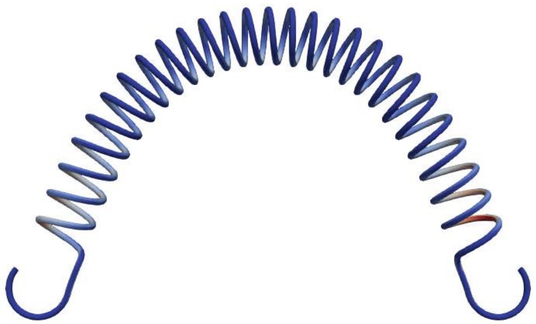
SAND2021-8802PE

Sandia National Laboratories

Verification and Validation of Reduced-Order Spring Model



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Manager: Joe Bishop
Mentors: Cory Medina & Jonel Ortiz

July 26, 2021
Virtual Intern Symposium

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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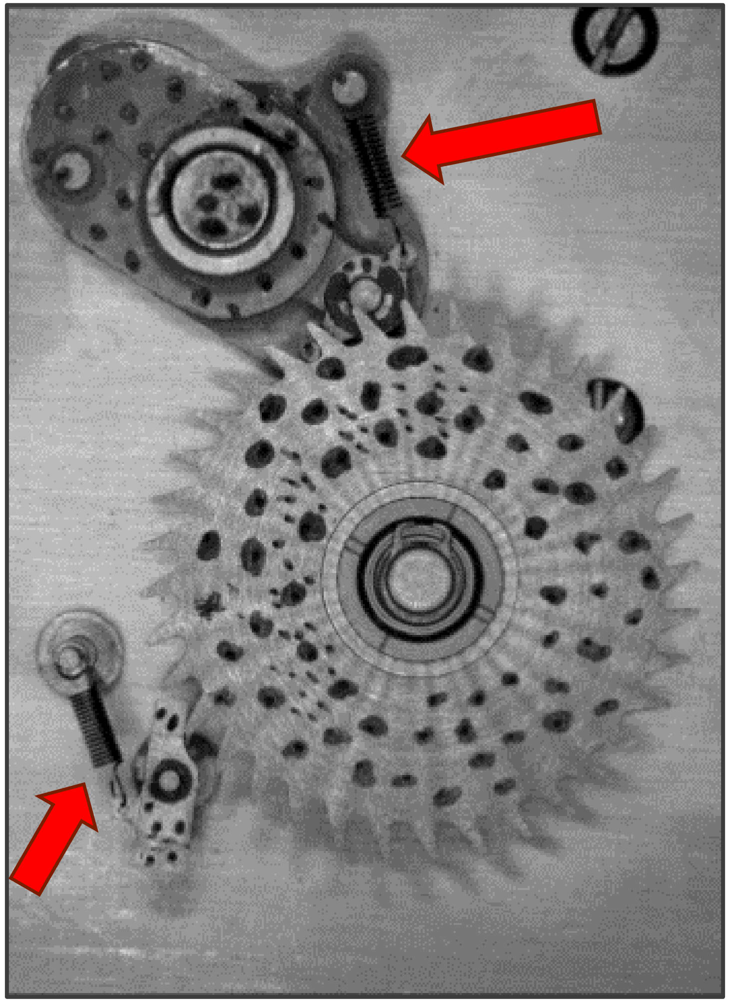
Industry Use of Reduced Order Models



Activated UUR Stronglink

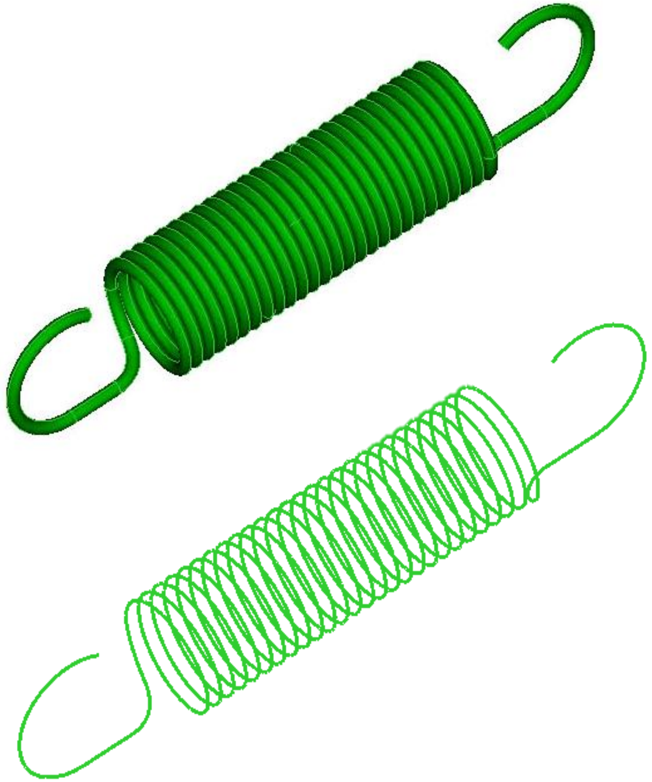
- Stronglinks provide a safety barrier for nuclear weapon operation
  - Springs are an integral part of this process
  - Finite element (FE) analysis is used to understand kinematic and structural response to different loading conditions and environments

How accurate is this process?

- Stronglinks contain small geometries, such as springs
  - Correlates to large computational cost
  - Reduced order models (ROMs) can be effective in balancing accuracy and cost

Balancing Complexity with Solution Integrity

- Explicit transient dynamics
  - Used for short duration event simulations
  - 3D element size determines necessary time increment
    - Smaller size = smaller time increment → longer simulation run time
- Stronglink springs can be thousandths of an inch in diameter
  - Small 3D elements are required to resolve the geometry and stress fields, but unfortunately produce prohibitively small timesteps
  - Instead, a series of 1D beam elements can model the wire as a ROM
- However, there is typically some inherent trade-off for simulation accuracy associated with the use of ROMs, which is the focus of this work



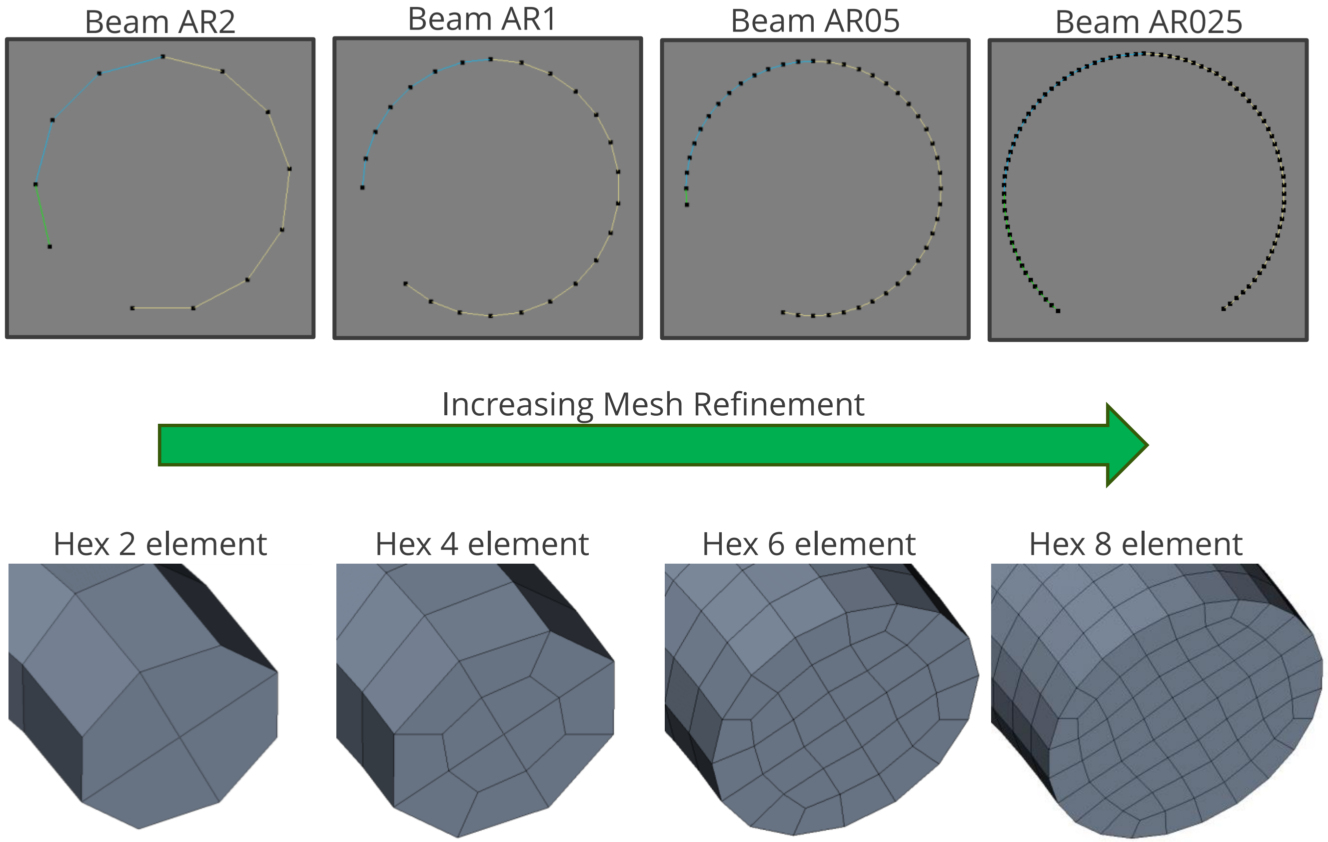
Top: original CAD model

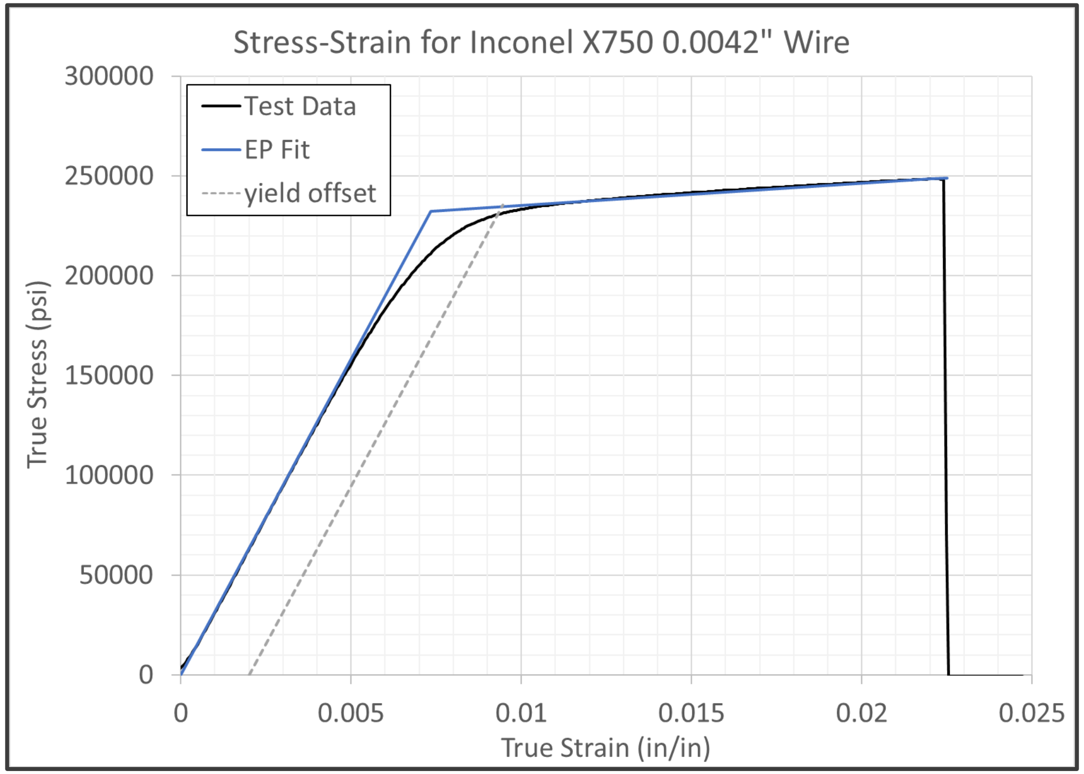
Bottom: beam model (ROM)

Finite Element Models

Meshes Considered:

- Hexahedral (Hex) element: 4 levels of mesh refinement
- Beam element: 4 various aspect ratios (AR)
  - AR = element length / beam diameter





The material of the spring is Inconel X750; an elastic-plastic material model has been fit to tensile test data.

