Design Optimization and Testing of Meta-Material Tank Track Pad

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Clemson Engineering Design Applications and Research

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Outline

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4. Investigation of Discrepancies
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    b. Boundary Condition Correctness
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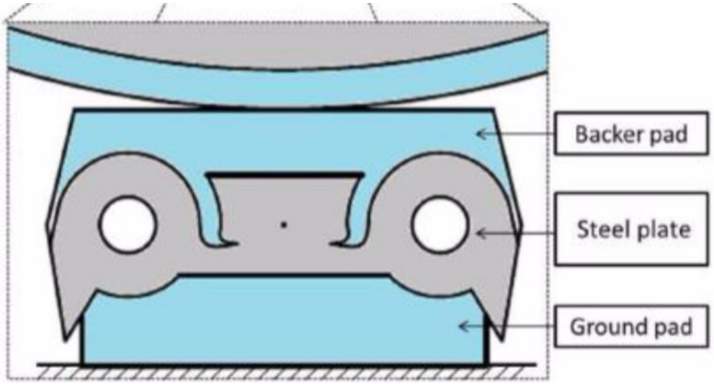
Section 1

BACKGROUND

Background

- Furthering the work of Neehar Kulkarni & Zach Satterfield
  - Original Goal: Develop/design a meta-material that exhibits non-linear deformation responses under loading conditions.
  - Aimed at replacing the rubber polymer backer pads of the M1 Abrams tank.
  - Blowout or deterioration of the current rubber pads is occasional, and changing them can be arduous.



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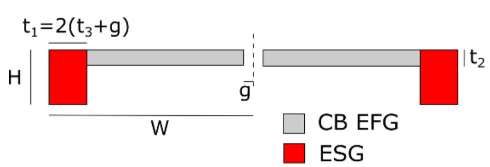
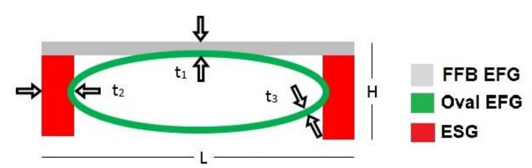
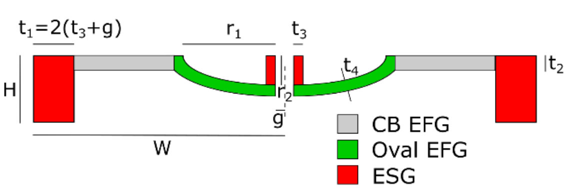
Background

- A unit cell synthesis method was developed for the design of meta-materials with non-linear responses
  - Utilizes several types of beams, set up in both series and parallel, much like resistors and capacitors in circuits
- Software Optimization
  - Using Abaqus and ModeFrontier, an optimized pad design was created to most accurately fit the polymer response curve
- Several designs were considered
  - Ultimately a canti-oval design was found to provide the closest mechanical response







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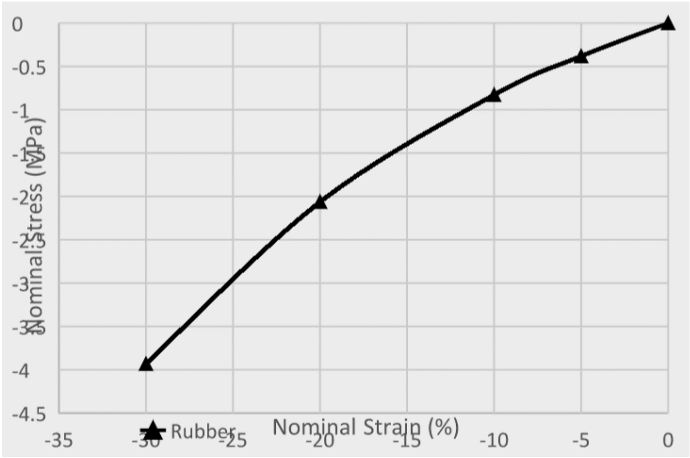
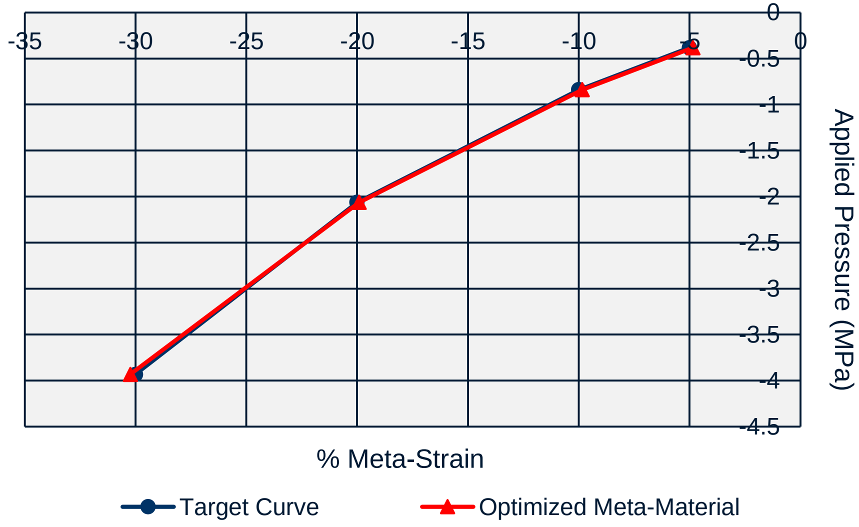
Background

