The development of asphalt surfacings for steel bridge decking

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The Development of Asphalt Surfacings for Steel Bridge Decking

Développement des revêtements en asphalte pour tabliers métalliques

Die Entwicklung von Asphaltbelägen für Stahlfahrbahnplatten

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Introduction

At the request of the Joint Consulting Engineers for the proposed new bridges over the rivers Forth and Severn, the British Ministry of Transport and Civil Aviation asked the Road Research Laboratory to make tests to help to decide on the choice of a surfacing that would be sufficiently impervious to protect the steel decking from rust and corrosion, and that would be durable, non-skid and of a thickness not exceeding 2 in. It was desirable to test the possible surfacings on the full-scale and steel panels 9 ft. long by 7 ft. wide of a construction similar to that of the then proposed decking were placed in the carriageway of the Colnbrook By-pass on Trunk Road A. 4. This road carries more than 40,000 tons of traffic per day and some of the test panels were subjected to this traffic for periods of up to six years.

The tests began in 1949 and continued until the end of 1957, resulting in a surfacing considered satisfactory for the bridge decking described. Table 1 shows in chronological order the types of test made and gives brief details of the results. Preliminary experiments indicated that a $1^1/_2$-in. layer of stone-filled mastic asphalt was sufficient, but that special care was necessary to prevent entry of water at the boundaries. Experiments were then made to devise methods of keeping the water out. The dynamic strains generated in the steel plate by heavy moving vehicles showed that the proposed surfacing made a significant contribution to the rigidity of the steel plate under winter conditions, but its contribution was negligible at summer temperatures. This paper describes all these experiments in detail.

Table 1. Time-Table of Tests on Mastic Asphalt Surfacings

Nov. 1949	4 panels set in roadway: 1-in., $1^1/_2$-in., 2-in., smooth panels $1^1/_2$-in. chequered panels	
Feb.–March 1950	Load Tests to $12^1/_2$ tons	No cracks produced in any surfacing
Jan.–April 1950	Panels inspected	Cracks started at junctions, and at sides. Crack between 1- and $1^1/_2$-in. sections. No cracks on surface proper
Nov. 1950	2-in. and chequered panels taken up, surfacing removed, 15-ft. panel put in, treated for waterproofing as described in text	Rust 7-in. in from edges, otherwise bond still intact
Mar. 1951	Panels inspected	Fine cracks in 1-in. surfacing over stiffeners
Mar. 1952	Panels inspected	Cracks widening – new ones forming
May 1953	Panels inspected	Cracks $^1{}_{10}$/-in. wide in 1-in. surfacing
July 1954	$1^1/_2$-in. and 1-in. surfacing panels removed, inspected	*1-in. panel* cracks $^1/_8$-in. wide down to steel. *$1^1/_2$-in. panel* $^1/_{16}$-in. wide crack over centre stiffener — did not penetrate to steel
July 1954	Panels instrumented with strain gauges, and replaced in roadway. Static load tests carried out. Panels resurfaced as before	Rigidity of both panels approx. the same
July 1954	Dynamic strain measurements carried out, at differing temperatures	Strain found to be highly dependant on temperature
1955	Laboratory studies of mastic asphalt	E_{mastic} found to be dependant on frequency and temperature
July 1956	15-ft. panel taken up and inspected	Sealing compound found successful. Mastic bond had failed

First Full-Scale Test, 1949

A preliminary test showed that good adhesion was obtained between mastic asphalt and a steel plate when the steel was sand-blasted and painted with bituminous paint, which was made from 18—25 penetration bitumen cut back to an easy brushing consistency with solvent naphtha.

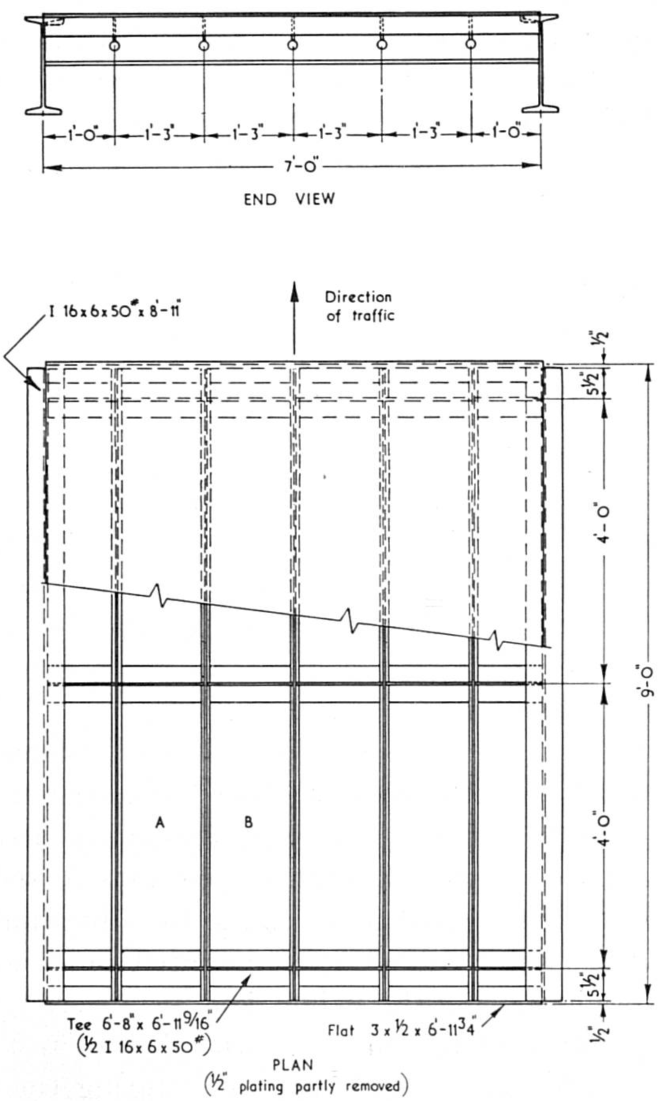

Fig. 1. Deck Panels for First Surfacing Test.

Fig. 2. Panels in Position Prior to Surfacing.

