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BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS

by
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1. ABSTRACT

In this report are presented abstracts of most of the work that has been performed during the past two decades on riveted and bolted joints. The last major bibliography on this topic was prepared by De Jonge and covered material published before 1944. Altogether 241 abstracts are included. The abstracts are preceded by some historical notes which show the development of fasteners, related materials, research and specifications.

Instructions are provided to aid in the use of this bibliography. Each abstract follows the format recommended by the Engineers Joint Council. A series of graphical summaries are also presented for many abstracts which provide a rapid summary of the type of connection and the variables studied.

In addition to the abstracts, several lists are included for the user. These include the subject and author indexes, a list of Research Council work and a list of references.
2. ACKNOWLEDGEMENTS

The investigation reported herein was conducted at Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pennsylvania. Professor W. J. Eney is Head of the Civil Engineering Department and of the Laboratory. The Research Council on Riveted and Bolted Structural Joints sponsored the research project.

Throughout the work has been guided by the Council's Committee on Bibliography (Mr. R. B. Belford, Chairman and Messrs. J. E. Burke, E. L. Erickson, T. R. Higgins, J. I. Parcel and E. J. Ruble, members). The authors acknowledge their advice and are appreciative of the support of the Research Council in this work.

Sincere appreciation is due Messrs. A. Gopal, J. H. Nieckoski and N. Parikh who prepared many of the abstracts. Special thanks are due to T. Tsuiji who prepared the tables for Section 7, which provide a graphical summary of many of the abstracts; to R. Kormanik who prepared the list of Research Council Reports and the Author and Subject indexes and to J. H. Nieckoski who prepared the list of references.

Thanks are also due Messrs. H. Izquierdo and J. M. Gera preparing the drawings; to Misses Rosalie Fischer and Valerie Austin for typing the manuscript; and to Mr. William Digel for reviewing the manuscript and abstracts.
3. **INTRODUCTION**

Much valuable research has been performed in recent years on bolted and riveted structural joints, much of which was initiated by the Research Council on Riveted and Bolted Structural Joints, formed in 1947. A list of published Council reports was presented in Ref. 202. The last major bibliography on this topic was prepared by De Jonge, covering material published before 1944.

A project was started at Lehigh University in September of 1963, sponsored by the Research Council on Riveted and Bolted Structural Joints (hereafter referred to as "the Research Council, or, RCRBSJ"), to prepare a bibliography on bolted and riveted structural joints. It was considered that such a bibliography would fill a number of functions. It would be useful to structural engineers and others who need ready access to the material published since 1944, especially to those concerned with the high-strength bolts which have come into use in the past seventeen years. It would provide researchers with summaries of past work to guide them in formulating new projects. Furthermore, it would help eliminate unnecessary duplication of literature searches in this field.

*Numbers refer to abstracts and list of references.

The initial emphasis was on Council-sponsored work. Important articles and reports published by others were abstracted if the publishing agency did not provide suitable abstracts. Because bolted joints have been more extensively investigated than riveted joints in the past two decades, most of the material selected for this bibliography deals with them. The coverage extends in time from 1944, taking up where De Jonge stopped, to June 1964. Articles published since January 1964 in the Journal of ASCE have had suitable abstracts prepared as this was when the ASCE information retrieval program was begun. Most of the articles described herein were reported in the English Language. A subsequent report will provide information on foreign literature.

When the project was started it was not anticipated that the results of the research reported in the various articles would be evaluated. However, in the following section some historical notes are presented which show the development of fasteners, related materials, research, and specifications.

Following the section concerned with "historical notes" is a section on procedures for use in the bibliography. These follow the abstracts proper and tables which provide a graphical summary of papers (types of tests and variables studied). The remainder of the report consists of aids in using the material. Section 8 is a list of Council reports. Author and subject indexes follow. The appendixes contain Council objectives, membership and discussion of
specification. The final item is the listing of references. The use of these materials is described in the section, "Procedures for Use."
4. **HISTORY OF RIVETED AND BOLTED JOINTS**

Most of this section is concerned with the developments in riveted and bolted joints during the past twenty years. The work before this period is mentioned only briefly because a detailed review and discussion of it is readily available in De Jonge's bibliography.

The possibility of using high-preload bolts in steel-framed construction was first demonstrated by Messrs. Batho and Bateman in their report included in the publication of the second report of the Steel Structures Research Committee in 1934.* Extensive laboratory tests were conducted and reported. It was concluded that bolts with a minimum yield strength of 54 ksi could be tightened sufficiently to give an adequate margin of safety against slip of the connected parts. It was recommended that the bolts be installed with a torque wrench in order to insure the attainment of the preload.

Subsequent tests on high-strength bolts performed at the University of Illinois by W. M. Wilson were reported in 1938.** It was concluded from the test results that "the fatigue strength of high-strength bolts appreciably smaller than the holes in the plates, was as great as that of well-driven rivets if the nuts were

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screwed up to give a high tension in the bolts".

In 1945 Maney\(^{(12)}\) reported on studies of single bolts and how to predict the bolt preload. At about the same time he began a research project directly related to bolted connections\(^{(9)}\). In a few preliminary tests the structural behavior of bolts torqued into the inelastic region was unimpaired. The results of these studies were reported in Ref. 24.

The Research Council on Riveted and Bolted Structural Joints, formed in 1947, provided the impetus for the rapid development of the high-strength bolt in the United States. The Council sponsored studies of high-strength bolts and of their use in structural connections. Also contributing to the development of the high-strength bolt at this early stage was the American Railway Engineering Association. Under AREA sponsorship Wyly and Carter in 1948 were studying the problem of fatigue failures of floor beam hangers of railway bridges\(^{(25)}\). The hypothesis was advanced that these failures were due to high stress and strain induced by rivet bearing, and a high-clamping-force bolt was proposed as a means of minimizing the effect of bearing. This hypothesis was verified and reported in Ref. 97.

The AREA initiated studies on the possibility of using high-strength bolts in bridge maintenance, and the Association of American Railroads began a program of field installations and feasibility studies\(^{(29)}(33)\). The earliest installation was in 1948 in a bridge of the Pennsylvania Dock Co., at Ashtabula, Ohio. This
program confirmed the adequacy of the behavior of bolted connections under load.

The American Society of Testing Materials is in conjunction with the Research Council prepared a tentative specification for the materials for high-strength bolts, a specification which was approved in 1949 and revised in 1951 under the ASTM designation A325.

A symposium on high-strength bolts was presented at the Engineering Conference of the American Institute of Steel Construction in 1950. The results of the studies reported in Refs. 28, 29, and 30 were summarized. Also discussed was some of the work being sponsored by the Research Council. Using the results of its research and other information, the Research Council prepared and issued its first specification in January 1951. This specification allowed the bolt to replace the rivet on a one-to-one basis.

By 1952 a number of laboratory and field investigations had been completed and the results were presented at a symposium on high-strength bolts at the Centennial Convention of ASCE at Chicago. Steward summarized the Research Council's activities and presented a brief resume of the development of high-strength bolts in the United States. Munse, Wright, and Newmark summarized the results of static and fatigue tests on small bolted structural joints. These tests confirmed earlier studies which indicated the superiority of high-strength bolts over rivets. Additional tests comparing the static and fatigue strengths of bolted and riveted joints were reported by Baron and Larson. An
extensive series of tests were described by Hechtman, Young, Chin, and Savikko regarding the slip characteristics of bolted joints under static loads\(^{(96)}\). Carter, Lenzen, and Wyly\(^{(97)}\) presented test results to support a hypothesis for the cause of and remedy for fatigue failures in structural joints. It was shown that fatigue strength decreases as bearing stress increases and that the fatigue strength of bolted joints exceed the fatigue strength of riveted joints. Higgins and Ruble\(^{(98)}\) reviewed the behavior of mechanically fastened joints; described the development of high strength bolts; and discussed tightening procedures, costs, and recent developments.

A number of studies of "joint efficiency" were reported in 1952. Wilson, Munse, and Cayci\(^{(55)}\) summarized results of completed tests and reported on a program of tests. This was followed by extensive tests of small joints and the formulation of empirical rules by Schutz\(^{(56)}\). This study indicated that a much closer correlation was obtained with the proposed "relative gage" method than with any previous method.

Additional studies to determine the strength of hot-driven rivets subjected to combined shear and tension were summarized, and an empirical interaction curve was given by Higgins and Munse in 1952\(^{(59)}\). Previous investigations had not covered the full range of shear-tension ratios.

An extensive investigation which included many tests of riveted double-shear aluminum joints was reported by Francis in
Theoretical solutions were presented for the elastic and inelastic ranges. Although it was concerned specifically with aluminum joints, this study contributed significantly to the knowledge of the behavior of all double-shear splices.

Minor revisions based on the Research Council's continuing research program (34)(65) were incorporated into the revised specification issued in February 1954. In December 1955 an appendix was issued to answer questions concerning the application of the specification.

The first German research work was reported in 1954 by Steinhardt and Mohler (242). Sufficient experience and knowledge had been gained through laboratory work, field studies, and reports of American practice to enable the German Committee for Structural Steelwork to issue a preliminary Code of Practice in November 1956 (243). After additional research had been performed and the behavior of structures in the field had been evaluated, this preliminary Code of Practice was revised and issued as a Code of Practice in 1963.

Tests at the University of Illinois in 1954 (74) demonstrated that high-strength bolts tightened well past their yield strength and then subjected to tension were not adversely affected (107).

Pre-tension control was the subject of several more recent investigations. The use of pneumatic impact wrenches was found to reduce field labor costs. The development of wrench calibrators led to the use of calibrated wrenches to provide bolt tension. In 1955
Drew(66)(85) reported on studies of several methods of tightening high-strength bolts and the development of a one-turn tightening method. This resulted in a one-full-turn-of-the-nut-from-the-finger-tight pretensioning procedure being approved by the Research Council and included in the Appendix distributed in 1955. Additional studies reported by Pauw(83)(86) supported this procedure.

The results of studies on the effect of bearing ratio on riveted joints subjected to static loads were summarized by Jones in 1956(104). This paper showed that joint strength will not be reduced if bearing stresses are increased. Additional test results supporting this conclusion were published by Munse in 1957(144). Studies of the behavior of large I-section connections were reported in 1955(82). Tests of riveted connections in truss-type members were described by Chesson and Munse in 1957(132).

Considerable interest in the slip behavior and ultimate strength of large bolted connections led to several preliminary tests of A7 steel bolted butt splices(75)(80)(95). These tests all indicated that the strength of the fasteners in shear far exceeded the strength of the net section. In 1957 a test was performed on an A242 steel joint connected by A325 and A354 bolts(113). An extensive research program was begun at Lehigh University in 1957 "to study the behavior, under static tension loads, of large plate joints connected with high-strength bolts to determine if fewer bolts may be used than required by specification". The results of the first phase, reported by Foreman and Rumpf in 1958(133), indicated that the 1954 design
specification was unduly conservative when slip into bearing could be permitted.

In 1958 a second symposium was sponsored by the Research Council during the meeting of ASCE in Chicago. A summary of Council-sponsored investigations and a list of Published Council reports was given by Ruble(202). Munse, Peterson, and Chesson presented results of tests to determine the behavior of connections in which the rivets and bolts carried loads in tension(203). Douty discussed these tests(204) and presented an approximate analysis(119). Tests to determine the moment-rotation characteristics of standard web angle connections were described by Munse, Bell, and Chesson(207). The specimens were similar to the riveted connections tested by Hechtman and Johnston(15). Hanson presented the results of numerous fatigue tests of joints of high-strength steels(208); joints connected with high-strength bolts had higher fatigue strengths than those connected by rivets. The type of connected steel had little influence on fatigue strength. The effects of punched holes, misalignment, painted faying surfaces, bolt tightening method, and faying surface conditions on the slip and ultimate strength were reported by Vasarhelyi et al(209). Ball and Higgins reported on studies and tests made to develop a modified turn-of-nut procedure(210) and the procedures developed for the bolt installation of the Mackinac Bridge was reported by Kinney(216).

In the United Kingdom, the general practice was to follow the American practice and specifications. In 1959 a symposium on
high-strength bolts was organized by the Institution of Structural Engineers. The results of laboratory and field experience were presented. Abstracts of the symposium papers are given in Refs. 147 to 161. The British Standards Institute formed a committee to prepare a directive on design procedure and field practice. The Institute issued British Standard 3139 in 1959(244). Dealing only with bolt material, it is almost identical to ASTM A325. In 1960 British Standard 3294(245) was issued to establish design procedure and field practice.

Several papers concerned with moment connections using high-strength bolts were published in 1959(151)(155). Different schemes for bolting interior beam-to-column connections were tested. It was shown that bolted connections could be designed to develop the plastic moment of the connected material. There were no premature failures except those which could have been predicted and prevented.

Chesson and Munse in 1959 reported on additional studies of large riveted and bolted truss-type connections(164) similar to the riveted connections reported on in 1957(132). The results of tests of a riveted plate girder with a thin web were reported by Vasarhelyi, Taylor, Vasishth, and Yann(181).

Several studies of the behavior of single bolts during tightening and calibration were reported in 1959. Bendigo and Rumpf reported on extensive calibration studies of single bolts(169).
Load-rotation and load deformation characteristics were discussed. A preliminary report on relaxation tests of high-strength bolts by Lewitt, Chesson, and Munse\(^{(170)}\), indicated that losses due to relaxation are small. Additional tests reported by Lewitt, Chesson, and Munse in 1960 showed that a hardened washer is not needed to prevent minor bolt relaxation resulting from the high stress concentration under the head or nut of the heavy-head A325 bolt\(^{(174)}\). Tests to determine the double-shear strength of single A325 bolts were reported in Refs. 137 and 142.

Due to the completion of extensive tests after the issuance of the 1951 and 1954 specifications, the Research Council completely revised its specification in 1960. Studies of the heavy structural bolt\(^{(174)}\) installed without hardened washers indicated that its performance under static and fatigue conditions is equal to that of the regular semi-finished bolt then in use with hardened washers. As a result, the new specification permitted the elimination of the washer at the bolt head or nut, whichever was not turned in tightening. For the first time since the introduction of the high-strength bolt, it was officially recognized that bolts have strength properties superior to those of rivets. Up to this time, design of bolted structural connections had followed the design for rivets with bolts substituted for rivets on a one-for-one basis. New design rules for bearing-type connections based on research at Lehigh University\(^{(175)}\)(201) established increased bolt shear stresses. The tests indicated that shear must be through the body and not through the threads to realize the full strength of the bolt. Also, because
of the desirability of high preload the required minimum tension (183) was increased to the bolt proof load. Allowable stresses in tension were increased substantially, for tests demonstrated that bolt fatigue strength under this loading condition was not adversely affected (203). The installation procedure for the turn-of-nut method was modified after extensive development by Bethlehem Steel Co. (127) (210).

In 1960 Rumpf (191) adapted the methods described by Francis (64) to bolted bearing-type joint of A7 steel. Excellent correlation was obtained between the theoretical values and the experimental data. In 1961 Hansen used Rumpf's analytical method in determining the effect of pitch in ten hypothetical joints (199). Also, Hansen and Rumpf reported several tests of large bolted connections (200).

Additional studies at Cambridge University of bolted beam-to-column connections were reported by Sherbourne in 1961 (195) and extended the work reported earlier by Johnson, Cannon and Spooner (155). A major investigation of high-strength bolted connections in plastic design was initiated at Cornell University in 1960. Part of this work was reported by Douty and McGuire in 1963 (231).

Tests conducted at the University of Illinois to determine the effect of the elimination of both washers on the static and fatigue strength were reported by Knoell, Chesson, and Munse in 1962 (218). This study showed no significant reduction in strength as a result of omitting washers. Additional bolt calibration studies
of heavy-head bolts were reported in Ref. 217.

Because of the continuing research the Research Council specification was updated in 1962. Washers were no longer required (225). Tightening procedures were modified as a result of the additional calibration studies (217)(233).

The results of tests on bolted lap joints and large riveted joints were reported in 1962 (221)(224). A few calibration and relaxation tests of A354 bolts were reported by Chesson and Munse (227). Calibration tests were begun at Lehigh University on A354 bolts having dimensions similar to the heavy-head A325 bolts. Preliminary results were presented by Christopher and Fisher in 1963 (229).

The results of a number of investigations conducted at the University of Illinois were published by ASCE in 1963. (Abstracts are provided with the published reports and are not repeated here.) Lewitt, Chesson, and Munse described the fatigue behavior of bolted connections (246). Consideration is given to joints assembled with bolts subjected to shear-type loadings and to direct tensile loading. Chesson and Munse reported on extensive tests of truss-type tensile connections (247). Several analyses of joint efficiencies are described and compared with test data. A subsequent report by Munse and Chesson (248) further discusses the factors which affect the behavior of connections and presents an empirical method for computing joint efficiency.
Bendigo, Hansen, and Rumpf published the results of tests of long bolted A7 steel joints and riveted joints in 1963\(^{(249)}\). It was shown that in longer connections, end bolts sheared before all bolts could develop their full shearing strength. The results of tests of A440 steel joints connected by A325 bolts were reported in the same year by Fisher, Ramseier, and Beedle\(^{(234)}\). Also, the calibration studies reported in Refs. 169 and 217 were published by Rumpf and Fisher\(^{(250)}\).

A criterion for designing bearing-type connections was proposed in 1963 by Fisher and Beedle\(^{(228)}\), who pointed out that the balanced design concept has little meaning. It was proposed that allowable stresses be based on the shear strength of the fastener.

Chiang and Vasarhelyi\(^{(232)}\) reported on tests involving misaligned holes in bolted joints. It was concluded that misalignment has little or no effect on joint strength. Miscellaneous studies of A325 and A354 bolts summarized by Chesson and Munse\(^{(233)}\) included relaxation tests, determining the effect of sloping surfaces on turn-of-nut installation, and fatigue studies of bolted connections without washers.

A report of progress of the Cornell University work on the plastic design of bolted connections was presented by Douty and McGuire in 1963\(^{(231)}\). The essential feature in the results of the beam-to-column connection tests is that the connections were able to carry the plastic moment and rotate inelastically through a very large angle. Tests of beam splices showed similar results. In fact, the
actual buckling failure occurred outside the connection in the member itself.

A recent report by Beedle and Christopher(251) summarized tests of bolted connections reported in abstracts 143, 155, 195, and 231.

Chiang and Vasarhelyi(236), reported on tests of small joints to determine the coefficient of friction. A36, A440, and Ti steels were studied. A basic friction test is also discussed and compared with the results of the bolted connection tests.

Recently Fisher(235) developed mathematical models which established the relationship between deformation and load throughout the elastic and inelastic regions for the component parts of bolted butt splices. A digital computer program was developed for the solution of bolted plate problems in order to make practicable what otherwise would be too tedious. The solution was used to study the effect of joint length, pitch, variation in fastener diameter, and variations in the relative proportions of the bolt shear area.

The results of tests of single high-strength bolts under combined tension and shear were reported by Chesson, Faustino, and Munse(238). Most of the tests were conducted on A325 bolts, but a few tests of A490 bolts were included. The interaction eclipse presented is similar to that described earlier for rivets(59).

The results of calibration tests of A490 bolts are reported in Refs. 237 and 239. These tests at Lehigh and the University of
Illinois were made on bolts taken from the same lot. The tests, conducted to determine whether testing procedures constitute a variable, were in close agreement.

As a result of the studies conducted on A354 and A490 bolts \(^{(229)(233)(237)(238)(239)}\), the Research Council revised its specification again in 1964 to include both A325 and A490 bolts.
5. PROCEDURES FOR USE

1. ABSTRACTS

The abstracts in Section 6 present comprehensive, factual, and concise information distilled from important articles, reports, papers, and other publications. They indicate as clearly as possible the contents of the original publications. Each abstract is printed in the middle of a special card-type format designed to facilitate its use. Each contains the four essential parts recommended by the Engineers Joint Council and used by the ASCE.* (Bibliographic information, abstract, key words, and an accession number.) The only modifications in the ASCE model format are the arrangement of the parts and the addition of a bibliographic number.

Complete bibliographic information is included with each abstract so that the reader who needs additional information can find the original publication. This information appears at the top of the abstract and is listed as author, title, and source. The author's name is placed first because searchers are often familiar with the names of those working on a particular topic. The title is shown next. All sources for each item are listed: the principle source is listed immediately following the title and the other sources are enclosed in brackets after the principle source. Articles published

by the ASCE in the Transactions are listed as principle sources even though they first appeared elsewhere. Original reports issued by universities and other agencies are included in the bracketed sources.

At the bottom of the abstract format is a list of key words or descriptors which indicate the contents of the item and are actually used by the author. They are provided as an aid in listing individually-assigned accession numbers on the appropriate key-word cards. Although they reflect each important concept in an article, they are not of equal importance.

The abstract number assigned in this bibliography appears in the bottom right-hand corner. These numbers are used for reference in the introduction, the graphical summary tables, and the author and title indexes.

Each abstract can be cut out and pasted on a 3 x 5 in. file card and included in a personal reference system. A document-accession number may be placed in the box provided in the upper-right-hand corner of each abstract card. The card file may also be used for abstracts from other sources. It is likely that some abstracts will appear in a similar format.

