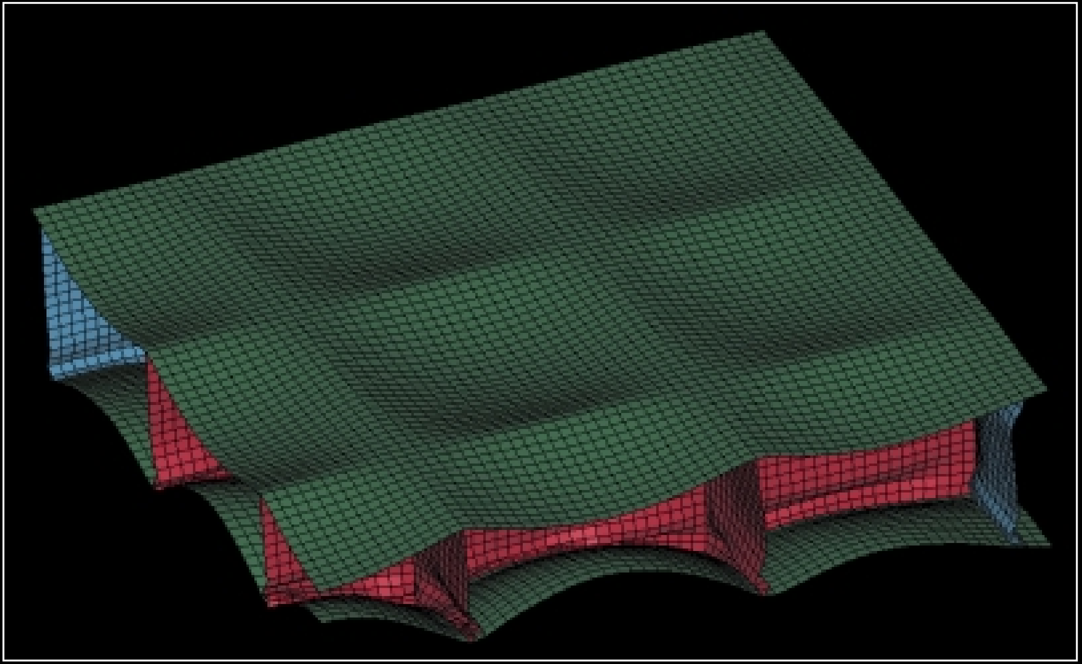
Study of Energy Absorbing Honeycomb Structure



By

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Class Project

MEG795 Energy Methods II

Objective

- To verify if honeycomb sandwich structure absorbs an energy from the blast load by plastic deformation

Introduction

- Honeycomb sandwich structure are increasingly employed when efficiency with high ratio of strength to weight is necessary.
- Honeycomb sandwich structure consisted of thin two face-plates separated by a core material.
- Hexagonal shape is the most popular among others; however, only square shape is studied for simplification of analysis.
- Units: grams, cm, microseconds, Mega-bars

Introduction (cont'd)

- ARL investigated the geometry effect and energy-absorbing materials by applying blast load to the various geometries and materials of pendulum structure at a given standoff position.

- Flat shape of aluminum foam material transferred more energy to the structure.

- Honeycomb sandwich structure is modeled to verify this result computationally. ConWep air blast function is used.

Design Constraints

- Area Density: $20\text{-lb/ft}^2 = 9.765\text{-g/cm}^2$
- Area of Plate: $2.25\text{-ft}^2 = 2090.32\text{-cm}^2$
- Standoff Distance: 0.8575-ft = 26.134-cm
- Mass of C-4 charge: 1.0-lb = 453.59-g

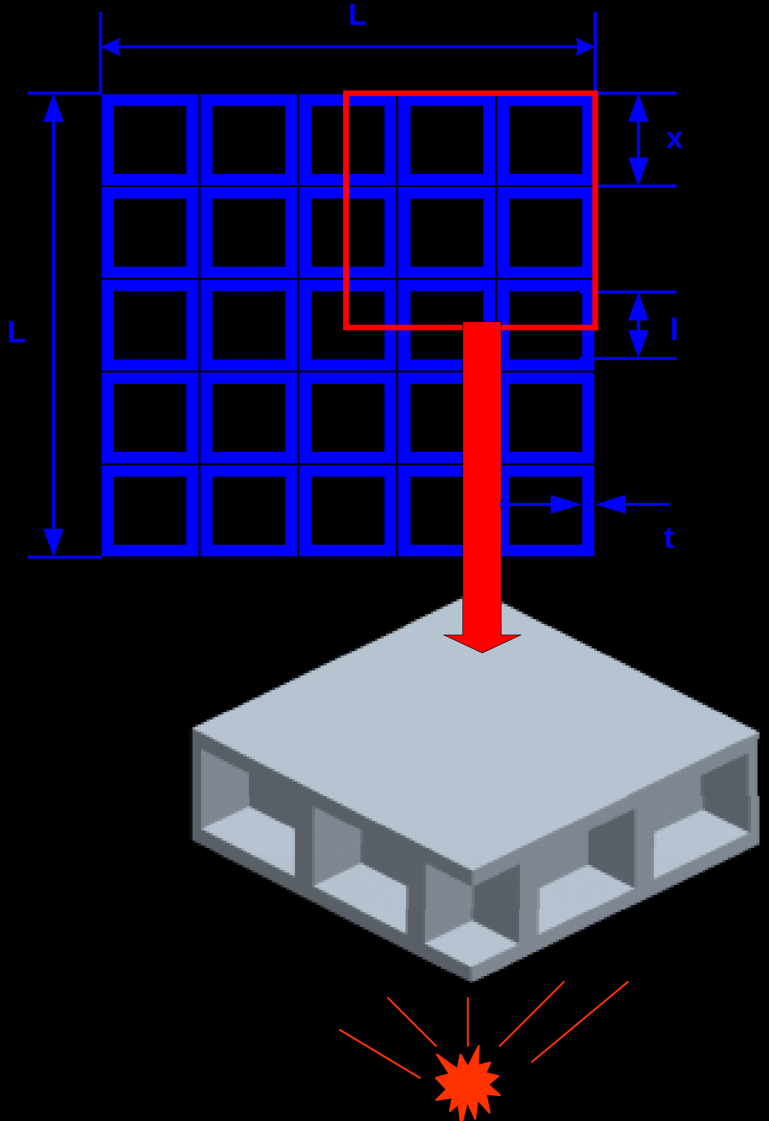
Material Property

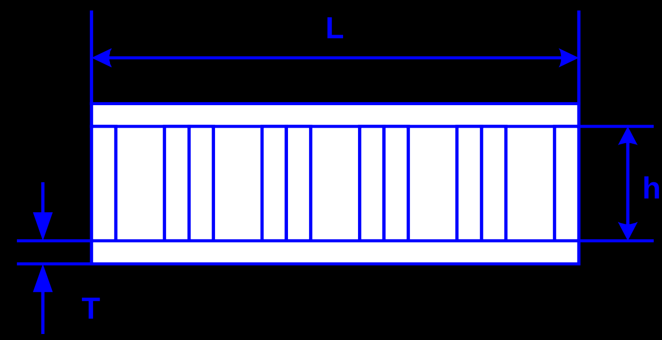
Material: Aluminum 5456-H116

- Density: 2.63-g/cm^3
- Elastic Modulus: 0.72-g/µsec cm
- Yield Strength: 0.0023-g/µsec cm
- Poisson's Ratio: 0.33

```
$
*MAT_PLASTIC_KINEMATIC
$HMNAME MATS       1Aluminum-5456
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$      MID        RO         E        PR      SIGY      ETAN      BETA
         1      2.63      0.72      0.33    0.0023
$      SRC       SRP        FS        VP
```

