T008: Self-Loosening of a Bolted Joint

Introduction

A simulation setup procedure to analyze self-loosening in a bolted joint is detailed below.

Problem Description

A DEFORM user wanted to model the self-loosening of a bolted joint, which is a major form of failure in machines and structures. The customer wanted to model the external cyclic loading of a bolted connection to see what influence it had on the clamping force. It is a well known fact that such cyclical loading causes the clamping force in the joint to gradually decrease, and the customer wanted to study this phenomenon in DEFORM.

Background Information

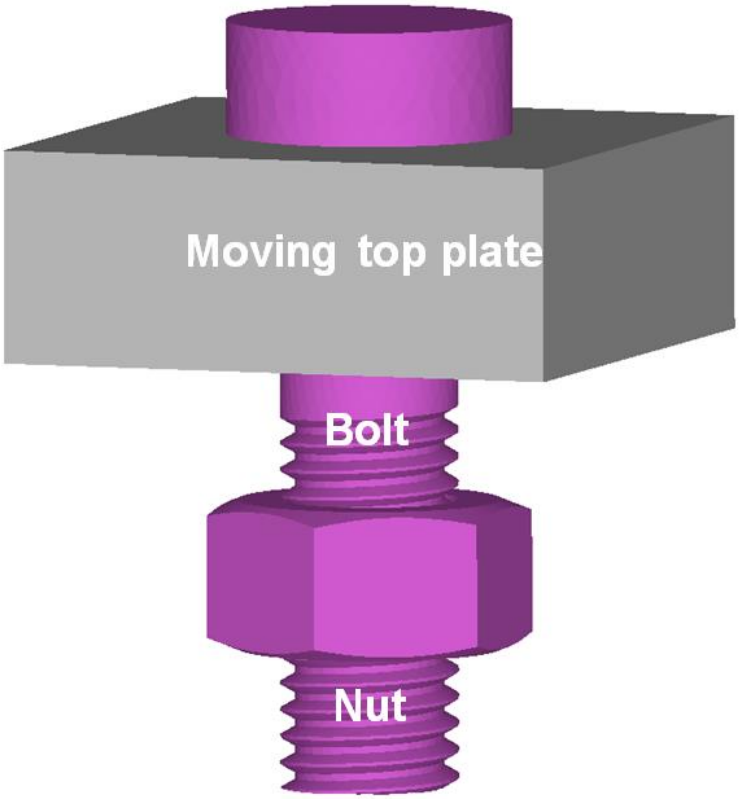
A literature search was performed and several papers were found detailing bolt loosening simulations performed using general purpose codes. These papers are listed below in the Related Information section. A DEFORM-3D simulation was run using a setup very similar to that used in the first paper (Izumi et al) listed.

