Accuracy Issues in the Simulation of Quasi-Static Experiments for the Purpose of Mesh Regularization

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Abstract

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Abstract

Generating a LS-DYNA material model from coupon-level quasi-static experimental data, developing appropriate failure characteristics, and scaling these characteristics to mesh sizes appropriate for a variety of simulation models requires a regularization procedure. During an investigation of an anisotropic material model for extruded aluminum, numerical accuracy issues led to unrealistic mesh regularization curves and non-physical simulation behavior. Sensitivity problems due to constitutive material behavior, small mesh sizes, single precision simulations, and simulated test velocity all contributed to these accuracy issues. Detailed analysis into the sources of inaccuracy led to the conclusion that in certain cases, double precision simulations are necessary for accurate material characterization and mesh regularization.

Outline

- Background & Characterization of Problem
- Investigation & Findings
- Conclusions and Suggested Steps

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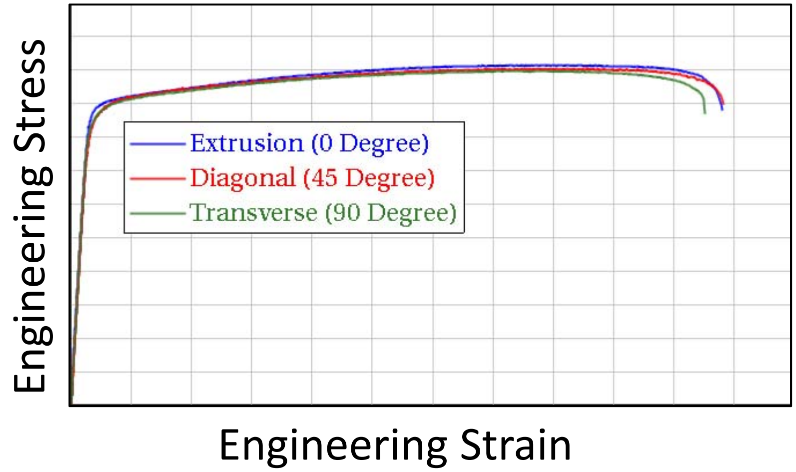
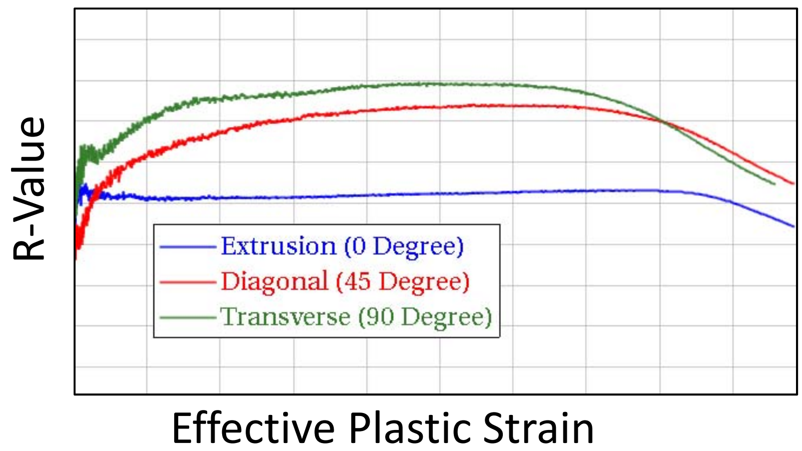
Background

- 6000 series extruded aluminum
  - High anisotropy in R-ratios
  - Little anisotropy in flow stress
  - *Mat_024 did not capture the correct failure mode
  - Used *Mat_036 to model the anisotropy





*Mat_024 vs. *Mat_036

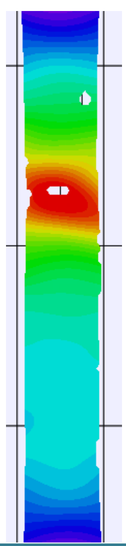
Extruded Aluminum
***MAT_024 -> *MAT_036**

*MAT_024

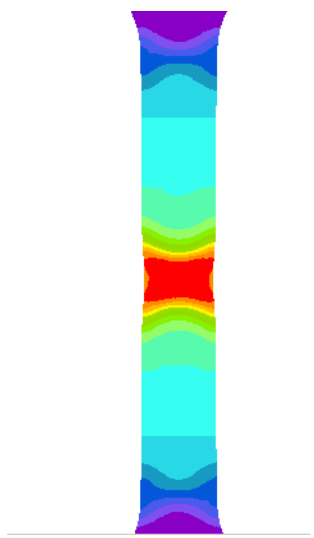
- Isotropic
- Input
  - One hardening load curve (0 degree direction)

*MAT_036

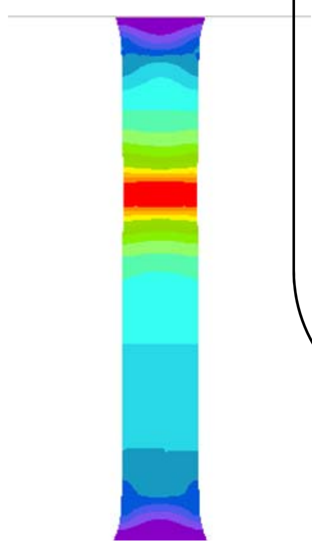
- Anisotropic
- Inputs
  - Three strain hardening load curves (0 degree, 45 degree, 90 degree directions)
  - R-values – 2 options:
    - Constant values in three directions
    - Load curve (R vs. Plastic strain) in each direction



