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

To the Commission

On March 21 1917 there was a derailment of freight train NY-1
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 east-bound track consists of 105-pound steel rails
joined by 6-hole angle bars, while the west-bound track consists of
100-pound steel rails joined by 4-hole angle bars. There are about
20 ties under each rail and land on 12 inches of crushed rock and gravel.

East-bound freight train NY-1 consisted of locomotive 5611, 82
loaded cars, and a caboose in charge of Conductor Reaves and
Engineer McMeans. It left Elkhart Ind., at 8:35 a.m., en route
to An Line Junction, Ohio, 180 miles distant passed Waterloo, 51
miles east of Elkhart, at 11:40 a.m., and was derailed at a point
about 2 miles east of Waterloo.

West-bound passenger train No 19 consisted of locomotive 4861, 1
buffet car, 7 sleeping cars, a dining car, and 1 observation car all of
steel construction, and was in charge of Conductor Sackett and
Engineer Moulton. It left Toledo at 9:58 a.m., passed Edgerton,
Ohio, 126 miles east of the point of accident, at 11:38, and at 11:50
a.m. collided with a derailed car of train NY-1 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
west-bound 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 2,800 feet west of that point a segment of a car wheel was found, being about two-fifths of the entire wheel. The top of the rail was deeply indented by the rolling broken rail 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 the 19 collided with wreckage. Views of the scene of the accident are shown in Figures Nos. 1 to 4 inclusive.

Conductor Reeves of train NY-1 reported that his train was unimpeded before leaving Elkhart, that the brakes had been applied and locked properly, that there had been no hot boxes and no trouble of any kind with the train, that the train had made no stop at Covington and the cars were again at Waterloo when leaving the train when passing through Covington was slightly less than sure as registered by his speedometer had been noticed throughout the train. He said that the last stop he had made was at anything wrong was when the train came to a sudden stop, and judging from the indications of the gauge, he thought that an hour and a half before it was cold. He took materials for repairing the hose and got off the train, then realizing that there had been a wreck, he phoned to the dispatcher. He immediately put on the phone the moment he heard his train over the newly 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.

Engineer McMeans of train NY-4 stated that when about a mile and a half east of Waterloo he looked back and noticed something like a track frame bumping along the rails 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. He looked back to find out the cause 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 midway of No. 19, engine. An instant later the engine rushed into it. He stated that this 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 had taken proper 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 Mathews of train NY-4 stated that his train had been inspected at Elkhart, was in good condition, all brakes working and
Fig. 1—Bottom and under of passenger train. View looking east.

Fig. 2—Underside of engine of passenger train. Bottom of freight train regulator or No. 143897, over on westbound track.
that no trouble had been experienced with it. He said that the first
motion 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 dust fly and a car begin to jump. He stated that just as the en-
gines of the two trains were about even he looked back and saw a
stock car shoot across the west-bound track.

Brakeman Robin on NY-4 stated that he was riding on the top
of a car about 20 car from theengine 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 on the track and that the train was going too
fast. At almost this instant No 19's engine crashed into the cars. After the acci-
dent he saw part of a broken wheel lying under the train and said
that it was not hot.

Conductor Sickell 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 going approximately 50 miles an hour when he felt the brakes
applied in emergency, that this was the first time he knew that
anything was wrong and that an instant later the cars left the track
and went off into a field.

Brakeman Wantling on No 19 stated that the brakes on his train
appeared to be in good condition and there had been no trouble of
any kind up to the time of the accident, that the first he knew of any-
thing being wrong was when he felt the emergency application of
the brakes. That at that time he was riding in the baggage compart-
mant he heard the crossing whistle but did not notice No 19 give
any alarm indication and heard no other whistle.

Engineer Monson 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 dis-
fant that is 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 co-
operation of Dr. P. H. Dudley and others of the New York Central Railroad and Mr. Chas. Cobb, secretary-treasurer of the Marshall Car Wheel & Foundry Co., found extended in acquiring data upon these wheels-

REPORT OF THE INVESTIGATING PHYSICIAN.

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 axle, cast by the same company, was numbered 90956. The records show that these wheels were pressed on the axle at the shops of the Fort Worth & Denver City Railway Company's Texas December 20, 1916, with a pressure of 50 tons each. They were placed under Swift Refrigerator Line car No. 10274 in Childress, Texas, 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 & 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 singly at the scene of the accident that the broken wheel was on one of the axles of the end 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 2500 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, plate, and hub were scattered along the track. Finally, at a distance of 1700 feet west of the point of derailment the balance of the wheel was detached from the axle and came to rest 30 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 attached 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. 96051, 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 1750 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 certain parts, 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 passed between the letters "S" and "H" of the word "Marshall," shown on figure No. 6, had its origin at a point 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 right angle.

