Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 6 (1960)

Artikel: General report

Autor: Dubas, Pierre

DOI: https://doi.org/10.5169/seals-6959

unserer Kenntnisse und auf die Schwierigkeiten hingewiesen, die mit einer korrekten Ausführung verbunden sind.

Unserer Meinung nach ist eine gewisse Vorsicht bei der Anwendung der HV-Schrauben noch am Platz. Es ist in der Tat nicht ausgeschlossen, daß sich im Laufe der Zeit die Klemmkräfte (Relaxation) und selbst die Reibungskoeffizienten mehr ändern werden, als es die Ergebnisse der bis jetzt durchgeführten relativ kurzfristigen Versuche vermuten lassen. Dieses Problem ist von höchster Bedeutung für auf Ermüden beanspruchte Verbindungen, bei denen die Tragfähigkeitsreserve zwischen Gleit- und Bruchlast sehr bescheiden ist.

General Report

a) Welding

Research on welding has become so extensive in recent years, that it is quite impossible to give even a brief outline in this report. We shall therefore merely discuss the problems dealt with in the six papers submitted and which are of particular interest to engineers concerned with bridges and structural engineering.

Effect of Longitudinal Stresses in Fillet Welds

The first paper by M. Faltus is mainly an experimental study of the effect of longitudinal stresses in fillet welds, subjected principally to shear forces. It will be recollected that this problem formed the subject of a paper read by MM. Wästlund and Östlund at the Lisbon Congress.

The tests described by M. Faltus were carried out on test pieces consisting of two wedges joined by welding along their edges, inclined at 1 : 10. With this arrangement, the longitudinal stresses should be practically constant and the shear forces uniformly distributed. This test would thus make it possible, in principle, to eliminate the effects of plastic equalisation of the shear strains and hence reveal more clearly the effect of the longitudinal stresses in the weld. The scatter over the values of the comparative stress, calculated in accordance with the criterion of constant energy of distorsion, is undoubtedly quite considerable, but this is readily explicable if it is borne in mind that this theory relates to yielding and not to rupture. The experimental results, however, clearly show that the longitudinal stresses reduce the shear strength of the fillet welds to an appreciable extent.

Brittle Fracture

There is certainly no need to recall, in this report, the fractures which have occurred in certain welded structures, particularly bridges, ships and penstocks. Although the number of serious accidents is comparatively small in relation to the number of structures that have been built, these fractures are none-theless both symptomatic and disturbing. They have greatly shaken confidence in welded structures and have thereby undubitably retarded their extension. The methodical study of these accidents has, nevertheless, led to technical progress by focusing attention once again on the problem of the brittleness of steels, which is of capital importance for welded construction, although it also arises in connection with riveted structures. This question is dealt with in the second paper by M. Faltus and in that by M. Rühl.

In his report M. Rühl gives a general outline of the present state of knowledge in regard to brittleness. He emphasises the considerable gaps which still remain and can only be filled by *systematic* researches, both theoretical and experimental.

It is well known that the capacity towards deformation of a well defined steel, with a given microstructure, depends mainly on the state of stress, the temperature, and the rate of application of the stresses. If one of these factors is varied, the work expended in fracture does not usually follow a law of uniform variation; the tests, which related mainly to the effect of temperature, show that this energy of rupture — expressed by the notch impact values — undergoes a sudden fall, within a fairly narrow range of temperature, and reaches a very low value. This temperature — known as the transition temperature — separates the region of fractures with considerable elongation from that of brittle fractures. When the rate increases or the state of stress becomes more severe, the transition temperature rises. These properties of the constructional material steel have long been known. It will suffice if we mention the work of *Considère*, *Le Chatelier*, *Frémont*, *Isod*, *Charpy*, etc., some of which dates back to the nineteenth century.

Opinions differ, however, as to the underlying causes of these phenomena and the laws which govern them, more particularly as far as the relationship between the critical temperature and the state of stress is concerned. As M. Rühl points out, the disadvantage is not very great in practice, since it is almost impossible to determine the total state of stress, which is largely dependent on internal tensions inaccessible to calculation.

According to M. Rühl, an analysis of various accidents caused by brittle fracture demonstrates that the overall behaviour of the structures exhibits characteristics similar to those of notch impact tests, where again the result obtained is either a brittle fracture with practically no elongation, which occurs without warning, or a fracture with considerable elongation. Furthermore, there is a fairly narrowly limited transition temperature between the two types of fracture, as in the impact test on a notched bar.

