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VII a

General Report.

Generalreferat.

Rapport Général.

Dr. Ing. K. Klöppel,

Leiter der technisch-wissenschaftlichen Abteilung des Deutschen Stahlbau-Verbandes, Berlin.

During recent years the steady pursuit of greater economy in construction has been combined with a desire to allow due weight to aesthetic feeling in the design of our bridges and in the development and application of steelwork generally. The artistic side of bridge design is now so much stressed that not infrequently a solution conspicuously good in this respect may be preferred even when it is not the cheapest that would satisfy the problem. To say this is not to imply that the aesthetic aspects of bridge building have been neglected in the past; for it is to those bridge builders who were at once engineers and architects, and who enjoyed the most unchallenged freedom of choice in their work, that we owe the existence of bridges of a aesthetic excellence beyond doubt and beyond the reach of change of fashion. We can only wonder at the boldness of the engineers who built long spans like the Britannia bridge and the Weichsel Bridge in Eastern Germany in the middle of the last century. Nor, in our present recognition of the primacy of the artistic side of bridge design, must we underrate the achievements of those engineers who, swept along by the rising flood of statical development which marked the years before and around 1900, envisaged their main objectives as mastery over statically difficult systems and in the choice of those structural forms which called for the smallest quantities of materials. The difficulties of that period — now almost at its end — were inherent in the designers' preoccupation with statical science, and they led, inevitably while they lasted, to a divergence between the engineer and the architect, the origin of which is now too readily forgotten.

This consideration is relevant when considering many of the old lattice bridges (such as the classical cantilever construction by Gerber over the Main at Hassfurt) which, though their "mathematical" form has become out of date, still stand as valuable and noteworthy monuments in the history of great bridge construction. From this intermediate phase of vigorous statical development we have now won through to a fortunate position in which we are enabled by the high standards attained in metallurgy, rolling practice, steel erection and statical procedure to subordinate the purely technical problems of bridge engineering to such refinements as (for instance) the choice of uniform and effective spacings for the stiffeners on the outside faces of plated girders, providing any additional

necessary vertical stiffeners on the inner face together with those horizontal stiffeners which may be particularly effective under conditions of heavy bending stresses.

Once again the eye is ready to recognise the beauty of clear-cut forms, and hence the reviving trend of co-operation between the engineer and the architect. But such co-operation is no longer understood to imply merely the addition of architectural trimmings; the architect now lends his aid in the actual detailing of steel bridges (as for instance in so arranging cantilever footways that they appear as a lateral closure of the bridge). In this it is right to acknowledge an important step — perhaps even a decisive step — forward in much debated ground; a step which marks the final escape of steelwork from that past period in which the architect looked upon steel as a medium foreign to his art, wherein he would build only with reluctance, and wherein his early efforts were often unpropitious. It was, however, a condition of this recent advance that the architect should consent to some initiation into the fundamental statical and constructional problems of the engineer.

The aesthetic value of a bridge is conditioned — apart from subjective aspects — by the primary laws of design in nature — namely, eurhythmy and symmetry. The fulfilment of these laws, which will give recognition to builders for all times, lies in the employment of the simplest forms of construction. In this matter beauty and suitability are one; always provided that suitability is understood as meaning not merely the solution of the problem with the least possible use of material but its solution against a background of general understanding of the way in which a structure operates — an understanding which is, in fact, much more wide-

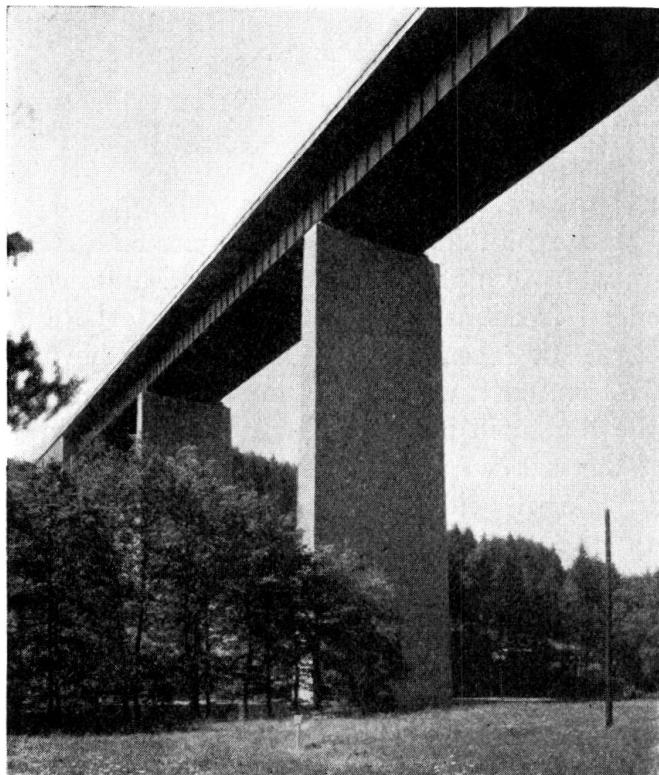


Fig. 1.