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 inclination of the line of rupture along 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. Figures Nos. 8 show the local shatter 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 of a cause of rupture. The limited wear on the tread had not etched the marks of the chisel made when the wheel was cast.
The S-Brokken shield No. 301, showing fragmentation and...
Fig. 10.—Luminous portion of inner plate, and part of broken wheel No. 906.1. Luminous rapports passed through eye hole and chinks of plate. Sparse metal at outside end of hub. Several of rings sketched around, which were detached from with of the wheel.
Fig. 11.—Cut used to remove wheel. Showing indent mark taken wheel, showing positions of cemented rings detailed illustration. Identification of cropped lengths. Outside 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 determination 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 eighths 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 set. The recorded pressure of 90 tons used in pressing on the wheel does not agree with it as 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 No 94051 and 96056

| Wheel | Carbon | Copper | Silicon | Manganese | Phosphorus | Tungsten
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>94051 P1</td>
<td>1.1%</td>
<td>2.2%</td>
<td>0.41%</td>
<td>0.7%</td>
<td>0.41%</td>
<td>0.04%</td>
</tr>
<tr>
<td>94051 P2</td>
<td>1.1%</td>
<td>2.2%</td>
<td>0.38%</td>
<td>0.7%</td>
<td>0.41%</td>
<td>0.04%</td>
</tr>
<tr>
<td>96056 Hub</td>
<td>0.4%</td>
<td>2.0%</td>
<td>0.75%</td>
<td>0.42%</td>
<td>0.01%</td>
<td>0.04%</td>
</tr>
</tbody>
</table>

The absence of a definite or probable cause for the rupture of the wheel according to its chemical composition or its physical appearance has to consider the presence of some other influence to which it may have been subjected. The local fire station at the line 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, secretary-treasurer of the Marshall Car Wheel & Foundry Co., advanced the same explanation. Mr. F. K. Yul, 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 the 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 detection. Internal stresses, whether due to assembling conditions or to cooling strains of fabrication, would not favor 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 uncoiling 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. Diastrophic 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 outer face of the hub plate and rim of figure No. 11 are entered on Table No. 2.

<table>
<thead>
<tr>
<th>Table No. 2</th>
<th>Wheel No. 96056, outer face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strains on gauged length</td>
<td>Stress on an el km.</td>
</tr>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Hub</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.057</td>
</tr>
<tr>
<td>B</td>
<td>0.06</td>
</tr>
<tr>
<td>C</td>
<td>0.075</td>
</tr>
<tr>
<td>D</td>
<td>0.066</td>
</tr>
</tbody>
</table>

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, was generally in a state of tension.

The equivalent stresses given in the table were based upon a modulus of elasticity of 17 000 000 pounds per square inch. Tests on cast iron under both tension and compression on an furnace gun iron and sand castings the result of which appear in Test 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 20,010 and 13,360 pounds per square inch on gauged lengths a and b respectively, yielding an average value of 16,800 pounds per square inch. In the rim 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 stresses and strains 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>
<thead>
<tr>
<th>Table No. 3 - Wheel No 96930 inner face</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Strains (in.)</th>
<th>On Gauged Lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hub</td>
<td>0.010</td>
</tr>
<tr>
<td>Rim</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equiv. Strains (Pounds per square inch on gauged lengths)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

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 the rim 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 the face of the rim were abreast the higher value of compression which was found on the opposite face. The tendency of the internal stresses of the rim in the hub and plate to reduce those at the wheels 5 and 7 near 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 existed 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 yielded to the cross-section of the rim shown on the No. 33 indicate the side locally heated on or abreast the different gauged lengths.

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 form; 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 the measurements were taken. A statement of the permanent sets is given on Table No. 4.

<table>
<thead>
<tr>
<th>Table No. 4—Rim of wheel 9605t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variations in different sections on rim, compared with that on the inner side of rim</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>1 1/8</td>
</tr>
<tr>
<td>2 in.</td>
</tr>
<tr>
<td>3 in.</td>
</tr>
<tr>
<td>4 in.</td>
</tr>
<tr>
<td>5 in.</td>
</tr>
<tr>
<td>6 in.</td>
</tr>
</tbody>
</table>

The effect of heating the tread of the wheel appeared to result in 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 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 tempature 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 abraded 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 1 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 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 furnace over night and cooling with them. The results of the annealings are shown in Table No 5.

