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SOME THIN PAVEMENTS IN GREAT BRITAIN

Quelques revêtements minces en Grande-Bretagne

Einige dünne Beläge in Großbritannien

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1. INTRODUCTION

Conventional surfacings for orthotropic plate decks consist of bituminous mixtures laid from $1\frac{1}{2}$ to $2\frac{1}{2}$ in (38 to 63 mm) thick. Such thicknesses impose a weight penalty on this form of deck which partly nullifies its economic and structural advantages. The first investigation carried out by the Road Research Laboratory, almost 20 years ago, was aimed at finding the thinnest mastic surfacing which could be used satisfactorily. It was found that surfacings less than $1\frac{1}{2}$ in (38 mm) thick will crack on the more flexible decks unless the traffic is light.

On a road, the surfacing material must be cheap and the simple solution is to increase the thickness. On a bridge, however, the cost of the material is relatively less important; for long span and moveable bridges the primary requirement is that it must be lightweight, i.e. capable of being laid thinly. For this reason resinous binders costing £500 ($1,200) or more per ton, compared with bitumen at £20 ($48) per ton, can be considered feasible.

2. THIN BITUMINOUS SURFACINGS

Before discussing resinous binders, however, it is worth considering possible ways in which bituminous materials might be utilized more thinly. One can make surfacings more flexible by increasing the bitumen content and by using softer bitumen. It is possible that by using a very soft asphalt, restrained from deforming by a metal grid of rectangular or hexagonal shape fastened to the deck-plate, one could reduce the surfacing depth to perhaps $\frac{3}{4}$ in (19 mm) or even less. This has not been put to the test, however, because the weight of steel in the mesh (Specific Gravity about 8.0) would largely counteract the weight of asphalt saved (Specific Gravity about 2.3). Such grids have of course been used with thicker surfacings in several European countries (Fig. 1).

Another form of thin bituminous surfacing is a single or double surface dressing with bitumen (preferably rubberised bitumen) and $\frac{1}{4}$ or $\frac{3}{8}$ in (6 or 9 mm) chippings. This type of surfacing is only suitable for medium or light traffic but has given good results on several less important road bridges, and was used on the footpaths and cycle tracks of the Forth and Severn Bridges thereby saving a considerable weight.

3. RUBBER-LATEX/PORTLAND CEMENT MIXTURES

For heavily-trafficked bridges, however, it seems probable that one must abandon bituminous materials, if very thin surfacings are required. One of the first non-bituminous mixtures to be tried in the United Kingdom was a mixture of aggregate and asbestos fibre with rubber latex and portland cement. Following road-machine trials, several mixtures of this type were laid on test plates set in a heavily-trafficked road in 1950. After 5 years, the surfacings were still in good condition but it was found that water had penetrated to the steel at the edges and through localised clusters of asbestos fibres. No further experimental work was, therefore, carried out on this type of material although it has subsequently been used on the footpaths of several bridges.

4. SURFACINGS BASED ON THERMOSETTING RESINS

Bituminous surfacings are thermoplastic: if they are made relatively soft and flexible to avoid cracking, then they tend to deform in hot weather. In the late 1950's, therefore, attention was turned to thermosetting resins as alternative binders to bitumen. There has been no difficulty thereby in eliminating the risk of deformation, but it has proved extremely difficult to find a resin which is sufficiently flexible to resist cracking while still retaining other properties such as weather resistance and adhesion to steel.

Several trials of surfacings made with epoxy and polyester resins on small bridges and experimental panels have been made from 1959 onward and progress has been reviewed from time to time(1-4). An important trial was that made in 1963 in connection with the surfacings proposed for the Severn Bridge, for which two large deck panels were set in Trunk Road A.40 at Denham (6). The panels have been described in detail in a paper under Theme I. Three epoxy-resin-based surfacings and one based on a polyester resin laid $\frac{3}{8}$ in (9 mm) thick were compared with two types of asphalt laid $1\frac{1}{2}$ in (38 mm) thick. The epoxy resin/hardener systems chosen were those found to be most promising from previous trials. The resins were the considered choices of three major manufacturers of epoxy resin and they provided a range of flexibility and strength. In each case, they were mixed with six times their weight of fine calcined bauxite aggregate (passing $\frac{1}{8}$ in B.S. sieve), to form a surfacing material trowelled by hand on to the deck panel to a depth of $\frac{3}{8}$ in (9.5 mm). Before laying the mixtures, a coating of unfilled resin was brushed on to the panel at about $\frac{1}{2}$ lb/sq. yd. (0.25 kg/m^2). The panel was delivered with a zinc-sprayed surface, coated with etch-primer. All the surfacing work was done under cover before the panels were taken to the experimental site. The layout of the sections is shown in Fig. 2.

For the fourth section (1D), which is only 7 ft (2.1 m) long and does not contain a transverse stiffener, a proprietary polyester resin/Portland cement binder was used in place of the epoxy resin. This material, known as "Estercrete", is cheaper than epoxy resins. Its mixing and laying is described in a later paragraph.

The panels were opened to traffic in November 1963. The first cracks appeared over the stiffeners in the wheel tracks on Sections 1A and 1D, early in 1964. Subsequently, there was a rapid deterioration of the condition of Section 1A, probably due to a defective constituent in the resin, and it was replaced in October 1964. The replacement was made with a fresh batch of the material to the same specification. It was more durable than the previous batch, but it deteriorated in a similar manner and was removed in April 1968. Cracks have developed in the "Estercrete" on Section 1D over all the stiffeners, but they have not widened appreciably and the material still firmly adheres to the steel.

