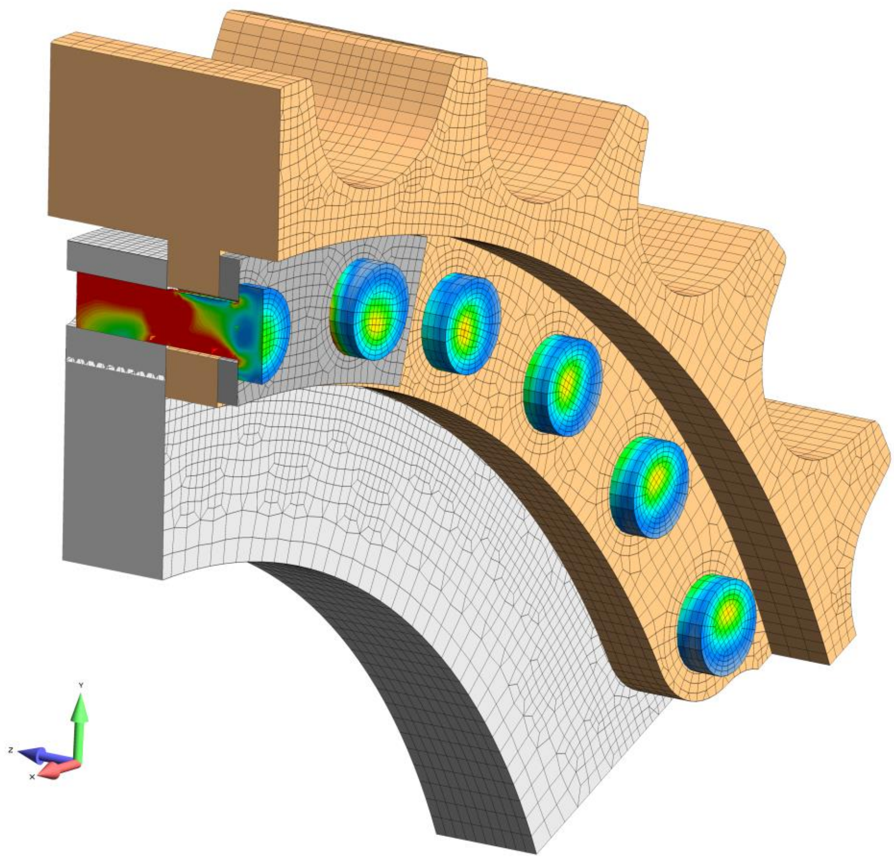
Title: Sprocket and Hub Bolt Analysis for Slip-Critical Bolted Applications in Mining and Mineral Processing Equipment

Case Study Section: FEA

Keywords: Bolted joints, bolted connections, slip critical bolt design, bolt preload, FEA of bolted joints, stress and fatigue analysis of bolts, NASA 1228 bolt analysis, Analysis of bolted sprocket and hub designs, nonlinear contact with friction,

Main Graphic:



Objective:

A typical design for large sprockets found on earth moving equipment and large conveyors, is to bolt the segmented sprocket onto a hub. Over time, as the sprockets are worn out, they can be replaced on-site without extensive downtown. These segments are bolted onto the hub and the chain load is ideally transferred by friction between the face of the sprocket onto the hub; thereby leaving the bolt in a perfect state of friction. If the design load is exceeded (i.e., excessive chain load), the sprocket can slip and the bolt is then placed in bending.

This project analyzed a large segmented sprocket and hub system under various chain loading conditions and interpreted the bolt stresses using the NASA 1228 bolt design criterion along with the MIL-HDBK-5J standard. Bolt sizing and preload recommendations could then be made to ensure slip critical design requirements were met.

The FEA model captured the complete chain load to sprocket to hub load line behavior through the use of contacting surfaces between all mating parts. The model used a mix of high density brick elements along with a carefully graded mesh of 10-node tetrahedrals. Through careful construction, the model was able to generate complete chain load to final converged state analyzes in a matter of minutes. This was an important consideration since a design matrix approach (Design of Experiments) was required to determine the sensitivity of the design to friction, bolt preload and reinforcement design modifications. The sensitivity analysis indicated that the most effective approach to ensure a slip critical design with large sprockets is to ensure the highest possible bolt preload.

