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Drop Test Simulation of a BGA Package: Methods & Experimental Comparison

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PREVIEW

Objective: Use ANSYS implicit solver to perform a transient dynamic simulation of a PC Board (PCB) drop test. Determine strains and accelerations at several locations and compare to experimental results to confirm accuracy.

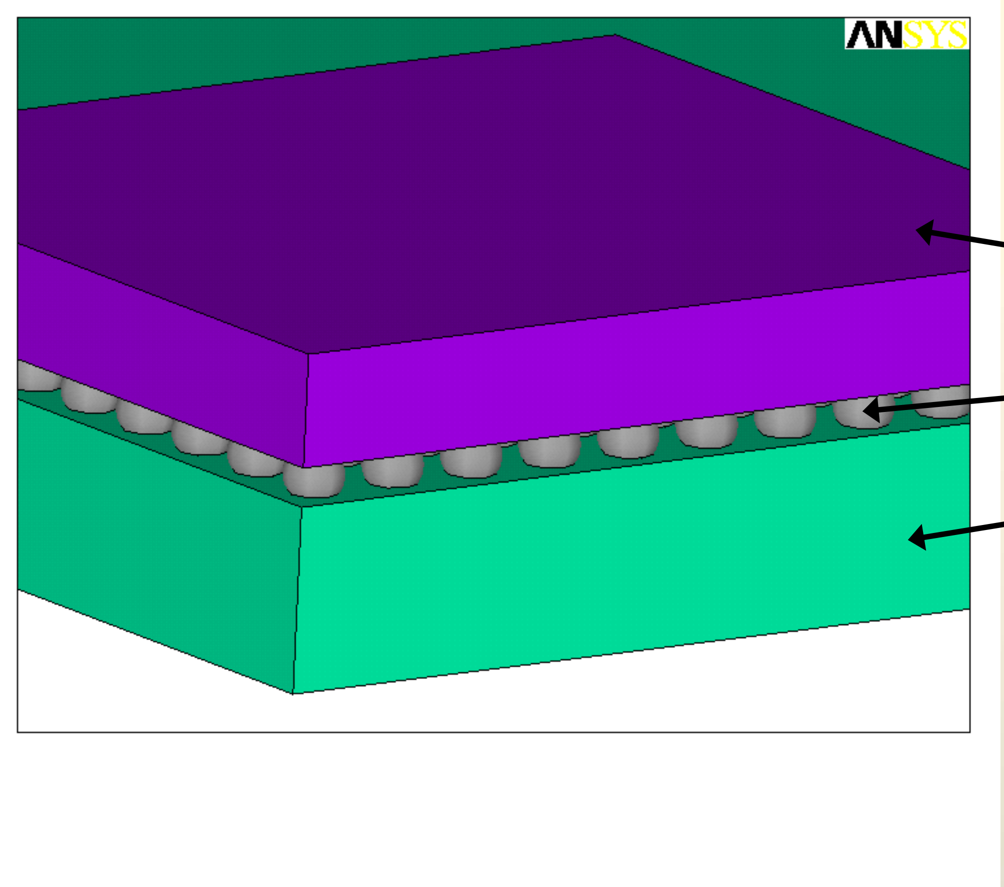
Method: Analyze a simplified model of a PCB with a single ball grid array package (BGA) and integrated heat spreader (IHS) attached at the center. Explore simulation options available in implicit ANSYS. Model is simplified in respect to materials, geometry

Practical Application: A means of obtaining accurate dynamic response and stress / strain results for a PCB. Maximize solder joint impact reliability using relative comparisons of PCB and BGA configurations.

Special Thanks: Harvey Tran and Nghia Lee at Intel for physical testing and material characterization. Dr. Metin Ozen for project support.

SOLID MODEL

- Generalized BGA Package



Substrate / Die / etc.

Solder ball

PC board

EXPERIMENTAL STANDARD

- JEDEC* Standard JESD22-B110A
  - Standardized mechanical shock acceleration to reduce experimental variation

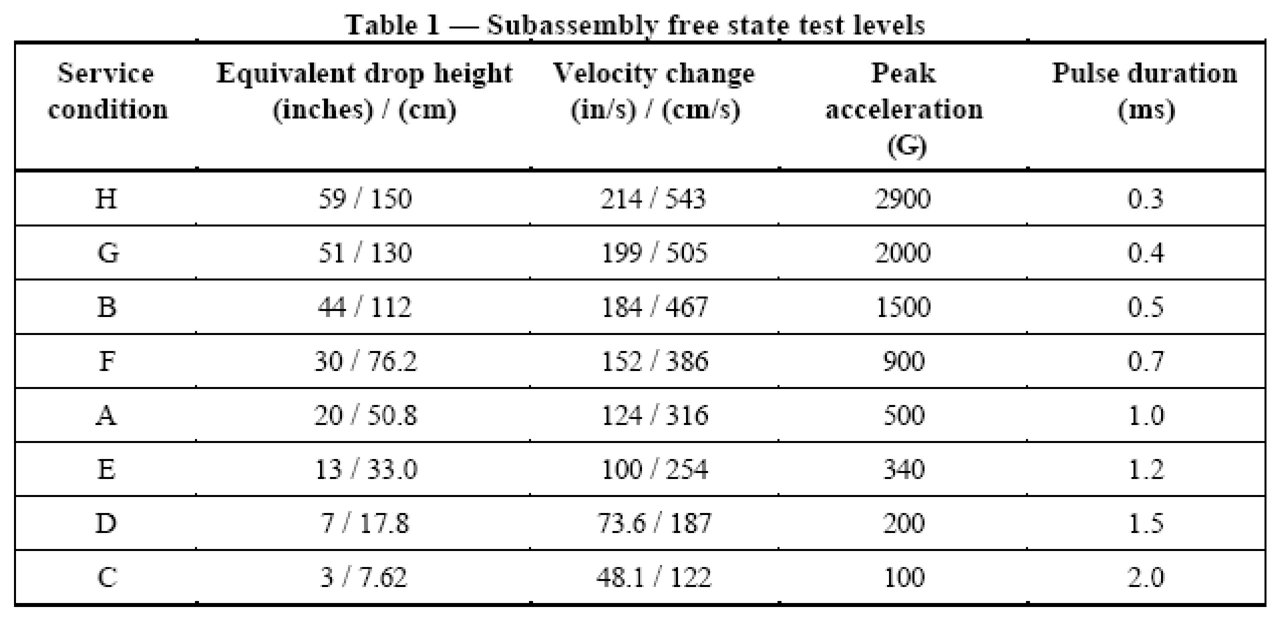


Table 1 — Subassembly free state test levels

Service condition	Equivalent drop height (inches) / (cm)	Velocity change (in/s) / (cm/s)	Peak acceleration (G)	Pulse duration (ms)
H	59 / 150	214 / 543	2900	0.3
G	51 / 130	199 / 505	2000	0.4
B	44 / 112	184 / 467	1500	0.5
F	30 / 76.2	152 / 386	900	0.7
A	20 / 50.8	124 / 316	500	1.0
E	13 / 33.0	100 / 254	340	1.2
D	7 / 17.8	73.6 / 187	200	1.5
C	3 / 7.62	48.1 / 122	100	2.0

Table from JESD22-B110A

- Half-sine pulse
- "Input-G" method

* Joint Electron Device Engineering Council (JEDEC Solid State Technology Association)

EXPERIMENTAL STANDARD

- JEDEC Standard JESD22-B111
  - Standardized Experimental Drop Test Board

- 15 components compare performance at 6 unique board locations
- PCB Young’s Modulus: 20 GPa +/-2GPa
- Mount PCB to drop test fixture with screws through 4 holes

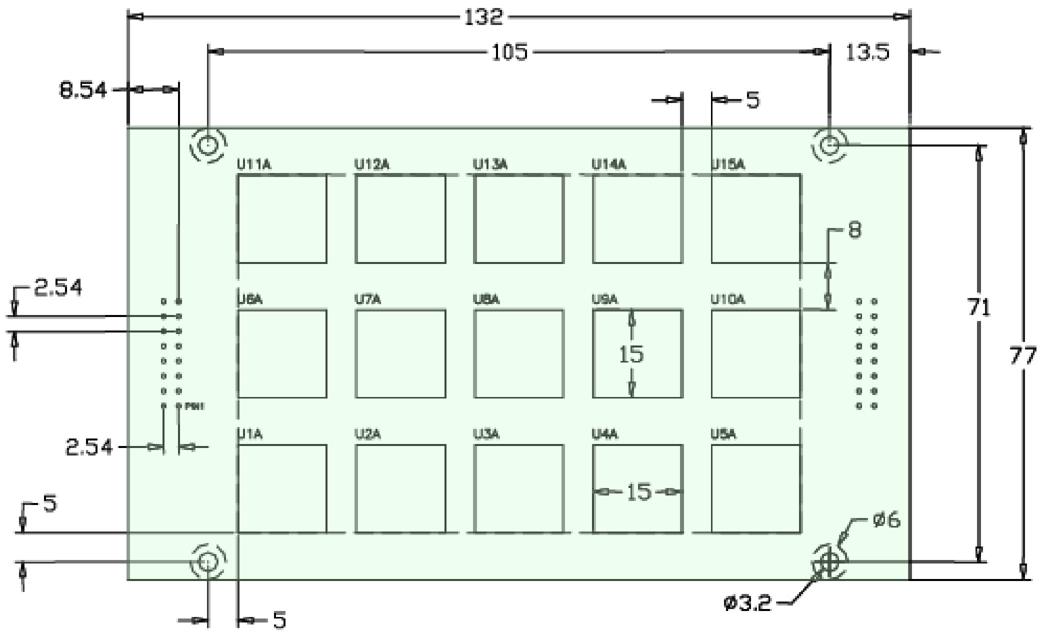


Figure 1 — Test board size and layout

Figure from JESD22-B111

- Horizontal board orientation with components facing down to maximize board flexure (primary failure mode)

