Introductory report

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INTRODUCTORY REPORT

Rapport introductif

Einführungsbericht

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1. The Orthotropic Plate

Attributing to every structural member an exactly defined function was a common rule during the classical days of bridge building, resulting in plain statical conditions, easily grasped by simple manual methods of computation.

Although the advantages of highly statically undeterminate systems had been known for a long time, a broad application of those systems was blocked at first by the tremendous expenses involved in their solution. In bridge building, the introduction of beam grids may be considered the first effort to achieve a more economical design of bridge decks.

The rapid progress made in pre-stressed concrete constructional methods about 20 years ago led to a reallocation of competive limitations between concrete and steel. That means, in terms of bridge building, the pre-stressed concrete is used for longer spans, previously reserved for steel structures. In order to stop these recession of structural steel in comparison to pre-stressed concrete, the development of new designs was necessary and, therefore, steel construction engineers were compelled to think entirely differently in terms of structural designing. This development was contributed to extensively in Germany by the limited production of steel, which lasted several years after World War II. It is not surprising, therefore, that, particularly in Germany efforts concerned with new solutions for steel bridge construction led to the production of a light-weight deck, called "orthotropic plate", an abbreviation for a rectangular (or ortho-gonal) shaped, anisotropical plate. At the same time the calculation of highly statically indeterminate systems, practically insolvable by usual manual methods, became possible by the introduction of electronics.

Except during the first years of development the design of steel bridges using the orthotropic plate has altered only to a small extent. Their structural development was brought to a speedy preliminary conclusion with the following determinations:

1. The steel plate should be 10, 12 or 14 mm thick (3/8", 1/2" or 9/16" appr.), the mean value being normal.
2. Normally, the stiffening ribs are spaced at 30 cm = 1 ft centers.
3. To date, the distance of beams is 1,5 m to 3,0 m = 5 to 10 ft. There is a tendency, however, to increase the distance so that the use of orthotropic plate is more economical.
4. At first, mainly flat steel bars and, preferably, bulbs were used for stiffening ribs, and in a few cases angles; later on the closed sections have been preferred increasingly, namely trapeziodals, V-, Y- and, more rarely, half circle-shaped sections. The torsional rigidity of closed sections considerably reduces the deflections of the steel plates, resulting in lower stress of the surfacing.

5. In any case, plate joints are made by welding, because early experience had already demonstrated that a surfacing, permanently stable and crack-resistant but limited in thickness, cannot by used as long as there are doubler plates and rivet heads in the relevant area.

2. Problems Arising

For about two decennia endeavours have been continuing in Germany to find out the most suitable surfacing for orthotropic steel plates as described above. There is a long way to go. In every case progress is to be expected only by long-term observations of the pavements already applied on bridges. Parallel to these, extensive laboratory tests have to be undertaken continously, aimed at an adequate explanation of the observed facts on the one hand and suitable to determine the next steps to clarify the problem on the other.

During recent years several countries have started construction of steel bridges using orthotropic plates:

United Kingdom : New Forth and Severn Bridges;
Switzerland : St. Albans's Bridge in Basle;
Austria : Europe Bridge near Innsbruck;
Hungary : Elizabeth Bridge over the Danube in Budapest;
USA : Poplar Street Bridge in St. Louis, Miss., spanning the Mississippi River;
San-Mateo-Hayward Bridge, San Francisco, Bay Toll Crossings, California;
Canada : Port Mann Bridge in Vancouver;
India : Jamuna River Bridge near Delhi

and several others.

For the time being, orthotropic steel plates have been used mainly on movable bridges, e.g. in Sweden, Denmark, the Netherlands and in USSR. I believe, however, that the problems to be mentioned here are already very well known to the experts concerned. Furthermore, publications dealing with wearing surfaces on orthotropic steel plates have already been used in several countries.

I may limit myself, therefore, to a brief enumeration of requirements the asphaltic wearing surfaces on steel decks - exclusively dealt with in Thema I - should fullfill in respect of durability, economy and traffic security.

Most important are:

Surface smoothness (smooth riding),
Skid resistance,
Wear resistance,
Ready and foolproof application by mechanical equipment,
Reliable protection of the steel plate against corrosion,
Stable at permanently high temperatures,
High cracking resistance at sudden drops of and low temperatures,
Good bonding to steel.

3. Existing Wearing Surfaces

In Germany many different wearing surfaces have been tried out since installation of the first orthotropic plate. Generally, all of them consist of several courses or layers, each of which fullfills a special function, except the so called "splittverfestigte Mastix-Decke" (Stabilized Mastix or Stone Filled Mastic Asphalt System). There has been a lively competition in proposing new compositions for asphaltic wearing surfaces - proposals being made by authorities concerned with the planning of forthcoming bridges and by numerous steel bridge and road construction firms as well as by the asphalt industry. Leaving aside any qualifying remarks the following tables show all of the surfacings applied up to day in Germany.

No.	anchoring device	bonding compound or bond coating	bonding layer or insulation	lower course (levelling course)	upper course (wearing course)
1	- - -	Okta-Haftmasse[@]	Mastix [@] 8 - 10 mm	mastic asphalt appr. 2,5 cm	mastic asphalt appr. 2,5 cm
2	- - -	Okta-Haftmasse	Mastix 10 mm	mastic asphalt 3 cm	fine aggregate asphalt concrete 2,5 cm
3	- - -	Okta-Haftmasse	Mastix 8 - 10 mm	Binder [@] 3 cm	mastic asphalt appr. 3 cm
4	- - -	Okta-Haftmasse	Mastix 8 - 10 mm with Pulvatex	Binder 2,5 cm	mastic asphalt 3 cm
5	- - -	Okta-Haftmasse	Mastix	stone-filled Mastix 2 - 2,5 cm	asphalt concrete 3 - 4 cm
6	- - -	Okta-Haftmasse	Okta-Mastix	"VABIT" Binder	fine aggregate asphalt concrete "VABIT"
7	- - -	Okta-Haftmasse	aluminum foil	mastic asphalt appr. 3 cm	mastic asphalt appr. 3 cm
8	- - -	Okta-Haftmasse on cold applied zinc paint	- - -	mastic asphalt appr. 3 cm	mastic asphalt appr. 3 cm
9	- - -	Okta-Haftmasse on hot sprayed zinc coating	Mastix 8 - 10 mm	binder course 2,5 cm	mastic asphalt 2,5 cm
10	- - -	Okta-Haftmasse on hot sprayed zinc coating	Mastix 8 - 10 mm	mastic asphalt 2,5 cm	mastic asphalt 2,5 cm
11	- - -	Okta-Haftmasse on hot sprayd zinc coating	- - -	mastic asphalt 2,5 cm	mastic asphalt 2,5 cm

[@] See remark on page 9

No.	anchoring device	bonding compound or bond coating	bonding layer or insulation	lower course (levelling course)	upper course (wearing course)
12	- - -	Okta-Haftmasse	- - -	stone-filled Mastix 4 cm in two layers	fine aggregate asphalt concrete 2,5 cm
13	zig-zag-bars	Okta-Haftmasse	- - -	stone-filled Mastix 4 cm in two layers	fine aggregate asphalt concrete 2,5 cm
14	zig-zag-bars	Okta-Haftmasse	- - -	stone-filled Mastix with Okta-additive	
15	- - -	cold applied bitumen coating	- - -	mastic asphalt 2 cm	mastic asphalt 2,5 cm
16	- - -	cold applied bitumen coating	- - -	mastic aspahlt 2 cm	mastic asphalt 2 cm
17	- - -	cold applied bitumen coating	aluminum foil	mastic asphalt 2,3 cm	mastic asphalt 2,7 cm
18	- - -	cold applied bitumen coating	copper foil	mastic asphalt 3,5 cm with Pulvatex	mastic asphalt 3,5 cm with Pulvatex
19	- - -	cold applied bitumen coating	Mastix 10 mm	mastic asphalt 2 - 3 cm	mastic asphalt 2 - 3 cm
20	with and without reinforcing steel fabric	cold applied bitumen coating	Mastix 10 mm	Binder 2 - 3 cm	mastic asphalt 3 cm

No.	anchoring device	bonding compound or bond coating	bonding layer or insulation	lower course (levelling course)	upper course (wearing course)
21	reinforcing steel fabric	hot applied bitumen	Mastix	mastic asphalt 3 cm	mastic asphalt 2 cm
22	- - -	"Proderit"-varnish	Mastix	mastic asphalt 2 cm	mastic asphalt 2,5 cm
23	- - -	"Proderit"-varnish	aluminum foil	mastic asphalt 2 - 3 cm	mastic asphalt 2,5 cm
24	- - -	"Proderit"-varnish	Mastix with Pulvatex	Binder 1,5 - 3 cm	mastic asphalt 2,5 cm
25	- - -	"Colzumix"-painting	Mastix 8 - 10 mm	mastic asphalt 2,5 cm	mastic asphalt 2,5 cm
26	- - -	"Colzumix"-painting	Mastix 8 - 10 mm	Binder 2,5 cm	mastic asphalt 3 - 3,5 cm
27	- - -	"Colzumix"-painting	Mastix 8 - 10 mm	Mastix 2 cm	asphalt concrete 2,5 cm
28	- - -	"Möllerit"-resin	hot applied bitumen	Binder 3 cm	mastic asphalt 3 cm
29	- - -	"Möllerit"-resin	- - -	mastic asphalt 2,5 cm	mastic asphalt 2,5 cm

No.	anchoring device	bonding compound or bond coating	bonding layer or insulation	lower course (levelling course)	upper course (wearing course)
30	- - -	"Vedag"proprietory cement	aluminum foil	mastic asphalt 2,5 cm	mastic asphalt 2,5 cm
31	- - -	2 x zinc-powder painting	"Pulvatex"-grouting	Binder 3 cm	mastic asphalt 3 cm
32	- - -	2 x Zinkplast-painting	Mastix 10 mm	Binder 3 cm	mastic asphalt 3 cm
33	zig-zag-bars	Okta-Haftmasse	- - -	mastic asphalt 3 cm with Pulvatex	fine aggregate asphalt concrete 2 cm with Pulvatex
34	zig-zag-bars	"Isotex" bonding primer	"Isotex"-insulation	mastic asphalt 3 cm	fine aggregate asphalt concrete 2 cm with Pulvatex
35	- - -	"Sempex" 1 mm	- - -	mastic asphalt 3,5 cm	mastic asphalt 3,5 cm
36	- - -	2 x red load paint	impregnated felt	mastic asphalt 3 cm	"Non-Skid" 2,5 cm

No.	anchoring device	bonding compound or bond coating	bonding layer or insulation	lower course (levelling course)	upper course (wearing course)
37	- - -	2 x bituminous Latex	- - -	mastic asphalt 3,0 cm	" Non-Skid " 2,5 cm
38	- - -	plastic bonding cement applied in two layers	tar-epoxy-resin	7 cm " VABIT " -(proprietory surfacing)	
39	- - -	epoxy-resin mortar	- - -	mastic asphalt 3 cm	mastic asphalt 3,5 cm

@ <u>Remark</u>

In cases, where there is no exact English equivalent for a German technical term, the word is capitalized to distinguish it as a special term.
cf. F. F. Fondriest and M. J. Snyder, "Research on and Paving Practice .....", 1966, Battelle Memorial Institute, p. 3 and A-1 / A-2.

