

Project Objectives and Goals

- Investigate the mechanics of structures held together by self-stress
- Create two simulation models: The A-frame and the Cobra Weave stick bombs

Background

Stick bombs are toys made solely from popsicle sticks and serve as prototypes for self-stress assembled structures:

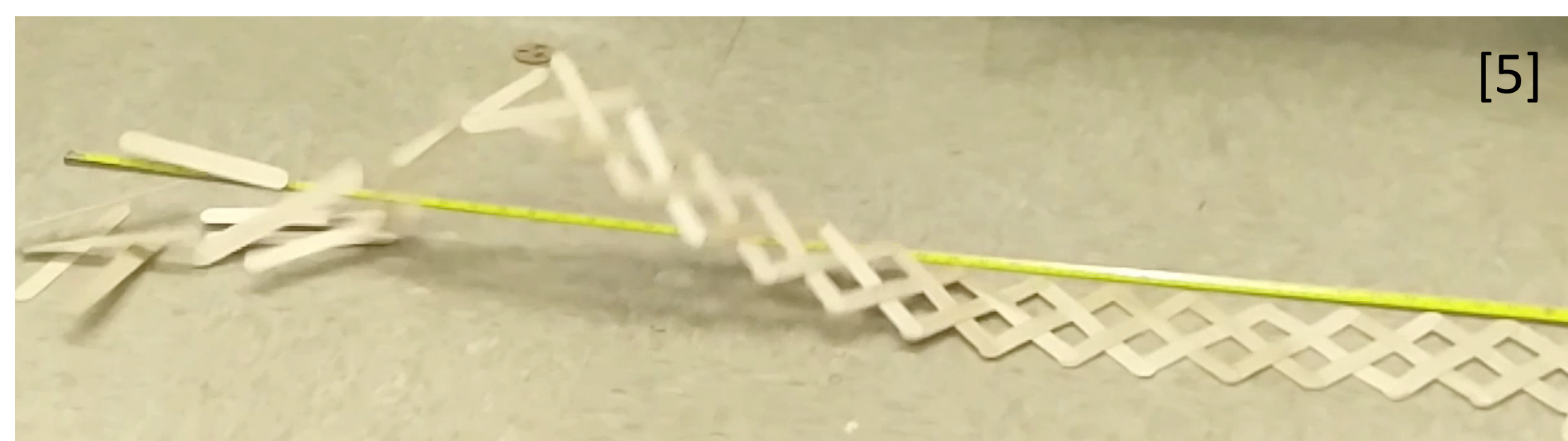
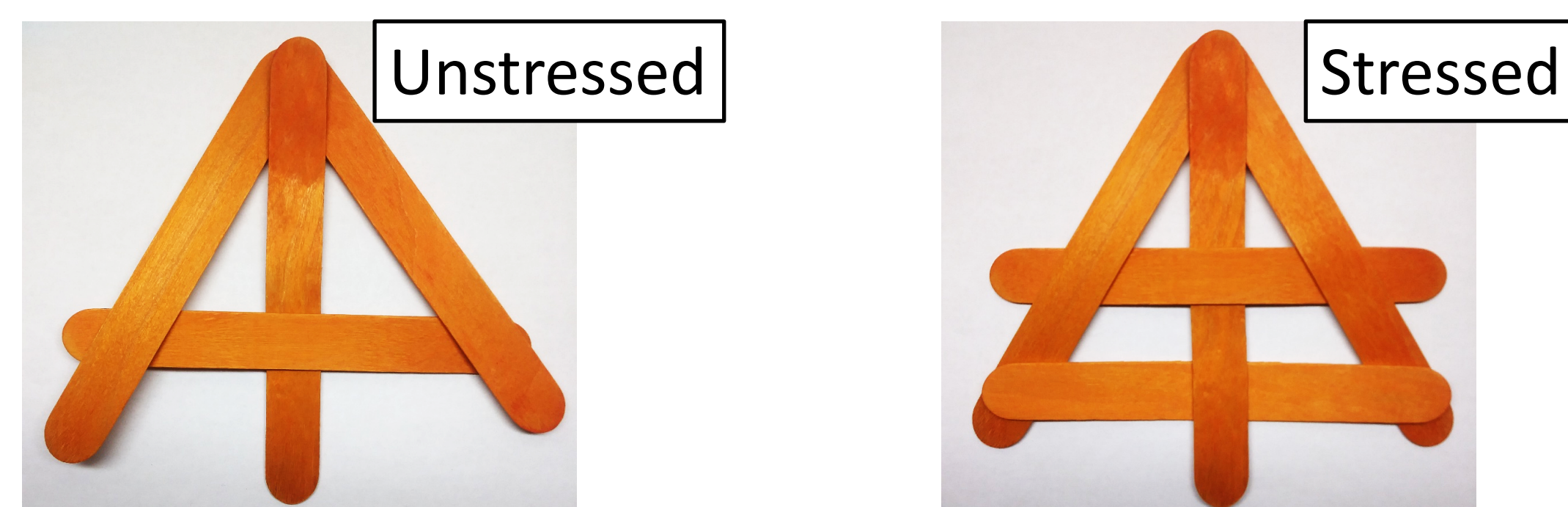
Some birds bend twigs to form their nest structure in a similar way [1-3]:



Engineering structures following this principle are of relevance due to potential new properties [4]:



Popsicle stick bombs are prototypes of such systems:



From an engineering perspective, they consist of a plurality of bent beams held together by stored energy. The stability of the structure is lost when one of the beams is removed. The stored energy is released in the form of a chain reaction and is converted to kinetic energy.

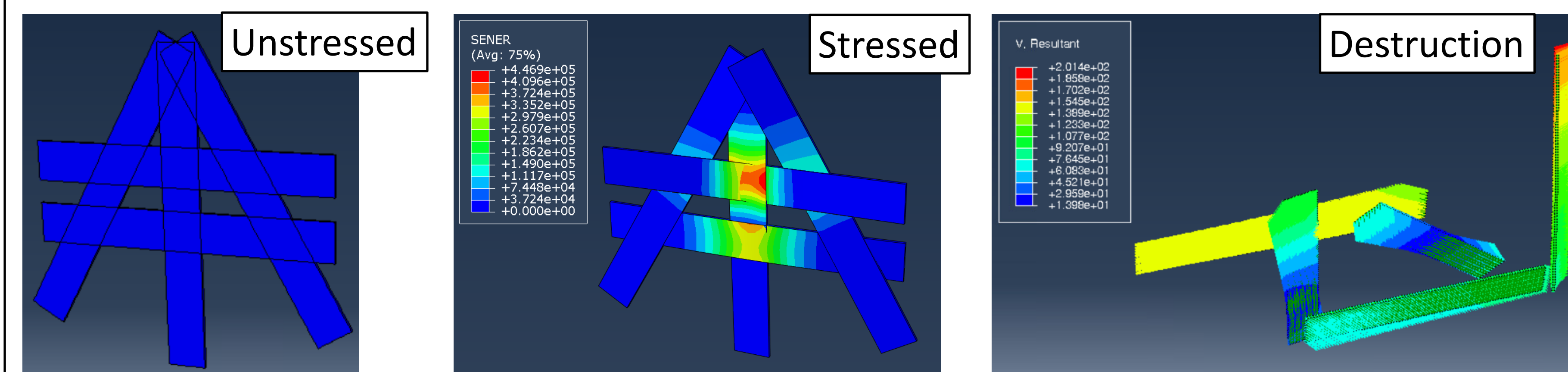
Simulations of stability are necessary to understand the reliability of the structure.

