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Investigation into the Necessity of Cover Plates for the Joints of Steel Columns.

Untersuchungen über die bei gestoßenen Stahlstützen notwendige Stoßdeckung.

Essais sur les couvre-joints nécessaires dans les colonnes métalliques avec joints.

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Purpose of the experiments.

The German standard calculations (DIN 1050 § 12, Section 2) for steel in structural work state that: "In the case of through struts which are subjected solely to compression and whose joints are placed beyond the middle half of the buckling length, the covers and the riveted connections of the joint can be dimensioned for half the load on the strut, provided the end cross sections be truly squared and in close contact. At the head and foot of struts subjected solely to compression, in which the end cross sections are machined truly square and provided with sufficiently thick bearing plates, the rivets of the connected parts need be dimensioned for only one quarter of the load on the strut." For bridge building, no such specification has yet been issued. The butting compression members are secured with covers corresponding to the full load. In building the Adolf-Hitler bridge over the Rhine at Urdingen, Krefeld, the joints arranged for the Pylons by the chief designer, Dr. Voss, were for the first time constructed as so-called "contact joint", in which only a portion of the compressive force is taken by the plate covers, whilst the remainder must be transmitted through the contact of the joint. Fig. 1 gives a detail drawing of the joint, together with an elevation of the Pylon. The saving in material amounted to 2.2 tons for each joint or 26 tons for the whole bridge. Though this saving, referred to the whole structure, may perhaps be insignificant, it should, nevertheless, not be ignored that, if followed, the course here indicated may lead to even greater savings of material in bridge construction. For example, it appears quite possible that the contact areas of joints in the compression flange of large lattice-girder bridges are made use of in the transmission of the forces, so that even this joint becomes a contact joint. However, the data for such joints, in conjunction with the general considerations concerning the diminished lateral stiffness caused by the butt joint, must be obtained from experiment. The following particulars relate to the experiments which provided the data for the contact joints of the Krefeld Rhine bridge. They were carried out at the Government material-test house at Dahlem, Berlin.

Design of the test struts.

The cross sections of the struts were, as shewn in fig. 2, cruciform in shape, made up of four angle sections with an interposed steel flat. The cross sectional area was 171.8 cm^2, the maximum moment of Inertia 4764 cm^4 and minimum 4659 cm^4. The length of the strut itself was 360 cm. Four of the struts were mounted between flat bearing plates, and four others were mounted between knife-edge bearing plates and eccentrically loaded, the amount of eccentricity being 2.09 cm. In the latter case, the buckling length was increased to 396 cm in consequence of the height of the knife-edge bearings, so that the ratio of slenderness amounted to $\lambda = \frac{l}{i} = \frac{396}{5.3} = 75$. The core radius of the cross section measured K = 2.09 cm. In the eccentrically loaded struts, the degree of eccentricity, e, was exactly equal to the value K. Half of the test bars were without any joint, the remainder having a midway joint. The butting surfaces were machined smooth and in addition a cover strap was provided having a sectional area 45 per cent that of the strut and a moment of Inertia 52 per cent that of the strut. One half the number of struts were supplied by the Dortmund Union Brückenbau A.G., and the remainder by Friedrich Krupp A.G.,