NON-LINEAR RESPONSE OF RUBBER BACKER PAD



META-MATERIAL RESPONSE COMPARED TO RUBBER RESPONSE



- Titanium characteristics were used in the models, and a titanium alloy powder was used to print a physical specimen for testing.

Section 2

EXPERIMENTAL TESTING

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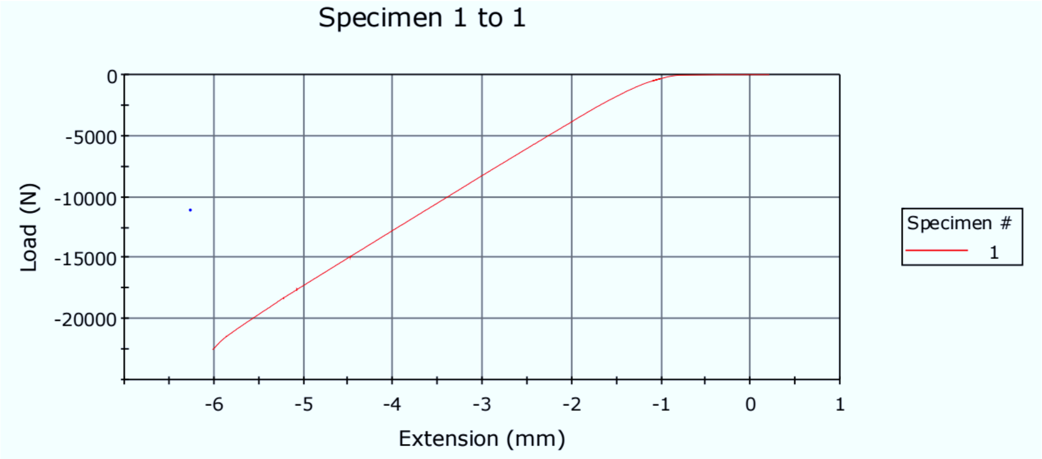
Experimental Testing