Reichsautobahn bridge at Siebenlehn.

spread than the engineer is disposed to admit. It is logical enough, therefore, that while the predominant type of bridge on the Reichsautobahnen is one of extreme simplicity advantage is being taken of the present development of technique to utilise economical forms of design of the beam type with the roadway above the girder, even in spans where arch bridges or compound forms of girder would previously have been preferred. In Germany there exist some masterly examples of this type of bridge, as for instance the Mangfall bridge at Darching (see Fig. 10, page 1348 in the Preliminary Publication). Later, in constructing

the viaduct near Siebenlehn (Fig. 1) the slender concrete piers were encased in natural stone, their vigorous pattern and varied tint being in pleasing contrast to the restful flatness of the rigid line of the steel superstructure. Another new development in the arrangement of steel bridge supports in the form of plate webbed portal frames (see Fig. 17, page 1355 in the Preliminary Publication). These supports give a paramount impression of boldness and slenderness which particularly suits the woodland setting of the bridge, and at the same time they serve to express some sense of the ease with which the interplay of forces is regulated and the great reserve of strength inherent in the steelwork.

Where it is possible through organic design of a deck girder bridge so to increase the constructional depth of the main girder that a trussed lattice construction becomes possible, and where this solution is not ruled out by the ver-

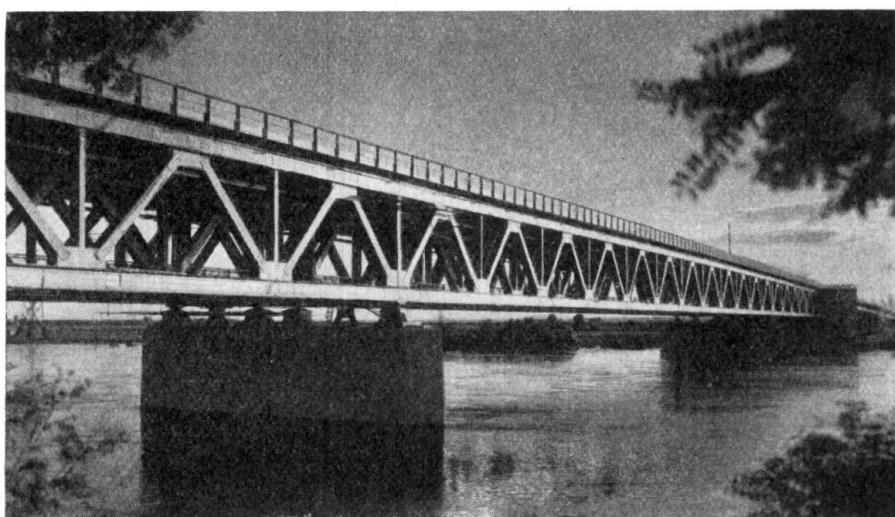


Fig. 2.

Reichsautobahn bridge at Hohenwarte.

tical and horizontal dimensions of the whole, the use of a truss should be contemplated not merely with a view to economy in material but also on account of its aesthetic effect which is in no way inferior to that of a plate webbed deck girder (see Fig. 2). It is generally and wrongly assumed that architects are flatly opposed to the use of trusses, whereas the fact is that they appreciate the varied expressiveness of this type of design and exult in the ornamental way that the interplay of forces is mastered therein. It is in this very choice of harmonious arrangement in the design of a truss — a choice always to be made with due regard to the scale dictated by the surroundings a matter too often neglected in the past — that co-operation between the architect and the engineer may hope to achieve its happiest results. In a suitable situation there should be no hesitation even in reverting to the use of fine meshed lattice work, for the well known objections to this form of construction no longer hold good, and it is one which can be made to harmonise excellently with a beautiful wooded landscape. The truss is the original form of steel bridge construction and the one which best lends itself to calculation, and there could be no justification for engineers ceasing to

develop this form of design. For long spans, in cases where the main girder must necessarily be placed above the roadway and where a trussed form of girder is, therefore, essential, its design has long been brought to a masterly degree of perfection (see Fig. 22, page 1358 of the Preliminary Publication).

Among the other basic types of steel superstructure the open-webbed arch with a suspended roadway is one which, during the last decade, has been used with advantage over very large spans of the order of 500 m, as for instance in the case of the Sydney Harbour Bridge. Here, just as was once the case in contemplating bridges of 100 m span, the impression of boldness tends to make one overlook the successful aesthetic effect. It is true that with spans of about 300 m slender plate-webbed arches also produce a very satisfactory aesthetic effect. In cases where the constructional depth is very small and the possibility of placing

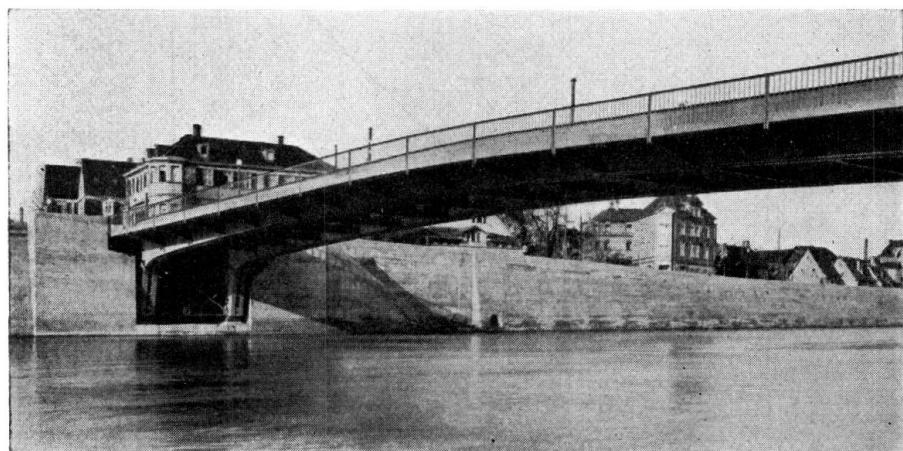


Fig. 3.
Wilhelm Bridge over the Neckar at Cannstatt.

the main girders above the roadway is limited by considerations of visibility, so that beam bridges with more than two main girders are ruled out, the true arch with a suspended roadway should again find scope for adoption over spans of less than 100 m. A recent development in this field has been the *Langer girder* (a particular type of bow-string girder, or beam reinforced with arch), presumably the result of difficulties in foundations.

