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FINITE ELEMENT METHOD MESH STUDY FOR EFFICIENT MODELING OF PIEZOELECTRIC MATERIAL

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14. ABSTRACT

The purpose of this study is to evaluate modeling of piezoceramic materials with maximum efficiency; that is high fidelity with shortest computer run time. To do this, the modeler varied the number of element layers and element types in each part to find the most efficient combination that would produce accurate bending in an activated piezoelectric material with less than 1% displacement error. A cantilever beam model, based on an example in the ABAQUS manual, was developed. The number of element layers varied from one to 10 per part. Low order, high order, and shell and brick elements with various hourglass controls were employed. Results show that the best combination of high accuracy and short run time was a model with a single layer of high order bricks for the piezoelectric layers and a single layer of low order bricks with enhanced hourglass control for the beam layer.

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INTRODUCTION

Piezoelectric materials such as piezoceramics are used widely in actuating devices, mainly due to ease of control of the piezoelectric through potential changes. These materials can provide simple, robust and light weight actuating mechanisms for a wide range of applications. They are particularly useful for canard actuation mechanisms, because they can improve reliability and decrease complexity of the canard actuating assembly (CAS) inside the projectile. For this application, the material exhibits a dimensional change or strains under an applied electric field. Alternatively, a piezoelectric material can also provide an electrical response to a mechanical stress (ref. 1).

Finite element analyses [FEA (ref. 2)] of piezoelectric materials can be employed to predict the electromechanical coupling response of these materials under varying conditions. In an effort to model these devices in an efficient manner, comprehension of the impact of element type and number of element layers on computer run time is necessary to optimize the parameters for high fidelity and small error. This is crucial for modeling these materials for highly dynamic events such as gun launch and projectile flight.

MODEL DESCRIPTION

A beam with piezoelectric materials bonded on both sides (fig.1) was modeled in ABAQUS/Standard, version 6.11. The model originated from the example problem "Transient Dynamic Non-linear Response of a Piezoelectric Transducer" in chapter 7.1.2 of the ABAQUS Example problems manual. The piezoelectric material employed in the example is the piezoceramic PZT-5H. The material is modeled using the elastic, dielectric, and piezoelectric material models, which are outlined in the example problems manual. The elastic model employed uses engineering constants to model the anisotropic behavior of the material. Dielectric describes the electrical permittivity of the material, which in ABAQUS can be isotropic, orthotropic, or anisotropic. For this model, orthotropic is employed. Piezoelectric defines the electromechanical coupling coefficients for the piezoceramic using stress or strain coefficients that cause electrical displacement in the 1, 2, and 3 directions (ref. 3). For this analysis, strain coefficients were used. Dielectric and Piezoelectric can be defined in the material editor in the material property module under Other → Electrical.

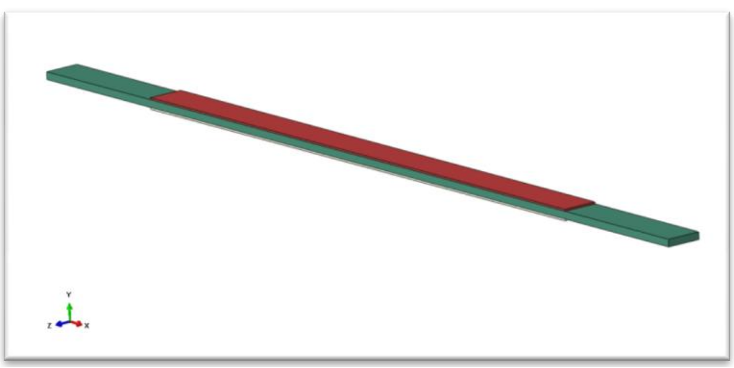

Figure 1
Model of optimize run time with high fidelity

The cantilever beam is modeled as linear elastic. The material properties are also outlined in the example problem in the ABAQUS Example Problems Manual. For piezoelectric materials, ABAQUS requires the use of piezoelectric elements that have electric potential and displacement degrees of freedom (ref. 3). For this analysis, solid continuum piezoelectric elements were employed. The beam is modeled using a combination of high and low order brick elements with varying numbers of elements through the layers.

