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Tests with Concrete Beams Reinforced with Isteg Steel.

Versuche mit Eisenbetonbalken mit Isteg-Stahl-Bewehrung.

Essais de poutres en béton armé d'acier Isteg.

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An account will be given below of the results of experiments on special reinforcing bars carried out in Poland. It is known that the yield point of such bars can be considerably increased by mechanical treatment (pre-stretching) and that in this way the tensile breaking stress may be raised; the most advantageous amount of pre-stretching appears, from experience, to be approximately 6 %. In reinforced concrete members subject to bending the yield point of steel -- or, the stress corresponding to an elongation of $\varepsilon = 0.4$ % — is a matter of primary importance, the failure of such members being almost always the result of the carrying capacity of the reinforcement being destroyed when ε reaches 0,4 %. Two kinds of reinforcement which have received preliminary treatment in this way are in practical use; namely Isteg steel and expanded metal.

a) Isteg steel.

Isteg steel is manufactured by twisting together two round bars of equal diameters. In 1934 experiments on the reinforced concrete members indicated in Table I were carried out in the testing laboratory of the Technical University of Warsaw, and these disclosed some valuable properties of Isteg steel for the reinforcement of beams and slabs.

The elements marked A were reinforced with Isteg and those marked B with ordinary round bars, the reinforcement being so designed that the cross section of the Isteg steel was 33 % smaller than that of the round bars in the corresponding members. The tests carried out on these materials gave the following average values:

Table 2.

Material	Yield point	Breaking stress	Modulus of elasticity
A. Isteg steel 5.5 mm	3738 kg/cm^2	4261 kg/cm^2	1 630 000
Isteg steel 7 mm	3723 „	4339 „	1 600 000
B. Round bars	2640 „	3630 „	2 101 000

It will be seen from these figures that the Isteg steel has a yield point averaging 41.3 % higher and that its strength is 18.5 % higher. The results obtained in the experiments with reinforced concrete elements led to the following conclusions.

1) *Bending strength.*

The breaking loads for elements reinforced with Isteg steel of 33 % smaller cross section were almost the same as those for members reinforced with larger section of round bars. If the amount of reinforcement was small, the first crack appeared earlier in the beams reinforced with Isteg than in those reinforced with round bars, but this difference disappeared when the amount of reinforcement was increased. With the round bars the first hair cracks spread almost immediately after their appearance into wide open fissures.

With the Isteg steel the cracks were at first almost imperceptible. They opened very slowly, even when the load was considerably increased, and did not lose the character of hair cracks. The reason for this is probably to be found in the better bond of the concrete on to the spirally wound steel rods.

The further conclusion may be drawn that the compressive stress conditions in the concrete at the instant of breakage are more favourable where Isteg reinforcement is adopted, as the deformation of the concrete takes place more uniformly, whereas with round bars this change of shape is strongly concentrated in a few short sections.

2) *Deflections.*

The deflections of the concrete elements containing Isteg steel were much greater than those of the corresponding elements containing round bars. This is easily understood on the following grounds:

a) The stresses in the Isteg steel are some 50 % higher under the same loading than those in the round bars of the control elements, and assuming a modulus of elasticity of the same value in both cases this would imply 50 % greater elongation of the Isteg bars.

b) Apart from this, the modulus of elasticity of the Isteg bars if lower, being $E = 1\,615\,000$, and this leads to a further increase in the elongations of approximately 30 %.

For these two reasons combined, the elongation of the Isteg steel is multiplied by $1.5 \times 1.3 = 1.95$, that is, it is increased by 95 %, and the greater deflections obtained are the result. Generally speaking, however, no disadvantage is to be apprehended from this as all reinforced concrete structures are in fact very stiff.

3) *Actual stresses.*

In the experiments carried out with elements IV and IVa the deformations ε in the steel and concrete respectively were measured by means of *Huggenberger* tensometers and the stresses were then calculated from the equation $\sigma = E \cdot \varepsilon$ by inserting the mean values of E already determined. These stresses may be regarded as directly measured, and therefore as actual stresses.

Table 1.

