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BOLTED CONNECTIONS

BY

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Project 243

Report 243.1

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Synopsis

This paper summerizes the results of a literature search of available information on static and dynamic tests of high tensile bolted connections made by the authors in preparation for further experimentation in this field. It was found that high tensile bolted connections exceeded the performance of riveted connections in all instances. Previous tests have proved the feasibility of raising the tension stress to shear stress ratio from 1 : 0.75 to 1 : 1.(1)* However, joints once critical in shear under the present specified tension to shear to bearing ratios (T : S : B) of 1 : 0.75 : 2 may be critical in bearing under the altered specifications T : S : B of 1 : 1 : 2. There is not at the present time experimental data which would justify the possibility of raising the allowable bearing stress in the same proportion as the allowable shearing stress, thereby bringing the joints so designed back to a "balanced state". The authors feel that this deficiency should be rectified before the major specification writing groups incorporate the increased T : S : B ratios in their specifications; therefore, a test program has been initiated by the authors in an attempt to justify an increase in bearing stress.

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* Numbers in ( ) refer to references listed in Bibliography.

ACKNOWLEDGMENT

Even though this report was prepared for an ASCE student paper contest, it was however the result of a literature survey made in the course of preparing for research in C.E. 103, Fritz Engineering Laboratory Project 243.

The authors wish to express their appreciation to Prof. F. W. Schutz, Jr., for his advice and instruction in this work.

Introduction

A chain is only as strong as its weakest link similarly a structure is only as strong as its weakest joint. In the past engineers have depended almost entirely upon riveted connections, lately however, bolted connections have been gaining in popularity in spite of the fact that present specifications penalize them. Two types of bolts are commonly in use in structural work today, the common bolt and the high strength or high tensile bolt. This discussion will be limited to the high tensile bolt and its performance under static and dynamic loads.

This paper is the result of a literature search performed by the authors in preparation for a proposed student research project, which will include the testing of 18 structural joints.

The person responsible for the initiation of the present interest in high tensile bolts is Professor W. M. Wilson of the University of Illinois who started investigations on high bolt tensions in 1938.(2) Through his interest and work the "Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation" was founded in 1947 and has directed intense investigations in this field at several universities. The American Society For Testing Materials describes the high tensile bolts under designation A325T Quenched and Tempered Bolts and Studs.(3)

Theory

The basic concept in the design of the high tensile bolted connection is that the load is transferred by friction between the plates rather than by shear in the fastener as is the assumption in riveted connections. To attain this friction a high clamping action must be developed by the fastener.(4) The high tensile bolt is especially well adapted for this job. The A.S.T.M. specifies a minimum yield point for high tensile bolts of about 85,000 psi. Figure 1 is a typical stress-strain curve(5) for high tensile bolts which shows that the average yield point is approximately 98,000 psi. The high strength of this material is appreciated better when one remembers that the specified minimum yield strength for mild steel is 33,000 psi.

