TORQUE AND TENSION

Why Consistent Torque Produces Inconsistent Results

The nut factor is a major reason why a consistent torque input does not generate consistent bolt tension. Torque produces inconsistent bolt tension even in ideal, controlled conditions. In this study, we perform controlled tests to demonstrate the variability in bolt tension that results from exclusive reliance on torque.

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Introduction

Fasteners must be clamped with a specific amount of tensile force (known as tension or preload) to properly secure a bolted joint. If a bolt has insufficient tension the bolted joint components can loosen or shift. A bolt with excessive tension risks being overstretched which can lead to a complete loss of strength and failure of the bolted joint.

It has traditionally been difficult to directly measure tension. Instead, it has become common to estimate the input torque that is required to generate a specific amount of bolt tension. Estimating this input torque requires the use of a short-form torque-tension equation:

T	=	K	*	F	*	D
Torque		Nut Factor		Tension		Diameter

Torque is a relatively easy force to measure. It is the rotational force used to turn a fastener within a bolted joint. Ideally, a specific torque input generates a specific amount of tension (Figure 1). The challenge encountered with torque is that it is an indirect estimate of tension. Many additional factors – such as friction – have a significant impact on the relationship of torque and tension. These additional factors are difficult to quantify and are collectively known as the nut factor.

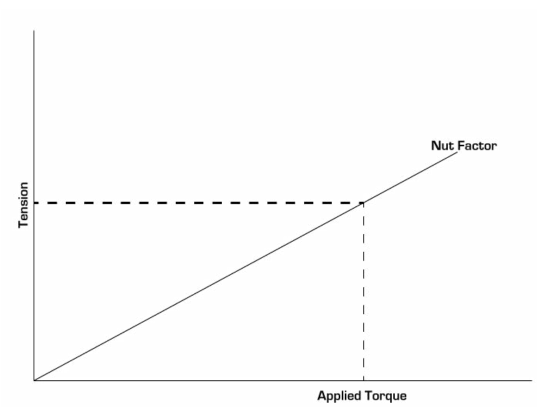


Figure 1

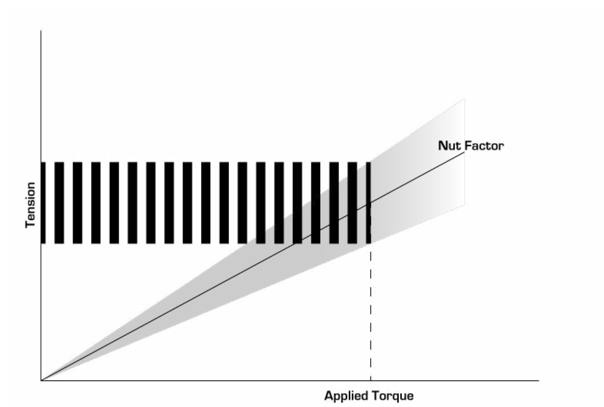


Figure 2

The nut factor becomes the determinant of how effectively a torque input will create a specific amount of tension in a bolt. If the nut factor changes, a consistent torque input will create variable bolt tension (Figure 2). And the nut factor changes all the time.

Lubricant, material, plating, finish, surface wear, and the number of times a bolt has been previously tightened are a few of the variables that change the nut factor. And every time there is relative motion between the bolt and the bolted joint, there is an opportunity for a different nut factor. The same bolt will have a fluctuating nut factor each time it is tightened.

The nut factor is a major reason why a consistent torque input does not generate consistent bolt tension. Torque produces inconsistent bolt tension even in ideal, controlled conditions. In this study, we perform controlled tests to demonstrate the variability in bolt tension that results from exclusive reliance on torque.

Torque-Tension Relationship Study: Background

The objective of this report is to analyze the torque-tension relationship with a series of bolt installations in controlled conditions and calculate the various nut factors from that analyzed relationship using the short form torque-tension equation identified by Bickford (1995) as T = K * F * D, assuming other variables as constant.

