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Simulating Photovoltaic Mini-Modules

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Abstract

The objective of this project was to use finite element models (FEM) to verify if photovoltaic (PV) mini-modules exhibit similar curvature and stress states as their full sized counterparts when subjected to mechanical loading. Models of a four-cell mini-module were constructed and loaded to represent an accelerated stress test protocol [1], and results were compared against a previously validated full module model when subjected to standard qualification loads of 1.0 and 2.4 kPa [2]. Results showed that mini-module curvatures could be matched to full modules at both loadings, and maximum principal stress and stress patterns of individual cells were generally similar but differed in magnitude.

Key Question

Do 4-cell mini-modules correctly represent the stress states of full modules under mechanical loading?

Figure 1: Accelerated testing of four-cell mini-modules [1]

Introduction and Motivation

PV modules are produced to survive harsh environmental conditions for decades. To mimic the conditions a PV module would experience after installation, accelerated environmental testing is conducted using climate chambers and artificial loading. These climate chambers are typically small and are unable to fit full PV modules. As a result, it is common to utilize smaller, four-cell modules for accelerated stress tests [1]. However, the true representativeness of these modules is unknown.

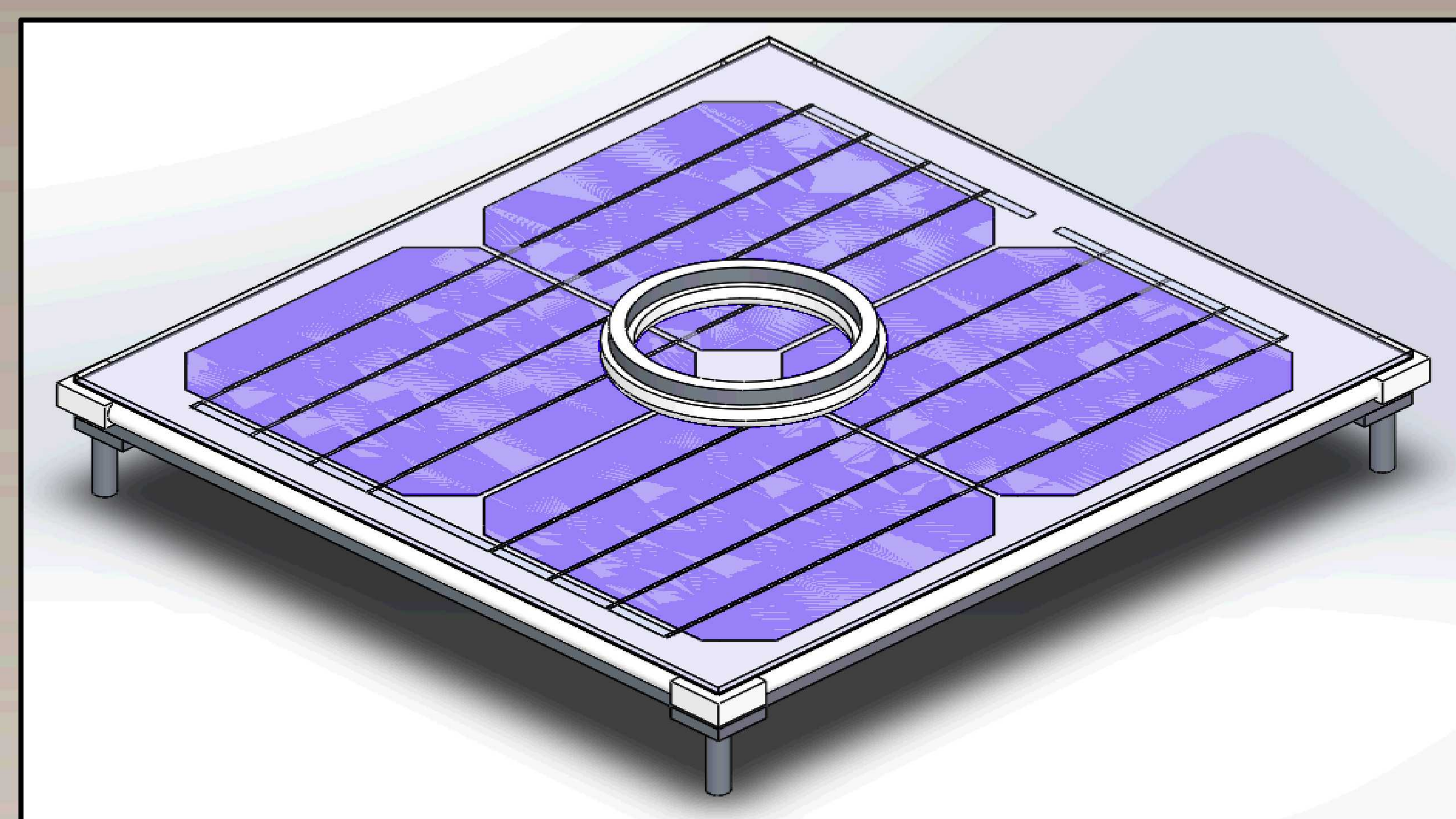

Figure 2: CAD Model of Fully Detailed Mini-Module

Using a mini-module FEM, this study sought to:
- Verify that mini-modules exhibit similar curvatures and stress states as full PV modules
- Validate the mini-module FEM against experimental mini-module deflection vs. load

Methods

A finite element model of the mini-module was developed directly from design specifications. This model included a simple square cell within encapsulant, laminated between a backsheet and glass pane. The model was meshed using approximately 190,000 hexahedral elements.

