General report

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V

General Report.

Generalreferat.

Rapport Général.

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Twelve papers have been submitted in reference to Question V. In what follows below it is proposed to analyse briefly each of these papers and to extract from them the propositions that can be regarded as conclusions of the Congress.

Paper by Dr. Grüning.

For the first time, in a bridge at Crefeld on the Rhine, contact joints have been utilised over the piers, with joint covers and rivets designed to carry only part of the total load. This arrangement was adopted after making two series of tests; in the first of these one half of the columns had no joints and the other half had joints with cover plates at mid-height representing 45 % of the cross section of the column and 52 % of its moment of inertia; in the second series one half of the columns were uncut while the other half were sawn across the middle and the two lengths simply butted against one another. The columns were subjected to compression extending over the whole cross section, either along the axis or eccentrically.

The tests showed that the columns formed with simple contact joints could carry the same loads as those without any joints, except for a reduction of 10 % in the case of those columns which had been sawn in two parts and were loaded eccentrically.

Dr. Grüning concludes that it is perfectly safe to use partially cover-plated contact joints in columns under compression provided that any peculiarities of the construction are taken into account when dimensioning the cover plates. Such a method of forming the joints may be extended to the compression members of bridges.

These indications are interesting, and the suggestion put forward by *Dr. Grüning* at the end of his paper on the subject of using contact joints in the compression members of steel structures deserves attention. It remains to be ascertained in practice, however, whether the economy realised in weight of metal and labour of fitting the cover plates will not be absorbed or outweighed by the cost of machining the contact surfaces.

Paper by M. Graf.

This paper deals with the testing of rivetted joints in steel St. 52 under alternating loads which change from tension to compression and back; or under repeated loads which do not change in sign. The tests showed:

1) that rivetted joints are capable of carrying a (30 %) greater amplitude of loading under alternating stress than under pulsating stress,
2) that the ratio between these two amplitudes falls off as the pressure around the edge of the holes is increased.

The author draws attention to those kinds of strain which produce a permanent effect. These are due to the play of the rivets in the holes and to the resistance of the members against slipping, the latter depending on the coefficient of friction of the surfaces in contact and on the adhesive force which results from rivetting. Usually fracture was found to begin at the edge of the rivet holes in the outer rows.

The striking feature of the interesting tests carried out by M. *Graf* is the relative magnitude of the forces applied to the joints. Even though we are concerned here with steel 52 which may have an elastic limit up to 35 or 40 kg/mm^2, the question arises whether, in practice, occasion is ever likely to arise for subjecting joints to such amplitudes of loading as were used in the tests (— 14 to + 14 kg/mm^2, or 0 to + 20 kg/mm^2). It would be valuable if experimental studies of joints under loads less intense than these could be carried out, especially with a view to ascertaining how great, under various conditions of test, are the alternating or pulsating loads at which the resistance to slipping of the portions joined is exactly reached (period of non-permanent strains).

Paper of M. Chwalla.

The author of this report makes a study of the buckling of the web plate in web plate girders. He deals with the case of a rectangular plate supported on all four edges without marginal restraint and subjected to pure bending on its own plane. He has found that where such a plate is provided with a horizontal stiffener placed at one quarter of its depth, as measured from the top, this stiffener will at first bear upon the plate; but as the rigidity of the stiffener increases the plate is reinforced after the moment is passed whereat the stiffener is no longer subject to buckling, and if the rigidity of the stiffener continues to increase, the plate may assume either of two different shapes under the same load: either a half wave in the direction of its length or a series of short ripples on either side of the stiffener. The author has found similar results in rectangular plates subject to compression and shear. He further shows that the approximate study of stiffened plates may be simplified by using the idea of a "substituted plate" which is assumed to exist in the compression portion represented by half the height of the plate under consideration.

The conclusion which the author draws from his experiments is that it is not possible to design horizontal stiffeners for thin plates simply from consideration of their own buckling tendency.

The report which has been briefly analysed above forms a theoretical contribution, of great interest, to the problem of stiffeners on plate web girders. One cannot but hope that the methods of calculation suggested by M. *Chwalla* may be applied in actual cases and may be followed by direct measurement of the actual deformations that occur in the webs and their stiffeners.

Paper by M. Ridet.

M. *Ridet* gives an account of experiments carried out for the purpose of measuring the secondary stresses in the verticals and diagonals of a single track N-truss steel railway bridge, with the decking below and the bracing above. He makes the following comparisons between the recorded results and the stresses calculated by the methods of *Pigeaud* and of *Fontviolant*:

Principal stresses.

Less by 28 % than the calculated stresses (owing to relief of the main girders by the longitudinal girders of the decking).

Secondary stresses.

1) In the diagonals the actual stresses are of the same order as those calculated.
2) In the verticals the actual stresses are at least twice those calculated.