Solution

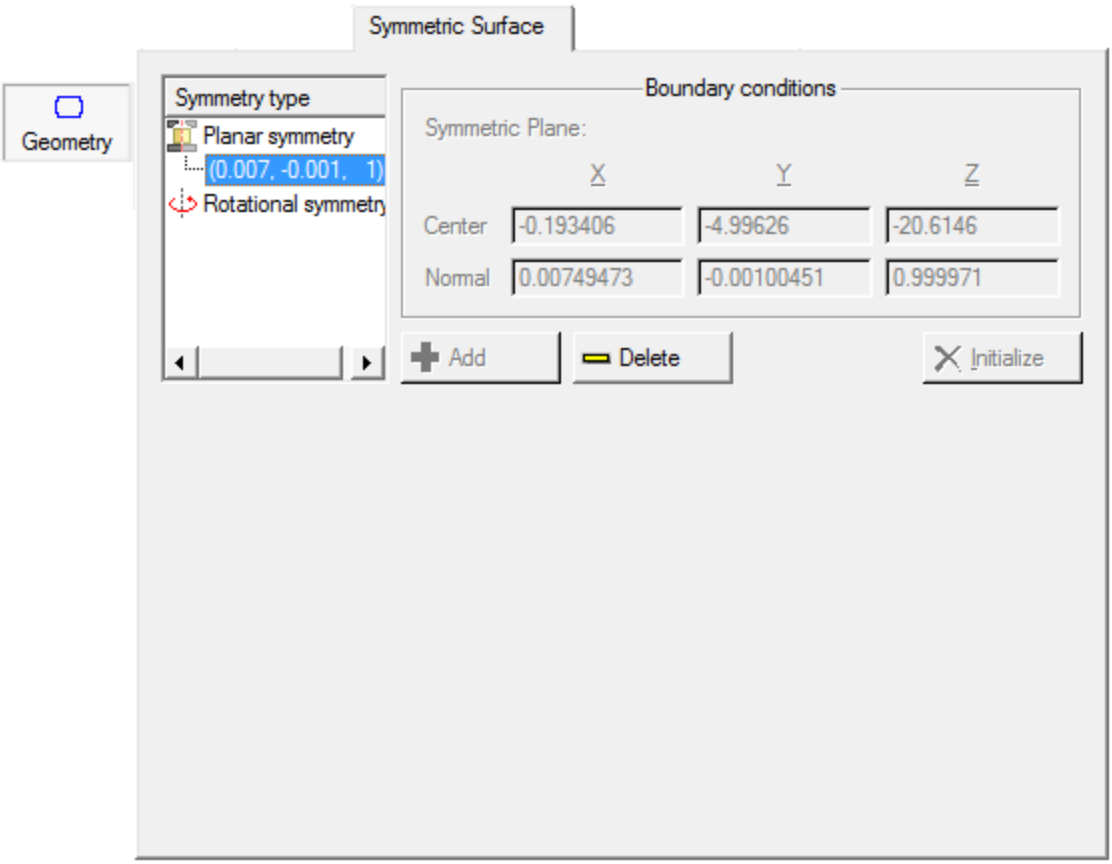
In order to accurately model the bolt loosening phenomenon, the initial preloading of the joint must be modeled in addition to the cyclic loading. The preload in the bolted joint will decrease if the threads on the bolt want to rotate and back off of the nut threads.

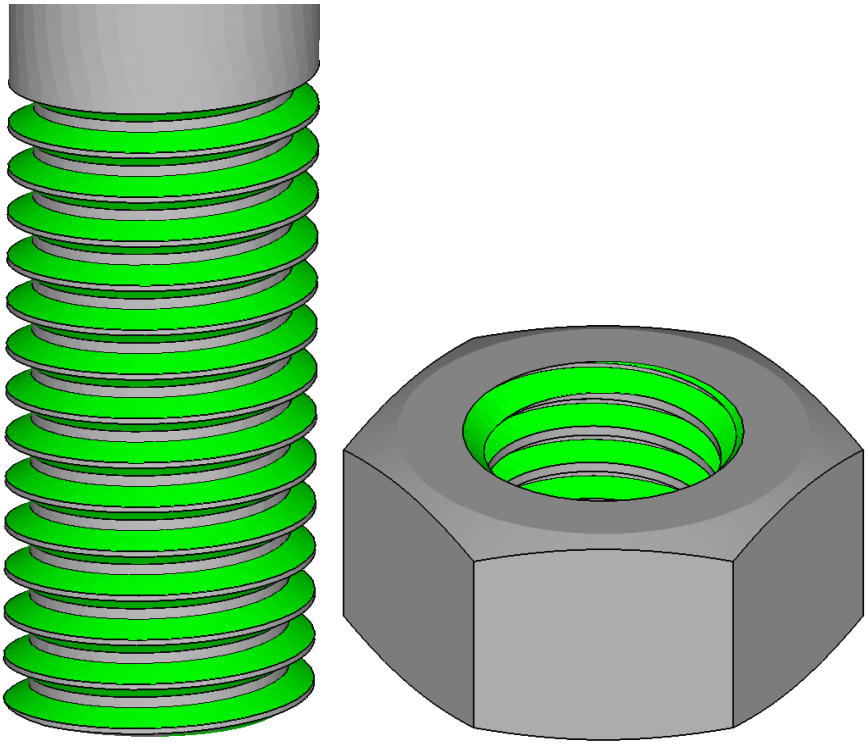
Since the reference paper specified lengths in millimeters and forces in Newtons, the DEFORM simulation was run using SI units.

The bolted joint was modeled using three objects: a bolt, a nut and a movable top plate. The bolt and nut were both modeled as elastoplastic (EP) objects, to capture any plastic deformation that may occur. The moving top plate was modeled as rigid.

