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subject: Hex Element Aspect Ratio and Formulation

Overview

When modeling thin structures, some analysts use shell elements. Others choose hex elements. Both element types have their advantages and disadvantages. This memo describes a weakness of using hex elements to model bending. Specifically, the accuracy degrades as the element aspect ratio increases. This study illustrates this effect for the mean quadrature and the selective deviatoric formulations. For the test case considered, the selective deviatoric formulation produces larger errors.

Finite Element Models

Figures 1 and 2 show hex element meshes with aspect ratios of 1 and 3, respectively. All the hex meshes have 5 elements through the thickness and width as well as 50 elements along the length. The simply supported beam under consideration is 20 inches long and 2 inches wide. (The meshes are 10 inches long and 1 inch wide since symmetry planes are used in the X and Z directions.) The beam thickness is varied from 1.0 to 0.05 inches to create elements with various aspect ratios. A uniform pressure load is applied along the entire top surface of the beam. This study only considers meshes with orthogonal elements. The mean quadrature simulations use the default hourglass properties. The selective deviatoric simulations consider deviatoric parameters of 0.5 and 1. Default strain formulations were used. The elastic modulus is 28×10^6 psi. The Poisson's ratio is 0.27.

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Analyses

The pressure loads were ramped and then held constant to produce small deformations and elastic material responses. Although explicit analyses were used for this study, damping was added to produce quasistatic results. Figure 3 shows the bending (longitudinal) stresses for one of the simulations. Figures 4 and 5 show the normalized bending stresses and displacements for different element formulations and aspect ratios. MQ indicates mean quadrature simulations. SD and DP denote selective deviatoric and deviatoric parameter, respectively. The stresses come from a single element with the maximum stress. The displacements are an average of the midspan nodes.

The maximum theoretical bending stress (3000 psi for all cases) is obtained from a strength of materials calculation at the midspan outer fiber. The expected midspan displacement varies from roughly 9 to 180 mils. The hex meshes don't have an integration point at the midspan outer fiber, so the maximum simulation stress is always less than the theoretical value. This underprediction is much larger when the element aspect ratio is high.

The predicted displacement is close to the expected value when the element aspect ratio is low. Figure 5 shows how the error increases as the aspect ratio increases. The mean quadrature simulation with an aspect ratio of 20 underpredicts the displacement and the stress by roughly a factor of 3. The errors are greater for the selective deviatoric simulations, especially with a deviatoric parameter of 1, which is currently the recommended value. As shown in Figure 6, the hourglass energy increases significantly as the aspect ratio increases for the mean quadrature simulations. (The reported hourglass energy is zero for the selective deviatoric simulations,)

It should be noted that bending problems like this example can be solved more efficiently with shell elements. Corresponding simulations using 10 shell elements (compared to 1250 hex elements) were also performed. The predicted displacements and stresses obtained with shell elements were within 1% of the strength of materials calculations for all cases.

Summary

Most analysts are aware that shell elements can produce poor results for thick structures. However, they may not fully appreciate that hex elements can produce poor results for thin structures. This limitation is especially true when bending is modeled using hex elements with an aspect ratio much greater than 1. An informal survey of analysts indicates that this is a fairly common practice.

The Sierra/SM Users Guide mentions potential problems related to shell element thickness. In addition, a warning is issued in the log files for models that contain shell elements with a thickness to element length ratio of one or more. However, the Users Guide does not discuss hex elements with high aspect ratios and no warnings are currently issued in the log files for models that contain them. The acceptable aspect ratio for hex elements is problem dependent. Nonetheless, some guidance seems warranted – especially when using the selective deviatoric formulation with a deviatoric parameter of 1.

