The ESG Report

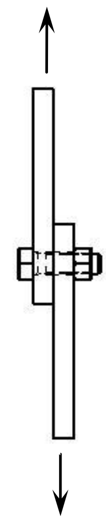
SPRING 2011

FASTENERS

The last two editions of the ESG Report discussed trusses and frames – inspired by a question about how to properly wrap temporarily installed truss spans using flexible roundslings. That simple question provided an opportunity to explain how forces are transferred through truss-like assemblies. Hopefully you learned some fundamental differences between trusses and frames, and that it's as important to understand the load path as it is to understand any given suspension method.

Not long after the release of our most recent edition, I read a notice from ESTA (now PLASA www.plasa.org) about a German Standard of Quality, *SQP1 Trusses*, published October 2010. This is a Code of Practice Standard of Quality, published in Germany by IGVW (translated as the Entertainment Technology Industry Association) as their first in a series of standards intended to address quality assurance for certain entertainment industry products and services.

The diversity of information contained in SQP1 is exceptional and is an excellent resource for those of you seeking more information on trusses. Although originally written in German, it has been very well translated into English and the electronic version is full of links to 3D examples viewable using the Adobe Reader. We recommend that you download the document directly from the IGVW website (www.igvw.org) under the Branchenstandards heading. Thanks to our friends Karl Ruling, Technical Standards Manager at PLASA North America, and Florian von Hofen at VPLT for helping us make a connection between you and a valuable entertainment industry resource.



Example 1

Fasteners

Speaking of connections, Reid Neslage of H & H Specialties asked us to write about fastener torque and the use of washers in bolted connections. Thanks Reid...we'll do it!

First, let's limit the scope of this article. A discussion about bolted connections would take volumes to cover. We're primarily interested in answering questions about fastener torque and about how washers affect the connection in any given circumstance, but to do that, we need to cover some basic connection types first.

Basic Connection Types

The AISC Steel Construction Manual categorizes bolted connections into three general types: Snug-Tightened, Pretensioned, and Slip-Critical. For structural bolts, all of these connection types are governed by the Research Council on Structural Connections (RSCS) *Specification for Structural Joints Using ASTM A325 or A490 Bolts*.

A simplified illustration of a snug-tightened connection is shown in Example 1. Notice how the applied loads cause the joint plies to bear on the bolt in shear across its axis. Provided that the connection is not subject to cyclic loads, or load reversals, then the magnitude of

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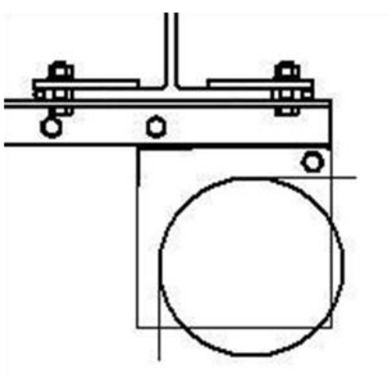
clamping force (fastener torque) is not important so long as the connection brings the contact surfaces firmly into contact.

Where load reversal, vibration or other cyclic loading is present, a pre-tensioned joint is required. These connections are not slip-critical, but do develop sufficient clamping force to counteract the loosening effect of the loading conditions. These connections are complex in application, but are easily described as being the result of applying torque to produce a desired clamping force, which distributes the connection forces more efficiently by using friction to an advantage. The range of tension required to achieve clamping force sufficient to resist the loads is called pretension.



Example 2

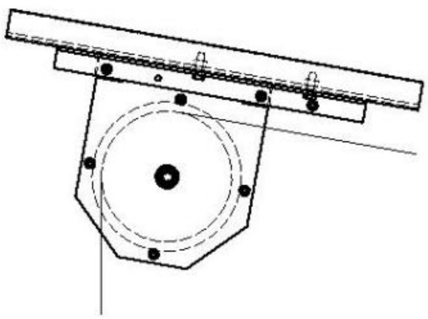
Example 2 shows a typical pretension connection for an underhung loft block. See how the block mounting clips hold the block assembly onto the beam flange, placing the fasteners in tension. Here, clamping force is important because the mounting clips must compress on the lower beam flange with sufficient clamping force so as not to loosen under the effects of vibration and cyclic loading.

However, since the typical block loads are applied perpendicular to the beam's major axis, this is not a slip-critical joint. In order to accomplish sufficient clamping force, a minimum amount of bolt pretension is required. According to the AISC manual, this minimum pretension force is *"...equal to 70% of the specified minimum tensile strength...when loaded in axial torsion."* The amount of torque required to achieve this pretension is easily calculated using standard connection design procedures.

Example 3 (next page) shows a typical parallel block mount using a slip-critical connection. The block is mounted to a pair of struts so the clamping force of the strut nuts must prevent the block from slipping along the beam flange. Parallel mounting the block using beam clips along the flange of a beam represents the same slip-critical condition. Slip-critical connections are joints wherein any slippage of the connect compromises the integrity of the joint. Slipping of the plies in a snug-fit connection might be permissible, but when slippage of the connection is unacceptable, the clamping forces must be such that the connection neither overstresses the bolt to failure, nor permits loosening of the joint. There is only one way to achieve this condition through clamping force alone: the bolt must be stressed to a point within - but not exceeding - its plastic limit. This plastic limit is the point on the material stress-strain curve below the material failure point, but above the point at which stress increases no longer produce proportionate strain.

About the author: Richard Nix is the Division Project Coordinator. His range of expertise includes rigging system design and installation, as well as several years as a stagehand and staff rigging supervisor. He is the author of many technical articles and has participated in ESTA's standards development efforts for over thirteen years.