The Swedish Mälarsee bridge, partly of welded construction, will be well remembered mainly on account of the instructive international competition of which it formed the object. In this design steel bridge engineers were offered the attractive (but unfortunately rare) problem of bridging across a wide sheet of water by means of an arch with an overhead roadway (see Fig. 1, page 1327 in the Preliminary Publication). Many of the details, also, are pleasingly successful (see Fig. 4, page 1329 of the Preliminary Publication) including the tubular supports, for which the use of welding proved particularly well suited. Welding may, indeed, be the means of reintroducing the use of tubes in bridge work to an important extent.

For small spans where the maximum possible rectangular opening is desired, as for instance over navigable waterways, a recent development has been the *rigid*

frame (see Fig. 3) in place of the arch, and there are many difficult problems from the points of view of construction, traffic or hydraulics to which no other satisfactory solution could be found than this space-saving type of steel bridge.

Finally, a brief reference must be made to *suspension bridges*. In America bridging problems reach an extreme which nothing but the suspension bridge is capable of solving, and it is there that the engineering world is now being staggered by the construction of the largest bridge in the world, namely the cable suspension bridge over San Francisco Bay with the prodigious span of 1,280 m (see Fig. 4).

The attraction of suspension bridges, both to the general public and more particularly to structural designers, is justification enough for the endeavours



Fig. 4.
Golden Gate Bridge.

that have been made in recent years to reduce the cost of such construction so that it shall be suitable even for the smaller spans encountered on the European continent and be competitive with other types. By improving, amplifying and simplifying the application of the "deflection theory"¹ — a method of design which takes account of the fact that elastic deformations relieve the loading of the stiffening girder and lessen its deflection — notable savings have been realised even in the case of suspension bridges of 200 m span with ground anchorage (see the original design for the Reich bridge at Vienna in Fig. 2, page 1278 of the Preliminary Publication). This form of calculation is true to the facts; in the case of pure arch bridges of long span it implies indeed an increased consumption of material (though the increase is small compared with suspension bridges), but when the span exceeds about 350 m it implies a reduction in the moments of the stiffening girder by more than 30 %, and a reduction in the deflection by as much as 50 % by comparison with the approximate method of calculation. If account is taken also of the economies that can be realised through using lighter roadway construction (reduction in the ratio of

¹ H. Bleich: Berechnung verankerter Hängebrücken (Springer, 1935). — F. Stüssi: Publications. I.A.B.S.E., Vol. 4, 1936. — W. Blick: V.D.I.-Zeitschrift, 1933, Vol. 77, No 34, p. 921.

live to dead load) there is ground for expecting a more frequent adoption of small suspension bridges, and the likelihood of this would be increased if it were possible to reduce the proportion of cost incurred in the cable.

This point may serve as a transition to considering questions of economics and development in steel construction; with special reference to the use of *high tensile steel* (a material to which many beautiful girder bridges owe their slender appearance) as well as the development of *welding* and the resulting use of *light construction*.

Recent fatigue tests² indicate that results obtained in usual statical tests provide no reliable criterion for the fatigue resistance of various kinds of steel and structural members.

Under repeated, non-alternating stress, the amplitude of stresses in St. 52 is not much greater than in St. 37, while on the other hand the suitability of St. 52 for fatigue stresses is indicated even in cases where the initial stress exceeds the yield point of St. 37. Hence in the German regulations for railway bridges the use of St. 52 is contemplated mainly for members in which the initial stress is considerable (as for instance on account of dead load), which is the usage suggested by the shape of the curve correlating permissible stresses with the ratio of maximum to minimum stress (see Fig. 5). This is the reason why originally St. 52 was developed for very large bridges, for in these the conditions of stress are such as to render an increase in the permissible stress of St. 52

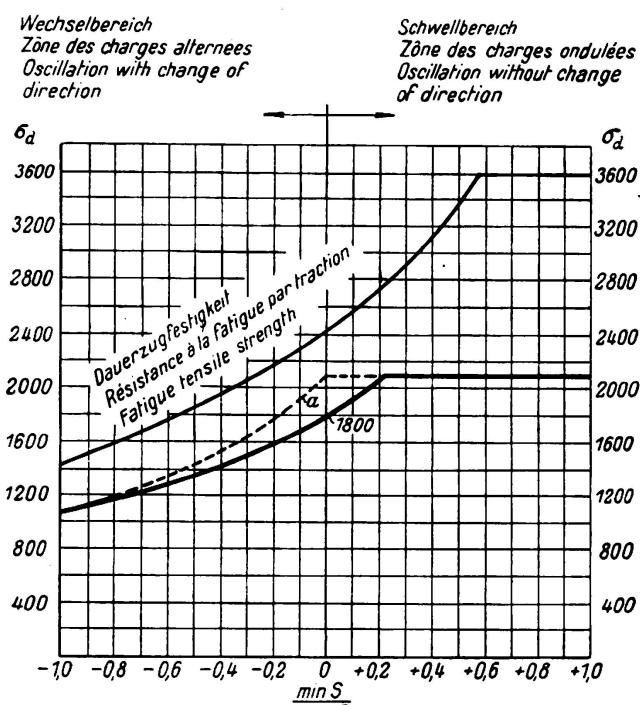


Fig. 5.