This anomaly may be partially explained by unequal distribution of the stresses over the cross section of a vertical member due to the method of connecting the latter to the booms; also by the warping of the main girders, and by the influence of the gussets.

From his results the author deduces the following rules:

a) In triangulated trusses the use of vertical members should be avoided.
b) The connections of the truss should be designed in such a way as to afford a uniform distribution of the principal stresses.
c) The influence of the gussets should be studied.

The report by M. *Ridet* is a valuable contribution to the experimental study of triangulated structures. Before definitely adopting his preference fo the V-truss by comparison with N-truss it would appear desirable that new experiments should be carried out with a view to throwing more light on the question of why the secondary stresses, as measured in the verticals, agree less well with the results of calculation than those measured in the diagonals.

Paper by M. Krabbe.

This paper is a study of the rhomboidal type of truss, which is a double truss withhout verticals. Usually such trusses are designed by considering them to be made up of two V trusses. From his earlier investigations, in which the diagonals were free over their whole length, and account was taken of the rigidity of the booms, the author concludes that:

a) The rigidity of the booms is the preponderating factor.
b) The girder is stable even without verticals, and in any case the influence of these is purely local.
c) It is desirable to limit the depth of the booms in order to avoid excessive bending stresses.

In this new report on the subject the author puts forward a complete method of calculation in which account is taken not only of the rigidity of the booms but also of that of the diagonals and connections, and of the inequality of section of the booms. By considering the case of a girder provided with verticals, first assumed to be framed in and then as pin-jointed, he reaches that of the girder described at the beginning and he works out influence lines for the deformations in the boom members and diagonals and also for the moments existing at the ends of the members. Despite its initial complexity the problem is solved by reference to only three systems of equations of the *Clapeyron* type.

M. *Krabbe* has made an important theoretical contribution to the calculation of multiple truss girders without verticals. It is to be observed, however, that the author himself points out how good an approximation may be obtained by simpler methods of calculating such girders, and the question may be asked what are the cases wherein it is of practical importance to apply the complete method as given by him. This is a point on which engineers would like to obtain further information.

Paper by Prof. Campus.

The author begins by drawing attention to the importance of the intersections in the construction of vertically superimposed continuous steel frames. He recalls his earlier tests made on various uni-planar models of sheet metal, from which he deduced that the best form of joint consisted of two curved gussets, one below and one above the girder. He has proceeded to make tests on rivetted structures of this type and has been able to show that the presence of curved connections, fitted tangentially to the booms and vertical members, has the effect of relieving the principal elements of the construction; also that the transmission of stresses through them is effected gradually, and that the maximum stress occurs in the neighbourhood of the joint between the gusset and whatever member receives the greatest bending moment. These results are confirmed by tests on welded structures. Finally the author explains the general characteristics of rigid intersections and their method of calculation. He insists on the necessity of using a higher factor of safety than in the remainder of the structure.

This very clear and well documented treatment by Prof. *Campus* leads to the conclusion that the type of intersection which he describes ought to be used wherever it is not incompatible with constructional or architectural considerations.

Paper by Prof. Baker

The author draws attention to two of the results achieved in the course of experimental work in England by the Steel Structures Research Committee:

1) The first of these conclusions refers to the distribution of the bending moments transmitted by a beam to a stancheon and to different parts of the connection. Generally it is assumed that the amount of moment so transferred is proportional to the "rigidity" of the respective elements of the stancheon, but it has been found in the case of industrial structures, with only one exception, that the lower parts of the column receive a larger proportion of the moments than this implies. The anomaly may be explained as follows: the connection consists of a bracket below and a cleat above the beam, and while the former is able readily to participate in the deformation produced, the latter bears against the stancheon and engenders an axial compression in the latter. This tends to lessen the bending moment in that element of the stancheon which is above and to increase the moment in the element below.

The same observations were made on a steel framework of several stories with beams unequally loaded.

2) The second of the facts established has reference to the torsional stresses in double T-sections. In the case of beams these are due to eccentricity of loading, and in the case of stancheons to imperfections in the form of connection. Practically speaking, in the usual forms of construction the resistance to torsion of the various elements is adequate, but this torsion should be taken into account when the girder is unsymmetrically loaded.

The points made in Prof. *Baker*'s contribution deserve all the more attention because the structures on which the observations were carried out appear to be of the usual industrial type. It would seem desirable to arrange similar tests on frameworks with other types of intersections in order to confirm whether the results are generally valid.

Paper by Mr. Andrews.

The tests already begun on steel frames were carried to destruction by the author, making measurements of the deflections. The tests were performed on a simply supported double T-beam, and also on frames built up from beams of that section with verticals dimensioned so as to attain their limit of resistance at the same time as the beams.

The author gives the diagrams and results obtained in these comparative tests. The cleats connecting the beams to the stancheons showed no deformation and the beams received much heavier stresses than the stancheons, a result which is at variance with the hypotheses used in the approximate calculation of this type of structure.

