Use of steel in bridge building: in general and in detail

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Use of Steel in Bridge Building. In General and in Detail.

Anwendung des Stahles im Brückenbau. Allgemeines und Einzelheiten.

Application de l'acier dans la construction des ponts; généralités et détails.

Geheimrat Dr. Ing. G. Schaper,
Reichsbahndirektor, Hauptverwaltung Berlin.

Introduction.

As is well known, in bridge-building steel is principally to be preferred to other materials such as wood, stone, concrete and reinforced concrete, when the building height available is limited or the form of substructure or other contingencies make it necessary to employ spans of the greatest practicable length. More attention is being paid today than was the case formerly, to the aesthetic factor of making new constructions harmonise with their surroundings. The designing engineer is of course expected to devote the greatest care to the artistic aspect, both in general and in detail, of his creation; yet when it is a question of an important project he will be well advised to cooperate closely with the architect. The latter must then be able to give due consideration to the flow of forces and also the question of costs. Only by really efficient collaboration between these two parties can structures be created that will not be found wanting when judged by the standards of posterity. When deciding upon the type of structure it has been found very profitable to use scale models or to sketch in the structure planned on photographic reproductions of the site and surroundings. In Germany recently new enterprises, and especially the construction of the new State Arterial Roads, have led to the building of numerous large bridges. Many of these bridges are welded, and in our paper we shall give a brief description of some of them.

I. *Frames.*

Example 1.

Fig. 1 illustrates a solid-webbed, all-welded, two-hinge frame for a bridge over a road. Its appearance gives an impression of great lightness. The distance between the hinges is 21.2 m. Over the width of the roadway below, the lower boom is almost horizontal, thus giving constant clearance. At the sides, too, the height is sufficient to accomodate the footpaths. Where the boom is bent downwards the decking is borne by supports carried by the main girders. The webplates are butt welded somewhere in the region of the zero point of moments.

The boom plates are continuous throughot the whole length. No special measures were necassary for the formation of frame angles. The frame footings are stiffened. The arrangement of the decking may be seen from the cross section.

The whole superstructure was welded in the workshop and transported by rail to site in one piece.

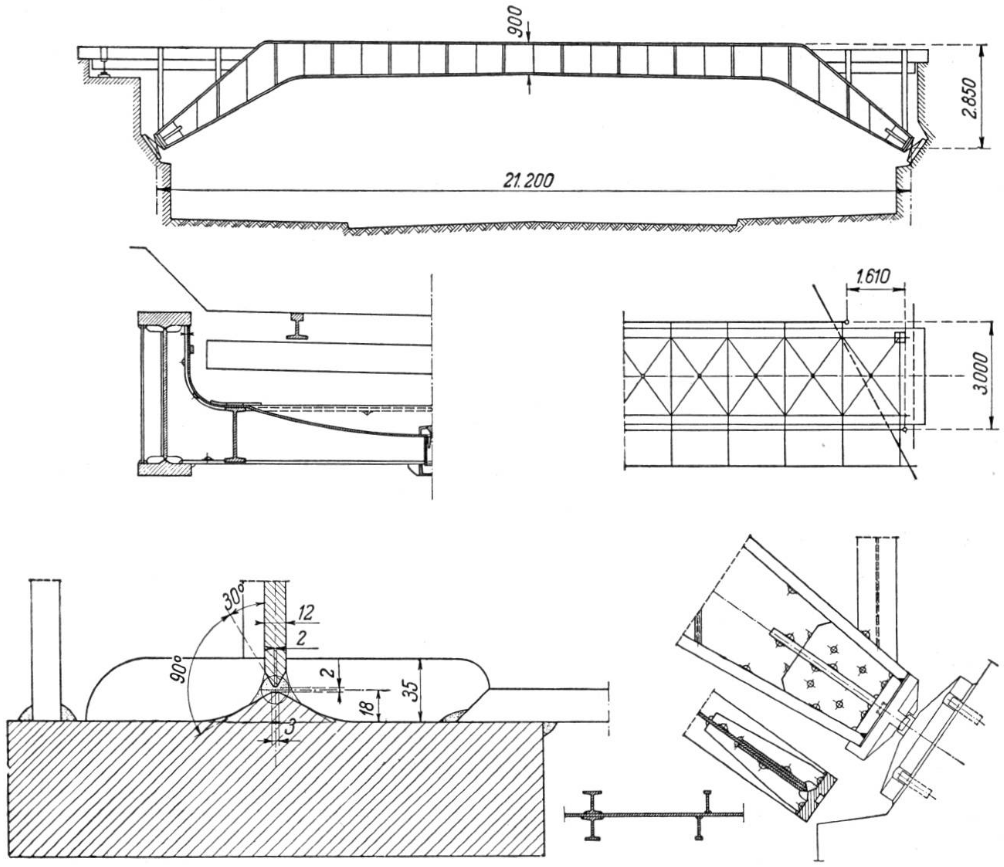


Fig. 1.

Example 2.

Fig. 2 depicts two-hinge frames used for an overbridge carrying a highroad over (right) a railway line, and (left) over an arterial motor road. In this —

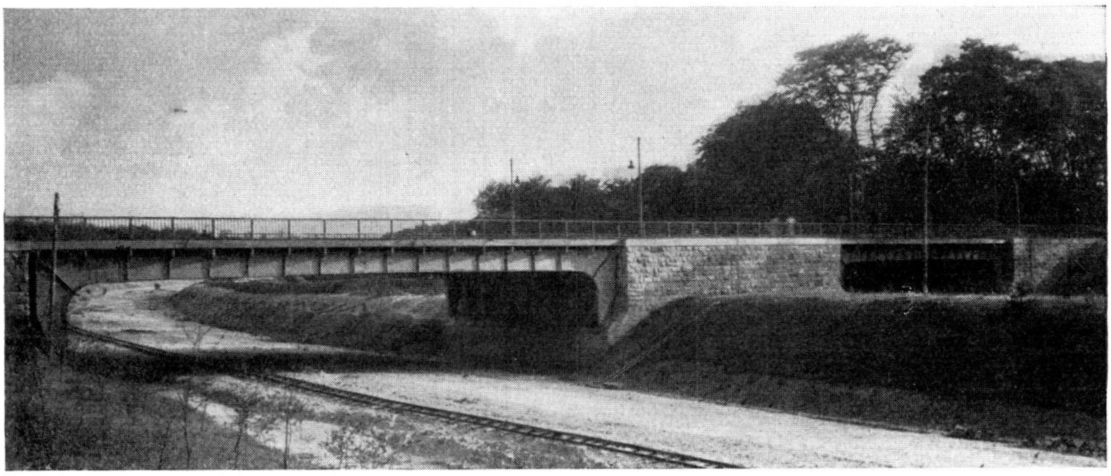


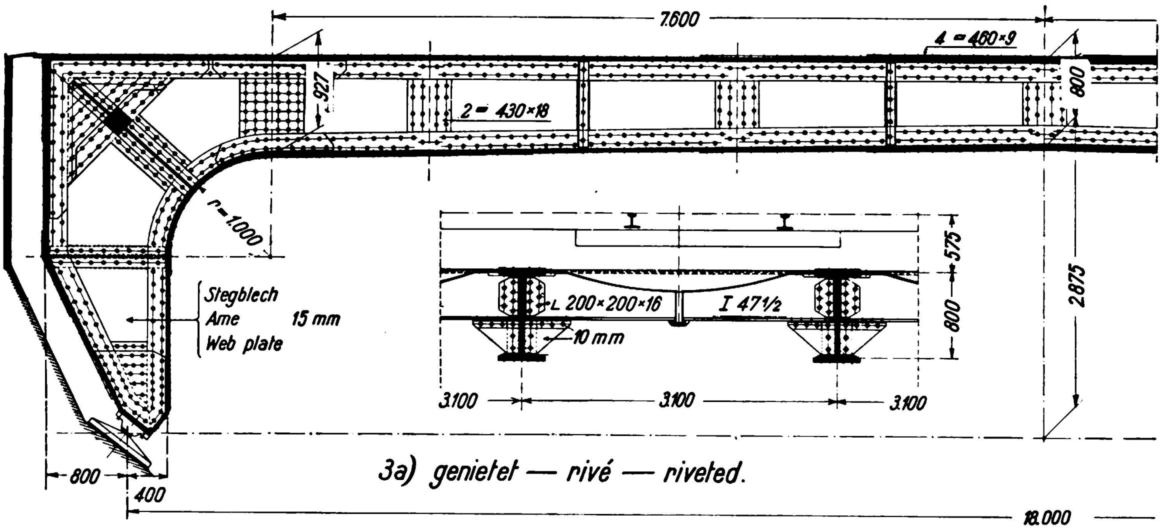
Fig. 2.

as indeed in all the constructions carried out for the State Arterial Roads — great attention was paid to outward appearance. The treatment of the masonry, the arrangement of parallel wing-walls and the continuity of the coping over the whole length of the bridge combine with the trim lines of the steelwork and the fine shadow effect thrown by the cantilevering footpaths to produce a harmonious structure that fits into its surroundings excellently. The distance between the hinges of the frame measures 33 m on the portion passing over the motor highway.

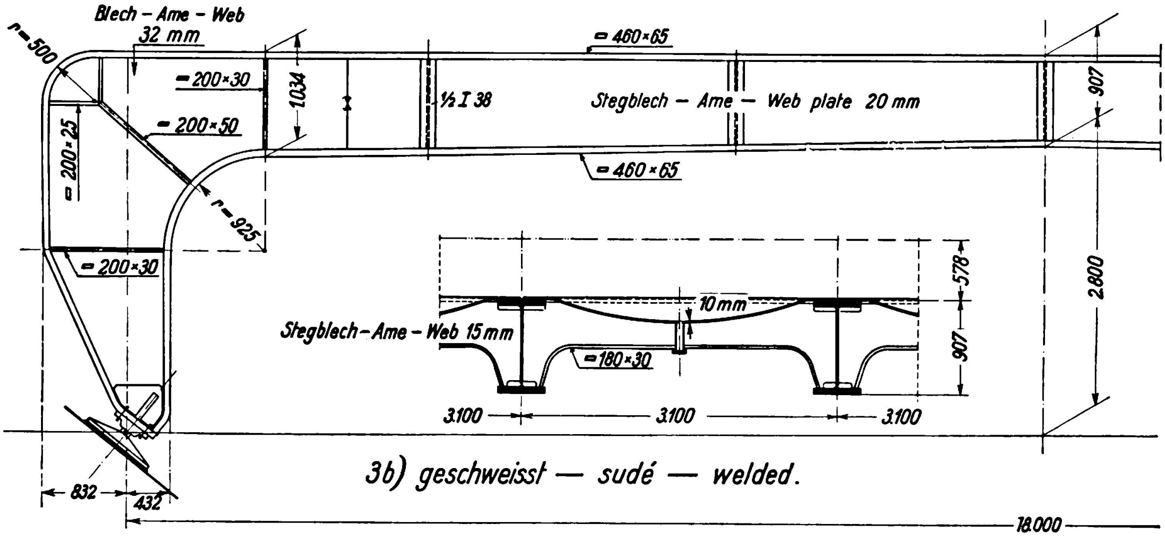
Example 3.

