Theme II: Special types of wearing surfaces

INTRODUCTORY REPORT

Rapport introductif

Einführungsbericht

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General and Historical. This theme is aimed at the miscellany of construction which does not fall into either theme I - Surfacing over 1" thick (2.54 cm) or theme III - Surfacing of less than 1" thick.

In fact, these themes, and indeed, the whole symposium, are primarily conceived in relation to road surfacing on steel plates which participate directly as part of the main structural members. This type of construction is itself the end product of various types of deck aimed at reducing deadweight, such as buckle plates, dished plates, steel trough floors, carrying comparatively thin layers of concrete or even roadstone filled with bitumen or tar.

In the past the problem of providing lightweight decks was most pressing on opening bridges. This was readily achieved on timber opening bridges by the use of timber deck construction with a top layer of timber planks which could be removed. This form of deck construction was transferred to iron and subsequently steel opening bridges and has continued to be used until comparatively recent times. Many such decks are still in service on important and busy roads. As a substitute for timber planks, wood block paving was adopted about the turn of the century on many large opening bridges, the blocks resting directly on a sand tar or bitumen layer directly over the steel plates, the joints being run in with hot tar. These blocks were frequently of Jarra wood, but, at least in Germany, beechwood has been used. In cases the blocks were elaborately dowelled together into panels with wooden pegs, key blocks being secured to the construction below in bascule bridges. The use of these blocks was originally made economical by their extensive use in paving city streets where they considerably reduced noise from horse-drawn and steel shod vehicles. So many of these bridges yet remain that efforts have been made to coat the wood blocks with epoxide resin or similar thin surfaces to provide skid resistance. The results do not seem to have been particularly successful, especially in regard to durability.

Buckle plate and dished plate decks. These have been used extensively from about the turn of the century until perhaps 25 to 30 years ago. Square plates arched on two axes at right angles, supported on two sides by the main beams and on the other two sides by stiffening ribs took advantage of the considerable enhancement of the strength of the shaped steel plate to carry local loads. The degree of arching varied but could be of the order of 3" (7.5 cm.) to 6" (15 cm.) on a 5 ft. (1.5 m) square.

These plates were generally filled over with concrete (sometimes tarred road surfacing only) the concrete being either very thin at the centre of the plate (buckle plates) or at its supports (dished plates). In spite of the lack of bonding techniques between the concrete and the steel, the relatively poor quality of concrete and generally its ready permeability to water, it is remarkable how durable this form of construction has been; this is no doubt due to the lack of oxygen in the water more or less permanently in contact with the steel plates.

The wearing surfaces used over this construction were originally tarmacadam, and today bituminous macadams or asphalts.

Bare Steel Plates. The most elementary of surfacing treatments falling in theme II is the bare steel plate itself. Variously this has been produced with projections, studs, corrugations and so forth, to give adhesion for traction, braking and resistance to centrifugal force.

Even when dry such surfaces are unreliable; when wet or fouled with the inevitable film of oil they become completely unreliable for vehicle control.

No protection is, of course, offered against corrosion and, in fact, the fretting caused by the action of wheels must inevitably accelerate deterioration.

Bare steel plates with superimposed open plate. In order to improve traffic adhesion, plates of expanded metal attached to the top of the steel plate have been used. This when new, clean and dry does to some extent improve skid resistance, but not to any satisfactory or reliable degree. The problems of corrosion are not alleviated and are probably increased by the existence of traps likely to hold grit and moisture in intimate contact with the plate.

Steel reinforcing fabric has also been used in the place of expanded metal, with even more unsatisfactory results.

So far as is known these techniques have only been used on temporary structures.

This type of construction has also been surfaced with a comparatively soft bituminous surfacing, having a thickness of some ½" (1.25 cm.) which relies almost entirely on the expanded metal or reinforcing fabric for its stability. This treatment is reported as being reasonably satisfactory on lightly trafficked roads and has been found to be quite useful, even placed directly on steel plates, on emergency bridges where long life is not a first requirement. Generally shear connected surfaces are dealt with in themes I and III.

Open Grid Floors. The open steel grid cover, long used in U.S.A. carries this pattern of development still further, although, of course, it actually precedes the steel plate deck in point of time and appears to have been used in U.S.A. for upwards of 40 years.

The construction consists of close spaced steel bars (generally small I sections) with suitable spacers, open top and bottom and resembling closely cattle grid construction as used in U.K. and elsewhere.

Its advantages are its extreme lightweight, excellent drainage, ready disposal of snow, and, as in the case of the Mackinac Bridge where open grids are used on two traffic lanes and the narrow centre median, improved aerodynamic stability.

Against this there remains the major disadvantages of lack of protection against corrosion accelerated by traffic abrasion and the considerable danger of skidding. It is understood that in certain locations the icing problem in these open grids can be exceptionally serious and that it has been necessary to limit traffic speeds in such conditions to between 3 and 5 m.p.h.

Efforts have been made in certain quarters to improve the skid resistance by applying thin epoxide coatings to the bars, the coating being impregnated with skid resistant materials such as aluminium oxide grits. As is to be expected these treatments have not proved durable and require to be replaced at quite short intervals (as little as 2 or 3 yearly periods).

While this expensive treatment is likely to give better skid resistance in dry or wet conditions, it seems unlikely to offer more than marginal improvements where icing occurs.

Filled Grid Floors. Filled grid floors are essentially an American development although it is understood they have also been used in Sweden and elsewhere. The steel construction is similar to the open grid deck but has the bottom surface completely closed with lightweight steel former strips. Typically, the main steel members would be of the order of 3" (7.5 cm.) deep rolled I beams at 4 " centres, combined with internal reinforcement.

The prefabricated steel grid is filled with concrete to a depth of some $\frac{3}{4}$" (20 mm.) over the top of the grid, to provide an integrated steel/concrete slab of approximately 4" (10 cm.) overall depth. Traffic may run on the concrete surface, or this can again be surfaced by one or other of the surfacings generally used on concrete decks, as e.g. 1$\frac{1}{2}$" (4 cm.) asphalt.

The concrete used may be either normal or lightweight. The lightweight concrete used on Mackinac bridge (where two lanes are carried on filled grids) is reported to have had a density of 108 lbs/cub.ft. (1730 Kg/cub. m) and a crushing strength of 4250 lbs/sq.in (298 Kg/s.cm.) at 28 days.

This type of construction clearly provides the facility of forming a road surface as good in its skid resistance and durability as can be provided on any rigid deck. The durability and performance have been reported as being very good. For example, a case is instanced of a filled grid deck some 27 years old carrying heavy traffic where no appreciable maintenance has been required. This appears to be generally the case.

As against normal concrete decks the system appears to present clear advantages in time of construction, dispensing with form work construction and the use of scarce types of labour. Particularly when lightweight concrete is used, a comparatively lightweight deck is provided which could be composite with main structural members.

The chief disadvantages are reported to be high cost and the problems of placing and fitting where the deck is warped because of curves and superelevation.

Laminated timber decks. Timber baulks have in the past been used extensively on lift bridges to provide light, stout and resilient decks. The chief objections to their use have been deterioration due to fungoid attack, swelling of the timber due to absorbtion of water and the difficulty of providing a reasonably non-skid surface to protect the timber. Wearing surfaces were often comprised of wood block paving or wooden

Asphalt Planks. Interesting reports have been received of the use of Asphalt Planks on the Harlem River and Bronx Kill Bridges in New York City.

The plank is 24" x 12" x 1" thick (60 cm. x 30 cm. x 2.5 cm.); it contains up to 50% asphalt, 35% to 45% Mineral Filler, and not less than 12% organic fibre. The materials are mixed at high temperatures and extruded under high pressure. Coarse trap rock aggregate is forced into the surface of the plank under pressure.

The planks are bonded to the steel plate by asphalt cement consisting of pure bitumen cut back by volatile solvents, applied at the rate of 0.2 gallons per square yard (1.1 L/sq.m.).

Prior to application of the cement the plate was painted with red lead paint.

The decks on which these planks were laid comprised a $\frac{5}{8}$" (1.5 cm.) thick deck plate supported on 7" (18 cm.) deep I beams at 14" (36 cm.) centres. This battle deck floor was not designed to participate with the main structural members. The battle deck units were broken into panels 22' (6.5 m.) long x a traffic lane width by welding 13/16" x $\frac{3}{8}$" (21 x 9.5 mm.) bars to the plate. This was intended to provide lateral and longitudinal support to the planks.

The reports on the behaviour of the plank surfacing indicate that it can be very satisfactory. On Harlem Bridge after 27 years life, 70% of the surface was still covered by the original planks. On the Bronx Bridge on the other hand the planking deteriorated much more rapidly and severely. It is understood that the difference in behaviour has been attributed primarily to variations in quality of materials, manufacture and placing, and that subsequent supplies of planks for replacement appear to have fallen short in quality as compared to the best of the original material.

Generally it seems clear that the adhesion of the planks, where workmanship was at its best, was very good and reports stress the difficulty of removing them after 27 years use.