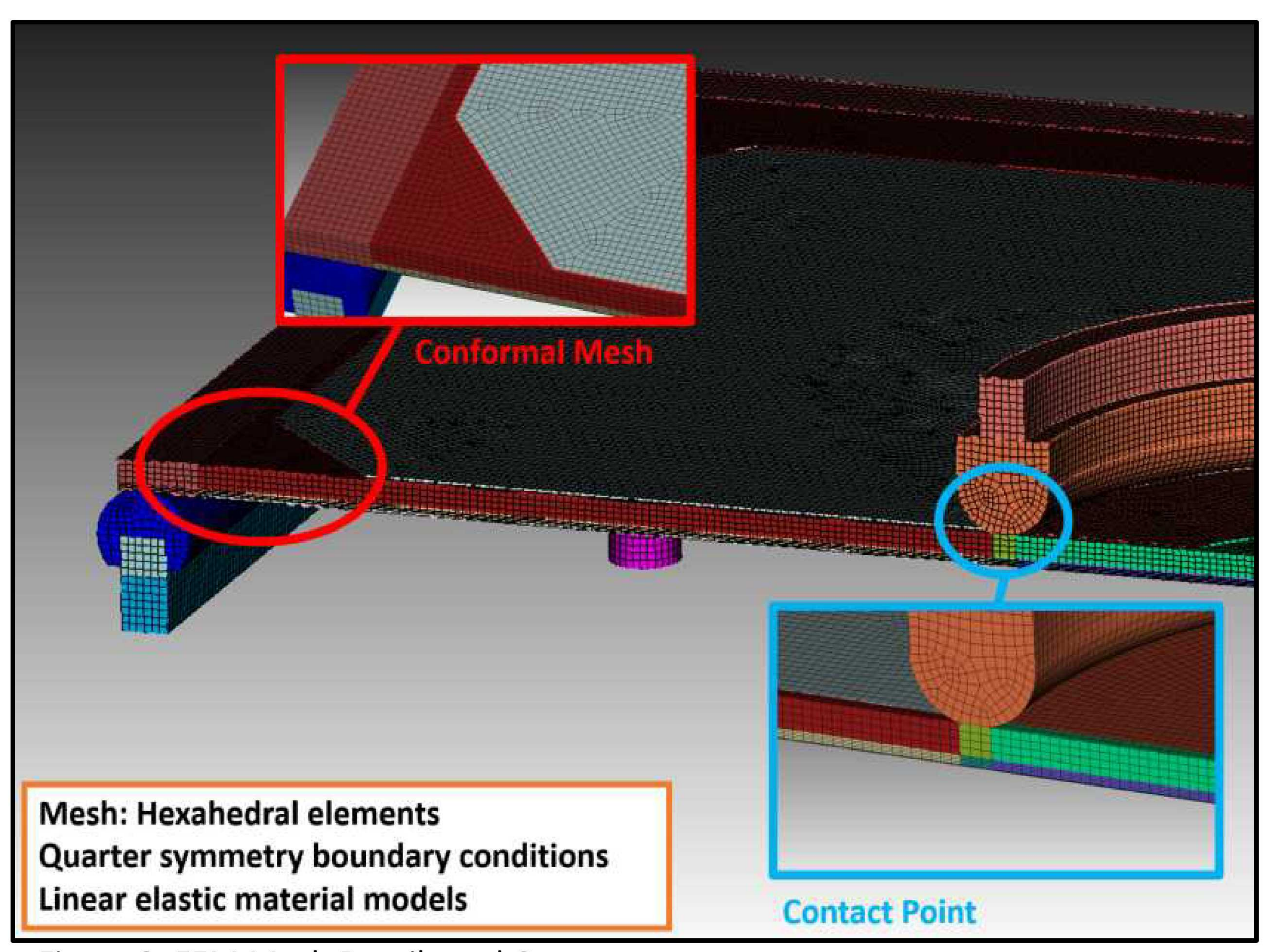

Figure 3: FEM Mesh Details and Contact

Codes and Tools

SolidWorks: CAD Geometry
CUBIT: Meshing