For the full-scale tests, four panels, each 9 ft. long by 7 ft. wide, were laid in the road (see fig. 2). Three of the panels had smooth deck plates while the fourth had a chequered plate which was included because it was feared that the surfacing might "push" on a smooth plate. The four plates were sand-blasted and painted as described, and then placed in the carriageway with their ends supported on concrete beams. The levels of the panels were stepped to permit thicknesses of surfacing of 1 in., $1^1/_2$ in. and 2 in. to be laid on the three smooth plates and a $1^1/_2$-in. surfacing on the chequered plate. Fig. 2 shows the panels in position before surfacing. Steel plates 12 in. wide covered the gaps between the sides of the panels and the road. The panels were sited on the braking side of a bus-stop and thus received maximum traffic forces. A proprietary brand of mastic asphalt was selected as suitable; this was supplied and laid by the Limmer and Trinidad Lake Asphalt Company Limited. The material complied in general with B. S. 1447, Table 1, Col. 3, but the penetration of the 50/50 mixture of Trinidad Lake asphalt and asphaltic bitumen was in the neighbourhood of 10. The penetration of the soluble portion of this binder was about 20. 40 per cent of granite chippings were added, as indicated in B. S. 1447. $^1/_2$ inch coated granite chippings were rolled into the surface of the mastic to provide a non-skid surface.

Loading tests were made on these panels on two occasions — 2nd February and 1st March, 1950 — to determine whether the surfacings would crack due to the deflection of the decking under the maximum design wheel load of $12^1/_2$ tons. The load was applied in turn at positions A and B (see fig. 1) on each panel. The load was applied to the plate by a hydraulic jack through a section of 14-in. wide solid rubber tyre mounted on a wooden block, and released rapidly by unscrewing the valve. The tests were repeated twice each day and the temperature of the mastic at the time of test varied between 1 and $4^1/_2$° C. The mastic surface did not crack during these tests. Since the stiffness of the decking on the proposed bridge is greater than that of the

Fig. 3. The Underside of the $1^1/_2$-in. Surfacing Removed From the Junction of the Smooth and Chequered Plate Panels.

$^1/_2$-in. plate used in the tests, it can safely be concluded that any local deflections of the decking plates occurring under maximum design loads will not cause the surface to fracture.

By January, 1950, three weeks after opening to traffic, cracks began to appear at the junction of the panels and the side plates, and, by April, 1950, the side plates on all the sections, except that with a 2-in. surfacing, were outlined by cracks. A crack also appeared between the 1-in. and $1^1/_2$-in. sections, no cracks were detected in the surfacing proper, although on that with a 1-in. surfacing, cracks appeared to be working in from the edges. In June, 1950, patches were cut from all sections and showed that rusting was occurring at the edges of the plates near the cracks. This spread under the bituminous

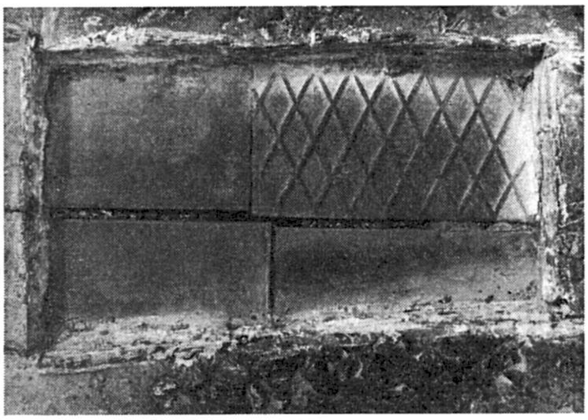

Fig. 4. Deck Plate on the Smooth and Chequered Plate Panels After Removing the $1^1/_2$-in. Surfacing. Rusting Can Be Seen Round the Edge of the Plates.

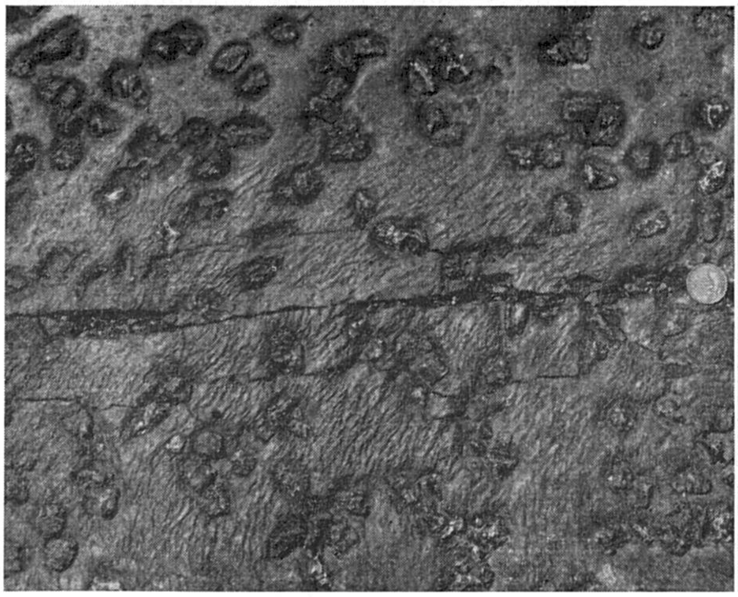

Fig. 5. Pushing of the 1-in. Mastic Asphalt Surfacing on the Side Plate Due to the Bond Being Broken Between the Surface and the Steel.

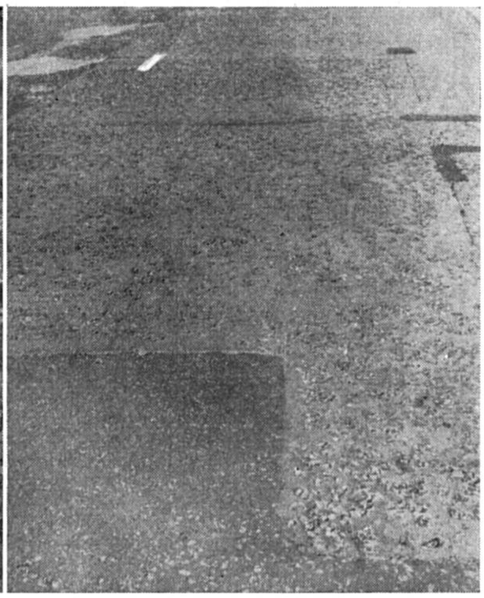

Fig. 6. View of the Surface on the Panels, Showing the Cracking Round the Side Plates.

paint and caused failure of the bond between the surfacing and the deck plate (see figs. 3 and 4). Where the bond had failed, traffic caused "pushing" of the asphalt (see fig. 5); the general appearance of the surfacing is shown in fig. 6.

These tests showed that:

a) A stone-filled mastic asphalt surfacing $1^1/_2$ in. thick was sufficient to withstand the traffic.
b) Although the priming coat of bituminous paint gave a reasonable bond between the asphalt and the sand-blasted steel plate, it afforded no protection once the surface became cracked.
c) Precautions were necessary to prevent ingress of water at the boundaries of the panels.
d) The chequered plate offered no advantage over the smooth plate.