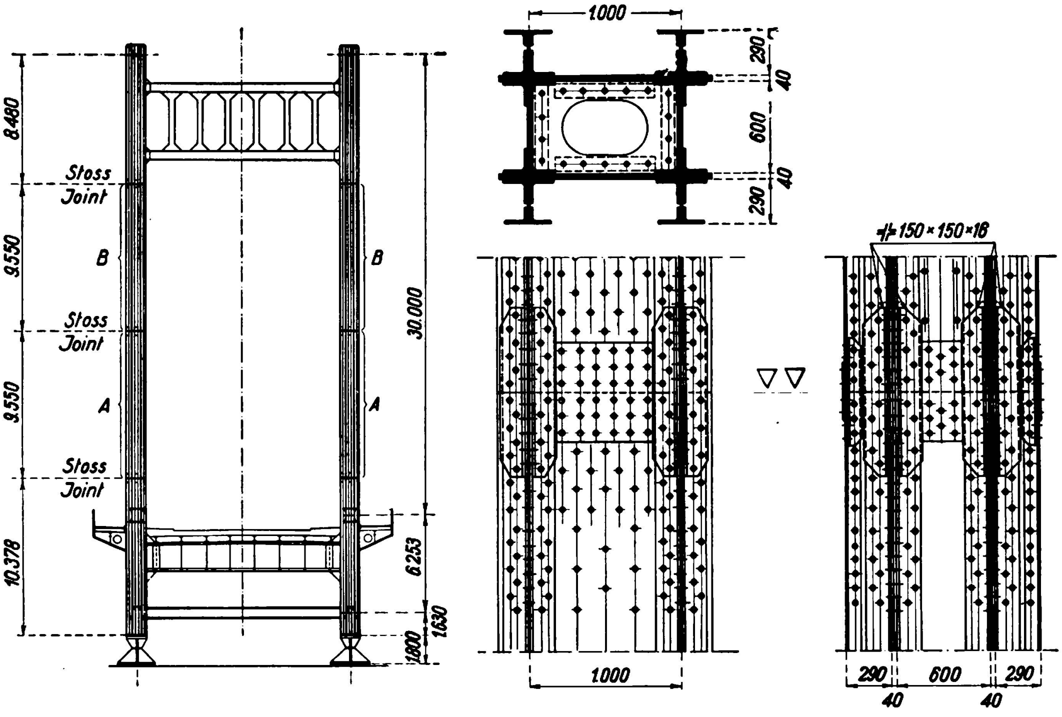

Fig. 1.

Elevation of pylone and design of joints with cover plates of the Adolf Hitler Bridge in Kreefeld-Uerdingen. (Diameter of rivets 26 mm.)

Friedrich-Alfred-Hütte, who had also built the Krefeld bridge. The material of the struts was St 52. The mechanical properties exhibited, in general, a high degree of uniformity. The elastic limit was in the region of 3600 kg/cm^2 and the tensile strength 5400 kg/cm^2.

The tests were carried out in a 600-ton vertical press. Fig. 3 shows a jointed test strut with centrally applied load after the buckling test in the machine. The lower part of the testing equipment is situate below ground level and is not seen in the illustration. As already mentioned, the centrally loaded test struts were tested directly between flat bearing plates, but those eccentrically loaded, between knife-edge bearings. All struts were, first of all, perfectly centred in mounting, by arranging them centrally in the machine, and a medium load was applied, the deflection of the strut being then measured. On releasing the load the strut is slid between the bearings in accordance with the result of the deflection measurements. On reloading, the deflections are already smaller. The treatment is repeated until, under this initial load, the deflections are insignificantly small. The method ensures absolutely reliable centering of the struts, especially when knife-edge bearings are used. After this adjustment, the struts to be tested under eccentric loading were moved between the knife-edge bearings, through a space of 2.09 cm, at right angles to the direction of the knife-edge. Then followed the actual buckling test in which the load was increased, by small increments, until the crippling load was reached.

