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Experiments on Models to Determine the Most Rational Type of Reinforcement.

Modellversuche zur Bestimmung der zweckmäßigen Anordnung der Bewehrungen.

Recherches expérimentales des systèmes d'armatures rationnelles.

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Compliance with the elementary condition that the reinforcing bars must be placed in the direction of the maximum tensile stresses is essential for good work in reinforced concrete construction. Obvious as this condition may appear, it is too often not satisfied in practice. In the design of thin walled structures especially, certain assumptions are made which are not entirely justified, and the results of the calculations can then be only an imperfect representation of the true conditions of stress. If experimental tests are made, either on actual work or on models, wherein the reinforcing bars have been arranged in accordance with such calculations, the only result will be to show whether the reinforcement so provided has in fact been adequate: but it is impossible to infer from such experiments whether the system of reinforcement is a rational one.

The object of this contribution to the discussion is to recall attention to the possibility of devising rational systems of reinforcement through research by the method of photo-elasticity. This method has been known in principle for a hundred years, and was made available in engineering practice thrity-six years ago by the eminent French engineer and scientist *Mesnager*, since when, through the notable work of *Coker, Filon* and other investigators, the scope of photo-elasticity has been extended to all branches of construction. For the bibliography of the subject reference may be made to the author's recent article in the fourth volume of the Publications.

Three-dimensional problems, wheter plane or curved, are capable of resolution by means of suitable experimental methods, and this applies to both thin-walled and massive constructions.

In order to reduce the length of this contribution to a minimum, reference will be made straightaway to an actual example of experimental investigation. Fig. 1 is an elevation of the cantilever bridge at Bry-sur-Marne, belonging to a type several examples of which have already been built in France, in the neighbourhood of Paris. The cantilevered portion is 22.5 m long on each side, and the simply supported central portion is 22 m long, giving a clear span of 67 m. There are no horizontal reactions. The cantilever is rendered stable by the weight of the filling over a floor which forms an extension of the lower girder of the heavy framework in which the cantilever is embedded. This frame leave a free passage, 3.50 m high by 8.60 m wide, for the roadway which runs along the river bank.

The bridge is of recent construction, the contractors being the firm of *Schwartz*-Hautmont. It was considered desirable by the Service des Ponts et Chaussées of the Seine Department (under Messieurs *Levaillant,* inspecteur général, and *Gaspard* and *Peyronnet,* ingénieurs, of that service) that photo-

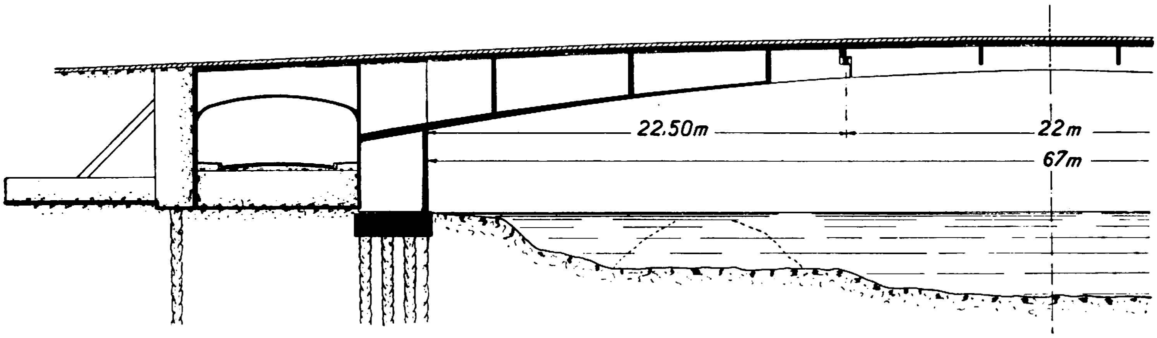

Fig. 1.

