THE CONCRETE TIE ON AMERICAN RAILROADS

BY

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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1913
UNIVERSITY OF ILLINOIS

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

EDWARD ERNEST REDDERSEN

ENTITLED "THE CONCRETE TIP ON AMERICAN RAILROADS".

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE

in

Railway Civil Engineering

APPROVED: Edward T. Schmidt

HEAD OF DEPARTMENT OF Railway Engineering

247442
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The question of the railroad tie has become increasingly important during the last few years, and since fair to speak a very serious one in the not distant future. The decreasing amount of timber available for ties, together with the increasing cost of labor and machinery, have resulted in a constantly increasing cost, which is rising not on a uniform scale, but by steps, each of which is greater than the preceding one. The extent to which ties are used, their total cost, and average cost are indicated in the following table:

Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>1910</th>
<th>1909</th>
<th>1908</th>
<th>1907</th>
<th>1906</th>
<th>1905</th>
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</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$76,500</td>
<td>$80,321</td>
<td>$92,222</td>
<td>$72,900</td>
<td>$43,912</td>
<td>$37,000</td>
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<tr>
<td>Per Cent Increase</td>
<td>20.3</td>
<td>26</td>
<td>-23.8</td>
<td>31.3</td>
<td>26.2</td>
<td>-</td>
</tr>
<tr>
<td>Number</td>
<td>148,281</td>
<td>128,751</td>
<td>112,447</td>
<td>152,703</td>
<td>106,844</td>
<td>81,300</td>
</tr>
<tr>
<td>Per Cent Increase</td>
<td>19.3</td>
<td>10</td>
<td>-23.8</td>
<td>49.6</td>
<td>12.4</td>
<td>-</td>
</tr>
<tr>
<td>Average Cost Per Tie</td>
<td>$0.51</td>
<td>$0.49</td>
<td>$0.30</td>
<td>$0.31</td>
<td>$0.49</td>
<td>$0.47</td>
</tr>
</tbody>
</table>

* (000) omitted.

From Table 1 it may be seen that the cost of ties has increased each year, with the exception of 1903 and 1904. It is noticeable that the increase has been in these years, and for the commercial and industrial depression from which the country was then suffering. The increase in the cost of ties since 1893 is even more noticeable, for in that year the average price of a tie was only seven-one-eighth cents.
The great amount of money invested in ties by the railroads each year, and the certainty that the price of all kinds of timber, especially ties, is bound to increase more rapidly each year, because of the decreasing supply, which is hereinafter more fully discussed, indicates that the tie question is one of vast importance to the railroads, and, consequently, to the public.

II. HISTORY.

In the days of the early American railroads ties were used only to keep the track in gage. There was little or no attempt to make the tie a support of the rail and a distributor of the load. Both stone and wood ties were sometimes used, although the stone ties were more common on the first railroads. One of the roads using stone sleepers was the Mine Hill and Schuylkill Haven Railroad in Connecticut, built in 1831. The track of this road consisted of flat iron strips bolted to stone sills, which were connected every fifteen feet by stone sleepers. In 1832 the stone sleepers were replaced by wooden ones of various kinds of timber, white oak, however, being the most. These ties were about five feet long, ten inches wide, and eight inches deep, and were spaced four feet apart. It had been found that fifteen-foot spacing was entirely too great. The success of the wooden ties on this road induced their adoption on many of the others, until, finally, at about 1840, the great majority of new roads put in wooden ties exclusively.

From 1840 to about 1880 the only developments in ties, and in the use of ties, were in increasing the number in a rail length, and in finding the best proportions of length, width, and depth. It is true that steel ties had been used in Europe as early as 1853, but they were not
very successful, so that nothing more than mere experimenting was done with them in the United States during this period. The wooden ties had gone into universal use by the railroads for several reasons, the more important of which were: satisfactory behavior in the track, durability, cheapness, and ease of spiking. The small cost of the ties was one of the chief reasons for the lack of interest in the European steel ties. In Europe, timber was beginning to grow scarce as early as 1880, but in the United States the timber seemed to be inexhaustible, and ties were so low in price as to make it almost profitless for one to go into the tie business.

In the pioneer days of railroading each road was able to secure ties from its own lands adjacent to its lines, or to buy them in the immediate vicinity for a few cents each. Ties were sold as low as fifteen cents, even after the Civil War, and the railroads had no trouble whatever in obtaining sufficient quantities to supply their needs. This condition of affairs persisted for a long time, but in 1866-1867 it began to be noticed that good tie-timber land was rapidly becoming scarce, and that consequently, prices were rising. Prices of ties had been fairly steady from 1837-1883, but from 1883 to 1902 they had risen rapidly. The seemingly inexhaustible forests were being rapidly depleted; most of the best wood had been utilized, and the consequent increase in price dictated the use of the poorer qualities for ties.

(The increase in prices of ties from 1867 to 1907 amounted to sixty-five per cent. Since 1907, the increase has been only about ten per cent, although it is almost certain that prices will advance in the future even more rapidly than they have in the past. The amount of timber used each
year seems enormous when compared with the available supply. In 1908 the
United States Bureau of Forestry said: "We feel certain that the present
rate of cutting is exhausting the supply rapidly, and how quickly the
supply is exhausted will depend on whether the private land owners,
states, or federal government will quickly institute a policy of conserva-
tive forest management." There is no doubt that the enormous demand for
ties alone is every year exterminating large areas of forest lands. In
the thickly wooded loblolly pine forests of Texas the average annual
yield per acre is less than 100 ties. If an average yield of 75 ties per
acre is assumed, the requirements for 1913 will cause more than 2,000,000
acres or 3100 square miles to be cleared. If a permanent forest were to
be set aside, and young trees planted each year to replace those cut, as
is done in Germany, a forest of 55,000 square miles would be required for
tie-timber alone, based on the present rate of consumption.