Permissible stresses according to the German Regulations for the Design of Steel Railway Bridges (Heavy Traffic), and tensile fatigue strength of riveted members in St. 52/44. Curve a applies when max S is compressive.

subject to the same considerations as those which entail a reduction in that quantity, in railways bridges, within the range of alternating stress and of the lower part of the range of pulsating stress. By the same reasoning there would appear to be scope for its use in road bridges and in building frames.

The applicability of results obtained on small specimens in a pulsator testing machine to the structural arrangement and conditions of stress in an actual bridge is problematical. Even though we know that the frequency of loading, and perhaps also the length of the intervals between traffic, are of no importance

² Klöppel: Gemeinschaftsversuche zur Bestimmung der Schwellzugfestigkeit voller, gelochter und genieteter Stäbe aus St. 37 und St. 52. Tests to determine the tensile surge load strength (tensile fatigue strength) of solid, perforated and riveted bars of steel 37 and steel 52. Stahlbau 1936, № 13/14, p. 97. And other references.

within the range which concerns us, many questions nevertheless remain unanswered. Lack of space prevents going closer into these here, though they are questions which must exert a decisive influence over the further development of the regulations. It will merely be stated that experience shows the dimensions prescribed by the regulations to be well on the safe side as judged by the results of fatigue tests carried out to date.

The concepts hitherto recognised such as yield point, ultimate strength, elongation at fracture, and reduction in cross section, are inadequate to explain the differing behaviour of the available steels under fatigue stresses, or many other observations which affect the suitability of designs — for instance, the circumstance that the effects of concentrations of stress increase with the size of the specimen, even though geometrical similarity and the same flow of forces is preserved. These are questions relating to the fundamentals of steel construction which can be cleared up only by reference to the *mechanics of materials*, and their use as criteria for the safety of a structure makes it necessary that they should be understood both in the sense of the mathematical theory of elasticity, and in that of general statical, constructional and practical application to the purpose in view. It follows that the mechanics of materials are an indispensable study for the steelwork engineer. He alone is in a position to determine which of the results will enable the known lacunae in the principles of steelwork construction to be filled. He must become familiar with how the mechanics of materials depend on physical data, while recognising that resistance is limited by susceptibility to corrosion and flow and is effected by concentrations of stress due to the presence of notches. In order to keep step with improvements in our methods of calculation it is necessary that our knowledge of the actual resistance of materials should be increased, and from this point of view research on the phenomena of plasticity acquires an additional though indirect importance beyond that appertaining to it in Question I of this Congress.

The welcome saving in weight represents no more than the first of the possibilities of increased economy in steel construction that can be realised through the adoption of *welding*. In this matter we are at the start of a development which is destined to be revolutionary in so far as riveted connections are replaced by weld seams, for welding, where advantageous, will direct the trend of steel construction towards monolithic forms of design which are of the very essence of light construction. The road leading to this goal is doubtless a difficult one, but the extraordinarily rapid development which has already taken place offers encouragement to follow it: a development illustrated in the application of completely welded sitejoints in plate-webbed railway bridges (as in the Rügen-damm bridge) and of butt joints in main girders of large bridges on the Reichs-autobahnen (as, for instance, at Rüdersdorf). The increasing reliability of butt welds gives grounds for supposing that butt-welded tensile and bending members may be subjected to higher specific fatigue stresses than riveted members, because the permissible stress thus escapes the considerable notch effect due to the rivet holes, well made butt welds with smooth surfaces over the seam being practically free from this notch effect. This requirement is satisfied in rolled beams only when they are made free from holes at heavily stressed parts.

In nearly all fields of application of metals constructional development is tending in the direction of *light construction*, an idea which has become a stimulus for new and revolutionary endeavours. On no account should this be understood as a mere makeshift in construction. It should rather be regarded as a higher stage in the utilisation of material, attained through careful structural arrangement taking due account of the inherent properties of the material, which renders the structure lighter and, at the same time, more resistant and stiffer than existing forms of design intended for the same purpose. Thus a reduction in the amount of material is made the means of improvement in quality. In reviewing the application of steel this fact must not be overlooked, particularly since development of certain elements of steel work is proceeding in the direction of light construction. Such elements will be primarily steel plates, flats, tubes and weld seams. In so far as it is not possible to publish tables of carrying capacity based on experiments, the calculation of increased capacity conferred by the monolithic character and three-dimensional action of these structures must be effected by simplifying the more difficult methods of calculation and permitting approximate methods of design to be used under the regulations. The successes attained in aircraft construction as, for instance, with torsion-proof rigid box shaped girders and posts or load carrying partitions from corrugated sheets, encourages the idea that in steelwork, also, a more economical type of construction may be realisable which shall be no less resistant than the present form. To set limits to the course which these developments are likely to take in the long run, on the basis of experience now available, must be abortive, for the economical application of light construction entails far reaching alterations in method of fabrication. Even to-day large edge bevelling machines are making their appearance in steel fabricating shops, and the adoption of cold pressed sheets (a trend which may greatly reduce the importance of rolled sections) is drawing attention to steels with increased ageing resistance. Thin rust-proof steel sheets, also, are attracting more and more attention. The stimulus towards overcoming the difficulties of the transition stage may be found in the certainty that light construction is destined to open out new fields of work.