It may be pointed out only that "Okta-Haftmasse" (a proprietary bonding compound or adhesive) has been used most frequently; that the insulating layer consisted of Mastix in most cases; and that "Gußasphalt" (mastic asphalt) was chosen predominantly for both layers of the actual surfacing.

4. Nature of Damage and its Causes

Blistering, cracking, shoving and rutting are damages most frequently observed in the course of the years.

Defects found more rarely are inter alia wet spots on the top surface, increase in joint width and breaking-off of the surfacing behind transverse bars. In detail the following may be said:

Blistering

Blistering is caused by small amounts of air entrapped underneath the surface during application, or is due to development of water vapor or gases. When heated, the small amounts of air or gas expand, forcing the surface to warp, not noticeably in the beginning. Subsequent cooling causes a vacuum in water-vapor traps, and a partial vacuum in areas with entrapped air or gases. As a consequence, more water vapor, air or gases are drawn in from the surrounding area. When the surfacing becomes heated again, it is forced farther up until, eventually, visible blisters are formed by this "pumping action". (See figure 1). However, on traffic lanes, such blisters are pressed down again by the live load so as to cause circular cracks. (See figure 2). Then, penetrating water will gradually detoriate the surfacing.

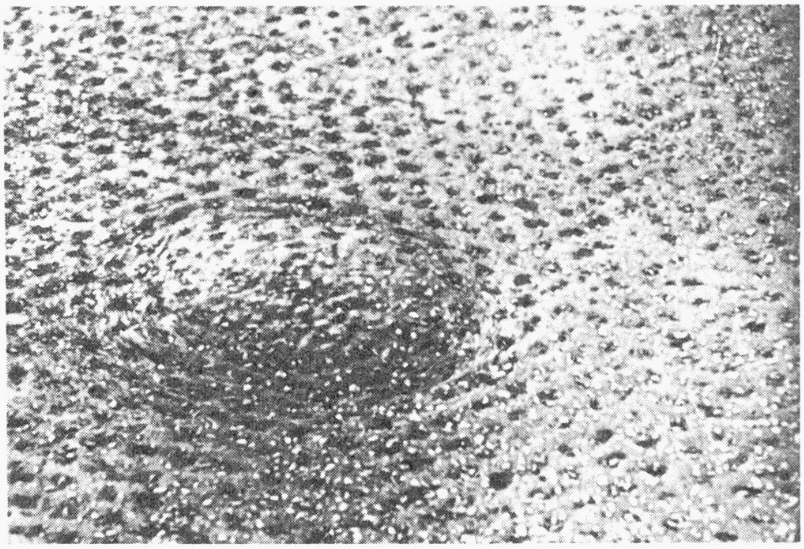


Figure 1: Increasing blister

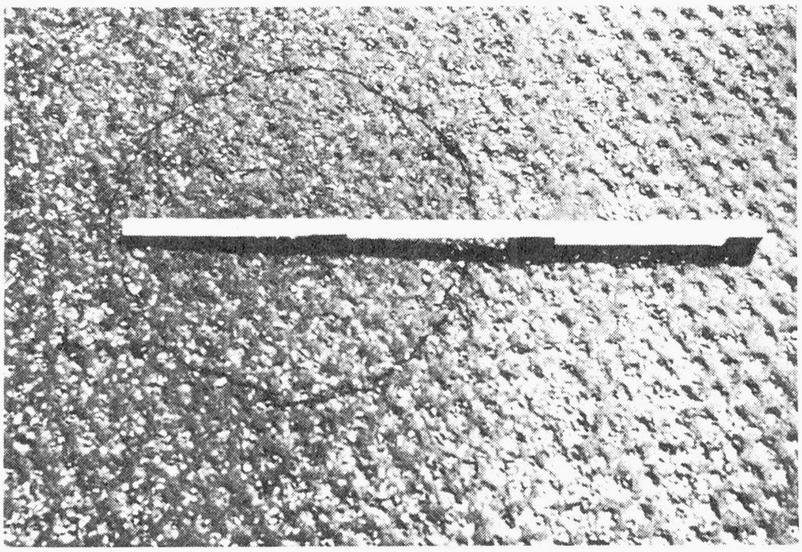


Figure 2: Crack caused by blistering; 35 cm dia.

Development of water vapor is to be expected, when there is moisture in the lower courses of the surfacing, e.g. when these are applied in damp air or on steel plates not fully dried after rainfall.

In this respect separators of paper or bituminized felt have a very adverse effect, since they prevent escape of entrapped moisture.

The danger of entrapping air, when separators are used, can be avoided by very careful application only.

Cold-applied zinc-paints may cause blistering as well. They contain resin binders, the volatile solvents of which have not entirely escaped when subsequent layers of the surfacing are applied. Furthermore resin binders do not resist to the high temperatures (up to 240°C = 464°F) of mastic asphalt.

Penetration of water occuring later may cause blistering too. This has frequently been observed when, for increased stability of the pavement, a binder course had been applied under an unpermeable wearing course of mastic asphalt. Rain-water, penetrating through unsealed edges or other damages of the surface course may easily spread out in the cavities in the binder course, particularly on sloping steel decks. The water will either emerge at a lower place or will cause blistering here and there when infiltrated into the binder course.

Cracking

There may be a certain relationship between cracking and the thickness of an orthotropic plate together with the spacing of its stiffeners.

However, the consistency of the bitumen used and its percentage in the mixture are much more important factors. As this had not sufficiently known, when the early surfacings were being applied, relevant records have not been drawn up, unfortunately, in many cases. For accurate statements, it is necessary, therefore, to obtain the desired information by making subsequent analyses.

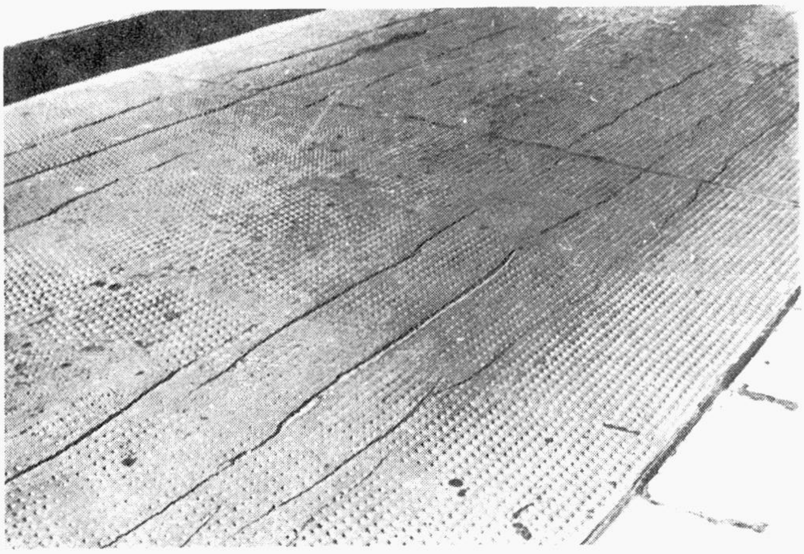


Figure 3: Longitudinal cracking, spaced like the stiffeners

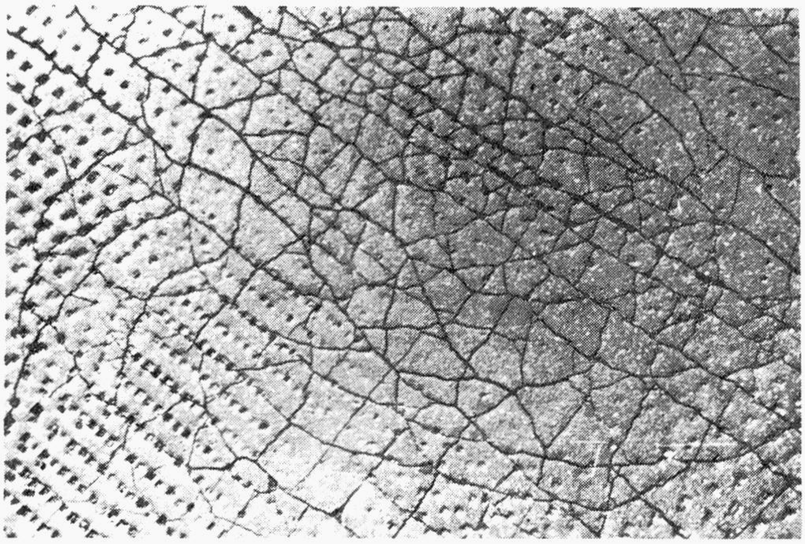


Figure 4: Small-gridded crack area

In most cases, the cracks are in parallel with the stiffeners, both at the top and in between. However, random cracks are not rare; they spread out to a great extent to form distinct crack areas. A destructed binder course, provided for increased stability underneath the mastic asphalt wearing course, has in several cases been determined as the cause of such cracking. (see figures 3, 4 and 5).

Penetrated water if, due to lack of slope, it stays within the binder course, may become aggressive by de-icing agents, and strip the bitumen coating from the mineral aggregates, the latter then being crushed by the live load. Eventually, due to lack of support the mastic asphalt course breaks in.

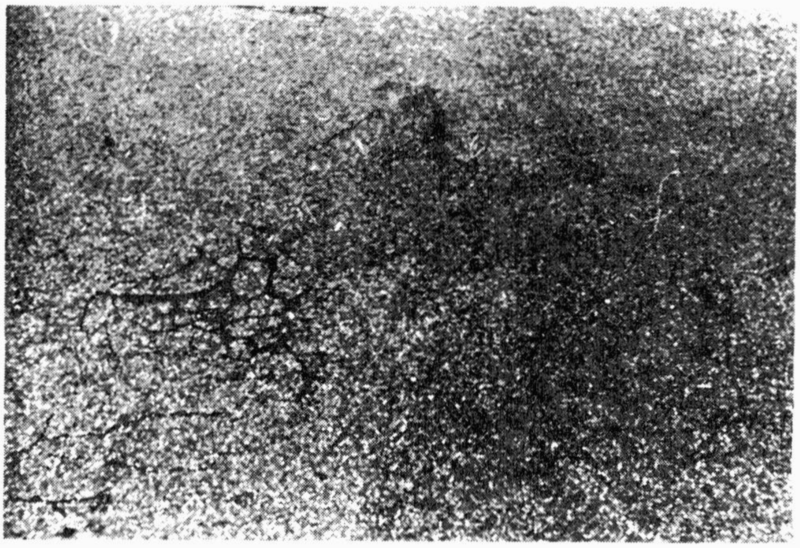


Figure 5: Places broken in over destructed binder course

Rutting

Rutting is a frequent problem, caused at high temperatures by a bitumen content either too rich or too soft. Ruts may be spaced regularly corresponding to the longitudinal stiffeners. See figure 6.