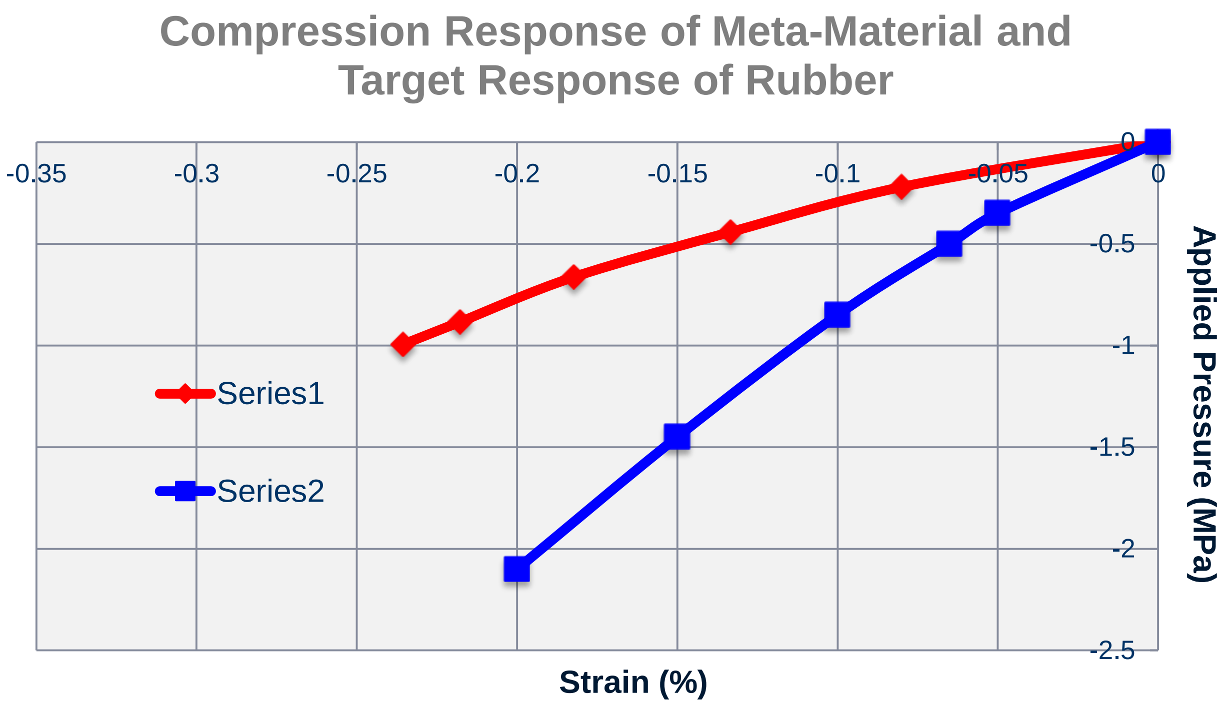
- Subjected the titanium pad to 5 loading conditions
  - 5kN, 10kN, 15kN, 20kN, 25kN

  - Graphed the extension of the load frame actuator vs. applied load



Experimental Testing

- Data Manipulation
  - Took the maximum extension at each load increment
  - Converted units: % Strain vs. Applied Pressure
  - Graphed new data with the expected results of the polymer pad



Section 3

RESULTS, OBSERVATIONS, & NEW RESEARCH QUESTIONS

Results

- Testing revealed that the pad does behave non-linearly when subjected to loading

- However, the displacements are much larger than expected at each loading increment
  - The displacement experienced at 2MPa in Abaqus was experienced at 1MPa in the testing

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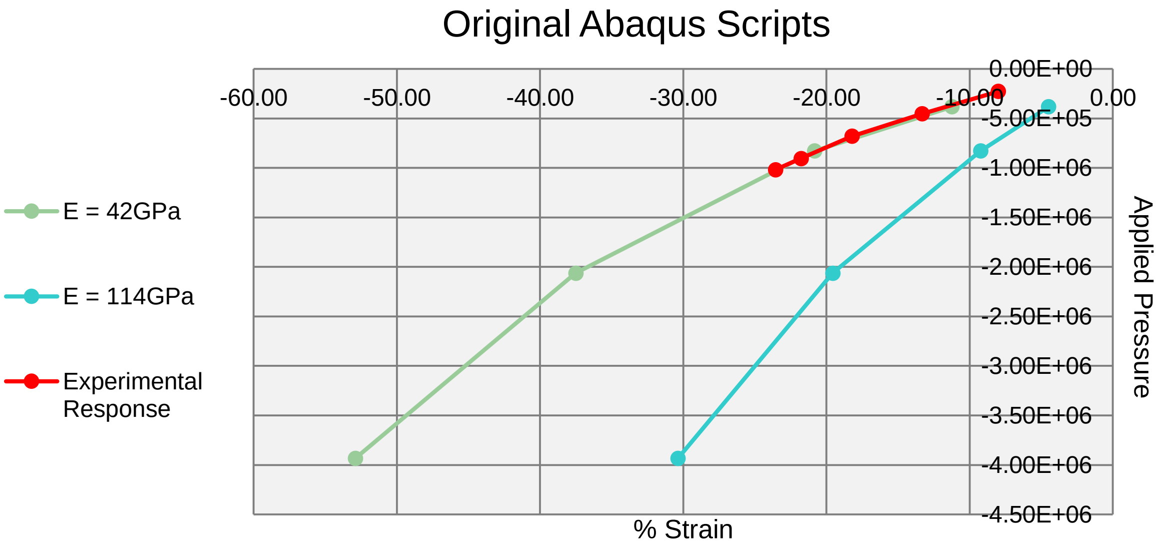
Observations