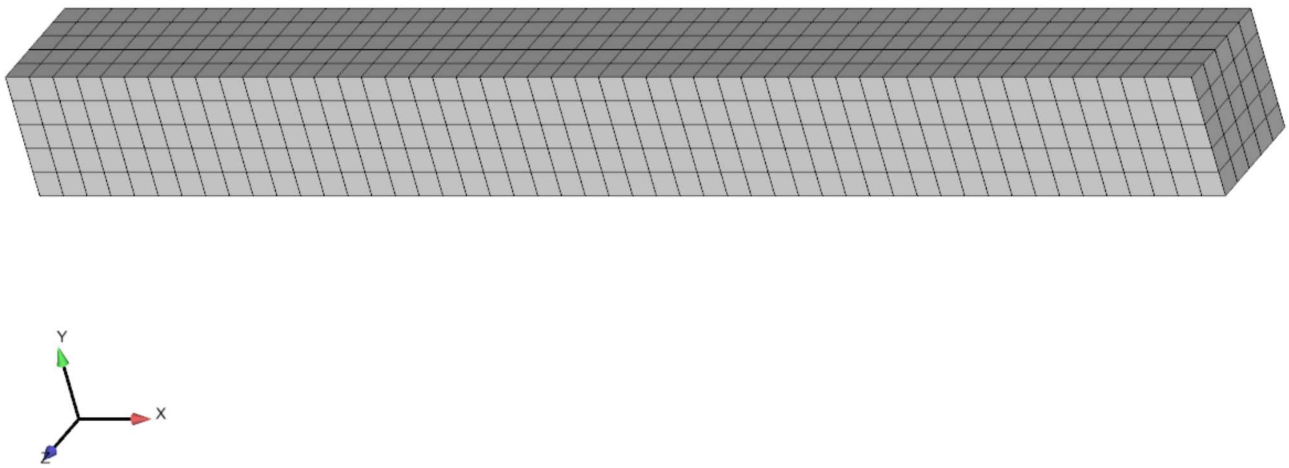

Figure 1. Finite Element Model (hex elements with an aspect ratio of 1)

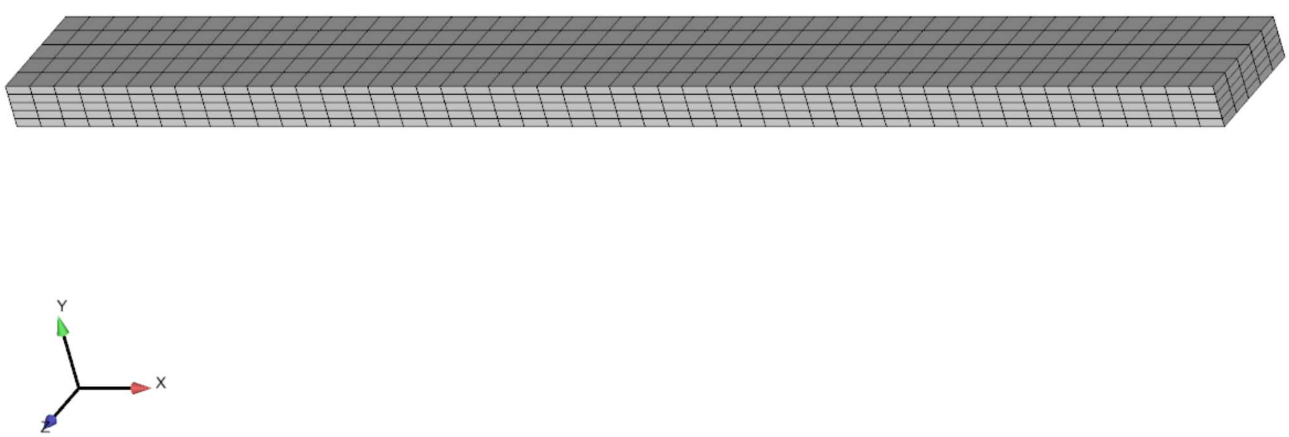

Figure 2. Finite Element Model (hex elements with an aspect ratio of 3)