On Sections 1B and 1C the surfacing was in good condition until the beginning of 1965. Then one crack appeared over the stiffener in the nearside wheel track. Since then additional cracks have developed in both the wheel tracks, but the materials still adhere firmly to the deck between cracks. The condition of the four resin surfacings in November 1967 is shown in Figs. 3-6. As reported in a previous paper the mastic asphalt laid at the same time is still uncracked and has vindicated its selection for the deck of the Severn Bridge in 1966.

The resin on Sections 1B, 1C and 1D would still be regarded as providing a good running surface with a good skidding resistance. However, they are not adequately protecting the steel in a region where a small amount of corrosion could have a serious effect on both the ultimate and fatigue strength of the bridge deck.

Apart from flexibility, however, it is clear that numerous thermosetting resins are available with all the other qualities desirable in surfacings i.e. durability, abrasion resistance, adhesion to steel etc. It may be confidently expected that more flexible resins will be developed in the future.

Two sizeable commercial uses of epoxy-resin-based surfacings on orthotropic plate bridges may be commented on. The 800 ft long prefabricated flyover at Camp Hill, Birmingham was bult in 1961.[5] It has a steel deck plate, ½ in (12.5 mm) thick, with angle type longitudinal stiffeners at 12in (300 mm) centres and transverse diaphragms 5ft (1.5 m) apart. For at least 6 years the epoxy-resin surfacing remained uncracked and in very good condition although a recent inspection has shown that a few hair cracks have now appeared in the surfacing in the wheel tracks. It is otherwise still good and another prefabricated flyover with a somewhat similar surfacing was erected in Bristol in 1967. In 1966 the historic suspension bridge over the Thames at Marlow was renovated and given an orthotropic plate deck with epoxy resin surfacing which is still in good condition.[6] This bridge has a deck plate ½ in (12.5 mm) thick with plate stiffeners at 12 in (300 mm) centres. Vehicles using the bridge deck are restricted to 5 tonf (50 kN) total load.

The epoxy resin surfacing material selected for the bridge was subjected to a dynamic plate bending test, simulating the strain cycle in transverse bending over the stiffener. The material withstood, without cracking, approximately 10^5 applications of a constant amplitude strain cycle oscillating between 5 tonf/sq. in. (77 N/mm^2) tensile and 1.5 tonf/sq. in. (23 N/mm^2) compressive on the upper surface of the deck plate. The temperature varied between 9°C and 15°C during the test. Because of the weight restriction it is estimated that a stress of 5 tonf/sq. in. (77 N/mm2) will only occur 4,000 times per annum.

At present, a difficulty discouraging the use of epoxy-resin-based surfacings is the problem of mixing and laying them on a large scale. The dense, tough, solvent-free mixtures which give the best ultimate results tend to be very viscous and tacky to handle, and the exothermic reaction of epoxies limits the size of batch which can be used. One suggestion for overcoming these difficulties is to build up the required ¼ to ⅜ in layer by the application of several successive spray-and-chip processes. The spraying of epoxy resins via metering pumps, mixing head, and spray bar has been successfully carried out for a number of years.

Another interesting solution to the handling problem may be found along the lines adopted in the proprietary material "Estercrete" (7-9). This material is supplied as a slurry of polyester resin and Portland cement with a latent catalytic hardener already in it. When this slurry is added to suitable aggregate with an appropriate volume of water a multiple reaction occurs. Hydration of the cement begins, the catalyst starts to function and the mixture cures in a few hours to a hard mass. Both the stickiness of the resin and exothermic heat are dissipated by the water and the size of batch is unlimited. At least one large road paving job has been carried out using conventional mixing and paving machinery handling $\frac{1}{2}$ ton (500 Kg) batches[11]. A small area (hand-laid) was laid on one of the Road Research Laboratory's Severn Bridge test panels in 1963. It has suffered very little wear and is still bonded well to the deck plate. Although, as with the epoxy-resin-based surfacings, cracks have appeared over the stiffeners, the material would appear to have considerable potential especially if greater flexibility can be incorporated into the basic resin.

In his introductory paper, Elliott[10] raises the questions of surface irregularity and wear. Recent experience in Britain would indicate that with welded construction of the deck, as typified in the Forth and Severn Bridges, a good profile can be obtained on the steel, which would, without surfacing, be acceptable for high speed motorways. The mastic surfacings, laid by hand, did not improve the riding quality. The wear on epoxy-resin surfacings has not proved to be a serious problem in Britain. Even with thin surface dressings, provided sufficient resin is used and the grit is well chosen, several years life has been obtained. Calcined bauxite has proved to be superior to more expensive abrasives such as silicon carbide and corundum. With trowelled mixes, the wear is not detectable after five years of heavy traffic, in terms of either thickness or texture. It should be mentioned in this connection that tyres with steel studs are not common in Britain at present.