Parameters of Structure





Parameters for Case I	*Full Model* (lbs, ft, s, psi)	*Quarter Model* (lbs, ft, s, psi)	*Quarter Model* (g, cm, μs, Mbar)
Area Density, $\frac{lb}{ft^2}, \frac{g}{cm^2}$	20.000	5.000	9.765
Material Density, $\frac{lb}{ft^3}, \frac{g}{cm^3}$	149.810	149.810	2.630
Area of Plate, ft^2, *cm2*	2.250	0.5625	522.580
Length of Plate, L, *ft, cm*	1.500	0.750	22.860
Length of Unit Cell, x, *ft, cm*	0.300	0.300	9.144
Length of Square, l, *ft, cm*	0.250	0.250	7.620
Scale Factor, λ	5.000	5.000	5.000

Vary thickness of Plate, T

Cases of Structure

- Total of four-cases were modeled varied by thicknesses of plate.

$$\rho_{Area} = \frac{\rho_{Mat}[(x^2 - l^2)(n\lambda T) + (2TL^2)]}{L^2}$$

where ρ_{Area} = area density $\left(\frac{lb}{ft^2}, \frac{g}{cm^2}\right)$

ρ_{Mat} = material density $\left(\frac{lb}{ft^3}, \frac{g}{cm^3}\right)$

L = length of plate (ft, cm)

x = length of unit cell (ft, cm)

l = length of square (ft, cm)

T = thickness of the plate (ft, cm)

$\lambda = h/T$, scale factor of height of core to the plate thickness

h = core height (ft, cm)

n = number of cells in honeycomb core

	Plate Thickness (cm)	Height of Core (cm)
Case 1: n = 25, λ = 5	1.1535	5.7673
Case 2: n = 100, λ = 5	1.1535	5.7673
Case 3: n = 25, λ = 10	0.8085	8.0850
Case 4: n = 100, λ = 10	0.8085	8.0850

*BLAST_LOAD Card

- Given mass of C-4: 1-lb ⟶ convert to equivalent TNT-mass = 517.9-g

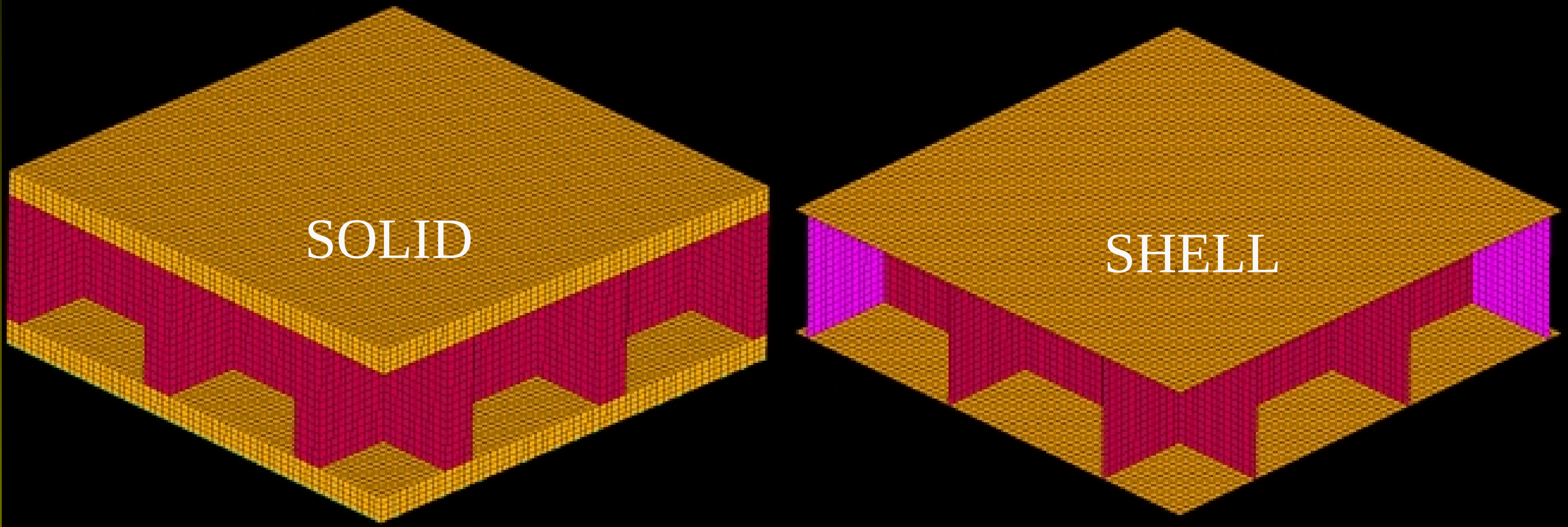
```
*LOAD_BLAST
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7
$      WGT       XBO       YBO       ZBO       TBO     IUNIT     ISURF
     517.9         0         0    -26.13         0         4         2
$      CFM       CFL       CFT       CFP

*LOAD_SEGMENT_SET
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7
$     SSID      LCID        SF        AT
       777        -2         1         0
$
*SET_SEGMENT
$HMNAME CSURFS       2Blast_surfac1
       777
      1710      1711      1704      1706
     .
     37199     37197     37192     37193
*SET_SHELL_LIST_GENERATE
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7
$      SID       DA1       DA2       DA3       DA4
       777
$    B1BEG     B1END     B2BEG     B2END
      7201     10800
```

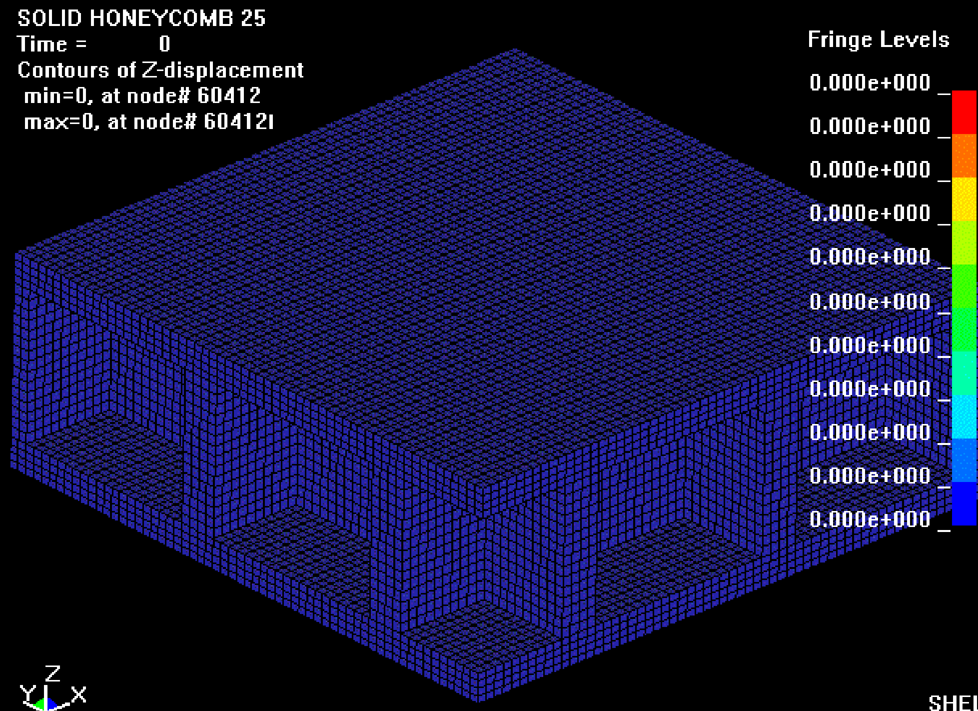
Boundary Conditions

Boundary Condition	Tx	Ty	Tz	Rx	Ry	Rz
x-z symmetry plane		√		√		√
y-z symmetry plane	√				√	√
z-direction	√	√		√	√	√

