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Fundamental Concepts, and the Development of Specifications for High-Tensile Bolted Joints

Notions de base et évolution des normes relatives aux joints boulonnés précontraints

Grundlegende Begriffe und Entwicklung von Normen für vorgespannt geschraubte Stöße

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1. Introduction

Following the establishment of the fundamental concepts of the behaviour of friction joints in original research, the development and application of such fasteners has been much influenced by specifications governing design and practice. The specifications of the American Society for Testing Materials (covering bolts, nuts, washers) and the 1951 specification of the Research Council on Riveted and Bolted Structural Joints permitted an immediate widespread application of the new fasteners in North America. Without the impetus provided by these specifications, it is likely that the application of the new method would have been delayed some years.

The part played by specifications in the development of engineering practice varies considerably from country to country. In the U.S.A. the tendency is for the specification to pioneer new developments while in the U.K. the standards which relate to design represent a consensus of established engineering opinion and therefore, by definition, lag considerably behind the most advanced practice. In this paper an attempt is made to examine the present status of the high tensile bolted joint in the light of American specifications which have now been used for some years, and also in the light of recent British developments.

2. Historical Development

There is, of course, nothing particularly new about the use of bolts in steel construction. Unfinished or machine bolts are almost universally used for erecting steel structures. Unfinished bolts, fitted bolts and ribbed bolts have all been widely used for permanent site connections, although their use has been restricted by the relatively low stresses permitted on the first and the high cost of the others. The use of plain bolts for permanent site connections has been perhaps more widespread in Europe than in North America.

The mechanical engineer has long been concerned with the tension in bolts holding together pressure vessels, machines and engines. Torque wrenches have, for instance, been widely used in the mass production of automobiles. The first application of controlled tension in bolted structural connections was in the work of the British Steel Structures Research Committee in 1934, where bolts were used to simulate rivets in beam-stanchion connections [1]. The bolts used were made of low-carbon steel, however, and the tensions developed were low by modern standards. The recent development of the high-tensile bolt has stemmed from Professor W. M. WILSON's work on the fatigue of structural connections [2]. In studies of riveted joints it was found that fatigue resistance depended largely on the frictional resistance in the joint developed by the clamping force set up in the cooling rivet. In 1938, preliminary tests of bolted joints in fatigue showed that bolted joints were as strong as riveted joints "if the nuts were screwed up to give a high tension in the bolts" [2]. Further exploratory work was done by WILSON at the University of Illinois and by MANEY at Northwestern University [3]. In 1947, mainly due to the efforts of these two men, the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation was established to study the behaviour of structural connections. Laboratory and field studies undertaken on behalf of the Council rapidly provided sufficient information [4, 5, 6] for a specification to be written by the Council in 1951 [7].

The initial test studies completed between 1947 and 1950, though followed by many other significant investigations, laid the foundation for present practice. It was shown quite clearly that joints with properly tightened bolts of suitable material [8, 9] would function as ideal friction joints with no direct shear on the fasteners. In fatigue loading of these joints no alternating stress is experienced by the bolts. Neither in field nor laboratory tests did any properly installed bolt ever fail, even after millions of cyclic fatigue loadings. Because of the absence of high stress concentrations around the holes in the plates, the fatigue strength of the plates was significantly increased and fatigue failures in fact usually occurred *away* from the net section. It was also found that once the friction capacity was exceeded in static load tests, the bolts slid into bearing and ultimate breaking strengths significantly higher than those with ordinary riveted joints were obtained.

The original Research Council specification [7], intended for the design of fatigue connections utilising high tensile bolts, has stood with little revision since its first writing. In essence, this specification provided for design on the basis of a one-for-one replacement of rivets by high tensile bolts of suitable material, etc.

Progress since 1951 would not have been as spectacular save for the discovery that a high tensile bolt could be installed in the field for less cost than a conventional hot-driven rivet. This situation, coupled with the increasing shortage of skilled riveters, led to an immediate widespread use of bolted joints in North America and by 1954 more bolts than rivets were being used in field erection. By 1958 field riveting had almost disappeared, with all field connections either by high strength bolts or electric arc welding.

