Appendix D

cantBeam.mac – the content

cantBeam.mac is a simple example of FEA code. A beam is modeled using solid elements and a simple, uniform mesh. This code was used for generating images in Figure D.10 and Figure D.11.

An FEA simulation consists of preprocessor, solver, and post processor. The preprocessor creates and meshes the geometry with the select elements, whose material properties must be specified. The solver performs the desired analysis using the prescribed method according to the specified parameters. The postprocessor allows us to view the results.

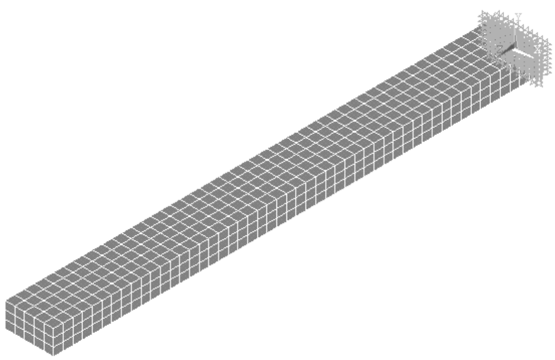

Figure 1: A cantilevered beam meshed by solid elements.

The cantBeam.mac file illustrates a typical modal analysis. The only differences between the modal analysis of the cantilevered and the doubly-clamped beam are the two lines that apply the boundary conditions at $z = bL$.

Material properties

The beam is made of Si. The material properties depend on the orientation of the beam. In the present code just two parameters were used for simplicity.

Units

In any simulation, it is important to use a consistent set of units. Any consistent set of units can be used. In MEMS, we naturally to think of geometry in micrometers and therefore it is convenient to choose a system of units that accommodates μm. The units for the mass density and the Young's modulus must be scaled to this requirement. Recall that the beam frequency is proportional to the square root of the ratio between the Young's modulus and the mass density (Appendix D, Eq. (D63))

$$\omega \sim \frac{h}{L^2}\sqrt{\frac{Y}{\rho}}$$

One consistent system of units is μm-kg-s. In this system we have

Unit(L,h) = μm

Unit(Y) = Pa = N/m^2 = kg/(m s^2) = $10^{-6}\times$ [kg/(μm s^2)]

Unit(ρ) = kg/m^3 = $10^{-18}\times$ kg/(μm)

Editor

Any text editor can be used for creating input files. However, it is easier to read the file with an editor that understands the syntax. Highlighting of the key commands and syntax greatly improves the readability of the code. Additional convenience, whose utility is often underestimated, is the ability to comment/uncomments blocks of code. One such (freely available) editor that supports ANSYS-APDL syntax is Crimson editor (http://www.crimsoneditor.com/).

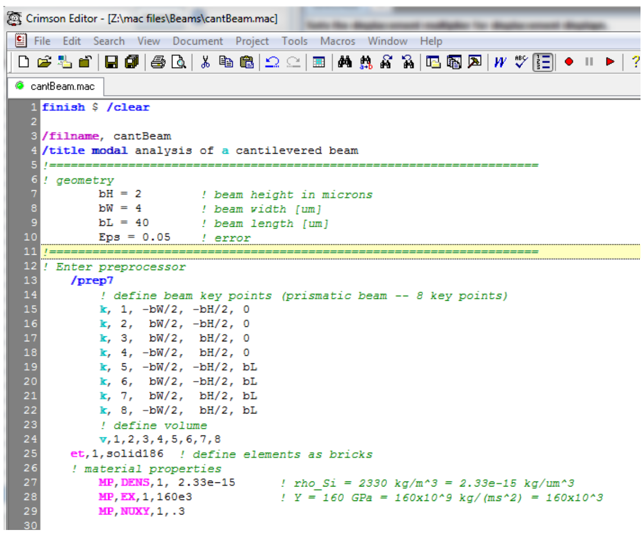

Figure 2: A snippet of ANSYS code in Crimson editor.

