphery of the shape at an earlier stage. Pickling in hot acid has brought into view lines of ferrite which by further pickling were converted into open seams. This is not held to indicate necessarily a difference in the rate of solubility of the microconstituents, but attributable to exposure of more area of surface at the seam upon which the acid acted.

The problem of the roll designer is directed to the production of definite finished shapes, the successive reductions from the ingot or bloom being arranged with the ultimate object of getting the metal into the exact cross section prescribed. In attaining this end the peripheral speed of different parts of the rolls vary from top to bottom of the grooves, affecting all shapes except flats, while the rate of travel of the rail as it emerges from a given pass is the same for all parts of its periphery From this circumstance there is, necessarily, a difference in the action of the rolls on different parts of the rail, without mentioning variations in temperature in different portions of its cross section. Taking these matters into consideration, it would appear advantageous to inquire into the influence of the latter passes of the rail mill in quest of contributory causes to the formation of surface seaminess.

Figure No. 9 shows an example of roll markings on the base of a rail, visible effects of differences in peripheral speeds of the rolls

But these markings are dissimilar to the appearance of the metal immediately below the surface. The formation of mill scale, magnetic oxide of tangible thickness, obscures seamy lines, which are revealed by the acid of the pickling bath. The rolled surface of the base furnishes evidence of seaminess in less degree than revealed by pickling. The usual inspection of rails for acceptance does not adequately guard against nor provide for the detection of this common defect. In consequence of this omission rails are inspected, meet the requirements of the specifications, are placed in the track, and promptly fail from seaminess of surface.

The pickling of steel is not a new nor untried requirement in the inspection and acceptance of materials for engineering purposes. In one of the most noted examples of modern engineering construction the pickling of the steel plates was a requirement. The pickling of a crop end of a rail, involving a minimum amount of labor, would reveal the condition of the surface obscured by the mill scale and show whether normal or unusual seaminess was present.

Figure No. 10 shows the bases of two rails, 100-pounds weight per yard, rolled in August, 1918, laid in the track and removed a few months later on account of half-moon breaks. The rolled surfaces on these rails furnished indications of seaminess but in less degree than subsequently revealed by pickling.

Figure No. 11 shows the appearance of the base, after pickling in hot acid, of one of the rails illustrated in the preceding cut. A progressive fracture had formed along a seamy line located near the middle of the width of the base. This fracture is represented by the heaviest dark line on the cut The other dark lines represent unruptured seamy metal.

Figure No. 12 is another illustration of a seamy or rather groovy surface on the base of a rail as it appeared after prolonged pickling The serrations, of a very pronounced order, were of the nature of semicircular grooves rather than sharply defined cracks. This rail was in service about nine years, failing by the development of transverse fissures, of which it displayed 11 in number It showed no crescent-shaped break.

Reentrant angles with rounded corners, as well known, are less menacing to the integrity of the metal than sharp angles The deductions of mathematical analysis concerning the relative intensity of the stresses at such places are confirmed by results experienced in the use of metals

Figures Nos 13, 14, and 15 are different views of the same rail, a 100-pound section, rolled in the month of May, 1918. This rail displayed a split head after having been in service about a year

The appearance of the base, after pickling, is shown by Figure No. 13. Fine seamy lines were distributed over its surface. They were not confined to the under side of the base but were in evidence at the edges of the flanges, on the upper side of the base near the edges and also on the sides of the head. Some wear had taken place on the running surface of the head and no longitudinal cracks or seams were visible thereon.

Figure No. 14 is an end view of this rail showing the split head fracture. Using this cut for the further purpose of illustrating the portions of the periphery of a rail most frequently affected with surface seaminess, circumscribing lines have been drawn thereon, embracing such portions. Between these bracketed portions the peripheral surfaces are commonly smooth and free from seaminess.

The cause of the fracture of this rail is attributed to interior, longitudinal seaminess, illustrated on the cut next following. The incipient point of rupture was about one-fourth inch below the running surface of the head Fractures of this type result from lateral flow of the metal caused by the wheel pressures encountering an interior seam or streak of structurally unsound steel The surface metal acts as a wedge, splitting apart the metal below Interior seaminess weakens the metal against crosswise stresses, facilitating the formation of split heads Provided no interior weakness is encountered the lateral flow of the metal causes only the formation of a rib or fin along the sides of the head. Wheel flanges commonly wear away the inside fin, the outer one remains in place.

A longitudinal fracture in a vertical plane has been given the terminology of a split head. Longitudinal fractures also occur in horizontal or slightly inclined planes, to which no specific name has been given. In the latter type the upper portion of the head is detached from the lower part. Such fractures seldom extend over any considerable length of the rail. They often terminate in the development of a transverse fissure. The transverse fissure does not appear to be a blending or coalescing with the horizontal plane of rupture of the head, but rather exhibits the reverse action, a separation therefrom. In some examples of horizontal shearing fractures, one end branches upward and reaches the top of the head, while the other end branches downward, separating the web and the base. If located in close proximity to the end of the rail a short piece of the head only is detached.

Figure No. 15 is a side view of the rail shown on the base and in cross section on the two preceding cuts, respectively. A fragment 24 inches long was split off the gauge side of the head, disclosing a seamy state in the steel. The seamy lines were of considerable length.

Not infrequently short seams and streaks located in close proximity to each other eventually merge into one long crack several feet in length, even extending from end to end of the rail.

