# INTERSTATE COMMERCE COMMISSION

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## REPORT OF THE CHIEF OF THE BUREAU OF SAFETY COVERING THE INVESTIGATION OF AN ACCIDENT WHICH OCCURRED ON THE NEW YORK CENTRAL RAILROAD NEAR WATERLOO, IND., MARCH 21, 1917

DECEMBER 23, 1918.

*To the Commission:*

On March 21, 1917, there was a derailment of freight train NY-4 on the New York Central Railroad near Waterloo, Ind., which obstructed the adjacent track and caused the derailment of passenger train No. 19, which collided with the wreckage a few seconds later, resulting in the death of 1 employee and the injury of 17 passengers and 2 employees. After investigation the Chief of the Bureau of Safety submits the following report:

The Michigan Division of the New York Central Railroad, upon which this accident occurred, is a double-track line over which trains are operated by automatic block signals. In the vicinity of the point of accident the eastbound track consists of 105-pound steel rails joined by 6-hole angle bars, while the westbound track consists of 100-pound steel rails joined by 4-hole angle bars. There are about 20 ties under each rail, laid on 12 inches of crushed rock and gravel.

Eastbound freight train NY-4 consisted of locomotive 5611, 82 loaded cars, and a caboose, in charge of Conductor Reeves and Engineman McMeans. It left Elkhart, Ind., at 8.55 a. m., en route to Air Line Junction, Ohio, 130 miles distant, passed Waterloo, 51 miles east of Elkhart, at 11.46 a. m., and was derailed at a point about 2 miles east of Waterloo.

Westbound passenger train No. 19 consisted of locomotive 4861, 1 buffet car, 7 sleeping cars, 1 dining car, and 1 observation car, all of steel construction, and was in charge of Conductor Sackett and Engineman Moulton. It left Toledo at 9.58 a. m., passed Edgerton, Ohio, 12.6 miles east of the point of accident, at 11.38, and at 11.50 a. m. collided with a derailed car of train NY-4 while running at a speed of about 50 miles an hour.

Thirteen freight cars were wrecked, six of which were destroyed. Locomotive 4861 was derailed and lay on its side parallel with the westbound track, with the tender torn loose and lying at right angles with the engine. The buffet car and four following sleeping cars were derailed to the north of the track but remained upright. These cars were considerably damaged. The fireman of train 19 was killed and the engineman seriously injured  The weather at the time was clear

The accident occurred on straight and level track  The first marks of derailment were about 2,500 feet west of point of accident and about 2,380 feet west of that point a segment of a car wheel was found, it being about two-fifths of the entire wheel  The top of the rail was deeply indented by the revolving broken wheel for several rail lengths, and six smaller pieces of the wheel were broken before the remaining portion of the wheel rolled out from under the train  This portion of the wheel rolled down the embankment about 50 feet away from the track and about 1,750 feet from point where train 19 collided with wreckage  Views of the scene of the accident are shown by figures Nos 1 to [illegible] inclusive

Conductor Reeves of train NY-4 stated that his train was inspected before leaving Elkhart, that the brakes applied and released properly, that there had been no hot boxes and no trouble of any kind with the train, that he had received signals [illegible] at Corunna and the crossing flagman at Waterloo indicating that his train when passing these stations was all right [illegible] pressure as registered by his gauge had been normal throughout the trip  He said that the first intimation he had of anything wrong was when the train came to a sudden stop, and judging from the indications of the gauge, he thought an air hose had burst  He took materials for repairing the hose and got off the train  then realizing that there had been a wreck he phoned the dispatcher  He further stated that just after leaving the phone he looked his train over and found nearly half of a broken wheel between the tracks about 50 car lengths behind the wrecked cars  He felt of the wheel and found it was cold

Engineman McMeins of train NY-4 stated that when about a mile and a half east of Waterloo he looked back and noticed something like a truck frame bumping along the ties and a car swerving out and up and down  He immediately applied the brakes in emergency  Just about this time he saw No 19 coming  The forward brakeman of his train leaned out on the left side with a flag and attempted to stop the approaching train  and at the same time he waved his cap and pulled the whistle cord in an endeavor to attract attention  He was told that when the two engines were very close together a car in NY-4 jumped to the north across the westbound track immediately in front of No 19's engine  An instant later the engine crashed into it  He stated that his train had had the customary inspection and that there had been no trouble with it up to the time the car began swerving, that his brakes were in good condition and took hold properly when he applied them in emergency, and that his train had slowed down to about 6 or 8 miles an hour when the collision occurred

Brakeman Matthews on NY-4 stated that his train had been inspected at Elkhart, was in good condition  all brakes working and

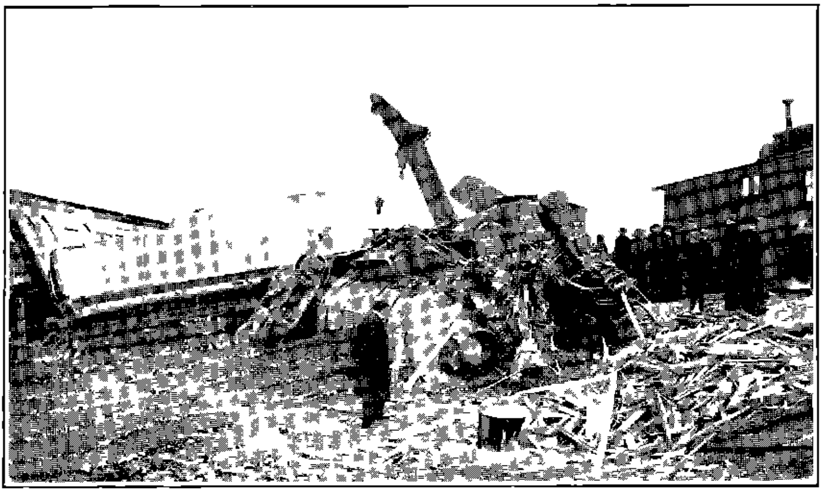

Fig. 1—Engine and tender of passenger train. View looking east.

Fig. 2—Underside of engine of passenger train. Tenth car of freight train, refrigerator car No. 141897, over on westbound track.

Fig. [illegible].—Third car of freight train, refrigerator car No. 1 [illegible] 17 [illegible]

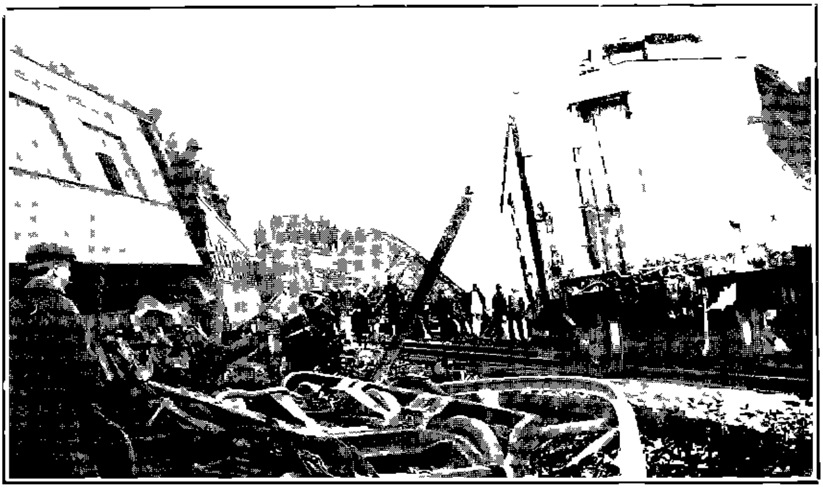

Fig. 4.—Tenth car of freight train, refrigerator car No. 111[illegible] [illegible] Stock car No. 26223 [illegible] of train [illegible]

that no trouble had been experienced with it. He said that the first intimation he had of any trouble in the train was while he was up on the tank watching the rear end for a signal when he saw the stones and dirt fly and a car begin to jump. He stated that just as the engines of the two trains were about even he looked back and saw a stock car shoot across the westbound track.