In Britain there are as yet no formal codes of practice or specifications, though in June 1959 a symposium will be held under the ægis of the Institution of Structural Engineers, and there has been sitting since early 1958 a Committee of the British Standards Institution. By the time this paper is presented at the Congress the outcome of these activities will be known. In the meantime, however, high strength bolts are being used in ever increasing numbers and they have already made a significant impact on the structural industry in Britain. They have virtually ousted site riveting and are making some inroads into site welding — a practice which is more widespread in Britain than in the U.S.A. They are also replacing black bolted connections to some degree.

At this juncture it may be pertinent to comment on the different nomenclature which has grown up in the U.K. where these connections are known as high strength friction grip bolted joints rather than high strength bolted joints. The reason for this is probably the desire to differentiate between the new bolted connections using high tensile steels and the high tensile fitted bolt connections which have been used previously in bridge work.

3. Developement of the Technique in Practique

The American Research Council specification issued in 1951 indicated required bolt tensions and suggested the torques that would be required to produce those bolt tensions. At that time only hand wrenches were used for tightening the bolts and a proper connection was dependent primarily on the workman's experience with the wrench. The specification accordingly provided for five to ten per cent of all bolts being checked by a hand-operated torque wrench. As soon as the bolts came into general use, however, hand wrenching was found to be impracticable and uneconomical. Pneumatic wrenches were readily available but early efforts in obtaining controlled bolt tensions with these tools were unsuccessful. Experience led eventually to successful techniques being developed. Using controlled air pressures and site calibrators which indicate bolt tensions directly (thus eliminating the inevitable errors associated with torque-tension relationships), it was found that consistent results could be obtained either by timing the application of the wrench or by adjusting the air pressure to cause stalling of the wrench when a suitable bolt tension had been reached. An alternative procedure was later made available by the development of special wrenches with automatic torsion control that switch off the wrench once the desired torque was attained. Such methods, in which some effort is made to calibrate the wrench, are still in common use.

Although further research has been pursued [10, 11, 12], progress since 1951 is related mainly to conditions of practice. With regard to tightening techniques, the trend in the U.S.A. has been away from controlled torque towards a controlled turn-of-the-nut method which limits the strain in the bolt. Laboratory studies of these methods have been more extensive in Britain, however, and will be enlarged upon later.

When high strength bolts were first used in Britain, American practice was closely followed and manual methods of controlled torque tightening were adopted. Bolts to British Specifications were generally used. With the increasing use of 1″ and larger diameter bolts and in the absence of suitable British impact tools (which require no reaction point) the problem of reacting the torque on the structure became important and led to the development of two new types of bolt carrying their own reaction point. With one bolt the torque is reacted on to the washer which has a suitable serrated edge. This device relies upon the fact that the frictional resistance of the washer to turning is greater than the torque due to the frictional drag between the nut and bolt threads. In the other bolt the reaction point is provided on the bolt itself in the form of an extension of the threads. A parallel development went a step further in that the extension piece is grooved so that it shears off at a predetermined torque, thus acting as a torque controlling device. This bolt has the further advantage that the torque applied is related to the actual strength of each bolt rather than the nominal strength.

The most significant development in Britain stemmed from the bolt and nut failures experienced in early application of the torque controlled or, as it is often called, the torque coefficient method of tightening. Laboratory tests indicated that greater safety against failure by over-tightening would be achieved by limiting the rotation of the nut rather than controlling the torque [13]. Satisfactory American experience with impact tools operating on a controlled time basis provided reassurance that bolts could be used safely in the yielded condition. This led to the "part-torque part-turn" method of tightening. With this method the joint is first bedded down by tightening all the bolts to a torque lying somewhere between one-quarter and three-quarters of the nominal torque which would be applied to tighten the bolts using the torque coefficient method. To complete the tightening the nut is driven a further half-turn or three-quarters of a turn in the case of long bolts. The essential feature of the technique is that regardless of the bedding down torque or the condition of the threads, there is very little scatter in the bolt preload induced (see fig. 1). Furthermore, this preload is about 30 per cent higher than the load which would have been obtained by the torque coefficient method even though the safety margin against failure of the bolt by over-tightening is in fact greater.