It would appear desirable to repeat these tests on small scale models, introducing different forms of joint at the intersections. This would, no doubt, enable more positive conclusions to be drawn than those derived from the tests of which Mr. *Andrews* has given an account.

Paper by M. Bleich.

The classical theory of bending in prism-shaped bars is based on the hypothesis of a linear distribution of stress over the whole of the cross section and on the absence of longitudinal forces in plain torsion. It has frequently been shown that this hypothesis is incorrect so far as bars built up of thin plates are concerned.

The authors propose to set up a general theory for such bars, whether of open or closed section. The hypotheses they adopt are the following:

a) The geometrical shape of the bar remains constant, the cross section not remaining plane but each element therein following *Navier*'s law.
b) Bending at right angles to the plane of the wall, and shear stresses due to bending, are neglected.

The differential equations of the problem are supplied by the equilibrium of the external and internal forces. The authors determine the strain energy in members of simple and multiple composition (the latter being the general case in actual application), and proceed to derive the differential equations for bending and torsion. These equations disclose the existence of an axis of torsion in the member, such torsion being zero when the resultant of the external forces passes through the centre of torsion of the section.

The authors then give indications as to how the bending and torsional stresses may be determined, and they further deal with the problem of unstable equilibrium:

a) buckling (member loaded concentrically), and
b) overturning (a member in which the median line has undergone deformation under the action of bending).

They show that the resistance to buckling of a member made up of thin sheets is less than the load calculated according to *Euler*, and does not attain that value unless the resistance to torsion is rather high. As regards overturning, the critical load is at a maximum when the normal force passes through the centre of torsion of the section.

There can be no question of discussion here the important contribution made by the authors to the study of the theory of bending and torsion in members formed of thin sheets, but the hope already expressed in regard to the theoretical studies of MM. *Chwalla* and *Krabbe* may here be repeated: namely that these results may form the object of practical applications and experimental confirmation.

Paper by M. Laffaille.

The problem involved in roofing over a building may be stated as follows: given the cubic volume and the external forces known to be acting, to construct a cover which will enclose the space and at the same time will carry to the supports the reactions derived from these external forces.

The author has solved this problem by forming the surface of thin sheeting. First of all he made semi-self-supporting roofs, with the sheeting carried on frames; then, after making tests on cardboard models, he abandoned the use of frames and stiffened the sheet itself transversely, so obtaining a roof that is entirely self-supporting. He gives several examples of such roofs which have been or might be carried out, and observes that in large spans it is necessary to take account of buckling.

He points out the novelty and pleasing appearance of these forms of roofing, and after explaining his theoretical and experimental investigations as regards the stiffeners he indicates the principle of the methods whereby stiffened sheet roofs may be designed.

The report of M. *Laffaille* would seem to offer some completely original solutions to the problem of roofing over buildings, and it may well be that this device, giving rise as it does to quite new forms, will be an enrichment of the art of architecture. It is too early, however, to pronounce on its economic importance, having regard both to first cost and to maintenance, and it is to be hoped that industrial applications will soon furnish an answer to this question.

Paper by M. Fava.

For the purpose of covering over the hall in the new station at Florence use was made of plate webbed girders of 30 m span of double T section with the axis bent at two points so that the ends make angles of 135^0 and 150^0 respectively with the central portion.

Tests were carried firstly on models made of transparent material, then on two steel girders constructed to a scale of $^1/_5$, finally on the girders themselves in position.

As a result of the preliminary tests the thickness of the flanges was made 20 to 30 mm at the ends, and the following observations were made on the finished structure:

1) In the straight portions of the girders the stress in the web obeys a law which is practically linear, but in the wings this stress falls off from the inside towards the outside face and from the middle towards the ends.
2) In the end portions the maximum stress differs by 250 % from that in the adjoining sections, but this stress agrees with the result of calculation when account is taken of the stresses in the wings.

These tests are of great interest and have been pursued very methodically. It may be hoped that a similar method may be applied in the study of constructional elements and may be repeated on a great many examples.

Paper by M. Kolm.

The author made tests on bridges in service in which measurements were made to ascertain how far a slab of reinforced concrete supported on steel girders contributes additional strength to the latter. It was found in the case of seven structures with slabs of very varying dimensions that the influence exerted by the slab is greater than can be attributed even to complete collaboration with the girders; the reason for this may lie in uncertainty as to the modulus of elasticity of the concrete, and also in the influence of the railings.

In an eighth structure tested the opposite result was obtained, the slab becoming detached. In the case of bridges of great width (in excess of 9 m) the slab exerts only a partial effect. In continuous girder bridges the slab is apt to crack in the zone of negative moment, and it is necessary, therefore, to design the reinforcement in this zone taking account of the collaboration between the slab and the steel girders.

Measurements of the kind discussed in this paper are extremely useful and it is to be hoped that they may be multiplied in all countries, so as to realise all possible economy in a type of bridge which is now universally accepted.