elastic experiments should be carried out on a small scale model in the laboratories of the Ecole Nationale des Ponts et Chaussées in Paris, with the object of checking whether the system of reinforcement as indicated by the usual form of calculations might not have been the cause of the cracking observal to have taken place in two instances of similar bridges previously constructed. The following is a brief description of the researches carried out. The model was made of xylonite, faithfully reproducing the dimensions of the bridge to a scale of 1:100 so as to ensure similarity between the conditions of stress in the actual work and those in the model. The model was strengthened, apart from the parts in compression, to correspond with the reinforcement as experimentally provided, wherever the proportion of the latter was in excess of 2 %. It had been found in earlier experiments that for ensuring similarity in the elastic phenomena there is in practice no need to take account of reinforcements if their percentages are less than 2 %, when using models of a homogeneous material such as glass, xylonite, bakelite, etc., as the homogeneous material in resisting tension automatically compensates for the absence of reinforcement in the model — always provided that the percentage of reinforcement, indicated above, is not exceeded.

Where, however, the reinforcement is heavier than this, it becomes essential to increase the strength of the tensile fibres in the model made of homogeneous material accordingly, and this may be accomplished either by increasing the thickness of the model or by attaching reinforcements to it to correspond with those in the concrete in excess of 2 % of the cross section.

In the present case, then, the additional thickness in the model served as its reinforcement, the cross sections so added being made equivalent to between ten and fifteen times the excess of reinforcement over 2 % in the tension zone of the concrete.

The model constructed in accordance with these principles (Fig. 2) was subjected to a system of forces to correspond with full load on the cantilever with minimum load over the remainder of the structure. Fig. 3 represents the first experimental stage, the plotting of *isoclines,* which are the geometrical loci of those points where the principal stresses are oriented along the plane

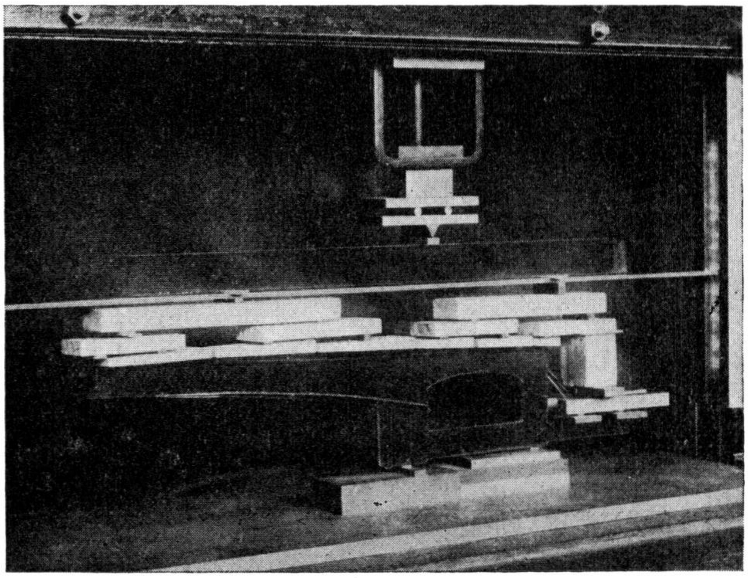

Fig. 2.

of polarisation, the arrangement of which is shown in the right bottom corner of the same figure. From this the corresponding *isostatic* lines Fig. 4 were derived. The stresses parallel to the isostatic lines, which are indicated respectively by broken and full lines, will be designated as v_1 and v_2.

The quantitative solution to the problem is furnished by Fig. 5 which gives the curves of compression (or tension) from which may be determined the moments, the normal forces and the shears at any desired section. Figs 6 and 7 show the isoclines and isostats for the right hand pier and for the girders embedded therein to an enlarged scale, together with certain details which could not be included in Figs. 3 and 4. It will be noticed that in these diagrams the isostats in the zones corresponding to the compression slabs are omitted, for as the present experiments were confined to observations in a single horizontal direction normal to the median plane of the model, they did not enable a detailed investigation to be made of the phenomena occuring in the compression slab, where, in addition to the stresses v_1 and v_2, there is a further stress v_3, the effect of which combined with that of the non-uniform distribution across the thickness of the slab, is to cause perturbations incapable of being analysed by observation in a single direction. An experimental solution of the stresses in the compression slabs would necessitate the use of a glass model made to a larger scale and the making of observations in several directions.