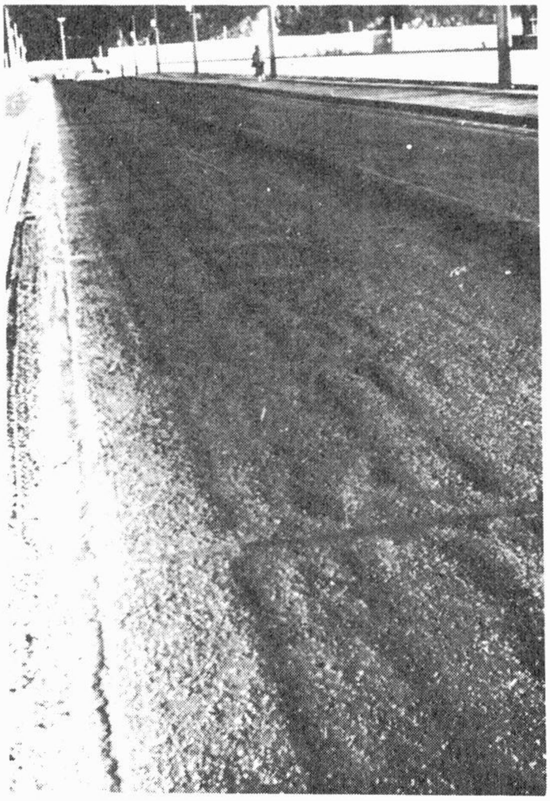


Figure 6: Rutting (transverse waving)

The surfacing may, however, have become so soft that, due to traffic, lateral shoving occours over long distances forming wide ruts superimposed on the aforementioned undulations, spaced like the stiffeners. See figure 7.

Shoving

Shoving, i.e. fulling or waving across the axis, occurs less frequently. Reasons are: faulty composition of the mixture, unsuitable grading of mineral aggregates and a content of bitumen, which is either too rich or too soft. Anchoring devices on steeper longitudinal slopes, made up of flat or angle sections and welded across the steel plate at long distances, increase the number of shovings and cause the surfacing, simultanously, to break loose behind of the anchorings in most cases. See figure 8. and 9.

Figure 7: Big-sized shoving,
up to 7 cm deep

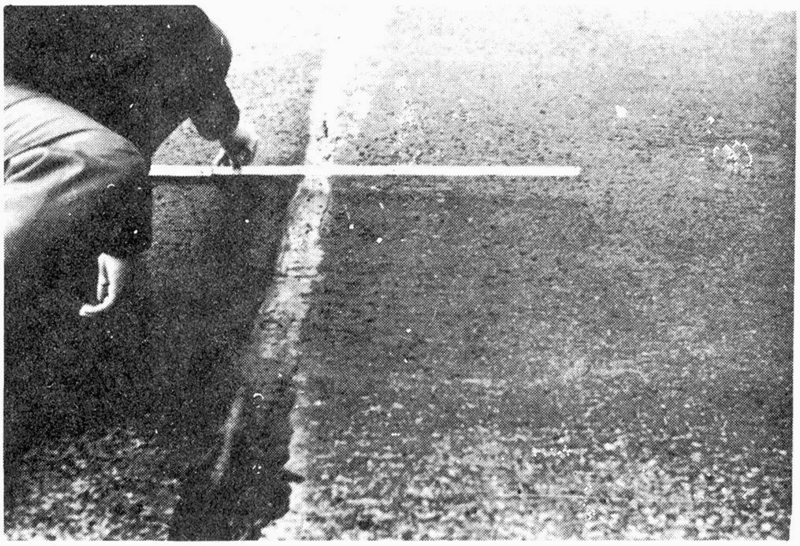


Figure 8: Transverse shoving
up to 4 cm high
ahead of anchor bars

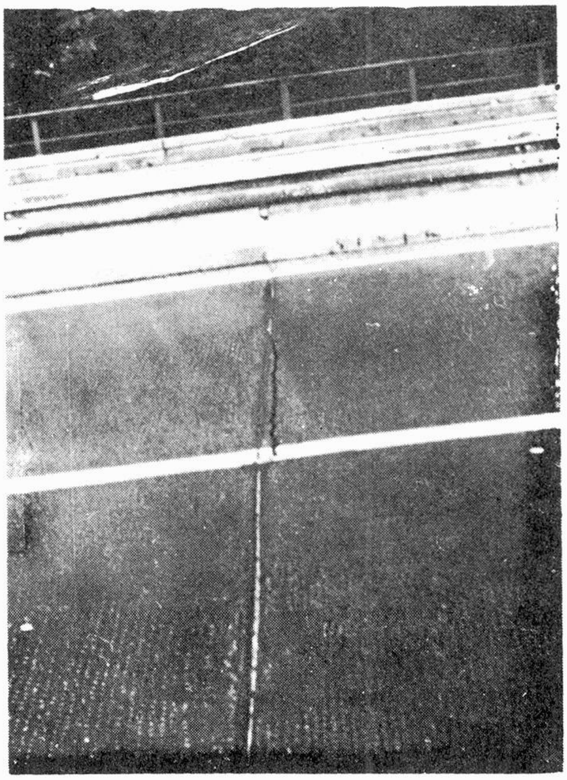


Figure 9: Transverse cracking behind steel anchor bar with joint on top

Even shoving and flowing of big areas has been observed on the top surface. See figure 10.

It may also be mentioned here that surfacings with a rubber-powder-additive contained in the bituminous binder sometimes have been found broken off its lateral supports.

Surfacings using a rubber-powder-additive have been proved to increase the tensile strength of the asphalt. On the other hand our observations have clearly shown that such surfacings tend to shove. We, therefore, believe that there is a connection between the a.m. properties and wide joints:

See figure 11.

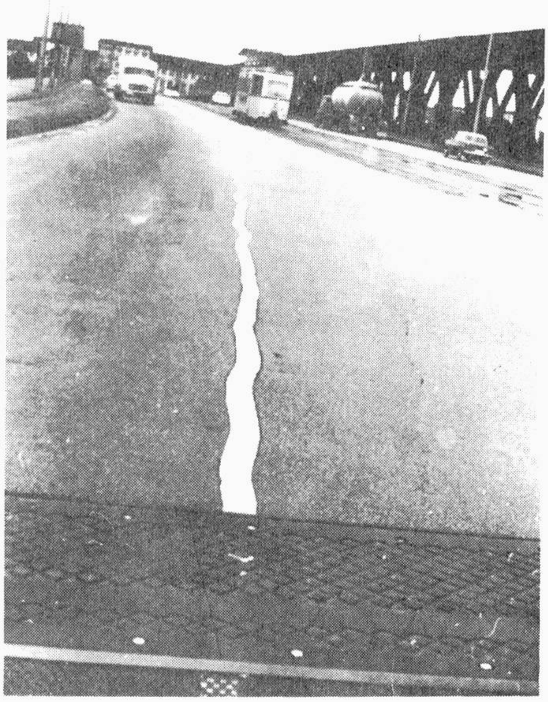


Figure 10: Shoving visible from deformed marking strip

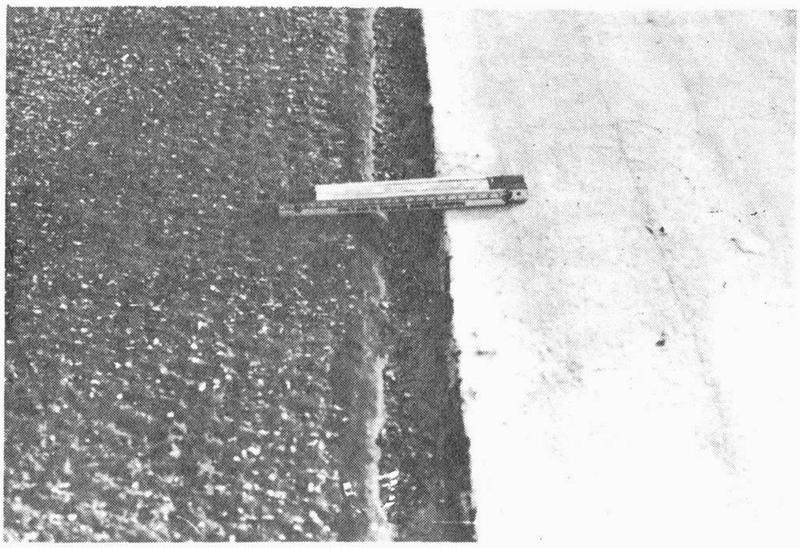


Figure 11: Enlarged joint (8 cm) at longitudinal connection

Across the axis the asphalt will not be prevented from contracting. Hair cracks will be excluded by its increased viscosity and the low stability will not hamper contraction. Warming up the surfacings will not bring back the particles to their original positions but, due to the increased tendency to yielding, the particles will shove away, i.e. upwards.

Wet Spots on Surfacing Top

Wet spots remaining on the surface some time after the last rainfall indicate that some big amounts of moisture have penetrated into the surfacing due to an improperly sealed wearing course. See figure 12. This has been noted on surfacings using a top layer of asphaltic concrete for better skid resistance. A content of de-icing agents will increase the danger of deterioration brought about by penetrated water. However, most of the bridges observed

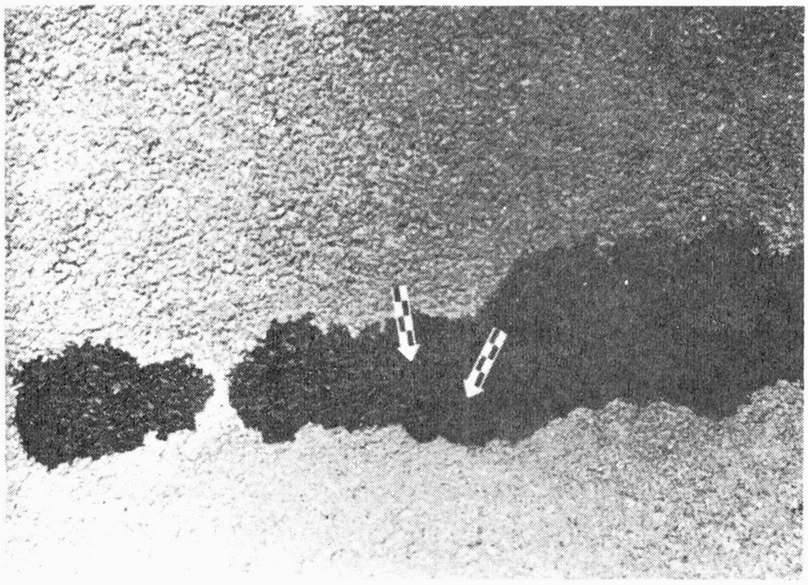


Figure 12: Wet area and visible holes (see arrows !)

have been opened to traffic only for short periods of time and are still performing well. It seems too early, therefore, to draw any final conclusion.