Summary of

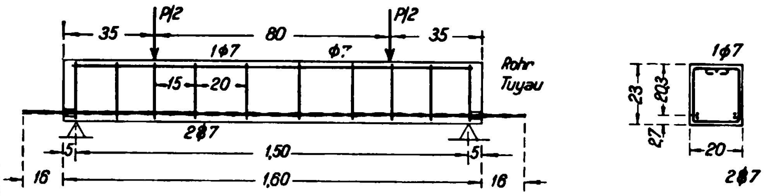
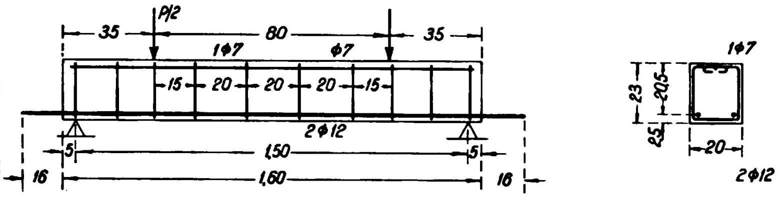
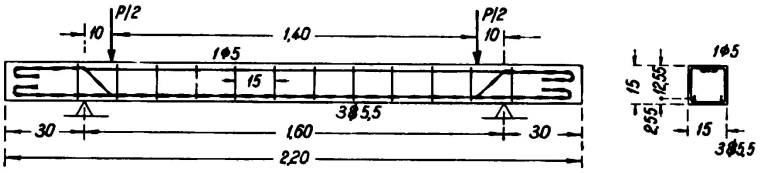
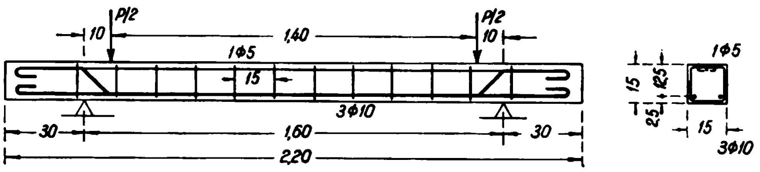
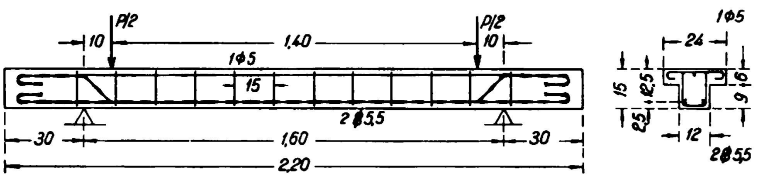
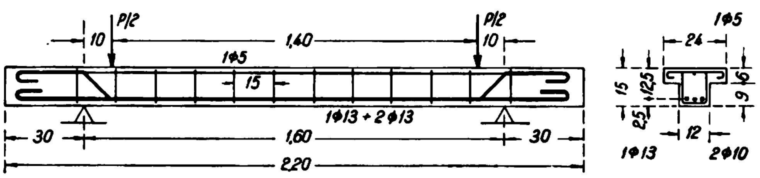
Nr.	Dimensionen — Dimensions	Beton Nr. Béton No. Concrete Nr.	Ausgeführt Exécuté Executed	Geprüft Essayé Tested	Zweck der Probe But de l'essai Purpose of testing
II-A		2	27/IX.	22/XI.	Haftung — Grip
II-B		2	27/IX.	22/XI.	
III-A		2	27/IX.	24/XI.	Druck — Compression
III-B		2	27/IX.	24/XI.	
IIIa-A		2	27/IX.	24/XI.	Druck — Compression
IIIa-B		2	27/IX.	24/XI.	

Table 1.

specimens tested.

