Developments in Construction Bolting

and, is all the torque worth the effort?

The use of construction bolt assemblies in terms of the new standard EN14399 has been underway for the best part of two years now. It has been a steep learning curve to say the least. This article has been written in order to share some of our experiences, to provide insights into technical jargon and to dispel some myths.

<u>Myth, South African Manufacturers are not geared up.</u>

Whilst it is true that manufacturers have been exposed to some nasty quality problems, these served as learning experiences and recent history has shown that there are at least two manufacturers who have stepped up to the challenge and who are able to produce the full requirements of the standard, including all testing and a subsequent zero failure rate is testimony to the achievement. When choosing the construction bolt route, clearly the first call is a supplier capability study with an audit of the quality system.

Up until the recent power station builds, very few construction bolts were being installed, hence there was a general lack of awareness and capability. This was on many fronts not just bolting. Medupi changed this and it has been clearly established that design engineers, manufacturers and construction companies had a long way to go to catch up with international developments and best practice standards. These include manufacturing, galvanising, erection and welding (as we have seen in the press recently) and this list is probably incomplete.

<u>Grade 10.9 vs grade 8.8</u>

A question often asked is, why use a grade 10.9 bolt when there is an inherent risk of hydrogen embrittlement (HE) on hot dipped galvanised product or other longer term risks such as hydrogen induced stress corrosion cracking (HiSCC)? Would a grade 8.8 bolt not be more advisable? In practice this is what some designers may suggest. However there are benefits to using a grade 10.9 bolt. Whilst the ultimate tensile strength of a 10.9 bolt is 25% greater than an 8.8 bolt, the clamping force is 41% greater, the yield strength being the defining difference. What benefit does this have? Firstly there is the potential to use fewer bolts which means fewer holes, less installation and therefore less cost. This is particularly the case in areas where installation conditions are challenging, for example, a mine lift shaft or structures with extreme height. Grade 10.9 is not much more expensive than grade 8.8 so this should not be the deciding factor. Secondly there is a far greater clamp load and in a fatigue application (vibratory movements or cyclical loading), the higher clamp load will avoid the cyclical loading risk. The risks of HE can be controlled by the manufacturer avoiding acid contact and controlling excessive hardness levels. Further risks associated with undue stressing of grade 10.9 HDG bolts will be avoided if good installation practice is adopted. What about the argument that grade 8.8 bolts have greater ductility and are friendlier to installation abuse (though not an excuse to engage in bad installation practices!)? This is perhaps a strong argument if the bolt has been tightened beyond the yield point, but this is generally not the case and the benefits of a higher clamp load over the grade 8.8 will apply. The greater elongation property of the 8.8 will result in earlier fatigue failure from stress relaxation. Environment can also be a deciding factor, for instance in mining shaft environments where corrosive conditions are harsh (chlorides).

Here the risk of long term failure of a hot dipped galvanised grade 10.9 bolt is elevated compared to a grade 8.8 bolts where long term corrosive risk is less likely. In this case, grade 8.8 would be advised.

EN14399-3 (grade 8.8 and 10.9) vs.EN14399-4 (grade 10.9 only)

Why a universal standard is not adopted is a puzzle. Clearly there were principles that were not negotiable which have led to two possibilities. The historical position has largely been maintained in that the EN14399-4 nut (previously DIN 6915), has a lower height. The intended reason is that the nut threads should fail first (not guaranteed) in the event of over tightening, purposefully avoiding a sudden bolt fracture, with installer safety being compromised. Usual construction practice is that one would like to see the bolt fail in the event of over tightening because one would know it had occurred, whereas with thread failure, this may not present immediately and a future calamity may be lurking when the right conditions prevail.