The test uses a Hytorc HY-115 pump and STEALTH 4 Hydraulic Torque Wrench to apply torque to bolts installed in a Skidmore-Wilhelm Model K. The results from these tests will determine the variation in tension that occurs when applying a constant torque.

Torque-Tension Relationship Study: Equipment and Methods

EQUIPMENT DESCRIPTION	QUANTITY
Calibrated Skidmore-Wilhem Model K	1
Calibrated Hytorc HY-115 Pump	1
Calibrated STEALTH 4 Hydraulic Torque Wrench	1
HHCS M36 – 4.0mm x 235mm CL 10.9 PL PTL	3
HHCS M36 – 4.0mm x 260mm CL 10.9 PL PTL	3
M36 – 4.0mm Hex Nut	6
M36 Plain Washer	6
Permatex Anti-Seize Lubricant	1

The test analyzed the performance of a series of installations of (3) HHCS M36 – 4.0mm x 235mm and (3) HHCS M36 – 4.0mm x 260mm. Each bolt was tested with a brand new M36 – 4.0mm hex nut and a brand new M36 washer.

HHCS M36 snugged in the Skidmore-Wilhelm Model K

Calibrated STEALTH 4 Hydraulic Torque Wrench connected to HHCS M36 in Skidmore-Wilhelm Model K

PSI gauge on Hytorc HY-115 Pump

The test procedure for each install was as follows:

PROCEDURE	PROCEDURE DESCRIPTION
1	Lubricate the bolt threads and the bearing surface under the bolt head using Permatex Anti-Seize Lubricant.
2	Hand-tighten and snug the lubricated bolt with a new nut and washer in the Skidmore Model K.
3	Adjust the pressure for the Hytorc HY-115 pump to 2000 PSI which will output 1093 Nm of torque from the STEALTH 4 Hydraulic Torque Wrench. Tighten the bolt until the pressure value reaches the 2000 PSI on the Hytorc HY-115 pump gauge. Record the tension value displayed on the Skidmore Model K gauge.
4	Adjust the pressure for the Hytorc HY-115 pump to 3400 PSI which will output 1846 Nm of torque from the STEALTH 4 Hydraulic Torque Wrench. Tighten the bolt until the pressure value reaches the 3400 PSI on the Hytorc HY-115 pump gauge. Record the tension value displayed on the Skidmore Model K gauge.
5	Adjust the pressure for the Hytorc HY-115 pump to 4800 PSI which will output 2596 Nm of torque from the STEALTH 4 Hydraulic Torque Wrench. Tighten the bolt until the pressure value reaches the 4800 PSI on the Hytorc HY-115 pump gauge. Record the tension value displayed on the Skidmore Model K gauge.

The results of these six installations are shown in the tables below:

HHCS M36 – 4.0mm X 235mm CL 10.9 PL PTL

	Procedure 3		Procedure 4		Procedure 5	
PUMP SETTING	2000 PSI		3400 PSI		4800 PSI	
TORQUE APPLIED	1093 Nm		1846 Nm		2596 Nm	
	Tension	**Nut Factor***	**Tension**	**Nut Factor***	**Tension**	**Nut Factor***
BOLT #1	133 kN	0.23	245 kN	0.21	334 kN	0.22
BOLT #2	156 kN	0.20	311 kN	0.16	467 kN	0.15
BOLT #3	178 kN	0.17	356 kN	0.14	512 kN	0.14
MAX – MIN DIFFERENCE	45 kN	0.06	111 kN	0.07	178 kN	0.08

*Nut Factor calculated with the following formula: K = T / (F * D)