Brakeman Robinson on NY-4 stated that he was riding on the top of a car about 20 cars from the engine; that he looked over the side and saw a few stones and some dust flying; that just as he looked he saw a car start up in the air and the next car go to the south. An instant later No. 19's engine crashed into the cars. After the accident he saw part of a broken wheel lying under the train and said that it was not hot.

Conductor Sickett on No. 19 stated that his train was inspected at Toledo and that his brakes were in good condition; that he was riding in the rear end of the second car from the engine and his train was moving approximately 50 miles an hour when he felt the brakes applied in emergency; that this was the first knowledge he had that anything was wrong, and that an instant later the cars left the track and went off into a field.

Brakeman Vantilburg on No. 19 stated that the brakes on his train appeared to be in good condition and there had been no trouble of [illegible] up to the time of the accident; that the first he knew of anything being wrong was when he felt the emergency application of the brakes; that at that time he was riding in the baggage compartment; he heard the crossing whistle but did not notice No. 19 give any alarm indication and heard no other whistle.

Engineman Moulton on No. 19 stated that just before he saw the freight train his train was running about 55 or 60 miles an hour; that he saw NY-4 when it was between a half-mile and a mile distant; that as they drew near he saw a red flag on the freight engine which a man swung out of the window; that just as he saw the flag his fireman called to him. That as soon as he saw the red flag he applied his brakes in emergency, but they had barely time to take hold when some cars toppled over from the freight train in front of No. 19, and the collision occurred. He said he had no time to shut off or pull the reverse lever.

At the time of the accident none of the employees had been on duty in excess of the statutory period and all had had the required rest period before going on duty.

Investigation definitely developed the fact that a broken wheel was the cause of the accident. The investigation of the broken wheel and its mate was conducted by Mr. James E. Howard, engineer-physicist, whose report follows. Acknowledgment is made of the cooperation of Dr. P. H. Dudley and others of the New York Central Railroad and Mr. Chas. Cobb, jr., secretary-treasurer of the Marshall Car Wheel & Foundry Co., for aid extended in acquiring data upon these wheels.

### REPORT OF THE ENGINEER-PHYSICIST.

The broken wheel which caused the accident to trains NY-4 and No. 19 on the New York Central Railroad, near Waterloo, Ind., March 25, 1917, was a 33-inch chilled-iron wheel weighing 625 pounds. It was cast by the Marshall Car Wheel & Foundry Co., Marshall, Tex., and bore the foundry number 94051. Its mate, cast by the same company, was numbered 96056. The records show that these wheels were pressed on their axle at the shops of the Fort Worth & Denver City Railway, Childress, Tex., December 20, 1916, with a pressure of 50 tons each. They were placed under Swift Refrigerator Line car No. 10274 at Childress January 11, 1917, from which it appears that they had been in service for a period of only 2½ months when the fracture of one of them took place.

Car S. R. L. No. 10274 was the first car of train NY-4, and it was the belief of the officials of the New York Central Lines who were early at the scene of the accident that the broken wheel was on one of the axles of the rear truck of the car, while it was undoubtedly on the south end of the axle.

Diagram of the track, figure No. 5, shows the relative positions which the fragments occupied after the accident. The first marks found were on the south rail 2,500 feet west of the point of derailment. Immediately beyond these marks a small fragment of the flange was found. Next in order a large fragment comprising about two-fifths of the wheel was found between the rails about 120 feet east of the first marks.

Next beyond this point six fragments of the rim, plates, and hub were scattered along the track. Finally, at a distance of 1,750 feet west of the point of derailment the balance of the wheel was detached from the axle and came to rest 50 feet from the track on the south side. The track was examined for a distance of 2 miles west of the scene of the accident but no further evidence was found attaching to it. Parts of the flange were not recovered.

The relative positions occupied by the fragments furnish evidence upon the manner of failure and the sequence in which the lines of rupture were developed. Fragmentation seemed to have begun at the rim, the earliest recovered fragment being a small piece of the flange. A large fragment was next detached, representing about two-fifths of the body of the wheel. The balance of the wheel remained on the axle for a short time thereafter, since at this stage more than one-half of the hub covering the wheel seat was unbroken.

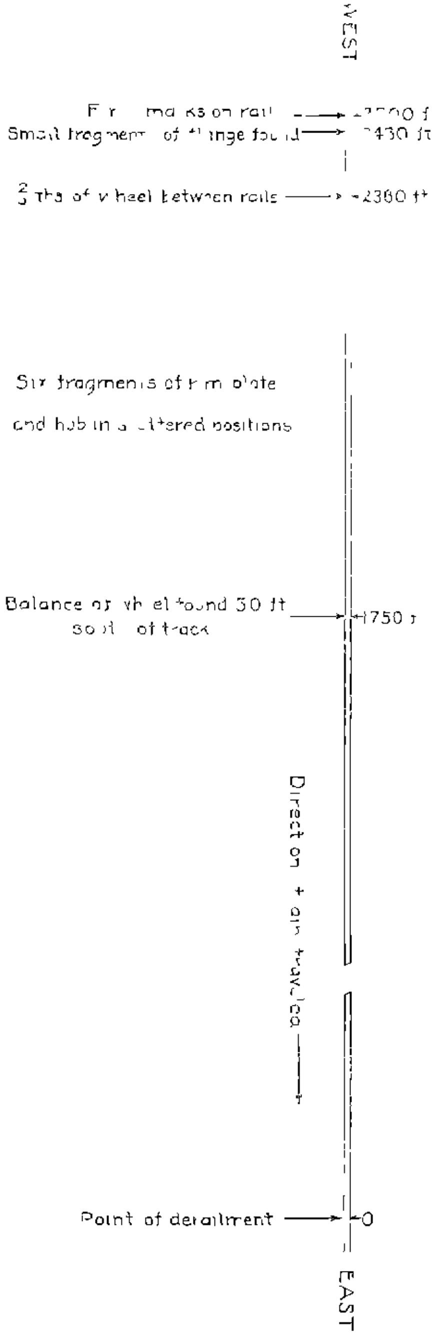

FIG 5.—Diagram showing the relative positions of the fragments of broken wheel No. 91051, as they were found after the accident

A sector representing one-twelfth of the body of the wheel was broken into small fragments, the pieces of which were next scattered along the track. More of the hub was then broken, releasing the balance of the wheel from the axle. This fragment, the largest of the wheel, came to rest on the south side of the track 50 feet away and 1,750 feet west of the point of derailment, as above stated.