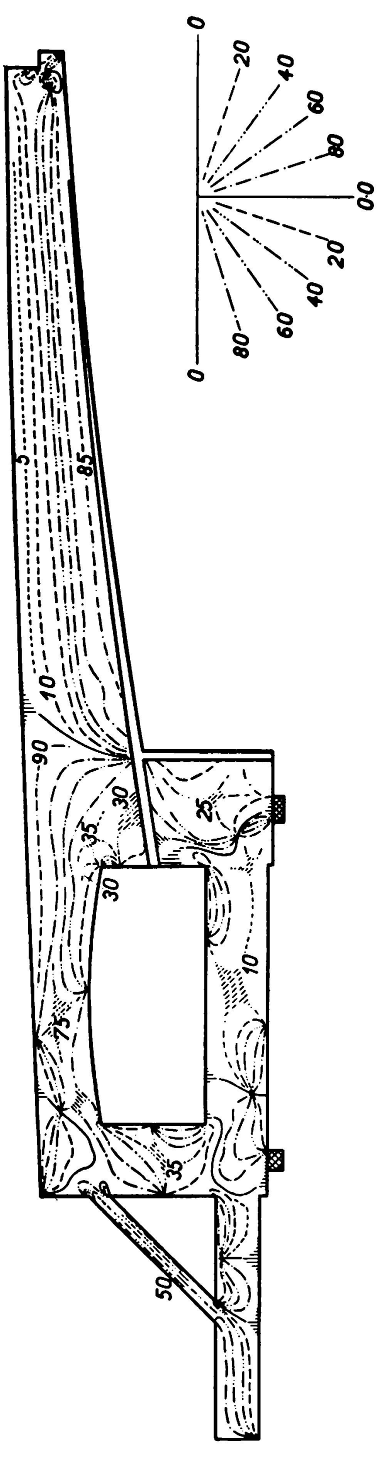

Fig. 3.

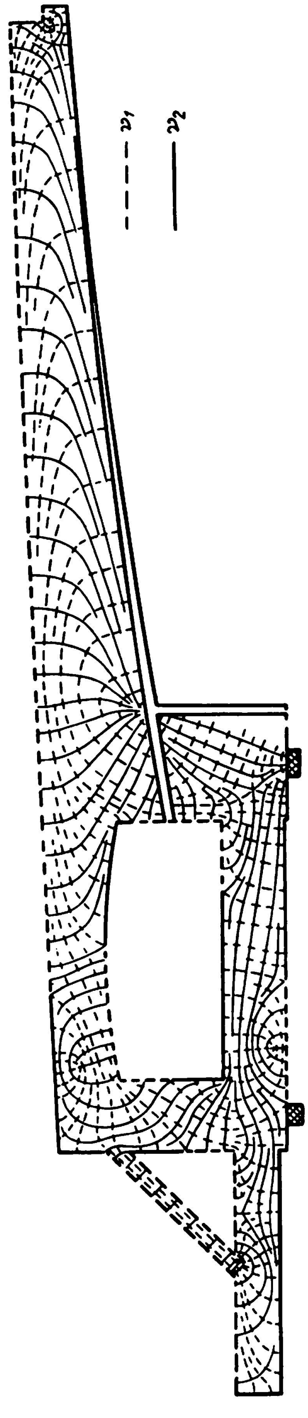

Fig. 4.

Fig. 9 represents the lines of equal stress v_1. The numerical values marked in Figs. 8 and 9 are expressed in tons per linear metre, and provide a means of obtaining the average values of the stresses across the thickness in kg/cm^2. This is done by dividing the numerical value v_1 or v_2, as read off the diagram by 10e, where e denotes the thickness in metres at the corresponding point in the actual structure.

The lines of equal stress v_1 have been indicated as chain lines where they represent tensions and as full lines where they represent compressions. It will be noticed that v_1 is always a tension except in the four cross-hatched zones, where it is a compression, but in Fig. 9 on the contrary, the stresses v_2 are all compressive, with the exception of one zone which is shown hatched to indicate tension.

