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Allowance for Temperature Stresses in the Design and Execution of Welded Structures.

Berücksichtigung der Wärmespannungen bei der baulichen Durchbildung und Herstellung geschweißter Konstruktionen.

Les contraintes thermiques dans la disposition constructive et l'exécution des constructions soudées.

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Professor *Bierett* draws a distinction between those shrinkage stresses which are produced by internal and those produced by external agencies — a distinction which is important not only as regards the distribution of stress in structural members, but also from the point of view of combatting the effects of shrinkage.

The internal stress can be dealt with only by making use of the properties of the weld metal and by control over the welding process, or by mechanical action such as clamping the work and hammering the seams. Annealing, which would be the most effective remedy, cannot be applied in bridge and structural work.

Difficulties from external stress can be met by due attention to the design of the structure, and also at a later stage in the construction. Recently the attention of engineers has mainly been concentrated on the jointing of plate web girders, and Professor *Bierett* shows in his paper how shrinkage may be compensated by the insertion of a previously bent strip of plate in the web.

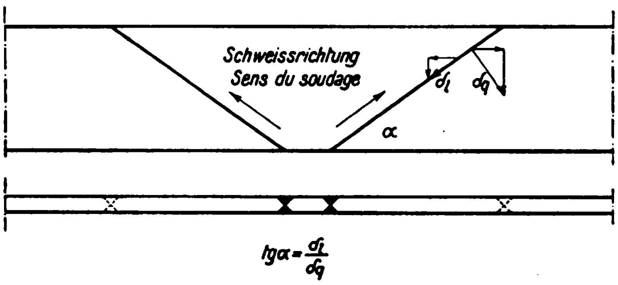

Fig. 1.
Wedge joint for plates.
(Schweissrichtung = welding direction).

In two large structures the flanges were connected by wedge shaped cover straps after the web had been welded (Fig. 1). The angle of bevelling was decided from the relation between longitudinal and transverse shrinkage as found by experiment. As welding was carried out from the narrow to the long side of the wedge, the longitudinal components of the shrinkage were relieved and the transverse components were increased, with the result that the cover plate was drawn uniformly into the joint. This effect was confirmed by preliminary experiments on thin plates.

In the formation of thick flange plates for bridges it was found, however, that the expected action was soon defeated by the internal stresses which arose through the welding of the tulipshaped seams, and when these seams had been filled to

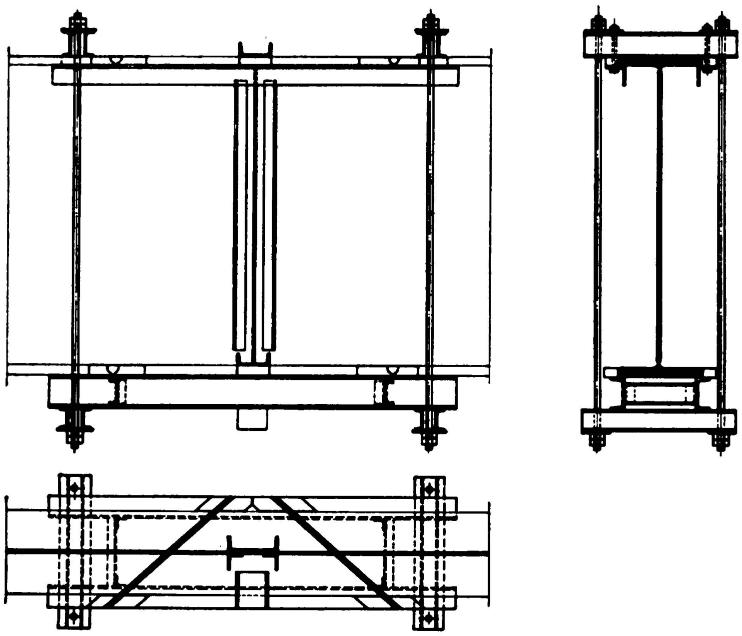

Fig. 2.
Testing arrangement for wedge joint.
Proposal.

two-thirds of their total dephth a powerful angular contraction occurred, which had to be counteracted by continually tightening the clamping on the parts to be joined. Fig. 2 shows the design of a clamping arrangement, and Fig. 3 in-

