Calculating Failure Rates for Bolts

An Online Continuing Education Course for Engineers

Course Number: MA-3009

Credit: 3 Hours / 3 PDH / 3 CPD

Calculating Failure Rates for Bolts

Prepared by Anthony Darmiento, PE, MSE

Introduction

This course covers fundamental and more advanced concepts associated with bolted connections. Bolts are a specific type of fastener, just like screws, rivets, and pins. The course material is presented so that an engineer with a basic mechanics background can understand it. This foundation will then be applied to focus on calculating the failure rates based on fatigue, from dynamic or fluctuating loads. Fatigue is commonly referred to as wear out, or wear and tear. A formal definition referenced in ASTM E1823 (Standard Terminology Relating to Fatigue and Fracture Testing) states fatigue is a process where localized and accumulating permanent damage to a structure occurs based on dynamic, alternating, or cyclical stress; after enough stress cycles, cracks may form or worse there may be a complete fracture of the structure. Dynamic or alternating loading particularly applies to bolted connections used for civil and mechanical engineering applications such as bridges, automobiles, maritime vessels, factories, and process and power plants. This course will examine a steel structure with a bolted connection for a notional steel structure that supports the weight of rotating machinery.

Bolt concepts such as nomenclature and configuration will be presented. Threads per inch, as well as thread series including coarse versus fine threads, are discussed. The course instructs on bolt markings as well as the specifications for ASTM and ISO bolts. More detailed subject matter about bolts would focus in detail on ASTM F3125 (Standard Specification for High Strength Structural Bolts).

Any discussion on failure rate will be in the context of fatigue. Hence, the fatigue failure rate calculation for bolts will be explained. This calculation is based on United States Navy's reliability research data within its Handbook for Reliability Predictions Procedures. The handbook will be cited in this course, such as referencing formulas and data tables to calculate a bolt's failure rate. As part of the bolt fatigue discussion, the concept of stress versus the number of cycles will be explored.

Bolted connections are used in many mechanical and structural applications. The reliability of bolted connections is its ability to perform its function of effectively maintaining a secure connection between two or more structural components. Understanding reliability is critical for engineers. This course provides a systematic and easy-to-understand method to calculate the reliability of common bolted connections by applying the concept of failure rate. The course material is at an introductory level, and no prior understanding of bolted connections is required. However, a general background in engineering mechanics is helpful for this course.

Methods of fastening or joining components include fastening, welding, brazing, and bonding with adhesives. One advantage of threaded fasteners such as bolts is they allow disassembly of the connection for inspection, maintenance, and repair, and they do not require as much skilled labor to assemble and disassemble. Threaded fasteners permit the use of automated and manual tools for assembly; the standard procedures for assembly promote reliability. The reliability of a threaded fastener connection depends on the strength of materials, method of the fastener fabrication, assembly procedures, and the stress on the fasteners due to loading and environmental conditions like temperature. A corroded bolt or an overloaded bolt are avoidable. However, the wear out, or wear and tear, of a bolt is not as avoidable.

This course will primarily focus on bolts for bolted connections, and more specifically, on calculating the failure rate for a structural bolt under cyclical or dynamic loads. The failure rate is based on the bolt undergoing fatigue from cyclical loading, also referred to as wear out. It is assumed that the bolt is properly designed, installed, and maintained (i.e., corrosion-free) for the application and that failure is due solely to wear out.

Acronyms

American Society for Testing and Materials (ASTM), or ASTM International
American Iron and Steel Institute (AISI)
Correction Factor for Fatigue Failure Calculation (C)
International Organization for Standardization (ISO)
Liquefied Natural Gas (LNG)
Society of Automotive Engineers (SAE)
Unified Thread Standard (UTS)
Unified Coarse (UNC)
Unified Fine (UNF)
Unified Extra Fine-Thread Series (UNEF)
Threads Per Inch (TPI)
KSI (thousands psi, 1 ksi =1,000 psi)
Stress versus Number of Cycles (S-N)
Reliability Analysis Center for the U.S. Air Force (RAC)
Reaction Force (R)
External Force or Load (L)
Tensile Stress (σ_T)
Temperature (T)
Base Failure Rate ($\lambda_{F,B}$)
ASTM Standard Specification for High Strength Structural Bolts (ASTM F3125)

Bolt Basics

There appears to be no established consensus on the difference between a bolt and a screw. However, the fundamental difference between screws and bolts is that a screw is typically used to assemble threaded objects, while a bolt is used to assemble unthreaded objects. Screws are turned with a screwdriver to assemble a joint or connection, whereas a bolt is secured in place by using a wrench.

A bolt is a form of threaded fastener with external threading requiring matching internal threading such as a nut or tapped hole. A bolt diameter is uniform, whereas most screws are tapered along their length. Machine screws are an exception with uniform diameters.