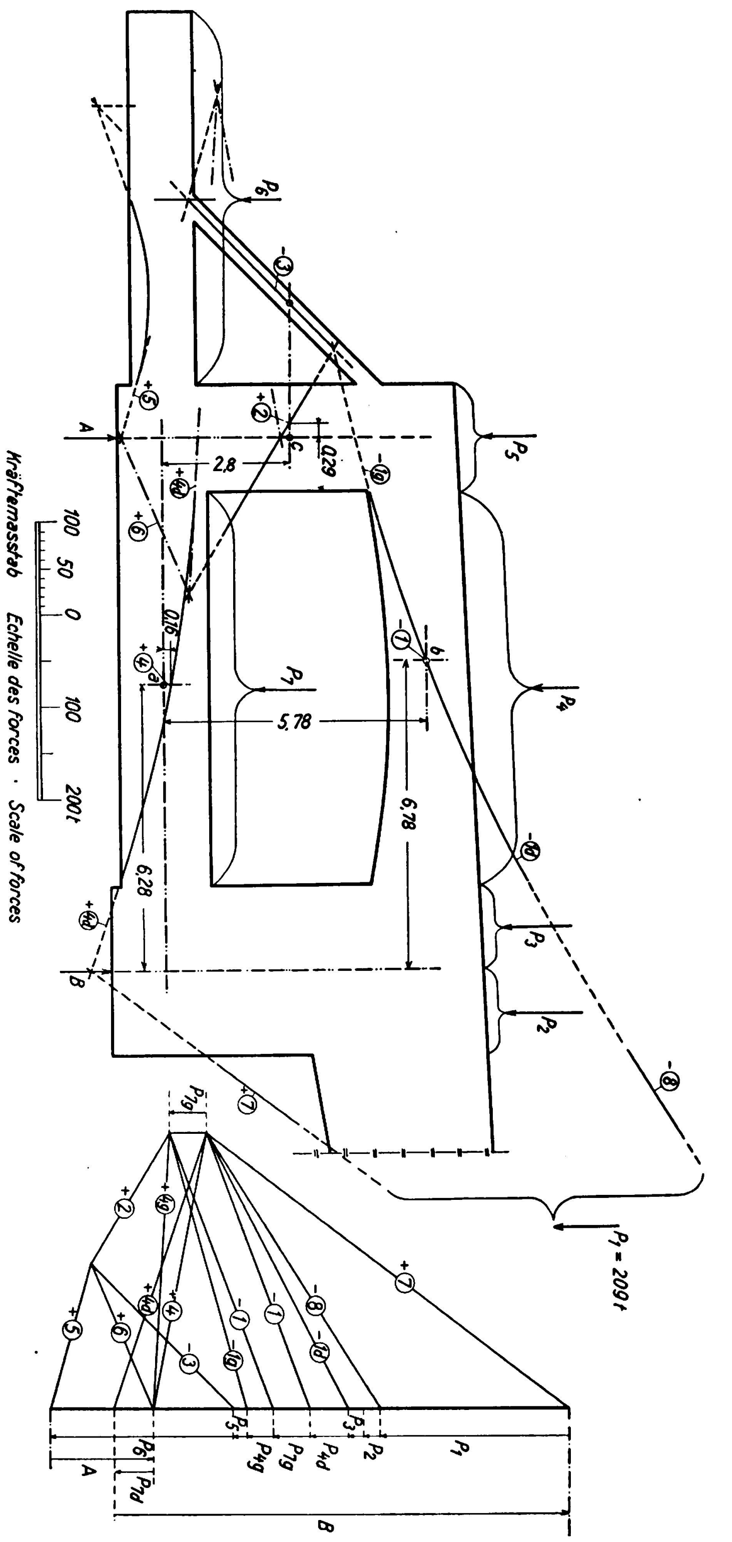

Fig. 5.

