Continuity in prestressed concrete

Autor(en): **Magnel, G.**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **4 (1952)**

PDF erstellt am: **22.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-5074

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Continuity in prestressed concrete

La continuité dans le béton précontraint

Die Kontinuität im vorgespannten Beton

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INTRODUCTION*

All those who have been pioneers in the field of prestressing have started by making exclusive use of simply supported beams; and they were quite right, as it was necessary to become thoroughly acquainted with the new technique by first applying it to the easiest case.

However, from the very beginning, the necessity has been felt for its application to statically indeterminate structures, and, indeed, it is unavoidable in many cases, as for example:

(*a*) the construction of multi-storey buildings;
(*b*) the construction of bridges with two or more spans; particularly when the spans are large and the height available for the bridge deck at midspan is very reduced, while the available height is much greater above the intermediate supports.
(*c*) the construction of buildings, even with only one storey, in areas subject to earthquakes.

In addition the desire to make use of continuity arises from the fact that it is a way to economise in anchorages and, consequently, to make prestressed beams with short spans economically; even in the case where anchored cables are used.

THE DIFFICULTY OF THE PROBLEM

Many difficulties were met by those who tried to apply prestressing to statically indeterminate structures. The following difficulties are worth mentioning:

(*a*) The method of design is not at first sight straightforward, although it is seen

* The word "prestressing" is taken to mean "stressed previous to the live load acting on it" and no difference is made between what in England are called "prestressing" and "poststressing."

immediately that it does not involve any new principles. Several specialists have published their methods and all that can be said is that they are all equivalent—being nothing else than the application of Hooke's law—and that the best is the one which one knows best and which one has applied many times.

(*b*) What is worth mentioning is that a rather small accidental displacement of the cable in a continuous beam—and this is also true for all statically indeterminate structures—produces an important variation in the external moments due to prestressing which the author has called the secondary moments.

Take, for example, continuous beams with three or two spans of 49 ft. each, calculated as shown in the author's book:* the secondary moments at the internal supports are the following:

Eccentricities	Case A	Case B
	Three spans	
At end support	0	0
At middle of end span	−8·5 in.	−9·5 in.
At middle of midspan	−3·3 in.	−3·3 in.
At interior support	+8·0 in.	−8·0 in.
Secondary moment at interior support	−27,100 lb.-in.	+8,300 lb.-in.
	Two spans	
At end support	0	0
At midspan	−10·1 in.	−11·0 in.
At mid-support	+0·9 in.	0 in.
Secondary moment at interior support	+837,000 lb.-in.	+975,000 lb.-in.

It will be seen that in the case of three spans the secondary moment changes considerably (even its sign changes) for a difference of 1 in. in the eccentricity of the cable; however, this is not important, as the absolute value of the secondary moment is in this case almost negligible.

In the case of two spans a difference of less than 1 in. in the exact position of the cable produces a difference of 16% in the value of the secondary moment, to which corresponds a variation in stress of 143 lb./in.^{2} in the beam, or about 7% of the permissible stress. It may be concluded from this that the exact position of the cable is of great importance and that it is the duty of the designer to see which is the best position and shape of the cables.

(*c*) The execution of statically indeterminate structures is not free from special difficulties, of which only three are discussed below:

(i) There is the frictional resistance of the cables in their housing; the loss of prestressing force corresponding to this friction exists also in the case of simply supported beams with curved cables, but is less important, as the cable has generally only one curvature. In continuous beams it is sometimes easy for the designer to use cables with several changes of sign of the curvatures and in these cases the loss through friction cannot be considered to be negligible. The ideal solution is to use straight cables, or cables only deviated at one point, being straight between this point and the ends.

* G. Magnel, *Prestressed Concrete*, p. 102, fig. 75, Concrete Publications, London.

However, this is not always possible. The author has made some tests on losses through friction and the results of the tests are given in an appendix.

(ii) There is the tendency for designers to achieve continuity by using short cables placed in the beam above the internal supports, with their ends protruding from the underside of the beam not far from the columns. The author does not think this is an arrangement that can be recommended except in cases of large spans. It is indeed, according to the author's experience, impossible to prestress short cables with sufficient accuracy. Take a cable of 15 ft. long to be prestressed up to 140,000 lb./in.^{2}, this means a total elongation of about 0·90 in.; in other words, by working with one jack at each end of the cable—as has to be done to decrease the frictional loss—the elongation to be produced by each jack is about 0·45 in. If it is remembered that in all known systems, where the wires are fixed in pairs or in larger numbers by a wedge, the difference from one case to another in slipping of the wires when (the wedge being driven home) they are released, amounts to 0·10 in., it is seen that the prestressing cannot be done with an accuracy of more than 22%, which the author considers as insufficient; moreover the error due to ignorance of the exact friction loss has to be added to this. In the present state of development, any other means of establishing continuity by means of short elements above the columns cannot be foreseen except through the use of steel bolts with a high elastic limit, the fixing device being a nut or something equivalent.

(iii) There is the difficulty in connection with expansion and contraction joints, where a special arrangement has to be developed to allow for the prestressing operation. This special arrangement is of course dependent upon the special kind of structure to be made. If the case of framed buildings is considered, two solutions are possible: Either make three spans continuous with a cantilever extending to about one-fifth of the fourth span; then leave the fourth span open in its central part and make the spans 5, 6 and 7 continuous with a short cantilever extending through about one-fifth of the fourth span. The ends of the two cantilevers in the fourth span can then be bridged over by a prefabricated beam in prestressed concrete simply supported on the cantilever ends. Or, alternatively, build the central part of the fourth span in ordinary reinforced concrete, provided dowel bars have been placed in the ends of the cantilevers.

A similar arrangement is going to be applied in Belgium in the case of a very important mushroom slab. It is intended to build the mushroom panel above the columns, using the prestressing technique in two directions; the remaining parts of the slab will be in ordinary reinforced concrete.

General remarks

The author would like to emphasise that in his opinion one should not be too afraid of the above difficulties. It must not be forgotten that the computations of stresses to be made are very inaccurate, as they are based on the elastic theory. Concrete has the great property of adapting itself to different conditions, mainly in statically indeterminate structures. Moreover, the factors of safety permitted for concrete are generally very high, and the concrete in prestressing work is not only made better than in ordinary reinforced concrete, but is cured under better conditions, and some of its hardening is done under pressure.

The main point, in the author's opinion, is to be sure of the value of the prestressing forces given by the steel at the time of prestressing and this should and can be done with an accuracy of about 5%.

Consequently, calculations which take too much time should not be made with the view of achieving better accuracy; let the designer concentrate on a good general conception of the structure to be made and see to it that the prestressing operation is done in the most perfect way.

