The bridge over the Esla in Spain

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The Bridge over the Esla in Spain.

Die Brücke über den Esla in Spanien.

Le pont sur l'Esla en Espagne.

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The bridge at Plougastel and the one at Traneberg built five years later are splendid achievements in the construction of long span arch bridges. The Esla bridge now being built in Spain will have a span exceeding either of the two just mentioned. At the site of the bridge the Esla is an artificial lake more than 40 m deep, and the bridge is intended to carry the railway connecting Zamora with Coruña, which is a double track standard gauge line (Fig. 1). The author was responsible for the definite planning of the work after a preliminary design by M. *Gil.*

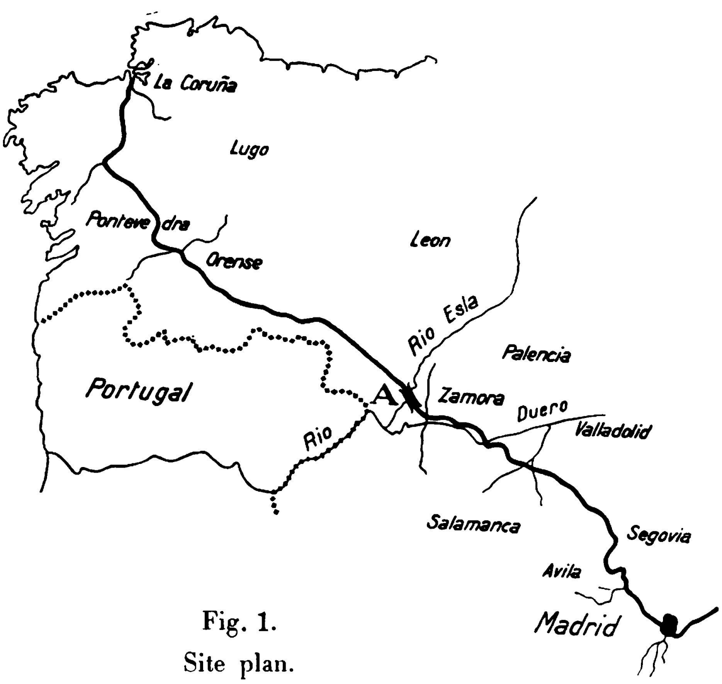

Fig. 1.
Site plan.

The following is a comparison of the principal dimensions of the three bridges just mentioned:

	Plougastel	Traneberg	Esla
Clear span	172.60 m	178.50 m	192.40 m
Theoretical span	186.40 m	181.00 m	172.00 m
Rise	35.30 m	27.00 m	38.80 m
Working stress in concrete	75.0 kg/cm²	98.5 kg/cm²	86.0 kg/cm²

The bridge consists of a main central arch and a series of side arches forming access viaducts on either bank (Figs. 2 and 3).

The central arch is hollow, containing three longitudinal cells, and the side faces are battered at 1.5 % uniformly for all elements of the central portion.

At the crown the width is 7.90 m and the thickness 4.52 m; at the springing the corresponding dimensions are 9.063 m and 5.50 m. The decking bears on the arch through the medium of columns. The access viaducts consist of five arches each of 22 m span on the Zamora side and three arches also of that span on the Coruña side.

I. Description of the Work.

Access viaducts. The arches forming the access viaducts are semi-circular with an intrados of 11 m radius; they are 1.10 m thick at the crown and are reinforced by rolled sections and round bars of steel (Fig. 4). The longitudinal deck girders are rigidly connected to the uprights which are 9.50 m high and situated vertically above the piers; intermediately they are carried by rockers on the uprights which are 2.10 m high, and at the crown they rest upon the extrados of the arch itself through the medium of sliding bearings. The piers of the viaducts are hollow, their longitudinal walls being 0.90 m thick at the top and the buttresses 0.10 m thick; the transverse walls are 1.50 m thick with buttresses 0.25 m thick. The height of the piers, measured from the top of the foundations to the springing of the arches, varies between 9.70 m and 38.70 m; the depth of the foundations between 1.22 to 6.77 m these being carried down to rock which is perfectly sound and compact.