BOUNDARY CONDITIONS

- Fixture attachment:
  - Locate “fixture attachment” point as specified in JESD22-B111.
  - Considered an ideal connection: no friction, no sliding
  - Set X,Y,(Z) displacement = 0 (excluding displacement and force method) at appropriate location
    - According to JESD22-B111, “The screw shall be tightened until the shoulder of the screw bottoms out against the standoff.”

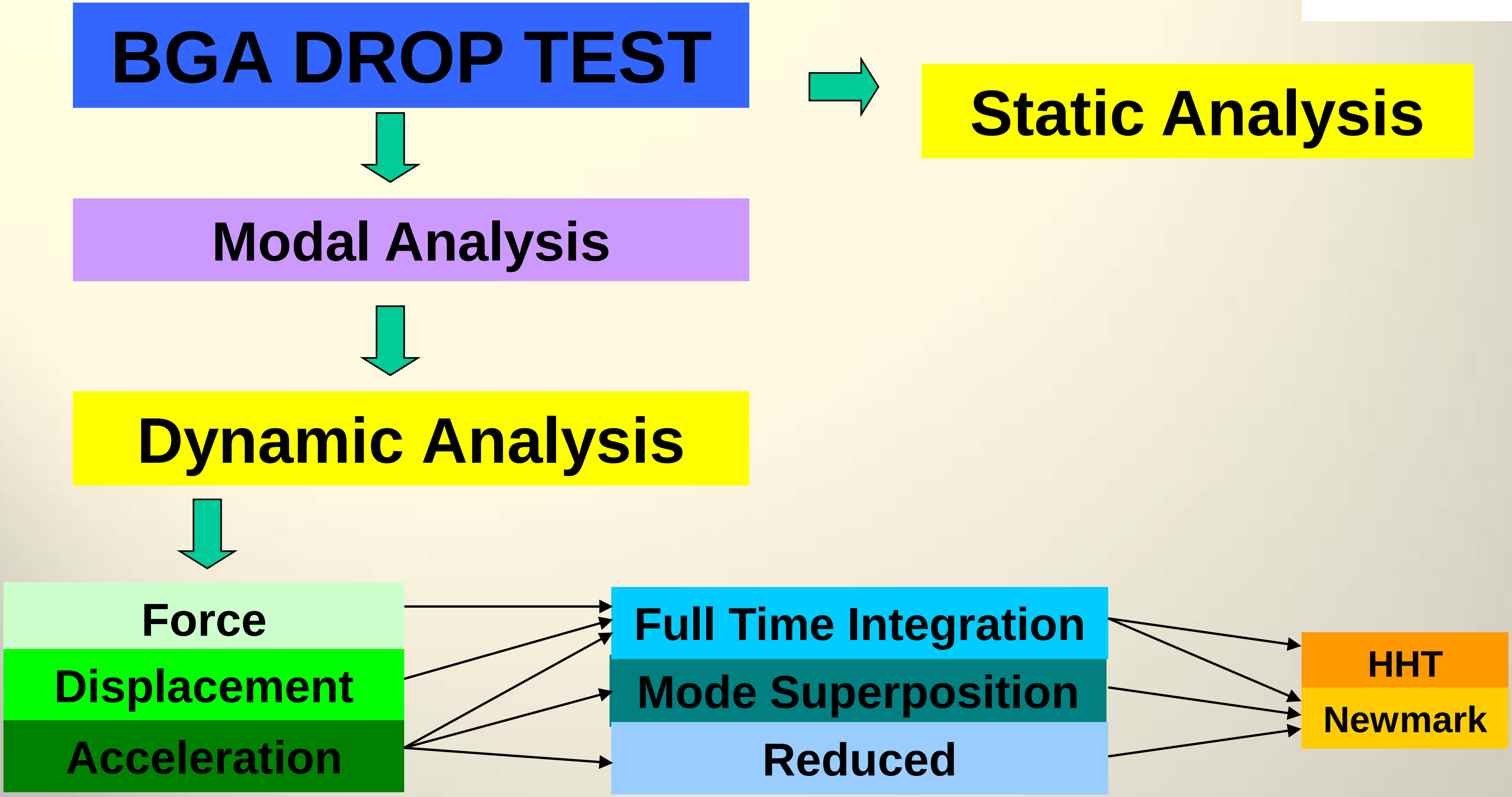
TIME STEP

- Guidelines for Integration Time Step (ITS)
  - Set ITS small enough to resolve highest mode that contributes to the response
  - Using approximately 20 points per cycle of highest frequency of interest results in reasonably accurate solution for the Newmark method
- ITS = 1 / (20*f*)
- Example

Mode	Frequency (Hz)	Critical Time Step (s)	Total Time (s)	Total # Steps	Sample Run Time
1	202.3	2.47E-04	0.008	32	65 min
2	487.6	1.03E-04	0.008	78	100 min
3	893.9	5.59E-05	0.008	143	3 hours
6	3749.0	1.33E-05	0.008	600	14 hours

* Run Time: 3 GHz PentiumD, 2 GB RAM, 15,000 elements, 17,000 nodes

PROCEDURE SUMMARY



BGA DROP TEST

Static Analysis

Modal Analysis

Dynamic Analysis

Force

Displacement

Acceleration

Full Time Integration

Mode Superposition

Reduced

HHT

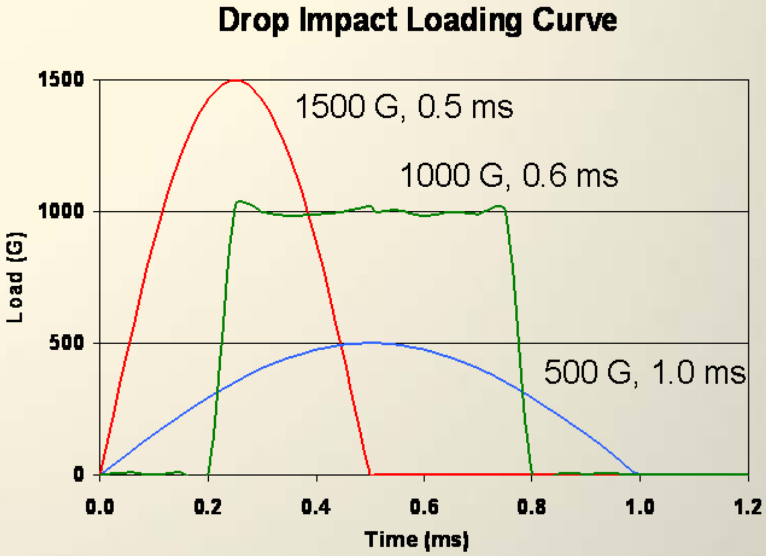
Newmark

LOADING

- A variety of loading methods…
  - Acceleration
    - Static or Time Transient
    - “Input-G” standard loading vs. Experimental
    - Fixture displacement = 0
    - Applied as body load on package

$$A(t) = P*\sin(\pi t/d)$$

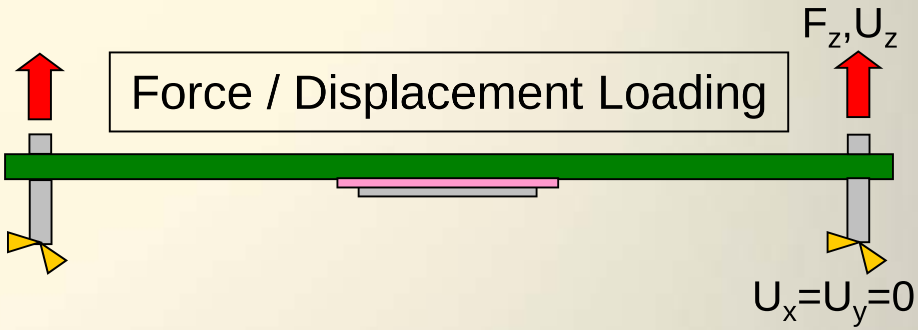
$A(t)$ = acceleration (m/s^2)
t = time (s)
d = duration (s)
P = peak acceleration (m/s^2)