In road bridge construction a conspicuous feature is the development of *light weight decking*, the most notable line of endeavour in this direction being the use of a fine mesh grillage which behaves statically as if it were a slab, and which has been rendered possible through the introduction of welding. It is true that in the suspended plates (trough plates) we already possess a form of supporting member which makes the use of plates possible in steel construction. But these are exposed to certain disadvantages which form an obstacle to reducing the weight of the roadway, namely the considerable weight of the concrete filling and also, the risk of corrosion which arises if trough plates are used over larger areas than has hitherto been the practice. Attempts are being made considerably to increase the area of trough plates with a view to economising in the number of girders of the deck construction, and, although it is not found that this increase gives rise to difficulties from the point of view of strength, there is no general regulation governing calculation of these plates. There is a risk, moreover, that under unfavourable conditions of loading (especially where the

trough plate with its relative lack of stiffness is used) the concrete may separate from the plate and allow water to enter. This matter will be mentioned again later.

With a view to reducing the dead load of the concrete filling in the suspended plate the expedient suggests itself of adopting a floor construction of flat sheets which are made to function as membranes, as has already often been done in movable bridges. These call for a very close spacing of the longitudinal joists. Another solution to the problem is offered by the use of welded grid plates often known as "cellular steel floors" (Fig. 6); the strength and stiffness, as deter-

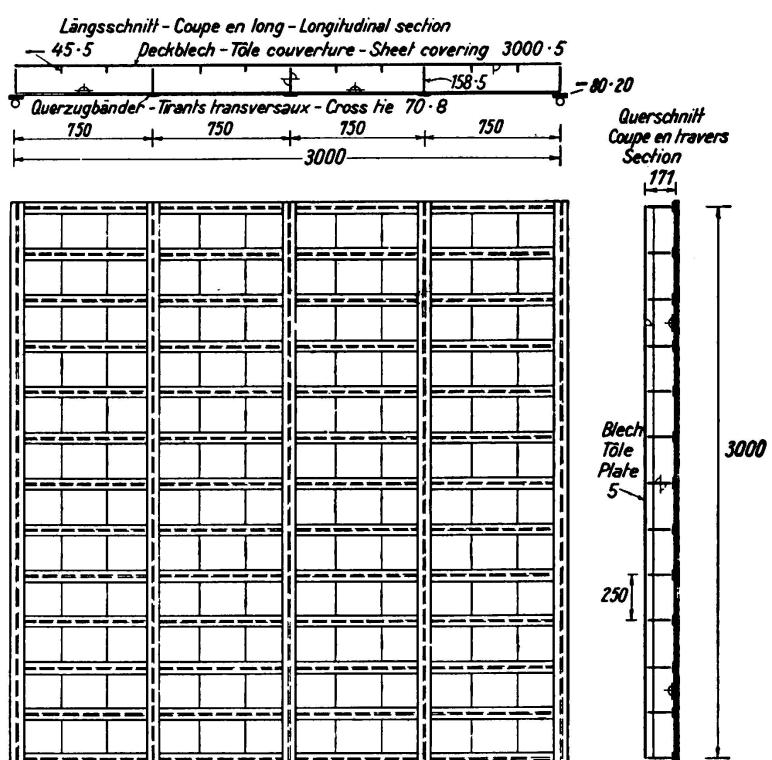


Fig. 6.
Tests on bridge floor members.

mined on specimens similar to those illustrated, are excellent, but the cost unfortunately is very high, as may be appreciated from the larger number of welded connections. Decking of this type has already been used with economy for field track crossings over the Reichsautobahnen. The limited amount of constructional depth required for the light-weight decking also enables economies to be realised in access ramps and other ancillary works, and in the case of small crossing bridges this may turn the balance of economy in favour of steel as against other methods of construction. The form of specimen shown in Fig. 6 (designed for a load of 110 kg/m^2) lends itself to a simple method of calculation applicable to these members which depends, in the first place, on an understanding of the load distributing action of the flat member in relation to its fixation around the edges and to the constructional details. In this way it is possible to arrive at a simple, realistic and economical method of calculation, similar to that employed for reinforced concrete slabs reinforced in two directions, and to incorporate this

in the regulations. The first of the relevant experiments at Stuttgart arouse the hope that justification may be found for adopting the approximate formulae for slabs stiffened against torsion which is laid down in the German Reinforced Concrete Regulations, seeing that in these steel members the necessary stiffness is easily

attainable by means of suitable connections and flat bracing bars welded to the corners of the plate. It is obvious that these members represent an important new type of load bearing element in steel construction, which is designed to be widely employed especially in building work.

Since the pavement, the sand and the reinforced concrete protective and insulating layers weigh something like 450 kg/m^2 , which is about one half of the

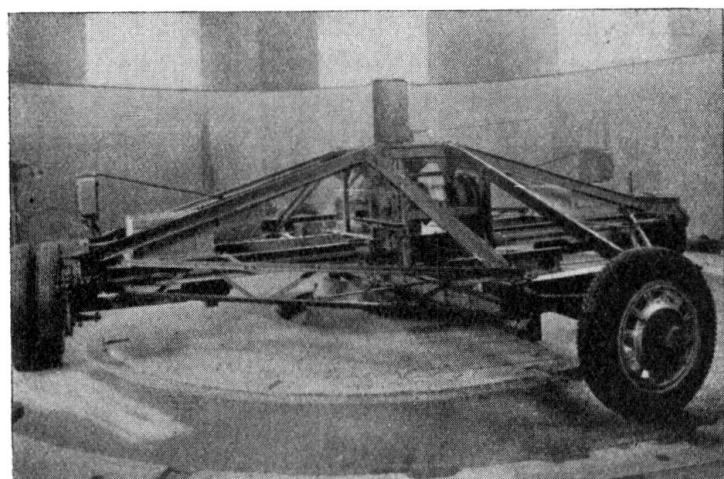


Fig. 7.