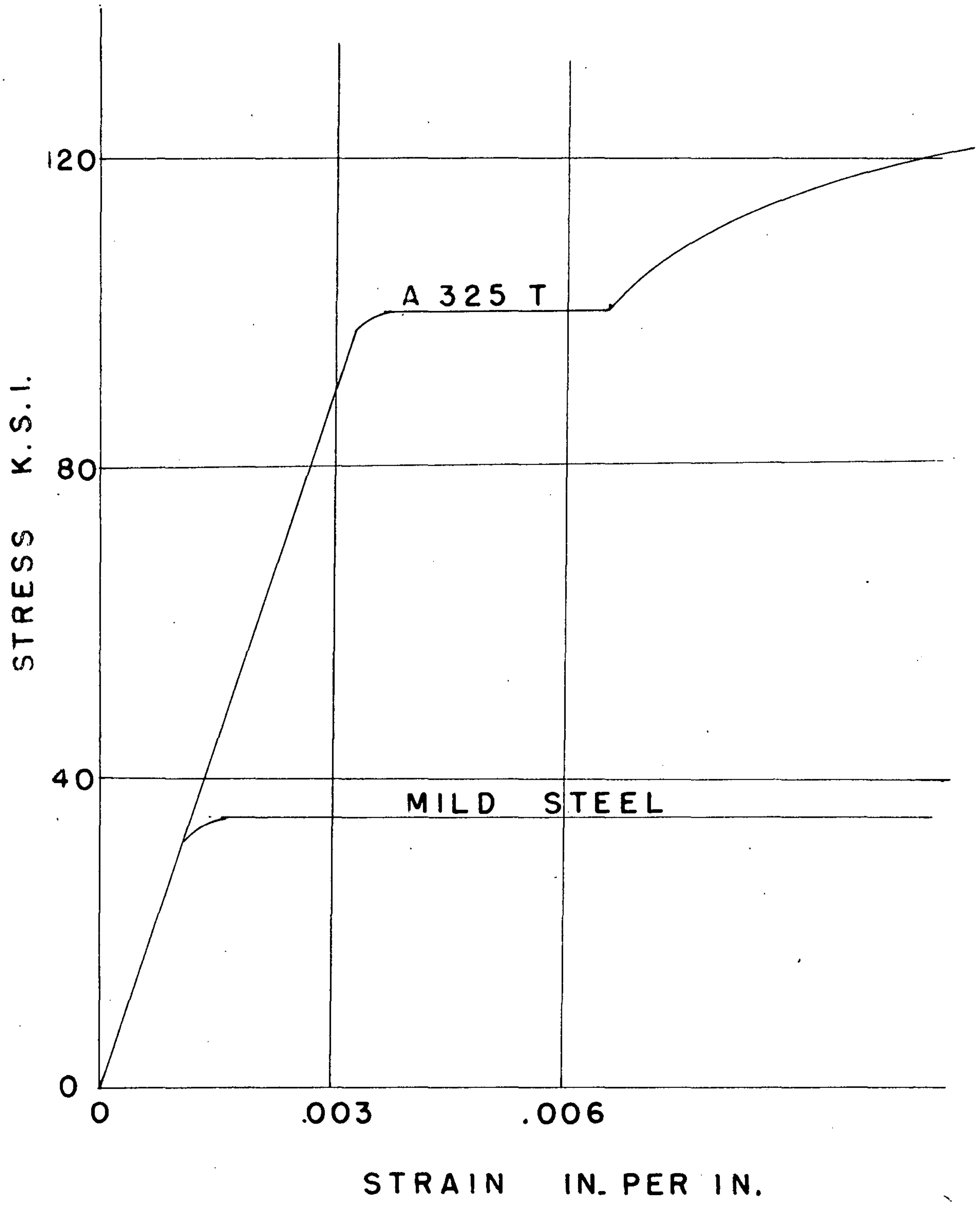
Test Results

The fact that the load is transferred by friction in bolted connections led earlier researchers to investigate the possible effects of various substances upon the coefficient of friction in such joints. It was discovered that paint on the faying surfaces lowered the coefficient of friction.(6)(7) This can be explained by the fact that paint forms small roller bearings under the high pressure as indicated in Figure 2. Tests were also made with various abrasives with similar results. Clean steel with no foreign substance aside from normal mill scale gave good results.(6)(7)

Where slippage of the plates into bearing is no problem such as in staticly loaded buildings present specifications(8) allow the joints to be painted and proportioned for rivets, with the rivets being replaced by bolts of the same nominal diameter.

