KOSTERS

Solid Floors-Railroad Bridges

Civil Engineering

B. S.

1913
SOLID FLOORS-RAILROAD BRIDGES

BY

STUART FARNSWORTH KOSTERS

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1913
UNIVERSITY OF ILLINOIS
College of Engineering

May 24, 1913.

I recommend that the thesis prepared under my supervision by STUART FARNSWORTH KOSTERS entitled Solid Floors-Railroad Bridges be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

H.B. Garver
Instructor in Civil Engineering

Recommendation approved

Jno O. Baker
Head of Department of Civil Engineering.
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INTRODUCTION

The object of the writer of this thesis is to review completely the history of the development of solid floor construction in railroad bridges, to investigate conditions both past and present, and to draw conclusions based on a careful study of theory and practice of those in the field of actual railroad bridge construction.

The importance of the subject is most easily realized by citing one of the most horrible examples of railroad wrecks which was directly caused by an inadequate bridge floor. The following is a report of the St. George disaster taken from the Engineering News, which occurred February 27th, 1889. "The worst accident of the year, so far, occurred on the Grand Trunk Railroad at St. George, Ont.; a bridge disaster due directly to the vicious system of half open, unprotected bridge floors which are so common. The train consisted of engine, tender, and baggage car, all of which passed over in safety, passenger coach which stripped off the ties, and piled them up together, and then fell over into the river, dragging with it the Pullman and dining car. The names of sixteen dead and thirty severely injured are reported. The facts as to the accident are somewhat obscure, but it appears clear that nothing serious would have happened except for the defects of the bridge floor". Many other wrecks have occurred which were directly due to the same cause, the most prominent among them being the La Salle, New York disaster in which eleven freight cars were dashed into the Cayugha creek.
At the time solid floor construction was introduced, arguments sprang up both pro and con. Those who favored the construction claimed that the dead load of a bridge with skeleton floor bore so small a ratio to the live load, that the vibrations caused were excessive, and the resulting deterioration of the structure unduly great. The only arguments brought by the other side were first; the extra initial cost, and second, the tendency of the iron floor to rust under ballast.

In a paper entitled "Railroad Structural Economics", delivered before the American Society of Civil Engineers in 1889, Mr. George H. Thomson, bridge engineer for the New York Central & Hudson River R.R., classifies floors for bridges, referring to railway structures alone, under the following heads:

First class floor: A solid floor of the type illustrated in figures one and two, and all other types which are closed and in which provision is made for ballasting.

Second class floor: A system of cross and longitudinal girders, used in New York State for the past thirty years.

Third class floor: A floor composed of wooden floor beams and cross-ties, as commonly used on through and deck plate and lattice bridges.

A derailed train is most admirably provided for in the first class floor, for the phenomenon of bunching and scooping which occurs in the second and third class floors, cannot be obtained with this style of floor. Again, the danger and loss from fire is reduced to a minimum.

Mr. Thomson also explained that the cost of masonry
Figure 1

Cross Section of Floor.

Plate 10\" x \(\frac{3}{8}\)\" x 12\'
Angles 3\" x 3\" x \(\frac{3}{8}\)\" x 12\'

End Elevation.

Figure 2

\(\frac{1}{4}\) Cross Section of Floor.

[Diagram of cross sections and elevations, including annotations and measurements]
for first class floor bridges is less than for second or third
class floor bridges, because:

A: No back wall is required for abutments. In short spans
this saving alone is sufficient to pay the difference in cost
between a second-and a first-class bridge floor.

B: First class floor bridges do not shake up the substructure
and cheap class masonry is all that is required in abutments.

EARLY TYPES

The first move which showed the real progressive
spirit in railroad bridge construction in this country was made
by the New York Central and Hudson River Railroad in 1888. Mr.
Thomson started reconstruction of floors on all bridges less than
one hundred feet span. The cross section and end elevation of
the first solid floor which he actually constructed is shown
in figure 1, page 3. This floor was built of Pencoyd standard
heavy-trough sections, weighing twenty-five pounds per square
foot and fastened together by a single row of rivets.

Bridge Over New York Sewer.

Figure 2, page 3, is a section showing half of the four-
track bridge over the One hundred and Sixty Fifth Street sewer
in New York City, which was built by Mr. Thomson. The total
length is twenty-four feet, twenty-one feet clear span, and two
feet depth of floor. The cost of the floor including iron,
ballast, etc., was five hundred dollars per track.

In 1889 the New York Central and Hudson River Railroad
Co. constructed the Oriskany Bridge with a span of 65 feet and
9 inches. In this bridge another of Mr. Thomson's progressive
solid floors was constructed. Figure 3, page 6, gives a detailed sketch of the floor in elevation.

Saundersville Bridge.

Owing to the great success which was realized with the solid floor construction on the New York Central and Hudson River Railroad, its merits were soon recognized, and in 1899 the New York, Providence and Boston Railroad constructed their first solid floor at Saundersville, Mass., in a 105 foot span bridge.

The design and construction of this floor was entirely under the supervision of Mr. E. P. Dawley, the chief engineer of the road. Figure 4, page 6, shows a section and elevation of this floor which was made of Pencoyd corrugated flooring.

Ogden Ave. Viaduct, Chicago.

In 1892, Mr. L. H. Clarke, City Engineer of Chicago, and Mr. W. M. Hughes, Engineer of Bridges for the city, designed a unique solid floor for the Ogden Ave. Viaduct. Figure 5, page 8, shows a section which fully illustrates the construction.

Swiss Northwestern Ry.

The main and distinguishing feature of the type of plate girder used on the Swiss Northwestern Railway in 1892 was the continuous bed of ballast carried without interruption from bank to bank. This mode of construction was found to make the structures ten to fifteen per cent heavier and more expensive, but on the other hand, their vibrations were reduced to a minimum. To serve as a support for the ballast, troughs made of mild steel were used and either laid longitudinally or transversely according to the height available for construction.
Figure 3

Side elevation of floor in 'Oriskany Bridge'.

