Steel Design Guide

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High Strength Bolts

A Primer for Structural Engineers

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Chapter 1

INTRODUCTION

1.1. Purpose and Scope

There are two principal types of fasteners used in contemporary fabricated steel structures—bolts and welds. Both are widely used, and sometimes both fastening types are used in the same connection. For many connections, it is common to use welds in the shop portion of the fabrication process and to use bolts in the field. Welding requires a significant amount of equipment, uses skilled operators, and its inspection is a relatively sophisticated procedure. On the other hand, bolts are a manufactured item, they are installed using simple equipment, and installation and inspection can be done by persons with only a relatively small amount of training.

Engineers who have the responsibility for structural design must be conversant with the behavior of both bolts and welds and must know how to design connections using these fastening elements. Design and specification of welds and their inspection methods generally involves selecting standardized techniques and acceptance criteria or soliciting the expertise of a specialist. On the other hand, design and specification of a bolted joint requires the structural engineer to select the type of fasteners, understand how they are to be used, and to set out acceptable methods of installation and inspection. Relatively speaking, then, a structural engineer must know more about high-strength bolts than about welds.

The purpose of this Primer is to provide the structural engineer with the information necessary to select suitable high-strength bolts, specify the methods of their installation and inspection, and to design connections that use this type of fastener. Bolts can be either common bolts (sometimes called ordinary or machine bolts) or high-strength bolts. Although both types will be described, emphasis will be placed on high-strength bolts. Because many riveted structures are still in use and often their adequacy must be verified, a short description of rivets is also provided.

1.2. Historical Notes

Rivets were the principal fastener used in the early days of iron and steel structures [1, 2]. They were a satisfactory solution generally, but the clamping force produced as the heated rivet shrank against the gripped material was both variable and uncertain as to magnitude. Thus, use of rivets as the fastener in joints where slip was to be prevented was problematic. Rivets in connections loaded such that tension was produced in the fastener also posed certain problems. Perhaps most important, however, the installation of rivets required more equipment and manpower than did the high-strength bolts that became available in a general way during the 1950's. This meant that it was more expensive to install a rivet than to install a high-strength bolt. Moreover, high-strength bolts offered certain advantages in strength and performance as compared with rivets.

Bolts made of mild steel had been used occasionally in the early days of steel and cast iron structures. The first suggestion that high-strength bolts could be used appears to have come from Batho and Bateman in a report made to the Steel Structures Committee of Scientific and Industrial Research of Great Britain [3] in 1934. Their finding was that bolts having a yield strength of at least 54 ksi could be pretensioned sufficiently to prevent slip of connected material. Other early research was done at the University of Illinois by Wilson and Thomas [4]. This study, directed toward the fatigue strength of riveted shear splices, showed that pretensioned high-strength bolted joints had a fatigue life at least as good as that of the riveted joints.

In 1947, the Research Council on Riveted and Bolted Structural Joints (RCRBSJ) was formed. This body was responsible for directing the research that ultimately led to the wide-spread acceptance of the high-strength bolt as the preferred mechanical fastener for fabricated structural steel. The Council continues today, and the organization is now known as the Research Council on Structural Connections (RCSC). The first specification for structural joints was issued by the RCRBSJ in 1951 [5].

At about the same time as this work was going on in North America, research studies and preparation of specifications started elsewhere, first in Germany and Britain, then in other European countries, in Japan, and elsewhere. Today, researchers in many countries of the world add to the knowledge base for structural joints made using high-strength bolts. Interested readers can find further information on these developments in References [6, 7, 8, 9].

1.3. Mechanical Fasteners

The mechanical fasteners most often used in structural steelwork are rivets and bolts. On occasion, other types of mechanical fasteners are used: generally, these are special forms of high-strength bolts. Rivets and bolts are used in drilled, punched, or flame-cut holes to fasten the parts to be connected. Pretension may be present in the fastener.

Whether pretension is required is a reflection of the type and purpose of the connection.