In the examination of the broken wheel and its mate conducted for the purpose of ascertaining, if possible, the cause of rupture, efforts were directed toward the identification of the initial point of fracture. The directions in which lines of rupture traverse cast iron, by means of which data the initial point is shown, are not as definitely indicated on the fractured surfaces of iron as on those of steel. In the present case such evidence for the most part was very obscure. However, one of the radial lines of rupture, that which passed between the letters "S" and "H" of the word "Marshall" shown on figure No. 6, had its origin, it is believed, at the rim and traversed the plate from the rim toward the hub. This line of rupture passed across the core leg opening of the inner plate, and on the opposite side of the hub it passed through the metal at a chaplet.

These circumstances are mentioned since the line of rupture which detached the first large fragment of the wheel took a course which has been described as a common one in the case of burst hubs. Much reliance, however, is placed upon the indications which were present on the fractured surfaces, leading to the belief that the first line of rupture started at a point beyond the core leg opening and not at its sides. There was a slight bifurcation of the line of rupture below the word "Marshall" which would be difficult to account for except upon the theory that the line of rupture started at the rim and traversed that side of the wheel toward the hub.

The lines of rupture on the outer and the inner faces of the wheel are shown by figures Nos. 6 and 7. The wheel broke into two principal fragments, between which there was a sector which was broken into a number of small pieces. Figure No. 8 shows the local shattering of the rim at the circumference of the small sector. Parts of the flange were not recovered. It is regarded as probable that the initial rupture of the wheel occurred within the limits of this shattered zone of the tread and flange. Fracture of the wheel from the hub, or core leg opening, extending outward would not be expected to result in such a degree of fragmentation as here witnessed. The strength of the rim would call for an intact plate at the time of being broken into a number of small fragments to furnish the necessary reactive force.

Figure No. 9 shows the appearance of the tread of the wheel. The surface was in good condition and not suggestive as a cause of rupture. The limited wear on the tread had not effaced the marks of the chiller made when the wheel was cast.

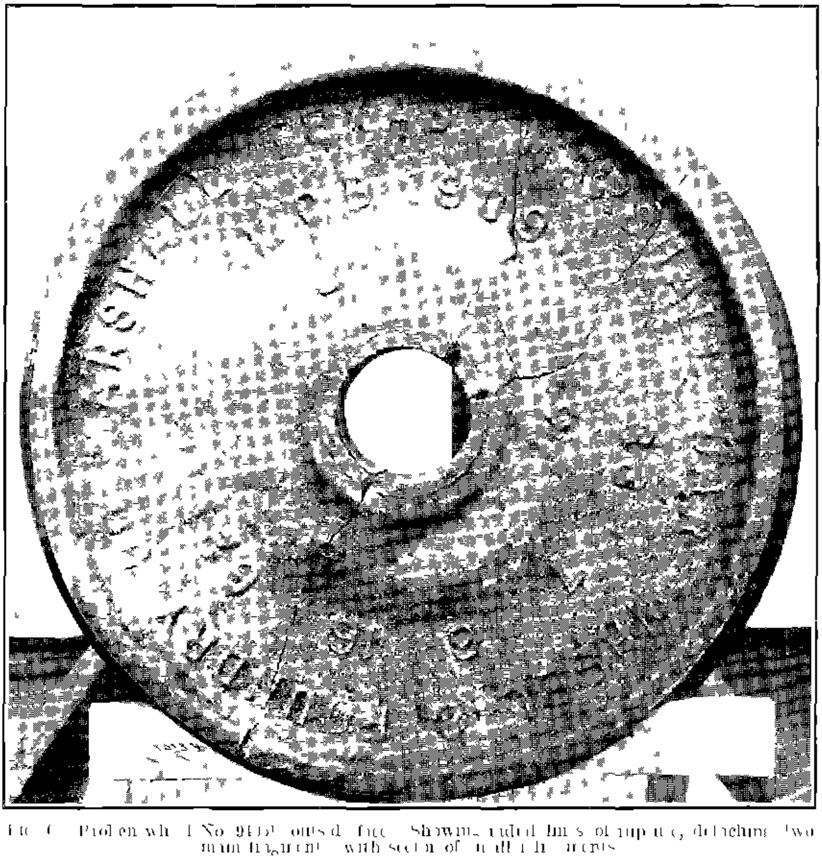

FIG. 6.—Broken wheel No. 9[illegible], outside face. Showing radial lines of rupture, detaching two main fragments with section of [illegible] [illegible].