FIG. 1

TYPICAL STRESS-STRAIN CURVE



SCHEMATIC DIAGRAM OF A PAINTED JOINT

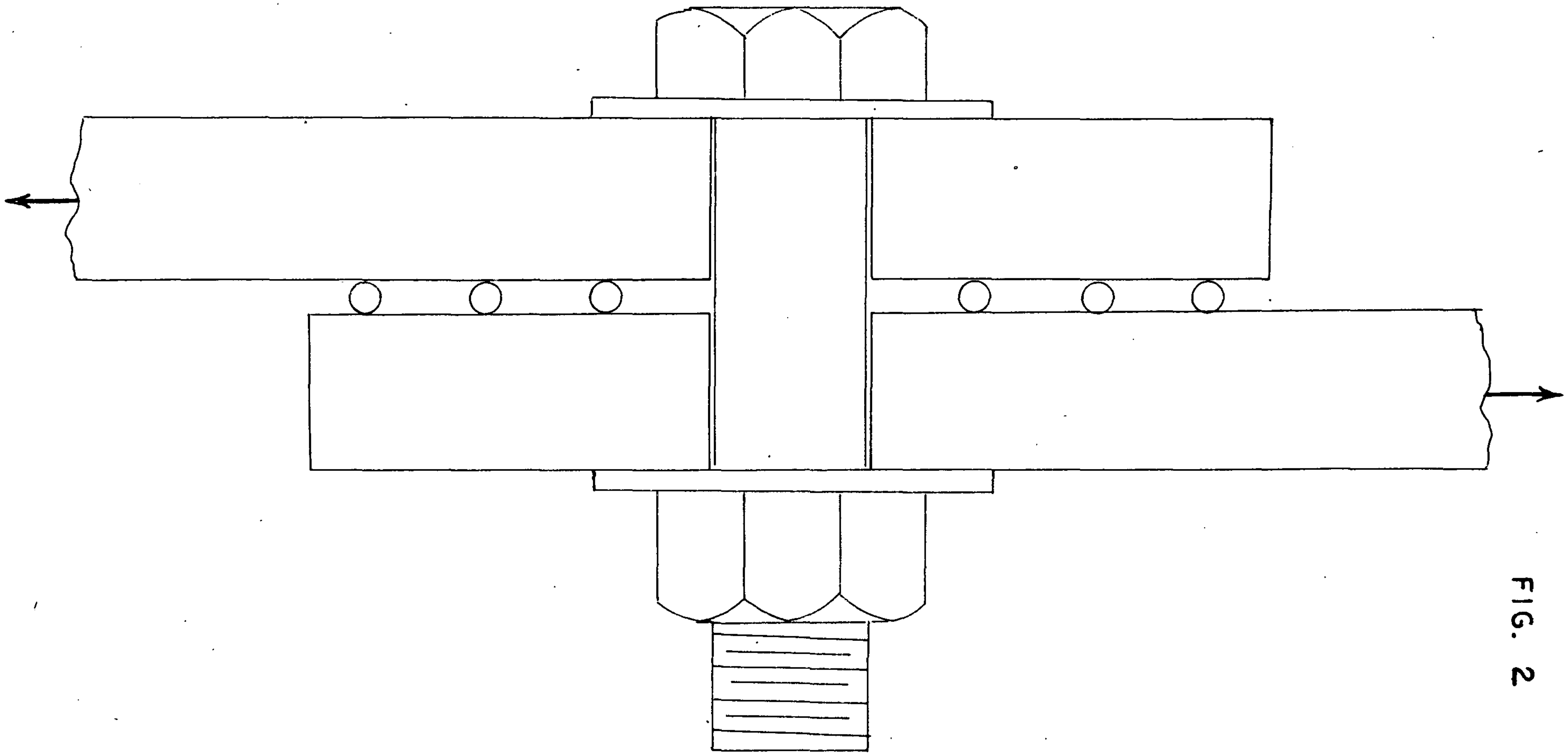


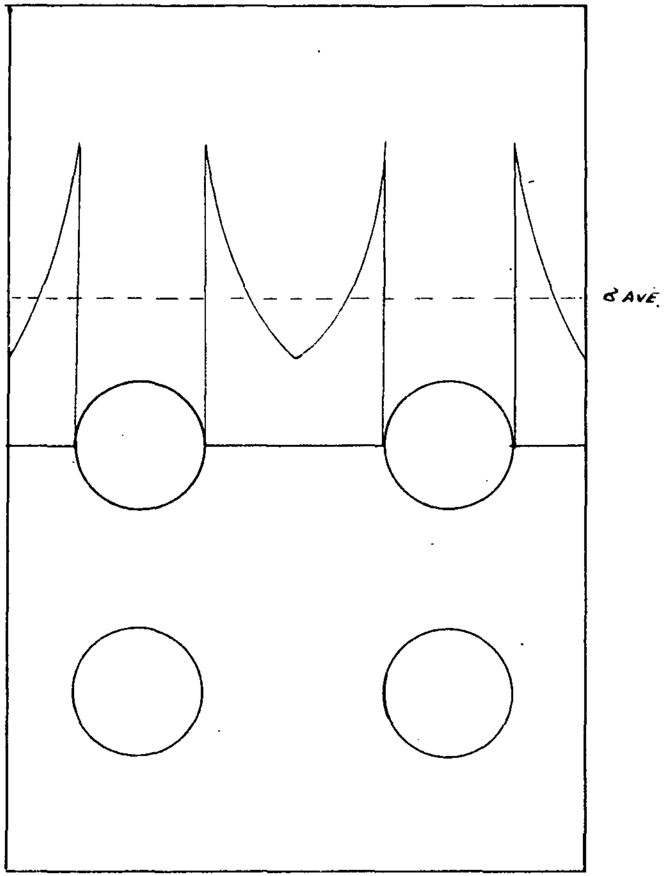
FIG. 2

Where variable loads exist present specifications(8) allow no paint or foreign material on the faying surfaces. This insures that no slippage will take place under working loads. In cases where fatigue failures are eminent a properly prepared bolted connection has proven vastly superior to a similar riveted connection.

