Note on the paper by Boussiron

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Note on the Paper by Boussiron.[1]

Bemerkung zum Referat Boussiron.[1]

Note concernant le rapport Boussiron.[1]

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Variation in moments of inertia.

The principle of varying the moments of inertia of different elements in a hyperstatic structure, so as to satisfy certain technical or economic conditions, is one which has undoubted advantages. It confers greater flexibility than the use of hinges and as a rule is simpler than the expedient of bringing initial stresses into play by artificial means.

In the general case of a structure covering several spans, wherein all the elements are monolithic, the distribution of the stresses depends severally on the characteristics of the arches, the piers, the abutments and the ground bed. By ringing the changes in these characteristics it is possible to modify the action of the hyperstatic system in question even without altering the arrangements of the spans, thus obtaining several solutions which give equal strength, but differ in appearance, deformations and cost. For instance, if the piers are relatively very rigid the section of the arches may be reduced to a minimum, because, in the limit, these tend to act as independent elements built into fixed supports. On the other hand if the arches are made stiffer it is permissible to adopt more slender piers, and in the limit the conditions of stress imposed upon the latter tend to approximate to those which would exist in posts carrying and rigidly embedded into a beam.

In two instances of structures with very high piers the author has been able in this way to realise advantages amounting to between 15 and 23 %, by comparison with the arbitrary method which consists of designing the piers as if they had to resist the difference in thrust between the adjacent spans, while the piers are assumed to be rigidly fixed. The comparative calculations for different sections can very rapidly be carried out, especially by using the rigorous graphical method already published by the author in the Bulletin Technique de la Suisse Romande in 1903 in an article entitled «Théorie Générale de l'arc élastique continu sur appuis rigides». As well as in Le Génie Civil, 1908, under the title «Calcul des ponts en maçonnerie». He has made use of similar principles in

[1] See Preliminary Publication of the Berlin Congress 1936, page 729.

his article entitled «Le réglage du fonctionnement des poutres continues» in Le Génie Civil, 1935.

The study by *M. Boussiron* is confined to the special case of a simple arch resting on supports which are assumed to be indeformable. It is based on the principle of greatly reducing certain of the sections, and it differs from the solution using semi-hinges in hoop-reinforced concrete, which was devised for the same purpose by Considère, in the avoidance of any sudden interruption of continuity. It has not been proved that an equalisation of the maximum bending moments at the springings and at $^1/_4$ span is the optimum condition from an economic standpoint, but the method of *M. Boussiron,* it cannot be denied, certainly enables a considerable reduction in the volume of reinforced concrete to be effected by comparison with other methods. Generally speaking, as stated by the present writer at the Liége Congress, the action of a reinforced concrete structure is far from being invariable in character. It changes in the course of time under the effect of diverse and complicated causes which are not yet sufficiently understood, and which operate especially on the linear dimensions, the elasticity and the plasticity of the concrete.

The author has observed, in the case of built-in arches of the ordinary type, that under the same external loading the strains grow less at the springings and greater at the crown and of $^1/_3$ span with the passage of time, the differences being sometimes of the order of 20% after a period of some ten years. Moreover, if calculations for hyperstatic structures are based only on considerations of elastic strains their results can be true only relatively and at a particular instant of time. The degree of uncertainty which attends them, should, therefore, logically lead to the adoption of a margin of safety greater in hyperstatic structures than in those types of structures which do not depend for their action on the amount of deformation. Again, the several experiments on small scale models which the writer carried out a few years ago went to show that, as a general rule, arches containing semi-hinges offer a smaller margin of safety against frequently repeated stresses than is the case with elements of practically uniform sections throughout. From this point of view it would appear, *a priori*, that arches of the type considered by *M. Boussiron* must occupy an intermediate place between semi-hinged and ordinary fixed arches. But the question is practically of academic interest only, for in long span bridges fatigue, properly so-called, scarcely enters into play.

As regards structures of exceptional size such as are anticipated in the future, the expedient of regulating the action of the arches would appear a priori, to offer fewer advantages in these than in bridges of smaller span, on account of the reduced ratio of live to dead load in the former. Nevertheless the suggestions made by *M. Boussiron* are so original in conception and so thoroughly worked out that their interest is a very real one, and they serve to illustrate the remarkable applications which he has made.

Limiting spans for road bridges.

If consideration is given only to the limits imposed by the mechanical strength of the material used, the approximate spans which admit of being obtained with the concretes now available, using the most perfect methods of manufacture and placing in the job, are approximately as follows:

1400 m for arch bridges, with rise-span ratio 1:5,
500 m for continuous girder bridges.

From the study entitled «L'avenir du béton armé et du métal pour les ponts de très grande portée», presented by the author before the Societé des Ingénieurs Civils de France and also in London in 1934, it would appear, from the economic point of view, that the cost of such works tends to increase very rapidly when something like the following spans are reached:

400 m for arches in lightly reinforced concrete,
800 m for arches in heavily reinforced concrete,
1000 m for steel arches,
1500 m for suspension bridges.

From a comparative point of view the economic advantage would appear to favour:

Lightly reinforced concrete arches for spans up to 250 m.
Heavily reinforced concrete arches up to 700 m.
Suspension bridges from 700 m upwards.

It need hardly be stated that these figures are based on hypotheses which may differ very appreciably from the truth in each particular case, and for this reason their value is entirely academic.

The principal factor which places reinforced concrete at an economic disadvantage by comparison with suspension bridges once a certain span is exceeded is its low "coefficient of utilisation", meaning the ratio of strength to the weight per volume unit. In order to increase this ratio it would be necessary to increase the former of these terms or to diminish the second. The author's researches now in hand appear to indicate that one method of simultaneously realising both these conditions would be to make use of concrete that has been mixed from light aggregates and is pre-compressed in a transverse direction by means of suitable binding. Approximately one half of the weight of a reinforced concrete member is represented by the gravel, so that by substituting natural or artificial materials of light weight the density of the concrete may be reduced considerably. These special aggregates, however, usually have a lower strength than the customary kinds of gravel, and it is essential to make use of them in elements which are subject to compression in all directions. Members made in this way are subject to larger deformations than those formed from ordinary aggregates, but this fact is not a disadvantage in very large structures where the dead load represents the largest part of the total.

In a later communication the author proposes to publish the results of French experiments now in hand regarding the use of cements which neither contract nor expand and which would enable reinforcing bars to be pre-tensioned *in all directions* on the job without the use of any special apparatus, thus subjecting the concrete to compression or integral interlocking. (This is dealt with in his article of 29th February 1936 in Le Génie Civil.)