- Abaqus Manipulation
  - Concluded that the pad exhibited the response of a material with a Young's modulus of roughly 42GPa
    - Young's modulus provided by the manufacturing company for the powder batch was 114GPa
    - 2.5-3x larger



  - Combination of boundary conditions, dimensions, and assumed material properties could be the cause of discrepancies

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New Questions

- New questions were raised after experimental testing, aimed at explaining the unexpected differences

1. Can the differences in expected and observed responses be explained by the dimensional accuracy of the printing process?

2. Does adjusting the boundary conditions of the analytical model, to more accurately reflect the static testing, account for any of the discrepancy in results?

3. Are the material properties of the titanium powder in accordance with the material properties of bulk material, and do any differences help explain the result discrepancies?

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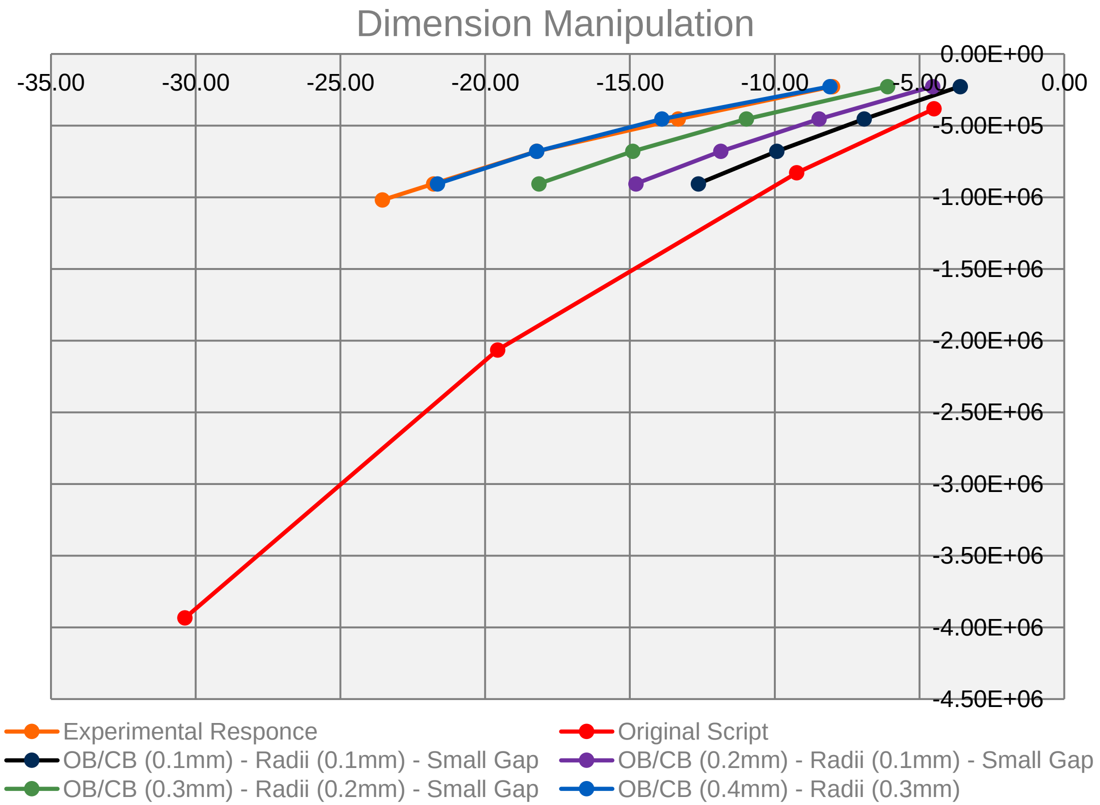
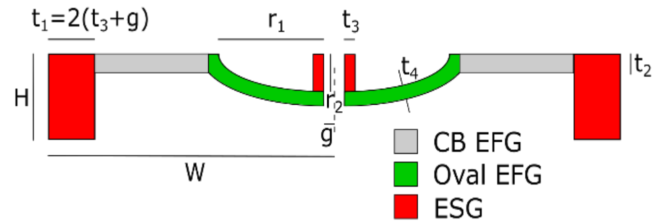
Section 4