The preceding paragraph indicates the seriousness of the tie ques-
tion to the railroads. It was seen in the late nineties that, (1) new fo-
restry methods must be adopted and the timber supplies conserved to pro-
vide for ties in the future, (2) the poorer woods must be treated with
some preservative, or (3) some substance other than wool must be resorted
to for ties.

The first expedient has resulted in very little as far. The forestry
departments of the states and the federal government have done some pre-
liminary work, but the conflict in authority between the two has operated
to prevent a sane policy of forest preservation from going into effect.
There is little hope in this direction for many years to come.

The second expedient, that of treating the cheaper woods with pre-
Preservatives is merely a method of prolonging the life of a tie, sometimes doubling it. Since the use of preservatives only reduces the rate of tie consumption about one-third, under the most favorable circumstances, it is only a question of time before even the cheaper woods become exceedingly high priced. In 1812 about twelve per cent of all ties used were treated. This compares with eleven and a half per cent in 1910, - a not important increase. Treating ties, therefore, has not tended to lessen the cost of the raw materials to any great extent.

The third and last expedient, that of making ties of some substance other than wood, appears to have more arguments in its favor than either of the other two. So far it involves the question of the steel and the reinforced concrete tie. The steel tie, which has been used extensively in other countries, has been tried on a limited scale in a number of somewhat different forms in the United States. Only one form - the Carnegie I-section tie - is in use to such an extent that its use can be reckoned in miles of track; most of the others may be reckoned by the dozen or the hundred. And, as this tie is manufactured and pushed by the Carnegie Steel Company, upon a railway owned by that company, it does not appear that the steel tie has yet commanded itself to general use. It will not be considered further in this article.

The first experiment in the way of reinforced concrete ties was the Harrell Tie, made in 1882, when first it was realized that good tie timber was getting scarce. This tie and those designed subsequently will be described in the section following.

III. DISCUSSION OF PRINCIPAL CONCRETE TIES.

THE HARRUE TIE: In the summer of 1882 some ties were designed by
Mr. J.J. Harrell and put into the main track of the Pittsburg, Ft. Wayne, and Chicago Railway in the Union Station, Chicago, Illinois. The tie consisted of concrete moulded around a truss of 1-in. rods put together on the style of a trussed pipe brake beam. The ties were 7 ft. 4 in. long, 3 1/2 in. deep under the rails, 10 in. wide on bottom under the rail seats and 3 in. wide under the middle portion of the tie. The ties were 30 in number, and were laid on a 3 1/2° curve. The traffic over the ties was very heavy, and it became apparent that the life of the ties would be short. They lasted 17 months. Some two or three ties broke in two in the middle, indicating that they had become center-bound and were unable to stand up under the loads. The greatest difficulty, however, was with the fastenings, which consisted of bolts set in the concrete with ordinary clips for holding the base of the rail. These bolts became loose in the concrete, and the side thrust and working of the rail shattered the material under the rail seats. This tie weighed about 300 pounds of which 55 pounds were metal.

**THE KIMBALL TIE:** The next concrete tie to be designed and tried out was that designed by Mr. J. H. Kimball, Chief Engineer of the Pere Marquette R.R. In 1901, Mr. Kimball made and tested under traffic a tie with quite a novel form. It consisted of two bearing blocks of concrete each 3 ft. long and shaped like a pole tie. Each of these blocks was 7 in. deep, and the face was 9 in. wide. Each pair of concrete blocks was joined by two 3 in. channels placed 3 in. apart, back to back, and moulded in the concrete. The general arrangement and details are shown in Fig. 1, Plate I. The rail bearing is taken by a 4 x 2 in. white oak cushion block 13 in. long. This block is attached to the concrete by 1/2 in.
square bolts moulded into the concrete block and jointed at the top. The wooden blocks were treated with carbolineum. Against the outside end of each oak block was a concrete shoulder to prevent spreading of the gauge in case the block should become loose. The weight of this tie was about 452 pounds, including 68 pounds of metal.

Thirty six of these ties were put in the track of the Pere Marquette R.R. in 1901 and at the end of two years were still in good condition. In 1906, 63 ties were put in the track of the Chicago and Alton Ry. near Lockport, Ill. In 1909 the track was found to be still in good condition, but several of the ties were cracked. Up to that time these ties had given good service, holding the track to line and gauge. Nine of the ties, however, had been removed on account of being badly cracked. Of the remaining ties, four were found with longitudinal cracks, and 31 with transverse cracks. It was found, that the plug in the concrete had not been bored to receive the spike, and in driving the spike the concrete was damaged. The Kimball tie is well designed; it prevents center-binding which so often causes trouble in the track, and will probably be used more in the future where the traffic is not heavy.

**THE BUHRER TIE:** This tie has probably been the most successful of any designed previous to the year 1913. It was designed in 1902 by C. Buhrer, Roadmaster of the Lake Shore and Michigan Southern Ry. The tie is made by molding a concrete body to the head of an inverted piece of old 65 lb. rail. It was 5 1/2 in. deep by 3 in. wide on the under face, except at the center, which is narrower to avoid center-binding. The fastenings consist of bolts and clips applied to the upturned base of rail.

There have been 4304 Buhrer ties put in service on a number of roads,
viz.: Ann Arbor 77; Lake Shore and Michigan Southern, 2943; Pennsylvania Lines West of Pittsburg, 450; Lakeside and Marblehead, 550; Lake Erie and Western, 25; Chicago and Northwestern, 15; and Sandusky Water Works Company's track, 120. Of these 40 were inserted in 1902, and up to 1907, there were only two failures; 707 were inserted in 1903, of which nineteen failures have been reported; and 3457 were inserted in 1904.