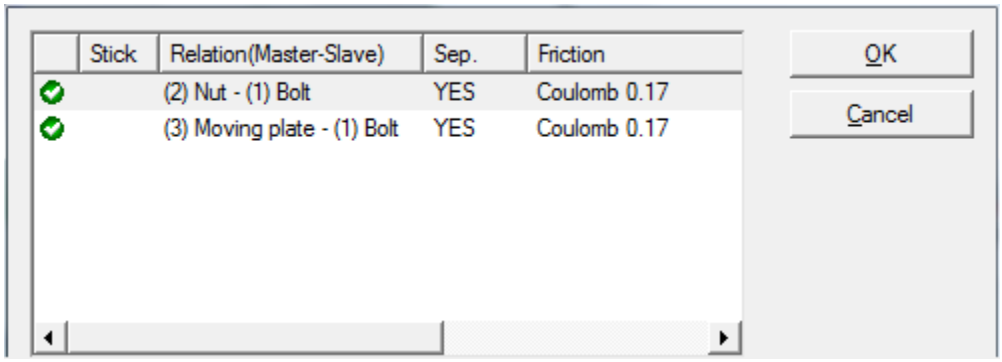


When meshing the bolt and nut, extra care had to be taken to make sure the geometric definition of the threads was not lost. When meshing these objects, “marking” the geometries helps to keep the meshed features from becoming rounded off or distorted. This feature is found in the Geometry page under the Symmetry Surface tab.

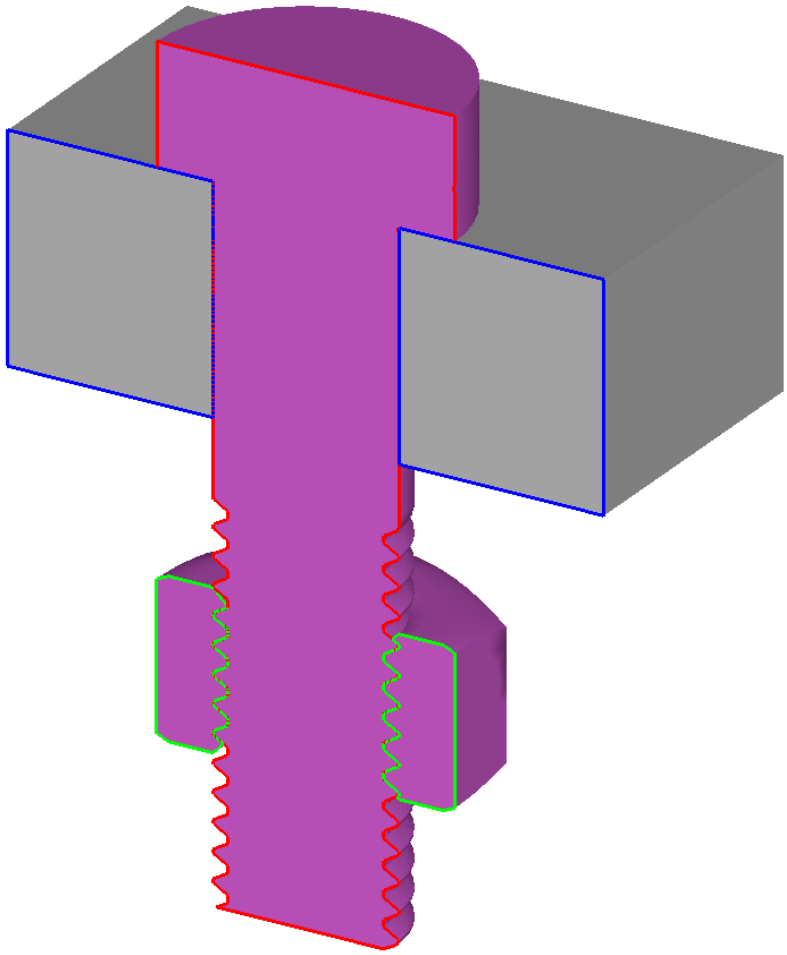

Symmetric Surface
Geometry
Symmetry type
Planar symmetry
(0.007, -0.001, 1)
Rotational symmetry
Boundary conditions
Symmetric Plane:
X
Y
Z
Center
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-4.99626
-20.6146
Normal
0.00749473
-0.00100451
0.999971
Add
Delete
Initialize



