

Life analysis of the bolted joint

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Abstract. The paper deals with the fatigue damage calculation of 2 types of computation model of bolted joints. The study is performed via a numerical analysis with support of finite element method (FEM) software ANSYS. One model was created with a thread on the bolt, another was only bolt with cylindrical surfaces, the second model was greatly simplified. It will be evaluated the fatigue damage for both types of models. Subsequently both types of computational models will be compared in dependence on the accuracy of the results and the speed of the calculation. There are also the theoretical backgrounds for preloaded bolted joint, which was used for calculation of preload load prescribed on body of screws.

Keywords: bolted joint, FEM analysis, fatigue

1 Introduction

The high strength bolted joints are often used in a variety of engineering industry. Usage of equipment in multiple applications (customer requirements) requires reassessing already defined limits. For efficient and reliable use of the equipment, it is necessary for the manufacturers to guarantee the same life of the components under the required operating conditions [1-3].

Fatigue assessment of bolted joints are considered in fatigue problem areas and requires research. The problem of determining the threaded joints fatigue strength and damage has been investigated for many years [14-16]. Fatigue limit affected by the stress gradients, size effect and surface quality for high reliability in industry are also in the problem areas. Offshore and subsea applications where bolted joints are the critical points can be found on wellheads, drilling risers, structural connections, flanges, and similar. Drill pipe threaded connections are susceptible to fatigue damage because of high stress concentration due to the geometry and high mean stress induced by preload [4-7].

2 Preload force calculation

For calculating the preload force, the value of torque on the torque wrench used to tighten the bolt or the nut was used (torque in screw thread + torque under the nut).

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Internal thread diameters are: D – major diameter, D_2 – pitch diameter, D_1 – minor diameter.
External thread diameters are: d – major diameter, d_2 – pitch diameter, d_1 – minor diameter.
Pitch of thread is shown as P and $H = 0.86 P$ (Fig. 1).

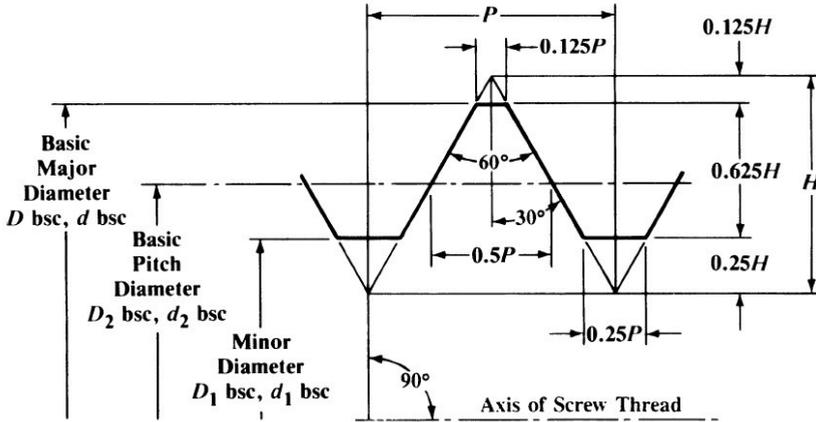


Fig. 1. Scheme of metric screw thread

$$M_k = F_Q \cdot \frac{d_2}{2} \cdot \tan(\gamma + \varphi') + F_Q \cdot f \cdot r_s \Rightarrow F_Q = \frac{M_k}{\frac{d_2}{2} \cdot \tan(\gamma + \varphi') + f \cdot r_s} \quad (1)$$

Parameters in formula 1:

M_k – tightened torque

F_Q – preload force

γ – the pitch of the thread, where:

$$\gamma = \tan^{-1} \frac{p}{\pi \cdot d_2} \quad (2)$$

φ' – friction angle (dry friction, no movement) taking into account the thread profile, where:

$$\tan(\varphi') = f' \cong 0.1 - 0.12, \quad (3)$$

f – coefficient of friction between nut (screw head) and material $f \cong 0.1$,

δ – diameter of the hole for screw,

r_s – friction radius, where:

$$r_s = \frac{s + \delta}{4} \quad (4)$$

After getting into formulas, force for preload was given 24981 N.

3 FEM simulation

Finite elements model consists of screw, nut, two plates a two washer one is under screw and the second is on nut (Fig. 2). Screws which have been contemplated in the simulation are

metric screws M8. The analysis was designed as a static analysis in a position which is one screw connects two plates (Fig. 2).