Investigation of Methods of Protecting the Steel Deck and of Sealing the Edges of the Mastic Asphalt

Laboratory tests showed that the bituminous paint alone did not protect the steel against moisture: better results were obtained when red lead priming was applied before the bituminous paint. When this technique was tried on a deck panel 15 ft. by 7 ft., it was found that the red lead would not dry out when applied in a thick coat. Consequently, the surface was sprayed with metallic zinc to a thickness of 0.001 in. and then primed with bituminous paint.

The large panel was similar in construction to those described earlier. Angle-iron was welded along its edges as shown in fig. 7 in order to contain the asphalt. Two of the existing panels, namely that with the chequered steel plate and that carrying the 2-in. mastic asphalt surfacing, were taken out of service and replaced by the 15 ft. by 7 ft. plate in November 1950. Two methods of laying the surfacing were employed and the methods used to seal the edges are shown in fig. 7. The panel was subjected to traffic and weathering for $5^1/_2$ years and was removed for inspection in July, 1956. The surfacing was removed near to the corners to inspect the sealing and the results were as follows:

Corner A. The edge here was formed by $1^1/_2$ in. by $1^1/_4$ in. angle and was filled with a proprietary rubber/bitumen sealing compound. The joint was found to be perfect.

Corner B. The edge here was formed from either $1^1/_2$ in. by $1^1/_4$ in. or $1^1/_2$ in. by $^3/_4$ in. angles and filled with damp-proof mastic. There was an obvious construction joint between the two courses of mastic and this was filled with dust and dirt. Little adhesion occurred between the damp-proof mastic and the angle-iron: the latter showed signs of rusting.

Corner C. The construction was as for *B*. The joint between the two mastic layers was more pronounced and showed evidence of pushing. The adhesion

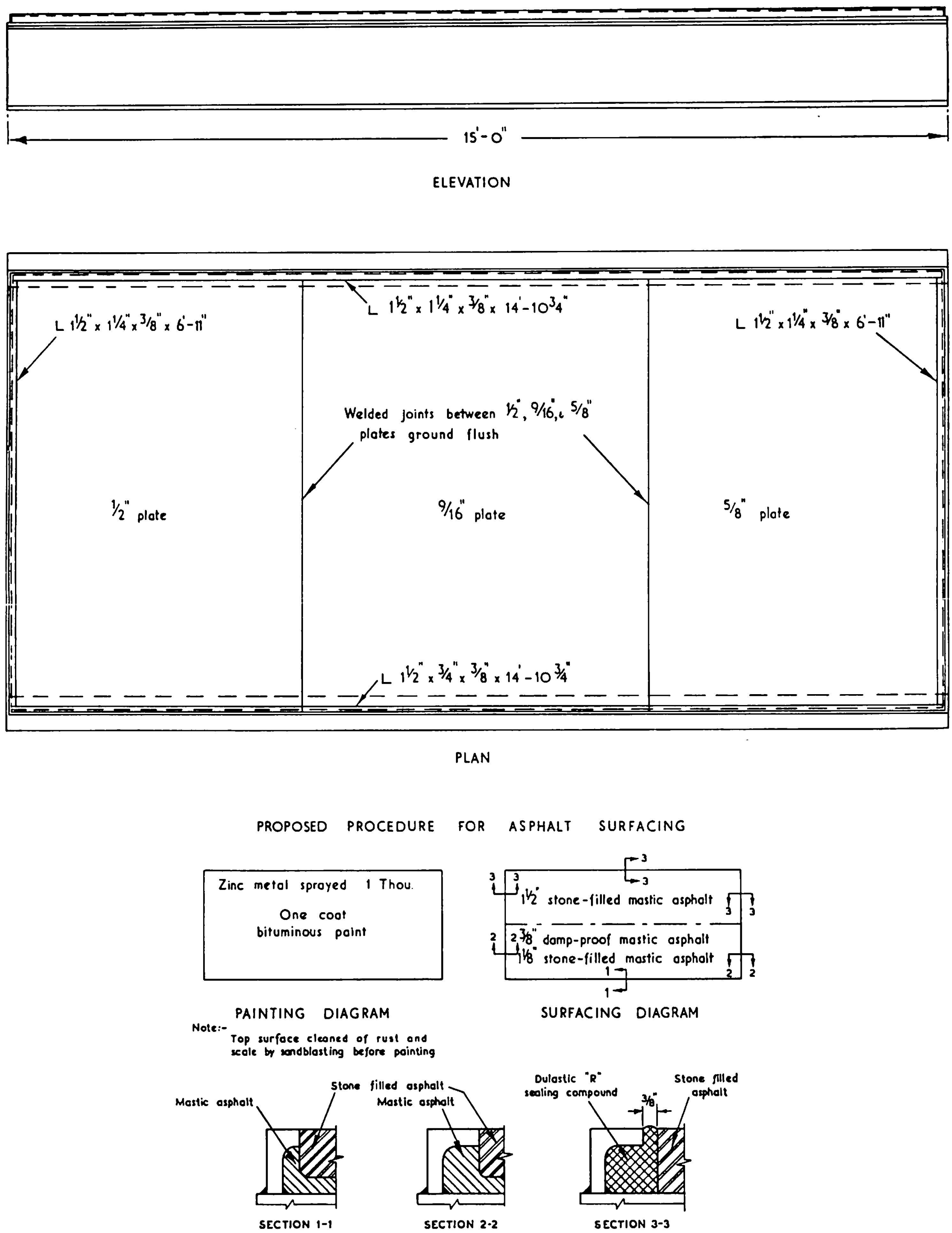

Fig. 7. Panel Used for Second Experiment.

to the angle-iron was poor and water had entered, causing some corrosion of the angle. The steel deck plate was undamaged.

Corner D. The construction was as for *A*. The joint appeared perfect but droplets of water were found in three small pockets (1 to 2 sq. in.) under the mastic. They caused some discoloration but the zinc film was intact and the deck plate undamaged. There was no evidence to indicate how the water had reached the small pockets.

No rusting of the deck plate occurred at any of these points.

Performance of 1-in. and $1^1/_2$-in. Surfacings Under Prolonged Trafficking

The two panels carrying respectively 1-in. and $1^1/_2$-in. surfacings of mastic asphalt and which had been installed in the road in 1949, were inspected at intervals until July, 1954, when they were removed for inspection after $4^1/_2$ years' service. By March, 1951, fine cracks had formed over the three central stiffeners in the 1-in. panel, and, by July, 1954, these cracks were $^1/_8$ in. wide at the surface and a penknife blade penetrated over $^1/_2$ in. By this time, a small crack, $^1/_{16}$ in. wide, had formed over the central stiffener of the $1^1/_2$-in. panel.