Test DIC Data



*Mat_024 Contour

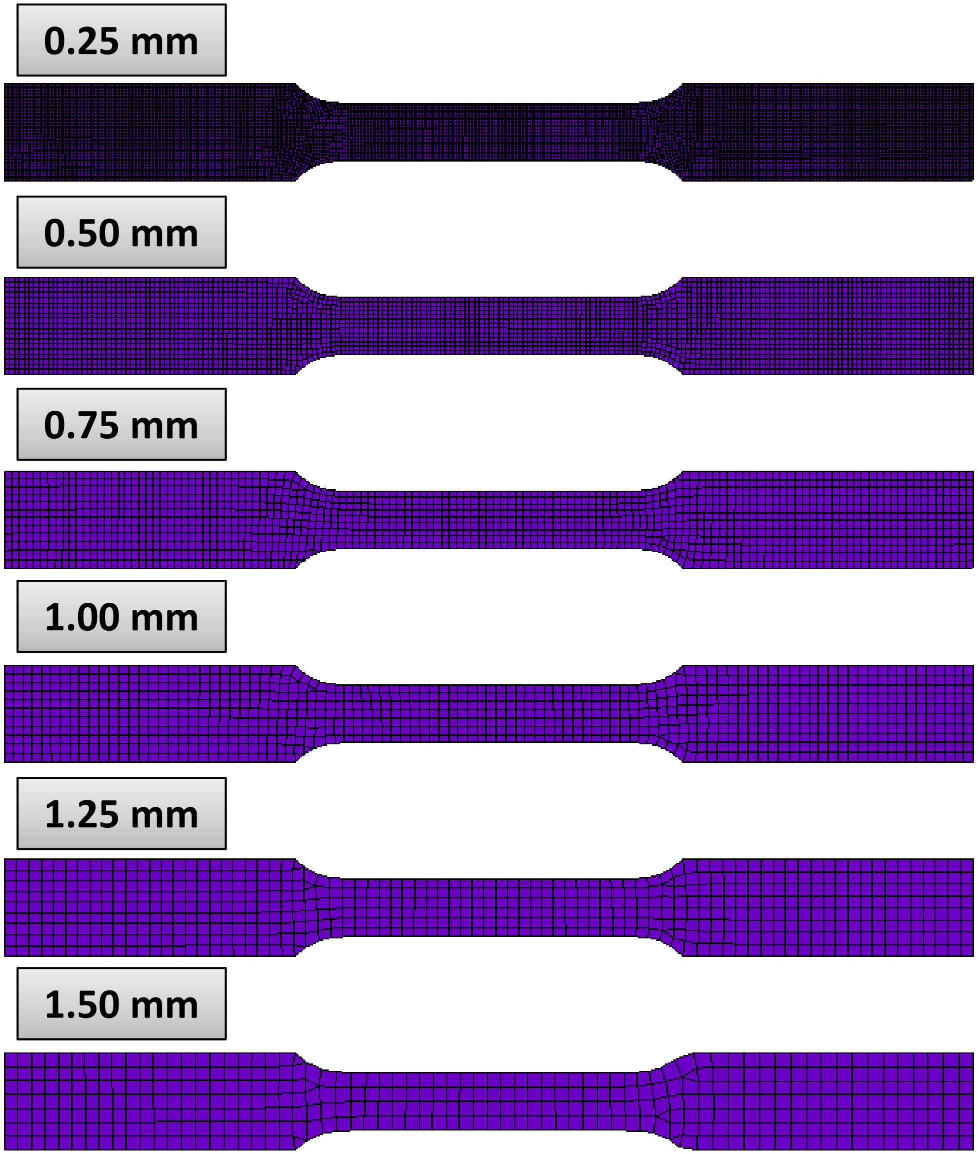


*Mat_036 Contour

$$R = \frac{\frac{dW}{d\varepsilon}/W}{\frac{dT}{d\varepsilon}/T}$$

Regularization Problems

- Mesh Regularization
  - Mesh regularization is the process of determining the effect of mesh size on failure strain.
  - Regularization curve: Plastic Strain @ Failure vs. Mesh Size
    - Extrapolated forward to apply failure strain at mesh sizes seen in full car models
  - Initially performed on only *Mat_036 in single precision
  - Investigation expanded to include double precision result

