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Systematic Tests on Floor Systems Comprising Reinforced Concrete Slabs on Steel Girders.

Planmäßige Versuche an Decken aus Stahlträgern mit Eisenbetonplatten.

Essais systématiques sur planchers constitués de poutrelles métalliques surmontées de dalles en béton armé.

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A brief explanation is given of the results obtained in the course of systematic tests carried out by the Bureau Securitas, in collaboration with the Office Technique pour l'Utilisation de l'Acier, on the strength of floors composed of steel joists carrying reinforced concrete slabs. These tests were made during the first few months of 1935 in the new Laboratories for Building and Public Works. (Laboratoires du Bâtiment et des Travaux Publics.)

At first sight the action of floors composed of joists embedded in concrete would appear to be similar to that of reinforced concrete members, assuming that adequate bond exists between the rolled sections and the concrete. But the mechanism of the phenomena of bond are so little understood that any theoretical investigation of the problem was deemed to be uncertain, and only systematic experiments, carried to the point of breakdown, were thought to be acceptable as a source of useful information.

It was sought to determine, for each such type of floor, the limits within which a simultaneous development of the strength of the concrete and of the metal might be relied upon as in reinforced concrete construction. With a view to studying separately the various factors usually taken into account which make up the resistance, two series of tests were carried out for each type of floor, the first being intended mainly to arrive at the factor of safety and the conditions of resistance to bending moments; the second more particularly for studying the effect of shear forces.

The mode of operation and results obtained in these tests have been described in greater detail in the Compte-Rendus du Centre d'Etudes Supérieures de l'Institut Technique (1934—35, 22nd Session), of which the following is a summary:

I. Types of floor studied.

It was sought to reproduce conditions corresponding to those likely to be encountered in the floors of the usual types of residential buildings. The cross section of the members considered are shown in the accompanying illustration (Fig. 1), each element consisting of two joists (I PN 10 in the first case and I PN 12 in the second) spaced at 0.80 m centres and supporting a slab 4.50 cm thick, the total depth being the same in the case of all the floors, namely 14.5 cm.