When the panels were removed and inspected, the following observations were recorded:

Panel with a 1-in. Surfacing of Stone-filled Mastic Asphalt

The cracks formed over the stiffeners are shown in fig. 8. On stripping the surfacing it was found to be cracked right through over the three central stiffeners for nearly the whole distance between the transverse supports. The

Fig. 8. General View of Bridge Panels After $2^1/_2$ yr. with 1-in. Surfacing in Foreground. Note the Pronounced Cracks Over the Three Central Stiffeners and Incipient Cracks Over the Outer Stiffeners.

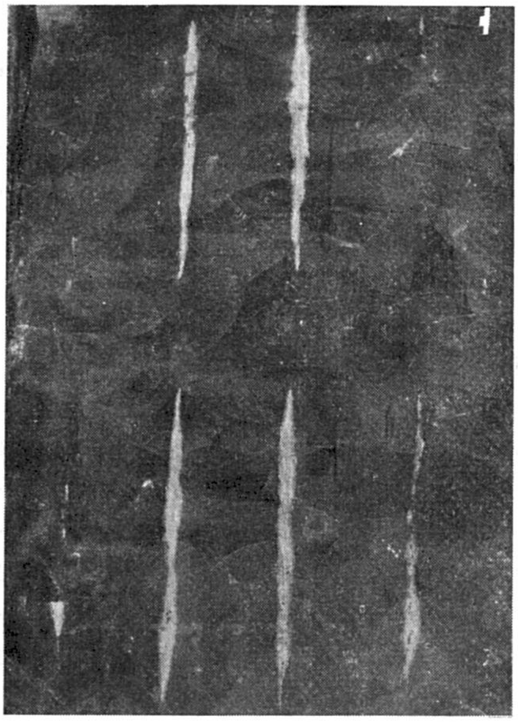

Fig. 9. The Steel Deck-Plate After Removal of 1-in. Surfacing. Note the Corrosion After $4^1/_2$ yr. Owing to Water Penetrating Through the Cracks Shown Above.

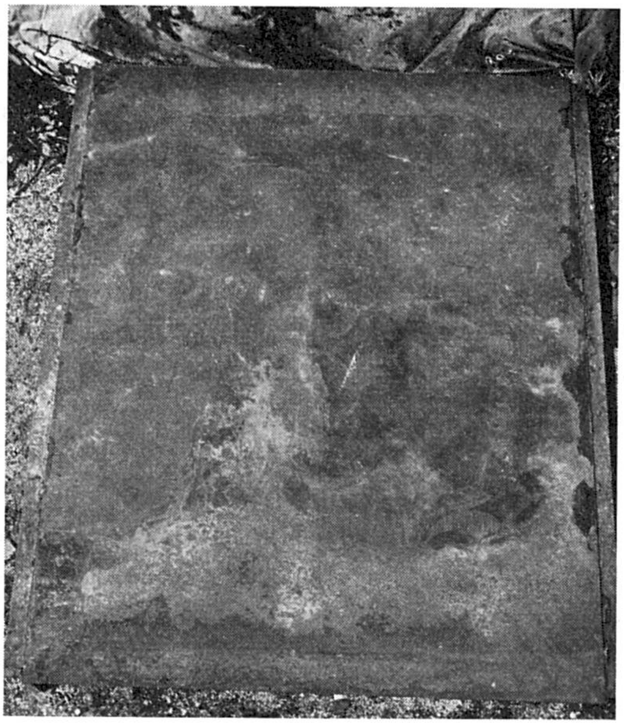

Fig. 10. The 9 ft. By 7 ft. Deck Plate After Removal of the $1^1/_2$-in. Surfacing. Note Absence of Any Corrosion After $4^1/_2$ yr., Due to Cracking; and Also the Very Considerable Corrosion Where the Mastic Asphalt Had Not Adhered Properly Over the Front and Centre Portions of the Plate.

cracks over the outer stiffeners were found to be in the form of a "vee", the point of the "vee" just touching the steel over a short distance. Where the cracks penetrated to the steel, and all around the edges of the panel, water had entered and caused considerable rusting. Fig. 9 shows the extent of this corrosion and also shows that, over the main area of the panel where the adhesion to the mastic had remained good, no penetration of water had occurred and hence no rusting. The considerable crack over the central transverse support did not extend through the surfacing and no water had penetrated to the steel.

Panel with $1^1/_2$ in. Surfacing of Stone-filled Mastic Asphalt

There was a fairly well defined crack about $^1/_{16}$ in. wide over the central stiffener and a very short, faint crack over each of the two adjoining stiffeners. None of these cracks penetrated to the steel plate. As with the 1-in. surfacing, water entered all around the edges of the plate and caused considerable corrosion, particularly at the west end of the panel (on which traffic first runs). Approximately a quarter of the whole area had no adhesion between the mastic asphalt and the steel. Here the plate was extensively rusted and the mastic asphalt was widely cracked over its underside. The cracks were filled with rust and slime, but did not penetrate to within $^1/_2$ in. of the top surface. No cracks were detected in the region where the adhesion to the steel was good. Fig. 10 shows a photograph of the steel plate after the $1^1/_2$-in. surfacing had been removed.

Contribution of the Mastic Asphalt to the Rigidity of the Steel Deck

The difference in the performance of the 1-in. and $1^1/_2$-in. surfacings under prolonged trafficking indicated that the surfacing might be making an appreciable contribution to the rigidity of the steel plate. To determine this contribution, dynamic strain measurements were made on the two panels while subjected to moving-wheel loads under varying conditions of speed and road-surface temperature. The steel plates were cleaned and thirteen resistance strain gauges were attached to each plate at the positions shown in fig. 11.