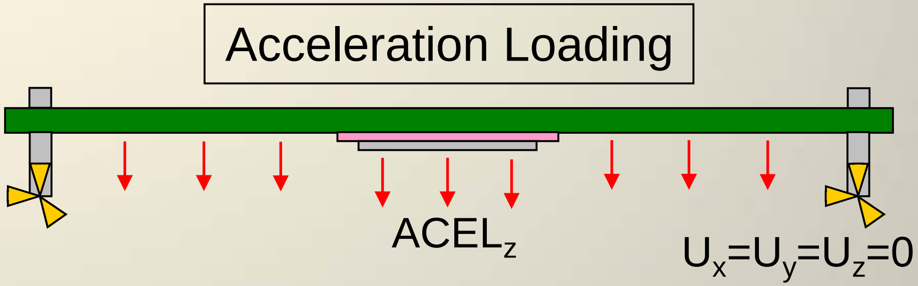
Simulated half-sine pulses and experimental trapezoidal pulse data

LOADING

- Loading continued
  - Displacement
    - $D(t) = \iint A(t)$
    - Boundary Conditions: $@t=0$, $V_o=0$ and $D_o=0$
    - Applied at fixture location
    - Complete package motion
  - Force
    - Add very large mass element to fixture location
    - Very Large = Package Mass x 1E5
    - Force = Total Mass x Acceleration
    - Complete package motion



Force / Displacement Loading



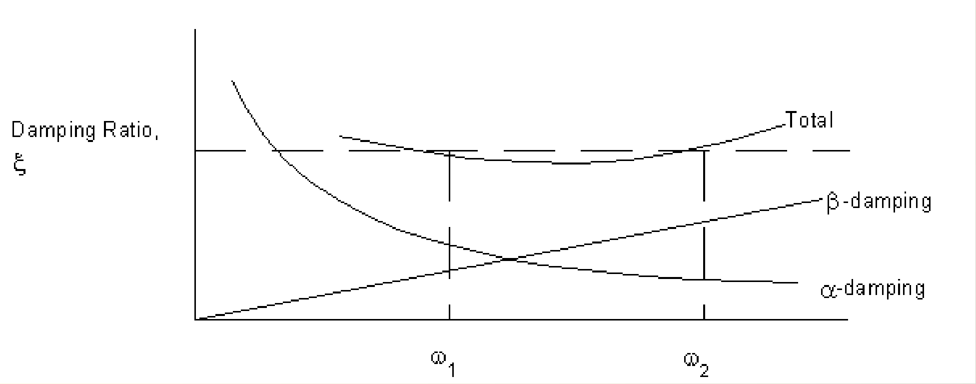
Acceleration Loading

DAMPING

- Coefficients calculated from % of critical damping
- Rayleigh damping coefficients (α,β)

$$\xi_i = \alpha/2\omega_i + \beta\omega_i/2$$

where:
ξ_i = critical damping ratio
α = Rayleigh mass damping coefficient
β = Rayleigh stiffness damping coefficient
ω_i = natural circular frequency = $2\pi * f_i$
f_i = mode frequency
i = mode number



ANSYS Inc. Theory Reference

Analysis Type	Alpha, Beta Damping ALPHAD, BETAD	Material Dependant Damping MP,DAMP	Constant Damping Ratio DMPRAT	Modal Damping MDAMP	Element Damping(3) COMBIN7, and so on	Constant Material Damping Coefficient MP,DMPR
Static	N/A	N/A	N/A	N/A	N/A	N/A
Transient						
Full	Yes	Yes	No	No	Yes	No
Reduced	Yes	Yes	No	No	Yes	No
Mode Sup	Yes	Yes(4,6)	Yes	Yes	Yes	No

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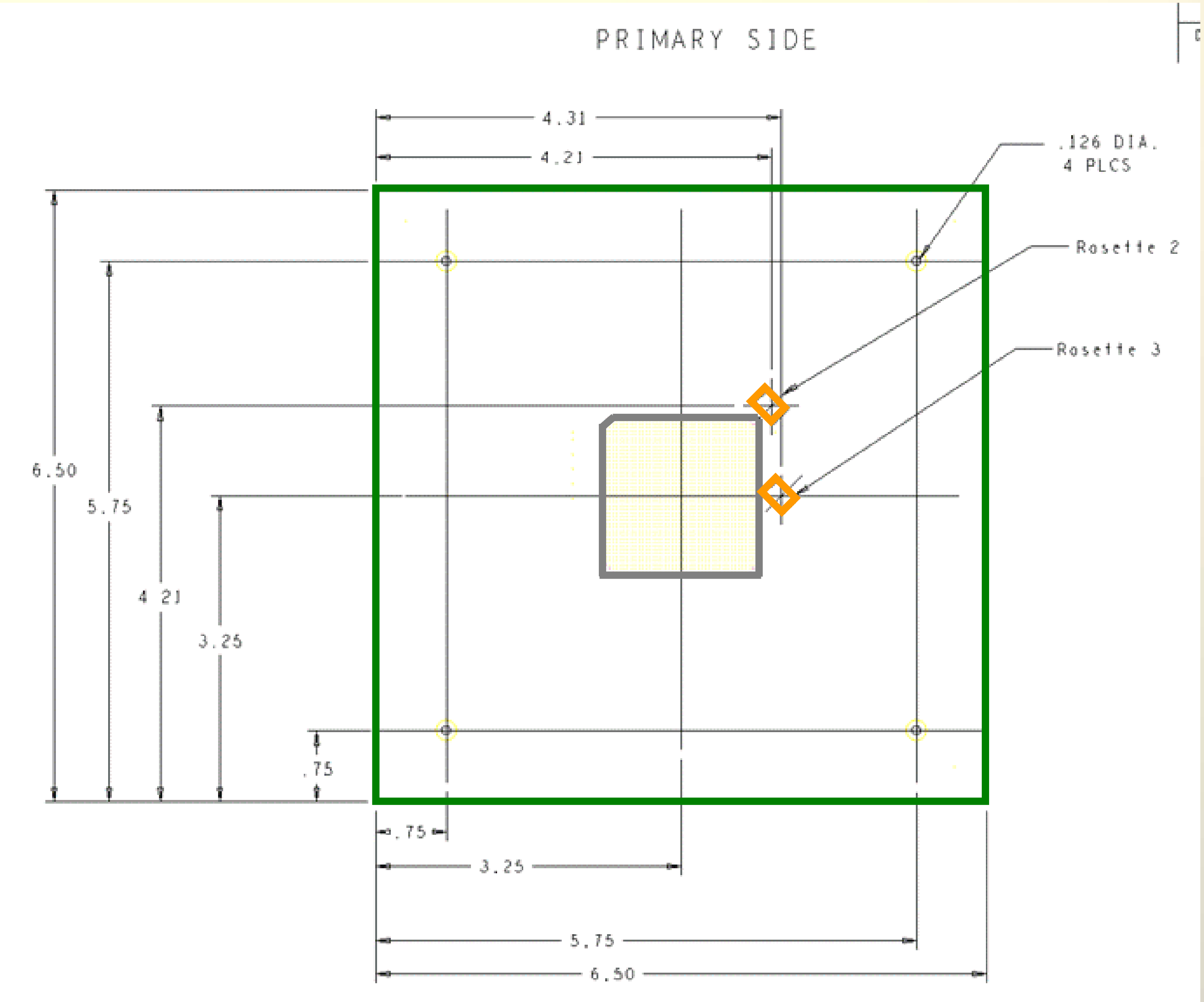
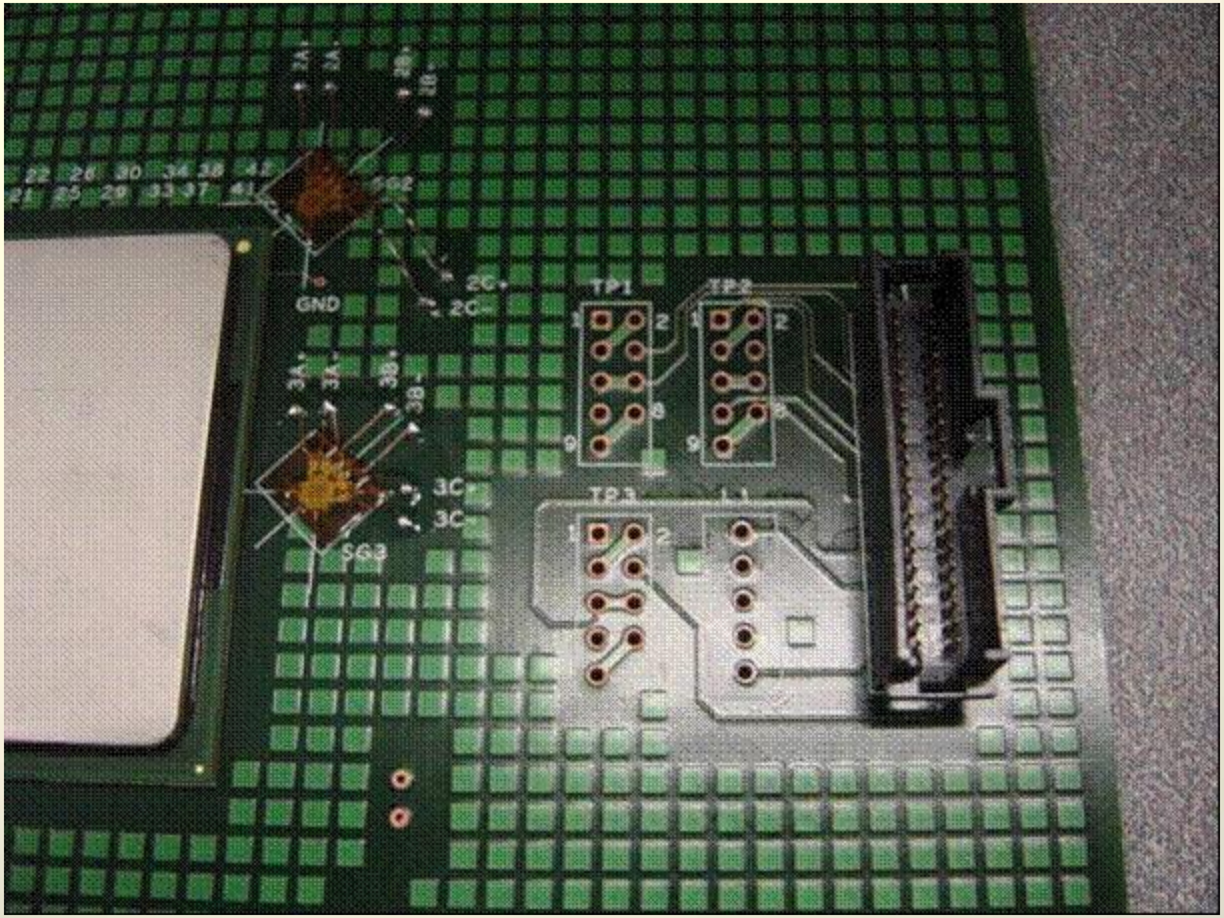
Experimental Comparison