Optional Exercises

1. Experiment with different solid elements, or beam elements for the analysis.
2. Experiment with different meshes. This analysis uses a uniform mesh. If the goal was to obtain only the behavior near the first mode, what kind of mesh would be preferred? Experiment with changing the mesh density and mesh uniformity.
3. Map the first resonant frequency as the function of the crystal orientation of Si (see Figure D15 and Figure D16)
4. Remove the boundary conditions at both $z = 0$ and $z = bL$. This is now the *free* beam. How many modes do we need to specify to see the first bending mode? What are the first (how many?) modes called?

Chapter 6

Two examples: circular plate and rectangular plate

circPlate.mac – the content

circPlate.mac is a simple example of FEA code for a circular plate. Here we have a simple disk with radius = 40 μm and thickness = 2 μm, meshed with solid tetrahedrons (see Figure 3).

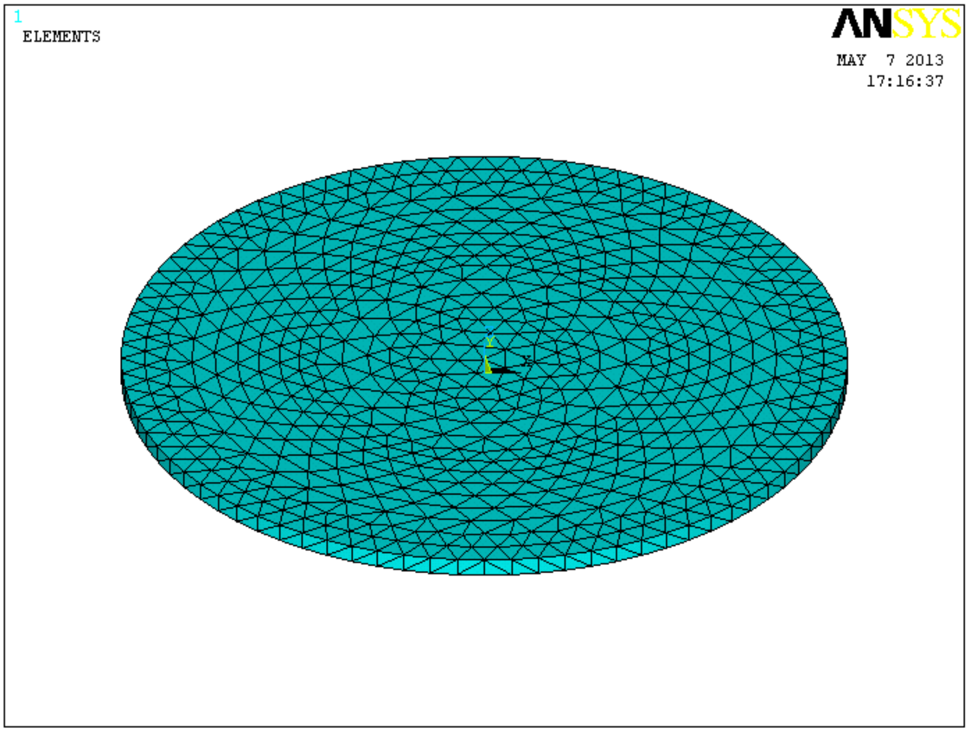

Figure 3: A simple circular plate fixed at its perimeter (BC's not shown).

The first six modes are shown in Figure 4.