Have comments or suggestions? Send them to us. We're listening.
Contact Richard Nix at 800-542-3302 or richard.nix@entertainmentstructures.com



Example 3

Fastener Torque

Now that we've discussed basic connection types, let's explore the importance of torque in each type of connection. Take a moment to consider how the torque is applied to the nut, which through mating helical threads, is translated into shear across the individual threads, which in turn is translated into axial tension in the bolt. Also consider how the mating threads make contact with each other; as axial tension and compression forces increase, angular forces are also created across the threaded surfaces, tending to shear the threads. When these forces exceed the material limits of the nut or the bolt, the threads will shear – you recognize this condition as a stripped thread. You can also over-torque a small-diameter fastener, snapping off the bolt head, which is another example of tensile failure related to material strength.

In all three connection types the bolt and nut must stay mated to each other in some varying degree of strength. A snug-fit connection relies solely on the bolt's ability to resist shear across its axis, so the nut must only stay on the bolt. This simple connection does not depend upon torque or clamping force to maintain the connection. In the other two connection types, torque and clamping force is increasingly important to maintain the connection strength.
Therefore, a well-designed bolted connection not only develops sufficient clamping force to maintain connection strength, but does so without shearing the threads that cause the fundamental transformation of torsional force into the axial clamping force of the connection. This demonstrates how a bolted connection is really a complex balance of forces which consider strength of materials in shear (for the threads), in tension (for the axial bolt forces) and in compression. Now let's briefly explore how material behavior relates to a bolted connection.

Bolted Connections

Basic material science demonstrates common stress-strain behavior. As strain on the material increases, the stress on the material increases. For steel and similar materials, this relationship is almost linear up to the material's yield strength (F_y), at which point stress relative to strain significantly decreases, but beyond which point the molecular bonds in the material break down, eventually resulting in ultimate failure (F_u) of the material. This range of stress between yield point and ultimate failure is called the plastic range. This behavior is especially critical in bolted connections because in order to achieve strength in the connection, without shearing threads or causing axial failure in the bolt, the material must be stressed to a point within its plastic range.

Intuitively, this should illustrate how the material for both mating components (nut and bolt) should have the same material properties, because if they are mismatched, then otherwise normal torque conditions could easily overstress and fail the weaker of the two materials. Now back to torque…

How can we achieve the required torque for any given connection?

The AISC Steel Construction Manual describes three distinct methods: use of a torque wrench, use of direct tension indicators (or DTI's), and the turn-of-the-nut method – a seemingly subjective process in which all contact surfaces are brought to a snug fit, then turned an additional $^1/_3$- to 1- full turn (depending upon the bolt length). Surprisingly, the AISC commentary notes that this method achieves a "*...more uniform bolt pretension than is generally provided with torque-controlled...*" methods.

Proper torque is achieved under ideal conditions where friction between the bolt and nut contact surfaces (relative to their respective joint ply contact surfaces) is minimized. Everything we've discussed so far, relative to material strength and bolt pretension, assumes that all of the connection materials are steel. Thus, if a joint ply is wood for example, then the mating surface contact friction is increased (the wood is softer), which inherently prevents the proper pretension from being achieved. Therefore it is safe to say that there is no such thing as a pre-tensioned or slip-critical connection in wood, because the wood material properties alone cannot adequately resist the compressive forces required to develop the required fastener preload.

With wood, bolted connections are usually dependent upon having a sufficiently large contact surface area across the bolt axis, where the wood on the inside of the hole(s) bear on the bolt. Wood is one example of materials that don't react well to localized compressive loads - as the connection is tightened, the nut and the bolt head gouge into the wood, weakening the connection. This leads us to the importance of washers.

Lock, Flat & Beveled Washers

Washers are not required for snug-tight connections, with two exceptions. First, when the bolt/nut contact surfaces are beveled > 1:20 relative to a plane normal to the bolt axis, then beveled washers must be used. Second, with slotted holes, flat washers must be used to maximize the contact surface area around the holes.

For both pre-tensioned and slip-critical joints the requirement for flat washers depends upon how critical the development of clamping force is to the connection, but they are almost always required in both cases. What's more, if the joint plies are of different materials or if slotted holes are used, then flat washers are mandatory to facilitate force distribution across the plies and to reduce localized damage due to compressive or friction forces as the connection is progressively tightened.

What about lock washers? You may find this surprising, but it's proven in most snug-fit connections that lock washers aren't as effective as other thread treatments such as thread-lock compound or thread peening, especially in cyclic loading or vibration conditions.

Furthermore, lock washers are useless in pre-tensioned or slip-critical joints because they inhibit the ability to fully develop the required clamping force in the connection. This is also true for nuts with Nylon inserts (aka Nyloks), especially when shallower versions of these components are used. Sufficient torque cannot be developed in the connection, so they must not be used in pre-tensioned or slip-critical connections. Unfortunately, our article space limitations prevent us from going into further detail.

Bolted Connections

At first glance, bolted connections appear simple. After all, they are "just" a bolt, a nut, and maybe a washer or three. In reality, bolted connections are very complex. When one considers the variety and range of materials, of corrosion-resistance and plating requirements, of mating thread tolerances, we've barely scraped the surface here. This is a great topic and there are countless resources available, but please don't let that stop you from asking questions. Send them to Richard Nix care of richard.nix@entertainmentstructures.com We're listening.

Disclaimer: This article is not intended to be a thorough treatment of the topic of structural evaluation. Local, state and national building codes should be consulted. The author cannot be responsible for any evaluation based solely upon this article.

Resources for bolted connections

- Steel Construction Manual, 13th Edition American Institute for Steel Construction, Part 7, Design Considerations for Bolts
- Machinery's Handbook
- Industrial Fastener Institute
- Research Council on Structural Connections (RSCS) *Specification for Structural Joints Using ASTM A325 or A490 Bolts*

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