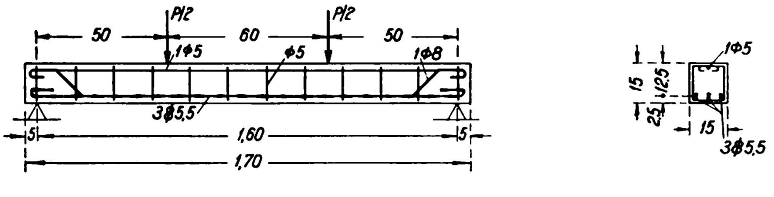
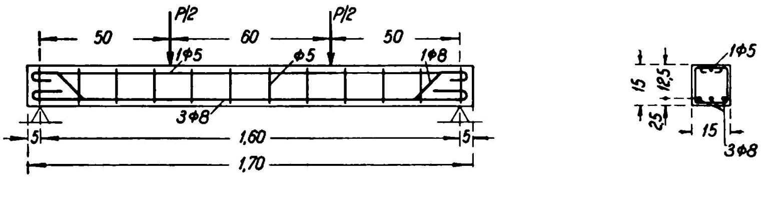
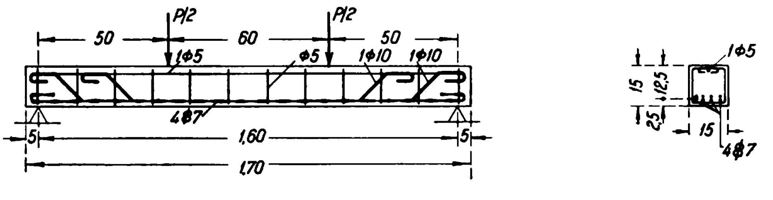
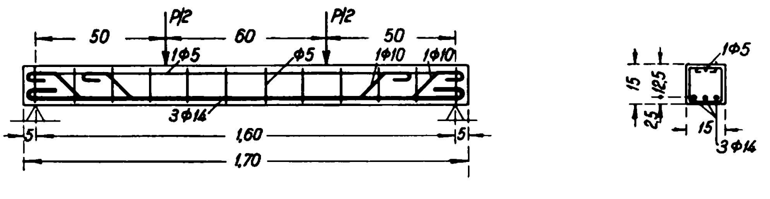
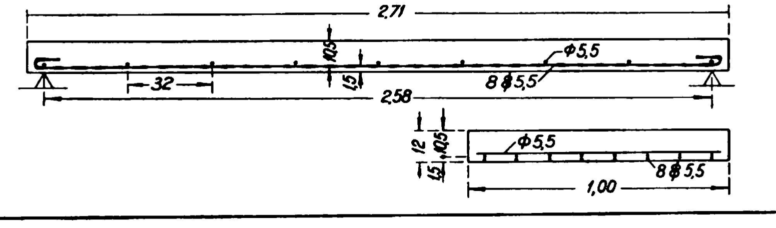
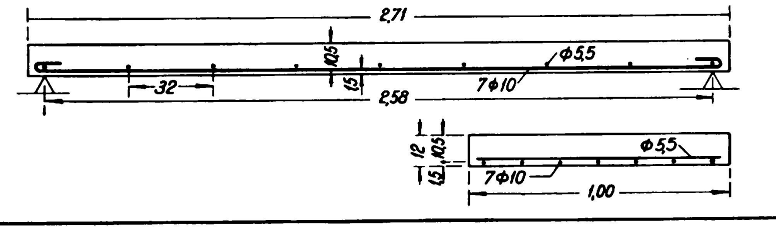
Nr.	Dimensionen — Dimensions	Beton Nr. Béton No. Concrete Nr.	Ausgeführt Exécuté Executed	Geprüft Essayé Tested	Zweck der Probe But de l'essai Purpose of testing
IV-A		2	27./IX.	21./XI.	Druck — Compression
IV-B		2	27/IX.	21./XI.	
IVa-A		2	27./IX.	21./XI.	Durchbiegung — Flèche — Deflection
IVa-B		2	27/IX.	21/XI	
I-A		1	18./IX.	18./X.	Durchbiegung — Flèche — Deflection
I-B		1	18/IX.	18/X.	

Table 3. Comparison between calculated and measured stresses.