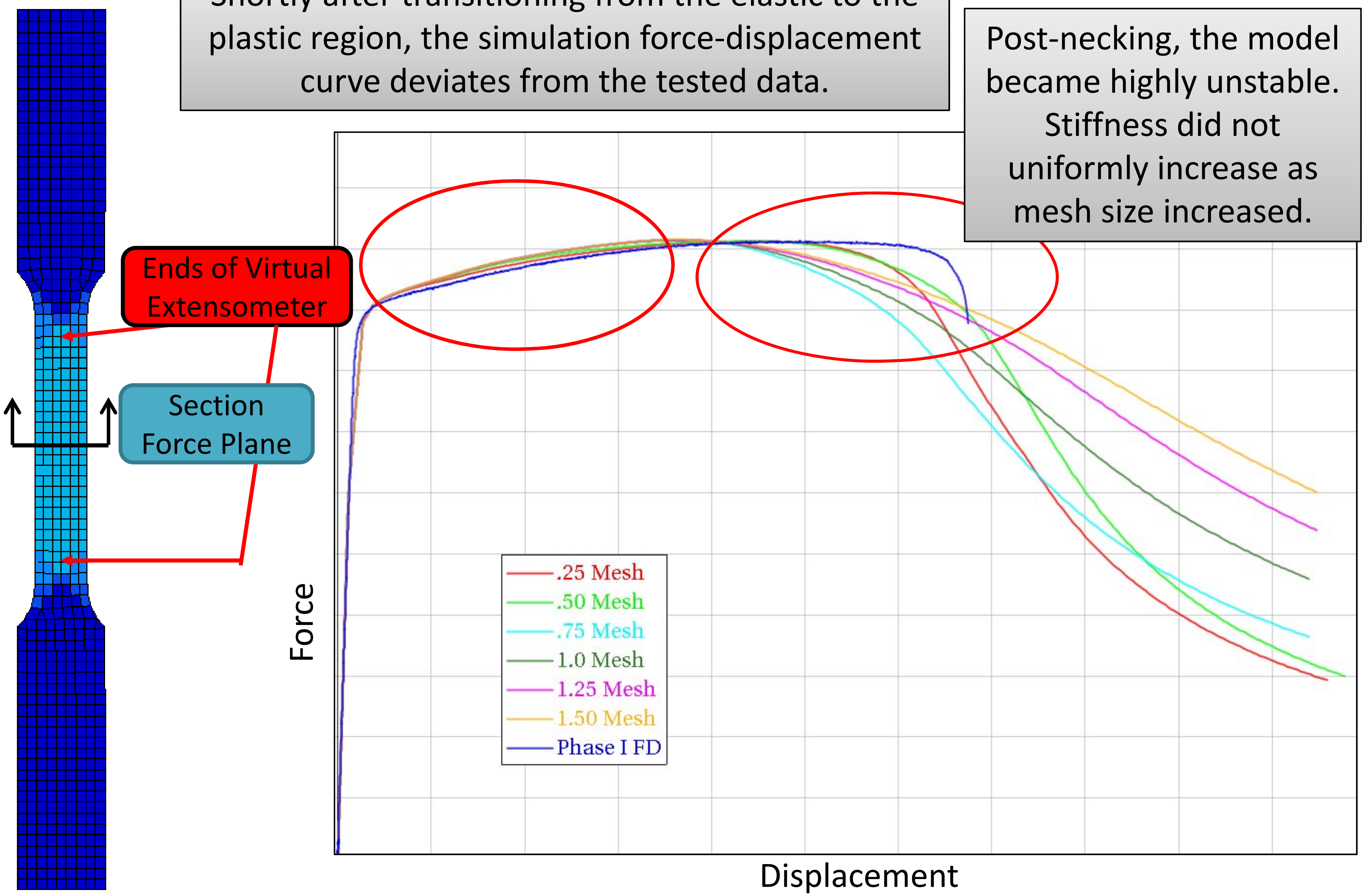


Mesh Regularization is required for implementing the material model with failure.

Mat 36 Mesh Regularization

Shortly after transitioning from the elastic to the plastic region, the simulation force-displacement curve deviates from the tested data.

Post-necking, the model became highly unstable. Stiffness did not uniformly increase as mesh size increased.