Main arch. The height and principal dimensions of the main arch have already been stated, and it may be added that the sections consist of two rings of equal thickness varying from 0.70 m at the crown to 1.05 m at the springing, connected together by four walls with a constant thickness of 0.40 m (Fig. 5). The reinforcement of the arch is provided solely with the object of resisting secondary stresses. The neutral axis is given by the equation

$$y = 206.7\,(x - 2x^2 + 2x^3 - x^4)$$

where y represents the absolute value and x is the ratio between the abscissa of the point under consideration and the span, the origin being taken at one of the springings. Under dead load this neutral axis has practically the shape of a catenary curve, and the total cross section of the arch, as well as its moment of inertia, are designed to ensure that their vertical projection shall remain constant.

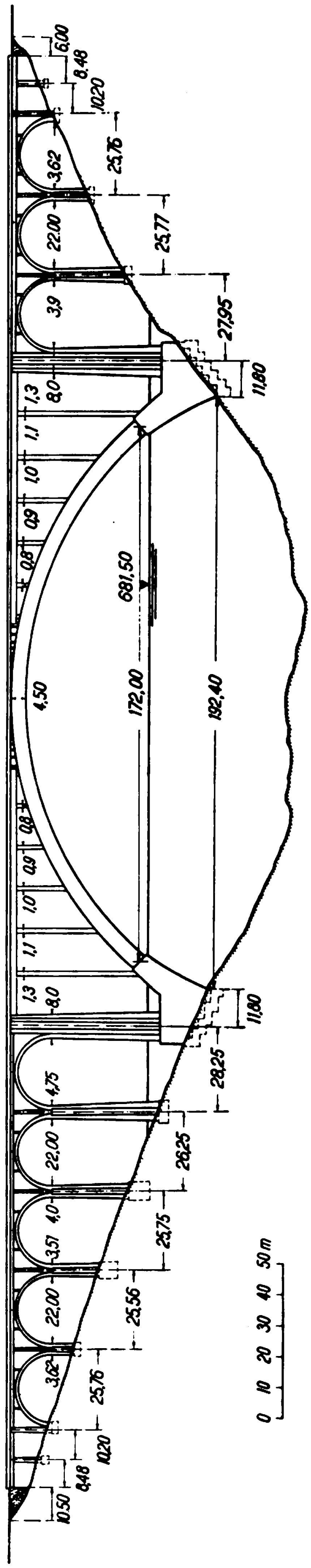

Fig. 2. Elevation of the bridge.

The superstructure of the main arch are in three distinct portions. The central portion, which is 20 m long, has small longitudinal walls which serve to retain a filling road metal. Intermediately, over a length of 12 m, the floor slab (which is continuous over five openings) is carried on cross walls built into the decking

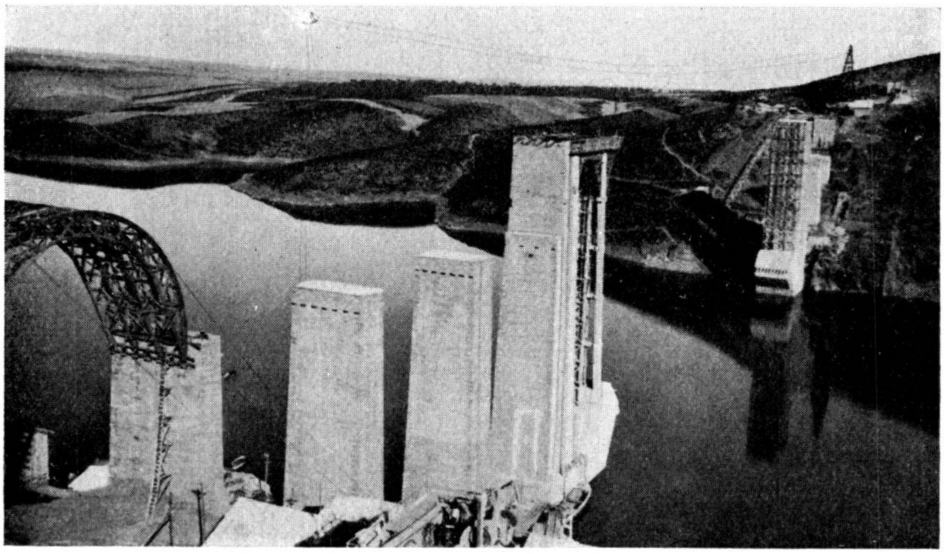

Fig. 3.
General view.

at the top and hinged at the bottom on the arch. The outermost part of the construction consists of 12.50 m spans carried onto the arch through columns. The floor itself consists of a slab 0.20 m thick supported on four beams measuring 1.80×0.60 m, the maximum height of the columns being 38.72 m.

