Bolted Connection

Connections are an essential part of any structure. It accounts for about half the cost of structural steelwork and so its design, installation and inspection are of primary importance to the economy of the structure. Connections transfer the loads from one member to another member, e.g. a beam to a column. In structural steel construction systems, bolted connections provide continuity in the structural members (Underwood & Chiuini, 2007). The strength of bolt connections is independent of whether the bolt is finger tight or fully tightened (Bickford & Nassar, 1998, p. 403). This typical performance has given rise to the classification of joints loaded in shear as either slip-critical or shear bearing (Bickford & Nassar, 1998, p. 403). This paper will present the types, installation and inspection process of both high-strength bolts and common bolted connections.

TYPES OF BOLTED CONNECTION

Bolted connections are specified in three types, namely Type N connection, Type X connections and Type SC connections (Underwood & Chiuini, 2007). Type N connections may have threads within a shear plane and can carry high loads. However, Type X connections have all threads excluded from shear planes and carries a greater load since the cross section of the bolt in shear is larger. Here, the primary concern is strength and not the occurrence of slip (Bickford & Nassar, 1998, p. 403). Specifying type N connection bolts make construction much simpler, as it is unnecessary to maintain stringent control over it, due to the cross-section of the bolts being larger (Underwood & Chiuini, 2007). Type SC are slip critical type connections which relies on high tension to create the frictional forces that keep the elements in place (Underwood & Chiuini, 2007). Here, connection strength is not the primary concern and slip cannot be tolerated (Bickford & Nassar, 1998, p. 403).

Here, the bolts are fully pretensioned to cause a clamping force between the connected components, which allows frictional resistance to develop between them. The fric-tional resistance prevents the connected components from slipping into bearing against the body of the bolt. Slips must be prevented to avoid minor changes in the geometrical relationship between members to ensure the integrity of the structure subject under static loads or to ensure the back-and-forth slippage of connections does not occur when they are subjected to significant reversal of loading or for other reasons (Bickford & Nassar, 1998, p. 411). Type SC connection are effectively used for moment –resisting connections (Sarkisian, 2016, p. 127).

INSTALLATION OF BOLTED CONNECTION

Bolts are cylindrical pieces of metal with a hexagonal head on one end and a thread cut into the shaft at the other end (Duffy, Heard & Wright, n.d., p. 145), as seen in figure 2. A bolt is intended to be used with a nut or hole that has an identical thread cut inside (Bickford & Nassar, 1998, p. 1). Figure 2 also shows the shank to be possess some measures of thread, and the length of the thread is dependent on the diameter of the bolt. The use of washers in the bolted connection may or may not be necessary, based on the application. Generally, a good practice is to provide washers beneath both the bolt head and the nut as shown in figure 3 to distribute the clamping pressure on the bolted member and to prevent the threaded portion of the bolt from bearing on the connecting pieces (Gambhir, 2013). The purpose of the bolt and nut is to provide clamping force (Bickford & Nassar, 1998, p. 1).

In the bolted connection depicted in figure 3, the parts to be joined are tightly clamped between the bolt head and the nut (Gambhir, 2013). Bolts are installed primarily by aligning and placing the bolts in their individual matching holes and then running the nut through the bolt thread until it makes contact with the connected plies. This can be achieved in several ways, either manually, by utilizing a spud wrench, mechanically by impact wrenches, or making use of a power tool, such as air-operated or electric wrenches (Raz, 2002, p. 34). The expectation is for the parts connected to be in close proximity to each other.

The installation process of bolted connection begins with the stiffest part of the joints and then progresses systematically. During this progress, some repetition may be required. The condition of the bolts at this time is known as snug-tight, and it is achieved by the ironworker effort using a spud wrench or by driving the nut down until the air-operated wrench first begins to impact (Kulak, 2002, p. 13). The bolt then will undergo some elongation during this procedure, and a resultant tensile force will be developed in the bolt. In order to sustain a balance, an equal and opposite compressive force is developed in the connected material. The amount of the bolt tension at the snug-tightened condition is generally large enough to hold the parts compactly together and to prevent the nut from backing off under static loads. The snug tight condition is the tightness attained by the full effort applied by a person using spud wrench (Raz, 2002, p. 34). For many applications, the snug-tight condition is acceptable, as it is an economical solution, but they should be specified whenever possible (Raz, 2002, p. 34).

Turn-of-Nut Installation Method

This installation involves the bolt being initially inserted into their holes and brought to a snug tight position (Raz, 2002, p. 34). If the nut continues to be turned past the location described as snug-tight, then the bolt tension will continue to increase (Raz, 2002, p. 34). In this section, the installation process described is that in which a prescribed amount of turn of the nut is applied. This is an elongation method of controlling bolt tension. As the nut is turned, conditions throughout the bolt are initially elastic, but local yielding in the threaded portion soon begins. Most of the yielding takes place in the region between the bolt thread run-out and the first few loaded threads of the nut (Kulak, 2002, pp. 14-47). As the bolt continues to elongate under the action of turning the nut, the bolt load with respect to elongation response flattens out, that is, the bolt preload tension force levels off.