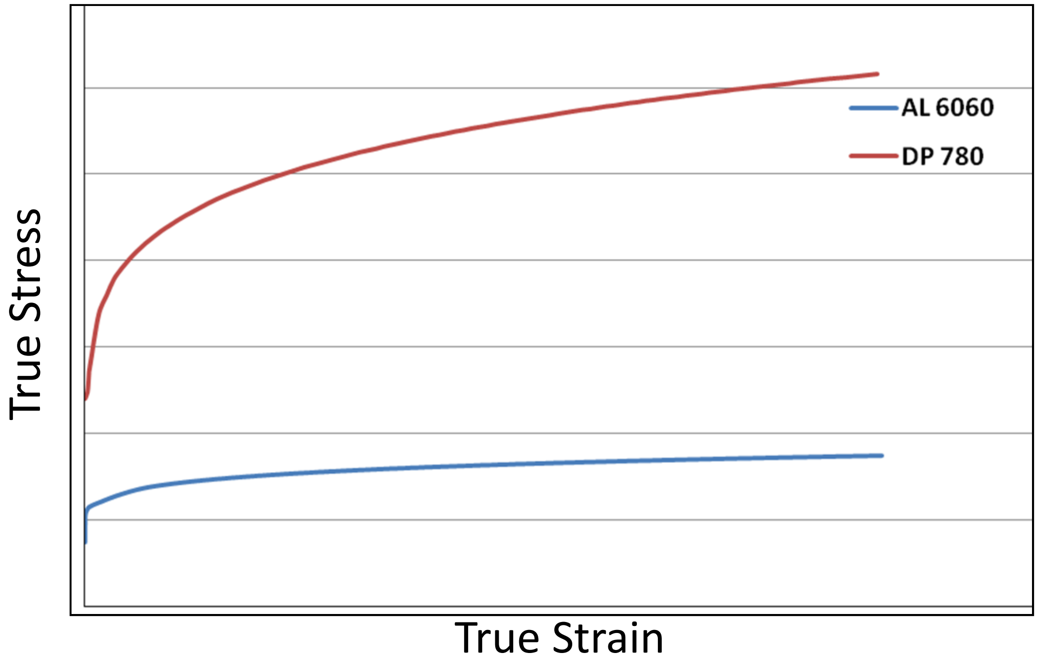


Mat 24 Mesh Regularization

***Mat_024 displayed the same deviation shortly after yield**

Sensitivity Complications

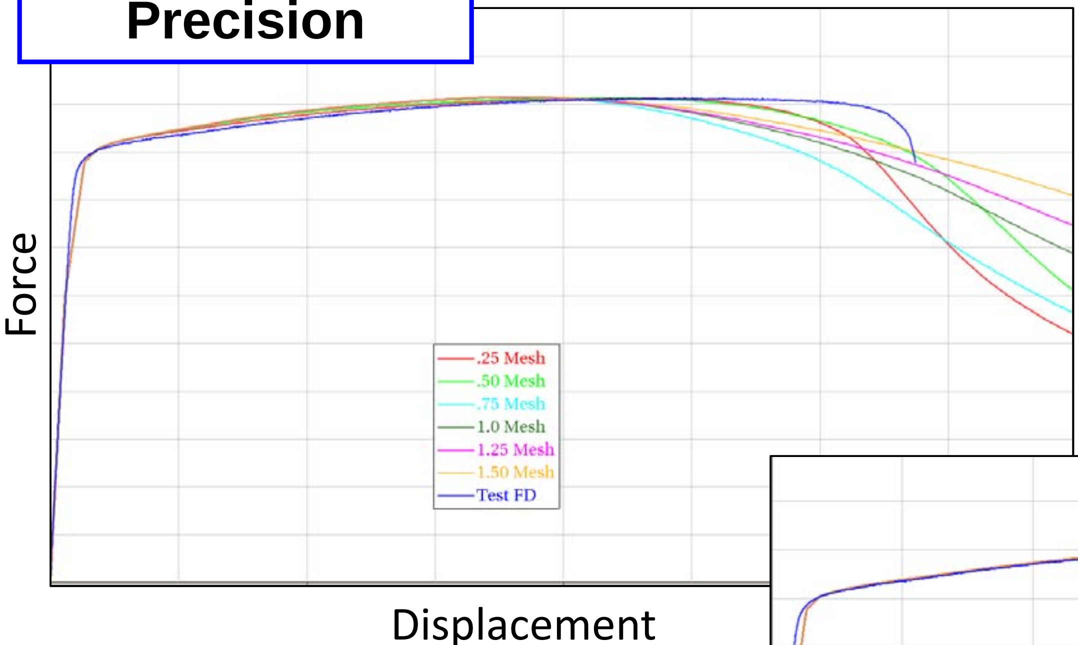
- These regularization results were highly sensitive
  - Slight changes to a range of variables led to very different results
  - We attributed the sensitivity primarily to the “flat” nature of the stress-strain behavior of this aluminum



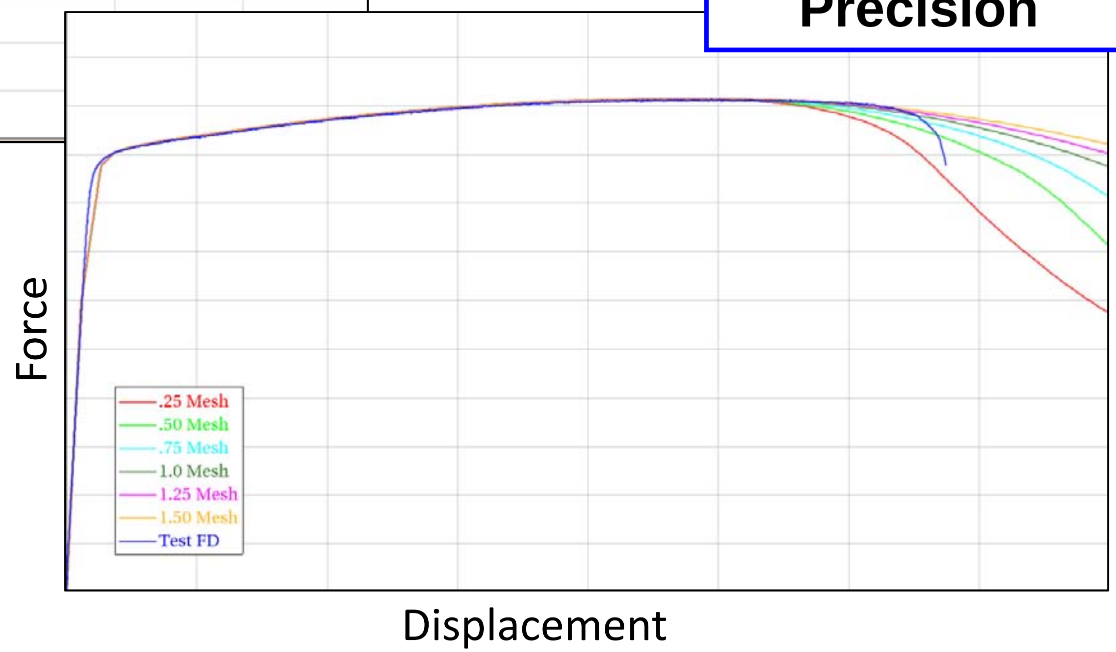
Single vs. Double Precision

Both problem areas (post-yield and post-necking) are fixed by running the simulation in double precision.

Single Precision



Double Precision



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Source of the Problem

- Due to a combination of our very fine mesh (L = 0.25 mm) and the slow testing rates which we were simulating (quasi-static), the model was producing over 3M cycles during the runtime.

    - Accuracy error was made clear by the drastic difference in single precision and double precision results.

    - Increasing the testing rate to compensate for this problem introduced dynamic effects into the results.

Tasks:

1) Identify the "single precision region" where the results are not negatively impacted by the number of time steps. (Single and double precision results are the same).

2) Identify the region that can be considered "quasi-static". (Changing input velocity does not change the results)