The file can be made more useful with the key-word system described in the CIVIL ENGINEERING reference mentioned previously. The article, which also offers information on setting up files and recommends adhesives, should be read by anyone who intends to make a file of abstract cards.
2. LIST OF REFERENCES (BIBLIOGRAPHY)

This list uses the same reference numbers as do the abstracts. It is provided as a convenience to the reader for quick access to the essential bibliographic information, but contains no information not already included in the abstract format.

Its location at the very end of the report is, again, a matter of convenience for quick reference in this particular present format of the report.

Following Ref. 241 are those references for which no abstracts are included, most of them being available elsewhere.

3. TABLES

The tables are designed to give a panoramic view of aspects of mechanically-fastened joints. The "Ref. No." is the same as that used in "Abstracts" and "List of References". The condition studied in the particular article is described by sketch, as to medium and type, and as to variables studied. Additional notes are provided as appropriate.

4. RESEARCH COUNCIL REPORTS

The list of Council reports is presented for information. It records those reports that were prepared either under the general Council auspices or in connection with the work of a particular project of the Council.

A word of explanation is in order about designation of
projects. Prior to 1960 the research work of the Council was conducted according to projects. After this date "Committees" were designated to act more on a task basis. Because work on some of the "Projects" was still underway, new "Committees" were set up to guide the continuing work. In such instances, the roman numeral in parenthesis following the Committee number is a designation of the former "Project" number.

5. INDEXES

The author and subject indexes follow standard format. The numbers designate abstracts.
6. **ABSTRACTS**

The abstracts in this section appear in chronological order. Complete bibliographic information is included with each abstract.
Maney, G. A. 

This paper is a review of German research into the importance of clamping force in riveted joints. For plain carbon steel rivets, a large percentage of the applied load is carried by the clamping frictional forces and hence the rivet may never be loaded in shear. In alloy steel rivets the desired clamping force may not be realized with certain alloys. The clamping force must stay close to the elastic limit load if it is to be effective. There is an increase in the strength of steel rivets with the working of the rivet but there is a subsequent decrease in clamping force.

KEY WORDS: design; force; clamping; joints; rivets; steel

Stewart, W. C. 
WHAT TORQUE? Fasteners, Vol. 1, No. 4, 1944, pp. 8-10.

Factors which influence the attainment of fastener tension by use of torque are discussed. The torque-tension ratio is recognized as a very important factor in fastener assembly. The theoretical torque-tension ratio for bolts or screws does not hold in practice due to frictional and other effects. The effects of friction and faying surface configuration are analyzed.

KEY WORDS: bolts; design; joints; torque

Wilson, W. M. 

Forty-year-old short deck-plate girders were removed from a railroad bridge and tested to determine the tension in the rivets. The tests showed that some rivets retained considerable tension, while other rivets were under almost no tension. Since the original tension at the time the rivets were driven was not known, no qualitative correlation could be made. The author finds it reasonable to suppose that layers of paint on all contact surfaces might be responsible for an appreciable reduction in rivet tension.

KEY WORDS: recovery; rivet; tension

Maney, G. A. 

A test method using SBA strain gages is described that will measure the tensile or clamping force strains in the bolt, the torsional shearing strains that result from friction drag on threads, and the direct transverse shear stress in the bolt. Relations between the clamping force or axial tension stresses and the torsional shearing stresses were proposed. It is shown that the reversal of applied torque at the end of a tightening operation can reduce the torque induced in a bolt by the tightening operation to about zero without affecting the clamping force.

KEY WORDS: bolts; electrical measurements; joints; strains; stresses
A short history of the cold driving process is given. The requirements for the process and the expected properties are evaluated. It is suggested that with properly controlled pressure, cold driving of large rivets offers a number of advantages. Holes are completely filled, caulking against leaks is unnecessary, rivets attain superior physical characteristics, and the cost is reduced by elimination of heating and easier handling of cold rivets.

KEY WORDS: fabrication; riveting, cold; rivets
Maney, G. A.
A detailed description is given of a fatigue testing machine built to test riveted joints. The 250,000-pound-capacity machine is modeled after a similar walking-beam machine at the University of Illinois.
KEY WORDS: bolts; fatigue; joints; steel; testing machine

Frankland, F. H.
The requirements for structural rivet steel and structural bolt steel, and the ASTM specifications for rivet and bolt steels are discussed. The use of cold-driven rivets is analyzed and the effects of cold-driving on the rivet steels are noted. Several design considerations concerning clamping force, rivet material and bolt material are presented.
KEY WORDS: bolts; joints; rivets; structural design

Maney, G. A.
The "twist-off" type of bolt failure, commonly believed to be a torsional shear failure, is shown to be a "pull-off" failure caused by the axial elongation of the threaded section of the bolt which in turn causes a mismatch of threads and an increase in friction between bolt and nut. An experimental technique for investigating this type of failure is presented.
KEY WORDS: bolts; failure; joints

Maney, G. A.
This study indicates that a predictable relationship exists between applied torque and bolt tension for low carbon steel bolts. An empirical equation is given to express this relationship. However, the relationship is only approximate because the bolt tension in a group of bolts may vary by plus or minus 30 per cent.
KEY WORDS: bolts; tension; torque
Tate, M. B., and Rosenfeld, S. J.
PRELIMINARY INVESTIGATION OF THE LOADS CARRIED BY INDIVIDUAL BOLTS IN BOLTED JOINTS,
NACA, TN 1051, 1946.

A general solution is presented for the determination of loads carried by individual bolts in symmetrical butt joint. With the help of expressions given for bolt behavior, the general solution is applied to calculate bolt loadings in joints made of any combination of materials common to air plane construction. Six symmetrical butt-joint specimens - three of the two-bolt joints and three of the three-bolt joints - were fabricated and tested to check the applicability of the theory. The test specimens were made of 24S-T aluminum-alloy plates fastened by two or three 1/4 in. alloy steel bolts with the bolt in a single line in line with the applied load. Curves are drawn to show bolt-load histories through the elastic and yield ranges to joint failure. Curves are also drawn to represent bolt action above the upper limit of elastic action. These curves combined with analytical equations provide a means for the prediction of bolt loads at any joint load.

**KEY WORDS:** bolts, loads, static; plates, aluminum-alloy

Pancoast, R. H.

An attempt is made to determine the best combined unit stress for use in design considerations of a bolt in combined shear and tension. By varying the angle between the applied load and the bolt axis, the applied stress was varied from pure shear to pure tension. The results of 57 tests led to the conclusion that the maximum shearing stress is the proper combined unit stress for design use.

**KEY WORDS:** bolts; design; shear stress; tension

Hechtman, R. A., and Johnston, B. G.
RIVETED SEMI-RIGID BEAM-TO-COLUMN BUILDING CONNECTIONS, Committee on Steel Structures Research, No. 206, AISC, November, 1947

Forty-seven riveted semi-rigid beam-to-column connections were tested at Lehigh University and the results interpreted for the development of a simple design procedure. Standard beam web angle connections and top and seat angle connections were investigated. Results showed that connections on each side of the column web, when tested against each other, were somewhat stiffer than similar connections to the column flange. It was also found that the rivet pattern of the tension rivets in the vertical leg of the top angle influenced the behavior of the connections. Also included is a suggested supplement to the AISC Specification for Structural Steel for Buildings to cover semi-rigid beam-to-column connections.

**KEY WORDS:** design; joints, beam-to-column; rivet; pattern

Millard, E. H.

"A review is presented of the history of the cold riveting process, including applications, design considerations, economy, and advantages and disadvantages.

**KEY WORDS:** joints; rivets; riveting, cold
Tests were conducted at Lehigh University, Bethlehem, Pennsylvania, to determine the reduction in tensile strength when bolts are torqued slightly beyond the yield point of the material. The test data presented indicates that when bolts are torqued to failure, the ultimate strength in tension is reduced by 25 to 32 per cent of their value in pure tension. When bolts are torqued to any degree short of failure, they still maintain their original tensile value for resistance to external load. The tests were made on 5/8 and 3/4 inch diameter galvanized bolts 11 inches long. The threads of the bolts were cut, class 2, coarse thread, series; and the hot-formed heads were square. The nuts were hexagonal. Carbon in the bolts was 0.15 to 0.24 per cent. Tension was applied between the head and nut by either the straight pull of a testing machine, tightening of the nut, or a combination of these two.

KEY WORDS: bolts; failure; torque

Vogt, F.
THE DISTRIBUTION OF LOADS ON RIVETS CONNECTING A PLATE TO A BEAM UNDER TRANSVERSE LOADS, NACA, TN No. 1134, 1947.

Presented are three theoretical methods of solution for the distribution of loads on rivets connecting a plate to a beam under transverse loads: in the first, rivets are treated as discrete members; in the second, they are replaced by a continuous system of jointing; and in the third, non-linear deformations occur in the rivets and the plate, but not in the beam. The methods are illustrated by numerous examples. These methods could be used in the design of light alloy structures where the design load is well above the limit of proportionality.

KEY WORDS: analyzing; design; distribution, load; rivets

Langdon, Howard, H., and Fried, Bernard
FATIGUE OF GUSSETED JOINTS, NACA, TN 1514, September, 1948.

Fatigue tests were made on 46 gusseted joints to determine the effect of gusset edge finish on fatigue life and to compare riveted with spot-welded assemblies. Neither finish was found to have any effect on the fatigue life of either the 248-T or the heat-treated alloy steel (X 4130-AN-QQ-S685, yield strength = 180,000 psi) gussets tested. The riveted 248-T joints had better fatigue characteristics than the spot-welded 248-T joints.

Additional data obtained in these tests and in a supplementing photoelastic study of the riveted-joint assembly indicated that at low load cycles, stresses set up in the gusset during the riveting operation affect the fatigue life of the gusset. At high load cycles fatigue life is governed by the geometry of the gusset, that is, stress concentration at the rivet holes. Results showed that stresses introduced across the center section of the gusset by the riveting operation may reach values as high as 50 per cent of the tensile stress. These tests indicate that gusset designs should be improved.

KEY WORDS: alloy steel; aluminum alloy; fatigue life; joints, gusseted; rivet

Grinter, L. E.
STRESSES IN GUSSET PLATES BY USE OF AN ANALOGOUS GRID ( WITH APPENDIX ON PROBLEM ANALYSIS BY Marvin Mass ), IASE, September 1948.

An analytic model of a gusset plate is developed, based on the similarity of a gusset plate continuum to the grid of a multiple storied frame. The grid analogy, making use of the physical concepts found in the analysis of structural frameworks, provides a method by which structural designers may approximate the stresses in a gusset plate if they know the point forces applied by the fasteners. Since the partition of load in the fasteners is not a consideration in this analysis, the approximation of the stress condition is valid only some distance away from the point of application of the load. A square plate symmetrically loaded is solved as an example.

KEY WORDS: fastener; gusset plate; stresses
A discussion is presented of the factors to be considered in designing bolts to function properly as threaded fasteners. The use of yield strength data is compared to the use of values called "elastic proof load". The relationship of bolt size to hole size is discussed; it is concluded that the actual body dimension should be equal to, or preferably less than the basic size of the hole. The diameter of the thread, taken to be midway between the root and pitch diameters, limits the ability to carry load. The radius of the fillet under the head of the fastener determines the stress concentration and is controlled by the size of the hole in the member and the size of the body diameter. The factor of thread fit is also discussed.

KEY WORDS: bolts; design; fasteners

The design of bolts to resist shock loading is reviewed. The effects of the following factors on such designs are analyzed: bolt tightening, rigidity of bolted members, bolt life, bending loads, rounding off the root of the thread, diameter of the shank vs. diameter of the thread, length of free thread, runout angle of the thread, radius under the bolt head, and stress relieving of notches on this design are analyzed.

KEY WORDS: bolts; design; fasteners; loading; shock

The consistent tightening of bolts and nuts is dependent upon thread surface, lubricant, material of the rubbing surfaces, and conditions of the nut face. Tests are described that measure the effect of the above parameters on the tightening characteristics of nut and bolt assemblies. A series of good torque application practices are presented and equations for computing the total stress involved are derived. Among the torque application practices suggested are: (1) bolts may be tightened to 75% of the yield strength, (2) nuts should apply a tension load to the bolt equal or greater than the external load to be supported in service, (3) minimum thickness of thread plating provides best results, (4) minimum clearance between bolt and hole gives best results.

KEY WORDS: assemblies; bolts; bolting: characteristics; joints

The results of fatigue tests on joints fabricated with high tensile (1038 steel) quenched and tempered bolts are presented. Thirteen fatigue tests were conducted under full reversal of load. In the static tension test, tension was applied until the joint slipped. The investigation shows that bolted connections exhibit extremely high fatigue strength. Furthermore, the study indicates that the fatigue life is increased by high bolt clamping force which introduces compressive stresses that overcome the tensile stress concentrations at the edges of the bolt holes. Carbonized washers also increase fatigue life by maximizing clamping force.

KEY WORDS: bolts; fatigue; static test; steel; testing
Wyly, L. T., Scott M. B., McCamey, L. B., and Lindner, C. W.

The report is basically a field study of the floorbeam hangers of the Illinois Central Railroad Bridge at Galena, Illinois. The particular object of the study, a form of hanger section consisting of two channels connected by occasional tie plates, was found to be a poor structural member because of excessive bending and uneven transfer of load from the floor beam. This uneven transfer of load should concern the designer (or detailer of gusset plates).

KEY WORDS: gusset plate; hangers, floor beam; stress concentration

Hechtman, R. A.

The slip in several types of bolted joints under load and the conditions which affect this slip are investigated and reported. The specimens consisted of double lap bolted joints made from plain-carbon structural steel plate. The bolts were rough forged from high strength structural steel. In one series of tests the bolt hole clearance was increased while the bolt tension was kept constant. The test results indicate that a reduction of the clearance in bolt holes is much more effective in decreasing the amount of slip than an increase in the bolt tension.

KEY WORDS: bolts; clearance, bolt hole; joint; slippage; tension

Kovac, J. J.

Experimental tests were conducted on NAS bolts to determine the relationship between bolt preload and torque. Bolts of the following sizes were tested: 3/8 in., 7/16 in., 1/2 in., 9/16 in., 5/8 in., and 3/4 in. Twelve bolts, two of each size, were tested with lubricated threads, while twelve more bolts, two of each size, were tested without lubricant. Eighteen bolts, three of each size, were tested with an ANC-147 anti-seize compound under the bolt head as well as on the threads. The completely lubricated bolt showed a considerable increase in efficiency for all six sizes. It was found that the loss in efficiency from friction at the bearing surface under the bolt head was more severe than from friction developed in the threads.

KEY WORDS: bolts; fasteners; lubricants; pretensioning

Wyly, L. T.

Presented is a study of structural members under repeated loading. The study was composed of a fact-finding survey of failures and an analysis of the failures, a study of stress distribution measurements in bridge hangers obtained in the field, and a study of stress distribution measurements in components of hangers obtained under controlled conditions. The author concludes that the bearing of rivets at the tops of rivet holes is the principal source of the high stress or strain concentrations which result in the low fatigue strength of hangers. These concentrations occur chiefly when rivets have lost, or never had, clamping force. A method of decreasing these concentrations is presented. Fatigue tests of bolted joints are explained. It was determined that superior fatigue performance may be achieved through the use of bolts, which have greater clamping force than rivets.

KEY WORDS: bolts; fatigue; force, clamping; hangers
An investigation was made of the relative effects of various fasteners on the fatigue strength of three groups of structural joints, identical except for the type of fastener. The three types of fasteners were hot driven rivets, cold driven rivets, and high-strength bolts. The plates, made of A7 steel, were joined by nine 3/4 inch fasteners in a square pattern. A total of twenty-four joints were fabricated and tested in fatigue under a complete reversal of load. The fatigue strength of the joints fabricated with high-strength bolts was appreciably greater than that of the riveted joints. The conclusions based on laboratory tests were supported by examinations of railroad bridges in which it was noted that bolts remained tight longer than rivets in structures subjected to vibrational loads.

KEY WORDS: bolts; fatigue; rivet; testing
In 1948 and 1949, the research staff of the AAR installed over 1,000 high strength bolts of various sizes and lengths in about 20 different types of joints on twelve different bridges. In most cases, the installations were made where vibration of the members had made it difficult to keep rivets tight. An account of the installation and inspection of these bolts is presented. A check with a torque wrench on the tightness of a representative number of bolts revealed that the majority of the bolts retained their original clamping force. Some of the bolts appeared to have lost some of their clamping force, but it was not known whether the bolts were not properly tightened when installed or whether the bolted members were reseating themselves. It was definitely found that high-strength bolts, properly installed, stayed tight longer than rivets in similar joints subjected to the same vibrational loads.

KEY WORDS: bolts; installing; inspection; testing
Pinkel, R. H.

An extensometer designed specifically for bolts and a testing method to determine bolt load elongation curves are described.

KEY WORDS: bolts; mechanical properties; testing

Merritt, F. S.

The use of extra large rivets in the construction of the United Nations Secretariat is described. Due to the design of the building (the height-width ratio is about 7 to 1) the builder was faced with unusual fabrication and erection problems. Heavy connections had to be designed to transmit high wind stresses from the girders to the columns. Rivets 1-1/4 in. in diameter were used because the use of smaller rivets would have been uneconomical or impossible. Rivets up to 8 inches in length were used for column connections because of the great thickness of the steel. Other design and erection problems and their solutions are also explained.

KEY WORDS: joints; rivets; structural engineering

Wyly, L. T., and Carter, J. W.

The effect of fastener clamping force and fastener bearing at the top of a hole on stresses around the hole is analyzed. The author shows that clamping force reduces the high tensile stress at the sides of the hole caused by the axial forces and also that bearing at the top of the hole causes stress 5.3 times as great as the average stress on the gross section. It is also reported that twisting and bearing caused by slip in a single lap joint increases the strain at the sides of the hole. The stresses due to strain concentrations at rivet and bolt holes are analyzed by photoelastic techniques. Suggestions are made to overcome the effects of the holes.

KEY WORDS: bolts; force, clamping; joints; rivets; stresses

Lappo, T.
EXTRA FLANGE RIVETS FOR WEB SPLICE EASILY COMPUTED, Civil Engineering, Vol. 20, 1950, p. 786.

Presented is a method for computing the pitch of the additional rivets required on the abutment side of a web splice of a girder designed for the full strength of the web in bending. Plates must be furnished in each flange to carry the web moment and additional rivets are needed to supplement those required for shear. The method is illustrated by two examples.

KEY WORDS: design; joint, web; rivets
Wright, D. T., and Munse, W. H.  
CALIBRATION TESTS OF HIGH STRENGTH BOLTS, Dept. of Civil Engineering, University of Illinois, SRS No. 9, January 1951.

A series of 38 tests was made on O.4% quenched and tempered high-strength steel bolts (A325, A.S.A. Spec. 18B.2) to determine the relationships of bolt elongation and torque to bolt load. The bolts were calibrated by either a torque-tension test, a static tension test or a combination of these tests. The results are presented graphically. Reducing the effective area of a bolt by such means as fully threading the shank was found to increase the overall elongation of the bolt for a given load and to reduce the elastic limit and ultimate capacity. It was also shown that lubricating the nut was as effective as lubricating both the bolt and nut in reducing the required torque for a given load.

KEY WORDS: bolts; nuts; tensile strength

Becker, W. K., Sinnamon, G. K., and Munse, W. H.  
THE EFFECT OF BEARING PRESSURE ON THE STATIC STRENGTH OF RIVETED JOINTS, Dept. of Civil Engineering, University of Illinois, SRS No. 8, January 1951.

The effect of high rivet bearing on the static strength and behavior of riveted joints is reported. The 32 specimens tested consisted of double strap butt joints with plates connected by five rivets. A constant ratio of rivet shear stress to plate tensile stress in the middle plate was maintained in all joints by varying the thickness and width of the butt plate. It was found that although the ultimate loads for companion specimens were in excellent agreement the test efficiencies were appreciably lower than their theoretical efficiencies. The rivet size had no noticeable influence on the static strength and a variation in the bearing ratio from 1.3 to 3.0 had little influence on the joint strength.

KEY WORDS: bearing; joints; rivet; slippage; strength, static

Young, D. R., and Rachman, R. A.  

The report is divided into two parts - Part I, The Effect of Bolt Tension and Faying Area Upon Slip and Part II, The Effect of Surface Condition of Faying Area Upon Slip. Part I describes twenty-three tests of plain-carbon structural steel double-lap joints assembled with high strength bolts. All of the joints had mill-scale faying areas. Eighteen joints were tested in Part II. Part II reports the effect of other surface conditions of the faying areas upon the slip of the joint, such as mill-scale finish with drilled holes, mill-scale finish with subpunched and reamed holes, red-lead paint, varnish, and sandblasted finish. The results showed that coatings should not be used on faying surfaces of a joint if prevention of slip is a criterion of design.

KEY WORDS: area, faying; bolts, high strength; joint; slippage

Higgins, T. R.  
BOLTED JOINTS FOUND BETTER UNDER FATIGUE, Engineering News Record, Vol. 147, August 2, 1951, pp. 33-36.