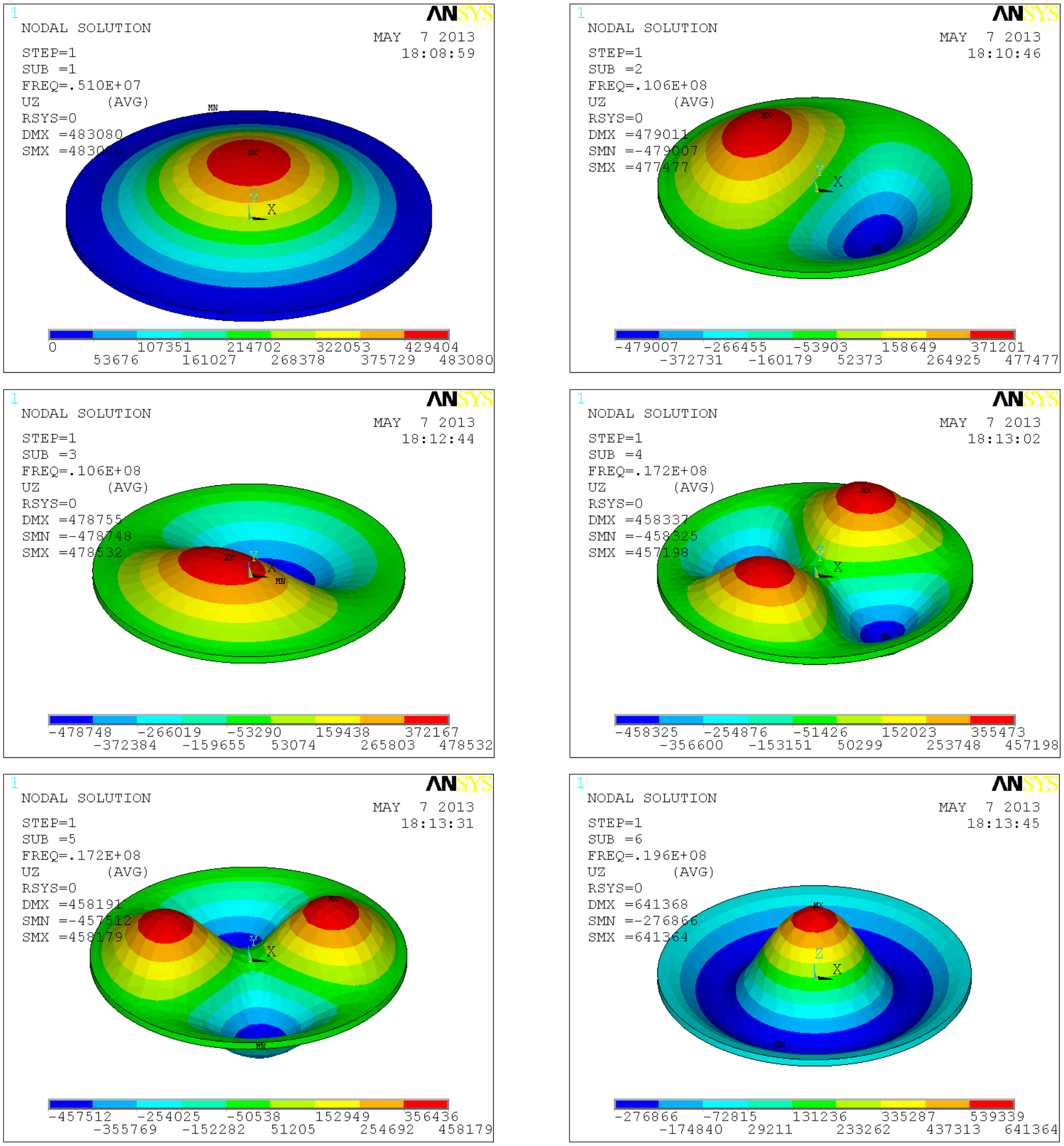

Figure 4: The first six modes of a circular plate with clamped perimeter.

Compare the mode shapes of this analysis with that using MDF code implemented in Python. Compare also the two scripts (Python and Ansys).

rectPlate – the content

rectPlate.mac is a simple example of FEA code for a rectangular plate. Here we have a simple 40×40 μm^2, 2µm thick plate, meshed with solid bricks. Figure 5 shows the elements of the plate.

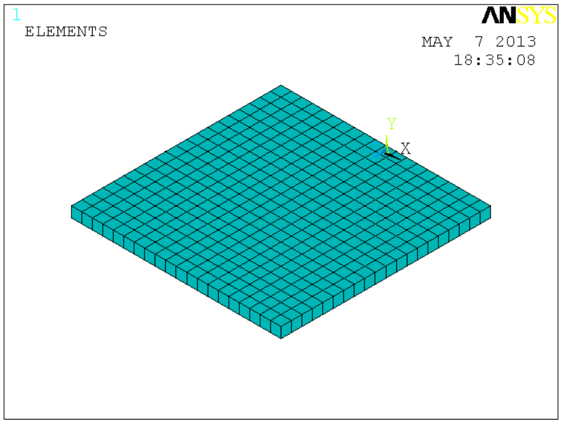

Figure 5: A simple rectangular plate fixed. All edges are clamped (the B.C.'s are not shown).

