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The Saalach Bridge on the German Alpine Road.

Die Saalachbrücke an der Deutschen Alpenstraße.

Le pont de Saalach de la Route allemande des Alpes.

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The discussions on solid walled reinforced concrete structures offer an occasion to describe a remarkable bridge on the German Alpine road, which illustrates the possibility of applying the available knowledge to skew arches also.

Fig. 1 shows the general layout of the Saalach bridge recently completed near Bad Reichenhall, consisting of three completely built-in reinforced concrete arches. The respective spans are of 23.8, 24.7 and 28.2 m with a thickness of the arch barrel of 0.60 m at the crown and 1.0 m at the springings. The two intermediate piers are 3.5 m wide and rest upon strong reinforced concrete foundations which were built inside sheet pile cofferdams.

All three arches are skew, the piers and abutments being parallel to the direction of the stream and making an angle of 60° with the axis of the road. The latter, which is 9.0 m wide, is enclosed between massive side walls and has a gradient of 5 % in the direction of the length of the bridge, in addition to which, since the bridge is situated at the end of a curve, the road surface has a super elevation of 3 %. The footway 0.80 m wide on the upstream side, and the kerb 0.25 m on the downstream side, are lined with granite. The parapets are 0.60 m high by 0.45 m wide and are covered over with coping stone slabs. The external faces of the bridge are lined with masonry.

Statical features.

As is well known, the statical examination of skew arches has hitherto been conducted from several radically different points of view. One method of calculation commonly adopted for such arches is to assume them to be divided up into a number of independent arched strips spanning between the abutments in a direction parallel to the side walls, but this assumption is unsatisfactory because the loads on the arch are in fact carried to the abutment along the direction of the skew span. Moreover, Navier's law of stress distribution holds good only for cross sections normal to the gravitation axis of the structure.

In the present work the statical investigation was made by considering the two side walls each 1.5 m thick as supporting the masonry lining over a thickness of 1.0 m and a radial height of 1.9 m and enclosing the sides to the arch, the