The boundary conditions are shown in figure 2. The displacement was measured at the points shown. A tie constraint was used to model the bond between the piezoceramics and the beam. Figure 3 displays the loads applied; a voltage potential was applied across the thickness of the piezoelectric material to drive the displacement of the beam. The voltage on the side of the piezoceramic at the interface between the beam and the piezoceramic was 0V, while the voltage on the opposite/top side was set to 100V. The total potential gradient was 100V.

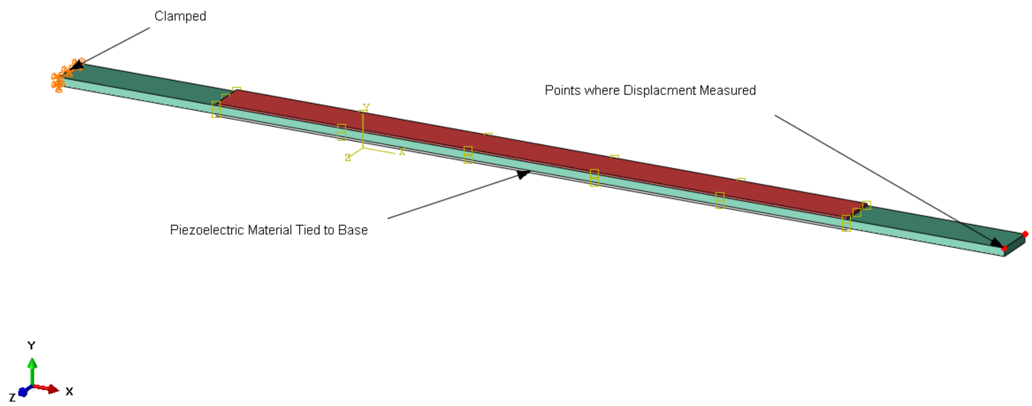

Figure 2
Boundary conditions

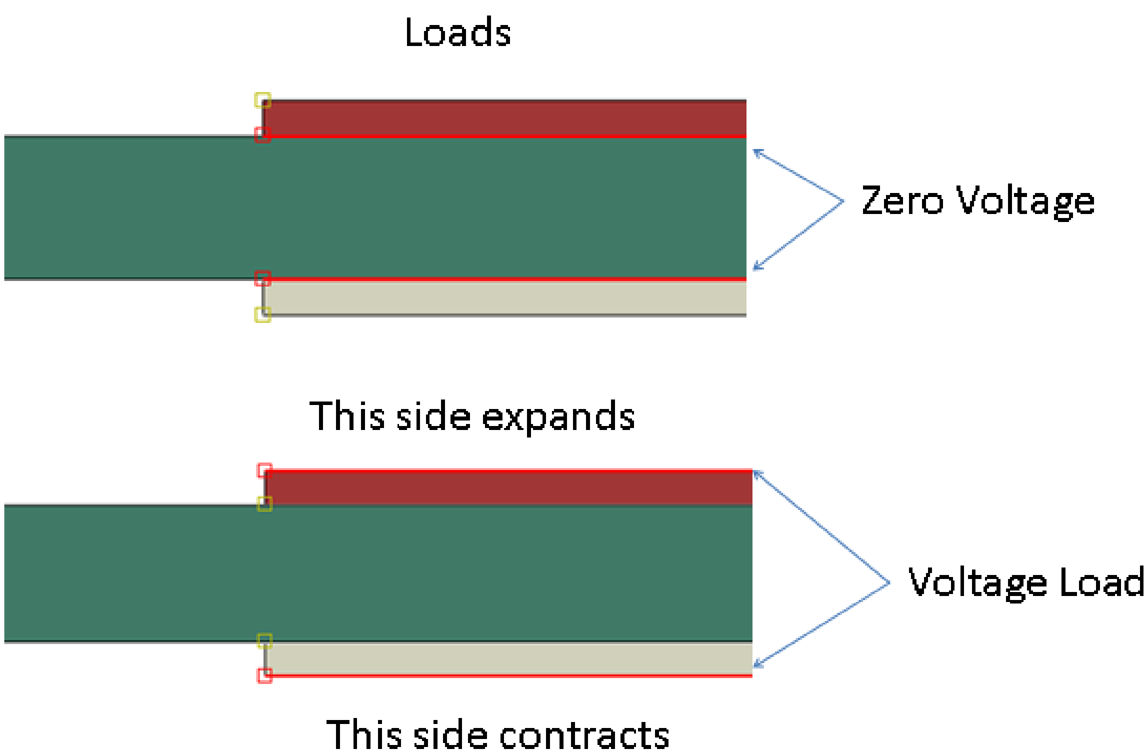

Figure 3
Loading

RESULTS