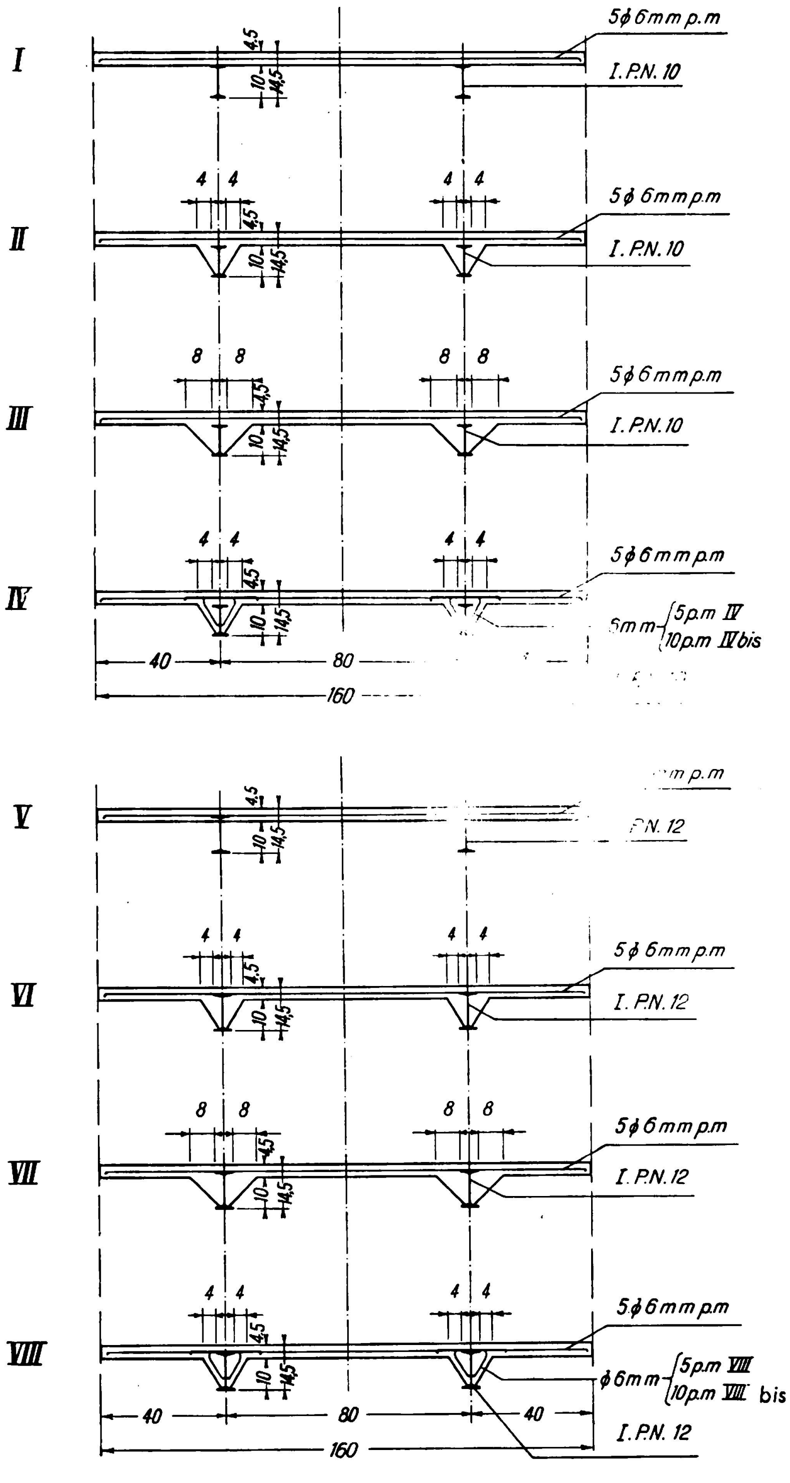

Fig. 1.

Cross sections of the types examined.

Item N° I comprises a concrete slab resting directly on the upper flange of the joists, a type which it was deemed desirable to examine in order to determine, in some degree, the lower limit of the phenomena producing bond between the concrete and the metal. Item N° V consists of two joists of 12 PN in which only the upper portion is embedded 2 cm deep in the concrete slab. All the other types involve concrete which encloses the web of the joists as far down as the fillet of the lower flange. In elements IV and VIII there are binding elements of 6 mm dia. which pass through holes punched in the web and are bent over into the slabs.

The steel used for the joists was of the usual commercial quality, having an elastic limit of 30 kg/cm^2 and a breaking stress of 40 kg/mm². The quality of the concrete was ascertained from a large number of samples which were tested in compression and in tension.

II. Arrangements made for the test.

A) *Bending Tests.*

These were carried out on specimens having a free span of 4.00 m, the loads being applied as shown in the attached illustration (Fig. 2) by means of a loading