Case 1: 25-Cells at $\lambda = 5$



- Thickness of Core: 0.762-cm
- Thickness of Plate: 1.153-cm
- Height of Core: 5.767-cm
- No plastic deformation occurred


SOLID HONEYCOMB 25
Time = 0
Contours of Z-displacement
min=0, at node# 60412
max=0, at node# 60412
Fringe Levels
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
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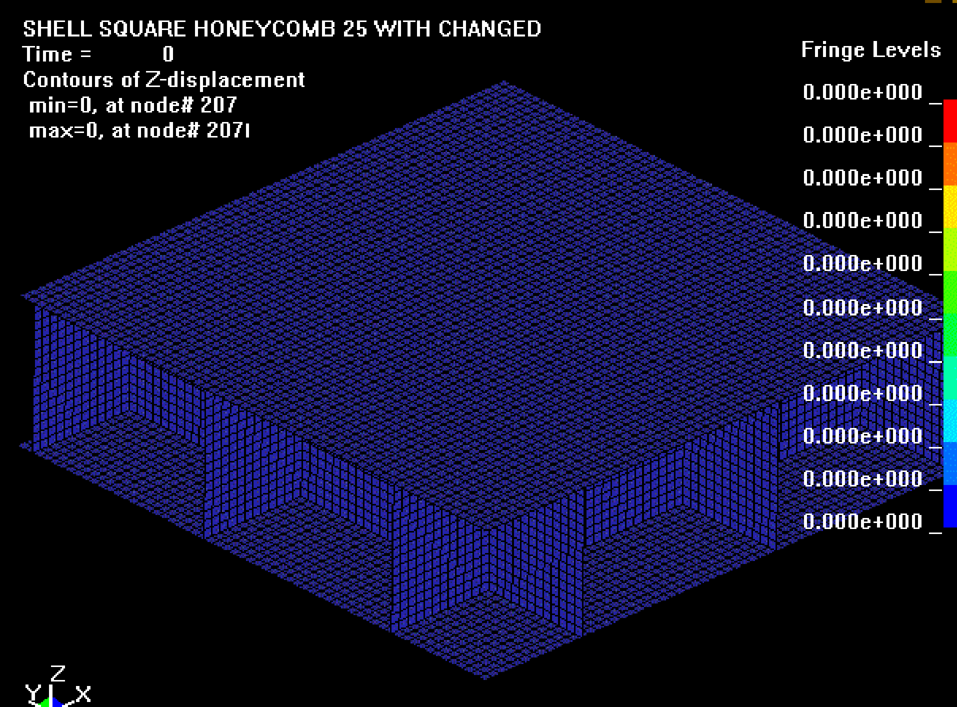
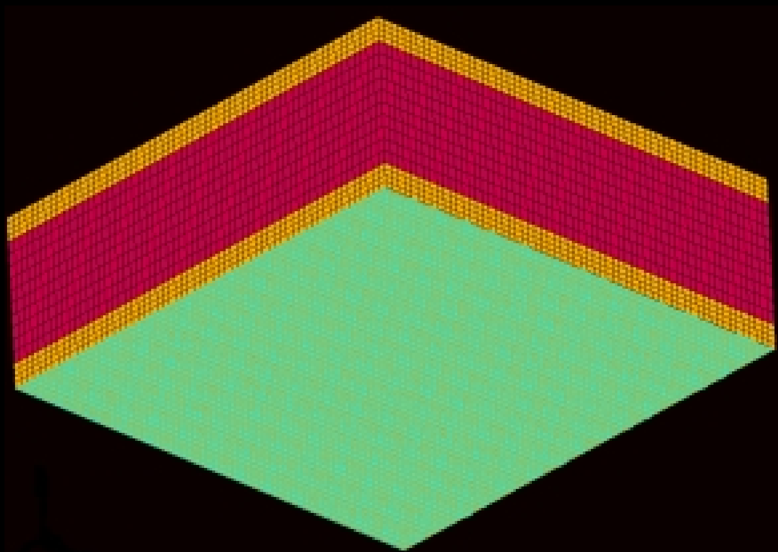
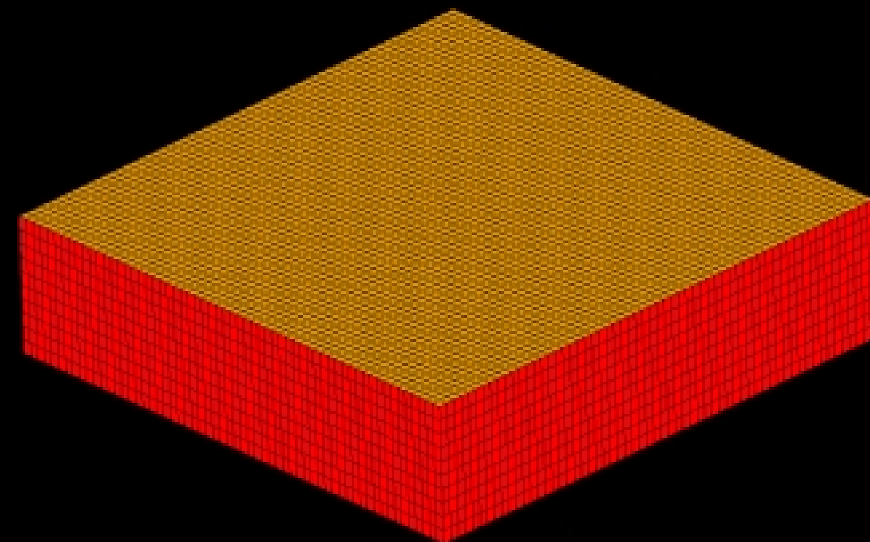
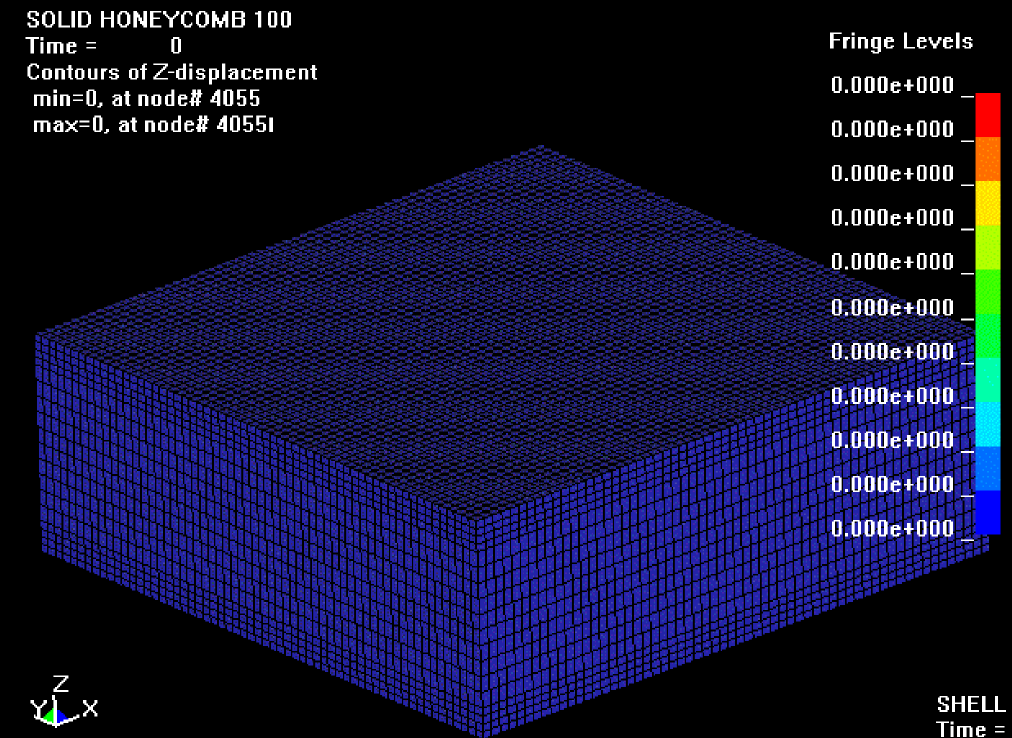
0.000e+000
Z
Y
X