Some examples of continuity in Belgium

Figs. 1, 2, 3, 4 and 5 give the general arrangement of framed buildings in

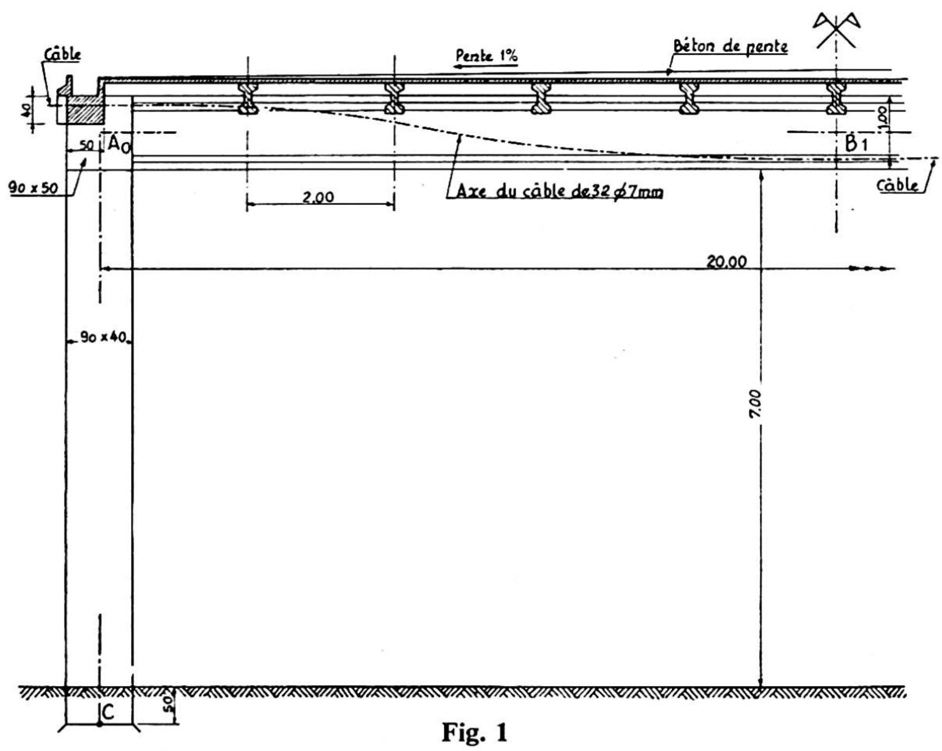


Fig. 1

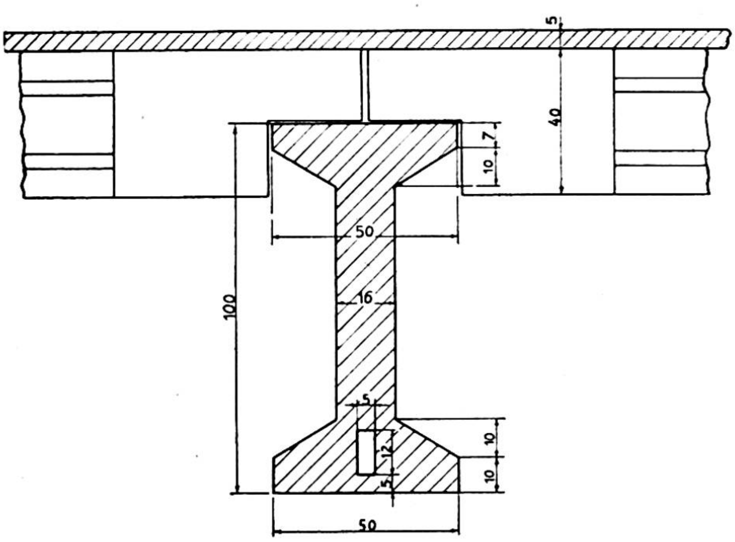


Fig. 2

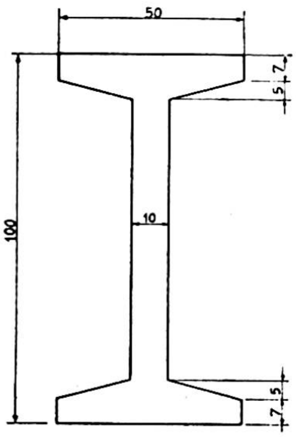


Fig. 3

prestressed concrete. Figs. 1, 2 and 3 show the case of a simple frame of 66 ft. span. Two possibilities are shown;

(i) the beam is either made monolithic with the cable hidden in it (fig. 2), or
(ii) the beam is made in prefabricated blocks with the cables placed at each side of the web (fig. 3).

In both cases the tops of the columns serve as end blocks for the beam. The columns are either in ordinary reinforced or in prestressed concrete. Fig. 4 shows a one-span multi-storey building. Fig. 5 shows a multi-span one-storey building.

