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ORIGINAL RESEARCH

Tension Control Bolts (TC Bolts)

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Abstract

Tension control bolts (TC bolts) are specialized fasteners mainly utilized in steel frame construction. They include a pre-assembled bolt, nut, and washer for simplified installation. In contrast to standard bolts, TC bolts have a domed head and a distinctive spline design that enables accurate tensioning during the installation process. This advancement has led to their growing popularity in the construction sector because of their effectiveness and dependability. In this article, examined this type of bolts, installation mechanism, their advantages over conventional high-strength structural bolts, challenges and considerations, durability comparison between traditional and TC bolts, design features, installation process, and also review the relevant standards associated with them.

Key words: Tension Control Bolts, TC Bolts, High-strength bolts.

Introduction

Tension Control Bolts, commonly referred to as TC bolts, are utilized for fastening steel to steel in high-strength applications. They are among the most frequently used fasteners in such contexts and are often favored over large hex bolts. The head of these bolts is dome-shaped and is not intended for use with standard tools; instead, a specialized wrench is necessary for installation. During the installation process, the bolt undergoes deformation, resulting in the shearing off of its extension due to applied torque. Additionally, the spline feature enables users to determine when the bolts have reached the appropriate tension level.

Fig. 1 Tension Control Bolts (TC Bolts)

In the study of Kulak et al. [1] investigates how various factors, such as material strength and environmental conditions, affect the pretension of these bolts from different manufacturers. The article concludes that tension control bolts (TCBs) are effective fasteners for achieving the required preload in bolted joints, particularly in high-strength applications. The study demonstrated that various factors, including material strength, thread conditions, and environmental exposure, significantly influence the preload achieved by these bolts.

In the of Kulak et al. [2] testing program described here assessed the preload in a substantial sample of approximately 850 bolts sourced from various manufacturers. It also considered different factors such as the age of the bolts and their exposure prior to installation.

In the study of Lowe [3] emphasizes that while TC bolts simplify high-strength bolted connections, proper techniques must be employed when a TC gun is not feasible. The turn-of-nut method is highlighted as the most effective approach for ensuring proper tension in such cases.

In the study of Tai et al. [4] , examined the remaining clamping force in corroded tension-control bolts and analyzed how each component contributes to the reduction of that force. A finite-element analysis indicated that loss of the bolt head section, particularly a reduction in bolt head diameter, has a lesser impact on clamping force compared to a decrease in nut width. The root sum square of these reductions, which correlates with nut width reduction, is suggested as a metric for estimating the residual clamping force in corroded tension-control bolts. To validate this method, the residual clamping force of corroded bolts extracted from actual steel bridges was measured, and the experimental findings demonstrated an accuracy of approximately ±15%.

ASTM F3043 twist-off type tension control bolt assemblies exhibit a nominal strength of 200 ksi, which is a 33% increase over ASTM F3125 Grade A490 bolts. The Grade 2 version of these bolts, first used in Japan since 2001, follows different installation procedures compared to those in the U.S., which are based on the Research Council for Structural Connections (RCSC) [5] specifications. Testing involving 210 pretensioned assemblies confirmed that RCSC procedures successfully meet minimum pretension requirements across various conditions, including exposure to moisture and temperature fluctuations [6]. Notably, all tested specimens at 70 °F surpassed the minimum pretension force, achieving an average that was 13% greater than required.

In the study of Neidel et al. [7], the twist-off bolts used in the assembly of combustion chamber components for heavy-duty gas turbine engines. These bolts sheared off at tightening torques below 25 Nm during final assembly, leading to a loss of functionality. A material graphic analysis revealed that the primary failure cause was non-compliance with drawing specifications, rather than design flaws. However, secondary design deficiencies were noted, particularly regarding untempered welded joints in martensitic chromium steels, which can act as metallurgical notches under dynamic loads, emphasizing the need for careful design and assembly practices in turbo machinery.