It is not possible within the present space limitation to attempt to review even the most significant applications of high tensile bolts in steel structures. Two examples might be cited, however, to indicate the potential of the bolted joint in both conventional and unconventional usage. In the Burdekin River Bridge in Queensland (Australia), 300,000 high tensile bolts were used in the ten 362-foot spans. This is the largest single application yet of the high tensile bolted joint, and in the customary way the use of high tensile bolts led to economy and effective connections. The recent addition of a bottom lateral bracing system to the Golden Gate suspension bridge was completed with high tensile bolts employed throughout. In this design, the characteristic load-slip relationship of a high tensile bolted joint (in which slip occurs only after the friction capacity is exceeded) was utilised as an energy-absorbing device. The effect, of course, is the same as for a rigid-plastic material with a limited maximum strain — in the case of the bolted joint the maximum slip is governed by the $^1/_{16}''$ clearance of the bolts in their holes. With 1″ bolts used throughout, it was calculated that the bottom lateral bracing system of the Golden Gate Bridge could absorb 7,000,000 foot lb. of energy per cycle of vibration.

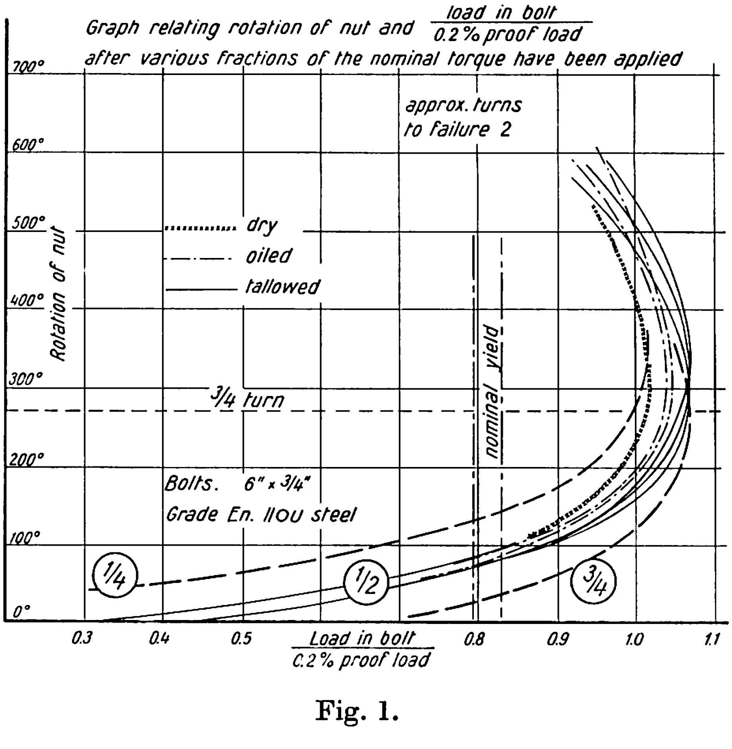

Fig. 1.

4. Discussion of Design Parameters

In studying the design of riveted or bolted joints it is convenient to describe the joint in terms of non-dimensional parameters. In this discussion the "T:S:B" ratio will be used to describe the relationship between joint proportions and/or design stresses in tension, shear and bearing. For riveted joints in North America the "T:S:B" ratio is 1:0.75:2.00, signifying that the design stresses in shear and bearing are respectively three-quarters and twice the tensile design stress; alternatively, that the effective shear area of the fasteners is four-thirds and the bearing area one-half that of the net tension area.

