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FACTORS AFFECTING PRE-TENSION AND LOAD CARRYING CAPACITY IN ROCKBOLTS – A REVIEW OF FASTENER DESIGN

Damon Vandermaat[1]

ABSTRACT: Recent studies into rock bolting parameters have suggested that increasing nut length has a positive influence on the pretension achieved during rockbolt installation. A literature survey on bolts and fasteners was undertaken, as well as a laboratory testing program to examine this suggestion. The testing program examined M24 nuts ranging from 1D to 1.5D (24 mm – 36 mm). These nuts were used to tension a rockbolt using an instrumented drill rig to measure torque, and a through-hole load cell to measure pretension. It was found that nut length has no impact on the pretension values achieved during rockbolt installation. The largest factor affecting pretension values was found to be the levels of friction acting between bearing surfaces. Overcoming this friction is estimated to account for 85-90% of the applied torque from the drill motor.

INTRODUCTION

Effective pre-tension in ground anchors is an important part of the ground support system. Pre-tension improves shear resistance between bedding planes, and actively works to prevent shear and vertical movement of strata layers. Correctly pre-tensioned rockbolts and cable bolts can make-or-break the effectiveness of installed ground support systems.

In order to improve the amount of pre-tension that can be achieved, it is important to understand the factors and forces that contribute to it. This paper will focus on the most ubiquitous form of ground support in underground coalmines, the rockbolt.

The majority of roof and rib bolts installed in the Australian underground coal industry are the M24 rockbolt. These bolts are typically 1.2 – 2.1 m in length, with a core diameter of 21.7 mm and metric M24 x 3 mm thread at the bottom end as shown in Figure 1. Pre-tension is applied through the procession of a 36 mm Across Flats (AF) nut along the thread, which reacts against a dome ball washer and a roof plate to impart a tensile load in the bolt.

Recent academic discussion on rockbolts has proposed an increase in nut length to improve geotechnical outcomes. An investigation into thread stability on rockbolt during pre-tension by Frith (2017), found that a 5 mm thread pitch allowed for ‘consistently higher’ pre-tension values compared to a 3 mm pitch. The conclusion from this finding was that rockbolt design should adopt a longer nut length to reduce the thread contact pressures, or move toward a 5 mm thread pitch as a means of improving thread stability during tensioning.

MECHANICS OF THREADS

The conversion of torque into pretension in a bolt is done through the procession of the nut along the thread. This procession uses the mechanical advantage of an inclined plane (helix angle) to convert the rotational energy of the drill motor into tension in the rockbolt. This helix angle is controlled by the pitch of the thread (Figure 3). The shorter or ‘fine’ the pitch the lower the helix angle and therefore, the greater the mechanical advantage.

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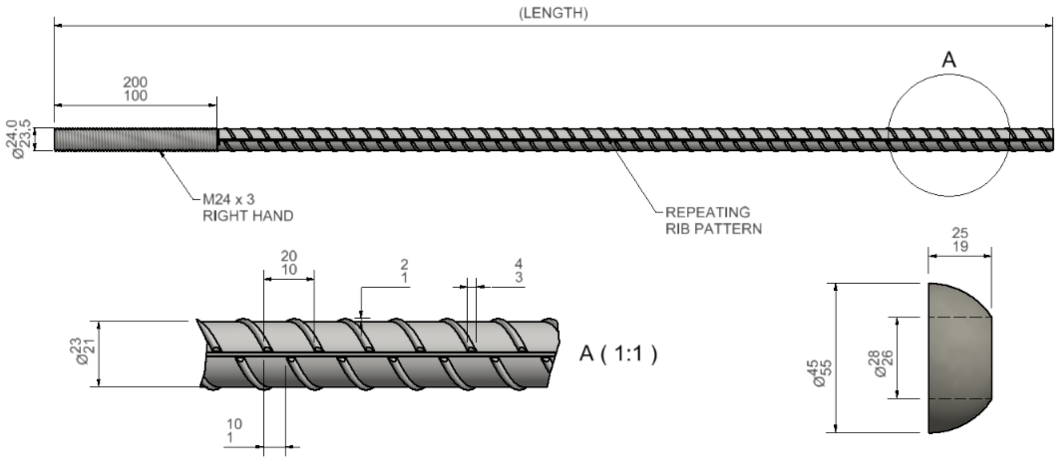

