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Technical note: AFI/01/002

MINIMUM THREAD ENGAGEMENT

WHAT IS THE OPTIMUM ENGAGEMENT LENGTH?

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Introduction:
The question of the minimum or optimum amount of thread engagement in a bolted joint is commonly asked. By optimizing the thread engagement, a more economical and functional design may be possible.

This paper discusses the parameters and methodology in determining the minimum or optimum thread engagement length.

Investigation:
First Order Analysis:
In general, the minimum thread engagement length depends on:

- Bolt material;
- Nut material;
- Bolt diameter;
- Nut Outside Diameter;
- Thread profile;
- Thread pitch;
- Thread friction;
- Desired bolt tension for the joint.

The general guideline for the design of a bolted joint is that the bolt shank should fail at the first exposed thread prior to the thread stripping. Based on this criterion, the following first order approximation can be made to evaluate the required thread engagement length.

Tensile stress area of an ISO Metric thread is given by:

$$A_t = 0.7854(D - 0.9382p)^2$$

where, nominal diameter D (mm), and pitch of the ISO metric thread is p (mm).

Thread shear area (mm^2) for external threads (bolts) over a length L_e (mm) is given by:

$$A_{sb} = 0.4375\pi\left(D - 0.54127p\right)L_e$$

Similarly, the thread shear area for internal threads (nut) over a length L_e is given by;

$$A_{sn} = 0.5625\pi(D - 0.54127p)L_e$$

If the yield stress of the bolt material is σ_{yb} (MPa) and the yield stress of the nut material is σ_{yn} (MPa) then the corresponding yield shear stresses can be approximated by;

$$\sigma_{sb} = 0.62\sigma_{yb}$$
$$\sigma_{sn} = 0.62\sigma_{yn}$$

In order for the bolt shank to fail before thread stripping in the bolt (assuming first order approximations);

$$A_{sb}\sigma_{sb} > A_t\sigma_{yb}$$
$$L_e > \frac{0.7454(D - 0.9382p)^2}{0.27125\pi(D - 0.54127p)}$$

In order for the bolt shank to fail before thread stripping in the nut (assuming first order approximations);

$$A_{sn}\sigma_{sn} > A_t\sigma_{yb}$$
$$L_e > \frac{0.7454(D - 0.9382p)^2\sigma_{yb}}{0.34875\pi(D - 0.54127p)\sigma_{yn}}$$

The larger of the above two L_e (for the nut and the bolt) should be used as the minimum thread engagement length. The minimum number of threads to be engaged (N) can now be calculated by:

$$N = \frac{L_e}{p}$$

The above first order analysis assumes:

- ISO Metric thread profile;
- The shear failure in thread stripping occurs along the pitch line;
- Threads are equally loaded;
- There is no deformation of the nut due to hoop stresses;
- There are no end effects (due to 3D nature) of the bolt;
- Shear strength of a material can be approximated by 0.62 of the tensile strength;
- No thread friction.

If the design tension load T (kN) for the joint is known and it is less than the load capacity of the bolt, the following formula can be used: to calculate the required minimum engagement length.

$$L_e > \frac{1000T}{0.27125\pi(D-0.54127p)\sigma_{yb}} \rightarrow\rightarrow \longrightarrow (Bolt)$$

$$L_e > \frac{1000T}{0.34875\pi(D-0.54127p)\sigma_{yn}} \rightarrow\rightarrow \longrightarrow (Nut)$$

Higher Order Analysis

Ajax Fasteners has conducted a comprehensive Finite Element Analysis (FEA) on a generic bolted joint. This analysis revealed some interesting facts regarding the micro level distribution of stresses [3]. In summary, it was found that the threads are not equally loaded and at typical applied load (65% Proof Load) the first engaged thread (closest to the head) will carry up to 33% of the applied load. The ensuing threads will carry ≈ 27%, 20%, 12% and 8% respectively. Any extra threads engaged do not carry any load. However, if the bolt ended flush with the outside of the nut (no excess thread), due to 3D end effects and typically ill formed end threads, the full engagement of the nut may not be achieved. Therefore it is good practice to leave two extra threads past the face of the nut in the design of a bolted joint.

As can be expected, the above load distribution among threads is affected by the bolt tension and the thread geometry and material properties of both the bolt and the nut. In general, considering the stress-strain relationship for steel, as the load is increased further the first thread will reach yield and plastically deform while carrying the maximum possible load on the first thread and distributing the remaining load over a few more threads. With further increasing load, the above process will continue over the full engaged-thread length until all the threads yield and subsequently fail. However, a bolted joint should be designed to always force the failure in the bolt and not in the thread and therefore if designed properly this type of thread stripping should not occur.

The above distribution suggests that even before the bolt reaches its yield load the first thread and subsequently some of the other threads may reach yield and proceed to plastic deformation. In general, the proof load specified for a fastener is less than the yield load and in most situations only the first thread may go into plastic deformation. This is evident by the difficulty of removing the nut if the bolt is heavily loaded. On the positive side, this effect can be used as a thread-locking feature. It is our experience that when a bolt is loaded larger than 65% of its proof load vibration loosening of the thread will not occur.

As highlighted in the above assumptions nut deformation also lead to higher order effects. Based on our Finite Element Analysis conducted on a generic bolted joint a hexagonal nut should have a minimum across flat (A/F) dimension of approximately 5/3 of the nominal diameter if the bolt to be loaded to its maximum design capacity. This will provide consistent torque tension and failure characteristics. For weight reduction purposes or material saving purposes some engineers reduces the thickness of the nut. This is not a recommended practice and the engineers should be mindful about the dominance of higher order effects and as a result inconsistent torque tension and failure characteristics resulting from such arrangements.

Conclusion:
If a bolt and a nut are made of the same material the minimum thread engagement length required is approximately 65% of the nominal diameter. For example a M10 bolt will need a minimum of 6.5mm of thread engagement. Typically standard nut height is approximately 80 – 90% of its nominal diameter. The across flat dimension of a nut should be approximately 167% if the nominal diameter.

If the joint will only be subject to a fraction of the proof load of the bolt, then the required minimum thread engagement length can be calculated by the formula described above. It is appropriate to apply a safety margin of approximately 30% on the calculated minimum length to account for higher order effects. It should, however, be noted that the torque tension relationship will be affected if the engagement length is altered.

If the designer has a good understanding of the maximum bolt load a particular tensile bolted joint may see in its design life; designing the minimum engagement length requirement using the above procedure may help achieve a better engineered design.

References:
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3. S. Fernando, "An Engineering Insight to the Fundamental Behaviour of Tensile Bolted Joints", Journal of the Australian Institute of Steel Construction, Vol. 35, No 1, March 2001.

4. S. Fernando, "An Engineering Insight to the Fundamentals of Screwed Sheet Fastening to Resist Cyclic Loading", 9th Wind Engineering Work Shop, James Cook University, Townsville, July 2001.

5. S. Fernando, D. Kershaw, "Threaded Fasteners in the New Millenium", Materials Australia, Vol 30, No 6, November/December 1998.

6. Ajax Fasteners Fastener Handbook, Bolt Products, 1999.

Ajax Fastener Innovations (AFI) offers a consulting service to assist in the design of bolted joints in specific applications. AFI has the experience; test equipment, analysis methods, and analysis tools developed over many years, to provide our customers with a greater level of confidence in the design of critical joints. Furthermore, AFI is dedicated to developing fastening solutions that cater for the specific needs of industry.

If you need any further assistance please contact us.