Zinc metal spray has been widely used in Britain as the initial coat for a steel deck, with the object of providing temporary protection from corrosion during the construction period and a second corrosion barrier should there be failure of the surfacing system. It is found, however, that its presence impairs adhesion. In "pull-off" tests on actual surfacings comparative figures for the adhesion to steel were: zinc spray - 300 lbf/sq. in. (2 N/mm^2); asphalt - 500 lbf/sq. in. (3.3 N/mm^2); epoxy resin - greater than 750 lbf/sq. in. (5.1 N/mm^2). Moresoever, when cracking of the surfacing has occurred and water has penetrated the surfacing, the zinc is sacrificed fairly rapidly, leaving a white corrosion product with low adhesive strength.

5. STRAINS IN DECK UNDER TRAFFIC

It is evident from the results of all the trials carried out hitherto that the failure of thin resin-based surfacings takes the form of cracking over the longitudinal stiffeners. This is a result of the large strains or strain gradients in the deck plate near the stiffeners due to transverse bending under local wheel loads. Measurements of these strains have been attempted under stationary and moving traffic and the main features of the results may be summarised as follows:-

(i) Because strain gauges are $\frac{1}{4}$ in (6 mm) or more in length, they cannot record the peaks of a strain in a stress field with high gradients, e.g. at the toe of a weld. It is, therefore, an average strain which is usually being measured.

(ii) Fig. 7 shows the distribution of transverse strain in the top of the deck plate, at the position of the wheel, due to various wheel loads and configurations. The gauges are located mid-way between transverse diaphragms that were 14 ft (4.3 m) apart. It is apparent that the distribution is sensitive to wheel position and that the strain gradients are high. The highest tensile strains are measured at the position of the connection between stiffener and deck and the highest compressive strains occur over a wider strip mid-way between stiffeners.

(iii) If the transverse strain at the position of the deck/stiffener connection, mid-way between transverse diaphragms, is plotted as an influence line against the longitudinal position of the wheel, the change in strain for three different tracks of the same twin-tyred wheel is shown in Fig. 8. In this case, the strain is measured under the deck plate so that compared with Fig. 7, strains for corresponding wheel positions will be reversed. It is found that for transverse bending, the neutral axis lies horizontally, near the mid depth of the plate. As the wheel crosses the transverse diaphragm in the direction of the gauge point, it causes a tensile stress followed by a short peak of compressive stress, when the wheel is at the gauge point, and a return to tensile stress. This pattern reflects the superposition of the longitudinal bending effects of the deck on the local transverse bending of the plate. The ratio of peak tension to peak compression varies markedly with the transverse position of the vehicle wheel tracks with respect to the strain gauge and also with the effective loaded area of the wheel. A dynamic test of a surfacing on a deck plate which does not take account of the change from tension to compression does not simulate conditions prevailing under traffic.

(iv) The effect of resin surfacings, $\frac{3}{8}$ in (9.5 mm) thick and less, on the spreading of the load to the deck plate is negligible. Also their contribution to the strength of the deck in transverse bending is very small.

6. ACKNOWLEDGEMENTS

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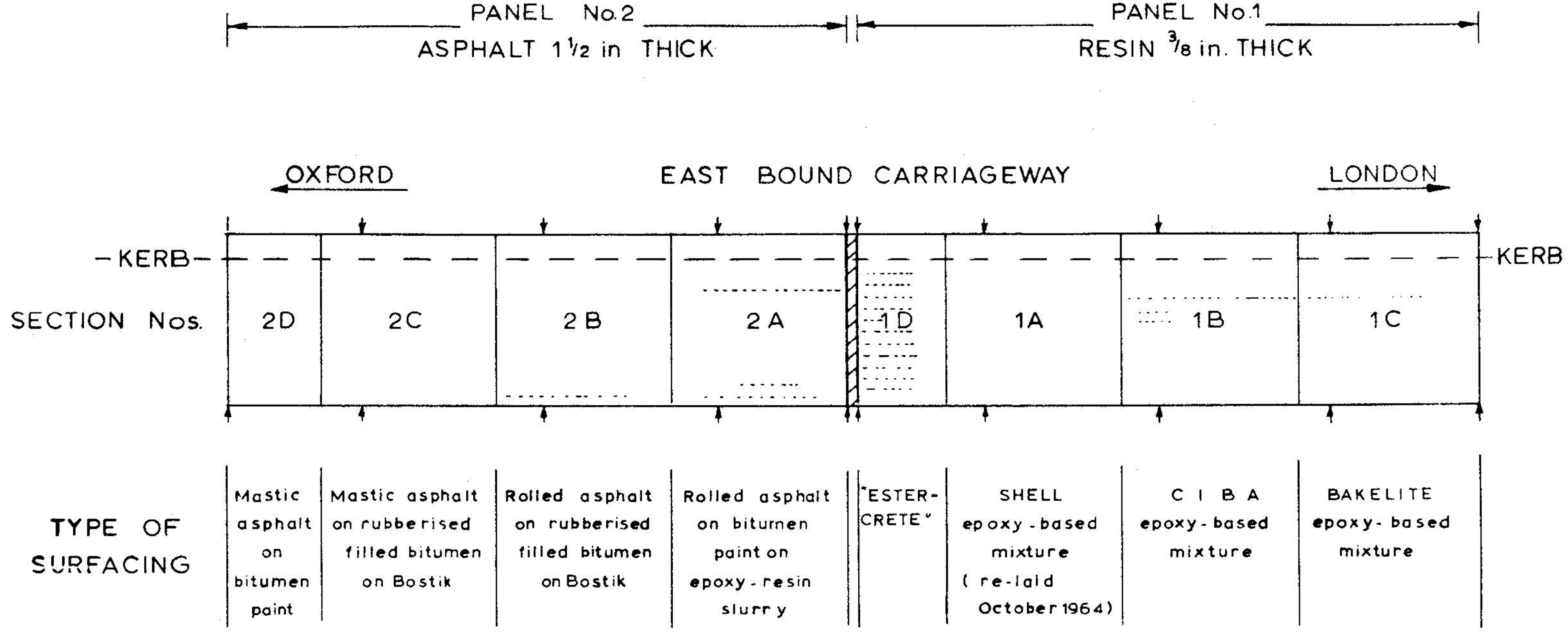
FIG. 1 HEXAGONAL GRID 1 in (25 mm) DEEP, ON AN ALUMINIUM DECK OF A BASCULE BRIDGE IN HULL.