Figure 1: Example of bolted sprocket and hub design on D11 Caterpillar

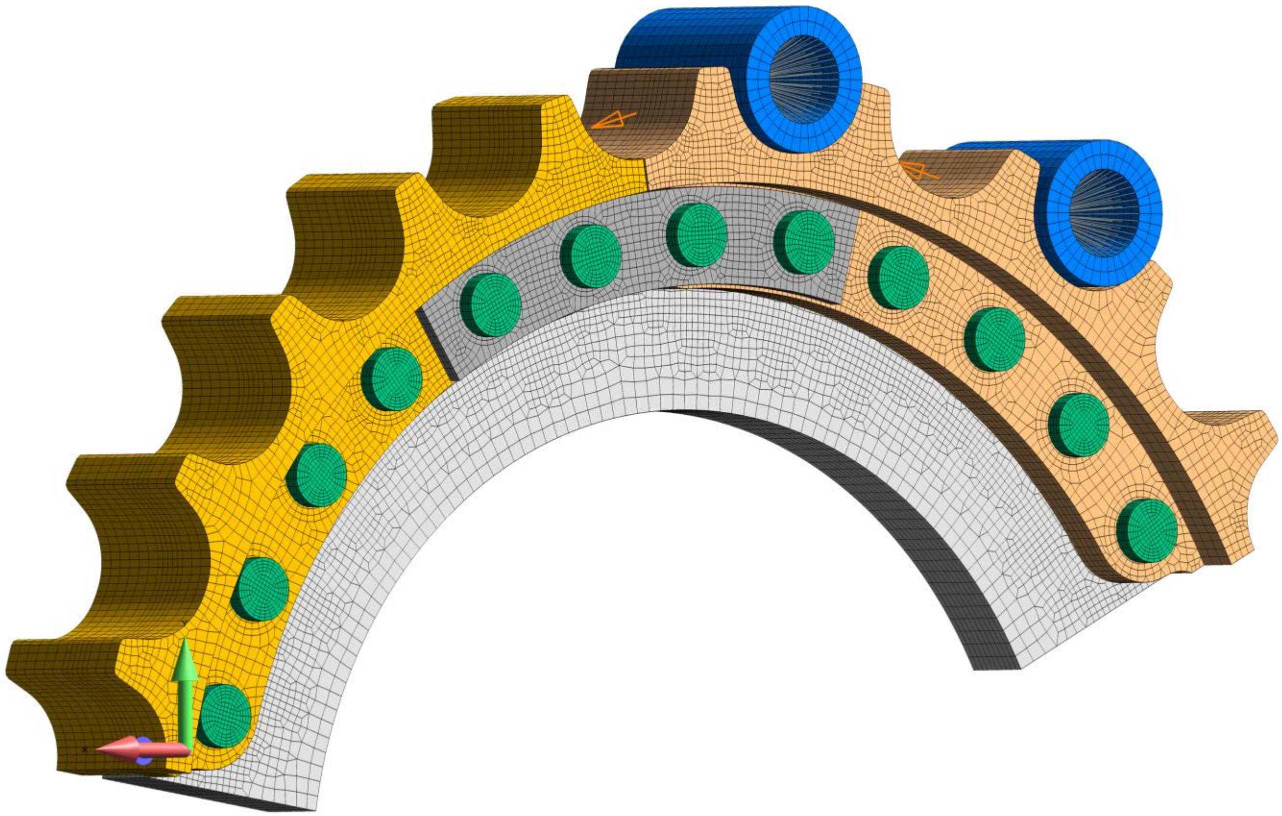


Figure 2: FEA model of the hub, sprocket and bolts.

The analysis sequence consisted of applying a preload to the bolts and then ramping up the chain load (arrows). Contact was enforced between all mating parts with a nominal frictional coefficient for steel-on-steel contact based on Marks Handbook. As the chain load was increased, the model accurately predicted the transfer of shear load from the sprocket/hub interface into the bolts as the critical slip condition was exceeded.