The advantages of using high-tensile steel bolts in place of rivets for structures subjected to widely fluctuating dynamic loading are discussed. Lower installation costs, less noise, and slip-free joints are the primary advantages. Bolt characteristics and clamping force are briefly discussed.

KEY WORDS: bolts; costs; fatigue; force, clamping
Redshaw, S. C.


The various factors influencing the design of aluminum alloy riveted joints are discussed, including the effect of different types of joint materials, and the fatigue resistance of the joint. The authors find that it is sufficiently accurate to assume that load is equally distributed among the rivets. It is recommended that for joint design the rivet alloy should be ductile and the plate alloy should have a sufficiently high ratio of proof to ultimate stress. It is further suggested that the length of the joint and rivet pitches should be as small as practicable and that the rivet diameter-plate thickness ratio should be such that the rivet has as high a ductility as possible.

KEY WORDS: aluminum; efficiency; fatigue; joint; rivet; shear stress

Bailey, J. C.


The progress made since 1946 in the development of aluminum alloy rivets larger than 3/8" diameter is outlined. Fabrication of a joint by Aluminum alloy rivets up to 7/8" diameter is said to be practical. Data on the closing pressures for cold squeeze riveting is presented. Ultimate shear stress values for hammer driven and squeeze driven rivets, maximum rivet sizes for pneumatic driving with various points, and shear strengths of cold driven rivets are also presented. Pneumatic hammer riveting, rivet points of reduced sizes and the factors influencing the rivet shear strength are discussed.

KEY WORDS: aluminum; clearance; joint; rivet; riveting, cold

Delaney, T. J.


The use of Alcan 16 S-T alloy cold driven rivets in the Arvida Bridge, Quebec, Canada is reported. The use of a new cold driving technique, utilizing a pneumatic gun usually used for hot driven steel rivets, is explained. The rivet gun with a conventional pan and flat head repeatedly slipped off the rivet head, producing misshapen and non-concentric heads, and damaging the surrounding plate material. Extensive research and testing resulted in the design of the annular head rivet, a new type of rivet. The annular head facilitates the spread of the metal to form the head and helps to prevent the gun from slipping off during the driving.

KEY WORDS: aluminum; head; rivet; riveting, cold

Ruble, E. J.


The Research Council on Riveted and Bolted Structures, organized in 1947, recognized that the existing practice in the design of riveted and bolted structures was developed empirically from experience and that many of the practices were not supported by definite experimental data. The council's aims and the plans of its research program are presented along with lists of the sponsors, representatives, and members-at-large. Recommended also are specifications for bolts, nuts, washers, bolted parts, assembly, and inspection.

KEY WORDS: bolts; nuts; RCRBSJ; specification; washers
Hartman, E. C., Holt, M., and Eaton, I. D.


Results are reported of static and fatigue tests on several types of joints fabricated from 755-T6, 24S-T4, and 148-T6 high strength aluminum-alloy extruded bar. All the specimens had the same net-section area. In the static tensile tests, the 755-T6 double-shear joint withstood the highest ultimate load and the 75S-T6 clamped-keyed joint the lowest. Of all the joints studied, the 75S-T6 double-scarf joint had the highest fatigue strength. It was also found that when the critical net-area was held constant, other design details had a greater effect in prolonging fatigue life than did a change in materials within the group studied. There was no apparent correlation between the static and fatigue strengths of the joints studied.

KEY WORDS: bolts; bolted joints; fatigue life

Massard, J. M., Sinnamon, G. K., and Munse, W. H.

THE EFFECT OF BEARING PRESSURE ON THE STATIC STRENGTH OF RIVETED JOINTS, Dept. of Civil Engineering, University of Illinois, SRS No. 21, January 1952.

The effect of high rivet bearing pressure on the static strength and behavior of double strap butt-type joints designed to fail in the outer plates is investigated. Tests of thirty-three riveted specimens are described. It is concluded that the strength of the joint as a whole is not affected by a variation in the bearing ratio while the strength of the net section of the joint varies with the bearing ratio.

KEY WORDS: bearing; joints; rivet; strength, static

Fisher, W. A. P., Cross, R. H., and Norris, G. M.


The prevention of fatigue in bolts by controlled pre-tensioning is investigated theoretically. It is shown that pre-tensioning reduces the alternating load in the bolt and that the fitting stiffness plays an important part in this reduction. Fatigue tests on 3/4 inch B.S.F. bolts with various amounts of pre-tension show how this reduction in alternating load can prevent fatigue failure. Unless pre-tensioning will be maintained in service, its benefits should not be relied upon.

KEY WORDS: bolts; fatigue; pre-tensioning
Wright, D. T., and Munse, W. H.

Static loading tests of 38 high-tensile bolted lap-type joints are discussed. Twelve tests of riveted joints are reported for comparison. For joints with 7/8 in. bolts, an end distance of 1-1/2 in. is sufficient to prevent end tearing. Two-fastener lap joints have greater ultimate tensile strength than three-fastener lap joints or two-fastener butt joints. The faying surface condition, the fastener type, and the bolt tension are the primary factors affecting the load-slip relations while joint type and shear ratio are secondary. Bolt tension and faying surface condition had no appreciable effect on the ultimate strength of either riveted or bolted joints. Bolted joints with a shear ratio of 0.75 failed in tension, while those with ratios of 1.0 and 1.25 failed in shear. On the basis of these results, the authors recommend a shear ratio of 1.25.

KEY WORDS: bolts; lap joint; ratio, shear; rivet; static test; surface, faying; tension

White, R. E.
EXPERIMENTAL INVESTIGATION OF STRESSES IN GUSSET PLATES, Bulletin No. 16, Engineering Experiment Station, University of Tennessee, Knoxville, May 1952.

Tests were made on 61-32 high-strength aluminum alloy, bakelite, and masonite joints to determine the stress distribution in certain types of gusset plates, including the maximum intensity of stress and its location, and to devise for use in structural design a simple method of approximating the maximum stresses. The test joints were designed as L joints of a Warren truss. Edge stresses were lower than expected and the straight-line distribution of stress customarily assumed in analyzing such plates was found to be incorrect.

KEY WORDS: gusset plates; joint; stress concentration; truss

Wilson, W. M., Munse, W. H., and Cayci, M. A.
A STUDY OF THE PRACTICAL EFFICIENCY UNDER STATIC LOADING OF RIVETED JOINTS CONNECTING PLATES, Bulletin No. 402, Engineering Experiment Station, University of Illinois, July 1952. (First distributed as THE EFFECT OF THE RIVET PATTERN ON STATIC STRENGTH OF RIVETED JOINTS CONNECTING PLATES, by Wilson, Munse, and Cayci, Dept. of Civil Engineering, University of Illinois, Progress Report-Project II, January 1950).

Discussion is presented of tests of 38 large riveted lap and double strap butt joints made with 1/2 or 3/4 in. plates and 3/4 or 7/8 in. rivets. The tests were concerned with static strength as well as the effect of temperature on strength and fracture. A comparison is made of the strengths of joints with various rivet patterns. Test efficiencies were 75-85%. It is concluded that an increase in the traverse distance between rivets in the outer row to more than 4-1/2 in. does not assure increased joint efficiency.

KEY WORDS: butt joints; efficiency; rivets; steel; testing

Schutz, F. W., and Newmark, N. M.

The development of the relative gage method for predicting joint efficiency, the effect of various fastener patterns on the static strength of double strap butt type riveted and bolted joints, and the variables other than fastener pattern influencing the static strength are presented. Tests show that fastener tension, mechanical properties of fastener material, and longitudinal spacing of transverse rows of fasteners have no great effect on the joint efficiency. However, staggering alternate fasteners in the first transverse row increases the joint efficiency, as does an increase in transverse spacing of longitudinal lines of fasteners. The joint efficiency is independent of the number of transverse rows and the number of longitudinal lines of fasteners.

KEY WORDS: bolts; ductility; efficiency; joint; measurement; pitch; rivet
The advantages of high-strength bolts over rivets are listed. High-strength bolts have higher shear strength and clamping force than rivets. Joints connected with high-strength bolts have greater fatigue strength than riveted joints when the high-strength bolt are tightened to high preload levels. Because high-strength bolts are unaffected by external tension, they may be used in moment-resisting connections. The author thinks high-strength bolts are practical and that their cost is competitive with other types of fasteners.

KEY WORDS: bolts; joints; rivets

The economic advantages of semi-rigid connections are presented. Examples are given in which designing beams with semi-rigid connections instead of simple spans resulted in savings in steel tonnage and cost. Other advantages of this type of design are: (1) reduced deflection of the beam when the ends are restrained; (2) the buckling of the beam is critical a shorter span length can be used in the allowable bending stress formula; and (2) the bending moment has no appreciable effect on the column.

KEY WORDS: economics; joints; semi-rigid; spans
Presented is a description of the demolition of the old Superior Foundry, Inc. facility at Cleveland, Ohio and the construction of the new foundry. It is estimated that bolting of field connections took less than half the time that other methods would have required. "When the job calls for speed and economy, the steel contractor calls for bolts".

KEY WORDS: bolting; economy

The "relative gage method" for predicting joint efficiency is explained. The formula is developed from the results of 1130 tension failure tests. The joints studied are riveted or bolted, lap and butt type and are made from a wide variety of materials including wrought iron, structural steel, and various aluminum alloys. This article is a synopsis of a thesis by F. W. Schutz (see abstract 56).

KEY WORDS: bolts; design; efficiency; joint; measurement; rivet

The results of static and repeated load tests conducted on seven double-strap butt-type joints fastened with high tensile steel bolts are summarized. The bolts were torqued far into their inelastic range. It is found that the static strength of the joints is not affected by the overstressing of the bolts and that the overstressed bolts are not likely to fail in fatigue.

KEY WORDS: bolts; fatigue; loads

The behavior of aluminum alloy riveted double shear joints under axial and eccentric static loading was determined through extensive experimentation. Also presented is a theoretical solution for the load partition and ultimate strength of joints. It is applicable to both the elastic and inelastic ranges. The solution is achieved through a semi-graphical solution based on control tests of the component parts.

KEY WORDS: aluminum; rivet; shear stress
This report briefly outlines the accomplishments of the Research Council on Riveted and Bolted Structural Joints and the status of the council's current projects listed below:

**Project 1:** "The Effect of Bearing Pressure on the Strength of Riveted Joints".

**Project 2:** "The Effect of Rivet Pattern on the Static Strength of Structural Joints".

**Project 3:** "The Strength of Rivets in Combined Shear and Tension".

**Project 4:** "Fatigue Strength of Bolted Structural Joints".

**Project 5:** "The Effect of Grip on the Fatigue Strength of Riveted and Bolted Joints".

**Project 6:** "Fatigue Strength of High-Strength Steel Riveted Joints".

**Project 7:** "The Effect of Rivet Pattern upon the Fatigue Strength of Structural Joints".

**Project 8:** "Fatigue Tests on Cumulative Damage in Structural Joints".

**KEY WORDS:** bearing; rivet; shear stress; tension; fatigue; slippage

High-strength bolts were installed in 16 railroad bridges to determine if such bolts retain their clamping force in structural joints subjected to vibrational loads at various temperatures. Because these bolts were found to be superior to rivets in this application, recommendations are made for the revision of the Specification for Assembly of Structural Joints using High-Tensile Steel Bolts in Steel Railway Bridges.

**KEY WORDS:** bolts; joints; railroad bridges

The three distinct advantages of high strength bolts—adaptability, strength, and economy—and the basic principle of the application of high strength bolts—load transfer due to clamping force—are presented. Included is a brief presentation of the specifications, assembly, design, slip, painting of contact surfaces, bolt load, fatigue strength, and economics of the use of high tensile bolts.

**KEY WORDS:** bolts; design; economic factors

The authors report on an investigation of a high-strength rivet steel which the Bethlehem Steel Co. has developed. The rivet steel has certain advantages over other steels meeting the requirements of ASTM specification A195-52T. This steel is as ductile and is driven as easily and quickly as ordinary carbon rivet steel. At short lengths of grip, the average clamping stresses of the high-strength steel rivets are about the same as those of carbon steel rivets. However, at grip lengths of 2 in. and greater, the average clamping stresses of the high-strength steel rivets are appreciably greater than those of carbon steel rivets. The behavior in static tension and in fatigue of butt joints fastened with rivets of this high-strength low-alloy steel was compared to that of joints fastened with rivets of ordinary carbon steel. The joint efficiencies for static loads and the fatigue strengths were about the same irrespective of the kind of rivet steel.

**KEY WORDS:** efficiency; properties; rivet; stress, clamping

Fifteen plate steels including 7 low-alloy steels, 4 silicon steels, 3 ordinary carbon steels, and 1 rimmed steel were investigated to determine fatigue strength, the relationship between fatigue strength and stress-strain characteristics. The fatigue strengths of the various steels increased with tensile strength and yield strength. Fatigue lives of the steels were more closely related to maximum stresses at the net sections.

KEY WORDS: fatigue strength; steel; tensile strength


Analytical and experimental research was undertaken to determine the stress distribution, stiffness, and strength of bolted, riveted, and welded plate girders under uniform twisting moment. Seventy-two tests were made on fifteen different specimens. Eleven of the specimens were finally tested into the plastic range. Test variables included the number of cover plates, the rivet pitch, variable tension in bolts, and girder cross-section, with or without stiffeners. Formulas are proposed for calculating rivet or bolt pitch and size of welds for the bolted, riveted, and welded plate girders. It was found that the maximum shear stress occurred in the fillet between flange and web, while the next highest stress occurred in the flange near the rivet (or bolt) head.

KEY WORDS: flange; plate; cover; pitch; rivet; shear stress


This report summarizes the results of tests made on 22 double-strap butt joints. Five different T:S:B ratios (ratios of tensile, shear, and bearing stresses to tensile stresses) were studied. The effect of fastener material and initial fastener tension on allowable bearing stresses was studied. Generally speaking, high bearing-to-tensile ratios (T:S:B=1:0.35:1.48) have little effect on the efficiencies of the high-tensile bolted connections. The authors conclude that it is possible to raise the balanced design ratio for both common and high-tensile bolts.

KEY WORDS: bolts; design; efficiency; joints; failure; tension test


Chapter I reviews and evaluates the effect of a number of variables on the properties of rivets and bolts. The basic properties of rivet materials are important in determining the characteristics of the finished rivets. Machine driving produces greater rivet strength than pneumatic hammer driving. The ratio of ultimate shear strength to ultimate tensile strength does not vary far from 0.75. The rivet strength varies inversely with grip length. Driven rivets experience a reduction of energy absorbed per unit volume of rivets. Chapter II explains the load-deformation relationship, effect of rivet pattern on plate and rivet strength, and ultimate strength of bolted joints. Chapter III discusses continuous frame connections. Generally these connections are welded rather than riveted. Chapter IV discusses the behavior of flexible and semi-rigid beam-to-column connections. In particular riveted seat and top angle connections, riveted web clip angles, and riveted connections with structural tees are discussed. In Chapter V a theoretical analysis of the behavior of column anchorages is presented.

KEY WORDS: analyzing; bolts; design; joints; rivets; steel
Hartman, E. C., Holt, M., and Eaton, I. D.
ADDITIONAL STATIC AND FATIGUE TESTS OF HIGH-STRENGTH ALUMINUM ALLOY BOLTED JOINTS,
Tests were made in the Aluminum Research Laboratory to investigate the static and fatigu strengths of stepped double-shear bolted joints; and the effect of bolt clearance and static preload on fatigue strength of bolted joints. Also discussed is the feasibility of the penetrant inspection method for locating fatigue cracks. The influence of fatigue cracks on the static load-carrying capacity is discussed. The stepped double-shear joint withstood fewer fatigue cycles than either the plain double-shear joint or double-scarf joint but its fatigue life exceeded that of all other joint designs tested. Bolt-hole clearance had no significant effect on the fatigue life of plain scarf joints. However, preloading bolts in tension to hold way between the yield and ultimate strengths increased the fatigue life of plain scarf joints by 5.9 to 1. The same preloading increased the fatigue life of double-shear joints by 1.4 to 1.

KEY WORDS: aluminum; bolts; fatigue; joints; static test; testing

Leahey, T. F., and Munse, W. H.
STATIC AND FATIGUE TESTS OF RIVETS AND HIGH-STRENGTH BOLTS IN DIRECT TENSION, Dept. of Civil Engineering, University of Illinois, SB 5, No. 80, July 1954.
The effects of initial bolt tension, applied load, bolt spacing parallel to web, and the non-parallel surfaces between the heads of the bolts and the joined members on the behavior of high strength bolts in direct tension are determined is compared with that of similar riveted connections. The static and fatigue behavior of high-strength bolted connections. Five static and eighteen fatigue tests were conducted on specimens consisting of two short sections of a 24 x 100 beam fastened with high strength bolts, and one static and three fatigue tests for comparison were conducted on similar specimens fastened with 3/4 in. rivets. The study shows that prestress in the bolts has a marked effect on their fatigue strength. The fatigue life of the bolts increased as prestress was increased. Bolts prestressed to 0.9 of proof load and subjected to a stress range from 0 to 0.47 of proof load did not fail during 2,000,000 cycles. The ultimate static strength of the bolts was independent of prestress. Also, the ultimate strength was adversely influenced by the prying action of the flanges.

KEY WORDS: bolts; fatigue strength; joints; prestressing; rivets; tension

Carter, J. W., McCalloy, J. C., and Wyly, L. Y.
This is a report of the behavior under static load of two full scale joints which represented the connections of a floor beam hanger to upper chord gussets of a railway bridge. One joint was riveted and the other was fastened with high-strength bolts. The results demonstrate that both rivets and high strength bolts work satisfactorily in structural joints. However, if rivets are replaced with high-strength bolts, the high local stresses and strains at the sides of the bolts are eliminated. Therefore, bridges can be protected against fatigue failure by replacing the rivets at the edges of the gussets with high-strength bolts.

KEY WORDS: beam; gusset plate; joint; rivet; slippage

Fasteners
A brief history of the trend toward the extensive use of high-strength bolts is presented along with the Research Council's reasons for research in this area. In 1951 the Research Council, in order to control the increasing use of high strength bolts, issued "Specifications for the Assembly of Structural Joints Using High Tensile Steel Bolts". After the completion of more research, the Research Council presents, in this paper, a first revision to the original specification. Four major areas are changed and the changes discussed: The areas include washers, painting, assembly, and inspection. Also presented are the specifications approved February 27, 1954 by the Research Council on Riveted and Bolted Structural Joints.

KEY WORDS: bolts; nuts; specifications; washers
The ease and speed with which the aluminum rivets (Alcan 55.8-T33 alloy) were cold driven into the Royal Canadian Navy's aluminum non-magnetic mine-sweepers are described. Fourteen of these vessels were constructed, each requiring 250,000 rivets. The ships commissioned in the Pacific and Atlantic, are entirely satisfactory.

KEY WORDS: aluminum; riveting, cold; rivets

Riveter, A. G.

The principles and uses of impact wrenching are presented in this article. The impact wrench can be used safely in any position, and it comes in sizes to handle nuts on bolt sizes ranging from a 1/16 to a 7" diameter. Power may be supplied by electricity or compressed air. A cutaway view of the wrench assembly is shown and a description of procedure of operation follows. The impact wrench has been highly useful in the fastening of high-strength structural bolts. No special skill is required of the wrench operator, the torque may be varied by changing the driving force.

KEY WORDS: bolts; safety; torque; wrench, impact

Beam, W. S., and Munse, W. H.

Three groups of small truss-type specimens having a tension:shear ratio of 1.0:0.75 were fabricated using either bolts or rivets from 6-in. 12.5 lb. I-sections. One specimen from each group was tested statically and the remaining four were tested in fatigue to determine the effects of repeated loadings on structural connections. It was found that, in general, the fatigue strengths of tension members with bolted connections and flexural members with bolted partial-length cover plates may be expected to be somewhat greater than that of similar riveted members.

KEY WORDS: bolts; fatigue strength; joint; loadings, repeated; rivet

Bacon, F., Larson, H. W., Jr., and kamarthv K. J.

Presented are the results of tests on the fatigue strength of structural steel joints, including the effect of varying the pitch between the rows of rivets; the effect of advancing certain rivets beyond the first row of rivets; and the effects of edge distance, gage distance, and certain rivet patterns. Fatigue lives of joints are not improved by either staggering the inner or outer rivets of the first row of rivets having a rectangular pattern or varying the pitch of 3/4 in., rivets from 2-1/4 in. to 6 in. Extreme values of edge or gage distance decrease the fatigue life. The fatigue lives cannot be predicted on the basis of static efficiencies. The static efficiencies of the various joints tended to increase with increases in values of g/d or 2a/d. The actual efficiencies of joints are closely related to theoretical efficiencies obtained by Schutz's rule and Wilson's rule than those obtained by other rules.

KEY WORDS: fatigue; joint; rivet; strength, static
The fifth and final progress report on slip in double-lap joints is presented. Seven tests were made on joints with A325 bolts and having tension:shear ratios of 1.0:0.75, 1.0:0.73, and 1.0:0.78. Mill-sealed-surface bolted joints loaded to design shear stress on the bolts slipped partly into bearing before slip stops. As the length of the joint increases, the two end rows carry an increasingly greater part of the load. It is imperative that static load be applied slowly enough to be really "static". Tests of small joints do not fully describe the action of large joints. Longer joints may be more critical than shorter joints in the cases of fatigue or brittle failure.