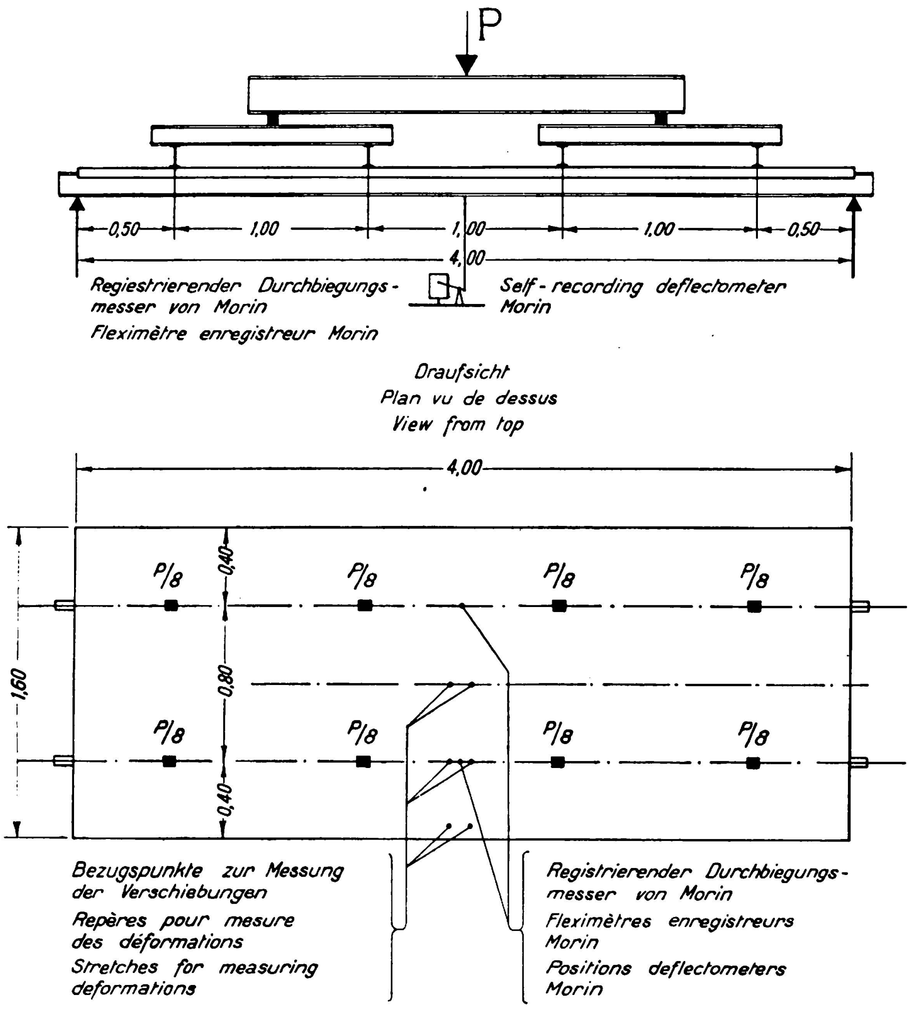

Fig. 2.

Bending test.

lever specially arranged for tests of this kind, in the Laboratory for Building and Public Works.

During the tests the elastic deflections were read by means of recording apparatus arranged underneath the axes of the joists. It was also sought to determine, by means of a *Huggenberger* extensometer, the elastic contraction of the concrete on the upper surface of the slab, and the elongation of the metal at the lower flanges of the joists.

B) *Tests of resistance to shear forces.*

These were made with the object of determining the conditions of breakage of the different types of floor under consideration when subjected to the action of concentrated loads applied in the neighbourhood of the supports, the intention being to determine whether such failure would take the form of a slipping of the rolled joist within its surround of concrete owing to breakage of the bond, or that of the slabs becoming detached from the joists.

The tests were made on elements 2.00 m in length which were subjected to concentrated loads successively applied in the neighbourhood of the two ends, by the agency of screw jacks forming part of the powerful loading machine which has recently been constructed at the Laboratory for Building and Public Works.

III. Results obtained.

A) *Bending tests.*

The results obtained in the bending tests on elements 4.00 m span are shown in table I.

Table I.

No. of specimen	Concrete: age in days	Concrete: compression kg/cm²	Concrete: tension kg/cm²	Bending moment causing breakage kgm	Limit of elastic behaviour kgm	Deflection in mm under total load P: 2000 kg	4000 kg	6000 kg	Stress under load P = 4000 kg: R_b calculated kg/cm²	R_b measured kg/cm²	R_a calculated kg/mm²	R_a measured kg/mm
				each beam								
I	29	270	23	*1350*	800	15						
II	28	280	23.4	*2915*	1550	5.05	9.8	16				
III	40	315	26.4	*2680*	1550	5.4	10.4	16	58.5 50	69 46.5	16.1 16.8	14.3
IV	20	255	20	*2340*	1550	6.2	12.9	19.5	58.5 50	58.5 39	16.1 16.8	15.8
V	31	325	27	*3330*	2050	5.2	10.4	15.5	51 42.5	52 34.7	13.3 13.8	11.3
VI	23	280	22,5	*3162*	2050	4.8	9.6	15.1	51 42.5	52 34.7	13.3 13.8	11.3
VII	23	225	20	*2910*	2050	4.75	10	15.5	51 42.5	50 33.3	13.3 13.8	11.5
VIII	20	275	18	*3020*	2050	5	10.2	15.6	51 42.5	52 34.7	13.3 13.8	15

Note: R_b = stress in concrete; R_a = stress in steel.

In all the types studied, with the exception of N° I, the bond between the concrete and the joists held good until failure occurred as the result of excessive tension in the steel, which agrees with the classical theory of failure of reinforced concrete members. That is to say, when the elongation of the metal becomes very great the axis is displaced towards the upper surface of the concrete between the joists, and the concrete is cracked by excessive compression.

Item N° I was the only one in which the slab was observed to become detached from the rolled joist before failure occurred, this detachment being observed at the centre of the span under a load of P = 1000 kg. In all the other types the simultaneous resistance of the steel and of the concrete slab certainly held good up to the point of failure under the same conditions as in reinforced concrete floors provided with round bars.

According to the permissible moments determined by the usual methods of calculation with m = 10 and assuming a limiting stress of 12 kg/mm², the factor of safety against breakdown works out at between 3.15 and 3.9.

By examination of the diagrams recorded on the deflectometers during the test it was possible to determine the limits of elastic behaviour for the different types of floor under definite conditions of application of the load. The bending moment so found corresponded to a stress in the metal calculated by the usual methods of the order of 37 kg/mm², and therefore close to the elastic limit of the metal.