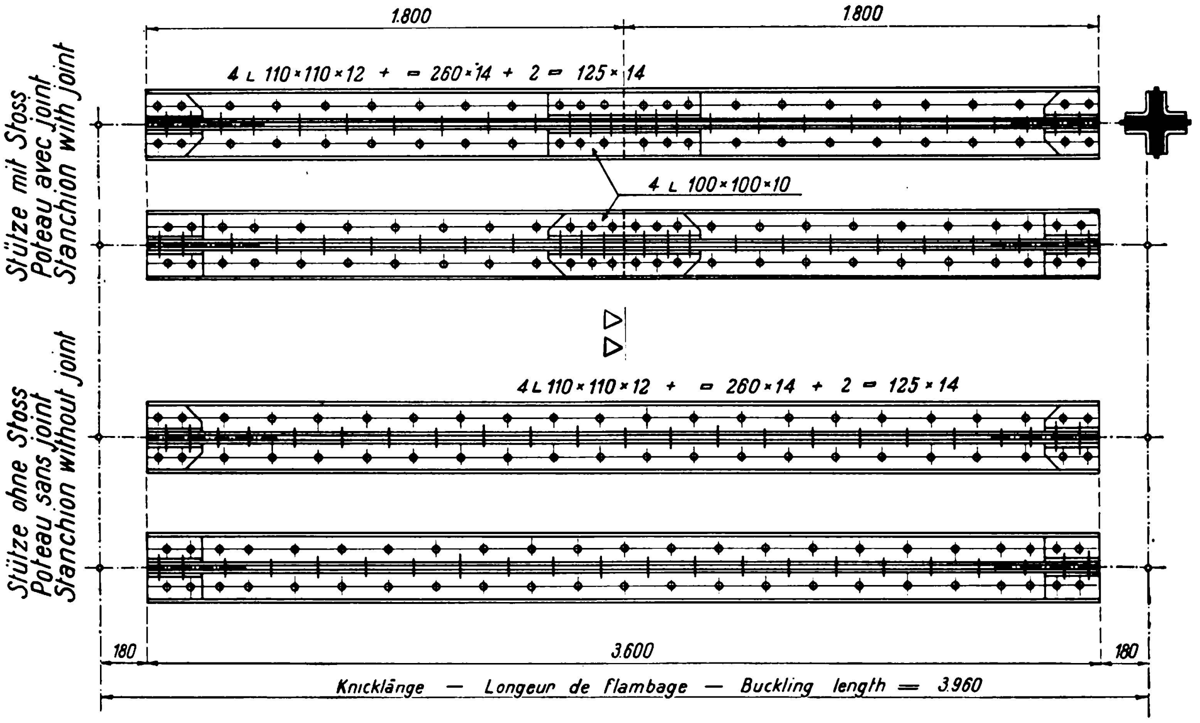

Fig. 2.

Design of test columns. (Diameter of rivets 23 mm.)

The deflections of the struts were measured in both principal directions by the Leuner method. The instruments were seated at the centre, at quarter points, and — to eliminate any spatial movements — also at the ends of the struts. In addition to the deflection measurements, Huggenberger tensiometers were applied at numerous points for measuring elongation in each test, the readings being noted at each increment of loading.

Test results.

A summary of the chief results obtained in the experiments will now be given.

Table 1.

(Tests performed at the Government material-test house, Dahlem, Berlin.)

	Test No.	Source of Material St 52	Design.	Greatest load P_{max} t (metric)	$\sigma = \frac{P_{max}}{A}$ kg/cm²
Centrally loaded struts	1	Krupp	with joint	603	3510
	2		without joint	599	3490
	3	Union	with joint	599	3490
	4		without joint	597	3480
Eccentrically loaded struts	1	Krupp	with joint	247.5	1440
	2		without joint	247.5	1440
	3	Union	with joint	253.7	1480
	4		without joint	252.5	1470

In the case of centrally as well as of eccentrically applied load the value of the stress and loads attained was independent of whether the strut was jointed or not. It even seems as though the butted struts stood up rather better, under the tests, than those in which there was no joint. This is still more apparent in the case of centrally loaded struts, if the time, during which the strut was under greatest load, be considered. The machine had a nominal maximum load of 600 t. The 603 t of the first jointed strut were therefore endured by the strut a short time before giving way, whereas the next strut (without joint) buckled immediately at 599 t. Under the maximum load the material attained a compression limit of about 3500 kg/cm² inch, although the buckling load diagram for fixed ends, based on the said slimnes ratio of $\lambda = 69$, indicates a buckling stress of only 3260 kg/cm². This higher value may be attributed to the restraining action of the flat bearings. That these actually do set up a restraint is, moreover, evident from the photograph, Fig. 3. Fig. 4 shews the load-deflection curve of two struts, both centrally loaded, the one without joint and the other with joint. It is clear that, in spite of the flat support in place of the more precise action of knife-edges, satisfactory centering was obtainable. The load-deflection curve of the jointed struts can be regarded as even better than that of the unjointed struts. In all cases it is evident that in well-constructed contact-jointed struts, with centrally applied load, no serious deflections are to be feared.

The deformation or stress measurements portrayed in fig. 5 form a somewhat more unfavourable picture. For the unjointed struts, under equal loading, all the measured values are nearly on a par. With P = 400 t (metric), the elastic limit is nearly reached, at $\sigma = \frac{400000}{171.8} = 2330$ kg/cm². In the case of P = 520 t (metric), local signs of flow are revealed at $\sigma = \frac{520000}{171.8} =$ 3000 kg/cm² which at the corresponding measuring points 11/12, are accompanied by an increased rate of progression of the upsetting effect.