KEY WORDS: joint, double-lap; ratio, shear; slippage; tension
A description of the several methods for tightening high-strength bolts is presented. The one-turn tightening method is dealt with in detail. Graphs showing the relationship between applied torque and nut turns, and between nut turns and impact wrench application time are included. The use of high-strength bolts in place of hot-driven rivets in erecting and maintaining steel bridges can save $460,000 a year for American railroads.

KEY WORDS: bolts; bolting

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Two questions are raised concerning the turn-of-nut procedure. (1) Can the adoption of the turn of the nut procedure under certain conditions lead to structural damage of the bolt, resulting in failure of the bolt or loss of clamping force? (2) If the concept of an "optimum target value" for the clamping force is abandoned, does the turn of the nut procedure necessarily provide the safest and simplest method for tension control? These questions are answered by studies at the University of Missouri. Bolt tensions achieved with pneumatic wrenches revealed that tensions equal to or greater than the minimum specified tensions are obtained with 0.6 to 0.9 revolutions of the nut for 7/8 in. bolts and 0.8 to 1.3 revolutions for 3/4 in. bolts. After the bolts were loosened, retightening requires about 1/4 of a revolution less than before to achieve specified tension. The turn of nut method appears to be adequate.

KEY WORDS: bolts; installing; prestressing

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The influence of fastener material on the distribution of load to individual fasteners is studied. "Joint modulus", property for the comparison of joints is introduced. It is defined as the movement of the outer plate with respect to the inner plates per unit load measured at the free outside end. It was found that to substantially improve the partition of load, the rivet material must be at least 10 times less rigid than the plate material. Also included is an electrical analog network for computation of the partition of load in the elastic range.

KEY WORDS: analyzing; distribution; load; rivets

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Presented is the 3-part final report on Assignment 9 of the AREA committee on iron and steel structures. Part 1 presents details of an inspection in 1956 of experimental installations of high strength structural bolts in 15 railroad bridges to determine if bolts would stay tight in locations where rivets had loosened. Most of the bolts performed satisfactorily. Part 2 describes a method of tightening high-strength bolts in which bolt tension is correlated with turns of the nut from a "finger-tight" position. Drew (abstract no. 85) covers essentially the same material as Part 2. Part 3 presents the revised Specifications for Assembly of Structural Joints Using High Tensile Steel Bolts in Steel Railway Bridges.

KEY WORDS: bolts; bolting; specifications
Data is presented on fatigue failures in ore bridges of the United States Steel Corporation. Significant factors in the failure in fatigue of the structural members are given, including riveted connection failure, fatigue cracks and strength of plates, state and gradient of stress, and others. A summary of laboratory tests on high-strength bolts shows that bolts can be substituted for hot-driven rivets.

Key Words: bolts; bridge; fatigue; metalliferous material


The results of an experimental investigation of the weakening effect of open holes in tension members and analysed according to the theory of plastic action. The technique is too complicated to be readily included in the already complicated elastic analysis of the gusset plate. Also presented is a list of references concerning the effect of holes, limit design, and safety factor as affected by holes.

Key Words: gusset plate; holes; plasticity


This paper was prepared as an introduction to a symposium on high-strength bolts in structural joints at the Centennial Convention of the ASCE at Chicago, Illinois, in 1952. The paper traces the history of the high-strength bolt and the organisation of the Research Council on Riveted and Bolted Structural Joints. It also describes the origin and development of the first set of specifications prepared by the Council.

Key Words: bolts; history; rivets


Results of static and fatigue tests conducted at the University of Illinois on structural joints using high tensile steel bolts are described. When the bolt tension exceeds 85% of elastic proof load, slip does not occur until plate stresses equal or slightly exceed normal working stresses. The type of joint-two-bolt or three-bolt lap joint or two-bolt butt joint-has little effect on the ultimate strength. The results indicate that the permissible shearing stress can be increased to 1.25 times the permissible tensile stress in order to obtain a balanced design. The high tensile bolts in the joint do not fail in fatigue. The fatigue strength of bolted joints is 25% greater than that of similar riveted joints. In short, high tensile bolted joints are generally superior to similar riveted joints in both static and fatigue loading.

Key Words: bolts; fatigue; joints; rivets; slippage; tension
Francis, A. J.


This is a discussion on the paper "Laboratory Tests of Bolted Joints" (Abstract No. 92). Mr. Francis notes that tests carried out for the Oakland Bay Bridge (California) have shown that the static strength of large joints failing in the rivets or bolts is less than the aggregate strength of the individual fasteners. Two factors - joint length and fasteners' ductility have opposite effects on joint strength and therefore it is not clear whether rivets or bolts are more efficient. Mr. Francis also notes that the conclusion drawn by Munse, Wright, and Newmark about the ratio of bolt shearing stress to plate tensile stress does not appear justifiable. In a balanced design, this ratio would vary depending on the relative strengths of the bolt material and the plate material.

KEY WORDS: bolts; fastener; ratio; stress

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Munse, W. H., Wright, D. T., and Newmark, N. M.


The authors (Abstract No. 92) say that the A7 steel joint assembled with A325 bolts contained the same number of fasteners as the similar joints assembled with A141 steel rivets, and not fewer as Mr. Francis stated (see Abstract No. 93). Even in large long joints it has been found that a high-strength bolted joint is at least as strong as a similar riveted joint. The behavior of a bolted joint depends on the proportions of the connections and therefore on the shear tension ratio. Although only three riveted specimens were used for comparison of fatigue strengths, the results resembled those of many previous tests.

KEY WORDS: bolts; fatigue strength; joints; rivet

(94)

Baron, F., and Larson, E. W., Jr.

COMPARISON OF BOLTED AND RIVETED JOINTS, Transactions, ASCE, Vol. 120, Paper No. 2778, 1955, pp. 1322-1334. (Appeared as COMPARATIVE BEHAVIOR OF BOLTED AND RIVETED JOINTS, Proceedings, ASCE, Vol. 80, Sep. No. 470, August 1954. Also appeared as Research Report C109, Northwestern University, 1952). The behaviors of bolted and riveted butt joints having a tension:shear:bearing ratio of about 1.00:1.75:1.50 and subjected to static and fatigue loads compared. The rivets were either hot or cold driven. The bolted joints were assembled with high-strength bolts. Several lengths of grip were considered for each type of fastener. Also considered were butt joints fastened with high-strength rivets and having a tension:shear:bearing ratio of 1.00:1.26:1.50. Seventy-four zero-to-tension and eighteen full reversal fatigue tests were conducted. Ten static tension tests were conducted to determine the relative behavior of joints. It was found that clamping force affects the fatigue strength of a joint and that fatigue strength of bolted joints are greater than those of riveted joints. The plate efficiencies in both types of joints are the same irrespective of the kind of fastener and length of grip and are higher than 80%.

KEY WORDS: bolts; fatigue; force, clamping; joint; load, static; rivet

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Heckman, R. A., Young, D. R., Chin, A. C., and Savicko, E. R.

SLIP OF JOINTS UNDER STATIC LOADS, Transactions, ASCE, Vol. 120, Paper No. 2778, 1955, pp. 1335-1352. (Appeared first in Proceedings, ASCE, Vol. 80, Separate No. 484, August 1954. This report summarizes the material reported in Progress Reports 1, 2, and 3, ON SLIP OF STRUCTURAL STEEL DOUBLE LAP JOINTS ASSEMBLED WITH HIGH STRENGTH BOLTS TO RCSRSJ, University of Washington, January 1951, 1952, and 1953. Slip in structural steel double-lap joints assembled with high-strength steel bolts and subjected to short-time static loading is analyzed. Altogether, 72 joints were tested; most were tested in tension, some in compression, and others in combined compression and torsion. Proper tightening of bolts prevented slip. Paying areas, net cross-sectional area, thickness of lap plates, and number of rows of bolts in the joint are important factors affecting slip. Painted paying areas are not desirable for bolted joints. The joints were compared on the basis of bearing stress on bolts, coefficient of friction, slip, and stress on net cross-sectional area. The application of the Gullander method to the design of eccentrically loaded joints is found sound.

KEY WORDS: bolts; lap joint; load, static; slipage; tension
Carter, J. W., Lenzen, K. H., and Wyly, L. T.


An explanation of a working hypothesis for, and a remedy for fatigue failures in riveted and bolted single lap joints are presented. It is hypothesized that the index to the fatigue strength of a structural member is given by the magnitude of the tensile stress concentrations computed on an elastic basis and the total tensile strain concentrations to which the member is repeatedly subjected. The bearing of the rivets in the holes nearest the edge of the gussets at the failure section is the source of the high stress and strain concentrations which result in low hanger fatigue strength. A hypothesis is also given to explain the results of fatigue tests of double lap joints.

KEY WORDS: bolt; clamping; fatigue; force; lap joint; rivet; slippage

Higgins, T. R., Noble, E. J.


Presented are examples of the use of high-strength bolts in building construction and a brief history of their use in structures. A description of various methods for controlling the torque exerted on the bolts by air impact wrenches is also included. Some of the work done by the Research Council is discussed along with the work which led to the present specifications. Possible future research and development of high-strength bolts are briefly discussed.

KEY WORDS: bolts; bolting; costs; structural engineering; utilization

Chesson, E., Jr., Peterson, K. S., Bell, W. C., and W. H. Munse

STATUS REPORT ON RIVETED AND BOLTED STRUCTURAL JOINTS, University of Illinois, Urbana, January 1956.

The progress of the test programs for the Research Council on Riveted and Bolted Structural Joints on Project I, II, III, IV, and VIII is reported (see Abstract 65). The scheduled and planned work of projects still in progress is also included. The projects briefly discussed are: I-The Effect of Rivet Bearing on the Static and Fatigue Strength of the Plates of Riveted Joints, II-The Effect of Rivet Pattern on the Static Strength of Structural Joints, III-The Strength of Rivets in Shear and Combined Shear and Tension, IV-The Fatigue Strength of Bolted Structural Joints, and VIII-Fatigue Tests on Cumulative Damage in Structural Joints.

KEY WORDS: bolts; RCRBSJ; research; rivets; status reports

Pope, R. G., Hyler, W. S., and Grover, H. J.

THE EFFECT OF INTERFERENCE FIT ON THE FATIGUE BEHAVIOR OF MONOBLOCK SPECIMENS OF 7075-T ALCLAD SHEET, Battelle Memorial Institute, Columbus 1, Ohio, June 6, 1956.

The effect of interference on the fatigue behavior of monoblock specimens of 7075-T Alclad sheet is evaluated. The fatigue behavior of monoblock specimens can be improved with Huck-bolts assembled with interference fit. The improvement is greater for brazier-head Huck-bolts than for countersunk-head Huck-bolts. As the depth of the countersink was increased, the fatigue strength decreased.

KEY WORDS: bolt, Huck; fatigue; fitting, interference; joint

The results of tests on 12 large bolted joints are presented. Two tension-shear ratios were investigated, 1.001/731 and 1.001/001. The tests were conducted to determine the effects of misaligned holes, punched holes, and low temperatures on the behavior of structural steel double-lap joints assembled with high tensile steel bolts. The effect of misalignment of holes on efficiency and ultimate strength of joints was negligible. The ultimate strength, efficiency, elongation, and strain-energy absorption of joints with drilled holes were greater than those with punched holes. Red lead paint on the faying surfaces decreased the coefficient of friction by 23/4 at room temperature. At -25°F the coefficient for ungated mill scale and red lead painted faying surfaces was about the same. At -25°F the ultimate strength and efficiency of the joints decreased 20% and the elongation and the strain energy absorbed decreased 80%.

KEY WORDS: bolts; hole; splitting; surface


The author examines the results of tests made by the National Luchtvaartlaboratorium in the Netherlands for the primary purpose of comparing several types of riveted joints and to study the effects of stress concentration factor, notch pattern, joint dimension, sheet thickness, dimpling mode, and other factors on the fatigue strength of lugs. Lugs in which the bolt is loaded in double shear, the theoretical stress concentration factor is approximately known, provided certain conditions are complied with. The most important of these is that the bolt is rigid enough so that bending can be discounted. The fit of the bolt itself has scarcely any effect on the stress concentration factor, provided the interference of the bolt is not too great. Recommendations for proportioning joints are made.

KEY WORDS: fatigue strength; lug; rivet; stress concentration

STATIC TENSION TESTS OF RIVETS AND HIGH STRENGTH BOLTS IN STRUCTURAL CONNECTIONS, Dept. of Civil Engineering, University of Illinois, SRS No. 124, November 1956.

The behavior of fasteners in a tension-type structural connection assembled with ASTM A325-37T high-strength bolts or A61 rivets is explained. The effect of the size and flexibility of the connected members and the effectiveness of the fasteners in members fabricated from wide-flange sections and assembled with more than two lines of fasteners. The tests show that four-fastener bolted specimens have efficiencies of 73.0 and 76.8% and similar riveted specimens have 101.1 and 77.1%. Eight-fastener specimens were only 40% efficient. The use of low prestress bolts of fully threaded bolts has little effect on the load-carrying capacity of the members. An increase in flange stiffness causes an increase in efficiency. The load carried by the riveted joints varied from 20% lower to 3% higher than that of similar bolted specimens.

KEY WORDS: bolts; fastener; rivet; tension


The work of Project Committee No. 1 which included a review of prior work on the influence of bearing on static strength and an experimental program carried out in the structural laboratory of the University of Illinois is summarized. Seventeen static tests, eighteen tensile tests, six single shear tests, and eighteen compressive tests were included in this project. The experimental work and a review of the prior work led to the conclusion that the strength of joints loaded in tension does not decrease if the ratio of bearing pressure to the net tensile stress on the net material does not exceed 2.25. The strength of a joint loaded in compression or shear will also not decrease if the ratio of bearing pressure to shearing stress on the rivets does not exceed 3.00. Limits are recommended for the ratio of rivet shear to plate tension. There is no reason to differentiate between the allowable bearing pressure on a rivet stressed in single shear and that on a rivet stressed in double shear.

KEY WORDS: ratio, bearing; rivet; slippage; static test
Sanks, R. L.

TWO USEFUL GAGES MEASURE BOLT TENSION AND SLIP IN A JOINT, Civil Engineering, Vol. 26, No. 11, November 1956.

The details of the design and operation of load cells for the measurement of tension in high strength bolts and clip gages for the measurement of slip in joints are explained.

KEY WORDS: bolts; cell; load; joint; measuring instrument; slippage

Duffy, A. R.

STATIC MECHANICS OF A DOUBLE-STRAP BUTT JOINT CONNECTED WITH HIGH-STRENGTH BOLTS, M. S. Thesis, Purdue University, Lafayette, Indiana, 1956.

The behavior of a joint assembled with high-strength bolt is discussed in relation to the clamping force in the bolts, frictional resistance between plate surfaces, slip between adjacent plates, and load distribution throughout the joint. The test results show that slip is usually a local matter; that strain, clamping force, and slip are closely related; and that frictional resistance to slip is a non-uniform phenomenon.

KEY WORDS: bolts; force, clamping; joint; slippage

Munse, W. H.


The effects and advantages of high initial tension in high-strength bolts as determined in static and fatigue tests of bolts and bolted joints, and the general behavior of bolted joints subjected to static and repeated loads are presented in synoptic form. It is stated that the initial tension in the bolt must be as high as possible to maximize resistance to static and fatigue loadings.

KEY WORDS: bolts; structure; tension

Munse, W. H., and Cox, H. L.

THE STATIC STRENGTH OF RIVETS SUBJECTED TO COMBINED TENSION AND SHEAR, Bulletin, University of Illinois Engineering Experiment Station, Vol. 54, No. 637, No. 29, December 1956. (First distributed by Dept. of Civil Engineering, University of Illinois, as BRS No. 23, January 1952).

The strength and behavior of rivets subjected to various combinations of shear and tension are determined through results of 403 tests. The strength of rivets subjected to loads ranging from direct tension to direct shear is expressed as a non-dimensional elliptical interaction curve. The paper also shows the manner in which the yield strength, ultimate strength, and deformation of rivets are affected by such variables as rivet grip, rivet diameter, method of driving, and type of manufacture of rivets.

KEY WORDS: driving; ratio, shear-tension; rivets; soaking; strength, static; tensile strength
The behavior of four large bolted joints tightened by the one-turn-of-the-nut method was investigated. The test joints were fabricated from two large joints which had been tested previously to determine their slip characteristics. The one-turn-of-the-nut method gave a lower coefficient of friction for the first major slip and a higher clamping force than the minimum-bolt-tension method. Calculated efficiencies agreed closely with experimental efficiencies.

Krickenberger, C. F., Jr., Chesson, E., Jr., and Munse, W. H.  
EVALUATION OF NUTS FOR USE WITH HIGH STRENGTH BOLTS, Dept. of Civil Engineering, University of Illinois, SRS No. 128, January 1957.

The results of tests of standard nuts and heavy nuts for A325 bolts are reported. The results show: (1) Regular series nuts are satisfactory for use with high strength bolts, particularly those nuts with medium carbon content or which have been cold worked or heat treated to increase their strength. Regular nuts of hardness less than 95 Rockwell B are unsatisfactory for 3/4 in. bolts. (2) Heavy series nuts of hardness less than 75 Rockwell B are unsatisfactory for 3/4 in. bolts. (3) All nuts give minimum specified bolt tension after one turn of the nut. (4) All nut and bolt assemblies retain tensions for a two day period. (5) Heavy series nuts require slightly longer impacting times for one turn and give slightly higher bolt tensions and smaller deformations than similar regular series nuts. (6) The average number of turns to failure is two for both regular and heavy series nuts.

KEY WORDS: bolts; nut; tension

Lu, Z. A., Vazirshah, C., and Yasazhalii, B. B.  

The behavior of four large bolted joints tightened by the one-turn-of-the-nut method was investigated. The test joints were fabricated from two large joints which had been tested previously to determine their slip characteristics. The one-turn-of-the-nut method gave a lower coefficient of friction for the first major slip and a higher clamping force than the minimum-bolt-tension method. Calculated efficiencies agreed closely with experimental efficiencies.

KEY WORDS: bolts; fabrication; joints; tension

Godfrey, G. B.  

Design developments in bridges and structures in post-war Germany are discussed. Included is a brief note on the use of high-strength bolts in bridges and structures and specifications for bolt holes, and recommendations for quality of bolts and nuts, tightening torque of nuts, and treatment of contact surfaces to provide frictional strength.

KEY WORDS: bolts; nuts; torque

THE EFFECT OF INTERFERENCE FIT ON THE FATIGUE BEHAVIOR OF ALUMINUM-ALLOY JOINTS, Battelle Memorial Institute, Columbus 1, Ohio, April 19, 1957.

The effect of interference, clamping pressure, sheet material, sheet thickness-to-Huck-bolt-diameter ratio, surface lubricants, and adhesives on the fatigue performance of joints assembled with Huck-bolt pins is investigated. The experimental fatigue data for joints assembled with interference of 0.000 and 0.007 in. between hole and Huck-bolt-pin was obtained at three nominal values of clamping force: 0, 1300, and 2500 lbs. Fatigue behavior of single-shear and double-shear lap joints assembled with or without moderate values of preload can be improved by assembling the Huck-bolt pins in interference as well as by high clamping forces. Fretting corrosion between the faying sheets is the most important factor governing the fatigue behavior of the joint. However, fretting failures can be relieved with pliable adhesives.

KEY WORDS: aluminum alloy; bolt, Huck; butt joint; fatigue; fitting, interference; force, clamping; lap joint
The behavior of high-strength steel joints assembled with high-strength bolts and subjected to tension is discussed. The reserve capacity for load at the first major slip is substantial. Increase in clamping force increases the friction force and the carrying capacity for A242 steel without slip increases with the increase in clamping force. The A325 bolted connection developed the full tensile strength of the main plate material at the net section.

KEY WORDS: bolts; friction; joint; slipage; tension; torque

White, M. W., and Thurlimann, R. 

This report presents a complete analytical and laboratory study of the strength of columns showing perforated cover plates in place of the lacing system or batten plates. Previous studies are reviewed and an analytical study of eccentrically and concentrically loaded columns, taking into account axial rigidity, bending stiffness, transverse shear, local buckling and stress concentration due to the perforation in presented. Two full size riveted columns were tested to failure. The columns were designed to existing specifications and the cross-section dimensions and perforation spacing was similar to the diagonal members used in the bridge over the Mississippi River at New Orleans, La. One column was fabricated from A7 steel and the other from a new high-strength steel. The tests were conducted to determine and compare their ultimate strengths, to check current design procedure and to check the analysis. The results indicate that the ultimate capacity was closely predicted using the tangent modulus. Also, the beginning of local buckling was not catastrophic. Design recommendations based on the analytical studies are given.

KEY WORDS: analyzing; columns; plates, cover; rivet; steel; testing


The theory of friction grip joints, the theory of tightening high preload bolted connections, the half-torque-half-turn technique, the Western Region code of practice of British Railways, and laboratory tests are discussed in synoptic form. The authors conclude that bolts to British Standard Specifications could be used either with the torque coefficient or the turn-limiting technique to produce satisfactory joints. Power tools might replace manual wrenches with large bolts in the torque coefficient technique. Because of the advantages of strain limiting technique, the 'half-torque-half-turn' could be adopted widely in conjunction with power tightening supplemented by manual methods.