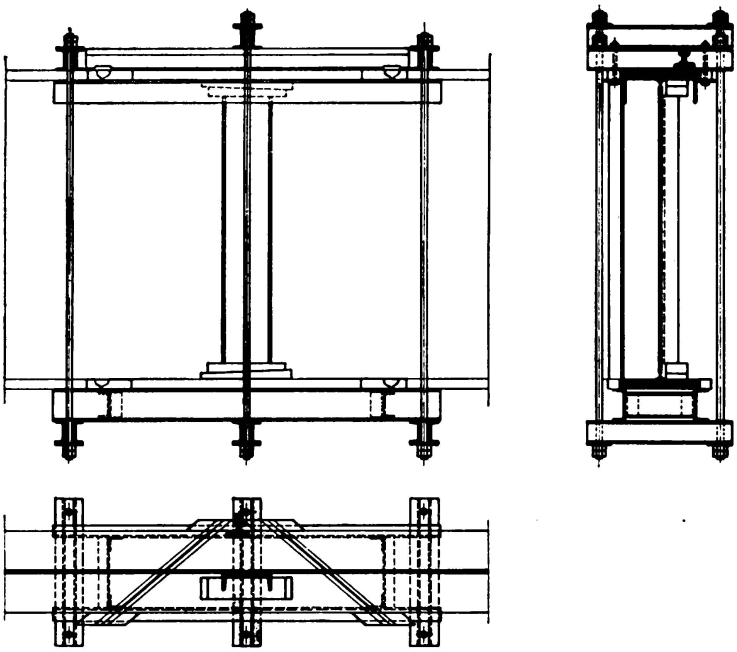

Fig. 3.
Testing arrangement for wedge joint.
Final arrangement.

dicates how strongly this has to be constructed in order to overcome the angular distortion in welding. It was found possible to make girders of St. 37 completely free from shrinkage cracks, but in St. 52 a tendency to these was observable and they were avoided by hammering the second half of the seam, a procedure whereby the direction of the shrinkage can be controlled. It is not yet definitely established, however, whether hammering may exert an unfavourable effect on the mechanical properties of the material.

Shrinkage cracks may also be avoided by adopting a proper sequence of operations in welding, and by pre-heating the parts. In one instance a plate girder of St. 52 was being welded in very hot summer weather when the operation had to be interrupted on account of a hailstorm, and the sudden cooling of the thin web plate, connected as it was to the much thicker flanges, resulted in this being torn away over the whole length of an incompletely welded joint. The latter was re-welded after preliminary heating, and by this means a perfect new weld was obtained.

It may be inferred from a number of publications that the chief part in avoiding shrinkage stresses is played by the designer, but, as these examples show, he is powerless against internal stresses. The external stresses may be reduced by the adoption, where possible, of sufficiently resilient connections. There should be no hesitation in preferring rivetted connections in situations where excessive shrinkage effects are to be apprehended and where rivets are not entirely ruled out by aesthetic considerations. It is a matter in which the demands of the architect may frequently be in conflict with the clear obligation of the engineer not only to secure the most economical arrangement of structural parts, but to combine this with safety and efficiency. Where rivetted connections are so used they may be regarded as playing much the same part as the discontinuities which are introduced into reinforced concrete structures on account of shrinkage effects.

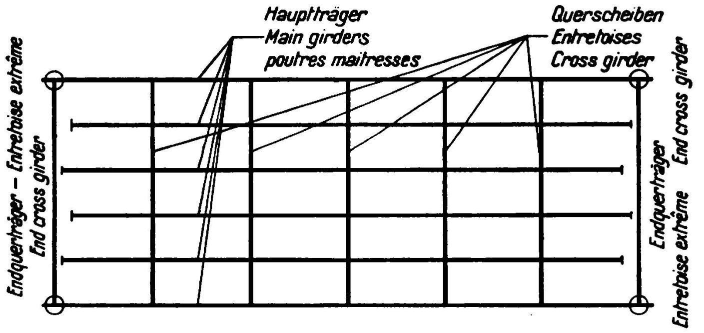

Fig. 4.

Shrinkage of main girders of a grated bridge.

Fig. 4 is a diagram showing a bridge floor in which the main and cross girders were welded on the site. The shrinkages accumulated to different totals on either side of the end cross girders, and this being the case it was found expedient to make the connection between the main girders and the end cross girders by means of rivetting. In this way the cross girders in question are not restricted as to position, and a more accurate alignment of the track is obtained.

Special difficulties attend the construction of members wherein the shrinkage effects are two or three dimensional. Fig. 5 shows the framed main girder of a bridge, and to a larger scale the corner of the frame. The statical stresses at different sections are indicated in the diagram, and the heaviness of the loads which have to be transferred by the fillet welds from the flanges on to the web is made apparent. The excessive thickness which had to be given to these fillet welds was especially conducive to cracking, especially since St. 52 was being used, and such cracking can as a rule only be avoided by hammering.