Torque vs. Clamp (tension)

The talk is always about torque, whereas the objective is clamp, a spring type condition holding surfaces together. Torque (or the torsional rotation effort) is merely the means to getting to the correct clamping force. This whole process would be simple were it not for the introduction of friction. When tightening a bolt and nut assembly, 50% of the effort is as a result of friction between the nut and washer face, 40% is in the thread contact and a mere 10% of the effort is creating the clamping force. This friction can vary. In a rusted bolt and nut (B&N), the coefficient of friction is as much as 0.35. In a un-lubricated hot dipped galvanised B&N it starts at 0.19 and increases up to 0.27 as additional torquing takes place. With molybdenum disulphide lubrication (MoS_2), the coefficient of friction is 0.10 to 0.16. So, by way of example, in the case of torquing a M20 bolt at 464 Nm with a coefficient of friction of 0.14, clamping force of 127kN is achieved; when the coefficient is 0.10, less torque of 363Nm will achieve an increased clamp load of 134kN.

This leads us to the next important point, the lubrication of nuts.

Pre lubricated nuts (with molybdenum disulphide)

There may be a misconception, since there has been so much talk and use of pre-lubricated nuts that this is a new standard requirement. Whilst we recommend pre lubricated nuts for the reason there is a tested coefficient of friction that can be relied upon, this is by no means a general requirement. EN14399 specifically makes reference to surface finish as processed, meaning lightly oiled, or as agreed between purchaser and manufacturer. Nevertheless, appropriate lubrication is required during installation, particularly with HDG bolts. In the case of no lubrication, galling will take place and in laboratory testing, we have established the potential of failure due to torsional tension.

In the case of the turn of nut method of fastening in the B&N assembly with lubrication, where potentially 25% to 35% additional clamp can be obtained than required by the standard without lubrication, the likelihood of thread failure is almost 100%. All the torque value will be absorbed by the galling effect of the soft galvanised layer and if the bolt has not started to fail due to torsion tension, the correct clamp will not have been achieved and a loose bolt left in place, with future potential failure consequences.

We really do recommend pre lubricated nuts that have been baked to a dry condition. The advantages; it avoids the wrong lubricant choice, incorrect lubricant application is avoided, the risk of attracting grit on nuts during installation due to sticky lubricant is reduced and, of paramount importance, certification of the coefficient of friction is supplied, together with recommended torque values.

Installation equipment

Many bolters rely on the torque wrenches having been recently calibrated. One of the over looked checks that needs to be undertaken is the wrench verification. This should take place on the day the wrench will be used by testing at least 3 bolts of the diameter to be installed with that wrench on that day. The verification takes place using a static torque meter. The reason for this verification is that calibration can change if, for example, the wrench was dropped. We have observed that many installers do not do verify their equipment, nor do they have the required equipment to undertake the verification.

Need it be said that hammer drill type impact wrenches are an absolute no! Their calibration cannot be verified.

Laboratory testing of Bolts clamp/tension.

One of the requirements of EN14399 is the need to perform a suitability test to ensure that the fastener assembly will perform to certain minimum requirements. In this process the angle of rotation is measured from a pre determined pre load through to the maximum bolt force obtained before the force starts reducing again and, where necessary, to failure. It has been most interesting to compare some of the results of the different angle options, or nut rotations, included in different standards and this raises some questions.

	DIN 18800-7:2008			EN 1090-2:2008			SANS 10094:2005		Bolt Capability	
Bolts Size	Min. clamp	Recomm-ended clamp	Angle method 120° result clamp	Min. clamp	Recomm-ended clamp	Angle 90° from75% torque, result clamp	Rec. clamp	Angle 180° from snug, result clamp	Ultimate Tensile strength Note 1	Max. bolt force Note 2
M20X120	160kN	172kN	160kN	172kN	189kN	220kN	178kN	217kN	274kN	241kN
M24X120	220kN	247kN	257kN	247kN	272kN	335kN	257kN	350kN	399kN	367kN
M30X135	350kN	393kN	495kN	393kN	432kN	560kN	408kN	575kN	636kN	603kN

Note 1-the ultimate tensile strength was obtained from a minimum of two samples tested from the same batch, not the bolt itself.