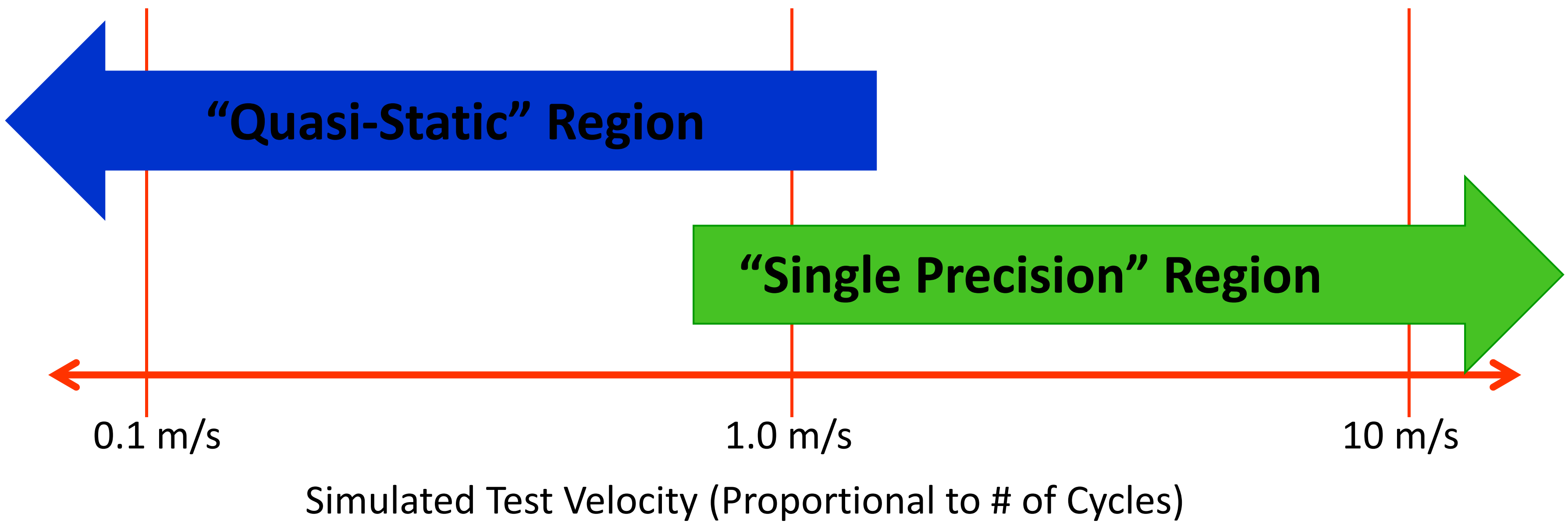
Objective

Purpose

Define a Solution Space

- **Ideally, an overlap will exist for the quasi-static region and the region where the number of time steps is acceptable.**

- **Regularization model tested with input test velocities ranging from 10 m/s to 0.1 m/s) in both single and double precision.**



Solution Space

Mat 24

Velocity. (m/s):	# Cycles	SP Region?	QS Region?
10	25512	YES	NO
2	127563	YES	NO
1	255125	NO	NO
0.5	510263	NO	YES
0.25	1020513	NO	YES
0.1	2551394	NO	YES

Mat 36

Velocity. (m/s):	# Cycles	SP Region?	QS Region?
10	25512	YES	NO
2	127563	YES	NO
1	255125	NO	NO
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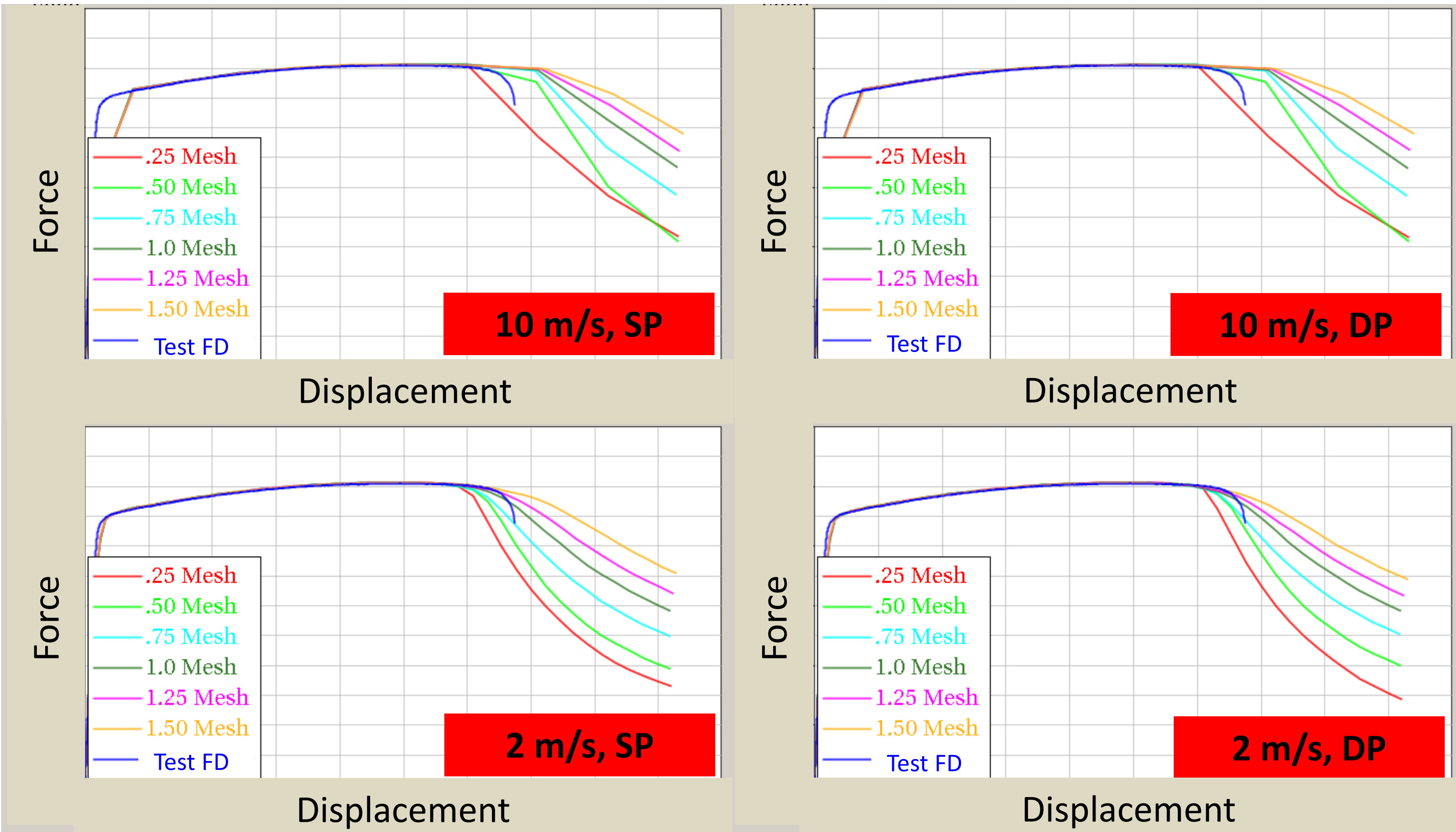
Mat 36

