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Aluminum Enters the Bridge Field

THE FIRST APPLICATION OF ALUMINUM to bridge construction has just been completed at Pittsburgh, Pa., where a new floor, including beams, stringers and deck, built entirely of aluminum alloy has been placed on the 51-year old Smithfield St. Bridge over the Monongahela River. A substantial dead load reduction permitted an increase in the safe live load, adding some 25 years to the useful life of the structure. Design and fabrication departed in no way from orthodox structural practice. Erection was facilitated by the light weight of the members as indicated in the above view of the novel deck.

BY ITS USE ON A MAJOR BRIDGE structural aluminum assumes added importance as a general utility material for the engineer. The story of the Smithfield St. Bridge job is told in this issue by Charles M. Reppert, Chief Engineer of the Department of Public Works of Pittsburgh.

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New York

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Aluminum Enters Bridge Construction

Historic Smithfield Street Bridge in Pittsburgh has been reconstructed for longer life by removing its old steel and timber floor and placing a new floor of high-strength aluminum alloy

By Charles M. Reppert
Chief Engineer, Department of Public Works, Pittsburgh, Pa.

FIRST application of aluminum to bridge construction has just been accomplished at Pittsburgh, Pa., where the Smithfield St. Bridge, principal crossing of the Monongahela River since its construction in 1882, has been reconstructed by building a new floor of high-strength aluminum alloy in place of the old steel and timber floor. The purpose of the reconstruction was primarily to lighten the dead load in order to make it possible to continue the bridge in service safely.

In this work the entire floor system of the bridge was reconstructed using aluminum alloy members designed and built quite like steel members. No unusual conditions were encountered in either design, fabrication or erection, and the construction procedure throughout was quite closely the same as followed in comparable steel work. The heavy timber floor of the old roadway was replaced with a battledeck type of floor constructed wholly of aluminum and topped with an asphaltic surfacing. This deck slab, whose design was developed by the Aluminum Company of America and checked by extended service tests, weighs, together with the asphaltic surfacing, only 30 lb. per sq.ft.

The Smithfield St. Bridge has been a continuing problem for many years. Its age of 51 years combined with the fact that it has been carrying heavier loads than intended, on both the streetcar and the vehicle roadways, led eight or ten years ago to recommendations for the replacement of the entire structure. It was then thought that while the bridge could be maintained for a few years, its early replacement was inevitable, and in consequence all except the most necessary maintenance work was discontinued. At the same time the wooden floor was not only a large item of maintenance expense but furnished an unsatisfactory roadway surface and constituted a fire hazard.

Fig. 1—By taking some 700 tons of dead weight from the load carried by its trusses, the old Smithfield St. Bridge in Pittsburgh, considered obsolete, was made capable of serving traffic for many years to come. The inherent lightness of aluminum and saving in deck weight through a novel ribbed slab of metal were prime factors in weight reduction.

Replacement of the bridge by a new sturcture was considered essential at that time also because the bridge was inadequate for traffic and was expected to become even more inadequate as time went on. Subsequently, however, the building of the new Liberty Bridge and Tunnel route and the modernization of the Point Bridge and the South Tenth St. Bridge (respectively below and above the Smithfield St. Bridge) rendered the structure less important to through traffic. Smithfield St. Bridge thus tended increasingly to become a local facility in respect to vehicular traffic, although as a street-railway bridge it still maintained the position of being an essential link in the city's transportation system.

Under these circumstances, some strengthening of the trusses of the bridge was carried out in 1928, and last year a careful restudy of the whole situation was carried out with

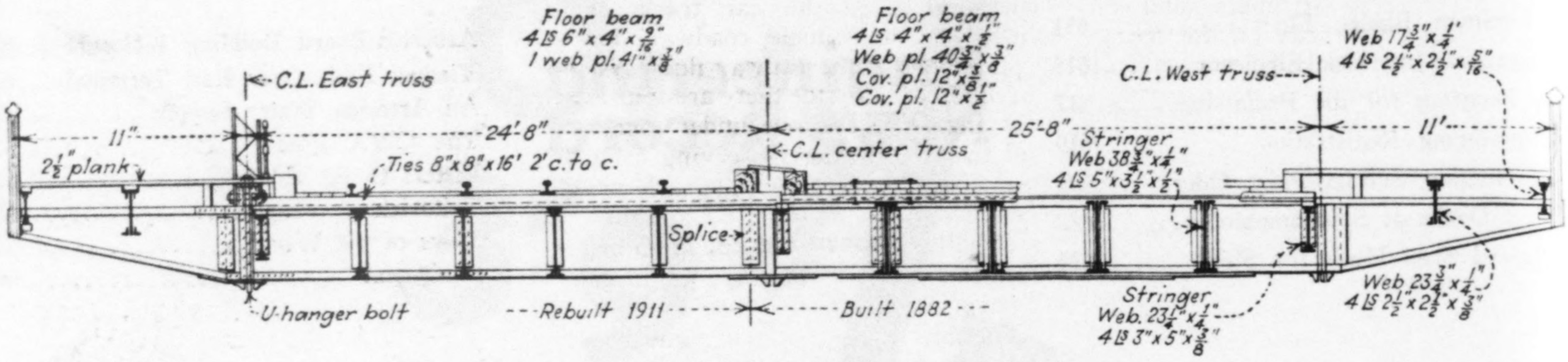


Fig. 2—Old wrought-iron and steel floor, with 11-in. timber decking for vehicle roadway.

a view to developing a plan by which the dead load on the bridge could be reduced and the structure thereby safely continued in service. The desired improvement was also intended to provide a better roadway surface, decrease maintenance expense and remove the ever-present fire hazard.