Displacement Controlled Extension, Implicit Setup

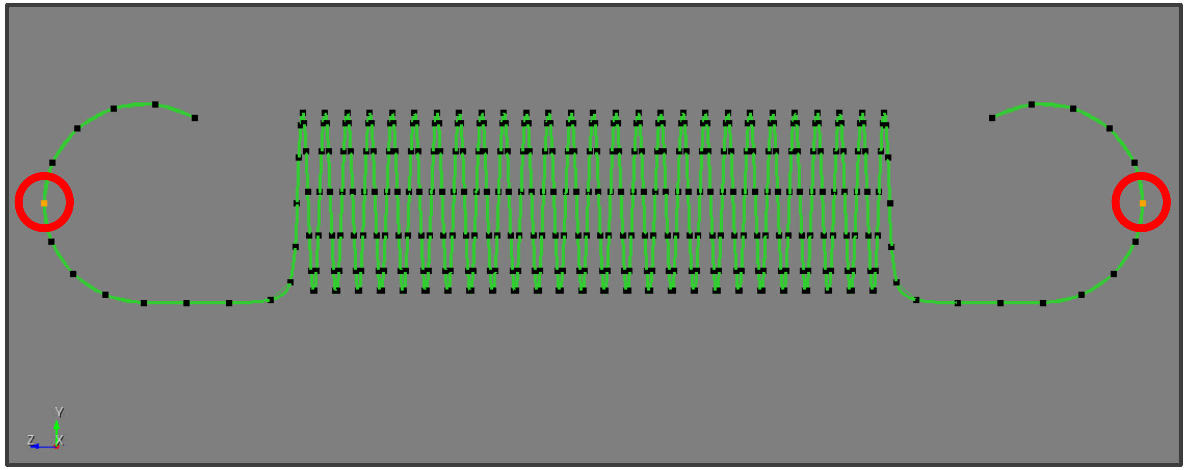
Boundary Conditions

- One hook fixed
- Linear displacement of 1.25in on second hook

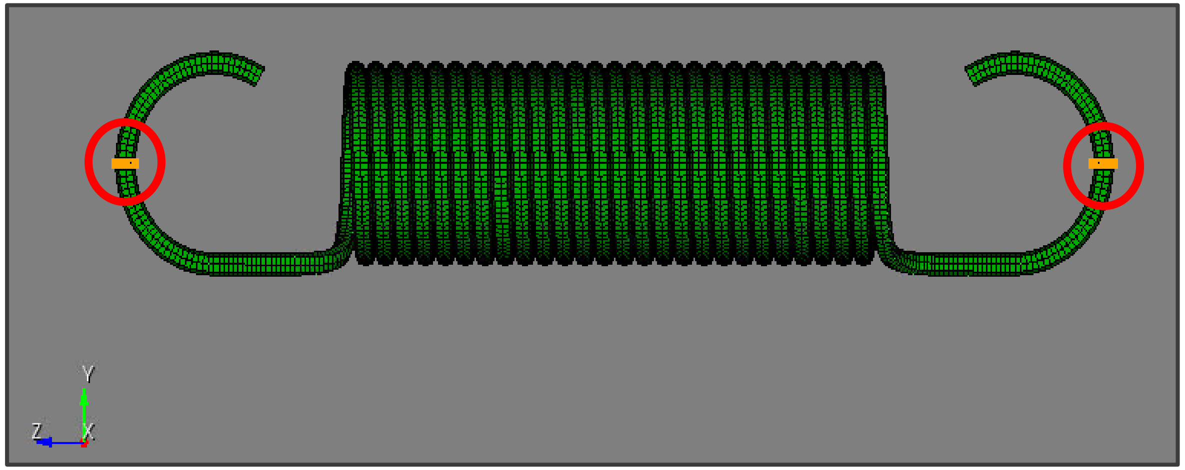
Quantities of Interest

- Nodal displacement
- Z-direction force on displaced hook
- Stress and Equivalent Plastic Strain (EQPS) as maximum over model