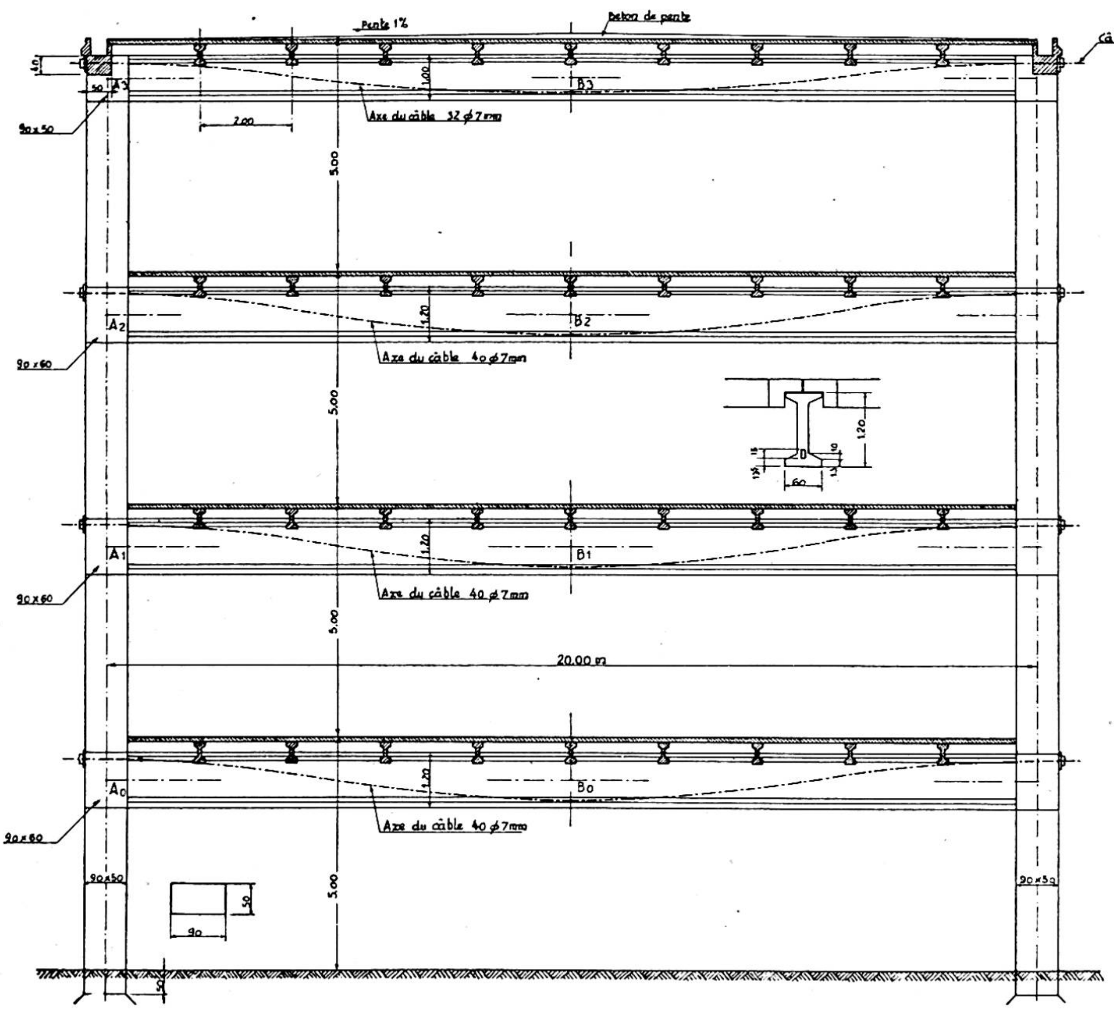


Fig. 4

Three examples of structures that have actually been built are given below:

(*a*) A two-storey building built in a contractor's yard; it was a much needed building, but it was decided to make it in prestressed concrete frames as a first experiment in this new direction (fig. 6). The span of the frame is about 53 ft.; the beams are made in prefabricated blocks, the cross-section of which is shown on fig. 6; the cables are placed outside the web on each side. Figs. 7 and 8 show some aspects of the structure.

(*b*) A four-storey office building built at Leopoldville in the Belgian Congo (fig. 9).

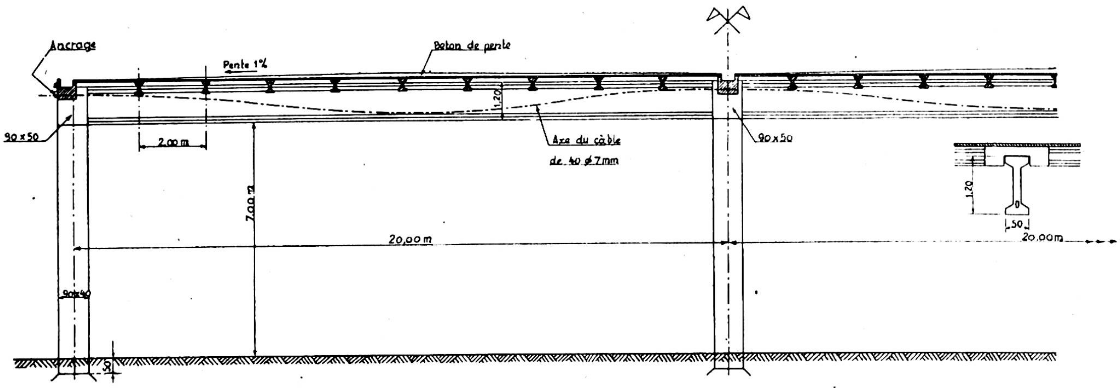

Ancrage
Pente 1%
Beton de pente
1,20
2,00 m
90 x 50
Axe du câble
de 40 ø 7mm
90 x 50
7,00 m
20,00 m
90x40
1,20
,50
20,00m

Fig. 5

Fig. 9 is self-explanatory (span about 46 ft.; height from floor to floor about 15 ft. 9 in.). Figs. 10, 11, 12 and 13 show some aspects of the building during its construction.

(*c*) Finally, the most important example of continuity is the Sclayn road bridge in Belgium. It has two spans of 205·72 ft. each, a roadway 23 ft. wide with two footpaths each 5 ft. wide. The structure is a box girder having a total depth of only 6·36 ft. at midspan and 15·58 ft. at the central support. The elevation and cross-section are shown in figs. 14 and 15; a photograph of the finished bridge is given in fig. 18; details of cables are given in fig. 16 and of the prestressing jack in fig. 17. The cables are straight in each span; at their mid-point, above the central support, they are 2·84 ft. higher than at their ends at the end supports. The girder is divided in three