The practical upshot of this is that the isostatic lines of Figs. 5 and 8 fail to confirm the propriety of the system of reinforcement derived from calculations made in the accepted way. *Moreover, the experimental study discloses the existence of tensile stresses in the concrete, which are not negligible, in those zones where the usual calculation assumes the absence of any such tensile effect, the supposition being that all tensile forces are taken by the reinforcement close to the tensile surface.*

In order to overcome the risk of cracking — or at any rate to ensure that any cracks that do occur will be so minimised as to be practically imperceptible — there is every reason for arranging the reinforcements along the direction of the tensile isostats. Apart from the principal reinforcing bars close to the tensile edge, which are required by the usual form of calculation, it is of value to add other bars in the region separating the compression concrete from these principal

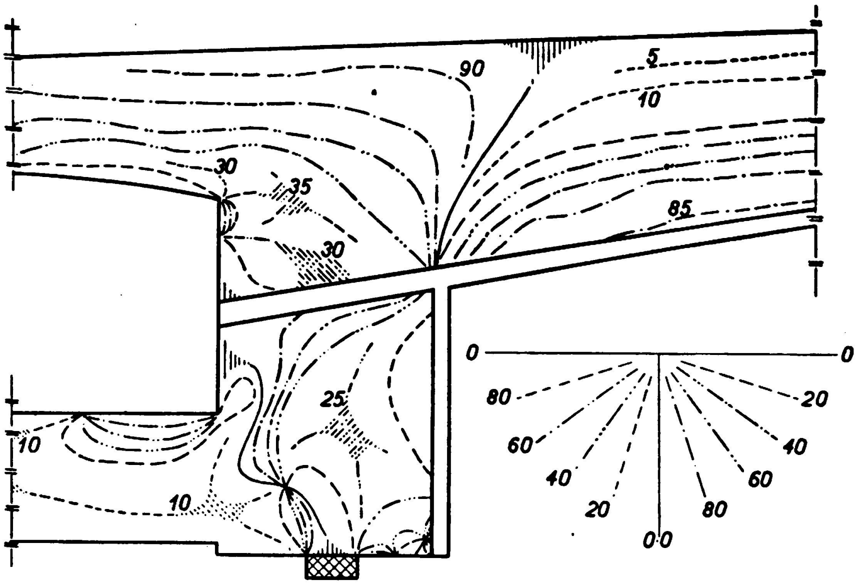

Fig. 6.

bars, wherever the amounts of tension as determined from Figs. 6 and 7 are in excess of the permissible tensile stresses in reinforced concrete.

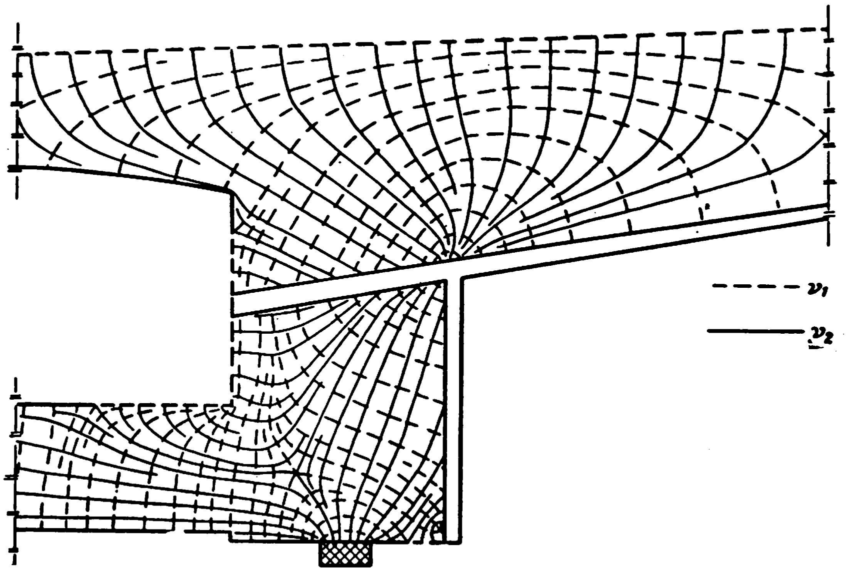

Fig. 7.