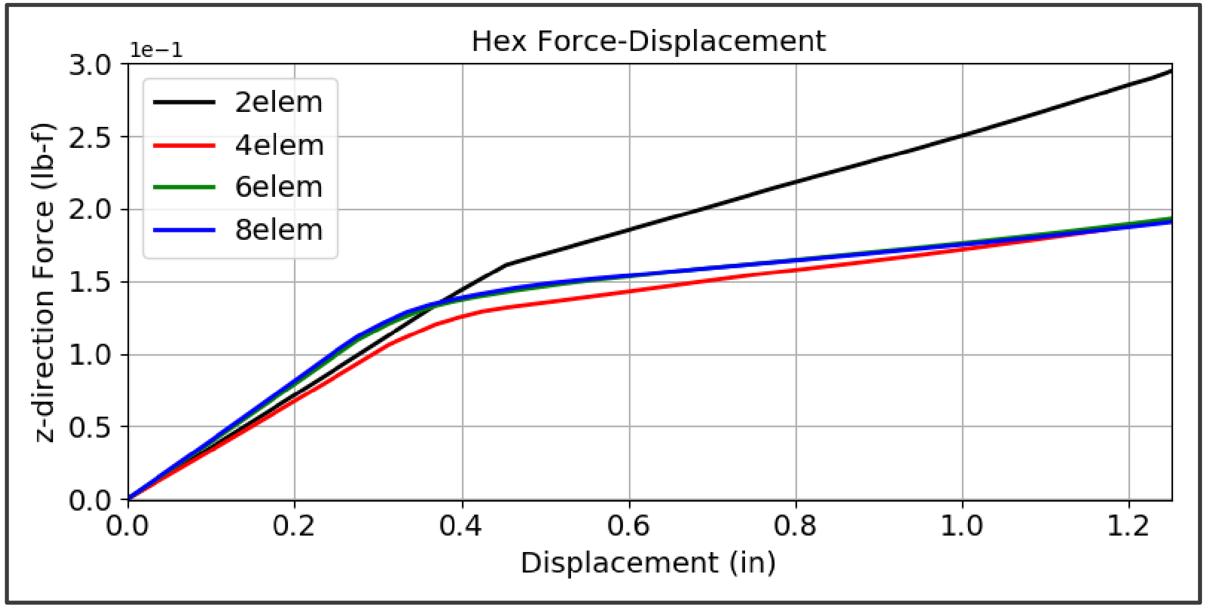
Spring Beam ROM

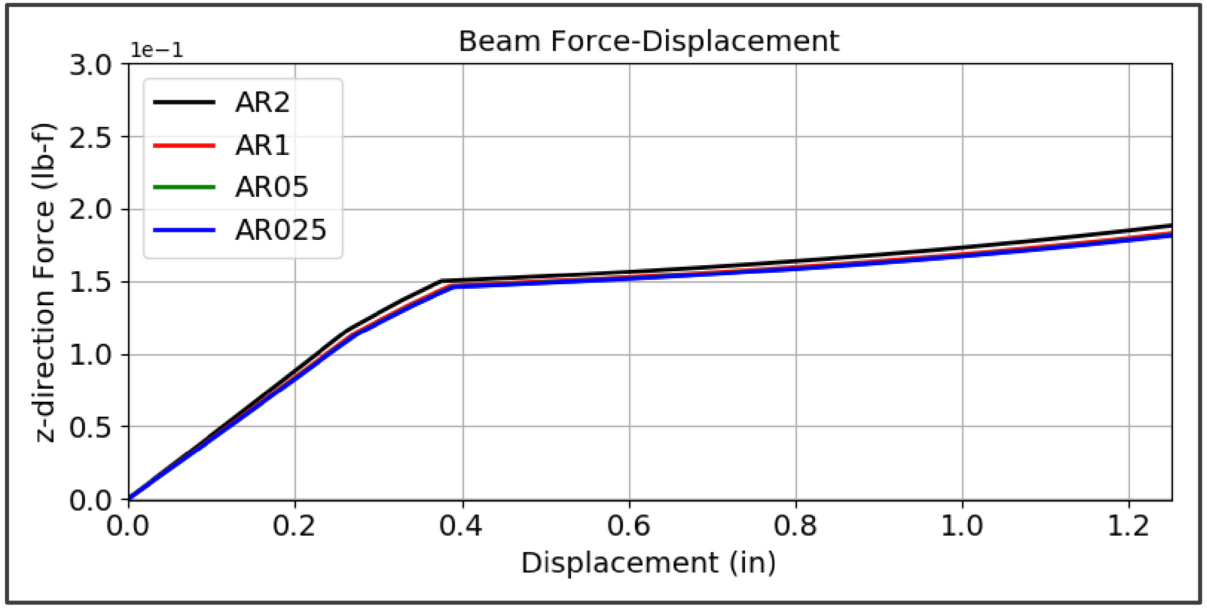


Spring Hex Model



Displacement Controlled – Force vs. Displacement

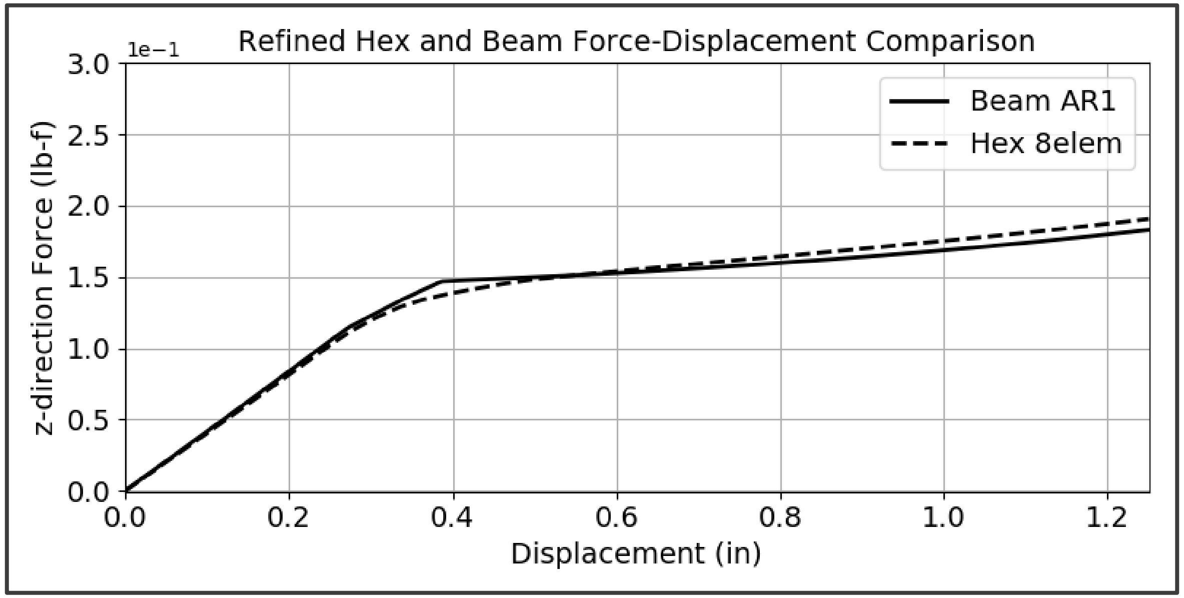


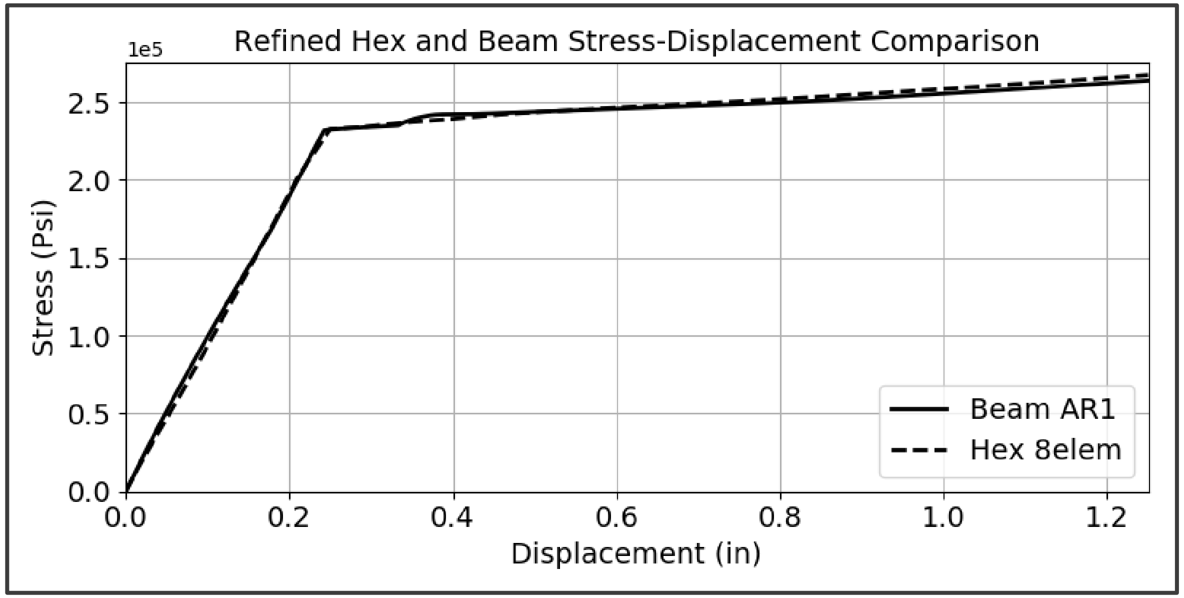


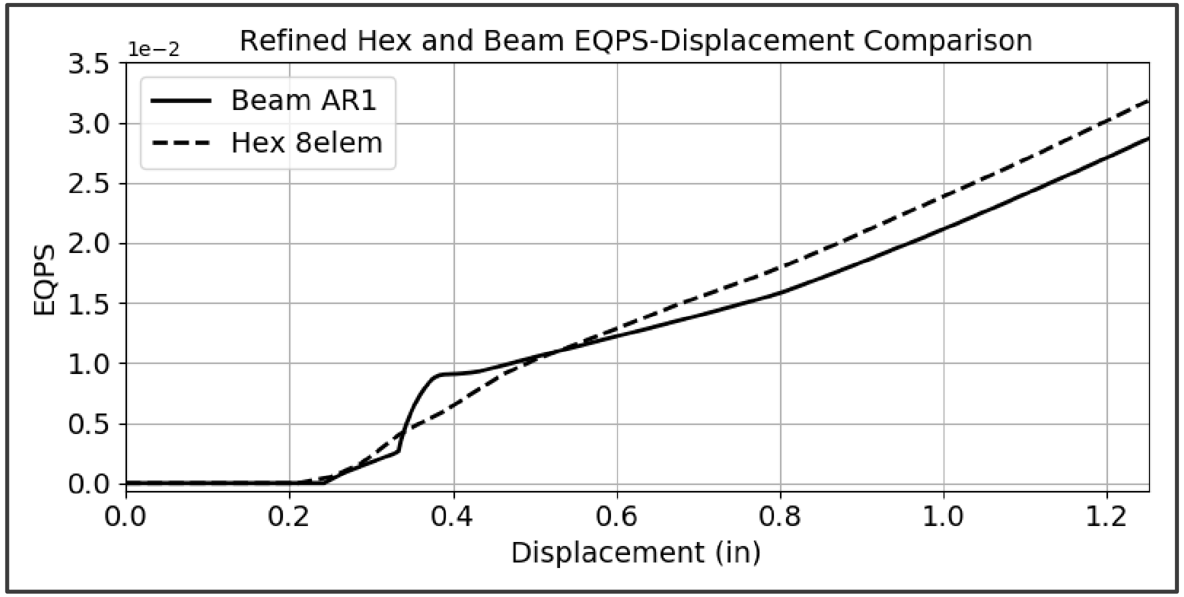
Hex model converges by 6 element mesh, beam model converges by aspect ratio 1.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	6 element	00:29:52	15	07:28:00
Beam	AR1	00:06:59	1	00:06:59

Displacement Controlled – Hex/Beam Model Comparison





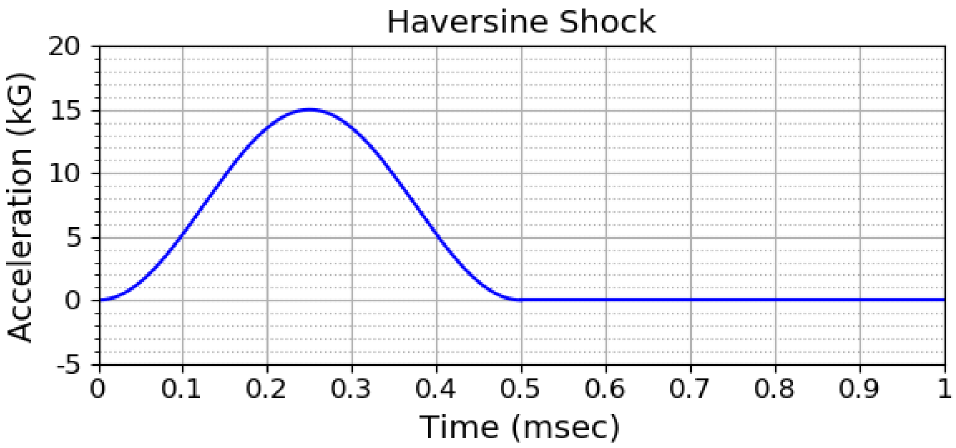


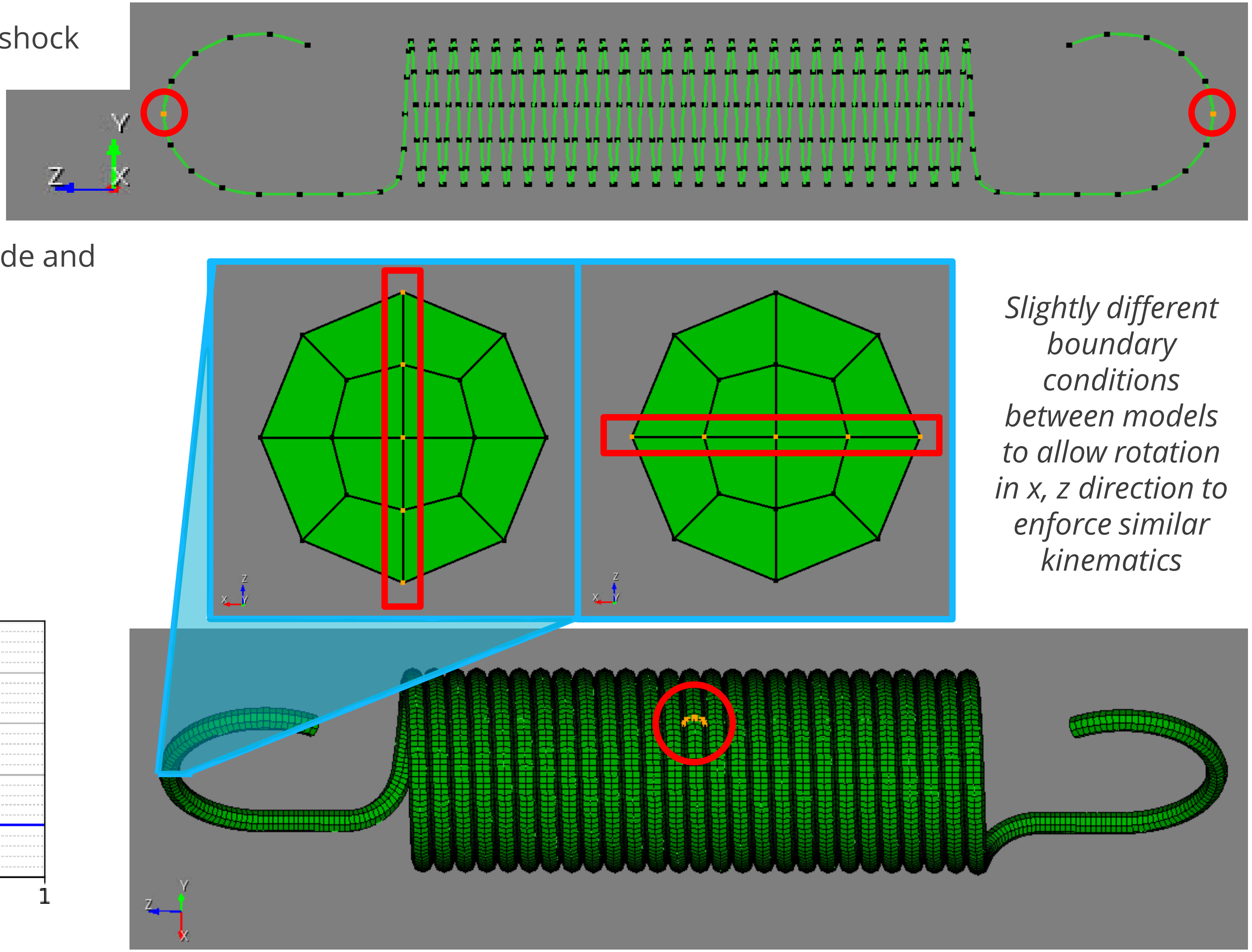
Stress, EQPS, and Force results are qualitatively acceptable

- Some slight deviations, but overall behavior is appropriate

Haversine Shock, Explicit Dynamics Setup

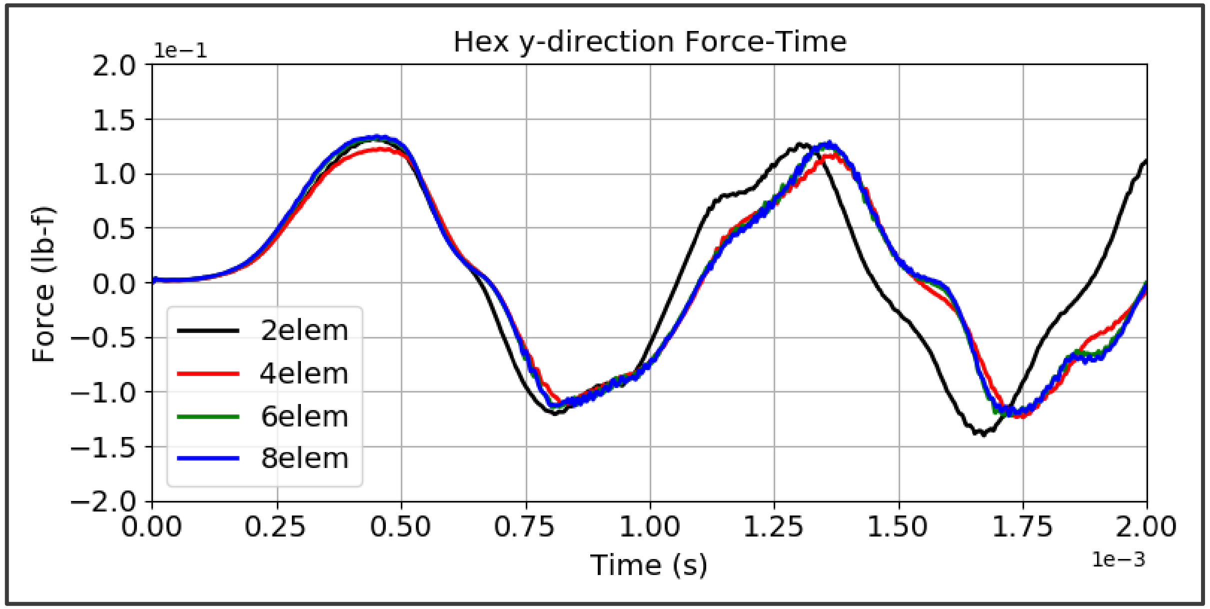
- Pre-stretch
  - The spring is stretched prior to applying the shock
- Boundary Conditions
  - Both hooks fixed in x, z direction
  - Hook ends allowed in-plane rotation only
  - Haversine shock in y direction, 15kG amplitude and 0.5ms full duration
- Quantities of Interest
  - Y-direction force on hook
  - Stress and EQPS as maximum over model
  - Y-direction coil displacement