Fig. 3 shows a single-webbed, two-hinge frame, 3a being the riveted, 3b the welded construction of same.

In the riveted frame (3a) the flanges of the lower brace pass in a gentle curve into the vertical. The upper flanges of the brace, however, and the outer flanges of the upright meet at right angles. The angles of the booms are mitred at this



3a) genietet — rivé — riveted.



3b) geschweisst — sudé — welded.

Fig. 3.

Two-hinged plate girders.

point. The flange plates of the brace, one of which is broader than the other to take the buckle plates of the decking, end in this corner, as do the outer flanges of the upright. As the forces set up in them and in the angles of the flanges cannot be transmitted by the web plate alone without its becoming overloaded, the contiguous legs of the angles of these two flanges are connected with each other by means of 30 mm thick, fitted cover plates which are also connected to the corner web plate by means of intermediary packing. The corner web plate itself is continuous right down to the bearing. The web plate of the brace is joined to the corner plate where the curve begins, the joint being covered on both sides by straps. Strong stiffening is arranged in the central line of the corner. The wall of the frame footing is reinforced by plates affixed on both sides. The angles and the flanges of the lower boom run unjointed from bearing to bearing.

Fig. 3b shows how much simpler the two-hinge frame can carried out in welding construction, and how much more satisfactory its appearance then is. Both main girders belong to the same structure, have the same dimensions and both are made of St 37. The riveted main girders weigh 19.4 t, and the welded ones only 14.3 t each. The constructional design of the welded girders is simple. The top flange plate, consisting of a Dörnen bulb section[1] measuring 460 × 65, also becomes the outer flanges of the uprights, that is to say, the top flange runs from bearing to bearing in one piece, across the whole 18 m width of the superstructure. The lower flange is also made in one single piece. Both flanges are interconnected at their ends by V-welds, the web being stiffened at the bearing by means of 10 mm thick plates affixed on both sides of it. These plates were fillet welded on top to the web and on the other sides tapered together with the web and welded to the flanges of the boom. (Present-day regulations for calculation would permit a further simplification, namely the use of one single web plate, of corresponding thickness, in place of the thin web stiffened by the two 10 mm stiffeners at the bearing. This one-piece web would then be butt welded to the other thin web.)

To prevent buckling under the action of the considerable compressive forces, the stiffening plates are connected with one another and with the web by means of rivets (this riveting would naturally be eliminated if the thicker web were used). Here the stiffeners are also welded to the booms. Today, the parts of the boom subject to tension would be provited with compensation plates where, in accordance with regulations, the bending stresses make this necessary.

II. *Beam stiffened with Arch (Stabbogen).*

Example 1.

In recent years numerous bridges have been constructed in Germany with Langer beams (so called after their inventor, the Austrian engineer Langer) having solid-webbed stiffening girders.

As will be seen in Fig. 4, the appearance of bridges thus designed is restful and pleasant, and the general impression one of charming harmony with the surroundings. The main span bridges the river in a single arch. The lateral spans are much smaller and comprise girders situated at the same height as

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[1] See Fig. 5 of Kommerell's paper, Theme IIId.

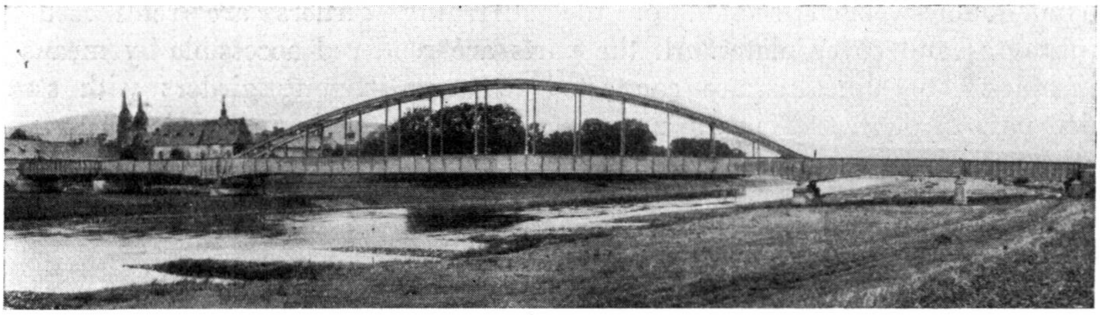

Fig. 4.

the stiffening girders of the central span and forming with them a continuous beam. In this uninterrupted system of girders the main span is set off in a natural and pleasing manner by the third boom — the arch — consisting of the Langer beam. The central span over the water has a length of about 120 m, the adjoining opening are 33.4 m and the end spans to the abutment about 26 m long. The whole bridge is riveted. The web of the single-webbed girders used in the end spans is 3.2 m high, that of the double-webbed girders in the intermediate spans increases gently from 3.2 m to 4.8 m at the piers of the main span. Fig. 5 is a detailed illustration showing the main girder at the end of the arch; Fig. 6 is a cross girder.

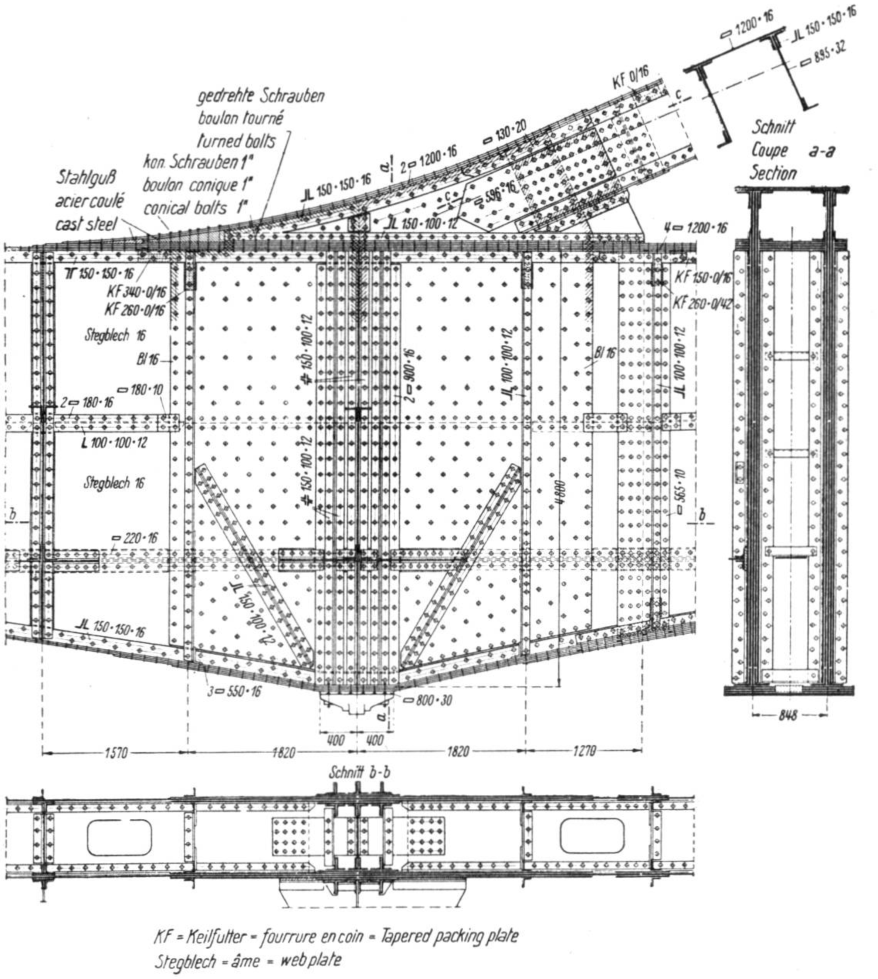

Fig. 5.

The double-webbed section of the stiffening girders are reinforced by diaphragms and cover plates. All the parts are rendered accessible by means of man-holes. The uprights are connected to the stiffening girders with straps which pass through slots in the upper flanges of the stiffening girder. The beam of the arch is also double-webbed.

