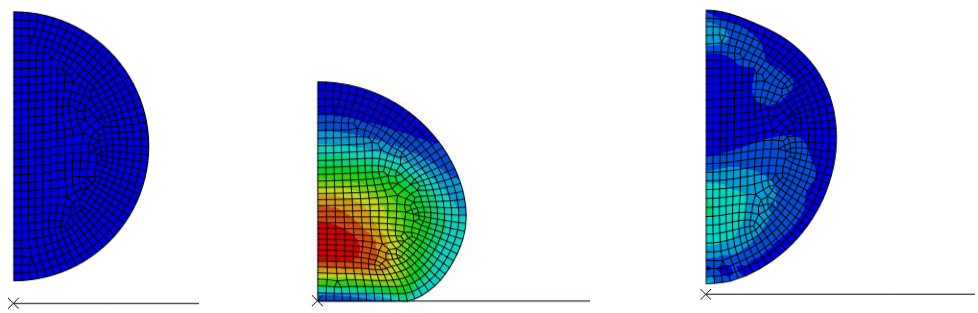
EN234: Computational methods in Structural and Solid Mechanics

Homework 1: Basic FEA with ABAQUS
Due Wed Sept 18, 2013

School of Engineering
Brown University



1. The figure shows an FEA simulation of a soft rubber sphere bouncing on a flat rigid frictionless surface. Your goal is to run an ABAQUS simulation of this problem.

- The sphere will be idealized as a near-incompressible neo-Hookean hyperelastic material with shear modulus μ and bulk modulus K and mass density ρ. You can find some background information about hyperelastic materials at http://solidmechanics.org/Text/Chapter3_5/Chapter3_5.php. You should also read section 19.5.1 of the ABAQUS theory manual to familiarize yourself with the ABAQUS version of the neo-Hookean material (in particular notice that their material constants C_{10} and D_1 are not the same as those in the textbook).
- The sphere has radius R and is launched with initial velocity V_0 towards the rigid surface.

Your goal is to run a finite element simulation of this problem. Various quantities could be calculated in this analysis, and you should feel free to calculate anything that might be interesting. But to focus on something specific, we will calculate (i) The time that the sphere is in contact with the surface t_0; and (ii) the force of the impact $F(t)$.

Before doing any analysis,

1.1 Make a list of the variables that appear in the problem definition. Calculate (using dimensional analysis) how many independent dimensionless groups govern the solution. Hence, write down dimensionless expressions for the general functional dependence of the contact time t_0 and $F(t)$ on parameters in the problem. Note that since we are interested in an incompressible material we are interested only in the solution for the limit $K/\mu \rightarrow \infty$, which we will try to approximate with a suitably large value for K/μ

1.2 Make a guess for how you would expect the contact time and maximum force to vary with relevant parameters (you don't need to be specific – just think about whether you would expect them to increase or decrease with impact velocity, for example. This will tell you how it varies with all the other parameters in the problem). You should be able to specify exactly how the force will scale with sphere radius.

1.3 List any ways you can think of to check the FEA solution (you don't actually have to do these checks).

1.4 Would you expect the magnitude of the velocity of the center of mass of the sphere after rebound to be equal to, greater than, or less than its value before impact? Why?

Now set up an ABAQUS simulation of the problem. The following parameters are suggested, at least for an initial computation. You can explore variations after getting an initial simulation to work:

- The sphere should be a 2D axisymmetric solid. Use a radius *R=0.01* (arbitrary units).
- The surface should be a 2D axisymmetric discrete rigid wireframe feature. You will need to add a reference point to the rigid object to be able to apply boundary conditions. In the Part module, use the Feature>Reference Point… menu to do this. It is best to put the reference point on the end of the surface at the axis of symmetry.
- The material should be a hyperelastic neo-hookean material with $C_{10} \approx 0.05$, and leave the *D* field blank (this makes ABAQUS use a default value to approximate incompressibility) and mass density $\rho = 1$ (again units are arbitrary since we are working in dimensionless form).
- Place the sphere and the surface a small distance apart in the assembly. The distance is not important.
- Use an implicit dynamic step, with time period of order 0.4, initial increment size around 0.001, and max increments of order 400. You can use automatic time incrementation. Make sure the NLGEOM parameter is set so you run a finite strain calculation. In the Output>Field Output Requests set the frequency of output to every 1 increment. Create a Set that contains the reference node for the rigid surface, and create a History Output that will ensure that reaction forces acting on this node are written to the output database. Add any other variables you might be interested in.
- The interaction between the sphere and the surface should be hard normal contact and frictionless tangential contact. The options for the contact (node region –v-surface) are not important – just use the surface to surface contact.
- For boundary conditions, constrain the radial displacement on the axis of symmetry of both solids. It is easier to move the rigid surface towards the sphere rather than to assign an initial velocity to the sphere and make the surface stationary, but you can do it either way. To constrain the rigid surface you need to apply boundary conditions to the reference point. Apply a vertical velocity of 0.1 *insert you favorite unit* and don't forget to constrain the rotation of the reference point.
- Mesh the solid with hybrid reduced integration axisymmetric stress linear quadrilateral elements. Make sure you check the hybrid formulation box for both quad and triangular elements, because the mesh generator will probably use a combination of both. You will also need to mesh the rigid surface as well as the deformable solid.
- Use the default options for the job submission

When you have managed to get your simulation to run (watch an animation of the contours of Mises stress, to see what is happening), plot a graph showing the variation of the vertical reaction force acting on the rigid surface with time. Work out how to change (i) the font size for the axis titles and labels; (ii) the background color of the window so the graph is legible. In addition, choose appropriate dimensionless measures of force and time for the plot and modify the data to plot the dimensionless force and time (to do this you have to (i) Create an X-Y data set using Tools>XY Data>Create and select the History output; then modify the data using Tools>XY Data>Operate on XY data.

Also, calculate the total impulse exerted on the sphere. Hence, calculate a value for the restitution coefficient of the impact (using rigid body collision formulas).

As a solution to this homework, hand in your answers to 1.1-1.4, your plot of dimensionless force-v-time; and numbers for the impulse and restitution coefficient.

As further exploration, try: (i) running a simulation with a stiffer sphere; and (ii) running a simulation with a softer sphere (reduce the shear modulus by a factor of 10 – you can try lower values but at some point the simulation will fail). You may need to try different element options to get soft spheres to run. Also for the soft sphere try running with a standard reduced integration element (uncheck the hybrid formulation box) and see what happens.

Optional: More advanced ABAQUS users could try writing a python script to automatically run a series of computations with varying shear modulus, and hence plot a dimensionless graph of the contact time as a function of shear modulus (or equivalently impact velocity).