INVESTIGATION OF DISCREPANCIES

Sensitivity Analysis of Dimensions

- The accuracy of the printing process is ± 0.1mm
- Adjusted the thickness of the oval and cantilever beam sections of the pad by 0.1mm increments
- Adjusted the radii of the major and minor axes of the oval beam by 0.1mm increments
- Required decreases of 0.4mm and 0.3mm respectively to fit the curve
  - Far larger than the 0.1mm accuracy



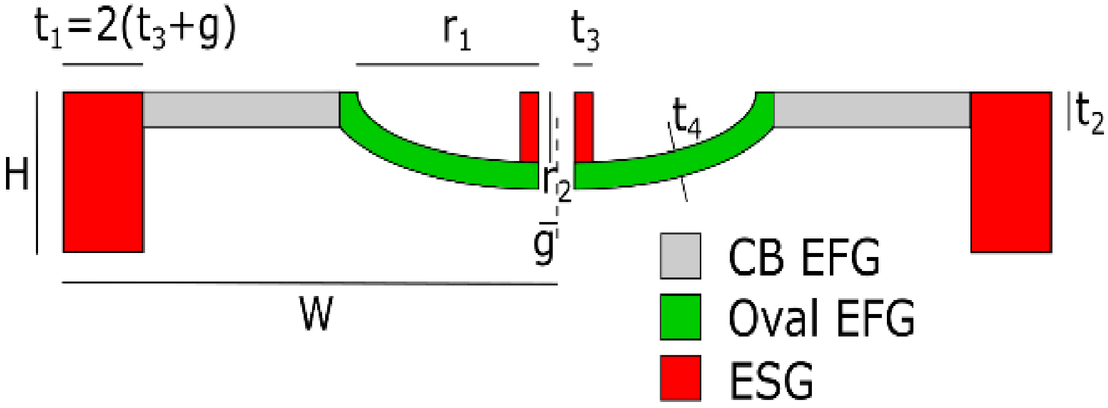


t_2 = CB thickness
t_4 = OB thickness
r_1 = OB major axis
r_2 = OB minor axis

D.O.E.

- In all, there are 8 independent dimensions established in the Abaqus script

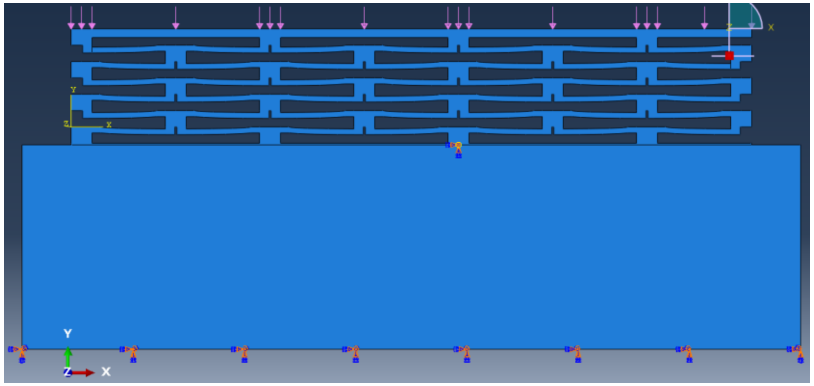
- Going to use an orthogonal array to study the effect of changing all 8 dimensions simultaneously



t_1 = ESG thickness
g = ½ gap
H = Unit cell height
W = ½ unit cell width

Boundary Condition Correctness

- Objective: To adjust the boundary conditions to more accurately reflect the static testing conditions
- Originally fixed bottom surface, allowed edges to slide in the y-direction
- Added a combination of top and bottom plates, much like the plates on the load frame
  - Added a combination of fixed/sliding points and surfaces