Figure 4

Cross Section

Side Elevation.
The least height is occupied by the bridge with ballast between the girders as shown in figure 6, page 8. The troughs are placed longitudinally and rest on flat straps of iron, twenty-five-thirty seconds of an inch high, and about two inches wide fastened to the tops of the floor beams by counter sunk rivets. These straps serve to protect the angles of the floor beams from being bent downward by stresses on the trough, and also serve to transmit the live load to floor beams axially. On both sides of the track sheets of iron are placed, resting against the gusset plates connecting floor beams to the main girders. The box thus formed receives the ballast to the height of twelve inches above the top of the troughs. The ballast rests upon a solid layer of concrete which covers the troughs entirely. A sheet of Holz cement (a material similar to our tarred felt) was used to cover the layer of concrete and give it a waterproof surface. The troughs were made of iron five inches high, the width of base being twelve inches; the weight per linear yard was 62.5 pounds. The bridge which permitted of greater clearance was constructed with the troughs running transversely.
Figure 5

Section of Floor - Ogden Av. Viaduct.

Figure 6

Transverse Section of Floor.

Swiss Northwestern Railway
TROUGH FLOORS

Design by Mr. J. R. Worcester.

From 1890 to 1893 the New York, Providence and Boston Railroad put in a considerable amount of iron and ballast bridge flooring on the same general principle as that which was constructed in the Saundersville bridge, but of entirely different design. In 1892 a floor was designed by Mr. J. R. Worcester, chief engineer of the Boston Bridge Co., for a bridge which carried the single track of the New York, Providence and Boston Railroad into the station at Worcester, Mass. The bridge consists of two plate girders 95 feet 8 1/2 inches long each, placed 17 feet 4 inches center to center. The bridge was located on a curve which necessitated the great width between girders. As seen from figure 7, page 10, the floor consists of a series of V-shaped troughs made up of angles and plates running transversely across the bridge and fastened to the girders by angles and brackets. Along the center line of the bridge the floor is stiffened by vertical V-shaped plates fitting into these being troughs and secured by angles. The troughs are filled with concrete to a height of 5 inches above their tops upon which the ballast and remainder of the track are laid in the usual manner.

The details and general construction of the floor are so clearly shown by the figures as to need no further description. The writer regrets that he is unable to give the weight and cost of this flooring compared with ordinary types, but the bridge company states that the simplicity of the shop
Longitudinal Section of Floor
New York, Providence & Boston R.R.

Detail of Stiffeners
work makes it very cheap. At any rate its economy was considered sufficient to make it worth while to have the system patented.


One of the most interesting features in the construction of the skew bridge for the Kansas City Outer Belt and Electric Railway in 1907-08, is the solid floor construction. This as shown in figure 8, page 12, consists of rectangular troughs, 10 7/32 inches to 11 3/32 inches wide, and 13 1/4 inches deep; they are secured to the bottom chords by gusset-plate connections. Very large ties are used, 8 x 10 inches (on edge) 10 feet long. In each trough are two blocks 4 1/2 x 8 inches x 2 feet upon which the ties rest, the tops of the ties being 1 1/8 inches clear above the tops of the troughs. Outside guard timbers are used, boxed out 1/2 inch for the ties, and secured at every tie by a 7/8 inch bolt which passes through the tie, block and bottom plate of trough.

All masonry is of concrete, reinforced with Johnson corrugated bars, and the buttressed type of design is employed for abutments and wing walls. The concrete is composed of Kaw River sand, Iola Portland cement, and crushed stone in proportions of 1: 3: 5.

The Railway Terminals at Providence, R.I.

Some very interesting and novel designs of solid floors were built in connection with the railway terminals at Providence, R.I. The Gaspee Street bridge and the style of flooring used was designed by Mr. E. P. Dawley and Mr. G. B. Francis. As shown in figure 9, page 15, it is a trough floor with bottom joints,
Figure 8

Vert. Pls. 13" x 7/8"  Top, Bot. Pls. 9" x 3/8"
L0 3 1/2" x 3 1/2" x 3/8"
11" 11" 1/2"

15"

Figure 19

Solid Floor - Denver & Rio Grande R.R.
so that the bottom is tight, the troughs resting on shelf angles on the webs of the girders. Drainage holes are drilled near the ends, and gutters and leaders are placed under these. All iron work is painted with red lead, and the floor is given a coating of asphalt composition containing about twenty per cent of crude petroleum to render it soft and tough. The troughs are filled with clean coarse gravel over which asphalt is poured, and upon this filling is placed the broken stone ballast. The Berlin Iron Bridge Company, of East Berlin, Conn., had the contract for this structure.

Figure 10, page 15, is a view of the one and one half acres of solid floor of the Francis Street bridge, 335 feet 6 inches long, and 202 feet 6 inches wide. In the main this floor was the same as shown in figure 9. The dimensions in detail are as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of sides of trough</td>
<td>3/8 in.</td>
</tr>
<tr>
<td>&quot; bottom of trough</td>
<td>3/4 in.</td>
</tr>
<tr>
<td>Weight of trough per lineal foot</td>
<td>30.9 lb.</td>
</tr>
<tr>
<td>&quot; cover plate 3/8 x 5 1/2 in. per lin. ft.</td>
<td>7.0 lb.</td>
</tr>
<tr>
<td>&quot; floor per sq. ft.</td>
<td>28.5 lb.</td>
</tr>
<tr>
<td>Depth of trough over all</td>
<td>6 in.</td>
</tr>
<tr>
<td>Length over flanges on bottom</td>
<td>15 1/2 in.</td>
</tr>
<tr>
<td>&quot; of each flange</td>
<td>2 1/2 in.</td>
</tr>
<tr>
<td>Distance c. to c. of floor troughs</td>
<td>16 in.</td>
</tr>
</tbody>
</table>

Track Elevation in Philadelphia.

The bridges on the track-elevation work in Philadelphia, completed in 1909, in general consists of lines of plate girders either parallel with the tracks or in many cases parallel with the curb lines in the streets. Their trough floors vary in depth from 12 to 24 inches. In some cases it has been possible to place a floor of girders and buckle plates approximately on
the level of the top chords. The waterproofing has been done in two ways, by the use of five layers of Hydrex felt laid on a base of concrete over the buckle plate floors and covered with a layer of brick to form a protection, or with natural rock asphalt mastic placed in and around the upper side of the troughs and draining to outlets through the trough floor into gutters and down-spouts beneath.

Sicilian asphalt mastic has been placed over all the surfaces including the vertical sides of the troughs, and has been successfully applied to the sides of the troughs, even in the case of those which were 24 inches deep. This was accomplished by first placing a 3/4 inch layer in the bottom of the trough; wooden forms like cores were then set in the trough, leaving 1/2 inch spaces on each side between them and the vertical trough plates into which asphalt was poured. After it had cooled, the core boxes were removed and the second coat of asphalt was placed in the bottom of the trough, increasing the thickness there to 1 1/2 inches. Afterward the troughs were filled in the usual manner with stone ballast applied directly to the asphalt coating.
Section of Floor of Subway Orders.