Examination of Figure 4 reveals the stress concentrations on riveted connections appear at the edges of the holes and the maximum stress is approximately three(4) times the average stress in the net section. This causes minute fatigue cracks to appear in the net section adjacent to the holes and results in a failure through the net section. Now, if this is compared with Figure 3b, an idealized load transferred sketch for a bolted connection, it will be noticed that the load is transferred evenly over the plate by friction. In this particular joint of four fasteners approximately one quarter of the load is out of the plate before the net section is reached.

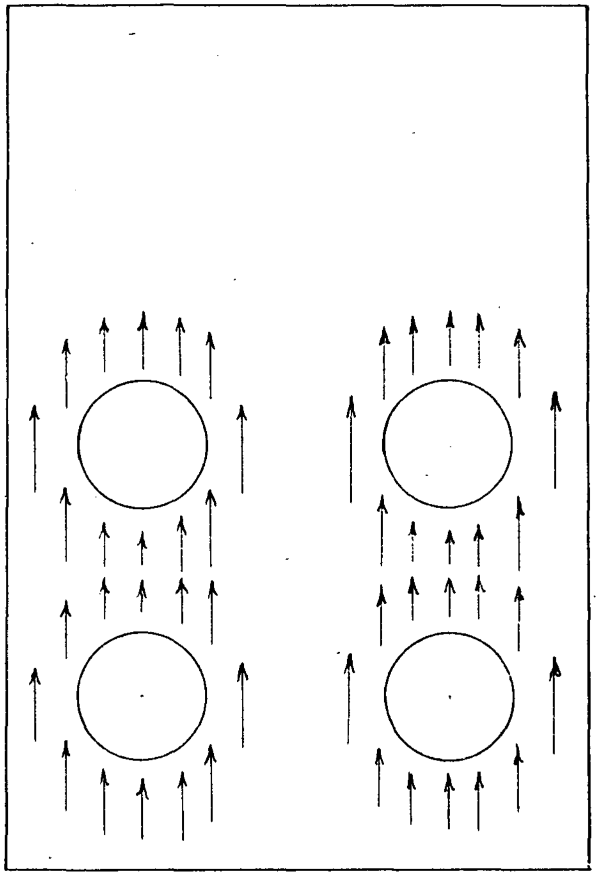
It will be noted on Figure 4(6) where diagrams have been reproduced from photographs of actual specimens tested in fatigue, that the fatigue cracks appear in front of the first row of fasteners. (4) Figure 5(4)(2) shows typical fatigue failures in riveted and bolted (Figure 5b) connections. In the riveted connection the failure occurred in the net section, while the bolted connection failed in the gross section in front of the first row of fasteners. The failure of the bolted connection in the gross section illustrates the fact that the severe stress concentrations have occurred in the gross section rather than in the net section as is the case for riveted connections.