Unsatisfactory Bond or Shear Strength

Any surfacing will be destroyed within short time due to insufficient shear strength or bond. It has been tried, therefore, to dowel the surfacing to the steel plates by mechanical means, e.g. by welding mesh reinforcing steel on studs to the plate. This method has not been successful. Due to different thermal expansions of steel and asphalt square targets in size of the mesh appeared on the top surface, presumably indicating insufficient bond. Small furrows up to 2,5 cm = 1" deep may develop atop of the mesh rods, causing cracks in harder types of asphalt and, eventually, destruction in total. See figure 13.

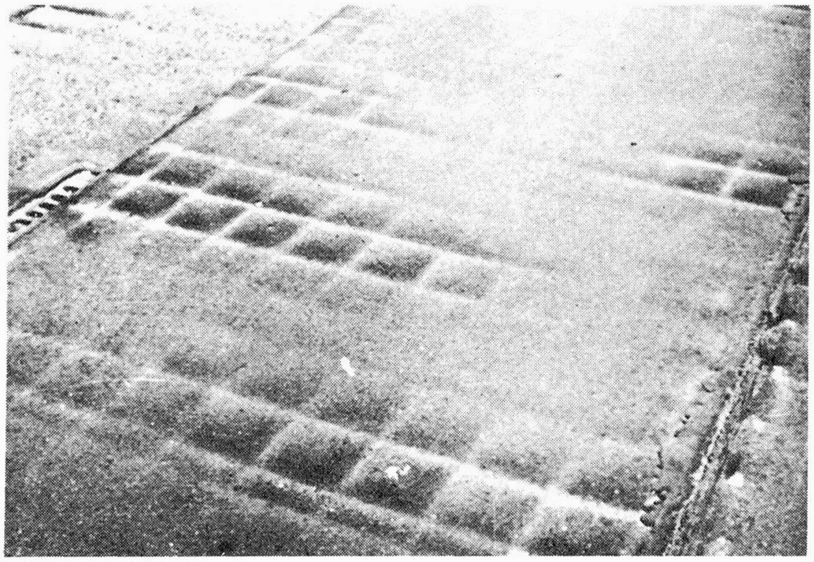


Figure 13: Steel mesh anchoring;
plasterlike top surface

Zig-zag-anchors have performed better. They consist of zig-zag-shaped flat steel bars welded normal to the steel plate at 15 cm = 6" centers by staggered fillet welds. In 1951, the zig-zag-steel bars had been 28 x 6 mm = appr. 1-1/8" x 1/4" in cross section and at 8 cm = 3-1/8" centers on the Düsseldorf/Süd Bridge (Southern Bridge) over the Rhine River. Six years later, on the

Düsseldorf/Nord Bridge (Northern Bridge) the cross section was reduced to 22 mm x 6 mm = 7/8" x 1/4", the spacing being increased to 15 cm = 6". In 1964, the cross section was reduced even more to 17 mm x 5 mm = 11/16" x 3/16" on the Danube-Bridge near Wörth. In this case the zig-zags were welded on flat steel bars 20 mm x 3 mm = appr. 13/16" x 1/8", arranged in flat positions corresponding to the distances of stiffeners. The prefabricated grids were laid on the bridge-plate. On these types of anchoring the stone-filled mastic asphalt surfacing has performed well.

Against these devices it has been objected that spot welding will considerably decrease the fatigue strength of the steel plate. This objection does not stand. The actual stresses are less than the allowable fatigue stresses in any case. Furthermore, relevant tests made on a plate with anchoring flats have demonstrated that such objections are unjustified. However, the stresses produced in the steel plate will be closer to the allowable ones.

There are, however, some good reasons why anchoring bars should not be used in general. It is recognized that the welded-on bars do increase the stability of the surfacing and the stiffeness of the deck plate, but the increased dead weight of the deck should not be neglected completely. Furthermore the structure becomes more expensive. We have arrived at good results even without these anchoring bars, and we believe, therefore, that their use should be limited to a few exceptional cases.

5. Preliminary Laboratory Tests

The first effort to give preliminary guidance has been made by publishing, in 1961, a leaflet entitled

> "Preliminary Specifications for Bituminous Surfacings
> on Light-Weight Steel Bridges"
>
> "Vorläufiges Merkblatt für bituminöse Fahrbahnbeläge
> auf Leichtfahrbahnen im Stahlbrückenbau", Ausgabe 1961,

based on the experiences gathered from surfacings on orthotropic plates in Germany during the first ten years. We had good reasons to call this leaflet a "preliminary" one, because we were well aware that our observations had not resulted in any profunded knowledge of the matter at that time.

Anyhow, one fact came out clearly even then: It is extremly important to get a bonding compound having the following properties: permanent reliable adhesion to the steel plate as well as to the surfacing, and a sufficient sealing capacity. The Federal Road Construction Institute ("Bundesanstalt für Straßenwesen") has been carrying out tests aimed at this goal for about ten years. The chief purpose of these endeavours has been to evaluate, by simple mechanical tests, various bonding compounds and adhesive coatings on a comparable basis and to single out suitable materials for additional tests, both in the laboratory and in the field.

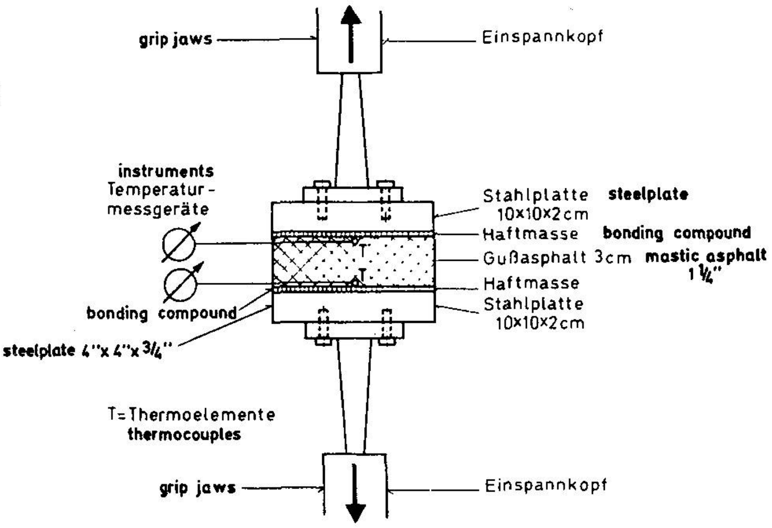
The tests conducted comprise the following:

Bond strength, direct pull normal to plate,
Bond shear strength and
Bond strength and ductility on bending around a mandrel

Figure 14 shows the pull-test schematicly.

Figure 14:

Arrangement for testing of bond strength (direct pull)



About 30 different types of surfacings have been tested. Failure stresses ranged from 15 to 38 kp/cm² = 210 to 540 lbs/sq.in at -10°C = 14°F and from 10 to 35 kp/cm² = 140 to 500 lbs/sq.in at -20°C = -4°F. Great importance has been attached to determinating the level of failure:

between the steel plate and the bonding
compound/bond coat,
within the bonding layer,
between the bonding and the upper courses or
within the upper courses.

Again at -10°C = 14°F and -20°C = 4°F in the second test, a shear failure was brought about between the plate and the pavement by one heavy stroke with a hammer, and the line followed by the crack was recorded, but no strength figures were determined.

For the tests of bending over mandrels, carried out in succession at temperatures of +25°C = 77°F, 0°C = 32°F, -10°C = 14°F and -20°C = -4°F, 1 mm-sheet-metal strips, 3 cm wide, were each coated with bonding compounds/coats and bent through 180° maximum around mandrels of 50, 20, 10 and 5 mm dia = appr. 2", 3/4", 3/8" and 3/16". It was determined at which angle cracks occured and which lines they followed. In some cases the bonding compound broke loose from the sheet-metal strip.

As a result of these tests quite a number of bonding compound/bond coating materials were excluded from further considerations. Ultimate loads (bonding strength on direct pull) and the lines followed by the cracks were voted in particular. A comparison of the part results of these tests showed that the conditions of the bending test over mandrel had been too exacting for bonding compounds. The chief purpose of these tests had been to determine the behavior of the compounds at low temperatures, so they don't disclose anything about stability of the surfacings at high temperatures. And they do not show either that a rapid drop of temperature has more influence on cold-cracking of asphaltic surfacings than the lowest temperature arrived at.

The applied testing methods appear to simulate unsufficiently the conditions prevailing on surfacings under traffic and the results should be judged with some reservations, because nothing but relations are shown between the various bonding compounds tested. However, these tests are offering the advantage of a quick, low-cost preselection among the proposed bonding compounds/bond coatings.

6. Inventory of Asphaltic Surfacings on Bridges

In addition to the laboratory tests a general stock-taking of all important practical applications of the various bonding compounds and pavement-compositions became necessary. From this we expected essential findings, which appeared very important for future dealing with the problem. The inadequacies to be determinated should above all indicate the direction for additional tests wich we have started in the meantime.

Checking of the asphaltic wearing surfaces on 56 orthotropic steel deck bridges started late in 1964. The determined damage has been recorded in each case systematically as well as its supposed causes. Some of these bridges had been completed as early as 1949. Two bridges abroad have also been covered , the "Europa-Brücke" in Austria and the St. Alban's Bridge in Switzerland.

The records were screened twice and two basicly different criteria were applied:

> First, the structural lay-out of orthotropic steel plates used was the basis and the performances of different pavements were checked accordingly.
>
> Second, the pavement itself was in the centre of the studies. Its specification, time of service, traffic conditions and the effects of climate during application, were the chief criteria for its appreciation.

Bridges and pavements to be studied were classified according to the structural lay-out of its deck plates, the thickness of the plate (10, 12 and 14 mm = appr. 3/8", 1/2" and 9/16"), the spacing of the stiffeners ($\lesseqgtr$ 30 cm; $\lesseqgtr$ 1') and the direction of the ribs (longitudinal or transverse) being taken as chief criteria.

With respect to structural design of orthotropic plates it was first supposed that torsionally stiff full-web steel ribs of V, Y and especially trapezoid cross sections were superior to flat or bulb steel ribs, since latter, for lack of transverse stiffness, could not greatly reduce the elastic deflections of orthotropic plates.

A comparison of pavements supported by plates 10, 12 and 14 mm (appr. 3/8", 1/2" and 9/16") thick, on the one hand, and rib-spacings of less than, equal to and over 30 cm = 1' on the other hand did not permit the conclusion that surfacings had a longer life on thicker plates and more narrowly spaced ribs, i.e. when the elastic deflections of the deck plate are smaller.

There is no reason, in our opinion, to change the design of orthotropic plates hitherto used. We do not think, either, that increasing the stiffness of the deck plate by zigzag-bars will be necessary in general. This should be limited to bridges with steep longitudinal slopes.

We are convinced, that there is the chance of there being errors in the composition of, or more precisely, in the specification for, an asphaltic surfacing, as well as in the preparation and mixing procedures, and in the methods of application. Unsufficient knowledge of these factors did positively cause many surfacings to fail prematurely in former years. The performance of quite a number of newly laid asphaltic surfacings substantiates this supposition indicating that as to the asphalt there are many good chances still unknown and unexploited.