Calibrated Torque Wrench Method

Theories suggests that there is a relationship between the torque applied to a fastener and the resultant pretension, as such, bolts can successfully be installed to specified preloaded tensions by application of known amounts of torque (Hsu & Gakkai, 1989, p. 21). The relationship between preloaded tension and torque is a complex one, which reflects factors such as the thread pitch, thread angle and other geometrical features of the bolt and nut, and the friction conditions between the various components of the assembly (Gong, Liu & Ding, 2016). As a consequence, it is generally agreed that derived torque with respect to preload tension are unreliable. A torque-based installation method is possible provided that the installation wrench is calibrated. This would have to be done using a representative sample of the bolts to be installed. This installation methods are used when wrenches are calibrated on a daily basis and when the washer is used under the turned element In comparison, the turn-of-nut method of installation is simpler, provides consistent levels of bolt preload, and leads to fewer disputes in the field.

Tension-Control Bolts Installation

The outer section of the tension controlled bolt or twist-off bolt is unthreaded but has a hexagonal shape which is driven by an assembly tool (Bickford, 2018). It is fastened by a reduced cross-section, breakaway collar to a cylindrical inner section which is threaded. As the limiting torque is reached, the hex section breaks away from the cylindrical inner section, which remains to hold the bolt as seen in figure 4. Additionally, the tension-control bolt has a splined end that protrudes beyond the threaded portion of the bolt and an annular groove between the threaded portion of the bolt and the splined end.

The special wrench tool required to install these bolts has two coaxial chucks—an inner chuck that slips over the splined end of the bolt and an outer chuck that envelopes the nut (Bjorhovde, Colson & Zandonini, 1996, p. 515). The two chucks turn in opposite directions to make the bolt tight. At some point, the torque established by the friction between bolt threads, the nut and the nut–to-washer interface overcomes the torsional shear resistance of the bolt material at the annular groove (Bjorhovde, Colson & Zandonini, 1996, p. 515). The splined end of the bolt then shears off at the groove. If the system has been properly manufactured and calibrated, the target bolt pretension is achieved at this point. Factors that control the preload are bolt material strength, thread conditions, the diameter of the annular groove, and the surface conditions at the nut–washer interface (Bjorhovde, Colson & Zandonini, 1996, p. 515). The installation process requires just one person and takes place from one side of the joint only, which is often an economic benefit. The wrench used to do the installation is powered by electricity, and this can be beneficial in the field (Kulak, 2002, p. 19).

Direct Tension Indicators

Direct tension indicators are hardened special washer-type elements with arched protrusions that flattens when the specified tension is achieved (Taranath, 2017, p. 815), as depicted in the figure below, which are placed under the bolt head or under the nut during installation. This is a method used to verify proper tension without relying on turn of the nut markings. As the nut is turned, small arch-shaped protrusions that have been formed into the washer surface compress in response to the preload tension that develops in the bolt. If a suitable calibration has been carried out, the amount of preload tension in the bolt can be established by measuring the size of the gap remaining as the protrusions close (Bickford, 2018). This calibration requires that a number of individual measurements be made in a load-indicating device and using a feeler gauge to measure the gap. The use of the direct tension indicating washers is to eliminate deformation such as bolt twist, heat loss in the threads (Bickford, 2018), and so it is not subject to the friction-related variables that are associated with the calibrated wrench and tension control bolt methods.

PURPOSE OF QUALITY CONTROL OF BOLTED CONNECTION

It is said that necessity is the mother of invention, as such necessary guidelines, standards, and regulations that aids keep structural operations safe for humans and the environment, must be put in place. Quality control is important to test the integrity of the bolted connection. As such, the inspection must be consistent with the need to examine the suitability of the component to fulfil its intended function, but it must not be excessive in order that the economical construction of the job is not affected.

INSPECTION OF BOLTED CONNECTION

In the inspection of the bolted connection, the first step is having an understanding of the function of the fastener in the joint. This knowledge helps give awareness of what features to look out for during inspection.

Some essential features in the inspection of installation of high-strength bolts are

- To know whether bolt pretension is required or not. If bolt pretension is not required, do not inspect for it.
- To know what pre-installation verification is required and to monitor it at the job site on a regular basis.
- To observe the work in progress on a regular basis. Using acoustic methods, it is possible to determine the pretension in bolts connection that have been installed in the field with reasonable accuracy. However, this process, which determines bolt pretension by sending an acoustic signal through the bolt, is uneconomical for all but the most sophisticated applications.

Joints Using Snug-Tightened Bolts

For those joints where the bolts need only to be brought to the snug-tight condition, inspection is simple and straightforward. Since, there is no verification procedure associated with snug-tightened bolt installation, the inspection should establish that the bolts, nuts, washers (if required), and the condition of the faying surfaces of the parts to be connected meet the requirements of the Standard Hole types (e.g., oversize, slotted, normal) and is in conformance with the contract documents being used. The faying surfaces should be free of loose scale, dirt, or other foreign material. Burrs extending up to 1/16 in. above the plate surface are permitted. The inspector should verify that all material within the grip of the bolts is steel and that the steel parts fit solidly together after the bolts have been snug-tightened. The contact between the parts need not be continuous.

Joints Using Pretensioned Bolts

If the designer has determined that pretensioned bolts are required, then the inspection process becomes somewhat more detailed than that required for snug-tightened bolts. Of course, the requirements already described for snug-tightened bolts are still applicable. In the case of turn-of-nut pretensioning, routine observation that the bolting crew applies the proper rotation is sufficient inspection. Alternatively, matchmarking can be used to monitor the rotation. However, it will be readily apparent that an air-operated impact wrench has been applied because the faces of the nut become peened during the installation operation. Inspection of the installation of twist-off bolts is also by routine inspection. Since pretensioning of these bolts is by application of torque, proper storage and handling is particularly important. This should include a time limit between removal of bolts, nuts and washers from their protected storage and their installation.