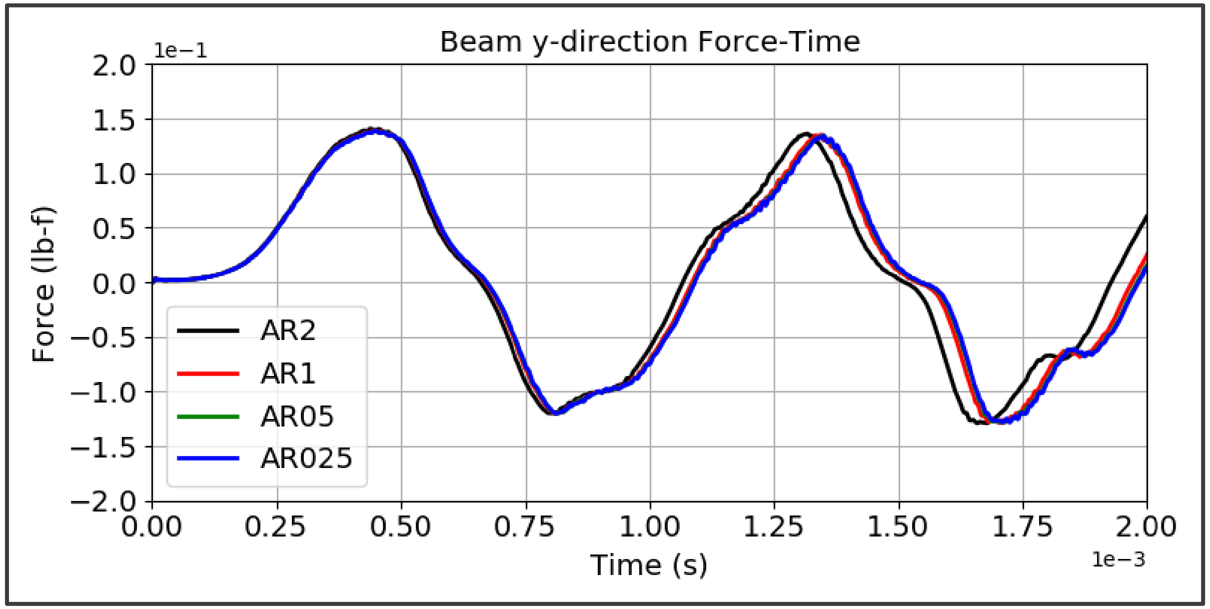




Slightly different boundary conditions between models to allow rotation in x, z direction to enforce similar kinematics

Haversine Shock– Force

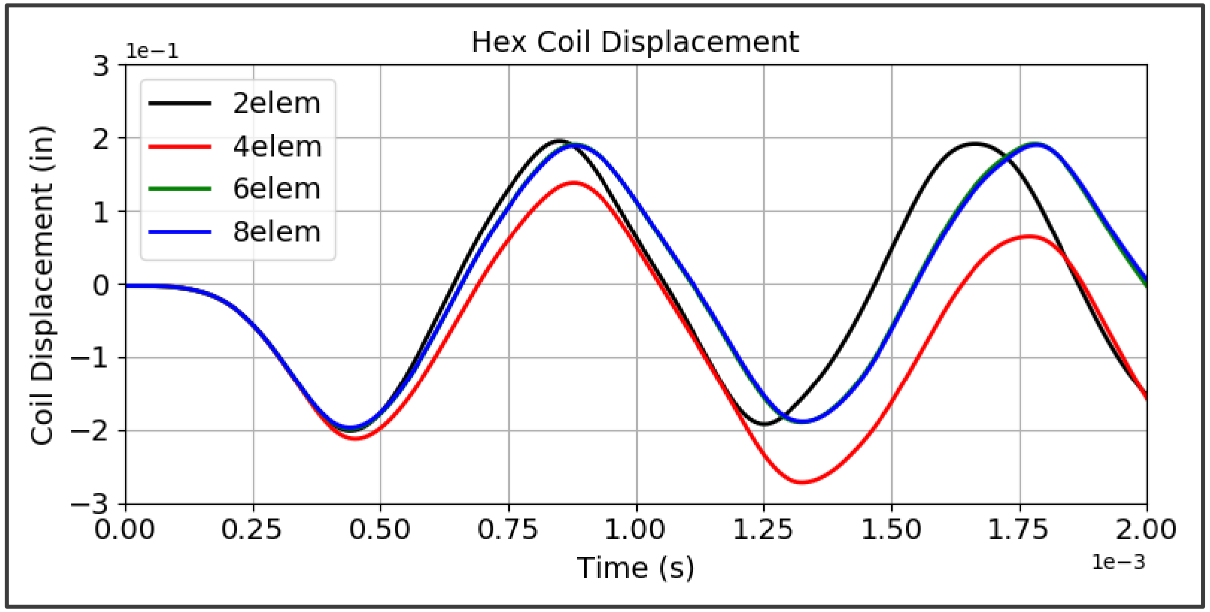


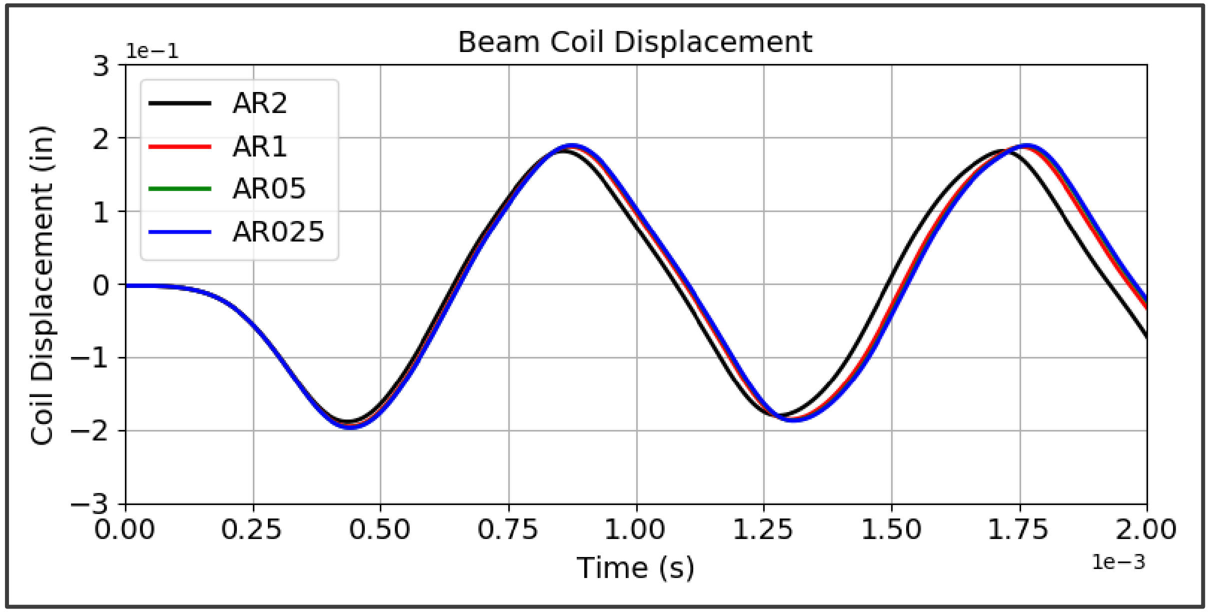


Hex model converges by 6 element mesh. Beam model converges by aspect ratio 1.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	6 element	20:13:44	20	16d 20:34:40
Beam	AR1	00:13:09	5	01:05:45