Objective: Compare strain & acceleration results from experimental board level measurements to ANSYS simulation

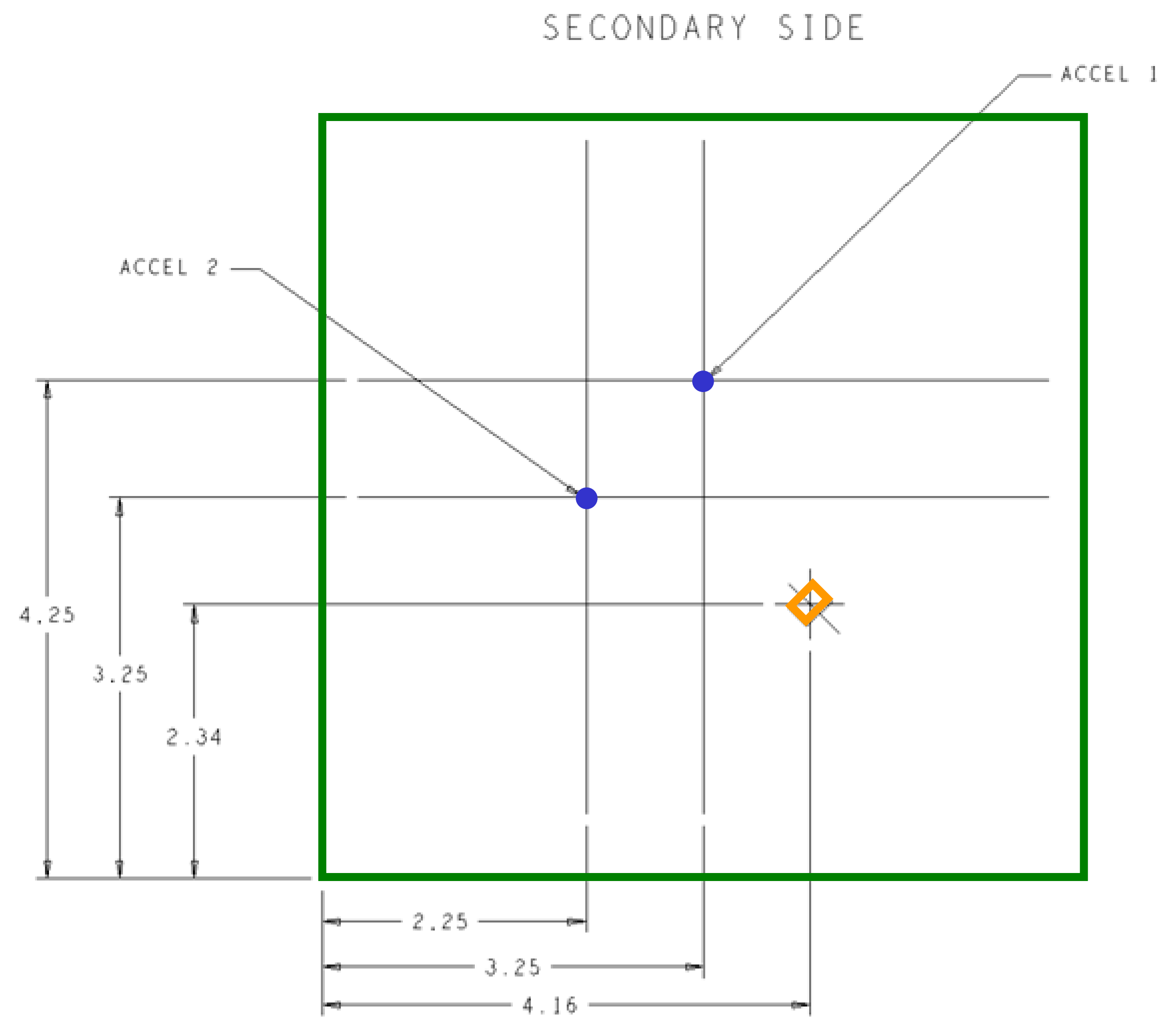
GEOMETRY


PRIMARY SIDE
4.31
4.21
.126 DIA.
4 PLCS
Rosette 2
Rosette 3
6.50
5.75
4.21
3.25
.75
.75
3.25
5.75
6.50