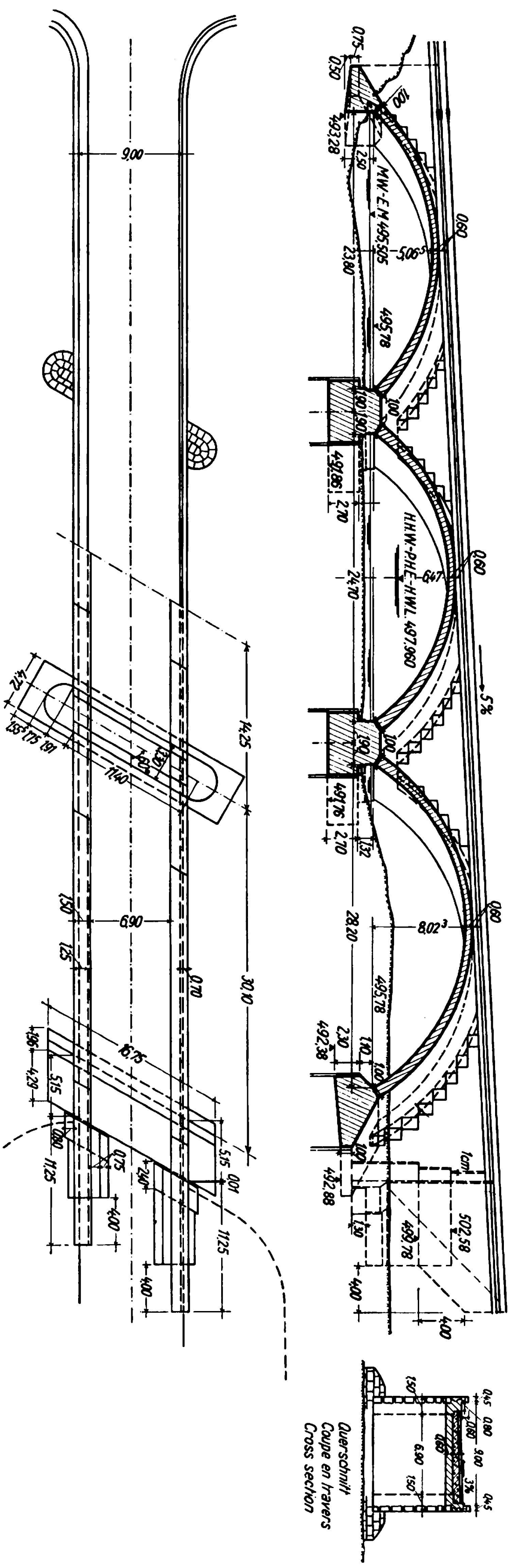

Fig. 1. Saalach Bridge, structural features.

upper parts of the construction being stepped to follow the coursing of the masonry. In this way a boxed section is constituted wherein the play of forces is three-dimensional, the arch acting as a circular cylindrical shell between the two lateral walls. In this way the combined loads acting on the arch barrel are transferred for the most part to these two facing walls. This action is due to the fact that the elements of beams, which exist in the direction of the generatrices of the shell, wedge against one another when loaded, so that if the arch has a sufficient curvature the condition of stress in these elements is almost free from bending effects.[1]

Over a certain width, known as the cooperating width, the shell participates in the deformation undergone by the above mentioned arched side walls. According to *Finsterwalder*[2] and *Craemer*[1] this width depends, among other factors, on the degree of fixation. It was determined at the crown as 1.2 m and at the springings as 1.8 m measured at right angles to the inner face of the aforementioned arched facing walls.

The loading which appertains to each such facing wall includes apart from its dead weight the loads transferred to it from the shell. These last were determined and include the live load according to the Class 1 of the German bridge standard, enabling the walls to be

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[1] *Craemer:* Zusammenwirken von Scheibe und Schale bei Bogenscheibenbrücken. Der Bauingenieur, 1936, p. 99.

[2] *Finsterwalder:* Die querversteiften, zylindrischen Schalengewölbe. Ing.-Archiv, 1933, p, 43.

designed at once in the usual way as built-in arches taking account of temperature and shrinkage stresses, and hence enabling the thrust and moments at various cross sections to be deduced. The three statical unknowns could then be

