Comparative Study of Analytical and Numerical Methods for Stress Analysis in Screw Thread Fillets

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In structures joined by bolted connections, bolts are the most critical components of the assembly, with thread tearing being one of the most significant failure modes. This work presents an analytical and numerical modeling of the stresses in screw threads using finite element analysis. The results show consistency between the two methods, although simplifications were adopted in this study.

Keywords: Stress in Screw Threads. Numerical Modeling. Finite Elements. Screws.

Screws are vital machine elements used for fastening and connecting mechanical components [1]. Their disassembling ability makes them a preferred choice over welding in many applications. However, screws are often the most vulnerable components in bolted connections [2,3], with thread tearing being one of the most critical failure modes [4]. Therefore, ensuring the reliability of analytical methods for designing bolted joints and calculating the associated stresses is crucial.

According to Norton [5], shear stress (τ) is responsible for thread tearing in screws and can be calculated using the Equation 1. In this Equation, F represents the force applied to the screw, d_r is the internal diameter, p is the thread pitch, and w_i is a factor equal to 0.8 if the screw meets the ISO standard [5].

$$\tau = \frac{F}{\pi d_r w_i \, p} \qquad \text{Eq 1}$$

Budynas and Nisbett [6] proposed that thread tension is composed of normal stresses in two axes, due to screw traction and thread bending, in addition to screw torsion. The bending stress (σ_f) and tensile stress (σ_t) of the screw can be calculated using Equations 2 and 3, respectively, where n_t is the number of engaged threads.

$$\sigma_f = \frac{6F}{\pi d_r n_t p} \qquad \text{Eq 2}$$

$$\sigma_t - = \frac{4F}{\pi {d_r}^2} \qquad \text{Eq 3}$$

According to Budynas and Nisbett [6], the stresses in the fillets are distributed in different ways. Experimental tests have shown that the first fillet supports 38% of the load F, the second supports 25%, and the third supports 18%, with the values becoming negligible after the seventh fillet. When using 0.38F as the axial force and considering only one engaged thread, the stress level for the thread-nut combination is at its highest. It is essential to account for these values when calculating the shear stress (Equation 1).

Subsequently, the stresses are transformed into equivalent stress using the Von Mises method, as represented by Equation 4, where σ_1 and σ_2 are usually stresses and τ is the shear stress.

This work presents a comparison between the stress results in screw threads obtained using analytical models, as described by the equations above, and numerical models via finite element analysis.

$$\sigma_{eq} = \sqrt{\sigma_f^2 + \sigma_f \sigma_t + \sigma_t^2 + \tau^2} \qquad \text{Eq 4}$$

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Materials and Methods

The analytical and numerical model of the thread stresses of an M16 and a pitch of 2mm with those of a nut were compared. The same material was used for both components. In all models, a traction force of 5000 N was applied. Stress calculations were performed using the methods described by Budynas and Nisbett [6] and Norton [5]. The Von Mises stress was then calculated for each model, considering the load distribution percentages presented by Budynas and Nisbett [6]. Figure 1 represents a finite element analysis, assuming the nut was fixed on the upper face. Structural steel was used, with an elastic modulus of 200 GPa and a Poisson's ratio of 0.3. For the 2D analysis, quadrilateral elements with a size of 0.1 mm were used in the regions of the thread fillets, and the contacts between the threads were defined without friction. Figure 1 illustrates the mesh, the loading, the restriction imposed on the nut, and the path for calculating the average stresses at the root of the fillet. Due to the axisymmetric nature of the analysis, torsional effects were not considered in the model.

Results and Discussion

The finite element simulation results indicated that the stress value successively decreased from the first fillet to the subsequent ones (Figure 2). A path created at the base of the thread (Figure 1) revealed that the first thread fillet had an average stress of 45.513 MPa at its root. This value is consistent with the analytical methods, particularly with the results found using Norton's methodology [5]. Table 1 compares the values obtained by each method. From Table 1, it is evident that the values show low deviations from each other. However, it is essential to note that the simplifications used in this study, such as the absence of friction between the screw and nut threads, can affect the results. While friction was ignored in the present work, some analyses use friction coefficient values between 0.05 and 0.2 [4].

In Figure 2, points of stress concentration are observed due to geometric discontinuities in the modeling of the fillets, leading to a significant increase in stress in these regions. Additionally, using a sufficiently ductile material allowed for stress distribution among the threads, which would

Figure 1. Finite element model.