Haversine Shock– Coil Displacement

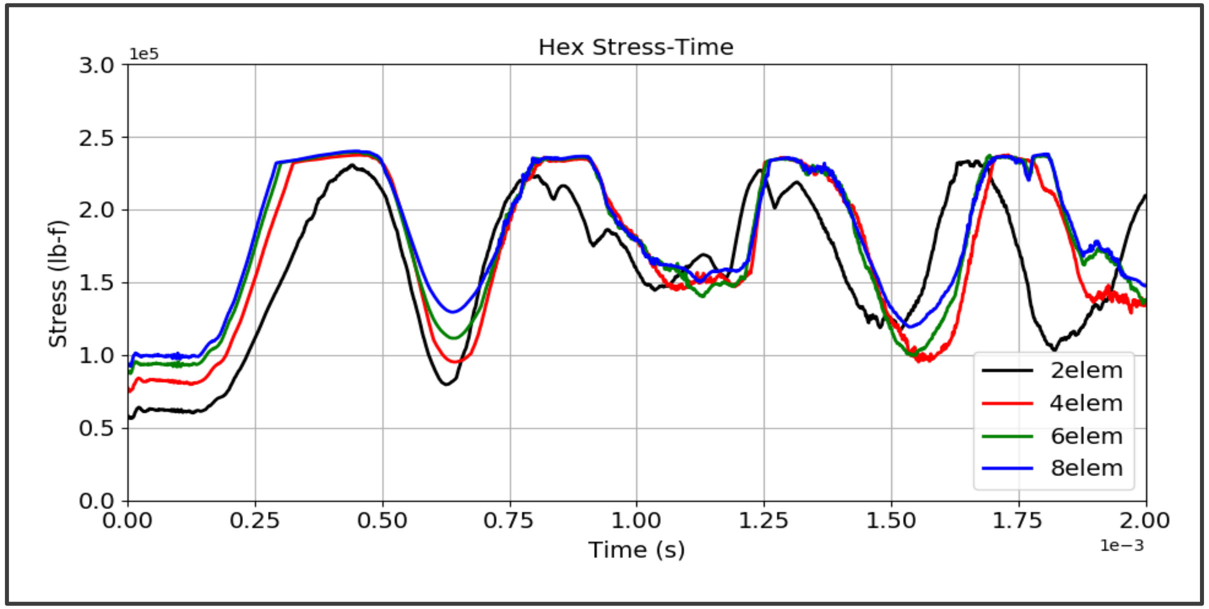


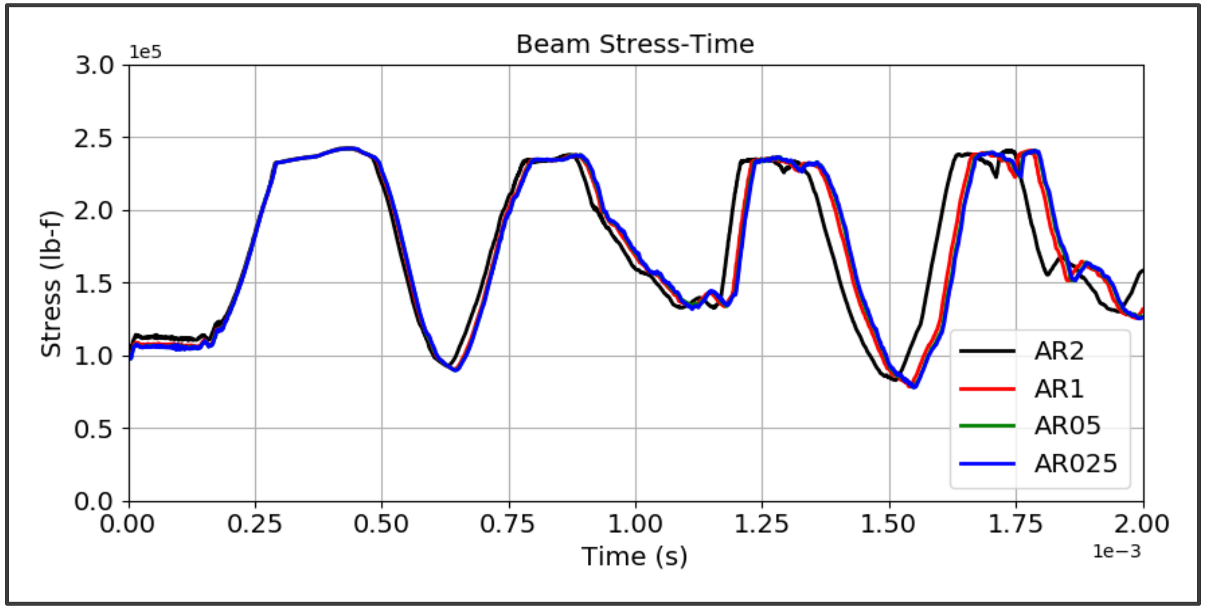


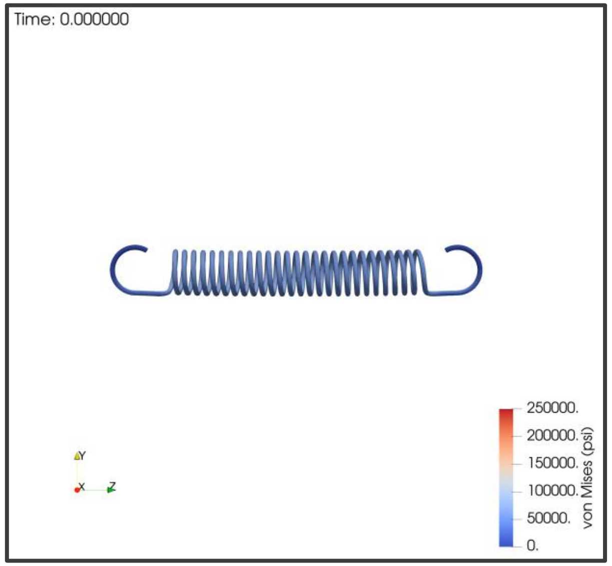
Hex model converges by 6 element mesh. Beam model converges by aspect ratio 1.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	6 element	20:13:44	20	16d 20:34:40
Beam	AR1	00:13:09	5	01:05:45

Haversine Shock– Stress

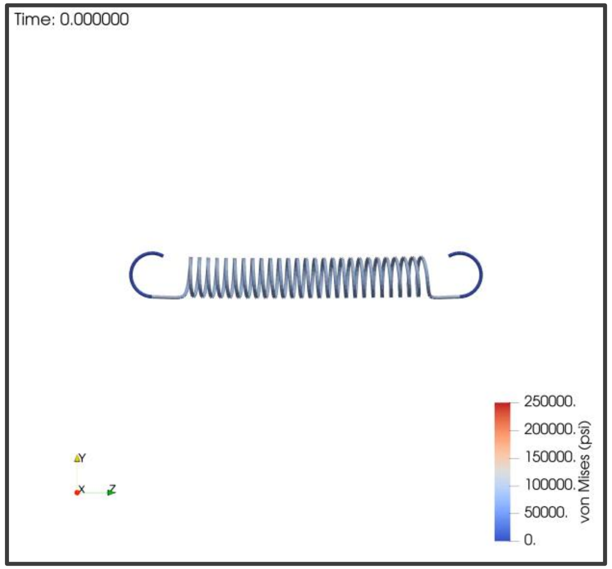




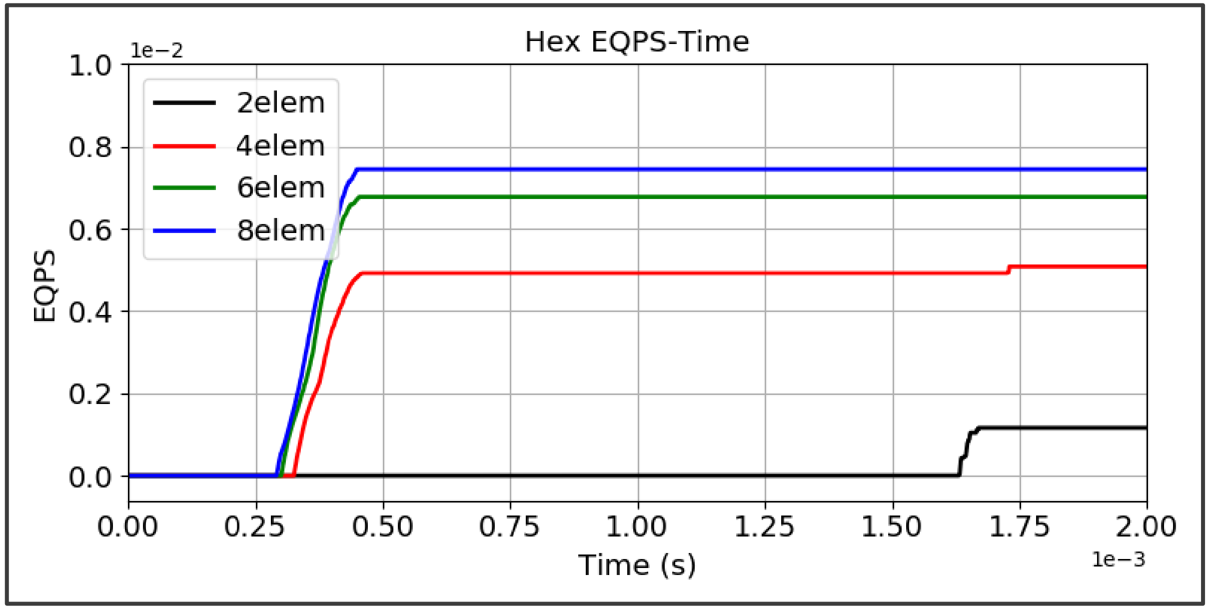


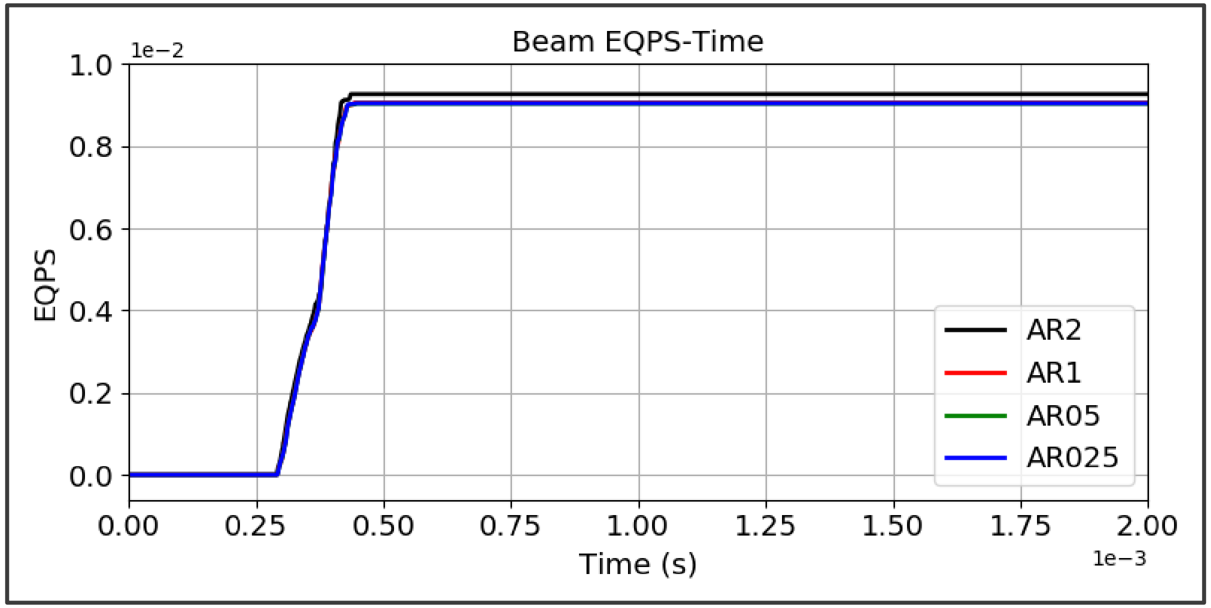
**No convergence for observed for hex model. Beam model converges by aspect ratio 1.*

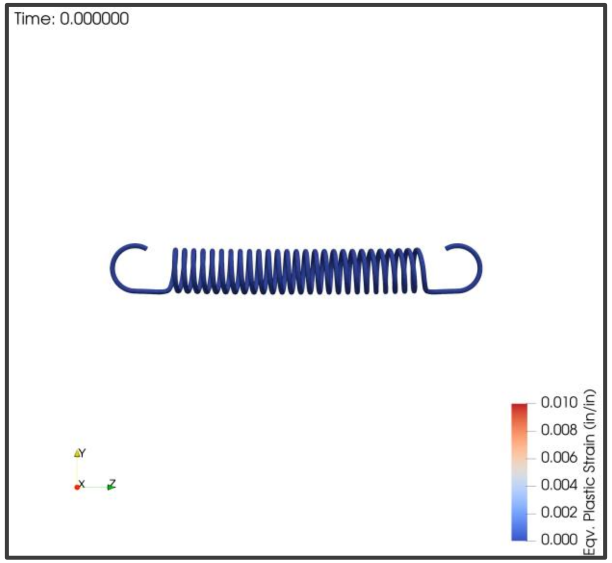
Model	Converged Mesh*	Time-to-run	Processors	CPU Time
Hex	8 element	41:49:46	40	69d 17:10:40
Beam	AR1	00:13:09	5	01:05:45