Rotary apparatus for testing plated steel floor.

total weight of a reinforced concrete slab floor, investigations were embarked upon to ascertain whether requirements might be met by covering the flat sheet

merely with an intermediate layer 4 cm thick of asphalt overlaid by a wearing course 3 cm thick of hard asphalt containing basalt chippings, stone dust and quartz sand as fillers, the tests being carried out on a circular road testing machine (Fig. 7) at Stuttgart. The flat plates were given a varying degree of stiffness from one section to another so that under the same load the deflections varied from 0.11 to 0.6 mm. After a test period which would correspond to four years of intense road traffic it was found that no separation had occurred between the covering material and the plate where these two were connected by expanded metal (Fig. 8), neither was there any sign of corrugation even for the softer plate. Powerful weathering effects were imitated in the tests and these disclosed the remarkably high resistance of the covering. In this way it is possible to construct light-weight decking with a depth of 80 mm weighing

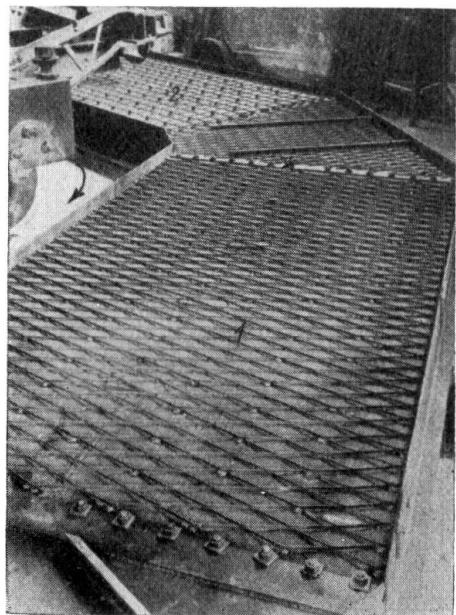


Fig. 8.

Expanded metal welded onto steel plates.

280 kg/m^2 not including the longitudinal girders (Fig. 9). It is obvious, of course, that adequate stiffness and watertightness must also be ensured.

A number of other interesting ideas for light weight deck construction are now

being tried out. In America steel grillages of the open type have been used as roadway deckings, and light non-ferrous metals are also being tried, but the question arises whether these will possess the necessary fatigue resistance.

When it is remembered that the weight of the decking, including the longitudinal girders, may vary between 1,050 and 300 kg/m², the necessity for

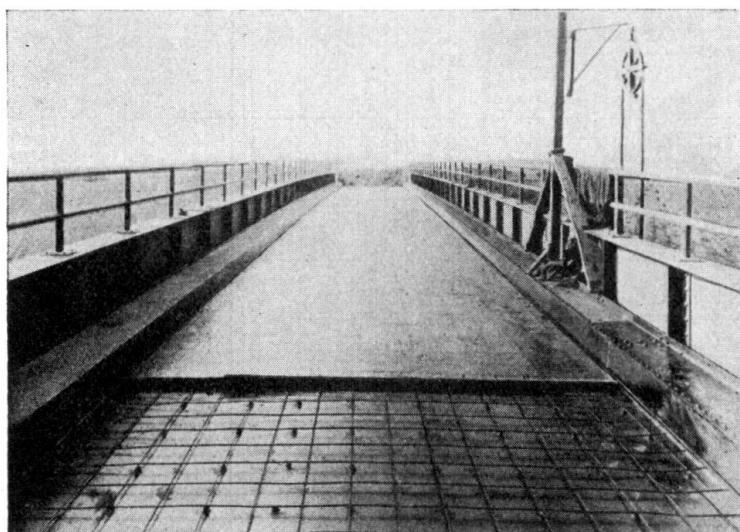


Fig. 9.
Light floor — Schaper system.

these endeavours becomes indubitable, even though the cost of the lighter construction may often be considerably higher than that of the type of decking hitherto in use. The economic problem is by no means settled merely by answering the question whether the reduction in weight and cost of the main girders

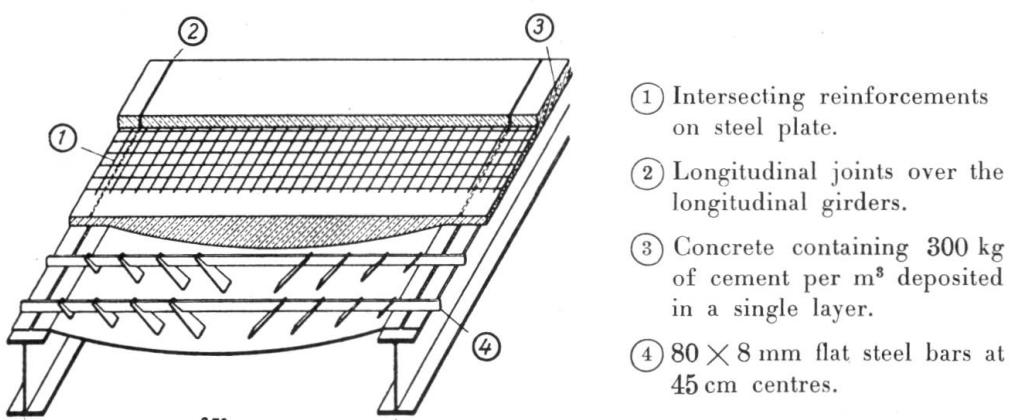


Fig. 10.
Stiffened arch-plate.

through adopting a lighter decking balances the greater cost of the latter, for, as already indicated, many cases arise where the reduction in constructional depth may be the deciding factor. Moreover it is relevant to point out that the economy of this new method of construction depends on the use of special workshop

methods which are far from having been fully exploited. The result is that present-day practice has made greater use of the long span arched plates and trough plates already mentioned, but in order to reduce the weight of the concrete filling these plates are being made with a very flat arch by comparison with earlier practice.