GEOMETRY

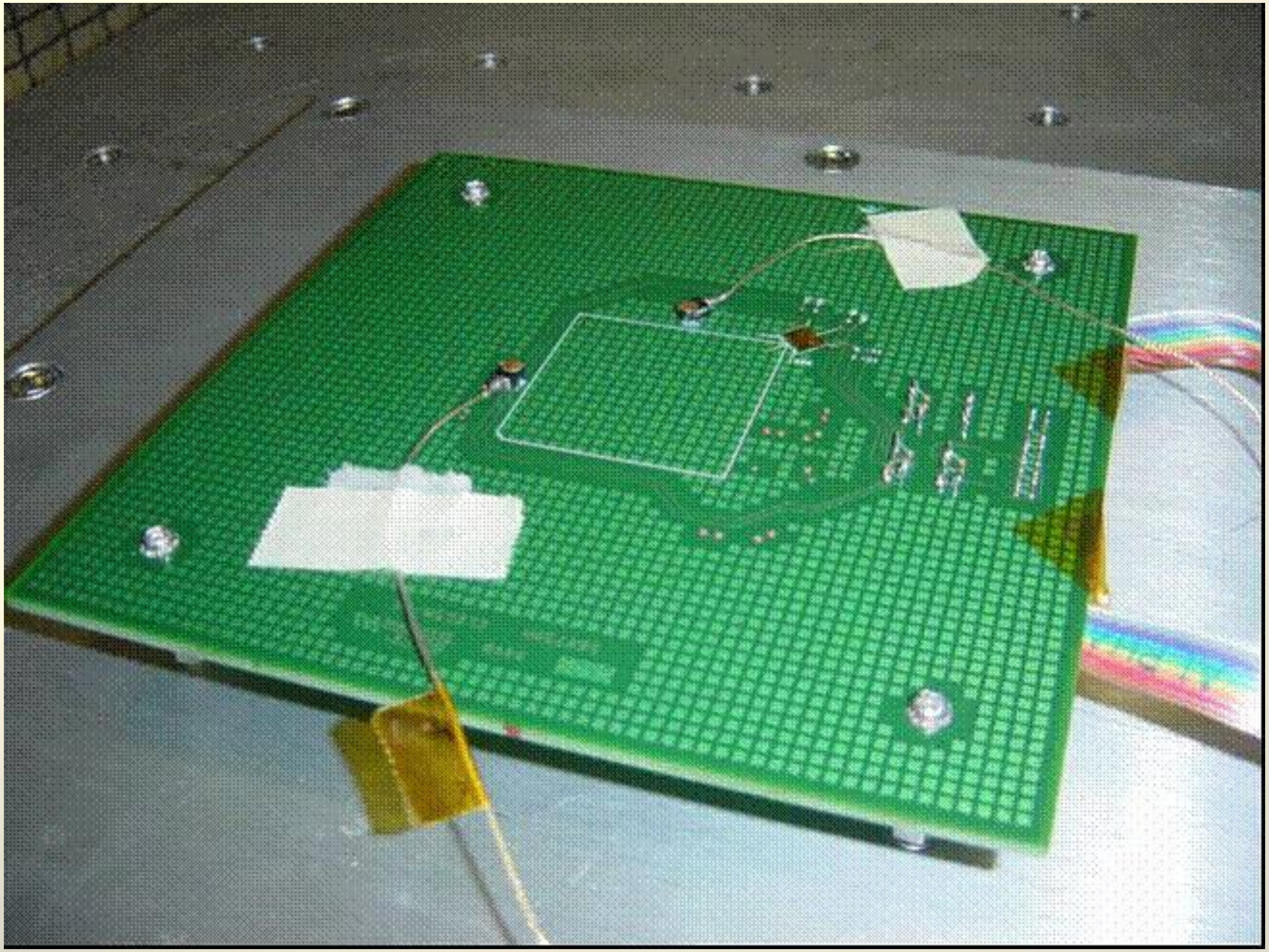

2A+
2A-
2B+
2B-
22 26 30 34 38 42
21 25 29 33 37 41
SG2
GND
2C+
2C-
TP1
TP2
1
2
9
8
3A+
3A-
3B+
3B-
3C+
3C-
SG3
TP3
L1

GEOMETRY



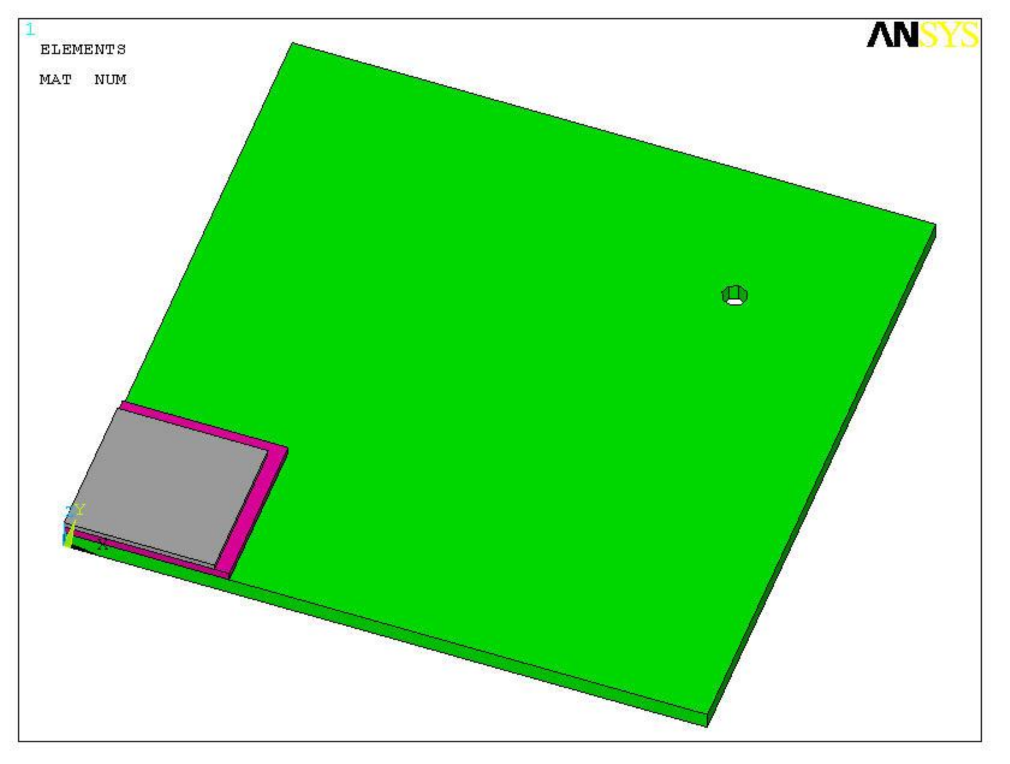
Bottom side, viewed from top

GEOMETRY



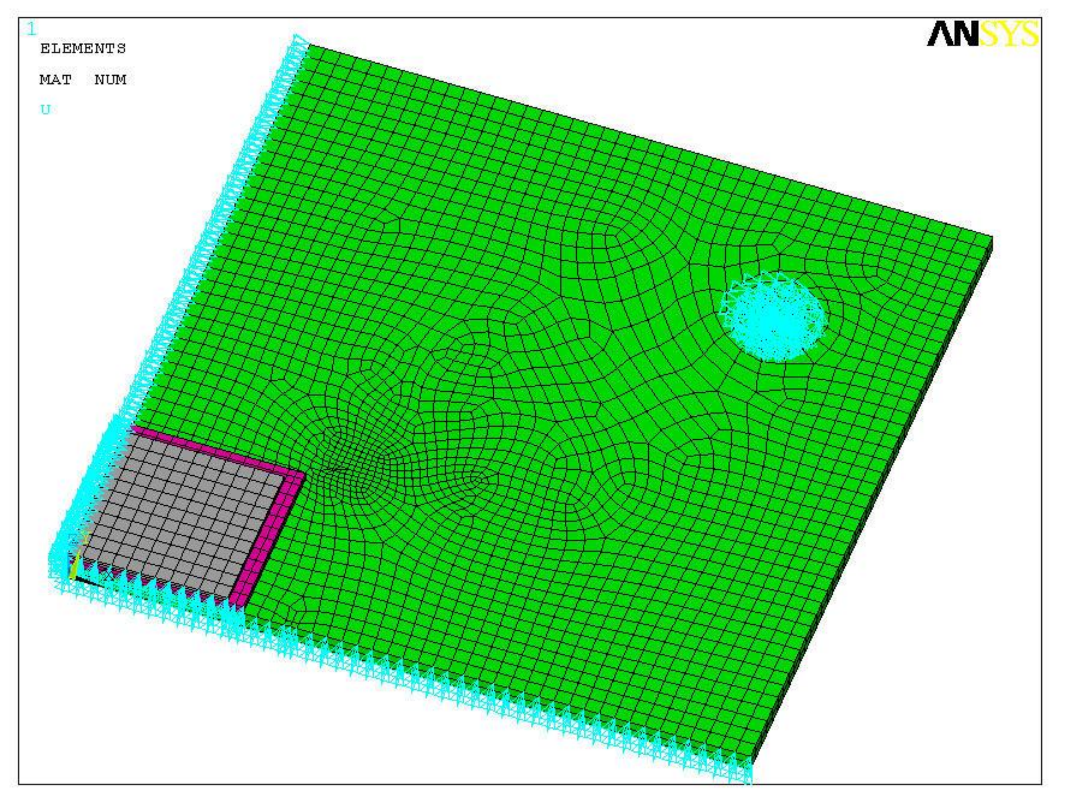
SIMULATION SETUP

- ¼ symmetry model
- BGA package approximated with bulk material
- Material properties determined through modal analysis method
- 1% damping
- Strain & acceleration simulation results taken at single node nearest to sensor location
- ANSYS implicit solver



BOUNDARY CONDITIONS

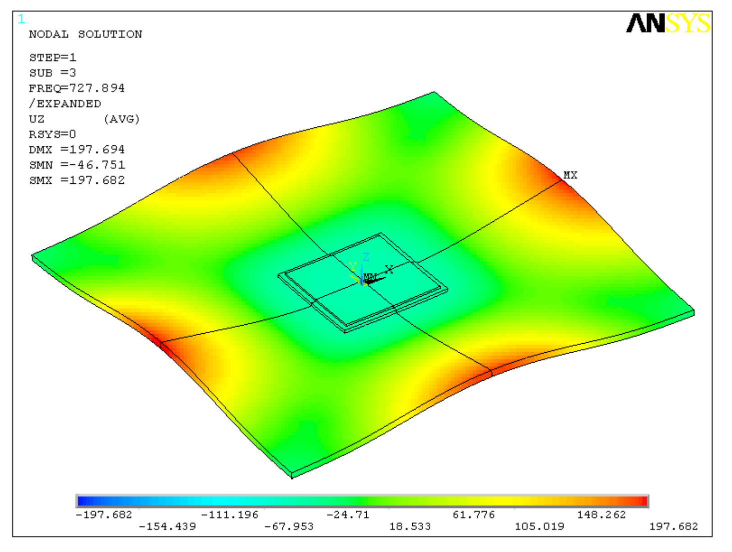
- ¼ symmetry boundary conditions
- Fix UX,UY,UZ at exact fixture locations