The measurements made of the shortening experienced by the upper face of the concrete slab, and of the extension undergone by the lower flange of the rolled joists, enabled the stress in the steel to be determined, and hence, by assuming a modulus of elasticity equal to 22×10^3 kg/mm², to determine the stress in the concrete, putting m = 10 or m = 15. Further calculations were made of the stresses existing in the concrete and in the steel under different loads, again taking m successively as 10 and 15. The results obtained are given in the last columns of the table above, and these show satisfactory agreement between the stresses as calculated from the deformations and the stresses as calculated directly from the hypothesis m = 10. This agreement being at least as good as in concrete slabs reinforced with round bars, the methods usually adopted in the calculation of ordinary reinforced concrete members may properly be applied in the design of floors consisting of embedded joists.

B) *Resistance to Shear Force.*

The results obtained in the test are shown in the table below.

In Specimen N° I the joists became detached from the slab under a load of the order of 4 tonnes, but it was not possible to observe any longitudinal slipping in the neighbourhood of the supports. It would appear, therefore, that from the point of view of increasing the safety of systems of this kind any devices intended solely to eliminate such slipping, such as the use of flat bars welded to the upper flange, are less effective than arrangements for anchoring the rolled sections to the concrete slabs by means either of binding wires passed through holes punched in the web or by means of a spiral welded to the upper flange of the joists.

In all the other specimens breakage occurred after the appearance of tensile cracks in the concrete, through an excess of compression which followed upon the excessive elongation of the steel. No failures of bond of the joists close to the supports appeared until fracture actually occurred, with very large deformation. The shear force at breakage is of the order of at least 7 tonnes for specimens containing joists 10 PN and 9 tonnes for those comprising joists 12 PN.

C) *Distribution of compressive forces in the slabs.*

Advantage was taken of the tests in an attempt to determine how the compressive forces are distributed within the slabs. Most of the official regulations in force lay down limits to be allowed for the width of the slab that may be

Table II.

No. of specimen	Concrete			Shear force causing breakage kg	Corresponding couple kgm
	Age in days	Compression kg/cm²	Tension kg/cm²		
I	29	340	27	4 675	1170
II	28	340	27	8 450	2175
III	40	305	24	8 300 6 900	2080 2080
IV	23	260	19.4	8 300 7 900	2080 2350
IV bis	20	225	20	8 050 8 800	2160 2640
V	30	340	27	10 500 9 000	2620 2700
VI	34	275	26	9 650 8 600	2420 2580
VII	30	230	19	10 300 11 900	2570 3570
VIII	20	280	20	12 500 12 800	3120 3850
VIII bis	20	225	20	12 600 13 200	3150 3950

assumed to act in compression at the centre of the span of the joists, but they give no precise rule applicable to the case where heavy concentrated loads produce maximum moments in sections close to the supports.

It was confirmed, in the first place, that in the specimens 4.00 m long which were examined the shortening of the concrete as measured at the upper face of the slab at the middle of the span (Fig. 2) was the same over the whole width of the slab. Compressive stresses, therefore, are uniformly distributed.

Extensometers placed close to the supports showed that the shortening was greater at the centre of the joists than at the edges; and the measurements made, which it would take too long to describe in detail here, indicated that the following simple rule is justified: if the effective width of slab acting in compression is taken as bounded by two straight lines making angles of 30 to 35° with the joists, the compressive stress so calculated for each section, by applying the usual method, differs only slightly from the maximum stress as measured immediately over the joist.

Conclusion.

To sum up, it may be said that in the case of *all types of floor* examined, except N° I, the results of the tests carried out indicate the propriety of calculating the normal stresses by the methods usually adopted in the case of reinforced concrete floors, the agreement between stresses so calculated and stresses which actually exist being at least as good as in the case of reinforced concrete members. These methods give a factor of safety of the order of 3.5.

As regards tangential stresses in the sections examined, the experiments show that with the exception of N° I the strength of the floor is in practice not limited by any excess in the tangential forces but by the value of the normal stresses.

It is proper to observe that these results were obtained with concrete of good quality. If it is desired to make use of the resistance afforded by the concrete it is necessary that the workmanship applied to this material should be sufficiently careful to ensure at least as high a resistance as in reinforced concrete work.

It is considered that the conclusions stated above apply only to sections similar to those actually studied, wherein, in particular, the neutral axis lies close to the lower surface of the slab and to the upper flange of the rolled joist. It is hoped to amplify these results by tests shortly to be undertaken on sections different from the above.