The first six modes are shown as follows:

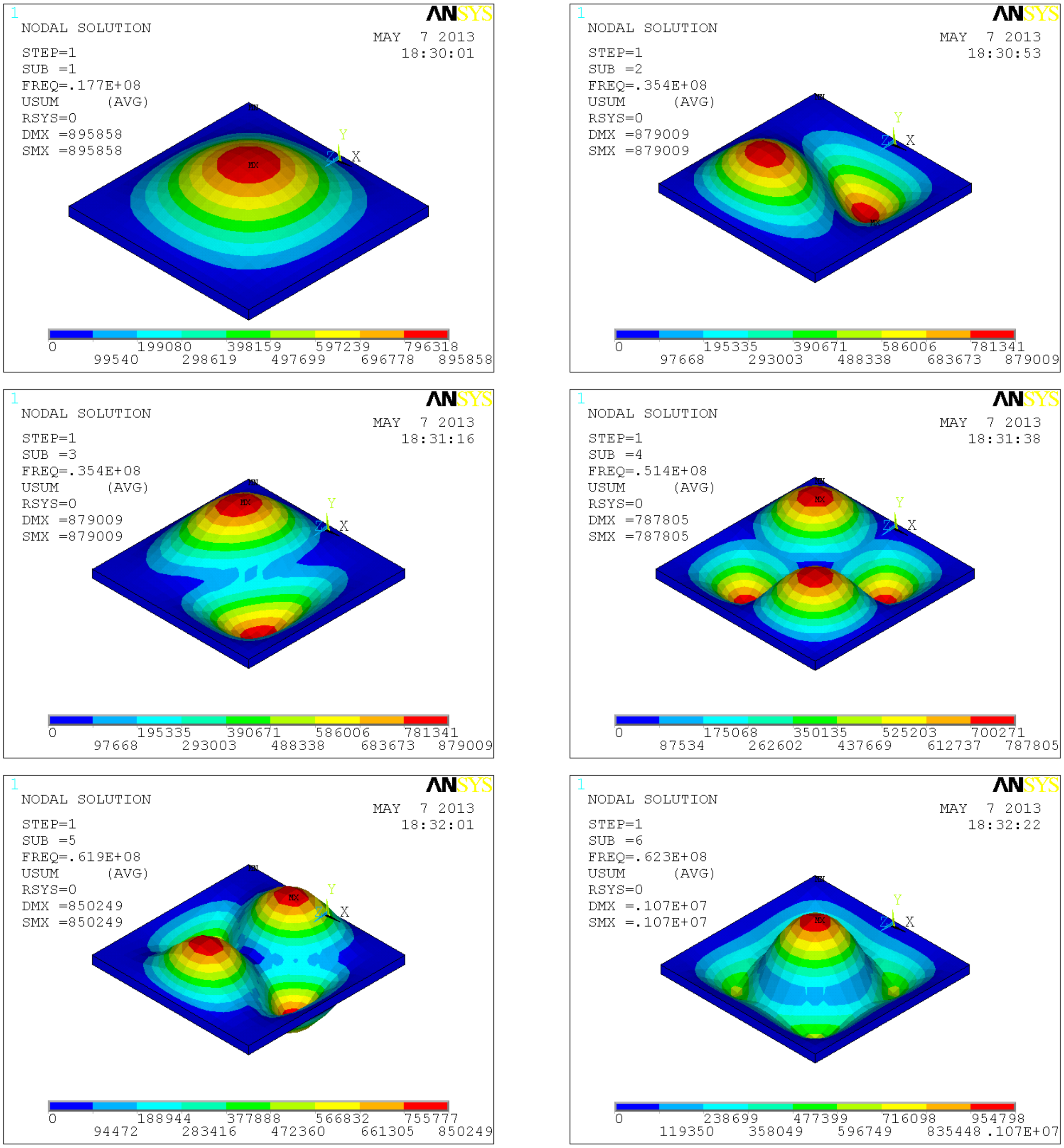

Figure 6: The first six modes of a simple rectangular (square) plate with clamped perimeter.

Compare these modes to the modes of the circular plate – they are topologically the same.