MODAL ANALYSIS

Mode	Frequency (Hz)	Period (s)	Cumulative Mass Fraction (z-direction)
1	259.62	0.0039	0.8514
2	578.51	0.0017	0.8515
3	727.89	0.0014	1.0000

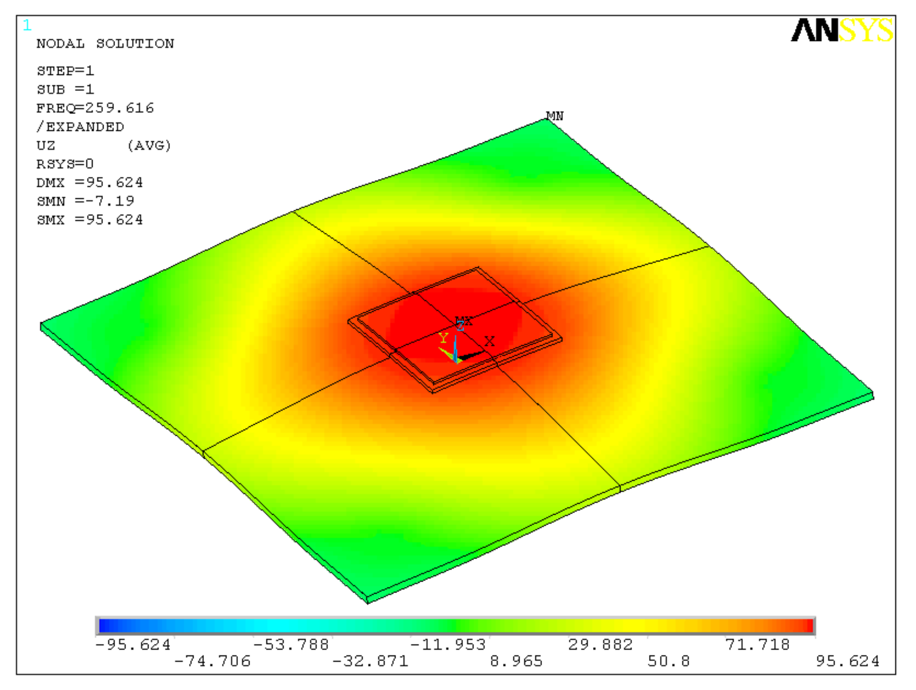
Mode 3



```
NODAL SOLUTION

STEP=1
SUB =3
FREQ=727.894
/EXPANDED
UZ        (AVG)
RSYS=0
DMX =197.694
SMN =-46.751
SMX =197.682
```

Mode 1



```
NODAL SOLUTION

STEP=1
SUB =1
FREQ=259.616
/EXPANDED
UZ        (AVG)
RSYS=0
DMX =95.624
SMN =-7.19
SMX =95.624
```

- Experimental data shows primary oscillating frequency = 259.94 Hz.
- 0.1% Difference

LOADING CONDITIONS

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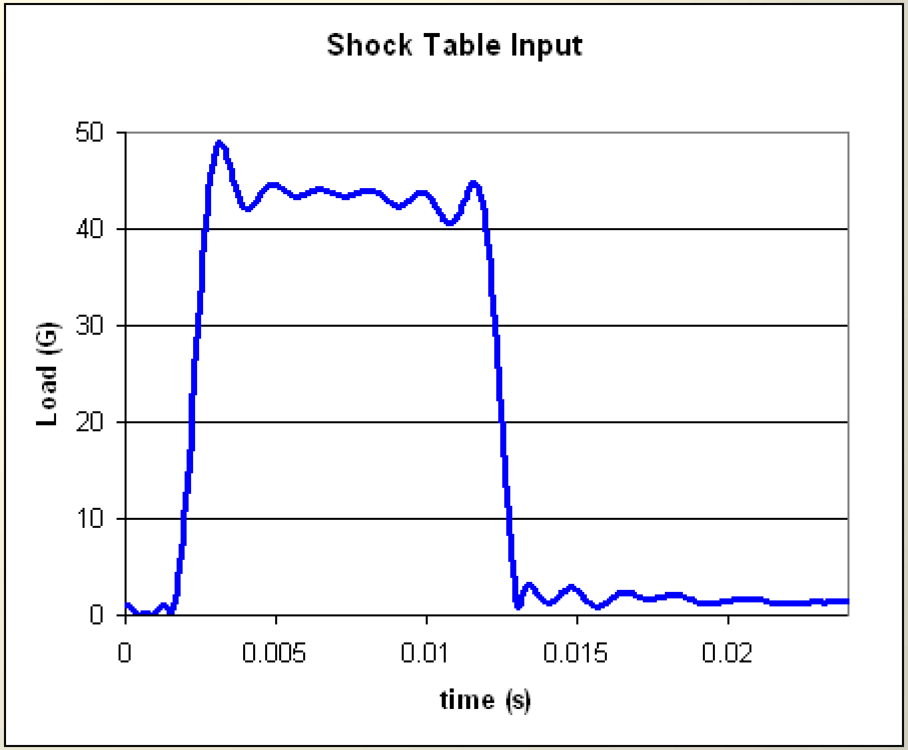
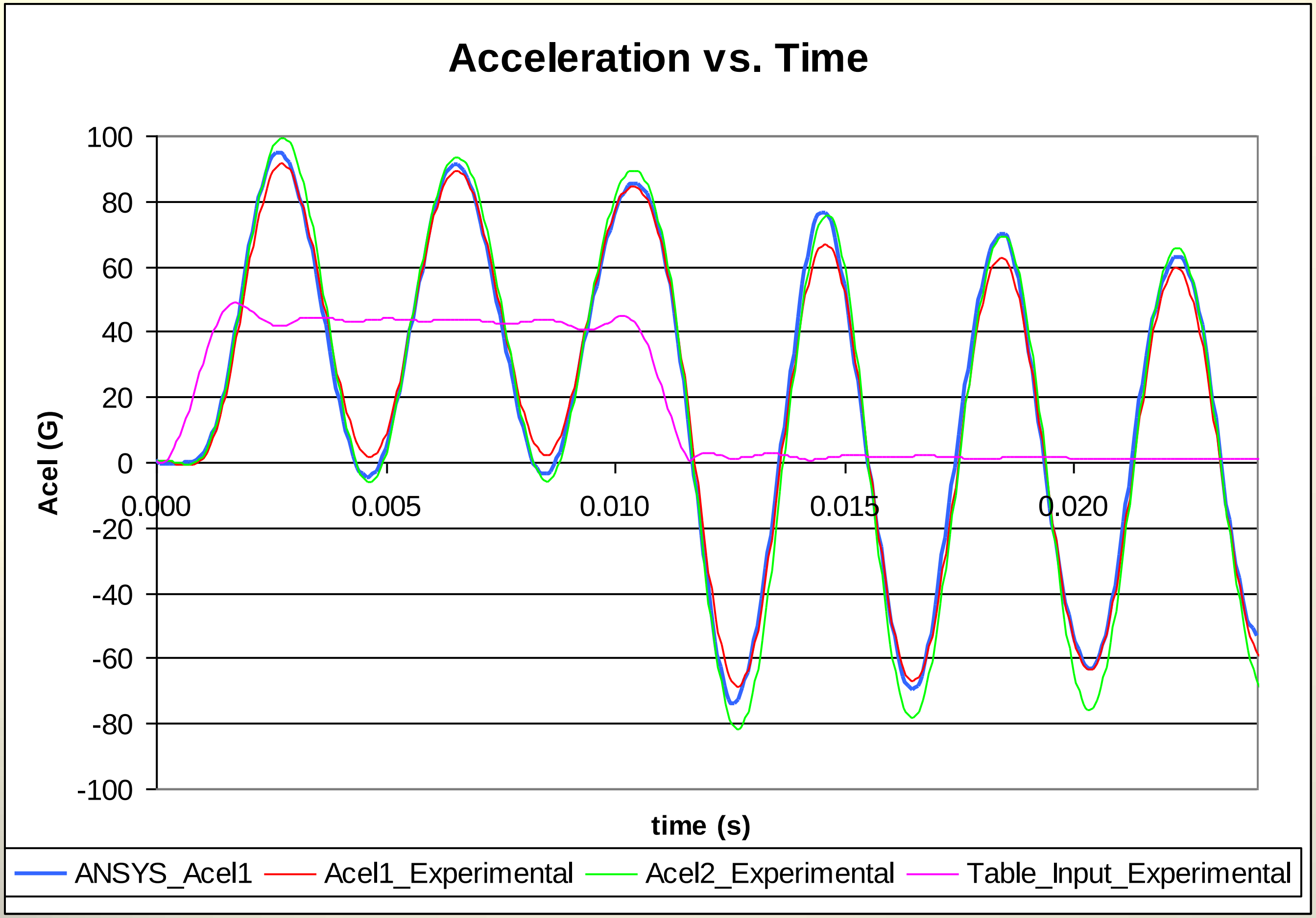
- Loads as recorded on testing table
- Trapezoidal shock profile
- 50 G, 11ms