CONNECTION STRESS DIAGRAMS



RIVETED

FIG. 3b



BOLTED

FIG. 3a

SPECIMENS SHOWING FATIGUE DAMAGE

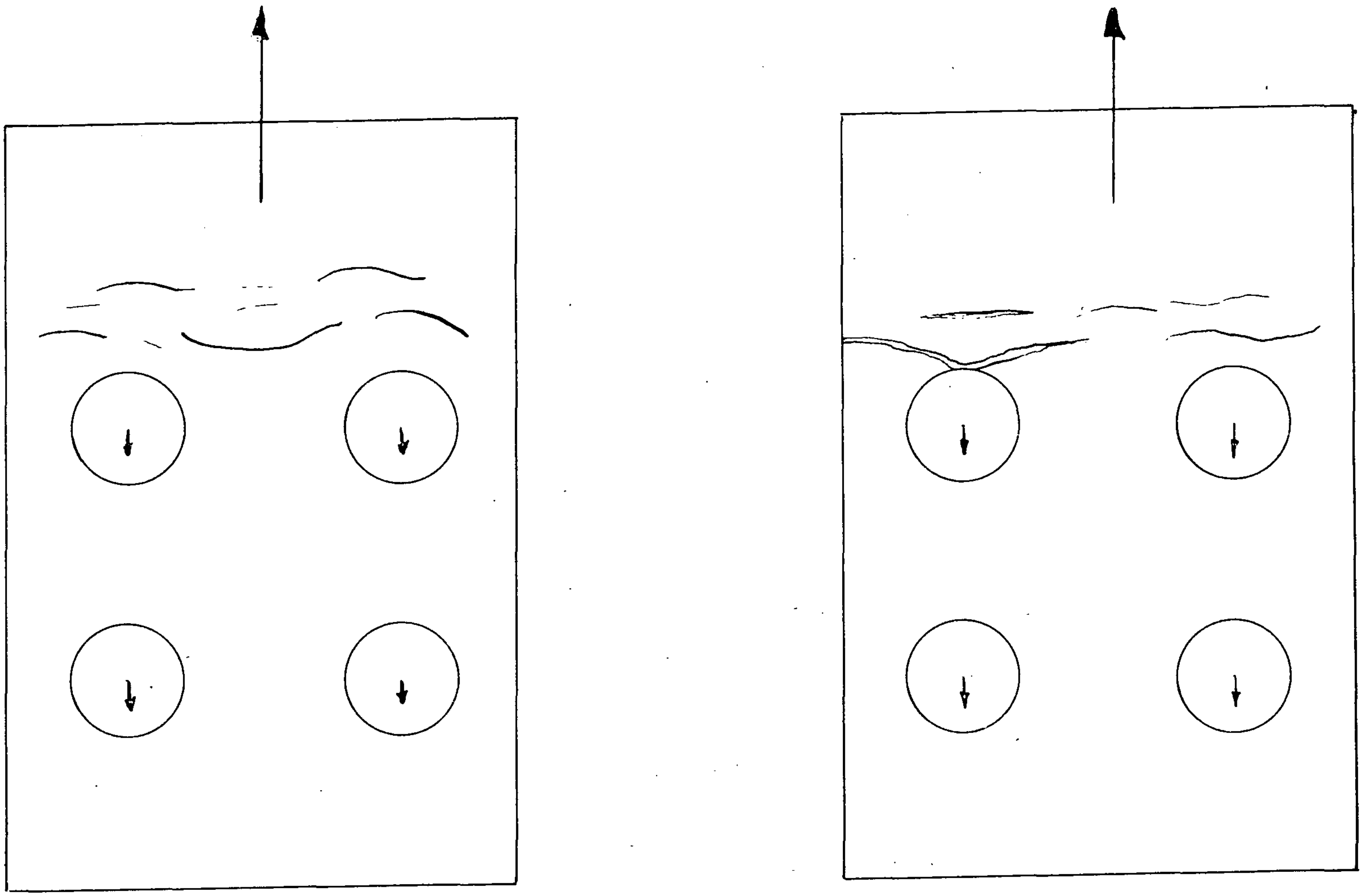
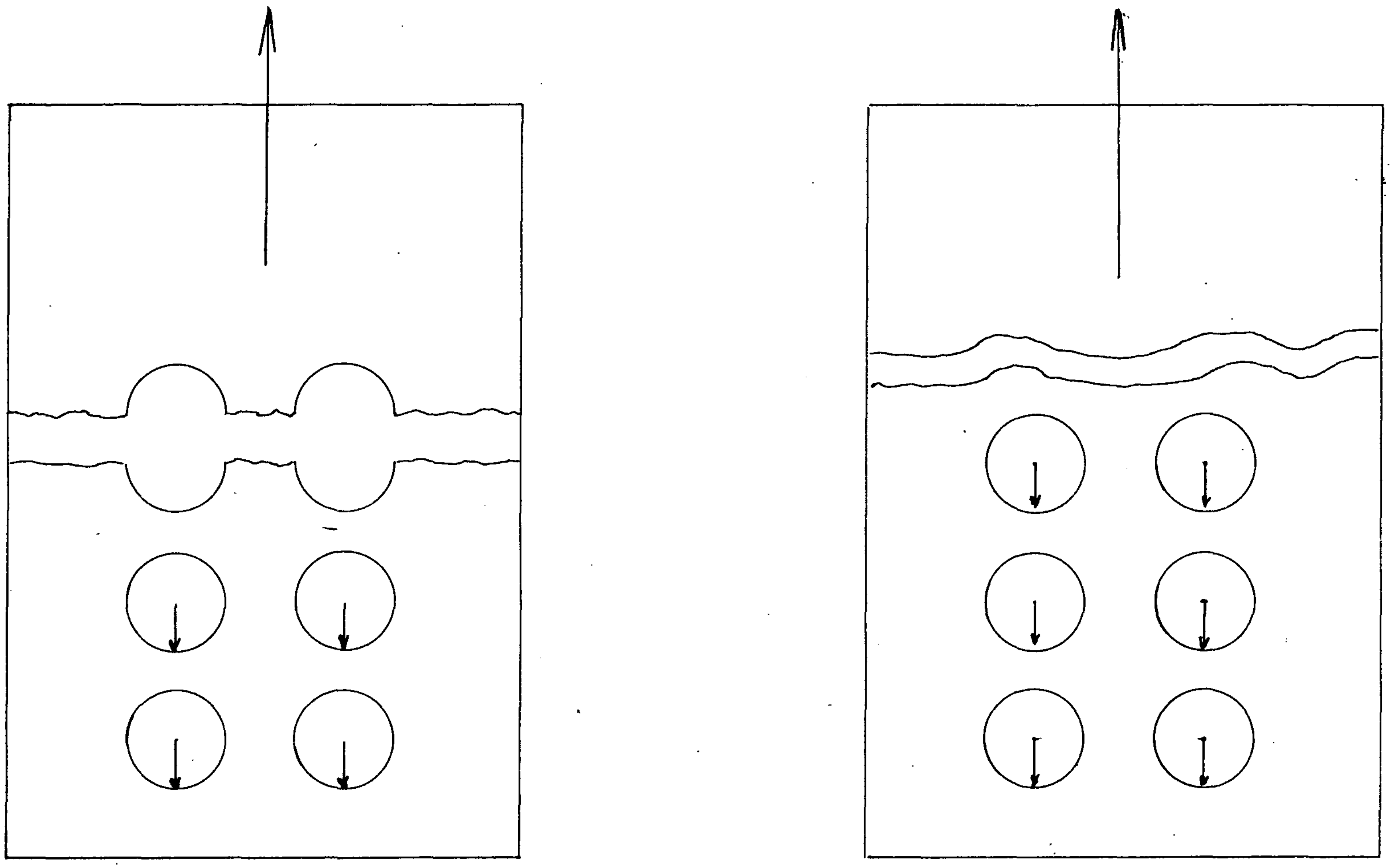