Rivets are made of bar stock and are supplied with a preformed head on one end. The manufacturing process can be done either by cold or hot forming. Usually, a button-type head is provided, although flattened or countersunk heads can be supplied when clearance is a problem. In order to install the rivet, it is heated to a high temperature, placed in the hole, and then the other head is formed using a pneumatic hammer. The preformed head must be held in place with a backing tool during this operation. In the usual application, the second head is also a button head.

As the heated rivet cools, it shrinks against the gripped material. The result of this tensile strain in the rivet is a corresponding tensile force, the *pretension*. Since the initial temperature of the rivet and the initial compactness of the gripped material are both variable items, the amount of pretension in the rivet is also variable. Destructive inspection after a rivet has been driven shows that usually the rivet does not completely fill the barrel of the hole.

The riveting operation requires a crew of three or four and a considerable amount of equipment—for heating the rivets and for forming the heads—and it is a noisy operation.

taken from the parent rivet or bolt.) Since the only reason for dealing with rivet strength today is in the evaluation of an existing structure, care must be taken to ascertain the grade of the rivets in the structure. Very old structures might have rivet steel of lesser strength than that reflected by ASTM A502. (This ASTM standard, A502, was discontinued in 1999.)

In fabricated structural steel applications, threaded elements are encountered as tension rods, anchor rods, and structural bolts. In light construction, tension members are often made of a single rod, threaded for a short distance at each end. A nut is used to effect the load transfer from the rod to the next component. The weakest part of the assembly is the threaded portion, and design is based on the so-called "stress area." The stress area is a defined area, somewhere between the cross-sectional area through the root of the threads and the cross-sectional area corresponding to the nominal bolt diameter. In the US Customary system of units, this stress area (A_{st}) is calculated as—

$$A_{st} = 0.7854\left(D - \frac{0.9743}{n}\right)^2 \tag{1.1}$$

where D is the bolt diameter, inches, and n is the number of threads per inch.

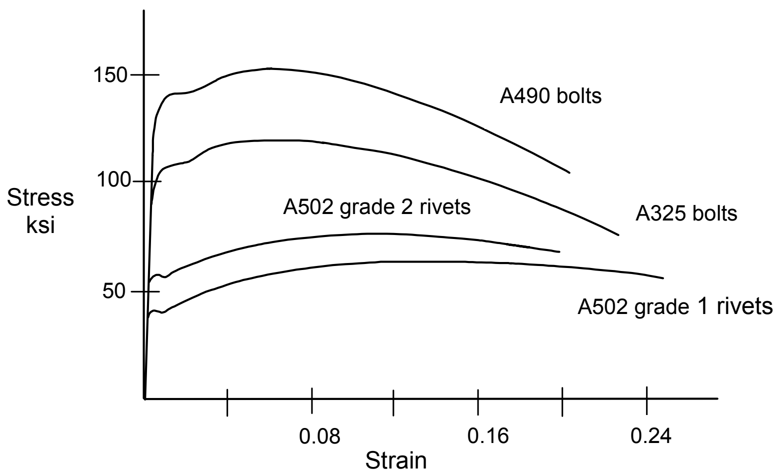

Fig. 1.1 Stress vs. Strain of Coupons taken from Bolts and Rivets

The ASTM specification for structural rivets, A502, provided three grades, 1, 2, and 3 [10]. Grade 1 is a carbon steel rivet for general structural purposes, Grade 2 is for use with higher strength steels, and Grade 3 is similar to Grade 2 but has atmospheric corrosion resistant properties. The only mechanical property specified for rivets is hardness. The stress vs. strain relationship for the two different strength levels is shown in Fig. 1.1, along with those of bolt grades to be discussed later. (The plot shown in Fig. 1.1 represents the response of a coupon

Threaded rods are not a factory-produced item, as is the case for bolts. As such, a threaded rod can be made of any available steel grade suitable for the job.

Anchor rods are used to connect a column or beam base plate to the foundation. Like tension members, they are manufactured for the specific task at hand. If hooked or headed, only one end is threaded since the main portion of the anchor rod will be bonded or secured mechanically into the concrete of the foundation. Alternatively, anchor rods can be threaded at both ends