In this instance, as is true of web plates in general, the shrinkage stresses may lead to bulging, or what is even more dangerous, may be superimposed on other stresses so as to cause failure of the plates. It is to be recommended,

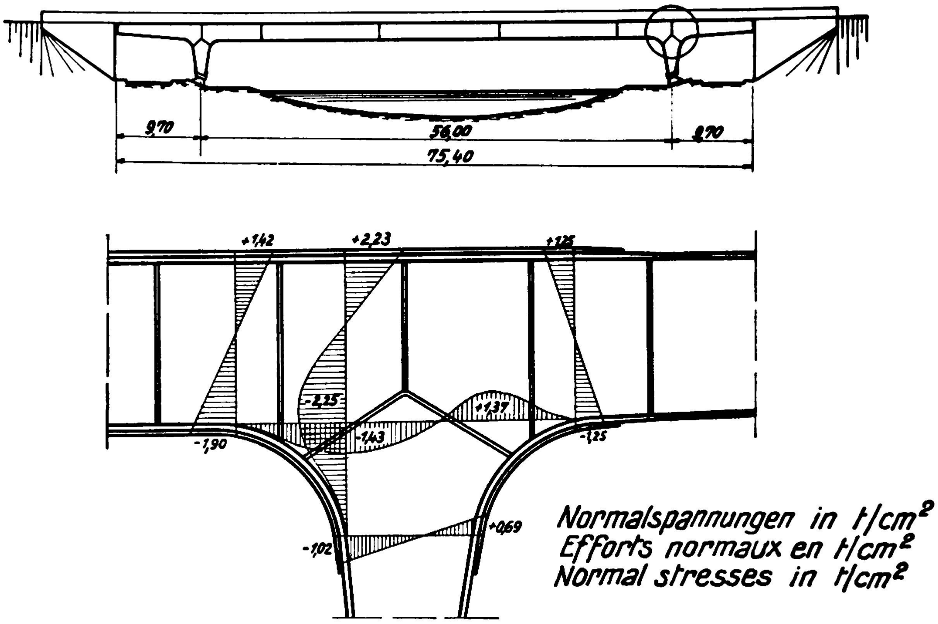

Fig. 5.

Static stresses in frame connection.

therefore, that in the region where the shrinkage stresses occur the stiffeners should be designed to carry the same longitudinal and transverse loads as would occur in a framed girder assumed to take the place of the plate web girder, and should not merely be dimensioned for the degree of stiffness required by the buckling theory.

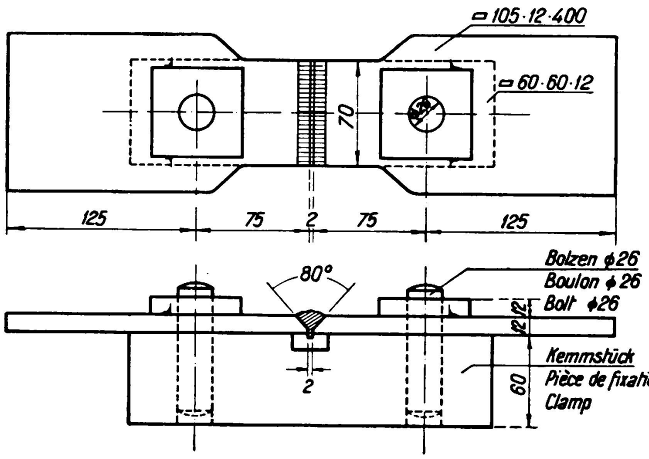

Fig. 6.

Arrangement for measuring shrinkage stresses.

Observations and measurements carried out in reference to distortion agree in indicating that the shrinkage stresses due both to external and to internal effects may approach the elastic limit. The experimental apparatus shown in Fig. 6 was used for the purpose of measuring shrinkage stresses due to external loading. The test pieces, to be connected by a V seam, were held in place during the welding process by pins fixed into a thick piece of steel, so as to prevent any movement. The free end of the specimen was held in the testing machine and was subjected to tension until it became possible to withdraw the pins by light hammering, thus indicating that the whole of the shrinkage stresses had been transferred from the pins to the machine. Fig. 7 shows the shape of the stress-strain curves obtained for St. 37 and St. 52, the shrinkage stresses being in the neighbourhood of the limit of elasticity. This also occurs when the specimens are repeatedly loaded and unloaded within the range of the stress that will arise in practice, namely 1.4 to 2.1 tons per sq. mm, before making the experiment. If the specimens are stretched by only a small amount in excess of the shrinkage stress value first measured, the shrinkage stress obtained on a second attempt amounts to only 50 to 75 % of the first value. The values which correspond to this higher degree of tenacity correspond to the upper limit for St. 37 and to the lower limit for St. 52. In this case it could even be observed that the steel