Protection against corrosion also appears to have been very good, although a limited amount of not serious damage occurred at and near the joints between the planks where a certain amount of breakdown of the corners of the planks and the adhesion seems to have taken place.

planks attached over the baulks.

It was generally considered necessary to leave narrow gaps between baulks and planks of the wearing surface to allow circulation of air and permit a degree of swelling. This operated against the use of asphaltic or bituminous wearing surfaces which tended to break up at the joints and deteriorate progressively from these points. Adhesion was rarely good.

Recently a timber decked rolling lift bridge has had the deck renewed in laminated timber. The baulks are some 6" (15 cm.) thick, 9" (23 cm.) wide and 24' (7.25 m.) long, made up of 9" x 1" (23 cm. x 2.5 cm.) thick planks fabricated in the factory, glued with an epoxy glue and shaped to the camber defined by the levels of the steel stringers by bending round formers. Impregnation of the timber with fungicides and sealing with epoxide resins appears likely to have minimised dangers from rotting and swelling of the timber. Tests have shown that there is no danger of failure of the glued joints in fatigue. The accuracy to which the baulks were shaped to the required curvature was remarkable, and, since they are tied down to the stringers they provide an effective distributing medium.

Surfacing is provided by a $\frac{1}{8}$" (3.25 mm.) thick epoxide resin dosed with calcined chips laid under tents in controlled conditions on $1\frac{1}{4}$" (3 cm.) thick timber planks screwed to the laminated timber baulks. On other opening bridges similar plank wearing surfaces have been used, but with the epoxide resin surface factory applied before laying the planks. Where these have been used and conditions on the bridge caused vehicles to follow closely on the same tracks, the wearing surface has tended to break up at the joints and then to deteriorate fairly rapidly. In other circumstances the method appears to be behaving more satisfactorily.

It has also been evident that where the planking has not been uniformly supported its flexure between "high" points rapidly promotes deterioration. This can be remedied by regulating with an epoxy mortar.

It is understood that the riding quality and skid resistance of these planks was quite satisfactory, and it would seem that they offer a potentially useful expedient provided satisfactory control of materials and workmanship can be ensured. A fairly stiff steel deck also seems likely to be essential in order to avoid damage at the joints between planks and loss of adhesion at these points.

P.V.C. Tiling. Surfacing formed from tiles of Polyvinylchloride have been used on several ferry ramps in U.K. The tiles are 2 ft (50 cm.) square x $\frac{1}{8}$ in (.32 cm.) thick and have a finely roughened surface on both sides. The tiles are cemented to the steel plate by a suitable compatible adhesive after thorough cleaning of the surface and grinding smooth of all welds.

The steel plate itself is grit blasted and zinc sprayed, any damaged areas of zinc spray being restored with a suitable zinc rich paint before laying the tiles.

Decks so surfaced have been in use for up to two years and are reported to have behaved in a thoroughly satisfactory manner despite the fact that they have been subjected to severe loading from solid wheeled vehicles and side loaders; traction forces are also considerable on these ferry ramps although traffic speeds are, of course, comparatively low.

Neoprene tiles. Experiments with neoprene rubber tiles have been conducted in Germany by Krupps. The principal difficulty with these tiles appears to have been in finding a suitable adhesive which would stand up to the strains occurring under moving traffic, the difficulties being particularly severe at the joints. The tiles were vulcanised on to the steel plate decks of two emergency bridges subjected to heavy traffic densities and on a gradient. After a year's use the surface appears to have responded very well. It is reported to have excellent properties, adhering firmly, being very wear resistant and having a good damping effect.

The vulcanising calls for high pressures and temperatures and the costs are stated to be considerable.

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THIN TILE SURFACES

Carrelages minces

Dünne Fliesenbeläge

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On page 7 of Dr. Henderson's report there is a reference to the use of P. V. C. tiles on steel bridge decks. This brief contribution gives further information illustrated by one or two examples.

Several movable bridge decks in Britain have recently been surfaced with embossed Verynyl-P. V. C. tiles, 50 cm. square and 3. 2 mm. thick. The minimum thickness of the tiles at the root of the indentations is about 2 mm. and the upper surface is embossed with a 5 mm. grid in diamond pattern to give a maximum thickness of 3. 2 mm. The tiles are stuck on with a normal commercial adhesive known as Bostik C, but it is essential to apply this as thinly as possible.

The first slide, Figure 1, shows these tiles being laid on an old swing-bridge at Liverpool Docks where tracks for road traffic comprised bare steel plates which had worn smooth and were dangerous in wet weather. Some of the tiles were cut and fitted around projecting rivet heads. This illustration shows the adhesive being applied by steel trowel, both to the steel deck, and to the undersides of the tiles.

The next slide, Figure 2, illustrates a roll-on roll-off ferry terminal at Immingham on the north-east coast of England. These bridge ramps are welded steel box girders pivotted at the shore end and adjusted to level by hydraulic ramps at the ferry end. The dead weight of this material is very small, about 1 lb. per square foot of deck (4. 8 kg/M^2).

It is essential to ensure that the steel surface is thoroughly clean and dry when the adhesive is applied and trouble is inevitable if laying is carried out in damp weather or rain. The contract for this terminal was accelerated in order to meet a date for the berthing of a new ship to inaugurate the service and in the rush for early completion some of the surfacing was laid in damp weather. As a result some areas of the tiles subsequently slipped and were replaced.

Repair work on this type of surfacing is quite simple. The defective tiles can be heated, peeled off the deck surface, and new tiles re-laid. It is not essential to remove the old adhesive from the deck plate unless this is in a dirty condition.

The next slide, Figure 3, shows a recent addition to the Dover Cross Channel ferry terminal and the steel decks to the ramps have been surfaced with these tiles. As a result of experience the contractors now seal the joints between the tiles by injecting adhesive with a gun. This has been found necessary in order to avoid the tendency for tiles to lift at the edges.

The fourth slide, Figure 4, shows a bridge ramp at a ferry terminal at Southampton Docks which has been in operation for several years. It is not yet possible to state the life of this type of surfacing, but similar tiles used on pedestrian crossings on heavily trafficked roads have been found to last for seven years. Probably in the case of more lightly trafficked ferry ramps of this kind a ten year life would be expected. The cost of the surfacing is approximately 6/9d. per square foot. Where these tiles are used for surfacing walkways, as illustrated in the slide, the tiles should be kept back about 12 mm. from the face of the kerb to avoid disturbance by pneumatic tyres rubbing the top edge and displacing tiles.

The final slide, Figure 5, illustrates the British Transport Docks Board ferry terminal berths at Southampton where there are three bridge ramps, all of which are surfaced with P. V. C. tiles.

Experience to date has shown that this is a convenient method of surfacing steel deck plates for movable bridges and ferry bridge ramps, but it is perhaps too early to assess the durability and maintenance costs over a long period.