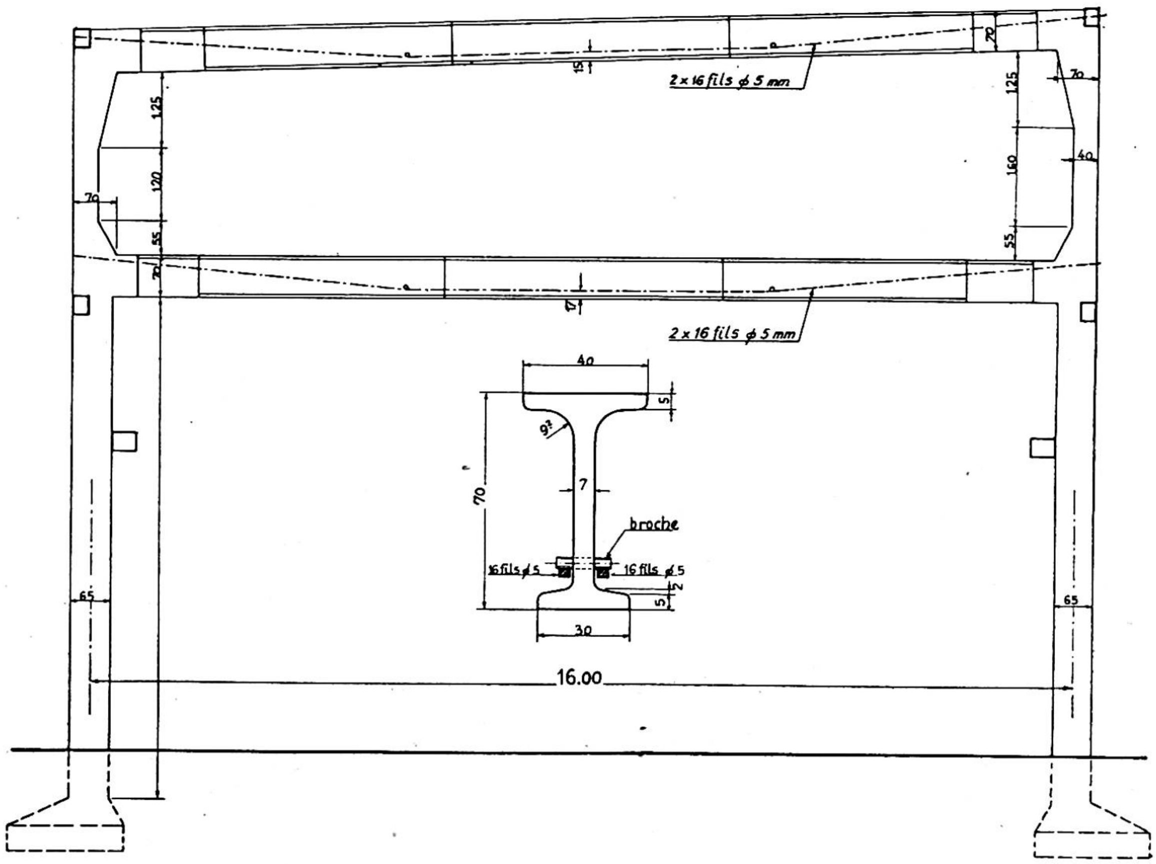


Fig. 6. Factory at Machelen. Depôt—Cross-section

compartments in which the cables are placed. In all 36 cables each of 48 wires of 0·276 in.^{2}, have been provided; they have been prestressed at both ends simultaneously up to 121,000 lb./in.^{2}, which gave initially a total prestressing force of 5,650 metric tons, dropping to about 4,800 metric tons in course of time. The working stress allowed in the concrete is 2,200 lb./in.^{2}

It is worth while pointing out that the secondary bending moment due to the prestressing is in this case initially equal to 67,138,000 lb.-ft., which one should compare with the 128,860,000 lb.-ft. which is the bending moment due to dead and live load at the point above the central support. These figures show that the secondary bending moment is far from negligible in this case. It is helpful above the support, but