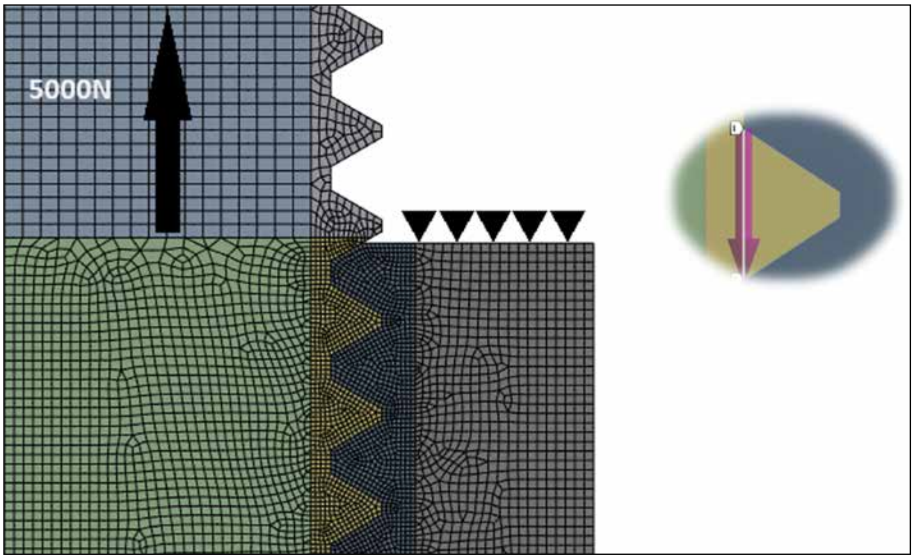

Figure 2. Von-Mises stress field - Scale 230:1.

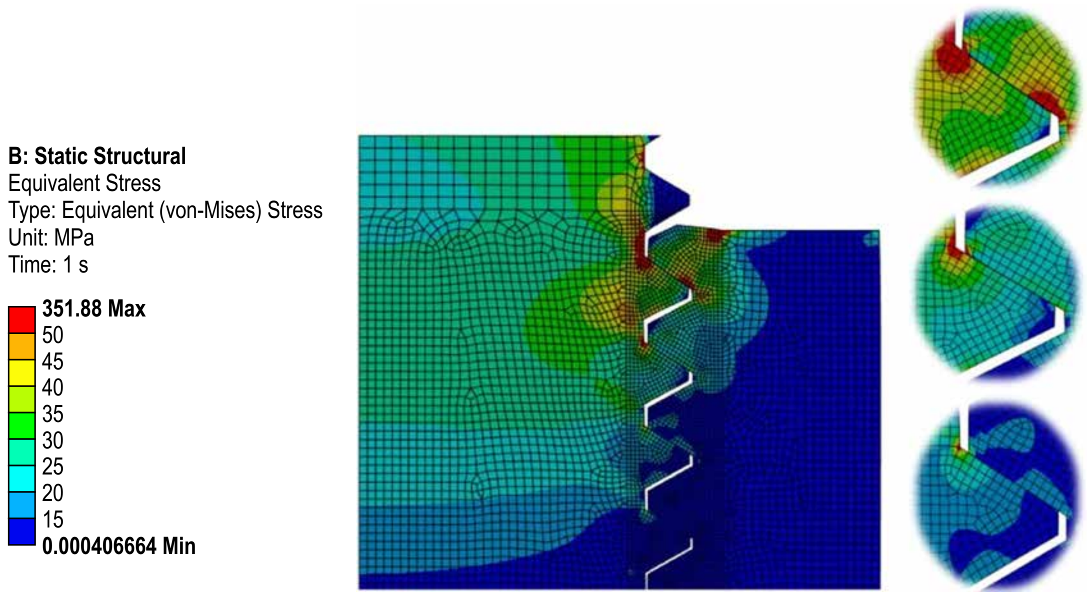

Table 1. Average Von-Mises stress results in the first three fillets.

Method	First Fillet Stress (MPa)	Second Fillet Stress (MPa)	Third Fillet Stress (MPa)
Finite elements	45.513	31.402	19.872
Budynas & Nisbett [6]	51.239	33.7096	24.2709
Norton [5]	47.3393	31.1443	22.4239

not be possible with a brittle material. According to Norton [5], if the material of the nut or screw is very rigid, the stress tends to concentrate on the first thread, while more ductile materials tend to distribute the stress among the threads. The numerical results allowed us to verify the load percentages supported by each fillet by dividing the total contact force by the applied force. The results showed that the first fillet supported 37.4% of the load, the second supported 27.5%, and the third supported 16.8%, consistent with Budynas and Nisbett's findings [6].

Conclusion

The analytical and numerical models used for comparison in this work showed good agreement. However, some simplifications, such as the absence of friction between the threads and geometric discontinuities in the model, affected the results. Using a malleable material allowed the stresses to be distributed across the threads without overloading the first thread fillet. For future work, the effect of friction should be included in the analysis, and small radii should be used at the sharp corners of the thread fillets to alleviate the stress concentrations more accurately.

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