KEY WORDS: bolts; friction; pretensioning; utilizations

Institution of Structural Engineers

After discussion it is concluded that a single tool could be used to apply the half-torque-half-turn technique. An impact wrench capable of applying the final part-turn could easily be modified to indicate the part-torque. Preload induced in service by the applied torque was higher than expected and resulted in thread stripping. Decrease of preload is discussed, and it is concluded that even if the stress in a bolt were not allowed to exceed the limit of proportionality there might still be some loss of preload in cyclic load application.

KEY WORDS: bolts; pretensioning; torque
Bell, M. H.

A brief history of the development of the high-strength bolt is presented together with a resume of the development of specifications for field assembly using these bolts. The use of the pneumatic wrench procedures for determining bolt tension are described. Many examples of the use of high-strength bolts are cited and illustrated.

KEY WORDS: bolts; specifications; utilizations

Thrasher, J. Q.
"SILENCE, IT'S GOLDEN!" Steelways, June 1957, pp. 22-23.

Presented is a brief history of the tendency to change from rivets to high-strength bolts for use as structural fasteners. The organization and development of the Research Council, its sponsors, and the work done by the engineering schools of five universities - Northwestern, Purdue, Illinois, Washington (at Seattle), and Lehigh - are discussed. The advantages of bolts over rivets, including lower noise, lower cost, and easier and faster installation and replacement, are noted.

KEY WORDS: bolts; economic factors; RCRBSJ; rivets

Douty, R. T.
CHARACTERISTICS OF FLEXIBLE FLANGE CONNECTIONS AND FASTENERS, M. S. Thesis, Georgia Institute of Technology, June 1957.

Presented is an investigation of the characteristics of a connection employing a flexible flange and a study of the additional load placed on the fasteners as a result of prying action of the flange. Test specimens consisted of six tee sections connected with A325 bolts and eight brackets fabricated of plates welded together. Equations are developed for computation of the effect of strain hardening of the flange on fastener tension. Initial pretension of fasteners has no effect on the ultimate load of high-tensile-strength bolted-flange-type connections. Also included are recommendations for design which incorporate the results of the investigation.

KEY WORDS: brackets; fasteners; flange; plastic analysis; tension


The report analyzes the slip characteristics of various joints fastened with high-strength bolts and subjected to static loading. It includes information on the effects of the one-turn-of-the-nut method on 4-bolt joints. The condition of the faying surfaces determines the value of the coefficient of friction. The factors that reduce the coefficient of friction are: (1) increasing bolt tension, (2) decreasing tension-shear ratio, (3) increasing size of joint, (4) increasing number of bolts, and (5) sustained loading.

KEY WORDS: bolts; friction; slippage; surface, faying; tension
Munse, W. H.
AN EVALUATION OF THE BEHAVIOR OF STRUCTURAL CONNECTIONS ASSEMBLED WITH HOOK-KNURL BOLTS,
University of Illinois, September 1957.

Five double-lap splices assembled with high-strength bolts and 9 similar joints
assembled with Hook-Knurl bolts behaved similarly under static and fatigue loading.
However, joints with Hook-Knurl bolts were superior to those with high-strength
bolts under slip-producing conditions, while the joints with high-strength bolts
were slightly superior under fatigue loading.

KEY WORDS: bolts; butt joints; fatigue; static test; testing

Chauner, R. W., and Vasarhelyi, D. D.
DOES VIBRATION AFFECT FRICTION IN A BOLTED JOINT, The Trend in Engineering, University

Sixty-five tests were run on one bolted double-lap joint. The faying surfaces were
belt-sanded to remove all mill scale. In most cases, load was applied until notice­
able slip was reached. After slip the specimen was dismounted and new fasteners
were installed. Three different levels of clamping force were investigated. For
each range of clamping force, the joint was subjected to static tension loading with
and without vibration. There is a 6 to 8% decrease in the load required to cause
slip of a bolted steel joint if vibrations on the order of 1800 cps are present.
There is a decrease in the coefficient of friction under vibrational loading.

KEY WORDS: bolts; friction; joint; steel; vibration

Peeler, L. J.
BOLT SHEAR TESTS, Final Report for C. E. 103, Lehigh University, Bethlehem, Pa., 1957.

Tests were performed at Lehigh University, Bethlehem, Pennsylvania, on 7/8 in. and 1
in. tensioned high-strength bolts to find the shearing strength. Tension load
applied by tightening the nut was measured on the dial of a 300k testing machine.
Shearing load was applied by the 300k testing machine. The results are analysed
by the use of Distortion Energy theory. The calculated ultimate shearing stress is
higher than that given for A325 bolts from data in which bending and frictional shear
are not included, and the yield stress is about 40 ksi, which is approximately 2.65
times the AISI allowable 15 ksi.

KEY WORDS: bolt; shear strength; tension; yield point

Wyly, L. T.
FATIGUE STUDIES ON STRUCTURAL JOINTS OF ASTM A-7 AND A-242 HIGH STRENGTH STEEL,

Data on the fatigue properties of structural joints is presented from field and
laboratory investigations. The clamping force in structural joints is highly
critical in fatigue applications. In general, bolted joints show better fatigue
resistance because they are free from the local stress and strain concentrations and
the varying clamping forces which characterize riveted joints. Fatigue failure in
riveted joints may be prevented by replacing the rivets with high-strength bolts
prevented from bearing on the plates by ample hole clearance and tightened sufficiently
to produce enough clamping force to prevent slip and to provide an initial compression
stress and strain at the sides of the holes.

KEY WORDS: bolts; design; fatigue; joints; rivets
Holt, J. A.
300,000 HIGH STRENGTH BOLTS-WORLD'S RECORD IN BRIDGE CONSTRUCTION, Fasteners, Vol. 12, Nos. 2 and 3, Fall 1957, pp. 2-3.

The use of 300,000 high-strength bolts, a record number for one project, is discussed. These 3/4 in. and 7/8 in. bolts (some of the 7/8 in. size with countersunk heads) were manufactured to specifications and installed with pneumatic wrenches. Torque was controlled by running the wrench to "stall" on a predetermined air pressure. The "full-turn-of-the-nut" procedure (AREA Bulletin 520) was tried, but it took longer than the "stall" method because initial hand tightening of the nut was required. A No. 325 Warren and Brown Manual torque wrench was used to test installed fasteners. The average total cost per fastener in place, including wrench maintenance was about $0.50.

KEY WORDS: bolts; bridge construction; fabrication; installing

Bean, S. Y., and Vazarehlyi, D. D.

Tests were made at the University of Washington to supplement previous tests (see Abstract 120) and to determine the effect of faying surface treatment on the coefficient of friction in bolted joints using high-strength bolts. The faying surfaces were thoroughly cleaned either by fire or sand blast and then in some cases treated with either red lead paint or profilm plastic of different grades. The results suggest that profilm develops friction greater than red lead and that a metallic bond contributes to friction. The slip test employed herein for determining the nominal coefficient of friction can be standardized as a test for comparison of frictional behavior of faying surfaces in structural joints.

KEY WORDS: bolt; friction; joint; slippage; surface, faying

Princke, M. H.

The development of a modified turn-of-nut method adopted by The Bethlehem Pacific Coast Corporation is outlined. The method is described. The nut is run up to a "snug" position with an impact wrench and is then given an additional 1/2 or 3/4 turn, depending on bolt length. A table listing compressor capacities for impact wrenches is given. Bolts assembled with this procedure will have no less than the minimum specified tension.

KEY WORDS: bolts; installing; prestressing

McDonald, D., Ang, A., and Massard, J. M.
AN INVESTIGATION OF RIVETED AND BOLTED COLUMN-BASE AND BEAM-TO-COLUMN CONNECTIONS UNDER SLOW AND RAPID LOADING, Dept. of Civil Engineering, University of Illinois, February 1958.

Presented are a description of and results from slow and rapid load tests to determine the resistance characteristics of riveted and bolted column-base and beam-to-column connections. The investigation was limited by the small number of specimens and the lack of variety of connections. The tests clearly indicate that the rate of deformation had a greater resistance of the connection; rapidly deformed specimens had a greater resistance at a given deflection than those deformed slowly. The type of fastener had little effect on the moment-rotation characteristics of the connections studied. Also presented is a procedure which accounts for strain hardening in the evaluation of resistance of a frame with semi-rigid connections as it is loaded into the inelastic range.

KEY WORDS: column; fastener; joint; beam-to-column; resistance
Economical and practical design considerations in the selection of a fastener are presented in synoptic form. They are: shear, bearing, tension, efficiency of the joint, fatigue, joint slippage, vibration, appearance, maintenance, installation clearance, portability, and noise abatement. A table is presented which shows material and direct labor costs for installing these field fasteners: rivets, ribbed bolts, high-strength bolts, unfinished bolts, and 5/16 in. fillet welds. Method of erection is a practical consideration in fastener choice.

**KEY WORDS:** bolts; design; joints; rivets; welded joints

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**Chesson, E., Jr., and Munse, W. H.**


Specimen configuration, method of hole preparation, and rivet size were the main variables considered in 16 tests of 5 types of truss-type riveted structural connections. Shear failures may be expected in long truss-type joints of "balanced design". The distribution of rivets in a joint should be similar to the distribution of areas connected to those rivets. Members with drilled holes were more susceptible to shear failures than were similar punched specimens. Larger rivet diameters and the resulting smaller number of holes may improve shear strength of large connections. To avoid gusset failure, narrower and stiffer gussets are preferred over thinner gussets having the same net area. To avoid tensile failures at lacing rivets, the edge distances should be made as large as possible. The efficiency of punched specimens and drilled specimens varies only slightly. The ARES net section rule can be used as a basis for efficiency specifications.

**KEY WORDS:** efficiency; gusset plates; joint; rivets; trusses
Six large butt joints of A7 steel connected with 7/8 in. A325 bolts were tested to failure under static loading. The fasteners were usually arranged in compact patterns with three to six fasteners in a line. Five joints had five lines of bolts and one had six lines. All bolts were installed by the turn-of-nut procedure. The specimens were designed with various tension-shear ratios (the ratio of the tensile stress on the net section of the plate to the shear stress on the fasteners). One riveted joint containing 25-7/8 in. A141 steel rivets was tested to provide comparative data. Results indicated that simultaneous failure in the A325 bolts and A7 steel plate would occur when the net plate area was approximately 110% of the bolt shear area. Major slip occurred at nominal bolt shear stresses which were 75% to 125% in excess of normal working stresses. The average slip coefficient was approximately 0.4.

KEY WORDS: bolts; joints; slippage; steel; strength; structural engineering; testing
This report is a summary of an investigation to determine the shear strength of a single A325 bolt subjected to double shear. Single bolts were subjected to double shear by applying a compressive load to the plates of the shear jig. The initial internal bolt tension was varied from zero to a maximum which corresponded to 1/2, or 1, or 1-1/2 turns-of-the-nut. The faying surfaces were either clean mill scale or mill scale lubricated with Molycote. The ultimate double shear strength of the bolt was unaffected by the amount of initial bolt tension. Bolts joining plates with clean mill scale surfaces showed a slight increase in shear strength over bolts connecting lubricated plates.

KEY WORDS: bolts; joint; steel; structural engineering; testing

Lewitt, C. W., Chesson, E., Jr., and Munse, W. H.
THE EFFECT OF RIVET BEARING ON THE FATIGUE STRENGTH OF RIVETED JOINTS, University of Illinois, SRS No. 170, January 1959.

The effect is reported of bearing pressure on the fatigue strength of A7 steel joints fastened with two rows of hot-formed, hot-driven A41 steel rivets. Twenty-six zero-to-tension tests and eight full-reversal tests were made. The bearing to tension ratios studied were 1.37, 1.84, 2.36, and 2.74. The zero-to-tension tests show that an increase in fatigue life is accompanied by a decrease in bearing pressure. The number of full reversal tests was insufficient to isolate the relationship of fatigue strength to bearing ratio. Also, the average clamping force of rivets increased with an increase in grip and increased clamping force was accompanied by, and probably caused, an increase in fatigue life.

KEY WORDS: bearing; fatigue strength; joints; rivet

Chesson, E., Jr., Lewitt, C. W., Dineen, R. L., and Munse, W. H.
STATUS REPORT ON RIVETED AND BOLTED STRUCTURAL JOINTS, University of Illinois, Urbana, January 1959.

Projects I - Effect of Rivet Bearing on the Static and Fatigue Strength of Riveted Joints, II - Effect of Rivet Pattern on the Static and Fatigue Strength of Bolled Structural Joints, and VIII - Fatigue Tests on Cumulative Damage in Structural Joints are briefly discussed to indicate which parts of the program had been completed or were in progress. Summaries of the results of those portions of the completed programs are presented.

KEY WORDS: R CRSJ; status report

Munse, W. H.
STUDY OF THE EFFECT OF FLANGED NUTS ON THE FATIGUE BEHAVIOR OF FLAT PLATES, University of Illinois, Urbana, January 1959.

The effects of flanged nuts on the fatigue behavior of structural steel are presented. The tests show that the fatigue strength of a plate with an open hole does not decrease as a result of turning a flanged nut on the surface of the plate. Gripping or keying action of the flanged nut coupled with the high clamping force of the bolt provides an increase in the fatigue strength of the plate. In general, the strength of members in joints assembled with flanged nuts is equal to or greater than that of members in joints assembled with ordinary nuts for A325 bolts.

KEY WORDS: bolt; fatigue strength; nuts; plates, flat; washers
Sixteen tests were made on 3/4 in. high-strength bolts of both 2.75 and 4.00 in. in length. The bolts were loaded in tension-shear ratios of from 1.0:0 to 1.0:0.67. The 4 in. bolts failed through the threads at T:S = 1.0:0, 1.0:0.20, and 1.0:0.42. The 2.75 in. bolts failed in the shanks at angles of fracture from approximately 90° to 45° with the bolt axes. The ratio of tensile strength to shear strength was 1.26.

Also presented is a proposal for a future testing program including further investigation of the grip, thread length, T:S ratio, bolt strength, bolt diameter, deformation measurements, and material in shear blocks. A proposal for a second series of tests concerning impact loadings and fatigue loadings is briefly discussed.

Key Words: bolt; tension; ratio, shear

Schutz, F. W., Jr.

Recent research is used to support a proposal for the development of an improved analysis and design procedure for moment connections using high-strength bolts. Typical test results are given for tee section moment connections, butt type moment connections, and conventional beam splices. The new design method can be based logically on some of the fundamentals of plastic analysis and design of rigid steel frames. Plastic design of bolted connections can reduce the number of bolts required and the amount of steel in connection parts, and increase usable space above and below beam ends. Several connections designed with the proposed criteria are compared with typical riveted and bolted connections.

Key Words: analyzing; bolts; joints; steel; structural engineering

Munse, W. H.
THE EFFECT OF BEARING PRESSURE ON THE STATIC STRENGTH OF RIVETED CONNECTIONS, Bulletin, No. 454, University of Illinois Engineering Experiment Station, July 1959.

The effect of bearing pressure on the static strength and behavior of riveted connections is determined from tensile and compression tests of 131 riveted joints. In the tensile tests the bearing ratio—the ratio of bearing stress to tensile stress—varied from 1.28 to 3.05, while in the compression tests the ratio varied from 1.78 to 4.21. Under static tensile loading, the strength or efficiency of the riveted joint is not reduced as a result of increasing the bearing stress to a value of 2.25 times the tensile stress in the connections. The increase in efficiency normally expected from the wide gage distances necessary for high bearing stress may not be fully realized.

Key Words: bearing; joint; rivet; strength, static
**Societe de la Tour Eiffel**


This article describes briefly the history of the Eiffel Tower, which was 70 years old in 1959. The tower is composed of 15,000 steel members connected by 2,000,000 rivets. It is 1025 ft. above ground and is supported by four legs which join at the second story, 380 ft. above the ground. The tower can resist an 82 lb. per sq. ft. wind load, and the top may move in a 7 in. circle due to member elongations on a sunny day. Rivet maintenance on the tower has been negligible, but it has to be painted every seven years.

KEY WORDS: loads, wind; maintenance; publicity; riveted joints

**Young, W. C.**

RESULTS OF TESTS OF STRUCTURAL CONNECTIONS ASSEMBLED WITH HIGH TENSILE STRUCTURAL RIB BOLTS-INTERUPTED RIBS, University of Wisconsin, May 1959.

The properties of structural steel lap and butt joints jointed with American Standard High-Strength Hexagon Head Bolts, ASTM A325 are compared to the properties of similar joined with high-strength structural rib bolts, ASTM A325. Up to a certain point the characteristics of these joints are identical. Beyond this point, the interference fit of the rib bolts prevents slip. For loads up to 60,000 lb. for the lap joints and 71,000 lb. for butt joints, the deformation of the joints using rib bolts are the same regardless of the type of nut and washer used. In addition, rib bolts carry greater shearing load at failure than ordinary A325 bolts.

KEY WORDS: bolt; deformation; structure; tension

**Steinhardt, O.**


This paper reports the German contribution to research concerning such aspects of strength bolts as bolt stresses, slip resistance, behavior under static and dynamic loading, bolt tension, extension of joints with increasing loads, types of construction with high strength bolts, and practical application. However, the paper is mainly concerned with slip resistance. The results of tests to determine the coefficient of friction are summarized. Treatment of the contact surfaces was shown to increase frictional resistance. A marked increase was noted for double or oblique flame-cleaned ST52 high-tensile steel. The coefficient of friction if for mild steel ranged from 0.181 to 0.593 for surface brushed and cleaned from 0.430 to 0.767 for surfaces sandblasted, and from 0.335 to 0.751 for surface flame cleaned. For high tensile steel the coefficient were 0.382 to 0.466 for surface brushed and from 0.574 to 0.805 for simple flame cleaning. A few tests of joints fastened with both high strength bolts and welds showed good interaction up to the limits of friction.

KEY WORDS: bolts; fatigue; friction; joint; load; research; slippage; static test

**Godfrey, G. B.**


This paper contains a brief history of high-strength bolts in various countries, American Specifications for assembly of structural joints using high strength bolts, and a comparison of American specifications with those of other countries. An explanation and analysis of British design of high-strength bolted joints is presented.

KEY WORDS: bolts; joint; specifications
Directives for the calculation, design, and assembly of non-slip high-strength bolted connections issued by the German Committee for Structural Steelwork are explained in this appendix. The principles for calculation of permissible loads, stresses, and bearing pressures are given in condensed form. The design considerations include the choice of the material and dimensions of bolts, nuts, and washers, and the treatment of the contact surfaces. A brief procedure for assembly and tensioning of bolts is prescribed.

KEY WORDS: bolts; computation; design; instructions; joints; structural engineering

Investigated are the contact surface conditions and the bolt tightening torques required to transmit a working load of 5 tons per bolt per contact surface with a safety factor of 1.5 in a structural joint assembled with 1 in. diameter UNF high-tensile steel bolts. The test specimens were double lap joints containing 1, 4, or 6 bolts. The slips were measured under static and dynamic loads. It was found that untreated rusty surfaces require a torque of at least 600 pounds-feet for static loading and 700 pounds-feet for dynamic loading.

KEY WORDS: bolt; friction; joint; torque

The behavior and design of a rigid beam-to-column connection assembled with special grade high-strength steel bolts and intended to transmit "fixed-end" moments and wind moments were fully examined. The behavior of the beam connection under load was studied by subjecting a full-size moment connection simultaneously to moment and shear. Graphs of deflection and separation of the end plate from the column were plotted as functions of load. Because the separation curves were observed by local deformation, it is difficult to predict the load at which separation occurs. Slip was not observed even at maximum load.

KEY WORDS: bolt; joint; rigid frame; moment; shear

A brief history of the use of high-strength friction-grip bolts is presented along with a discussion of their advantages as an alternative to rivets or fitted bolts in site connections. The results of 108 tests to determine the torque-tension relationship for 3/4 in. bolts are presented graphically.

KEY WORDS: bolt; structure; utilization

Investigated was the effect of sprayed metal coatings of faying surfaces on the load-slip characteristics of double-lap structural steel joints assembled with high-strength bolts. The 24 specimens were made from semi-killed plain carbon structural steel. The surfaces were either rolled, painted, metal sprayed, or sand blasted. The rolled surfaces were wire-brushed and cleaned mill scale. The painted surfaces were wire-brushed mill scale coated with red lead. The metals used in metal spraying included zinc, aluminum, and chrome nickel steel. It is concluded that protective coatings of sprayed metal may improve the coefficient of friction under static loading.

KEY WORDS: bolts; friction; joints; slippage; steel; testing


Nine tests were made on HE30-WP aluminum double-cover plate type butt joints. This joint design was selected to assure a tangential load between rubbing surfaces. Load at major slip was used to calculate the coefficient of friction, which was 0.140 for a joint with 1 bolt, 0.121 for 2 bolts, and 0.131 for 3 bolts. It is concluded that shot-blasting the faying surfaces creates satisfactory friction in aluminum alloy joints.