NOTE: The small arrows show position of the transverse stiffener.
The cracks visible in the surfacings in April 1965 are shown thus.........

Fig. 2 LAY-OUT DIAGRAM. SEVERN BRIDGE TEST PANELS ON TRUNK ROAD A40 (WESTERN AVENUE), DENHAM, BUCKS., NOVEMBER 1963.

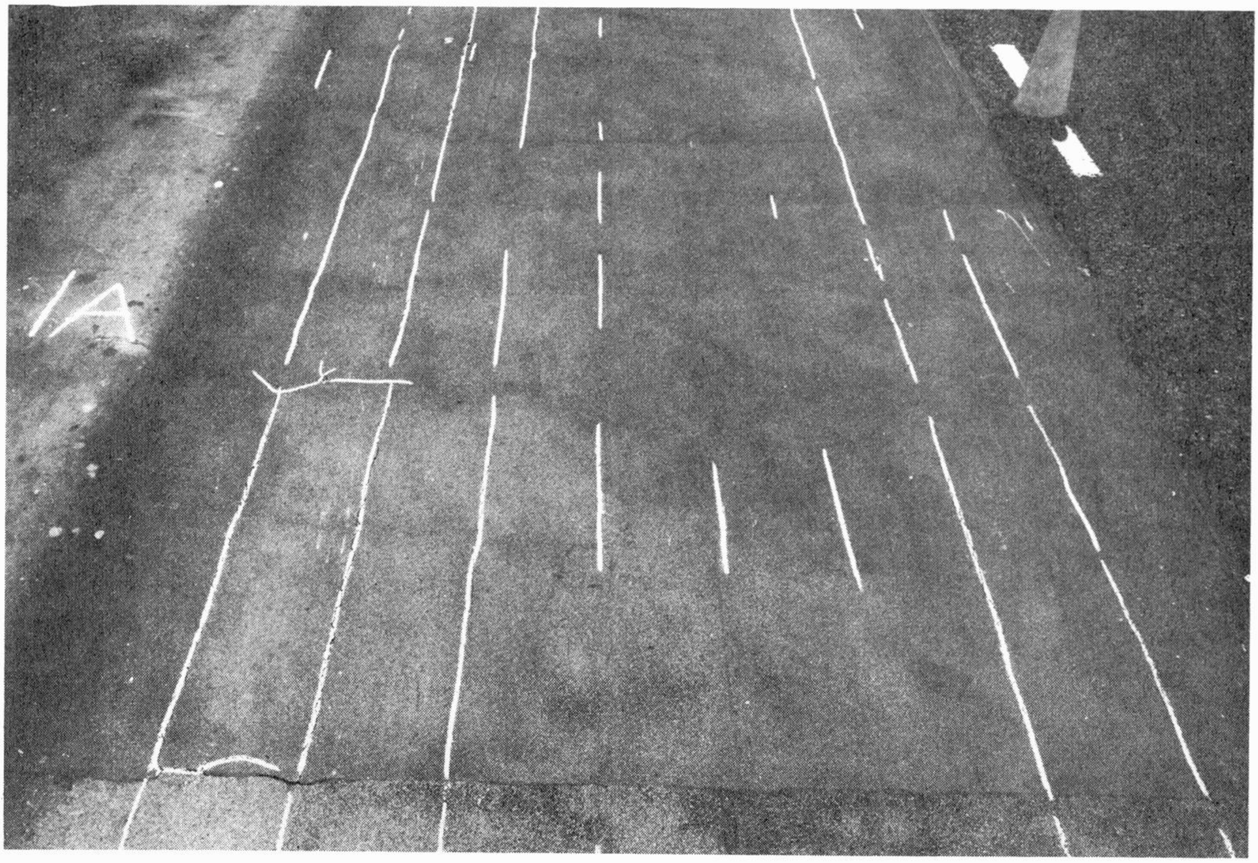


FIG. 3 CRACKING IN EPOXY RESIN SURFACING ON SECTION 1A, NOVEMBER, 1967

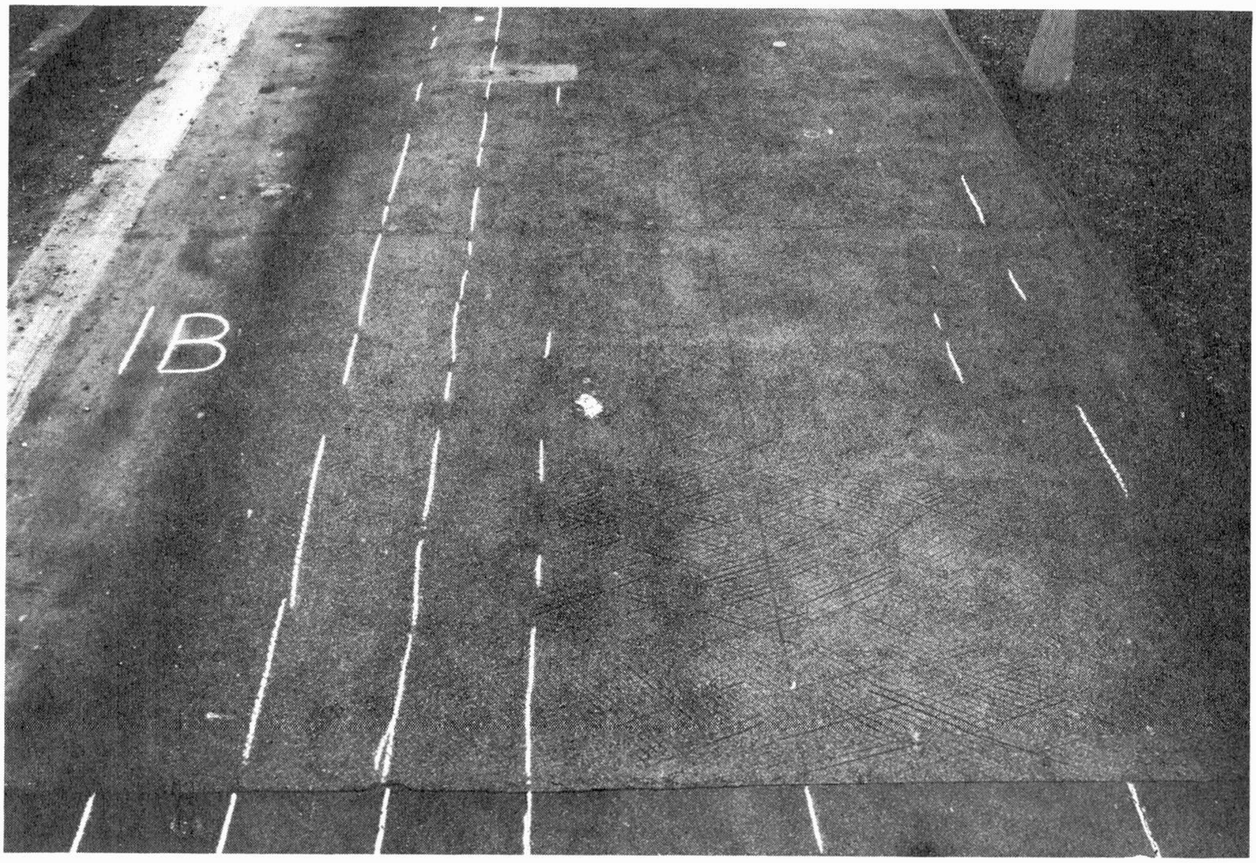


FIG. 4. CRACKING IN EPOXY RESIN SURFACING