1955

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REPORT ON RESEARCH METHODS C.E. 400

Some Preliminary Investigations Into the Use of High Tensiled Bolted Connection in Steel Structures Designed by Use of Plastic Analysis

by

Tadahiko Kawai

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Feb '55

Report No. 245
Recently method of plastic design has been much used in the field of steel structures. Most of the past investigations were confined to welded joints.

However, it would be possible to connect the shop welded structure in the field with high tensile bolts. The moment-rotation characteristics of such bolted connections should be ascertained before they may be used in plastic design.

In this sense, pure bending tests of wide flange beams with high tensile bolted connection are being planned to study its behavior.
II. INTRODUCTION

A. Purpose and Scope of Study

1. Field-erection of steel structures and high tensile bolted connections.

Past investigations in the field of steel structures, designed by plastic analysis, have assumed fully-connected welded joints. There is good evidence that field welded structures are at an economic disadvantage in the United States. Thus if plastically designed structures must be field welded, they may lose some of their merits.

However, it is not necessary that plastically designed structures be all welded. It seems very likely that it would be economically feasible to have a steel structure which would be shop welded and all field connections made with high tensile bolts.

2. Determination of moment-rotation characteristics.

Before they may be used in plastic design, it is necessary to study the moment-rotation characteristics of such bolted connections.

In addition to analytical studies, it will be necessary to test several connections to determine the relative merits of various designs, and to compare the analytical results with their actual behavior.

B. Historical Background and Review of Previous Work

1. Slip failure of riveted or bolted connections.

The problem of bolted and riveted connections is not new to the engineer, and numerous papers on this problem have been published. Unfortunately, however, very little is known
about the plastic behavior of bolted or riveted connections.

One of the intangible and troublesome unknowns connected with riveted joints is that of slip.

It has been demonstrated that in case of properly driven rivet, the initial tension in the shank produces sufficient friction between the under sides of the rivet heads and the outside surfaces of the connection to prevent slip for the usual designed loads.

In view of these demonstrations, it was inevitable that, sooner or later, the idea of using high tensile steel bolts would occur to someone, and that a reliable method would be devised for controlling the tension in them so that slip would not occur, as in the case of driven rivets.

2. Recent research on high tensile bolted connections.

In recent years, considerable research on high tensile steel bolted joint has been carried out by the Research Council on Riveted and Bolted Structural Joints, by the A.R.E.A. and by the A.I.S.C. The University of Illinois and Northwestern University have contributed much of the actual findings under the auspices of the first mentioned organization above.

This research has now reached the stage where the engineer may feel reasonably secure in using this type of connection. It has been used with success in old and new railway bridges where considerable difficulty had been encountered with rivets working loose. In fact, it is now being used in old and new structures and in both bridges and buildings.

In a high tensile steel bolted joint or splice, briefly speaking, high tensile steel bolts, with hardened washers,
replace the rivets or ordinary bolts. The nuts are drawn up by means of torque wrenches so calibrated that total tension in the bolt may be determined. The desired amount of tension is covered by specifications.

3. Specifications

The design value of a rivet or ordinary bolt is listed in the steel handbook (Steel Construction, American Institute of Steel Construction, 1949), or it may be computed from the specified allowable shear or bearing stress. The design values of high tensile steel bolts for the purposes of joint design are not provided in specifications. The design strength of the bolt is based on the friction between the under sides of the washers and the connected parts, induced by the tension in the bolt.

In other words, the value of a high tensile steel bolt, for joint design purposes, is a function of the induced tension in the bolt and the coefficient of friction of steel on steel. This may be expressed by the formula

\[
\text{bolt value} = \frac{\text{tension in bolt} \times \text{coefficient of friction}}{\text{safety factor}}
\]

There are thus three factors involved in the design strength of the bolts.

Present specifications cover only one, that of tension. (See Table I)
Until values for the two other factors have been decided upon and adopted by specifications, a value of 0.33 would seem to be conservative for the coefficient of steel on steel. As to the safety factor, it would be premature, but 0.6 of their double shear value might well be used for design purposes.