<table>
<thead>
<tr>
<th>Ring</th>
<th>Annealing temperature (degrees F)</th>
<th>Gross effect on gauged lengths</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1400</td>
<td>-0.0003</td>
<td>Total annealing</td>
</tr>
<tr>
<td>A</td>
<td>1600</td>
<td>+0.011</td>
<td>First annealing</td>
</tr>
<tr>
<td>A</td>
<td>1800</td>
<td>+0.018</td>
<td>Second annealing</td>
</tr>
<tr>
<td>A</td>
<td>2000</td>
<td>0.022</td>
<td>Total annealing</td>
</tr>
<tr>
<td>B</td>
<td>1400</td>
<td>+0.010</td>
<td>Total annealing</td>
</tr>
<tr>
<td>B</td>
<td>1600</td>
<td>+0.016</td>
<td>Total annealing</td>
</tr>
</tbody>
</table>

Positive values indicate expansion, minus values contractions in gauged lengths.
After exposure to 1400° F. the first annealing temperature ring A showed a contraction on each diameter the value 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 0.0633 inch respectively, after the highest annealing temperature, 1900° 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 1600° to above 1900° F. The heating was done in a gas furnace the capacity of which was of course by the size of the rim. It was inconvenient to heat the rim uniformly throughout, but it was decided to do so. Table No. 6 gives the size as amount which the rim expanded after each annealing together with the total and aggregate effects.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>1600°</th>
<th>1700°</th>
<th>1800°</th>
<th>1900°</th>
<th>Total</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length 1</td>
<td>0.0023</td>
<td>0.0025</td>
<td>0.0027</td>
<td>0.0030</td>
<td>0.0030</td>
<td>0.0030</td>
</tr>
<tr>
<td>Length 2</td>
<td>0.0026</td>
<td>0.0028</td>
<td>0.0030</td>
<td>0.0033</td>
<td>0.0033</td>
<td>0.0033</td>
</tr>
<tr>
<td>Length 3</td>
<td>0.0027</td>
<td>0.0029</td>
<td>0.0031</td>
<td>0.0034</td>
<td>0.0034</td>
<td>0.0034</td>
</tr>
<tr>
<td>Length 4</td>
<td>0.0028</td>
<td>0.0030</td>
<td>0.0032</td>
<td>0.0035</td>
<td>0.0035</td>
<td>0.0035</td>
</tr>
<tr>
<td>Total</td>
<td>0.0085</td>
<td>0.0101</td>
<td>0.0111</td>
<td>0.0128</td>
<td>0.0128</td>
<td>0.0128</td>
</tr>
</tbody>
</table>

After annealing, the rim was annealed for a second time, 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 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.
aggregate effect of the three annealings was an increase in circumference of 17232 inches.

Without showing the relative effects of annealing temperature 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 lowest temperatures. But these results must be taken in connection with the effects of local heating in which evidence was presented of a latent 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 not in service after the formation of thermal cracks. It is a matter of deep interest to ascertain what is the 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. It is necessary to hold the pieces together. Thermal cracks must be viewed with gravity. Notwithstanding the presence of thermal cracks in chilled wheels, with combs, treads, shell outs, and solid back types, they continue to perform their necessary function. While this excellent of performance is well known the reasons are not well understood. Some of the results have presented to us 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 compression in the hub of wheel No. 90056 would not seem to allow the metal in resisting butting strains at the wheel, it is forced by pressing the wheel on its axle. Mr. F. K. Vial, in discussing the subject of the proper turning and allowances in height of the wheel seat, calls attention to "burst hubs" so-called and says that 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 trusses the course of the line 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 state of the present 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. 12—Pressed steel wheel. Impressed part of rim run on the outside of the plate in the hub indicated by a line extended on the rim.
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 in the ratio of 4,080 to 23,010. 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 the 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" 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 blow or side flanges. The flange or side wheel and rails testily to this action. In the design of chilled iron which meets strength of section is provided against side blows. The double plate at the hub to resist the blows, of which there is little to support the strength of the single plate at the main portion to meet the same type. Losses of the flange of the wheel are extensive from which the plates and hub are required to resist the spangles of metal at the outside ends of the hub, if these wheels would detract from their strength in this direction, still there was no evidence of failure in that 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 intensifies the radial strain of tension in the latter while the internal strain 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 chilled 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 braying of the wheel. The fractured surfaces showed no casting seam or crack. In the subseuent examination the flange of the wheel was broken with a sledge hammer, detaching fragments from the entire circumference of 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 or compressions in the hub of the mate, which, if they were of the same degree as in the broken wheel before its fracture would materially strengthen it against future beginnings at the hub. Strains of tension existed in the plates of the mate.

It is hardly probable that the point of rupture was at the plates of hub but rather that it occurred at the rim at or near the flange. The position of the broken piece of the wheel as they were scattered along the track leads to the belief that fracture began at the rim. Furthermore, one of the unmistakable lines of rupture judging from the somewhat indistinct markings on the fractured surface appeared to have had its origin at the rim. The general condition 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 hub at the broken wheel in the examination of its mate, features of general interest were developed. The state of stress within the metal of the wheel as determined also data acquired upon the effects or normal heating of the metal as relating to the conditions of heating 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 and cast iron 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 shell. 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

W P Borland
Chief Bureau of Safety