Multiphysics coupling: 3D-2D solid mechanics model coupling

A granular tissue can be found within gaps at the bone-implant interface of a femoral stem. It is assumed that bone-healing process after stem implantation is related to deformation within this granular tissue. The objective of this exercise is to estimate volume ratio (current volume/initial volume) within this granular tissue. We assume here a circular layer of granular tissue located at the middle of the femoral stem.

Build a simplified 3D femur, represented by a hollow cylinder with an external diameter of 2.8 cm, a thickness of 7 mm and a length of 48 cm. Insert in the upper part of the femur a stem with a length of 10 cm. Bone is assumed elastic, with a Young's modulus of 18 GPa, a Poisson's ratio of 0.3, and a density of 1800 kg/m^3. The stem is made of titanium. On the upper part of the stem, apply a force of 2 kN in the axial direction, and a force of 200 N in a transverse direction. Constrain the lower part of the bone. Plot and verify the bending deformation of the bone.

In the 3D model, add a work plane perpendicular to the stem axis and in the middle of it (5 cm from the top). On this work plane, draw a ring with the same dimension as the bone, to represent the 2D surface containing the granular tissue. Add a new 2D solid mechanics model to your COMSOL file. Build a ring of bone corresponding to the 3D work plane. Add a step to Study 1. The first step solves the 3D model only, while the second step solves the 2D model only. The 3D and 2D model are coupled with a general extrusion operator, which is defined in the 3D model, and called in the 2D model. In the 3D model, go to Definitions, right-click and choose Component Coupling/General Extrusion. Select the work plane ring. Set x in x field, y in y field, and 0 in z field, for both source and destination map. In the 2D model, add a prescribed displacement for u and v, on the inner and outer boundary, using the defined general extrusion operator:

u = comp1.genext1(u)
v = comp1.genext1(v)

Verify that the displacements u and v are the same in the 2D model and the 3D work plane.

In the 2D model, add a new ring with a thickness of 1 mm around the implant to represent granulation tissue with a Young Modulus of 1 MPa, a Poisson's ratio of 0.17 and a density of 1000 kg/m^3. Verify again that the displacements u and v are the same in the 2D and 3D models. Plot the volume ratio ($J = \det \boldsymbol{F}$) within the granular tissue.