About a mile of track was laid with Buhrer ties on the L.S. and N.S. in 1904 at Sandusky, Ohio, including a 3° curve. The track was reported in 1902 to be in first class condition as to surface, gauge, level, and line. The clamps, bolts, and the other track fastenings were tight, and it was stated that the Buhrer ties gave much less trouble than the wooden ones. There were no renewals up to September, 1903, even though the track was used for freight and heavy passenger traffic.

Both Buhrer ties and wood ties were used on the Sandusky Water Works track. At the end of five years (1908), fully one-third of the oak ties were badly decayed and required removal; while the concrete ties were in first class condition. There was very little rust on the top of the Buhrer tie. The rail bearing was but little worn, and the concrete was in perfect condition, with no signs of cracking. The ties, it should be added, rested in cinder ballast. The general shape of the tie is shown in Fig. 2, Plate I.

About 600 of these ties were used on the Northwest System of the Pennsylvania Lines during 1903 and 1904 in stone ballast. Nearly 500 of them were subject to high-speed heavy traffic, and the remainder to medium traffic. The ties failed under traffic; the concrete failing, and crumbling from the reinforcement. The ties were removed from time to time
and by December, 1903, all had been removed because of breakage.

In 1904, 19 Buhrer ties were put in the track of the Chicago Junction Ry. They were all removed after a few month's service because of breakage.

In 1903, 25 Buhrer ties were placed in the track of the Lake Erie and Western Ry. in gravel ballast. They too, were removed in a few months on account of breaking.

(The Chicago and Northwestern Ry. laid 15 ties of this kind in its main track in Milwaukee in 1902. They were reported in 1908 to be in good condition.)

Five hundred and fifty Buhrer concrete ties were placed in the track of the Lakeside and Western Ry. in 1906 on a 12³ curve. There have been only ten failures of these ties in four years, and there has been no trouble whatever with gauge or alignment, which had been the case when wooden ties were used. It should be mentioned that this track was subject to heavy, low-speed traffic.

From the examples above it is seen that the Buhrer concrete tie has been fairly satisfactory, especially on low-speed light traffic tracks. The tie is not expensive, costing about $1.20.

THE ALFRED TIE: The Alfred concrete tie was brought out in 1902 by the Chief Engineer of the Pere Marquette R.R. Fourteen of these were put in the track at Saginaw, Michigan, but were all removed in 1904 because of breakage between the rails. The tie was re-designed and new ties were inserted in the summer of 1904. Of these, it was reported in 1907, that one was broken close to the track rail, while several others showed signs of rail cutting, there being no cushion or protection between the top of
the tie and the base of the rail. One of the ties was cut one inch in
three months, others almost as much. Ten of these ties were put in track
in 1904, on the same road, at a water tank, where the wooden ties were
continually being destroyed by cinders. These ten ties were still in good
condition in 1907, and seemed fit for ten more years of service. This tie
adds to the conviction imparted by the previous examples that under light
traffic, the concrete tie is successful and very durable.

THE BURBANK TIE: In this the reinforcement consists of an iron plate
and a twisted bar of iron, bent at each end, and welded to the tie plates,
which rest on wooden blocks and support the track rail. One hundred and
forty-seven of these ties were put in the track of the Heceta Mining Com-
pany, near Bay City, Michigan. These were found to be so badly broken
after a few months' service that there was no question that the design
was defective.

THE HICKEY TIE: A number of these ties were placed in the track in
the St. Thomas Yard, Ontario, in 1903. They lasted about four years, the
cause of removal being cutting, cracking, and breaking. The ties were
about 3 ft. long. The reinforcement consisted of a 7-ft. piece of scrap
rail imbedded in the concrete. In this as well as most of the ties pre-
viously described, one of the primary causes of failure was the poor fast-
enings. The bolts worked loose, permitting the full hammer effect of the
rail to reach the tie. To alleviate the latter trouble, tie plates were
used, and were quite successful, but in the later ties a cushion of wood
was used instead of the tie plate. The Hickey tie weighs 500 lb. and costs
about $2.25.
THE BRUNSON TIE: The reinforcement in this tie consists of some small strips of iron embedded in concrete, wooden plugs being moulded in the concrete in which to drive the spikes, the track rail resting directly on the concrete. Nineteen of these ties were placed in the track of the Chicago Junction Ry. in 1904 in Chicago. After several months service cracks appeared between the rails in a majority of them, some being cracked in two places. Rail cutting had also commenced with several of them, especially with the joint ties. These ties were subject to only slow switch-train movement which, however, was heavy. This test again illustrates the difficulty of designing a concrete tie for heavy traffic.

THE COLORADO AND SOUTHERN TIE: In the summer of 1901 the officials of the Colorado and Southern Railway had three ties made and put in the yard at Argo, near Denver. The reinforcement in each tie consisted of three steel strips 1/2 in. thick, 4 in. wide and 1 ft. long. After about eight months' service the ties were broken beyond further use by an engine derailment, there being no protection on the outside of the tie to withstand any such shock.

THE APPLEGATE TIE: There are two designs of ties of this name, one in which the main reinforcement consists of a 2 1/2" x 2 1/2" x 5/16" angle, and another in which a 3" I beam is used. In the other details the ties are identical. In the angle-tie, the angle is split at each end to give it better anchorage. The rails are held by clamps and bolts, the latter passing through the tie with their heads fitting in recesses on the underside. Beneath and parallel to each rail there is a shallow depression in the upper surface of each tie in which is fitted a wooden plank flush with the top. The tie weighs 400 lb. and costs $1.75. A cross-section of the
tie is shown in Fig. 3, Plate I.

One of these ties was placed in a side track of the Lake Shore and Michigan Southern Ry. at Dune Park, Indiana, in 1803. It cracked in several places, but was still in service in 1807. In 1804, fifteen more were put in at Chesterton, Indiana, and although slightly cracked, were still in service in 1807. The roadmaster of the L.S. and M.S. at that time said that they were fairly satisfactory.