End Elevation of Steel Trough Floor.
Fig. 9. - Style of Solid Floor Used.

Solid Floor - Providence Railway Terminals

Francis St. Bridge - Providence
RAIL FLOORS.

An Old Rail Floor.

The variety of uses to which old rails can be put by railway companies is recognized in connection with the construction of a solid bridge floor of old rails used on the Chesapeake and Ohio Railway. The illustration in figure 11, page 18, shows the floor applied to a plate girder span of 101 feet; but exactly the same general construction is followed in shorter spans. For double track, a single rail length extends across both tracks of all four girders, and is fastened to the outside girders only. The rails rest directly on the topmost cover plate, and consequently there is a break in the uniform level of their tops at the end of each cover plate. Each rail is attached to the first or bottom cover plate by a bolt to prevent it shifting crosswise of the bridge, and the angles and plate for holding the ballast prevent movement lengthwise of the bridge. It will be noticed that the bottom cover plate is extended laterally for the purpose of attaching the holding bolts, and it may also be noted that the rivets in the top cover plates are spaced so that the rails just sit between the transverse rows, that is, a space the width of a rivet head exists between each rail which admits of perfect drainage through the broken stone ballast. To prevent the waste of the ballast through the opening between the ends of the girders and the parapet wall, a plate covering the opening is riveted to the ends of the girders by means of an
angle. The simplicity of the device for holding the ballast in place and the lateral extension of the first cover plate to hold the rails in place are the two noticeable features of the construction illustrated. It will be noticed particularly that the extension of the cover plate obviates any necessity of riveting the rails to the structure, and that any other floor can be substituted for the rail floor without any change in the structure or indeed without any material loss due to the extra cost of special construction for the rail floor.

The particular floor illustrated was designed by the chief engineer of the Chesapeake & Ohio R.R., Mr. H. Frazier, M. Am. Soc. C. E., in 1896. The cost of this floor was $6.00 per lineal foot of bridge for double track, as against $1.75 per lineal foot for a wood floor. However the comparative maintenance costs for the two types easily proved that the rail floor was less expensive in the long run.

In an article entitled "Railway bridges of short span", written for the Engineering News in 1896, Mr. F. W. Wilson, Jun. Am. Soc. C. E., says that the use of rail-floor bridges is not to be recommended for clear spans of more than 12 feet if 65 pound rails are used, and 14 feet if 80 pound rails are used. He says: "Owing to the slight depth of the rails, when compared with greater lengths than 14 feet I do not think it advisable to use them". In connection with this article Mr. Wilson gives a table of weights of rail-floor bridges such as shown in figure 12, page 18. Below is the table for clear spans of 8 to 16 feet.
Solid Floor of Old Rails For 101-Ft. Plate Girder
Chesapeake & Ohio Ry.

Short Span Bridge Floors
One of the principle features of a rail-floor bridge which commends it for railway purposes in general is that all work can be done by the road department forces and hence no contracts or special appropriations are necessary to their construction. In this manner old rails which have been abandoned for heavier sections can be utilized to the best possible advantage. There is however the objection that if the execution of such work is left entirely in the hands of the road department forces without inspection of any kind, it may sometimes lead to the use of a fewer number of rails than is called for on the plans, in case they do not happen to have the requisite number of rails on hand.

The rails should be given a preservative coating of some kind, applied hot.

New York Central Floors-1896.

For spans ranging from 14 to 28 feet in the clear, longitudinal trough bridges of the type shown in figure 13, page 20, were used extensively on the New York Central Railway for a considerable period. While this type of bridge offers several important advantages, yet these are almost or quite offset by
Figure 13

\[\text{\(\frac{1}{2}\) cross section} \quad \text{\(\frac{1}{2}\) end elevation}\]

Longitudinal Troughs

Figure 14

Design by Mr. F.W. Wilson
the serious consideration that they are not easily inspected or painted. To do either or both with any degree of frequency involves considerable expense, since it involves the removal of the ballast. Further than this, the temptation to neglect those things which are not apparent superficially is a serious one to most bridge inspectors, and the result is that a bridge so difficult of access is likely to be left untouched from year to year until rusted to such an extent as to endanger its efficiency and demand its renewal.

The same inaccessibility may also be charged against a rail-floor bridge, but this at least has the advantage of having the metal work in more compact masses, and the loss of section from rust would proceed more slowly than in the case of plates and angles such as are used in the construction of longitudinal through spans.

Both of the foregoing types possess one great advantage, which is, that the ballasted track may be so perfectly surfaced in conjunction with the track approaching the bridge that no shock is felt in crossing or in the change from the solid road bed to the bridge floor.
In connection with his routine duties for the New York Central Railway, Mr. Wilson designed a type of floor for short span bridges in 1896. The plan is shown in figure 14, page 20, arranged for a double track span of 17 feet total length. The track support is essentially made up of four I-beams to each track, these being so spaced that all are equally loaded. A sway frame near each end holds the I-beams in position. Across the tops of these main beams are laid 7-inch I-beams spaced about 14 inches center to center, and running transversely the full width of the bridge. Over these beams a 5/16-inch plate is riveted, being spliced as frequently as desired in the length of the bridge. The rail is supported upon tie-plates which rest in a continuous channel lying upon the 5/16-inch plate.

The rail connection secures the track rails direct to the metal flooring and is in some respects novel. The bolts used are straight instead of curved as they were heretofore usually made, and the two beveled washers hold the rails securely in place; but when the nuts are loosened the rails may be moved laterally 1/2 inch in either direction, owing to the slotted hole in the lower washer. The rail is cushioned upon a sheet of indurated fibre 1/4 inch thick, and two clips of fibre 1/8 inch thick, one on each side, are placed between the washer and the rail. By means of a very simple interlocking of the bottom sheet of fibre, and two side pieces of fibre and and two lower washers, all of the five pieces are secured by the two bolts.
The introduction of the fibre is primarily to form a cushion for the rail, and to deaden the noise; but, as shown in the details, it also serves as a complete insulation for the rails, which becomes a necessity where the rails are used for conducting electric currents in the operation of automatic signal systems.