1. Installation Mechanism:

The use of a specialized electric shear wrench simplifies the installation of tension control bolts. This tool features two sockets: an inner socket that clutches the bolt's spline and rotates it in a clockwise direction, and an outer socket that turns the nut counterclockwise. Once the required tension is achieved, the spline shears off, offering a clear visual signal that the bolt has been correctly tensioned. In the Fig. 2, the electric shear wrench is shown. Installation advantages include visual inspection, consistent tension, Single operator installation reduces labour costs, non-impacting electric shear wrenches, no air compressors or hoses required, calibrated torque wrenches are not required, and environmentally friendly coating.

Fig 2. Electric shear wrench of TC bolts

In the study of Lowe et al. [8] discusses the issue of tightening tension control (TC) bolts when a TC gun cannot be used due to space constraints. The results revealed that When a TC gun doesn't fit, using a torque wrench is not recommended due to poor correlation between torque and bolt tension. The preferred alternative is the turn-of-nut method, which requires only a wrench and marker.

3. Benefits of Tension Control Bolts

3.1. Simplified Installation:

TC bolts can be installed by one person, which lowers labor expenses and decreases the likelihood of mistakes during the installation process.

3.2. Precise Tension Control:

The design of TC bolts enables precise tensioning, eliminating the uncertainty often found in conventional bolting techniques. The calibrated shear wrench guarantees that the appropriate preload is consistently attained.

3.3. Reduced Inspection Needs:

The visible sign of correct installation (the sheared spline) removes the necessity for extra inspection techniques such as direct tension indicators (DTIs) or heavy hex bolts.

3.4. Compliance with Standards:

TC bolts are acknowledged by leading standards organizations such as the American Institute of Steel Construction (AISC) and the Research Council on Structural Connections (RCSC), which confirms their dependability in structural applications.

4. Challenges and Considerations

Despite their advantages, tension control bolts come with certain challenges:

4.1. Lubrication Sensitivity:

TC bolts are factory-pre-lubricated, and any deterioration of this lubrication may result in failure during inspection. Once they arrive on-site, it's crucial to store them correctly to preserve the integrity of their lubrication. Re-lubricating these bolts in the field is not allowed; if the lubrication is compromised, the bolts must be sent back to the manufacturer for reconditioning.

4.2. Cost Considerations:

Although many contend that TC bolts are more cost-effective because of their simplicity and lower labor demands, they may have a higher initial cost compared to conventional heavy hex bolts and DTIs.

4.3. Environmental Impact:

Moisture or extreme temperatures can impact the performance of TC bolts by changing their lubrication characteristics. To maintain their effectiveness, it's crucial to store them in a way that protects them from these elements.

5. Durability comparison between traditional and TC bolts

Tension control bolts (TC bolts) and traditional bolts differ significantly in terms of durability, particularly in high-stress applications like steel construction. Here’s a comparative analysis based on their properties and performance.

5.1. Material Strength and Fatigue Resistance

TC bolts are made from high strength steel, providing them with exceptional tensile and shear strength. They are specifically crafted to endure cyclic loading conditions, ensuring high fatigue resistance. As a result, they can handle repeated loading and unloading without substantial loss of structural integrity, making them ideal for heavy-duty uses. While conventional bolts can be constructed from robust materials, they frequently do not offer the same degree of fatigue resistance. The effectiveness of these traditional bolts can be hindered by incorrect installation methods, which may result in uneven tension distribution and a heightened risk of fatigue over time.

5.2. Installation and Preload

The installation of TC bolts involves a distinctive method in which the bolt is preloaded to a designated tension using a shear wrench. This technique guarantees that the tension is evenly spread throughout the joint, minimizing the likelihood of loosening when subjected to dynamic loads. The shearing of the spline indicates that the correct preload has been achieved, which enhances both the strength and durability of the connection.

5.3. Resistance to Vibration and Movement

The design of TC bolts reduces the likelihood of slipping and loosening when exposed to vibrations or structural shifts, such as those caused by cranes or heavy equipment. Their capacity to sustain tension in dynamic environments enhances their long-lasting durability. Although certain traditional bolting systems can work well, they typically need extra parts such as lock nuts or washers to avoid loosening. This requirement can make installation and maintenance more complicated.