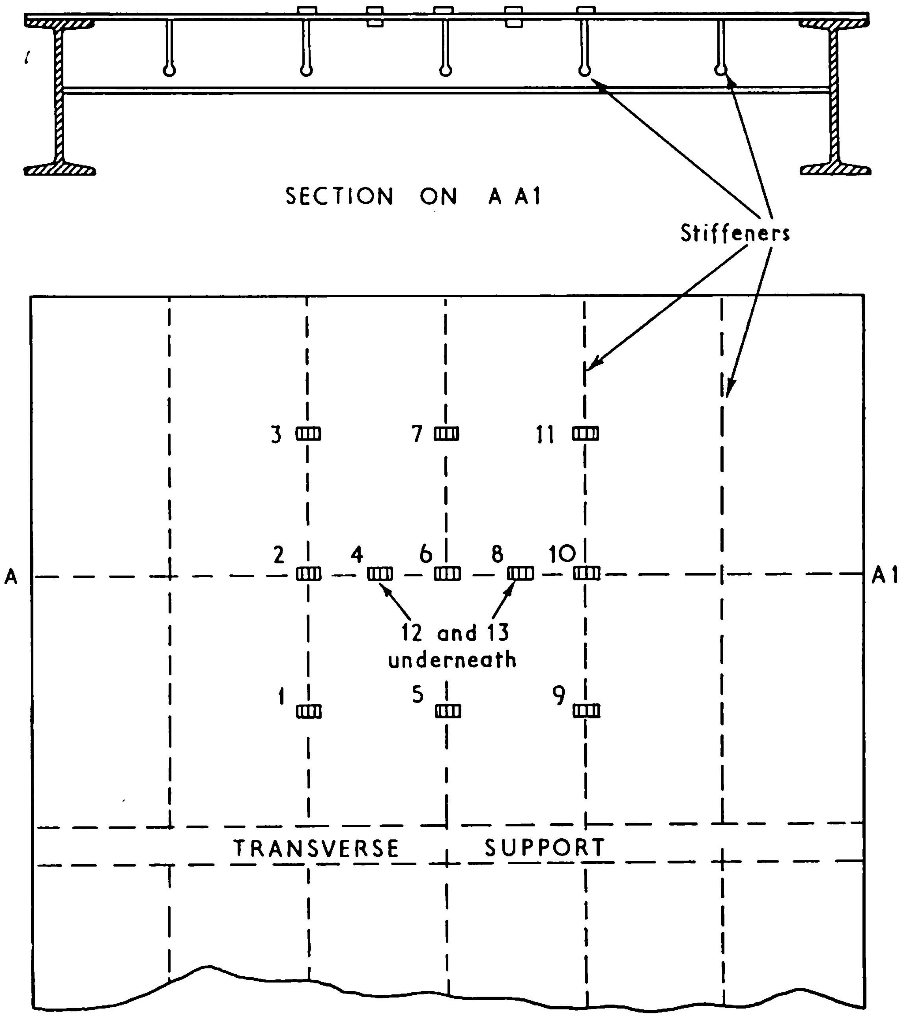

Fig. 11. Portion of Deck Plate Showing the Positions of Strain Gauges.

Gauges 1 to 11 were used on the upper surface of the steel and gauges 12 and 13 were attached to its under side. The strain gauges were of the foil type and were cemented to the steel by an epoxide resin. A thermocouple was also attached to each steel plate to measure the temperature of the asphalt surfacing.

Preliminary tests on the steel plates before resurfacing. The two panels were replaced in the carriageway of the Colnbrook By-pass and static tests were made before resurfacing with mastic asphalt. The hydraulic jack was used as in the earlier tests, but the load was applied through a rubber disc 11 in. in diameter. The jack system had to be employed because it was not practicable to run a loaded vehicle across the sections. The positions at which the tests

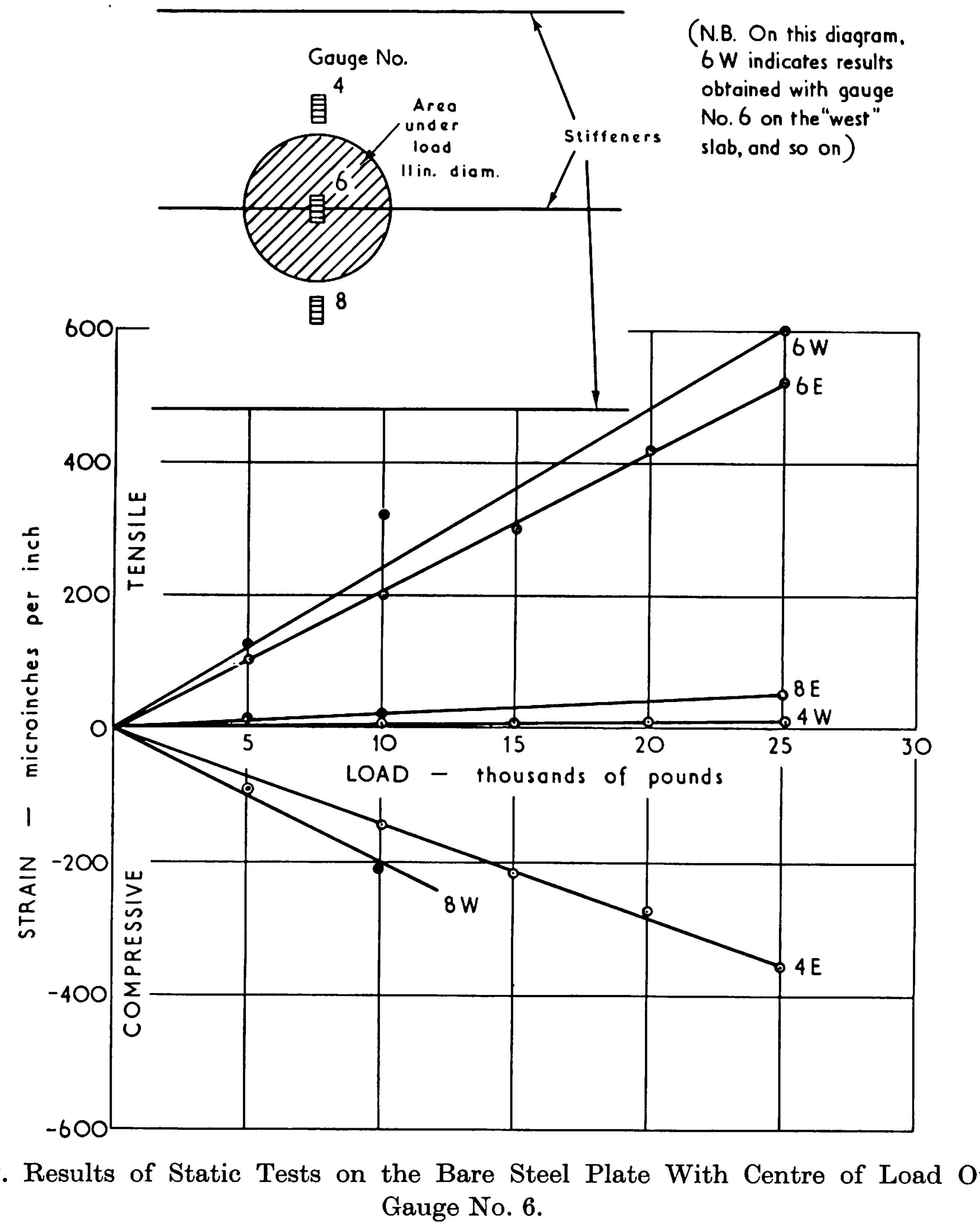

Fig. 12. Results of Static Tests on the Bare Steel Plate With Centre of Load Over Gauge No. 6.