The longitudinal beams are provided with sole plates at their ends, and rest upon creosoted timber blocking which assists in providing some elasticity to the bridge, and also assists in distributing the loads upon masonry.

The girders at the side of the bridge are intended to support the ends of the transverse beams in case of derailment, and they project about six inches above the floor of the bridge in order to serve as guard rails. An angle iron is riveted along the sides of the floor and against the outside girders, partly as a finish to the floor and partly to reinforce the top of these girders in case they should be called into play as guards for a derailed car. By making the transverse beams of such section that the stress per square inch will be tolerably high, the deflection of the portion between the longitudinal supporting beams might be made sufficient to about represent the elasticity to be had if wooden ties were to be used.

These bridges were easily inspected, cleaned and painted, easily shipped and erected, and cheap as to first cost and maintenance. One of the elements of economy in this type of construction is the very small amount of shop work required. Using as a standard of comparison a span of 17 feet total length, double track, the cost for a bridge of this type complete was about $1.48
per square foot of floor area, while the cost for a longitudinal trough span of the same capacity and dimensions was about $2.05 per square foot. This difference represented a total of $270 for a single span of these dimensions. Where there were numbers of such spans as was the case on the New York Central Railway, this saving was of considerable consequence. Then, again, the depth from base of rail to the lowest part of a structure was often a matter of importance, and a saving, from 3 to 5 inches in this depth was made by using the I-beam construction above described instead of the longitudinal troughs.

Solid Floors on Track Elevation in Chicago.

In 1899, in connection with the track elevation work in Chicago, solid floor construction was used extensively. Mr. L. H. Clarke designed and superintended a solid floor which has served to the present time on the joint tracks of the Chicago, Rock Island and Pacific Railway and the Lake Shore and Michigan Southern Railway. Five girders make up a four track bridge. The floor is made up of 10-inch 33-pound I-beams, 62 for each track, cut at the ends to an angle of about 60 degrees, with hanger plates 7/16 x 9 1/4 inches riveted to each end in the shop by means of angle lugs riveted to the webs. These floor beams are riveted to the girders in the field with 5 rivets connecting each hanger to the web, and with two rivets to the 21 inch chord cover plate for side stiffness. A continuous sheet of 5/16 inch steel plates is placed upon the floor beams and riveted to them. It is also riveted to the sides of the girders with a continuous seam through the angle irons provided, and is spliced at the
joints with lap plates 3/8 x 5 inches, placed below the surface.

The drainage is from the centre of the girder span to the ends, due to the camber, and at each end the steel-sheet covering is finished up with an angle iron and provided with a gutter of 1/8 inch steel, which drains into a groove cut into the roadbed. Upon the plate covering of the floor, and riveted to it and the floor beams, are laid the rail plates and guard rails.

Erie Railroad Bridge Floors.

A simple type of ballasted floor has recently been applied to a number of short span bridges on the lines of the Erie Railroad. These bridges are of trough plate-girder construction with I-beam floor beams about thirteen and one half inches center to center, riveted to the main girder webs and covered with a continuous flat sheet of 7/16 inch steel supported on the top flanges and fastened to them with counter-sunk rivets. The joints of the plates occur over the floor beams and no splice cover-plates are used. This plate extends beyond the track to within about 18 inches of the girder webs and thence is carried up about 24 inches at an angle of 30 degrees with the vertical and supported on horizontal continuous top and bottom angles riveted to the sway brace gusset plates.

The plate trough thus formed is waterproofed, a four ply Hydrex felt laid with Hydrex compound being generally used. The upper edges of the waterproofing are flashed over the upper longitudinal angles and both horizontal and inclined surfaces are protected by a single course of hard-burned shale brick laid flat with dry joints. The upper courses of bricks are protected and locked into position by longitudinal angles or bent plates.
bolted to the upper side angles.

The floors are pitched toward one abutment and the floor plate at the end is continued over the back wall of the masonry to carry the drainage behind the abutments. On the brick protection the ordinary ballast and track is placed in the usual manner. The floors as built have proved tight and are considered satisfactory.

The first application of this type was made in 1908 at a crossing of the Erie and Jersey Railway over the New York, Ontario and Western Railway tracks near Campbell Hall, New York, where it was desired to use a ballasted floor and to avoid a closed construction which would hold the locomotive gases and promote corrosion of the steel work. Since then the same type has been used at several crossings over streets where ballasted floors were desired.

The chief reasons for adopting this design were: 1- to secure a ballasted floor over steam roads which would not hold smoke and gases; 2- to give as smooth and perfect a surface to waterproof as possible, avoiding all difficulties of flashing around stiffeners and girder webs; 3- to have all main connections of floor beams and girders accessible for inspection and painting.

This work was done by the construction department of the Erie Railroad, Mr. Francis Lee Stuart, chief engineer, Mr. F. A. Howard, assistant engineer of bridges and buildings; and the bridges were erected and waterproofed by the bridge department forces under Mr. W. H. Wilkenson, inspector of bridges.
Although the writer has heretofore spoken of the fireproof qualities which the solid floor possesses, he has not considered this detail in specific instances.

In 1900 the Union Railway handled the freight between the three large plants of the Carnegie Steel Co., namely, the Edgar Thomson Steel Works, the Homestead Steel Works, and the Duquesne Steel Works. Bridges and viaducts were of common occurrence on this line, including in all seven bridges and five viaducts. Many of these structures were on what was called hot metal routes. These routes were used for hauling cars carrying ladles of molten metal from one works to the other; and it was absolutely necessary to provide protection for steamboats and other craft in the river, the teams and pedestrians using the streets below, and the railway trains passing underneath. It was also thought necessary to protect the steel in the structure to prevent it being cut by molten metal, should some splash over from passing trains of hot metal-laden cars, or should a ladle upset when passing over the structure. The fireproof construction adopted is shown by figure 15, page 28. Briefly described, it consists of a through-shaped floor of fire-brick laid on steel plates, with a high side fencing of galvanized corrugated iron over the through spans. The section shows the construction in detail. The metal floor carrying the fireproofing weighed about 700 lb. per lineal foot of single track, and 1200 lb. per lineal foot of double track and of course this extra load had to be provided for in designing the steelwork.
Figure 15

**Fire-Proof Floor**

Figure 16

**Interlocking Cast-Iron Arch Solid Floor**

Weight 22½ lb per sq. ft.
An Interlocked Cast-Iron Arch Solid Floor.

