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New Experiments on Reinforced Concrete Beams.

Neue Eisenbetonbalkenversuche.

Nouveaux essais effectués sur des poutres de béton armé.

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Comparative Experiments with Different Amounts of Cover to the Steel and Different Arrangements of Stirrups, and Experiments on Very Heavily Reinforced Beams.

The degree of safety possessed by a reinforced concrete structure cannot be correctly assessed by designing it on the ordinary "n" method.[1] The experimental results show great differences between the actual degree of safety and that assumed from calculation or that which it is desired to ensure.[2] If the stresses in the material are calculated from the breaking moment by the aid of the "n" method, values are obtained which differ considerably above or below the values which are to be regarded as governing the properties of the material, namely the cube strength of the concrete and the elastic limit of the steel.[3] In particular, consideration of the curves for extension of the steel and compression of the concrete indicates that no justification can be put forward for using the "n" method of calculation.[4]

The author, continuing his investigation of the correctness of his views, has carried out a further series of experiments on beams. In one set of these experiments beams with different amount of cover to the steel (from 2 to 5 cm) were made the subject of comparative tests, and beams with ordinary stirrups were compared with those having the stirrups inclined at 45°.[5]

The dimensions of the beams were b : h = 20 : 20 cm. The reinforcement consisted of three round bars of St. 37 of 10 mm dia. and the proportion of steel

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1 *Stüssi:* The Safety of Simply Reinforced Rectangular Beams. Publications I.A.B.S.E., Vol. I, Zürich 1932.

2 *Abeles:* Über die Verwendung hochwertiger Baustoffe im Eisenbetonbau. Beton und Eisen, 1935, Nos. 8 and 9.

3 *Gebauer:* Berechnung der Eisenbetonbalken unter Berücksichtigung der Schwindspannungen im Eisen. Beton und Eisen, 1934, No. 9.

4 *Gebauer:* Das alte n-Verfahren und die neuen n-freien Berechnungsweisen des Eisenbetonbalkens. Beton und Eisen, 1936, No. 2.

5 *Gebauer:* Vergleichsversuche über den Einfluß der Dicke der Eisenüberdeckung und den Einfluß der Bügellage auf das Tragvermögen von Eisenbetonbalken. Beton und Eisen, 1937, No. 8.

was 0.59 %. The cube strength of the concrete was between 416 and 425 kg per sq. cm; the elastic limit of the round steel bars was between 2859 and 2959 kg per sq. cm, and the span of the beam 2.00 m. In the case of the beams of 22 cm total depth carrying two isolated loads at 80 cm centres, the average breaking load was 5.725 tonnes, and in that of the beam of 25 cm total depth it was 6.06 tonnes; taking account also of the shrinkage stresses in the reinforcement the calculated breaking loads work out at 5.70 and 5.93 tonnes respectively. Taking no account of the shrinking stresses in the steel and of tensile stresses in the concrete, but having regard only to the actual dimensions of the beams, the calculated breaking loads were between 4.50 and 4.57 tonnes. Whereas the actual breaking loads differ from those calculated by the first method by only 0.4 or — 2.1 %, using the latter method of calculation they differed by — 21 and — 25 % respectively. Calculating with the aid of the "n" metod, the elastic limit of the steel bars should be attained under a load of 4.05 tonnes regardless of the depth of cover, and the difference by comparison with the actual breaking load amounts in this case to between — 29 and — 33 %.

Using the "n" method the depth of the compression zone amounts to $x = 6.82$ cm, whereas in the trial beam the cracks extended to within about 1 cm of the compression face. According to the method of calculation which does not involve "n" the calculated compression depth works out $x = 0.82$ cm.

The Steuermann method of calculation,[6] which takes no account of the depth of cover to the steel and assumes a triangular compression diagram for the concrete, likewise implies considerably greater depths of the compression zone than appear from the bending test of the beam: for instance with $\sigma_{b_z} = 25$ kg per sq. cm, $x = 2.66$ cm and the breaking load is 6.27 tonnes. Since in this instance the tensile strength of the concrete was not ascertained no more accurate comparison could be made.