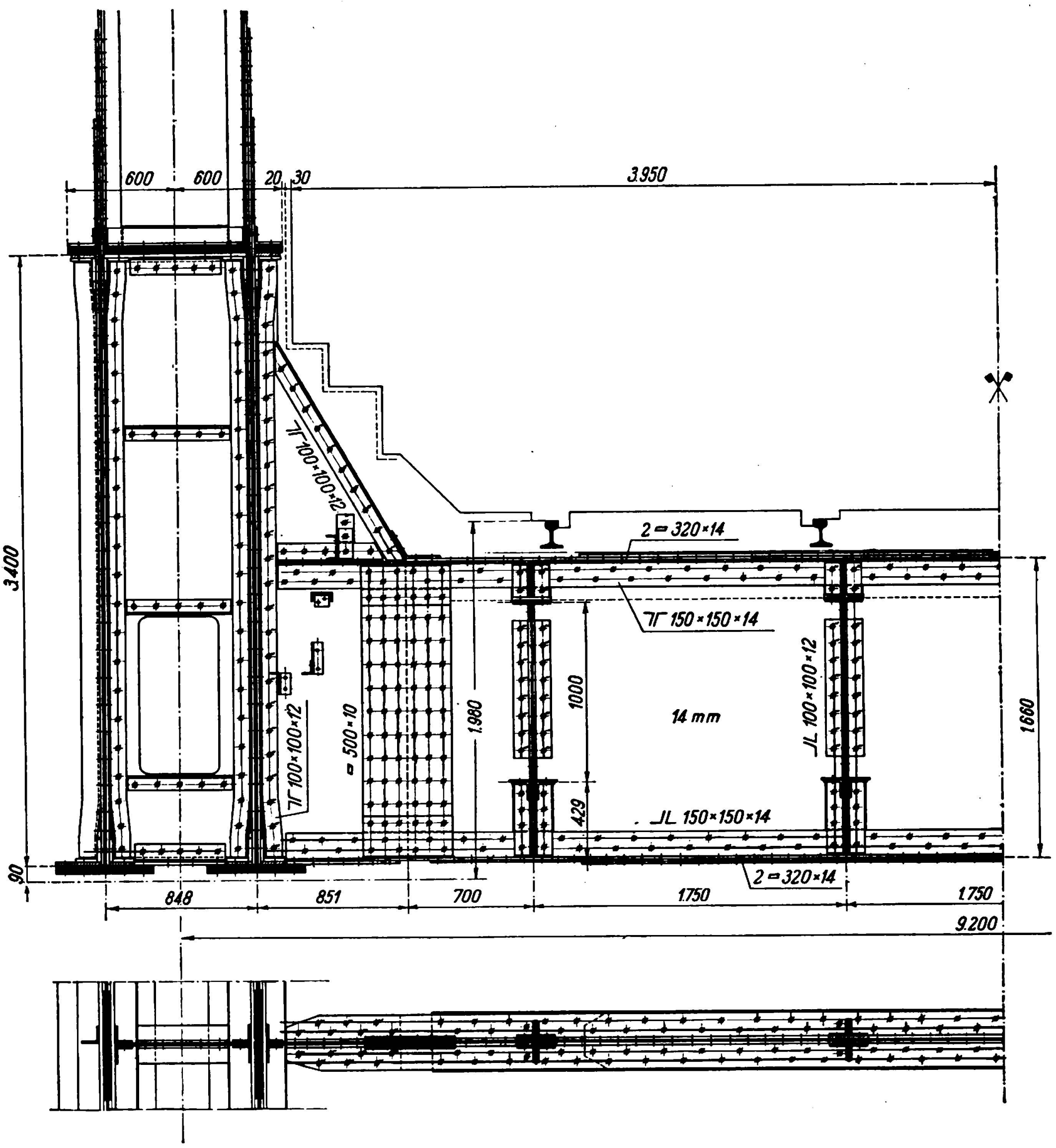

Fig. 6.

The respective arches from which the two main girders are suspended are interconnected by strong upper wind bracing (Fig. 7), whose horizontal forces are conveyed to the supports via the portals. Fig. 8 depicts the top brace of the portal.

Example 2.

Fig. 9 shows an example of a completely welded bridge superstructure of the "Stabbogen" type. Its span is 103 m, the panelpoints lying in a parabola. Each of the members comprising the arch is curved.

The stiffened girder is of one-webbed section, the arch, however, double-webbed. Suspension is effected by means of round steel bars.

Beside the finished superstructure can be seen portions of the adjacent superstructure, still incomplete, which are carried on turning appliances so that the welds can be carried out in the horizontal.

III. *Solid-webbed Girders.*

The construction of the arterial motor roads often necessitated the building of large viaducts in mountainous and hilly districts.

Example 1 is that of a continuous plate beam bridging three spans of 90, 108 and 90 m respectively (Fig. 10). Apart from the question of appearance, it was principally the soil conditions that led to the choice of this type of structure. The two intermediate supports consist of two pairs of hollow reinforced concrete piers, each pair on a common foundation. They are connected on top by a solid cross brace (Fig. 11). The interior of the piers is accessible from outside. The bridge carries two roadways of standard width (7.5 m each) across the valley at a height of 68 m. The decking, composed of two separate reinforced concrete slabs (Fig. 12), is borne on continuous longitudinal I 50 beams, which are rigidly connected with the cross beams, spaced at 6 m intervals, by means of small bearing plates and lateral cleats. Although the decking slab itself is extremely rigid, a k-type bracing was provided at the level of the cross-girder bottom booms; this was chiefly necessary for erection purposes. The cross girders are of the half-frame type (Fig. 13), so that they supply the necessary lateral stiffening action for the bottom booms of the main girders. The web-height of the cross girders is 1.8 m. The web of the brackets

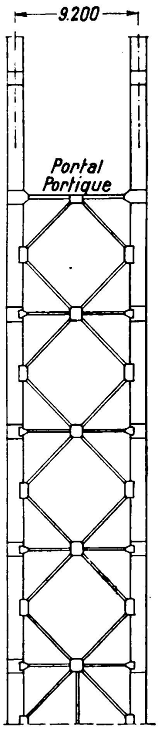

Fig. 7.

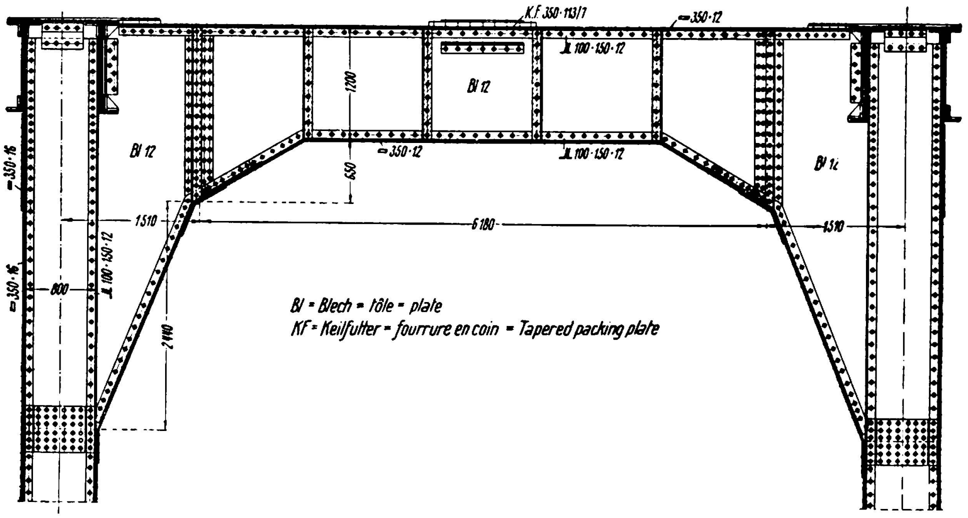

Fig. 8.

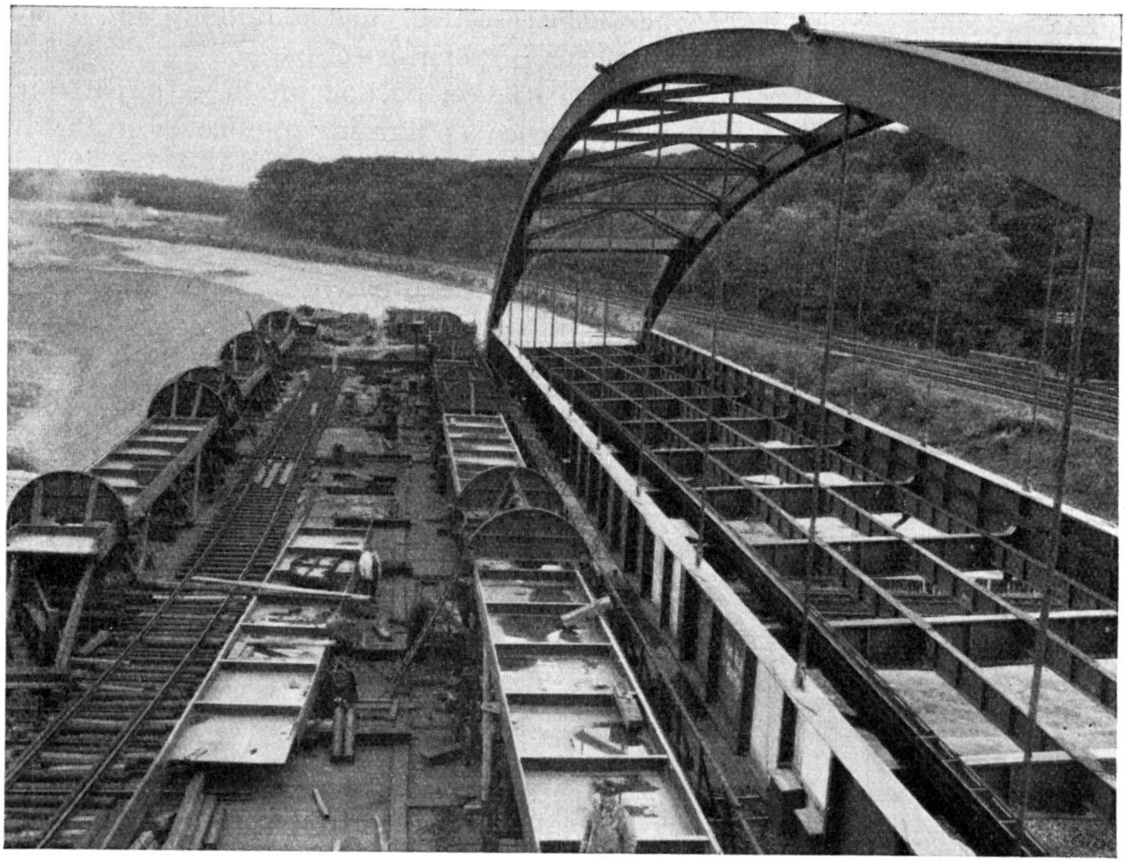

Fig. 9.

as well as that of the cross girders butts against the main girder. A direct transmission of tensile forces from the bracket to the cross girder is not possible, since the web of the main girder could not be slotted. The tensile forces are taken up by broad straps fastened to the main girder flange. The webs of the main girders are joined along their whole length at half their height. The

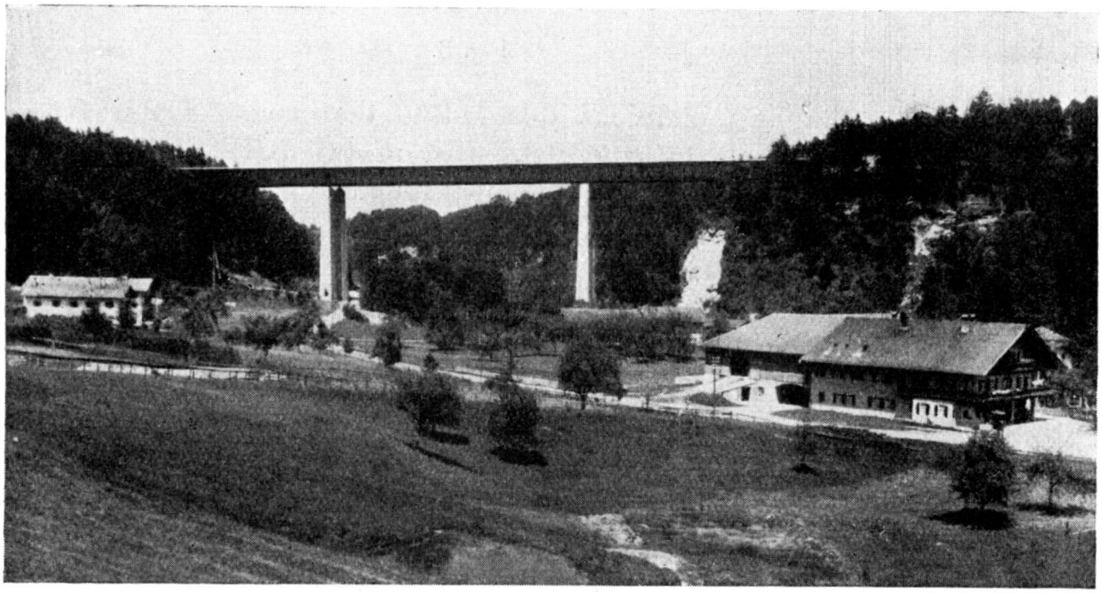

Fig. 10.