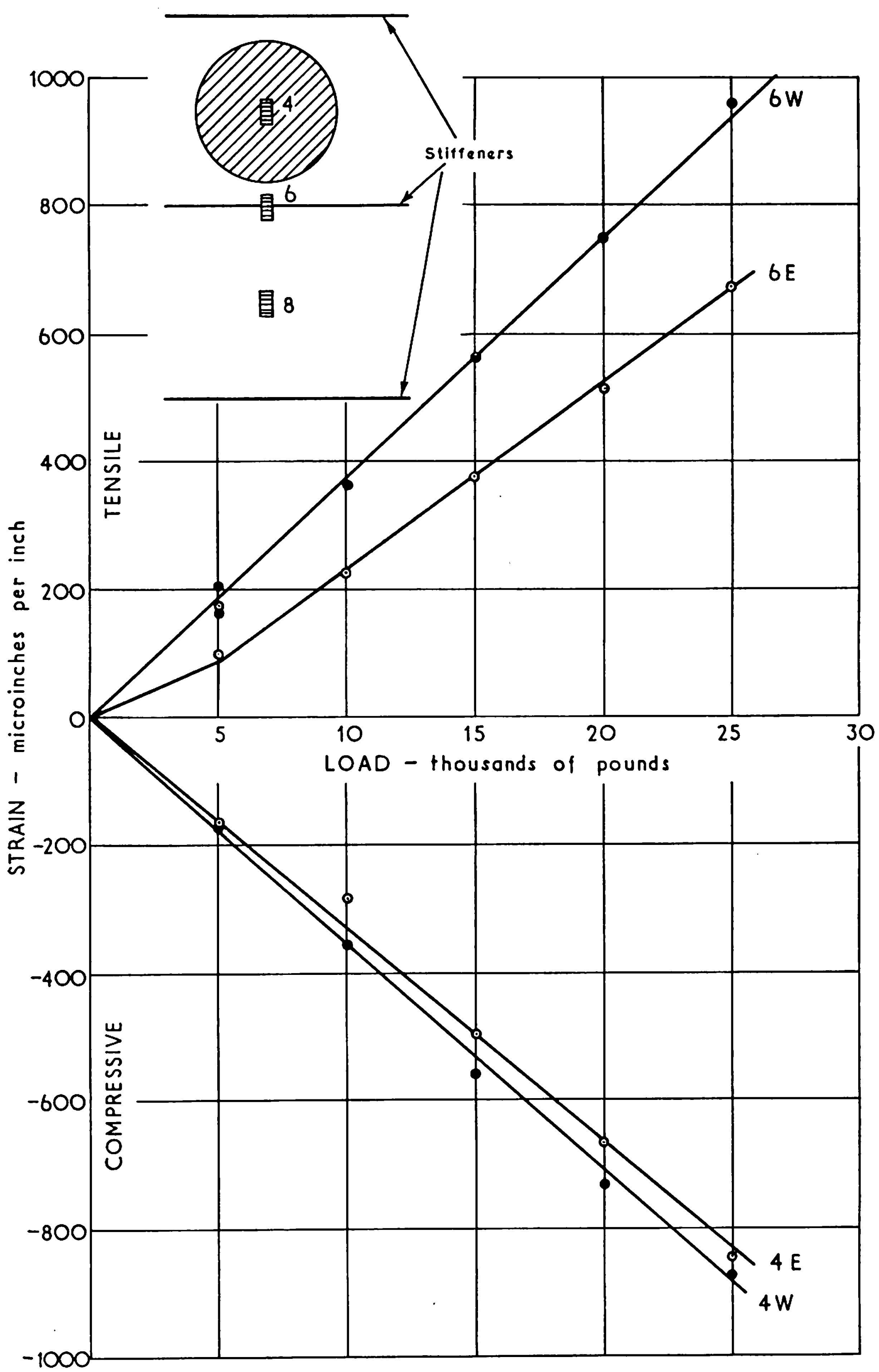

Fig. 13. Results of Static Tests on the Bare Steel Plate With Centre of Load Over Gauge No. 4.

were made are shown in figs. 12 and 13, one test being made directly over the central stiffener and the other midway between two stiffeners. Figs. 12 and 13 show the measured strains plotted against applied load. Linear relationships occurred between strain and load in all cases, hence these diagrams could be used to determine the strain in the steel at a load equal to that applied by each wheel when tests were made later with a moving vehicle. The largest tensile strains in the transverse direction occurred at gauge No. 6 on both panels, this gauge being that placed across the stiffener. As figs. 12 and 13 show, the rigidity of the panels (marked "East" and "West") was approximately equal, particularly having regard to the variations that might occur in producing the complicated welded structures.

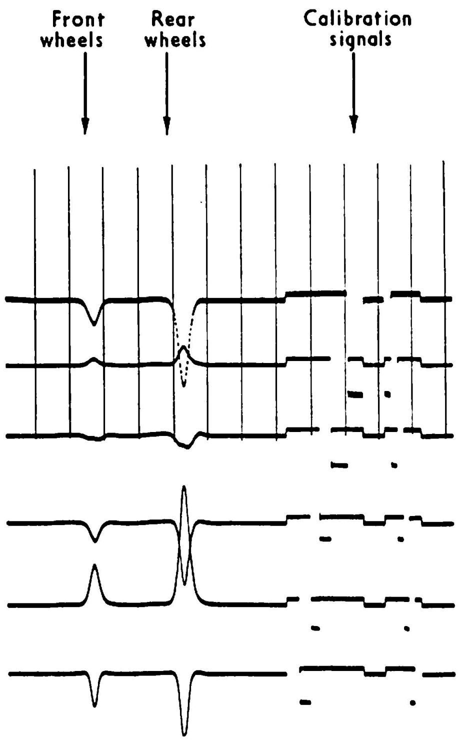

Fig. 14. Dynamic Strain Record. Vehicle Travelling at Creep Speed (About 3 mile/h).

Resurfacing of the panels. Surfacings similar to those used in the earlier tests were laid on top of the steel decking plates after the initial strain measurements had been made. The east panel had a surfacing 1 in. thick, while that on the west panel was $1^1/_2$ in. thick. The temperature of the steel was observed during the laying process and the maximum recorded was 108° C, which was considered unlikely to damage the resistance strain gauges.