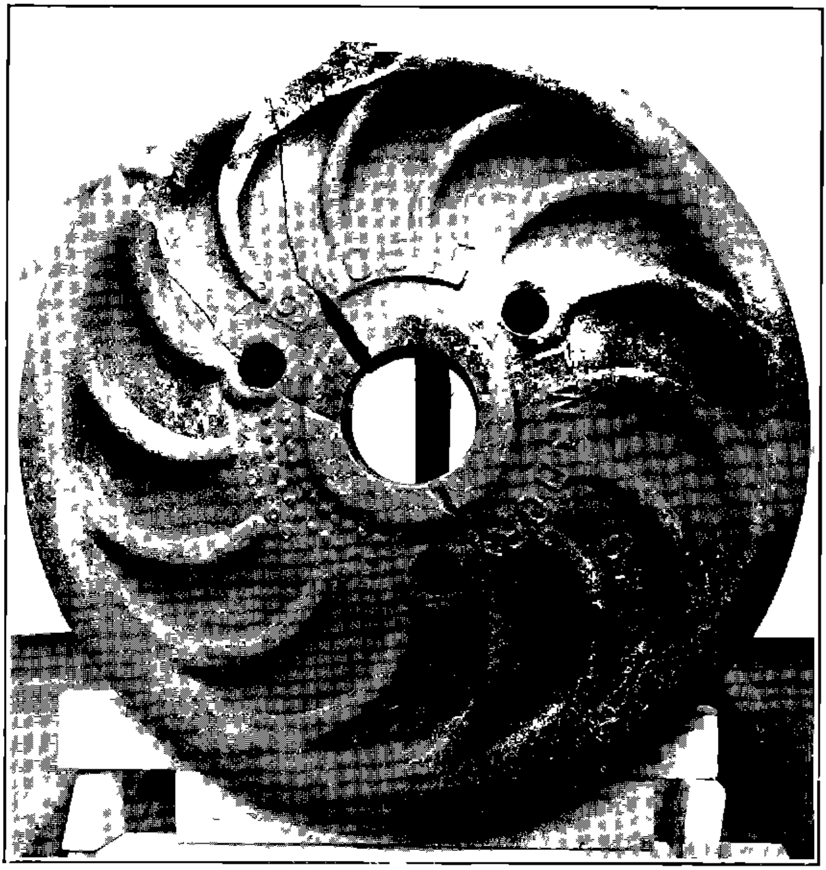

Fig. 7.— [illegible] No. [illegible] face

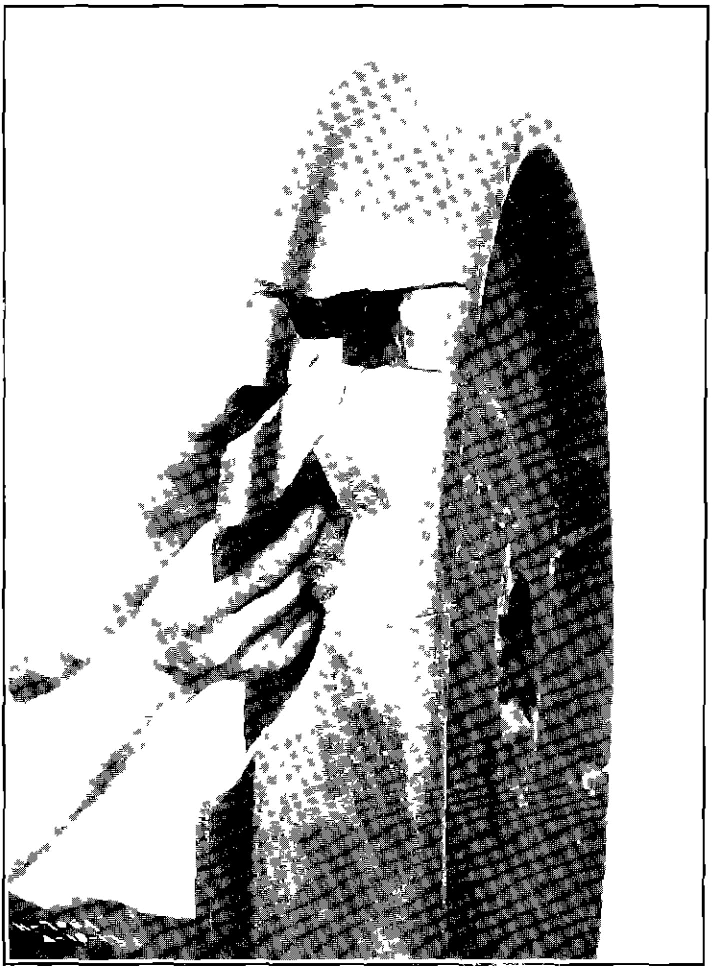

Fig. 8.—Broken wheel No. [illegible]4051, showing fragmentation of tread

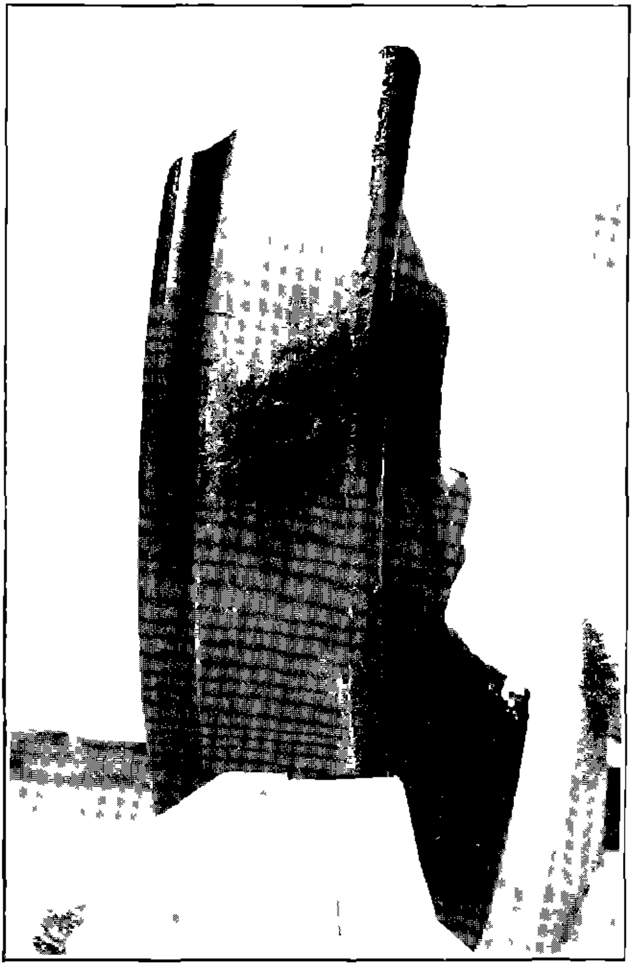

Fig. [illegible] Frozen wheel No. [illegible]. View of the tread showing very little wear, chilled metal is not obliterated.

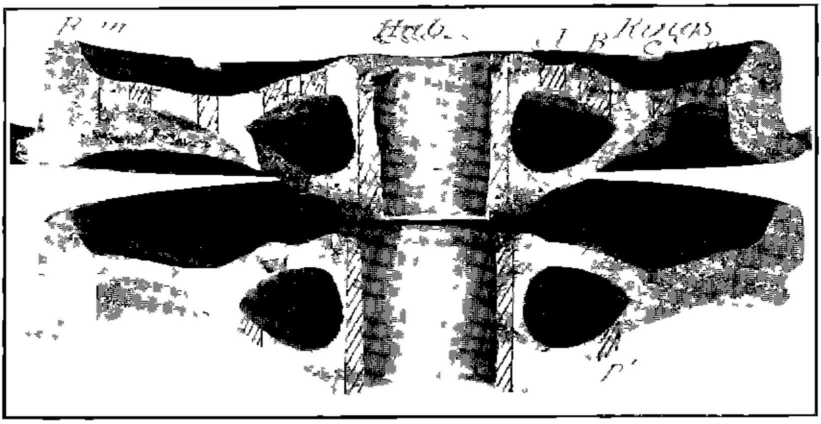

Fig. 10.—Fractured surfaces of rim, plate, and hub of broken wheel No. 9401. Lines of rupture passed through core legs and chaplets of plates. Spongy metal at outside end of hub. Positions of rings sketched on cut, which were detached from mate of the wheel.