After various preliminary designs had been developed, the possibility that structural aluminum alloy might offer a solution was taken up, and it was found that through this material not only could the overstressing of the trusses be relieved but a permanent hard-surfaced roadway floor could be provided that would assure satisfactory service of the structure for many years. From the economic standpoint, deferring the replacement of the structure over a period of years would still mean a large net saving to the city after taking into account the cost of the floor reconstruction. On this showing it was decided to adopt an all-aluminum floor system.

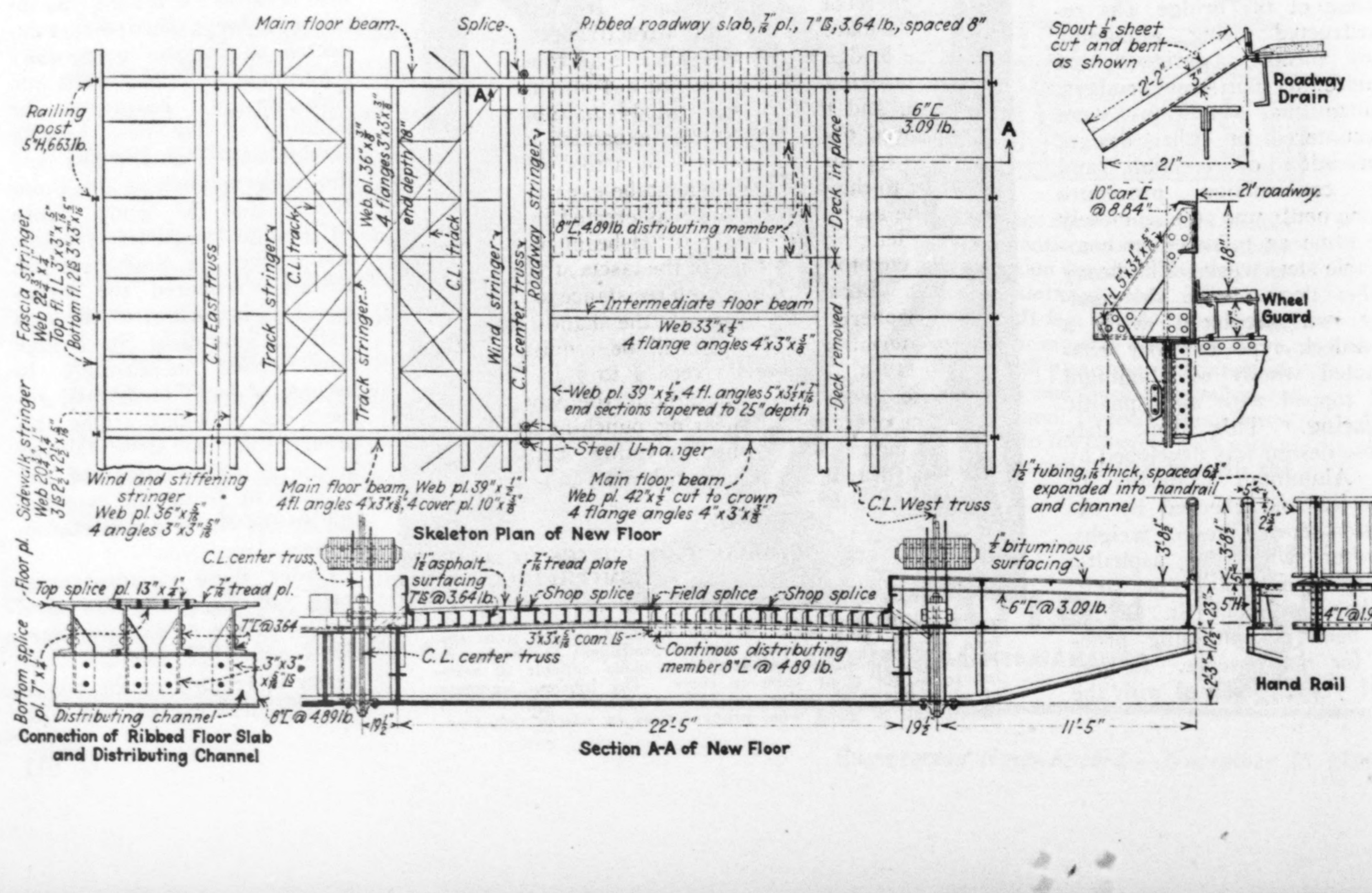
The old structure

The Smithfield St. Bridge spans the Monongahela River in a north-south direction at a strategic central location in downtown Pittsburgh. The present structure, designed by Gustav Lindenthal and erected in 1882, replaces the first suspension road bridge of John A. Roebling. It is the third bridge across the river at this point—the first, a covered wooden bridge, having been built more than 100 years ago. Mr. Lindenthal's own description of the bridge ("Rebuilding of the Monongahela Bridge at Pittsburgh," *Trans.*, Am. Soc. C.E., 1883, pp. 353-392) may be consulted for detail, but in general the present bridge as built consisted of two identical spans, each 360 ft. long, of two Pauli or double elliptical trusses spaced 25 ft. 8 in. on centers, carrying a roadway suspended below the trusses by pin-connected hangers. Both steel and wrought iron were used in the construction of the bridge, the use of steel at that time being a distinct innovation.

A third truss was added to each span in 1890, 20 ft. 8 in. upstream from the existing bridge, to provide a second roadway; the piers had been built long enough at the time of original construction to provide for the addition. At first one street-car track was placed on each side of the middle truss, but in 1911 the new (upstream or east) truss was moved 4½ ft. farther upstream, widening the second roadway to 24 ft. 8 in. between truss centers, so that both street-car tracks could be placed on the east roadway and the west roadway kept free for highway traffic. At that time also (1911) the present floor system was installed under the street-car tracks, while the floor system of the west or downstream roadway remained the same as in 1882 except for repairs and occasional replacements.

