Thread Connection Response to Critical Pressures

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Abstract: Thread connections are widely used in oil and gas industry. Determination of burst and collapse response of threads under critical pressure is important in a design process; however, a straight forward analysis of helical thread connections would require a huge model and long computing time. This paper will discuss other techniques that can determine the required information more efficiently. For example, a finite element analysis (FEA) model using a straight-groove model that can account for pre-stress due to make up torque via suitable interference between pin and box threads has been formulated. Using this model, only an axis-symmetric model is needed for critical burst-pressure determination. The response to collapsing pressure, however, usually requires a full 3D model since symmetry is lost under collapse buckling. For this case, an efficient technique based on symmetric results transfer capability in ABAQUS has been applied for calculation of critical collapsing pressure. Results from applications of the methods in actual cases will be provided to demonstrate the efficiency and effectiveness of the new techniques.

Keywords: Threads, Burst, Collapse, Critical Pressure, Buckling, Finite Element Analysis, FEA, Stress.

1. Introduction

Thread connections are widely used in the oil and gas industry. The burst and collapse strength of a thread connection often determines the ultimate pressure to which a pipe string or downhole tool can be subjected, and therefore, determination of the collapse and burst pressure of a thread connection is critical in a design process. Calculation of the burst and collapse pressure via FEA is a relatively straight-forward exercise. But, a straight-forward analysis of a helical thread will require a huge FEA model and long computing time. This is especially true when pre-stress has to be accounted for in a thread connection for an accurate determination of collapse strength of a tightened thread connection. Using a straight groove representation of a helical thread is a common practice, and it enables an axis-symmetric model for the analysis of thread connections under critical load. To determine a thread connection under burst pressure, we use a similar approach, but we introduce a suitable interference between the pin and box thread to account for the pre-stress in the thread connection due to make-up torque. The response to collapsing pressure, however, usually requires a full 3D model, even when a straight groove model is used, since symmetry is lost under collapse buckling. For this case, an efficient technique based on symmetric results transfer capability in [1 (ABAQUS 2005)] has been applied for calculation of critical collapsing pressure. The symmetric results transfer capability is widely used in tire analysis (e.g. [2 (ABAQUS 2005)], [3 (Zhong, 2006)], but less so in other types of analysis.

An issue for the numerical prediction of the collapse or burst of a thread connection is the definition of collapse and burst. This is because in the oil and gas industry (per American Petroleum Institute (API) standard), a component burst or collapse occurs when stress in the component reaches yield stress under pressure, but a thread connection typically reached yield stress already during make-up.

In the following sections, a brief description of the techniques used in the analysis of thread connections subject to critical pressure is presented. How a burst/collapse pressure is determined from FEA results is described in section 2. In section 3, a case study of a thread failure under bursting pressure is presented, and a simple way for prevention of that type of burst is proposed. The superior efficiency of a technique based on symmetric results transfer capability in ABAQUS for the determination of collapse of a thread connection is demonstrated in another case study. The paper ends with a summary and discussions on effective application of FEA in collapse analysis.

2. Numerical Methods

Designers in the oil/gas industry typically use pressure that leads to initial yield as collapse or burst pressure, so the first question in a collapse analysis frequently was 'What is the definition for collapse — geometrical instability (i.e. buckling under pressure) or initial yield?' The approach taken is that the lower pressure of the pressures that lead to initial yield and to elastic buckling is the collapse pressure. For thread connections, the question becomes trickier because make-up of pin and box has already introduced plastic deformation to the parts. The approach taken is that the lower pressure of the pressures that lead to additional yield and to elastic buckling is the collapse pressure. Burst pressure determination is typically based on initial yield or additional yield if a part is pre-stressed or on the onset of a rapid part-dimension change.

2.1. Burst pressure determination

Using a straight groove representation of a helical thread is a common practice, and it enables an axis symmetric model for the analysis of thread connections under critical load. This approach is used for analysis of thread connection under burst pressure, but we introduce a suitable interference between the pin (external) and box (internal) thread to account for the pre-stress due to make-up torque in the thread connection. The amount of interference is estimated through hand calculation. The analysis includes two steps – interference fit and pressure up. Burst pressure is determined based on the pre-determined criteria described earlier.

It is noted that an analyst also must address the issue if pressure penetrates into the thread mating surface for a proper determination of burst pressure.