In a bolted friction joint the shearing load is transferred between the parts by the friction induced by the clamping action of the bolt. The shear capacity is thus simply the product of the bolt tension and the coefficient of friction for each friction plane. More generally:

$$\begin{pmatrix}\text{Nominal bolt}\\ \text{Tensile stress}\end{pmatrix} = \begin{pmatrix}\text{Plate tension}\\ \text{Stress}\end{pmatrix} \times \frac{S}{\mu},$$

where S is the shearing ratio as defined above and μ is the coefficient of friction. Numerous tests have been carried out to determine the coefficient of friction or slip factor, as it is usually called in the U.K., for various surface conditions ranging from paint and lacquer to flame cleaned surfaces. Typical values are:

Rusted and wire-brushed	$\mu = 0.51$
Sand-blasted	0.47
Mill-scale, flame-cleaned and wire-brushed	0.43
Mill-scale	0.30
Lacquered	0.28
Red lead	0.07

Several of the American test programmes were extended to cover the behaviour of joints at ultimate failure. It was found that ultimate strengths were independent of bolt preload. The reason for this is that as failure approaches, transverse plate deformations are such as to cause complete loss of bolt preload. It is apparent, therefore, that the only difference between the ultimate strengths of riveted and bolted joints is associated with the change in fastener material. In a conventional riveted joint the intent of the designer (and the specification writer) is to provide a joint in which the full tensile capacity of the net section of the main plate can be developed without rivet shear or bearing (tearing) failure. In North America this is secured for such materials as ASTM-A 7 plate and A 141 rivets with a "T:S:B" ratio of 1:0.75:2.00. Static load tests of bolted joints revealed that for a similarly balanced design a shearing ratio of the order of 1.25 would be appropriate.

That is, the shearing capacity of the bolts is some fifty per cent greater than that of ordinary (ASTM A 141) structural rivets. A secondary effect of increased shear capacity in the fastener was that usual end-distances for rivet holes were found to be inadequate.

Of the early research on friction joints the most notable result was that under normal conditions of load bolt failures could not be produced in fatigue tests [4, 6]. So long as the friction capacity of the joint was not exceeded the bolts were not sensibly subjected to any alternating stress and failure, if it occurred, would be found in the main plate material. It was also noted that if properly installed, high tensile bolts would not loosen and that lock-washers or burring of the threads was not necessary. The fatigue tests revealed that for joints with "T : S : B" ratios 1 : 0.75 : 2.00 the endurance limit for 2,000,000 cycles of fully reversed loading were:

For cold-driven rivets	± 14.7 ksi.
For hot-driven rivets	± 15.8 ksi.
For high strength bolts	± 20 ksi.

It was thus found that the practical endurance limit of a bolted joint was as good as the ordinary design stress for riveted joints under static loading.

The first design specification issued by the American Research Council in 1951 provided for bolts to be designed as riveted joints with bolts simply substituted for rivets on a one-for-one basis. With regard to surface finish, the faying surfaces were to be free of paint, oil, dirt, rust or other defects which would prevent the development of friction between the parts. It should be noted that no reference whatsoever is made in the design to the coefficient of friction. With specified bolt preloads equivalent to 54 ksi. on the nominal bolt area it follows that the coefficient of friction implied is about 0.28. It will be seen that this value provides a small margin of safety for the surface finish demanded.

In the 1954 revision of the Research Council's specification, recognition was given to the absence of fatigue loading in certain types of joint. For such cases, where slipping of the bolts into bearing is not objectionable, permission was given for faying surfaces to be painted. Other design provisions were not changed, however, and thus calculations were unmodified even though the coefficient of friction was obviously greatly reduced. Further revisions were provided in 1955 through an interpretative appendix. The main provisions of this appendix related to the design of compression members and of connections where direct tensions were applied to the bolts.

When first used in the U.K. the design of friction grip bolts followed the American "replacement for a rivet" technique. It was soon realised, however, that this technique was only economic when bolt preloads of the order of 34 tons/sq. in. were being used. As bolt preloads equivalent to 50 and 60 tons/sq. in. were envisaged, design on the frictional capacity of the joint became necessary and this method of design rapidly gained favour. In this respect it must be remembered that as there was no British Standard covering the grade of steel to be used or the design of the bolts, the engineer had complete freedom in these respects. For clean, dry, paint-free surfaces a slip factor of between 0.3 and 0.4 coupled with a factor of safety of 1.5 is now generally used with no distinction between static and fatigue loading conditions.