For purpose of this paper was used two types of connection with screw, the first type is when screw is without thread and the second type is when using screw with thread (Fig. 2). For the best results were generated contact areas between the individual components. Between head of screw and top washer, top washer and top plate, top plate and bottom plate, bottom plate and bottom washer, bottom washer and nut were prescribed symmetric frictional contacts with value of friction 0.2. Then in model where was used thread is prescribed between nut and screw frictional contact with coefficient of frictional 0.1 on thread. In model without thread is prescribed between screw and nut bonded contact.

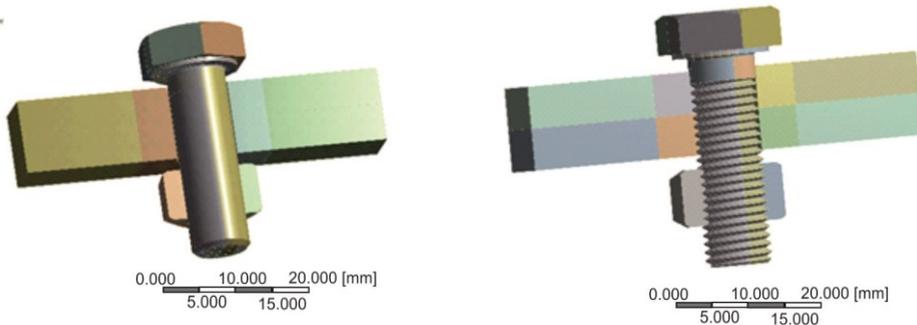


Fig. 2. Two types of numerical model used in calculation, left side model without thread and right side model of model with thread

3.1 Loads and boundary conditions

For the screw was prescribed preload on volume of screw model which was calculated according to analytical formulas presented in this paper (1). Value of preload force is 24981 N.

In simulation, two steps were used, first step was used for load screw with preload force then in second step load of preload force in screw was locked. First step was only used for preload screw. Subsequently, external force on plates was considered in second step.

Therefore load of value 1000 N was prescribed on both plates, it is shown in red colour (Fig. 4) and on the opposite side of plates was prescribed fixed support shown in blue colour on figure 3.

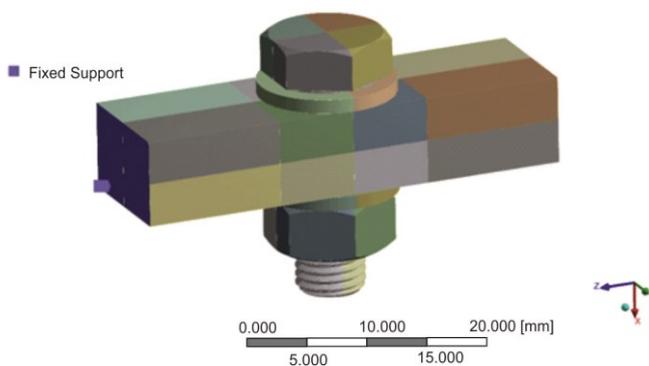


Fig. 3. Fixed support (blue colour) on side of plates

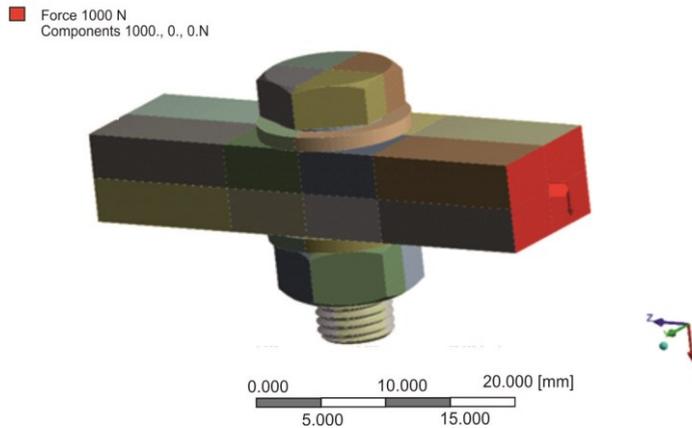


Fig. 4. Force on side of plates of value 1000 N used in second step

4 Life calculation of bolts

For calculation of bolt service life was used data from experimental measurement for material 42CrMo4 which is typical for bolt of strength grade 10.9 (Fig. 5). The definition of the S – N curve model in the double logarithmic system is that the linear damage accumulation is done with the amplitude stress tensor of the particular hysteresis [8-13].