2.2 Collapse pressure determination

The response to collapsing pressure, however, usually requires a full 3D model, even when a straight groove model is used, since symmetry is lost under collapse buckling. For this case, an efficient technique based on symmetric results transfer capability in ABAQUS is used for calculation of critical collapsing pressure. It makes use of the symmetry analytical results to determine the stress/strain state for a full 3D model. The analysis procedure is as follows:

1) Conduct make-up analysis via interference fit on axis symmetric model
2) For deformation analysis:
    a) Pressure up the connection from OD, and determine a possible collapse pressure per previously discussed criteria
3) For buckling analysis:
    a) Convert the symmetry model results to full 3D model
    b) Conduct eigenvalue buckling analysis on the full 3D model.
4) The lower pressure from 2) and 3) is the collapse pressure

3. Case study of a thread connection under bursting pressure

In this case study, a UNS thread connection for the bottom sub and housing under closed-end internal pressure is analyzed to determine its burst pressure. The axis symmetric model of this connection with interference is given in **Figure 1**. The close end condition is realized through proper boundary condition prescription. Two burst analyses were conducted; i.e., one with no pressure penetration into the thread mating surface (see **Figure 2**) and one with pressure penetration through the mating surface.

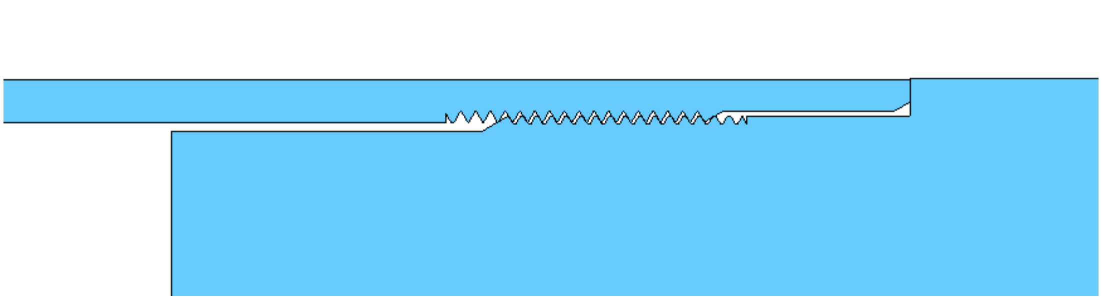

Figure 1: UNS thread connection between a bottom sub and housing.

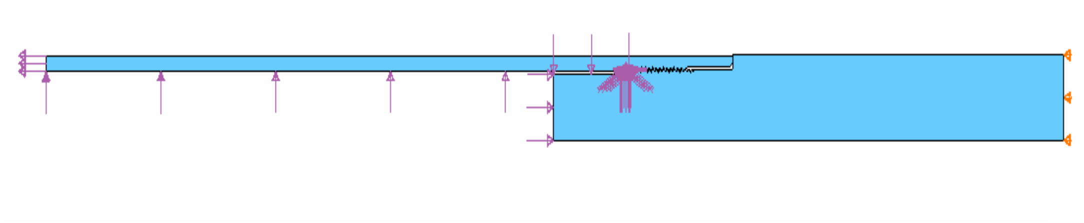

Figure 2: Boundary conditions for the case with no pressure penetration through thread mating surface.

The make up of the pin and box thread is properly represented by the interference fit (See **Figure 3),** which shows that plastic strain has developed at the leading edge of the thread with the connection tightened. It is shown that the thread connection can hold 5000-psi pressure without burst (**Figure 4**). When the pressure is assumed to penetrate through the thread mating surface, the box-thread burst occurs at 4500 psi (see **Figure 5).**

