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Finite Element Specialists and Engineering Consultants

Rigid Body Motion Test

The rigid body motion test of a finite element model is a useful one that can highlight a number of modelling issues including poorly posed constraint equations. When an unsupported model is given a rigid body motion there should of course be no stress generated and if there is then this indicates a potential problem with the model that needs further investigation.

A good example of a case where a rigid body motion produces stress would be a model in which non-coincident nodes are coupled. An example of a planar frame constructed of six beams is shown in figure 1. The free ends of the two diagonal beams are coupled together in the two translations as shown.

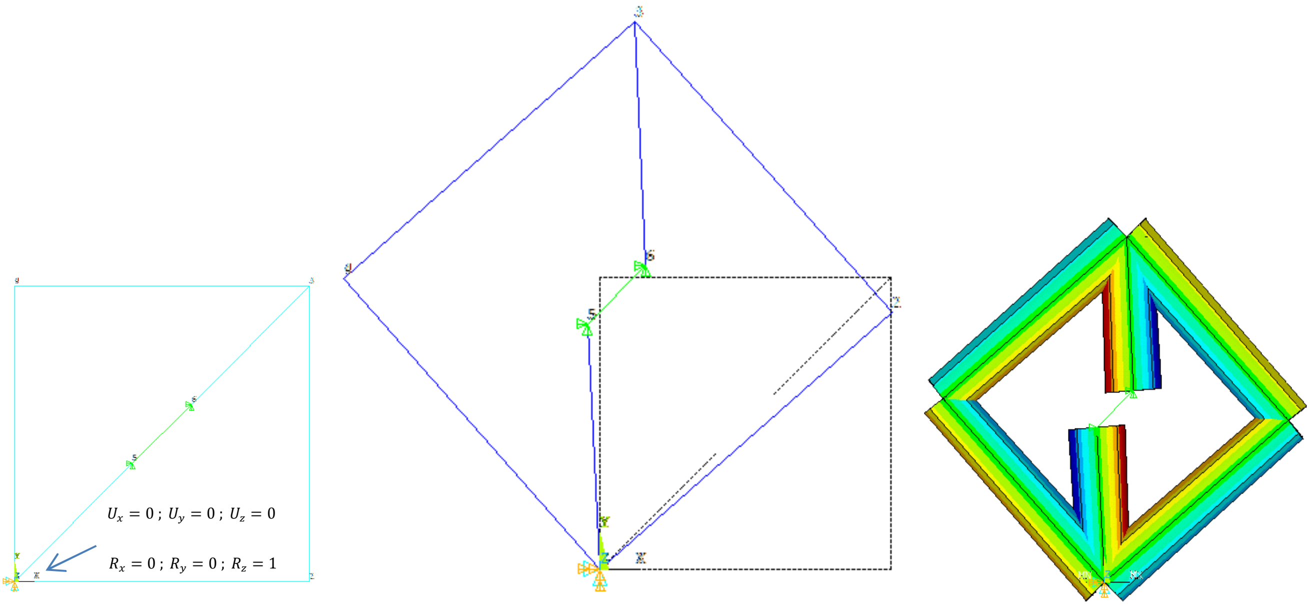


Figure 1: Rigid Body Rotation leading to a Stressed Structure

The node at the origin is given prescribed displacements in the six directions as indicated in the figure so that the structure undergoes a unit (radian) rotation in the plane about the origin. The displaced shape is shown in the second image and because of the small displacement assumption used in a linear-elastic finite element analysis the distance between the coupled node has changed thus setting up a force between the coupled nodes as can be seen by the contour plot of axial stress in the third image. The force generating these stresses is induced by a moment M_z reaction at the node where the displacements were prescribed.

During a recent project the author discovered significant stresses being induced in a model when applying the rigid body check but could find no obvious problems with the way in which the model had been set up. Further exploration showed that for one particular member in the model the analyst had used a very high value of elastic modulus, something of the order of a million times that for the rest of the model. This had been done to simulate a near rigid part of the model and when the elastic modulus was reduced to that of the rest of the model the stresses induced by the rigid body motion essentially disappeared.

The author's initial thoughts were that this was an example of numerical ill-conditioning in that widely varying stiffnesses in a model can lead to ill-conditioning of the structural stiffness matrix. However, further exploration showed that this was not the case since if the entire model was given the artificially high elastic modulus then significant stresses were again developed during a rigid body motion. The following graph was plotted for a single unit square shell element model (SHELL281) with 0.1m thickness. The peak von Mises stress was recorded as the elastic modulus was increased from 1 to 1e40 in steps of 1000 and has been plotted in figure 2.