For bolted connections such as connecting two plates, the bolt generally is not threaded along its entire length; it has a shank. Screws do not have shanks except for wood screws. Figure 1 below is a diagram of a bolt with its components labeled. This diagram shows a nut connected to a bolt.

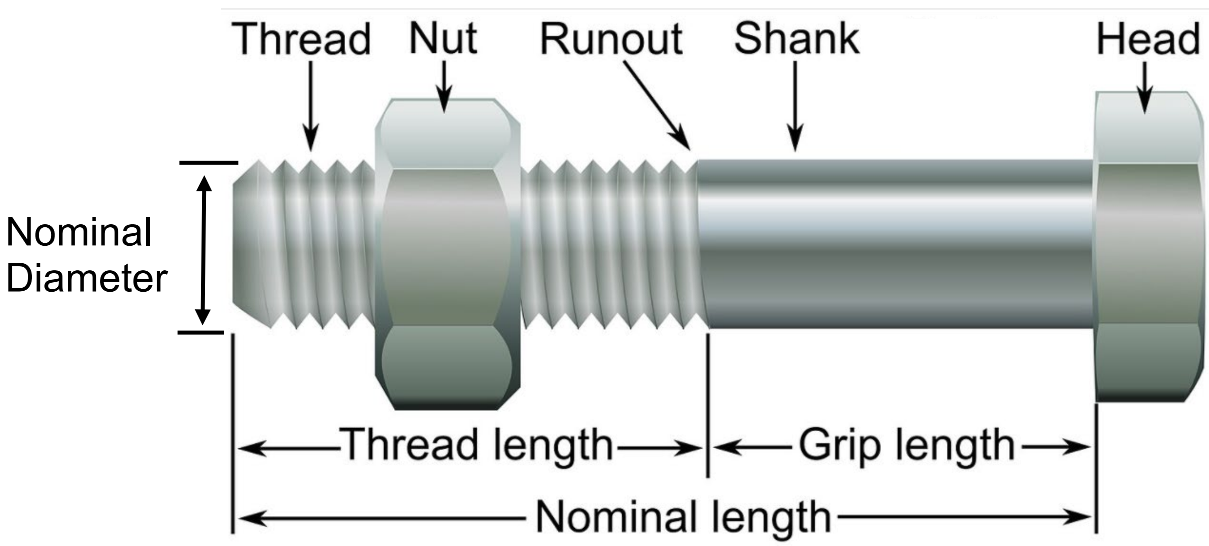

Figure 1: Configuration of a hexagonal head bolt

Figure 2 below shows four different types of machine screws based on their head design and drive type. The figure also includes a typical hexagonal bolt with a washer and nut as a visual comparison to the machine screws. This course will focus on bolts and primarily on the most common bolt, which is the hexagonal (or hex) bolt. The hex bolt is used in machinery and construction. Hex bolts can be used with a nut or in a tapped hole. Fully threaded hex bolts are also known as tap bolts.

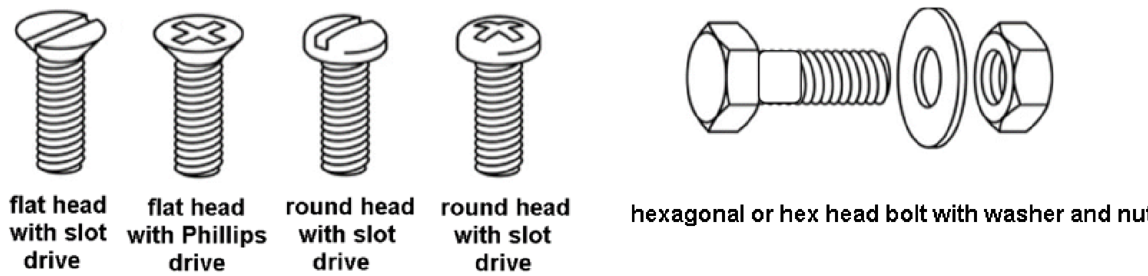

Figure 2: Common types of machine screws (left) and a hexagonal bolt (right)

Another display of common screws is shown in Figure 3 below. Wood screws have large threads and a smooth shank for pulling two pieces of material together. They can be used in wood and other soft materials. A lag screw is a large wood screw with a hex head and is typically used for wood construction and landscaping. Sheet metal screws have sharp points and threads and are designed to be driven directly into sheet metal. They can also be used in softer materials like plastic, fiberglass, or wood.

Figure 3: Common types of screws

Structural bolts are installed through prepared holes in the material to be joined. Various lengths of bolts are selected to accommodate the thickness of the material to be fastened and the additional length of thread needed for proper engagement with the nut or with the internal tapped thread (i.e., tapped hole). These fasteners are subjected to loads placed on the joint or joined material. The different types of bolt loads are shown in Figure 4 below.