There are many things left to be discussed about those factors. However, if connections are designed following to the above specification, the bearing and shearing strength of the bolt comes into play only after failure in slip has taken place.

As the preliminary investigation of this program, it may be the first problem to study the moment rotation characteristics of such bolted connections.

In this sense, pure bending test of several wide flange beams with high tensile bolted connection are being planned.
III. TEST PROGRAM PLANNED

A. Specimens

1. Type of connections.

Three kinds of test specimens are being prepared. That is, flange connection type, web connection type and flange and web connection type. (See Figure 1)

2. Bolt-extensometer

In preparation of test specimen, it would be necessary to give same tension in bolts as required in Specification. In order to determine the tension in bolts, the bolt extensometer can be used satisfactorily. (See Figure 1).

That is, the elongation of bolt subjected to the specified tension can be read by the Bolt-Extensometer, and so tension in bolts can be adjusted by torque wrench so as to yield the same elongation in bolts.

B. Test Procedure

1. Third point loading method.

Pure bending tests of those specimens will be carried out by hydraulic type universal testing machine, using the well known method of third point loading.


Measurement of rotation will be done by three sets of dial gages attached to the test specimen. (See Figure 2)
IV. SOME APPROXIMATE THEORY

It would be impossible to establish the exact theory about this problem, since the behavior of high tensile bolted connection itself has not been well known enough.

However, it seems to be possible to predict slip moment, based on some assumption.

1. Flange connection type

Let us consider the flange connection type beam.

In this case slip moment $M_{\text{slip}}$ may be equal to $F_{\text{slip}}$ times $d$

$$M_{\text{slip}} = F_{\text{slip}} \times d$$

where

$F_{\text{slip}}$: slip load of flange connection

That is

$$F_{\text{slip}} = n \mu T$$

$n$ = number of bolts

$\mu$ = coefficient of bolt

$T$ = Tension in bolt.

2. Web connection type

In this case, the problem becomes more complicated and hard to analyze. But we can conclude that

$$\sum_{i=1}^{n} F_i = 0$$

$$\sum_{i=1}^{n} r_i F_i = M$$

0: centre of rotation
This is statically indeterminate when number of bolts are more than two, and so the deformation must be taken into consideration.

3. Flange and web connection type

This is the most complicated case to analyze but it would be the most useful for practical applications.

The only thing which we can assume and it looks nearly true is the following moment relationship

\[ M = M_w + M_f \]
V. ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. F. W. Schutz for his kind guidance and helpful suggestions.
<table>
<thead>
<tr>
<th>Diameter</th>
<th>Required bolt tension* (lb.)</th>
<th>Equivalent torque** (lb.-ft.)</th>
<th>Inside diameter (in.)</th>
<th>Outside diameter (in.)</th>
<th>Washer Birm Wire Gage No.</th>
<th>Nominal thickness (in.)</th>
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<td>1 11,500</td>
<td>100</td>
<td>9/16</td>
<td>1 3/8</td>
<td>12</td>
<td>0.109</td>
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<td>0.134</td>
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<td>2 1/2</td>
<td>8</td>
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<td>1 3/8</td>
<td>3</td>
<td>8</td>
<td>0.165</td>
</tr>
</tbody>
</table>

* Equal to 90% of the specified minimum elastic proof load of the bolt.

** Equal to 0.0167 lb.-ft. per inch bolt diameter per pound tension with nonlubricated bolts and nuts.
Type of Connection

(i) Flange Connection Type

(ii) Web Connection Type

(iii) Flange & Web Connection Type

Bolt Extensometer

Dial Gage

High Tensile Bolt

Grip of Testing Machine
Test Set Up (Third Point Loading)
SOME PRELIMINARY INVESTIGATION INTO THE USE OF HIGH TENSILE BOLTED CONNECTIONS IN STEEL STRUCTURES DESIGNED BY USE OF PLASTIC ANALYSIS

REFERENCES