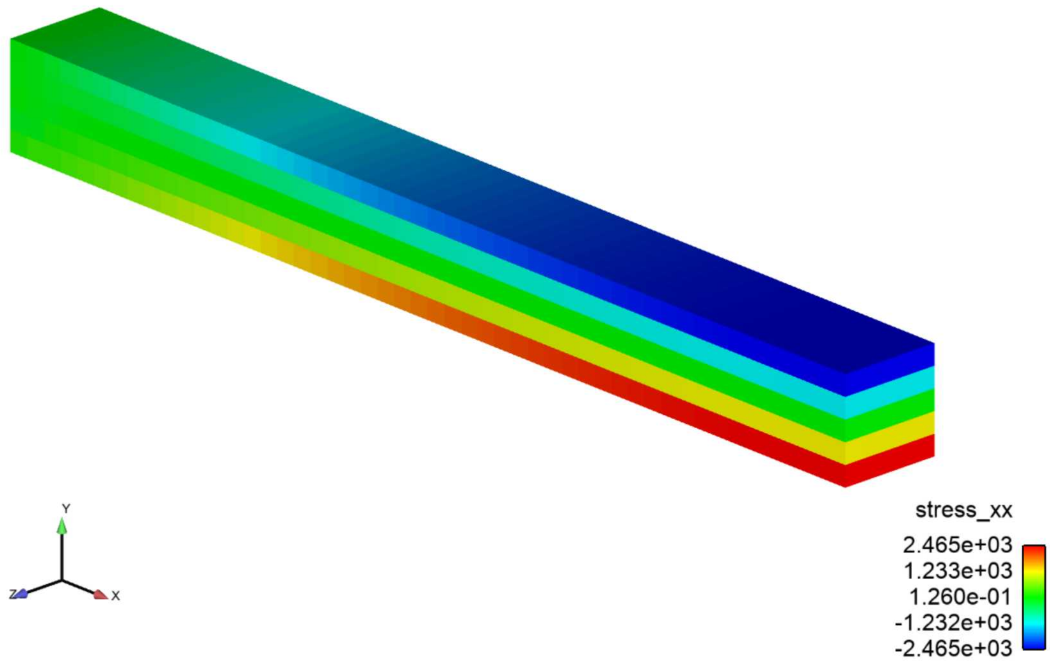

Figure 3. Bending Stress (mean quadrature elements with an aspect ratio of 1)