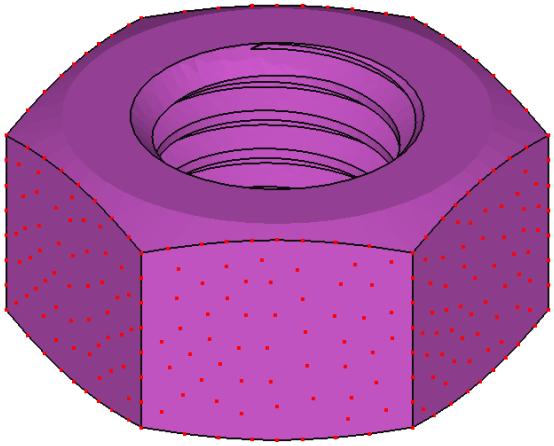
After the bolt and nut were meshed, the objects were positioned and Inter-Object relationships were defined as shown below. Again, these values were taken from the reference paper.



This sliced section through the parts shows a better view of the initial positioning of the objects.



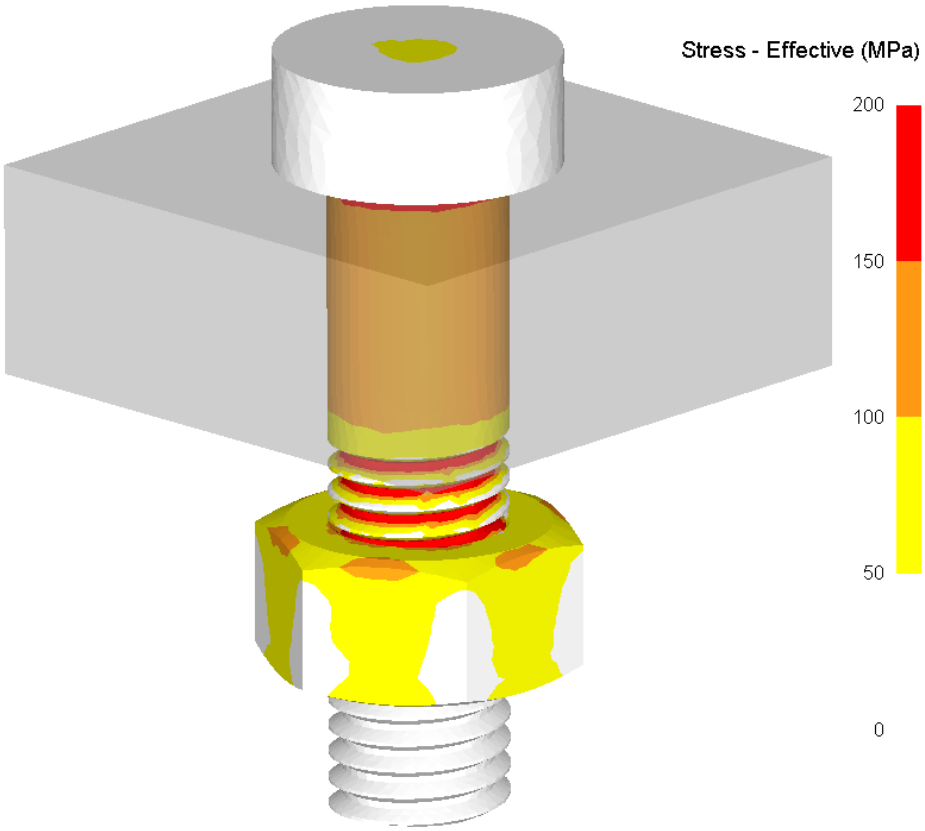
The entire outer surface of the nut was constrained using Vx=0, Vy=0 and Vz=0 velocity boundary conditions, as shown below. The only constraint on the bolt was the contact it had with the nut and top plate.