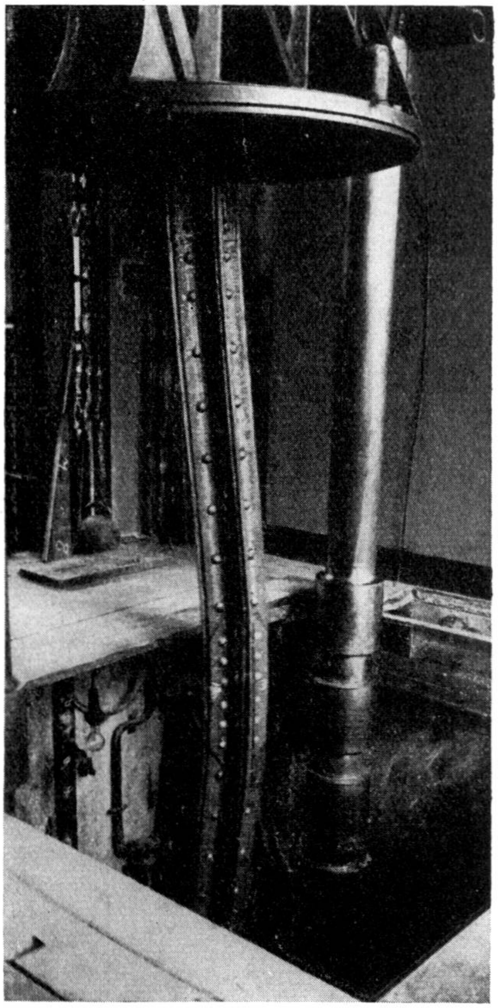

Fig. 3.
View of a centrically compressed member in the testing machine.

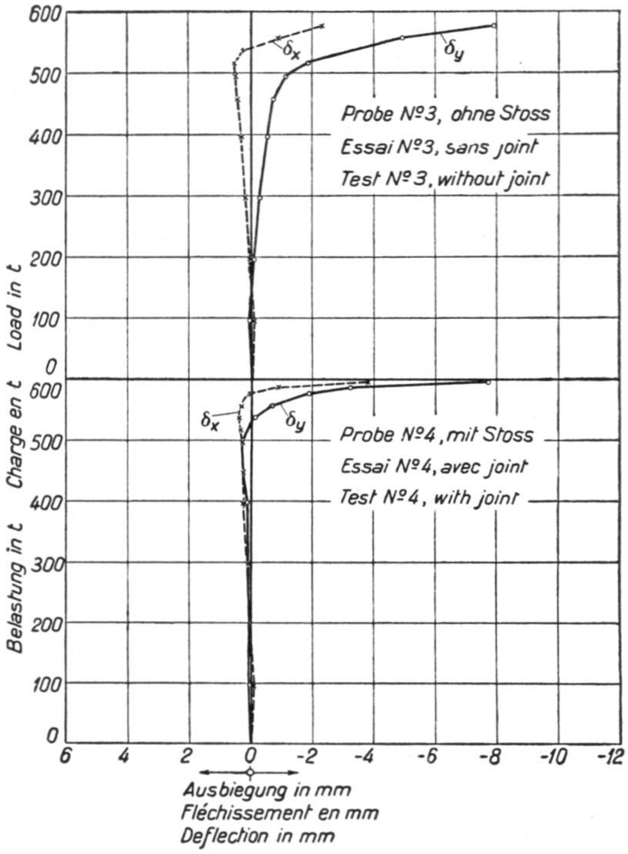

Fig. 4.
Deflection of the middle of two centrically compressed columns.

In the case of the jointed struts, the points at which the elongation was measured were arranged on the flat bar close above or under the joint, in order to test whether all parts of the cross section are actually in contact and take part uniformly in the transmission of the forces. This must be correlated after the elongation measurements. Some of the measuring points did not share in the transmission of the load at first, and only to a small extent as the loading increased; whilst others, in spite of the cover plates, registered higher stresses than in the unjointed struts. From the elongation measurements on both the centrally-loaded jointed struts it can also be deduced that, for a load of P = 400 t (metric), 48 or 17 per cent of the force applied to the bar was transmitted through the joint angle, whilst the remainder was absorbed by contact.