Figure 16, page 28, is a transverse section of a solid floor made up of interlocking cast iron arches which was designed by Mr. A. L. Wymer of Youngstown, Ohio, in 1901. As will be seen from both figures 16 and 17, the arches with interlocking edges are simply laid upon the supporting beams without riveted or bolted fastenings of any sort. The arches can be made of other material than cast iron such as cast steel or terra cotta, but cast iron is considered the material most available and least expensive for general purposes. The following claims of merit for this construction are pointed out:

The arches can be made of any dimensions to give the required strength and of such shape to use most economically the metal in them. Cast iron being much stronger in compression than in tension, the strength of a floor-plate may be varied considerably by a change in the cross section of the plate with very little change in the weight. The fibre stress can be much more than doubled, while the weight is decreased only six or seven percent. Not only can the form of cross section be varied or reinforced by ribs in various positions, but the span and rise of the arch should be varied to correspond with the work it has to do.

It will readily be seen that even with a fibre stress much lower than is usually employed for cast iron, a section weighing much less than that shown in figure 16 would be adapted for use for bridge sidewalks and for floor of buildings. So far as dead weight is concerned it would be much less than in hollow-
tile construction. In a fire, tile floors fail after a comparatively small distortion of the supporting beam, thus allowing the fire to spread to the adjacent story. The cast arches would remain intact longer, in fact until complete failure of the beams had taken place. These floor-plates are well adapted to be supported on shelf angles between beams, on the top flanges of the beams, or on their bottom flanges if tie rods are used as shown in figure 17, page 31. There being no rigid connection between the floor-plates and the joists, and the floor being frequently at a different temperature from other parts of the structure, an adjustment would be possible that would have an important bearing on the life of the pavement. Another advantage, so far as the life of the pavement is concerned, would be the superior stiffness of the arched plates over the buckled plates. Steel corrodes more rapidly than iron, and especially more than cast iron. Cast iron has, therefore, not only a longer life, but is cheaper in first cost than steel, and especially than steel in the special form for floors manufactured by but a few companies. It is believed that the simplicity of this form of construction, its adaptability to various conditions, and its low cost will commend it to engineers and architects.
Methods of Support—Interlocked Plates

Proposed Floor for Deck Plate-Girder Bridge.
SOLID CONCRETE FLOORS

Solid Floor—No Ballast or Cross Ties.

Mr. J. W. Schaub, Am. Soc. C. E. and a consulting engineer in Chicago, claims to be the first man who proposed to do away with ballast and cross ties in railroad bridges. In 1905 Mr. Schaub, in connection with a long viaduct, designed the floors shown in figure 18, page 31. Previous to this Mr. Schaub had made a similar design, excepting that the rails rested directly upon the concrete instead of upon longitudinal timbers. Tie plates were inserted under the track rails for two purposes, one to distribute the load properly on the timber and the other to drain the space between the track rails by permitting the water to flow out under the rails. Screw spikes were used instead of ordinary spikes. In connection with this design Mr. Schaub writes as follows for the Engineering News:

"The floors proposed for bridges need no explanation. The necessity of some form of solid floor for bridges has long been known, and all sorts of schemes have been resorted to, but all with the view of using cross ties for supporting track rails. With the use of cross ties goes the ballast, and with the latter go all the ills that go with the attempts to make bridge floors waterproof. Some engineers will tell you that they have succeeded in making bridge floors waterproof, but all such attempts can be answered, in the light of our present knowledge, by saying that unless such floors are made of concrete or some other indestructible material, or unless such floors are properly drained, the moisture will be retained by the ballast, and this will ultimately destroy the floor. There are some excellent illustra-
tions here in Chicago among the recent structures in connection with the track elevation work.

"As to the cost of such floors the first question appears to be: does not the increased weight of the floor itself add materially to the cost of the bridge? Not at all, when proper allowance is made for impact, or rather for the diminished impact and vibration due to the increased dead load. In other words, impact formulae are in use which depend upon the relation between the fixed load and the moving load to such an extent that for bridges with ballast floors no increase in the amount of metal to be used is necessary. As to the floor itself, such floors can be built for less than one half the cost of buckle plate or flat plate floors, and when the maintenance and renewals are considered, such floors will cost no more than the ordinary open floors, to say nothing about the advantage of having a floor which is proof against fire, and also against the drip of salt water from refrigerator cars and derailments".

Solid Floor-Chicago and Oak Park El. Ry. Bridge.

The floor construction in the bridge built to carry the Chicago & Oak Park Elevated Railway over the Chicago & Northwestern Railway Terminal approach across Lake Street, is one of the special features of the bridge, being designed to meet the requirements for a solid floor (as a protection to trains passing beneath) and for the protection of the steel against the effect of smoke and gases from the locomotive. Between the bottom chords are fitted 15-inch transverse I-beams, 18 1/4 inches apart, and between these are lines of diaphragms of 12 inch I-beams, one under each rail. The bottoms of the diaphragms are
coped at the ends so as to fit the flanges of the transverse beams and bring the bottom flanges of the beams and diaphragms in the same plane. Under each line of diaphragms is a continuous plate, 3/8 x 8 inches, riveted to the bottom flanges of both the transverse beams and the diaphragms. The object of this continuous plate connection is to give a better longitudinal distribution of the wheel loads. The construction makes practically a continuous longitudinal girder, the effect of which is to bring more floor beams into action under any concentrated load.

The steel frame work, including the bottom chords is embedded in a concrete floor of about 24 inches maximum depth; but in order to reduce the weight, cells or hollow spaces are cored between the I-beams and diaphragms. These were made of wooden box forms, which remain in place, being entirely built into the floor.

The concrete was composed of one part of cement to three parts of torpedo sand. It was mixed wet, and well rammed in order to get a dense and waterproof concrete and to fill all interstices and vertical corners. The waterproofing composition was applied to the surface of the floor.
SLAB FLOORS.

Standard Construction—Burlington Ry. 1907.

Some features of plate girder design were revised in 1907 for standard construction on the Chicago, Burlington and Quincy Railway, where no bridges are considered up to date without ballasted floors, and both deck and through plate girder spans are designed to receive reinforced concrete floors, although wooden floors may be used with them if desired. In a 75 foot through span there are two girders 15 feet 6 inches apart on centers and 8 feet 4 1/4 inches deep back to back of flange angles. Two lines of horizontal angles 18 inches apart in the clear and field riveted to the inner faces of the webs, with vertical legs inside form connections for the concrete floor construction, the top of the lower 4 x 4 x 3/8 inch angle being flush with the top flanges of the stringers. With this construction the height from the top of the tie to the masonry is 3 feet 10 1/4 inches; and with open floor, it is 3 feet 2 inches.