Sierra Adagio: Simulation Code

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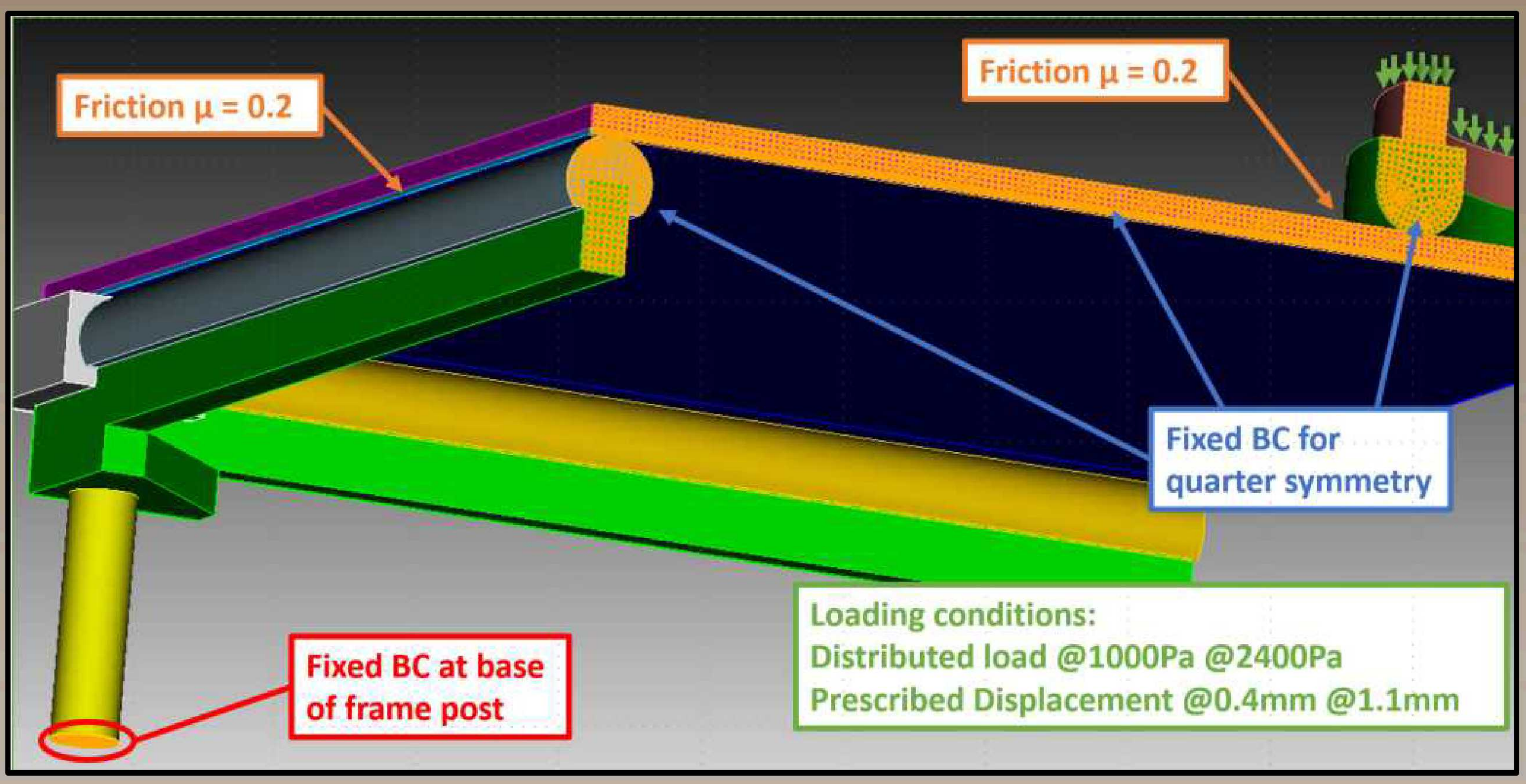