Eighty-seven Affleck ties were tested by the Pennsylvania Lines West of Pittsburgh at Smaworth, Pa., in 1804. After about a month's use it was found necessary to remove six of them because of cracks and breakage. These ties were laid on broken rock ballast in a track subject to much heavy traffic and numerous trains, where the conditions were very severe. By April, 1805, all the ties had been removed.

THE ULSTER AND DELAWARE TIE: In 1803 a reinforced concrete tie was made by the Ulster and Delaware Ry. and placed in its track. After more than a year's time it shows no signs of failure whatever; the nuts and clips are still tight, and have not been touched since installation. The tie consists of a solid prism of concrete, 3 ft. long by 7 in. thick, and battered from 10 in. wide at the base to 3 in. at the top, moulded in wooden forms and reinforced with a piece of angle-iron placed with the corner about 1/4 in. below the top surface. The plates 1/4 in. thick, and set flush with the top of the tie, form a seat for the rail which is held by two 3/4 in. x 3 1/2 in. square-head bolts passing through the angle iron and having clips fitting over the flange of one rail. This tie is like the Affleck tie excepting that in the latter the angle-iron is set nearer the center of the tie. The tie weighs 450 lb. and is said to cost 42 cents,
which, however, is obviously much too low. It should be mentioned that
the traffic over these ties is comparatively light.

THE PERCIVAL TIE: This tie was designed by Mr. H.T. Percival of Gal-
veston, Texas, and has given good results in its preliminary tests. It
is 3 ft. long, 9 1/4 in. wide, and 3 1/2 in. deep. The ends of the tie
for two feet, have a parabolic cross-section to give greater bearing area
under the rails. In the center it is V shaped to make it self-tamping,
and to relieve the central binding pressure, which is always present in a
flat-bottomed tie. The reinforcement consists of 3 - 1/2" bars bedded
near the top surface, and 3/4 in. bars bedded near the apex of the V-sec-
tion. In addition, each 18 in. of length has a steel wire bound around
the longitudinal bars to give further reinforcement from crushing. The
top surface of the tie is recessed out under each rail to take a treated
hardwood block 2"x2"x14", which forms a cushion for the rail. The rails
are fastened to the tie by means of spikes which are screwed through the
cushion blocks into sockets composed of screw-socket Cebill metal. A
sketch of the tie is shown in Fig. 4, Plate I.

The Galveston, Harrisburg, and San Antonio Railway installed 100
Percival ties at Bayou Sale, La., in January 1910, and 100 at Edgewater,
Texas, October, 1908.

At Bayou Sale the ties were installed under 78 lb. rail, in gravel ballast. Traffic at this point is low speed and very heavy. The ties are lo-
cated at the end of double track where fires are cleaned, and the concrete
ties were, up to 1911, very satisfactory.

At Edgewater the ties are under 90 lb. rail in gravel ballast. Traf-
fic over these ties is high speed and very heavy, and up to September, 1911,
they were in good condition excepting for a few minor cracks.

**THE KEEFER TIE:** The Keffer tie is of massive construction; it is 3 ft. 6 in. long, 3 in. wide and 7 in. deep. Its general outline is shown in Fig. 5, Plate II.

Under the rails the tie broadens out to 12 1/2 in. This broadened portion surrounds an open cast iron box molded in with the material. The box is 5 in. deep, and is wider at the bottom than the top, so that 2 oak blocks can be love-tailed into it. The blocks fill a space 12 in. long and 6 in. wide, and, when spread by inserting a wedge between them, cannot be withdrawn from the iron pocket. They project one inch above the top of the tie, and the rail is spiked to them in the ordinary manner. The reinforcement consists of a number of steel rods.

In December, 1805, forty-four of these ties were placed in the Scully Yard of the Pennsylvania Lines. Shortly after they were out in, breakage commenced, and by June, 1806, all had been removed.

The Pittsburg, Cincinnati, Chicago and St. Louis Ry. also installed some of these ties in 1806. After seven months' service, however, they were all broken through and in universal sad shape. They could not stand up under the heavy traffic and high speed, and had to be removed.

**THE CAMPBELL TIE:** This tie was first introduced on the Algin, Joliet, and Eastern Ry. The tie is 6"x5"x3 1/2" and is of beveled section excepting under the rails where it widens to ten inches for a distance of 3 1/2 in. on each side of the center of the rail. The corners of this widened section are also beveled off to meet the body of the tie. The reinforcement is furnished by two 2 in. wrought iron pieces, scrap boiler tubes being utilized for this purpose. The pieces are 7 ft. in length and are placed
side by side with a single thickness of common chicken wire surrounding them. On the center of the tie, below each rail, there is a 6 in. by 3 in. plate of heavy wire netting inserted through specially rounded openings in the pipes. The rail is held by beveled slip washers and a single U-bolt placed obliquely to the center line. A metal plate is imbedded in the tie under the rail.

Many of these ties were placed in the track of the Elgin, Joliet, and Eastern Ry., and, after a year's service in the main track, where the traffic is very heavy, are still in very good condition. They have given no indication of being affected by the weather, and afford a uniform surface for the rail base.

The ballast, and the rails under which they are laid, keep in excellent surface. The cost of the tie is said to be $1.50, but this seems much too low; the real cost is probably around $2.50. (Fig. 6, Plate III shows the general form of the tie.)

THE ATKINSON TIE: Five of these ties were placed in the main track of the Pittsburg and Lake Erie Ry. in October, 1903. An examination in 1911 found them in very good condition, the track was in good line and surface, and the track insulation was still unimpaired.