Increasing use is being made in the U.K. of connections in which the bolts are subject to external tensile loads. Under these conditions the bolt preload does not remain constant and, depending upon the relative stiffness of the bolt and bolted parts, a proportion of the external load is transferred to the bolt itself. Since the part-torque part-turn method of tightening causes yielding of the bolt any increase in the bolt load will result in some permanent extension. Loss of preload results when the external load is removed [13]. Under cyclic conditious the absolute value of the preload and the load range also become important as these factors determine the fatigue life of the connection. Only a limited number of tests concerning the behaviour of joints under tension have been carried out and, at present, the design of such joints is probably overcautious. Their design is generally based on the assumption that the external tensile load on any bolt in the joint shall not exceed a certain fraction of the preload. A value of 0.4 to 0.5 is usually used (i.e. a factor of safety against separation of roughly 2) and this empirical method of design is applied to both static and fatigue loading.

The recent specifications issued on a preliminary basis in Germany [14] for the calculation, design and assembly of high-strength bolted connections are significantly different from the American Research Council's specifications. In essence, the German specifications provide for design based directly on considerations of friction capacity. Shearing capacities per bolt per friction face are calculated from bolt tensions and coefficients of friction. The specifications further provide that contact surfaces be flame-cleaned or sandblasted, with this treatment being undertaken not more than five hours before the connection is completed. With this rigorous requirement, coefficients of friction of 0.45 (for St. 33 and St. 37) and 0.60 (for St. 52) are suggested. Furthermore, for normal loading, different factors of safety are specified depending upon use: for ordinary structures, a factor of safety against slip of 1.25 is required, whereas for bridges and cranes (dynamic loading) a factor of safety against slip of 1.60 is required.

5. Commentary

From the preceding discussion it is clear that there is a distinction between fatigue and static shear loading. The favourable behaviour of a high-tensile bolted joint in fatigue depends entirely upon the ability of the joint to with-stand working loads without slip. In the case of static loading on the other hand, whilst working loads *may* be within the frictional capacity of the joint no distress is experienced if the bolts do in fact slip into bearing. Some cognizance of these factors is indicated in current specifications and practice.

In the American specification a statically loaded joint may have its contact surfaces painted before assembly even though it is known that such joints will slip into bearing under small working loads. Although the actual capacity of the bolt in shear is ignored, the fact that static joint strength is primarily dependent upon direct bearing rather than friction is thus implicit in the code. In the German specification the difference between static and fatigue loading is treated by differing factors of safety though, unlike the American specification, both types of loading must be resisted by the frictional capacity of the joint. In the U.K. a specification covering the design of high-tensile bolted joints is not available and the question of differentiating between static and fatigue shear loads is entirely in the hands of the engineer. At present, it would appear that no attempt is made to distinguish between the two types of loading and all joints are designed on a frictional basis with a common factor of safety against slip.

At this point it would appear advantageous to formulate general principles of design for joints subject to static or fatigue shear loading. For fatigue loading it is essential that the joint be designed for the load to be carried entirely by friction. It is therefore suggested that the American specification should be modified to provide a direct friction-joint design method similar to that currently in use in the U.K. and Germany. Bolt tensions should be specified and a series of coefficients of friction established for different kinds of surface preparation. It does not appear desirable to always demand high quality joints with say flame-cleaned or sandblasted surfaces and it would be more reasonable to provide for alternatives such as:

Flame-cleaned, or sandblasted surfaces	$\mu = 0.43$
Plain mill scale surfaces	0.30

A joint proportioned in this fashion would be able to resist fatigue loadings with full reversal between tension and compression for an endurance life of at least 2,000,000 cycles with ordinary plate tension stresses.