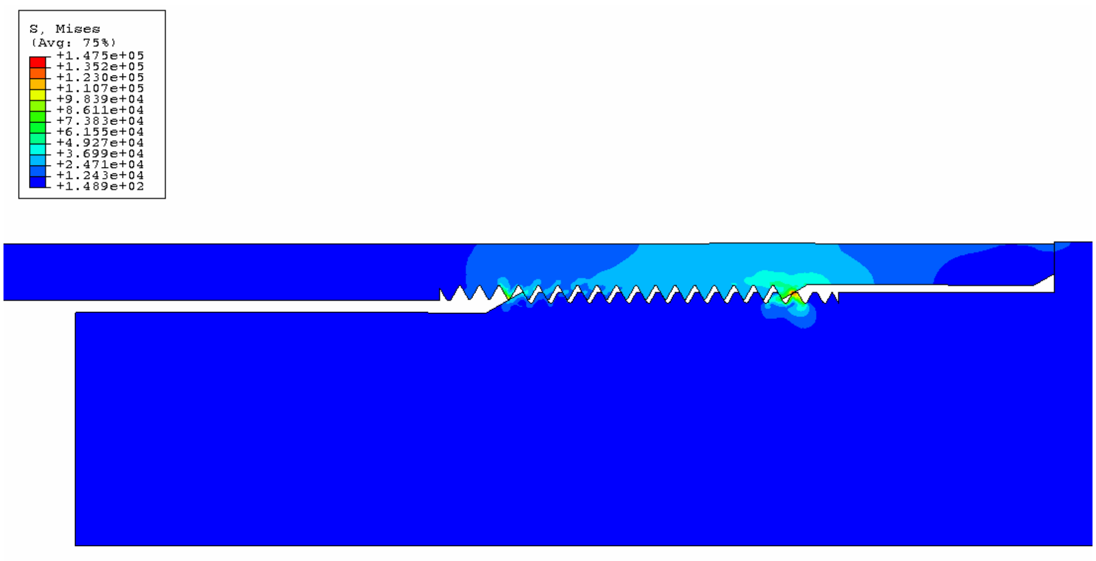

Figure 3: Stress contour in the thread connection after make-up and application of torque – represented by interference fit.

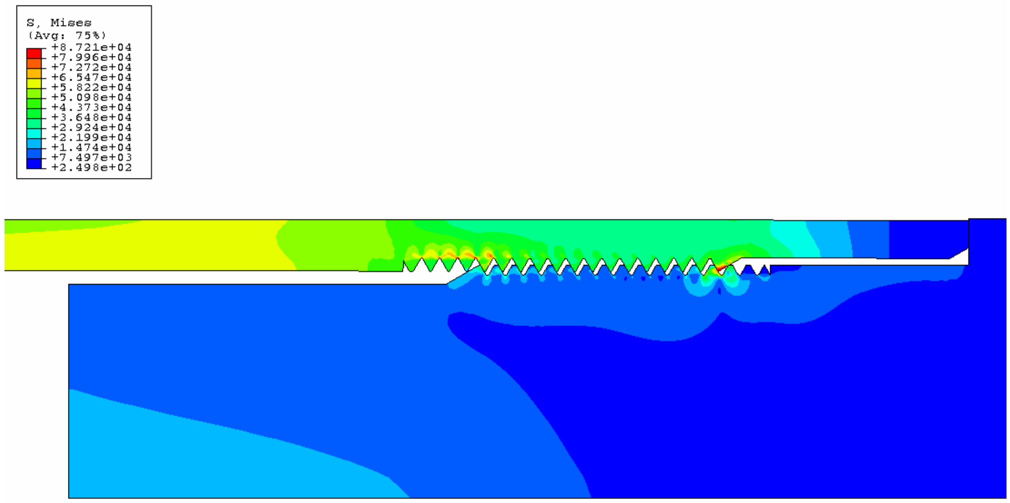

Figure 4: Thread connection is intact up to 5000-psi pressure.