Figure 4: FEM Boundary Conditions and Loading Details

A conformal mesh was assigned to capture glued or welded surfaces at the:

- steel frame
- load ring
- backsheet, encapsulant, cell, and glass laminate

Results

The stress distribution in the mini-module shows concentrations on the glass face and at the frame and post connection. The deflection is exaggerated (x10) for visualization.

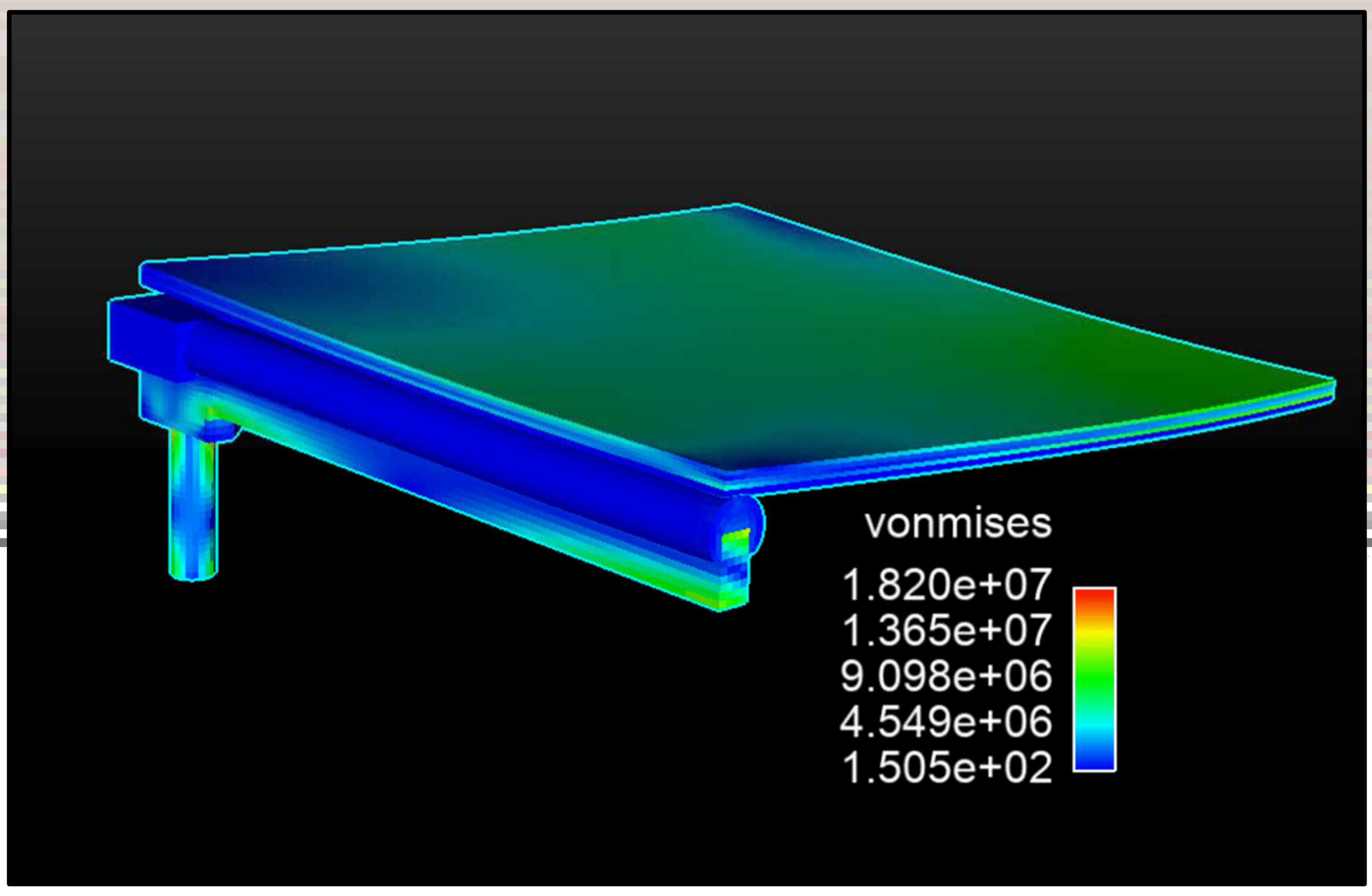

Figure 5: Mini-Module Stress Distribution

Under distributed loads of 35 N and 50 N, mini-module backsheet curvature matched that of a full module under loads of 1 kPa and 2.4 kPa (Fig. 6).