Briefly, the highway floor system consisted of wrought-iron plate-girder floor beams and six longitudinal stringers, supporting a laminated timber floor 11 in. thick, surfaced with two rows of steel traffic plates on each of the two traffic lanes. The floor system of the east roadway consisted of floor beams

Fig. 3—Aluminum-alloy floor framing and ribbed slab surfaced with asphaltic concrete reduce the dead load of Smithfield St. Bridge by more than 1 ton per lin.ft.



and four lines of stringers, and the track ties rested directly on the stringers. Sidewalks, bracketed out on both sides of the bridge, were floored with a single layer of 2-in. plank.

Reinforcement to reduce high stresses

A careful analysis of the stresses in the bridge was made in 1926; it showed that the east and center trusses were stressed to a point regarded as excessive, considering the age of the bridge. In 1928, therefore, additional steel bars were welded to the face of the outside eyebars of the upstream and center trusses, with the effect of reducing the live-load stresses somewhat, though having no appreciable effect on dead-load stresses.

Examination of the bridge in 1932 revealed the necessity for numerous repairs to the main stringers, trusses and floor system, including renewal of the wooden floor and the repair or replacement of the street-railway stringers. Because of the magnitude of the necessary repairs and the increasing fire hazard in the wooden floor, a study of alternate types of floor was undertaken. Concurrently there was developed the idea of reducing the dead load on the structure in order to decrease the stresses in the main members of the trusses and thereby prolong the useful life of the structure. Although the bridge was then 50 years old, it did not seem to have deteriorated unduly in its essential structure.

In this situation, attention was directed to a comparatively new material, structural aluminum alloy. Structural shapes and plates of this material had been used in railway cars, trucks and buses, dirigibles and airplanes, overhead traveling cranes and dragline booms for a number of years, but never as a major part of a bridge. Nevertheless, the fact that structural aluminum could be obtained with strength characteristics equal to those of structural steel, but at a saving of 65 per cent in weight, made possible the design of a floor system which, according to best judgment, would add some 25 years to the life of the bridge—in other words to the limit of safe prediction from the traffic standpoint. Considered in another way, the reduction of dead load would justify an increase of live load without exceeding present stresses and would allow certain existing restrictions on traffic to be removed.

New floor designed like steelwork

In general, the design of the aluminum floor beams and stringers is similar to that of corresponding steel members, except that more attention than usual was given to saving material. The floor beams, 39 in. deep in the street-car roadway and 42 in. deep under the crown of the vehicle roadway, are spliced just east of the center truss, as were the old floor beams, to facilitate erection without interrupting the street-car service, as the car tracks were shifted to the vehicle roadway during replacement of the railway floor system. On the street-car side there are four load-carrying stringers, one under each rail, and two side stringers serving as wind chords, all 36 in. deep. The track stringers are reduced in depth toward the end by bending the bottom flange upward from the middle bracing panel, in order to save weight.

The floor system of the highway side of the bridge consists of a $\frac{5}{16}$-in. tread-plate as decking, supported by 7-in. channel joists spaced 8 in. on centers, which joists rest on intermediate and main floor beams. The effective span of the joists is 9 ft. $2\frac{1}{2}$ in. At the middle of each of these joist spans, a transverse 8-in. channel is rigidly attached to each of the joists as a distributing member, to cause several joists to cooperate in carrying a wheel load and thus give to the entire floor system the action of a deep slab. The arrangement of the supporting framing and the construction of the slab floor are shown in Fig. 3. A pavement or surfacing of cold-laid asphaltic mixture, $1\frac{1}{2}$ in. thick, forms the wearing surface of the roadway; the projections of the aluminum deck plate provide an anchorage to prevent the surface material from creeping under traffic.

Like the roadway, the sidewalks are carried by aluminum-alloy framing and decking. The surface is $\frac{1}{2}$ in. of cold-processed asphaltic paving on a smooth $\frac{1}{4}$-in. aluminum-alloy plate reinforced by 2x2-in. angles riveted to the under surface. This plate is supported by 6-in. channels resting on plate-girder stringers which, in turn, rest on extensions of the main floor beams outside the trusses. The sidewalk hand-rail also is of aluminum alloy, but of a different composition from that of the floor material, to give higher corrosion resistance. Its design adds materially to the attractiveness of the bridge. The top rail is oval tubing 5 in. wide, the bottom rail a 4-in. channel, and the balusters of $1\frac{1}{2}$-in. tubing spaced $6\frac{3}{4}$-in. on centers, expanded into the top and bottom rails by a tool similar to the ordinary boiler-tube expander. The assembled railing was erected in 9-ft. lengths, between 5-in. H-beam posts riveted to the outside of the fascia stringers. Because of the high resistance to atmospheric corrosion of the hand-rail material, no painting will be required.