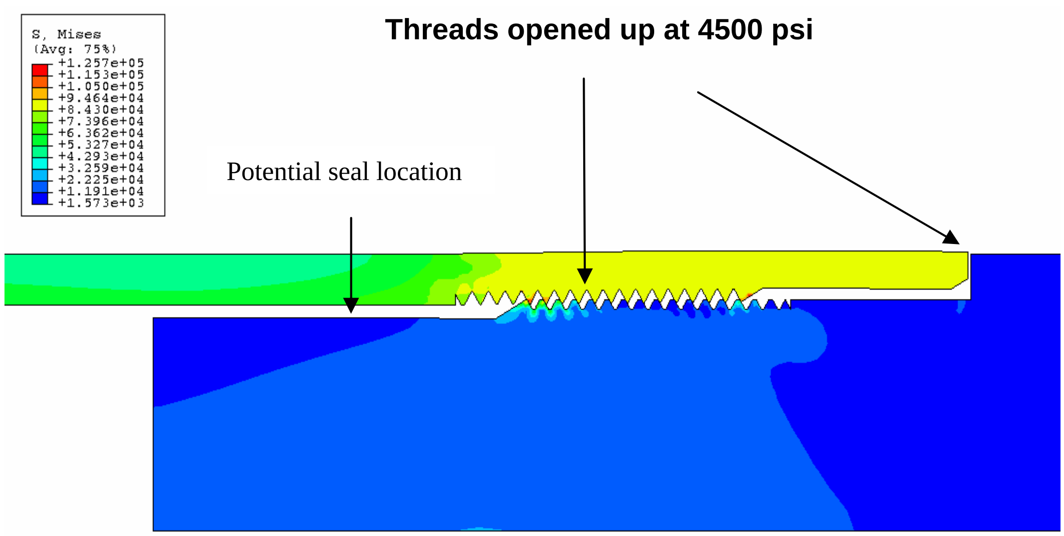

Figure 5: Boxed (internal) thread burst begins at 4500 psi when pressure is assumed to penetrate the thread mating surface.

In a physical test, the actual failure occurred at approximately 4500 psi. FEA prediction and physical test results indicated that the pressure penetrated the thread mating surface. Based on FEA, it was determined that the thread connection should be capable of sustaining more than 5000-psi internal pressure if no pressure penetrated the threads. A simple and obvious solution is to add a seal or o ring at inside of the thread as shown in Figure 5 to eliminate pressure penetration. It was also determined that changing the profile of the box and pin at the bearing area would not solve the problem, because under close end conditions, the box would be pulled away from pin axially at that area.

4. Case study of a thread connection under collapse pressure

As discussed in Section 2.2 for collapse analysis, we basically performed two different analyses – one for deformation under pressure, and one for buckling under pressure. The ACME thread connection under study has different minimum yields for pin and box thread material; the pin has an initial yield of 110 ksi, and the box has an initial yield of 125 ksi. Again, the make up is simulated via an interference-fit analysis, and the deformation analysis is conducted using an axis symmetric model. Initial yield occurs during make up, so it is not easy to determine the collapse pressure per yield; instead, radial growth of the thread at ID or OD is used as a measure for collapsing pressure determination per deformation analysis (see **Figure 6**).

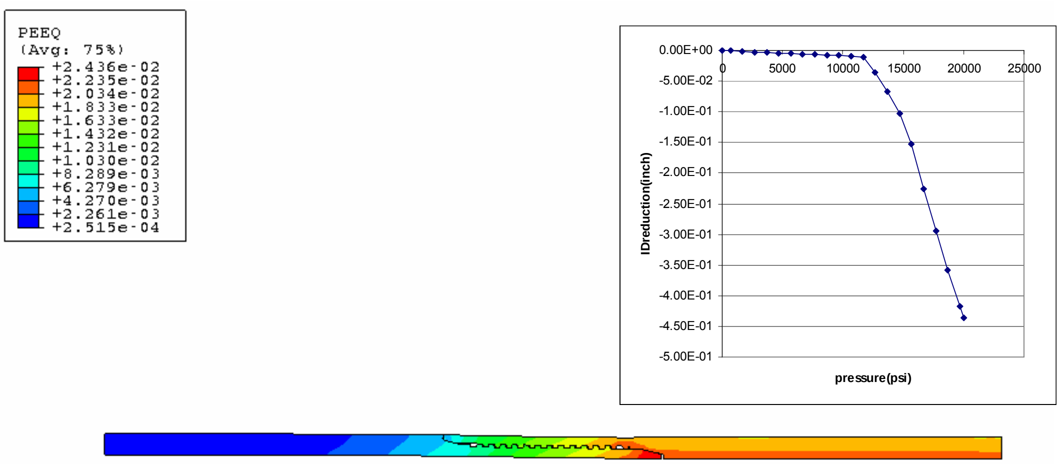

Figure 6: Rapid caving at box side starts at 11.7-ksi external pressure.

A collapse analysis following the procedure described in Section 2.2 was conducted. The first collapse mode is shown in **Figure 7**.