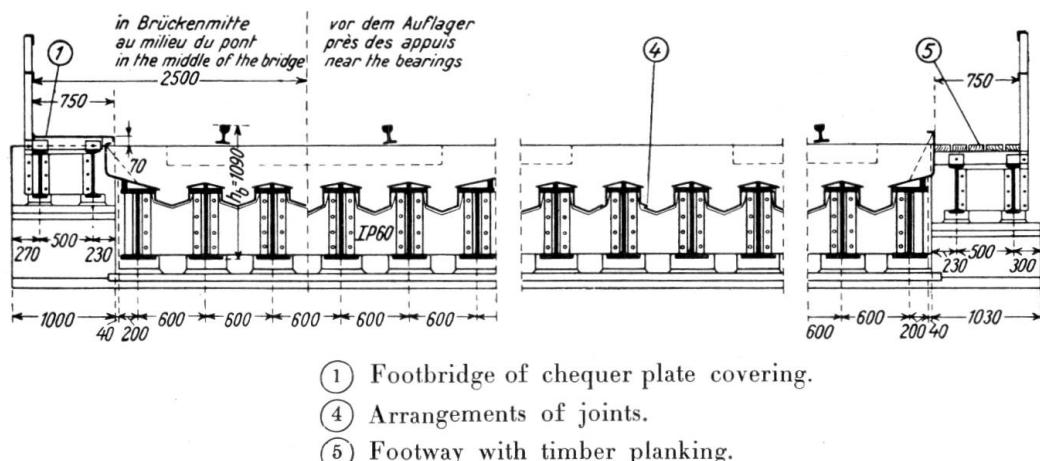


Fig. 11.
Section through the bridge.

Where arched plates are used it is necessary to provide an obstacle to any movement between the concrete filling and the plate itself, which may be done by stiffening the latter with blades welded on to it, as for instance was done on the arched plates of 240 cm span and 8 mm thickness used in the Sulzbachtal

bridge (Fig. 10 herein, and Fig. 16 on page 1354 of the Preliminary Publication). Horizontal flat bars are provided to ensure that only vertical reactions can occur. It was found by experiment that these compound elements, when calculated in accordance with reinforced concrete theory, gave a factor of safety against statical breakage of at least 8 when subjected to the prescribed loading. The weight, not counting the longitudinal joists, is 470 kg/m^2 , this low value

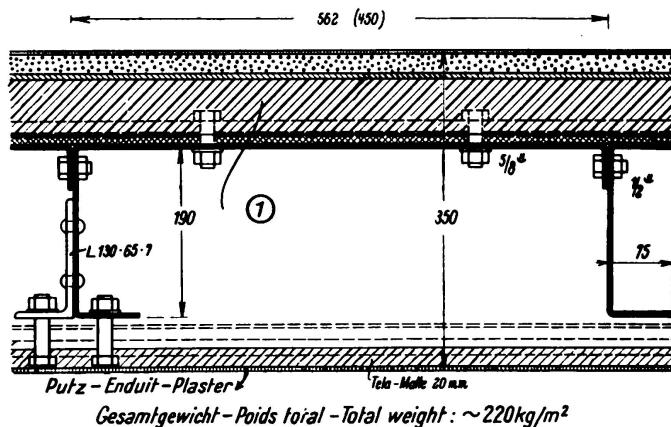


Fig. 12.
Schröder-type floor.

being explained by the omission of a waterproofing and protective course. The wearing course is a single layer of concrete placed in situ immediately over the concrete filling, 40 mm thick. Special attention must be paid to the impermeability of the concrete, and drainage of the surface is ensured by a cross slope of 1.5 %. Such a decking will also function as wind bracing, and its

use replaces the shuttering which is otherwise necessary in building a reinforced concrete floor.

Further experiments must show how far it is necessary to stiffen the plates where these take the form of *trough plates* (3.5×5 m) under a covering of



- ① 4 mm linoleum,
- 21 mm asphalt,
- 6 mm Ezo asphalt,
- 60 mm pumice concrete,
- 10 mm Absorbophon-Ezo,
- 5 mm sheets with turned-up edges.

Fig. 13.

Light steel floor.

special materials with the possible addition of a wire netting, and with the use of a special working procedure. The question of troublefree maintenance of the continuous layer of concrete over the floor girder may be a matter of some considerable difficulty unless a gap has been left for the purpose.

The form of bridge construction illustrated in Figs. 11 and 12, in which there are no cross girders but the joists are *embedded in concrete*, may also be looked upon as a form of lightweight construction. Measurements of deflection made on these joists and on the plates welded to them have shown that the joists and the plates co-operate somewhat after the manner of T-beams in reinforced concrete. It is to be hoped that further measurement of deflection will show whether in the design of a construction of this type it is permissible to assume some width, of plate as co-operating with the joists, or whether an increased deflection, say $1/700$ instead of $1/900$, may be allowed in the joists themselves.

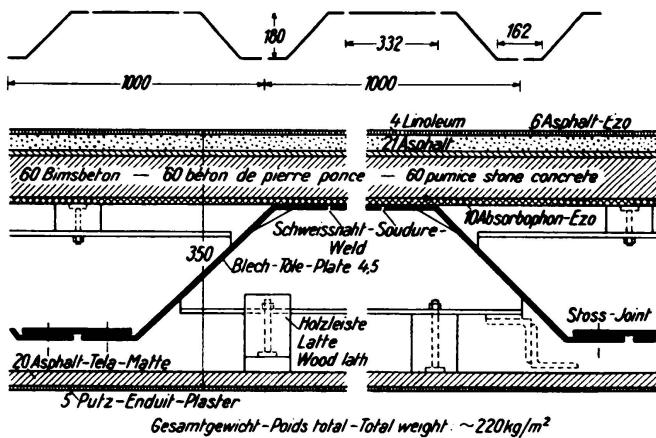


Fig. 14.