ON SECTION 1B, NOVEMBER, 1967

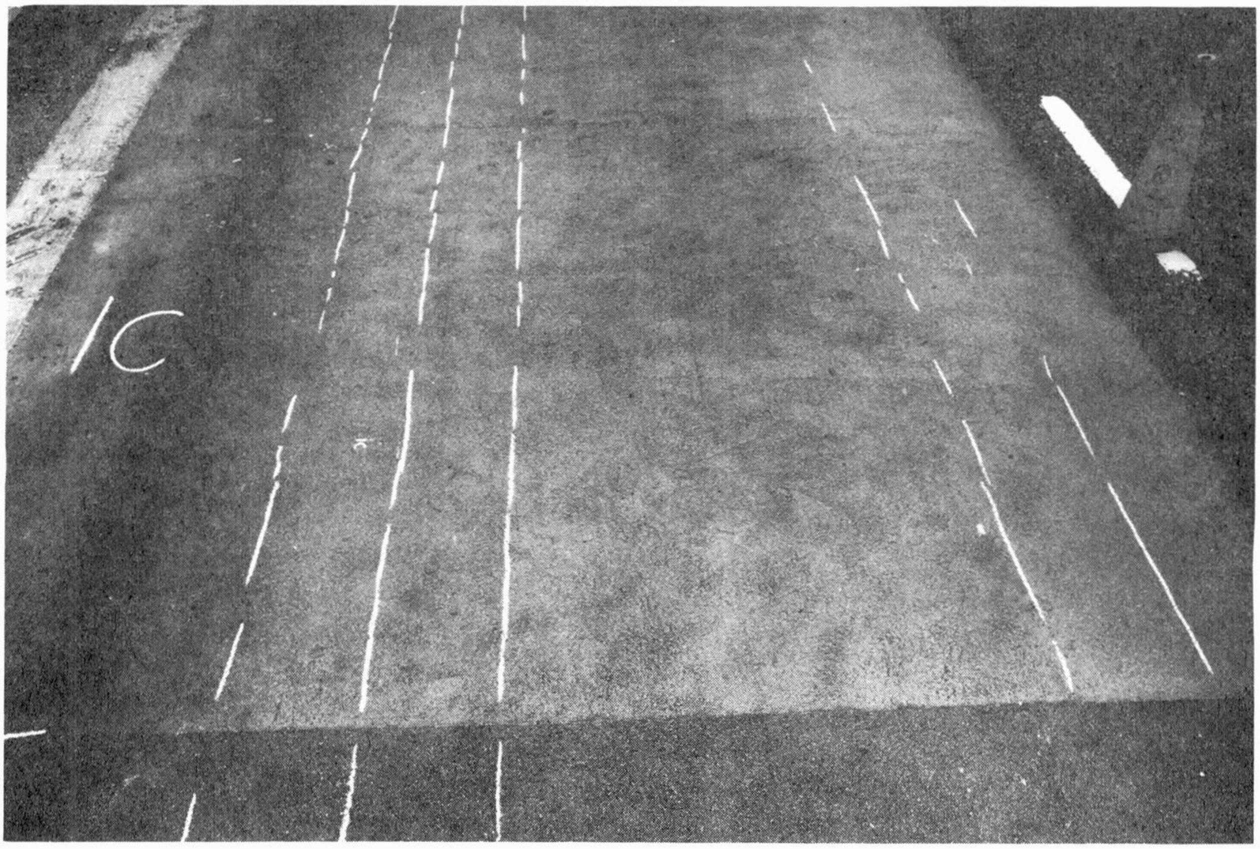


FIG. 5 CRACKING IN EPOXY RESIN SURFACING ON SECTION 1C, NOVEMBER, 1967

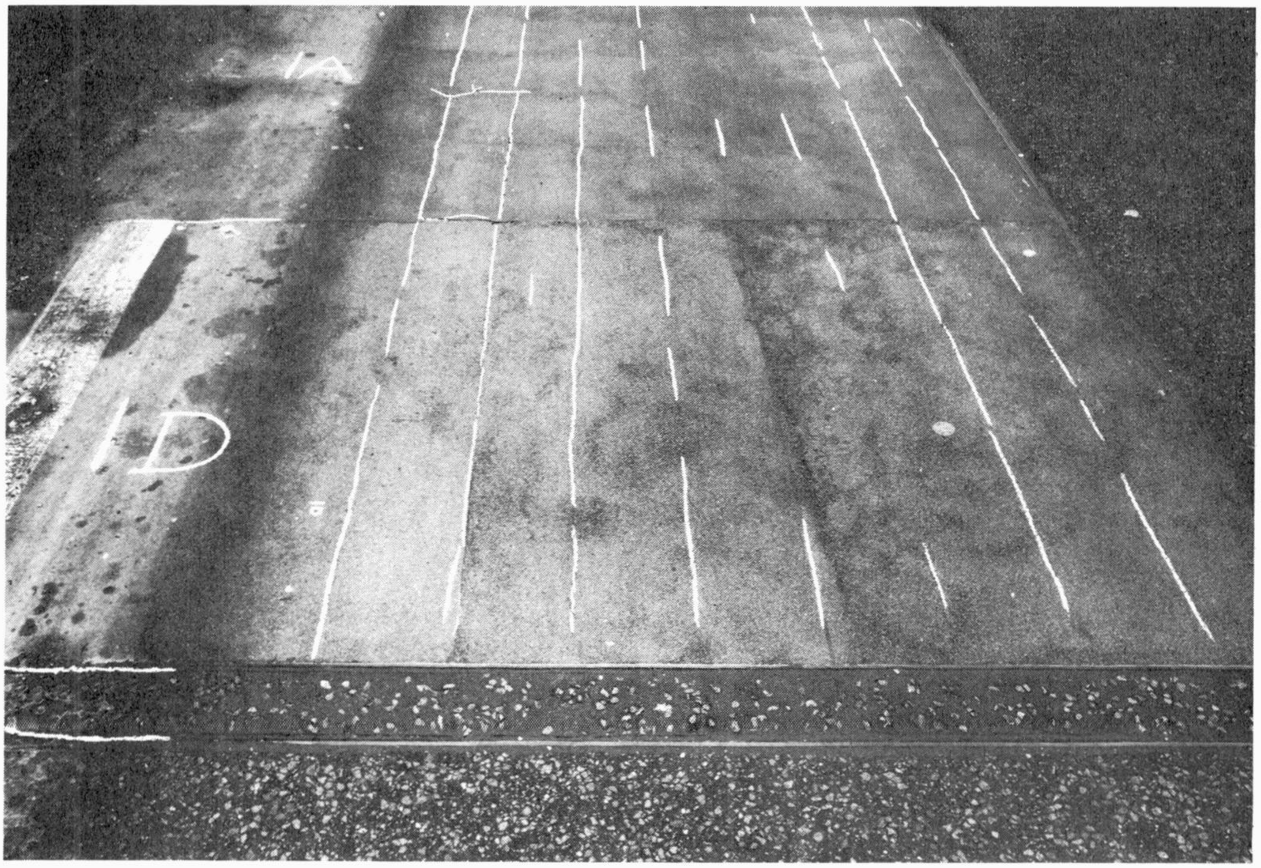


FIG. 6 CRACKING IN "ESTERCRETE" SURFACING