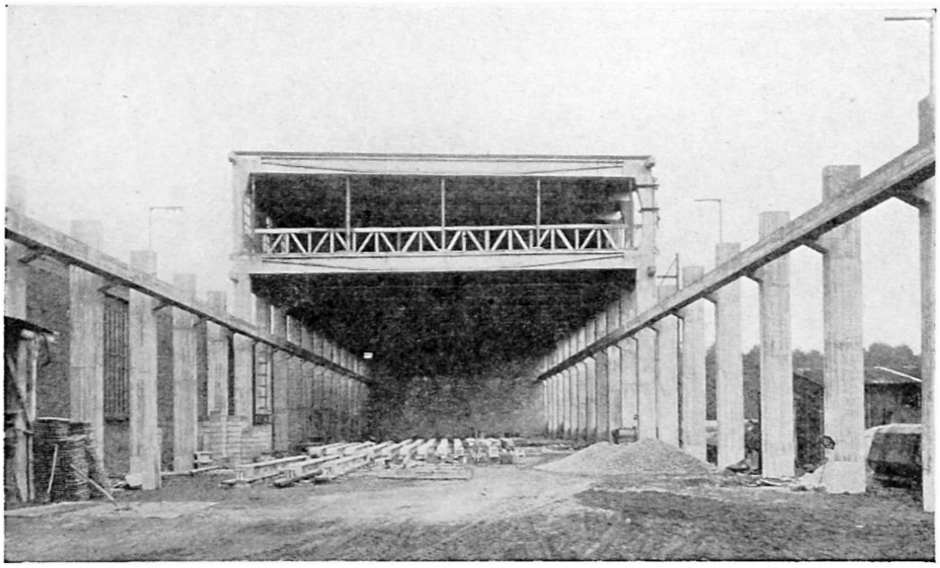


Fig. 7

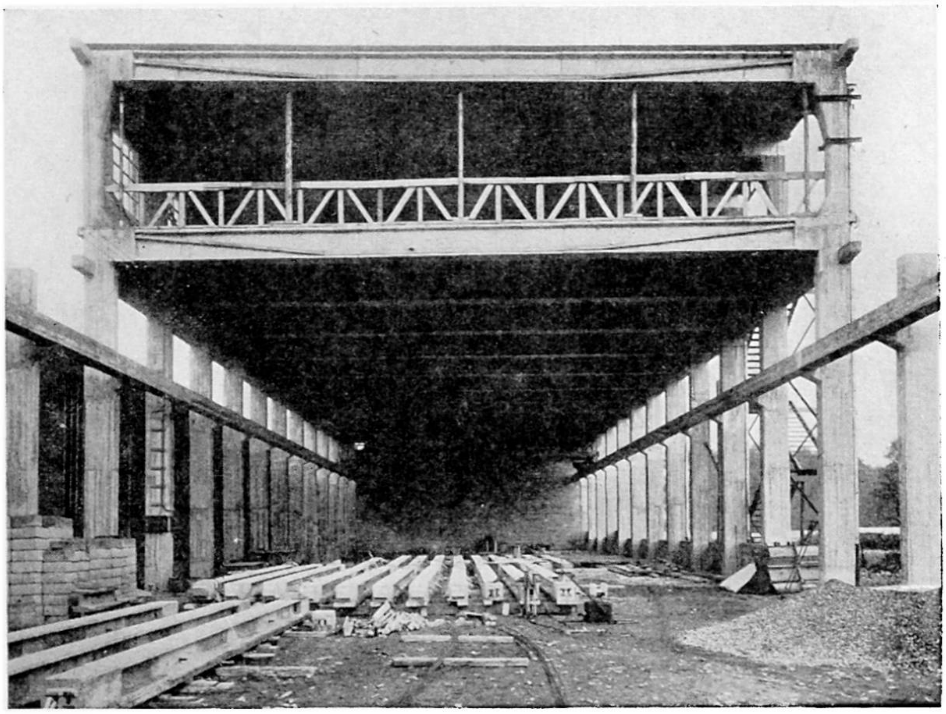


Fig. 8

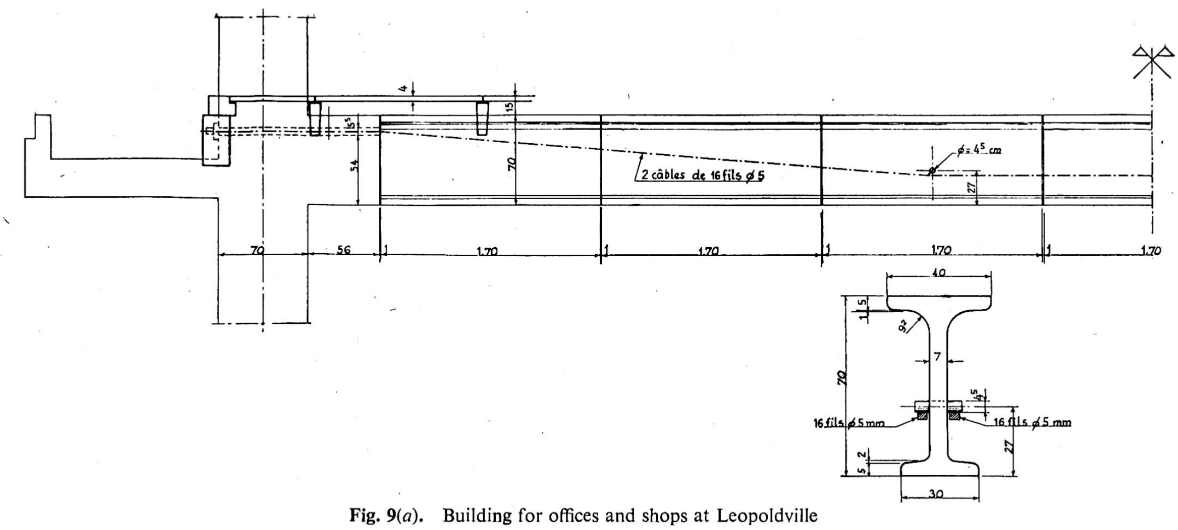


Fig. 9(*a*). Building for offices and shops at Leopoldville

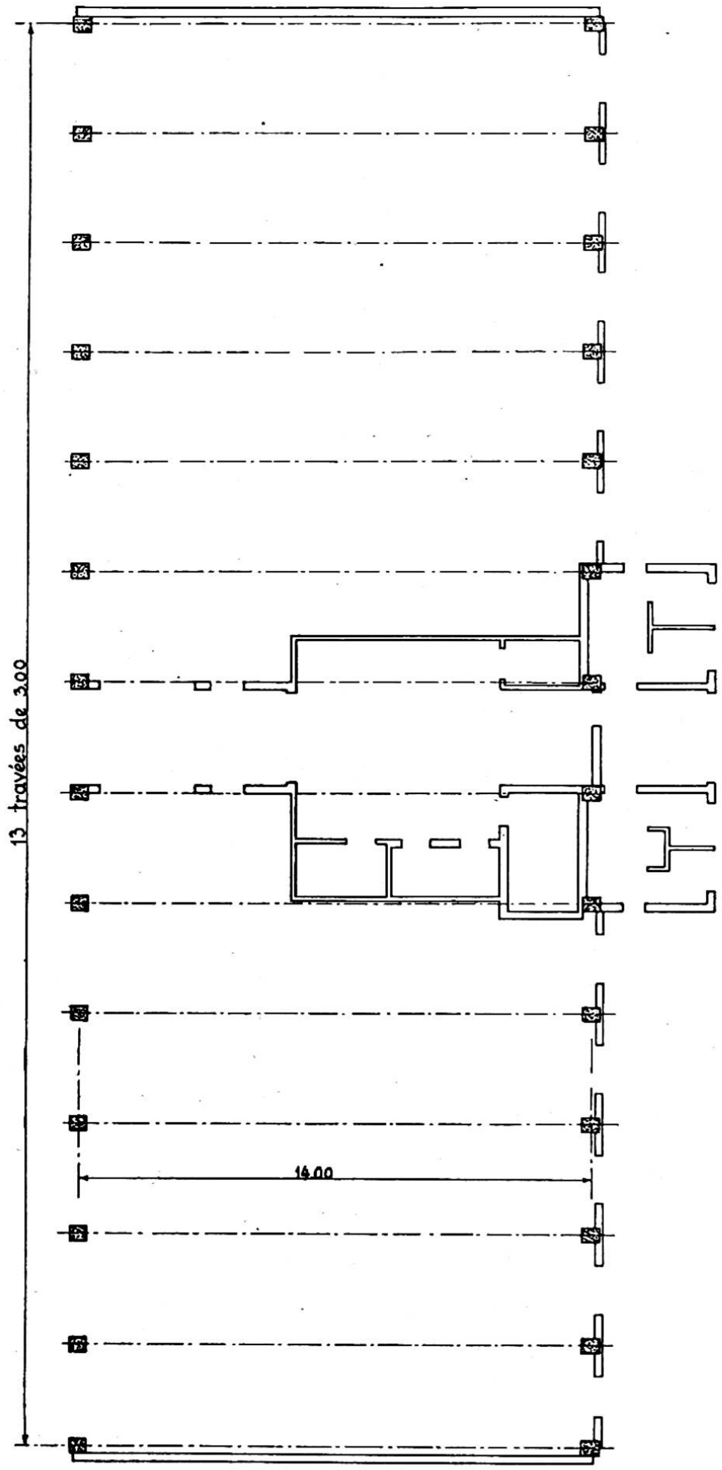


Fig. 9(*b*). Building at Leopoldville—Plan disadvantageous at midspan, when the maximum bending moment due to dead and liveload is 28,500,000 lb.-ft. With another arrangement of the cable the value of the secondary bending moment changes considerably. It is the duty of the designer to find the most economic arrangement.