Since the actual bending value is not known, a mesh convergence study was done. For this, the beam was modeled using one to 10 layers of C3D8R elements in each part and the displacement was measured at the points shown in figure 2. Figure 4 displays the displacement of the beam once the voltage gradient is applied. Figure 5 displays the results of the mesh convergence study. The percent error is relative to the 10 layer model (10 elements through the thickness of each part). All future results were compared to the 10 layer model.

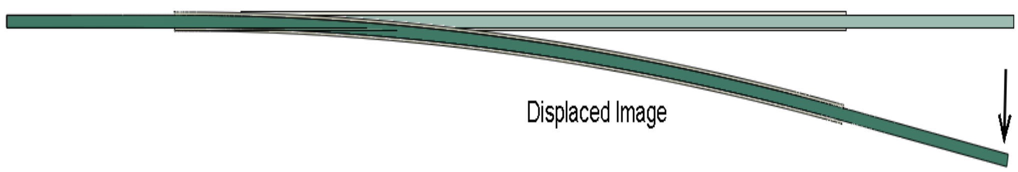

Figure 4
Beam displacement after voltage applied

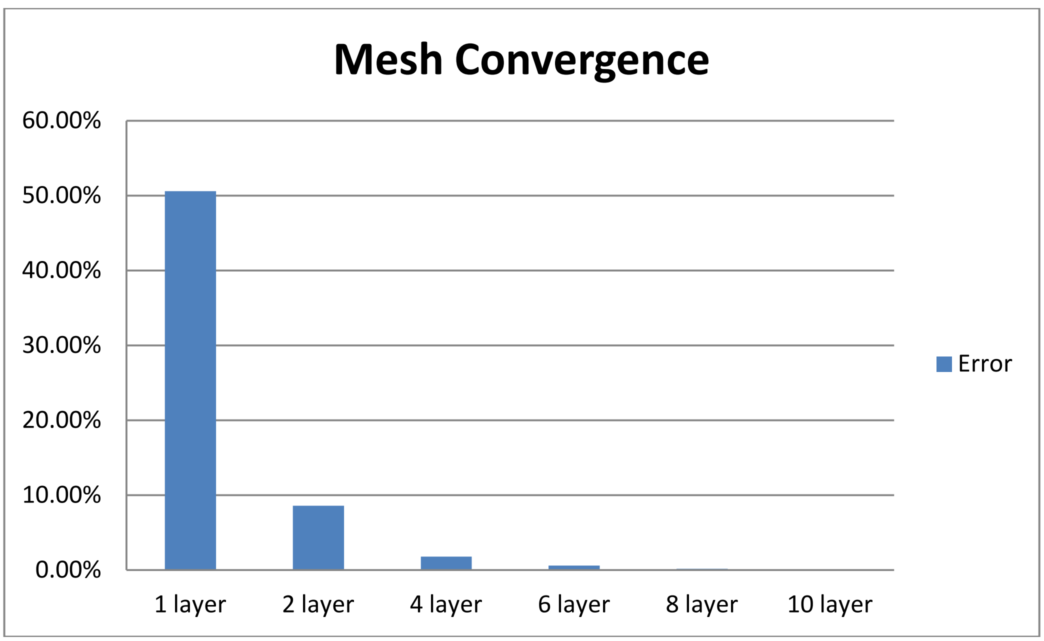

Figure 5
% Error versus number of element layers in each part

Results of the Mesh Refinement and Element Type Study are displayed in table 1.