SHELL SQUARE HONEYCOMB 25 WITH CHANGED
Time = 0
Contours of Z-displacement
min=0, at node# 207
max=0, at node# 207
Fringe Levels
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
Z
Y
X

Case 2: 100-Cells at $\lambda = 5$

- Thickness of Core: 0.381-cm
- Thickness of Plate: 1.153-cm
- Height of Core: 5.767-cm
- Unfortunately, no plastic deformation occurred in any of four cases


SOLID HONEYCOMB 100
Time = 0
Contours of Z-displacement
min=0, at node# 4055
max=0, at node# 4055
Fringe Levels
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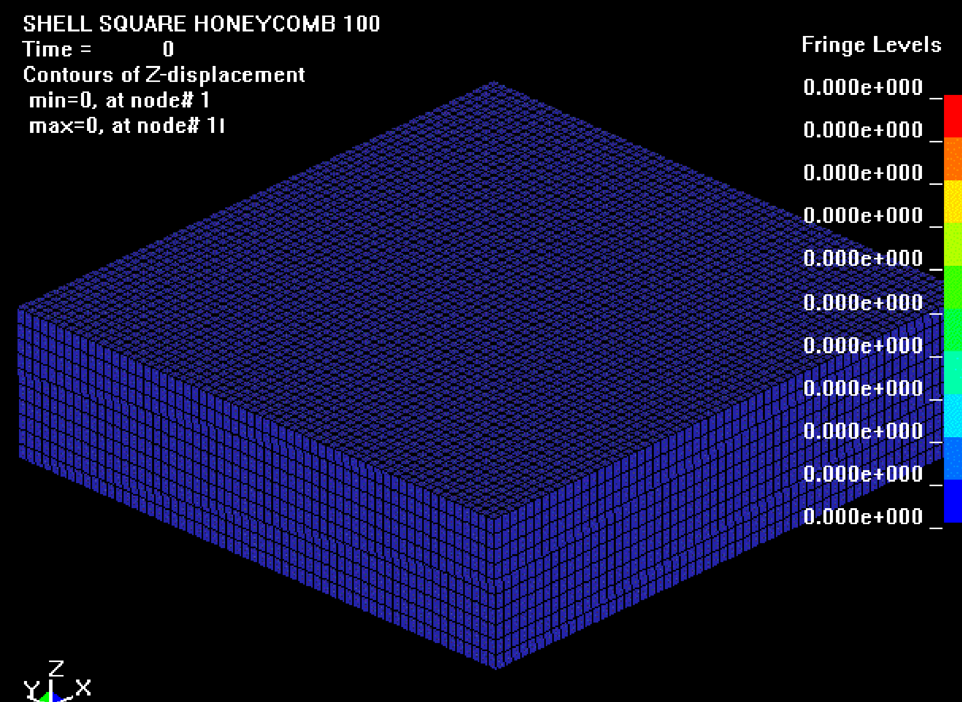
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
Z
Y
X


SHELL SQUARE HONEYCOMB 100
Time = 0
Contours of Z-displacement
min=0, at node# 1
max=0, at node# 1
Fringe Levels
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
0.000e+000
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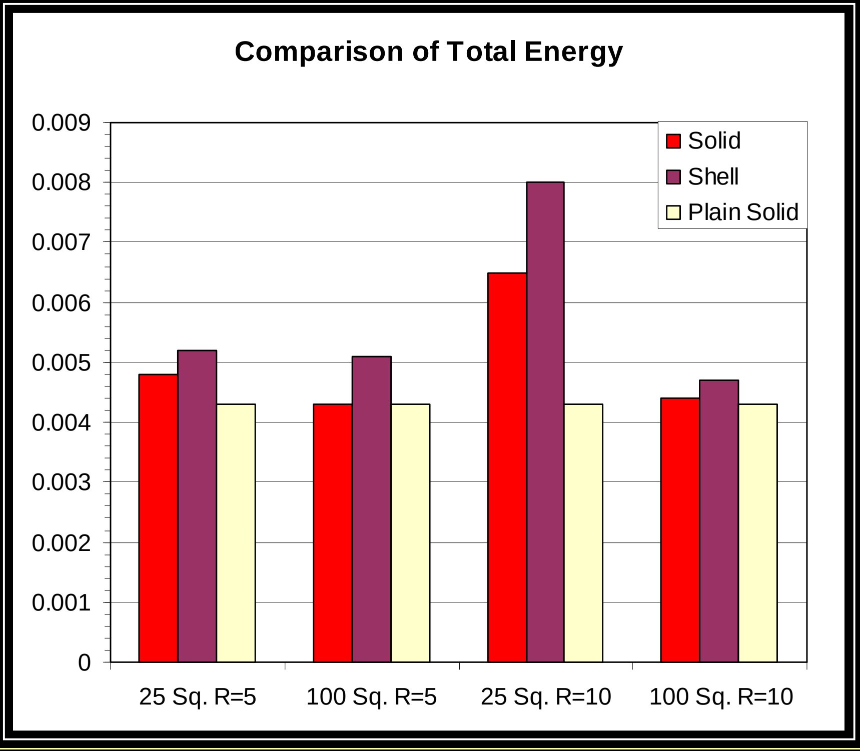
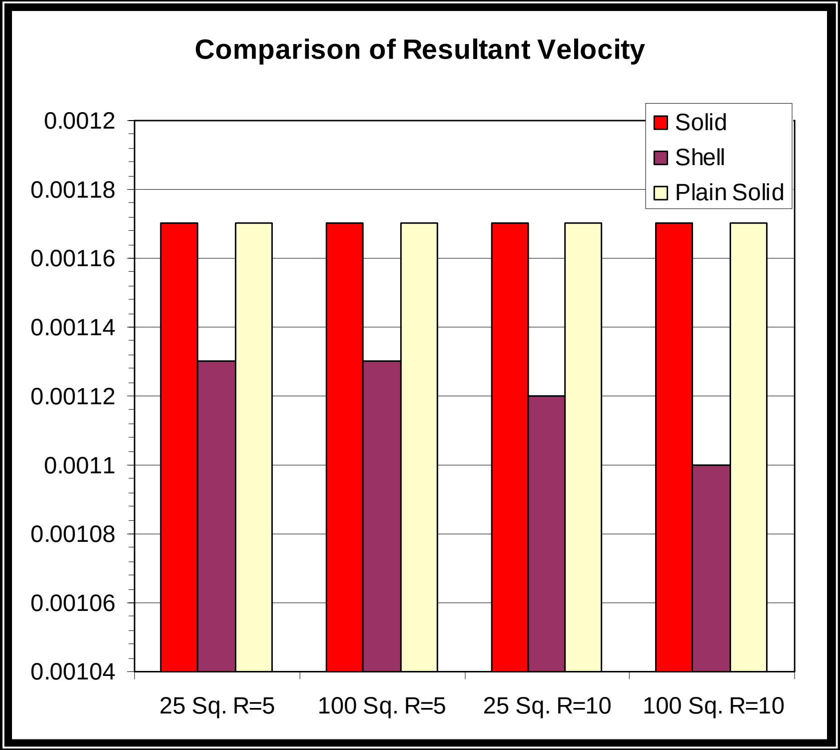
0.000e+000
0.000e+000
0.000e+000
Z
Y
X