Figure 1: Typical Australian M24 rockbolt and dome ball washer dimensions

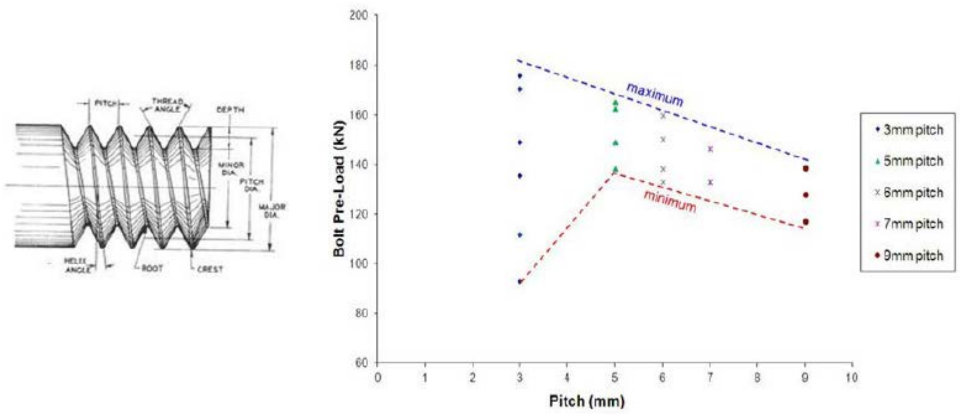

Figure 2: Impact of pitch height on pre tension values (Frith, 2017)

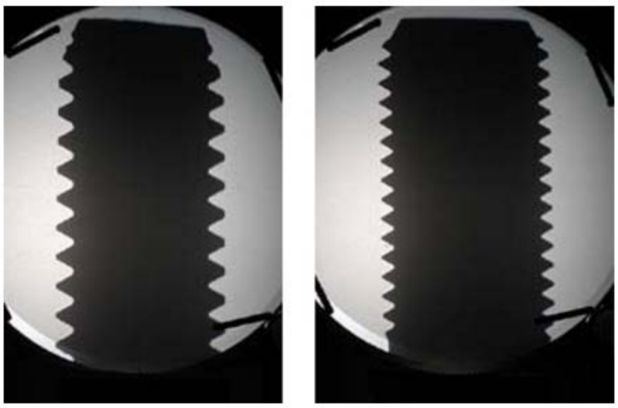

Figure 3: A coarse thread (left) and a fine thread (right)

There are a number of factors which can affect the amount of pretension that can be achieved during installation. This can include the amount of lubrication between mating parts, the thread pitch, and the quality, accuracy and tolerance class of the thread (Yan, 2014). The main contact points in the tensioning system are between the mating threads, and between the bearing face of the nut and the dome ball washer. All of these factors will affect the amount of efficiency of torque to pre-tension conversion.

An examination of the equations that govern the amount of torque required to generate a tensile force in a bolt, shows that the relationship between torque and load is independent of nut length. A commonly used equation for calculating the torque required for a specified bolt tension is given in Equation 1. This equation is a function of the bolt diameter, and a torque coefficient, which is calculated using Equation 2. The torque co-efficient considers the geometry of the thread, as well as the co-efficient of the friction between the contact surfaces (Barret, 1990). An example of calculated values for varying friction levels is presented in Table 1 and Figure 4.

$$T = FKD_b \tag{1}$$

$$K = \frac{d_m}{2d}\left(\frac{\tan\psi + \mu\sec\alpha}{1 - \mu\tan\psi\sec\alpha}\right) + 0.625\mu_c \tag{2}$$

Where:
T = Torque (Nm)
F = Tension (N)
K = Torque Co-efficient
μ = Friction co-efficient threads (usually between 0.15 and 0.2 for steel-on-steel contact)
μ_c = Friction co-efficient bearing surface
D_b = Bolt diameter (m)
ψ = Thread helix angle (2.5^0 for an M24 x 3 thread)
d_m = mean thread diameter (m)

Table 1: Calculation of pretension from a given torque input based on Equations 1 and 2 for a range of friction values.