It is not at all aneasy task to find that pavement most suitable for the structural relations between, and for the composition of, its different layers. The requirements to have stability during summer and resistance to cracking in wintertime are contradictory and, therefore, a compromise only will be the best solution, The dominating factors are:

Structural lay-out of pavement,

Consistency of bitumen
(softening and breaking points),

percentage of binder-content in compound,

quality of mineral aggregate,

aggregate grading and

physical and chemical properties
of the surfacing layers.

As observed on 56 bridges certain types of damage are corresponding to special criteria of the surfacings. We believe, that an evaluation of certain materials should be possible to some extent as far as the suitability in general and the special applications they are be used for are concerned. In respect of the causes of damage we are referring to section 4.

7. Laboratory Tests at Stuttgart

Now, for additional systematical laboratory tests, an extensive program had to be fixed based an the results of the preliminary statical tests conducted by the Bundesanstalt für Straßenwesen (Federal Road Construction Institute), and on the knowledge gained in the field in the meantime. The main task consisted above all in various, mostly dynamical, tests subjecting the specimens to loading conditions which would simulate the reality as close as possible. The performance of bonding compounds had to be studied by fatigue tests subjecting them to fatigue loads at different temperatures in order to limit the number of currently available bonding compounds. For we are convinced that the fatigue strength of a wearing surface of good composition in other respects is in accordance to the quality of the bonding compounds.

The Otto-Graf-Institute of the Institute of Technology in Stuttgart has been entrusted by us with the carrying-out of this research program. In doing so we have proceeded on the provisional assumption that all of the other criteria for the pavement have in general already been established on the basis of sufficient experience, unless a special composition of the wearing surface is specified by the respective manufacturers of bonding compounds.

The steel plate must be sand-blasted to metallic white. A bonding compound and subsequently one layer of mastic, 8 mm = 5/16" thick are applied, followed by two courses of Gußasphalt (mastic asphalt) applied at 180°C = 360°F and 220°C = 430°F respectively, totalling 50 mm = 2" in thickness.

The following 8 bonding compounds have been tested:

1. Cold-applied bituminous primer (5 - 10 μ = 0,2 - 0,4 mils) according to AIB (Instructions for the sealing of civil engineering structures - Specification of German Federal Railroad).
2. "Okta-Haftmasse" (800 g/m^2 = 1,5 lbs/sq.yd.) - a bituminous, highly cyclical bonding compound, manufactured by Teerbau, Gesellschaft für Straßenbau mbH, Essen.
3. "Isotex" - an insulating and bonding compound, manufactured by Smid & Hollander, Hoogkerk, Netherlands, using unvulcanized rubber powder ("Pulvatex") of Rubber-Latex-Poeder-Compagnie N.V., Amsterdam. The Isotex system consist of a primer and a special type of Mastix, followed by two layers of mastic asphalt (Gußasphalt).
4. "Colzumix" cold-applied painting (250 g/m^2 = 0,46 lbs/sq.yd.), manufactured by Westfälische Mineral- und Asphaltwerke, W.H. Schmitz KG, Dortmund.

5. Coal-tar pitch epoxy-resin (700 = 28 mils), sprinkled with aggregate.
6. "Tenaxon" - a modified epoxy-resin, manufactured by C.Fr. Duncker & Co., Hamburg, to be applied in two layers sprinkled with basaltic chippings. The mastic asphalt is appplied directly to the second epoxy-resin layer as long as that is not hardened yet; there is no mastic course.
7. "Prodorit" - tar-epoxy-resin combination, manufactured by Th. Goldschmidt AG, Mannheim.
8. "VABIT"-insulation - a multi-stage system consisting of three coats based on tar-epoxy-resin, and of one VABIT insulating layer, 1 cm = 3/8" thick. On this one binder course, 3 cm = 1/4" thick, and one VABIT wearing course, 2 cm = 3/4" thick, are applied.

Apparently the composition of surfacings using the no. 3, 6 and 8 bonding compounds differs from that of the remaining types.

The laboratory equipment and the testing methods were checked by several preliminary tests.

The surfacings to be tested were applied in a width of 15 cm = 6" over the total length of steel plates which were 70 cm = 28" long, 20 cm = 8" wide and 12 mm = appr. 1/2" thick. See figure 15. These strip-shaped samples were supported by three rollers spaced at 2 x 30 cm = 2 x 12" in the form of two span beams. The whole arrangement was quite a realistic spot sample, similar, by sufficient approximation, to a strip-shaped transverse cutting of an orthotropic plate. The fatigue flexural tests, planned for the first series, have been conducted on these specimens up to 2 x 10^6 cycles or until failure by applying two equal, increasing loads, arranged slightly out of midspan and 35 cm = 14" apart.

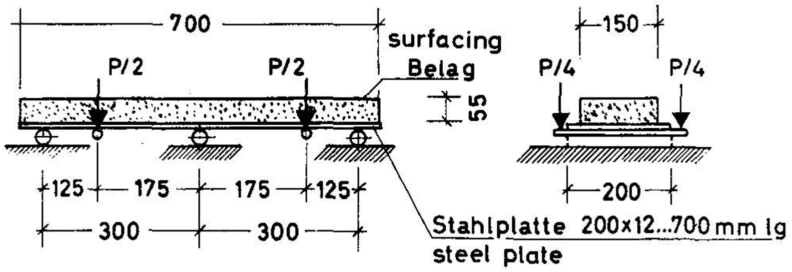


Figure 15: Arrangement for testing fatigue strength by continous flexing

It was determined by a preliminary test that the surfacing did not stand an appropriate load applied directly to its top surface. The loading props penetrated into the surfacing, squeezing it aside at the same time. So we turned to an indirect application of the loads, transmitting them to the protruding edges of the plate. The deflections were measured by dial gages, arranged at the same points and having a read-out precesion of 0,01 mm = 0,4 mils.

In order to determine the composite action of the steel plate and the surfacing, statical tests were run first. For this the applied load was set to a magnitude which, when slowly increased, eventually caused a deflection of 0,5 mm = 2 mils, equal to 1/600 of the span. The same deflection under the same load was reached on a bare plate, without any surfacing, which showed that the surfacing was statically ineffective under slowly applied loads. The bituminous surfacing adapted itself by creeping to the new condition, so that the composite action was lost, when a certain time after load increase had elapsed.

Minimum load and maximum load for the following dynamic tests were set to such magnitudes that the resulting range of load (increasing load) corresponded to the load applied for the statical test.

At first time all tests were conducted at room temperature (+20°C = 68°F). At the beginning of the test, run at a relatively high frequency of n = 300 cycles per minute, a considerable composite action of the surfacing was observed. The total deflection was only 27% of that measured previously during the statical test ($\ell/600$). The surfacing broke loose from the plate at 7×10^5 cycles and the test had to be terminated.

It was the purpose of a second test, conducted at about half of the previous frequency (n = 160/min), to reach a deflection of $\ell/600$ by increasing the maximum load. The deflection, however, was raised from 27% to 65% only, in spite of a tripled load. The surfacing broke loose after few cycles, when the load had been increased again to get a deflection of 0,5 mm = 20 mils, equal to $\ell/600$.

As shown by this test the bituminous surfacing continously loaded at 160 cycles per minute is far from following a deflection of 1/600 of the spacing of the longitudinal stiffeners.

From this fact we concluded that the increasing load, used in the previous test, had been appropriate for our planned flexural fatigue tests except that for the following tests a frequency of n = 160/min should be used. It is doubtfoul, wether or not this frequency corresponds to the actual conditions on bridges. Measurements, therefore, are being conducted now and their results will be taken account of in the next test series.

At room temperature the number 1 to 7 surfacings have been tested twice up to now. The results do not reveal much, because the performance of both surfacings and bonding compounds re-

respectively will still be tested at extreme temperatures of $-20^{o}C = -4^{o}F$ and $+60^{o}C = 140^{o}F$. The results of these test will be much more significant then those obtained at room temperature.

When the testswere started, deflections from 0,12 mm = 5 mils = $\ell/2500$ to 0,29 mm = 12 mils = $\ell/1030$ were obtained. The numbers of cycles sustained by the materials were different as well:

> Whilst the no. 5 surfacing (coal-tar-pitch-epoxy) broke loose from the bond coat immediately after starting pulsation, the no. 6 surfacing (Tenaxon) did sustain $1{,}4 \times 10^{6}$ cycles prior to losing bond. After $2{,}4 \times 10^{6}$ cycles the surfacing had broken loose on one span and the deflections had been increased on both spans up to 0,22 mm = 9 mils and 0,45 mm = 19 mils respectively. It was observed later that the shear failure occured within the mastic asphalt course leaving a thin layer of mastic asphalt over the total area of the Tenaxon bonding compound.

The tests at room temperature will be repeated at lower frequencies; only after that the performance of the surfacings will be studied at extreme temperatures.

We expect that we shall have to deal with flexural fatigue tests for a long time yet. It seems to be of little use to arrange for details of further tests prior to having obtained results from the fatigue tests. We just want to say, that we intend to enlarge our test program by the following test groups:

Rutting tests,
Shoving tests,
Dropping-ball test
Blistering tests
Temperature tests and
Test, as to protection
against corrosion.

8. Measurements of Temperatures

It was the purpose of additional tests conducted by the Railroad and Highway Construction Institute of the Munich Institute of Technology to clarify, wether there is any connection between the many cases of rutting and temperature variations, presumably caused within the surfacing by the radiator effect of the longitudinal stiffeners. A test plate has been made 8,8 m = 29'-4" long, 2,7 m = 9' wide; stiffeners on both halves of the deck plate, 12 mm = appr. 1/2" in thickness, were trapezoidals and flat steel bars, respectively. For reading and recording temperatures all the year round, thermocouples were installed at different depths of the surfacing and underneath the plate. See figure 16.