Stage 1 – Preload application

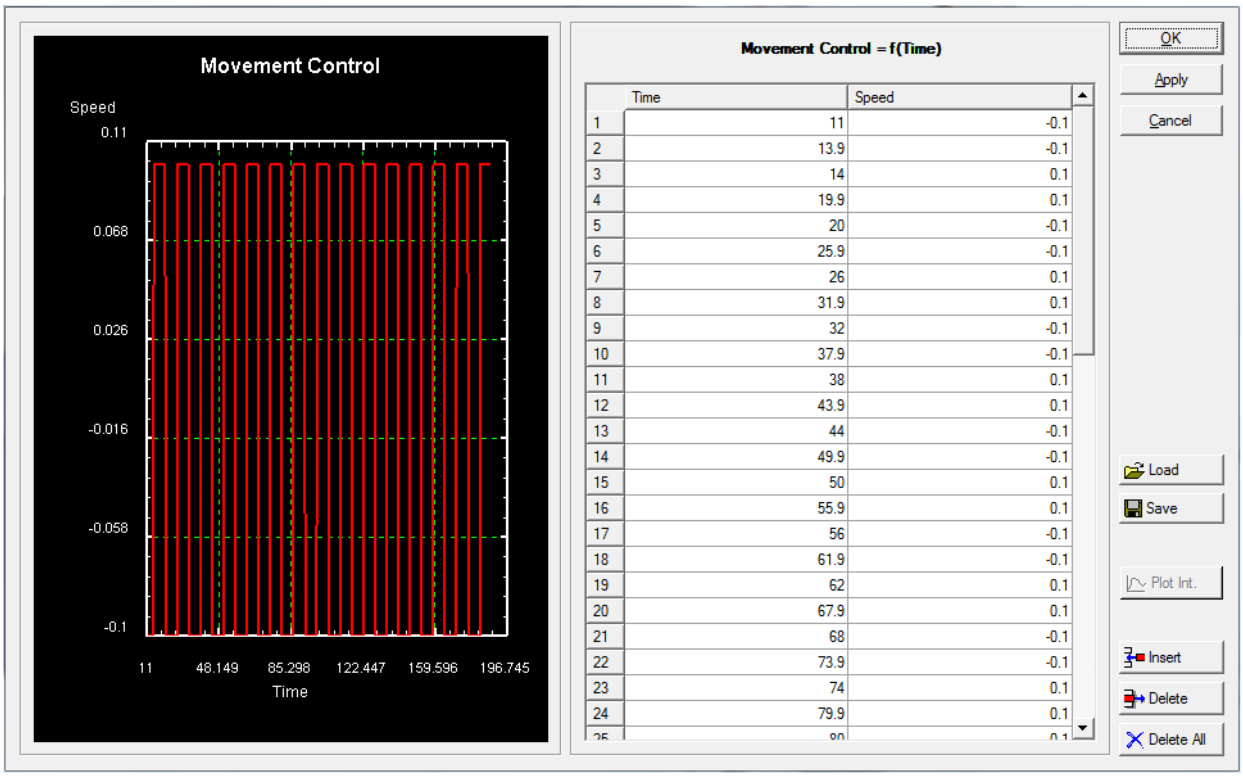
The first stage of the simulation was the application of the preload. A constant load of 9800N was applied upward on the rigid top plate. Ten 1 second steps were run for this stage. Multiple steps were used so that contact had a chance to come to a state of equilibrium.

The preload stressed the joint and pulled the bolt threads tight against the threads of the nut.