μ	K	$T\ (Nm)$	F (T)
0.00	0.02	350.00	72.88
0.05	0.08	350.00	18.73
0.10	0.14	350.00	10.27
0.15	0.16	350.00	9.09
0.20	0.19	350.00	7.73

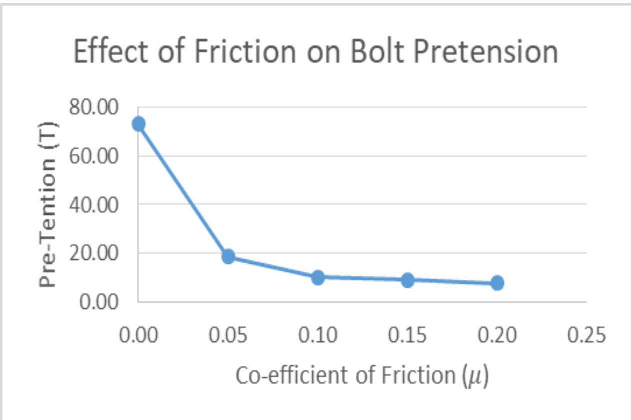

Figure 4: Pre-tension achieved for various levels of friction for a 350 Nm input torque

It can be seen that friction has a very large impact on the effectiveness of a given torque input. Realistic friction values for lubricated steel contactsare 0.15-0.2. Overcoming the effects of friction accounts for 85-90% of the applied torque. It is clear that reducing the effects of friction between mating surfaces can have a very significant impact on achievable pre-tension levels.

Deciding on thread pitch is a compromise between strength, tensioning efficiency and practicality. A coarser thread has larger pitch measurement and is less prone to stripping as a result of there being more material in the thread 'teeth'. A finer thread has a smaller helix angle and can achieve higher bolt tension for a given torque due to a greater mechanical advantage. However, finer threads are more susceptible to corrosion, galling and contamination. Ultimately, the pitch of the thread should be kept as fine as practicable without compromising the strength and serviceability of the thread. Table 2 presents the pros and cons of fine and course threads.

Table 2: Pros and cons of coarse and fine threads

Fine Threads	
Pros	**Cons**
Smaller helix angle – more mechanical advantage	Lower stripping strength
Higher torsional strength	More prone to cross threading
Higher bar strength	More prone to contamination (dust, corrosion etc.)
Coarse Threads	
Pros	**Cons**
Higher stripping strength	Lower bar strength
Less prone to contamination	Lower torsional strength
Less prone to cross threading	Larger helix angle – less mechanical advantage

It is important to appreciate that load is not uniformly distributed on the threads along the length of the nut. The majority of loading is experienced at the face of the nut, and within the first 2 - 3 thread pitches. Up to a point, increasing the length of the nut will reduce the intensity of loading experienced at the bearing face of the nut, however there are very large diminishing returns as nut length increases (Sopwith, 1948).

An analysis was carried out based on the calculations presented by Sopwith (1948) to examine the loading characteristics on M24 x 3 threads with various nut lengths. The results of this analysis are presented in Figure 5, which presents the load intensity per unit length of thread helix. For convenience, the data is presented in terms of distance from the nut bearing face. Nut length is given in proportion to the diameter of the thread.

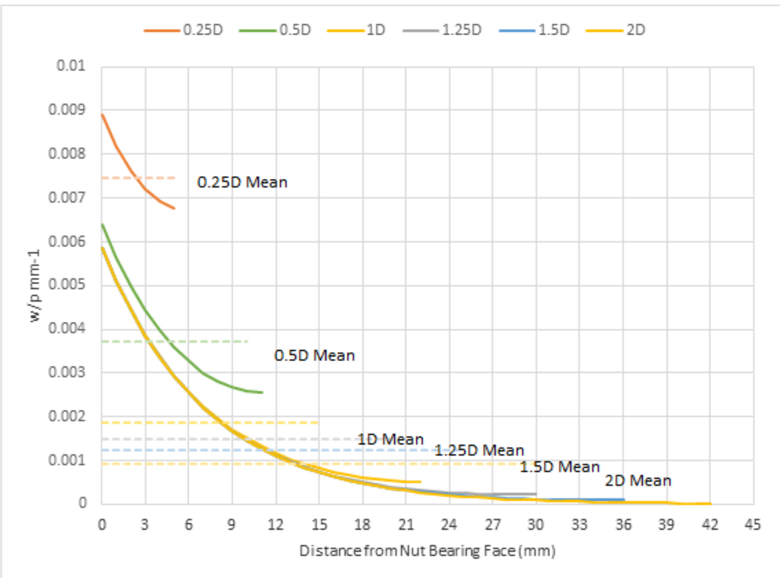

Figure 5: Distribution of loading intensity along an M24 x 3 nut of varying lengths. Lengths are represented propositionally to the diameter of the thread (After Sopwith, 1948).