Table 1
Mesh refinement and element type study results

Base (layer no., element type, hourglass control) Piezo (layer no., element type, hourglass control)	Displacement (mm)	Run time (s)	% error
1, C3D8R, default 1, C3D8E, default	8.28699	367	50.6
2, C3D8R, default 2, C3D8E, default	5.97927	722	8.6
4, C3D8R, default 4, C3D8E, default	5.67927	2,457	1.8
6, C3D8R, default 6, C3D8E, default	5.53749	6,758	0.6
8, C3D8R, default 8, C3D8E, default	5.51482	11,625	0.19
10, C3D8R, default 10, C3D8E, default	5.50434	18,979	0.0
6, C3D8R, default 1, C3D8E, default	5.72338	946	4.0
6, C3D8R, default 1, C3D20RE, default	5.53814	2,807	0.39
1, C3D20R, default 1, C3D20RE, default	5.49629	5,516	0.15
2, C3D20R, default 2, C3D20RE, default	5.49712	15,821	0.13
4, C3D20R, default 4, C3D20RE, default	5.49626	63,757	0.15
1, C3D8I, default 1, C3D20RE, default	5.49344	1,193	0.20
1, SC8R,enhanced 1, C3D20RE, default	5.47774	2,491	0.48
1,C3D8R, enhanced 1, C3D20RE, default	5.49397	1,098	0.19
2,C3D8R, enhanced 1, C3D20RE, default	5.4944	1,421	0.18
4,C3D8R, enhanced 1, C3D20RE, default	5.49429	2,207	0.18
1,C3D8R, enhanced 1, C3D8E, default	5.677	332	3.1

All the models with less than 1% error are shown in figure 6. Though all of these models have errors less than 1%, the run time varies from about 1,000 to 63,000 sec. From this group, the top five models with high accuracy and short run times are shown in figure 7. Table 2 is the key describing the points in figure 7.