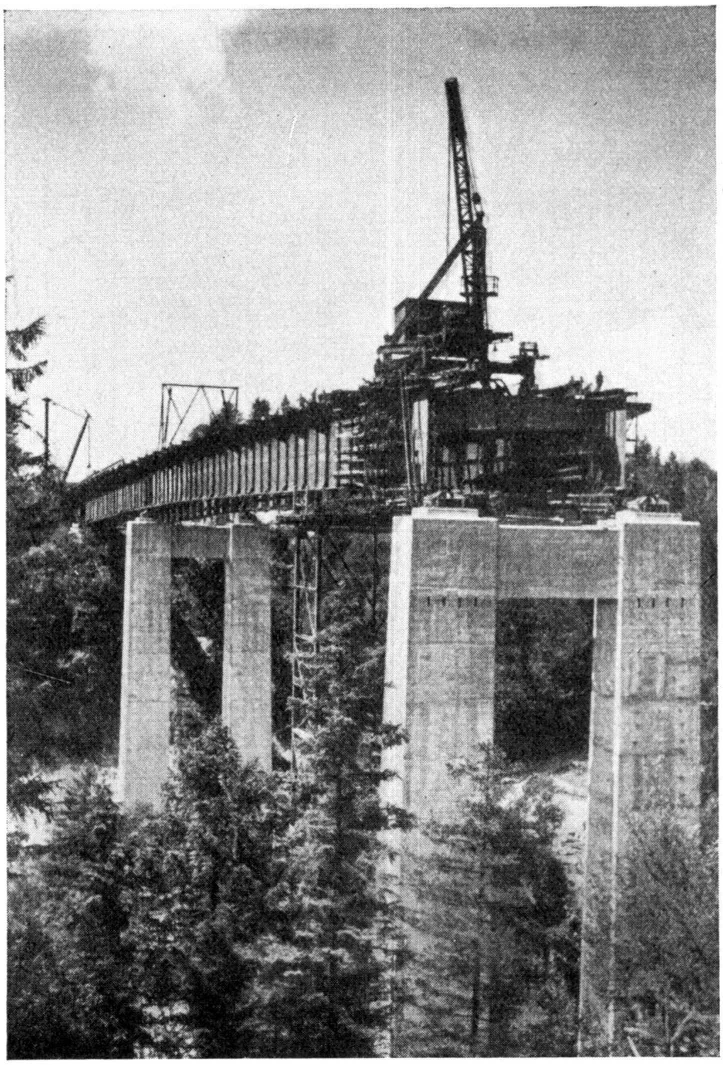

Fig. 11.

vertical connections, with a few exceptions, occur at intervals of 12 m. To improve appearance, the horizontal Z. 18 stiffeners are applied to the inner side of the main girders, so that only the vertical stiffeners are visible from outside. The flanges of the main girders (Fig. 14) are each composed of

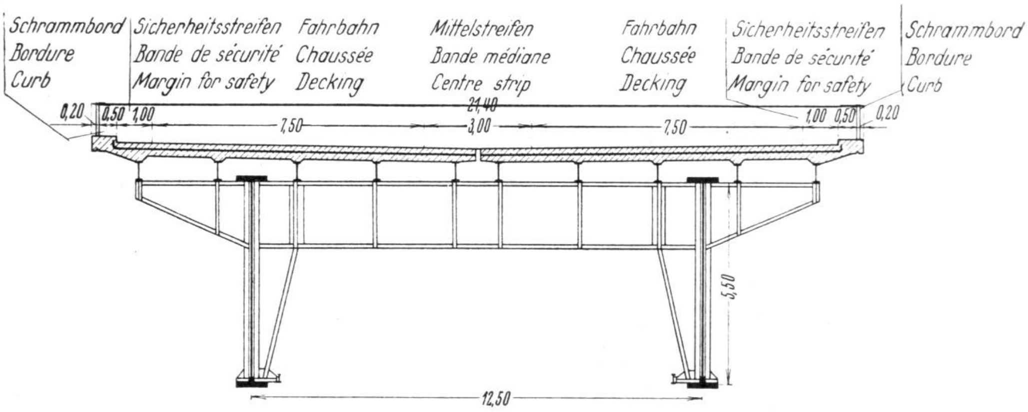

Fig. 12.

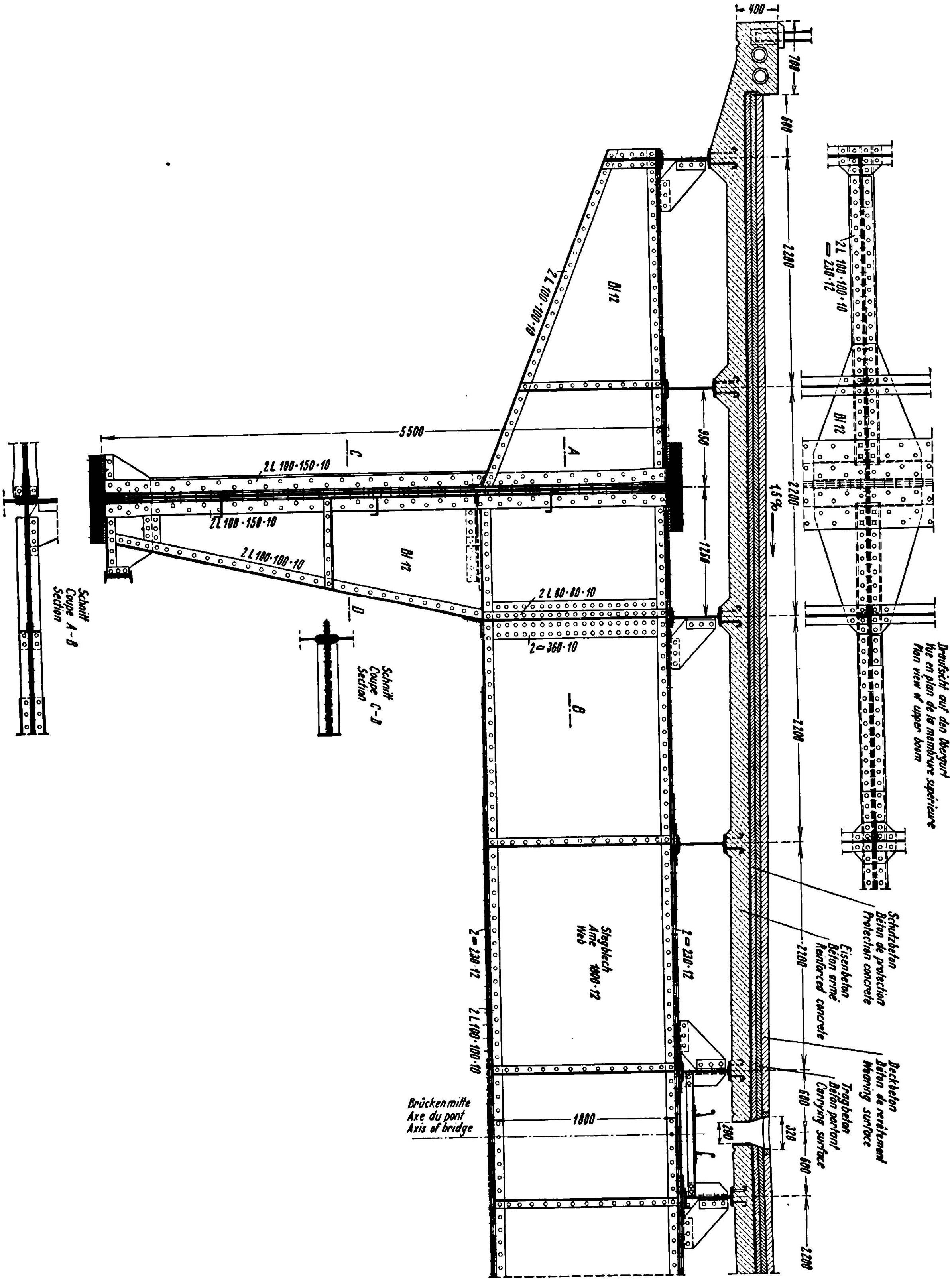

Fig. 13. Normal section of superstructure

two 200 × 200 × 20 angles and 850 × 20 flange plates, the number of which is suited to the flow of bending moment lines.

Special supports or brackets are provided at the points of support to facilitate the application of jacks.

In order to enable those parts of the superstructure lying beneath the decking and high above the bed of the valley to be maintained in good condition, an inspection carriage was installed between the main girders, running the whole length of the structure.

The main girders and cross girders are of St 52, the remaining parts of St 37.

The great height of the bridge (see Fig. 11) necessitated the application of the free cantilevering system of erection.

Example 2.

In this example the moderate height of only 43 m above the bed of the valley, and also the fact that the topographical conditions at the site were favourable, enabled the 365.4 m long viaduct under consideration to be divided into a larger number of spans. There are 7 spans in all, the largest being the middle bay with a length of 63.8 m, decreasing to 40.6 m at either side (Fig. 15).

The decking, with centre drainage, is carried by arched plates. These are provided with flat bars and diagonals which ensure good binding with the concrete filling (Direktor bei der Reichsbahn Schaechterle: Bautechnik 1934, p. 564. Neue Fahrbahnkonstruktionen (New Types of Decking). The arched plates rest on longitudinal I 45 girders spaced at intervals of 2.37 m. The erection bracing necessary in the free cantilevering system of erection is situated in the plane of the lower boom of the cross girders. Outside the main girders, in the plane of the cross girders, i. e. at intervals of 5.8 m, are arranged brackets with a cantilever of 3.3 m which carry part of the decking (Fig. 16). The tensile forces set up in the brackets are transmitted over the top flange of the main girder to the flange of the cross girders.

The flanges of the main girders are composed of ┘└ 200 × 200 × 16 and flange plates 700 × 16, the number of which is suited to the flow of the moment line.