KEY WORDS: aluminum; bolts; friction; joints; slippage; testing


The effect of preloaded high-strength bolts on the plastic moment of the connected members of certain rigid joints was determined in six tests. The flange plates stiffen the parent joint and the section acts as a compound member. Preload is not guaranteed by tightening bolts to a given minimum torque. Maximum frictional grip is developed when the faying surfaces are not prevented from bedding closely together.

KEY WORDS: bolts; components; joints; moment; pretensioning


The load-carrying characteristics of pretensioned bolts in tensioned joints are discussed. The bolt load does not increase unless the working load exceeds the bolt preload. When the working load exceeds the preload the increase in bolt load is very small. The increase in bolt load depends on the stiffnesses of the bolt and the bolted members, and the point at which the working load is applied. A few advantages of high preload are discussed.

KEY WORDS: bolt, pretensioned; joint, tensioned; load
Discussed and illustrated are uses of high-strength bolts as structural fasteners, the design of high-strength bolt connections, and sample check tests on specimen connections and shop practice for the preparation and fabrication of such connections. The advantages in cost, ease of handling, and in simplicity of equipment and site organization of high strength bolts over traditional structural fasteners such as rivets, black bolts, and welds are also discussed.

KEY WORDS: bolts; joints; steel; structural engineering

A descriptive discussion of the uses and advantages of high-strength bolts, torque limiting wrenches, torque multiplying wrenches, surface preparation of the plies, Prolong bolt, and Torshear bolts is presented. Brief notes on the turn-of-the-nut method of tightening high strength bolts using pneumatic wrenches and the application of high strength bolts to the site joints of plate girders and railway bridges are also included. The Prolong bolt has a longitudinal serrated extension which provides a built-in anchorage to take the reaction. The bolt was developed for applications where use of a geared torque-multiplying wrench required a reaction point on the adjacent structure. The Torshear bolt has a threaded portion which extends beyond a machined concentric groove outside the nut. When being tightened with a special wrench load is induced until the extension is sheared off in torsion.

KEY WORDS: bolts; friction; joints; steel

A brief history of the development and use of the high-strength bolt is given, together with examples of its application in building and bridge construction in the U. S. Pretensioning and the means of achieving it with calibrated impact wrenches and the turn-of-the-nut method are discussed in detail. Research conducted at the University of Illinois, The Association of American Railroads, and Lehigh University is described as having shown that A325 bolts can be tightened past their yield strength without injury.

KEY WORDS: bolts; design; installing; joints; steel; structural engineering
The history of the use of high-strength bolts in the construction of railway and highway bridges in Germany is traced. The advantages of high-strength bolts over other fasteners, the use of wrenches in tightening bolts, and the form of bridge construction adopted are reported.

KEY WORDS: bolt; bridges; joints; installing

The report contains a review of bolt calibration procedures and a discussion of the procedure used at Lehigh University, Bethlehem, Pennsylvania. The bolts used for the tests were regular head ASTM A325 high-strength bolts with quenched and tempered washers and heavy semi-finished nuts. 7/8", 1", and 1-1/8" bolts were used for direct tension calibration, torqued calibration, and load-unload-reload tests. The method used to induce the internal tension in the bolt in direct tension calibration and torqued calibration had no effect on the tension-elongation relationship in the elastic region. However, a very definite decrease in ultimate strength was apparent beyond the proportional limit for bolts torqued to obtain tension.

Thirty truss-type specimens were tested to provide information on the distribution of load to gusset plates of double-plane built-up members and to determine the effect of the method of hole preparation, type and size of fasteners. The comparative behavior of the specimens is described. The formula $\frac{P}{A} = \frac{1}{E}$ was satisfactory for use in elongation computations for truss members. Gusset plates were not always fully effective over their entire width, and punched members were less efficient than drilled members. A comparison of predicted and actual efficiencies is made and the following items are recommended for consideration when designing tension members: (1) joint pattern, (2) method of hole manufacture, (3) distribution of area in the connection, and, (4) length of the connection. These items could be expressed in a simple expression. If separate design stresses are specified for punched and for drilled members, a maximum of 90% gross area should be considered as effective in resisting tensile loads.

KEY WORDS: bolt; gusset plate; rivet; shear test; tension; trusses

Munse, W. H., and Chesson, E., Jr.
SUMMARY-INVESTIGATION OF HIGH-TENSILE BOLTS AND BOLTED CONNECTIONS, University of Illinois, Urbana, November 1959.

Compiled are conclusions drawn by the staff at the University of Illinois from the 17 progress report summaries on the "Investigations on High-Tensile Bolts and Bolted Connections" for which research was started in 1947 for Project IV of the RCRBSJ, the Illinois Division of Highways, and the Department of Commerce-Bureau of Roads. The details of the tests, test specimens, and test results may be obtained from the original reports which are listed in the Table of Contents. A list of publications is also presented.

KEY WORDS: bolts; joints, bolted; RCRBSJ
A descriptive article is presented on preload and strength of bolted joints. Graphs of the bolt tensile stress vs. torque are shown for different diameter steel bolts. A formula, \( T = f \times D \times L \), where \( T \) is torque, \( f \) is the surface finish factor, \( D \) is nominal thread diameter in inches, and \( L \) is tension load in lbs., is given to predict required torque.

**KEY WORDS:** bolt; force, clamping; joint; pretensioning; torsion

The results of 18 static tension tests of double lap tension splices are reported. Twelve of the joints had 1 row of 4 high-strength bolts. Two of the joints had 4 rows of 3 high-strength bolts. Eight of these specimens had one or more of the fasteners misaligned. In addition, 4 joints were connected by 1 row of 4 A141 steel rivets. All joints had red lead paint on the faying surfaces. The test results indicate that even severe misalignment has no significant effect on most of the characteristics of bolted joints. Neither the slip, elongation, joint efficiency, nor ultimate strength were significantly affected.

**KEY WORDS:** alignment; bolt; efficiency; joint; shear test; tension

5/8 in. bolts were tested in single and double shear, using 1/2 in. by 2 in. steel test pieces drilled with 11/16 in. holes. The bolts failed in single shear at an average load of 26,900 lb. and in double shear at 54,000 lb. Bearing stresses on the structural members, not bolt shear, are the limiting factors in design.

**KEY WORDS:** bearing strength; bolts; shear stress

A review of structural fasteners is presented in this article. The more than 100 million structural fasteners manufactured annually provide safe, dependable joints in structural applications. Riveting is the oldest known method of joining metal. The designer selects a rivet on the basis of load transference through shear on the rivets and bearing of the rivets against the walls of the rivet holes. Unfinished bolts are suitable for joining low-tonnage, light-framework structures. They should not be used for dynamic loading, stress reversal, or impact conditions. The high-strength bolt clamps a joint together so tightly that working loads are transferred from member to member by friction and not by shear and bearing. Various conditions for fastener use and installation are discussed in the article. Special structural fasteners are described and their basic uses are discussed.

**KEY WORDS:** bolts; bolt, unfinished; fasteners, special structural; rivets
The results of 110 direct-tension and torqued-tension tests of regular head A325 bolts are reported. The major variables studied included grip, thread length between thread run-out and nut face, continuous vs. incremental torquing, and number of applications of a given nut rotation. The behavior of the bolts is examined and typical data are presented. Bolt calibration procedures are reviewed. For usual grips, the grip length was found to have no appreciable effect on the load-elongation characteristics when the length of thread under the nut was approximately the same. Nut rotations greater than one-half turn from snug give little additional clamping force. Decreasing the amount of exposed thread under the nut results in a decrease in the deformation capacity of the bolt.

KEY WORDS: bolts; joints; steel; structural engineering; testing

Load-elongation relationships determined in tests of two bolts are presented graphically. Both were manually tightened to 5000 lb. One was tightened 1/2 turn more with a hand torque wrench, while the other was impacted the same amount. Both had the same total load. It is concluded that manually torqued and impacted bolts produce the same nominal coefficient of friction in joints if the bolts have the same tension load and if other factors are equal.

KEY WORDS: bolts; installing; joints; slippage; testing

Relaxation tests of high-strength bolts are reported. The turn-of-the-nut method produces bolt loads above the specified minimum. The load relaxations for bolt assemblies with and without washers are essentially the same and are on the order of 4% after one week, based on the "one minute" load. There is no obvious advantage in using the special head bolt, except that the large head simplifies assembly.

KEY WORDS: bolt; bolting; fatigue; relaxation test

Load-elongation relationships determined in tests of two bolts are presented graphically. Both were manually tightened to 5000 lb. One was tightened 1/2 turn more with a hand torque wrench, while the other was impacted the same amount. Both had the same total load. It is concluded that manually torqued and impacted bolts produce the same nominal coefficient of friction in joints if the bolts have the same tension load and if other factors are equal.

KEY WORDS: bolts; installing; joints; slippage; testing

Presented is a very brief article reporting that photostress plastic has been used with apparent success in predicting fatigue life of plate material around rivets in small-scale tests.

KEY WORDS: fatigue life; plates; stress concentration
A fabricator, a bolt manufacturer, and a consulting engineering firm estimated after study that the substitution of high-strength bolts for rivets will increase a fabricating plant's production 66% without increases in labor force or plant size.

The main advantage, reduced labor costs, and other advantages are listed and discussed.

KEY WORDS: bolts; fabrication; joints; rivets; steel

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In 46 tests, washers affected neither the clamping force nor fatigue life of high strength A325 bolts connecting A7 steel.

KEY WORDS: bolts; fatigue; force, clamping; washers

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Detailed are tests of 12 long A7 steel butt joints assembled with 7/8 in. A325 bolts installed by the turn-of-nut method. Bolts were installed in joints in two lines, each with 3 tp 10 bolts. Joints were proportioned so that the net plate area was always 10% greater than the bolt shear area. The major variable of the test series was joint length. Eight of the joints failed when one or more of the fasteners sheared. The remaining 4 joints failed when the plate fractured at the first line of bolts. The average shear strength of the bolts decreased with increasing joint length. With 10 fasteners in a line the average shear strength was approximately 75% that of a single bolt. The load at which a joint slips into bearing has no relation to the ultimate strength. The slip coefficient determined experimentally from tests with dry mill scale surfaces was 0.45. When the mill scale was removed with a power tool, the slip coefficient was only about 0.25.

KEY WORDS: bolts; joints; slippage; steel; strength; structural engineering; testing

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The 1954 specification prepared by the Research Council on Riveted and Bolted Structural Joints for the use of A325 bolts in structural joints is discussed. The council approved a higher working stress value based on Council-sponsored tests on large bolted joints at Lehigh University. Tests conducted at the University of Illinois showed that bearing pressure for rivets in double or single shear has no effect on the strength of the connected parts, so long as this pressure does not exceed 2.25 times the tensile stress on the net area. A comparison of total costs of bolting vs. riveting made from time and motion studies sponsored by a bolt manufacturer in cooperation with a large fabricator show that savings of up to 17% may be possible.

KEY WORDS: bolts, A325; costs; economic factors; specifications
Ely, J. F.
TRUSS BRIDGE PROJECT AT NORTHWESTERN UNIVERSITY, Proceedings, AISC, May 5-6, 1960, pp. 10-16. (Also appeared as TRUSS BRIDGE PROJECT, Progress Report No. 5 to U. S. Army Engineer Research and Development Laboratories, Northwestern University Technological Institute, March 1, 1961).

At the time of writing, tests were still in progress on a half-scale steel truss bridge which can be loaded in varying patterns and amounts. The test program was divided into three phases: (1) performance of preliminary investigatory tests to establish successful methods of operation for the tests to follow, (2) establishment of a method of estimating the ultimate load of damaged end posts, and (3) determination of the effects of the floor system in truss action and of the stresses introduced by the erection of the floor system. The facility may be used to check new design concepts and to verify new analytical theories on steel bridge up through ultimate loads.

KEY WORDS: testing; truss bridge

Lloyd, S. J.

The load distribution among the bolts of a bolted double-lap tension splice at ultimate load was determined. The deflections of each bolt in 1 line of each of 4 test joints were measured. A single bolt from the same lot was subjected to increasing load increments in a shear jig and the deformations of the bolt at various known loads were measured. Plots of the deformed profile of the bolt were made and compared with the profiles of the bolts in the four test joints in order to determine the load that each bolt in the test joint was carrying.

KEY WORDS: bolts; distribution; load; steel; strength; structural engineering; testing

Thurlimann, B.

Tension-elongation curves of high-strength steel bolts, static tests on large compact bolted joints, and use of impact wrenches for inducing high initial bolt tension are comprehensively described. The 1960 American Specifications on high-strength bolts are reviewed.

KEY WORDS: bolt; elongation; joint; tension; wrench

Johnson, L. G., Cannon, J. C., and Spooner, L. A.
HIGH-TENSILE PRELOADED BOLTED JOINTS FOR DEVELOPMENT OF FULL PLASTIC MOMENTS, British Welding Journal, September 1960, pp. 560-569.

The results of 6 tests to investigate the use of high-tensile preloaded bolts for the development of full plastic moment of the connected members in certain rigid joints found in mild steel structures are reported. Flange plates have a stiffening effect on the parent joint. The half-torque, half-turn method of guaranteeing preload is better than the method of tightening bolts to give a minimum torque value. Maximum frictional grip between two members with bolts acting in equivalent shear is developed only when the contact surfaces are not prevented from bedding closely together.

KEY WORDS: bolt; joint; moment, plastic; slippage
A full-size riveted plate girder with a web plate much thinner than that required under the conventional design specifications was tested. Methods for the determination of the critical buckling loads on the basis of theoretical formulae as well as from experimental results are outlined. A study is made of the change in the shear-carrying behavior of the web after buckling occurs and the ability of the web to withstand loads in excess of the critical buckling value. The mode of failure of the web is discussed. The behavior of the flanges of the girder was carefully observed. Particular emphasis is given to the stress distribution in the region where the cover plates are terminated.

KEY WORDS: failure; girder; plates; shear test; stress concentration; webs

Lind, H. H.

This article discusses the formation of the Research Council and the development of high-strength bolting for structural steel. The Research Council on Riveted and Bolted Structural Joints has done much to further the acceptance of high-strength bolts by extensive research and field testing. From 1938 to 1947, intermittent research had been done on high-strength bolts. In 1947 the Research Council was formed with the financial backing of several sponsors, and a constitution was drawn up. From that time to the present, the Council has initiated extensive research in all facets of the application of high-strength bolts to structural joint conditions. Specifications have been established for the use of these bolts.

KEY WORDS: bolts; fatigue test; research; specifications; testing

Reiford, B.

The developments in the redesign of the high-strength bolt are presented. The new bolt is known as the heavy hexagon structural bolt. The width across flats on the new bolt head has been increased by 1/8-in. for all sizes. Under most circumstances, a washer is now required only under the bolt head or the nut, depending upon which is tightened. Also, the increased size of the bolt head requires the use of only one size wrench, for bolt and nut sizes are now identical. The thread length for the heavy bolt is shorter.

KEY WORDS: bolts; hexagonal-head bolts; hexagonal nuts; tolerances, manufacturing

Baltz, A. H.
INTERFERENCE-BODY BOLTS, Fasteners, Vol. 15, Nos. 2 and 3, Fall-Winter 1960, p. 22.

The application and advantages of interference-body bolts are discussed. The new bolts have either knurled or ribbed shanks interrupted at intervals to allow the flow of excess metal into unoccupied areas. Interference-body bolts are easier to drive through badly misaligned holes than standard high-strength bolts.

KEY WORDS: bolts, interference-body; installing; joints
Significant changes in joint assembly using ASTM A325 bolts are discussed. An increase in the required minimum bolt tension from 90% to 100% of bolt proof load is specified so that all properly tightened bolts will be preloaded into the plastic range. Also, all information on torque is deleted from present specifications because the highly variable torque-tension relationship makes torque an unsatisfactory criterion for proper preloading. The "turn-of-nut" tightening procedure or the calibrated impact wrench to be used instead of the torque-tension relationship. The shank of the ASTM A325 nut and bolt assembly will fail before the threads will strip, so identification and replacement of failed bolts is easy.

KEY WORDS: bolts; load; tension; tension, minimum bolt; torque

The reasons for two major changes in hardened washer use since 1960 are given. The circular washer has been made smaller because the larger area was not fully effective in distributing bolt load. One washer is now used instead of two and it is used only at the bolt assembly end which is being turned. The number of washers was reduced because their primary purpose is to provide a non-galling surface under the element being turned.

KEY WORDS: joints; steel; washers

A tightening procedure for high-strength bolts is discussed. A seven-step outline followed by Bethlehem fabrication crews is as follows: (1) Fair-up holes with enough pins to maintain dimensions and plumbness of the structure and do not remove pins until bolts in balance of holes have been tightened; (2) Install bolts in the remaining holes; (3) Tighten enough bolts to snug to bring all of the connected parts firmly into contact. Snug condition is indicated when the wrench starts impacting solidly. For best results, tighten bolts progressively away from the fixed or rigid points to the free edges; (4) Tighten to snug each bolt not used to fit up the fixed or rigid points to the free edges; (5) Replace pins with bolts, tighten to snug and then tighten prescribed turn; and (7) Mark completed joint with identifying symbol. The results of some of these operations are discussed.

KEY WORDS: bolting; bolts; procedure; tension

The new ASTM A325 bolt specifications have encouraged the use of bolts in connections formerly fasten by rivets. Because of the high strength of the A325 bolt, it can be used in smaller quantities than the rivets it supersedes. A basic table of allowable stresses for tension, friction-type shear, and gearing-type shear is included. Sample calculations are presented for a connection in which the usual rivets are replaced by high-strength bolts. A similar example is given for a moment connection.

KEY WORDS: bolts; design; joints; steel; structural engineering
Graves, F. E.

High-strength bolting, already proven superior in the field, is discussed as a substitute for riveting in shop fabrication. A shop study was conducted on twelve trusses which were designed for shop riveting rather than bolting. Half were riveted and the remainder were bolted. The results showed that with high-strength bolted connections there is more output for a given labor force and production facility, a definite decrease in fit-up and alignment time, and a saving of material and operations, all of which cut costs. Also, design economy and greater plant flexibility indicate that high-strength bolting has definite advantages over riveting in the shop.

KEY WORDS: bolting; costs; fabrication; force, equipment; force, labor; riveting; time study

Rumpf, J. L.

A theoretical solution for the unequal distribution of load among the bolts of a double shear splice under static axial load is developed. Attention was centered on the region between slip load and ultimate load in which the bolts and the plates are deforming in a non-linear manner. Determination of the unknown bolt forces was accomplished by the solution of an equilibrium equation and a set of compatibility equations. The non-linear relationships of force to deformation were determined experimentally by tests of representative portions of plate and of single bolts. The solution has been used to predict the ultimate strength of the bolts in connections with 3 to 10 fasteners in a line. The theoretical solution was verified by comparing the results with tests of 8 full-size connections. A limited study made of the effect of variations in the tension-shear ratio indicated that a surplus of plate material will reduce plate strains and will result in a more uniform distribution of load among the fasteners.

KEY WORDS: bolts; joints; steel; strength; structural engineering; tensile strength

Vasishth, U. C.

Such aspects of the behavior of rivets and plates of girders subjected to point loads as how rivets fill the holes and the location of gaps between the shanks of rivets and the rivet holes are discussed. In manufacturing processes, gaps are liable to occur along the shank of the rivet. The behavior of riveted joints is similar to that of bolted joints before any major slip occurs. In both joints the friction resulting from the clamping force influences the action of the joint. An attempt is made to estimate the clamping force of a riveted joint. The clamping force relieves much of the stress on the rivet by developing friction in the plates. It was found that for up to 2.13 times the design load, plastic deformation does not take place in either the end rivets or the plates.

KEY WORDS: force, clamping; joint; plate; rivet; stresses
Heap, W. J., and Gill, P. J.

Tests were carried out on simple single-bolt, double-lap joints to investigate the variation of slipping load with varying clamping forces on the slipping surfaces. The faying surfaces were wire-brushed to remove mill scale. The relationship between slipping load and clamping force is approximately linear. When an external tensile load is applied to a joint, the reduction in interface clamping force is equal to the applied external tensile force. The slipping load is nominally proportional to tightening torque. The coefficient of friction varied from 0.4 to 0.7 in these tests.

KEY WORDS: bolt; force, clamping; joint; slippage

Viner, J. G., Dineen, R. L., Chesson, E., Jr., and Nunae, W. H.

The behavior of heavy, finished thick, and finished nuts over a range of hardness values when torqued to failure using ASTM A325 high strength bolts was investigated in tests of 700 3/4 in., 7/8 in., and 1 in. bolt assemblies. Some bolts and nuts were also tested in direct tension to compare static strength with torqued strength. Bolts having nuts of the heavy, finished thick, and finished type of proper hardness develop proof loads at 1/2 turn from snug and if loaded in tension to failure will fail through the bolt threads.

KEY WORDS: bolts; nuts; strength, static; strength, torqued

Sherbourne, A. N.

Five tests were made on mild steel specimens, each in the form of a plate welded to the end of a beam and fastened to the flanges of a column with preloaded high-strength bolts. Various combinations of end plate and column stiffeners were tested. For the connection to be most efficient, the component parts must be proportioned so that they all reach the required strength and yield simultaneously. General conclusions are drawn regarding the plastic design of many types of bolted connections.