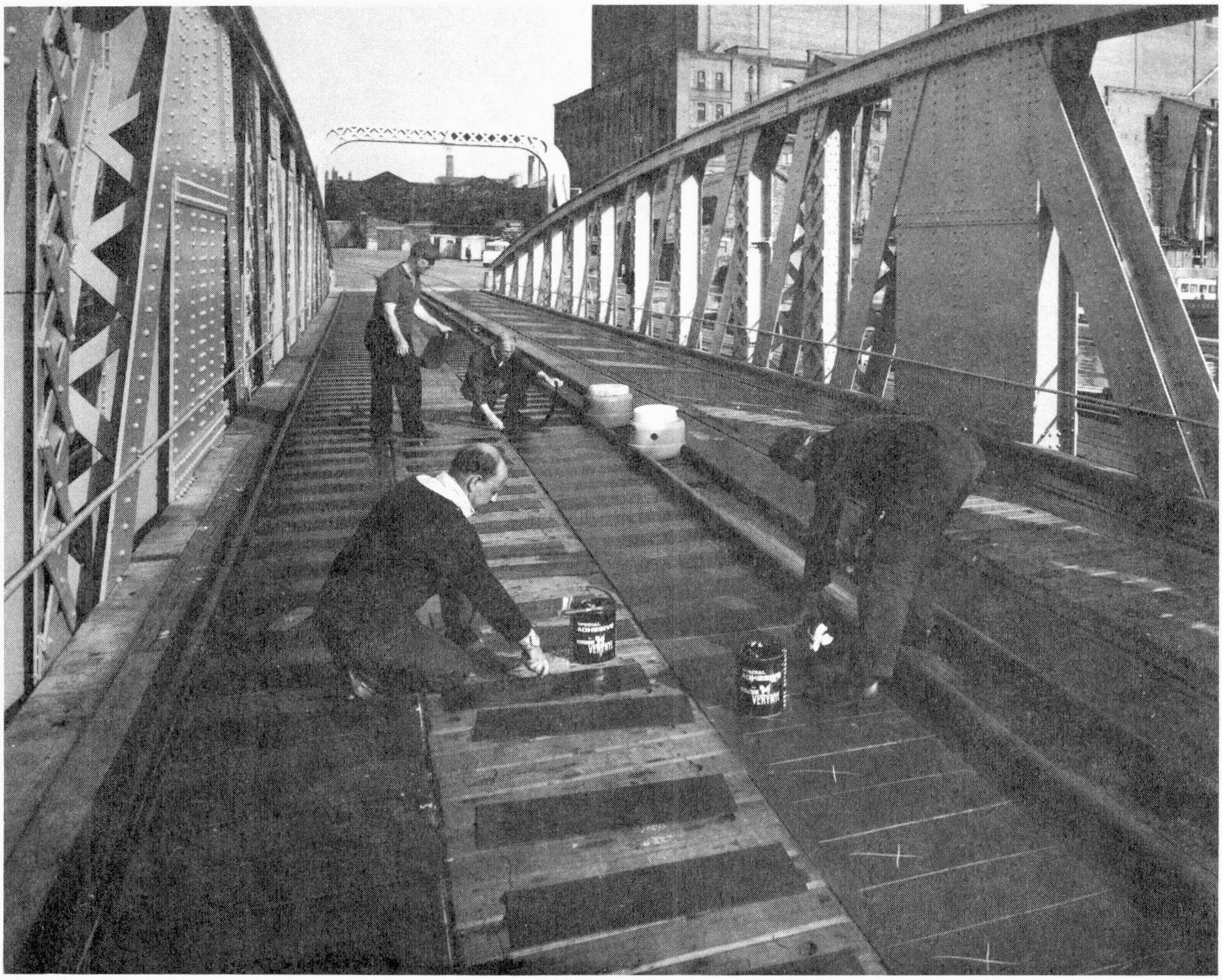

Figure 1

Figure 2

Figure 3

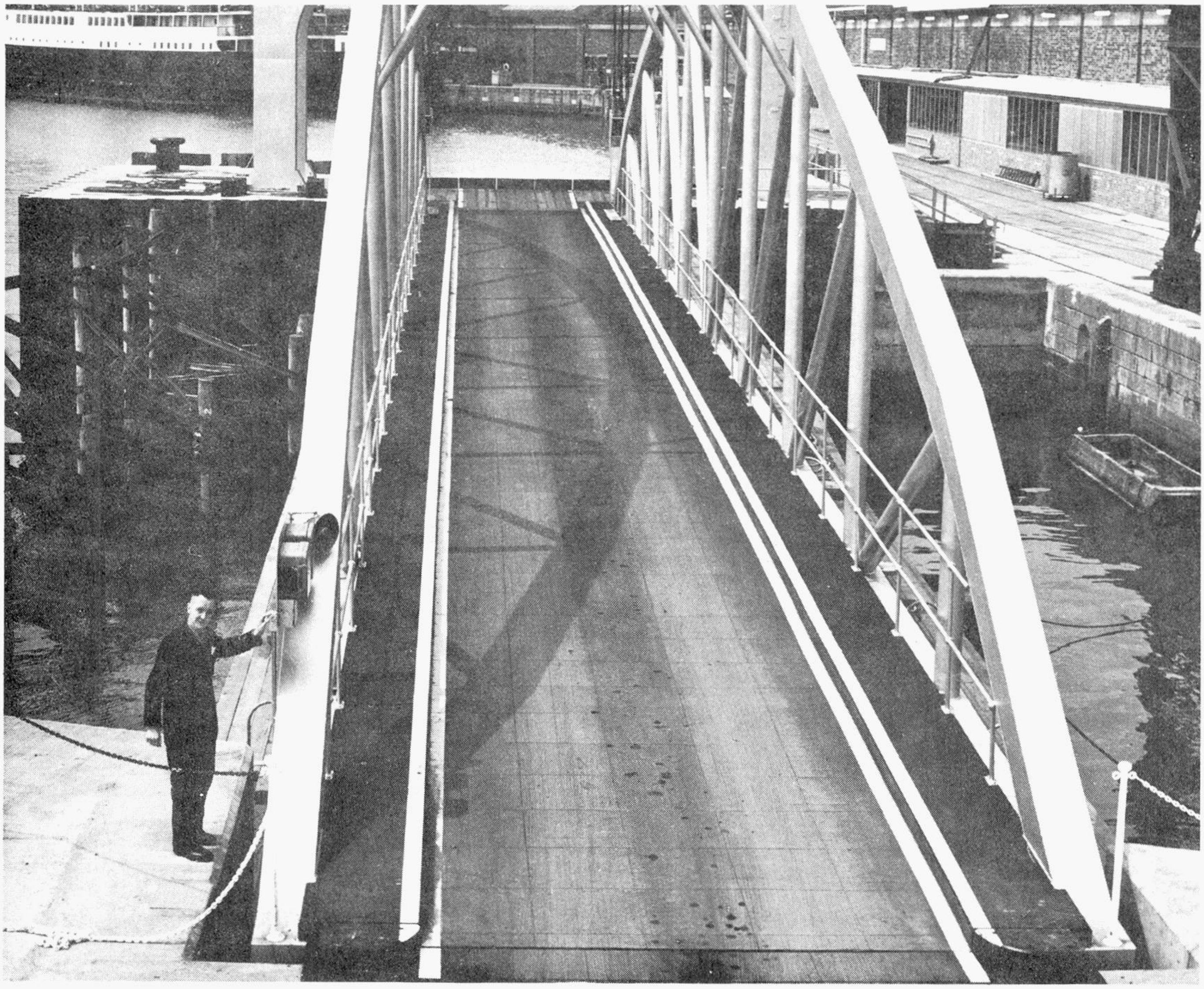

Figure 4

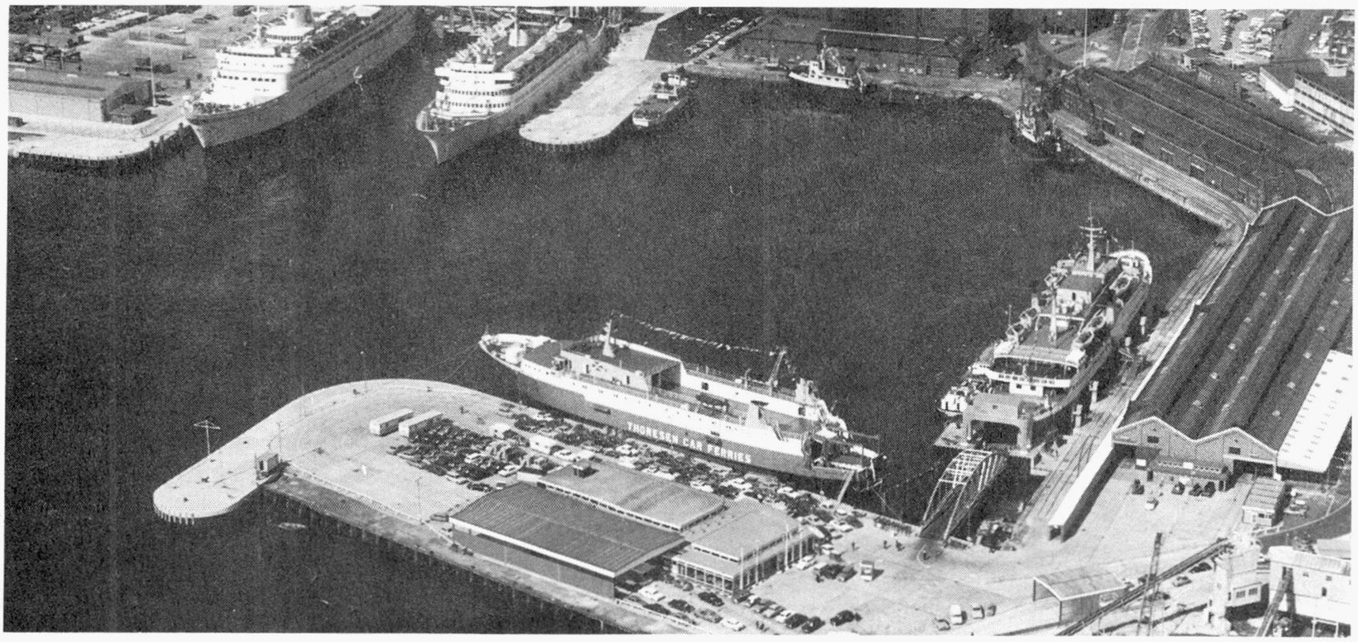

Figure 5

SUMMARY

This contribution describes and illustrates the use of Poly-Vinyl-Chloride tiles secured by adhesive to steel decks as a method of surfacing movable bridges.

RESUME

Cet article décrit et explique l'emploi de dalles en P.V.C., collées sur le tablier, comme revêtement routier très avantageux pour ponts mobiles.

ZUSAMMENFASSUNG

Dieser Beitrag beschreibt und veranschaulicht den Gebrauch von Poly-Vinyl-Chlorid-Fliesen, die durch Haftung auf den Stahlplatten gesichert sind, als Anwendung von Fahrbahnbelägen auf beweglichen Brücken.

STEEL GRID FLOORS

Tabliers en grilles d'acier

Stahlgitterdecken

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Steel grid floors have been used extensively in the United States for more than 40 years. The primary use for this material is on long span and movable bridges where weight is such a critical factor. Other applications have been found in the reconstruction or rehabilitation of older bridges for the purpose of maintaining or sometimes increasing the live load capacity of the structure. A special use has been found for long span suspension bridges where grid floor sections provide "wind slots" which contribute to the aerodynamic stability of the structure. The relative high cost of this floor system limits the application to these or other similar special conditions.