The Belgian specialists have taken the opportunity of this large bridge to make experiments on the loss of prestress in course of time. Therefore they have provided

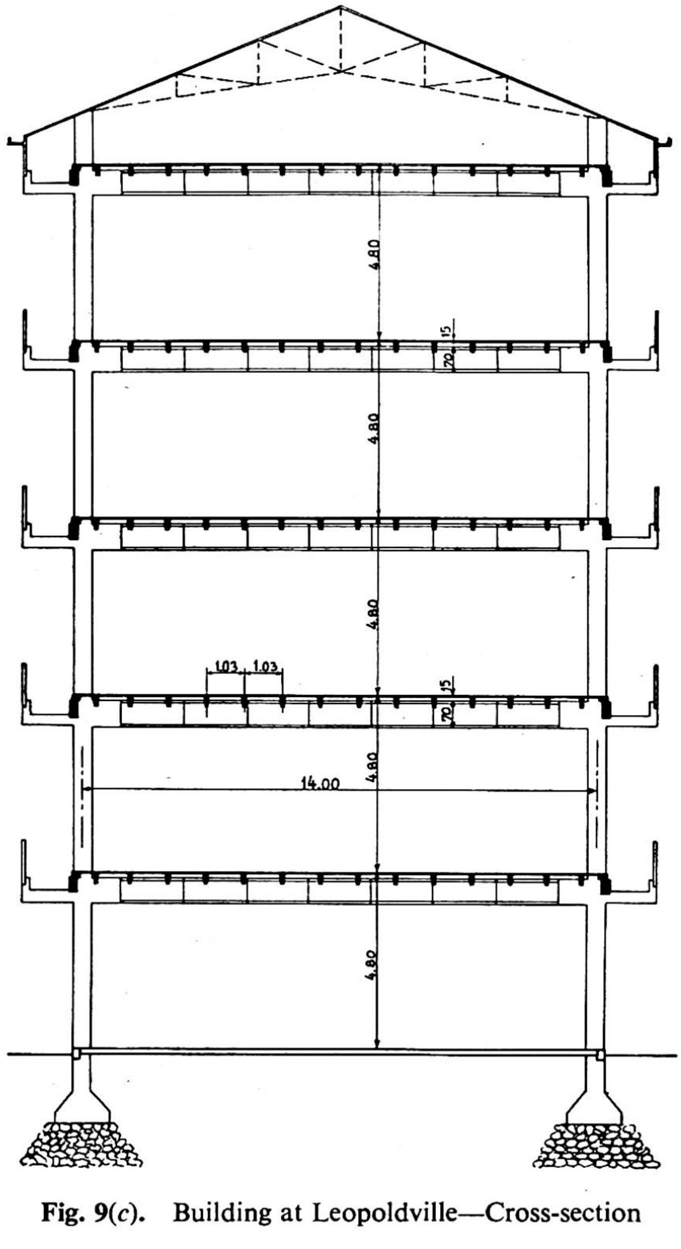


Fig. 9(c). Building at Leopoldville—Cross-section

in the box girder two supplementary cables of eight wires each; these cables are not grouted and as their wires remain free, it is possible to measure periodically the variation in stress. Up to the present the measurements made show (after more than two years) that the loss of prestress through all causes is rather smaller than what is generally accepted by designers.