Model Setup

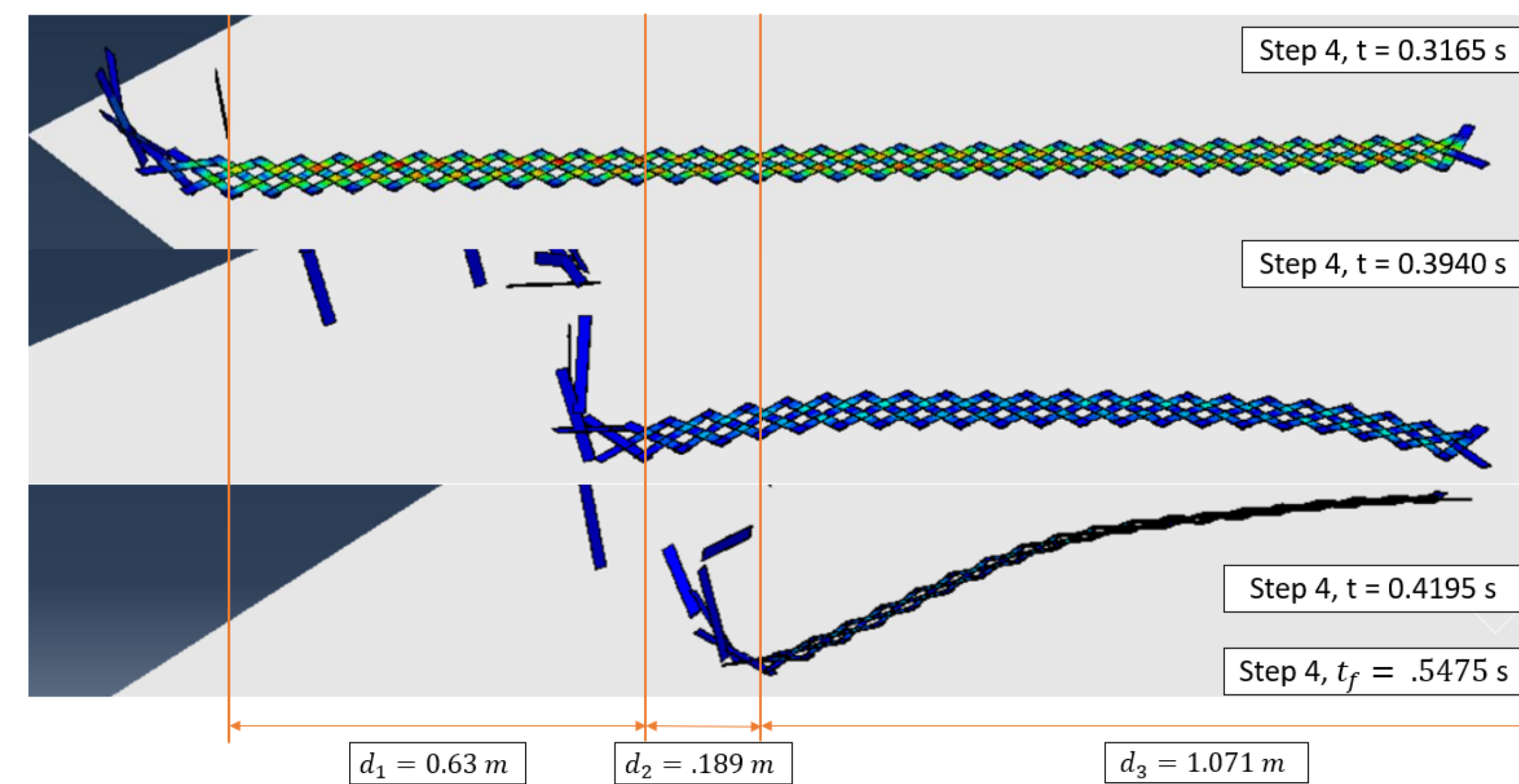
The popsicle sticks are simulated by three-dimensional linear elastic solid parts in a lattice pattern. Assemblies are created using a python script. Tangential friction and normal pressure-overclosure relations are used to simulate contact between the beam surfaces. Simulations consist of the following steps:

- Sticks are arranged in lattice pattern with overlap;
- Contact defined stick surfaces and the self-stressed state is reached (static);
- Ground contact with the sticks is initiated (Cobra Weave only) (static);
- Contact is removed for the trigger stick (dynamic).

Results: A-Frame



Results: Cobra Weave



$$v_1 = \frac{0.63 \text{ m}}{(0.3940 \text{ s} - 0.3165 \text{ s})} = 8.13 \frac{\text{m}}{\text{s}}$$

$$v_2 = \frac{0.189 \text{ m}}{(0.4195 \text{ s} - 0.3940 \text{ s})} = 7.41 \frac{\text{m}}{\text{s}}$$