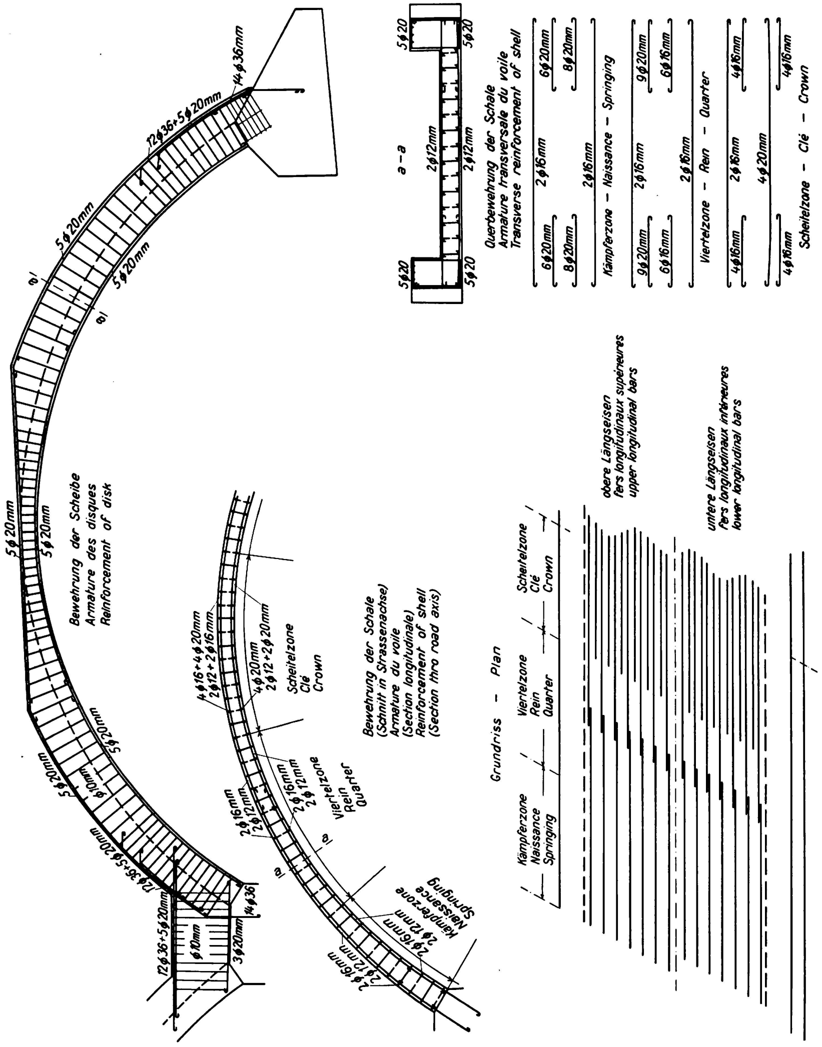

Fig. 2. Reinforcement of the arch.

solved from the deformations of the arched wall, displacements and rotations resulting from all loads and temperature changes being brought directly into the calculations. In the same way the effect of live loads was considered, on the assumption, firstly, that such loading covered one half of the span, and secondly that it covered the whole arch. The most unfavourable stresses, determined from the moments at the nuclear points and referred to the cross section at the crown of the largest of the arches made up of the "walls" and cooperating portions of the shell, were 42.6 kg/cm^2 (compression) and -16.4 kg/cm^2 (tension). The corresponding stresses at the quarter points were 4.2 and -8.1 kg/cm^2, and at the springings 52.6 and -55.4 kg/cm^2.

The reinforcement required may be seen from Fig. 2. Assuming a permissible stress of 1200 kg/cm^2 in the steel, it amounts to five round bars of 20 mm diameter in the crown and to twelve round bars of 36 mm diameter plus five bars of 20 mm diameter at the springings. The reinforcement at the crown was inserted on top and soffit and made continuous to the springings. The heavy reinforcements and the heavy stresses existing in the concrete under full load show that the walls, as explained above, do the greater part of the work. Fig. 3 shows the completed reinforcements in the facing walls.

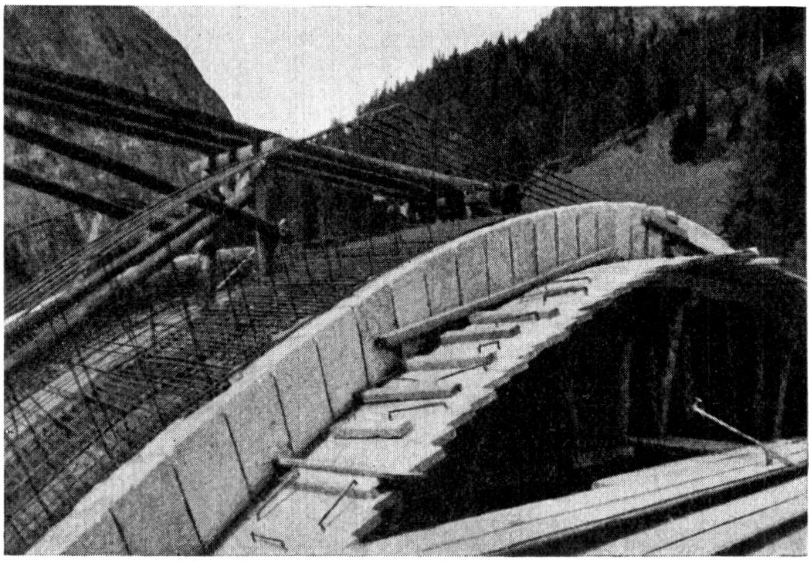

Fig. 3.