There are still very few experimental results in this field and special interest therefore attaches to the paper by M. Faltus which deals with the effect of gussets, welded to flanges under tension, on the brittleness of deflected beams. For the steels employed in the tests described, the critical temperature is almost always higher than $-40°C$, whatever may be the shape adopted for the gussets. However, if internal compressive stresses are introduced in the zone of the joint, by means of suitable hot spots, brittle fracture only takes place in the case of gussets without a graduated joint. These experiments thus clearly reveal the influence of the state of stress, due both to internal stresses and to the effect of structural discontinuities.

It would have been instructive to establish, for every type of gusset and every kind of steel employed, the zone of transition between granular fracture and fibrous fracture, and to compare the results with the critical temperatures given by the notched bar test pieces.

This aspect of the problem is of particular interest to the engineer responsible for determining the grade of steel to be utilised in a welded structure. It is, of course, out of the question to have recourse solely to special steels of thoroughly suitable composition and manufacture which have been subjected to appropriate treatments; the simplest considerations of economy and competition preclude it. A choice must consequently be made, from among the various grades listed in the standard specifications or suggested by the steelworks, the grade which offers adequate guarantees, having regard to the given conditions.

At the present time, the steels available are usually classified, as far as their tendency to brittleness is concerned, by means of the results of impact tests on notched specimens. Two principal parameters exert an influence: the temperature and the type of notch, which are determinative as regards the severity of the triaxial stressing. The tests may therefore be carried out either with variable critical temperatures and a given notch, or with notches of increasing severity at constant temperature; eventually the two systems will be combined. For further details reference should be made, for example, to the Recommendations drawn up by Commission IX of the International Institute of Welding (Bonhomme report), the new German standard DIN 17100 or the B.S. 2762. We should merely point out that no explicit mention of the conception of critical temperature appears in these specifications; indications are confined to fixing a relatively lower value of the notch impact properties, which is required at a given temperature.

In order to select a suitable grade of steel, it is obviously essential to know with certainty the relationship between the tendency to brittleness of the welded structure — or of the welded structural member — and that of the material characterised by tests on specimens. In order to do this, it would be possible, for example, to determine the type of notched test piece which gives the same transition temperature as the structural member under consideration. This is the procedure adopted by M. SCHNADT. On the other hand, M. RÜHL proposes to employ a single type of test piece and to classify the structural members according to the difference between their critical temperature and that of the test pieces. In both cases, it is assumed, by implication, that the conformity between the structural member and the notch test which is used for classification, does not depend on the quality of the steel, which is far from being proved.

The real difficulty, therefore, is not to classify the steels, but to classify the structural members. In our opinion, the experimental bases are still insufficient for the solution of the problem. Our knowledge regarding the transition temperatures of structures is, in fact, of a fragmentary nature, and we are still at the stage of estimating the effect of the principal factors, which depend on the general conception as well as on the technics of manufacture: the thickness, the arrangement and the constructional shapes, the cold deformations during manufacture (ageing), the electrodes employed, the welding sequence adopted (residual stresses) and the care with which the welding operations are carried out, the stress relief heat treatment, the value of the stresses in the structure when it is in use, particularly the permanent stresses, etc. The mere enumeration of these factors — and the list is far from being complete — shows that the problem is complicated and can hardly be reduced to some over-simplified form.

The tendency to brittleness is, moreover, not the only property of the steel to be considered; the characteristics which exert an influence on the tendency to cracking or to the formation of serious defects in the weld bead and its transition zone, are equally important, since it is essential to ensure that the welding operation does not give rise to any sharp nicks, which would constitute incipient sites of fracture. Cold cracking depends mainly on the hardening capacity of the metal and on the toughness of the transition zone under multi-axial stresses. As far as hot cracking of the weld deposit and the formation of pores or inclusions are concerned, the properties of the parent metal also play a part. In principle, at least, the examination of the resilience of the parent metal should consequently be complemented by tests carried out on the weld and the transition zone. For low-carbon and practically unalloyed steels, it is possible to dispense with such tests for standard structures, provided the problem is thoroughly understood and that the necessary precautions are taken, for example, in the choice of electrodes.

Quality and Tests

In their papers, Mr. Dixon, M. Ch. Dubas and Mr. Thompson deal with the problems arising in the execution of welded structures, and more particularly with the question of quality and the controls required in order to achieve and maintain it.