Stage 2 – Cyclic loading

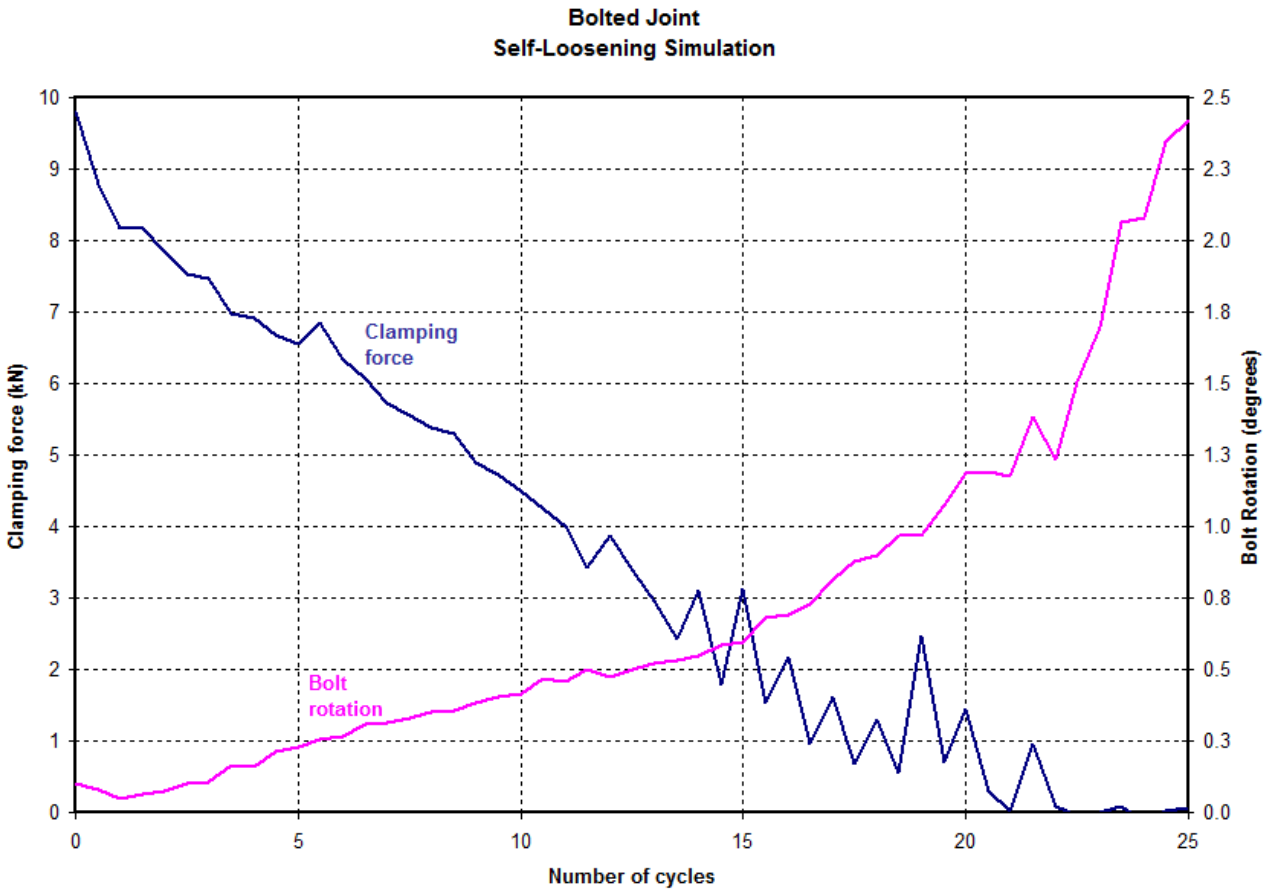
For the second stage of the simulation, the movement of the top plate was changed from load control to speed control. To create a cyclical motion of the top plate, a function was used that cycled the plate back and forth from side to side. The function data used in the simulation is shown below. Enough data was used in the function to cover 25 movement cycles back and forth.



	Time	Speed
1	11	-0.1
2	13.9	-0.1
3	14	0.1
4	19.9	0.1
5	20	-0.1
6	25.9	-0.1
7	26	0.1
8	31.9	0.1
9	32	-0.1
10	37.9	-0.1
11	38	0.1
12	43.9	0.1
13	44	-0.1
14	49.9	-0.1
15	50	0.1
16	55.9	0.1
17	56	-0.1
18	61.9	-0.1
19	62	0.1
20	67.9	0.1
21	68	-0.1
22	73.9	-0.1
23	74	0.1
24	79.9	0.1

A time step of 0.3 seconds/step was used for this portion of the simulation. Each cycle was performed using 40 steps, i.e. it took 10 steps to go from the center datum position to the extreme left or right.

The simulation was stopped after 25 cycles. The following graph plots the reduction in clamping force that was observed in the simulation, as well as the amount of bolt rotation. You can see that the mechanism behind the reduction in clamping force is indeed the self-loosening and rotation of the bolt.



Related Information

The following papers deal with the finite element modeling of self-loosening of bolted joints. The setup used in this paper is that used in Izumi et al.

1) S. Izumi et al., 2005, “Three-dimensional finite element analysis of tightening and loosening mechanism of threaded fastener,” Engineering Failure Analysis, **12**, pp. 604 - 612.

2) N.G. Pai, D.P. Hess, 2002, “Three-dimensional finite element analysis of threaded fastener loosening due to dynamic shear loading,” Engineering Failure Analysis, **9**, pp. 383 - 402.

3) M. Zhang et al., 2007, “Finite Element Modeling of Self-Loosening of Bolted Joints,” Journal of Mechanical Design, **129**, pp. 218 - 226.