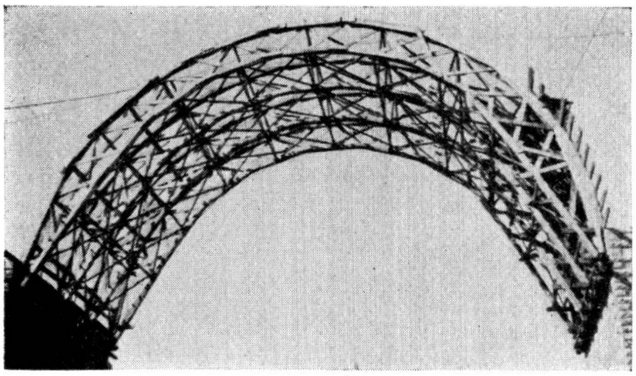

Fig. 4.
Centreing for 22 m arch.

The massive pier-abutments (Figs. 6 and 7) have a cross batter of 2 %. The abutments proper (springings) are reinforced with rolled sections and round bars, the former surrounded by circular hooping. At the springing the piers are 10.41 m wide by 6.70 m high.

As regards foundations, slate and quartzite lie exposed in the ground; hence all that was necessary was to reach down to a sound portion of the rock.

Materials. The end abutments of the access viaducts were built in ashlar masonry and the foundations of cyclopean concrete containing 150 kg of cement per cubic metre. The facings were formed of concrete blocks with 250 kg/m^3; the filling is of concrete with 200 kg/m^3; the small arches and decking of concrete with 350 kg/m^3. Under the main span the foundations were built of cyclopean concrete containing 200 kg of cement per cubic metre; the abutments of concrete containing 325 kg/m³; the arch itself of concrete containing 400 kg/m³ and the superstructure of concrete containing 350 kg/m³. Artificial Portland cement was used throughout.

The total cost of the work has been estimated at 6.5 millions of pesetas.