From the top of the tie to the clearance line is 3 feet 3 1/4 inches; and with the open floor, it is 2 feet 7 inches.

Four deck spans have floors 15 feet wide over all, with concrete slabs 8 1/2 inches thick reinforced with transverse and longitudinal bars in the upper and lower surfaces. The outer edges of the slab are inclined upward at an angle of 30 degrees to make flanges 9 inches deep to retain the ballast. The top lateral system and the top angles of the sway brace frames are lowered clear of the top flange angles of the girders, to permit the forms for the concrete to be set with greater ease and to be supported on the transverse frames and lateral angles.
The outstanding flanges of the vertical web stiffener angles is such girders are punched for connecting bolts to the knee-braces of concrete form. A 75-foot deck span weighs 95,800 lb. and one girder weighs 17,900 lb. For a 75-foot through span the corresponding weights are 144,400 lb. and 40,860 lb. A 105-foot deck span over Pope Creek on the Galesburg division weighs 208,000 lb. Its concrete floor weighs about 1.2 tons per lineal foot and raises the unit stress from 4.86 tons allowed for ordinary floors to 5.5 tons.

Double Track Work-Eagle River Canyon.

Just a few words and an illustration of the floor which was used by the Denver and Rio Grande Railway in the double track work through the Eagle River Canyon. The girders were designed for a reinforced concrete floor-slab and track ballast, in conformity with the Denver and Rio Grande Specifications for Steel Bridges, and as a result they are somewhat notable on account of their great weight. The ballast used is of the best quality of broken stone, and unusual care was exercised in order to secure a desirable character of concrete in the floor slabs. No explanation is need to explain the details, for a glance at figure 19, page 12, clearly shows the construction.

Separate Floor Slabs-N.C. & St. L. Ry.

A type of separate floor slab for short span concrete bridges has been used to some extent by the Nashville, Chattanooga and St. Louis Railway. Where it is possible to carry traffic clear of the work, without serious delay to trains, the slabs are built in place; otherwise they are built at the side and rolled into position between train movements. The details
of one of these slabs on an 18-foot span, single-track waterway opening are described as follows. The structure has abutments placed normal to the track, and was built to carry flood flows. The abutments were constructed by shoring the track up temporarily so traffic was not hindered while the work on them was in progress. Both abutments consist of 1:3:6: concrete, which is not reinforced, and their tops are finished to a smooth, flat surface to provide seats for the ends of the floor slab. In this instance the slab was cast meanwhile on a platform built up at one side of the track to a height that brought the bottom of the slab level with its final position.

The slab for openings of this size is 13 feet wide, 21 feet long, and 2 feet thick, so it has a bearing 1.5 feet wide at both ends of the abutments. It is made of 1:2:4: concrete, and is reinforced with old 40 lb. T-rails and 3 inch No. 10 expanded metal. The rails are placed longitudinally and are spaced 10 inches apart on centers, with their heads down. They are 2 3/4 inches from the bottom of the slab, while both their ends are 5 inches from the ends of the latter. A continuous layer of expanded metal is placed directly under the tier of the rails. The slab also is reinforced vertically by expanded metal, to provide for diagonal tension stresses and for unequal loads.

The ballast for the track is held in place by side walls, 1 foot 1 inch high and 6 inches wide, along both sides of the slab. The rails rest directly on cross ties which in turn rest on the ballast.
WATERPROOF FLOORS

In all previous descriptions of solid floors, the writer has given very little attention to an important item in the construction, namely, waterproofing. At a meeting of the Association of Railway Superintendents of Bridges and Buildings in 1908, a committee report was submitted giving particulars regarding methods of waterproofing concrete-covered steel floors of bridges. The first method described was that used by Mr. W. H. Moore, bridge engineer of the New York, New Haven and Hartford Railway, on solid floor bridges on the Harlem division of that line. In solid floor construction he has principally used trough floors, but I-beams have been employed sometimes; and recently some reinforced concrete floors have been used on a few through and deck plate girder spans.

In the girder spans the waterproofing is carried up the side of the girder a short distance above the track level. In some cases a water-guard, like that of the Hydrex waterproofing system, is used; while in other cases the water-guard is omitted and the adhesion of the waterproofing to the web of the girder is depended upon to maintain a tight joint. Where trough floors are used for three or more spans and expansion must be provided for, a special construction with copper flashing has been adopted to care for the expansion.

The work is done by cleaning and drying the surface of the concrete thoroughly and then applying a priming coat of Sarco concrete paint, which is put on cold with brushes and serves as a binder between the concrete and the waterproofing coat of Sarco No. 6 which is next applied. This is used hot and put on with
a mop. It is protected from the ballast by brick laid flat or by a 1 3/4 inch layer composed of one part of Sarco No. 6 to four parts sand and gravel, ironed to a smooth finish and covered with a thin coat of hot Sarco No. 6. The waterproofing in the standard work is carried backward over the abutments by a curtain of burlap saturated with Sarco No. 6.

On through girder bridges, the Central Railway of New Jersey, Mr. Austin Lord Bowman, bridge engineer, used a steel floor plate supported by 15-inch I-beams on 18-inch centers. This plate was thoroughly cleaned and painted with one coat of red lead and oil, and a filler of mastic asphalt was placed along the webs of the girders so as to form a curved surface of considerable radius instead of leaving a right angle to be waterproofed. Five layers of Hydrex felt cemented together with Hydrex compound were then put on the floor plate and carried as far as possible up under the flashing angles, which were fastened along the webs and around the stiffeners and the ends of the girders. The felt was not cemented to the floor plates but was thoroughly cemented to the webs of the girders. A layer of brick was then placed on the felt in a hot layer of Hydrex compound, the brick being laid length wise of the bridges. The joints between the brick were thoroughly poured with the compound, and the whole surface mopped with it. The stone ballast was laid on the brick.

The work per square of 100 square feet required 1.66 hours of time from a foreman, 11.71 hours waterproofer's time, and 7.75 hours laborer's time. The best record was 750 square feet in one day of ten hours, while the average time was 40 per cent longer. The materials cost 20 3/4 cents and the labor 10 3/4
cents per square of 100 square feet.