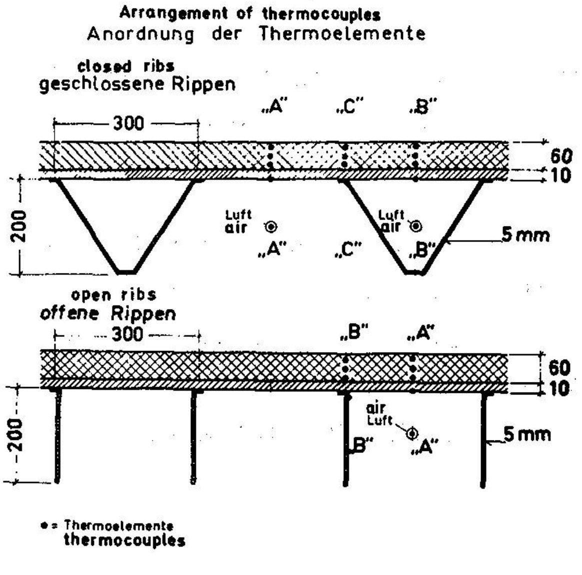


Figure 16:

Measuring temperatures of a test plate

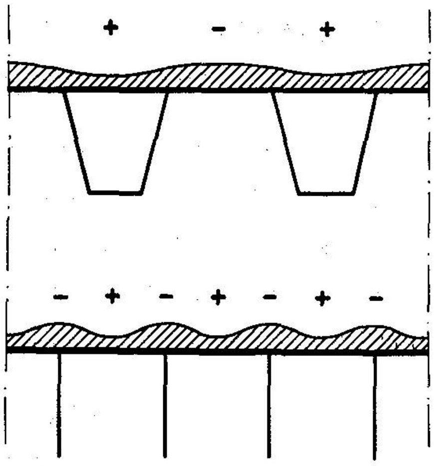


Figure 17:

Waving due to temperature differentials

For the trapeziodal ribs the measuring points were arranged in three vertical cuts, one each between the ribs, at one connection and on the centerline of the trapezoid. For the flat steel bars only two vertical cuts were made, arranging the thermocouples amidst and on top of the ribs.

The results of the first measurements, carried out in the autumn and winter of 1966/67, showed that during some autumn-days with ambient temperatures of more than +25°C = 77°F, the temperatures measured in the lower surfacing course above the rib centre-line on the plate portion with trapezoidal ribs were higher by about 2°C = 3,6°F compared with those between the ribs. Temperatures on the plate portion stiffened by flat steel bars were higher amidst than atop of the ribs. In this case the difference of about 3°C = 5,4°F was even more distinct.

The a.m. figures were measured on the lower course of the surfacing; readings from the upper course were half that high only.

By this test our opinion has been confirmed, that the magnitude of the supposed temperature differentials can be measured. These differentials were lasting for up to 5 hours, a fact which appears to be very important.

As a result the modulus of elasticity varies significantly. In the warmer zones, the asphalt is prone to become plastic and will be squeezed towards cooler areas by the moving wheel loads. That means: The wave-crests will in between the ribs in the case of closed rib systems (trapezoidal, V- and Y-shaped ribs), but atop of the ribs for open ribs (flat or bulb steel bars). See figure 17.

The final report, containing the measurements made during the spring and summer of 1967 has not been completed yet. On the basis of some details already known one may conclude that temperature differentials during summer are about twice those measured in the preceding fall.

9. Field Tests

Looking for the wearing surface most suitable on an orthotropic deck plate we have not limited our endeavours to laboratory tests only. They have been paralled by observations in the field and the results have been incorporated in the previous reports, containing a stock-taking of our bridges as well as an attempt, to evaluate the performance, taking into special consideration the period of time elapsed since opening for traffic, and the concentration of traffic. We want to get confirmation by field tests of the results newly obtained at the laboratories. Field tests, therefore, have been started again on some bridges erected during the two preceding years. At first we shall test various bonding compounds, the composition of the surfacing being as closely as possible the same in other respects. A few exemples are given below:

The "Colzumix" bond coat applied in 1965 on the first section of the Stephanie Bridge, Bremen, has been compared to the "Okta" bonding compound applied on the second section during the last year.

On the upstream platform of the Brücke über die Norderelbe (bridge over the northern part of the Elbe River) - located in a new section of Bundes-Autobahn (Federal super-highway) called "Southern Hamburg Bypass" - the first surfacing had been applied in 1962 according to the "Möllerit"-method. A partial replacement became necessary during 1966 and has been made using the "Durastic"-solution of Duncker & Co. for the bond coat. Now, resurfacing of an other section has been done by using Okta-Haftmasse.

Finally, on the new bridge over the Rhine River at Rees (see figure 18), zig-zag-anchoring bars 20 x 6 mm = 3/4" x 1/4" at 15 cm = 6" centers have been placed on one half of the main span. Four types of pavement using "Isotex" and "Okta" bonding compounds will be compared:

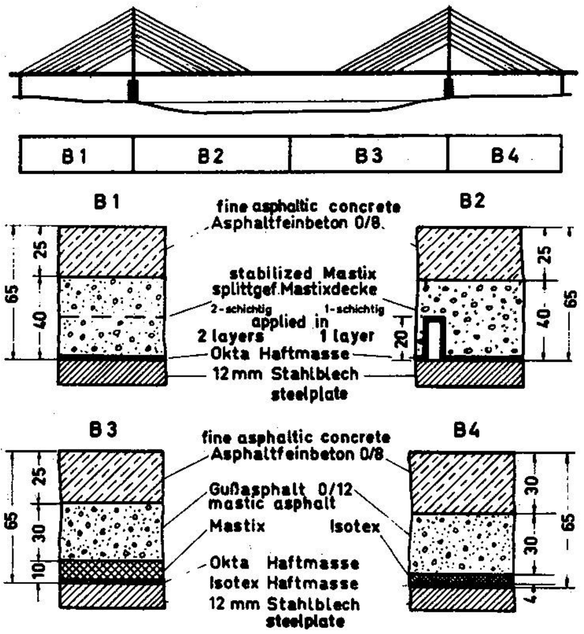


Figure 18: Field testing of various surfacings on the Rees Bridge over the Rhine River

1. "Okta-Haftmasse"; two layers of stone filled mastic surfacing, 40 mm = 1-9/16" thick in total;
2. "Okta-Haftmasse"; stone filled mastic surfacing, 40 mm = 1-9/16", on zig-zag-anchoring bars;
3. "Okta-Haftmasse"; 10 mm = 3/8" mastic;
   30 mm = 1-3/16" mastic asphalt (Gußasphalt);
4. "Isotex"-insulating and bonding compound, 4 mm = 5/32" thick;
   30 mm = 1-3/16" mastic asphalt (Gußasphalt).

On top of the a.m. surfacings one wearing course of fine aggregate asphalt concrete is applied, 25 mm = 1" thick for the no. 1 to no. 3 surfacings, and 30 mm = 1-3/16" thick for no. 4 surfacing. The total thickness is 65 mm in any case.

However, it is a common drawback of such tests that results normally are obtained but gradually and after quite a number of years. And: there should be at last one summer and winter with extreme temperatures since the completion of the wearing surface. Otherwise criteria for performance are not available.

10. IABSE Inquiry

On the meeting of IABSE's Working Commission II (steel construction) held in Ankara on September 5, 1966, it has been decided to work out a questionary dealing with wearing surfaces on light-weight steel bridge decks, and to send it to all National Groups. Anwers received from 12 countries have been transmitted by the German Group for evaluation to the reporters on the Symposium's three Themata.

Anwers to questions ranging within the scope of Theme I (Asphaltic Wearing Surfaces 1" to 3" thick) have been tabulated below with no comment. The fact that anwers have been received from 12 different countries clearly shows that there is a widespread common interest in solving the problem under review. The other fact that several questions could not be answered underlines the need of starting a world-wide exchange of experiences gained in such an important field within the scope of modern bridge design.

The questions belonging to Theme I are:

1. Which construction methods and "recipes" (for instance, asphalts or rolled asphalts) do you think appropriate for carriageway surfacings?
2. Is there any possibility for a durable marking of those surfacings?

3. What is the behavior of the upper layer with respect to
   a. Roughness
   b. Resistance to wear
   c. Chemical resistance
      (salts, water, oils, gases) ?
4. How is the stability and crack resistance at extreme temperatures ?
5. What is the behaviour of the surfacing with respect to shrinking and creeping ?
6. What is the behaviour of the surfacing with regard to aging and fatiguing ?
7. To what extent is the surfacing sound insulating and heat resistant ?
8. Is the surfacing permanently insensitive to unequal elastic bedding (formation of waves) ?
9. To what extent is the surfacing load distributing
   a. during a short-time loading
   b. during a long-time loading ?
10. How do you judge tne composite action with steel deck plate ?
11. Can the surfacing by faultlessly repaired if local damage may occur ?
12. Does the surfacing offer a sufficient protection against corrosion for the carriageway plate ?

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DENOMINATION					COMPOSITION OF BRIDGE-SURFACING						PROPERTIES									REMARKS
					question 1			question 2	question 3		question 4	question 5	question 6	question 7	question 8	question 9	question 10	question 11	question 12	
crt. no.	country	reporter	no.	structure location	thickn. cm	bonding and insulating layer	surfacing	marking	resistance to skid and wear	resistance to chemicals	stability and resistance to cracking	shrinking and creeping	ageing and fatiguing	sound- and heat-insulating	waving, rutting and shoving	load-distributing, short- and long-time	composite action	ability to be repaired	protection ag. corros.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	CANADA	The Government of the Province of British Columbia; Department of Highways	1.1	Port Mann Bridge near Vancouver	5,5	Sandblasting; red-lead-epoxy primer; coal-tar-epoxy bonding coat sprinkled with chippings	1/2" levelling course: sand asphalt containing 8% air voids max.; bituminous bond coating; 1-1/2" wearing course: asphalt concrete containing 6,5% of bitumen and mineral aggregate up to 1/2"	---	sufficient	sufficient	no difficulties up to now	see col. 12	see col. 12	not known	not sensitive up to now	---	---	yes, repairable	yes, sufficient	steel deck plate: 7/16" to 1/2" thick minimum asphalt concrete according to specifications of Department of Highways
2	DENMARK	Ministry of Public Works, Road Dept.	2.1	Langebro bascule bridge	5,0	cleaning by steel-wire brooms; removing loose rust and shale;	2 cm soft mastic asphalt containing bitumen 10%	yes	at 50 km/h value of friction μ = 0,6 to 0,7; wheel inclined and on wet surface	---	performing very satisfactory; no shoving, no rutting, no waving	---	---	---	---	---	---	yes, not necessary up to now; repairs according to spot samples o.k.	insulation still o.k. on spot-samplings	steel deck plate: 13 mm minimum thickness; stiffeners at 50 cm centers; anchoring device: 2o mm by 10 mm flat steel bars, welded to deck plate
			2.2	Guldborgsund bascule bridge Kong Frederik IX's bridge		bitumen coating, containing 5% rubber additive (250 g/m^2)	2,5 cm mastic asphalt containing bitumen 8% Trinidad-Epuré 2% limestone filler 45% grit (2/6 mm) 45% bituminized chippings (12/15 mm) additive													
		Port Authority	2.3	2 movable bridges in Copenhague Port					as on normal road pavements		as on normal road pavements	see col. 12	see col. 12	no experience; no measurements	no waving since 13 years	at 45° angle, when loaded instantanously	very satisfactory			
3a	GERMANY, EASTERN	Kammer der Technik F.U.A. Straßenbrücken; Berlin - Ost	3.1		6,0	sprayed zinc coating, sometimes combined with aluminum-coat 50 microns or: Mastix (asphalt mastic) shear forces are poorly transferred by insulating foils; surfacing shoves	2,5 cm binder course of stone-filled Mastix containing bitumen B 200 2,5 - 3,0 cm wearing course of asphalt concrete or: 3,0 cm binder course containing bitumen B 200 2,5 cm wearing course of fine aggr. asphalt concrete	yes, white Mastix 3 - 5 mm th. or: epoxy-trowel-compound	same as normal road pavements; may be improved by indentations or sprinkling with bituminized chippings	---	resistance to cracking more important than stability; cracks are caused by high-frequent vibrations	no experience	see col. 13	no measurements taken	shoving ahead of expansion joints, when improperly applied or using too soft mastic asphalt	not tested	not accounted for, because not existing at high temperatures	yes, when carefully done, using painting materials and heating devices	resistance to cracking not sufficient; protection against corrosion, therefore, necessary	steel deck plate: 10 mm minim. thickness using torsional-rigid longitudinal stiffeners at ≦ 300 mm centers and transverse beams at ≦ 3 m centers; anchoring device recommended on slopes steeper than 3% only.
3b	GERMANY, WESTERN	Bundesverkehrs-Ministerium (Ministry for Traffic), Bonn	3.2		6,5	bonding compound or bond coating; course of Mastix	2 layers of mastic asphalt	Yes inserting thermoplastic material	same as normal road pavements	sensitive against oils; oil-drippings are not dangerous	even at extreme temperatures good results prevailing, when carefully applied	bituminous surfacings with rubber-additive tend to shrinking; creeping in laboratory test only observed	performing like road pavements	sound - and heat-insulating quality improved	depending on "receipe", composition of surfacing and on structural features of orthotropic plate	not depending on loading time; depending on thickness, composition and temperature of surfacing	depending on loading time and temperature (modulus of elasticity) furthermore on efficiency of bonding layer; good composite action, in the cold and under instantaneous load	yes to be done easily with no objections	surfacing only not sufficient; insulating and protecting layer is necessary (Mastix)	- - - - -
	UNITED KINGDOM	Scottish Development Department; Road Research Laboratories	4.1	Forth-Bridge	6,0	grit blasting to "white" metal finish; sprayed zinc coating, followed or not by a protecting coat of bitumen; "Bostic 1255" bond coating	2 mm course of Mastix containing bitumen 23% Pulvatex 2% limestone filler 75% 4 cm asphaltic Mastix acc. to B.S. 1447 containing bit. chippings up to 18 mm or: rolled asphalt acc. to B.S. 594	yes	performing well when materials are compsed carefully	---	no objections at temperatures between - 10°C and + 50°C	no objections	---	heat-insulation of surfacing 5 cm thick amounts to appr. 10°C	-----	at low temperature load distributing and composite acting; at high temperature negligible	composite action not considered	yes	additional insulating layer highly desirable	B.S. : British Standard
			4.2	Severn-Bridge		o.1" cushion layer of a rubberized mastic	1-1/2" mastic asphalt acc. to B.S. 1447/1; 3; containing chippings up to 3/4".													