Light steel floor with doubly bent steel sheets.

In building work *light floors* as shown in Figs. 13 and 14 have been used, after careful tests under load and investigations of their acoustic and thermal properties have proved their suitability. The dead weight amounts to only about

220 kg/m² for a span of 6.50 m, a depth of 350 mm, and a live load capacity of 500 kg/m². The construction is readily adaptable to different conditions of loading and span by altering the thickness of the plate and the other dimensions,

and this can be done very economically. The lightness of such a floor is an aid to new methods of constructing steel building frames with partial use of welding, and an example of this is provided by the two-storeyed signal cabin at Mainz (Fig. 15) in which the plating serves both as a curtain wall and as a cantilever girder.

As regards new design of aircraft hangars, reference may be made to Fig. 25 on page 1323 and Fig. 24 on page 1321 of the Preliminary Publication. In America suspended plates have been used for roofing over a bunker with the aid of welding.³

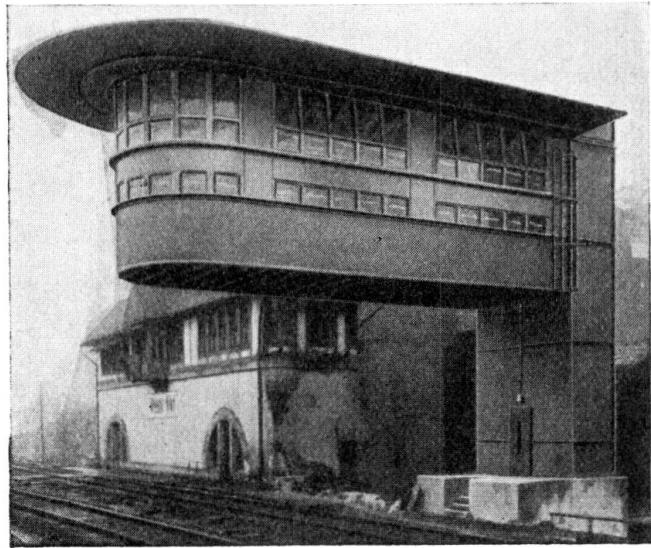


Fig. 15.
Signal box at Mainz station.

ding.³ Fig. 16 shows an example of development in aircraft hangar construction in Germany, in which the self-supporting roof constructed of troughing with tie bars serves also as the upper flange of a truss which is well adapted to carry

point loads, and the lower flange is provided in the form of a tie bar. Considering the advantages of a steel roof-covering the weight of this type of construction is surprisingly low. Surface structures (as, for instance, roofing over halls) which are stressed mainly in compression throughout their effective cross section, and which are kinematically sensitive, require special investigations of stability (theory of the second order) as relatively small differences between the ori-



Fig. 16.
Self-supporting roof formed of doubly bent steel sheets.

ginal and the actual shape of such a system may have a decisive effect on its safety. Fortunately steelwork construction is not affected by the phenomena of deformation due to the material itself.

³ Stahlbau, 1933, p. 152, №. 19.

In the construction of large halls, as for instance the new airship hangars at Frankfort on Main and at Rio de Janeiro, the trussed form of construction still predominates.

Further attention has been paid to the co-operation of steel construction and concrete. In Switzerland small road bridges (Fig. 17) have been made with the upper flange of the main girders and the longitudinal girders embedded in the reinforced concrete slab: the combined action enables the longitudinal girders to be made lighter and also has a favourable effect on the natural condition of vibration of the bridge. There are also special cases (as where St. 52 is used) where the compound action serves to reduce the amount of steel otherwise involved in the larger girders necessitated by considerations of deflections. In Germany the Reinforced Concrete Regulations do not allow this co-operation between rolled steel joists and concrete to be taken into account unless the joists lie entirely in the tension zone, and apart from this the Reichsbahn insists on permanent accessibility of the rivets in the flanges, a requirement which operates in favour of welding.

In the design of steel building frames, the use of which has become particularly widespread in France and Great Britain in recent years and of which an example exists in the new construction of the Reichsbank in Berlin at the present time, it is permissible to allow in the design for the co-operation of steel columns with their concrete cores,⁴ and this results in increased economy. Here again the use of light flooring has proved very advantageous in certain cases. Finally a wide range of fire tests on loaded steel columns of full size, variously encased, yielded valuable results and have indicated that it is possible with limited means to attain a high degree of fire resistance⁵ in such columns (see DIN 4102, part I).

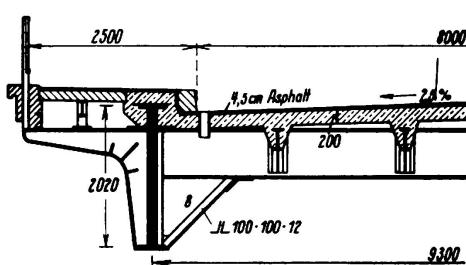


Fig. 17.

Bridge over the Limmat at Engstringen (Switzerland).

⁴ Stahlbau, 1934, p. 59, Nos. 7 and 8; Zentralblatt der Bauverwaltung, 1935, №. 23.

⁵ Report on the XXIXth scientific meeting of the Reichsverein Deutscher Feuerwehringenieure (published by the same, Berlin, № 15).