KEY WORDS: analysing; bolts; joints; steel; structural engineering; testing

Jones, R., and Baker, A. R.

The effect of bolt preloads above 20% of proofload on the structural efficiency and ultimate strength of a joint was investigated in tests of 8 double-lap tensile butt joints fastened with high-strength bolts. In these joints, bolt preload raises the yield point of the joint without affecting the ultimate strength of the plates.

KEY WORDS: bolts; joints; slippage; steel; strength; testing
Diemer, C. P.

THE RIVET...USE IT RIGHT AND YOU CAN'T BEAT IT, Fasteners, Vol. 16, Nos. 1 and 2, Spring-Summer 1961, pp. 3-5.

The author discusses rivets and their development. Rivets are one of the oldest and most dependable methods for fastening structural steel. The full shear strength attained from a filled rivet hole and the high tensile prestress in a cooled hot rivet are not affected by stress reversals or other forces. Rivets cost 1/3 as much as high-strength bolts, and overall economy results from their use. However, the labor saves in field erection by using high-strength bolts may drop total costs below those of riveting. Shop erection makes use of the low cost and versatility of rivets.

KEY WORDS: bolts; construction, shop; fabrication; rivet; structural steel

Hansen, R. M.

THE EFFECT OF FASTENER PITCH IN LONG STRUCTURAL JOINTS, Fritz Engineering Laboratory Report No. 271.15, Lehigh University, Bethlehem, Pa., May 1961.

The results of an analytical study of ten hypothetical joints is presented. The hypothetical joints were A7 steel plates fastened with A141 steel rivets or A325 bolts. The bolted joints had nine fasteners in a line and the riveted joints thirteen fasteners in a line. For a given number of bolts or rivets in a line, the ultimate strength of the connections decreases as the pitch increases.

KEY WORDS: bolts; joints; rivets; steel; structural engineering; tensile strength; testing

Hansen, R. M., and Rumpf, J. L.


The results of tests of 4 large A7 steel butt joints connected with 7/8 in. A325 bolts are reported. The bolts were arranged in two lines of from 10 to 16 bolts each. The joints were proportioned so that the net plate area was always 10% greater than the bolt shear area. The major variable was joint length. The longitudinal distance between fasteners was 3.5 in. except for one joint in which it was 2.63 in. Failure occurred in all cases with the shearing or "unbuttoning" of one or more end fasteners. The average bolt shear strength at failure for the joint with 16 bolts in line was about 60% of the shear strength of a single bolt. Pitch significantly affected connection behavior. The total joint length, not the number of fasteners, was the most important variable in determining average shear strength. The dry mill scale faying surfaces yielded slip coefficients between 0.31 and 0.46.

KEY WORDS: bolts; joints; slippage; steel; strength; structural engineering; testing
Static tension tests of 8 large A7 steel butt joints fastened with A325 bolts arranged in compact patterns and installed by the turn-of-nut method are described. One large riveted joint was tested to provide comparative data. Six of the specimens were connected with 7/8 in. A325 bolts with 3 to 6 fasteners in a line. Five of these joints had 5 lines of fasteners and 1 joint had 6 lines of fasteners. The other two joints were connected by 1 in. and 1-1/8 in. A325 bolts respectively. The 1 in. bolts were arranged in a 4 x 4 pattern and the 1-1/8 in. bolts were arranged in a 4 x 3 pattern. The specimens were fabricated at various tension shear ratios (the ratio of the tensile stress on the net section of the plate to the shear stress on the fasteners).

The joints were pulled to failure under static loads. The tests indicated that simultaneous failure of the A325 bolts and the plate would occur when the net plate area was approximately 10% greater than the bolt shear area. Major slip occurred at nominal bolt shear stresses 75 to 140% in excess of normal working stress. The average slip coefficient was approximately 0.4.

**KEY WORDS:** bolts; joints; rivets; slippage; steel; strength; structural engineering

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The behavior of fasteners in tension-type structural connections assembled with ASTM A325 bolts or with rivets of A141 steel is studied and discussed. Twelve riveted connections and 16 bolted connections were tested. The test specimens consisted of two wide-flange tees with the flanges butted together. Four variables were studied: (1) the number of lines of fasteners (either 2 or 4), (2) the flange width, (3) the flange thickness, and (4) the type of fasteners. The tee sections were cut from 24WF30, 30WF210, and 36WF300 sections. The efficiency of the joint is about the same for both types of fasteners. Members with 8 fasteners in 4 lines were generally less efficient but stronger than similar members with 4 fasteners in 2 lines. The stiffness of both the flanges and the fill plates affects the efficiency of the members.

**KEY WORDS:** bolt; force, clamping; rivet; testing

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This is a discussion of Abstract 203 "Strength in Tension" by Munse, Petersen, and Chesson. Mr. Douty performed tests similar to those described in "Strength in Tension" except that high-strength bolts were used in one line on either side of the web of the tee. The results were used to substantiate a theoretical investigation of the tension in the bolts throughout the elastic, plastic, and strain-hardening range of the flange. This analysis provides a means for designing the connection so that its plastic moment capacity is equal to or larger than that of the connected member. It is possible to use a bolted connection to develop the plastic moment capacity of a section and to use plastic analysis to predict the tension in the fasteners. The bolt tension is a function of flange rigidity, edge distance, and reduced section due to fastener holes.

**KEY WORDS:** bolts; fasteners; force, clamping; rivet; testing

The comments of the authors of “Strength in Tension” (Abstract 203) on its discussion by R. T. Douty, W. R. Penman, and E. F. Ball are presented. Although the discussers maintain that stripping failures are uncommon this was not the case before the proof loads for heavy hexagon series nuts were increased in ASTM specifications (at the request of the Research Council on Riveted and Bolted Structural Joints because of results of laboratory tests). The authors reiterate that there were still a few specifications such as AASHTO and ARRA specifications which did not sanction the use of bolts or rivets in tension. The authors show that the nominal cross-sectional area of a 3/4 inch rivet is 0.500 sq. in. and not 0.442 as suggested by Munse, Penman and Ball and that the value of 0.518 sq. in. as originally recommended by the authors results only in 4% error.

KEY WORDS: bolt; joints; nuts; rivet


Four members with standard connections consisting of angles fastened to the beam web and column flange were tested. Three of the test specimens were assembled with rivets and high-strength bolts and tested at different ratios of moment to shear. The fourth specimen was assembled entirely with rivets to provide a comparison of the effect of the type of fasteners upon the general behavior of the connections and to permit a correlation with previous tests. As the connections were loaded to failure a study was made of the moment-rotation characteristics, moment-resisting capacity, the position of the center of rotation, the deflection-rotation characteristics, the deformation of the fasteners, the separation of the column flanges, and the slip and shear deformation. These connections, although assumed for design purposes to behave as simple supports, actually do provide some restraint. The restraint provided by the connections was increased slightly by the use of high-strength bolts in place of rivets to fasten the connection angles to the column flanges.

KEY WORDS: bolts; joints; rivet; testing


Tests were performed to determine how much increase in cyclic load can be allowed when steels other than A7 steel are used in structures. Rivets of carbon steel (A193) and manganese steel (A155) and A325 high-strength bolts were used as fasteners. The joints were tested in direct tension with the loading cycle varying from zero to maximum. Two test programs are reported. In the first program 16 different steels were tested in the form of plates with single holes. The effect of the stress concentration was assessed by comparison of tests of similar plate specimens. Over 100 tests were made. A total of 210 double-lap joints were tested in fatigue in the second program. The specimens were fastened with rivets or bolts. Ten different steels were considered, including 7 from the first program. Joints which have high clamping force have high fatigue strength, and joints connected with high-strength bolts have higher fatigue strength than those connected with rivets.

KEY WORDS: bolt; fastener; fatigue; force, clamping; rivet
This report summarizes Progress Reports 1-9 of the University of Washington to the RCSBJS. The effects of punched holes, misalignment, and painted faying surfaces were investigated in 19 tests of double-lap joints. Fifteen joints were connected by twelve 3/4 in. A325 bolts and 4 were connected by 4 7/8 in. A325 bolts. Misalignment and painted faying surfaces have little influence on the joint efficiency. The punching of holes influenced the efficiency to the same extent for both riveted and bolted joints. The effect of the one-turn-of-the-nut tightening method upon slip and efficiency was investigated in tests on 4 large joints and 26 4-bolt joints. The method provided high clamping forces. Both load partition and joint efficiency were the same as for joints with bolts tightened to the minimum tension. An analysis was made of the nominal coefficient of friction in joints using the results of tests conducted at Northwestern, Illinois, and Washington Universities. The most critical factor influencing the coefficient of friction is the condition of the faying surface. Among the factors reducing the coefficient of friction are increasing bolt tension, decreasing tension-shear ratio, increasing size of joint, and increasing number of bolts.

KEY WORDS: bolts; friction; holes, misaligned; holes, punched; installing; joints; surfaces, faying; temperature; testing

Ball, E. F., and Higgins, J. J.

The procedures which have been used by Bethlehem Steel Co. to ensure that high-strength bolts are installed and tightened to produce the minimum bolt tension required by specifications are described. The studies and tests that were made to develop a safe, practical, and economical method of bolt tightening are also presented. Included are a brief history of the use of the high-strength bolt as a fastener for structural steel joints and instructions given to erectors by Bethlehem Steel Co. for tightening high-strength bolts.

KEY WORDS: bolt; fastener; procedure; tension

Zweig, B. A.

The paper "Installation and Tightening of Bolts" (Abstract 26) is discussed. Mr. Zweig observed the erection of the National Bank Building in Detroit, Michigan, and the Plymouth Assembly plant in St. Louis, Mo., where the method described in the above paper proved efficient. But the tightening of the fitting-up-bolt, as suggested in the procedure, is not as rigidly and rationally controlled as that of the other bolts. The writer therefore suggests that a simple method be devised to alleviate this shortcoming.

KEY WORDS: bolts; force, clamping; installing; nuts

Zar, M.

Mr. Zar notes in his discussion of Abstract 210 that bolts will always be above minimum tension when nut are tightened 1/2 turn beyond snug position. However, because many experienced workmen rely on their judgement and fail to observe the turn-of-nut procedure, a thorough inspection of the work is usually necessary. Instruction No. 6 in the authors paper which reads, "check the tightness of each fit-up bolt with impact wrench", is vague because the meaning of check is unclear. The original fitting-up bolts may lose tension as other bolts are tightened.

KEY WORDS: bolts; installing; joints; fabrication
The relationship between torque and clamping force is inconsistent. Tests indicate that the turn-of-nut method preloads bolts more accurately than the torque method. But even here a procedure should be laid down to provide a clamping force which exceeds slightly but not excessively the initial yield elongation of the bolt material. The procedure described by the authors of Abstract 210 comes close to this. Although the half-turn method appears to be simple, repeated application of this method may cause the bolt assembly to fail.

KEY WORDS: bolt; force, clamping; procedure

The authors' instructions for tightening high strength bolts (Abstract 210) may be universally accepted. However, Instruction No. 6 is vague. After the joint has been completed, the fitting-up bolts should be loosened and tightened in the same manner as the other bolts to ensure that the nuts have been turned 1/2 or 3/4 turn beyond snug position.

KEY WORDS: bolt; bolting; fastener; force, clamping; instructions

The doubt expressed by Zweig, Zar, and Archibald that the turn-of-nut method may not control the tightening of the fitting-up bolts as rigidly as that of the other bolts is unjustified. In field testing of completed joints with calibrated torque wrenches it was found that the tension in the bolts used for fitting-up is the same as the tension in the other bolts. This was also found to be true in tests at Lehigh University, Bethlehem, Pa. Better results can be obtained by using a large number of bolts in a joint for fitting-up purposes. A thorough inspection of the joint is desirable and this can be done only with the calibrated-torque wrench. Tests show that bolts can be re-used five times.

KEY WORDS: bolts; fastener; procedure; strength

A brief description of the Mackinac Bridge project and details of the particular applications of bolted connections are given. The procedure for bolting and inspection as developed for the project is outlined. Some of the more common troubles are described and illustrated. Among the conclusions drawn from experience are: (1) considerably more time must be spent on bolt inspection than on rivet inspection, (2) the trend toward bolting will continue, and (3) upper limits should be set for allowable torque.

KEY WORDS: bolts; construction; joint; structural engineering
The behavior of bolted joints subjected to fatigue tests is explained. Fatigue life of bolted joints does not change much as a result of omitting the washers if the bolts are tightened to at least minimum specified tension. Most of the loss in bolt tension occurs in the first few cycles of loading—whether or not hardened washers are used.

The results of 42 direct-tension and torqued-tension tests of 7/8 in. heavy-head A325 bolts with short thread length are presented. The test results are compared with the results of studies of regular-head bolts with longer thread lengths. Head type was not a significant factor in bolt behavior. Decreasing the amount of exposed thread under the nut resulted in a decrease in the deformation capacity of the bolt. The 1/2-turn-of-nut procedure produced initial bolt tensions 30% in excess of the minimum tension requirements. The rotational factor of safety against twisting off decreased with a decrease in exposed thread length. Grip length had no appreciable effect on the load-elongation characteristics of the bolt.

KEY WORDS: bolts; joints; steel; structural engineering; testing

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(Knoell, A. C., Chesson, E., Jr., and Munse, W. H.)

FATIGUE BEHAVIOR OF BOLTED JOINTS ASSEMBLED WITHOUT WASHERS, Dept. of Civil Engineering, University of Illinois, SRS No. 242, February 1962.

The behavior of bolted joints subjected to fatigue tests is explained. Fatigue life of bolted joints does not change much as a result of omitting the washers if the bolts are tightened to at least minimum specified tension. Most of the losses in bolt tension occurs in the first few cycles of loading whether or not hardened washers are used.

KEY WORDS: bolt; fatigue; force, clamping; joint; slippage; washers

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(Radzimovsky, E., and Kazoza, R.)


An analysis of the effects of flexural deformation on bolted assemblies is presented. The deformity of the connected members is the main factor influencing the bending stresses in the bolt. In certain connections these bending stresses considerably influence the strength and reliability of the assembly. Assembly clearance is a factor upon which the flexural deformation of the individual members and bending stresses in the bolts greatly depend. Pre-tightening load was found to have little influence on the bending stresses, while reduction of bolt width in the plane of bending produced a reduction in the bending stress.

KEY WORDS: assemblies; bending; bolt; stresses

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(Chu, T. Y.)


The effects of bearing stresses on the fatigue strength of a structural joint are discussed. The endurance limit of joint with no clamping force decreases linearly with increase in bearing stress. The endurance limit of a bolted joint with enough clamping force depends in essence on the material properties of connections and this limit approaches the yield point of the material for all geometries. Geometry changes the strength of S-Series joint; clamping force eliminates this change. A relationship could be developed between the plate thickness and stress concentration. The endurance limit in bolted joints is given by $S_e = S_y(0.8)^{0.2}$

KEY WORDS: bearing; bolt; fatigue; joint; rivet; stresses
Dlugosz, S. E.

The results of an experimental and theoretical study of 3 long A7 steel butt joints assembled with 7/8 in. A141 steel rivets are reported. The net plate area was 75% of the rivet shear area. Joint length was the major test variable. The specimens had 2 lines of rivets with 7, 10, and 13 rivets in a line. The end rivets sheared before all rivets could develop their full shearing strength. The average shear strength of the joint with 7 rivets in a line was 84% of the shear strength of a single rivet and was 74% for the joint with 13 rivets in a line. Slip occurred in all 3 joints.

KEY WORDS: joints; rivets; slippage; steel; strength; structural engineering; testing

Yaskel, W. R.

A short treatise on the construction of the Space Needle at the Seattle World's Fair is presented. The 600 ft. structure is entirely of high-strength bolted and welded construction. The 3 legs are curved to almost meet at a height of 373 feet and then flare out at the top to support a revolving restaurant. The use of high-strength bolts allowed the steelwork to be completed in five months and also allowed the actual conception of the design. The Needle is designed to withstand twice the seismic load required by the building code and one-and-one-half the maximum wind load ever recorded in that area.

KEY WORDS: bolts, heavy head; construction; design; fabrication; structural engineering

Hotchkiss, J. G.

A review of new provisions for fasteners in the AISC Specification for the Design, Fabrication, and Erection of structural steel for buildings is presented. Comparisons are made among shear and tension design loads for rivets, A325 high-strength bolt, and the new A354 high-strength bolt. Combined shear and tension are related by a graph, and fatigue is discussed.

KEY WORDS: bolts; construction; design; fatigue; fillers; rivets; shear test; strength; stresses; structural steel; tension

Bendigo, R. A., Fisher, J. W., and Rumpf, J. L.

The results of tests of 4 large lap splices connected by 2 lines of 7/8 in. A325 bolts are reported. The major test variable was joint length. Rotation of the connections due to eccentricity was restrained by an external bracing system. Failure occurred with the shearing of 1 or more of the fasteners. The behavior of the lap splices is compared with that of the double-shear tension splice. A lap splice can be considered equivalent to half of a double-shear splice of similar dimensions and materials, and a similar number of bolts. The joints had faying surfaces with the mill scale removed with a power tool. The average slip coefficient was 0.27.

KEY WORDS: bolts; joints; slippage; steel; strength; structural engineering; testing
Belford, R. B.  
NEW SPECIFICATIONS FOR HIGH-STRENGTH BOLTING, Fasteners, Vol. 17, No. 3, Fall 1962, pp. 6-10.

New specifications for high-strength bolting as approved by the Research Council on Riveted and Bolted Structural Joints in March 1962 are presented. Washers are no longer required when heavy hexagon-head structural bolts are tightened by the turn-of-nut method. Semi-finished hexagon bolts have been dropped from the specification because the Council has decided to recommend only the best bolt types. Special fasteners can be used if they meet the chemical and dimensional requirements of the specification.

KEY WORDS: bolting; hexagonal-head bolts; shear test; specifications; tension


The physical design, manufacturing specification, and driving method for a new lower-cost rivet are proposed. The rivet itself has a new shape, and the finished head will take on a distinctive shape from a new hammer head. The rivet will be cold driven for speed, ease of fabrication, economy, and development of high clamping force. It will be stronger in shear, bearing and tensile strength. It will reduce peak stress concentrations around holes.

KEY WORDS: clamping; deformation; fabrication; joint, friction; rivet; riveting, cold; riveting, hot; stresses

Chesson, E., Jr., and Humee, W. H.  
STATUS REPORT OF PRELIMINARY STUDIES COMPARING A354 AND A325 HIGH STRENGTH BOLTS, Dept. of Civil Engineering, University of Illinois, August 1962.

This report summarizes the results of direct-tension and torqued-tension calibration tests of A325 and A354 BC and BD bolts. Also included are the results of 12 relaxation tests of A354BD bolts in A7 steel plates. Interaction curves for combined tension and shear are also presented. The report compares the A325 and A354 bolts. Both bolts exhibit torque strength of about 85% of tensile strength. When hardened washers are provided at the turning surface, the torque relationship T = 0.27D holds for both bolts. The A354 bolt requires more turns to reach proof load than the A325 bolt. Relaxation studies and combined tension and shear behavior are similar. In general, thread reduction in the grip increases maximum bolt load but decreases turns to failure.

KEY WORDS: bolt; relaxations; shear test; torque; washers

Fisher, J. W., and Beadle, L. S.  
CRITERIA FOR DESIGNING BOLTED JOINTS (BEARING TYPE), Fritz Engineering Laboratory, Report No. 298.7, Lehigh University, Bethlehem, Pa., February 1963.

This report reviews the current criteria for proportioning bearing-type bolted joints. The concepts and practices that led to the "balanced design" concept are discussed. Results of tests of bolted butt joints of A7 or A440 steel connected with A325 bolts are analyzed and compared with theoretical results. The examination of the current design concept showed that: (1) the concept of balanced design leads to inconsistent allowable bolt stresses for different plate materials, (2) the A325 bolt behaves similarly under shear in a compact joint regardless of the type of connected material, and (3) the balanced design concept has no meaning in long joints because the bolts unbutton before the plate material can attain its full strength. A different design basis is suggested and possible design guides are outlined.

KEY WORDS: bolts; design; joints; steel; structural engineering
Christopher, R. J., and Fisher, J. W.

CALIBRATION OF A325 BOLTS, Fritz Engineering Laboratory Report No. 288.8, Lehigh University, Bethlehem, Pa., February 1963.

Presented are the results of 34 direct tension and 110 torqued tension calibration tests of individual ASTM A354 and A354D quenched and tempered alloy steel bolts. The bolts were 7/8 in. and 1 in. in length under head which varied from 3-1/4 to 9-1/2 in. The major variables studied were diameter, grip, thread in grip, and thread lubrication. The results indicate that: (1) the ultimate strength in direct tension is 6 to 7% greater than in torqued tension, (2) a lesser amount of exposed thread under the nut results in an increase in ultimate strength and a decrease in rotation capacity, (3) thread lubrication has no appreciable effect on bolt performance and, (4) proof load can not be reached by 1/2 turn-of-nut for grips between 7.6 and 8 in.

KEY WORDS: bolts; joints; steel; structural engineering; testing

Chang, W. N., and Vasarhelyi, D. D.

