Discussion of Basic Construction Terms and Topics for High-Strength Bolted Connections

There are many types of bolts used for structural applications. Quality for all of the various bolt types is ensured through compliance with applicable American Society for Testing and Materials (ASTM) standard specifications. These national specifications clearly denote specific mechanical properties, chemical composition, and dimensions for each type of fastener.

Where lower strength fasteners are required, ASTM A307 mild steel fasteners and anchor bolts are commonly used. These are usually not preloaded, have a minimum yield strength of 36 ksi, are extremely ductile, and can be welded (when S1 supplementary requirements are specified) and zinc coated.

The main type of high-strength (HS) structural bolt frequently specified in Caltrans contracts for steel joints in bridges, overhead sign support structures, and buildings, is designated as Grade A325 bolts (commonly referred to as A325 bolts), and is available only in a heavy hex headed style and in diameters from 1/2 inch through 1-1/2 inches. A325 bolts are almost always specified for major structures and have a minimum tensile strength of either 105 or 120 ksi, depending on the bolt diameter; the minimum proof load is either 81 or 92 ksi. Because Caltrans wants to ensure maximum plastic ductility of fasteners in structural joints in the event of a large earthquake, we specify A325 fasteners or F1852 tension control (TC) bolts almost exclusively. These can be zinc coated to ensure a long life in corrosive coastal environments. While an A490 structural bolt is available, its lower ductility and inability to be zinc coated make it less desirable for use in coastal regions where long-term corrosion protection is vital and earthquakes are likely to occur.

Where larger sizes of HS fasteners or threaded rods having properties identical to those of A325 bolts are required, an A449 series of bolts and rods is readily available. Mechanical properties and chemical composition of this fastener are identical to those of A325 bolts; it is available in a wider variety of sizes, from 1/4-inch to 3-inch diameters, can be ordered in a number of different head styles, and can be zinc coated.

Another type of HS bolt and threaded rod, which is quenched and tempered alloy steel, and is called an ASTM A354 is also readily available; it comes in two grades - BC and BD and in diameters from 1/4 inch to 4 inches. Because the tensile strength of Grade BD fasteners may exceed 150 ksi, they cannot be zinc coated. These two grades of fasteners are frequently used for large bolts or rods, where high strengths are required.

1 - Discussion of Various Topics Related to High-Strength Bolting

In the following paragraphs, various topics related to HS bolting are discussed:

a. Types of Connections:

A bolted connection may be designed as either a *bearing type* or a *slip critical* connection. The *Contract Specifications* require that all connections made with HS bolts must be considered as (slip-critical) *friction-type* joints and must be tensioned as a typical slip-critical joint, unless otherwise designated on the contract plans or specifications. To ensure that adequate friction is developed between joint plies, faying (contact) surfaces of all HS bolted connections must be free of rust, mill scale, dirt, grease, or any other material foreign to the steel, before assembly. The *Contract Specifications* may require faying surfaces of bolted connections to be coated with either a hot-dip zinc coating that has been hand wire brushed prior to assembly, or with an approved inorganic zinc primer prior to assembly.

b. Bolt Holes:

Bolt holes must be either punched full size, drilled full size, sub-punched and reamed, or sub-drilled and reamed. Flame cutting of holes is not permitted. Reference *Contract Specifications*, Section 55- 1.02E(6)(b), *Steel Structures – General – Materials – Fabrication – Bolt Holes* and Table 3.1*, Nominal Bolt Hole Dimensions,* in Section 3.3, *Bolt Holes,* in *Specification for Structural Joints Using High-Strength Bolts*, of the *Research Council on Structural Connections* (RCSC) Specification.

c. Thread Stickout:

Determining and purchasing the correct bolt lengths for each different joint is the responsibility of the Contractor. The amount of exposed thread beyond the outer face of the nut is called “thread stickout”. After HS bolts have been installed and tensioned, the permitted range of thread stickout is from flush to no more than 1/4 inch beyond the outer face of the nut. Note: On TC bolts, frequently there are a few partial threads adjacent to the groove where the splined tail breaks off. Therefore, for TC bolts, thread stickout must be measured from the outer face of the nut to the first full thread near the sheared end of the bolt (after the splined end has been sheared off).

d. Hardened Washers:

According to *Contract Specifications*, Section 55-1.02E(6)(c), *Steel Structures – General – Materials – Fabrication – Bolted Connections – Installation,* one (flat) hardened washer (ASTM F436 or F436M) must be installed under the nut or bolt head, whichever is the element turned in tightening. A maximum of one

additional hardened washer may be installed under the non-turning element of the fastener assembly to correct excessive thread stickout. Regardless of the method used to tension the bolt, or the type of connection design, lock washers are not an allowable substitute for hardened washers.