In order to fabricate a welded structure of high quality, the first essential is to employ thoroughly suitable material. At the present time, the choice of material will be mainly governed by considerations relating to brittleness, a problem we have just discussed, with a brief outline of the principal factors to be considered. At this point, we would merely add that the choice of electrodes plays an important part; under certain conditions a high-quality electrode will make it possible to specify less severe requirements for the steel. We have particularly in mind the use of basic electrodes which are little sensitive to brittleness and to impurities in the parent metal.

As a rule, a check on the properties of the steel should be made before delivery from the rolling mills. For ordinary steel structures, however, proper inspection tests are frequently waived and the steels reach the user without being tested by an independent body, and sometimes without even being tested by the steelworks. The question arises as to whether, in view of the importance assumed by problems of brittleness in welded constructions, firms concerned with structural steelwork will not be obliged to set up a small testing laboratory where it will be possible to carry out chemical analyses and simple metallographic examinations, to determine the mechanical properties of steels, and in particular, their notch impact properties, and even to ensure, by means of ultrasonic tests, that they are free from laminations which unfortunately, are a frequent occurrence in grades of steel killed by aluminium. In some countries, a few firms have already adopted this solution, especially those engaged in boiler-making. Such a laboratory would, of course, also perform the destructive and non-destructive tests on welds to be mentioned later.

The drawing office should determine the general design of the structure and the constructional details, taking into consideration not only the advantages, but also the specific requirements of welding. Particular care must be taken to avoid whatever is likely to cause accumulations of stresses which reduce the fatigue strength and increase the risk of brittle fracture. Every effort must be made to ensure that the loads are transmitted as smoothly as possible and to facilitate plastic adaptations.

When plans are being made, the drawing office should always work in close cooperation with the departments responsible for the execution of the work. Manufacture must be made as easy as possible, since this reduces the probability of the occurrence of serious defects. It is often advisable and advantageous to draw up detailed welding instructions, taking into account the properties of the electrodes employed. In any case, the specified sequence of welding can only be a compromise, since the problem is to limit simultaneously two opposing phenomena: the residual stresses and the shrinkage distortions.

The planning of the work for the welding shop will also cover the question of thermal treatments (preheating, annealing) and devices designed to facilitate welding in positions where it is easily accomplished (manipulators and positioning devices). As Mr. Dixon points out, thorough planning of the work is always advisable; not only does it enable the quality of the work to be improved, but it often results in a saving of labour.

The quality of a welded structure naturally depends very largely on the high quality of the work in the welding shop. In the first place, the component parts must be accurately prepared. It is perhaps unnecessary to specify planing in every case, as Mr. THOMPSON suggests, but there can nevertheless be no doubt that smooth cuts and grooves do make the work of assembly and welding easier, while at the same time they reduce the risk of forming porous welds.

Inspection should, however, be mainly directed to the actual welding. For this purpose, close control of the welders, rather than the welds, is essential. Inspection must commence during the welding operations and must extend to the grinding and the backing run. At this point, we should draw attention to the fact that certain details, which appear unimportant at first sight, may, in actual fact, be critical as far as safety is concerned; thus the striking of the arc on the workpiece to be welded may possibly causes a notch which is detrimental when the steel is brittle. This danger is revealed by one of the tests carried out by M. FALTUS.

The examination of the finished welds is of particular importance. The inspection will be directed, in the first place, to the dimensions of the welds, which must be in accordance with the measurements indicated on the drawings, and to the external appearance of the weld which is highly revealing to the experienced eye. But an X-ray (or γ-ray) examination complemented, if necessary, by ultrasonic testing, provides the most important information. It makes it possible to train welders and improve their technique and the effects of this will also be observed in workpieces which have not been specially inspected.

On the other hand, destructive tests on specimens provide sooner information regarding the quality of the steel and the filler metal and their mutual adaptability. As far as loading tests (or pressure tests) are concerned, although these are very advisable, they only reveal certain defects of design and construction; their value, which is mainly of a subjective and psychological nature, is consequently far from being absolute.

In conclusion, we should mention the final check on the geometrical dimensions of the finished workpieces which will show the degree of accuracy with which the drawings have been respected. Mr. THOMPSON discusses in detail the precautions to be taken; dressing, pre-setting of the flanges, additional camber, cutting to length, etc.

Conclusions

In common with all other engineering structures, welded constructions must satisfy both safety and economic requirements.

