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## AII 3

### Measurement of strains in a slab subjected to a concentrated load

### La mesure des contraintes dans une dalle soumise à une charge concentrée

### Spannungsmessungen an einer Platte unter Einzellast

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#### INTRODUCTION

For designing reinforced-concrete slabs it is desirable to know the stress distribution produced by concentrated loads.

In the theory of plates as it has been developed up to now, the material is usually supposed to be ideal: homogeneous, isotropic and elastic and meeting the requirements of Hooke's law.

In order that the results of the measurements can be compared with these existing theories, measurements have to be made on a practically ideal material. This is one of the reasons why a steel model was chosen. Moreover a steel model can be constructed on a fairly small scale, and besides it is possible to make a great number of observations on such a model for many different schemes of loading.

In order to interpret the results of the measurements on reinforced-concrete constructions it will be necessary to carry out tests on reinforced-concrete slabs during which the specific behaviour of this material will be observed. Only part of the investigation has been completed, however, several results have already been obtained and some conclusions can be drawn.

#### DESCRIPTION OF MODEL AND TESTS

The model (fig. 1) contains two rectangular slabs for testing. The upper slab is the web of a beam DIN 100, length 580 cm. Rotation of the flanges is prevented, so that the sides of the web are practically fixed. The web has a thickness of about 1.9 cm. The lower slab (about  $96 \times 1.9 \times 506$  cm.) has a hinge-bearing along the entire length of each long side. The distance between these hinge-bearings is 92 cm and is called the span.

One short side of each slab is completely fixed and the other short sides have hinge-bearings. In the future these hinge-bearings may be removed in order to make these short sides entirely free.

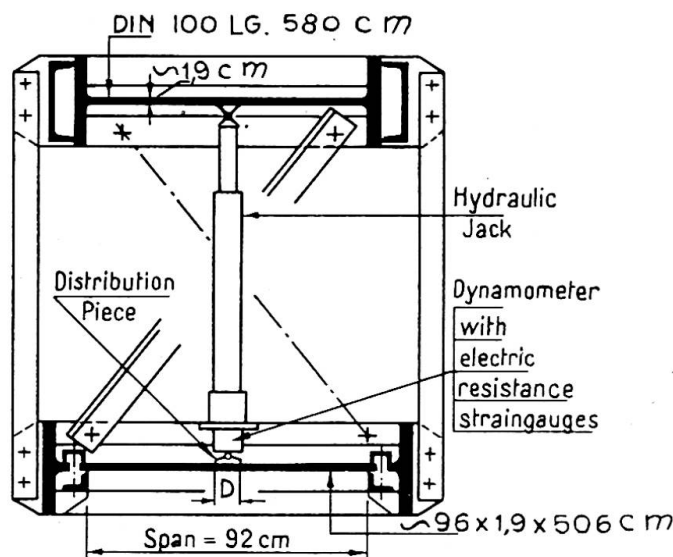


Fig. 1. Cross-section of model

The model is rigidly united by vertical and diagonal members.

The load is applied by a hydraulic jack placed between the slabs. The magnitude of the load is measured by a dynamometer provided with electrical resistance strain-gauges and is kept limited to assure the validity of Hooke's law.

The load was concentrated on a circular area with a varying diameter  $D$  (7.6—5.4—3.6—1.6 cm.) or transmitted by a ball with a diameter of 1 cm.

The influence of different packing such as 3 mm. of cardboard and 3 mm. of rubber between the slab and the distribution piece was also tested.

Up to now, measurements have been taken only in the middle part of the lower slab. It may be supposed that the supports along the short sides of the slabs do not influence the stress distribution in the central part; in other words, in this case the slab may be considered to be infinitely long. The load is placed respectively in different points of this central part, while the strains are measured in several places. Because no strain-rosettes were used, a special scheme had to be designed for fixing the strain-gauges and placing the load, so that for a point at a certain distance from the load the values of  $\epsilon_x$  and  $\epsilon_y$  could be determined in a simple way.