Originally the grid floors consisted of two basic designs, rectangular and hexagonal. The rectangular pattern resulted from the fabrication of a combination of flat rolled bars placed at right angles, in slots and welded to specially rolled I beams. The hexagonal pattern is the result of riveting flat rolled main longitudinal bars to specially bent spacer bars. Due to its lighter construction, the hexagonal design is used for short stringer spans and the heavier rectangular design is used for longer stringer spans. More recently a design was developed which added a diagonal member to the rectangular pattern.

The three basic designs are illustrated in the attached photographs. The grid floor sections are produced in a variety of weights and dimensions to fit almost any beam or stringer spacing. Metal grid flooring will support standard truck loading when placed on properly designed beams or stringer system.

If the bridge owner considers the increased tire noise or reduced traction objectionable the metal grid floor may be filled or overfilled with concrete. The effect of the increased weight can be partially reduced by using light weight aggregate in the concrete mixture. An additional advantage that can be considered in the concrete filled grid is the composite action that is developed between the floor and the supporting stringer. A flush filled grid floor can also be overlaid with bituminous concrete to produce a different texture for the wearing course.

Other methods for increasing the traction or skid resistance of the metal grid floor is to use serrated bars on the surface or to weld metal studs on the surface of existing grating. The 1/4-inch round welded studs are shown on a portion of the deck in photograph No. 5.

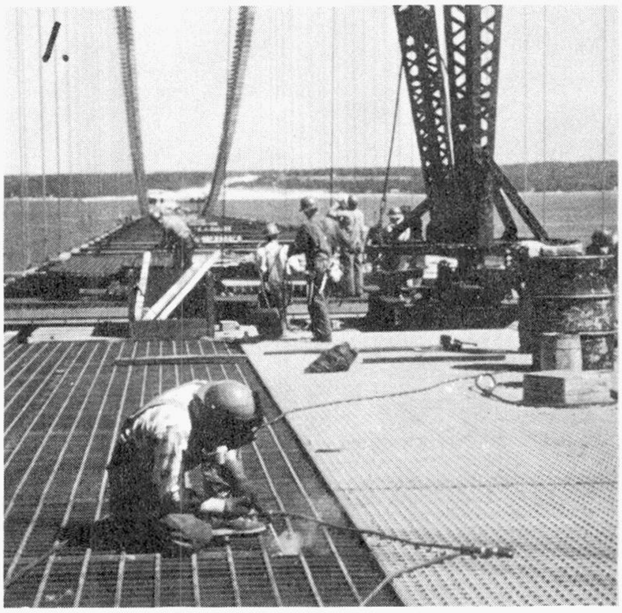
The fabrication of aluminum shapes into a grid floor system is of recent origin and is still in the development stage.

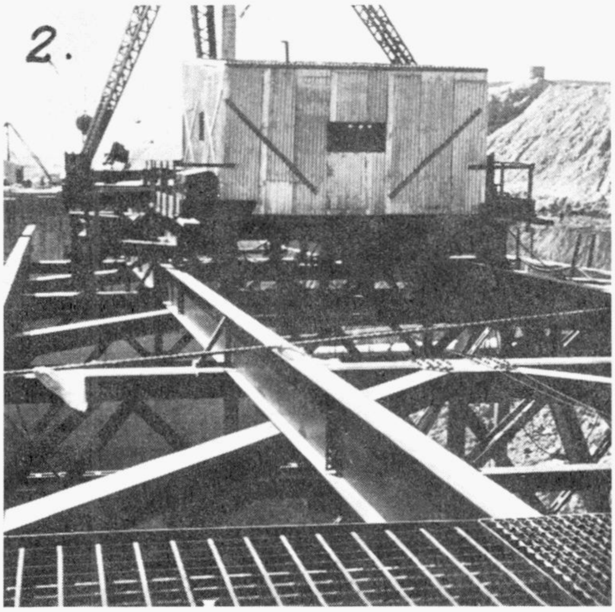
The preferred method of attachment of the grid flooring to the supporting members is by welding. However, metal clips, bolts and clamps have been devised to make these connections.

The relative weights of the various floor systems are as follows:

Type of Deck	Weight in Pounds per square foot
Aluminum type	10-12
Steel type	19-21
Concrete filled	38-54
Reinforced Concrete	75-100
Reinforced Lightweight Concrete	55-75

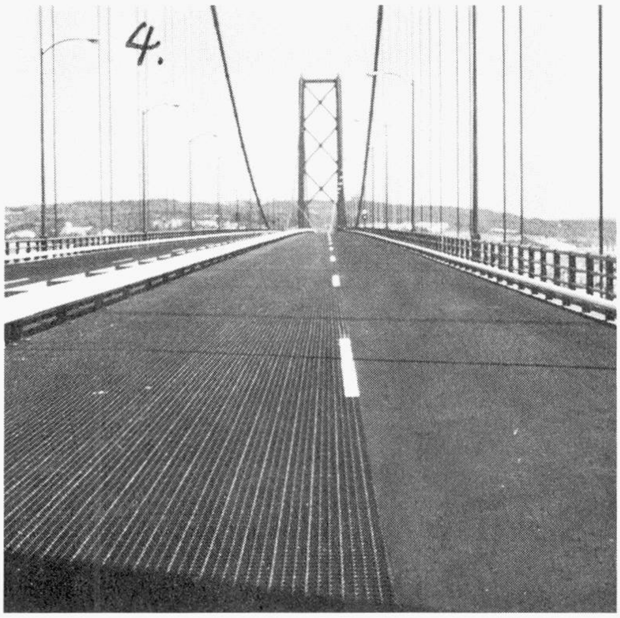
Due to the special nature and application of metal grid floors there is little meaningful cost data available except that the cost of the steel grid floor is approximately four times as costly as the conventional reinforced concrete bridge floor.



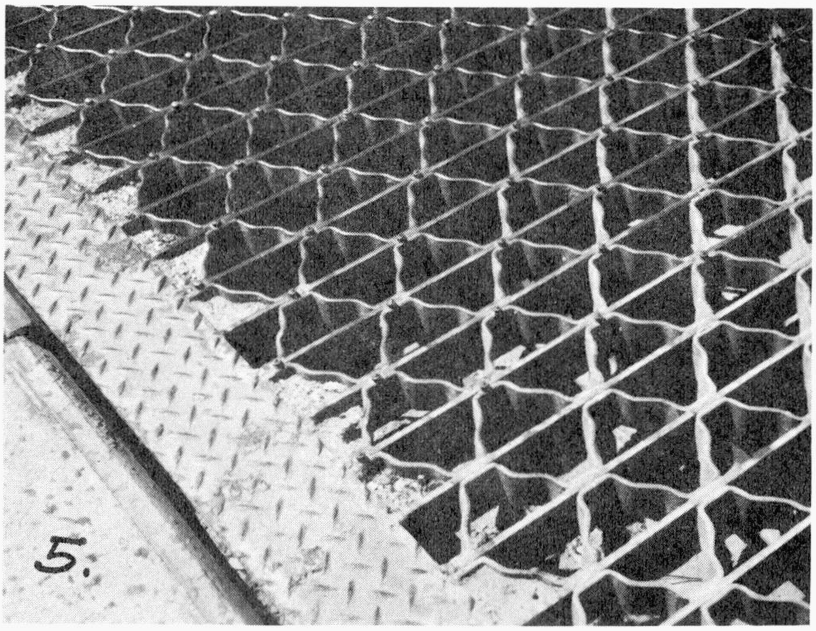


Photographs 1 and 2. Installation of steel grid floor for the Tagus River Bridge in Lisbon, Portugal. Two types of rectangular grid floor are shown. The close-spaced pattern on the right of each photograph is an open grid design and the panels on the left are to be concrete filled.

Photograph 3 shows some additional details of the grid floor which will be filled with concrete.



Photograph 4 shows the completed bridge deck of the Tagus River Bridge. The left lane has an open grid floor and the right lane has a concrete filled grid floor.



Photograph 5 shows an open grid on a bascule bridge in Connecticut which has a hexagonal pattern. This photograph also shows the modification which has been made to improve traction. One quarter inch round studs have been welded on the top of the longitudinal bars to give a rough texture. A portion of the floor on the lower right does not have the additional studs.

SUMMARY

Steel grid floors have been used in the United States for more than 40 years. The primary use is for long span or movable bridges where weight is critical. There are two basic designs; rectangular and hexagonal. In some applications the steel grid floors have been filled with concrete.

RESUME

Des tabliers de ponts en grilles métalliques ont été employés aux USA depuis plus de quarante ans. Leur poids léger les prédestine pour les ponts à grande portée ou les ponts mobiles. On distingue deux types de base: grilles rectangulaires et grilles hexagonales. Parfois, on remplit la grille avec du béton.