In welded structures, safety constitutes a dual problem, because it is essential to guard against the risk of brittle fracture as well as against the occurrence of excessive stresses, capable of resulting in the structure being destroyed.

The question of brittleness can only be solved by the choice of a suitable steel, taking into account the structural arrangements adopted and the effect of the methods of fabrication. In this connection, it should be pointed out that, in many cases, it is practically useless to reduce the permissible stresses, even to a large extent; this would, in fact, result in greater thicknesses being provided, and thus increase the risk of brittle fracture.

The other aspect of safety, which is concerned with the stresses due to external loads, is more familiar to engineers, because it is common to all methods of construction. Whether we are dealing with plastic destruction or with fatigue, the strength depends mainly on the working stresses and very little, or not at all, on internal tensions. Even in the case of welded construction, it appears therefore possible, when the problem of brittleness has been solved, to reduce the requirements of the control of fabrication and to endeavour to compensate the effect of possible defects by limiting the permissible stresses. Nevertheless, it is obvious how uncertain such a procedure must be, as far as the effective safety of the structure is concerned. Is this method at least *economical?* We do not think so.

In relation to the savings in raw materials that are achieved, the additional costs entailed by stricter requirements are, in fact, relatively moderate, as regards both the cost of the actual testing (staff, laboratory, equipment, films, etc.) and any possible increase in labour, due to a reduction in output. In this connection, Mr. DIXON gives some valuable data and he recalls that this reduction in output, although considerable when new methods are first introduced, subsequently becomes quite moderate. In certain cases, the adoption of a stricter control may even reduce the number of hours spent in fabricating; indeed, according to Mr. DIXON, the drawing office tended formerly to take excessive precautions by specifying, for example, excessive sizes and lengths of welds. Lastly, we should point out that the improvement in the quality will be apparent throughout the whole of the output: a workshop subjected to a particular organization will produce a given average quality, practically irrespective of the workpieces on which the inspection is actually carried out.

In our opinion, quality pays in the long run; and the experience of a large number of workshops has proved that it is true. As Mr. DIXON and M. CH. DUBAS both emphasise, the difference which still existed, even a few years ago, between boiler-making and structural steelwork, is tending to disappear. High quality, necessitated by safety considerations in regard to penstocks and pressure vessels, has also been shown to offer advantages in the field of bridges and structural engineering.

b) High-Strength Bolts

It is hardly more than ten years since high strength, preload bolts (HS bolts) began to be widely employed in the United States on bridges and structural steelwork; in Europe, the use of such bolts is still more recent. The bolts in question thus provide a method of assembly that is comparatively new and appears on the programme of our Congresses for the first time. It should be pointed out, however, that machine manufacturers have, for many years past, been employing bolts exerting a particularly large clamping force to withstand tensile loadings and, in certain special cases, shear loads (pre-tightening couplings).

In structural steelwork likewise, the favourable effect of friction on the behaviour of assemblies was well known and it was possible, as a rule, to envisage loads transmitted solely by friction, as a result of powerful transverse prestressing. Nevertheless, many years of research work were necessary in order to overcome the principal difficulties: to obtain, in an economical manner, a clamping force of the bolts that can be controlled and is permanent, with friction as high as possible.

The problem now appears to be largely solved; specifications for their use have been established and HS bolts have found wide and varied fields of applications. With the aid of the four papers submitted, we shall attempt to give a brief outline of the present state of our knowledge, by summarising the main results of the research work and the special features presented by the use of these bolts.

Mode of Operation of High Strength Bolts

It is well known that the shanks of properly hot-driven rivets are subjected, owing to the effect of thermal shrinkage, to tensile stresses exceeding the elastic limit, and that this enables certain loads to be transmitted by friction. The tightening of ordinary bolts, whether unfinished or fitted, produces the same effect. However, since the yield point of ordinary rivets and bolts is relatively low, these clamping forces are only moderate; their effective value which, in any case, it is difficult to control in practice, varies within wide limits according to the conditions of fitting; in course of time, connectors subjected to dynamic forces may even, in certain cases, become completely loosened.

In calculating conventional assemblies, it would therefore be inadvisable to take friction into account; only the shear load acting on the shanks and the lateral pressure, which are determinative factors as soon as friction is overcome, are taken into consideration.