THE CHENOWETH TIE: This tie was patented and manufactured by A.C. Chenoweth. They are 3 ft. long, the width on top is 7 in., on the bottom 3 1/4 in.; they are 6 in. thick. The concrete is built about a coil of No. 18 gage wire mesh. The coils are 1/2 in. apart, and, in addition, 6 rein-forcing rods 1/2 in. in diameter are used, three on the top and three on the bottom of the tie near the surface. The rail rests on a wooden block 7/3"x7"x12" on top of the tie and is secured in position by screw spikes.
and clips. The hole for the screw spike is \( \frac{13}{16} \) in. in diameter at the top of the tie and \( 1 \frac{1}{3} \) in. at the bottom. A helical lining 3 \( \frac{3}{8} \) in. long is used.

In 1906, 101 of these ties were installed in the track of the Pittsburgh Division of the Pennsylvania Lines. Part were placed on a 2° curve, and part on a transition curve. The ballast consisted of cinders. Traffic at this point was almost constant and the equipment was of the heaviest type, with a speed about eight miles an hour. In 1907, it was found that the wooden blocks under the rails were wearing out very fast, the rails cutting through them. The cushion blocks were then replaced by tie plates, but this only changed the form of the trouble. The ties now started to crumble under the rails, and when the crumbling had proceeded to such an extent that the rails began to pound, it progressed much more rapidly. The primary cause of the failure of these ties was the loosening of the fastenings which permitted the rails to pound. In 1908, ten of the ties were removed for reasons of safety; all of them were badly crumbled under one rail. Up to 1909 only 41 of the ties were in good condition, while most of the remainder were crumbled and cracked. The failure records show that 87 per cent of shoulder ties, 55 per cent of joint ties, and 43 per cent of intermediate ties have either failed or shown signs of ultimate failure. The Chenoweth tie costs $1.75.

**The Rissler Tie:** This is one of the latest reinforced concrete ties, having been designed in 1903. It is the strongest and the best tie thus far described, leaving out the consideration of cost. The concrete body is not only reinforced by two longitudinal steel rods embedded within it, but is also partially inclosed in a steel shell. On each side is a steel shan-
nel with a curved web, having slots punched to form projecting tongues which are bent inward. Thus all the projecting parts are embedded in the concrete. The channels are connected by transverse strips riveted to the flanges. There is a considerable amount of work involved in the manufacture of these ties. The fastenings are especially strong; bolts are used with heads lying in the bottom of the tie, and the nuts are screwed down upon clamps which hold the base of the rail. There are four bolts to each rail. The rails rest on metal plates which are in contact only with the concrete—the flanges of the side channels being cut away at these points in order to prevent metallic contact from causing trouble where a track circuit is used for signaling.

The ties have a large bearing surface, so that only fifteen are used under a 33 ft. rail. The weight of the tie is 350 lb., which includes about 175 lb. of steel.

Fifteen of these ties are in use in the main track of the Pittsburg, Ft. Wayne and Chicago Ry., west of Emsworth Pa. This track carries through and suburban trains, and a number of freight trains daily. The ties were laid in May, 1903. At the inspection in 1905, they were found to be in good condition. The bolts were tight with the exception of one, the nut on which could not be tightened on account of the bolt turning in the tie. The section foreman stated that he had not found it necessary to tighten the bolts for a period of five months previous to the inspection. The ties also held their lines better than the wooden ties, required less surfacing and caused no trouble with the signal circuit. The tie is 7 in. by 12 in. by 3 ft. 6 in. Its cost (estimated) is about $2.00.

THE ISRAEL TIE: This is a sectional tie with a hinge in the center
to obviate the effects of center-binding. On the top of each section there is a cast-iron plate on which the rails rest, and to which the latter are bolted. In 1902, twenty of these ties were made under the Israel patent and were installed in the main track of the Cleveland, Cincinnati, Chicago and St. Louis Ry. Early in 1911, three ties were found to have failed completely; the concrete was crushed, and the top plate was broken in several places. The balance of the ties have the top plate either cracked or broken. The life of these ties is seemingly but two or three years.

THE SEELEY TIE: The plain concrete tie has not been mentioned thus far. Very few plain concrete ties have been designed, it being obvious to most designers that concrete alone could not take up the bending stresses. The Seeley tie is one of the very few plain concrete ties tested in practice. Ten of them were placed in the track of the Toledo Terminal Ry. in August, 1903. They lasted only two weeks. They crumbled and broke to pieces, and had to be removed. Six were tried on the Lake Shore and Michigan Southern Ry. with a similar result. The Seeley tie has proved to be impracticable, as might be expected of any concrete tie which did not make provision for the bending stresses.

IV. ANALYSIS OF CONCRETE TIE FAILURES.

Whenever a radical departure is made in existing practice in any line of endeavor, there is always an early period of pioneering. During such a period there is often such floundering around in the dark, first grasping this idea and then that, only to discard each, perhaps, and to seek after others. The process of development goes hand in hand with the sifting of good ideas from the bad. At first there are a great many poor
ideas, and, consequently, a great number of failures in that particular branch of trade, industry, or manufacture. As the development proceeds, the poorer ideas and impractical schemes, which would have obtained consideration in the pioneering stage are discarded at once. No more attention is paid to them.

The preceding paragraph applies in a general way, to the history of the development of the reinforced concrete tie. At first, when the suggestion of reinforced concrete was considered, it was thought sufficient to place a few bars of steel at random in the concrete. It was "reinforced", and the magic of that word was supposed to lend sufficient strength to the tie, so that it would support almost any load and last forever. The section preceding has shown the fallacy of such early practice. The concrete tie was just discarded from the pioneer stage.