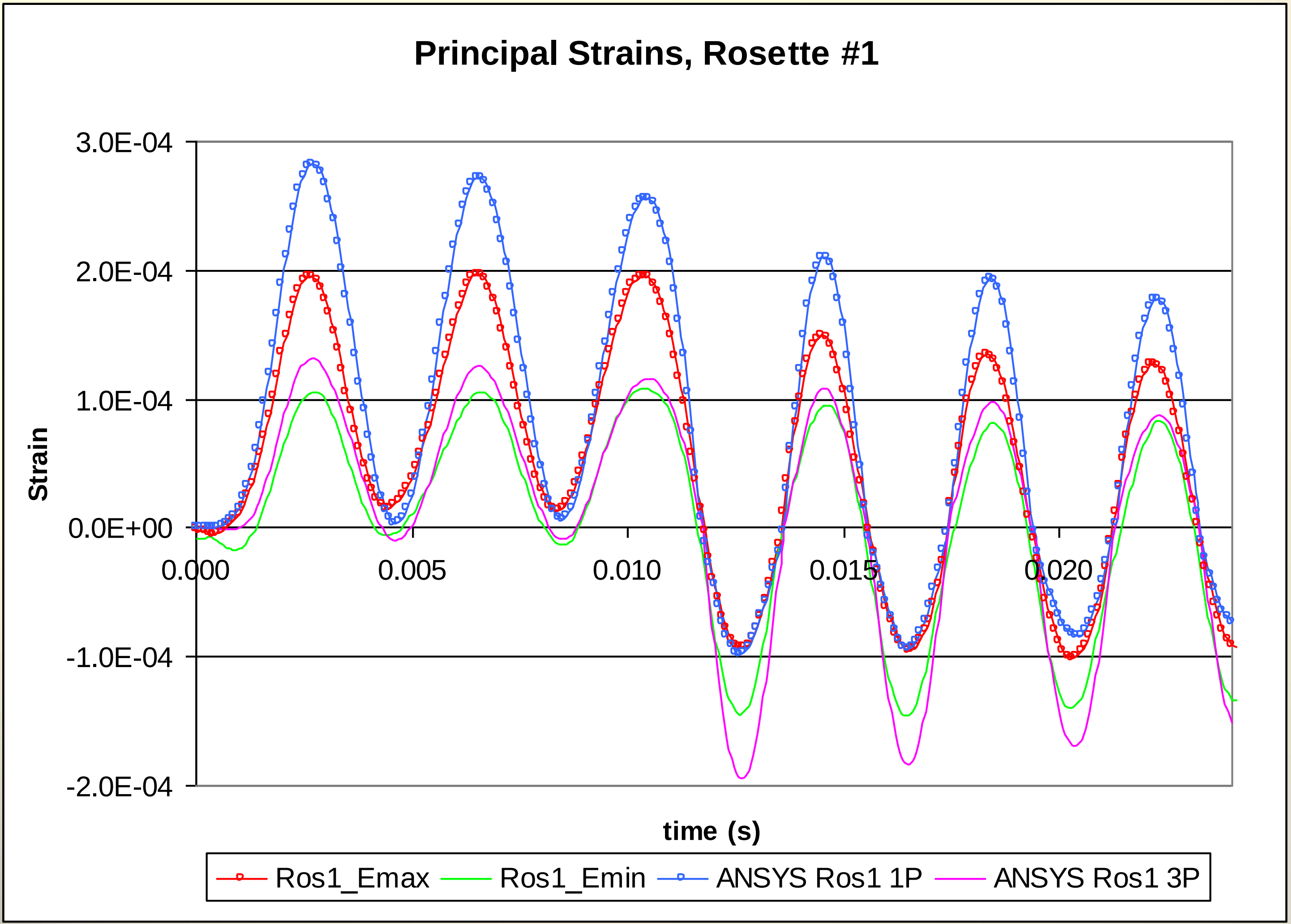


ACCELERATION



Acceleration = Second Derivative UZ + Table Input

STRAIN ROSETTE #1



Calculate Principal Strains (Plane Stress)

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STRAIN ROSETTE #2

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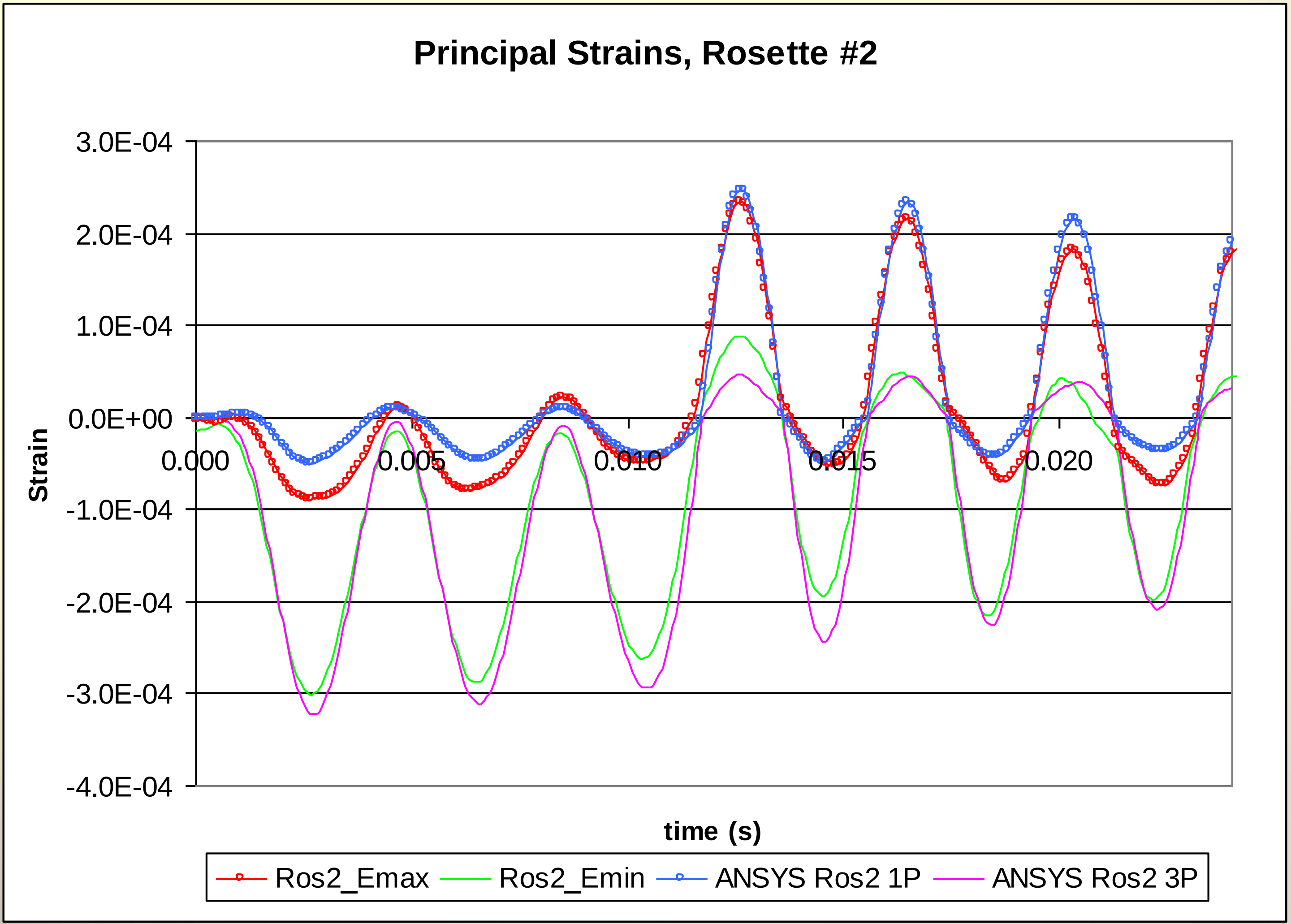
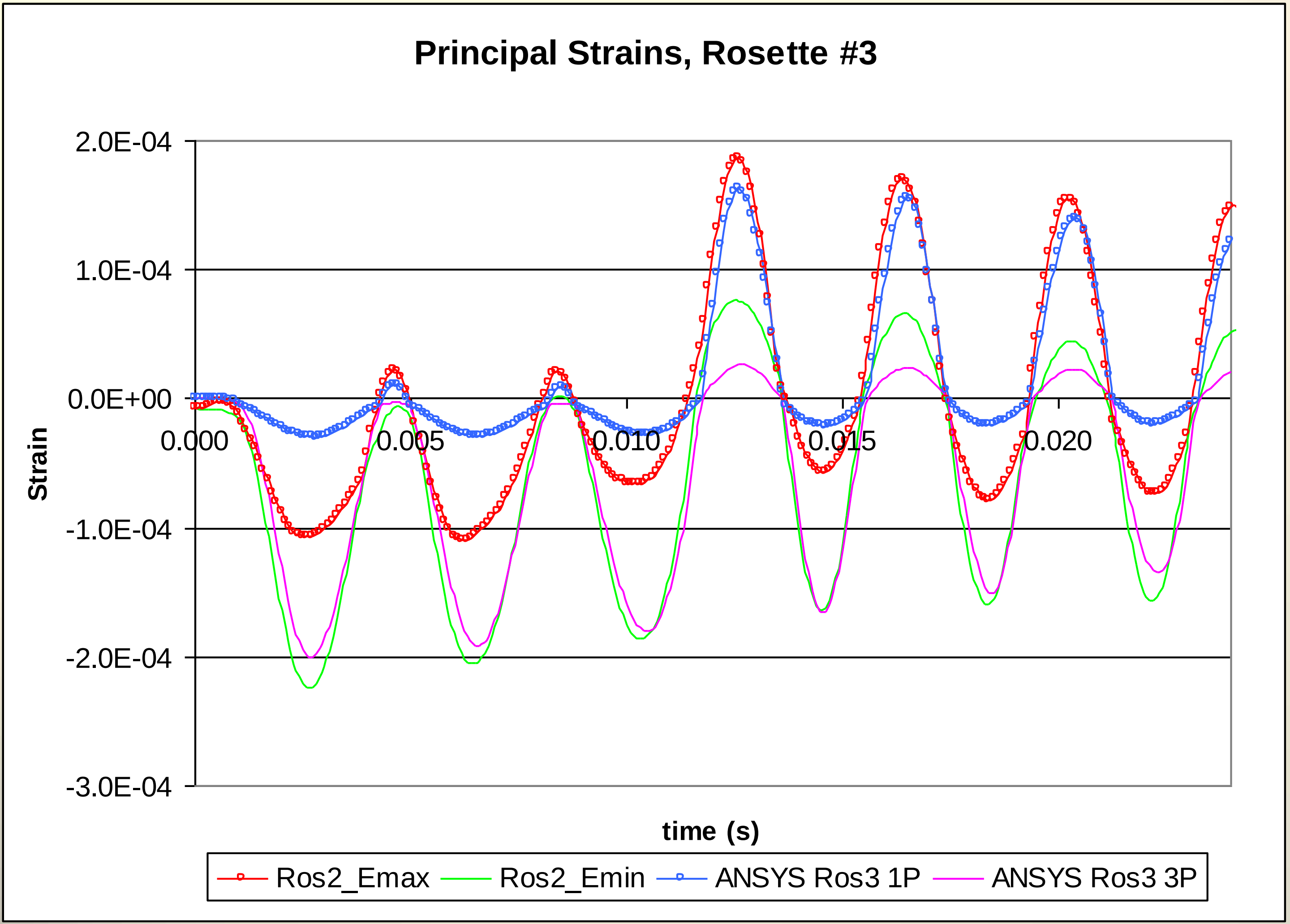