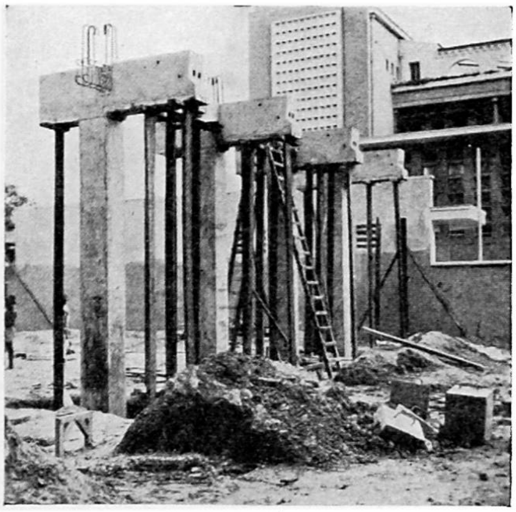


Fig. 10

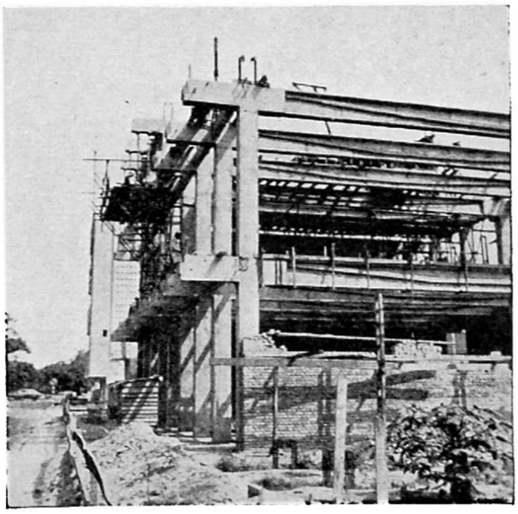


Fig. 11

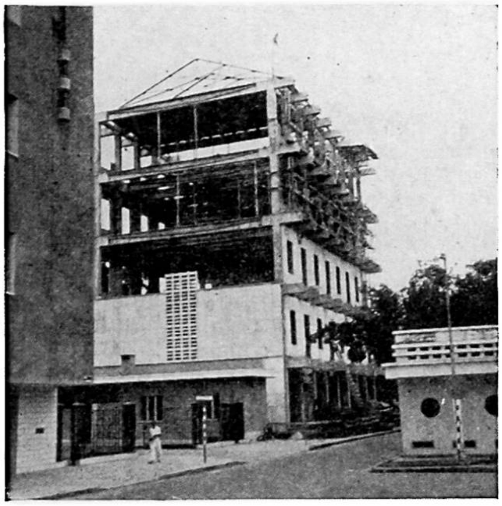


Fig. 12

Fig. 13

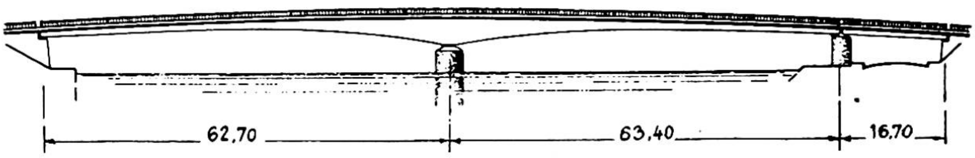


Fig. 14. Bridge over the Meuse at Sclayn in prestressed concrete—Elevation

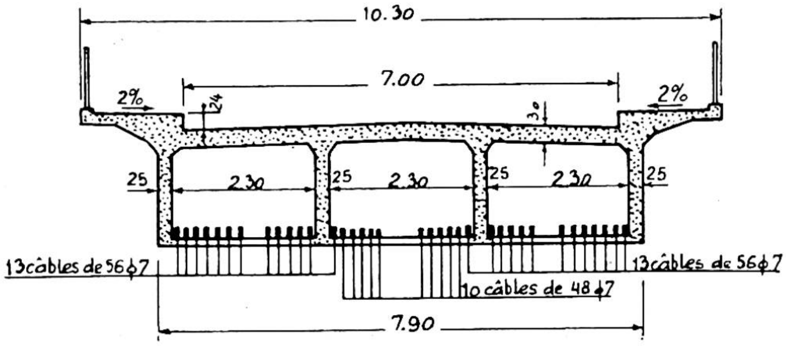


Fig. 15. Bridge over the Meuse at Sclayn in prestressed concrete—Cross-section

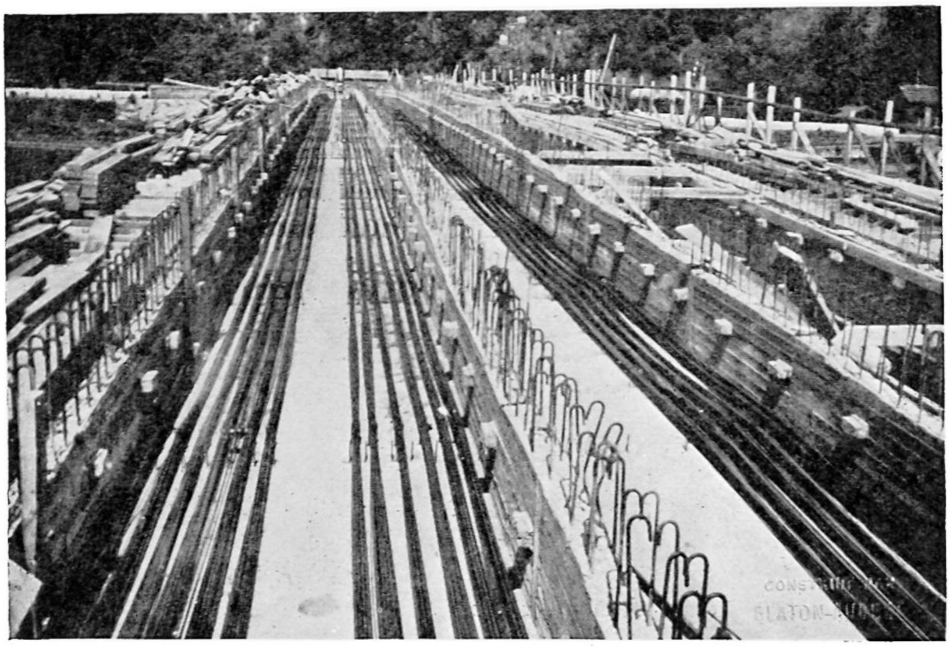


Fig. 16

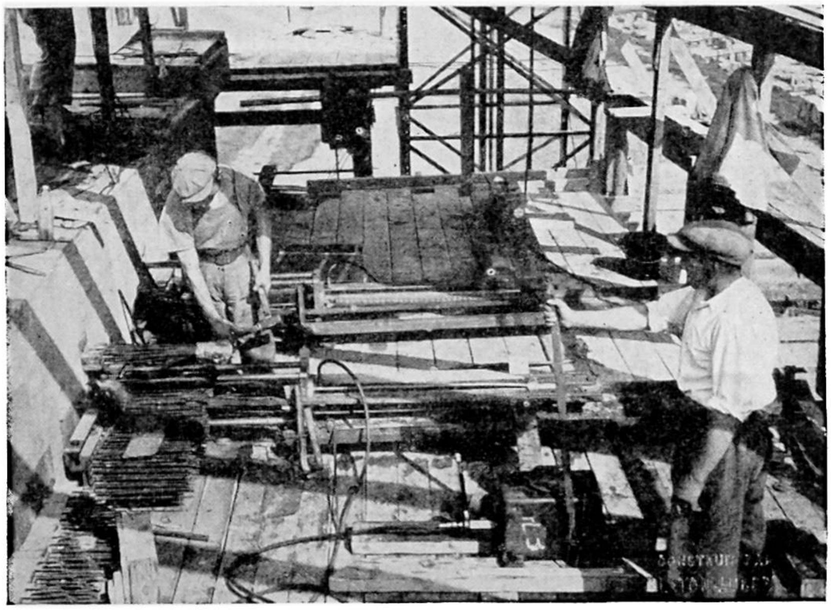


Fig. 17

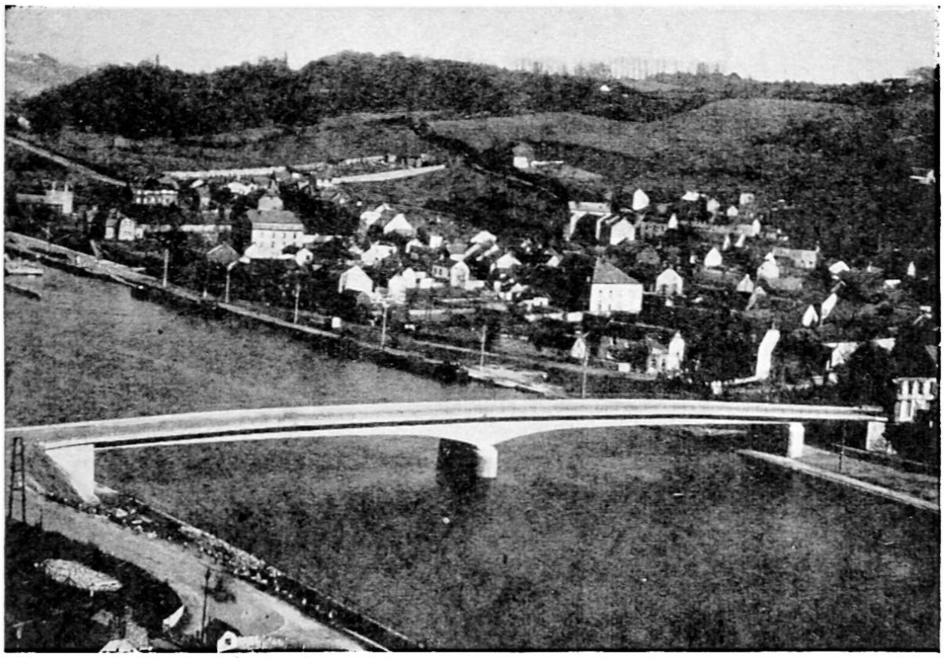


Fig. 18

APPENDIX

RESULTS OF TESTS FOR FRICTION LOSSES

The testing method is shown in fig. 19. A wire (5 or 7 mm. in diameter) is fixed at one end (A) and attached to a jack (D) at the other end (B). The middle of the wire (C) can be deflected by means of a special device; the deflection is called *e* and the base length *l* ($l = 13{\cdot}40$ m.).

Strain gauges are attached to the wire at the two places indicated in fig. 19. Details of the cast-iron plate (C) used to cause the deflection are given in fig. 20.

Tests have been made for different values of *e* by stretching the wire with the jack, and measuring the difference in strain indicated by the two strain gauges for a series of jack loads. The results are summarised in Table I for 5 mm. wires and Table II for 7 mm. wires.

Figs. 21 and 22 show the loss in stress as a function of the angle α for different values of the stress in the wire. The author has checked that the speed with which the wire is stretched to its maximum stress has virtually no effect on the magnitude of the loss due to friction.

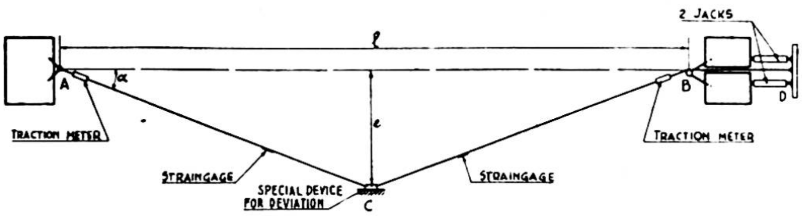
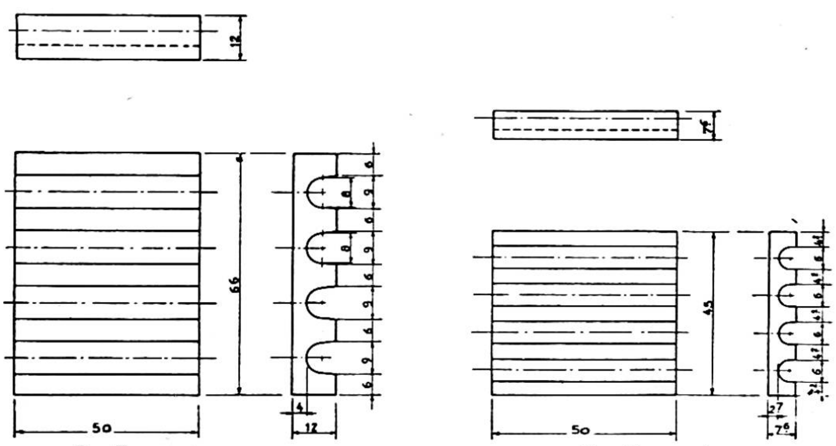