ZUSAMMENFASSUNG

In den Vereinigten Staaten werden Stahlgitterdecken seit mehr als 40 Jahren benutzt. Der hauptsächlichste Gebrauch liegt bei weitgespannten oder beweglichen Brücken, wo das Gewicht kritisch ist. Zwei Formen sind üblich: recht- und sechseckig. In einigen Fällen ist das Gitter mit Beton gefüllt worden.

THE DEVELOPMENT AND USE OF THE ROBINSON COMPOSITE DECK IN FRANCE

Développement et applications de la dalle Robinson en France

Entwicklung und Anwendung der Robinson-Verbunddecke in Frankreich

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I - INTRODUCTION

This Symposium is devoted to the examination of the carpets to be applied to the light steel decks of highway, bridges that is to say primarily to orthotropic decks.

As the rapporteur, Dr. W. Henderson, has stated, this type of deck is the latest version of many artifices introduced by bridge engineers in order to :

- reduce the dead weight of the bridge deck,
- employ the decking material as an element capable of resisting the bending induced in the superstructure as a whole,
- reduce the overall depth of the superstructure.

Nonetheless, there are decks other than orthotropic which fulfil all these functions. There is, for example, in France a thin concrete deck, reinforced by a continuous supporting steel plate, which was developed and tested in 1950 by J.R. Robinson (Technical adviser to the IABSE) and J.R. Courbon, and which is known as the "Robinson deck" (1).

This deck has been used since then in dozens of French steel

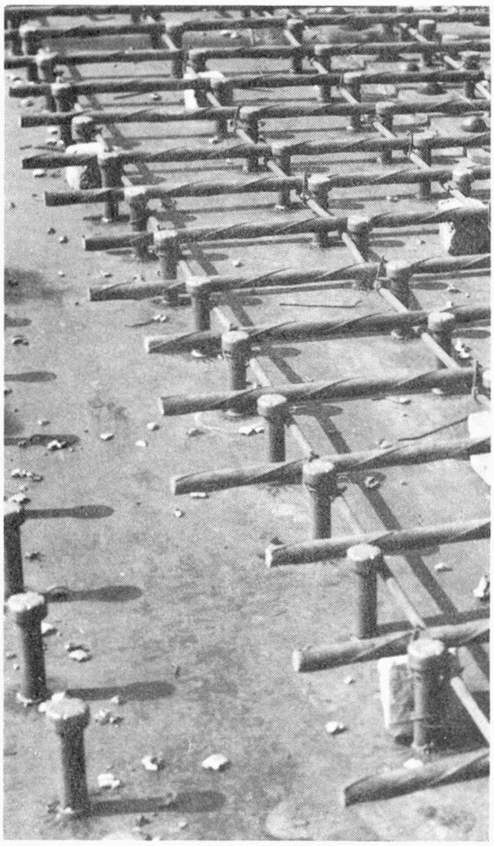
(1) See especially :
J.R. Robinson, Preliminary publication, 4th Congress, IABSE, Cambridge, 1952
A. Schmid, Platelages légers pour ponts-routes, 7th Congress, IABSE, Rio de Janeiro, 1964.

bridges, including some of the most spectacular and some whose headroom requirements were critical. None of these schemes have caused the slightest trouble from the point of view of surfacing or decking or the system adopted.

By contrast, problems concerning the adherence of the carpet are presented when aluminium decking, which is used in moving bridges in docks, or orthotropic decks are employed, although the latter have been little used in France because the obstacles to be crossed require relatively small spans.

II - DESCRIPTION OF THE ROBINSON DECK

The deck is of composite steel and concreteconstruction, consisting of :



- a continuous steel supporting plate the thickness which is at least 6 mm (2),
- a concrete slab, poured onto this plate, to which it is attached by shear connectors which are either :
  - studs which transfer the shear forces between the steel and the concrete, as in Fig.1, or,
  - strips, bent at 45°, the lower parts of which are welded to the steel plate and the upper presenting horizontal portions, to which the reinforcement rods are welded, thus absorbing the shear forces by bond to the concrete, as in Fig. 2

Fig. 1

(2) The French regulations for steel bridges (CPC-61-V) require that every structural element shall have a thickness of at least 8 mm, unless it is protected on one side (as is the case with the Robinson deck, thanks to the concrete slab), when it may be reduced to 6mm. Nevertheless, to limit the deflection in the plate under the load from the concrete and the effect of welding stud connectors, it is unusual to descend below 8 mm.

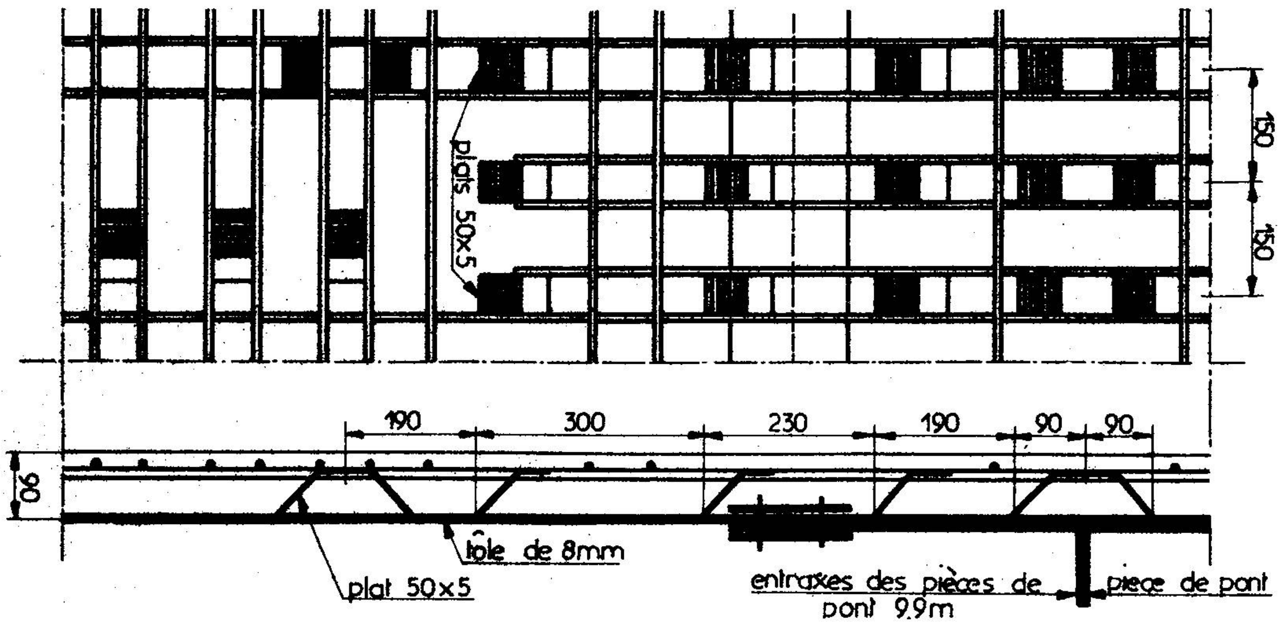


Fig. 2

The thickness of the concrete slab is considerably less than that required for a reinforced concrete slab, which on account of punching shear could scarcely descend below 16 cm.

By contrast, in the case of the Robinson deck, the continuous supporting steel plate, which is connected to the girders, acts as a membrane and avoids any risk of punching shear in the deck.

The minimum thickness of the slab is therefore fixed by the resistance to bending. Under the transverse bending moments between the girders, the compressive stress in the concrete must not exceed 0.6 σ_{28} (which in practice limits the stress to between 175 and 200 kg/sq.cm).

As the spacing of the stringers varies from 1.0 to 2.5 m, the thickness of the slab varies from 6 to 10 cm.

<u>The supporting steel plate</u>, like the upper plate of an orthotropic, deck, plays several rôles :

- it resists local transverse bending between the main girders (or the stringers)
- as it is connected to the main girders and to the stringers (if there are any), it acts as the top flange of these members

in resisting bending.

III - SPHERE OF USE

Comparison with other kinds of surfacing

Let us compare the weight per sq.m. of reinforced concrete, Robinson and orthotropic decks. In the first two cases, the wearing surface has a thickness varying from 4 cm (where it is necessary to keep the weight down, as in a swing or lifting bridge) to 6 cm. For orthotropic decks, a thickness of 7 cm is considered necessary. The densities considered are : 2.25 tons/cub.m for bituminous carpets, 2.5 tons/cub.m for concrete and 7.85 tons/cub.m for steel. Finally, the weight of the orthotropic deck is calculated by considering an "equivalent thickness" (12 mm thick plate + stringers and cross girders) of 25 mm.

Weight in kg/sq.m

Deck	Reinforced concrete	Robinson	Orthotropic
Surfacing	(0.04 to 0.06)x2250= ∿100	100	0.07x2250=∿150
Concrete	0.18x2500 = 450	0.08x2500=200	-
Steel	-	0.008x7850=65	0.025x7850=∿200
TOTAL	550	365	350

This comparison demonstrates that the Robinson deck and an orthotropic deck are of about the same weight.

It must be said, however, that :

- As far as general bending is concerned,all the steel section of the orthotropic deck acts, equally in tension as in compression, while, by contrast, only the bottom plate (of smaller section) of the Robinson deck can resist tension in the zones subjected to negative moments (and where the concrete is also in tension).