FIG. 4

TYPICAL FATIGUE FAILURES



RIVETED

BOLTED

FIG. 5

All this "talk" of failure may give the wrong idea of the strength of bolted connections. The facts are that the investigators found it difficult to make the joints fail in fatigue. An illustration of this is that one connection subjected to complete reversal of stress from 16,000 psi compression to 16,000 psi tension survived 5,567,000 cycles without signs of failure(4). Another program showed that for a given fatigue life of 2,000,000cycles a riveted connection exhibited a fatigue strength of 16,000 psi while a similar bolted connection has a fatigue strength of 20,000 psi, thus the bolted joints showed a 25% increase in stress intensity for this fatigue life(9). There are many such examples of the superior behavior of bolted connections. In still another series of tests where the load was varied for 0 psi to 21,000 psi the riveted joint failed after 900,000 cycles while the bolted joint survived 12,300,000 cycles.(2)

Field Use

The question naturally arises "How do such joints stand up under strenuous field conditions?".

In 1948 the Association of American Railways arranged with the American Railway Engineering Association to replace over 1000 rivets with high tensile bolts in 12 of their bridges across the country. This was made possible due to the fact that every year rivets had to be replaced since they had worked loose because of excessive vibration and repeated dynamic loads. It was found that the high tensile bolts have retained their initial tension over a period of five years while rivets in identically stressed joints continued to work loose yearly. This led to a recommendation by the special committee to the A.R.E.A. to change the specifications so as to allow bolted connections because of the "....superior behavior of high strength bolts over that of rivets...".(10)

Future Development

What is the future for high tensile bolts? There is a great need for specification clauses which will adequately utilize the capacities of high tensile bolts. A step has been made in this direction by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation with their Specifications for Assembly of Structural Joints using High Strength Steel Bolts(8). But this specification does not change the allowable stresses presently used, as they only allow a rivet to be replaced by a bolt of the same nominal diameter.

Tests at the University of Illinois show that it is feasible to raise the tension to shear to bearing ratios from 1 : 0.75 : 2 allowed under present specifications to 1 : 1 : 2(1) in cases where slippage is not objectionable. On Figure 6 it can be seen that the T : S : B ratios of 1 : 0.75 : 2 corresponds to A.I.S.C. allowable stresses of 20,000 psi tension; 15,000 psi shear and 40,000 psi bearing. Past tests(1) have shown that for joints where slippage is allowed that the allowable stresses could be set at 20,000 psi in tension, 20,000 psi in shear and 40,000 psi in bearing giving T : S : B ratios of 1 : 1 : 2. With these new ratios it was found that none of the joints failed in shear. However, under such increased allowables a joint whose design was previously controlled by shearing stress may now be governed by bearing stress. The authors are carrying out a test program to investigate the possibility of raising the allowable bearing stress

		TENSION	SHEAR	BEARING
A.I.S.C.	P.S.I.	20,000	15,000	40,000
	T:S:B	1	0.75	2
TEST U. OF ILL.		1	1	—
PROPOSED TESTS		1	1	2.67

COMPARATIVE STRESS CHART

FIG. 6

to tension stress ratio in the same proportion as the shearing stress to tension stress ratio can be raised. If this is possible the present balance between joints controlled by shear and those controlled by bearing will be maintained.