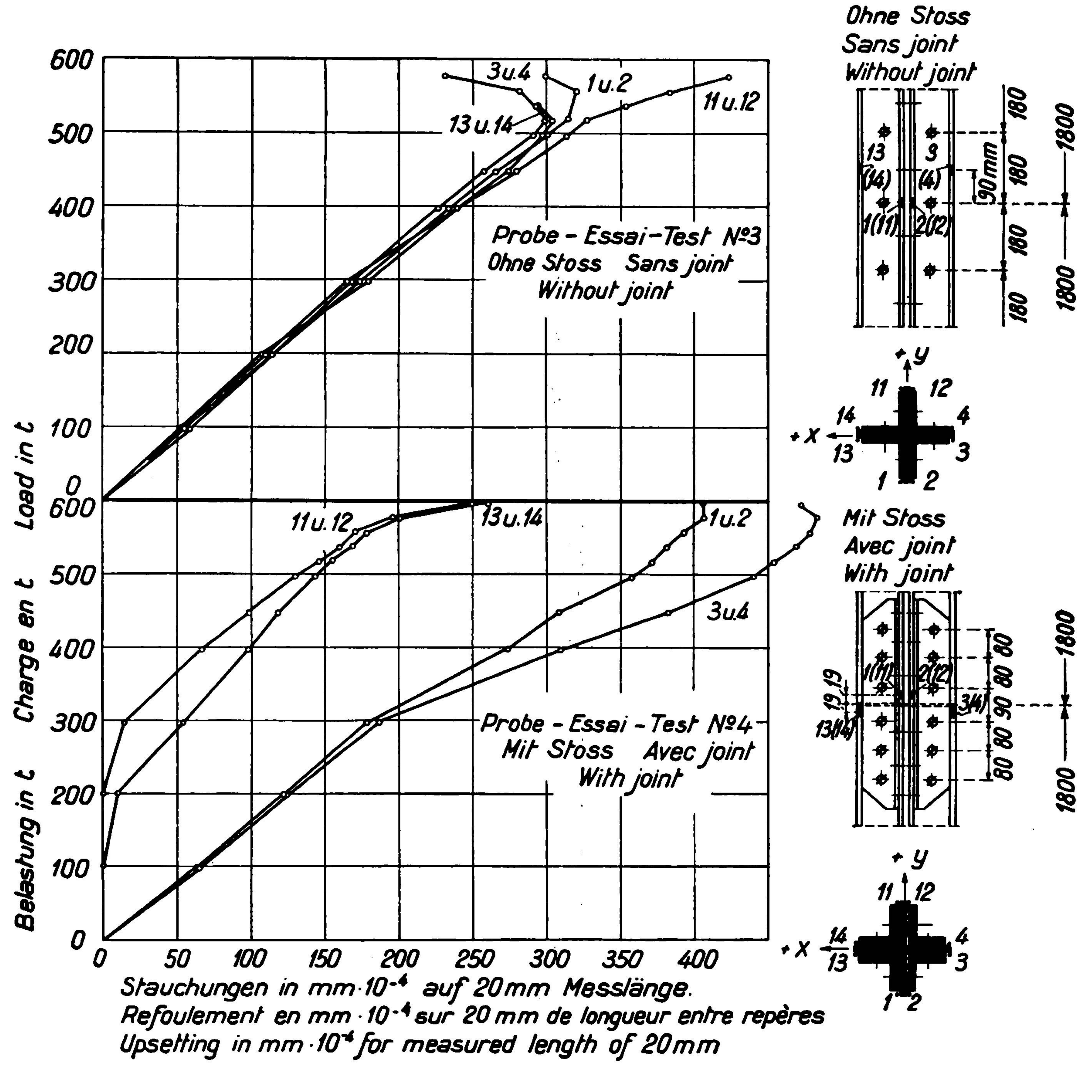

Fig. 5.

Measurements of upsetting of two centrically compressed columns (mean values of corresponding test measurements).