Beam	Reinforcement	Concrete (measured)		Steel (measured)		Concrete: calculated for			Steel: calculated for		
		total	elastic	total	elastic	Phase	Phase II with		Phase	Phase II	
		ε	ε	ε	ε	I	n = 15	true n	I	n = 15	true n
IV B	Round bars	30.1	26.8	903	420	21.4	31.9	37.9	105	785	772
IV A	Isteg	49.2	35.2	536	363	24.6	34.9	45.3	120	772	748
IVa B	Round bars	24.3	21.8	307	202	19.3	22.1	24.9	82	258	249
IVa A	Isteg	29.7	23.6	377	194	19.7	24.5	30.8	90	380	360

In Table 3 two sets of values of the "measured" stresses are compared, namely those calculated from the total elongations and those calculated from the elastic elongations within the range of load of 500 kg. Corresponding stresses are calculated for Phase I with $n = 8$ and for Phase II with $n = 15$. Also with

$$\text{true } n = \frac{\text{true value of E for steel}}{\text{true value of E for concrete}}.$$

It must be stated that although the measurements were actually made in Phase I the measured stresses correspond more closely with those calculated for Phase II. In the concrete the agreement between the measured and the calculated stresses is fairly good with $n = 15$, especially if account is taken only of the elastic elongations. Reasonably good agreement between the measured and the calculated stresses for the total deformation is also obtained, especially if the true value of n is used.

As regards the reinforcement, however, only those stresses which are calculated from the total elongation approximate to the calculated stresses in Phase II, the measured stresses for the round reinforcing bars being a little higher and those for the Isteg bars a little lower. Stresses calculated on the basis of elastic deformation alone worked out lower, without any exception, by about 50% in comparison with the calculated stresses for Phase II, but from two to four times higher than the calculated stresses according to Phase I. The true stresses therefore lie between those found from Phase I and Phase II. This can only be explained on the assumption that n is considerably greater for the tensile zone in Phase I than the usually assumed value $n = 8$.

It may be assumed as probable that the measured stresses in the reinforcement agree with the unknown actual stresses, but as regards the stresses in the concrete matters are different for the following reasons:

1) Within the scope of the measurements the reinforced concrete sections are working according to Phase I, so that the statical behaviour is not like that which would correspond to Phase II.

2) The actual distribution of stresses is very different from the *Navier* distribution, and — especially in the case of the round bars — the stresses around the bars are smaller and the stresses close to the neutral axis greater than is implied by the linear diagram. It may be concluded from this that the actual stresses are lower than is implied by calculation from the measurements as above. The mean value of E in bending must be smaller than in pure com-

pression. Several foreign experimenters have given the following values for concrete:

$$E_{\text{for bending}} = \frac{2}{3} \text{ to } \frac{1}{2} E_{\text{for axial compression}}.$$

The close agreement of the measured stresses with the calculated stresses (according to the usual formula for Phase II) is, therefore, relevant to the present case.

4) *The coefficient n.*

The results of the present experiments do not entail the adoption of another value of n than that which is now usual in calculations where Isteg steel is adopted, although direct measurement of the elastic characteristics of Isteg steel by comparison with concrete gives an average value of $n = 9$. In practice, however, the calculated stresses are almost independent of n. Moreover, according to a number of experiments which have been carried out, the true value of n varies a great deal and depends upon the stresses, even assuming the same kind of concrete.

5) *Gripping stresses.*

The Isteg steel with 33 % smaller cross section gave more than 20 % higher grip resistance than the ordinary round bars, and if the load was further increased the Isteg steel was found to slip more slowly than was the case with round bars.

6) *Shear.*

There can be no doubt that in the experiments carried out on beams III and IIIa the governing factor was not the compressive strength of the concrete but the shear forces. Under bending loads the weakest part of each beam was the cross section immediately below the concentrated load, because at this point most of the reinforcing bars provided for the purpose of resisting the bending moment were bent up at a place where the magnitude of this moment was still at a maximum.

The compressive stresses in the concrete were calculated for Phase I and Phase II. The stresses in the reinforcing bars were calculated both for the bent up bars and in reference to all the bars.

Table 4 shows the stress values in kg/cm^2 when the first crack appeared, and it will be seen that this happened at practically the same time with either methods of reinforcement.