Velocity. (m/s):	# Cycles	SP Region?	QS Region?
10	25512	YES	NO
2	127563	YES	NO

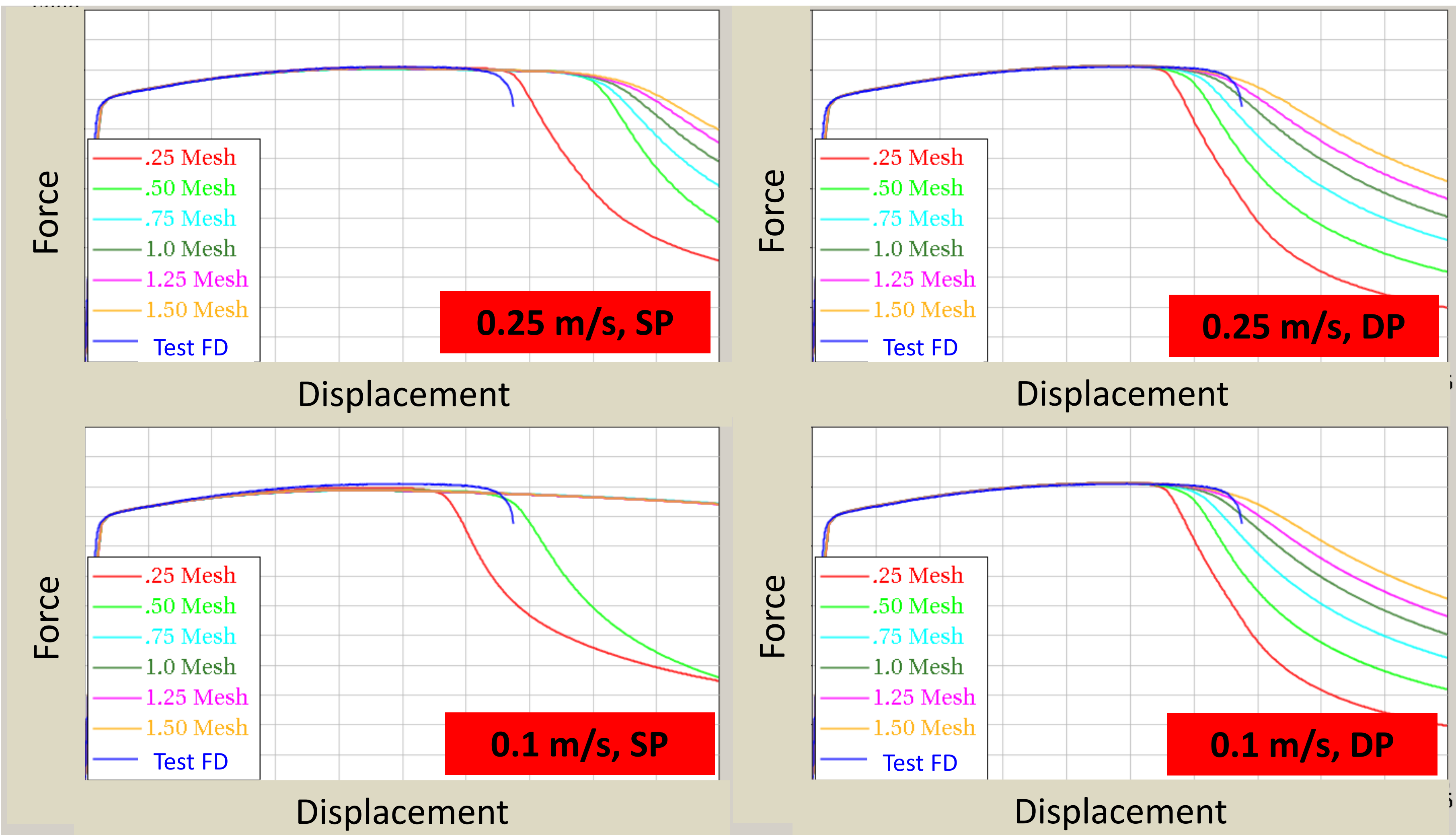
Single precision results = Double precision results



Mat 36

Velocity. (m/s):	# Cycles	SP Region?	QS Region?
0.25	1020513	NO	YES
0.1	2551394	NO	YES