Mr. R. R. Reid, of the Lake Shore and Michigan Southern Railway, has under his charge at Winona Lake, Indiana, a reinforced concrete bridge used as a subway at the station for the use of passengers. This reinforcing consists of 15-inch I-beams, 16 feet long, spaced one foot six inches on centers, the clear span of bridge being 12 feet. The I-beams were placed in position and the under part of them was covered with wire fabric of No. 10 woven wire, meshes being 3 x 8 inches. The spaces between the I-beams were then filled with concrete down to a point 2 inches below the bottom of the I-beam, completely covering them with concrete. The concrete was carried to the top of the I-beams, covering them about 1/2 an inch. On top of this the waterproofing was placed, consisting of Barrett's roofing laid six ply, thoroughly covering each ply with Barrett's coal tar pitch before the next ply was put on. On top of this water proofing another coating of concrete was placed, making the thickness in center of span 6 inches, sloping to the ends of the I-beams where it was about 4 inches, the ends of the I-beams being enclosed in the concrete, which was rounded off so as to shed away the water. On top of this concrete is placed the stone ballast which is about 6 inches thick in the center of the span and 8 inches thick at the ends of the bridge between the concrete of the bridge and the bottom of the track ties.

For the waterproofing work on the metal and concrete structures of the Chicago and Northwestern Railway, Mr. W. H. Finley, assistant chief engineer, has recently revised his requirements to the following form: "Asphalt shall be used which
is of the best grade, free from coal tar or any of its products, and which will not volatize more than one half of one per cent under a temperature of 300 degrees F. for ten hours. It must not be affected by a 20 per cent solution of ammonia, a 25 per cent solution of muriatic acid, nor by a saturated solution of sodium chloride. It should show no hydrolytic decomposition when subjected, for a period of ten hours, to hourly immersions in water with alternate rapid drying with warm air currents.

For metallic structures exposed to the direct rays of the sun, the asphalt must not flow under 212 degrees F., nor become brittle at 0 degrees F. when spread on thin glass. For structures under ground, such as masonry arches, abutments, retaining walls, foundation walls of building, subways, etc., a flow point of 185 degrees F. and a brittle point of 0 degrees F. will be required. A mastic made from either grade of asphalt by mixing it with sand must not perceptibly indent at a temperature of 130 degrees F. under a load of 20 lb. per square inch. It must also remain pliable at a temperature of 0 degrees F.

Before applying asphalt to a metal surface, it is imperative that the metal be cleaned of all rust, loose scale and dirt; and if previously coated with oil this must be burnt off with benzine or by other suitable means. The metal surface must be warm to enable the asphalt to adhere to it, and the warming is best accomplished by covering it with heated sand, which should be swept back as the hot asphalt is applied.

When waterproofing masonry structures, if the surface cannot be made dry and warm, it should be first coated with an asphalt paint applied cold. This is particularly necessary for
vertical surfaces. It is difficult to make either hot or cold asphalt adhere to the surfaces of concrete or mortar when the latter is covered with a thin film of cement. To overcome this the surface of the structure should be covered with a finishing coat of mortar composed of one part of cement to one part of sand. If this is not permissible the surface should be cleaned with a sand blast.

The asphalt should be heated in a suitable kettle to a temperature not exceeding 450 degrees F. If this is exceeded it may result in pitching the asphalt. Before the pitching point is reached the vapor from the kettle is of a bluish tinge, which changes to a yellowish tinge after the danger point has passed. If this occurs the material should be tempered by the addition of fresh asphalt. The asphalt has been cooked sufficiently if when a piece of wood can be put in and withdrawn the asphalt clinging to it. Care should always be taken not to prolong the heat to such an extent as to pitch the asphalt. Should it become necessary to hold the kettle for any length of time, bank or draw the fire and introduce into the kettle a quantity of fresh asphalt to reduce the temperature.

The first coat should consist of a thin layer poured from buckets of the prepared surface and thoroughly mopped over. The second coat should consist of a mixture of clean sand or limestone and screenings, free from earthy admixtures previously heated and being dried, and asphalt, the proportion one part of asphalt to three or four parts sand or screenings by volume. This is to be thoroughly mixed in the kettle and then spread out on the surface with warm smoothing irons, such as are used in laying asphalt streets.
The iron should be hot enough to burn the asphalt.

The finishing coat should consist of pure hot asphalt spread thinly and evenly over the entire surface, and then sprinkled with washed roofing gravel, torpedo sand or stone screenings, to harden the top. The entire coating should not be less than one inch thick at the thinnest place.
STANDARD PRACTICE FOR DIFFERENT RAILROADS.

Wabash Railroad.

Through the courtesy of Mr. A. O. Cunningham, chief engineer, the author was able to obtain the standard designs of the Wabash Railroad for solid floors.

For through girders, a reinforced concrete slab varying in thickness from 6 inches to 8 inches rests directly on I-beams which in turn are supported on the bottom flanges of the girders. The I-beams are spaced 18 inches centre to centre. 8 inches of broken stone ballast is placed upon the slab and the cross ties are supported on this ballast.

For deck girders the same slab rests on I-beams spaced 17 inches apart, which are supported on the upper flanges of the girders.

In another design the varying slab is replaced by a uniform 12 inch slab. The thickness of slab necessarily depends upon the span and loading.

C. R. I. & P. Railroad.

Through the courtesy of Mr. I. L. Simmons, bridge engineer for the Rock Island Lines, the standard plans and specifications (embodied in the drawings) were obtained by the author. Like the Wabash Road all solid floor construction is composed of reinforced concrete slabs. The following specifications accompany the detail of the slabs.

Bars shall be of deformed type.

Bars which intersect shall be securely wired together at intersections with No. 16 wire.

Splices shall be made by lapping the bars at least 2 feet and
wrapping the lap with not less than 24 turns of No. 16 wire.

Care must be taken to place all bars to exact dimensions as shown on the detail.

Concrete must be 1:2:4 mixture.

Daily construction joints shall be vertical and parallel to centre line of the tracks.

Slabs must be allowed to set at least 60 days before placing ballast or allowing live load on the bridge.

In waterproofing concrete apply with brushes a coating of asphalt primer and allow to dry. Apply with mops a coating of asphalt waterproofing which has been heated to proper temperature, and while the asphalt is still hot apply a layer of burlap. Continue in same manner until three layers of burlap have been applied. Mop last layer with coating of waterproofing and then apply a layer of concrete about 2 inches thick reinforced with triangle mesh No. 7.