Fig. 19



For 7mm wires   For 5mm wires

Fig. 20

TABLE I

Size of wire: 5 mm. diameter

Deviations		Loss of stress due to friction for different stresses in kg./mm.²							
		25		50		75		100	
e (cm.)	α ° ′	strain gauge	jacks	strain gauge	jacks	strain gauge	jacks	strain gauge	jacks
0	0	0	0	0	0	0	0	0	0
24	2 3	0·5	—	0·8	—	0·8	—	1·2	—
48	4 5	0·7	—	1·4	—	1·4	—	2·0	—
72	6 10	1·0	—	1·6	—	2·2	—	3·4	—
100	8 30	1·2	—	2·0	—	2·8	—	4·0	—
124	10 30	1·4	1·0	2·4	—	3·4	2·5	5·0	3·1
148	12 30	1·7	1·5	3·0	4·1	4·1	4·6	5·6	5·6
176	14 40	2·0	2·0	4·1	4·1	4·0	4·6	5·9	5·6
200	16 40	2·3	2·5	4·2	4·1	5·6	6·6	8·0	8·1
224	18 30	2·5	3·0	4·0	4·6	6·2	6·6	9·1	8·1

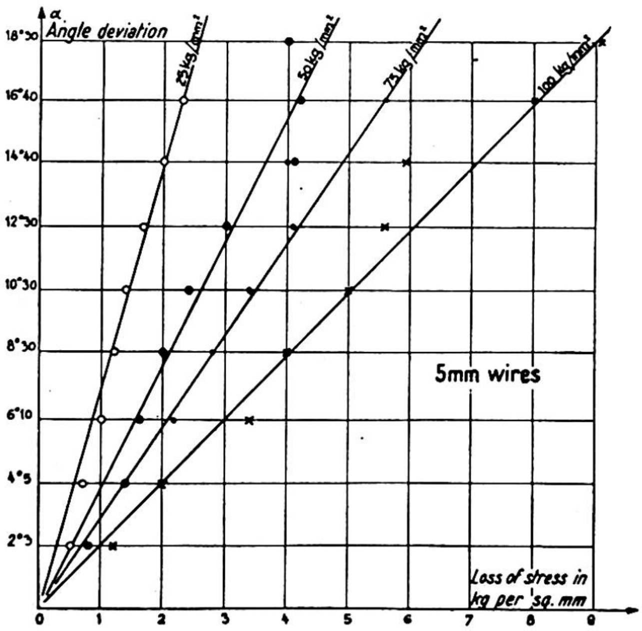


Fig. 21

TABLE II

Size of wire: 7 mm. diameter

Deviations			Loss of stress due to friction for different stresses in kg./mm.²							
e (cm.)	α °	α ′	25 strain gauge	25 jacks	50 strain gauge	50 jacks	75 strain gauge	75 jacks	100 strain gauge	100 jacks
0		0	0	0	0	0	0	0	0	0
24	2	3	0·8	—	1·2	—	1·2	0·9	1·5	1·6
48	4	5	0·6	0·6	0·8	1·0	1·2	1·3	2·0	2·1
72	6	10	0·3	0·9	0·5	1·0	1·8	1·9	2·5	2·6
100	8	30	0·3	1·7	1·1	2·1	1·8	2·4	2·7	3·6
124	10	30	1·5	1·3	2·2	2·1	3·2	3·6	4·2	4·4
148	12	30	1·2	2·1	3·0	3·2	4·2	4·9	5·0	6·7
176	14	40	1·3	2·1	3·6	3·9	4·3	5·2	6·2	7·1
200	16	40	2·8	2·1	4·2	3·9	5·2	6·2	7·8	8·2
224	18	30	2·6	2·1	5·1	4·9	7·6	7·0	9·0	9·1

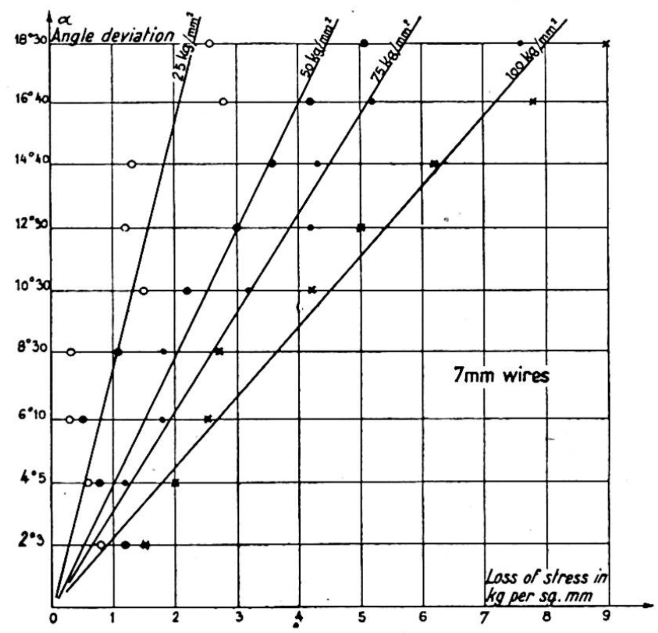


Fig. 22

Summary

The author explains the reasons why it is unavoidable to make continuous statically indeterminate structures in prestressed concrete, and states the theoretical and practical difficulties in connection with this.

Some examples of statically prestressed structures in Belgium are given: these include a two-storey building at Brussels, a four-storey building at Leopoldville, and the Sclayn Bridge across the River Meuse, which is the most important application of continuity made up to the present time in bridge building.

The paper gives some results of measurements of the loss of stress due to friction.

Résumé

L'auteur expose les raisons pour lesquelles il est nécessaire d'associer l'hyperstatisme à la précontrainte; il montre les difficultés corrélatives, tant théoriques que pratiques.

Il cite quelques exemples d'ouvrages hyperstatiques en béton précontraint, réalisés en Belgique: un immeuble à deux étages à Bruxelles, un immeuble à quatre étages à Léopoldville et le pont Sclayn sur la Meuse. Ces exemples constituent les applications actuelles les plus intéressantes de la continuité dans la construction en béton précontraint.

L'auteur termine en reproduisant quelques résultats de mesures concernant les réductions de contraintes dues au frottement.

Zusammenfassung

Der Verfasser erklärt die Gründe, weshalb es unvermeidlich ist, durchlaufende, statisch unbestimmte Konstruktionen in vorgespanntem Beton zu bauen und legt die damit verbundenen theoretischen und praktischen Schwierigkeiten dar.

Einige Beispiele von statisch unbestimmten vorgespannten Bauten in Belgien werden beschrieben: Ein zweistöckiges Gebäude in Brüssel, ein vierstöckiges Gebäude in Leopoldville und die Sclaynbrücke über die Meuse, welche gegenwärtig die wichtigste Anwendung der Kontinuität im Bau vorgespannter Brücken darstellt.

Die Abhandlung enthält einige Ergebnisse von Messungen über den Spannungsverlust infolge Reibung angibt.

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