5.4. Corrosion Resistance

Many TC bolts are equipped with protective coatings that improve their corrosion resistance. However, if they are not stored correctly prior to installation-such as being exposed to moisture-they can quickly lose this protection and begin to corrode. Therefore, proper handling is essential to ensure their longevity. Conventional bolts may be prone to corrosion, particularly if they lack protective coatings or treatments. Nevertheless, they are generally simpler to re-lubricate or replace when damaged.

5.5. Installation Impact

The installation procedure for TC bolts is intended to ensure they reach the appropriate preload without causing torsional shear during the tightening process. This lack of torsional deformation preserves their structural integrity over time, minimizing the relaxation of the preload. Incorrect installation methods can result in problems like over-torquing or under-torquing, potentially undermining the bolt's performance and longevity.

6. Design Features

6.1. Structure and Components

Neck and Spline: Tension control bolts have a narrowed neck at the end of the threaded area that leads into a splined tip. This configuration enables accurate installation control, as the spline fits into a specific tool called a shear wrench.

Head Design: Usually, these bolts feature a rounded head that is not intended for driving, setting them apart from regular hexagonal bolts. This design helps to minimize slippage while tightening.

6.2. Material and Strength

Tension control bolts are typically constructed from high-strength steel, commonly rated as Grade 10.9 or above, which guarantees their ability to endure substantial loads without breaking.

The mechanical characteristics of these bolts are essential for uses that demand significant tension and shear strength.

7. Installation Process:

The installation of tension control bolts involves several key steps:

7.1. Preparation:

All parts of the joint should be fully assembled and tightened securely before starting the tensioning process.

7.2. Engagement of the Shear Wrench:

The outer socket of the shear wrench fits onto the nut, while the inner socket attaches to the splined end of the bolt.

7.3. Tensioning:

When activated, the shear wrench applies torque to the nut, increasing tension in the bolt until the spline shears off at a pre-calibrated torque level. This shearing action indicates that the desired tension has been achieved

8. Overview of International Codes for Tension Control Bolts

Tension control bolts (TCBs) are unique fasteners designed for structural use, especially in steel construction, where accurate tensioning is essential for maintaining joint integrity. Their specifications, testing, and applications are regulated by various international standards.

8.1. ASTM F1852 [9]

This specification pertains to assemblies of heat-treated steel tension control bolts, nuts, and washers, which are commonly known as "sets."

It sets forth the specifications for the mechanical characteristics, chemical makeup, and measurements of the bolts, which are required to achieve a specified tension when installed using a particular torque technique.

8.2. ASTM F3043 [10]

This standard outlines the specifications for heat-treated alloy steel TCB assemblies that have a tensile strength ranging from 200 to 215 ksi.

It outlines testing techniques for assessing materials' vulnerability to embrittlement and offers recommendations for the environmental conditions appropriate for these fasteners.

8.3. AISC Specification for Structural Joints Using High-Strength Bolts

This specification categorizes bolting assemblies into groups based on tensile strength (120, 144, and 150 ksi).
It covers installation techniques, inspection criteria, and pre-installation verification testing to guarantee the reliability of structural joints.
Table 1 shows the difference between ASTM F1852 and ASTM F3043.

Table 1. Difference between ASTM F1852 and ASTM F3043

Feature	ASTM F1852	ASTM F3043
Minimum Tensile Strength	120 ksi	200 ksi
Material Composition	Various steels	Alloy steel with embrittlement testing
Intended Use	Primarily dry environments	Interior and exterior applications
Design Features	Standard design	Enhanced design for high stress
Status	Superseded	Current standard

9. Pre-installation Verification Tension Testing

Skidmore bolt tension calibrators play a crucial role in verifying the proper installation and performance of pretensioned bolts in construction projects (Fig. 3). These devices are essential for ensuring that high-strength bolts used in buildings, bridges, and other major structures meet the required specifications and capacity.

Skidmore bolt testing, also referred to as Pre-installation Verification Tension Testing, serves two main purposes:
1. Ensuring fastener systems achieve required tightness thresholds
2. Verifying that the installation procedure is being carried out properly.