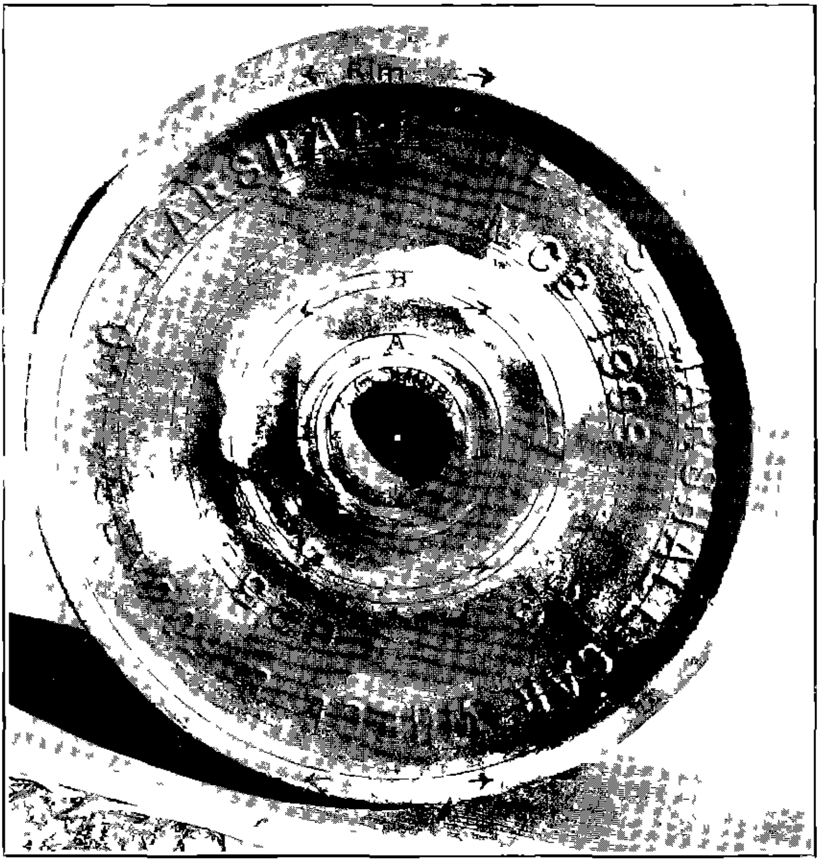

FIG. 11.—Cut used to represent wheel N[illegible] [illegible] of the broken wheel, showing positions of concentric rings detached therefrom. [illegible] of [illegible] lengths. Outside face of wheel.

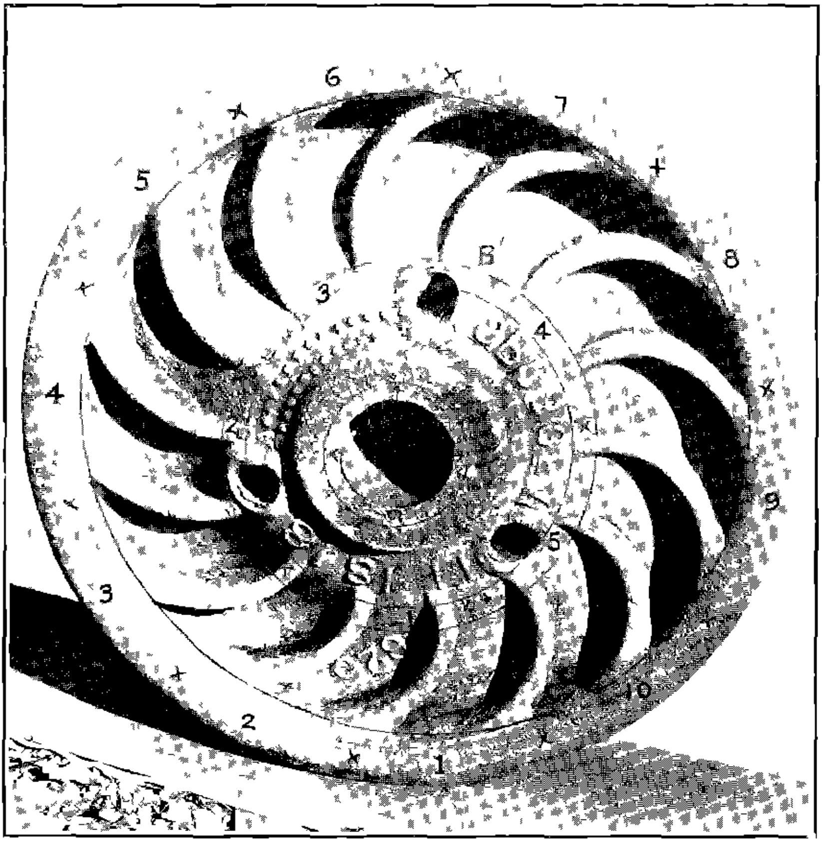

FIG. 12.—Cut used to represent wheel No. 9606, mate of the broken wheel, showing positions of core openings detached therefrom, with locations of cracked length. Inside face of wheel.

Figure No. 10 shows the appearance of the fractured surfaces of the rim, plates and hub. A normal depth of chill was presented with a progressive gradation from the white iron of the tread through mottled iron to gray in the plates and hub. The metal at the outer end of the hub in both this wheel and its mate was spongy. In other places the metal was sound. In the examination of the mate of the broken wheel concentric rings were taken out in the determinations of the state of internal strains. The positions of these rings are for convenience sketched on this cut.

Finally, the flange of the fragments of the broken wheel were broken off with a sledge, all of which showed sound fractures with a depth of chill ranging from one inch at the flange to nine-sixteenths inch at the tread. No thermal cracks or shrinkage cracks were revealed. A cause for the rupture of the wheel was not disclosed in the examination of these fragments. The bore of the hub showed a smooth turned surface, which appeared to have had a good bearing over the full length of the wheel seat. The recorded pressure of 50 tons used in pressing on the wheel does not carry with it a cause for rupture.

Table No. 1 gives the chemical composition of the broken wheel No. 94051 and its mate No. 96056.

TABLE No. 1.—*Chemical composition of metal in wheels Nos. 94051 and 96056*

| Wheel | Carbon |  |  | Manganese | Phosphorus | Sulphur | Silicon | Copper |
|---|---|---|---|---|---|---|---|---|
|  | Combined | Graphite | Total |  |  |  |  |  |
| 94051 Plate | 1.18 | 2.23 | 3.41 | 0.3[illegible] | 0.41 | 0.141 | 0.556 | 0.04 |
| Flange | 1.53 | 1.99 | 3.52 | [illegible] | .42 | .155 | .61 | .04 |
| Hub | .96 | 2.32 | 3.28 | .36 | .43 | .100 | .64 |  |
| 96056 Hub | .91 | 2.45 | 3.36 | .42 | .37 | .155 | .600 |  |

The absence of a definite or probable cause for the rupture of the wheel attaching to its chemical composition or its physical appearance leads to a consideration of some other influence to which it may have been subjected. The local fragmentation at the rim suggests the possibility of some object having been encountered of sufficient size and hardness to have broken off pieces of the flange and injured the tread. The speed of the train when trouble was first noticed afforded little or no opportunity for any object to get between the wheel and the rail excepting some part of the brake rigging. That some part of the brake rigging fell upon the track in front of this wheel and was responsible for the local shattering of the metal of the flange and tread seems a tenable explanation for its fracture. Primarily no other part of the train was involved in the derailment, the cause of which was confined to this wheel or the conditions to which it was exposed.

The view was entertained by some of the officials of the New York Central Railroad that the failure was due to bursting pressure at the hub. Mr. Chas. Cobb, jr., secretary-treasurer of the Marshall Car Wheel & Foundry Co., advanced the same explanation. Mr. F. K. Vial, chief engineer of the Griffin Wheel Co., furnishes data upon the assembling of a 725-pound wheel which was pressed upon its axle with 61½ tons pressure, thereby resulting in a circumferential stress of 17,000 pounds per square inch tension in the hub. But this wheel was subsequently loaded with over 200,000 pounds without rupture.

The highly plausible cause of a bursting pressure at the hub being the primary or a contributory influence in the fracture of the wheel was taken under consideration in the examination of the broken wheel and its mate. Evidence of bursting pressure at the hub would necessarily disappear upon the breaking of the wheel, hence this feature did not admit of direct investigation after the derailment. Internal stresses, whether due to assembling conditions or to cooling strains of fabrication, would act for or against rupture of the wheel, according to their direction in the hub, plates, and rim.