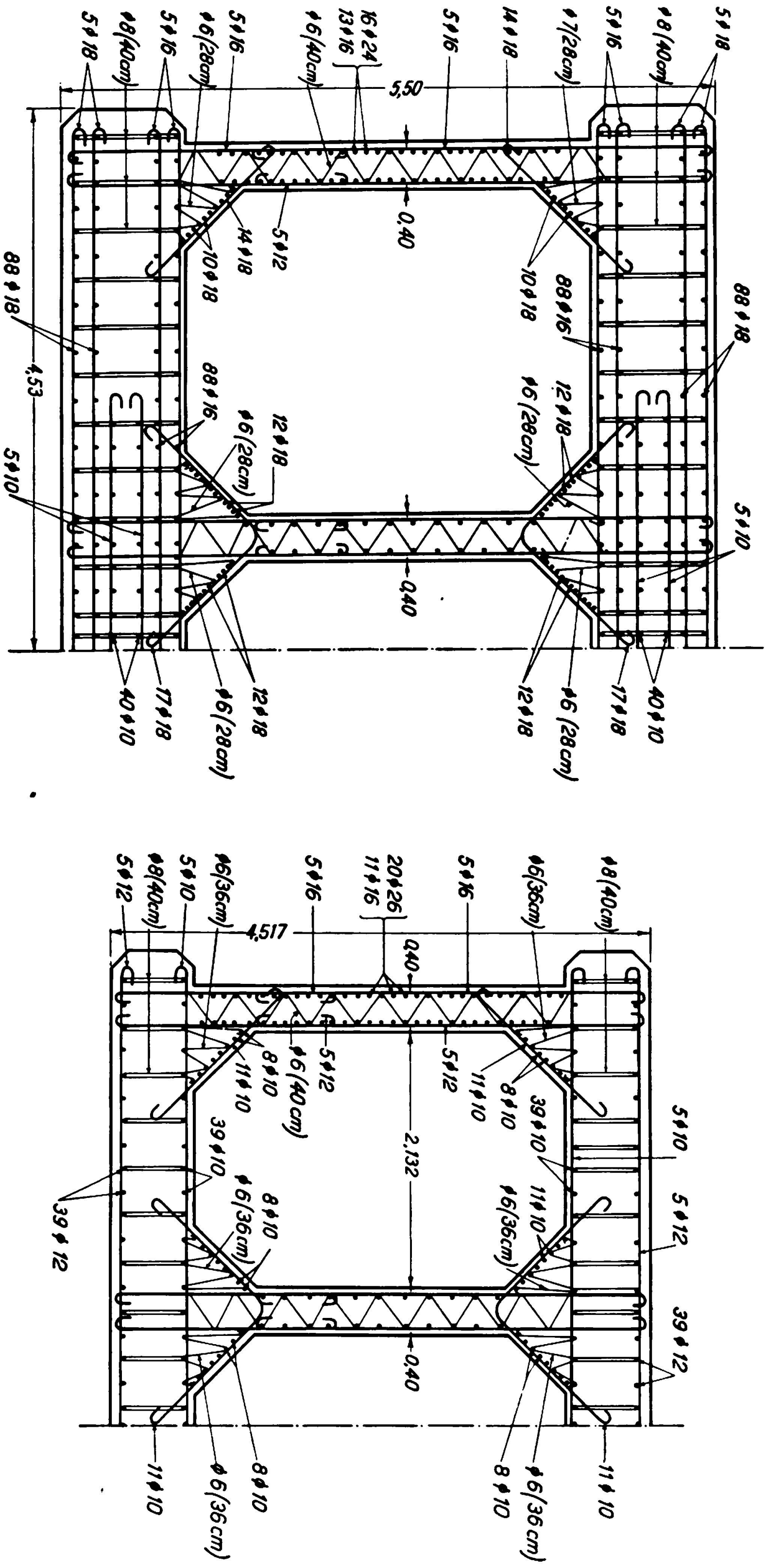

Fig. 5.
Sections at springing and crown.

II. Statical Calculations.

a) *Access viaducts.* The circular arches have a theoretical diameter of 23.40 m. They were designed with an allowance for a variation in temperature of $\pm 20^0$ C, including shrinkage. The maximum stresses, taking account of braking loads and wind, amount to 46.5 kg/cm² for the compression of the concrete at the springing and 1010 kg/cm² for tension in the steel. The shear stresses due to torsion in the arch may reach 5 kg/cm². Flexure of the piers and strains in adjacent arches were taken into account when designing each arch.

The frames working the superstructure were very exhaustively calculated, taking due account of all possible effects.

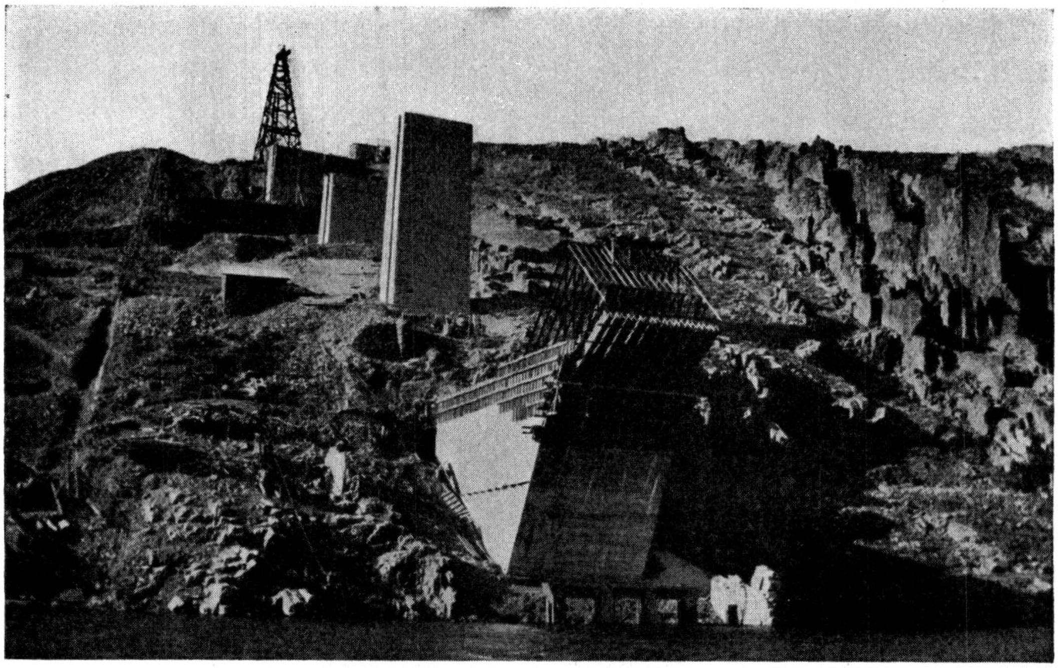

Fig. 6.