How is it possible that this increased bearing stress may be allowed without changing the material being connected? The authors' hopes are based upon the fact that a confined material is stronger in compression than when it is unconfined. Figure 7a shows a sponge with a vertically applied load, it will be noticed that there is a large deflection accompanied by a bulging at the sides. Figure 7b shows the same material under similar loading with the addition of restraining forces at the sides indicated by the arrows. It is readily understood that a larger load may be carried when restraining forces prevent the bulging.

It may be possible that this analogy can be carried over to the structural joint as shown in Figure 8 which is a schematic diagram of riveted and bolted joints under applied loads. Since the rivet offers only a small restraint the plates deform in much the same manner as does the sponge in Figure 7a. The high tensile bolt, however, does offer restraint indicating that there may be an increased load carrying capacity over a similar riveted joint. Now, one might ask, why is there no restraint offered by the hot driven rivet since they have an initial tension? Referring once again to Figure 1 it can be seen that when the plate is in the plastic state so also is the rivet, since they are both made of steel with approximately the same yield point. However, this is not the case with bolted connections as it can be seen that when the plate is in the plastic condition the bolt may still be in its elastic range thereby still able to resist the bulging of the plate.

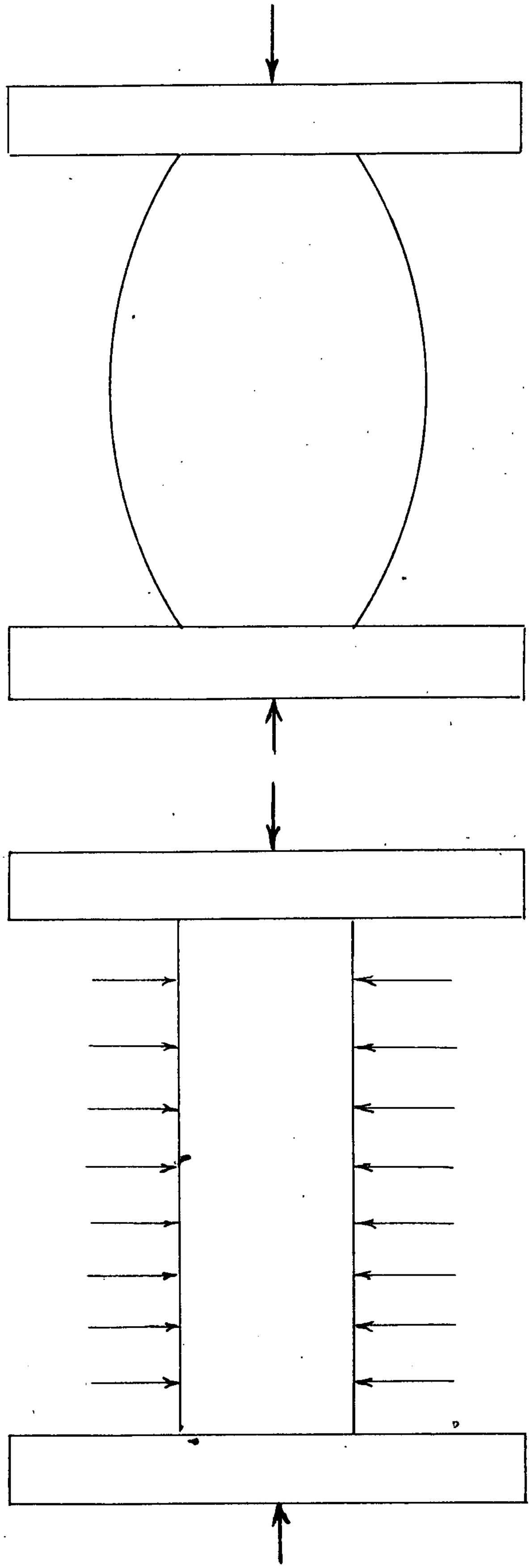


FIG. 7 a

FIG. 7 b

RESTRAINT DEMONSTRATION

SCHEMATIC DIAGRAM OF JOINTS UNDER LOADS

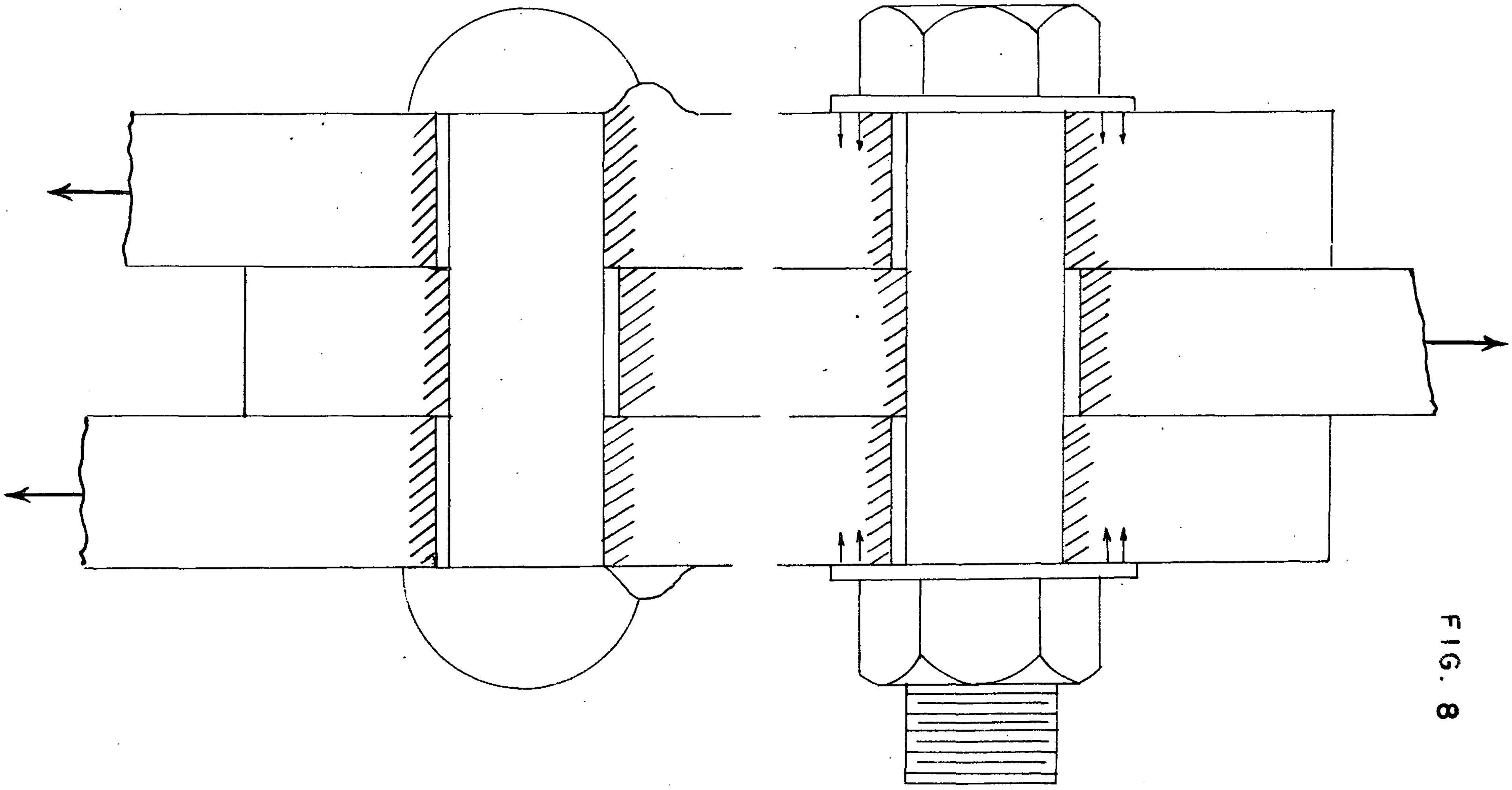


FIG. 8

Summary

As the authors have tried to show by citing some of the many successful experiments performed on high tensile bolted connections it seems that the expression "High Tensile Bolts" is written into the future of structural design. As engineers and future engineers the authors suggest that the reader keep in mind the advantages and future deveopment of the high tensile bolt not only in strength but in economy as it only requires two men to install a bolt while it takes a minimum of 4 men to drive a rivet.

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