HHCS M36 – 4.0mm X 260mm CL 10.9 PL PTL

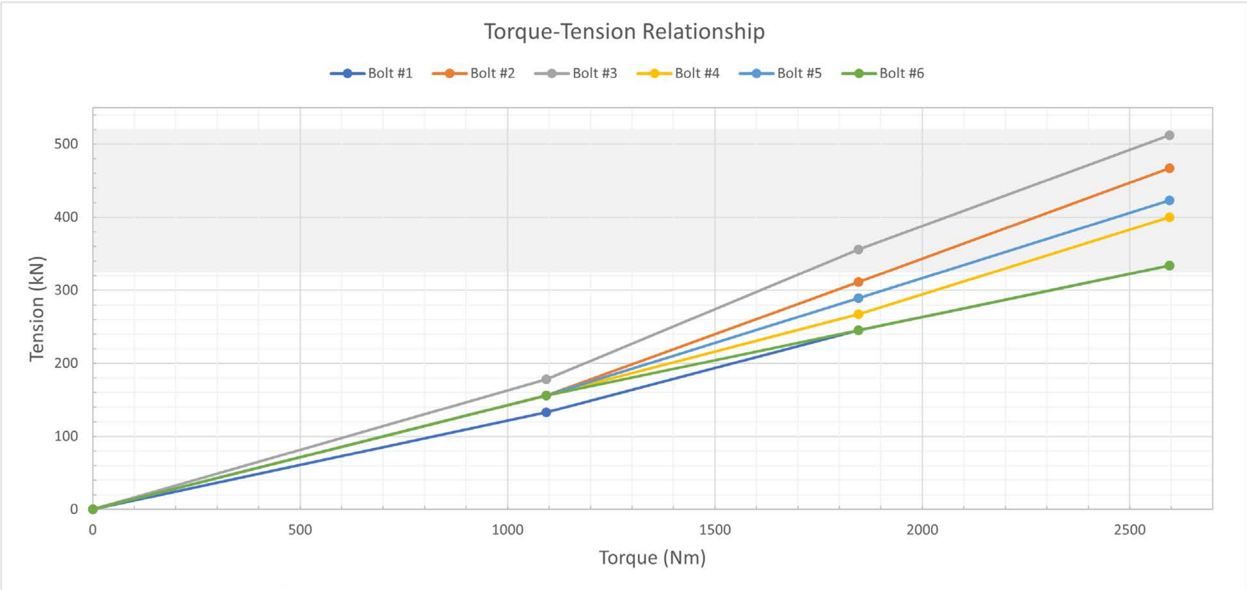
	Procedure 3		Procedure 4		Procedure 5	
PUMP SETTING	2000 PSI		3400 PSI		4800 PSI	
TORQUE APPLIED	1093 Nm		1846 Nm		2596 Nm	
	Tension	**Nut Factor***	**Tension**	**Nut Factor***	**Tension**	**Nut Factor***
BOLT #4	156 kN	0.20	267 kN	0.19	400 kN	0.18
BOLT #5	156 kN	0.20	289 kN	0.18	423 kN	0.17
BOLT #6	156 kN	0.20	245 kN	0.21	334 kN	0.22
MAX – MIN DIFFERENCE	0 kN	0.00	44 kN	0.03	89 kN	0.04

*Nut Factor calculated with the following formula: K = T / (F * D)

Torque-Tension Relationship Study: Results and Analysis

Even though we used a controlled, simple bolted joint environment for the installation of these bolts and maintained consistent torque values during the test procedures, a wide range of calculated nut factors (0.14 – 0.22) led to a broad scatter of developed tension (334 kN – 512 kN).

	MINIMUM VALUE	MAXIMUM VALUE	DIFFERENCE (%)
NUT FACTOR	0.14	0.22	44%
TENSION	334 kN	512 kN	48%



We can verifiably conclude that the nut factor is a major reason why a consistent torque input does not generate consistent bolt tension. Torque produces inconsistent bolt tension even in ideal, controlled conditions.

References
Bickford, J.H. (1995). An introduction to the design and behavior of bolted joints (3rd ed.). New York, NY: Taylor & Francis Group