For joints subject to static loading there is a fundamental difference between current European design practice and the latest American trend. In the U.K. and Germany it is felt that slip of the joint is still undesirable and that design should again be based on frictional capacity. In America it is felt that frictional capacity of the joint is unimportant, that slip should be accepted and design based upon principles similar to those used for riveted joints. Test results have indicated that a "T:S:B" ratio of approximately 1:1.25:2.00 would provide a properly balanced design. No precautions need be taken regarding cleaning of contact surfaces and large bolt tensions are not necessary.

Bolt tensions of the order of one-half those specified for friction joints would be adequate to prevent undesirable looseness in connections. With such reduced tensions it would be possible to use smaller washers, without hardened surfaces, and also to use ordinary nuts instead of the heavy nuts necessary for high tensions.

Development in any branch of engineering implies further exploitation of the technique to meet the same functional requirements more cheaply. For example, in America the trend is to relax field requirements for joints subject to static duties. In Germany different factors of safety depending upon the nature of the loading and, by special treatment of the faying surfaces, very high slip coefficients are used. In the U.K. the striving for greater efficiency is taking the form of the use of higher strength bolts of alloy steels and some cognizance in design of the greater clamping forces which the part-torque part-turn method gives. Artificially increasing the slip coefficient between the faying surfaces by the introduction of abrasive or other materials is being approached by several workers. The British author is currently concerned with the promising developments in this field using glue like materials. This work is perhaps the logical step following the pioneering efforts of his colleagues in the field of glued metal aircraft structures and latterly by German structural engineers in the bridging field.

References

1. C. Batho and E. H. Bateman, "Investigations on Bolts and Bolted Joints", Second and Final Reports, Steel Structures Research Committee (1934, 1936).
2. W. M. Wilson and F. P. Thomas, "Fatigue Tests of Riveted Joints", Bull. No. 302, University of Illinois, Engineering Experiment Station (1938).
3. K. H. Lenzen, "The Effect of Various Fasteners on the Fatigue Strength of a Structural Joint", Bull. No. 480, American Railway Eng. Association (1949).
4. W. H. Munse, D. T. Wright and N. M. Newmark, "Laboratory Tests of Bolted Joints", Trans. ASCE, v. 120, p. 1299 (1955); (first published in 1951 for ASCE Centennial).
5. "Symposium on High Strength Bolts in Structural Joints", Trans. ASCE, v. 120, p. 2778 (1955); (first published in 1951 for ASCE Centennial).
6. "The Use of High Strength Structural Bolts in Steel Railway Bridges", Reports by Subcommittee to Committee XV, Iron and Steel Structures, Bulls. Nos. 485 and 506; American Railway Eng. Association (1950, 1953).
7. "Specifications for Assembly of Structural Joints Using High Strength Steel Bolts"; Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation (first issued 1951, revised 1954).
8. ASTM-A325-55T; "Tentative Specification for Quenched and Tempered Steel Bolts and Studs with Suitable Nuts and Plain Hardened Washers" (first issued 1949).
9. American Standards Association, ASA-B18.2 and B27.2 (Bolt, nut and washer dimensions).
10. R. A. Hechtman, A. G. Young, J. M. Chin and J. M. Savikko, "Slip of Joints Under Static Loads", Proc. ASCE, v. 80, No. 484 (September 1954).

11. W. H. Munse, "Bolted Connections-Research", Proc. ASCE, No. 650 (1955).
12. D. D. Vasarhelyi et al, "Effects of Fabrication Techniques on Bolted Joints", Proc. ASCE, v. 85, No. ST3, p. 71 (March 1959).
13. F. M. Easton, E. M. Lewis and D. T. Wright, "Some notes on the Use of High Preload Bolts in the United Kingdom", Jnl. Inst. of Structural Engineers, v. 35, No. 5, p. 167 (May 1957).
14. "Preliminary Directives for the Calculation, Design and Assembly of Non-Slip Bolted Connections for Steel Structures, Bridges and Cranes", German Committee for Structural Steelwork (1956).
15. "Code of Field Practice for Assembly of Structural Joints using High Tensile Steel Bolts"; Canadian Institute of Steel Construction (Adopted 1954 — revised 1956).