Table 4. Shear stresses.

Beam	Reinforcement	Stress in Concrete		Stresses in reinforcement	
		Phase I	Phase II	Bent-up bars	all bars
III B	Round bars	21.0	30.8	4780	1970
IIIa B	„	18.7	37.6	2930	1604
III A	Isteg steel	21.2	29.7	7260	3010
IIIa A	„	18.1	34.9	4675	2450

It is a matter of great difficulty to estimate the stresses in the bent-up bars. The usual method of calculation, which assumes that in the absence of stirrups the whole of the shear force is carried by the bent-up bars, is:

$$\text{Stress in bent-up bars} = \frac{\text{Total shear}}{\text{Area of bent-up bars} \times \sqrt{2}}$$

but this led to quite impossible values in the present case, greatly exceeding the breaking stress of the material. This explains the effective cooperation of the straight bars on account of the good anchorage provided outside the supports.

When, however, the stresses in the reinforcement are calculated in reference to the straight bars by the formula:

$$\text{Stress in bars} = \frac{\text{Total shear}}{\text{Area of straight bars} + \text{Area of bent-up bars} \times \sqrt{2}}$$

values are obtained which correspond almost exactly with the bending stresses. It follows from the comparison of the breaking load stresses calculated in relation to the whole of the bars that in this case, also, the carrying capacity of the Isteg steel is 1.5 times as great as that obtained with ordinary reinforcement.

b) Expanded metal.

Expanded metal, as is well known, consists of a network of rhomboidal spaces which is produced by special machines from annealed steel sheets. The smaller angle of each rhomboid is about 41°, this optimum value having been determined by experiments. The side strips of such a rhomboid undergo an elongation amounting to

$$\frac{1}{\cos 20.5^0} - 1 = 0.067 = 7\,\%.$$

This value practically agrees with the elongation of the material used for Isteg steel, which is about 6%.

Expanded metal is manufactured from sheet thicknesses of 0.5 to 4.5 mm. The width of the strips varies from 2.5 to 10 mm and the sizes of the rhomboid are 10/42, 20/62, 40/115, 75/200 and 150/400 mm respectively. Expanded metal has already been in use for some forty years and has frequently been examined in testing stations.

Table 5. Tests on Expanded Metal.

Plate			Expanded metal			% change through working		
σ_p kg/cm^2	σ_s kg/cm^2	ε %	σ_p kg/cm^2	σ_s kg/cm^2	ε %	σ_p kg/cm^2	σ_s kg/cm^2	ε %
2848	3375	22.1	3736	3993	11	+ 30.1	+ 18.1	— 50.3
3042	4205	26.2	4544	4715	10.9	+ 49.2	+ 12.2	— 58.4
3129	4204	23.9	4728	5001	12.1	+ 51.1	+ 18.8	— 49.4
3234	3787	23	4607	4667	7.7	+ 42.4	+ 23.3	— 66.5

In the autumn of 1934 experiments were carried out in the testing laboratory of the Technical University of Warsaw to determine the increase in the yield point which results from the permanent elongation of the sheet metal strips in the production of expanded metal, and the results of these experiments are given in Table 5 above.

It was found, in agreement with foreign experiments, that the yield point of the expanded metal may be in excess of 3600 kg/cm^2 and that the best results are obtained with soft sheets having a maximum amount of extensibility ε. Reinforced concrete elements containing expanded metal have been in practical use for years. The cooperation between the expanded metal and the concrete is very similar to that of Isteg steel. The deflections obtained are greater than with round bar reinforcement A 35, but the cracks are smaller, more numerous and more uniform, with the result that the stress on the concrete in compression is more uniform. The greater resistance to slip possessed by Isteg steel is easily explained by its special shape, each of the many intersections acting as a separate hook. Expanded metal by itself would be subject to a great deal of deformation. Embedment in the concrete has the effect of considerably stiffening the intersections of the network, and thus hinders deformation of the spaces enclosed. In order to render this stiffening effective the sizes of the openings should not be too small. The conclusions obtained in regard to Isteg are fundamentally valid also for expanded metal.