Philips strain-gauges mostly were used with a measuring length of 12 mm. In some places Baldwin strain-gauges were used with a measuring length of 12 and 3 mm.

## RESULTS

From the strains measured ( $\epsilon_x$  and  $\epsilon_y$ ) for a certain magnitude and position of the load  $P$ , the bending moments  $M_x$  and  $M_y$  are determined by means of the formulae:

$$M_x = \frac{E}{1-\nu^2} \cdot (\epsilon_x + \nu \cdot \epsilon_y) \cdot \frac{1}{6} h^2$$

$$M_y = \frac{E}{1-\nu^2} \cdot (\epsilon_y + \nu \cdot \epsilon_x) \cdot \frac{1}{6} h^2$$

in which the modulus of elasticity is assumed to be  $E = 2.15 \cdot 10^6$  kg./cm.<sup>2</sup>, and Poisson's ratio  $\nu = 0.3$ .

$M_x$  is the bending moment transmitted by sections perpendicular to the span, and  $M_y$  the bending moment transmitted by sections parallel to the span.

The relation between elongation and load ( $\epsilon_x$ ,  $\epsilon_y$  and  $P$ ) was fairly linear. For that reason it was possible to use one certain magnitude of  $P$  for calculating.

Fig. 2 shows the values of  $M_x/P$  and  $M_y/P$  at several points of sections below  $P$ , one in the direction of the span and the other parallel to the long side of the slab.