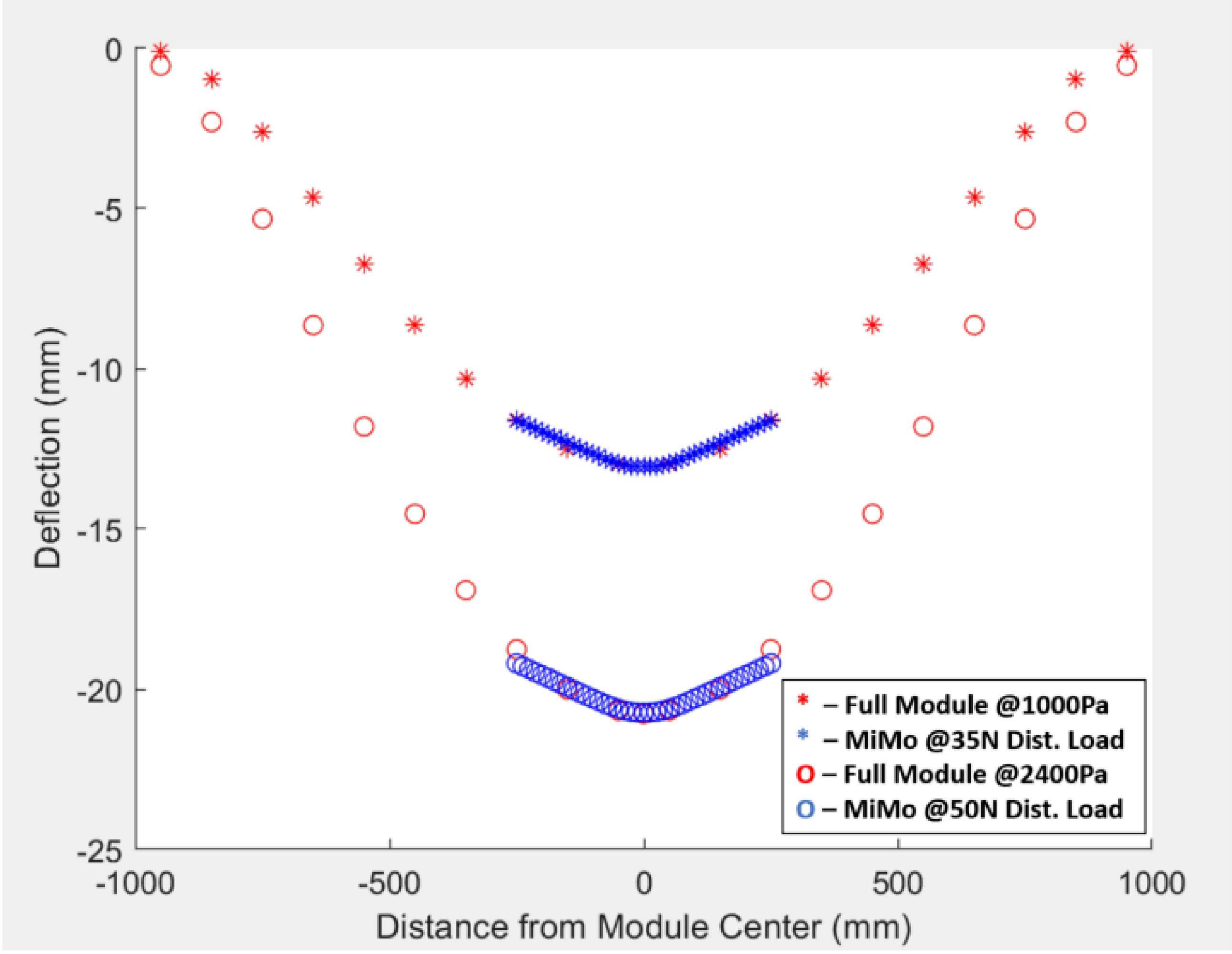

Figure 6: Mini-module (y-offset: [Upper] -12mm [Lower] -19.6mm) vs. full module curvature

The max principal stress patterns of cells in the full module (left) and mini-module (right) with matching backsheet curvatures are displayed (Fig. 7).