The mate of the broken wheel was examined in respect to its state of internal strains, that is, the residual cooling strains of fabrication after the customary period of annealing to which all chilled wheels are subjected. On figures Nos. 11 and 12 are sketched the locations of the concentric rings on which the internal strains of this wheel were measured. Diametrical and chord measurements were made on each face, the gauged lengths of which are indicated on these two cuts. Wheel No. 96056 was not photographed prior to taking out these concentric rings, hence the photograph of another wheel is used on which to indicate the positions of the rings and gauged lengths.

The measured strains and their equivalent stresses which were released on the outside face of the hub, plate, and rim of figure No. 11 are entered on Table No. 2.

TABLE No. 2.—*Wheel No. 96056, outer face*

[Strains released and their equivalent stresses on gauged lengths of 10 inches each, except on hub 6.52 inches, when wheel was cut into concentric rings. Location of gauged lengths shown on fig. No. 11.]

| Rings | Strains on gauged length | | Stresses on gauged length | |
|---|---|---|---|---|
| | *a* | *b* | *a* | *b* |
| | *Inches* | *Inches* | *Lbs. per sq. in.* | *Lbs. per sq. in.* |
| Hub | 0.0077 | 0.0052 | 20,010 | 13,560 |
| A | .0028 | .0026 | 1,700 | 4,420 |
| B | −*.00[illegible]* | .0036 | *610* | 6,120 |
| C | −*.0010* | −*.0010* | *1,[illegible]00* | [illegible] |
| D | −*.0009* | −*.0014* | *1,5[illegible]0* | *2,[illegible]* |
| Rim | .0020 | .0002 | 4,120 | 310 |

Italic figures represent strains and stresses, respectively, of tension.

Strains of compression prevailed in the metal of the hub in the inner ring A and in the rim. Rings C and D were in tension, and one chord of ring B. The other chord of ring B appeared to have been in compression; its value, however, was such as to cast a doubt upon the reliability of the determination. The metal of the plate, it may be said, was generally in a state of tension.

The equivalent stresses given in the table are based upon a modulus of elasticity of 17,000,000 pounds per square inch. Tests on cast iron under both tension and compression, on air furnace gun iron and sand castings, the results of which appear in Tests of Metals 1887 and following years, show a range in the value of the modulus of gray and mottled cast irons from 17,000,000 to 20,000,000 pounds per square inch. The lower value has been adopted in converting the strains into stresses in these measurements.

It will be noted that the internal stresses of compression at the hub were 20,040 and 13,560 pounds per square inch on gauged lengths *a* and *b*, respectively, yielding an average value of 16,800 pounds per square inch. In the ring next the hub the compressive stresses had an average value of 4,590 pounds per square inch. In order to balance these compressive stresses at the hub both inside and outside plates were in a state of initial tension. At the rim there was a compressive stress of 4,420 pounds per square inch at one chord, while at the other chord the stress was negligible in value.

The strains and stresses of the inside face of the wheel are given on Table No. 3, referring to the gauged lengths which are shown on figure No. 12.

TABLE No. 3.—*Wheel No. 96056, inner face.*

[Strains released and their equivalent stresses on gauged lengths of 10 inches each, excepting on hub, 5 inches. Tension shown by italic, compression in ordinary figures. Location of gauged lengths shown in figure No. 12.]

STRAINS (INCHES) ON GAUGED LENGTHS.

| Ring | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Hub | 0.0[illegible]2 | 0.0[illegible] | | | | | | | | |
| B | *.0016* | −*.002[illegible]* | *0.0007* | *0.000[illegible]* | −*0.000[illegible]* | | | | | |
| Rim | −*.0090* | .00[illegible]7 | .0008 | .0019 | .0011 | 0.000[illegible] | 0.000[illegible] | *0.0005* | *0.0007* | *0.0007* |

EQUIVALENT STRESSES (POUNDS PER SQUARE INCH ON GAUGED LENGTHS).

| Ring | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Hub | 23,910 | 27,030 | | | | | | | | |
| B | *2,7[illegible]0* | −*4,0[illegible]0* | *1,[illegible]0* | *[illegible]0* | *1,3[illegible]0* | | | | | |
| Rim | *[illegible]* | 1,1[illegible]0 | 1,360 | 3,230 | 2,380 | 1,[illegible]30 | 1,3[illegible]0 | *8[illegible]0* | *[illegible]0* | *1,190* |

Italic figures represent strains and stresses, respectively, of tension.

At the hub the compressive stresses were 23,910 and 27,030 pounds per square inch, respectively, on diameters at right angles to each other. The average of these two values is 25,470 pounds per square inch. On ring B′ 5 chord gauged lengths were established. Each chord of this ring was in a state of initial tension, the maximum value of which was 4,080 pounds per square inch. At the rim 4 of the gauged lengths showed a state of tension, and 6 a state of compression. The tensile stresses on this face of the rim were abreast the higher value of compression which was found on the opposite face. The tendency of the internal strains of fabrication in the hub and plates to reduce those at the wheel seat and augment those in the plate created when the wheel is pressed upon its axle will be noted.

The fragmentation of wheel No. 94051 precluded any data being obtained upon the tangential or circumferential strains which resided in it before it was broken. There were no longitudinal strains remaining in the hub.

Upon the completion of these measurements the detached rim of wheel No. 96056 was heated locally abreast several of the gauged lengths by means of an acetylene torch. The heating was done at one place each on each of the four sides of the rim and at a fifth place on the edge of the flange. The figures affixed to the cross section of the rim shown on Fig. No. 13 indicate the side locally heated on or abreast the different gauged lengths.

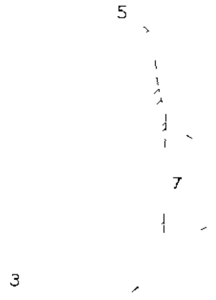

FIG. 13.—Cross section of rim of wheel No. 96056. Rim locally heated on sides indicated by the numerals of the gauged lengths respectively. [illegible] on inner edge of rim, where all gauged lengths were established.

The torch was directed against one spot on each section, raising the temperature at that place to a cherry-red color over an area of about 1½ inches diameter. During the period of cooling cracks developed on the areas on the tread and on the outer edge of the rim. On the tread of the wheel the cracks were of irregular formation; on the rim they developed in radial planes parallel to the axis of the wheel. No surface cracks were visible on the inner surface nor on the inner edge of the rim following the first heating with the torch.