Comparison of Total Energy



CASE	Solid vs. Shell Element
Honeycomb with 25-Square Holes, R=5	8.33 %
Honeycomb with 25-Square Holes, R=10	18.6 %
Honeycomb with 100-Square Holes, R=5	23.1 %
Honeycomb with 100-Square Holes, R=10	6.8 %
Plain Solid Plate (no honeycomb)	11.6 %

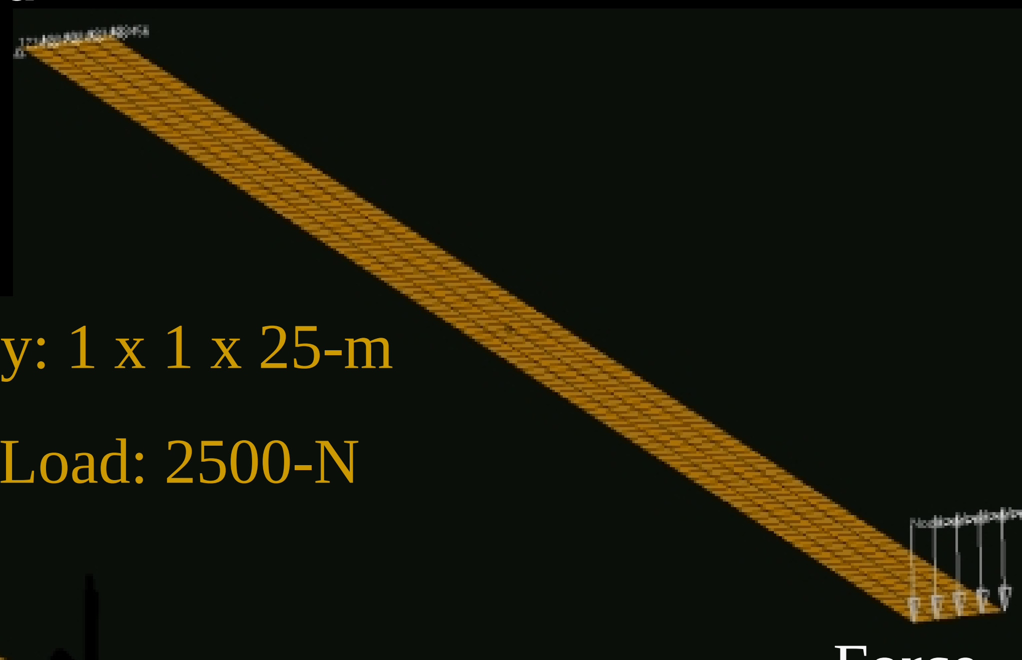
Comparison of Rigid Body Velocity



CASE	Solid vs. Shell Element
Honeycomb with 25-Square Holes, R=5	3.42 %
Honeycomb with 25-Square Holes, R=10	3.42%
Honeycomb with 100-Square Holes, R=5	4.27 %
Honeycomb with 100-Square Holes, R=10	5.98 %
Plain Solid Plate (no honeycomb)	5.12 %