Note 2- the maximum bolt force is of the bolt under test itself and is lower in strength than the ultimate tensile strength because of additional torsion tension in the threads reducing the yield point of the bolt.

- Generally in terms of the angle method recommended by DIN 18800-7, in the three samples tested, the clamp load achieved was at or above recommended. In the case of M24 and M30, while the clamp loads were above recommended clamp, this was not more than 82% of the maximum bolt force achieved (M30).

- In terms of EN 1090-2:2008 the angle method prescribes 75% of the torquing by wrench first and only a final 90° turn. The clamp achieved is above recommended in all case and consistently +-92% of the maximum bolt force in each case.

- In respect of the 180° angle method, again the clamp force is above recommended and in the case of M20, 9O% of the maximum bolt force, M24, 95% of the maximum bolt force and M30, 95% of the maximum bolt force. The start snug point used in the case of the M20 was according to recommended DIN18800-7 table, ~ 11% of clamp; whereas when the full force of a spanner on a tension/torque meter was used to determine snug tight under this condition, there was a difference of 40°. This would have had increased the clamp load by ~18kN, resulting in 235kN clamp, 97.5% of maximum bolt force. This illustrates one of the disadvantages of the angle method, namely 'snug' rather subjective.

In terms of ISO 898 bolt testing requirements, the proof load test is 80% of ultimate strength, whereas in the result above, clamp loads of up to 90% of the ultimate tensile strengths are being obtained (M30). More importantly, clamping levels of 95% to 98% of the maximum force of the bolt are being obtained. These high levels of clamp beg the questions; is all the effort for this stretch of the bolt capability necessary and does it leave any reserve should a shock event occur? Does any risk arise from the fact that the bolt has moved out of an elastic property to a plastic condition? Further, because of the elevated stress in the bolt, does this not create a fertile condition for HiSCC to arise? Nevertheless, the angle method is still widely and internationally applied and it is acknowledged that use of this method will result in the bolt moving into the plastic zone beyond the yield point of the bolt.

<u>Fat tail outcomes and conclusion</u>

Recently an economist referred to "a fat tail outcome", a phrase I have not come across. The reference was to our weakening Rand and the consequences thereof, still to be witnessed. When Googled, I found the meaning: "The relatively high probability of a relatively extreme outcome".

My experience in the field is that there is poor communication between original design engineers through all the manufacturers of components including B&N manufacturers to the installer tightening the final bolt. This can result in mistakes. Medupi Power station is testimony to this and it is no wonder the delays being experienced. Some of infield mistakes these we have observed will not result in fat tail outcome, include, a request for Nylock nuts for EN 14399 construction bolts, failing this, Clevelock nuts. We advised accordingly and implemented training. Another example is, torquing M20 grade 10.9 bolts to M24 levels. Fortunately in this case the installers had no lubrication with the result that the increased coefficient of friction was absorbed in the torquing and the resultant clamp was 205Kn, and whilst 19% above recommended, was 16% below the yield point of the bolts. Luckily threads were not damaged either. Fortunately, many mistakes are covered by the tendency to "over design/deliver", not only in bolt manufacture but also in structure design. As a result problems get caught in a normal distribution curve of applied margin of safety and no fat tail outcome emerges.

The greatest “fat tail outcome” has been where design engineers have not been involved in the pre qualification of manufacturers and audit of their quality systems, nor have they ensured that complete certification based on comprehensive testing is in place. Thereafter, they have not been on site verifying compliance to their original specification, a responsibility prescribed in regulations of the Occupation Health and Safety Act. On the contrary, where all this has been undertaken timeously and diligently, we have seen trouble free, home runs. Where this was deficient, particularly in the early stage of manufacturer pre qualification, fat tail outcomes have often prevailed.

Design engineers and primary contractors must be tasked with the “cradle to grave” responsibility in order to avoid a high probability of a negative extreme outcome. Both local and international players need to learn from these experiences (where some significant school fees have been paid), to benefit from bolting future major projects together.

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