- Although the spacing of the main girders for orthotropic decks may be large, for the Robinson deck it must be limited. Alternatively, intermediate stringers may be used which of course increase the amount of steel employed beyond the figure mentioned above.

From the experience gained in competitions and in the structures erected in France, it is possible to say that at the present time in our country :

a) The Robinson deck is the type of deck to adopt for steel bridges required for spans of about 100 m or less, when the depths are less than 1/30 of the span (a reinforced concrete deck is too thick in comparison with the Robinson deck which allows a reduction in depth of about 10 cm).

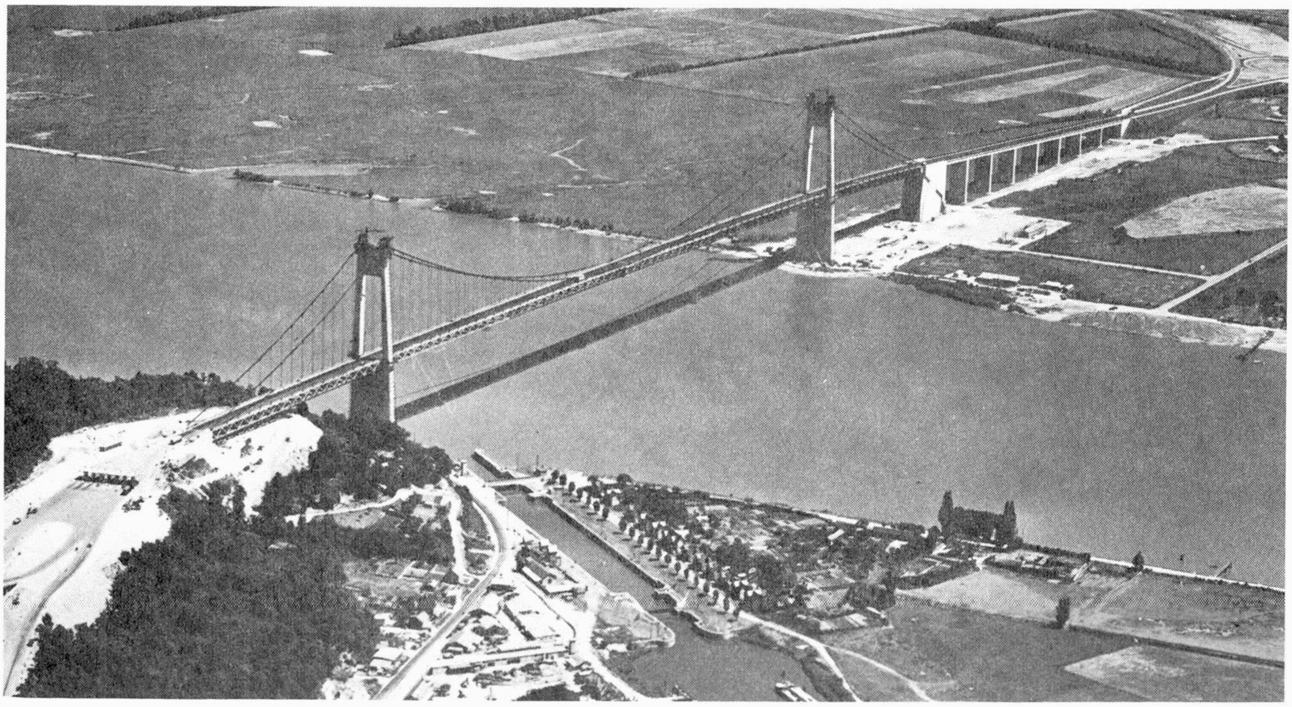
b) The orthotropic deck, intrinsically more expensive because of the price of steel, which is more than that of concrete, and of the expense of fabrication and multiple welds, is considered for structures whose spans are at least 150 m.

IV - PRACTICAL EXAMPLES

IV.1 - Suspension bridges

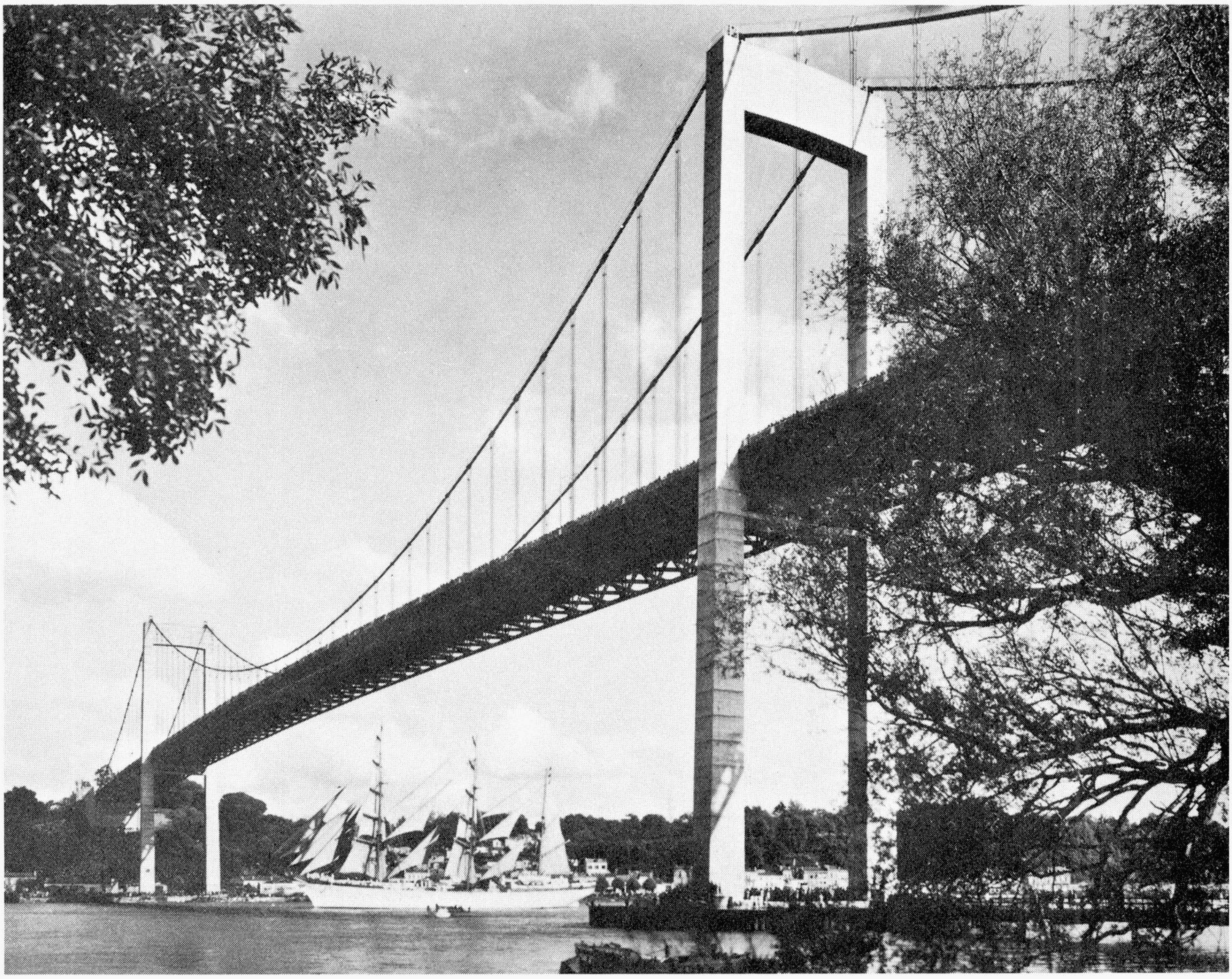
The two latest (and greatest) suspension bridges built in France have a Robinson deck.