It has been shown in Section III that the chief cause of failure in the reinforced concrete tie was faulty design. The most glaring failure of any tie was, perhaps, that of the Seeley tie, and, after all, its failure was not surprising. This tie contained no reinforcement, which simply goes to show what absurdities may occur in the pioneering stage of a new article. The designer seemingly had no knowledge of mechanics or track design, otherwise he would have known that some provision should be made for bending stresses.

Another example of faulty design is shown by the Affleck tie. Its only reinforcement was a piece of angle-iron inserted at the center of the tie. It is well known that the greatest bending stresses in a beam, such as a tie, occur farthest from the neutral axis, or at the surface. The Affleck tie, then, is reinforced at its strongest part, and unrein-
forced where the reinforcement is most needed, i.e. near the top and bottom. Apparently this design also was not intelligently worked out.

The greater number of failures have resulted from the eccentric and variable conditions to which the tie is subjected in the track. Many ties were designed to meet one set of conditions, whereas they have been found to fail in a manner apparently not considered in the calculations. For example, in the Kimball tie, center-binding was almost done away with, but the tie did not prove a success because it was not properly reinforced, the channels were too light.

Another example in point is the Keefer tie, which also succeeded in preventing center-binding. This tie failed, however, by poorly designed reinforcement. The fastenings in this case were of good design and gave no trouble.

The fastenings by which the rail is nailed to the concrete tie have been the source of continual trouble. This is as might be expected; for, although wooden ties have been in use for eighty years, the search is still on for a perfect fastening. One tie which showed defective design in the matter of fastenings was the Harral tie— the first tie described in Section III. In fact the fastenings, which consisted of bolts set in the concrete, were the primary cause of failure. They became loose, so that the thrust and working of the rail shattered the concrete under the rail-seats, destroying the bond between the steel and the concrete. The tie then failed quickly.

Another tie which showed the effect of poor fastenings is the Alfred tie. This tie suffered most from rail cutting, which followed the loosening of the bolts. Similarly, the Hickey tie failed primarily because of
poor fastenings. The bolts worked loose, and permitted the full hammer effect of the rail to reach the tie. The Brunson tie fastenings were inferior even to those just described; they consisted of spikes driven into plugs of wood molded in the concrete. Loose spikes and rail cutting developed rapidly. The resulting increased effect of the superimposed loads led to the final complete failure of the tie. The Chanowetn tie fastenings at first consisted of screw spikes passing through wooden cushion blocks into a steel helical lining molded in the concrete. It was found that the wooden blocks wore out very rapidly, as has been mentioned. Tie-plates were then used, but now crumbling under the tie-plate ensued, and failure soon followed.

From the preceding discussions it is seen that the question of proper placing of reinforcement and adequate fastenings are very difficult ones in designing reinforced concrete ties. The primary causes of failure may in many cases be traced to weaknesses in these particulars.

One of the remaining causes of failure not foreseen by designers is the effect of derailment on ties. When a truck is derailed it is sometimes miles before it is discovered and re-railed. In the meantime, the ties have been subjected to blows and eccentric strains much different from those ordinarily occurring. The wooden ties usually stand up very well under such conditions. Reinforced concrete ties do not. This is aptly illustrated by the Colorado and Southern tie. Some of these were being tested in ordinary service when an engine derailment occurred, and the ties were broken beyond further use. None of the ties described in this article, with the exception of the Kimball, Israel, and Riegler ties, had any safeguards in case derailment occurred. The Kimball tie has a long
wooden block under the rail, which prevents the wheels of a derailed truck from striking the concrete, and also serves as a cushion to absorb the shock. The Israel tie had a cast-iron plate on the top to prevent the wheels from crushing the concrete. Neither the Kimball tie, nor the Israel tie, fulfilled the designers expectations. When derailments occurred the concrete was somewhat crushed in spite of the protecting plate. The only concrete tie which has been immune to injury by derailment was the Riegel tie. This tie, as has been pointed out, had two channels with curved webs as its sides, the flanges being exposed on the upper and lower surface, respectively. This served to protect the corners of the tie. The tie was successful in preventing injury by derailment, but was unsatisfactory in other respects, one of which was its great cost as compared with the other concrete ties.

Section III, dealing with illustrations of reinforced concrete ties, and Section IV, dealing with a discussion of the causes of failure of those ties, show clearly that the reinforced concrete tie has passed through its embryo or pioneer stage, and is now entering on a new period, the second in its course of development. This new stage promises better results than its predecessor, as is usually the case with such an enterprise. The first period was handicapped at its very inception by the fact that much of the effort in concrete tie construction was made prior to the comparatively recent development and improvement in concrete design and construction. The workmanship was usually very crude, and as a consequence, did not produce sound concrete. The new period may be said to have started with 1912, with all the momentum of the preceding 13 years behind it.
V. SUGGESTED DESIGN FOR A REINFORCED CONCRETE TIE.

The standard of comparison in the discussion and design of cross-ties is the wooden tie. Until some other kind of cross-tie shall be found to be, upon the whole, better and cheaper, there will be no advantage in adopting a substitute. Disregarding for the present the question of cost and economy, the qualities requisite in a cross-tie are as follows:

1. Sufficient area of bearing surface upon the ballast to safely transmit to the roadbed the weight and impact of the rolling stock.

2. Sufficient strength, resilience, and endurance to give satisfactory service under the conditions to which it is exposed.

3. Capacity to hold the rails to gauge and in a position perpendicular to the plane of the track.

4. Sufficient frictional resistance or "grip" in the ballast, to prevent lateral movement of the track.

5. The interval between supports to the rail must be so short that deflection of the rail under its loads will be practically zero.

6. The attachment between rail and tie must be secure and efficient, and should be as simple and accessible for adjustments and repairs as possible.

7. Facility of Maintenance: The tie should be of such form and section as will permit the ballast to be properly and securely tamped under it, and the track kept in line and surface.