Reinforcement of the side walls.

In the shell (arch barrel), on the contrary, the reinforcement is only lightly stressed. At the middle it has to transmit normal forces so long until equilibrium is attained between the arched facing walls and the barrel arch; the magnitude of this depends, among other factors, from the load on the arch and therefore varies from one section to another. Shear stresses are produced which give rise to normal stresses in the direction of the generatrices of the shell. Differences in the respective stresses where the shell is bonded into the "walls" necessitate transverse reinforcement at the crown, quarter points and springings, as shown in Fig. 2, but in the middle portion of the arch barrel which is free from bending effects the light reinforcement there indicated is sufficient. Fig. 4 shows the completed reinforcement of the shell.

The transfer of the arch loads to the abutments and intermediate piers is effected mainly by the "facing walls" so that the skewness of the arch is of little statical significance. The maximum pressure on the foundation amounts to 4.9 kg/cm² on the right abutment and 4.4 kg/cm² on the piers. The left abutment is founded on rock and exerts a maximum pressure of 6.9 kg/cm².

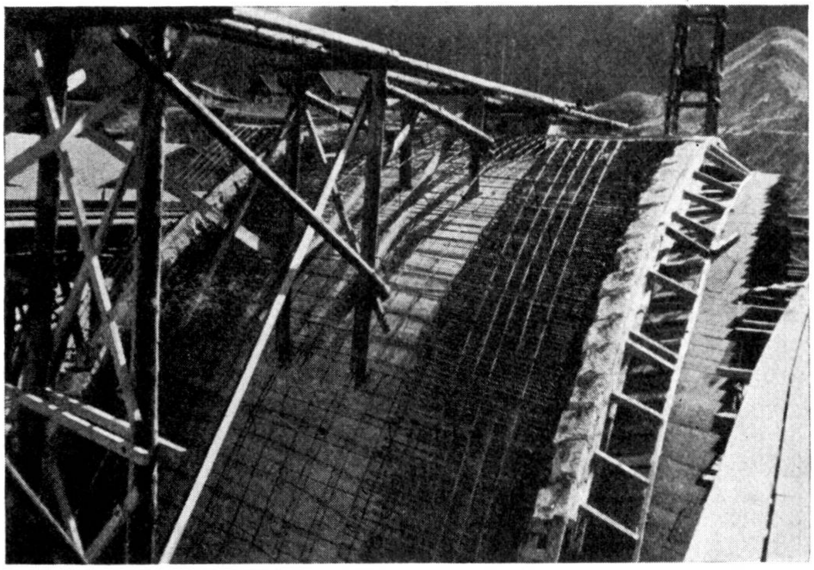

Fig. 4.

Reinforcement of the shell.

Construction.

The concreting mixing plant was placed on the right bank. The concrete was made with an admixture of 250 kg of trass Portland cement per m³ in the case of the foundations and abutments, and 300 kg/m³ cement for the arch barrel and facing walls. The construction of the cofferdams for the foundations of the piers and right abutment was begun in October 1935, and when excavation