It can be seen that beyond a nut length of 1 x diameter (1D), the advantages of reducing the peak load intensity on the threads close to the bearing face is essentially zero. The distribution of load intensity on the thread beyond nut length of 1D is practically identical within the first 4-5 thread pitches. Longer nuts are able to carry very small amounts of load over their full length from pitches 6 - 15, however, the load intensity in this region is 8 – 12 times less than the peak intensity at the bearing face. The mean loading intensity also experiences diminishing returns, albeit not to the same degrees as peak load intensity. Given that pretension levels are highly dependent on the action of friction, it is unlikely that increasing the length of nut will sufficiently reduce the overall bearing pressure on the threads to meaningfully impact pretension levels.

EXPERIMENTAL TESTING

An experiment was carried out to examine the effects of nut length on pre-tension values. In this experiment 1D (24 mm), 1.25D (30 mm), 1.5D (36 mm) M24 x 3 nuts were examined. A Jennmar X-Grade rockbolt was used for the purposes of the test. A number of friction reducing agents were also used to examine the effect of friction on pre-tension. These included Teflon washers and a dry Molybdenum Disulphide coating. The tests carried out are highlighted in Table 3. The testing setup is depicted in Figure 6 and the method was as follows:

- An 1800mm rockbolt was point anchored in a 1700 mm hole (ϕ28 mm) using a 500 mm fast-set resin capsule. This produced a 900 mm un-encapsulated section at the bottom of the bolt, which represented the 'slow' portion of a two-speed resin capsule.
- A through-hole load-cell was placed over the thread of the bolt, and was set between two flat steel plates.
- A plate, nut and the dome ball were placed over the thread, and the nut was tensioned using a hydraulic drill rig instrumented with a digital torque sensor. Maximum torque for each test was recorded.
- The test bolt was cleaned of debris between tests, and the nut was changed after five consecutive tests.

The results of the testing are shown in Figure 7 and Table 4. The drill rig was capable of output torques of between 240-400 Nm, and pretension values ranged between 4-12T.

Table 3: Range of test specimens.

	24 mm (1D)	30 mm (1.25D)	36 mm (1.5D)
As Machined	√	√	√
Teflon Washer	√	√	√
Moly Coated Teflon Washer	-	√	-