The greatest loads supported by the eccentrically-loaded struts amounted to more than half those of the centrally-loaded ones, although with an eccentricity equal to the core radius, the marginal stressing of the eccentrically-loaded struts before reaching the compression limit is more than double that of the centrally-loaded ones. The cause resides in the plastic equal distribution of the stresses over the cross section, a point which has already been dealt with by many authers. A comparison between the greatest strut load attained and the values calculated from Chwalla's graphical method, was carried out by the author and published elsewhere[1]. It revealed a very satisfactory agreement between theory and experimental practice. Fig. 5 gives the load-deflection curves of a jointed and an unjointed strut, the deflections of both struts are practically identical and agree very well with the calculated values. Fig. 7 represents some elongation

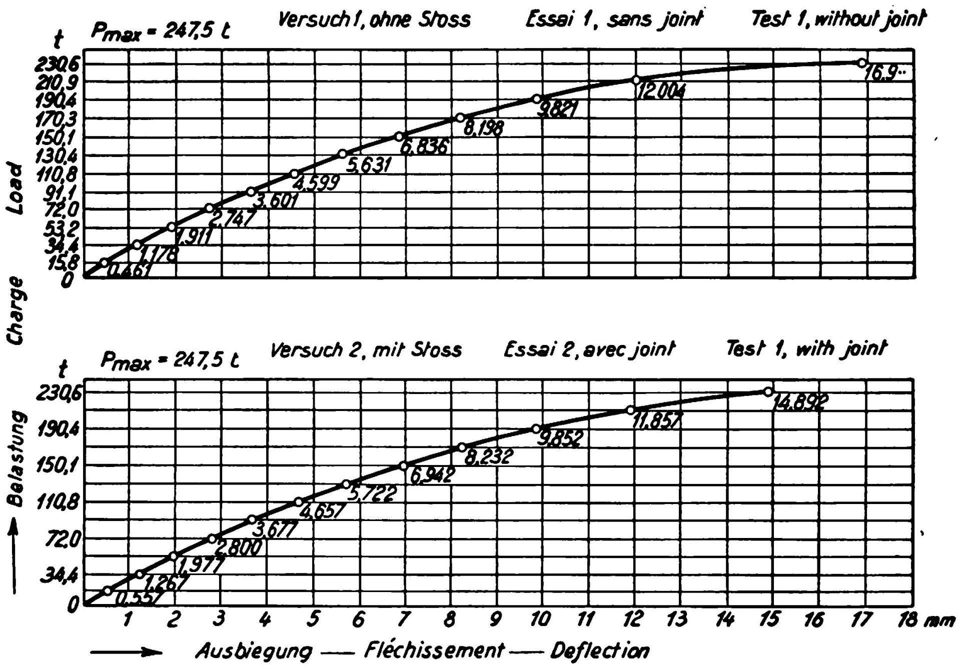

Fig. 6.

Deflection of the middle of two eccentrically compressed columns, relative to the ends of the columns