Hot-driven steel rivets, $\frac{5}{8}$ to $\frac{7}{8}$ in. in size, were used throughout the work. The operation of shearing, punching and reaming in the shop, riveting, fitting and drawing together with drift pins in

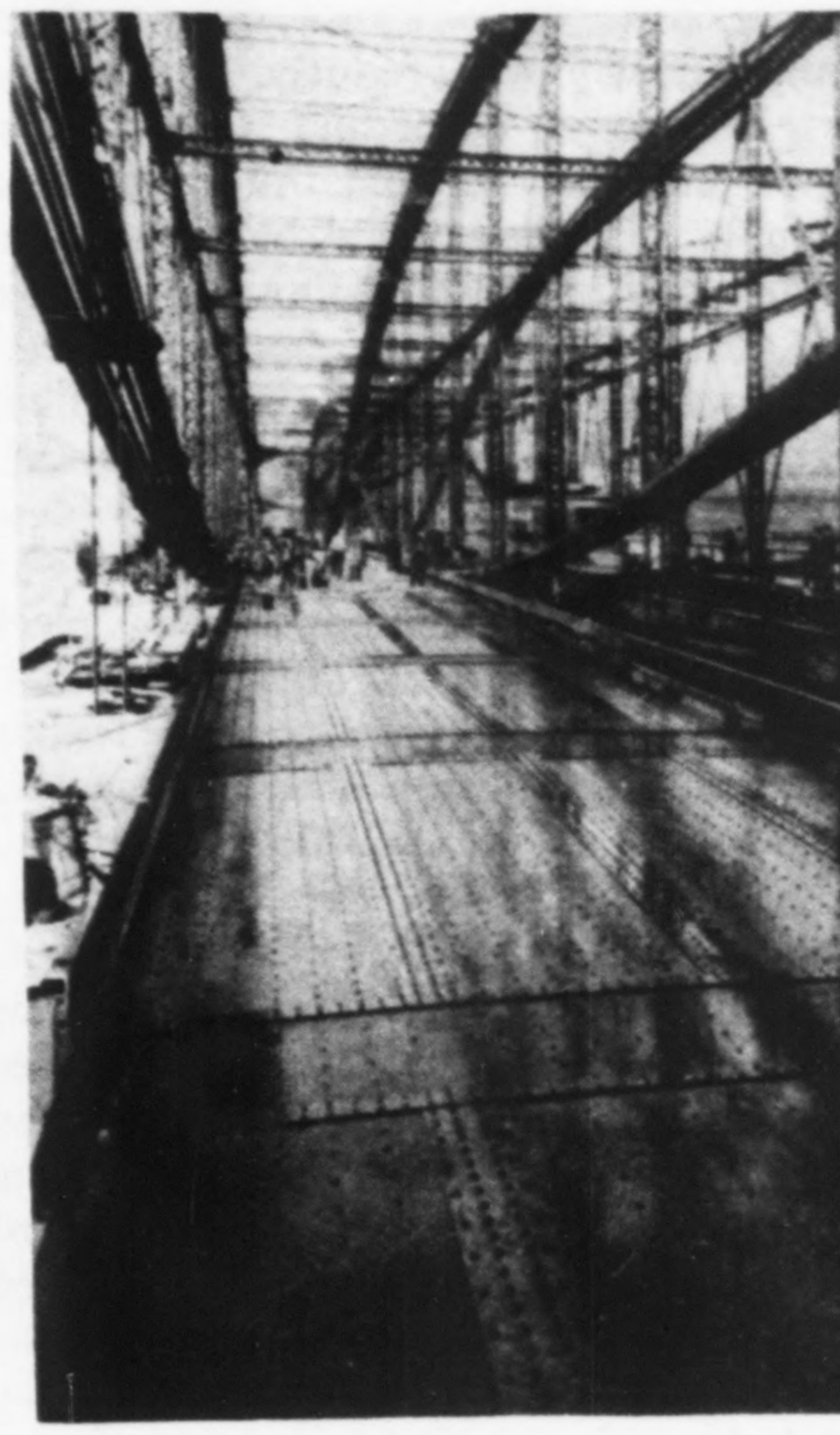


Fig. 4—The aluminum roadway floor ready for surfacing.

the field, etc., involved no methods or problems essentially different from those of steel bridge work. Reaming required only the lightest air tools on the market. While the aluminum alloy on the floor system is more resistant to corrosion than the steel or wrought iron which it replaced, nevertheless all the structural members are painted with a priming coat of iron oxide and zinc chromate paint covered with two field coats of aluminum paint.

Material and stresses

The physical properties of the aluminum alloys employed in the reconstruction of the Smithfield St. Bridge are given in the accompanying table. For a number of years the Aluminum Company of America has been experimenting with and developing a new structural alloy, commercially designated as 27 ST. After the design had been developed on 17 ST, but before work had actually begun, this new alloy was made available to the trade. In addition to its superior physical properties, it is more resistant to corrosion than is 17 ST. It also possesses other properties that make it particularly adaptable for structural work. It was, therefore, substituted for 17 ST but without changing the design.

The design of the floor system was based on the use of the strong aluminum alloy, 17 ST. The design stress was fixed at 15,000 lb. per sq.in. in tension and

PHYSICAL PROPERTIES OF ALUMINUM ALLOYS USED ON SMITHFIELD ST. BRIDGE

Alloy	4 SH	53 ST	27 ST	17 ST
Ultimate strength	42,000	36,000	60,000	58,000
Yield point	38,000	30,000	50,000	35,000
Elongation in 2 in.	3	12	12	20
Brinell hardness	80	80	118	100
Where used	Tubing for hand-rail	Rolled shapes for hand-rail	All floor members	Basis of design

compression. The stress on compression members was reduced for unsupported lengths according to formulas which take into account the modulus of elasticity of the material but are otherwise similar to those customarily used in steel design.

The maximum deflections in the floor system of the Smithfield St. Bridge are limited as follows: floor beams, 1/400 of span; stringers, 1/600 of span; roadway deck, 1/500 of span; and sidewalk deck plate, 1/100 of span. These conservative deflections result in stresses less than the permissible design stress in certain of the members.