The rim was heated a second time, on which occasion the torch was moved along an element, heating each of the zones a length of

6 to 8 inches At this time the edge of the flange was heated in addition to the four other places Thermal cracks developed on each of the heated zones during the cooling of the rim following the second heating

A permanent change in length was found to have taken place on each of the gauged lengths which embraced the heated sections of the rim, one of which showed an increase in length while each of the other four showed a decrease in length The rim was allowed to reach substantially a uniform temperature throughout when these measurements were taken A statement of the permanent sets is given on Table No 4

TABLE No 4—*Rim of wheel 96056*

[Effect of local heating of different sections of the rim [illegible] on gauged lengths established on the inner edge of the rim]

| Location | Gauged length | Permanent set after— | |
|---|---|---|---|
| | | First local heating | Second local heating |
| On tread, 90° from | 1 | −0.0001 | −0.0002 |
| Edge of flange, abreast | 3 | | −.0004 |
| Outside edge of rim 180° from | 5 | +.0008 | +.0015 |
| Inside of rim [illegible] from | 7 | −.0010 | −.0027 |
| Inside edge of rim on gauged length | 9 | .0011 | −.0034 |

Plus and minus values indicate expansion or contraction of rim on the several gauged lengths

The effect of heating the tread of the wheel appeared to result in a slight diminution on gauged length 1 It will be borne in mind that all of the gauged lengths were located on the inner edge of the rim The heating of the tread, therefore caused a slight shortening of the inner edge of the rim to occur abreast the place which had been heated Ordinarily an apparent change in length of one or two ten-thousandths of an inch on a gauged length of 10 inches would not be regarded as significant, owing to the manipulative conditions under which these measurements are generally required to be taken It is not feasible to regulate the temperature of the material under examination and bring it to exactly that of the standard reference bar to which all measurements are referred These indications on the tread were, however confirmed in the more pronounced differences found on the other sections of the rim The local heating of a section resulted in its final shortening, notwithstanding at an intermediate stage of the cooling thermal cracks by tension were developed on the heated area

The outer edge of the rim was heated abreast gauged length 5 Upon cooling there was a permanent set in a plus direction on the gauged length located on the inner edge of the rim After the first heating this amounted to 0 0008 inch, and after the second heating 0 0015 inch The permanent set in a plus direction is explained by reason of the final shortening of the opposite heated edge bending the rim as a beam and lengthening the edge which was measured.

Heating the edge of the flange abreast gauged length 3 caused a contraction of 0.0004 inch. A greater contraction was observed on gauged length 7 when the inner face of the rim was locally heated and still a greater contraction on gauged length 9 when the inner edge of the rim was heated between the marks defining its extremities.

These results show that local heating had the effect of causing an ultimate contraction along the edge or the side of the rim on which the heating was done. These data add to our information upon the effects of those conditions to which wheels are exposed. The explanation of the phenomena requires further experimental inquiry into the intermediate phases through which the metal passes, the relations which one part of the rim bears to another during the interval of rapid heating and the more moderate rate of cooling. The transmission of strains through the rim takes places immediately without sensible lag, differing essentially from the slower transmission of heat; hence the intermediate states of strain present many combinations of variable factors according to the rate of heating and the mass of the metal acted upon. When the entire mass of the rim was heated to high annealing temperatures there resulted a final expansion on each gauged length. Similar results were reached by annealing the rings of gray iron which had been detached from the plate.

Rings A and B from the outer plate of the wheel were annealed at several temperatures. They were heated in tempering furnaces with gas as the fuel, and slowly cooled, remaining in the furnaces over night and cooling with them. The results of the annealings are shown in Table No. 5.

TABLE No. 5.—*Wheel No. 96636.*

Effects of annealing at different temperatures detached rings from outer plate on gauged lengths of 10 inches each. For location of gauged lengths see Fig. No. 11.]

| Ring | Annealing temperature (degrees F.) | Successive effects on gauged lengths | | Remarks |
|---|---|---|---|---|
| | | *a* | *b* | |
| A | 1,400 | -0.0023 | -0.0027 | First annealing |
| A | 1,600 | .0013 | [illegible] | Second annealing |
| A | 1,800 | .0209 | [illegible] | Third annealing |
| A | 1,900 | .0572 | [illegible] | Fourth annealing |
| | | .0771 | [illegible] | Total effects |
| B | 1,400 | -.0010 | .0038 | First annealing |
| B | 1,900 | .0776 | .0567 | Second annealing |
| | | .0766 | .0605 | Total effects |

Positive values indicate expansions, minus values contractions in gauged lengths.

After exposure to 1,400° F., the first annealing temperature, ring A showed a contraction on each diameter, the values of which were 0.0023 inch and 0.0027 inch, respectively. Exposure to higher temperatures resulted in an expansion after each annealing which reached a total of 0.0751 inch and 0.0638 inch, respectively, after the highest annealing temperature, 1,900° F. Ring B expanded nearly the same amount after annealing at the same maximum temperature.

Subsequently the rim was annealed three times at temperatures ranging approximately from 1,600° to above 1,900° F. The heating was done in a gas furnace, the capacity of which was overtaxed by the size of the rim. It was inconvenient to heat the rim uniformly around its circumference and no attempt was made to do so. Table No. 6 gives the successive amounts which the rim expanded after each annealing, together with the total and aggregate effects.

TABLE No. 6.—*Wheel No. 96056.*

[Effects of annealing at different temperatures detached rim of wheel on gauged lengths of 10 inches each. For location of gauged lengths see Fig. No. 12.]

| Approximate annealing temperature (degrees F.) | Successive effects on gauged lengths | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| 1,600 to 1,800 | 0.1061 | 0.0082 | 0.0253 | 0.0147 | 0.0101 | 0.0326 | 0.0174 | 0.0388 | 0.0998 | 0.1269 | First annealing. |
| Do. | .0024 | .0023 | .0050 | .0046 | .0104 | .0065 | .0031 | .0093 | .0046 | .0021 | Second annealing. |
| 1,800 to 1,900+ | .0709 | .1012 | .0856 | .1013 | .1943 | .3216 | .0606 | .1374 | .0161 | .0537 | Third annealing. |
| | .1794 | .1117 | .1159 | .1206 | .2148 | .3607 | .0811 | .1855 | .1418 | .1827 | Total effects. |

Aggregate effect on all 10 gauged lengths, 1.7232 inches circumferential expansion.

During the first annealing of the rim a heavy scale was raised on the section covered by gauged lengths 9, 10, 1, and 2. On other parts of the rim a red oxide was formed. When cooled, the rim showed a permanent expansion on each gauged length varying in amount according to the temperature to which that part had been exposed. On the side which reached the highest temperature the expansion reached a maximum of 0.1269 inch. On the side of the lower annealing temperature the minimum expansion was 0.0101 inch. The total expansion on the 10 chord measurements, representing the entire circumference of the wheel, was 0.4799 inch, an amount which is nearly four tape sizes, as wheels are measured.

The second annealing of the rim was at substantially the same temperature as before, resulting in a limited increase only in circumference. The gain was 0.0503 inch. The rim was annealed for a third time, on which occasion a very high temperature was reached, especially on the side near a gas port of the furnace. A heavy scale was raised on the section covered by gauged lengths 4 to 8, inclusive, while in that part covered by gauged length 7 the flange was softened by the heat and sagged. The rim, as a whole, was warped. This annealing softened the chilled surface of the tread. There was now a further decided increase in circumference amounting to 1.1930 inches. The aggregate effect of the three annealings was an increase in circumference of 1.7232 inches.

Without showing the relative effects of annealing temperatures upon gray, mottled, and white cast iron, these results, nevertheless, showed the decided increase in dimensions which each kind of iron experiences when exposed to the higher temperatures. But these results must be taken in connection with the effects of local heating, in which evidence was presented of a limited amount of contraction in dimensions, results in which the direction of the permanent sets were reversed.