Abutment (on Zamora side) showing reinforcement; in the background a mast of the cableway crane.

b) *Main Arch.* The axis of the arch is a parabola of the fourth degree, this being the shape which conforms most closely to the dead load pressure line out of dead weight. The load assumed in the calculation consists of two typical trains as prescribed in the Spanish regulations, and this gives rise to stresses which are less than one half of the dead load stresses.

In long span arches of this type secondary stresses become very important. For the purpose of calculation account was taken of variations in temperature, collaboration between the arch and its superstructure, and buckling of the arch. In view of the great size of the structure it was assumed that the wind would act only on one part of the bridge at a time.

The method of calculating the polar moment of inertia for the solid and hollow rectangular sections was that given by *Mesnager* and *Föppl. Lorenz* and

Pigeaud have worked out the general case of a section of any shape, but have stated only approximate solutions. For the case where the sections consist, as here, of several cells there is a choice of several methods:

1) The section may be assumed to be solid, the distribution of stresses on that assumption may be explored, and the stresses which ought to be carried by the non-existent hollow portions may be transferred to the top, bottom and the vertical elements. This solution is positive and simple, but gives too heavy stresses.

2) The central vertical diaphragm wall is neglected, so that the section has in effect only one internal cavity. On this supposition a great deal of the actual rigidity against torsion is neglected.

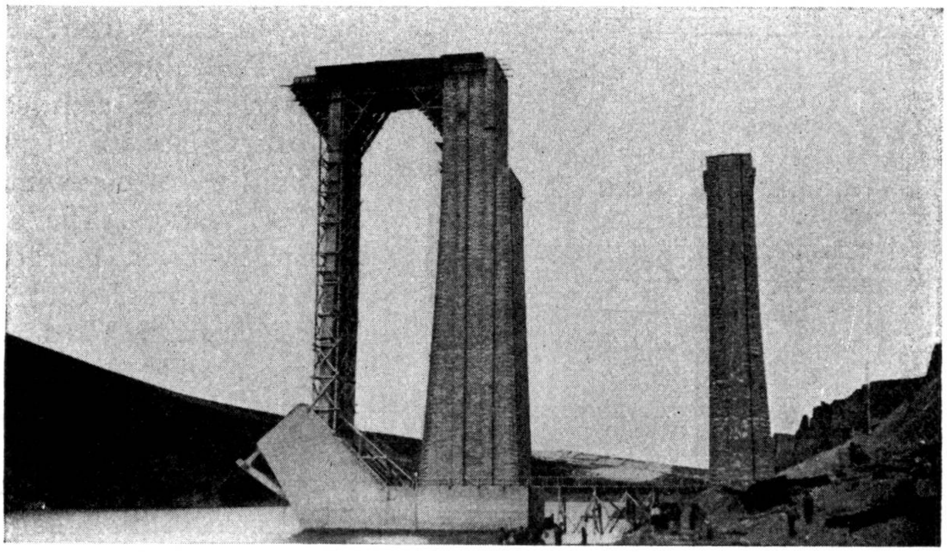

Fig. 7.

Abutment pier with a portion of the superstructure for erecting the centreing of the main arch.

3) It may be assumed that the twisting moment is distributed among the three cells and that the three portions of the section have the same angle of deformation. It was this last method that was in fact adopted.

The influence lines for all the hyperstatic reactions were determined by the method of virtual loads and superposition of forces. A variation of temperature of $\pm$ 150^0 C was assumed. In designing the columns account was taken of braking and acceleration, also of the effect of deformation of the arch and columns, etc.

Large arches need to have very solid abutments in order to ensure the fixation of the arch. In order to check the elasticity possessed by these abutments influence lines for the deformation were calculated, by assuming the arch to be comparable to a beam of varying moment of inertia which was rigidly built in. These influence lines were calculated by *Müller*'s method, and it was found that the displacement of the extreme section of the arch at the abutments amounted to 0.0044 mm, which value is very low.