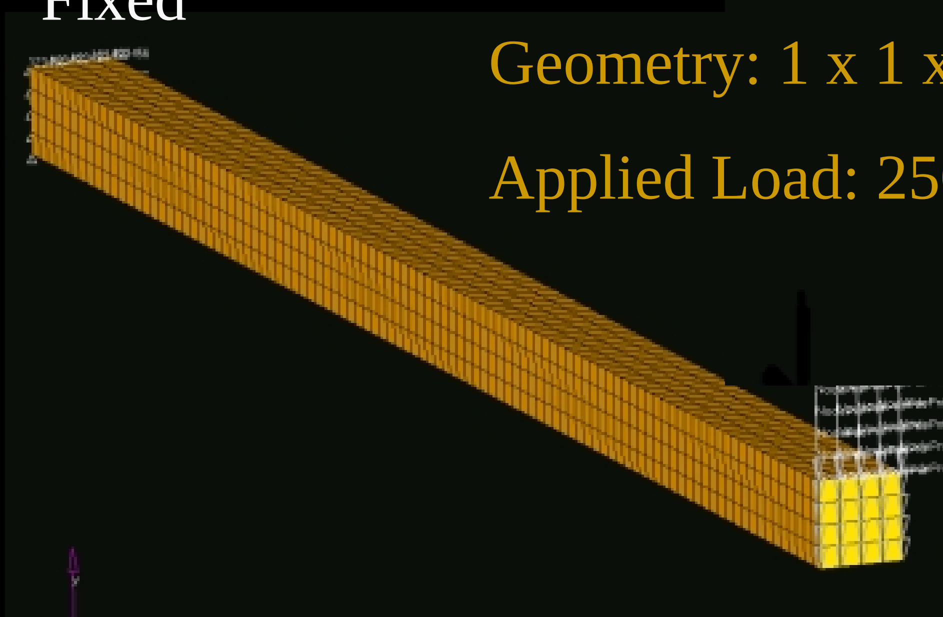
Comparison of Simple Cantilever Beam

Fixed



Force

Fixed



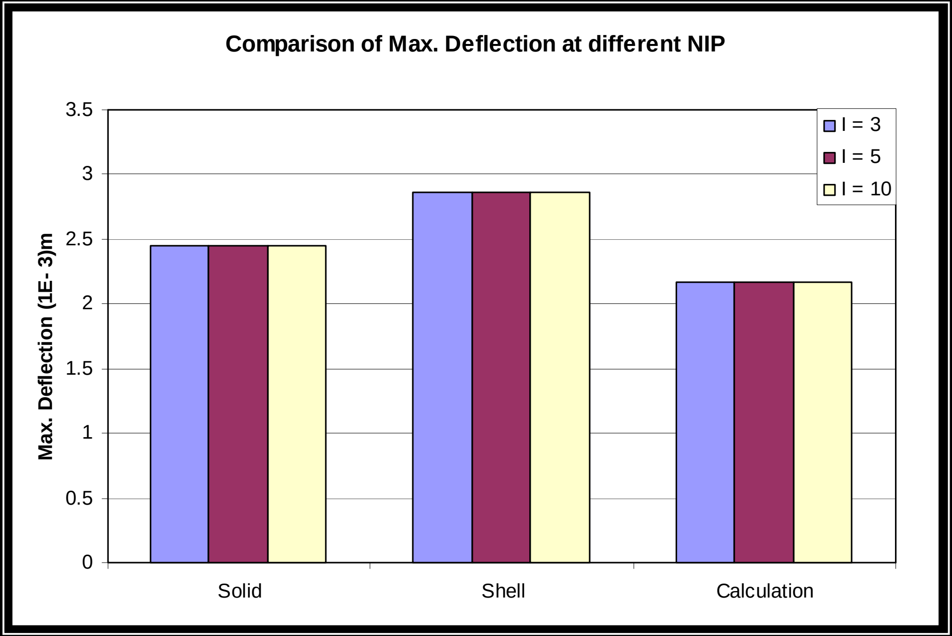
Force

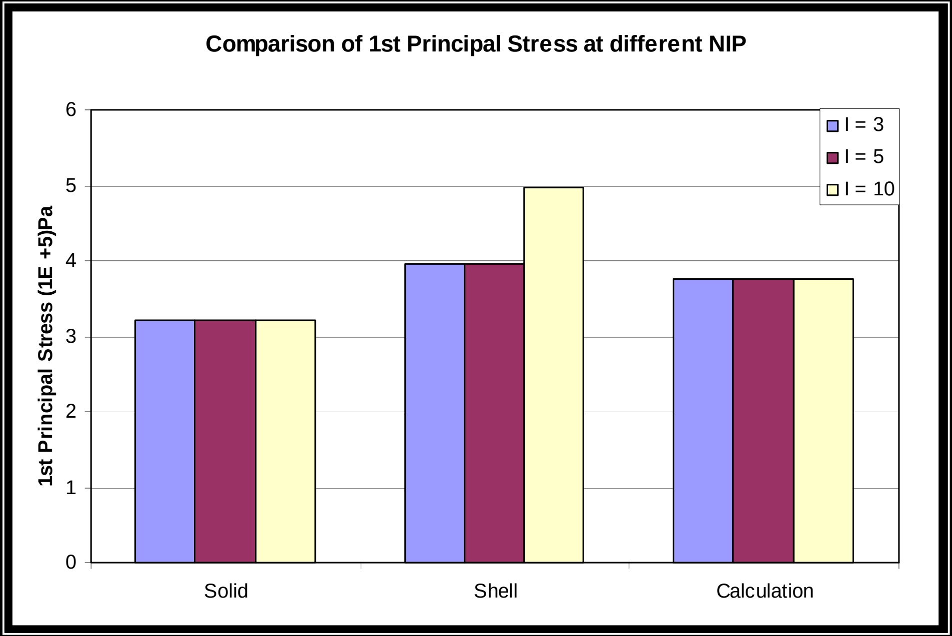
Geometry: 1 x 1 x 25-m

Applied Load: 2500-N

Beam Result

- Run a shell model with three different NIP (3,5,10).
- Max. deflections at different NIP were same for shell model.
- Shell models deflected 23% more than solid models.
- Shell models have higher 1st principal stress 33%