Fig. 3



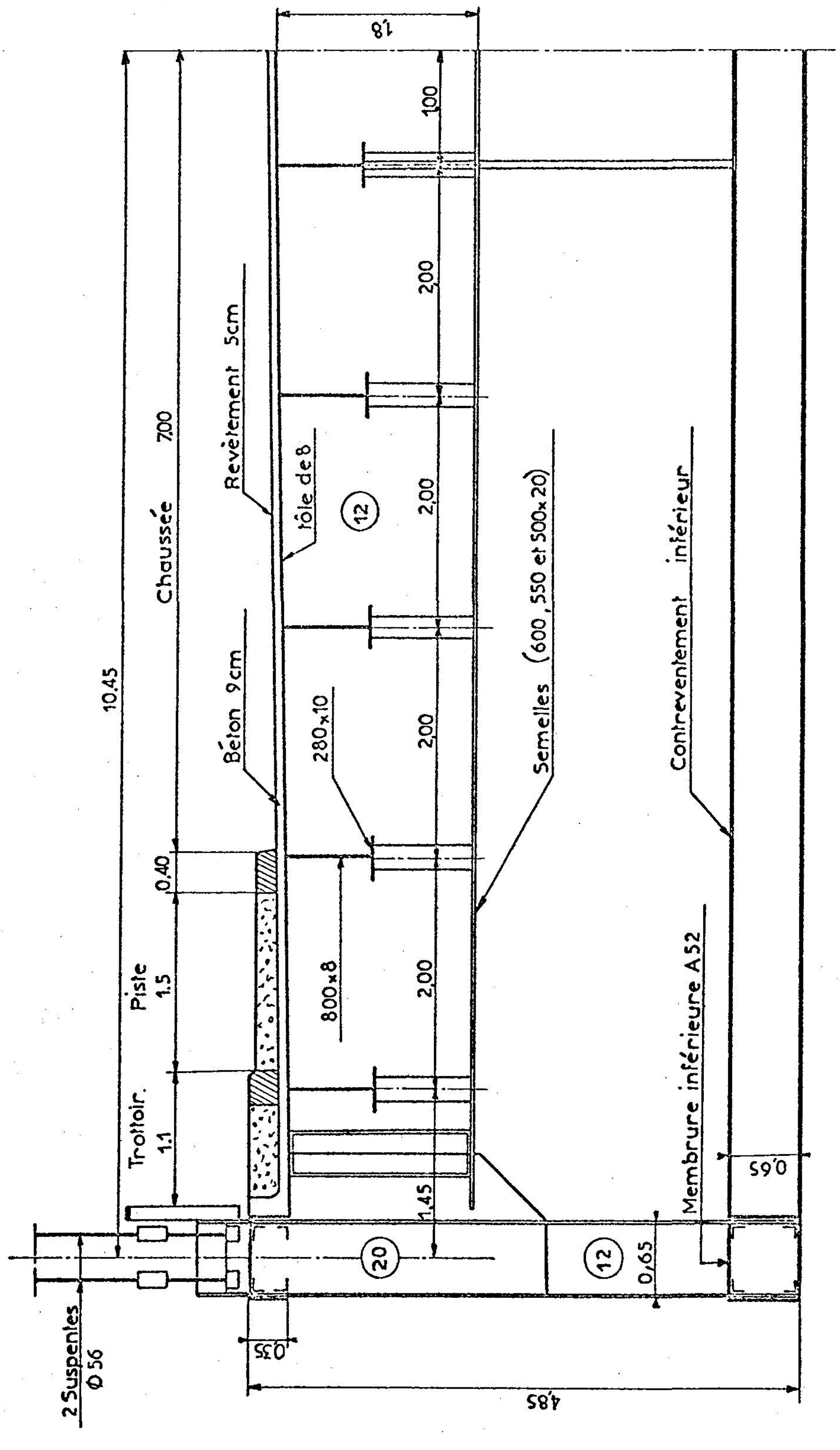
Bridges	Spans m	Spacing of stringers m	Thickness of decking		Connectors
			Plate cm	concrete cm	
Tancarville (Fig.3)	176+608+176	2.0	1.0	9.5	Studs
Bordeaux (Fig.4.5)	150+384+150	2.0	0.8	9.0	Strips at 45°

Fig.4



PONT SUSPENDU DE BORDEAUX

Demi.coupe transversale



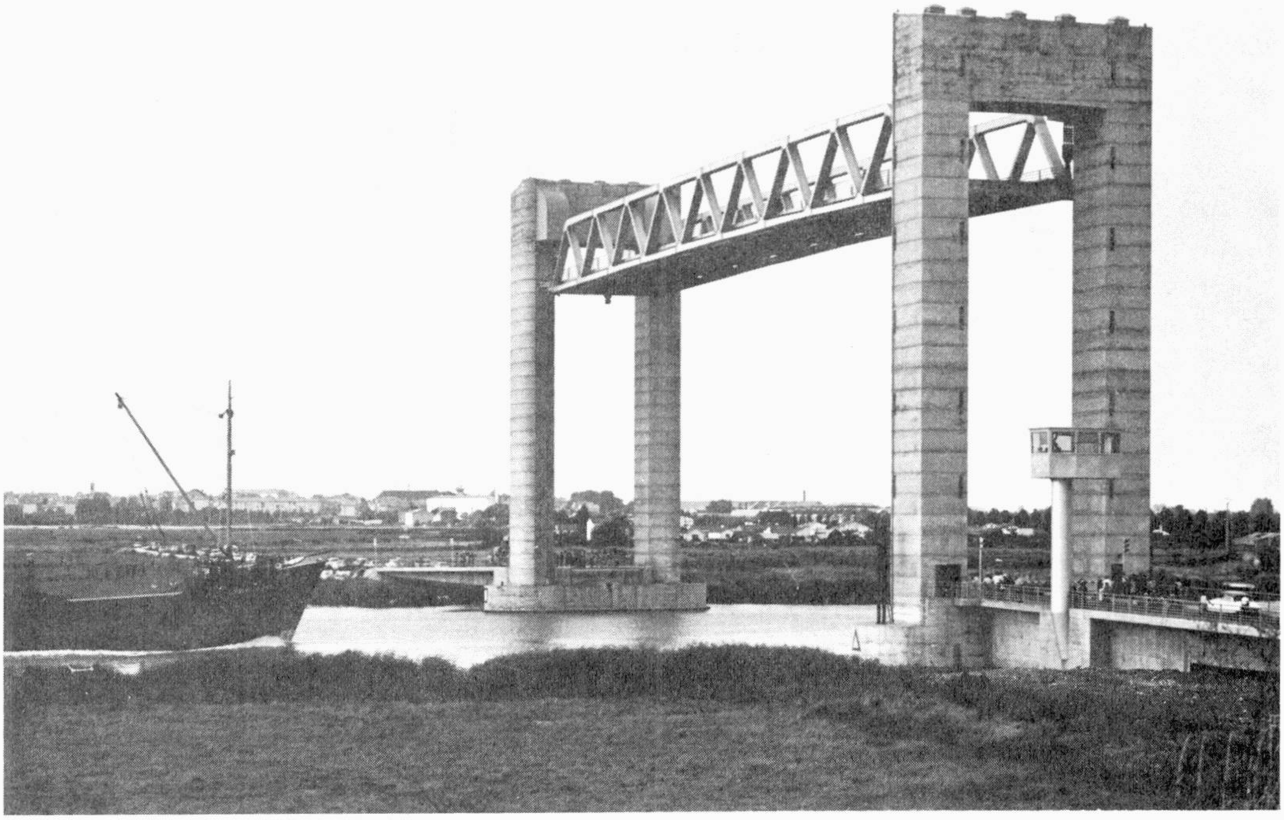


Fig.6

IV.2 - Moving bridges

The last two moving bridges built in France were lifting bridges. They are of the through type with Warren girders and a Robinson deck.

In the case of the bridge at Brest, the slab rests on a curved plate, the minimum thickness being above the girders and the maximum at mid-span.

Bridge	Span m	Spacing of stringers m	Thickness of decking		Total depth of superstructure
			Plate cm	Concrete cm	
Brest	87.50	1.50	0.6	5 to 9 (curved plates)	1.35
Martrou (Fig.6)	92.43	1.10 to 1.60	0.8	6 to 9	1.01

IV.3 - Slender bridges

Kind of bridge	Bridge	Span m	Total depth of superstructure m	Thickness	
				Plate	Concrete
Single span girder bridge	Attigny	21.5	0.575	1.2	5 to 9 (curved plates)
Continuous girders bridge	Lorient	63+95+63	3.70 to 2.18	0.8 to 2.0	6
Portal	Jeumont	32.9	0.69	1.0	5 to 18 (curved plates)
Triangulated through girder bridge	Rangiport	102.52	1.222	0.8	6 to 10 (curved plates

V - CONCLUSION

In the last twenty years many French steel bridges have been built with the Robinson composite steel and concrete deck, scarcely heavier than an orthotropic deck.

The thickness of the bituminous carpet, which is normally 6 cm, could be reduced to about 4 cm for moving or highly trafficked bridges.

There have been no difficulties connected with :

- the adherence of the surfacing (which is the same as that in current use for concrete bridges),

- the resistance of the supporting steel plate to corrosion. It seems that its top surface is protected by the concrete. In addition, as the plates are usually made continuous by welding, no water can pass through them.

SUMMARY

Light bridge decks in composite construction of the Robinson-type have been used in France for nearly 20 years, especially for bridges with spans up to 100 m and/or with relatively small depth, as well as for movable bridges.

A brief description of this type of deck and some examples of such structures are given.

RESUME

La dalle mixte légère, système Robinson, est employée en France depuis près de 20 ans, notamment pour des ponts à portées jusqu'à 100 m ou à hauteur de tablier relativement faible, ainsi que pour des ponts mobiles.

Une description sommaire de ce type de dalle ainsi que des exemples de ponts construits sont donnés.

ZUSAMMENFASSUNG

Die leichte Verbunddecke System Robinson wird in Frankreich seit fast 20 Jahren angewandt, und zwar hauptsächlich für Brücken mit Spannweiten bis zu etwa 100 m, und/oder mit relativ kleiner Bauhöhe sowie für bewegliche Brücken.

Eine kurze Beschreibung dieses Deckensystems und einige Anwendungsbeispiele werden angegeben.