Floor slab under load test

As already stated, the ribbed floor slab was originally designed by the Aluminum Company of America, but before it was proposed for use in the Smithfield St. Bridge it was subjected to extended load test. A panel of ribbed floor slab, 13 ft. 10 in. by 11 ft., was built over a masonry pit in a heavily traveled truck driveway and tested under H-20 loading.

Stresses and deflections in all parts of the structure were accurately measured. These tests resulted in the substitution of 7-in. channels, spaced 8 in. on centers, for 8-in. channels, spaced 11 in. on centers. The remarkable effectiveness of the transverse 8-in. channel in distributing concentrated loads over a number of the longitudinal channels and preventing differential deflections was well demonstrated by the test.

Results obtained by reconstruction

The extent to which dead load and stresses were reduced is shown in the following data:

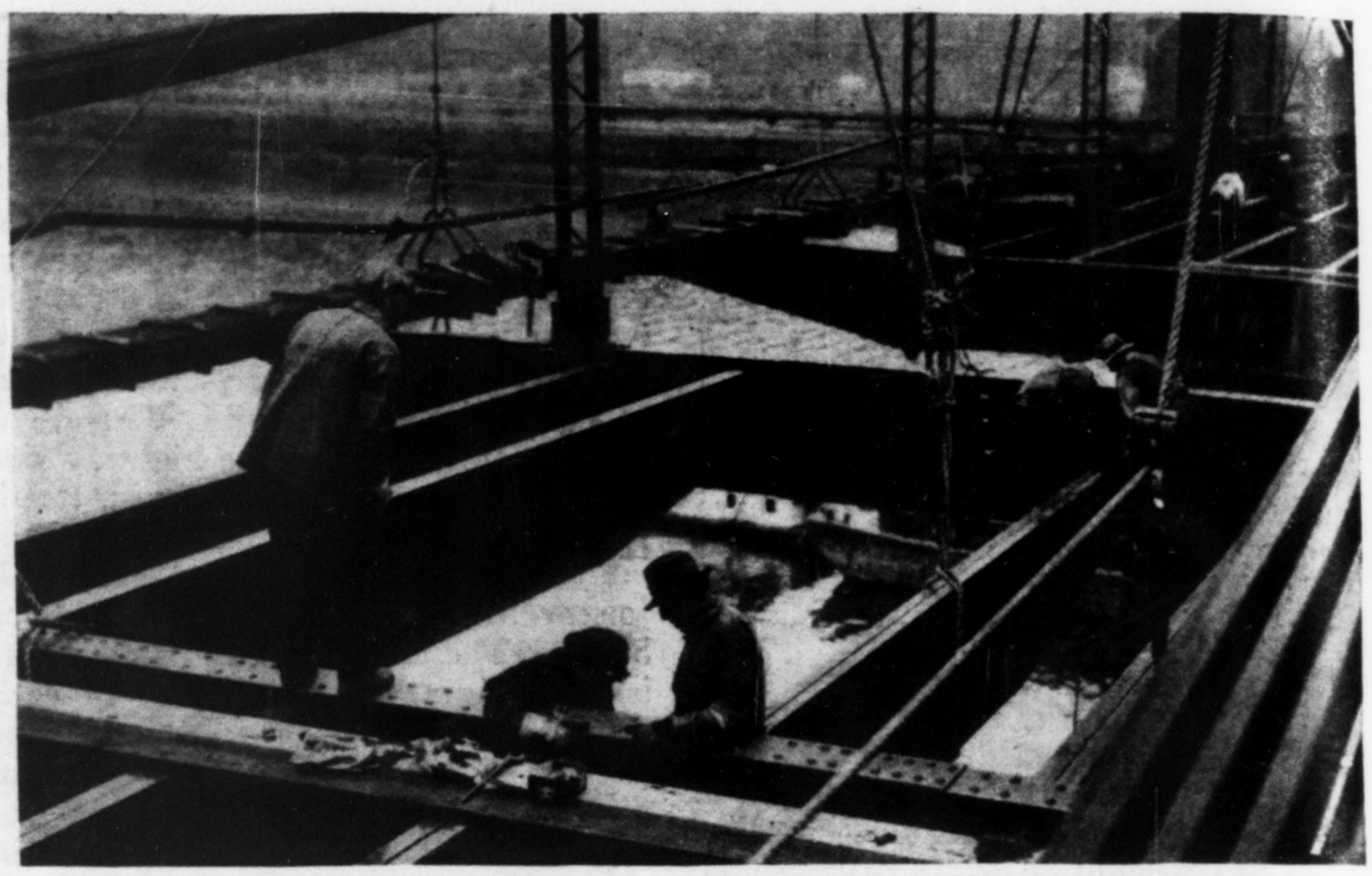
Combined panel load on 3 trusses of the floor system and floor removed, lb.	119,153
Combined panel load of new system, lb.	61,350
Reduction in weight per panel, lb.	57,803 (28.9 tons)