III. Construction.

The volume of concrete required for the construction of this work amounts to 32000 m³, which represents 28000 m³ of broken stone and 15000 m³ of sand. The available plant provided has a capacity of 100 m³ of stone and 30 m³ of sand in eight hours. The site is served by a cable-way 500 m long carried on two wooden pylons 28 m high, the speed of travel being 1 m per second vertically and 4 m per second horizontally. It is operated by a 46 H.P. motor.

The falsework as designed is a timber arch consisting of frames 3.50 m high, built up of pieces measuring 23 × 7.5 cm. The arch will spring from brackets made of reinforced concrete, and on these brackets hydraulic jacks will be provided for the adjustment of the centreing.

The falsework will be erected with the aid of a suspension bridge consisting of three sets of carrying cables (Fig. 8), and will be braced by a network of cables to ensure stability (Fig. 9). The suspenders will be rigid cables of 8.1 mm dia., and the 15 carrying cables will be arranged in groups of five.

The falsework is relatively very light in design as a special sequence of operations is to be followed in concreting: first the lower third of the arch resting on three rollers, then the corresponding portion on two rollers, finally the remaining two-thirds of the arch at the

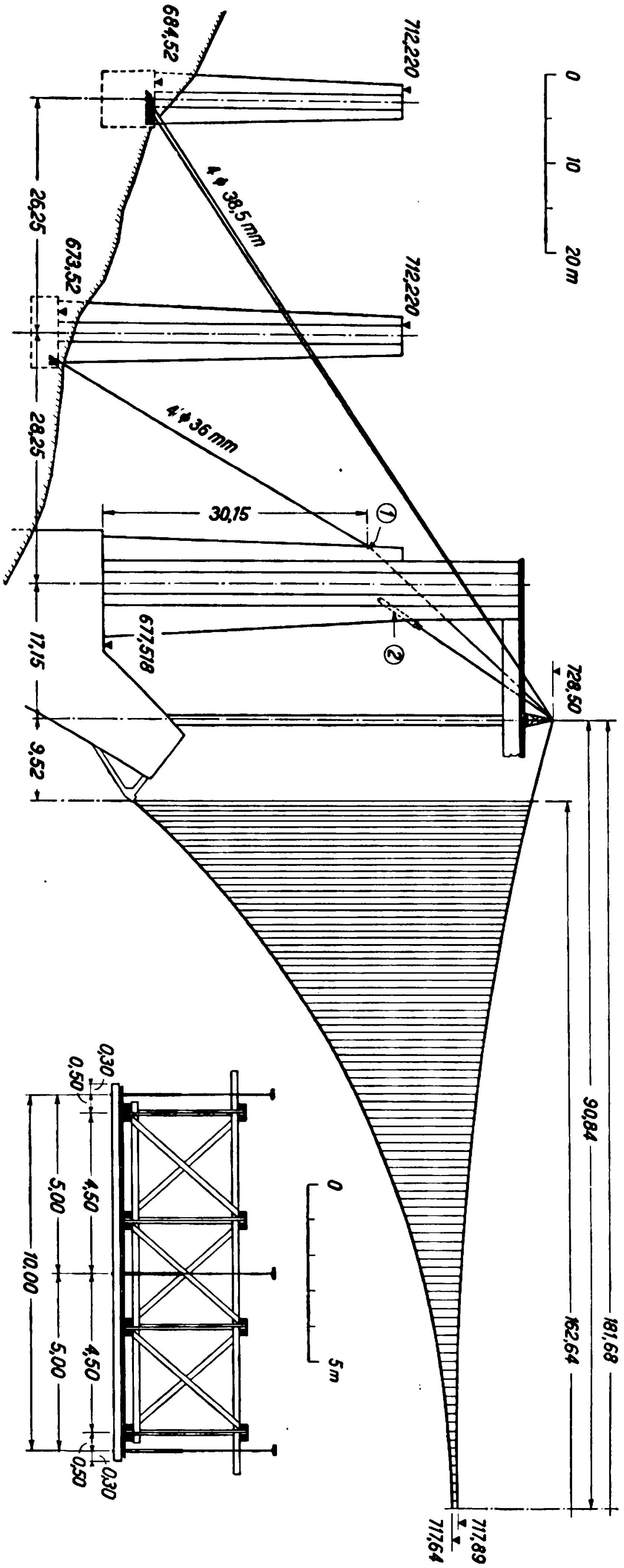

Fig. 8. Suspension bridge for erecting the centreing:
① Notched timber member. ② Anchorage of cable.

crown. The maximum stress imposed on the timber of the falsework will amount to 78 kg/cm^2.