In assemblies fastened with HS bolts, the roles are reversed; the clamping and frictional forces are of the greatest importance, in the calculation, and the load at which slip would occur is the characteristic magnitude which is determinative for the estimation of safety. The resistance to shear and the lateral pressure, on the other hand, only come into play when rupture takes place. In order to satisfy the assumptions upon which the calculation is based, a controlled and durable preload must therefore be employed and a given coefficient of friction must be attained. We shall see in the sequel the means that are employed to fulfill these essential conditions.

HS bolts may also be used to transmit tensile loads acting parallel to their axis. They are then stressed as a rule like ordinary bolts; their great strength and high degree of preload do, however, give them certain advantages.

Shape and Characteristics of High-Strength Bolts

Since the coefficients of friction obtained in assemblies by means of friction grip joints are appreciably less than 1, HS bolts must be preloaded to a considerable extent in order to be capable of transmitting forces equal to, or greater than, those taken up by rivets or ordinary bolts. As its name implies, the HS bolt will thus have very high mechanical properties. The designations and specifications vary according to the countries concerned, with ultimate tensile stresses ranging from 70 kg/mm^2 (45 tsi) (B.S. 1083, R 45/55) to 120 kg/mm^2 (76 tsi) (DIN 267, 12 K) and yield stresses ranging from 53 (34 tsi) to 108 kg/mm^2 (69 tsi). It is, of course, tempting to employ bolts with very high strength, but it must be borne in mind that their elongation at break is small, and this may give rise to certain difficulties during the fitting of the bolts.

Externally, an HS bolt is scarcely distinguishable from an ordinary bolt. But the radius of fillet under bolt head has been increased, because it was found by experience that this was a weak spot. Furthermore, the bolt is always used with two washers, one under the head and the other under the nut. These washers are made of hard steel and they distribute the clamping forces over the parts being assembled, and thereby obviate excessive plastic deformations, which would, in course of time, bring about a considerable reduction in the preloading. No special precautions to prevent slackening of the nuts are necessary. As regards the holes, they may, without risk, be given a diameter greater than that of the shank, because the bolt is not normally subjected to shearing stress neither to lateral pressure; the clearance usually amounts to 1—1.5 mm ($^1/_{16}$"), and this facilitates drilling and makes it possible to eliminate reaming during erection.

Research Work on the Clamping and Frictional Forces

The development of the new method of assembly by friction grip necessitated a large number of tests and thorough investigation. This research work, which was commenced in the United States, where it was continued for many years, was also undertaken in Europe, particularly in Germany. The papers by Mr. BERRIDGE, by MM. WRIGHT and LEWIS and by M. STEINHARDT give an historical account of the work and we shall confine ourselves to summarising the principal experimental results. We shall first of all describe the tests in connection with the clamping and frictional forces.

The first problem that arises is to measure the preloading force that is applied. In order to do this, a relationship was derived connecting the torque M_t exerted on the nut, which is comparatively easy to determine, with the clamping force P generated in the shank. This relationship may be written: $M_t = k \times d \times P$, where d denotes the nominal diameter of the bolt and k is a dimensionless coefficient. It is apparent from the paper by Mr. BERRIDGE that this coefficient depends both on the thread and on the conditions of internal friction, that is to say, on the materials, on the state of the surface, the extent of the lubrication and even on the shape of the threads and the method of manufacture.

For suitably lubricated bolts of a given type, the scatter of the experimental values of k is, however, acceptable and of the order of 5 to 10%. Since the measurement of the applied torque is itself affected by an error, which may amount to 10%, the effective pre-loading will not be known very accurately, whence some uncertainty arises. There are many control devices available which enable the spanners employed to be calibrated by measuring the tensions in a standard bolt, whereby certain of the causes of error are eliminated. It would be an advantage, however, to have a simple apparatus available which would enable a direct and accurate measurement to be made of the effective clamping force of the bolts when they have been fitted.

The difficulty may, of course, be evaded by substituting a rough estimation of the elongation for the accurate measurement of the force; this is the principle of the method known as "part torque — part turn" mentioned by Mr. BERRIDGE and by MM. WRIGHT and LEWIS. The bolt is first tightened by hand, that is to say, to a value between ¼ and ¾ of the nominal force. The nut is then turned ½ to 1 turn, by means of a pneumatic impact wrench, and this introduces into the bolt shank tensions greater than the conventional elastic limit (0.2%). Owing to the plastic behaviour of the steel, these tensions depend very little on the initial preloading of the bolt tightened by hand, as is evident from the diagram shown in the paper by MM. WRIGHT and LEWIS. One or two additional turns of the nut must be given to cause the bolt to break; the safety margin against lack of precision during erection would thus seem to be adequate.