Dynamic strain measurements with surfacings in place. Between July, 1954, and March, 1955, a series of dynamic strain measurements was made on three separate occasions when the plate temperatures were respectively 0° C, 8° C and 30° C. A heavy vehicle was specially loaded to give a single rear-wheel load of 11,000 lb. and was run over the panels at various speeds. The position

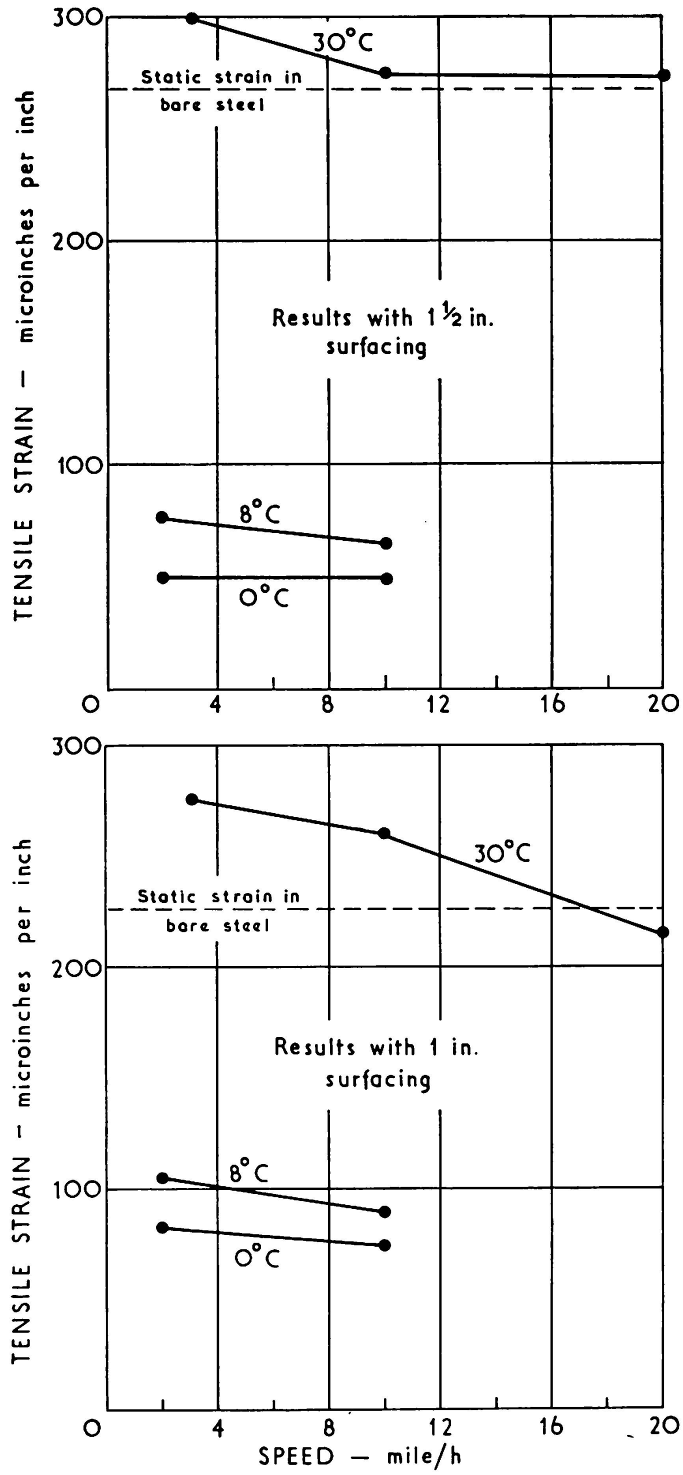

Fig. 15. Effect of Vehicle Speed and Temperature on the Dynamic Strains in Bridge Panels Caused By a Wheel Load of 11 000 LB.

of the centre line of the loaded wheel was judged by eye in relation to chalk marks on the panels. Selected strain gauges were connected to a six-channel recording galvanometer and measurements of strain were made during each run. The strains recorded by gauge No. 6 over the central stiffener were found to be the largest in each case, and, consequently, were used to compare the performance of the panels under different conditions of vehicle speed and temperature of surfacing.

The waveform of the recorded strain did not vary with vehicle speed, but the duration of the strain was, of course, inversely proportional to the speed. A typical set of records is shown in fig. 14.

Values of the peak tensile strain recorded by gauge No. 6 in each test run are shown in fig. 15 plotted against the vehicle speed, separate curves being shown for the three surfacing temperatures studied. Separate sets of curves are shown for each panel, and each diagram shows the tensile strain deduced from the static tests at a load equal to that applied by the rear wheel of the moving lorry, i.e. 11,000 lb. The distribution of strain occurring under the load applied by the jack to a rubber disc 11 in. in diameter and that applied by the vehicle tyre having an elliptical contact area about 12 in. by 8 in. will not be identical. The static strains have been included in fig. 15 merely as a yardstick by which to judge the strains recorded under the moving vehicle. The fact that, at 30° C, the dynamic strain recorded with, say, a surfacing $1^1/_2$ in. thick, was actually greater than that recorded statically, with the load applied to the bare steel, therefore, has no significance.

Both sets of diagrams on fig. 15 show much larger strains in the steel when the surfacings were at a temperature of 30° C than at 0 and 8° C. The diagrams indicate that at 30° C, the surfacings made only minor contributions to the rigidity of the steel plate, whereas at the lower temperatures, their contributions were appreciable. If it is assumed that the strains measured in the static test were directly comparable with the dynamic values, it would appear that, at 0° C, the $1^1/_2$-in. surfacing contributed about 80 per cent as much as the steel plate to the overall rigidity, while the contribution of the 1-in. surfacing was 60 per cent. If the mastic asphalt behaved elastically under the stresses and rates of loading applied by the moving vehicle, it would be expected that the elastic modulus would be higher at the low temperature than at 30° C. Tests on bituminous materials have indicated that the change of modulus corresponding with this temperature change may be of the order of three to four times greater and this would largely explain the recorded differences in strain at summer and winter temperatures.

The trafficking tests which lasted $4^1/_2$ years showed a difference in the performance of the 1-in. and $1^1/_2$-in. surfacings. It is possible that summer temperatures only applied for a small proportion of the period of test and, at lower temperatures, as fig. 15 shows, there was a difference in the strains generated in the steel plates by vehicles travelling over the two thicknesses of surfacing.

The greater strains generated in the plate under the 1-in. surfacing may possibly account for its inferior performance, plus the fact that any crack generated in the surfacing had a smaller thickness to travel through than was the case with the $1^1/_2$-in. layer.