The standard wooden tie meets these requirements fairly well. The standard tie may be said to be 5 ft. long, 3 in. wide and 6 in. thick. Its effective width, however, may be taken as 3 1/2 in., because of the
large number of pole ties used. Taking 16 such ties to the 30 ft. rail, the bearing surface on the ballast is about 2.28 sq. ft. per linear foot of single track. This gives 1.46 sq. ft. per lineal foot of rail. Under the heavy loads produced by the large, modern locomotives, such a tie may have to transmit a load of at least 2 tons per sq. ft. of its bearing surface. Considering the fact that impact must operate to increase the load, there appears to be good reason for the conclusion that any new tie should have no less bearing area than the present timber tie.

The wooden tie is sufficiently rigid to hold the rails perpendicular to the plane of the track, and in addition has an excess of strength to hold the rails to gage, providing that the spikes do not become loose. When good tie plates are used, the lack of good nailing power in the spikes is overcome, and by the use of screw spikes, this defect would probably disappear, excepting where soft wood ties are used. In frictional resistance to lateral track movement, the wooden tie is not always satisfactory, particularly on curves, where the tendency to lateral deformation of track is greatest. Any substitute for the wooden tie must then be at least as good as the wooden tie in this respect.

When 16 ties are used for each 30-ft. rail length, the rail is supported at intervals of less than two feet. As the weight of rolling stock is more than keeping pace with the increased strength of heavy rail sections, the distance between supports can not be safely increased.

The question of the fastenings, by means of which the rail is attached to the wooden tie, has long been a very important one. It is still in an unsatisfactory state, even though it has been in the lime light for eighty years. Besides the liability of the spikes to be withdrawn from the wooden tie, the frequent driving of them into the wood destroys
the floor, impairs its holding power, and promotes the decay of the wood. When tie plates are not used, the cutting action of the rail becomes a serious defect. These weaknesses become more serious as the life of the tie is increased by preservative processes. But with good tie plates and screw spikes these defects may be largely mitigated. The width and spacing of the wooden tie affords ample facility for tamping and manipulating the ballast under it, and for keeping the track in surface and in line.

The preceding discussion has been for the purpose of establishing the qualities of the wooden tie as standards by which all kinds of other ties, and the reinforced concrete tie in particular, must be measured. Any new tie must certainly be better than the wooden tie; otherwise there is little reason for using it. Any fair comparison between a new kind of tie and the wooden tie must be based upon equal capacities to meet the same essential requirements as the timber tie.

In considering the strength of a tie, it is necessary, in the first place, to discover the nature of the stresses to which the tie is subjected. Ordinarily a cross-tie acts as a continuous beam, but for purposes of design it may be considered a beam supported at two points - the rails - and uniformly loaded with a pressure of the ballast due to the weight of the wheels of the rolling stock on the rail. The ends of the beam then form cantilevers. Under the action of the uniform load, the upper side of the tie between the rails - the points of support - is in tension, while on the cantilever portions, the upper side is in compression. At a point directly under the rails on the under side of the tie the fibers are in tension.
While the conception of the stresses in ties which has just been explained is theoretically correct, in practice there are many conditions which qualify the theory. In the first place, the tamping of the ballast usually is not as uniform as was assumed in the theory. Secondly, the frictional resistance among the component fragments of the ballast may be such that, under any deformation of the tie, the loading will not be uniform.

For practical purposes, in comparing the strength of ties, they may be considered as simple beams placed upon supports, an equal distance apart and uniformly loaded throughout their length. Stating this in another way, it may be said that the strengths of two ties are to each other as the moments of resistance of their sections. The reinforced concrete tie shown in Plate III, was designed on the latter basis. Its dimensions and construction are as indicated on the sketch. In this design, it was of course essential that the tie be considered a continuous beam. At the middle of the tie the reinforcement must be at the top, while under the rails it must be at the bottom of the tie. It should be noticed that in order to secure this result, two sets of rods have been used, one set in the top and the other in the bottom, overlapping each other at the point of contra-flexure. The moment of resistance of this tie is about the same as that of the wooden tie, both at its middle and under the rails, allowing a fiber stress of 12,500 lb. per square inch of steel. This tie, therefore, from this standpoint, may be considered equivalent to the wooden tie.

The tie requires about 0.131 cu. yd. of 1:2:4 concrete, and 23 lbs. of steel, which includes anchor plates, bolts, and a large tie-plate.
The cost of this tie can only be roughly estimated, because at present the writer has been able to obtain no reliable data on this class of work. Among the data on which accurate figures could not be obtained may be noted the cost of molding concrete into such small forms, the danger of injury and breakage in removing the ties from the forms and storing them; and the very important fact that the ties must be stored and otherwise cared for for at least four months before they become sufficiently set to be ready for use. A fair estimate of the cost of the concrete would be about $7.00 per cubic yard, and of the steel 2 cents a pound. To this must be added the cost of transportation and the labor of handling. As four of these ties weigh over a ton, an allowance of 21 cents for these items would seem fair, if not somewhat low. The cost of the tie complete would then be approximately $2.50. This is nil in comparison with the stated costs of the ties already described, but is probably nearer correct than the usual optimistic estimates of the designers of such ties.

The question of fastenings for a reinforced concrete tie is a serious one, as has been previously pointed out. Anchor bolts built into the tie with anchor plates at the bottom and rail plates at the top seem to promise the best results, and have indeed proven themselves so. This has been indicated in preceding sections. The fastenings, however, are by no means perfect; the future will no doubt show many better designs. It should be noticed at this point that the ordinary tie plate is not used under the rail, but instead a plate of steel, 5" x 1/2" x 2 1/8" is used. The plate is purposely large in order to protect the tie in case derailment occurs, and to prevent the initial failure mentioned in Section IV.
VI. ECONOMY OF THE REINFORCED CONCRETE TIE.