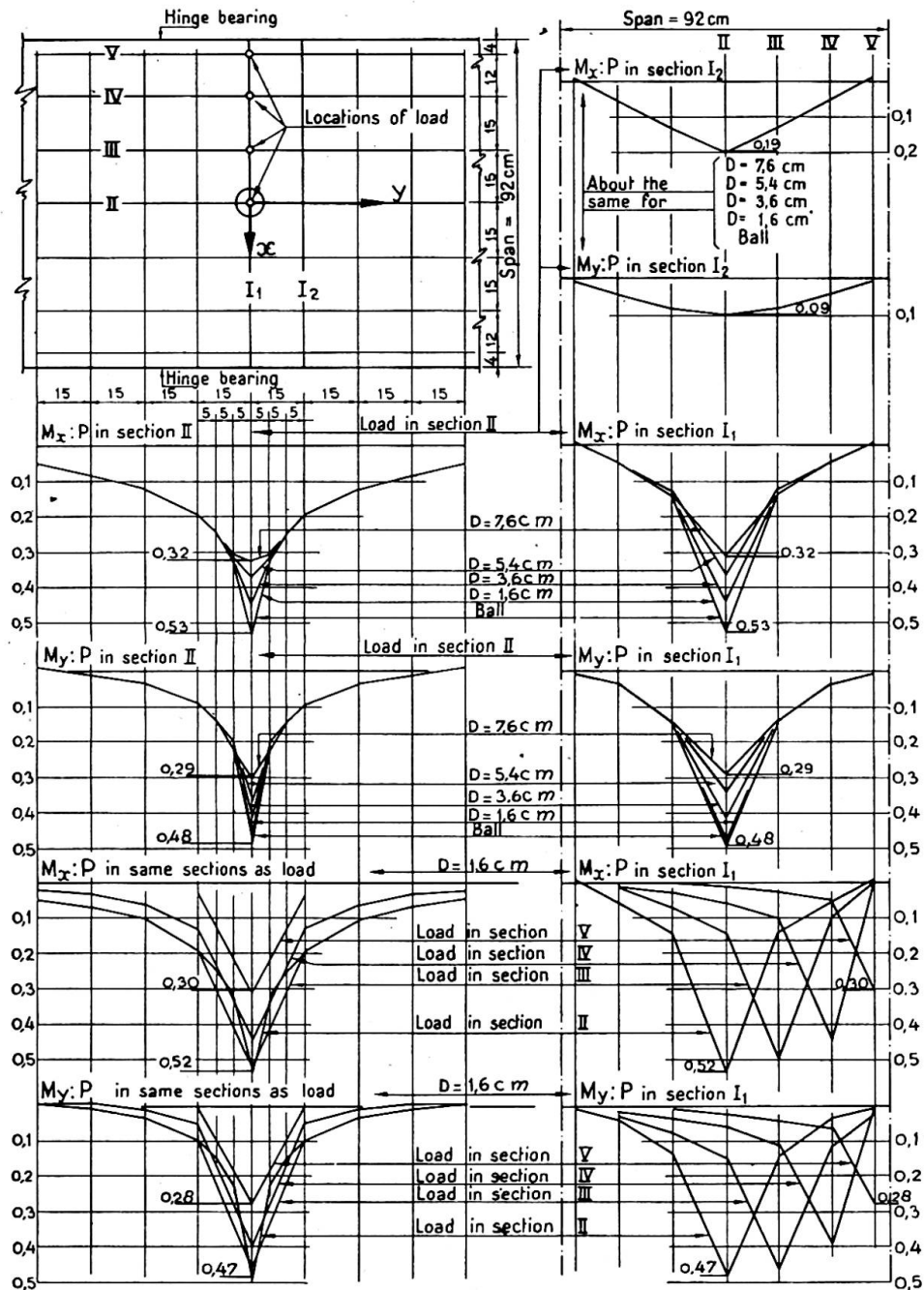


Fig. 2. Moment-load ratio from measured strains

In this case the load  $P$  is placed without any packing in the centre of the span.

In the neighbourhood of the load, and especially below the load, the influence of the concentration of the load proves to be very important. This influence, however, may be neglected when the point is chosen at a greater distance from the load. The influence of the packing also appears to be limited to the close surroundings of the

load. Generally the results of the formulae concerning the elementary theory of plates<sup>1</sup> agree well with the T.N.O. results.

Fig. 2 also shows the values of  $M_x/P$  and  $M_y/P$  at points in sections below  $P$ , one parallel and the other perpendicular to the span. In this case a concentrated load with diameter  $D=1.6$  cm. without any packing is placed respectively at different points of the span.

When the load is moved from the centre to the vicinity of the supports it appears that in the beginning the values of  $M_x/P$  and  $M_y/P$  decrease only slightly.

Fig. 3 again shows the values of  $M_x/P$  below the load as a function of the concentration of the load in the case where the load  $P$  is placed at the centre of the span. The observations obtained with three different kinds of strain-gauges and with two different packings and without any packing show a certain deviation. During loading without any packing, generally lower values are found, and during loading

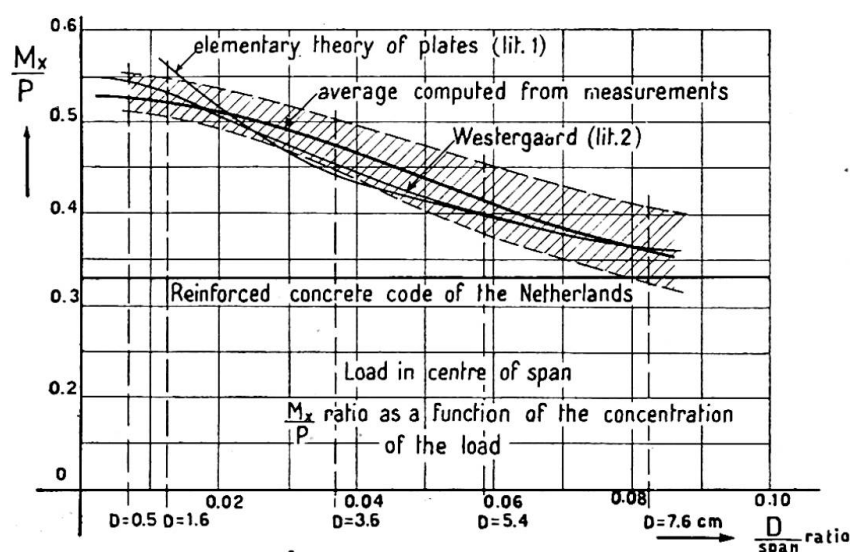


Fig. 3.

with a rubber packing of 3 mm., higher values of  $M_x/P$  are found. For comparison the values according to the elementary theory of plates<sup>1</sup> and those from the formula of Westergaard<sup>2</sup> are also given. Those of Westergaard also agree well with the test results when the load is concentrated on a very small area.