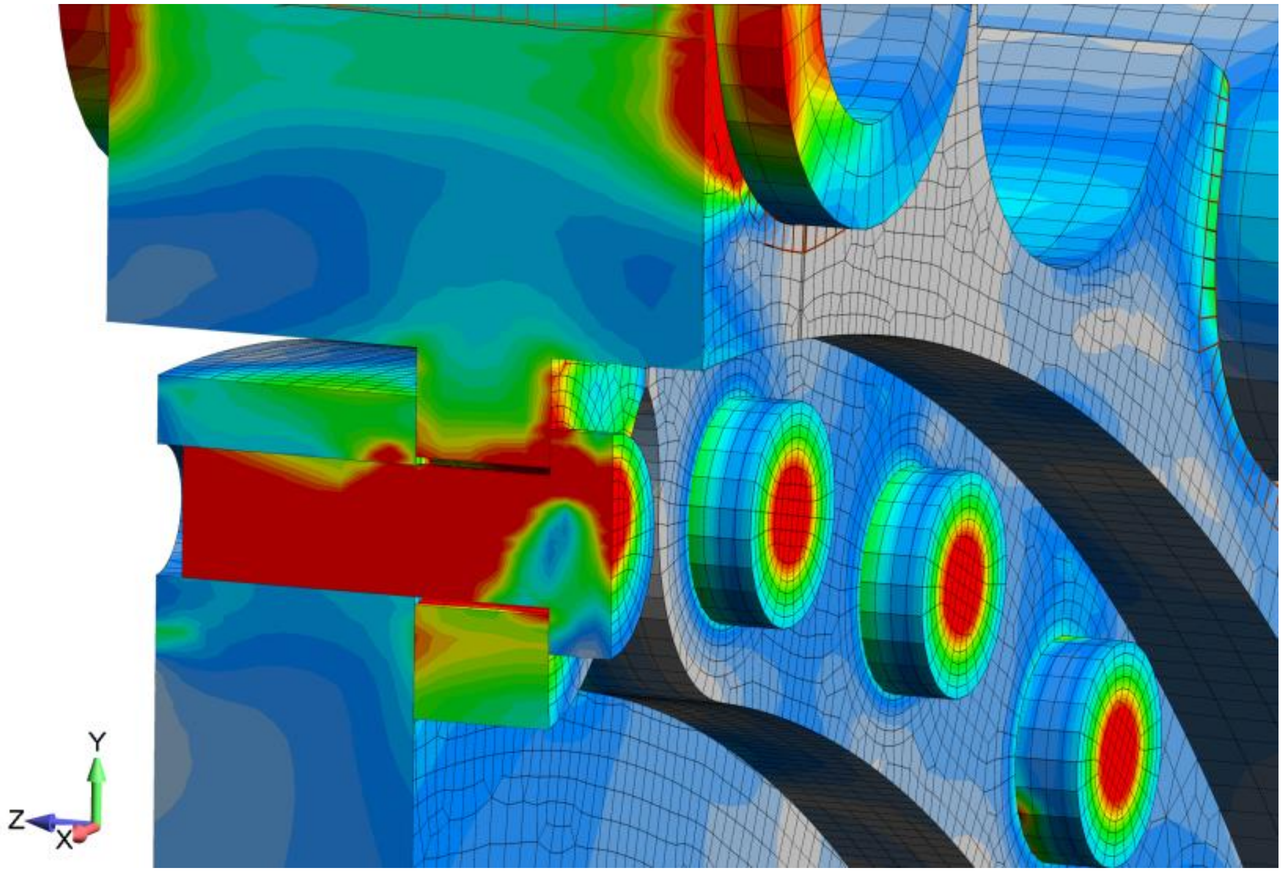


Figure 3: Stress results for the bolted sprocket/hub system are shown at the point where the sprocket has started to slip against the hub