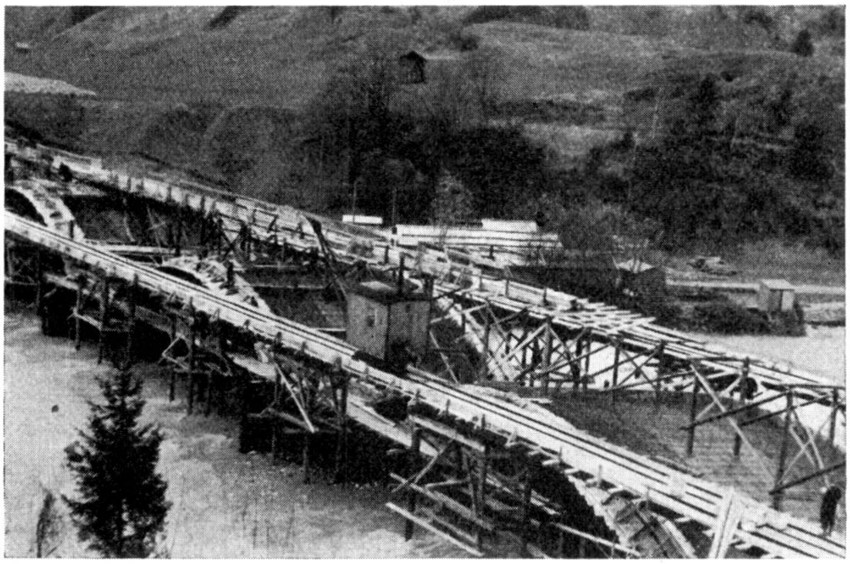

Fig. 5.

General view of work on site.

had been completed the concreting of the foundations and abutments was undertaken.

Once the piles to carry the falsework had been driven the latter was erected simultaneously in all three openings, consisting of eight frames with a system of bracing. Screw jacks were provided to allow of lowering the falsework without shock. A service bridge was constructed, both upstream and downstream of the falsework, with rails for the travelling cranes used in placing the masonry lining. Fig. 5 is a general view of the site.

The concreting of the arches, by chuting through flexible pipes from a high level scaffold, was carried out in strips in such a way that those portions of the arch which had already hardened would not be stressed by movements of the falsework. Cube tests at 28 days gave compressive strengths of approximately 250 kg/cm^2. After allowing a period of four to six weeks for the concrete in the arches to harden the scaffolding was dropped from below all three arches, the maximum amount of sinking which then occurred at the crown being 1.4 mm. After removing the shuttering from the barrel arches the masonry lining of the end walls was carried up simultaneously with the concrete. The provision of continuous expansion joints was not necessary.

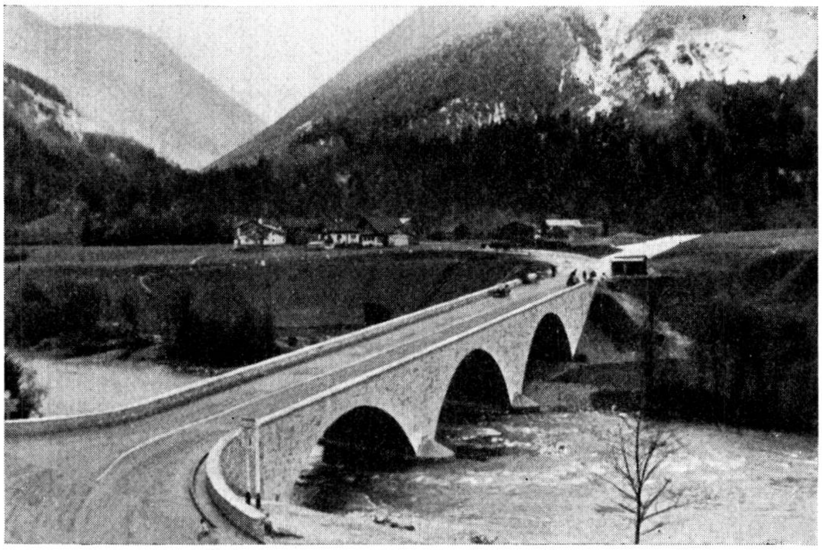

Fig. 6.

View of the finished bridge.

Fig. 6 shows the finished bridge. The 120 m length of the structure makes it visible from afar, and it blends pleasingly in to the surrounding mountain landscape.

The design of the bridge was entrusted by the Bavarian Staatsbauverwaltung to the author who also had to deal with all statical and constructional details and was responsible for supervising of the work. The plans for issue to the contractors, and the statical calculations, were carried out by *Dr. Craemer*, to whom is due also the utilisation of the "facing walls" as part of the carrying system.