Summary

Specifications and codes of practice have perhaps a greater significance in structural engineering than in any other field of technology or science. It has been seen that the development of the hightensile bolted joint has been due in large part to the early provision of a specification for design by the American Research Council on Riveted and Bolted Structural Joints. These rules were laid down in 1951 following early research work on fatigue connections and provided for design on the basis of a simple substitution of bolts for rivets with the note that such an approximation would be needed only "until independent rules for the design of bolted joints can be developed". This paper suggests that the present knowledge concerning bolted joints has developed to the point where such independent rules can be established. It can be shown that the circumstances for static and fatigue loading are essentially different and that different design procedures should be used. A friction joint is essential for fatigue and in this case design should be based on a knowledge of bolt tensions and coefficients of friction. For static loading, strength depends neither on bolt tension nor coefficient of friction but upon the ultimate strengths of the materials. Design in this case should be based simply on material properties.

Résumé

Dans le domaine du génie civil, les normes et règlements jouent peut-être un rôle plus grand encore que dans tout autre domaine de la technique ou de la science. L'évolution des joints boulonnés précontraints est manifestement la conséquence de la publication en temps opportun de normes par l'American Research Council on Riveted and Bolted Structural Joints. Ces prescriptions ont en effet été publiées dès 1951, sur la base des premières recherches concernant la fatigue; elles prévoient le calcul à l'aide d'une simple substitution d'un rivet au boulon, avec cette remarque qu'une telle approximation n'est nécessaire que jusqu'à la mise au point de prescriptions particulières pour le calcul des joints boulonnés. Les auteurs montrent que les connaissances actuelles concernant les joints boulonnés ont atteint un stade suffisant pour l'établissement de telles normes. Il est possible de montrer que les conditions de charge statique et de fatigue sont essentiellement différentes les unes des autres et qu'il est nécessaire de prévoir corrélativement des procédés différents de calcul. Pour la fatigue, il est essentiel que l'assemblage travaille à la friction. Dans ce cas, le calcul doit donc être basé sur la connaissance des contraintes dans les boulons et des coefficients de frottement. En ce qui concerne les charges statiques, les contraintes ne dépendent ni des efforts dans les boulons ni des coefficients de frottement, mais bien de la charge de rupture du matériau. Dans ce cas, le calcul doit donc être uniquement basé sur les caractéristiques de ce matériau.

Zusammenfassung

Normen und Vorschriften haben vielleicht im Bauingenieurwesen eine größere Bedeutung als in irgendeinem anderen Gebiete der Technik oder Wissenschaft. Offensichtlich ist die Entwicklung des vorgespannt verschraubten Stoßes weitgehend eine Folge der frühzeitigen Aufstellung von Entwurfsnormen durch das «American Research Council on Riveted and Bolted Structural Joints». Diese Vorschriften entstanden 1951 auf der Basis von ersten Untersuchungen über die Ermüdung und sahen die Berechnung mit Hilfe einer einfachen Substitution der Schraube durch einen Niet vor, mit der Bemerkung, daß diese Näherung nur nötig sei, «bis unabhängige Vorschriften für die Berechnung geschraubter Stöße entwickelt werden können». Die vorliegende Arbeit zeigt, daß die heutigen Kenntnisse über geschraubte Stöße einen für die Aufstellung von solchen Normen genügenden Stand erreicht haben. Es kann nachgewiesen werden, daß die Bedingungen für statische Belastung und Ermüdungsbelastung grundsätzlich verschieden sind und daß entsprechend verschiedene Berechnungsverfahren angewendet werden sollten. Bei Ermüdung ist es wichtig, daß der Stoß auf Reibung arbeitet. In diesem Falle sollte die Berechnung also auf der Kenntnis der Schraubenspannungen und Reibungskoeffizienten basieren. Für statische Belastung sind die Beanspruchungen weder von der Schraubenspannung noch von den Reibungskoeffizienten, sondern von der Bruchfestigkeit des Materials abhängig. Die Berechnung sollte also in diesem Falle nur auf Grund der Materialeigenschaften durchgeführt werden.