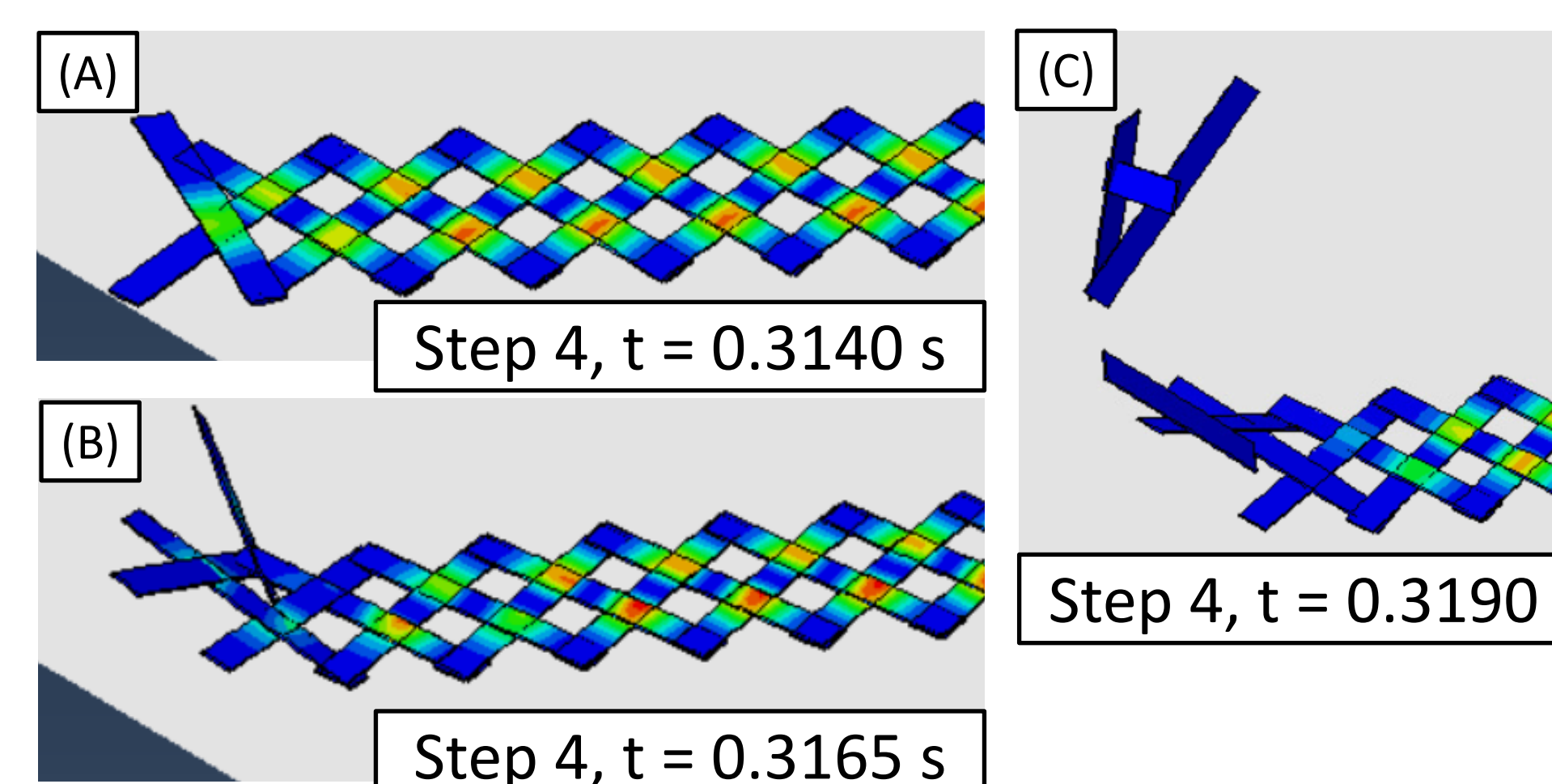
$$v_3 = \frac{1.071 \text{ m}}{(0.5475 \text{ s} - 0.4195 \text{ s})} = 8.37 \frac{\text{m}}{\text{s}}$$

$$v_{AVE} = 7.97 \frac{\text{m}}{\text{s}}$$

$$V_{exp} = [0.5, 3] \left(\frac{\text{m}}{\text{s}}\right) [5]$$

$$V_{exp} = [5, 20] \left(\frac{\text{m}}{\text{s}}\right) [6]$$

- Initial state (strain energy density)
- Removal of single stick
- Sequential destruction



$$V^* \propto \sqrt{\frac{T}{\rho}} \propto \sqrt{\frac{E \cdot f \left(\frac{h}{L}\right)}{\rho}}$$

$$V^* \propto \sqrt{\frac{E}{\rho}} \left(\frac{h}{L}\right) [6]$$

Conclusion

- Assembly in the unstressed state followed by contact insertion leads to self-stressed structures.
- Stability of such structures is limited if contact is lost globally (A-frame) or locally (Cobra Weave).
- Model simulations are very sensitive to the contact conditions. These strongly affect the numerical performance of the finite element model
- Predicted speed of disintegration of the cobra weave is in the range of physical parameters, however, not matching. This is attributed to the energy stored in the contact springs.
- Reliable structures will need redundancy to ensure stability

Future Studies

- Find a quantitative relationship between stick length, width, and thickness with the wave propagation speed.
- Analyze models which combine sticks with different properties or geometry. Thereby I can analyze transient wave propagation events

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Publications

This project currently has no publications.

References

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