Lock washers generally do not have adequate surface contact area, or sufficient corrosion resistance, and due to different steel chemistry and thinner protective coatings, corrode at a higher rate than adjacent steels. If the slope of the exterior face(s) of the connected parts exceeds 1:20 (approximately 3 degrees) relative to the bolt or nut face, a hardened beveled washer(s), meeting requirements in ASTM Specification F436 must be inserted against each sloped surface.

e. Snug-Tight Condition:

No matter which of the approved tightening methods is used to tension HS bolts, the first step in tightening a joint is the same - bring all plies in the joint in contact by snugging the fasteners. This requires all fasteners in a joint to be brought to a snug-tight condition using a systematic tightening sequence (starting from the center of the joint). “Snug-tight" is defined as the full effort of a person using a spud wrench or a few impacts of a pneumatic wrench applied to the nut. While snugging fasteners, if plies are not initially in contact, care must be taken to avoid bending of the connection parts. Following snugging, all plies in a joint must be in firm contact with each other.

f. Systematic Tensioning Pattern:

All bolts in a joint need to be tensioned in a systematic manner to produce a consistent even tension in each bolt. The tensioning pattern may be done in a crisscross or alternating fashion and needs to be systematic to produce an even tension in all bolts. This tightening pattern should be used to bring bolts to the snug condition, and also to their final minimum required tension. In joints having a rectangular or square bolt pattern, bolts must be tensioned, starting at the center (most rigid part) of the joint and proceeding toward the free edges. For joints having a circular bolt pattern, a crisscross alternating pattern is appropriate. Writing a sequential number on each fastener in a large joint is a good way to ensure all bolts are tensioned in their correct order, and none miss their turn. To ensure that all fasteners are fully tensioned, this final tightening process may require more than one cycle.

g. Fastener Storage and Handling:

i. Storage: Regardless which of the approved methods is chosen to tension HS bolts, the condition of the fastener components (especially threads on both the nuts and bolts) is critical; all fastener components must be furnished and maintained in good condition until installed and final inspection has been performed. The original lubricant on all fastener components must be kept intact as supplied from the manufacturer, and all fastener components must

be stored so that they do not get rusty or dirty. As soon as fastener containers are received at the job site, they must be stored in the original containers and protected from dirt and moisture. Containers should always be covered and be kept off the ground.

ii. Handling: Fastener components from different lots must never be inter-mixed. Only those fastener components that are to be used in one shift are allowed to be removed from containers. Components not used during that shift must be returned to their original containers. The following information must appear on the outside of the shipping/storage containers:

1. Manufacturer's name and address
2. Contents (size and numbers)
3. Component lot number
4. Rotational capacity lot number

Note: All components of galvanized fastener systems (including bolts, nuts, washers, and direct tension indicators (DTIs) must be shipped and kept together as an assembly.

h. Lubrication:

i. Plain (black) Fasteners: Most plain or "black" fastener components have been heat-treated and all parts are coated by the manufacturer with a thin film of water-soluble (oily) lubricant that can be easily washed-off if exposed to moist elements. Prior to being installed, threads on bolts and nuts must be oily to the touch, as received by the manufacturer. Should the bolts, nuts, or washers show signs of improper storage, such as rust and dirt accumulation, or absence of original lubricant on the threaded fastener components, this must be cause for rejection.

ii. Zinc-coated Fasteners: All zinc-coated nuts used on HS zinc-coated bolts must be coated by the manufacturer with a lubricant that is clean and dry to the touch, unlike black bolts that are furnished in an oily condition. To make identification easier, a colored dye, or an ultraviolet dye that can be seen with a black light, is required in the lubricant used for all galvanized nuts. No attempt should be made to tension a HS, zinc coated bolt whose nut has not been lubricated with a dry lubricant or properly "tapped" oversize. Without the proper lubrication applied on the nut threads and base, the fastener threads can gall, strip, or seize, causing the bolt to shear off before the required bolt tension is reached.

i. Rotational Capacity (RoCap) Test:

See Section 1, Phase 1.3, *Rotational capacity (RoCap) testing,* of Attachment 2, *Inspection Procedure for Checking Tension in High-Strength Bolts*.