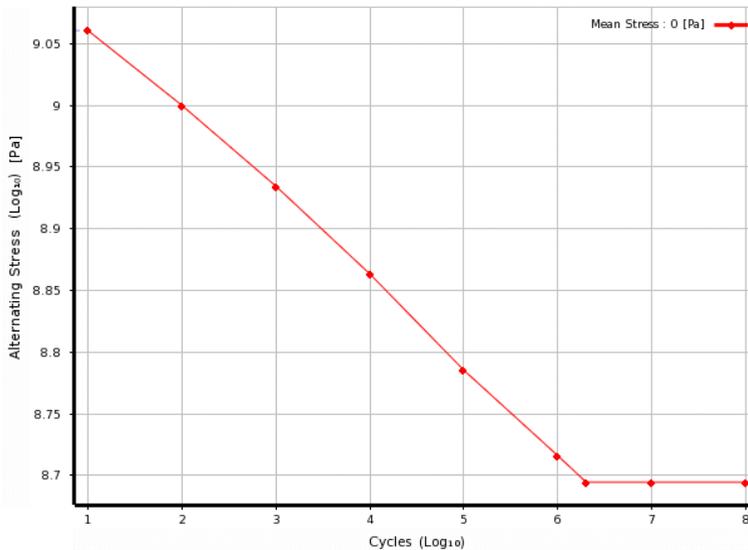


Fig. 5. S – N curve for 42CrMo4 steel

Fatigue damage was evaluated after $1 \cdot 10^6$ cycles on both models. The chosen location for damage evaluation was selected on the axes of the screws. The course of the damage on the screws axis is shown on the graph. With red colour is represent model of screw with thread and model of screw without thread is represent with blue colour (Fig. 6). The course of both types of models to length of 12 mm is similar, then model with thread starts to have bigger

value like model without thread. Model with thread has maximum value of 0.82 at length about 17 mm therefore maximum value of model without thread is 0.67 at length 18.4 mm.

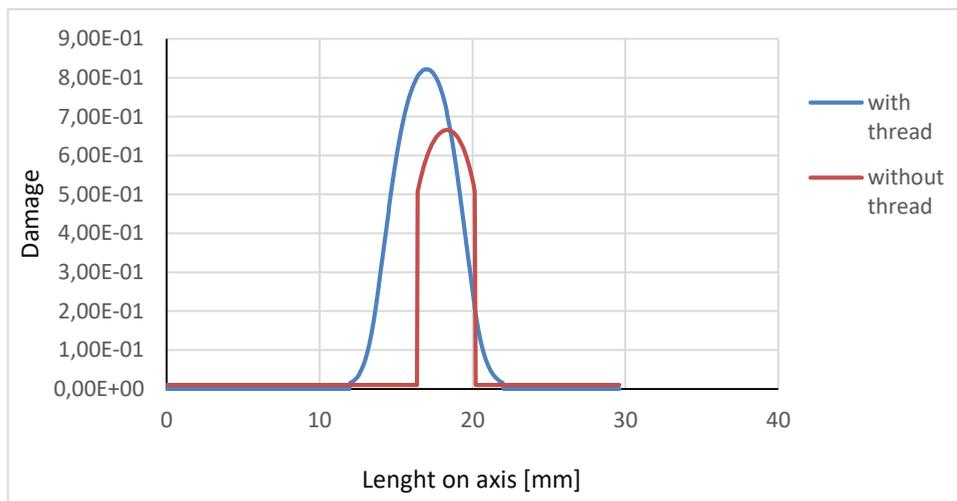


Fig. 6. Graph of dependence of the damage to the distance on the screw axis for both types of models

5 Conclusion

Two types of screw connections models were created. One was considered with thread on screw and between threads on screw and nut was contact with friction. Another was without thread and between screw and nut was only bonded contact. Preload force of same value was prescribed on body of screws for both models. Preload force was calculated according analytical relationships from tightened torque. There were also prescribed force and on the opposite side fixed support on plates between bolt connections. After the numerical analysis, the fatigue analysis of the screws was evaluated.