Haversine Shock– Equivalent Plastic Strain

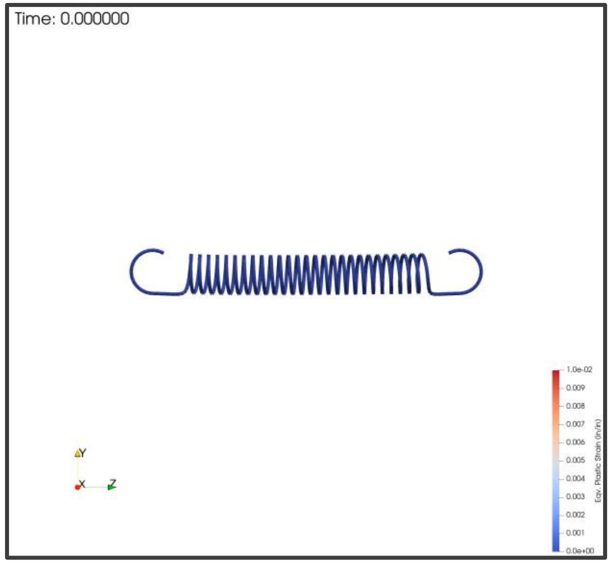




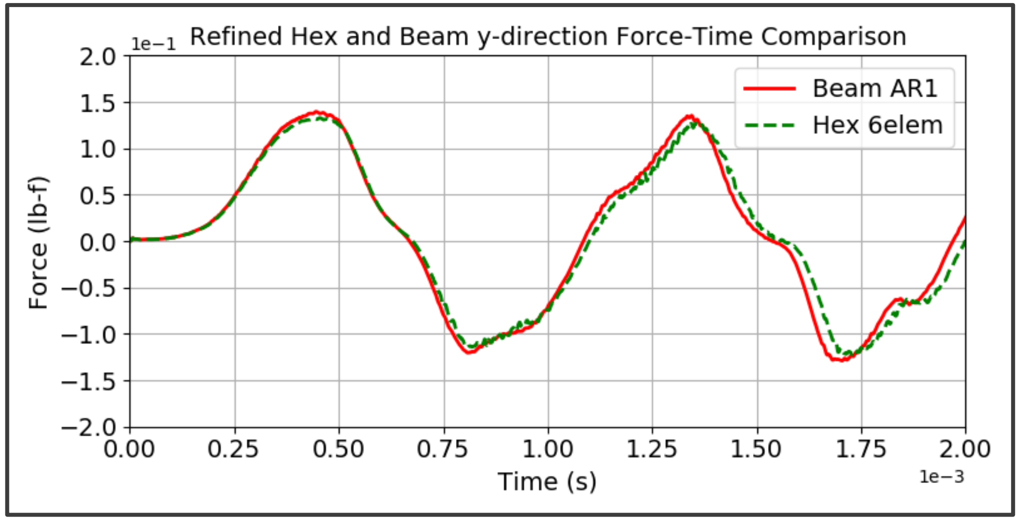


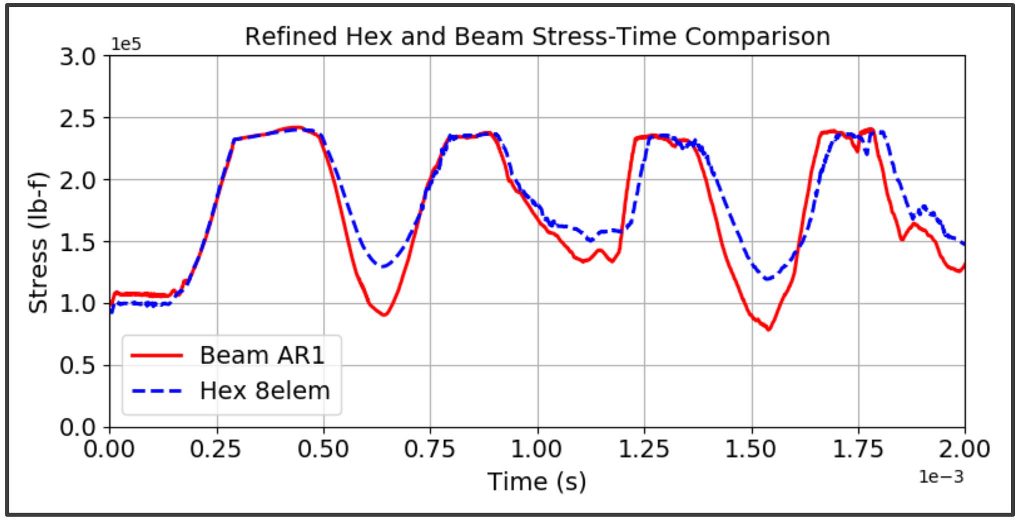
**Convergence process observed in hex model, but final maximum EQPS is different. More data will be needed to determine final converged mesh. Beam model converges by aspect ratio 2.*

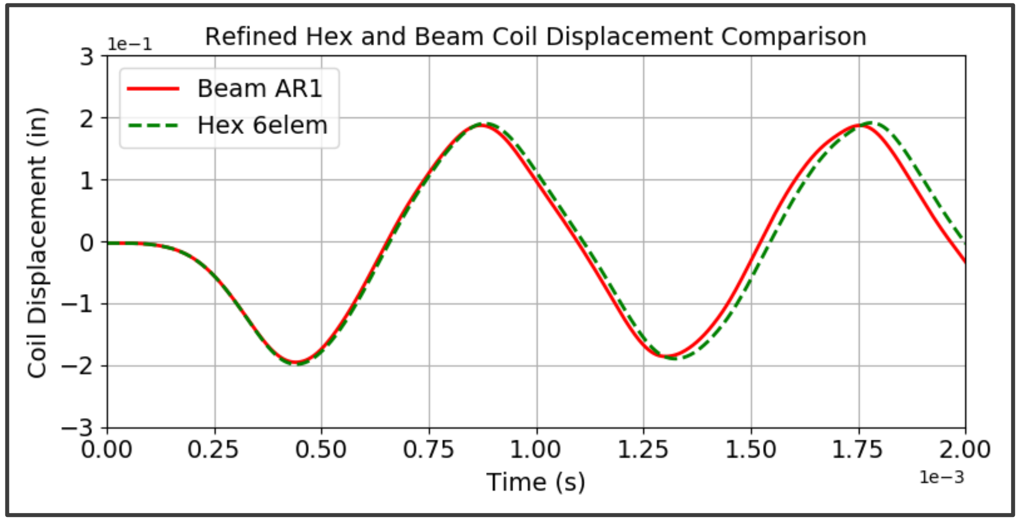
Model	Converged Mesh*	Time-to-run	Processors	CPU Time
Hex	8 element	41:49:46	40	69d 17:10:40
Beam	AR1	00:13:09	5	01:05:45

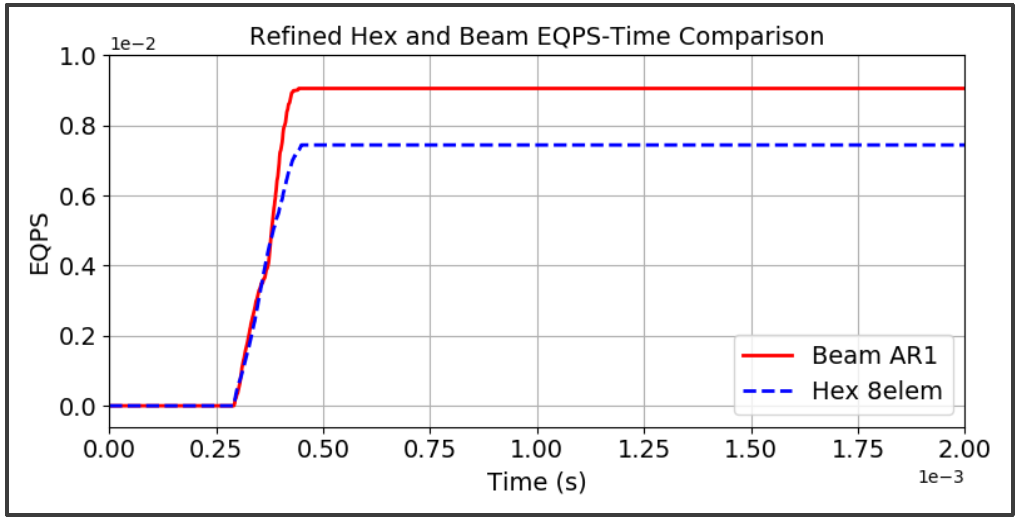


Haversine Shock – Hex/Beam Model Comparison









Conclusions

Suggested Uses

- Force and coil displacement (primary variables) show good agreement with the hex model
- Seeing convergence at an aspect ratio of 1 on all variables within beam model

Limitations

- More analysis needed to quantitatively determine accuracy
- Results may be dependent on spring geometry
- Stress and EQPS (secondary variables) need higher fidelity mesh for hex model to converge

Further Considerations

Current work

1. Continue assessment on current results
2. Test shocks of different magnitude, duration, and direction
3. Lofted beam surfaces study

In the coming weeks

1. Friction study
2. Mass correction
3. Solver tolerances study

Future goals

1. Spring calibration
2. Including spring post with contact interaction
3. Investigate other spring geometries

Acknowledgements

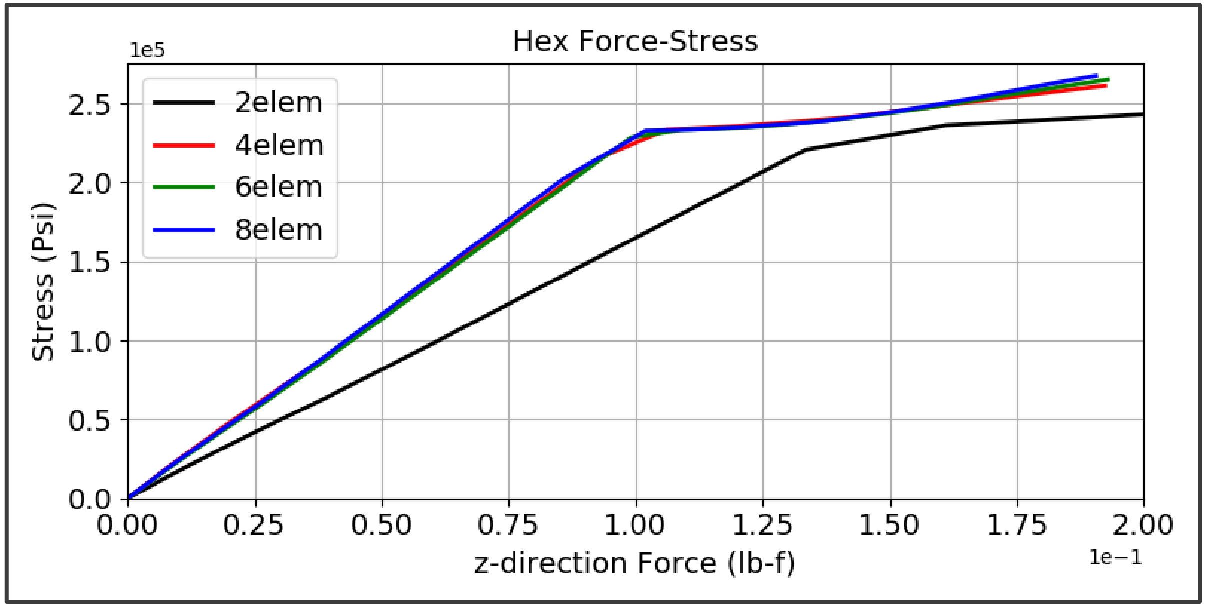
I'd like to thank my mentors Cory Medina and Jonel Ortiz for providing all of their help over the course of this project, as well as for taking the time to answer all of my questions! I could not have completed this project without them.

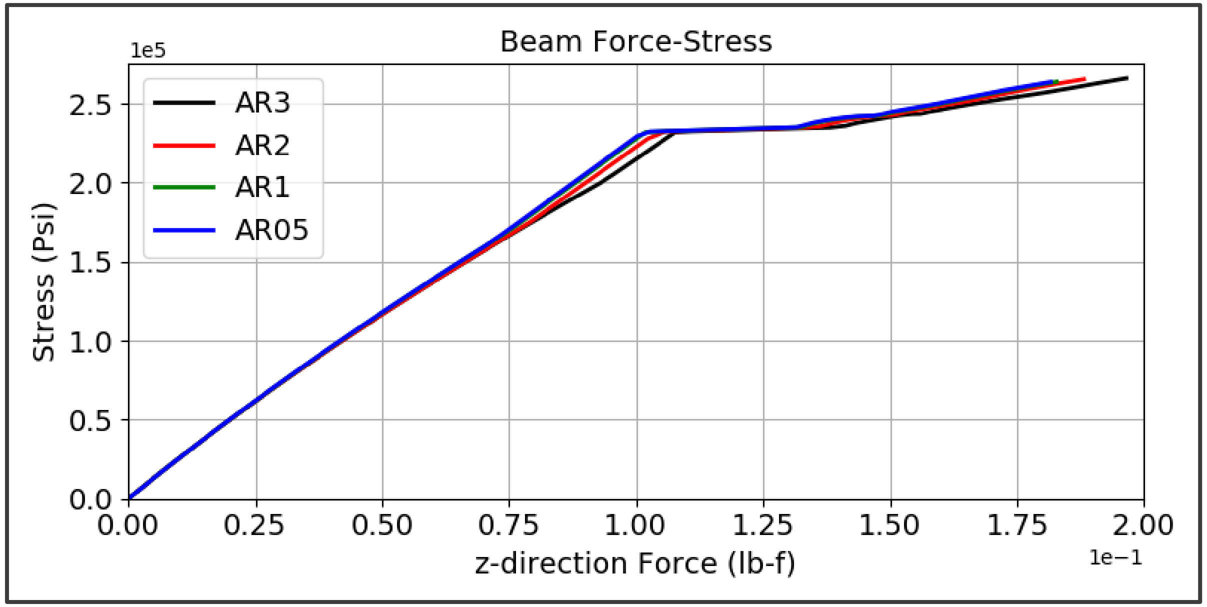
I would also like to thank my manager, Joe Bishop, and all of the staff in 1556 for making this a great summer experience!