No special arrangements for releasing the falsework are being made, as adjustments will be carried out with the aid of 36 hydraulic jacks placed at the crown.

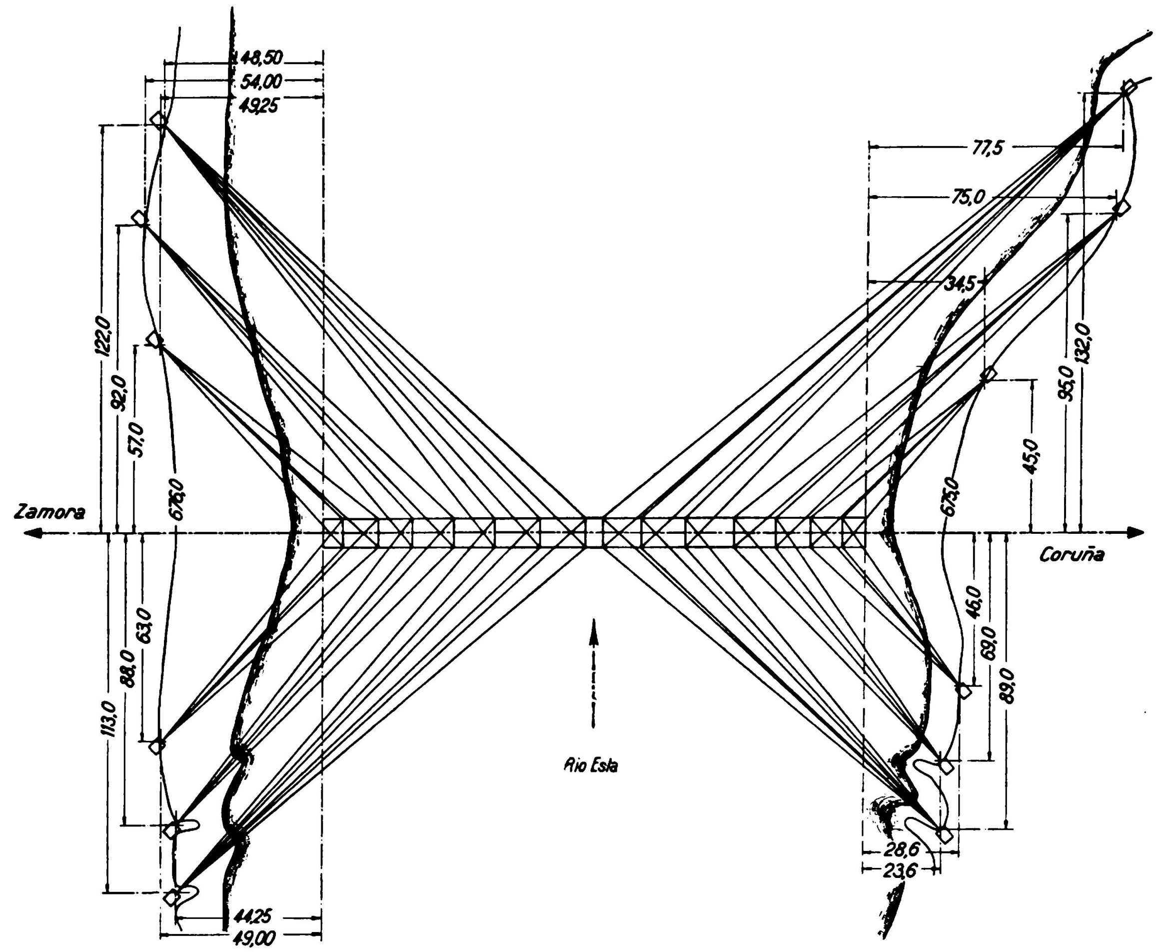

Fig. 9.
Cable system to ensure stability.

Provision has been made for 86 auscultators to be embedded in the concrete mass, thus, enabling the accuracy of the calculations and hypotheses to be checked at any time. The site is in a district where the climate is hard and dry, and these observations may be expected to furnish important knowledge on the phenomena of shrinkage and creep, especially when compared with the results already obtained at the Plougastel and Traneberg bridges which are situated on northern coasts where the climate is damp and cold.

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