The extremely slender steel columns contribute very effectively to the pleasing appearance of the lengthy structure. They are composed of frames (Fig. 17) of hollow box section. The columns of the frame taper off towards the bottom. The brace, 3.2 m high, is also hollow and is provided with man-holes giving access to the interior; these can be entered from the inspection carriage. The web of the bracing was designed so high to allow the construction of a particularly rigid frame corner. The peculiarity of the soil, which is prone to slipping, is counteracted by the construction of two separate cylindrical piers for each frame column. These oppose the least resistance to any shifting of the upper layers of soil that may take place.

Example 3.

In the five-piered bridge of which a general view is shown in Fig. 18 the reinforced concrete decking slabs rest movably on the cross girders (Fig. 19). In each bay a special bracing is provided to take up and transmit the forces caused by braking. Horizontal forces are absorbed by a horizontal brace arranged in the upper third of the cross girders. The bottom flanges of the main girders are held at their sides by the portal-like cross girders.

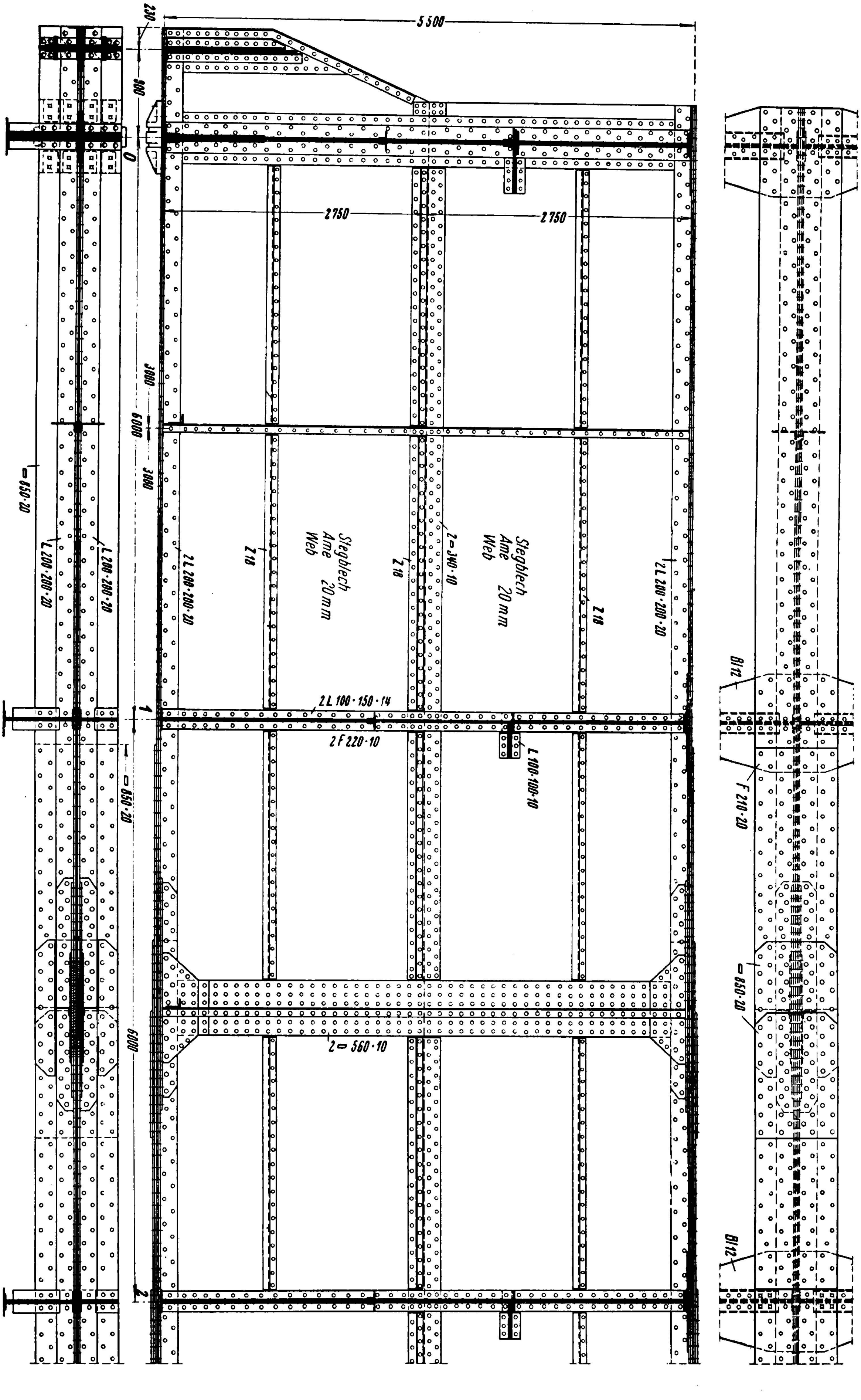

Fig. 14. Main girder between cross beams 0 and 2. Interior view.

IV. *Lattice Bridges.*

In addition to the solid-webbed structures already discussed, a large number of latticework superstructures have also been built in Germany in recent years. The most noteworthy are the following! —

Example 1.

The beam shown in Fig. 20 is continuous over two spans. Its total length is 292 m, its height 16.5 m. The latticing used is a pure strut system, i. e. one of diagonals placed zig-zag and without stays. This arrangement looks extremely effective when the four main girders of the two parallel bridges (road bridge and railway bridge) are viewed from the side. The distance between the two beams of each pair is 10 m, that between the adjactent beams in the middle 4 m. In spite of the fact that when seen from an oblique angle the diagonals seem to cross and recross, the whole structure gives a restful impression, the reason for which is to be found in the lack of uprights. One peculiarity of this system as against constructions having uprights in the vertical plane of the cross girders is illustrated in Fig. 21, showing a constructional detail of the railway bridge. In a system with uprights the restraint moment emanating from the deflection of the cross girder is transmitted to the uprights. In the railway bridge, which has no uprights, other arrangements had to be devised to take up this restraint moment. It is transmitted to the vertical diaphragm situated at the connection of the cross girders by means of a corner web stiffener 2.99 m high. The diaphragm in turn transfers it to the gusset plate of the lower wind bracing and to the traverse at the height of the upper corner of the stiffener. This traverse is connected to the webs of both diagonals. Here the reaction at the support of the traverse is passed on to the diagonals, which conduct it to the upper wind bracing and, with the assistance of the horizontal diaphragm of the lower boom to which the webs of the diagonals are connected, to the lower wind bracing.

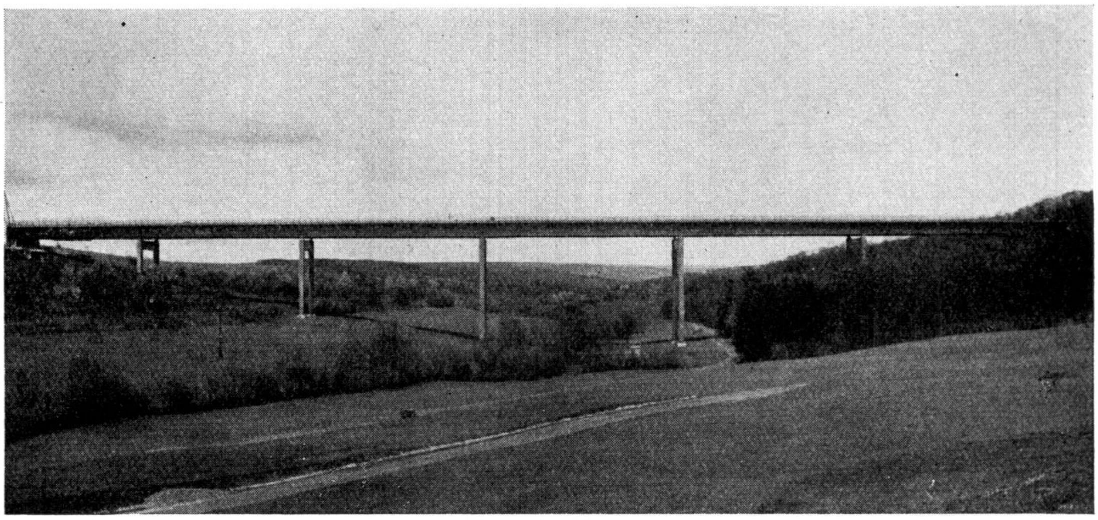

Fig. 15.

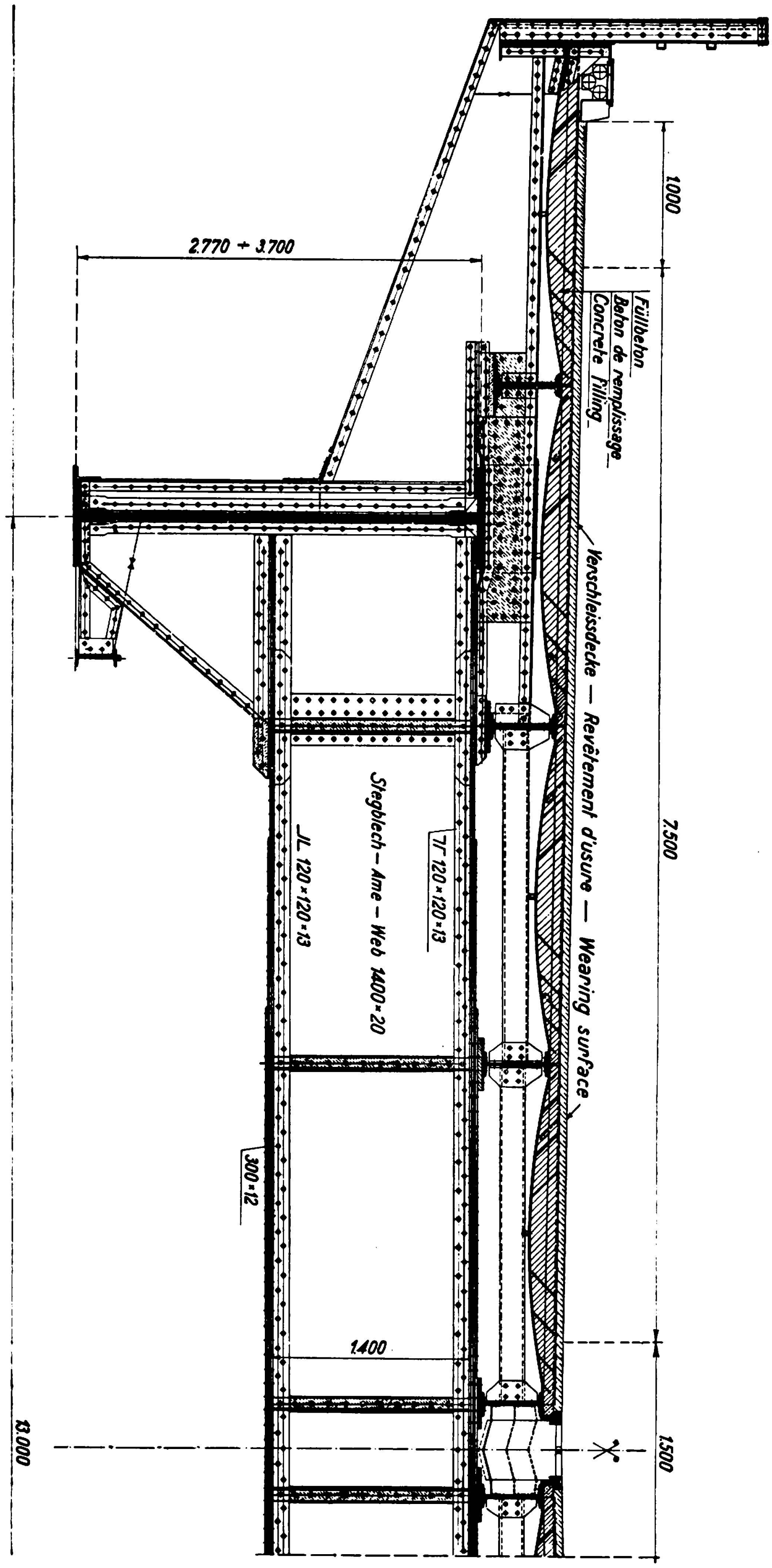

Fig. 16. Normal cross beam.