And finally thank you to Sandia for providing me with this internship opportunity, and to all of the people working behind the scenes to make this happen, including the RAMS Institute Coordinator Kelsea Davis.

Thank you! Any questions?

Displacement Controlled – Stress vs. Force

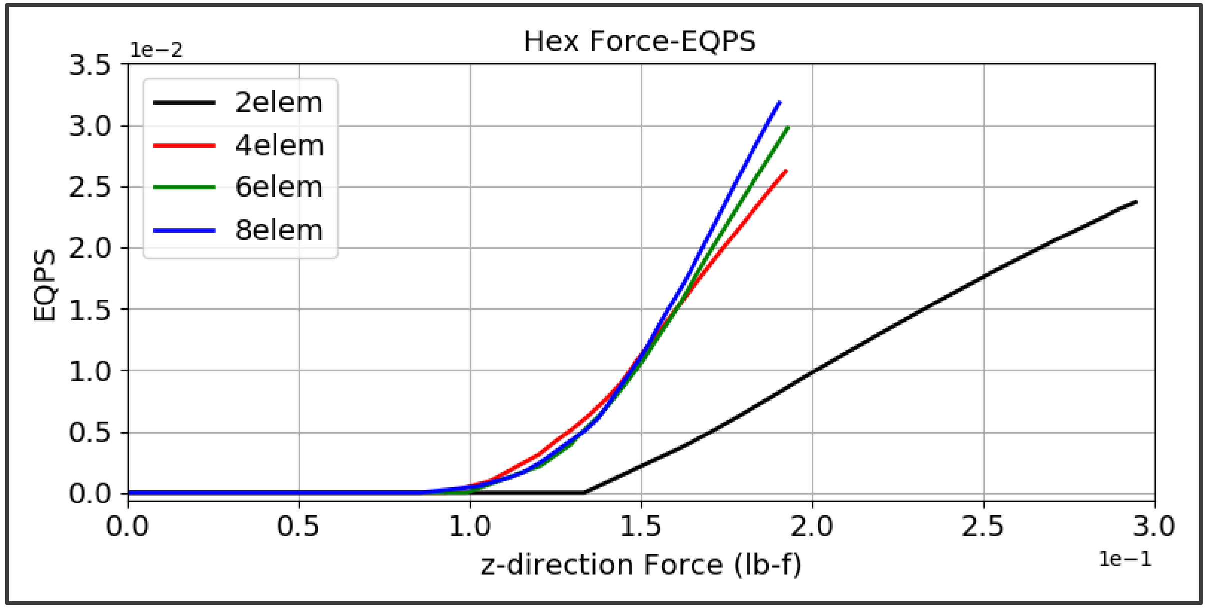


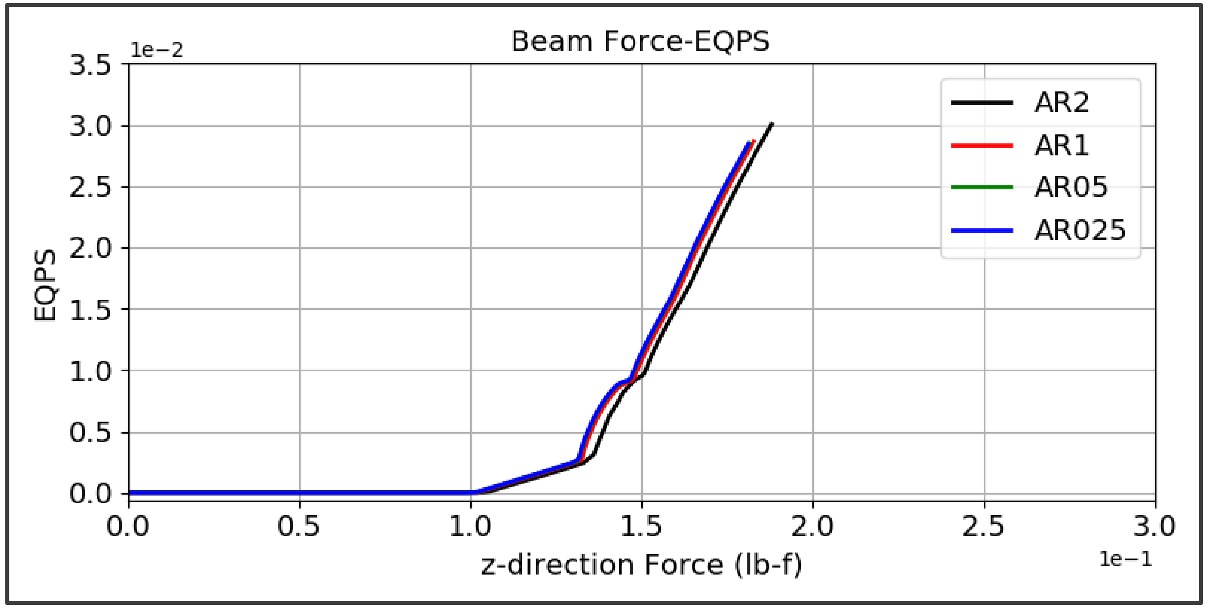


Hex model begins to converge at 4 element mesh, and fully converges by 6. Beam model converges by aspect ratio 2.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	Begins at 4 element	5min 59s	15	5min 58s
Beam	AR2	1min 26s	1	1min 25s

Displacement Controlled – EQPS vs. Force

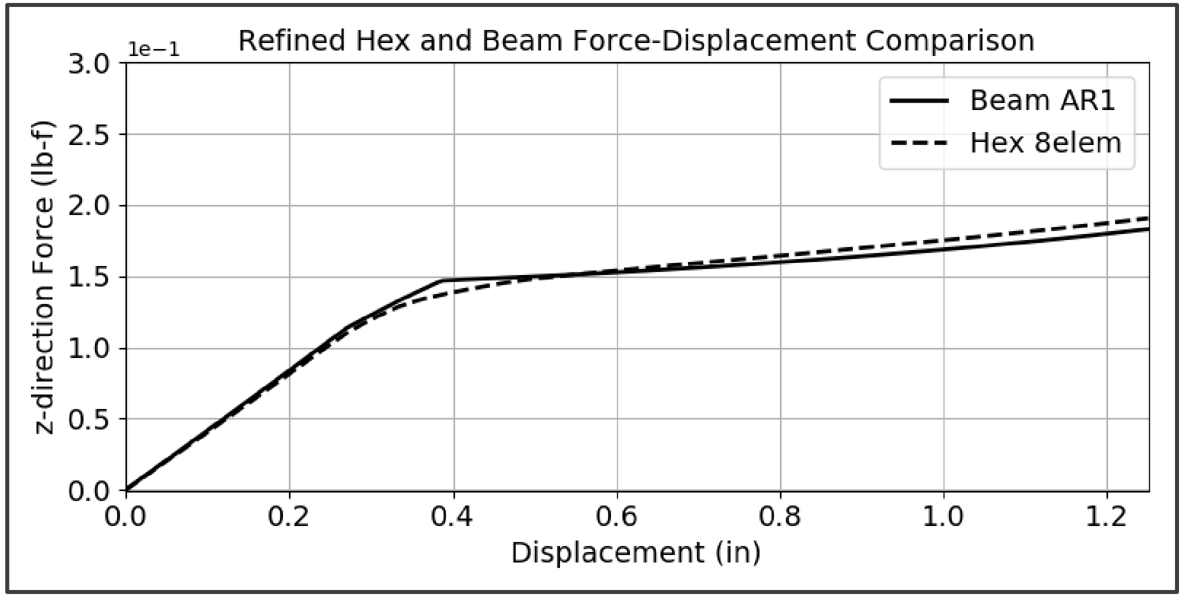


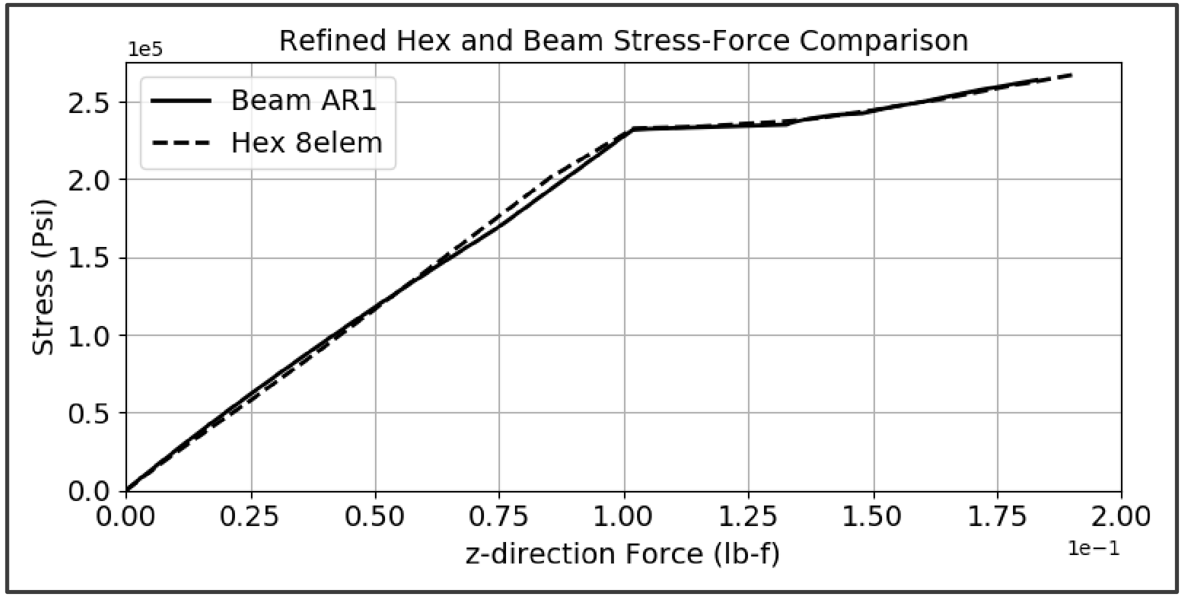


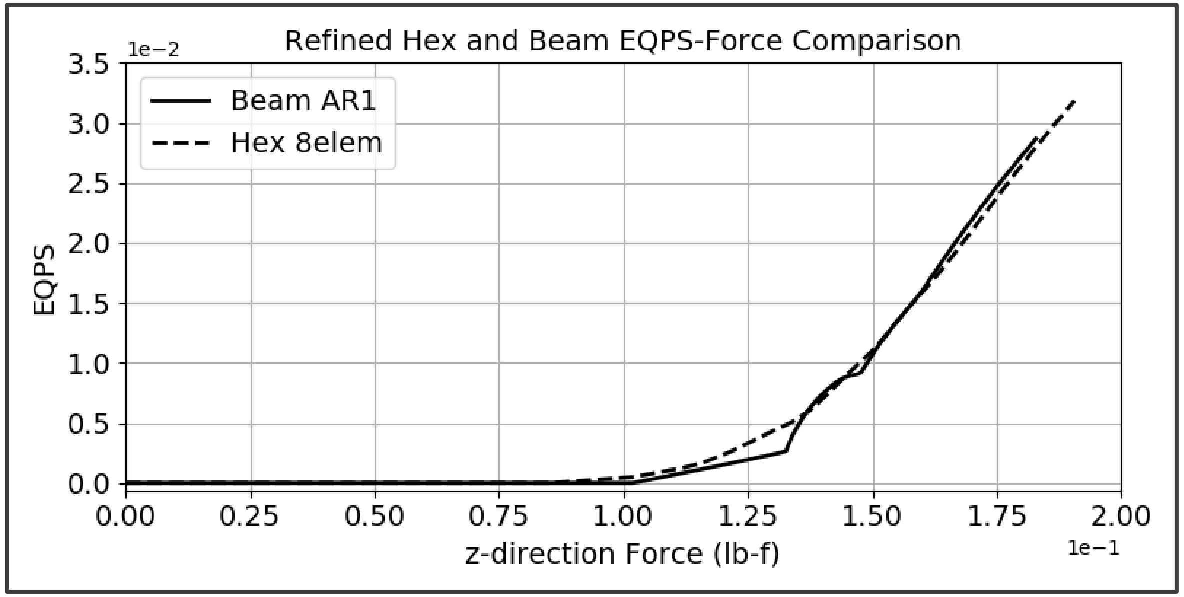
Hex model converges by 6 element mesh, but deviates from this convergence around 0.15 lb-f. Beam model converges by aspect ratio 1.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	6 element – deviation at 0.15lb-f	29min 52s	15	29min 51s
Beam	AR1	6min 59s	1	3min 56s