This method of tightening to "a turn of the nut" is mainly employed in Anglo-Saxon countries; it seems attractive, at first sight, since it enables powerful and relatively accurate clamping force to be obtained without expensive equipment. Preloading exceeding the elastic limit might, however, exert an untoward effect on the safety of the assembly. It is true that hot-driven rivets are stressed in a same manner, but they are milder than HS bolts and have a far greater plastic reserve. As far as relaxation effects are concerned, it is improbable that they should not manifest themselves dangerously in course of time. As MM. Wright and Lewis point out, cautiousness would seem to be imperative, particularly for assemblies subjected to external tensile loads.

More thorough investigations would therefore seem necessary in order to elucidate the problem of the preloading that is permissible in HS bolts, when allowance is made for the effect of relaxation or creep.

The force which an HS bolt is capable of transmitting depends not only on the value of the preloading, but also on the *coefficient of friction* of the faying surfaces. At the outset, this aspect of the problem had not been thoroughly investigated in the United States. The purpose of the tests was, in fact, strictly limited, and was confined to the determination of the conditions under which a rivet might be replaced by a corresponding HS bolt. Since the permissible shear stresses in rivets are low in the United States, a coefficient of 0.25 to 0.30 is adequate, provided that the preload amounts to about 50 kg/mm^2 (32 tsi). Friction of this order of magnitude is attained without difficulty, if the surfaces are clean and free from oil, paint, etc.

In Germany, on the other hand, special attention was devoted from the outset to the problem of friction and attempts were made to improve the coefficient of friction by suitable treatment. M. Steinhardt reports that sand-blasting or flame-cleaning have given the best results, namely, a minimum coefficient of 0.45 for mild steel 37 and 0.60 for steel 52. As regards mild steel, these values are corroborated by tests undertaken in other countries.

Research Relating to the Strength of the Assemblies

We shall, first of all, consider those assemblies where the loads act *perpendicularly to the axis of the bolts* and are transmitted by friction practically without any relative movements of the faying surfaces. The assembly is consequently fully rigid and the distribution of the loads over the various bolts will be far from uniform: the outer bolts will take up practically the entire load and the others will be inoperative. When, on the first bolt, the load at which slip would occur is exceeded, the second bolt will begin to act effectively and so on, until a point is reached where the applied load is equal to the sum of the frictions of the bolts. The whole of the assembly will then begin to move and will only stop when the bolts come into engagement with the sides of the holes: the critical load at which slip would occur, a characteristic magnitude of assembly by friction, will then have been reached. For a greater load, the mode of action of the HS bolts will begin to approximate to that of ordinary rivets and bolts, and rupture under *static* loading will, as a rule, be similar to that of conventional assemblies; in particular, the ultimate breaking strengths, which are usually much higher than the frictional capacity, will be practically independent of the initial preloading and of the state of the faying surfaces.

It is well known that the strength of structural members subjected to *fatigue* depends mainly on the inevitable concentration of stresses in the vicinity of discontinuities, holes and notches of various kinds. High strength assemblies transmit the loads by friction of the faying surfaces, and this considerably reduces the peak tensions. Their fatigue strength will thus be greater than that of drilled test pieces and riveted assemblies. In the majority of the tests, fractures occurred away from the net section.

As we have already mentioned, the longitudinal distribution of the stresses in a very rigid assembly — such as an assembly by friction grip joints — is characterised by a concentration at the ends of the assembly. As far as dynamic stresses are concerned, the question arises as to whether an equalisation of the loads on the bolts takes place by small relative sliding movements, as in the case of connectors subjected to a static stress. Moreover, the effect of these sliding movements on the value of the friction requires to be investigated, because tests recently carried out in Eastern Germany show a marked decrease in friction when the assembled parts have already been subjected to a series of sliding movements. It would also be advisable to extend the researches to those cases, most important for practical applications, where there is a moderate number of repetitive loadings, until the results link up with those of static tests.

As for assemblies subjected to forces acting *parallel* to *the axis of the bolts*, relatively little is yet known. As a result of preloading, the external tensile forces cause only a slight increase in the tension of the bolts so long as the assembly does not become separated. This results in a considerable reduction in the deformation of the connector and an appreciable increase in the fatigue strength. Research in this field is being actively pursued and interesting results will certainly be obtained very shortly.