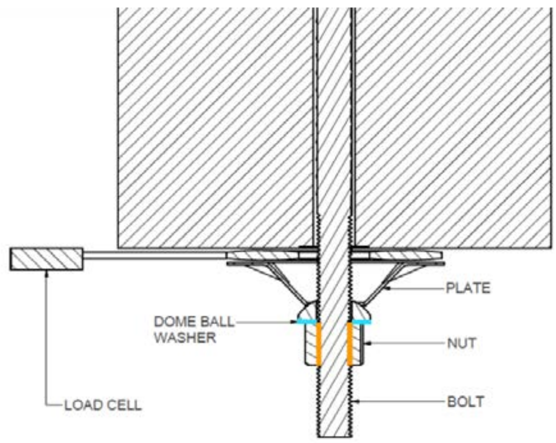

Figure 6: Experimental setup highlighting major points of friction

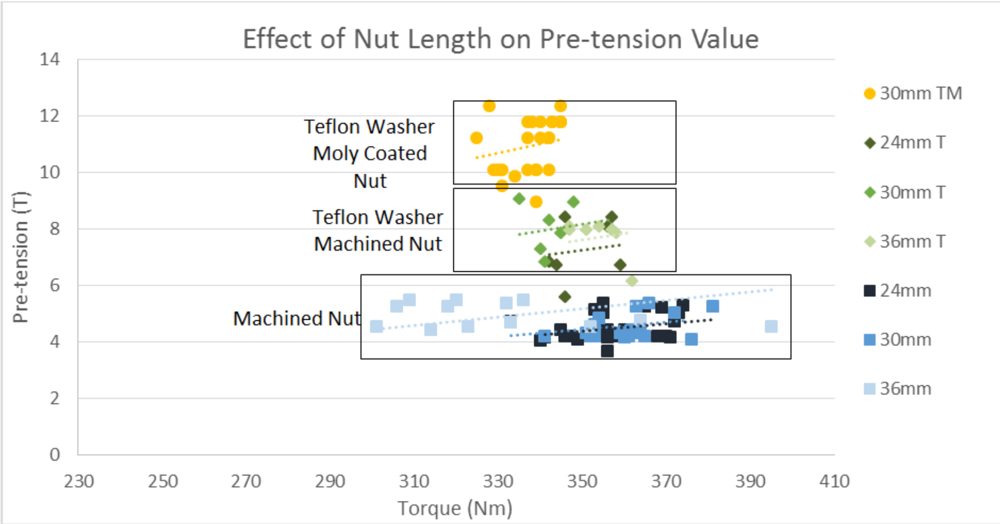

Figure 7: Torque v's tension for 1D, 1.25D, 1.5D nut lengths with various friction reducing agents.

Table 4: Testing results

	Average Tension (T)	St Dev (T)	Average Torque (Nm)	Nm/T
	As Machined			
1D (24mm)	4.5	0.5	357	79
1.25D (30mm)	4.5	0.4	360	80
1.5D (36mm)	4.9	0.5	331	67
	As Machined with Teflon Washer			
1D (24mm)	7.25	1	348	48
1.25D (30mm)	8	0.8	343	43
1.5D (36mm)	7.71	0.6	354	46
	Moly Coated with Teflon Washer			
1.25D (30mm)	8.6	0.5	301	36

From the results of this testing, the impact of reducing friction can clearly be seen. Each progressive addition of a friction reducing agent increases the pretension achieved with a given input of torque. The average pretension values doubled between the as machined nut, and the molybdenum coated nut with a Teflon washer. There was no indication that increasing the length of the nut impacts the amount of pre-tension achieved. By examining the range of tests for the as machined, and As Machined with Teflon washer samples, the change in nut length made no difference to the pre-tensions achieved.

For relatively close levels of torque measurements, there is still a large scatter of pre-tension values achieved. This is likely to be due to variations in the friction co-efficient between tests. The tests were conducted over several days and it is possible that variations in temperature and humidity could impact on the levels of friction in the system. It is also expected that debris, dirt, oils, corrosion or the quality of the threads surface finish between samples may have affected the results between tests, despite efforts made to control for these variables.

CONCLUSIONS

Of all the factors that affect the amount of pre-tension achieved during rockbolt installation, friction plays the largest role. Friction can account for 85-90% of the torque required to tension a rockbolt. The main sources of friction in the rockbolt tensioning process are between the threads, and the contact face between the nut and dome ball washer. The main methods used by manufactures of rockbolts is to use a low friction washer in-between the nut and dome ball, as well as lubricants on the thread and nut. The two types of lubricants are dry lubricants such as Molybdenum Disulphide, and wet lubricants such as grease. Wet lubricants have a higher risk to pick up dust and debris as they are transported around site, which will affect their anti-friction properties.

Nut length will have no impact on pre-tension levels. Beyond nut length of 1-1.25D, nut length will also have little impact on nut thread stability, as most of the load carried by the thread is with the first 4-5 thread pitch. Destructive testing carried out at Jennmar Australia has found that 1.25D nuts are capable of exceeding an X grade rockbolt to ultimate tensile failure - meaning that the nut is stronger than the bolt. A 3 mm thread pitch is the most widely used in the industry as it has been proven to provide the best compromise between thread strength, tension ability and resistance to contamination/corrosion.

REFERENCES

Barret, R, 1990. *Fastener Design Manual.* NASA Reference Publication 1228.

Frith, R, Reed G and McKinnon M, 2016. *Fundamental principles of an effective reinforcing roof bolting strategy in horizontally layered roof strata and three areas of potential improvement*, in Proceedings of the 17th Coal Operators' Conference, University of Wollongong, 8-10 February 2017, pp149-170.

Sopwith, D G, 1948. *The distribution of load in screw threads*, in Proceedings of the Institution of Mechanical Engineers - 159(1): pp373-383.

Yan, L X, 2014. *Experiments on effects to rock bolt pretension by thread rolling accuracy*. Material, Mechanical and Manufacturing Engineering II, 2014, pp346-352.