ON SECTION 1D, NOVEMBER, 1967

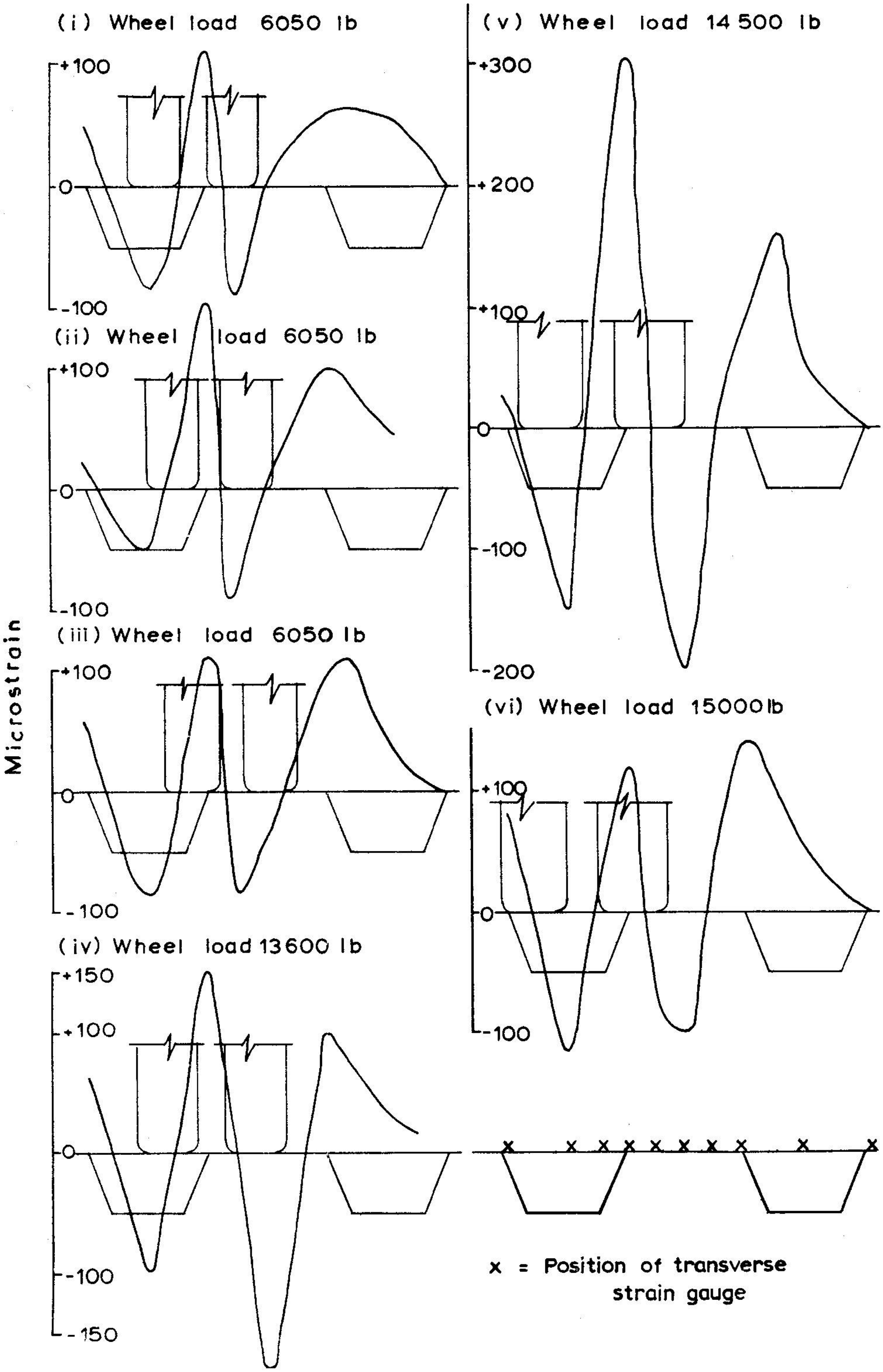


Fig. 7 DISTRIBUTION OF TRANSVERSE STRAINS IN THE DECK PLATE UNDER WHEEL LOADING SHOWING THE POSITION OF THE WHEELS RELATIVE TO THE DECK STIFFENERS