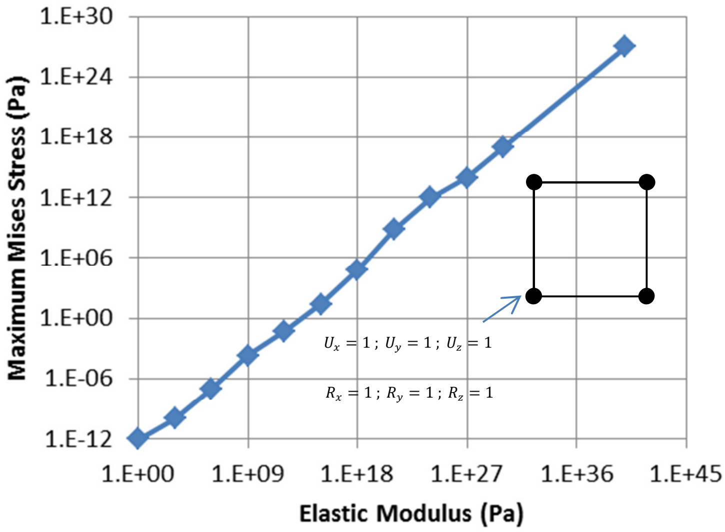
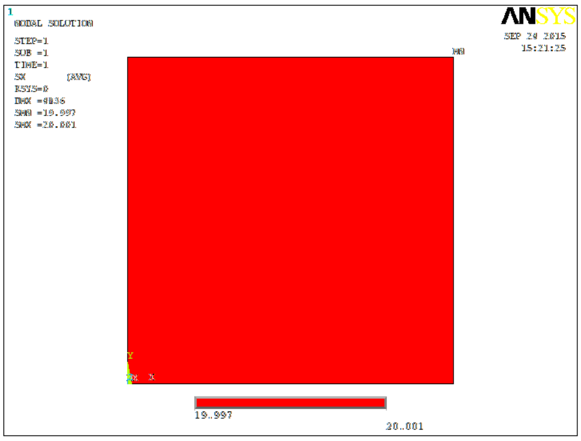
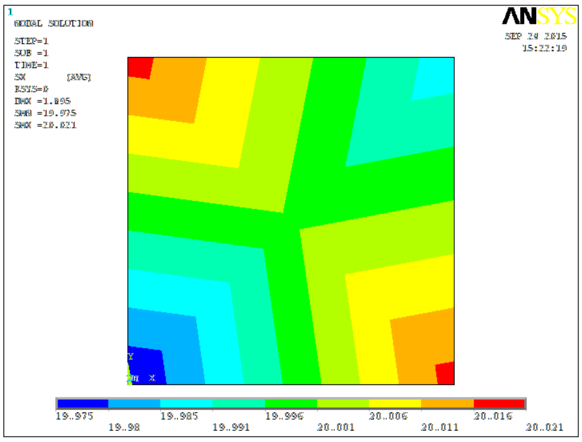


Figure 2: Stress as a Function of Elastic Modulus due to a Rigid Body Motion in ANSYS

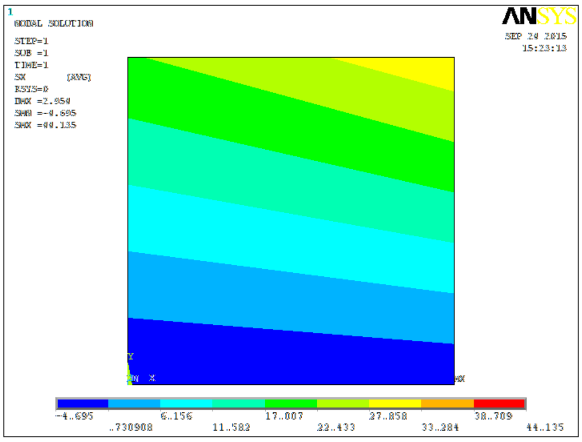
This anomaly appears to be peculiar to ANSYS as the same test run in ABAQUS leads to zero stress which is independent of the elastic modulus. Another problem has been run in which the plate is loaded in its plane to simulate a constant stress in the X direction. The mid-side node of the bottom free edge is then given the unit rotation. The stress, which should be 2Pa for the applied loading and geometry, can be seen to very soon be influenced by the magnitude of the elastic modulus as shown in figure 3.



(a) 1GPa



(b) 1TPa



(c) 1PPa

Figure 3: Stress for a Constant Stress Problem with a Unit Rigid Body Motion