Chilled iron wheels maintain their integrity as a whole and remain in service after the formation of thermal cracks. It is a matter of deep interest to ascertain what inherent state or condition of the metal enables this to be accomplished. All wheels under present conditions of service are liable to overheating locally through brake action. The effect on brake shoes is obvious. They are broken up by numerous thermal cracks. Inserts are necessary to hold the pieces together. Thermal cracks in steel extend with great rapidity. Notwithstanding the presence of thermal cracks in chilled wheels, those with comby treads, shell outs, and slid flat spots, they continue to perform their necessary functions. While this excellence of performance is well known, the reasons are not well understood. Some of the results here presented, it is expected, will aid in such a line of inquiry.

Another phase of the subject pertains to the cooling strains of fabrication. They occur in mass and are probably less complex than those which result from local heating. The initial strains of compressions in the hub of wheel No. 96056 would necessarily aid the metal in resisting bursting strains at the wheel seat induced by pressing the wheel on its axle. Mr. F. K. Vial, in discussing the subject of the proper turning and allowances in fit at the wheel seat, calls attention to 'burst hubs,' so called, and says: "The start of a burst hub is not next the wheel seat, but occurs at the core leg and progresses toward the wheel seat, the crack gradually widening until the wheel seat is reached. At this point the crack has widened to such an extent that a positive fracture of the metal occurs, giving what is termed a 'burst hub,'" previously having remarked that fractures of this kind starting at the core leg have "crossed the head of the pan core opening and made their appearance on the face side of the wheel, splitting across the chaplet and then running into the single plate."

This description by Mr. Vial traces the courses of the lines of rupture in the present wheel in respect to the hub and adjacent parts of the plates. The initial compression in the metal of the hub and the initial tension in the plates as witnessed in the mate of the broken wheel each tends to locate the incipient point of rupture in the plates, since a bursting pressure at the wheel seat must first overcome the

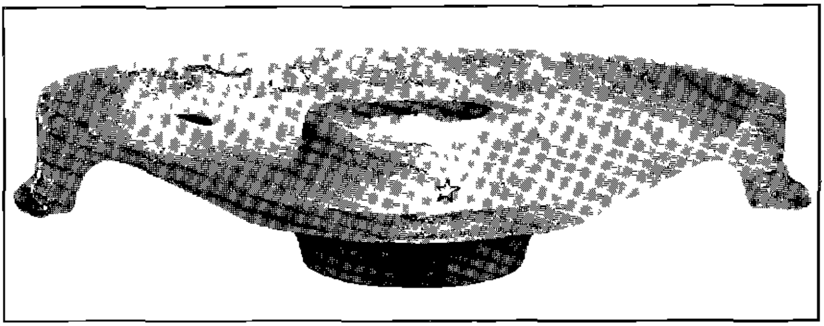

FIG. 14.—Fractured forged steel wheel. Incipient point of rupture on the outside of the plate near the hub indicated by a star stenciled on the cut.

state of initial compression before a tension fracture can occur. The maximum tensile stress in the inner plate and the minimum compression at the inner end of the hub stood to each other as 4,080 to 23,910. If the mate of the broken wheel is a fair example, the relations between the hub metal and the plates for other chilled wheels are represented in these results. The evidence furnished by the fractured surfaces of the broken wheel indicated, however, that the line of rupture separating the first large fragment from the small sector and passing between the letters "S" and "H" of the word "Marshall," as before described, had its origin at the rim and thence traveled through the single plate toward the center. The shattered portion of the tread and flange furnished evidence consistent with that of the fractured surface of the plate.

Wheels are subjected to side blows on their flanges. The flange wear of wheels and rails testify to this action. In the design of chilled iron wheels great strength of section is provided against side blows. The double plate at the hub, together with the brackets, of which there are three, reinforcing the strength of the single plate, are the means provided to meet these requirements. Blows against the flange of the wheel cause tensile strains which the plates and hub are required to resist. The sponginess of metal at the outside ends of the hubs of these wheels would detract from their strength in this direction, still there was no evidence of failure in this manner.

Forged steel wheels have exhibited fractures attributable to repeated flange blows. Figure No. 14 illustrates such a fracture in a forged steel wheel. The initial point of rupture is indicated by a star sketched on the cut. From this point the line of rupture extended in each direction until the fracture of the plate and rim was complete. A hot rim and cool plate intensify the radial strains of tension in the latter, while the internal strains of compression acquired at the tread due to the cold-rolling action of a forged steel wheel would still further increase the strains in the plate. The rigidity of the metal of the tread of a chilled iron wheel probably preserves it against change of internal strains augmenting those of the plates by service conditions. Upon this feature, however, we are without experimental evidence.

## SUMMARY

Direct evidence attaching the responsibility of the failure of this wheel to any structural defect exhibited by the fragments, or suggested by the results of the examination of its mate, was wanting, and by the process of elimination attention is directed to some extraneous source as the probable proximate cause of its failure. The wheel was practically new. It had been in service only about two months, during which time the wear at the tread had hardly removed the chiller marks of fabrication. The surface of the tread was in good condition. There were no thermal cracks in evidence. The fragments when examined at the time of the accident were cold

The brakes had not been set for some time prior to the accident, hence no occasion arose for the heating of the wheel. The fractured surfaces showed no casting seam or crack. In the subsequent examination the flange of the wheel was broken with a sledge hammer, detaching fragments from the entire circumference, the flange displaying sound metal throughout.

The metal at the hub on the outside of the wheel was spongy in both the broken wheel and its mate—a source of weakness. On the other hand there were internal strains of compression in the hub of the mate, which, if they were of the same degree in the broken wheel before its fracture would materially strengthen it against fracture beginning at the hub. Strains of tension existed in the plates of the mate.

It is hardly probable that the initial point of rupture was at the plates or hub but rather that it started in the rim at or near the flange. The position of the broken pieces of the wheel as they were scattered along the track leads to the belief that fracture began at the rim. Furthermore, one of the principal lines of rupture, judging from the somewhat indistinct indications on the fractured surface, appeared to have had its origin in the rim. The general shattered state of the flange and rim locally also leads to the inference that the origin of rupture was at that place.

In quest of a cause of the failure of the broken wheel in the examination of its mate, features of general interest were developed. The state of strain within the metal of the wheel was determined; also data acquired upon the effects of local heating of the rim, assimilating to the conditions of braking experienced in service. In addition to these determinations there were observations upon the changes in dimensions of gray iron rings from the plate and the chilled iron of the rim of the wheel after each had been subjected to annealing temperatures.

The problem presented in this examination was to find the cause of rupture of a comparatively new wheel having a satisfactory chill, the fractured surfaces of which showed good metal, the condition of the tread also being good. The train movements were normal and satisfactory.

The explanation is advanced in the body of the report that some part of the brake rigging was responsible for the local shattering of the rim of the wheel and the proximate cause of its rupture. Other explanations have not consistently met and harmonized with the conditions known to have prevailed; responsibility therefore attaches to some extraneous cause, of which failure of the brake rigging seems the most plausible.

Respectfully submitted,

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