Calculate Principal Strains (Plane Stress)

STRAIN ROSETTE #3



Calculate Principal Strains (Plane Stress)

ERROR SUMMARY

- Large strain gradients at rosette locations
- Rosette #1 is located on opposite side, dimensioned from chip, possible error source
- Simplified model with bulk BGA
- Rosette #1 difference (44%) is same magnitude as location difference of 1/8 inch on gradient

	During Pulse Duration	After Pulse
Accelerometer 1,2 (avg)	2%	3%
Rosette #1	44%	34%
Rosette #2	7%	5%
Rosette #3	11%	13%
Oscillating Frequency	0.1%	

NON-LINEAR BGA MODEL

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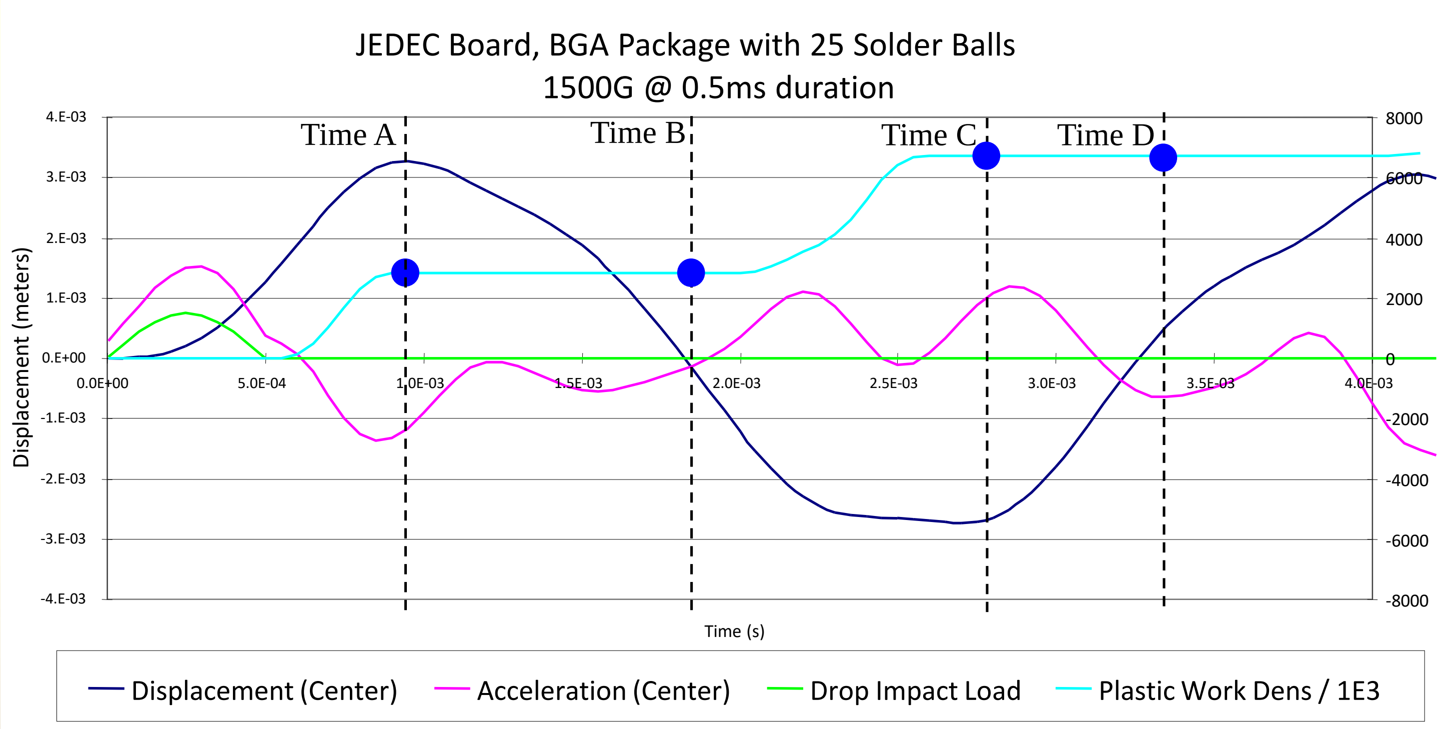
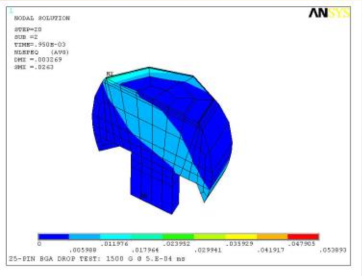
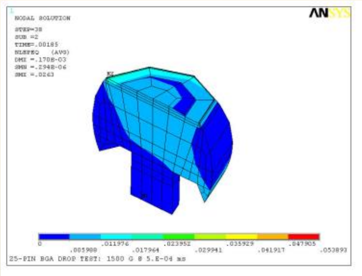


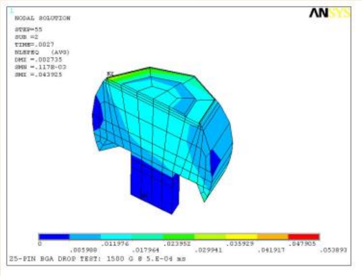
Time A



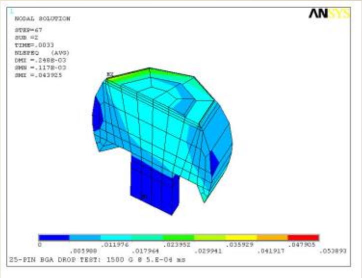
Time B



Time C



Time D



Critical Ball Plastic Work Density Evolution Through First Cycle