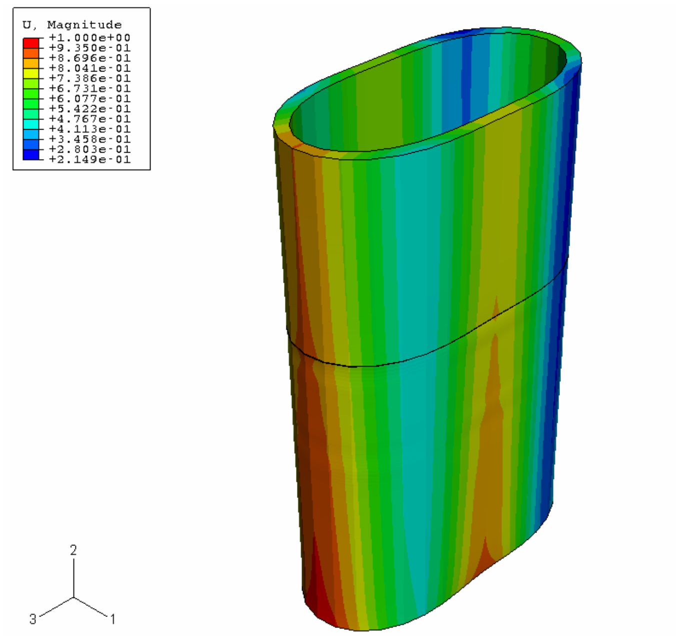

Figure 7: First buckling mode occurred at 12.6-ksi external pressure

Therefore, for this thread connection, rapid caving due to plastic deformation occurred before buckling occurred. The collapsing pressure for this connection is 11.7 ksi.

5. Summary and Concluding Remarks

When compared to a full three-dimensional analysis of thread make-up (**Figure 8**), the interference fit simulation seems to be quite good, since the stress contour in the 3D model is close to symmetric. However the 3D model, with rather coarse mesh at the thread, is huge in size. It takes approximately 36 hours of CPU time just for make-up analysis compared to 1 hour CPU time using the proposed approach, for the whole make-up simulation and collapse-buckling analysis with fine mesh at the threaded area. Symmetric results transfer capability significantly reduces analysis time to generate a buckling analysis of pre-stressed axis symmetric parts.

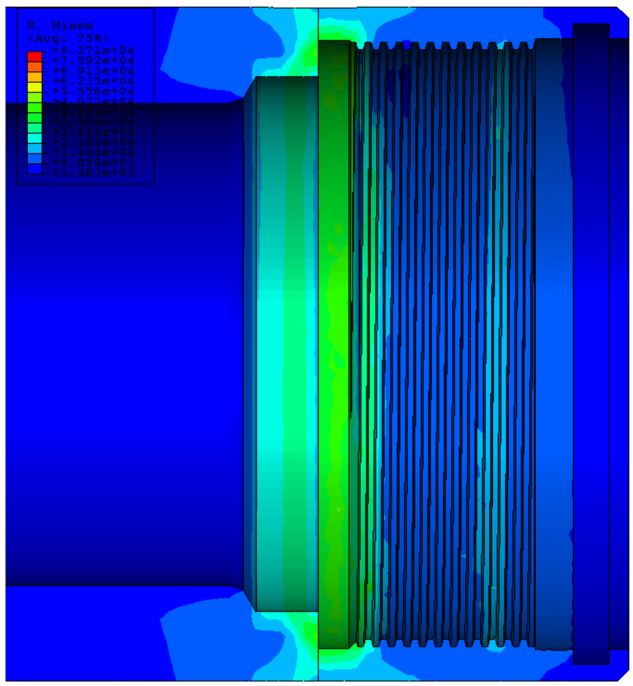

Figure 8: Stress distribution in a box thread during torque make-up.

Our approach to determine critical pressure for thread connections is shown to be accurate and highly efficient compared to full 3D model or physical test. Through case studies, it is demonstrated that a good formulation of the FEA model is very important in solving real world problems. The efficient approach for collapse buckling analysis of a pre-stressed part with symmetry can be applied to many other completion products, such as expandable liner hangers and base pipe.

6. References

1. ABAQUS, Inc. (2005), ABAQUS USER'S MANUALS
2. ABAQUS, Inc. (2005), Example Problems Manual, Chapter 3 Tire and Vehicle analyses.
3. Zhong, X. A. (2006), Computational Fracture Mechanics Analysis of Truck Tire Durability, ASME Journal of Applied Mechanic, p. 799 – 806 , 73(5), September 2006

7. Acknowledgements

The author is grateful to Halliburton management for permission to write and publish this paper.