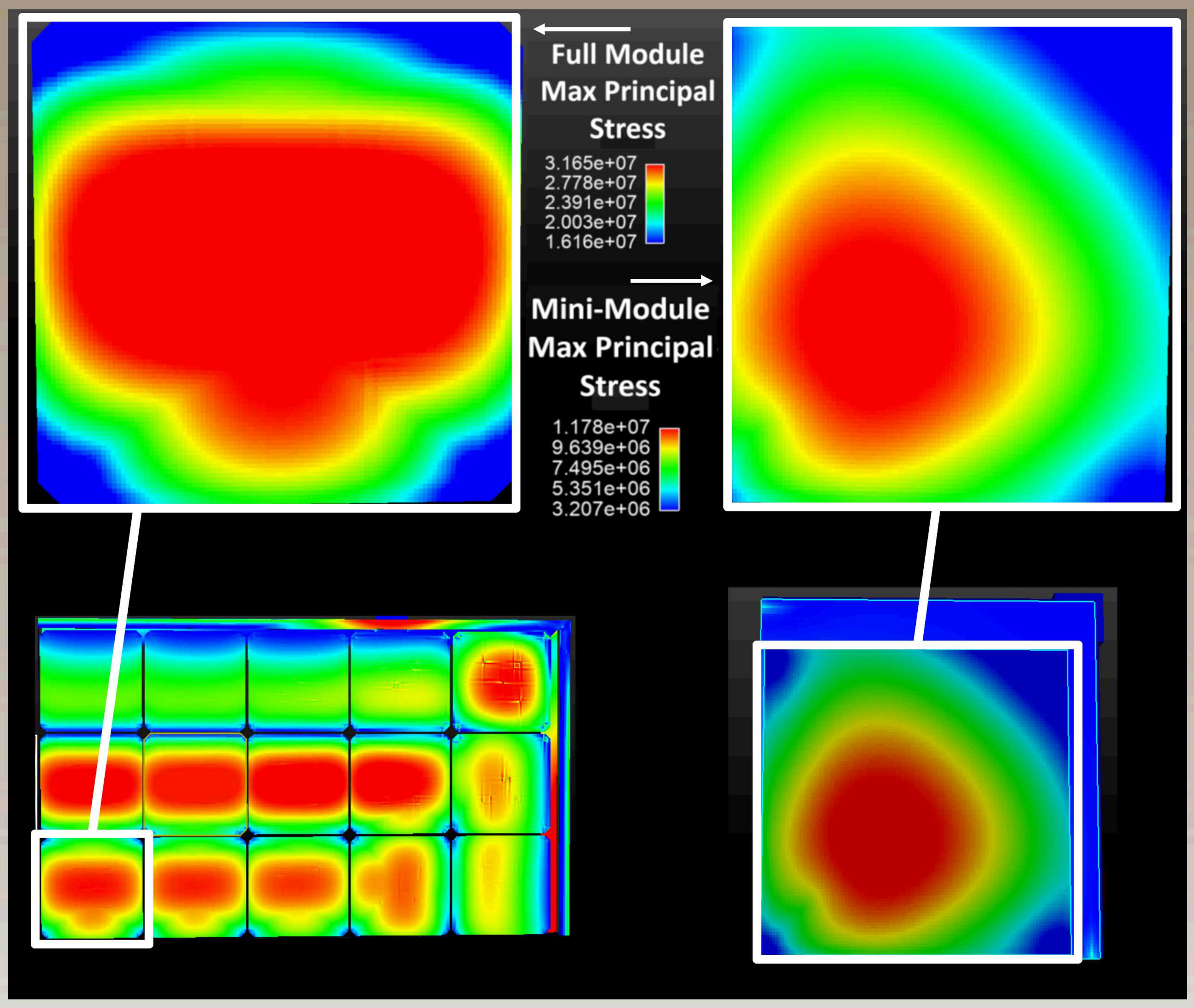

Figure 7: Cell Stress Pattern Comparison

The stress distributions in the cells are generally similar, though not exactly the same in magnitude. The mini-module shows stress concentrated primarily below the load ring. As the full module is loaded with a pressure distributed across the entire module, the pattern is more evenly distributed and centered about the middle of the cell. Both cells exhibit regions of lower stress around the corners.

Conclusion

The mini-module appears to adequately match deflection curvature of full modules under mechanical loading. Stress distributions are generally matched as well with highest stresses at the center of each cell, though differences were found in stress magnitude. To best match cell stress distributions, other loading conditions should be explored.

Future Work

- Determine exact loading conditions and curvatures needed for mini-module cell stress states to best match those of the full module
- Add additional details to the mini-module FEM to determine how mechanical loading affects internal components (i.e. solder, bussing)
- Add in temperature effects to current model
- Determine the effects of including a junction box

References

[1] S. Spataru, P. Hacke, and M. Owen-Bellini. "Combined-Accelerated Stress Testing System for Photovoltaic Modules". 3943-3948. 10.1109/PVSC.2018.8547335.

[2] J. Hartley et al. ""Effects of Photovoltaic Module Materials and Design on Module Deformation Under Load"". *2019 IEEE 46th Photovoltaic Specialists Conference (PVSC),* Chicago, IL.

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