j. Reuse of High-Strength Fasteners:

Black A325 nuts and bolts may be reused once if allowed by the Engineer. However, neither A490 fasteners nor galvanized A325 fasteners will be reused after they have been tensioned. Reuse of black A325 bolts and nuts should only be considered if they are in good condition (clean and with lubricant), the bolt threads are not excessively elongated (checked by spinning the nut by hand over the entire length of bolt threads), and each fastener lot is retested and passes the new pre-installation and rotational capacity tests. Once installed, neither TC bolt assemblies nor DTIs may be reused.

k. Inspecting a Completed Bolted Joint:

The *Contract Specifications*, Section 55-1.01D(3)(c)(iv), *Steel Structures – General – Quality Assurance – Quality Control – Field Quality Control – Verification Tension Testing,* requires that fastener tension testing to verify minimum tension in HS bolted connections be performed no later than 48 hours after all fasteners in a connection have been tensioned. At least 10 percent of the fasteners in each joint must be checked. Verification of bolt tension must be done by the Contractor in the presence of the Engineer and in such a manner that the Engineer can read the torque wrench gage or see gaps around the DTI during checking. The job inspecting torque must first be determined by the Contractor by testing five fasteners from each lot of bolts according to the procedure detailed in Section 10 of *Specification for Structural Joints Using High-Strength Bolts* of the RCSC Specification. To verify adequate tension in each of the fasteners selected for inspection in a completed joint, a suitable manual torque wrench (dial or digital read out only) is used to apply the job inspecting torque value to nuts (or bolt head, if turned). During the inspection, if any of the nuts turn, then 100 percent of the bolts in the connection must be tested, and all bolts found to be under tensioned must be tightened, and then reinspected.

2 - Definition of Terms Commonly Used in HS Bolting

Terms commonly used in HS bolting operations and specialized tools need to be clearly understood. The following is a list of terms and tools that are frequently used when dealing with HS bolts. Inspectors and construction personnel need to be familiar with these – what they are and how to use them. They include:

a. Bolt tension calibrator: A machine to measure bolt tensions (i.e., Skidmore-Wilhelm, or Norbar).

b. Direct tension indicator (DTI): A DTI as depicted in Figure 1 is a device installed on HS bolts to monitor bolt tension. It must conform to requirements in ASTM F959/F959M.

Figure 1. Typical Direct Tension Indicator

c. **Electric installation tool for tension control (TC) bolts:** An electric tool used to install TC bolts.

d. **Faying surfaces:** Contact surfaces between structural plates within a HS bolted joint.

e. **Grip length:** The total thickness of all plies in a joint, including washers (distance between the underside of the bolt head and the inside face of the nut).

f. **Pre-installation testing:** A test series performed on each lot of fasteners, and at the beginning of a shift or job, in which the installer demonstrates that with the actual installation equipment and lot of fasteners to be used on the structure, he can properly install them and obtain the proper tension.

g. **Job inspecting torque** (referred to as **"arbitration torque"** in the RCSC Specification)**:** A torque value established for each lot of fasteners and used after a joint has been completed to check that bolts have been tightened to at least the minimum tension.

h. **Match marking:** A series of four marks made on the outer surface of a joint after all the fasteners in a joint have been snug tightened, to monitor the amount that the nut has been turned. Match marking is required if the turn-of-nut tensioning method is used.

i. **Mechanical deposited and hot-dip zinc coating:** Two different coating processes where zinc metal is applied to surfaces of fastener components.

j. **Rotational capacity (RoCap) test:** A preliminary test performed both by the manufacturer and at the job site on new fasteners to ensure that there is proper lubrication on fastener threads and that there is adequate ductility.

k. **Snug tight:** The preliminary tightening stage that all fasteners in a joint must be taken to, that produces a tension in each fastener of about 10% of its final tension, and that brings all plies of a joint into firm contact.

l. **Tension control (TC) fastener:** A TC as depicted in Figure 2 is an alternative HS fastener system, which includes a nut, washer, and bolt with a splined end. It must conform to requirements in ASTM Specification F1852.

Figure 2. Typical Twist-off Type TC Fastener System

m. **Thread stickout:** Amount of threaded bolt tail projecting beyond the outer face of the nut on an installed bolt.

n. **Torque multiplier:** A tool used to amplify tightening effort applied to tension (install) or inspect large HS bolts.

o. **Torque wrench:** A tool (dial or digital type permitted) used to tighten and inspect HS bolts.