Conclusions

The tests described in this paper show:

1. A 1-in. thickness of stone-filled mastic asphalt would be too thin for use on the deck of the proposed bridge. Cracks would probably form over the longitudinal stiffeners and permit water to penetrate through to the steel plate.
2. A $1^1/_2$-in. thickness of stone-filled mastic asphalt behaved satisfactorily for 5 years under heavy traffic. Cracks formed in it but did not penetrate through to the steel. These tests were made with a steel plate $^1/_2$ in. thick; thus it is reasonable to expect that a $1^1/_2$-in. surfacing would behave well on the plate proposed for the bridge.
3. Special construction is necessary to keep water out of the edge joints. Angle-iron at the edges of the deck plates, filled with rubber/bitumen sealing compound together with a surfacing of $1^1/_2$ in. of stone-filled mastic asphalt gave a joint that withstood heavy traffic for at least 6 years.
4. When angle-iron was used with a two-course surfacing consisting of stone-filled mastic asphalt overlying $^3/_8$ in. of damp-course mastic, the resistance to the ingress of water at the edges was not so good as that given by (3).
5. It was found advantageous to sand-blast the steel plate, spray it with metallic zinc, and to prime it with bituminous paint to minimise rusting and corrosion and to improve the bond between the surfacing and the plate.
6. Strain measurements made on the steel decking plates under heavy moving vehicles showed that the asphalt surfacing $1^1/_2$ in. thick made a significant contribution to the overall rigidity of the decking in winter, but under summer temperatures it contributed practically nothing to the rigidity.
7. The tensile strains generated in the steel appeared to be independent of the speed within the range of 2 to 20 miles per hour at which the heavy vehicle travelled across the surface.

Acknowledgements

The work described in this paper was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The paper is published by permission of the Director of Road Research. Thanks are due to the various officers who took part in these tests, notably Mr. F. H. P. Williams who made the first series of full-scale tests.

Thanks are also due to the Joint Consulting Engineers for the Severn

Bridge, Messrs. MOTT, HAY and ANDERSON and FREEMAN, FOX and Partners, who co-operated throughout the work and to the Limmer and Trinidad Lake Asphalt Company who gave valuable advice and assistance.

Summary

The paper describes full-scale tests undertaken to select suitable bituminous surfacings for the steel decking on the proposed bridges over the rivers Severn and Forth.

The tests were made on steel panels inserted into the carriageway of a trunk road carrying about 40,000 tons of traffic daily.

A surfacing of stone-filled mastic asphalt was tested in thicknesses of 1, $1^1/_2$ and 2 inches. Precautions were taken to keep water out of the edge joints, and to prevent rusting of the plate, and these are described. The minimum thickness of surfacing necessary to withstand 5 years of heavy trafficking was found to be $1^1/_2$ inches.

Strain measurements, made on the steel deck plates under standard wheel loads are described.

It was found that the contribution of the asphalt surfacing to the rigidity of the deck plates depended upon the temperature at which the tests were carried out. Under winter conditions (0° C) the surfacing contributed about 80 per cent to the rigidity of the steel plate for the $1^1/_2$ in thickness and 60 per cent for the 1 in thickness.

At temperatures of 0 to 8° C, dynamic strains under the $1^1/_2$ in asphalt were only about 70 per cent of those measured under the 1 in thickness. This may account for the differences of performance under traffic.

Under summer conditions (30° C) the contribution of the surfacings to the stiffness of the deck was negligible.

Résumé

Les auteurs exposent les essais en vraie grandeur qui ont été effectués en vue du choix de revêtements bitumineux appropriés pour les tabliers métalliques des ponts projetés sur les rivières Severn et Forth.

Ces essais ont été exécutés sur des panneaux métalliques qui ont été incorporés à la chaussée d'une grand'route devant assurer un trafic quotidien de l'ordre de 40000 tonnes.

Un revêtement asphaltique a été essayé dans les épaisseurs de 1, 1,5 et 2″; des dispositions ont été prises pour assurer l'étanchéité des joints sur les bords et empêcher la corrosion des tôles métalliques. Les essais ont montré qu'un revêtement destiné à supporter un trafic lourd pendant cinq années doit avoir une épaisseur de 1,5″ au minimum.

Il a été également procédé à des mesures tensométriques sur le tablier, sous l'influence des charges de roue normales; on a constaté que le concours apporté par le revêtement dépend de la température sous laquelle les essais sont effectués. Dans les conditions hivernales (0° C), un revêtement de 1,5″ contribue pour 80% environ à la rigidité du tablier; la part prise par un revêtement de 1″ est de l'ordre de 60%.

Sous des températures de 0 a 8° C, les dilatations mesurées dues aux contraintes du trafic, pour une épaisseur de revêtement de 1,5″, n'atteignent que 70% de celles qui se produisent avec une épaisseur de 1″. Ceci peut expliquer les differences du comportement sous le trafic. Dans les conditions d'été (30° C) la contribution des revêtements à la rigidité du tablier est négligeable.

Zusammenfassung

Die Abhandlung beschreibt die Durchführung verschiedener Prüfungen in Naturgröße, um geeignete bituminöse Beläge für die Fahrbahnplatten der projektierten Stahlbrücken über die Flüsse Severn und Forth zu finden.

Die Tests wurden auf Stahl-Blechen, wie sie für die Ausbildung der Fahrbahn verwendet werden sollen, ausgeführt, welche in einen Straßenkörper, der ungefähr 40000 t täglichen Verkehr trägt, eingebaut wurden.

Ein Asphalt-Belag wurde in den Stärken von 1, 1,5 und 2 Inches geprüft, wobei Maßnahmen zur Dichtung der Fugen und Verhinderung der Korrosion getroffen wurden. Die minimale Belagsstärke, welche einem 5jährigen Schwerverkehr standhalten soll, wurde mit 1,5 Inches ermittelt.

Es sind auch die Dehnungsmessungen auf der Stahlplatte infolge Standardradlasten beschrieben, wobei gefunden wurde, daß die Mitwirkung des Belages von der Temperatur abhängig ist, bei welcher die Versuche durchgeführt werden. Bei Winter-Verhältnissen (0° C) trägt ein Belag von 1,5 Inches etwa mit 80% zur Steifigkeit der Platte bei und ein solcher von 1 Inch mit ungefähr 60%.

Bei Temperaturen von 0 bis 8° C waren die gemessenen Dehnungen infolge von Verkehrsbeanspruchung bei 1,5 Inches Belagsstärke nur 70% derjenigen, die bei 1 Inch gemessen wurden. Dies mag die Unterschiede des Verhaltens unter Verkehrslast erklären. Bei Sommertemperaturen (30°) ist die Mitwirkung des Belages an der Steifigkeit der Fahrbahn vernachlässigbar.