Example 2.

Fig. 22 shows a structure of the same type and with a total length of 456.9 m. Its three spans measure 212.2 m, 66 m and 178.7 m respectively.

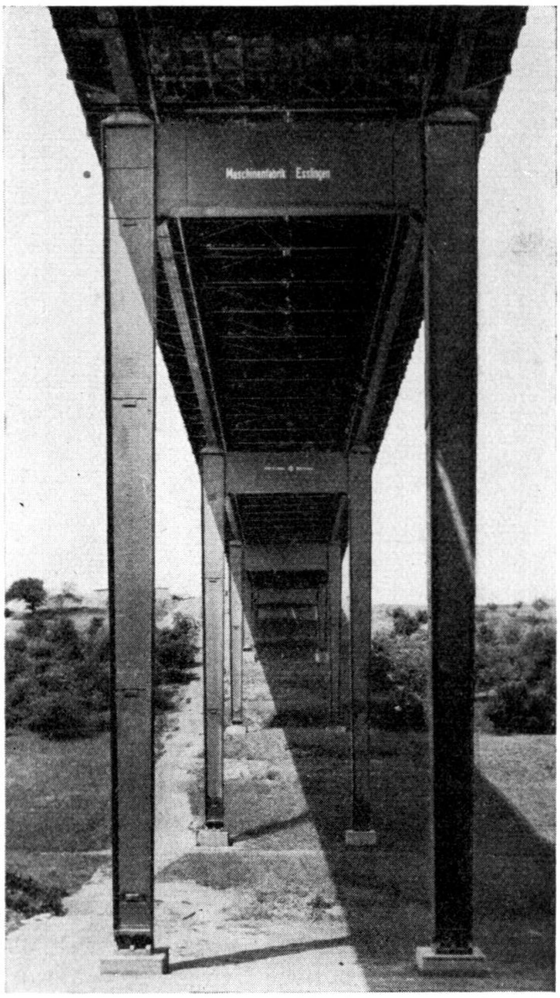

Fig. 17.

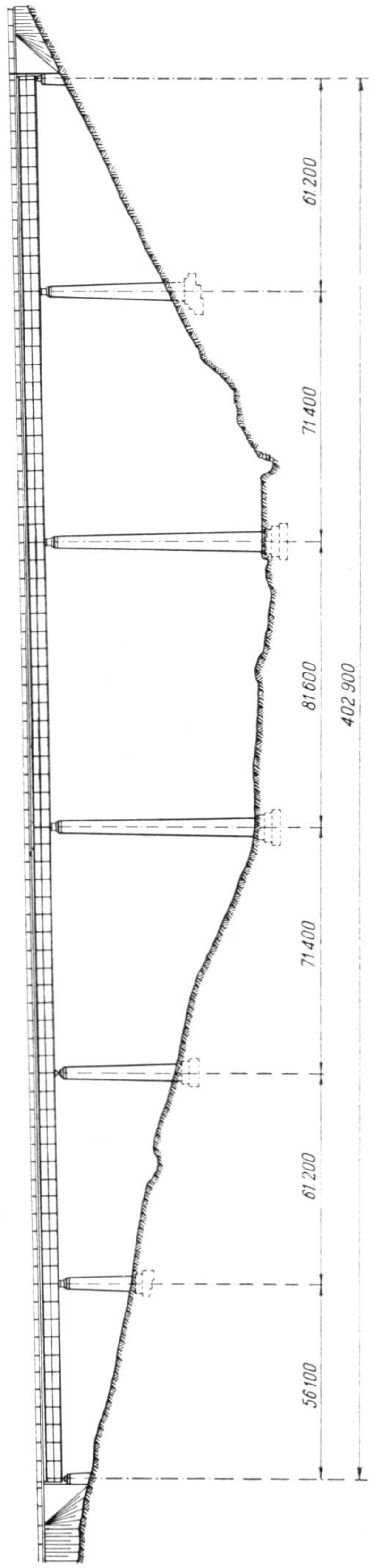

Fig. 18.

The two middle piers at either end of the 66 m span are built on an islet in the river. The main girders are 16 m high. Between them there is a decking 8.5 m wide, on each side of which runs a 2 m wide footpath. The main girders are of St 52, the other members of St 37. The surface of the roadway is formed by a rolled in layer of asphalt 6 cm thick, based on buckle plates filled with concrete. The restraint forces of the upper wind bracing, which is formed of crossed bars, are transmitted to the abutments and piers by the portals situated in the planes of the diagonals.

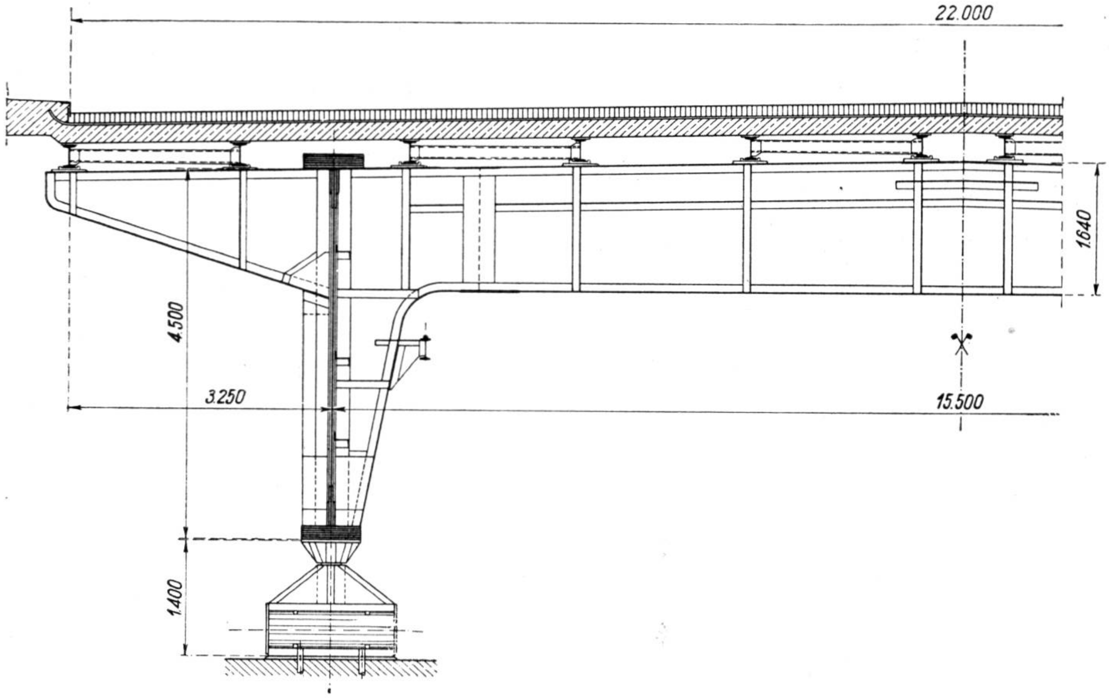

Fig. 19.
Cross beam at point of support.

Example 3.

Another structure worth considering is a river bridge on one of the German State Arterial Motor Roads. Its total length is 456 m, the span across the actual river being 130 m.

Before the system was finally decided upon detailed investigations were carried out with a view to ensuring proper harmony between the whole arrange-

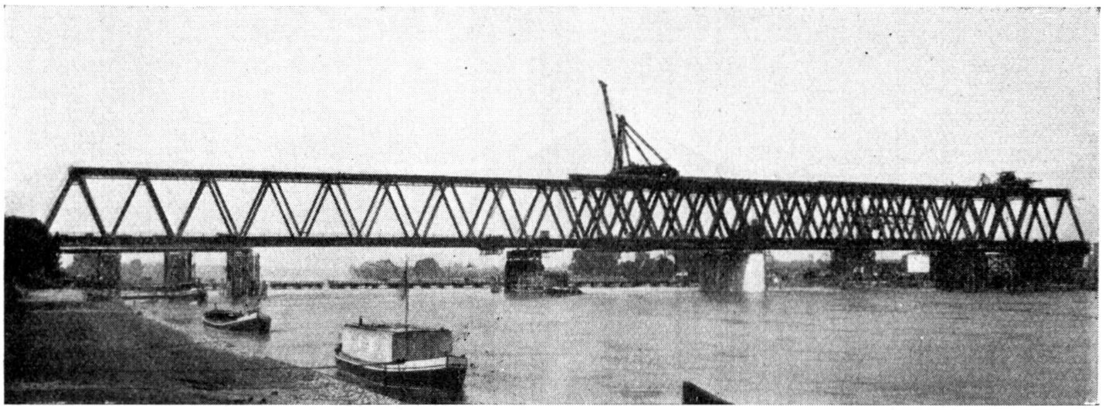

Fig. 20.

ment of the bridge and its surroundings. Owing to lack of space, the results of these investigations cannot be gone into here, for which reason we would like to refer to what has already been written on the subject (Weiß, Bautechnik 1935, p. 473).