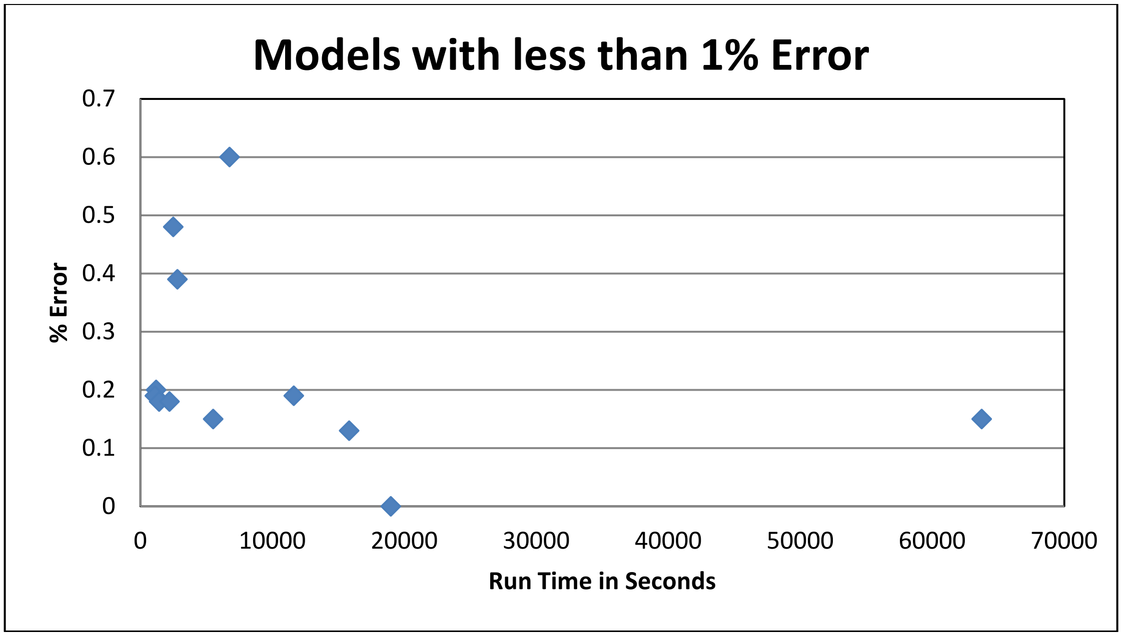

Figure 6
Models with less than 1% error

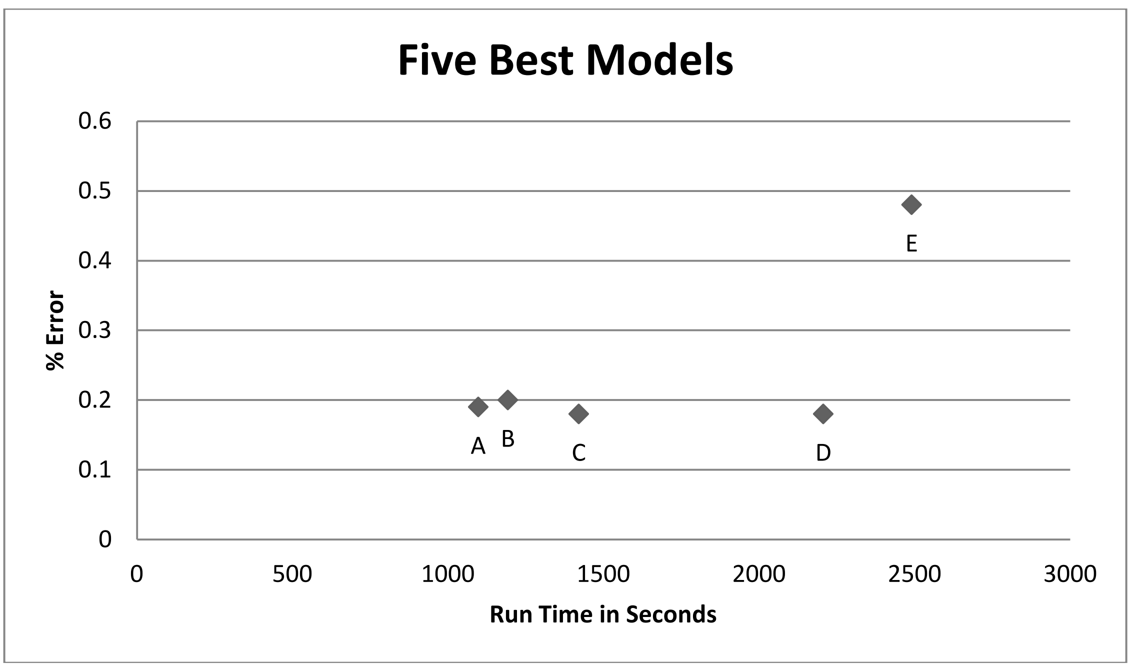

Figure 7
Five Best models

Table 2
Top five plot key

	Base layer	Piezo Layer
	No. layers, Element, Hourglass	No. layers, Element, Hourglass
A	1, C3D8R, Enhanced	1, C3D20RE, default
B	1, C3D8I, Default	1, C3D20RE, default
C	2, C3D8R, Enhanced	1, C3D20RE, default
D	4, C3D8R, Enhanced	1, C3D20RE, default
E	1, SC8R, Enhanced	1, C3D20RE, default

CONCLUSIONS

The combination of single layer of high order bricks for the piezoelectric material and a single layer of low order bricks with enhanced hourglass control for the beam material was the most efficient combination. This combination was accurate to 0.19% and ran 17 times faster than the 10 layer model. If other element types are required for the beam material, changing the beam material element type to incompatible mode brick gave accuracy to 0.2% and was 16 times faster. If continuum shells are used for the beam material the accuracy drops to 0.48% though the run time was still 7.5 times faster than the 10 layer model. This gives the choice of using varying element types for the beam material and still getting less than 1% error. It was observed that it was most efficient to keep the piezoelectric material as one layer of high order elements.

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3. ABAQUS Analysis Users Manual, Version. 6.11.

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