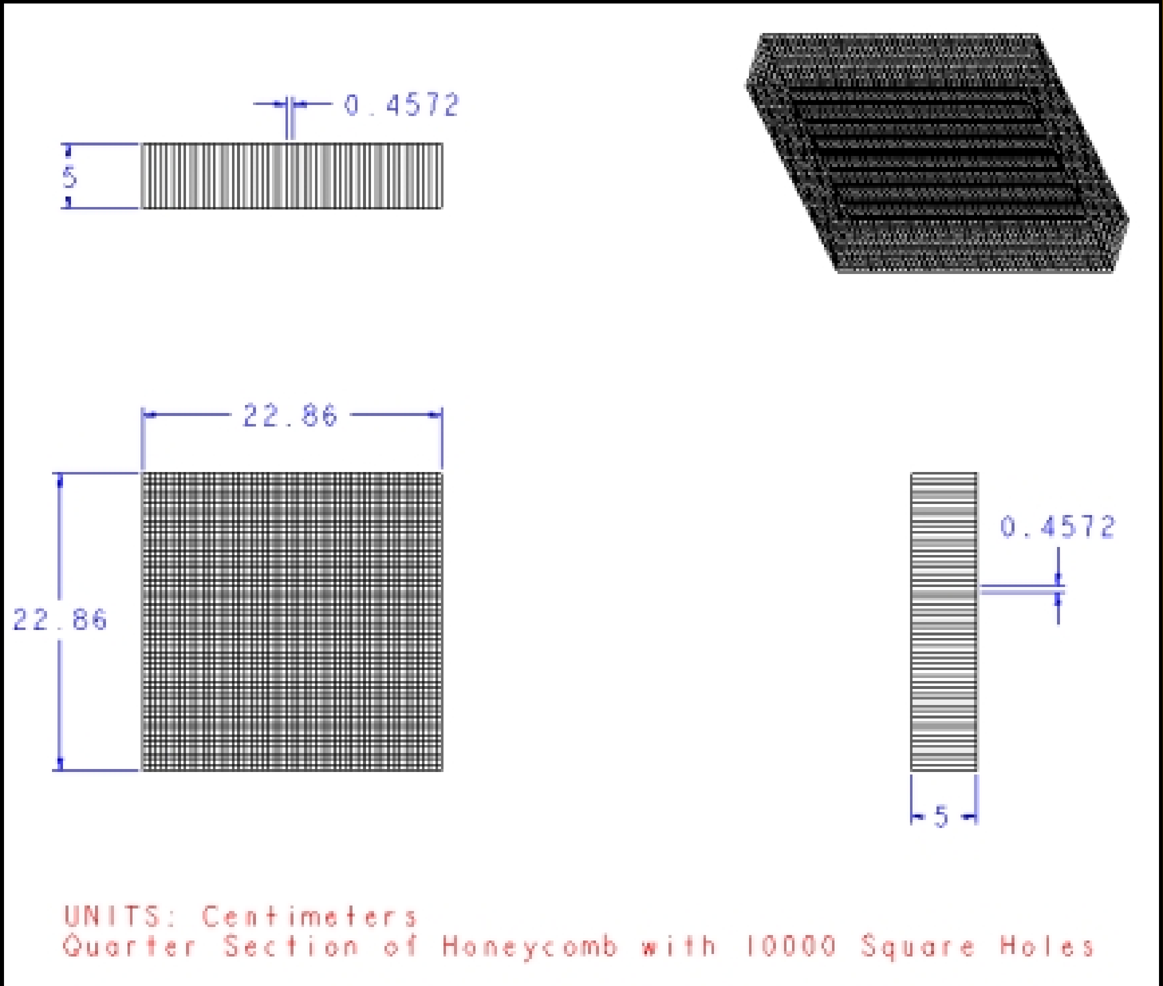


Results of Honeycomb and Beam Cases

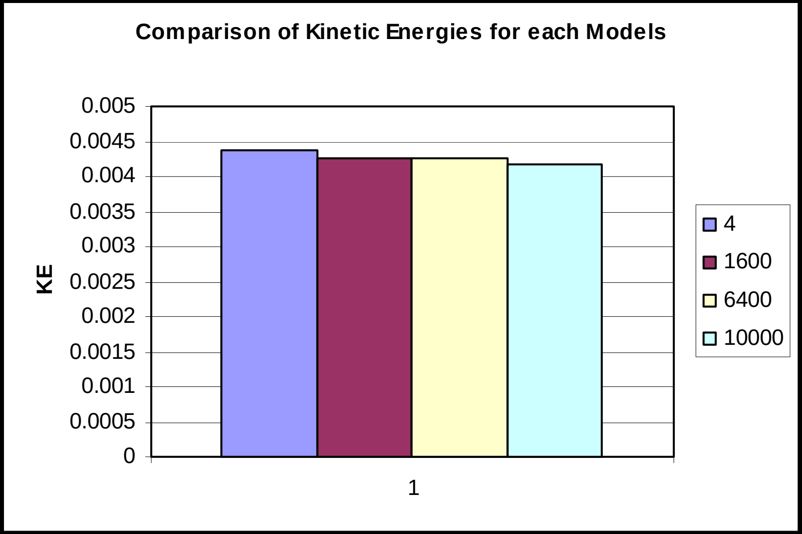
- No plastic or buckling deformation occurred on honeycomb models that the velocities for Solid-Honeycomb and Plain-Solid were same. Velocities for Shell-Honeycomb and plain-solid models have small difference of 3 to 6%.
- Shell models have higher total energies and it deflects more than solid models that the shell models appears to be less stiff than solid, based on the results of honeycomb and beam cases.

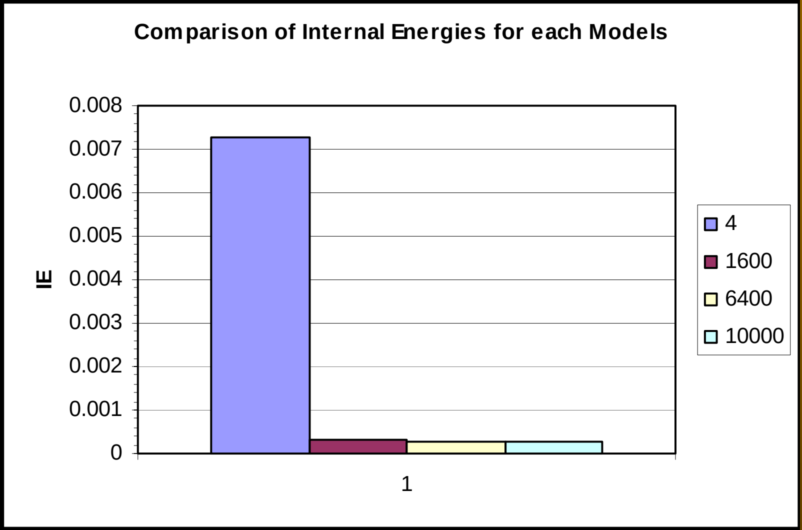
Varying Number of Cell Case (Part 2)

- To see the trend of energy absorption by varying # of cells.
- Number of cells created for 4, 1600, 6400, and 10000.
- Mass and Plate-thickness was fixed and plain plate was created according to the mass and results were compared.

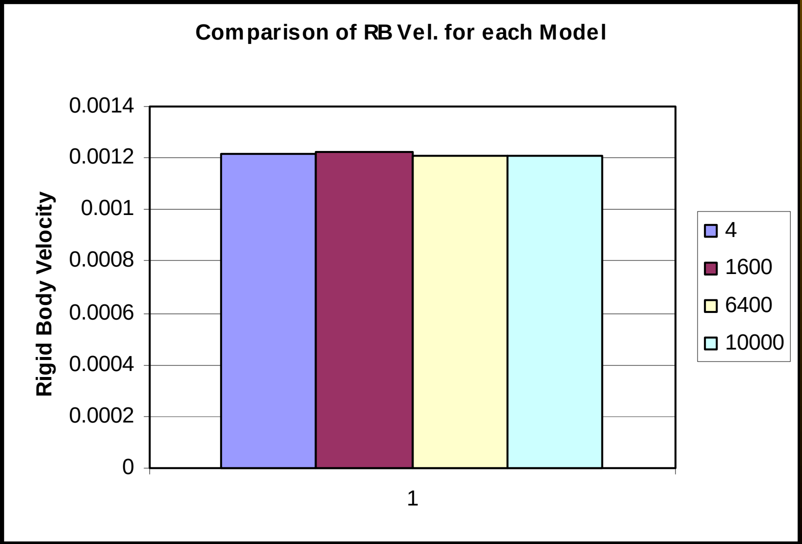


Results of Varying Number of Cell Case





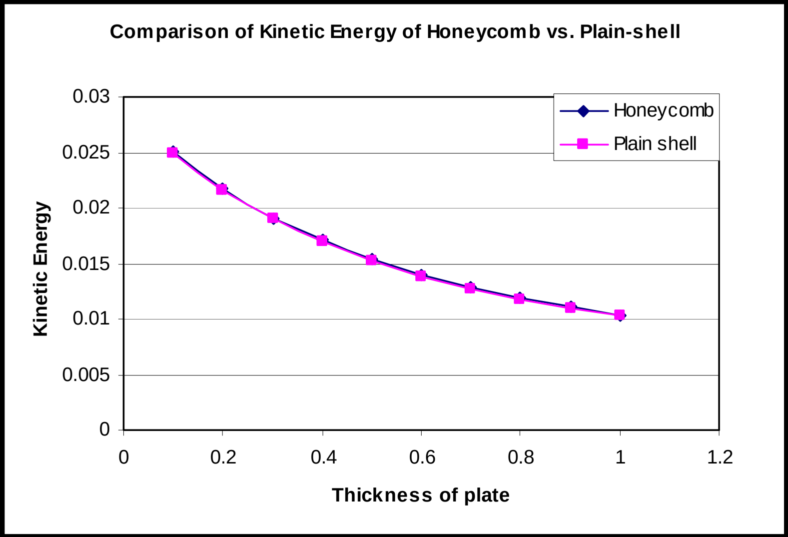
- ➢Kinetic energy came out to be consistent for all four models.
- ➢Model of 4-cells' Internal energy should not be so high since no plastic deformation in any of four models have occurred.
- ➢Rigid Body Velocity are consistent for all models, that indicates varying # of cells are independent of energy absorption. But, more study is necessary to make conclusion.