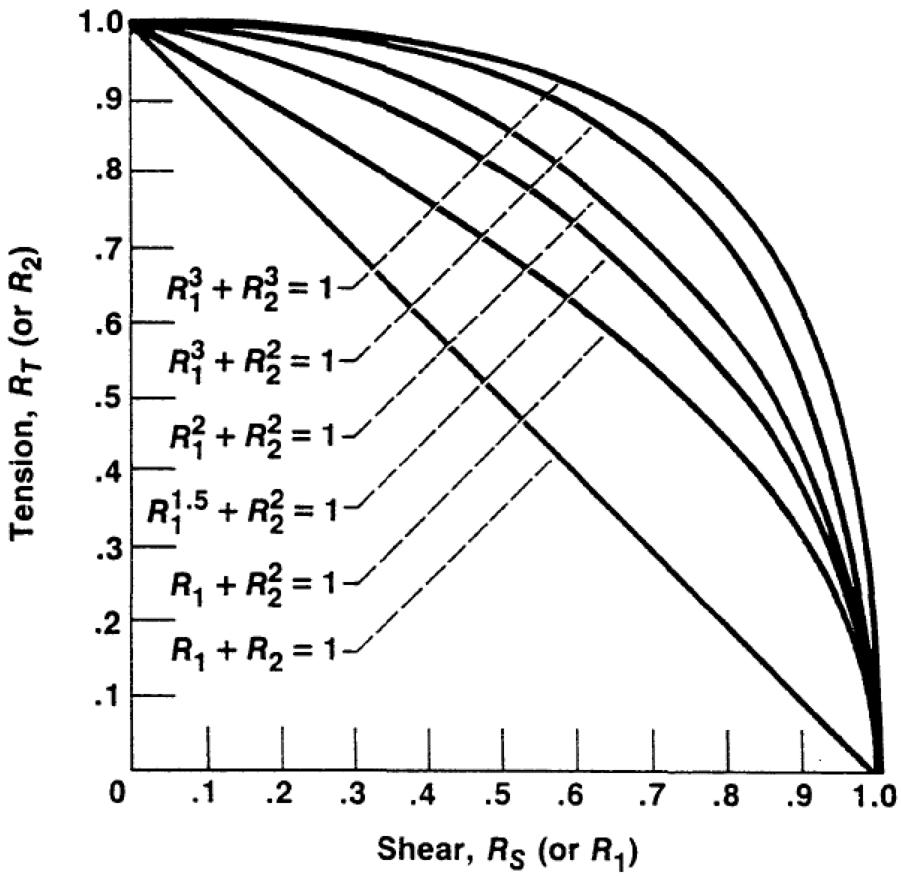


Figure 31.—Interaction curves.

Figure 4: NASA publication 1228 shear-tension interaction curve for bolt analysis

Once stresses are extracted from the FEA model, the NASA 1228 publication can be used as a guideline to determine the safe limit for the bolt. It should be noted that interpreting stresses from a 3-D bolt model is messy since the full-field stresses are obtained over the complete bolt and not just axial and shear loads as that typically obtained using a beam element approach. The utility of having full field stresses is that one can observed the mechanics of the bolt loading process from full frictional lock where the bolt is in a state of pure tension to that of a mixed mode condition and bending stresses are present.

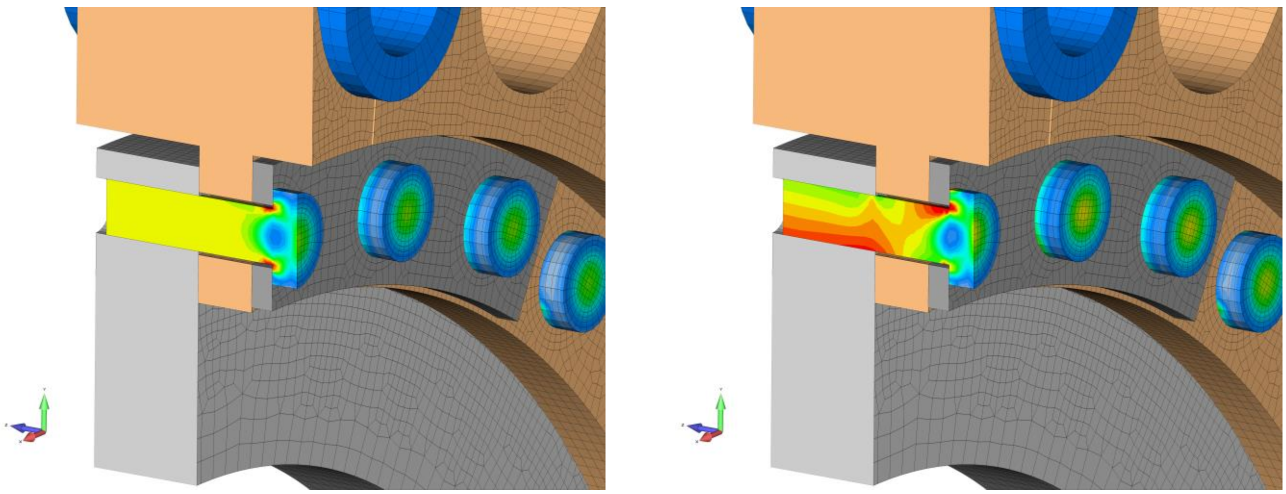


Figure 5: The bolt stress state at design condition is uniform with only stress peaks under the bolt head. As slip occurs, the bolt stress state becomes non-uniform and its fatigue life is compromised.

Bolted connection analysis requires careful mesh preparation and attention to details around the bolt holes. As the bolt is preloaded the contact zone directly underneath the bolt head should be carefully mesh to capture the compression bolt preload effects that determine the frictional stick-slip behavior. The above figure shows the bolt stresses at low and high chain load. It can easily be seen that at low load, the bolt behaves as designed with a uniform stress state. As the load is increased, the stress state in the bolt becomes non-uniform and bolt failure is likely.