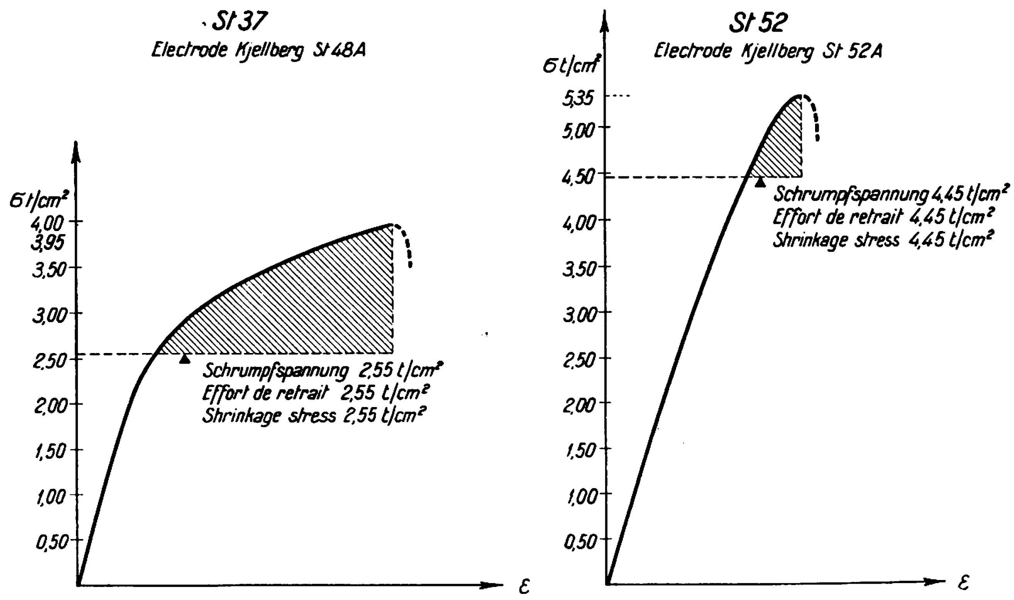

Fig. 7.

Elongation diagrams for shrinkage stresses.

requires a certain amount of time to take up its shrunken condition. The reserve of strength which remains after taking up the shrinkage stresses is usually adequate in the case of St. 37 but is very small for St. 52, and this accounts for the greater susceptibility of the latter to cracking.

Under external static loading, shrinkage stresses after welding are no more dangerous than other dead load stresses, but stresses which cause unstable equilibrium form an exception to this statement. Additional shrinkages due to neighbouring welds, or new internal stresses due to temperature effects, may lead to cracking, and this occurs more readily in St. 52 than in St. 37 on account of the smaller margin of stress and elongation possessed by the former.

It would be desirable to carry out fatigue tests using the experimental apparatus shown. Pre-stressing, in the sense the term is applied to ordinary fatigue tests, is present only if the loading acts in such a way as to counteract the shrinkage stresses. In such a case the fatigue strength must approximate to the elastic limit, and the available amplitude for butt welds, according to the fatigue tests carried out by the relevant German Commission,[1] amounts to 10 kg/mm² for St. 37 and 13.1 kg/mm^2 for St. 52. According to German regulations when $\gamma = 1$ this requires a value of α of approximately 0.65 for St. 37 and approximately 0.58 for St. 52. Where the shrinkage stresses are of the same sign, and usually also when they are of opposite sign, there can be only one distribution of stress in the member for which the fatigue strengths may be at a maximum but require to be determined in each case.

Thermal stresses still frequently offer difficulties to the engineer both in the drawing office and in the workshop. It may be hoped, however, that research and experience may in the near future, lead to welding processes being so far perfected that shrinkage stresses will cease to offer any more difficulty than secondary stresses in rivetted work.

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[1] Dauerfestigkeitsversuche mit Schweißverbindungen (report of the commission on fatigue tests in the welding technical committee of the Verein Deutscher Ingenieure), p. 27 and 35—37.