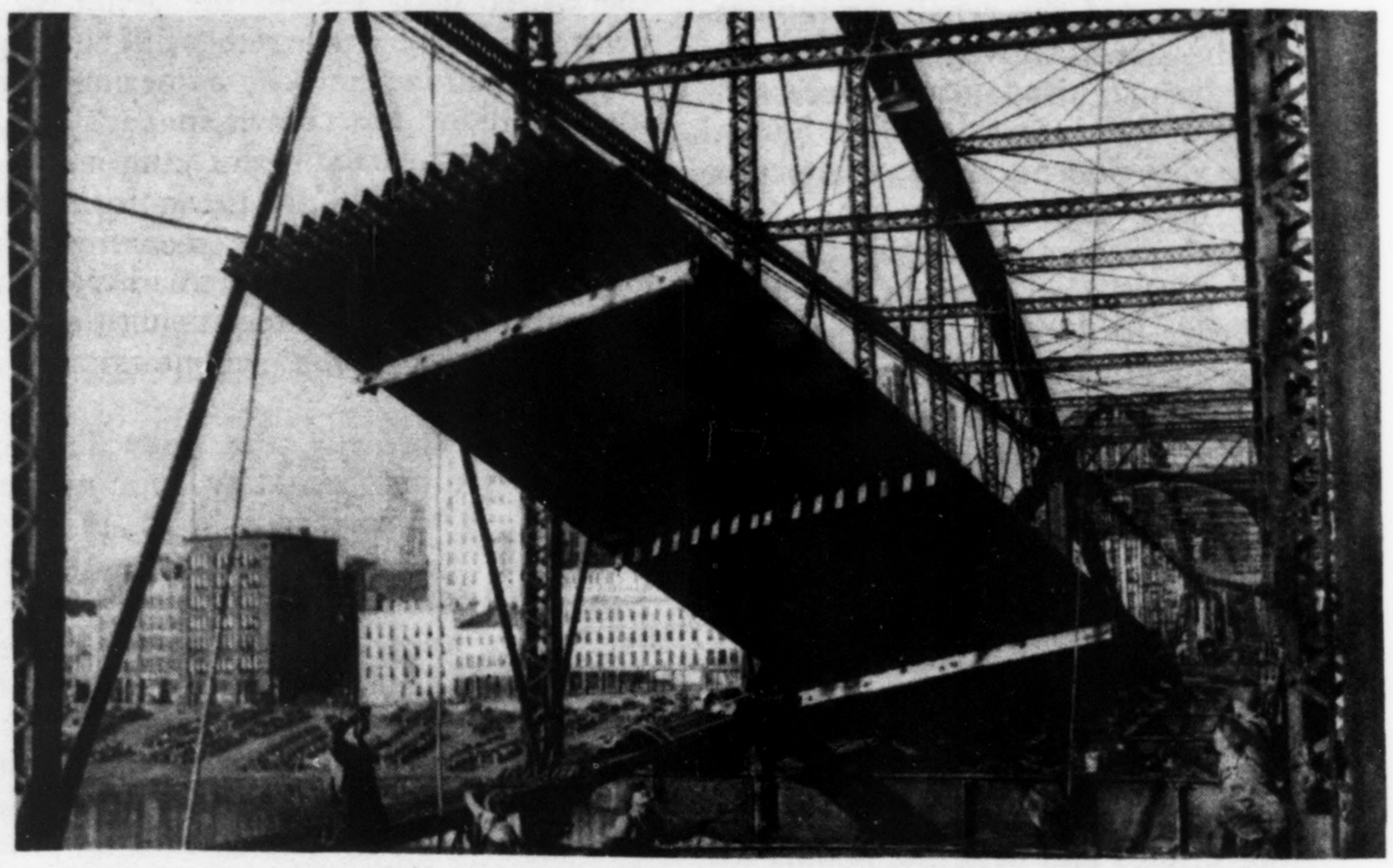
There being 26 panels in the bridge (two spans), the total reduction in weight was 751.4 tons, or a little over 1 ton per linear foot of the bridge.

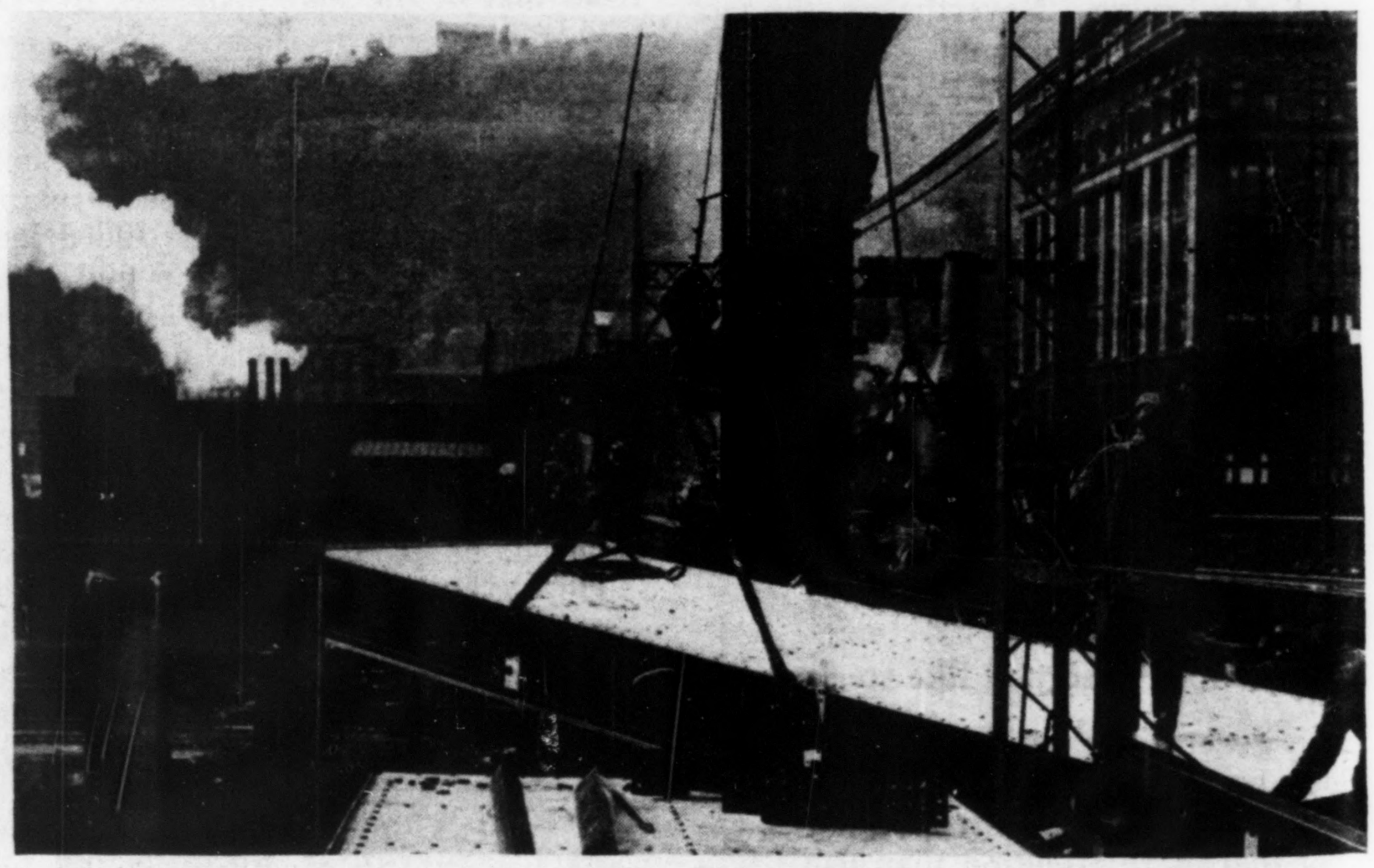
The panel load of the new system is subdivided as follows:

Aluminum, lb.	26,200
Steel rivets, lb.	3,000
Other steel, lb.	400
Total metal, lb.	29,600
Sidewalk surfacing, lb.	3,000
Roadway surfacing, lb.	9,000
Railway track structure, lb.	19,750
Total weight, lb.	61,350

With regard to the permissible loading on the bridge, vehicular loads have been limited to vehicles of 13 tons on four wheels prior to the reconstruction. The new floor has been designed to carry 20 ton trucks on four wheels. With regard to the street-railway side, the type of car in general use weighs from 66,000 to 70,000 lb. Prior to the reconstruction, a regulation has been enforced requiring an interval of 50 ft. to be preserved between street-cars operating over the bridge. With the reconstructed floor, this required spacing can be reduced or perhaps entirely eliminated. The floor system is designed for occasional cars weighing 90,000 lb., since the street railway company has actually operated such







Figs. 5, 6 and 7—As the upper view shows, erection of the new aluminum railway floor was much the same as steel erection. However, the light weight of the material facilitated operations. Fully assembled panels of the ribbed roadway slab (middle view) and of the sidewalk (lower view) could be set in place as single pieces.

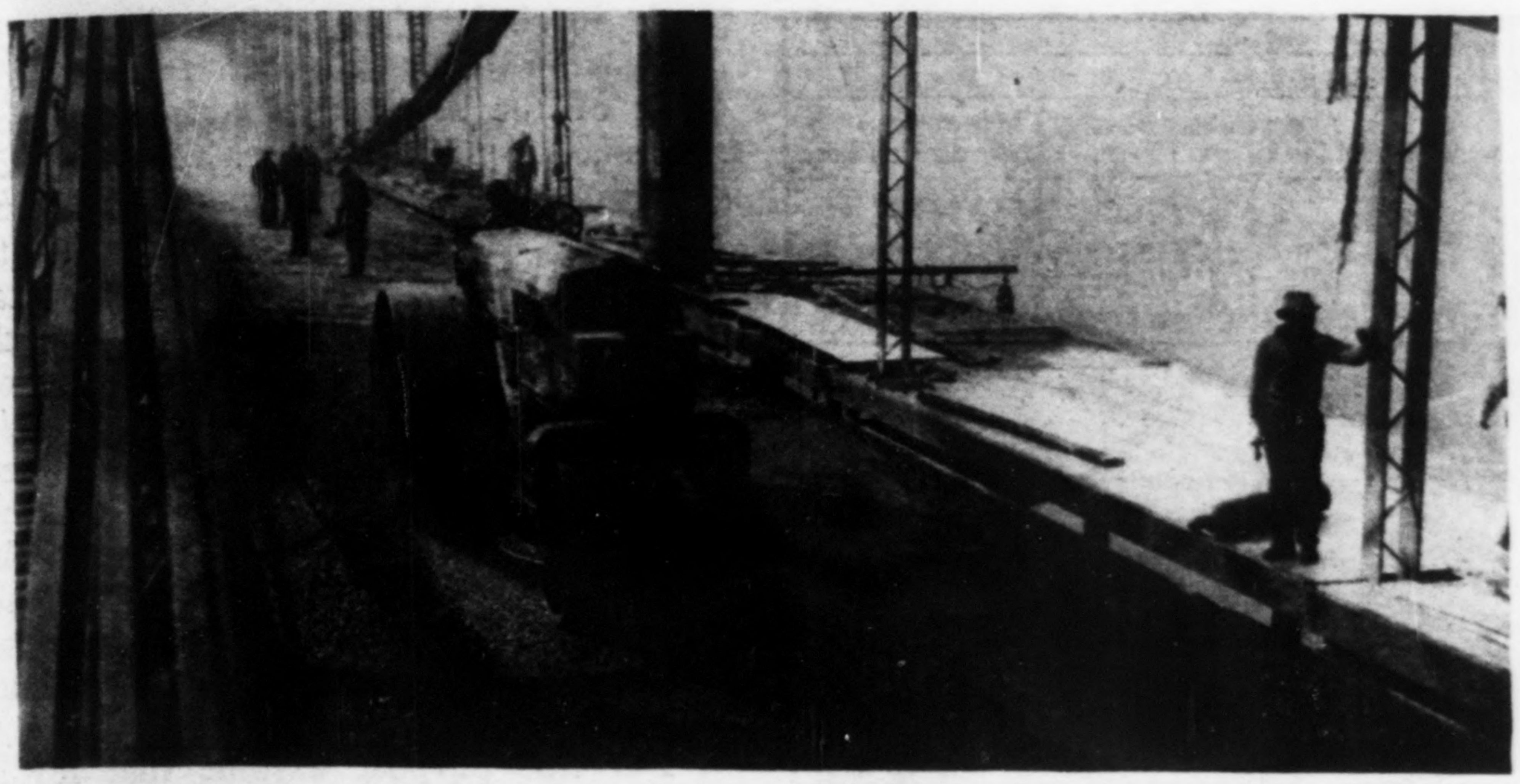


Fig. 8—Asphaltic surfacing laid on the roadway slab was compacted by rolling.

cars in the past and may find it necessary to do so again.

Cost and construction

Proposals for the floor reconstruction were received on July 12, 1933, and the contract was awarded to Walter S. Rae, of Pittsburgh, the subcontract for the fabricated structural aluminum to the Aluminum Company of America, and the fabrication itself to the Fort Pitt Bridge Works. The total contract price was $276,436, of which $192,000 was for the fabricated aluminum. The cost was covered by a ten-year $4\frac{1}{4}$ per cent serial bond issue of $300,000, whose ultimate cost to the city will be $370,125. This latter figure may be considered the total cost to the taxpayers of delaying for 25 years the building of a new bridge. As traffic conditions may change radically in the meantime, and the possible construction of a rapid-transit subway system would doubtless affect any bridge plan, the present estimate of the cost of the new bridge under conditions of today might be placed at $1,250,000. These bonds, if of the type sold for the reconstruction work but extending over a period of 25 years, would cost the city $1,935,000. The taxpayer has therefore saved by the adoption of the aluminum floor system the sum of $1,564,875, or more than the estimated first cost of the new bridge.

The contract provided that construction be carried on under a schedule limiting the diversion of vehicular traffic to a period of 24 days. Pedestrian and street-car traffic had to be maintained throughout this period. All work was done according to a prearranged and planned program. The details of these operations will be described in another article to be published soon.

This improvement was made under the direction of Edward G. Lang, director, and the writer, as chief engineer of the department of public works of Pittsburgh. Ross M. Riegel is division engineer of bridges, and Henry D. Johnson, Jr., is engineer of construction. J. P. Growdon was in charge of the work for the Aluminum Company of America, and C. G. Schade, chief engineer, for the Fort Pitt Bridge Works, which handled the fabrication.

Efficiency of Aggregate Interlock in Concrete Roads

By Clifford Older