The analysis shows that the model which has been considered with thread on the screw is more accurate because the value of damage is there a greater (Fig. 6). Overleaf computing time of model with thread was 9 h 21 m while in model without thread it was only 5 h 31 m with using an appropriate number of elements to achieve optimal results. The model using a thread is recommended to use in calculations where there is a requirement for accuracy in area of bolt connection. The model without thread is suitably used in assemblies where such connections are large number and the calculation is not focused on the area of the bolt connection.

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References

1. H. Sungkon, Fatigue analysis of drillstring threaded connections, Proceedings of The Thirteenth International Offshore and Polar Engineering Conference Honolulu, Hawaii, USA, May 25-30, pp.202-208, (2003).

2. L. Jakubovičová, M. Sága, M. Vaško, *Numerical study of influence of mutual slewing of roller bearing rings on the principal stresses at contact area*. Scientific journal of Silesian University of Technology – Series Transport **84**, 83-91 (2014)
3. P. Kopas, M. Blatnický, M. Sága, M. Vaško, *Identification of mechanical properties of weld joints of AlMgSi07.F25 aluminium alloy*. Metalurgija **56** (1-2), 99-102 (2017)
4. A. Sapietová, M. Sága, I. Kuric et al., *Application of optimization algorithms for robot systems designing*. International Journal of Advanced Robotic Systems **15/1** (2018)
5. V. Baniari, M. Blatnická, M. Šajgalík, M. Vaško, M. Sága, *Measurement and numerical analyses of residual stress distribution near weld joint*. Procedia Engineering **192**, 22-27 (2017)
6. P. Kopas, M. Sága, V. Baniari, M. Vaško, M. Handrik, *A plastic strain and stress analysis of bending and torsion fatigue specimens in the low-cycle fatigue region using the finite element methods*. Procedia Engineering **177**, 526-531 (2017)
7. M. Handrik, P. Kopas, V. Baniari, M. Vaško, M. Sága, *Analysis of stress and strain of fatigue specimens localised in the cross-sectional area of the gauge section testing on bi-axial fatigue machine loaded in the high-cycle fatigue region*. Procedia Engineering **177**, 516-519 (2017)
8. P. Pecháč, M. Sága, *Controlling of local search methods' parameters in memetic algorithms using the principles of simulated annealing*. Proc. Eng. **136**, 70-76 (2016)
9. L. Jakubovičová, M. Sága, *Computational analysis of contact stress distribution in the case of mutual slewing of roller bearing rings*. Novel Trends in Production Devices and Systems, Applied Mechanics and Materials **474**, 363-368 (2014)
10. I.Hren, P. Hejma, Š.Michna, M.Svoboda, J.Soukup, *Analysis of torque cam mechanism*. MATEC Web of Conferences **157**, 06004 (2018)
11. A. Sapietová, L. Gajdoš, V. Dekýš, M. Sapieta, *Analysis of the influence of input function contact Parameters of the impact force Process in the MSC. ADAMS*. Advances in Intelligent Systems and Computing **393**, pp. 243-253 (2016)
12. A. Sapietová, J. Bukovan, M. Sapieta, L. Jakubovičová, *Analysis and Implementation of Input Load Effects on an Air Compressor Piston in MSC.ADAMS*. Procedia Engineering **177**, pp. 554-561 (2017)
13. T. Domański, A. Sapietová, M.Sága, *Application of Abaqus Software for the Modeling of Surface Progressive Hardening*. Procedia Engineering **177**, pp. 64-69 (2017)
14. J.Flizikowski, M. Macko, J. Czerniak, A. Mroziński, *Implementation of genetic algorithms into development of mechatronic multi-edge's grinder design*. ASME 2011 International Mechanical Engineering Congress and Exposition, IMECE. (2011)
15. M. Macko, J. Flizikowski, *The method of the selection of comminution design for non-brittle materials*. Conference Proceedings AIChE, (The American Institute of Chemical Engineers) Annual Meeting in Salt Lake City - session: Comminution - Experiments, Theory & Modeling. (2010).
16. M. Dudziak, A. Kołodziej, G. Domek, K. Talaška, *Multi-angularity - identification of parameters and compatibility conditions of the axisymmetric connection with form deviations*. Procedia Engineering, Vol. **177**, pp. 431-438 (2017)