Fig 3. Skidmore

The following discusses the M16 and M20 bolts test on the Skidmore device. The specifications of the M16 and M20 are provided in Table 2 and Table 3 respectively.

Table 2. specifications of the M16 bolt

Nominal diameter [mm]	16
Pitch p [mm]	2
Length [mm]	55
Coating	Non

Table 3. specifications of the M20 bolt

Nominal diameter [mm]	20
Pitch p [mm]	2.5
Length [mm]	65
Coating	Non

The Fig. 4 and Fig. 5 appear to represent the relationship between clamping force (kN) and total torque (Nm) for M16 and M20, respectively. It's a plot of experimental data, where torque was applied to the bolt, and the resulting clamping force was measured. The diagram can be used to determine the appropriate torque value to achieve a desired clamping force. For example, if a specific clamping force is required for a joint, the diagram can be used to find the corresponding torque value.

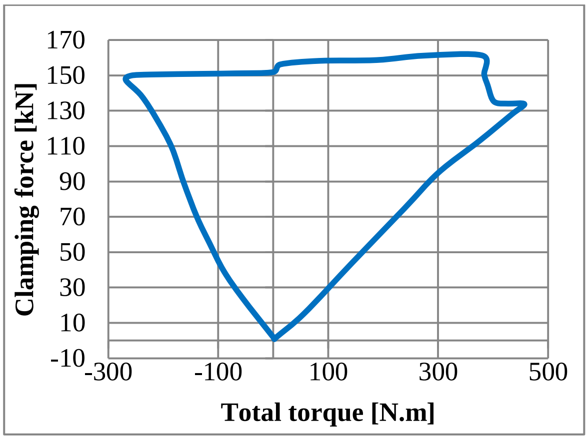

Fig 4. Torque-preload diagram (M16)

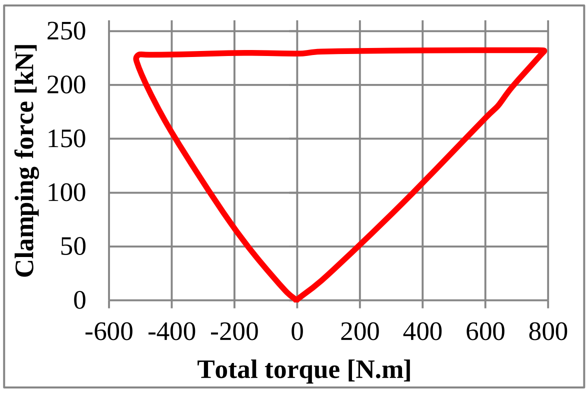

Fig 5. Torque-preload diagram (M20)

Non-linear Relationship:
The relationship is not linear. As torque increases, the clamping force initially increases rapidly, and then the rate of increase slows down. This indicates that the bolt material's behavior is not perfectly elastic.

Initial Torque:
There's a small but non-zero torque value where the clamping force starts to increase. This suggests that some initial torque is required to overcome friction and other resistance before the bolt starts to stretch and generate significant clamping force.

Maximum Clamping Force:
The diagram seems to plateau at a certain clamping force. This could be due to reaching the bolt's yield strength or other material limitations.

Desired preload and required torque is presented In Table 4 and Table 5 according to Fig. 5 and Fig. 5, respectively.

Table 4. Desired preload and required torque (M16)

Desired preload [kN]	Required torque [N.m]
120.00	404.48
130.00	446.68
140.00	383.78

Table 5. Desired preload and required torque (M20)

Desired preload [kN]	Required torque [N.m]
180.00	614.00
190.00	641.08
200.00	669.90

Conclusion

Tension control bolts are a notable improvement in fastener technology for structural uses. Their straightforward installation, accurate tension management, and adherence to industry standards make them a preferred option for construction endeavors. Nonetheless, it is essential to handle and store them properly to preserve their performance quality. As construction methods advance, TC bolts are expected to become even more crucial in enhancing structural safety and efficiency.

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