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THE TESTS described in the valuable article "Tests of Aggregate Interlock at Joints and Cracks," by A. C. Benkelman, which appeared in *Engineering News-Record*, Aug. 24, 1933, demonstrate the serious weakness in our concrete pavements that may prevail at unprotected transverse cracks and joints, and the prime need of devoting serious thought to ways and means for eliminating this weakness. There can be but little doubt that the tests show that when cracked slabs are held in close contact, aggregate interlock is adequate to effect as much load transfer as may be expected at any joint or crack. The question of just how close the contact must be, as well as other points involved, seem worthy of discussion.

Moving loads at joints and cracks

Mr. Benkelman used an 18,000-lb. load in his tests. At first sight this might seem to be unnecessarily large. However, when it is remembered that traffic loads are more or less suddenly applied to the edge of the slab on the far side of free joints, and that a suddenly applied load in the theoretical case is equivalent to double the static load, the magnitude of the test load no longer appears excessive and the seriousness of a lack of protection becomes evident.

V. L. Glover, engineer of materials, Illinois division of highways, in "Reports of Investigations" Vol. 1, p. 1, writes of suddenly applied loads at free joints as follows: "It was found from tests with a Liberty truck, conducted by the Illinois division of highways, that this type of load, within attainable speeds, has a maximum effect equal to the effect of a static load about 1.5 times as great as the wheel load, and indications are that this effect is maximum at a speed of about 14 miles per hour." Thus, at free joints and cracks the effect of an axle load of 16,000 lb. may be equivalent to a total static load of about 24,000 lb. applied at two places only about 5 ft. apart upon the edge of the far slab.

At efficiently doweled transverse joints and interlocked cracks not only is the 50 per cent increase (due to the sudden application) largely if not wholly eliminated, but also that part of the static load which each slab is called upon to bear is cut about in half. The effect of adequate provisions for load transfer is therefore approximately equivalent to a reduction of the load at transverse edges to about one-third of that which applies at free joints and cracks. Pavement designs that permit unprotected transverse joints and or cracks are therefore decidedly unbalanced, and much concrete is elsewhere wasted in order that these locations may be strong enough to support the loads that the pavements are called upon to bear.

The very great advantage of designs in which there can be no free joints or cracks would seem to be so obvious as to command far more attention than the scant amount that they have received to date.

Aspects of load transfer

It is obvious that any ordinary amount of longitudinal tie steel, used to prevent transverse cracks from widening, is in itself of no value as an agency for transmitting load. Its value depends upon its ability to hold the more or less roughly fractured concrete in close interlock. It is also obvious that after cracks have widened a certain amount (dependent upon the character of the fracture) there will be no load transfer at all.

Mr. Benkelman's Fig. 5 (reproduced herewith) indicates an apparent load transfer of about 10 per cent at cracks opened 0.07 in. or more. Searcy B. Slack's tests of a joint, from which all connecting material had been carefully removed, indicated a deflection of the unloaded slab amounting to about 10 per cent of that of the loaded slab. The