In conclusion it may be apposite to recall the fact that photo-elastic methods of measurement offer a means for arriving at the proper amount of preimposed stress to be applied to reinforcing bars with the object of favourably pre-stressing the concrete, and of judging its effectiveness.

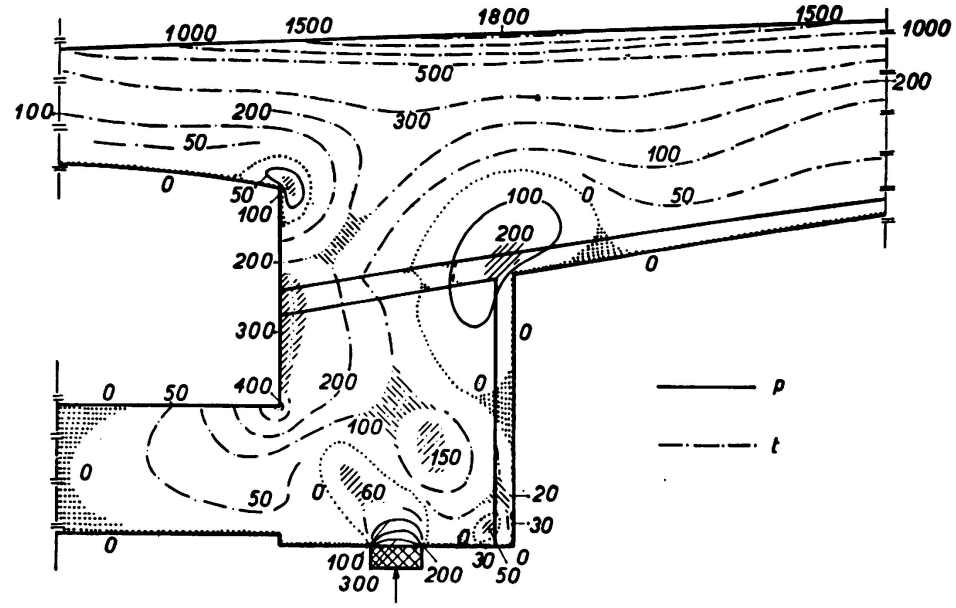

Fig. 8.

Lines of equal stress v_1 values in t/m.

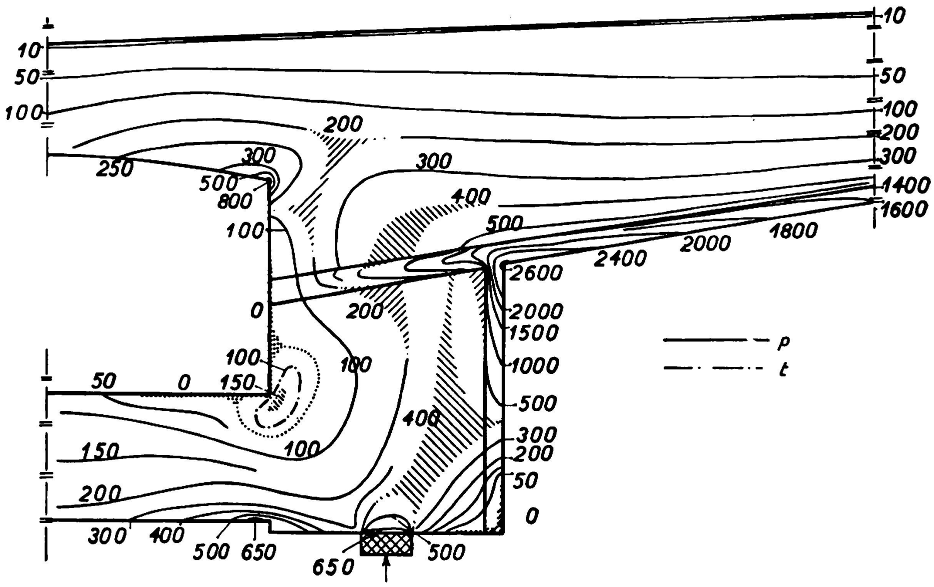

Fig. 9.

Lines of equal stress v_2 values in t/m.