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	DENOMINATION				COMPOSITION OF BRIDGE-SURFACING			PROPERTIES												REMARKS
					question 1			question 2	question 3		question 4	question 5	question 6	question 7	question 8	question 9	question 10	question 11	question 12	
crt. no.	country	reporter	no.	structure location	thickn. cm	bonding and insulating layer	surfacing	marking	resistance to skid and wear	resistance to chemicals	stability and resistance to cracking	shrinking and creeping	ageing and fatiguing	sound- and heat-insulating	waving, rutting and shoving	load-distributing, short- and long-time	composite action	ability to be repaired	protection ag. corros.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
4	UNITED KINGDOM	Husband & Co. Consulting Engineers, London	4.3	---	--	removing of all loose dust and dirt; sprayed metallic coat; tack coat of "Bostic C"; 1/8" ins. layer of rubberized filled bitumen. insulating foils render difficult bonding	1-¼" wearing course of mastic asphalt according to B.S. 1447/1 col.3 including 40/45% of coarse aggregate	---	---	---	---	--	---	---	insulating layer must be neither too thick nor too soft	angle of load-distribution is assumed to be 45° according to B.S. 153	stiffness of steel deck plates, designed to carry B.S. wheel loads, is sufficiently high; composite action no problem	---	---	B.S. : British Standard anchoring devices required on very steep slopes only
5	INDIA	The Central Road Research Institute, New - Delhi	5.1	road and railroad-bridge over Jamuna River near Delhi	--	---	mastic asphalt surfacing containing bitumen, limestone filler and chippings	yes, using sterene-based paints; but not durable	good, by spreading and tamping aggregate while the mastic is still hot	good against water and salt; poor against natural oils and gases, due to solubility of asphalt	the surfacing is both stable and crack resistant at extreme temperatures	no inconveniencies observed over a period of 3 years	not very appreciable so far	reasonable	reasonably insensitive	---	composite action quite good	yes	yes; effective protection against corrosion	3 years of service time
		Government of Maharashtra, Bombay; Designs Circle	5.2	---	--	---	asphalt concrete or cement concrete					good resistance to shrinkage	asphalt oxidizes and is rendered brittle	not tested	asphaltic surfacings form waves	---	not to be considered			- - - - -
6	THE NETHERLANDS	Rijkswaterstraat Directie Bruggen, Den Haag	6.1	---	5,0	protecting coat: bitumen B 150/250 0.8 - 1,0 kg/m² bonding coat: bitumen 95% Pulvatex 5% mastic asphalt: bitumen 20/30 19,0% filler 39,5% aggregate 41,5% insulating foils are not required	2,0 cm Gußasphalt (mastic asphalt) cont.: bitumen 20/30 4,0% bitumen 50/60 4,0% Trinidad asphalt 8,0% filler 24,0% sand 40,0% fine grit 20,0% 2,2 cm Gußasphalt (mastic asphalt) cont.: bitumen 50/60 5,5% Trinidad asph. 5,5% filler 16,0% sand 33,0% grit 2/5 mm 40,0% sprinkled with bituminized chippings 5 - 6 kg/m²	yes	resistance to skidding not high; (μ = 0,45 to 0,50) light tracks after 10 years under traffic	good against water and salt; sensitive to oils;	at extremely high temperature indentations caused by vehicle tires; sensitive to cracking at low temperature, especially on unequally stiffened spots	good, as far as shrinking is concerned	no experience	very well	no; waving on spots of discontinuity of the plate e.g. at plate joints	very good during a short-time loading; not existent during a long-time loading	good composite action with surfacings properly designed and applied	yes	yes; insulating layer provides for adequate protection against corrosion, even in cases where there are cracks in the surfacing	anchoring devices to be rejected on account of discontinuity produced
7	AUSTRIA	Tiroler Landes-Regierung, Landesbaudirektion, Innsbruck	7.1	Europabrücke, Innsbruck	6,0	sandblasting; hot sprayed "Okta-Haftmasse" (bonding compound)	3,5 cm stone-filled asphalt mastic (Mastix-Asphalt) 2,5 cm fine aggregate asphalt concrete according to "VABIT"-method	yes; e.g. with "Helabit"	with "VABIT"-surfacings good experiences	---	no inconveniencies observed during 3-½ years	see col. 12	see col. 12	appropriate insulation by 6 cm thickness of surfacing	no waving observed so far	load-distribution to be expected during short-time loading only	composite action due to zig-zag-grids	yes	time of service still too short	steel deck plate using welded-on zig-zag-grid
8	SWEDEN	Secretary of the Swedish Group	8.1	movable bridges: 5 bascule bridg. 1 lifting bridge 1 swinging bridge	5,0	sandblasting; insulating foils render difficult bonding; sprayed zinc coating 150 microns thick	5,0 cm asphaltic surfacing cont.: bitumen B 55 11,0% Trinidad-Epuré 2,5% rubber powder 6,5% limestone filler 16,0% sand 32,0% hard rock chipp. 32,0%	---	experiences do not allow for final conclusions	see col. 10	see col. 10	see col. 10	see col. 10	---	---	---	using round steel bars for anchoring device	no significant repairs necessary so far	---	steel deck plate: 12 mm minimum thickness; longitudinal stiffeners at 300 mm centers; 18 mm ø round steel bars, 60 mm long, welded-on at 200 mm centers
9	SWITZERLAND	Tiefbauamt of Basle Town	9.1	St. Alban's Bridge, Basle	6,0	8 mm asphalt Mastix	2,5 cm levelling course of mastic asphalt (Gußasphalt) 3,0 cm wearing course of hot bituminous mixture	yes; frazed-in marking "Signofalt"	good	good	good, so far	not known	not known	depending on thickness of surfacing	almost no shovings	not known	seems to be good during short-time loading	yes	yes	- - - - -