The project as executed comprises a continuous, riveted lattice girder over five spans with decking at level of upper chords. The height of the girder (5.2 m) is adapted to suit the length of the actual water span. The continuation on one side forms an overbridge over a road and railway track, and here the beams are welded plate girders. The decking of each of the two roadways is carried on a separate superstructure, as may be seen from the cross section shown in Fig. 24. The decking, composed of a jointed reinforced concrete slab, is carried by continuous longitudinal standard sections. These are movably supported by the cross girders and lengthy cantilevers. On one side of the roadway there is a footpath, on the other a passage for cyclists. The distance between the axes of the main girders of each superstructure is

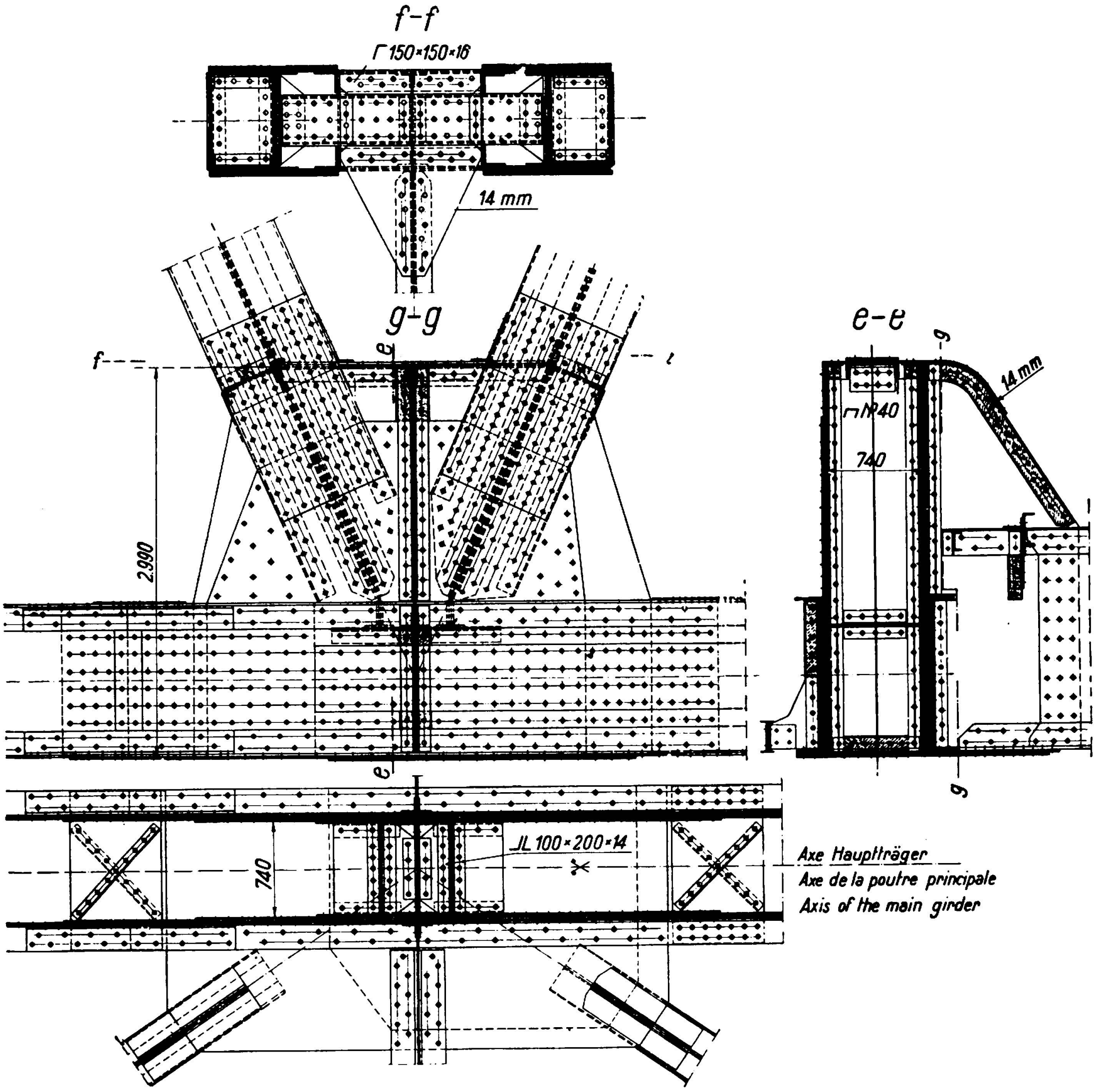

Fig. 21.

7.5 m. The outer arms cantilever to an extent of 4.25 m, and at their connection have the same height as the cross girders. The space between the two superstructures is covered over by a reinforced concrete slab which rests on girders having their supports on small cantilevers. The upper edges of the cross girders are connected with those of the main girders, so that there was no difficulty in transmitting the tensile forces in the upper flange of the large cantilever arm over the top of the main girders by means of tension straps.

Fig. 22.

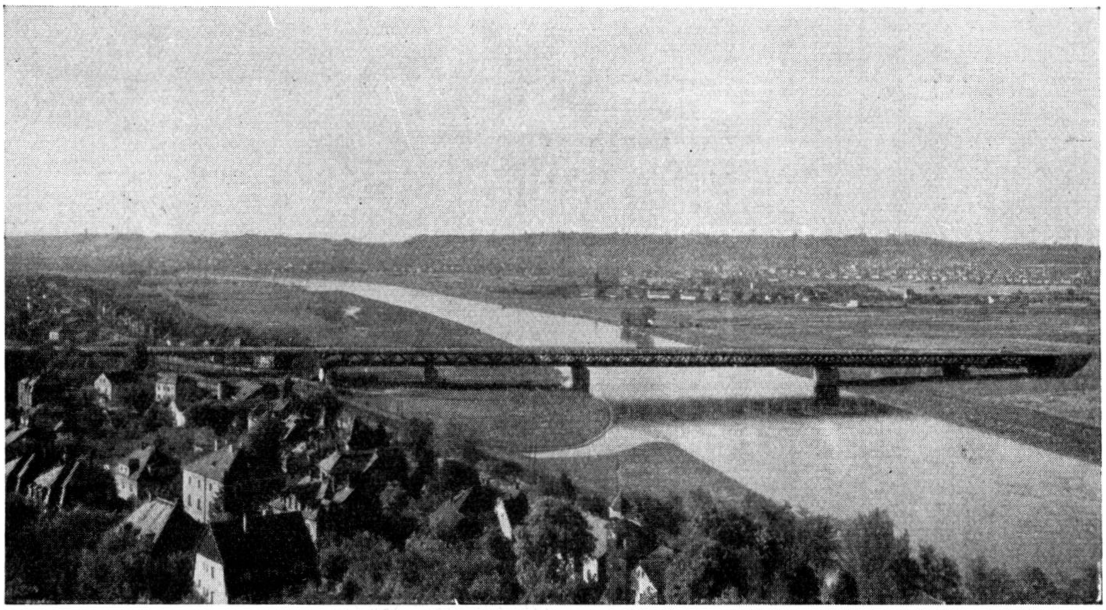

Fig. 23.

In the planes of the upper and lower flanges braces are provided to take up the lateral forces. This bracing, like the main girders, is composed of girders on six supports. The upper bracing transmits its restraining forces to the supports via stout portals (Fig. 25). In the solid-webbed, welded superstructures of the approach bridge (Fig. 26) the distance between the main girders is greater than in the case of the river section. The object of this arrangement was to reduce the additional forces set up in the brackets owing to the smaller effective spans, by shortening the cantilever arm of the brackets.

Example 4.

Fig. 27 illustrates a river bridge whose length far surpasses that of any of the structures discussed in the foregoing. The middle span of this bridge is 250 m long, and on each side of it there is a secondary span of 125 m. Six flood bridges of lattice girders each with a span of 45 m, and an 87 m long transitional structure link up via the approaches with the roads of the district. The total length of the whole construction between the abutments is 857 m. As it was stipulated that from any point of the bridge an open view of the river and both its banks should be obtained, the type chosen was that of a cantilevering bridge. Over the approach bridges the roadway has an up-gradient of 1: 60, and over the spans adjoining the central section a rise of 1: 125. This enables the specified clearance of 9.1 m above the highest navigable level of water to be attained for shipping. The two portals have a height of about 40 m above mean water level. The total width of the bridge between the railings is 19.5 m, of which 11 m is allotted to the roadway, 2 × 1 m to the two paths for cyclists, and 2.15 m for each of the two footpaths, which run outside the main girders.

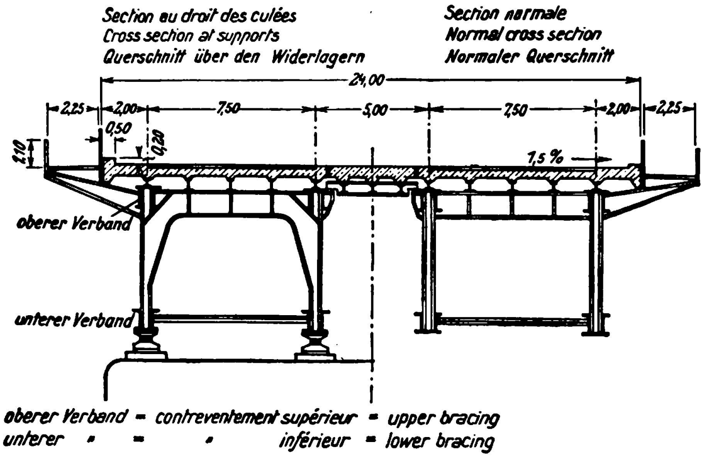

Fig. 24.

Example 5.