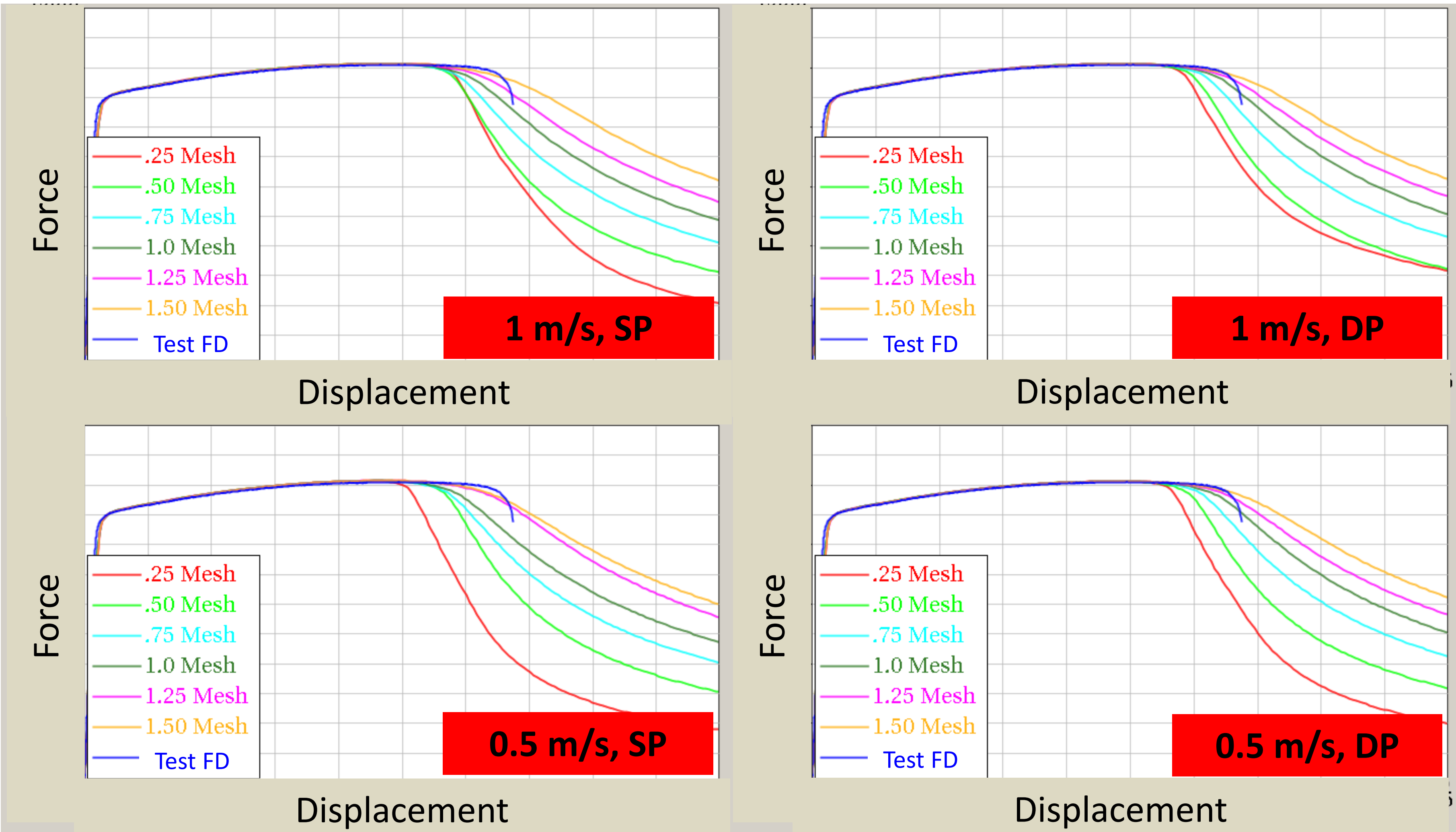
In double precision, changing simulated test velocity does not change force-displacement results



Mat 36

Velocity. (m/s):	# Cycles	SP Region?	QS Region?
1	255125	NO	NO
0.5	510263	NO	YES

The simulation with an input velocity of 1 m/s does not fall within the "single precision" or "quasi-static" regions

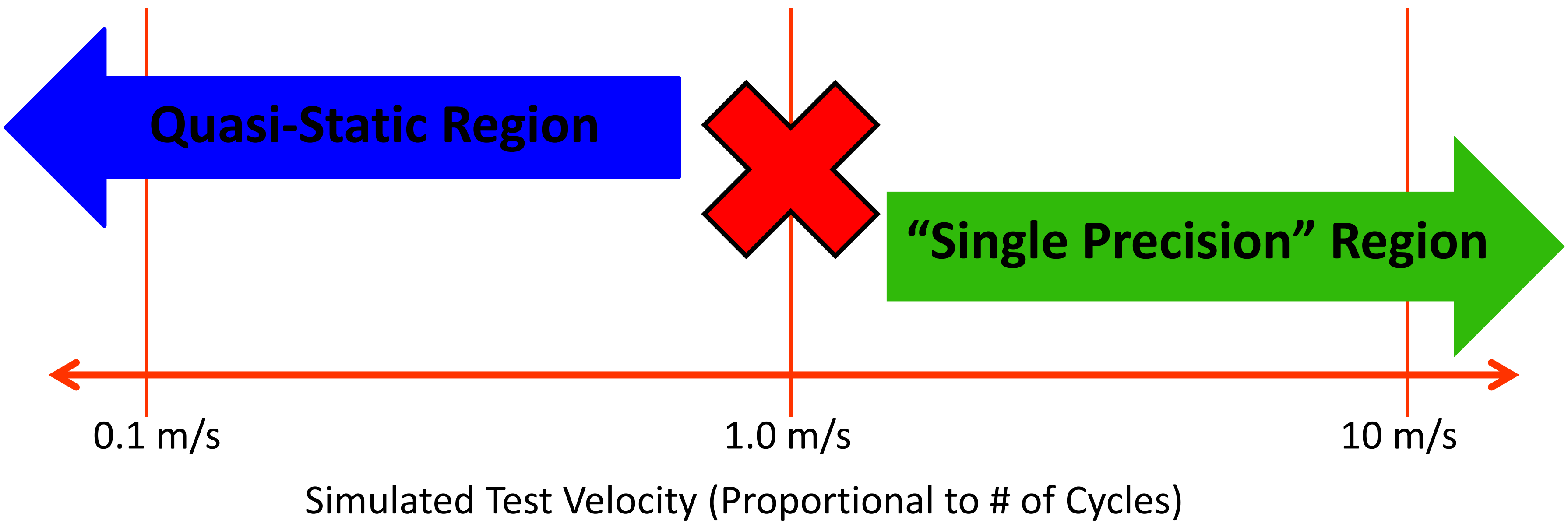


Conclusion

Define a Solution Space

- **Based on this investigation, the solution space defined previously does not exist for this simulation and these material models**