Slag inclusions constitute a prolific source for such seams, to which incompletely welded blowholes contribute their share of responsibility. In the ingot the slag is in globular form. Its presence is not always confined to any one locality but disseminated over different parts of the ignot. In the reduction of the ingot to the finished rail these inclusions are drawn into acicular lines.

When viewed on a polished and etched cross section of the rail these streaks or seamy lines appear as dots or dashes; dots in certain parts of the head and base, and dashes in the web and adjacent parts of the cross section. The direction in which the metal is laterally displaced in the reduction of the ingot has its influence on the shape of these markings. On longitudinal sections they appear as lines running parallel to the axis of the rail. They represent a condition in the structural state of the metal rather than pertaining to its chemical composition as a whole, segregation of some elements being in evidence.

Figure No. 16 shows the appearance of a polished and etched cross section of another rail which displayed a split head fracture. The origin of the fracture is shown to be at a streak. Three drilled holes in the cross section indicate the places where chips for chemical analysis were taken, according to current methods of inquiry. Inasmuch as such failures are due to structural rather than chemical causes, this method of investigation does not commend itself. Attention, preferably, should be directed to casting conditions and the stages of fabrication of the rail.

Returning to the subject of exterior seaminess, figure No. 17 shows the appearance of two new rails after hot pickling. The upper figure of the cut represents a portion of the base of one rail, the lower figure a portion of the head of the other rail. About one-half of the side of each rail was planed off before pickling. The segregation of seamy lines along the middle of the base and their more general distribution over the top of the head is prominently shown The unpickled portions of each rail indistinctly show the presence of some seams, while others are not in evidence.

The state of seaminess revealed by the pickling of these two rail sections might naturally excite distrust in both the head and the base. However, fractures due to surface seaminess in the head, if such there are, are of rare occurrence. Conditions of service which affect the upper surface of the head are quite different in their results from those which affect the undersurface of the base. The malleability of the steel enables the surface metal at the immediate top of the head to respond to wheel pressures. The amount of elongation which steel will display under tensile stress is but a fraction of its capacity for malleable flow. This explains the difference in action between the metal at the immediate top of the head and at the underside of the base.

Touching upon the relations of the passes in rolling structural shapes with the matter of surface seaminess, figures Nos. 18 and 19 illustrate the appearance of the opposite flanges of an 8-inch beam after pickling. Figure No. 20 shows the appearance of three structural shapes after pickling—a 4-inch channel, angle, and beam, respectively. Surface seaminess in the channel was in the vicinity of the junction of the flanges and web; in the angle at the exterior corner, at the junction of the legs; in the beam along each surface midway the width of the flanges.

These descriptive remarks upon the behavior of steel have been extended in order to make clear the distinctions which should be taken into account in judging of its strength and durability according to the intensity of the stresses and the manner of loading. Improvements admit of being made, it is believed, which will prolong the life of the rail and in so doing provide an increased margin of safety which may be retained for a time. Whatever may be accomplished the fact will remain that the controlling feature in rails is found in the manner in which they are loaded. Motive power and equipment are carried on wheels the impinging pressures of which upon the head of the rail are the ultimate limiting factors.

Choice of chemical composition in the adoption of the grade of steel employed is optional, and improvements may be made in producing a rail structurally superior to other rails, but the super rail will nevertheless have its limitations in strength and durability measured by the intensity of the wheel pressures which it will sustain.

The fixing of wheel pressures is under control They may be heavy or light, according to the will of the designer of the rolling stock, the establishing of which loads as such requires no special skill in the mechanic arts. The production of structurally sound steel and its conversion into commercial shapes presents a problem of quite another order, incomparably different from the former. Notwithstanding the great disparagement in size between a locomotive and the rail which supports it, and the seeming inadequacy of the foundation on which the rail rests, very few rails fail by direct bending stresses. Failures, directly or indirectly, are chiefly connected with intensity of wheel pressures. Limitation of wheel pressures and elimination of seaminess in the steel, interior and exterior, are chief factors in the steel rail problem

SUMMARY.

The present accident caused by the fracture of a rail of the crescent-shaped type, was fortunately one of a minor character. The right of way was substantially on the same level as the track, which circumstance and the low speed at which the train was moving at the time were favorable conditions not always present in an occurrence of this kind The type of fracture of the rail is a common one, and therefore possesses interest from both the point of view of safety and from its economic importance The reported number of rail failures due to half-moon base breaks is large As pointed out in the report of the engineer-physicist ambiguity attaches to many rail failures which are reported as square breaks There is reason for believing that an explicit description and report upon those rails which are now classified as square breaks would reveal a larger number of crescent-shaped base breaks than are being reported as such.

All or nearly all base fractures have been found to exhibit an initial seam at the undersurface, along the middle of the base It is clearly evident that the elimination of this initial seam should result in an improvement and prolong the life of the rail Efforts should therefore be directed and maintained to accomplish this result

In order to ascertain the cause of surface seaminess and the stage or stages in the process of manufacture at which seaminess makes its appearance, the pickling of the shapes affords a favorable method of inquiry. It has been found a serviceable method in other branches of engineering, and is no doubt applicable in the case of rails, using crop ends of same There should be definite assurance that rails with seamy bases which promptly fail when they are put into service should not reach the track before the discovery of their condition is made

Respectfully submitted.

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Chief Bureau of Safety.

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