Displacement Controlled – Hex/Beam Model Comparison



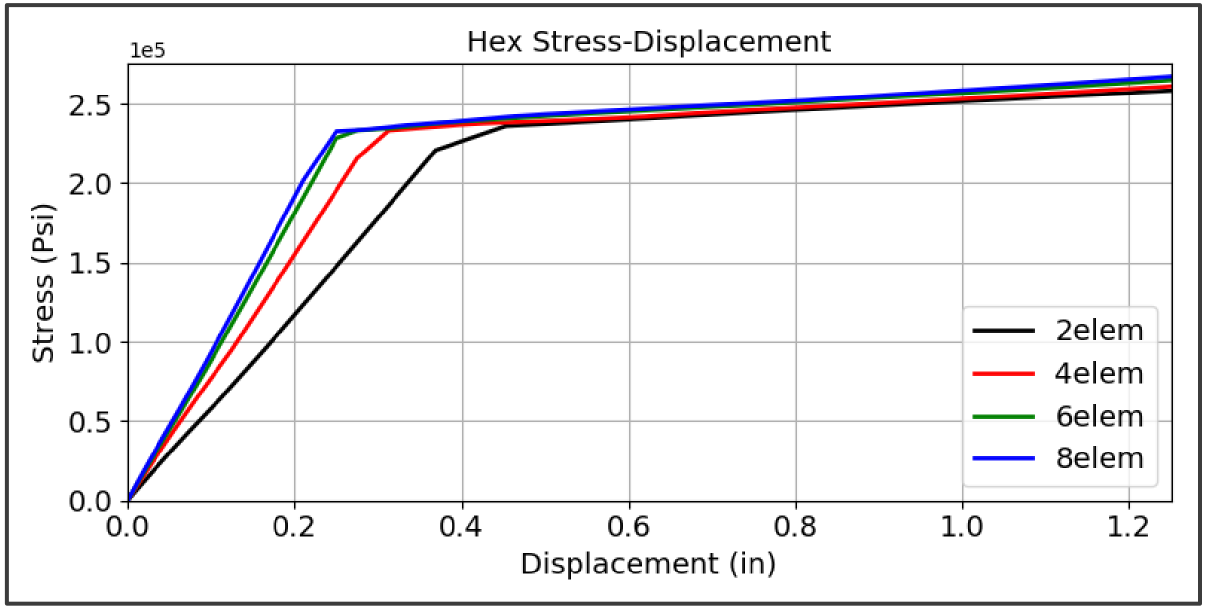


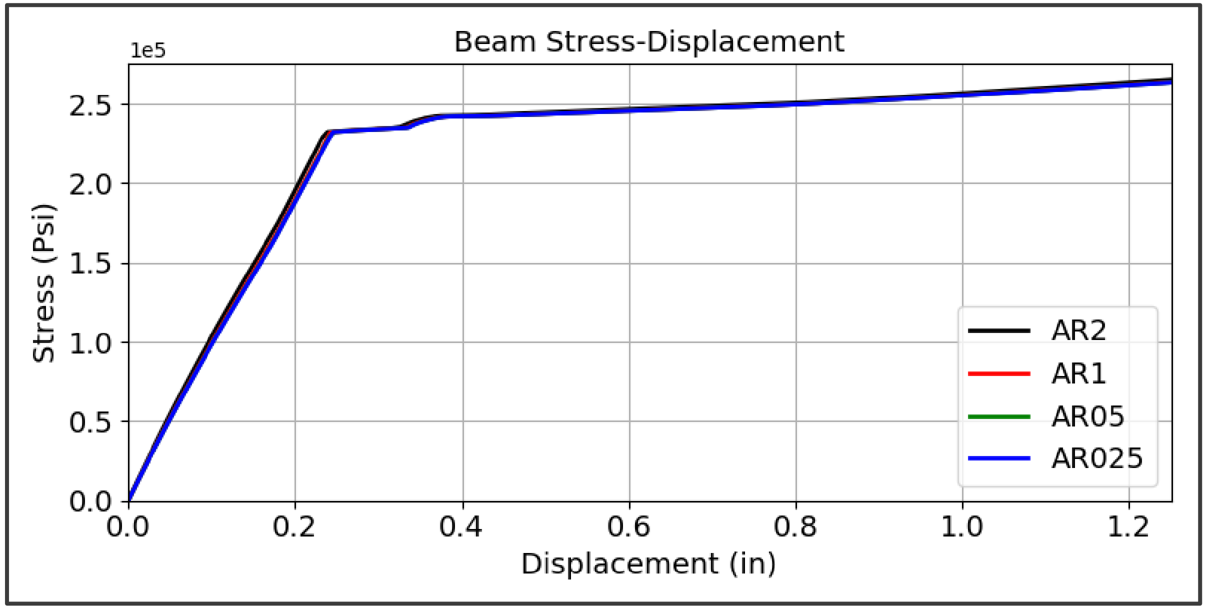


Stress, EQPS, and Force results are qualitatively acceptable

- Some slight deviations, but overall behavior is appropriate

Displacement Controlled – Stress vs. Displacement

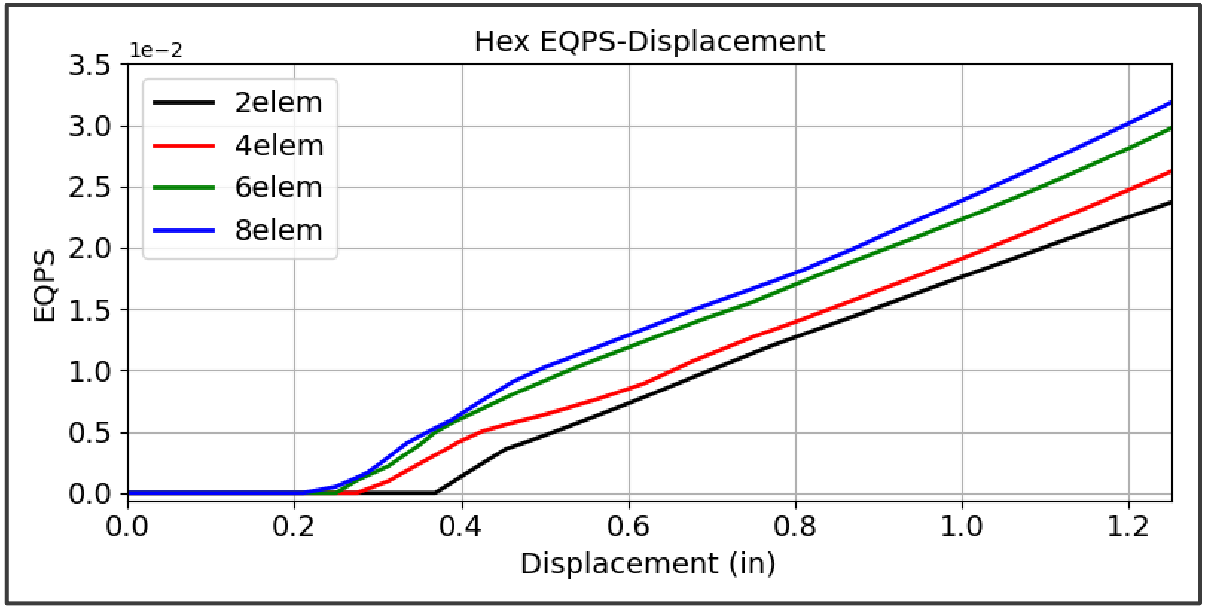


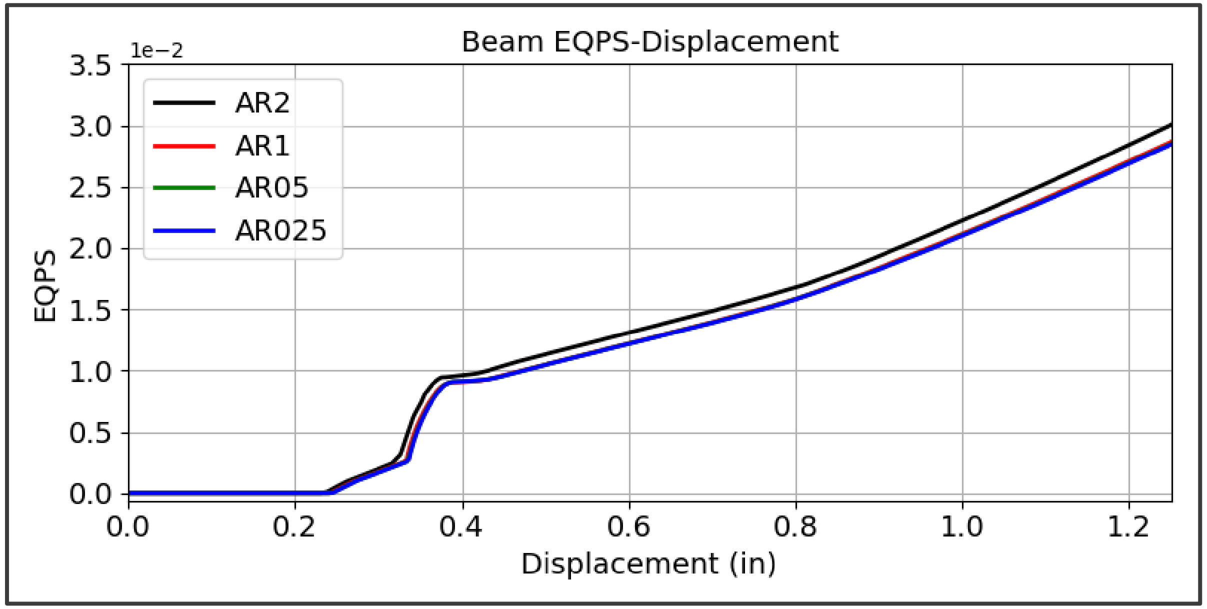


Hex model converges by 6 element mesh, beam model converges by aspect ratio 2.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	6 element	29min 52s	15	29min 51s
Beam	AR2	1min 26s	1	1min 25s

Displacement Controlled – EQPS vs. Displacement





Hex model starts to converge at 6 element mesh, but more data is needed to determine the actual point of convergence. Beam model converges by aspect ratio 1.

Model	Converged Mesh	Time-to-run	Processors	CPU Time
Hex	8 element	28min 42s	100	28min 2s
Beam	AR1	6min 59s	1	3min 56s