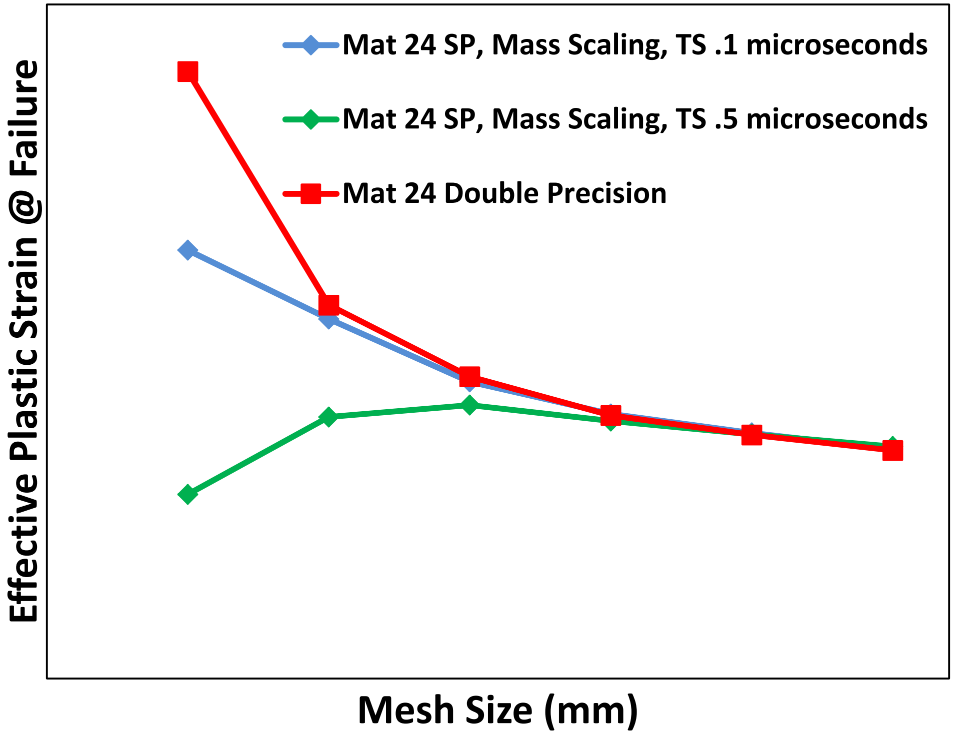
  - **There is no overlap between the quasi-static region and the single precision region.**



Mass Scaling

```
*CONTROL_TIMESTEP
$     TDINT    TSSFAC      ISDO    TSLIMT     DT2MS      LCTM     ERODE     MSIST
                  0.9         0        0.     -5E-7         0         0         0
$    DT2MSF   DT2MSLC     IMSCL                          RMSCL
                    0
```

- With increasing mesh size, this approach seems to provide a solution.
- At low mesh sizes, a large discrepancy still exists.
- Greater mass scaling (larger amounts of added mass) leads to a greater discrepancy at small mesh sizes



Imposing a timestep of 0.5 microseconds led to 3.12 kg of added mass to a 46 g model, an increase of 6806%

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Conclusions

- In this model there is no overlap in the quasi-static region and the region where single precision results are acceptable.
- This problem is caused primarily by the very fine mesh used in the model and the quasi-static testing rates being simulated.
- The velocities that fall within the quasi-static region or the single precision region are not consistent between all material models.
- For *Mat_036 with variable R-values, simulations with as few as 125K time steps are showing noticeable differences between single and double precision results. For *Mat_024 and *Mat_036 with constant R-values, this result was present when the simulation ran with 250K time steps.

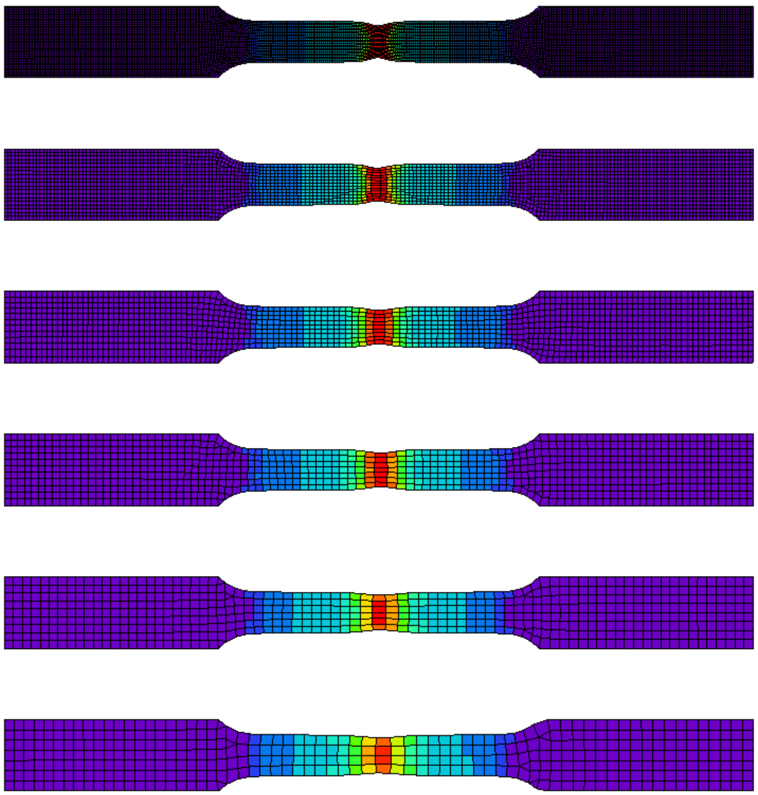
Suggested Next Steps

The author suggests one of two approaches to eliminate this accuracy problem from the regularization process.

1) Perform all regularization tasks in the quasi-static regime using double precision simulations. This will provide the correct result, and regularization can be applied to general cases that do not approach the limit for number of time steps.

2) Perform regularization tasks in the quasi-static regime using mass scaling within the simulation. Take note of discrepancies between the single precision, mass scaled result and the accurate double precision result at small mesh sizes.

Thank you for your attention



Questions?