The T.N.O. results also agree with those of tests on rectangular slabs of aluminium made by R. G. Sturm and R. L. Moore.<sup>3</sup>

The tests will be continued. The load will be placed at different points of the lower slab near the short sides (different boundary conditions: hinged, fixed, free). Thereafter tests will be made on the upper slab.

Fig. 3 also shows the maximum moments according to the Netherlands Code (G.B.V. 1950).

When the load is concentrated on a small area, the moments determined from the observations are considerably bigger than those according to this code. However, it must be taken into consideration that a reinforced-concrete construction that is loaded up to the limit of its bearing capacity does not follow Hooke's law. Usually the thickness of a reinforced-concrete slab is, in relation to its span, bigger than for

<sup>1</sup> For references see end of paper.

the T.N.O. model. For this reason the results of this investigation are compared with those of the tests of Prof. Dr. Ing. Mörsch.<sup>4</sup>

During these tests on reinforced-concrete slabs (span 200 cm., thickness 14 cm., and sides perpendicular to the span 300 cm.) a load is applied that is distributed over an annular area with an outer diameter of 10 cm. He concludes that it is allowable to take into account a co-operating width in the slab equal to or bigger than the span. This means that the moment is equal to or smaller than  $0.25P$ . In the tests of Mörsch the diameter of the loaded area amounted to 0.05 of the span. In the steel model the diameter would thus be 4.6 cm. From the results of the steel-model tests a maximum moment of  $0.40P$  to  $0.47P$  would then be found (fig. 3).

It remains to be decided how far the difference between these values and  $0.25P$  is due to the differences in the relation between the thickness of the slab and the span or to the differences between the properties of steel and those of reinforced concrete.

Another problem which arises is what moments must be taken into account for the design of reinforced-concrete slabs that are very thin in relation to their span and carry a load that is concentrated on an area as small as possible.

More data concerning the above problems can be obtained by testing reinforced-concrete slabs upon which dead loads as well as live loads are applied.

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#### Summary

The purpose of these experiments is to obtain data for designing reinforced-concrete floor slabs for bridges and other structures, subjected to concentrated loads.

The tested model was a steel slab which had been stress-relieved.

Electrical resistance strain-gauges have been used.

The results have been compared with some existing theories, other experiments already made on this subject and the reinforced-concrete code of the Netherlands (G.B.V. 1950).

#### Résumé

Le but des présentes recherches est de réunir des données en vue du calcul des dalles de tablier en béton armé, pour ponts et autres ouvrages, dans le cas d'une charge concentrée.

Le modèle qui a été soumis aux essais était constitué par une dalle en acier ayant subi un traitement d'égalisation. Les mesures ont été effectuées à l'aide d'extensomètres électriques à résistance.

Les résultats obtenus sont comparés avec certaines théories, avec ceux qui ont été fournis par d'autres recherches expérimentales antérieures sur la même question, ainsi qu'avec les prescriptions néerlandaises concernant le béton armé.

#### Zusammenfassung

An einer spannungsfrei gemachten Stahlplatte, die durch eine konzentrierte Last beansprucht wurde, sind Messungen ausgeführt worden, um Unterlagen für die Berechnung von Stahlbetonplatten bei Brücken und sonstigen Konstruktionen zu erhalten. Benützt wurden Dehnungsmessstreifen.

Die Ergebnisse wurden mit einigen schon bekannten Theorien, mit weiteren Forschungen auf diesem Gebiete, sowie mit den niederländischen Stahlbetonbestimmungen verglichen.