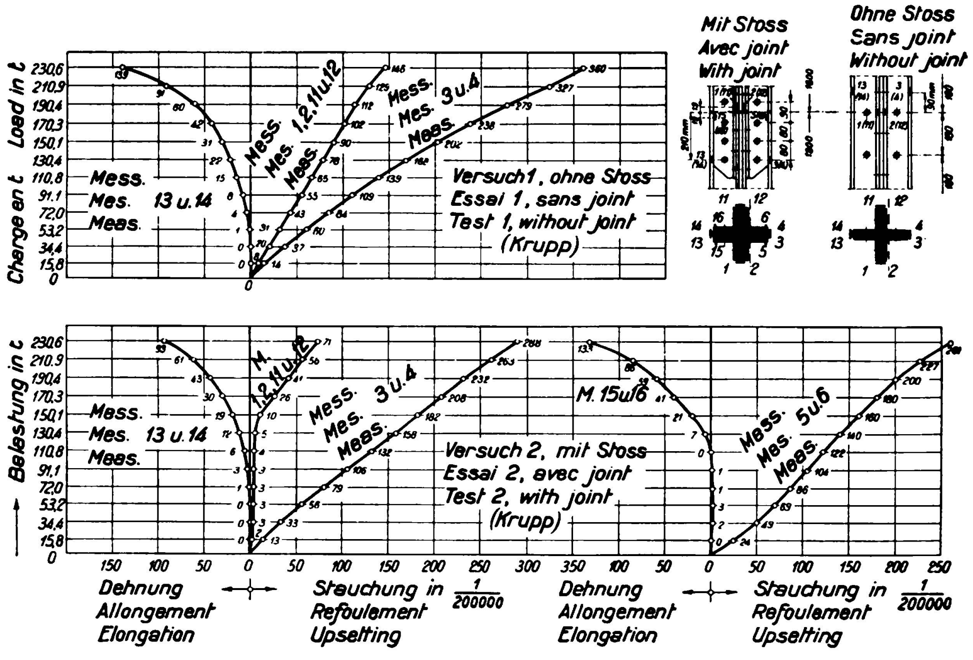

Fig. 7.

Measurements of upsetting of two eccentrically compressed columns. (Upsetting in mm 10—4 for a measured length of 20 mm, mean values of corresponding test measurements).

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[1] Knickversuche mit außermittig gedruckten Stahlstützen. Buckling tests with eccentrically loaded steel struts. Der Stahlbau 1936, part 3.

measurements on an eccentrically-loaded jointed and an unjointed strut. The elongations of the unjointed struts progress quite normally. At the measuring points 1, 2, 11 and 12, of the jointed struts, the results obtained correspond to central loading, and it appears that the places in the neighbourhood of contact are unaffected up to the considerable loads beyond which, however, they share normally in the transmission of the load. Accordingly, the covers (measurements 5 and 6) act very strongly at first, but less so again under heavy loading.

In addition to the main tests described above, with St 52 struts, some unjointed and others jointed at $\frac{h}{2}$, up to 45 per cent, the cross section of the joint being covered by straps, some supplementary tests were carried out in which the joint was not provided with any covering. The test pieces were lengths of Joist 16×16, the material St 37. The length of the pieces was 162 cm, and the total length between knife-edges $162 + 2 \times 18 = 198$ cm. The slenderness ratio was $\lambda = \frac{198}{3.81} = 52$. The knife-edge lay parallel to the web of the section. The struts 2 and 4 were sawn through the middle before the test, both halves being put together again without any further preparation of the joint surface or any sort of cover placed upon the joint. Struts 1 and 2 were loaded at an eccentricity of 1.81 cm equal to the semi thickness at the core of the cross section. Struts 3 and 4 were centrally loaded. The principal results were:

Table 2.

Buckling loads of 16 x 16 Joists.

Test.	Design.	Application of load	Greatest load P_{max} t (metric)	$\sigma = \frac{P_{max}}{A}$ kg/cm²
1	Unjointed	eccentric	90,4	1580
2	Sawn through	„	81,2	1420
3	Unjointed	central	147,5	2570
4	Sawn through	„	157,5	2750

It is evident from the above that even the perfectly bare contact joint can do no harm. With an eccentricity equal to the core radius, in which, at higher loads, considerable tension stresses occur, a bare contact joint at $\frac{h}{2}$ naturally results in a lowering of the maximum load. Nevertheless, even here the lowering of the resistance to buckling is only 10 per cent. Fig. 8 gives the load-deflection curve of the two eccentrically-loaded struts. That of Test 1 again agrees with the graphical methods, whilst that of Test 2 deviates considerably therefrom under higher loading.