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USE OF P.V.C. TILES BY PORT OF LONDON AUTHORITY

L'emploi de dalles en P.V.C. par la "Port of London Authority"

Anwendung der P.V.C.-Fliesen durch die Port of London Authority

R.E. WEST
Port of London Authority

The Port of London Authority are responsible for a number of bridges in the docks under its control and most of these are of moving type to permit the passage of shipping. To reduce the power required from the operating mechanism as much as possible all the dead-weight of the span has to be counter-balanced with the result that the loan on the supporting rollers or bearings is much higher than it otherwise would be.

Much has been done of recent years to reduce structural weight and considerable thought has also been given to deck surfacings. The P.L.A. have considered the use of various alternatives to rolled asphalt; which weighs some 11 lb. per sq. ft. for each inch of thickness, and for their new bridge which they have recently designed for the South Dock Entrance at India & Millwall Docks they intend to adopt a p.v.c. material containing ground mineral fillers. This will be 2.5 millimeters in thickness and weighs only 1 lb. per sq. ft.

This surfacing has been extensively used for a number of years as a road marking material and was first adopted by the P.L.A. for surfacing the lifting section of a covered footbridge which was completed in 1964.

The new bridge will have the sheeting on the road as well as on the pavements and the reasons which led to its adoption are perhaps of interest.

The carriage-ways will be formed from a welded battle deck structure which has been designed for full H.B. loading and some deflection of the $\frac{7}{8}$" road plating is of course expected. This deflection will not be much reduced by the use of a thin light-weight surfacing and the flexible tiles are therefore to be preferred to a material which has a hard setting characteristic, such as many epoxy compounds.

The sheeting has a highly non-skid triangular embossed surface and has good wear resistant properties, which have been amply proved by tests on trunk roads and pedestrian crossings in areas of intensive traffic. It will be laid in tiles 2' square and replacement will be an easy matter when eventually required.

An incidental advantage of the sheeting is that it is available in several colours including black and white making it possible to build carriageway lines etc. permanently into the surface.

It is obviously essential that the surfacing should adhere strongly to the deck plating and close attention has been given to this feature and to the necessity for protecting the steel-work from corrosion. This latter problem is aggravated by the necessity for leaving a gap of $\frac{1}{8}$" between the tiles when they are laid to allow for spread in service and these gaps have to be effectively sealed to prevent moisture seeping underneath.

It was originally intended to first prepare the deck by grit blasting followed by zinc spray with the tiles bonded to the zinc and sample plates for this treatment were made up for testing. It was found that the adhesion of the zinc to the steel was substantially less than of the tiles to the zinc and that better adhesion altogether was obtained by the grit blasting followed by a weldable primer only between the tiles and the steel. This treatment will be adopted for the new bridge and the joints between the tiles will be sealed with the adhesive.

SUMMARY

The author discusses the considerations leading to the adoption of polyvinyl chloride tiles as a carriageway surface on an opening bridge.

RESUME

L'auteur explique les raisons pour l'emploi de dalles en P.V.C. comme revêtement routier sur des ponts mobiles.

ZUSAMMENFASSUNG

Der Autor erklärt die Beweggründe, welche P.V.C.-Fliesen als besonders günstig für Straßendecken auf beweglichen Brücken erscheinen lassen.

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CONCLUSIONS

Schlußfolgerungen

Conclusions

W. HENDERSON
Great Britain

Interest in Theme II has centered round the grid decks, both open and filled, described by Mr W. J. Wilkes, the "Robinson" deck described by M. D. Sfintesco and F.J. Fauchart and the use of industrially manufactured tiles (in particular polyvinyl chloride), as a surface discussed in a paper by Mr K. H. Best and a contribution By Mr R. E. West. That is to say the theme has crystallised into two diverse subjects; one, the development of lightweight decks other than the simple steel plate of the orthotropic deck, and the other, the development of industrially pre-manufactured tiles cemented to the steel plate by adhesives.

The grid deck continues to be used in U.S.A. after forty years of application. In its open form it clearly is of considerable value on suspension bridges in providing wind-slots to combat aerodynamic instability on an area of deck which can still be used by traffic. The open form has, however, disadvantages as a running surface; these have been referred to in the preliminary report. To overcome loss of adhesion Mr Wilkes has mentioned the practice of welding steel studs or serrated bars to the top surface of the grid and the question of the extent to which these might damage the tyres of vehicles was raised. Whatever the efficacy of these devices may be, there can be little doubt that viewed solely as a riding surface for vehicles, the open grid deck is inferior to other types of construction, although these shortcomings may well be more than offset by other considerations such as the provision of wind-slots, for example. It is also feasible that the use of this expedient could be used to convert a wholly open wind-slot into a useful "pull off" area for broken-down and damaged vehicles, where its shortcomings as a running surface would not be significant and might indeed be turned to advantage.

The grid deck filled with lightweight concrete clearly provides a robust and sound road surface which can, if desired, be paved with one or other of the orthodox road materials without concern for the flexural problems associated with orthotropic steel plate. The concrete over and around the steel fabric of the grid should offer considerable protection against corrosion and as the grid with its infill can be used compositely with the supporting stringer, the adoption of this type of construction seems to depend solely on economics. Mr Wilkes has given a useful table of comparative weights of various types of deck which shows the filled grid to be about twice the weight of an orthotropic plate and about half that of a reinforced concrete deck. Comparisons of cost are not possible without consideration of the effect of varying load on the supporting structure, but it is extremely doubtful if the filled grid would be economically competitive except where it is available as a standardised factory-made product, and even then it appears likely to be costly.

The "Robinson" deck has now been used extensively in France over a period of up to 18 years and has given excellent service. The presence of a layer of 2½" (6 cm.) to 4" (10 cm.) of concrete over the supporting steel plate and acting compositely with it provides an excellent and stiff foundation for surfacing materials. Since these bond well to concrete and the concrete is shear connected to the steel, adhesion problems appear to have been overcome. The facility with which a concrete surface can be regulated, given proper care and supervision is also of considerable advantage in providing good riding quality on the road. This type of construction appears to have considerable potential and to be well worthy of cost studies in countries other than France where it is said to have been trouble free in use. The question of the effects of cracks in tension zones on corrosion problems was raised in discussion but it was indicated by the author that he knew of no difficulties in this respect.

Twenty years is probably an insufficient period for corrosion damage to become obvious; nevertheless it seems quite possible that this is not likely to become serious even over a very much longer period. Shear connection should prevent "fretting" as a consequence of one surface moving over another, the oxygen content of any water which penetrates through cracks may become minimal and the cracks may become sealed with the first products of corrosion. This aspect is worthy of further investigation. It is perhaps relevant to note that on many old bridges where dished or buckle plates covered in concrete were used, corrosion, where it has taken place, has often done so much more slowly than might be expected. There is also evidence of quite considerable shear connection through friction alone without the aid of shear connectors.

It was also suggested that welding shear connectors to the steel plate could introduce "stress-raisers" and the risk of fatigue cracking or, alternatively, raise the cost unduly by designing at suitably reduced steel stresses. It appears that no adjustment of working stress on account of fatigue is made in France and that no damage has been observed. It seems likely that the adverse effect of steel shear connectors in this respect has been considerably exaggerated in some quarters; however, 20 years is again probably too short a period from which to draw conclusions from performance on site and some research in this field may be desirable.

The use of factory-made tiles of asphaltic material was tried some thirty years ago and gave satisfactory results over a long period on one bridge. Subsequently, it seems, the product did not come up to the same standard of quality and the use of this material seems to have been abandoned. That a factory-made product should not maintain a standard of quality is deplorable.

At the present time the only material of this sort which seems to have been used to any extent is the polyvinyl chloride tile described by Messrs Best and West. They appear to be tough, durable and to offer a considerable co-efficient of friction. They also appear to be reasonably easily stuck to the steel plate and to offer good protection against corrosion. Their use so far has been confined to structures where the traffic is heavy in terms of weight, but slow moving. It remains to be established whether these tiles would be satisfactory on bridges carrying dense, fast traffic. An important consideration in this respect (and for other thin surfaces) is the specified tolerance on irregularity of the surface which can be limited to, e.g., $\frac{1}{8}$" on a 10' chord length. This degree of flatness would be very expensive to achieve on fabricated large plates, but tiles, being of uniform thickness, will follow the contours of the plate. It seems unlikely that regulation could be achieved in the adhesive layer, but this requires investigation. Perhaps more important; is such a degree of flatness really necessary when associated with great cost? Could greater tolerance be allowed without inconvenience or danger to traffic, possibly with the qualification that the "high" spots do not occur at regular intervals likely to coincide with vehicle spring frequencies at prevailing traffic speeds?

These P.V.C. tiles must be laid with a small gap between them to allow for plastic flow under the effects of traffic. The gaps are filled with adhesive and this seems likely to introduce a region of vulnerability, both in respect of corrosion and of damage to the tiles. Is it possible that this need might be obviated by pre-treatment and that the tiles could be butted in construction?

The general impression is that there is a great potential in the application of this sort of synthetic material, but that much more research and study of the properties required and the conditions to be met is necessary. This calls for close collaboration between chemist and engineer and it is to be hoped that further efforts will be made in this field.