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		DENOMINATION				COMPOSITION OF BRIDGE-SURFACING					PROPERTIES									REMARKS
						question 1		question 2	question 3		question 4	question 5	question 6	question 7	question 8	question 9	question 10	question 11	question 12	
crt. no.	country	reporter	no.	structure location	thickn. cm	bonding and insulating layer	surfacing	marking	resistance to skid and wear	resistance to chemicals	stability and resistance to cracking	shrinking and creeping	ageing and fatiguing	sound- and heat-insulating	waving, rutting and shoving	load-distributing, short- and long-time	composite action	ability to be repaired	protection ag. corros.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
10	U.S.S.R.	Ministry for Traffic, Central Administration for Bridge Building	10.1	movable bridges and some fixed bridges	--	not concerned with; bitumen coating	as specified by special construction firms	---	no observations	no observations	not required by administration for bridge-building	---	one surfacing performed well during 30 years	not investigated	---	no observations	---	comp. action by anch. bars: stiffnes produced by c.a. unknown; not to be cons'ed	---	steel deck plate and anchoring bars made of stainless steel
11	UNGARY	Secretary of the Ungarian Group	11.1	Elizabeth-Bridge, Budapest	7,5	sandblasting; hot sprayed zinc coating with 2 layers of 50 and 150 microns respectively 1 kg/m^2 rubberized bitumen-coating 5 - 8 mm rubberized bituminous mortar, containing: bitumen B 144 14,8% rubber powder 1,2% limestone powder 42,0% fine sand 42,0% insulation by aluminum foils difficultly to apply; to be used for mastic asphalt surfacings only.	3 - 4 cm rolled-on asphalt, cont.: bitumen B 144 5,5% limestone powder 6,5% fine sand 4,6% coarse sand 9,6% basaltic chippings 0/5 mm 12,3% 5/12 mm 21,1% 12/20 mm 40,4% 3 cm mastic asphalt, cont.: bitumen B 45 9,0% rubber powder 0,7% limestone powder 22,0% fine sand 9,4% coarse sand 13,6% basaltic chippings 0/2 mm 9,1% 0/5 mm 9,0% 2/5 mm 13,6% 5/10 mm 13,6%	yes; using chlorium-rubber for marking in order to avoid cracking	skid-resistance produced by rolling-in of chippings (10 to 15 mm), mixed with 1,5 to 2,0% of bitumen B 90; about 1 to 2 mm per year worn off under traffic of 20 000 tons/day	good against water, salts and oil-drippings; dissolvable by gasoline and light oils	cracking occured already during the first winter on areas, where the mastic asphalt had been applied in 2 layers; on the other hand the mastic asphalt applied on binder-course is still o.k. after several years of service	service-time of 3 to 4 years is still too short; no experience yet	test results of Research-Institute only have been evaluated; specification for surfacing written accordingly	not investigated	no waving observed so far	tests conducted without results, because composite action and load-distributing quality cannot be separated	see col. 17	no experience	surfacing is not providing for adequate protection against corrosion; top surface of steel deck plate, therefore, to be cleaned by chromium-acid and sprayed with zinc-coating	steel deck plate: 12 to 14 mm minimum thickn.; stiffeners spaced at 300 to 340 mm centers; opinions based on results of Institute of Research; anchoring device, e.g. zig-zag-grid, on slopes steeper than 4% only
12	U.S.A.	State of California, Dept. of Public Works, Division of Bay Toll Crossings, S.Francisco	12.1	San Mateo - Hayward Bridge San Francisco, California	--	epoxy bonding coat asphaltic epoxy	5 cm asphalt concrete, containing coal-tar and resin	yes	not determined; satisfying	---	not investigated	satisfactory so far	see col. 13	see col. 13	yes	distribution of load at non-plastic condition only	composite action determined by flexural fatigue test	not known	yes, provided by zinc-coating	surfacing applied on 37 500 sq.m of orthotropic steel deck plate
		State of California, Dept. of Public Works, Division of Highways, Sacramento	12.2	---	5,5 —	hot sprayed zinc coating 1/4" coal-tar-epoxy bonding layer, sprinkled with chippings	5 cm asphalt concrete containing coal-tar and resin	yes, using white asphalt	highly depending on mixture and mineral aggregates	sensitive to gasoline	may tend to waving at high temperatures	no experience yet	see col. 13	see col. 13	see col. 12	no experience	existing on surfacings free of crackings	yes, but no experience	surfacing only not sufficient	surfacing applied on 900 sq.m of orthotropic plate of 1 structure only
		State of Illinois, Dept. of Public Works and Buildings, Springfield	12.3	Poplar-Street-Bridge, St. Louis, Miss.	--	sandblasting to metallic white; zinc coating; coal-tar-epoxy bond coating (2 coats), sprinkled with chippings	bond coating of bitumen with fluid latex additive; levelling and wearing course: levelling 5 cm asphalt concrete cont. latex additive	yes, using marking paint	no experience	---	good stability is expected; hair-cracking will be possible	no difficulties expected according to test-results	see col. 13	see col. 13	no problem expected	not to be considered	not to be considered	yes, readily and adequately	no; surfacing does not offer sufficient protection	according to tests and experiences made on Troy Test Bridge during 4 years of service-time
		Bethlehem Steel Corporation, Bethlehem, Pa.	12.4	Humphreys-Creek-Bridge	--	metal-foils and plastic films rejected	5 cm asphalt concrete acc. to specification of the Maryland State Road Commission, Art. 33.12 or: 5 cm asphalt concrete with elastomer type asphalt cement	---	---	---	---	---	---	---	---	---	not to be considered	yes, most of the surfacing systems	special protection is required	ARBA and AASHO committees are working on new specifications for surfacings

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11. Results and Conclusions

Up to now there are no final results available from both laboratory and field tests respectively. We can, therefore draw but provisional conclusions based on observations made by us during nearly two decennia. These conclusions have to be discussed time and again and, if necessary, revised. As far as we know, a suitable pavement, as widely agreed, should be constructed as follows:

The surface of the steel plate, after sandblasting to metallic white, has to be protected against moisture and dirt.

The bonding compound (or bond coat) applied on the prepared plate has to provide for a shear-resisting bond of the surfacing with the steel plate.

A special sealing layer is required, because we have not found, up to now, any bonding compound also providing reliable protection of the steel plate against corrosion. This sealing layer likewise will have to protect the bonding compound underneath against heat-convection from the wearing surface proper to be applied at high temperatures.

Normally, the sealing or insulating layer consist of asphaltic mastic, 8 to 10 mm = appr. 5/16" to 3/8" thick, containing about 15% by weight of bitumen. Sometimes rifled strip-metal has been used.

In general, on top of the insulating layer a wearing surface of mastic asphalt (Gußasphalt), 5 cm = 2" thick, is used today and applied in two courses. The lower or levelling course compensates for out-of-planenesses of the steel deck, inevitable in steel construction. Being a wearing course the upper or surface course must contain an harder bitumen.

Either one of the Gußasphalt-layers contains about 8 to 9% by weight of bitumen.

In deviation from this type of construction most frequently used in Germany one binder course and one course of fine aggregate asphalt concrete may, instead of Gußasphalt, be used for both the lower and upper course respectively.

The so called stabilized (or stone filled) mastic system, as developed by Teerbau GmbH, Essen, is of a fundamentally different type of construction compared to the afformentioned ones. It is applied in one layer or in two, and Okta-Haftmasse (bonding compound) is used in either cases.

The field tests now under way on the Rees bridge over the Rhine will determine whether or not zig-zag-steel bars are useful.

Searching for the most suitable bonding compound still remains the central point of our considerations. The different bonding compounds/bond coatings tried out by us may be classified into two groups according to physical behavior:

The hard and shear-resistant compounds
on the one hand, and

the thermoplastic compounds, transferring
limited shear forces only, on the other.

As shown by our investigations, the first group of products, i.e. bituminous varnishes, resin coatings, zinc paints with a binder consisting mainly of resin, and hot-sprayed zinc coatings, cannot, in the long run, cope with the shear stresses produced by braking and accelerating vehicles as well as by the elastic deflections of the deck plate. The stresses are extremely high at low temperatures since then all of the asphalt loses its thermoplastic behavior, and composite action has its full effect. Either the pavement springs loose from the steel plate, or the asphaltic surfacing is separated from the bonding compound. But splitting-up of the zinc layer for instance may occur as well. Then, the deflection of the steel deck is increased, due to lack of composite action, to a degree the superimposed asphaltic surfacing cannot cope with. Destruction then is just a matter of time.

The second group comprises soft bonding compounds having little resistance to shear forces, e.g. the Isotex-Masse containing rubber powder (Pulvatex), and the Okta-Haftmasse. For about 15 years the Okta-Haftmasse has been used in many pavements, and experience has been good in general.

It may well be possible that special, if not highest, importance must be attached to a property of bonding compounds that has not been studied by us so far: The ability to regenerate an effective and reliable bond as soon as, after a period of separation from the superimposed wearing surface, the thermoplastic condition has been regained. However, this ability to regeneration may be expected in bonding compounds of the second group only.

Checkered copper or aluminum foils, frequently used during the fifties, are rarely installled today; plastic films and intermediate layers made up of paper or of bituminized felt are no longer used. It is not even understandable why the risk of later damage should be taken as long as there are other means to positively protect the steel plate against corrosion. Foils and films may be damaged very easily during installation and cannot be used at all for rolled-on asphaltic surfacings. This opinion is shared by other countries, as shown by the inquiry of IABSE.

Furthermore, it is widely agreed that using zig-zag-steel bars will be suitable only for pavements on bridges with a steep longitudinal slope or on bascule bridges.

The problem of the correct composition of the upper layers of a pavement has not been solved yet. This will largely depend on the climate of the location as well as on application methods and mechanical equipment normally used for pavement construction in the respective countries. In case Gußasphalt for instance should finally prove to be the material most suitable for bridge surfacings, nobody will expect the North American road construction industry, exclusively used to rolled asphalt for asphaltic roads, to switch to Gußasphalt.

Although things are still developing, it may be said that orthotropic steel decks are no longer in danger of fading out of the picture due to surfacing. The Syposium on Wearing Surfaces for Steel Bridge Decks will no doubt confirm this opinion.

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SUMMARY

In steel bridge engineering the most important innovation in two decennia has been the orthotropic plate. It will not, however, find final acceptance before a surfacing of adequate durability is found.

Today, therefore, it can safely be said only that the wearing surface will be a bituminous one, having a thickness of about 6 cm = appr. 2-1/2 inches. The causes of damages to wearing surfaces could be determined by observations of many different types of pavements installed. The number of competing systems is continually being limited by tests both in laboratories and in the field.

The most important results of the IABSE inquiry consist in that similar experiences have been gathered likewise in countries other than Germany and that solution to the problem cannot be found by modifications of the structural features of the orthotropic plate. Further systematic investigations will reveal one day what a bituminous wearing surface must be like to best meet the requirements to be made in the interest of durability, economy and riding safety.

RESUME

Le tablier métallique léger (dalle orthotrope) constitue l'innovation la plus importante des deux dernières décennies dans le domaine des ponts métalliques. Il ne pourra toutefois être sanctionné définitivement que lorsque l'on disposera d'un revêtement suffisamment durable.

A l'heure actuelle, on peut uniquement indiquer que ce sera vraisemblablement un revêtement bitumineux d'environ 6 cm d'épaisseur. Les observations effectuées sur de nombreux revêtements réalisés de façon différente ont permis de déceler les raisons des dégâts constatés. Les essais entrepris tant au laboratoire que sur des ouvrages existants tendent à réduire constamment le nombre des types de recouvrement entrant en ligne de compte.

L'enquête réalisée par l'AIPC a conduit au résultat principal suivant : dans les autres pays, on a fait les mêmes expériences qu'en Allemagne, et la solution du problème ne consiste pas à modifier la conception structurable du tablier métallique. Des recherches nouvelles et des observations systématiques montreront un jour quelle doit être la composition d'un revêtement bitumineux satisfaisant au mieux les conditions relatives à sa durabilité, à l'économie et à la sûreté de la circulation.

ZUSAMMENFASSUNG

Die orthotrope Platte ist seit zwei Jahrzehnten die wichtigste Neuerung auf dem Gebiete des Stahlbrückenbaues, sie wird jedoch ihre endgültige Bestätigung erst dann erhalten, wenn ein ausreichend dauerhafter Belag gefunden ist.

Mit ziemlicher Sicherheit läßt sich daher bisher nur sagen, daß es ein bituminöser Belag von etwa 6 cm Dicke sein wird. Die Beobachtung einer Vielzahl verschiedenartiger ausgeführter Beläge ermöglichte es, die Ursache der Belagschäden zu erkennen. Durch Laborversuche sowie Großversuche auf Brücken wird laufend eine Einengung der Zahlen der miteinander im Wettbewerb stehenden Belagsysteme erreicht.

Die IVBH-Umfrage zeigt als wichtigstes Ergebnis, daß man auch in anderen Ländern ähnliche Erfahrungen gemacht hat wie in Deutschland, und daß die Lösung des Problems nicht in einer Änderung der konstruktiven Merkmale der orthotropen Platte zu suchen ist. Weitere systematische Untersuchungen und Beobachtungen werden eines Tages erkennen lassen, wie der bituminöse Belag aufgebaut sein muß, damit die im Interesse seiner Haltbarkeit, Wirtschaftlichkeit und Fahrsicherheit zu stellenden Forderungen in optimaler Weise erfüllt sind.

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