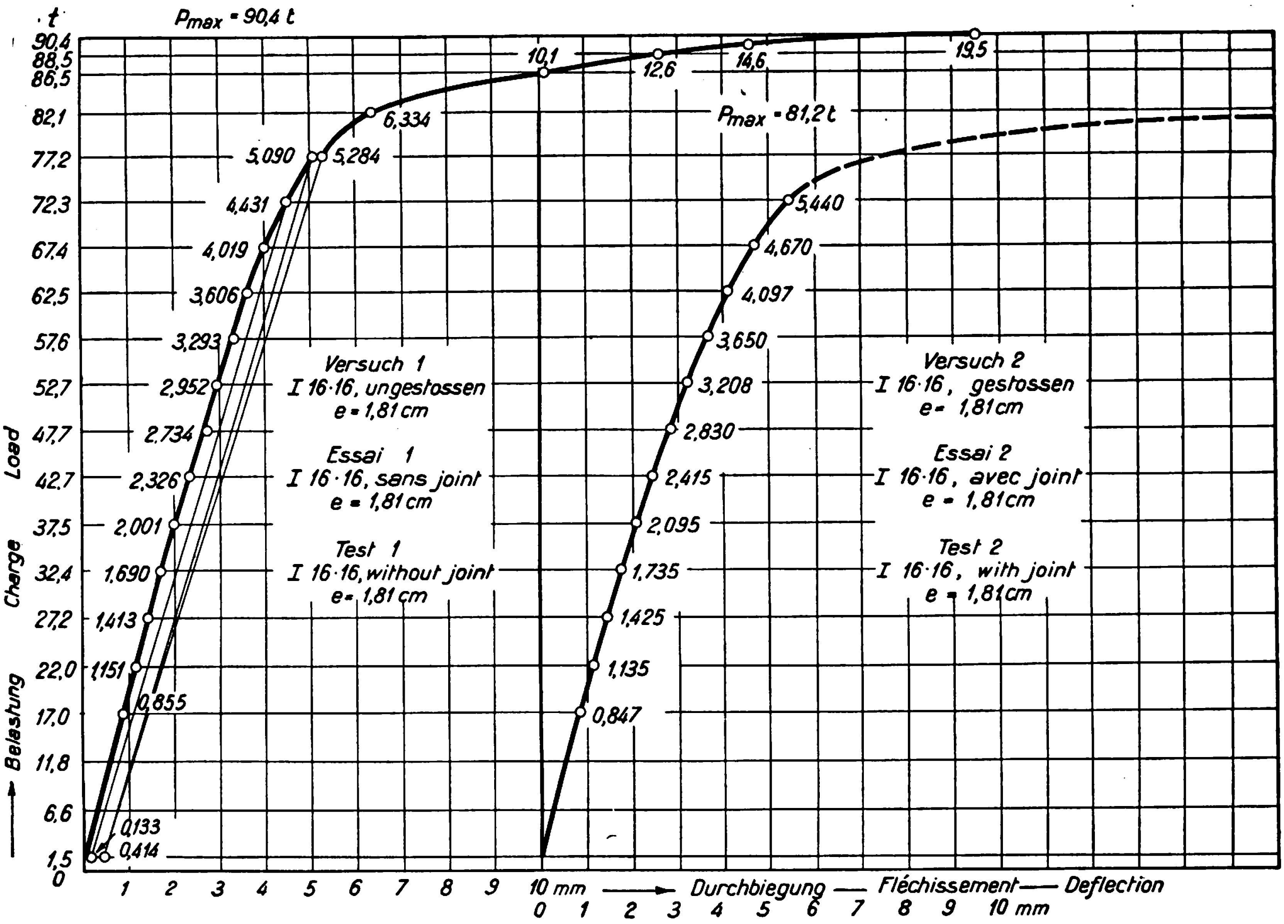

Fig. 8. Deflection of the middle of the column relative to the knife edge supports of two additonal tests.

Summary and conclusion.

The experiments show that even for loading at eccentricities, equal to the semi thickness at the core, no diminution of the maximum load occurs in the case of the covers chosen, by reason of the contact joint. In the supplementary tests a perfectly bare centrally-loaded contact joint shewed no diminution, and a joint, eccentrically-loaded at a distance equal to the core radius, gave a diminution of only 10 per cent.

From the test results, the consideration of the contact joint in the calculations for the joint is therefore thoroughly justifiable from the point of view of safety. The percentage proportions of the total load which should be allotted to the cover plates must depend on the general design in order that box-shaped constructions may be avoided. Special precautions must be taken if the cover plates are welded. The experiments have shewn that (chiefly under small loads) even with very well prepared butt surfaces there is no contact, or only an imperfect one. However, any cracking of the cover seams before contact is reached must be avoided.

If the above considerations are observed it seems quite within the range of possibility that — perhaps on the basis of further tests on the compression members of lattice girder bridges — contact joints will be adopted which will be only partially covered by plates. It is hoped that the above report may lead to a discussion on the matter.

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