In conclusion, the longest-spanned lattice bridge in Germany should be mentioned (Fig. 28). The lattice girder with rhombic arrangement of members is continuous over two spans, the main span being 256 m and the secondary span 154 m. The height of the girder is 24 m. Flood and approach bridges link up on both sides with the roads of the district. The total length of the structure is about 756 m. Between the main girders runs a roadway 12 m wide, on each side of which there is a 1.5 m wide path for cyclists. A can-

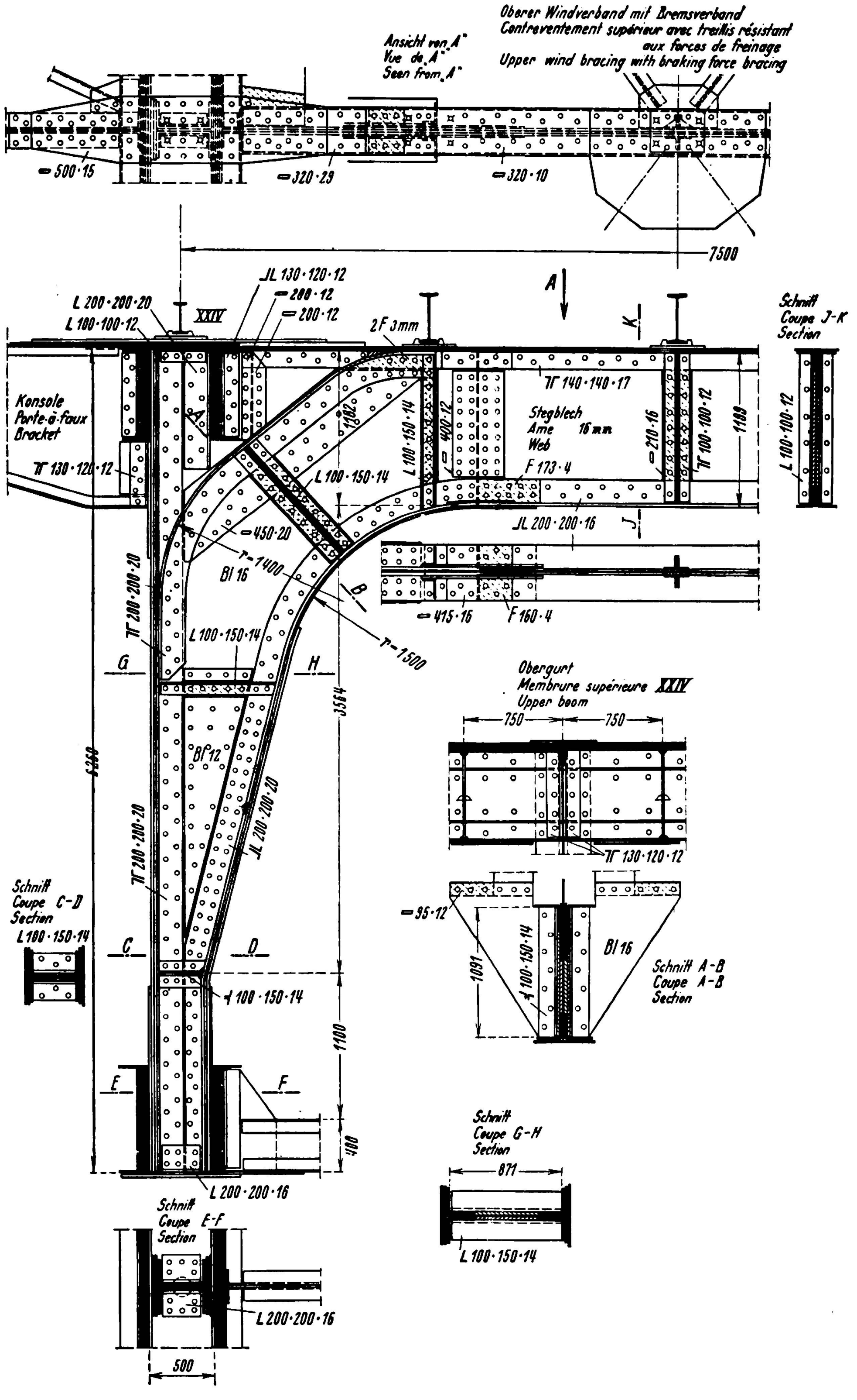

Fig. 25.

Section of portal above piers II and III.

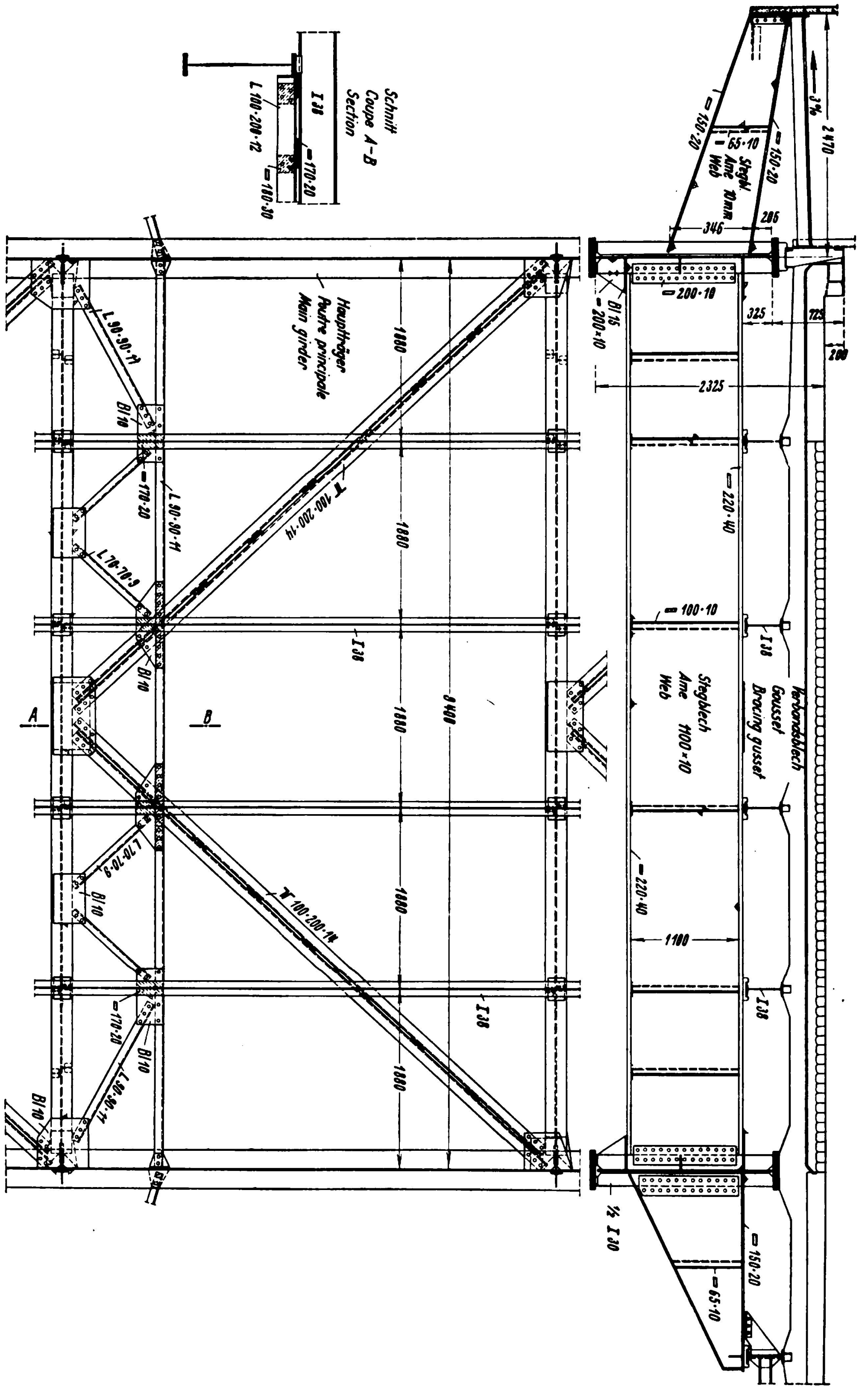
Schnitt
Coupe A–B
Section
I 38
L 100·200·12
▭ 170·20
▭ 180·30
Hauptträger
Poutre principale
Main girder
L 90·90·11
Bl 10
▭ 170·20
L 90·90·11
L 70·70·9
Bl 10
T 100·200·14
1880
1880
1880
1880
1880
9400
I 38
I 38
A
B
▭ 150·20
▭ 65·10
Stegbl.
Ame 10 mm
Web
▭ 150·20
346
286
3%
2470
▭ 200·10
Bl 15
▭ 200×10
325
725
200
2325
▭ 220·40
▭ 100·10
I 38
Stegblech
Ame 1100×10
Web
Verbandsblech
Gousset
Bracing gusset
▭ 220·40
1100
I 38
½ I 30
▭ 150·20
▭ 65·10

Fig. 26.

Fig. 27.

tilevering footpath, 2.75 m wide, runs along the outside of each main girder. In order to reduce the weight of the decking, the bays between the principal panel-points of the rhombic lattice are divided up by posts which transmit their forces at the intersection point of the diagonals. The horizontal forces are absorbed by two braces, the upper of which transmits its restraint forces via the two end portals and that over the central pier to the supports.

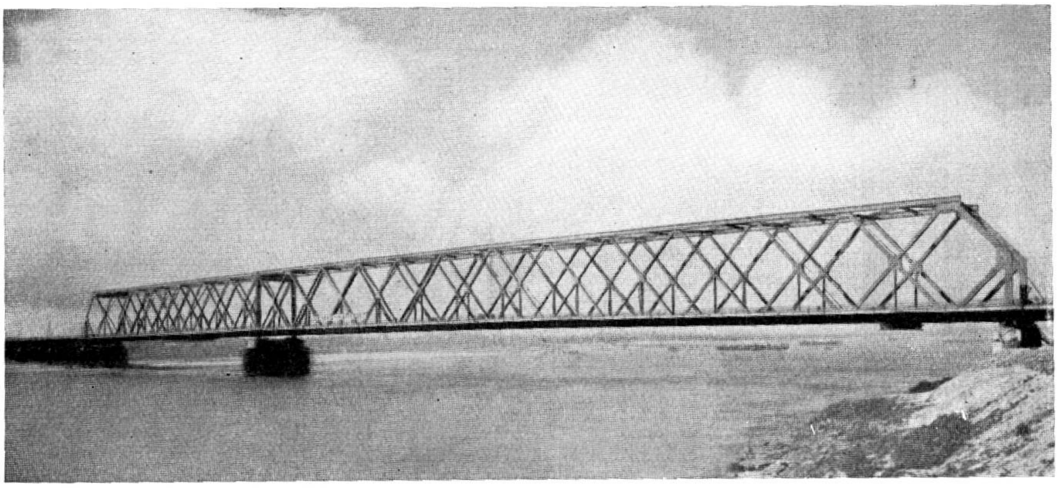

Fig. 28.

Summary.

Many new steel bridges have been built in Germany in recent years. In contrast to former times, when such constructions were planned in the first line with a view to purely economic and technical efficiency, today the arch-

itectural standpoint is given due consideration, and new bridges are required to harmonise with their natural surroundings.

When discussing the frames of the bridges dealt with in this paper, reference is made to their harmonious lines and practical detailing.

Three examples are given of large viaducts constructed under the German Arterial Motor Road scheme. With the exception of their actual construction, these solid-webbed bridges, all of which are supported on concrete piers or steel columns, are alike.

Further examples of the use of steel are given in the description of a number of lattice bridges of various types.

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