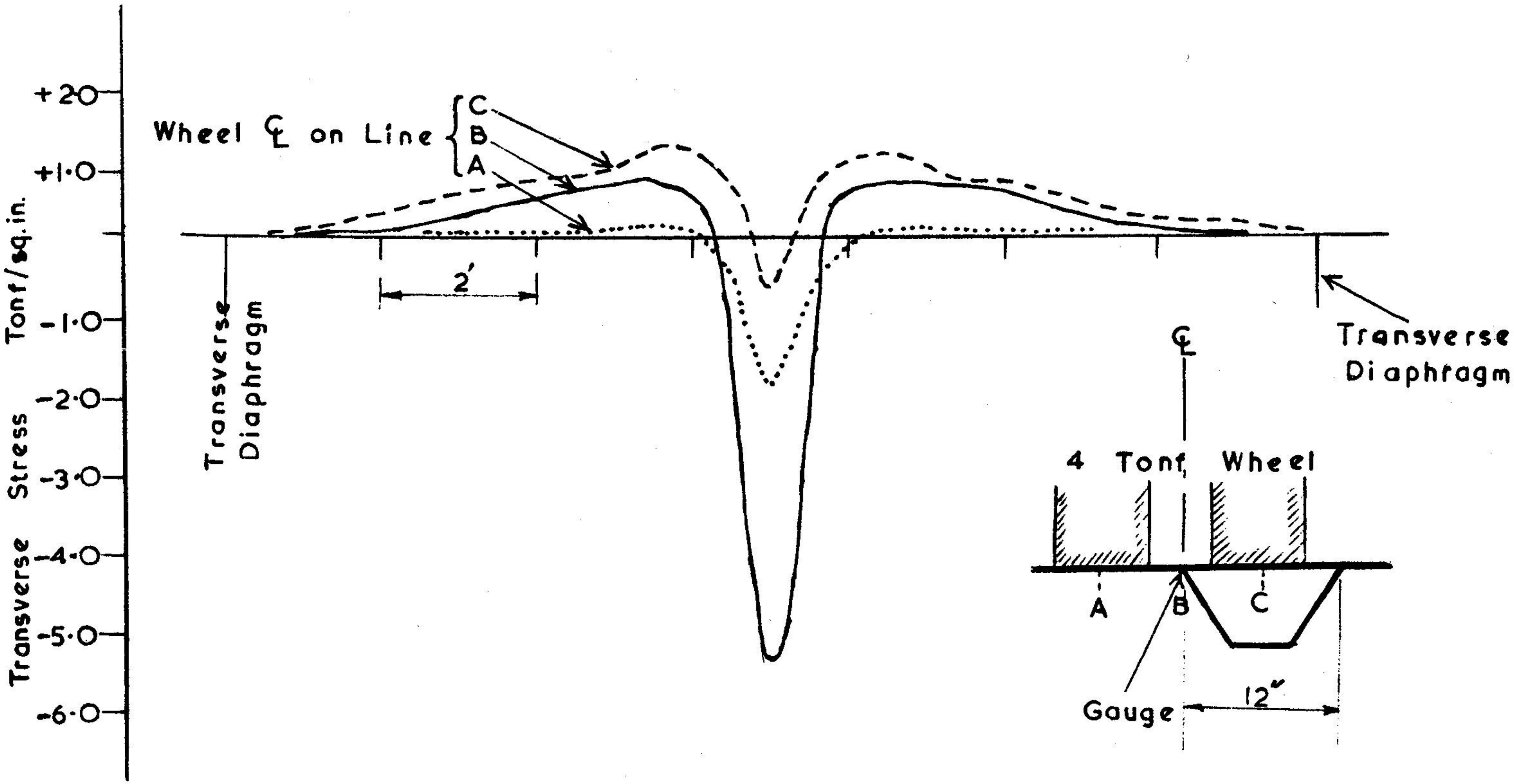


FIG. 8 TRANSVERSE STRESSES IN A DECK PANEL AT THE STIFFENER CONNECTION

SUMMARY

The experience in Great Britain with the performance of thin surfacings on bridge decks and on experimental panels is described in general terms. Thin bituminous surfacings are found to be suitable only on lightly trafficked bridges and on footpaths and cycle tracks. Neoprene or Rubber-latex/portland cement mixtures have tended to be lacking in waterproofing quality and have hitherto been less satisfactory than surfacings based on thermosetting resins. Epoxy resin surfacings have been used with moderate success on the stiffer decks and there are examples of such materials performing satisfactorily on temporary flyovers. On the more flexible decks, resin-based surfacings tend to crack over the deck stiffeners, and are likely to be less durable than mastic asphalt, 1 1/2 in (38 mm) thick.

RESUME

L'article décrit en grandes lignes les expériences faites en Grande Bretagne sur le comportement de revêtements minces sur des tabliers de ponts et sur des panneaux modèles. Les revêtements légers en goudron ne sont acceptables que sur des ponts à faible trafic ainsi que sur des voies de piétons ou de cyclistes. Des mélanges de ciment de Portland avec du néoprène ou du caoutchouc-latex ont tendance à laisser passer l'eau et ont donné jusqu'ici moins de satisfaction que les revêtements à base de résines thermoplastiques. Les résines d'époxy ont été utilisées avec un succès modéré sur les tabliers rigides, et il existe des cas où de tels revêtements donnent satisfaction sur des viaducs temporaires. Sur les tabliers plus flexibles, les revêtements à base d'époxy ont tendance de fissurer au-dessus des raidisseurs, et sont probablement moins durables que l'asphalte coulé, d'une épaisseur de 38 mm.

ZUSAMMENFASSUNG

In allgemeinen Zügen wird die Erfahrung über das Verhalten dünner Beläge in Großbritannien auf Brückendecken oder experimentellen Platten beschrieben. Geeignete dünne, bituminöse Beläge sind für leicht befahrene Brücken, Gehwege und Radstreifen gefunden worden. Neopren oder Gummi-Latex/Portland-Zement-Mischungen neigten zu einem Mangel an Wasserdichtigkeit und sind bisher weniger zufriedenstellend denn thermoplastischer Harz. Epoxyd-Harz-Beläge sind mit unterschiedlichem Erfolg auf steifen Decken gebraucht worden und Beispiele solcher Stoffe erfüllten auf provisorischen Überführungen befriedigend ihren Zweck. Auf biegsameren Decken neigen Beläge auf Harzgrundlage zu Rissen über den Plattenaussteifungen und sind weniger dauerhaft denn 38 mm dicker Gußasphalt.