Denver and Rio Grande Railroad.

Through the courtesy of Mr. E. M. Camp, engineer of bridges and buildings, the author has obtained the standard designs of the Denver and Rio Grande Railway for solid floors in bridges. This road also uses the reinforced concrete slab type on all types of their bridges.

For deck girders the slab is supported by I-beams spaced 18 inches centre to centre. These beams rest directly on the top flanges of the girders.

For through girders, the slab rests on either longitudinal or transverse I-beams. The longitudinal beams are supported by a continuous plate which rests on the lower flanges of the
girders. The transverse beams rest directly on the lower flanges.

Illinois Central Railroad.

Through the courtesy of Mr. F. L. Thompson, engineer of bridges and buildings, the author has obtained several prints of past and present designs of solid floors used on the Illinois Central Railway.

One type of construction, using transverse I-beams on which are placed creosoted planks which support the ordinary ballast and track ties, was good design in one respect but poor in another. It has the advantage that it is easily waterproofed, and the steel can be painted without a great deal of trouble; but on the other hand, it is hard to prevent the ballast from crowding up against the girders on each side, and it is usually necessary to dig out this ballast every time the bridge is painted.

Another type of I-beam floor construction, with a continuous rail plate under the rail, is used considerably where waterproof construction was not essential but a shallow floor was desired. However with the installation of automatic block signals, this type is not satisfactory, because the rails cannot be insulated.

Still another type of I-beam floor is used with the ties resting on the beam, with a continuous rail plate on the top of the beams to prevent the ties from slipping off. This type has been used where it was desired to have a shallow floor and at the same time to have the rails insulated from the bridge.

Another design shows a solid I-beam floor with concrete casing around the beams. This type has the advantage that the beams are well protected and do not require any maintenance cost.
for painting. The floor is easily waterproofed and ordinary track ties can be used for the rails on account of the use of ballast. Placing the concrete however is expensive where the traffic is heavy, as great care must be taken in placing this concrete to prevent vibration while the concrete is setting.

When track elevation work was first taken up through the large cities, a shallow floor was considered to be very desirable in order to keep the elevation of the track to a minimum, thus keeping down the cost of embankment and retaining wall. However, with the use of reinforced concrete slabs it has been found, provided the city will permit the use of supports in the center of the street and on the sidewalk thus making short spans, that concrete slabs provide a very desirable floor, very readily waterproofed, readily adapted to any special track arrangement, and practically noiseless during the passage of trains.

Lackawana Railroad.

Through the courtesy of Mr. A. E. Deal, bridge engineer, the author has obtained plans and specifications for solid floor construction on the Delaware, Lackawana and Western Railway. The plans include: (a) solid floor construction for through plate girders with I-beams incased in concrete, (b) reinforced concrete floor slabs for through girders, and (c) reinforced concrete floor slabs for deck bridges. The designs are very similar to those previously described, so the description will be omitted. However, it may be well to quote the following specifications as to loads, unit stresses, etc.

If one axle load is used, it is distributed over an area 5 x 10 feet.
For slab construction where beams are spaced 3 feet center to center or less, a slab 6 inches in depth is used.

Where I-beams are spaced more than 3 feet center to center, the thickness of slab is figured for concentrated loads.

The reinforcing steel shall have an elastic limit of not less than 50,000 lb. per square inch and shall be capable of meeting a cold bending test of 180 degrees on a radius of two diameters of the piece tested.

Rods shall lap at least 40 diameters.

All longitudinal and transverse reinforcement shall be securely wired together.

All bars to be corrugated or cold twisted.

The unit stresses used are as follows: Compression in concrete -- 650 lb. per square inch. Tension in reinforcing bars -- 16,000 lb. per square inch. Impact -- \( \frac{L^2}{L+D} \)

Concrete mixture 1:2:4.

C & N. W. Railroad.

Through the courtesy of Mr. W. C. Armstrong, engineer of bridges, the author was able to obtain the standards used by the Chicago and Northwestern Railway for solid floor construction. This road uses various types of construction, namely: longitudinal troughs carrying concrete within the troughs and ballast upon the concrete; troughs carrying the ballast directly within the troughs; and reinforced concrete slabs. The designs are similar to ones heretofore described and for this reason descriptions are omitted.

Modern Tendencies.

A study of the standard designs for the different rail-
roads of the present time, clearly shows that the concrete and reinforced concrete floors are given the preference in nearly all cases. Reinforced slab types are the most common, but troughs or beams embedded in concrete are also widely used. This tendency is only to be expected however, for we are living in an age of concrete and reinforced concrete.
CONCLUSION.

In an extended article written for the American Railway Engineering and Maintenance of Way Association (Bulletin February 1908) entitled "Open Versus Ballast Deck Structures" by Mr. A. F. Robinson, bridge engineer for the Atchison, Topeka and Santa Fe Railway, Mr. Robinson figures in detail the costs of open floors and solid floors and compares the results in the following statement:

"The comparisons are almost entirely devoted to what may be termed the money side of the case. They show that roads using open deck bridges are having to pay more per lineal foot per annum for them than for ballast deck structures, even though the first cost of the open decks may be the lower of the two types. These comparisons show that it is best to use ballast deck structures, even though they do not materially reduce or absorb the effects of impact".

Surely figures do not lie, so is not this reason alone sufficient argument to overthrow any claims to the contrary? Besides this large item of cost there are other advantages of solid floors, namely:

(1) Ballast to a large extent absorbs or dissipates and distributes the effects of impact in such a manner as to materially increase the life of the structure.

(2) Ties will not "bunch" in good stone or gravel ballast, and this kind of floor gives increased safety in case of derailment.

(3) It is almost entirely a preventative for accidental fires that may catch from falling coals, thereby rendering insurance unnecessary.
(4) It gives a more nearly perfect riding track, there being no breaks in ballast from beginning to end of a division.

(5) It gives an increased feeling of safety to the traveling to public, to the trainmen, and operating officials.

(6) It gives a more stable structure in time of high floods.

(7) By use of solid floors we are enabled to use the poorer or second grades of timber, thereby tending to reduce the great and dangerous drain on our visible supply of first grade material.

(8) Noise is lessened.

(9) It avoids leakage of dirt and moisture through the floor.

In final conclusion, the writer believes solid floor structures are advisable from all points of view and should be used on railroad bridges of all kinds, both on main and branch lines. The writer further believes the time is not far distant when open forms of bridge floors will be past history.