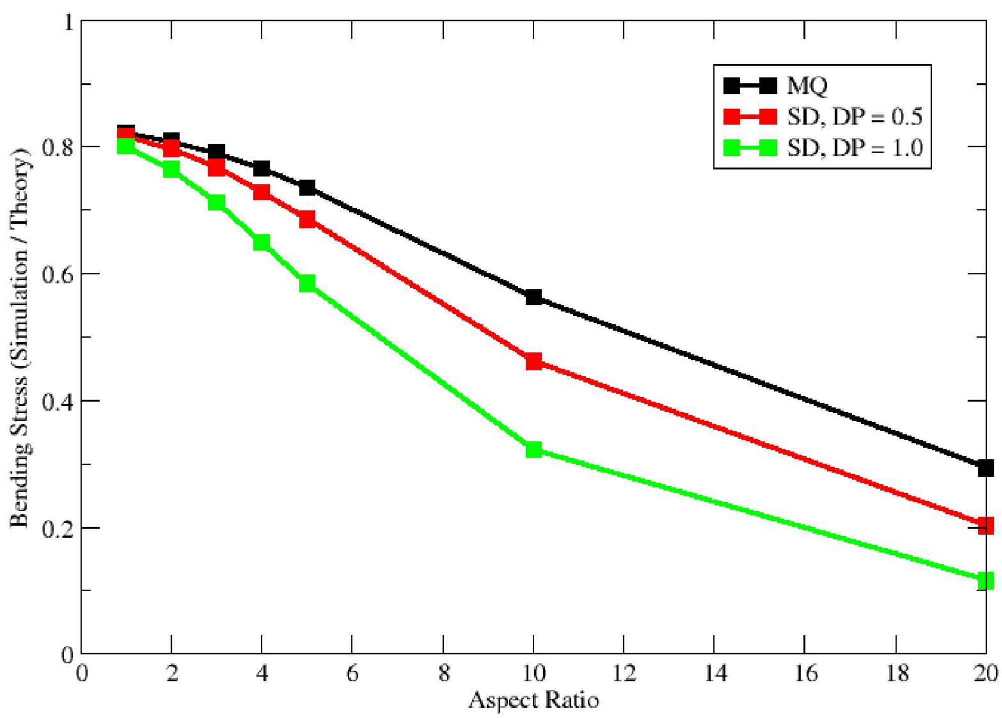

Figure 4. Normalized Bending Stress

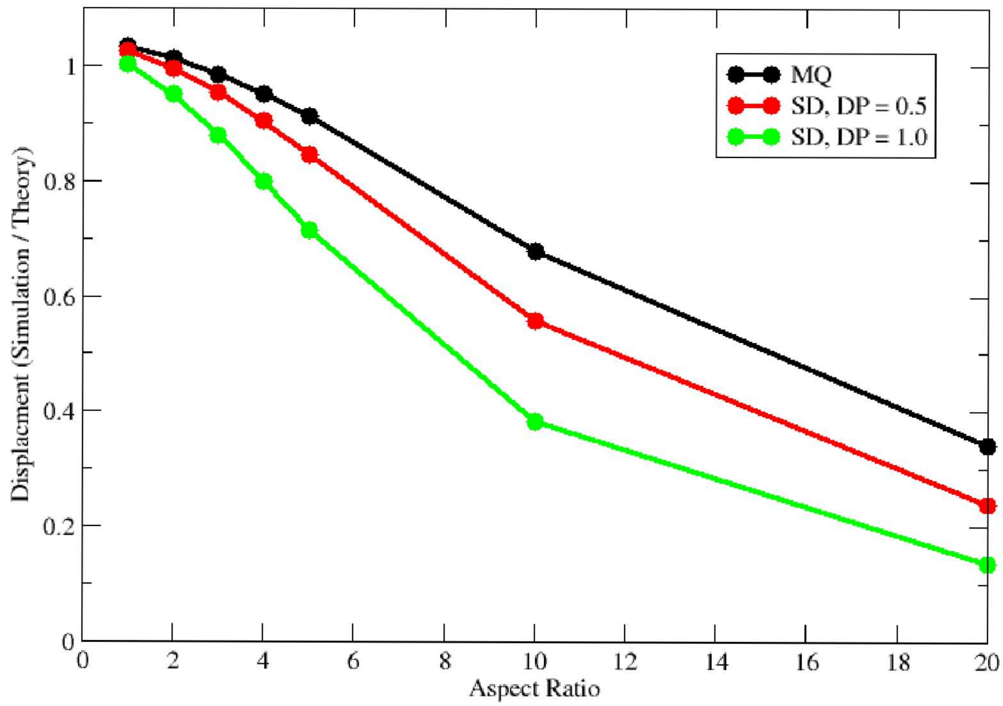

Figure 5. Normalized Displacement

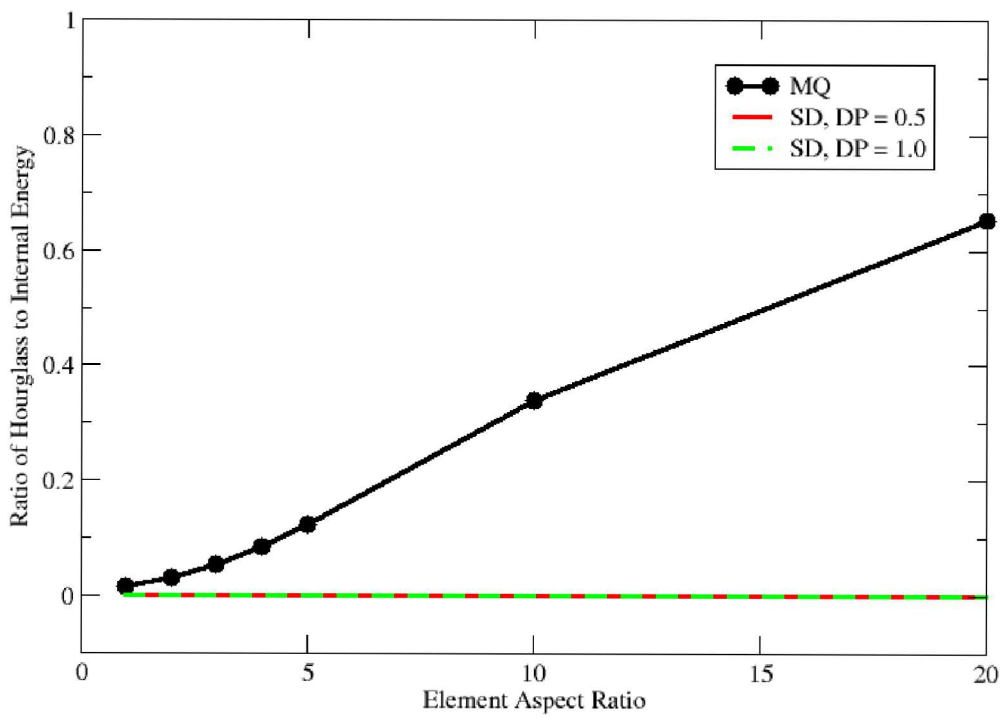

Figure 6. Ratio of Hourglass Energy to Internal Energy