Boundary Condition Correctness

- Abaqus script has proved temperamental
  - No boundary condition combinations have run AND returned significant results
- We have identified a narrowed set of conditions that we are currently running
  - Utilizes sliding top plate and fixed bottom plate, with four uniaxial points under the same constraints

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Section 5

CONCLUSIONS

Conclusion

- Built a pad based on the dimensions of the optimized analytical model
- The pad displays non-linear deformation under loading conditions, as expected
- However, deformations are larger than expected
- Identified 3 potential causes for the discrepancies
  - Dimensional sensitvity
  - Boundary condition correctness
  - Future: Material property testing

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Section 6

FUTURE WORK

Future Work

- Tensile Testing
  - Samples produced by the same manufacturer, all be it with a different batch of powder
  - Allow for the measurement of material properties of the metal powder
  - Potentially explain the presence of discrepancies in expected performance

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Future Work

- High Cycle Fatigue
  - To replicate the repetitive high impact loading incurred by the pad
  - Use the load frame to simulate the tank road wheel, in a static environment
  - Using known data, we can determine the frequency of interaction
    - 500 miles of travel = approximately 53,000 interactions per pad

Using full track length

Speed	Wheel Interactions/sec	# road wheels	Seconds per interaction
45	1.325	7	0.755
40	1.178	7	0.849
35	1.031	7	0.970
30	0.883	7	1.132
25	0.736	7	1.359
20	0.589	7	1.698
15	0.442	7	2.264
10	0.294	7	3.396
5	0.147	7	6.793

Using corrected track length

Speed	Wheel Interactions/sec	# road wheels	Seconds per interaction
45	4.562	7	0.219
40	4.055	7	0.247
35	3.548	7	0.282
30	3.042	7	0.329
25	2.535	7	0.395
20	2.028	7	0.493
15	1.521	7	0.658
10	1.014	7	0.986
5	0.507	7	1.973

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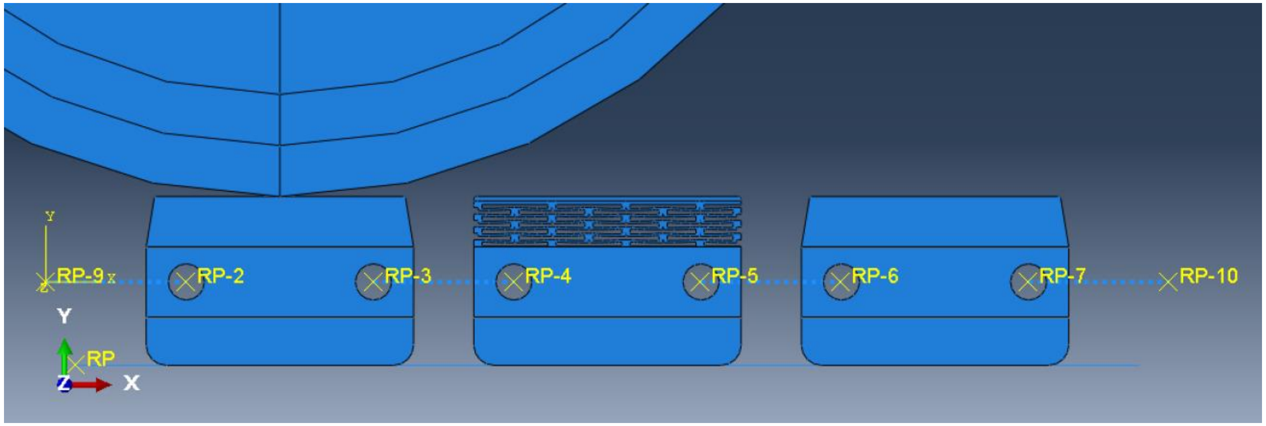
Future Work

- Dynamic Analysis of Wheel/Pad System
  - Use Abaqus or other high fidelity models to accurately depict the dynamic interaction between the road wheel and backer pads
  - Design a shear band for the road wheel to couple with the meta-material backer pad
  - Study the effect on the wheel/pad system



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Thank You!

Questions??

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