In these cases[6] the shapes of the elongation curve for the steel and of the compression curve for the concrete show particularly well that the "n" method cannot be regarded as a proper method of calculating either the breaking condition or, still less, the stresses that arise under working loads.

The author carried out a further series of tests on experimental beams with a view to examining the effect of exceptionally heavy reinforcement.[7] Three pairs of beams were tested containing respectively 3.14, 4.91 and 6.53 % of steel. The dimensions were $b : h = 20 : 20$ cm, total depth 25 cm, span 2.00 m. The reinforcement was of St 37, namely four round bars of 20 mm dia, four of 25 mm dia, and, in the last example, three round bars of 30 mm with one of 25 mm dia. To prevent the beams failing prematurely through shear stresses their end portions were furnished with heavy inclined stirrups in addition to the bent-up main bars. The elastic limit of the reinforcing steel was 2.580 kg per sq. cm without any notable deviation. One beam from each pair was tested after four weeks and the other after six weeks. The concrete strengths at four weeks

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[6] *Steuermann:* Das Widerstandmoment eines Eisenbetonquerschnittes. Beton und Eisen, 1933, Nos. 4 and 5.

[7] See also *Gebauer:* „Neue Balkenversuche zur Klärung der Schwindspannungsfrage und des Verhaltens von Balken bei außergewöhnlich starken Bewehrungen." Monatsnachrichten des österr. Betonvereins 1937, Heft 5.

amounted respectively to 466, 458 and 410 kg per sq cm and after six weeks to 473, 512 and 514 kg per sq cm. The breaking loads on the beams (stated in the same sequence as above) were 22.0 and 22.0 tonnes; 28.9 and 29.9 tonnes; and 32.9 and 36.0 tonnes. The decisive part played by the concrete strength is easily recognisable in the breaking loads.

Using the method of calculation which take no account of "n" but which is based on the elastic limit of the steel, on the cube strength of the concrete and on the assumption of a uniform distribution of compressive stress with (or without) taking account of the shrinkage stresses, the breaking loads in the several beams after hardening for four weeks work out at 21.5 (20.0) tonnes, 30.8 (28.7) tonnes and 33.1 (30.7) tonnes. The corresponding loads after six weeks hardening are 22.9 (20.4); 32.8 (29.7); and 40.4 (37.1) tonnes.

Comparison between the calculated and the experimental results shows that in the case of the beams reinforced with 3.14 % of steel, a better agreement is obtained when the shrinkage stresses are taken into account than when they are ignored, but generally speaking the discrepancies in the case of beams containing more than 4 % of reinforcement are not large, whether the shrinkage stresses have been considered or not. For beams containing 4.91 % and 6.53 % of reinforcement the experimental results approximate to those found by calculation regardless of the shrinkage stresses, though if the latter are taken into account the difference amounts to 12.2 % in the case of only one of the beams (N° 64). Hence the tolerance of 10 % which is usually regarded as acceptable is only slightly exceeded. This deviation of 12 % is easier to explain in view of the uncertainty which attends the calculation of shrinkage stresses in any case, and of the difficulty of constructing heavily reinforced beams in which the spaces between the reinforcing bars are very narrow. Moreover a yielding of the concrete at the end hook was observed to occur immediately before the actual breakage, so that the full resisting moment of the beam could not be developed.

From the experiments hitherto carried out it may also be inferred that where the reinforcement is particularly heavy the shrinkage stresses exert a smaller influence because of the smaller proportion between the circumference and the area of the cross section of the bars; on the other hand thinner reinforcing bars have a proportionately larger area of contact and with these the effect of shrinkage is consequently greater.

Supported by the experimental results explained above, the author has advocated the abandonment of the "n" method before the Second International Congress on Bridge and Structural Engineering in Berlin. It is to be noticed that Prof. *Saliger*, also, has taken up this point of view in the Preliminary Report of the Congress, though he has left the question of shrinkage stresses out of account and instead of using the cube strength has worked on the prism strength of the concrete which is about one quarter lower, with the result that calculation gives breaking loads somewhat lower than are determined in these experiments.