No mention has been made thus far of the relative economy of the reinforced concrete tie as compared with the wooden one. It is true that statements have been made that it is probable that, owing to the increasing cost of timber, the concrete tie will prove economical. But as yet no figures have been given. The question of economy will now be discussed.

The elements that enter into the problem of relative economy are:
1. The first cost of the tie, delivered.
2. The useful life of the tie.
3. The cost of tie renewal and end of track maintenance, in so far as it may be affected by the kind of tie used.
4. The cost of interest on the investment, and of a sinking fund.
5. The value of the worn out tie when removed from the track.

It has been often assumed that the cost of track maintenance would be materially less if concrete ties were substituted for those of wood. Experience, however, has shown that there has been little, if any, difference. Excluding the cost of renewal, it is reasonable to expect that with ties of equal strength and bearing area, the cost of track maintenance would be about the same, regardless of the material of which the tie is composed. The cost of putting a new tie into the track, and of taking it out when worn out, may be properly considered apart from the cost of track maintenance and charged to the cost of the tie. The cost of putting in a wooden tie seems to be about 10 cents; the cost of taking it out 3 cents. For a concrete tie, because of the great weight, the cost would probably be about 17 cents. On the other hand, the wooden tie has no value when worn out. The concrete tie, however, has some scrap value,
but considering the cost of marketing it, a quotation of $10.00 per ton for the steel would be a liberal allowance.

The most satisfactory unit by which to measure the economy of a cross-tie is by the annual cost method, described by Mr. S. Whinery, in the Railroad Gazette, of November 11, 1904. In this method, the annual cost of ties per linear foot of track is found for each tie and the results compared. This gives a true basis of comparison.

The annual cost per linear foot of track may be expressed algebraically as follows:

Let \( x \) = the required annual cost of ties, per lineal foot of track.
\( c \) = the first cost in place, per lineal foot of track.
\( v \) = value of worn out tie, per lineal foot of track.
\( L \) = useful life of the tie in years.
\( i \) = rate of interest.
\( s \) = an annual payment into a sinking fund which at \( i \) rate of interest for \( L \) years will amount to 1.00

Then

\[
x = ci + (c-v)s
\]

Applying this to both the wooden and concrete ties, the results shown in the following table are deduced.

<table>
<thead>
<tr>
<th>Life of tie in years</th>
<th>Wooden Tie</th>
<th>Reinforced Concrete Tie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of tie delivered</td>
<td>$1.00</td>
<td>$2.50</td>
</tr>
<tr>
<td>Cost of renewal</td>
<td>.13</td>
<td>.17</td>
</tr>
<tr>
<td>Cost of tie in track</td>
<td>1.18</td>
<td>2.27</td>
</tr>
<tr>
<td>Value of worn-out tie</td>
<td>0.00</td>
<td>.85</td>
</tr>
</tbody>
</table>
Spacing of ties, center to center, feet

<table>
<thead>
<tr>
<th></th>
<th>1.375</th>
<th>2.0</th>
</tr>
</thead>
</table>

Cost of ties per lineal foot of track

<table>
<thead>
<tr>
<th></th>
<th>$.60</th>
<th>1.42</th>
</tr>
</thead>
</table>

Value of worn out ties per lineal foot of track

<table>
<thead>
<tr>
<th></th>
<th>0.00</th>
<th>.12</th>
</tr>
</thead>
</table>

Annual cost of ties per lineal foot of track

<table>
<thead>
<tr>
<th></th>
<th>.023</th>
<th>.123</th>
</tr>
</thead>
</table>

Annual cost for one mile of track

<table>
<thead>
<tr>
<th></th>
<th>$422.00</th>
<th>$623.00</th>
</tr>
</thead>
</table>

The figures in the last two lines show the relative economy of the two kinds of ties. They seem to indicate that the wooden tie is still the most economical, but it must be remembered that the life of the concrete tie was taken at 15 years. This is a low figure for a well-designed tie, and when the fact is considered that in slow speed tracks, such as yards and sidetracks, the life will be much longer, it seems certain that the concrete tie is almost as economical as the wooden tie.

VII. CONCLUSIONS.

The reinforced concrete tie is now in the second period of its development. It has passed through the pioneer stage of rough experimentation and cut-and-try methods, and has entered a period in which more attention is paid to adapting it to the actual conditions of service in the track. Many of the early ties were designed with improper notions of the requirements of cross-ties. In this second period, however, this is no longer true, and the ties are now designed with a fairly satisfactory, although not complete, knowledge of the requisites of a good cross-tie. This fact and the constantly increasing scarcity of timber make it probable that the reinforced concrete tie will rapidly come into general use, especially on light traffic tracks and yards.

Although the reinforced concrete tie is being made much more than
formerly, it is not yet mechanically perfect. The chief elements of weakness are:

1. The fastenings.
2. Poor protection in case of derailment.
3. Inability to stand up under heavy traffic.
4. Inadequate reinforcement.

These difficulties are not insurmountable; in fact they are in the process of being overcome. The future promises soon to produce a concrete tie without most of these defects.

From the standpoint of economy the concrete tie is still at a disadvantage with the cheap, wooden tie. The increasing scarcity of all kinds of timber, together with the decreasing cost of cement, makes it seem probable that, in the near future, the concrete tie will be the most economical to use. As yet the advantage is still with the wooden tie.
PLATE I

FIG. 1

4' x 9' x 18'

3" Channels

THE KIMBALL TIE

FIG. 2

THE BUMMER TIE

FIG. 3

THE AFFLECK TIE

FIG. 4

THE PERCIVAL TIE
PLATE II

FIG. 5

THE KEEFER TIE

FIG. 6

THE CAMPBELL TIE

FIG. 7

SUGGESTED DESIGN FOR A CONCRETE TIE