THE COEFFICIENT OF FRICTION IN BOLTED JOINTS AND MISALIGNMENT IN BOLTED JOINTS, Dept. of Civil Engineering, University of Washington, Eleventh Progress Report to RCRBSJ, February 1963.

Part I, which is in general concerned with friction, discusses a proposed program of 18 tests on 4 bolt double-lap butt splices. Eight of the specimens are to be fabricated from A36 steel, 2 from A440 steel, 2 from T1 steel, and 2 from A36 and A440, 2 from A440 and T1, and 2 from A36 and T1. A preliminary study of means of measuring the roughness of mill scale surfaces is described. Among the methods described are mechanical measurements, photography, and micro-stereo-photogrammetry. A standard bolted specimens proposed for tests to determine the coefficient of friction consists of a 1 in. main plate and two 1/2 in. lap plates connected by 4 3/4 in. A325 bolts. Four of the joints had 1 or more holes misaligned. In joints with misaligned fasteners a marked geometric adjustment takes place between the load causing first slip and the load at which the joint yields. The presence of initially misaligned fasteners did not significantly reduce the ultimate load-carrying capacity or the joint efficiency. Non-impairment of the self-adjusting capacity of the misaligned joint due to cleavage does not take place until after slip occurs.

KEY WORDS: alignment; bolts; friction; slippage

Douty, R. T., and McGuirre, W.


Presented is a summary of tests conducted at Cornell University on high-strength bolted moment connections. The tests, which were made on T-stub, flange splice, and end plate moment connections, were designed to provide more information about the use of these connections in plastically-designed structures. The conventional beam splices had 3/4 in. or 7/8 in. A325 bolts designed for nominal shear stresses on the body diameter varying from 15 to 30 ksi. All splices were able to develop the fully plastic moment of the gross section. A theoretical solution was developed for the behavior of flange and bolts in the T-stub connections. The theory was compared first with straight tension tests of T-stub bolts to rigid and flexible bases. Finally three tests of assembled beam-to-column moment connections were made. Specimens were fabricated with web clips omitted off one beam of each specimen. The authors conclude that the web clips are desirable. Six end plate moment connections were tested, five in pure bending and one in an assembled beam-to-column connection. The variation in bolt tension and the development of prying forces as well as the deformation and resistance of the plate and bolt combinations were studied. It is concluded that the critical design condition for the end plate is horizontal bending on a line through the lowest bolt row caused by the tension in the beam flange, and that only as being fully effective if the end plates are flexible. Both the stiffeners and rotation characteristics were excellent for the end plate connections.

KEY WORDS: analyzing; bolts; joints; steel; structural engineering; testing

Chang, W. N., and Vasarhelyi, D. D.


The effect of misalignment on slip, elongation, efficiency, and adjustment are outlined. Six tests were conducted on bolted butt splices connected by 12 high-strength bolts (3/4 in.). The holes were misaligned in 5 specimens by various patterns. The test results are analyzed and compared with similar tests reported in Abstract 209. The results indicate that in misaligned joints the geometric and plastic self-adjustment occurs at loads between the load causing first slip and the load at which the member yields. Slip was found to occur more gradually in the misaligned joints and no effect was noted on the overall elongation of the joint. The authors conclude that a single row of misaligned fasteners show a slight reduction in efficiency whereas a misaligned pattern on or about a diagonal had little influence on efficiency.

KEY WORDS: alignment; bolts; efficiency; joints; slippage; strength; testing

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A325 and A354BD bolts were used in tests which demonstrated that washers have no significant effect on the clamping force of high-strength bolts tightened with a turn-of-nut method. Additional turning is required in a turn-of-nut method when the surfaces at the head and nut are on 5% slopes. Thirty-eight fatigue tests were made with 4-bolt double-lap shear-type joints. Some specimens had the outside plates critical, while others had the inside plates critical. The tests showed that washers generally have no effect on the fatigue lives of properly-bolted A325 joints.

KEY WORDS: bolts; fatigue; joints; steel; structural engineering; testing
Troup, E. W. J., and Chesson, E., Jr.
CALIBRATION TESTS OF A490 HIGH-STRENGTH BOLTS, Dept. of Civil Engineering, University of Illinois, SRS No. 280, March 1964.

Over fifty calibration tests on 7/8 in. ASTM A490 high-strength bolts were conducted. Data on bolt tension, elongation, turns of nut, and general behavior were taken and analyzed. Comparisons made of bolt behavior when torqued in a commercial load cell and in a solid steel block show that a significant difference exists between these two conditions. The general characteristics of the A490 high-strength bolt appear to be similar to those of the familiar A325 bolts, but the physical properties of the new bolt will provide greater fastener strength and joint clamping.

KEY WORDS: bolt; elongation; physical properties; tension

Chesson, E., Jr., Faustino, N. L., and Nurse, W. H.
STATIC STRENGTH OF HIGH-STRENGTH BOLTS UNDER COMBINED TENSION AND SHEAR, Dept. of Civil Engineering, University of Illinois, Urbana, March 1964.

Presented is a study of the strength and behavior of single high-strength bolts under static loadings of tension and shear. A total of 115 A325 and A354 Grade BD high-strength bolts were tested. The results were analyzed with consideration being given to such factors as location of the shear plane of loading, proportion of tension and shear loads, length of grip, bolt type, and type of material bolted. The maximum strength of a bolt may be realized at a combination of tension and shear which is only predominantly tension and rather than pure tension.

KEY WORDS: bolt; shear test; tension; tensile strength

Sterling, G., and Fisher, J. W.
TESTS OF A490 BOLT (PRELIMINARY REPORT), Fritz Engineering Laboratory Report No. 288.15, Lehigh University, Bethlehem, Pa., March 1964.

Tests were conducted on 2 lots of A490 bolts at Lehigh University and the University of Illinois to determine if testing procedures constitute a major variable. The results of the work at Lehigh are given in this report. The results of 20 direct-tension and 30 torqued-tension tests made on 7/8 in. x 5-1/2 in. and 7/8 in. x 9-1/2 in. A490 alloy steel bolts are reported. The torqued-tension tests were conducted in a hydraulic calibrating device and in a solid block of A440 steel. The tests showed that the direct tensile strength was 10 to 20% greater than the torqued tension strength. The average load at 1/2 turn from snug was less than proof load for the longer bolts. The shorter bolts reached proof load at 1/2 turn when tightened in the solid steel block, but only those specimens with 1/8 in. of thread in the grip reached proof load at 1/2 turn when tightened in the hydraulic load device. This study shows that additional rotation beyond 1/2 turn is necessary for the longer A490 bolts if the proof load is to be reached.

KEY WORDS: bolts; joints; steel; structural engineering; testing

Chesson, E., Jr.

The equipment used at the University of Illinois for measuring strain, stress, and deformation in studies of riveted and bolted structural joints are described. Besides that which is commercially available, such as electrical resistance strain gages, specially designed equipment is used. It includes hollow cylinders with strain gages to record axial load produced by bolt tightening, "C-frame" extensometers equipped with direct-reading dial gages, and a counter-weighted device which also measures bolt elongation. A device for measuring the slip of truss bridge joints to ±0.0005 in. was made for field testing of a 310 ft. railway span.

KEY WORDS: bolts; instrumentation; joints; rivets; testing
Chesson, E., Jr.

A brief history of the use of rivets and bolts as structural fasteners is presented. The changes in specifications by ASTM and RORB&J are briefly discussed. The physical properties of various types of rivets and bolts are compared along with the advantages and disadvantages of both from the standpoints of cost of materials, equipment, and labor. The trends toward more and more use of high-strength bolts are explained.

KEY WORDS: bolts; costs; fasteners; force, clamping; properties; rivets
7. TABLES

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| 152     | A325 steel       | Butt splice| ![Sketch](image)                                                         | Number of bolts Tightening method Grip                                   | Static Tension Tests 16 tests 3/8" bolt | 1. Computation of coefficient of friction  
                      | bolts              |             |                                           |                                                                         |                                                                         | 2. Computation of safety factor                                      |
| 153     | 3580 steel       | Butt splice| ![Sketch](image)                                                         | Tensile load on bolts Surface preparation                                | Static Tension Tests 24 tests 7/8" bolts                              | 1. Computation of coefficient of friction                           |
| 154     | B.S.F. bolts      | Butt splice| ![Sketch](image)                                                         | Number of bolts                                                           | Static Tension Tests 9 tests 7/8" bolts HE30-WP plate                | 1. Computation of coefficient of friction                           |
| 157     | A325 steel       | Lap splice  | ![Sketch](image)                                                         | Bolt diameter Surface preparation                                         | Number of tests conducted is not reported                            | 1. Computation of coefficient of friction                           |
| 163     | A325 steel       | Test jig   | ![Sketch](image)                                                         | Bolt diameter Loading method                                              | Direct Tension Tests 18 tests 7/8" bolt  
                      | bolts              |             |                                           |                                                                         | 10 tests 1" bolt   
                      |                   |             |                                           |                                                                         | 5 tests 1-1/8" bolt  
                      |                   |             |                                           |                                                                         | Torqued Tension Tests 6 tests 7/8" bolt  
                      |                   |             |                                           |                                                                         | 3 tests 1" bolt  
                      |                   |             |                                           |                                                                         | 2 tests 1-1/8" bolt |
| 164     | A141 steel       | A325 steel | ![Sketch](image)                                                         | Specimen Configuration Joint size Fastener Bolt preparation Rivet or bolt pattern | Static Tension Tests 8 tests 5/8" rivet  
                      | rivets             | bolts       |                                           |                                                                         | 6 tests 3/4" bolt  
                      | A325               |             |                                           |                                                                         | 8 tests 7/8" rivet  
<pre><code>                  | bolts              |             |                                           |                                                                         |                                                                   |
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| 160     | A325 steel bolts  | Beam splice   | ![Beam splice sketch](image) | Cover plate length, Number of bolts | Static Tests: 2 tests 3/4" bolt | 1. Computation of coefficient of friction  
2. Computation of plastic moment capacity |
|         |                   | Beam-to-column | ![Beam-to-column sketch](image) |                                | Static Tests: 4 tests 3/4" bolt |                                                                  |
| 161     | A325 steel bolts  | Butt splice   | ![Butt splice sketch](image) | Joint size, Number of bolts in line | Static Tension Tests: 4 tests 7/8" bolt | 1. Computation of theoretical ultimate load  
2. Computation of slip coefficient  
3. Computation of joint efficiency  
4. Computation of unbolting factor  
5. Determination of the load partition |
| 162     | A321 steel rivets | Portion of the plate girder flange | ![Girder flange sketch](image) | Location of specimen in the plate girder, Joint type, Grip length | Rivets gaps: 16 specimens | 1. Estimation of clamping force |
| 163     | A325 steel bolts  | Butt splice   | ![Butt splice sketch](image) | Bolt diameter, Bolt tension | Static Tension Tests: 18 tests 3/4" bolt, 18 tests 1" bolt | 1. Computation of coefficient of friction |
2. Computation of plastic moment |
| 165     | A325 steel bolts  | Beam-to-column | ![Beam-to-column sketch](image) | Bolt diameter, Number of bolts, End plate thickness, Column stiffener thickness | Static Tests: 3 tests 3/4" bolt, 2 tests 7/8" bolt | 1. Computation of load capacity of column web stiffeners  
2. Computation of plastic moment |
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<td>Joint size, Plate thickness, Pitch, Number of fasteners in line, Tension-shear ratio, Fastener type</td>
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<td>A325 steel bolts</td>
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<td>1. Computation of coefficient of friction</td>
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<td>218</td>
<td>A325 bolt</td>
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### Analysis
1. Development of the relationship of endurance limit to bearing ratio.
2. Computation of theoretical ultimate load.
3. Determination of prying action.
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<td>Static Tension Tests 8 tests 3/4&quot; bolt</td>
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<td>Plate width, Bolt tension, Bolt head type, Washer, Stress range, Bolt tension</td>
<td>Static Tension Tests 6 tests 3/4&quot; bolt A460 steel plates</td>
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<td><img src="image4" alt="Sketch" /></td>
<td>Bolt length, Nominal grip, Thread in grip, Loading method</td>
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<td><img src="image5" alt="Sketch" /></td>
<td>Bolt length, Total grip, Thread length in grip, Loading method</td>
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<td>Test jig</td>
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<td>Type of bolt, Bolt length, Bolt diameter, Bolt hardness, Grip length, Test block materials, Tension-shear ratio</td>
<td>Static Tests 86 tests 3/4&quot; A325 bolt 10 tests 1&quot; A325 bolt 20 tests 3/4&quot; A354 BD bolt</td>
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<td>Joint type, Plate material, Plate thickness, Initial bolt tension</td>
<td>Static Tension Tests 29 tests 1&quot; bolt</td>
<td>1. Computation of coefficient of friction</td>
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8. RESEARCH COUNCIL REPORTS

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2. RCRBSJ-'NEW CONCEPTS IN STRUCTURAL JOINT DESIGN', December, 1953, (Abstract No. 65)

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2. SPECIFICATIONS FOR ASSEMBLY OF STRUCTURAL JOINTS USING HIGH STRENGTH BOLTS

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4. SPECIFICATIONS FOR STRUCTURAL JOINTS USING ASTM A325 BOLTS

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Project V - EFFECT OF GRIP ON THE FATIGUE STRENGTH OF RIVETED AND BOLTED JOINTS


Project VI - (See Committee 13)

Project VII - EFFECT OF RIVET PATTERN UPON THE FATIGUE STRENGTH OF STRUCTURAL JOINTS


Project VIII - (See Committee 7)

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3. Chu, T. Y.

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Committee 6 - SLIP OF BOLTED BRIDGE JOINTS

Committee 7 (VIII) - CUMULATIVE DAMAGE


Committee 8 (IV) - BEARING AREA REQUIREMENTS UNDER BOLT HEADS

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Committee 16 - GUSSET PLATES

Committee 17 - EPOXY JOINTS

Committee 18 - GALVANIZED JOINTS

Committee 19 - COLD DRIVEN RIVETS

Committee 20 - INSTALLATION OF BOLTS
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11. APPENDICES

1. OBJECTIVES OF RESEARCH COUNCIL ON RIVETED AND BOLTED STRUCTURAL JOINTS

Because it is generally recognized that current practices in the design of riveted and bolted connections have been developed empirically and that many of these practices and the joint capacities predicted therewith are not supported by scientific data, the Research Council on Riveted and Bolted Structural Joints has been organized to carry on investigations to determine the suitability and capacity of various types of joints used in fabricated structural frames. It is expected that the Council's work will result in the promulgation of more economical and efficient practices.

2. CHAIRMAN OF THE RESEARCH COUNCIL

T. R. Higgins 1947-1950
W. C. Stewart 1950-1954
E. J. Ruble 1954-1958
E. L. Erickson 1958-1961
R. B. Belford 1961-1965

3. CURRENT AND PAST MEMBERS OF THE RESEARCH COUNCIL

*R. Archibald, Alaska Dept. of Highways (Ret.)
*R. W. Armer, Pennsylvania Dept. of Highways
E. F. Ball, Bethlehem Steel Co.
*B. A. Bakhmeteff, Columbia University
R. B. Banks, Northwestern University
*T. Baron, University of California
+D. C. Beam, Canadian Inst. of Steel Construction
J. L. Beckel, New York Central Railroad
+L. S. Beedle, Lehigh University

* Based on statement appearing in abstract 34.

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R. B. Belford, Industrial Fasteners Institute
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C. A. Ellis, Northwestern University
S. Epstein, Bethlehem Steel Co.
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B. Farquharson, University of Washington
J. W. Fisher, Lehigh University
E. T. Franzen, CRI and P Railroad
E. H. Gaylord, University of Illinois
J. Gliberto, U. S. Army Mobility Command
H. C. Graham, Screw and Bolt Corp. of America
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R. M. Hansen, Lamson and Sessions Co.
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L. G. Holleran, Clark, Rapuano and Holleran
W. S. Hyler, Battelle Memorial Institute
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K. H. Jensen, Pennsylvania Dept. of Highways
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F. Kellam, Indiana Dept. of Highways
E. F. Kelley, Bureau of Public Roads
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E. Kirkendall, The Engineering Foundation
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E. W. Larson, Jr., Northwestern University
K. H. Lenzen, University of Kansas
H. H. Lind, Industrial Fasteners Institute
F. H. Lovell, Pennsylvania Railroad
G. M. Magee, Association of American Railroads
S. W. Marras, Fasteners Research Council
A. S. Marvin, American Bridge - U. S. Steel
N. P. Maycock, The Steel Co. of Canada, Ltd.
A. A. Maney, Northwestern University
J. P. Matte, Jr., Albert Kahn Assoc.
L. B. McCammon, National Engineering Science Co.
W. A. Milek, American Institute of Steel Constr.
4. SOME NOTES ON THE RESEARCH COUNCIL SPECIFICATIONS

1951

The Research Council, formed in 1947, approved its first specification on January 31, 1951, after examining the results of the research it planned and sponsored on high-strength bolts. The reliability of structural joints fastened by high-strength bolts had been demonstrated in field tests performed by the Association of American Railroads under actual
operating conditions and in laboratory investigations. This initial specification allowed the replacement of A141 steel rivets with A325 bolts of the same nominal diameter. Additional details are given in Ref. 44 and 48.

1954

Because the initial specification was prepared while research was still in progress, it was necessarily conservative. On February 27, 1954, the Research Council approved a revised specification based on further laboratory and field experience. Among the changes was permission to use flat washers on wide-flange beams with a 1:20 sloping flange. Painting of the faying surface was approved for joints in which slip into bearing was permissible. The installation procedure with impact wrenches was modified. In recommending that bolt tension be set 15% above the minimum tension the Council recognized that torque measurement is not a dependable means of determining bolt tension. Also, the inspection procedures were relaxed because of the dependability of the high-strength bolt.

1955

As a result of questions by users of the specification, the Research Council provided authoritative guidance in an Appendix on December 15, 1955. Also, as a result of studies of installation methods (66,84,85), the Council endorsed the one-turn-of-nut-from-hand-tight method as a satisfactory method of tension control.

1960

In March 1960 a new edition of the specification was issued which recognized the greater strength of joints connected by high-strength bolts. Up to 1960 the accepted design practice was direct substitution of bolts for rivets of equal size. However, the Council had accumulated sufficient
data to permit establishment of an adequate design practice for bolted joints. Two different designs were allowed, friction-type connections and bearing-type connections. Designers could take full advantage of the higher-strength bolts, and allowable bolt stresses were increased 45%. A newly designed heavy-hexagon structural bolt with a larger head and shorter thread length was approved. Tightening procedures were clarified and the minimum bolt tension was increased to the bolt proof load. Installation by the turn-of-nut method was modified and reliance on torque measurement as a means of determining bolt tension was discouraged by the elimination of all torque information. The required size of hardened washers was reduced and the omission of the washer under the bolt head or nut (whichever was not being turned in tightening) was permitted. A commentary similar to the 1955 Appendix was added to interpret many of the requirements and furnish the user with reference data. Comments related to this specification are given in Refs. 183, 185, and 186.

1962

In March 1962, a revised specification was adopted which clarified and modified the 1960 edition. Bolts installed by the turn-of-nut method were no longer required to have washers under either bolt head or nut. Also, research had indicated that 1/2-turn-of-nut after proper snugging was sufficient to load the bolt beyond the minimum tension regardless of size or length. An additional quarter turn was required for each bevel surface (1:20) when bevel washers were not used. The heavy-hex structural bolt was adopted as standard, while the regular semi-finished hex bolts were accepted as substitutes. In addition, special-type fasteners were sanctioned provided certain criteria were satisfied. Additional discussion of the 1962 specification is given in Ref. 225.
The latest Council specification was adopted in March 1964. It incorporates the results of additional research and is applicable to both A325 and A490 bolts. Most of the research since 1962 was conducted to develop a higher-strength bolt for use with high-strength steels. In making the specification applicable to both A325 and A490 bolts it was necessary to modify existing practice for uniformity. The required size of hardened washers was further reduced because their primary function is to provide a non-galling surface. Washers are required under both the nut and bolt head when the A490 bolt is used with A7 or A36 steel and under the turned element in higher-strength steels. Installation by the turn-of-nut method was again modified because tests\(^{(229, 237, 239)}\) had shown that long A490 bolts require a greater nut rotation to produce the required minimum tension. Although the A325 bolt does not need the additional rotation, the same provision was applied in the interest of uniformity in field practice. A new section included in the specification defines the inspection procedure recommended by the Research Council.
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Abstracts of most of the work that has been performed during the past two decades on riveted and bolted joints are contained in this report. The bibliography covers the period from De Jonge's bibliography in 1944 up to the present time. Altogether 241 abstracts are included. The abstracts are preceded by historical notes and discussion which cover the development of fasteners, related materials, research efforts and specifications. A series of graphical summaries are also presented for many of the articles abstracted. These provide a means of rapidly assessing the type of joints tested and the variables studied. In addition to the abstracts several lists are provided for the user. These include the subject and author indexes, a list of Research Council work and a list of references.

KEY WORDS: aluminum; bibliography; bolts; connections; rivets; steel; structural engineering; testing