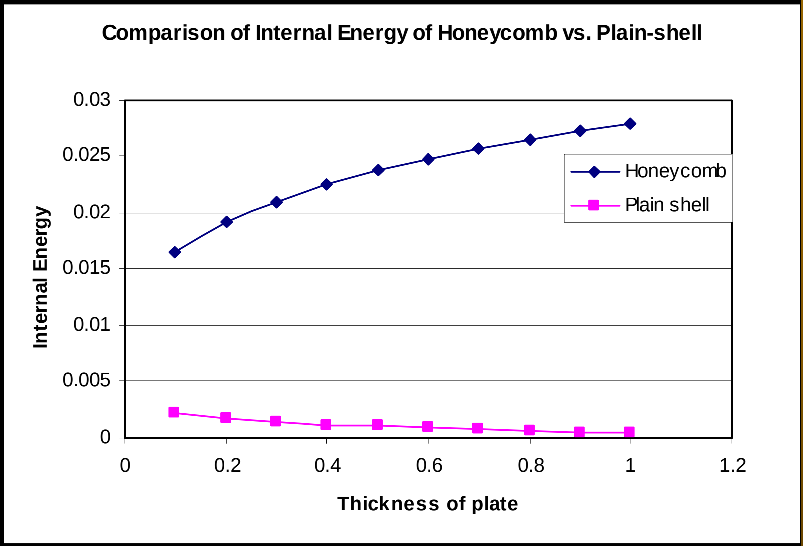


Varying Plate Thickness Case (Part 2)

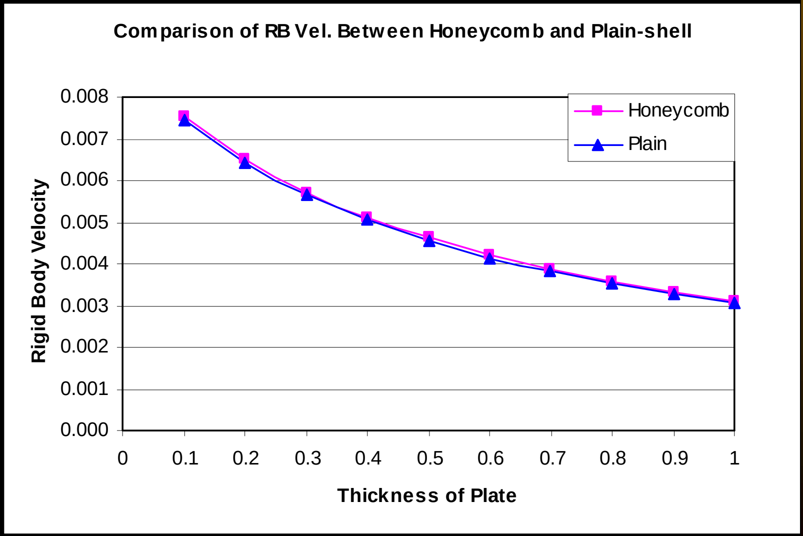
- 25-Square shell model was used in this case and the thickness of plate was varied from the .k file.
- All the variables were fixed except the plate thickness. There were top and bottom plates and one of them was fixed and only one plate was varied with thickness.
- 01_005_02_03 corresponds to the thicknesses of inner-core_outer-core_top-plate(or back plate)_bottom_plate(front plate), respectively.

Results of Varying Plate Thickness Case

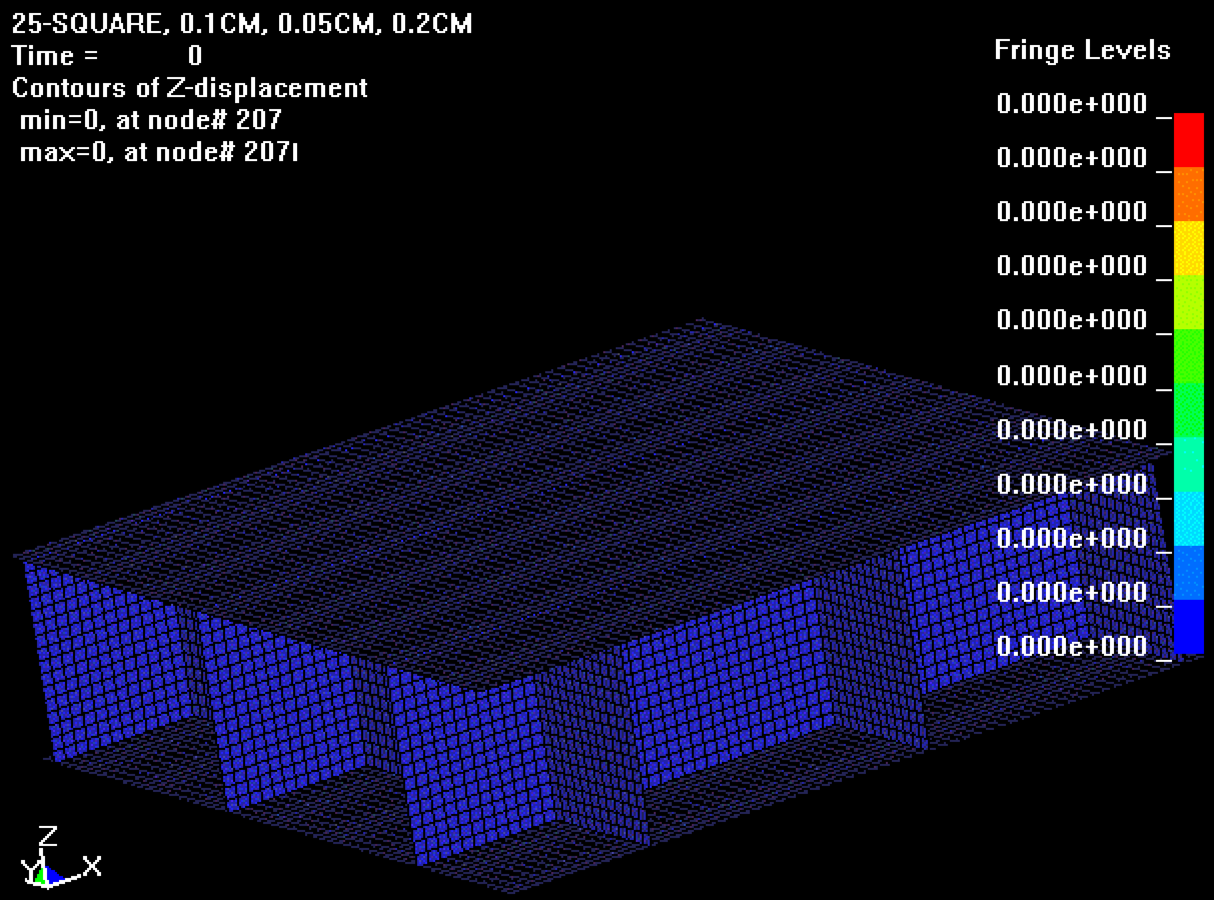




- ➢Kinetic energies for honeycomb and plain models were almost same.
- ➢However, internal energies were different that honeycomb absorbs more energy as the plate thickness increased, plain model behaves opposite to honeycomb model that energy absorption decreased as plate thickness increased. Maybe this is one of reason caused ARL's experiment results.



- ➢ However, velocity appears to be same.



- One of buckling structure and dimensions shown above.
- 6.6% difference in Rigid Body Velocity between Honeycomb and Solid models.

Summary of Results

- From both part 1 and part 2 cases, increasing or decreasing number of cells did not significantly effected the energy absorption of the model.
- There were around 14% differences of results between solid and shell models.
- The results from beam models differentiated about 23% of maximum deflection that solid model appears to be stiffer than the shell model.
- From the varying plate thickness case, the result appears based on the graphs of kinetic, internal energies, and rigid body velocity that increase in energy absorption through the material as mass of the structure increases.

Any Questions ?