Regulations

At this point, we would merely draw attention to the fact that the present American regulations, in common with the tests which enabled them to be established, relate to the simple one-for-one replacement of rivets by HS bolts, whereas the German standards regard the HS bolts as a fundamentally new method of assembly. This attitude seems to us to be preferable and it is also tending to compel recognition in the United States.

Consequently, the safety of the assembly will be determined in relation to the load which would cause slip to occur. For structural members subjected to static stresses, however, it might be possible to take into account the margin of strength up to the breaking point. It must nevertheless be borne in mind that the slippages of HS assemblies are considerable, on account of the clearance in the holes, and that the overall deformations of the structures, which may be brought about by these displacements, are inadmissible in certain cases.

Utilisation and Equipment

In order to satisfy the calculation hypotheses, it is essential to ensure that the assumed friction forces are actually attained; the clamping force and the coefficient of friction must therefore be carefully checked during erection.

In order to obtain a given preload, it is possible, as we have already mentioned, to measure the tightening torque or to turn the nut through a certain angle. The first of these procedures has been employed from the outset; it is still widely used, and it is indeed the only method permitted on the continent of Europe. In his paper, Mr. BERRIDGE describes in detail the various types of wrench — torque measuring or pneumatic — that are employed. We should also mention the new "Self-Reactor" bolts: the reaction of the tightening torque applied to the nut is transmitted to an extension of the threads. By providing a calibrated groove between the shank and its extension, a weakened section is formed which shears off as soon as a given torque is reached, depending upon the effective strength of the bolt; the control is thus operated by the bolt itself, which bears the name of "Torshear".

As M. STEINHARDT points out, the value of the coefficient of friction can also be measured on the site of erection.

The order in which the bolts are tightened must be determined with care. Otherwise, the bolts first subjected to preloading might no longer exert the desired clamping force at the end of the operation.

Applications of High-Strength Bolts

Mr. BERRIDGE's paper, which describes the many uses for HS bolts by the British Railways, clearly shows the wide variety of possible applications.

The paper by M. SATTLER is devoted to a special method of use, namely, the connection between the steel beams and the concrete slabs in mixed structures. The tests described by M. SATTLER show that, provided certain precautions are taken, it is possible to replace the shear connectors, which are always expensive, by HS bolts which clamp the slab tightly to the girders.

The loads are transmitted by friction, with a coefficient of the order of 0.45. The static breaking load is far greater than that which causes the onset of slippage. Further tests will be necessary to determine the behaviour of these connectors under fatigue.

Like all other assembly devices, HS bolts have their characteristic features, and these have a considerable influence upon the design of the connectors and even of the structures. A tendency is to be observed towards a development somewhat similar to that of welded construction, although more limited, and which will give HS assembly its own specific forms, differing from those of riveting. In particular, the very great rigidity of assemblies by friction grip and the resulting concentration of the stresses at the ends, makes it essential to provide connectors that are as short as possible; moreover, attempts will be made to improve the longitudinal distribution, for example, by specially designed shapes for the gussets, or by taking up the dead load by internal bolts alone.

In conclusion, some reference should also be made to the economic advantages to be derived from the use of HS bolts. At the present time, the bolts themselves cost more than rivets. However, the simplification of the preparation of the components of the assembly in the workshop and above all the fact that the fitting of the bolts during erection is effected more rapidly and with less noise, requiring less workmen and a small set of tools, enables this difference in cost to be compensated to a greater or lesser extent. Hence, in certain countries, such as the United States, where the rates of wages are high, site riveting has almost entirely disappeared. Furthermore, paradoxical though that may seem, the development of welding, by creating a shortage of skilled riveters, has promoted the extended use of HS bolts.

Conclusions

In the HS bolt, the constructor has available a new method of assembly, with most valuable features. We have briefly summarised the technical and economic advantages of these bolts, while at the same time we have emphasised the gaps in our knowledge and the difficulties inherent in the correct use of the bolts.

In our opinion, a certain degree of caution is still necessary in the use of HS bolts; indeed, it is by no means out of the question that the clamping forces (relaxation), and even the coefficients of friction, may vary to a greater extent, in course of time, than the results of the tests of relatively short duration, which have been obtained at present, would lead us to suppose. This problem is of the greatest importance for assemblies subjected to fatigue stresses, in which the margin of strength between the frictional capacity and the ultimate breaking strength is very small.