Reconstruction of Soil Stress-Strain Response Using Optimisation

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About Me:

- Started as a PDRA as part of the IROE group ~2 months ago
- Almost finished PhD at University of Sheffield (viva delayed due to Covid) (Supervisors: Colin C Smith; Jonathan A Black)

- Current research is on recovery of geotechnichal design parameters from undersea soils via geophysics/seismic data
- Aiming to introduce data science techniques to geotechnics

- This presentation is a summary of my PhD project

Motivation and Introduction

- It is necessary to find soil properties for engineering design
  - Either for direct use or as parameters for further numerical modelling
- Many such methods are used, either in the lab or in the field
  - Triaxial
  - Shear vane
  - Cone penetrometer
  - Shear box
  - Scale model testing
  - + more
- However all methods have pros and cons

Motivation and Introduction [2]

- Potential Issues
  - Sample disturbance
  - Sample representativeness
  - Result interpretation
- Inaccuracy in measured soil response could cause e.g. mismatch between physical and numerical modelling

- Image processing now allows the strain field to be reconstructed in plane strain model tests (and in 3D with transparent soils).
- Hence the physical model test itself (e.g. bearing capacity, retaining wall) can be the 'element' test.

Methodology: Equilibrium and Strain processing

- Conservation of Energy:

- Work done by applied loading e.g. a footing displacing due to load must equal work done by deformation.

- External work = Internal work

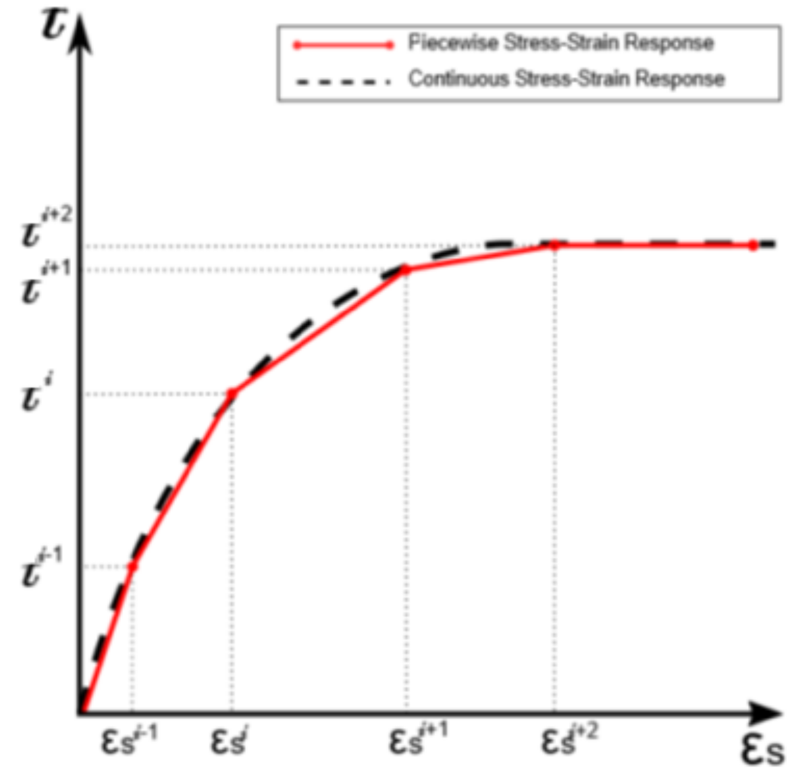
Methodology: [2] Equilibrium and Strain processing

- For homogenous isotropic undrained soil (Clay) a number of assumptions can be made:
  - Associative flow, i.e. same principal angles for stress and strain
  - No volumetric strain, i.e. total volume of soil stays the same, it just moves around
  - Simple isotropic relationship between shear stress and strain i.e. $t=f(\varepsilon_s)$
- Resulting the simplest form of the equilibrium equation:

$$\int_{u^{j-1}}^{u^j} P\,du = \left(2 \cdot \int_{\epsilon_s^{j-1}}^{\epsilon_s^j} t\,d\epsilon_s \cdot V\right)$$

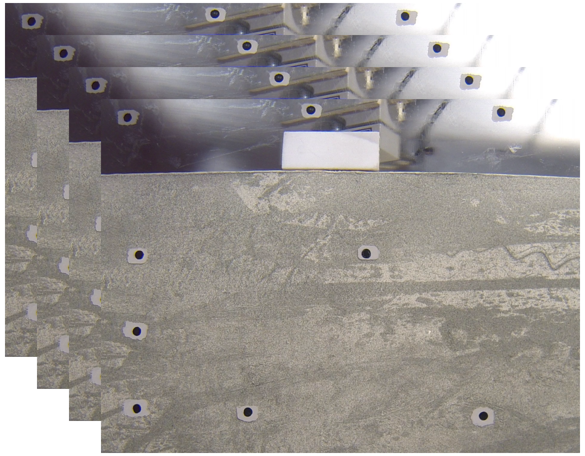
Methodology: "Segment" based method

- Define a piecewise representation of the shear-stress shear strain curve in *m* parts
- This means there are a set of *m* unknown values of τ to be identified
- Optimization is used to find the curve that produces the lowest difference between internal and external energy



Methodology: General Procedure

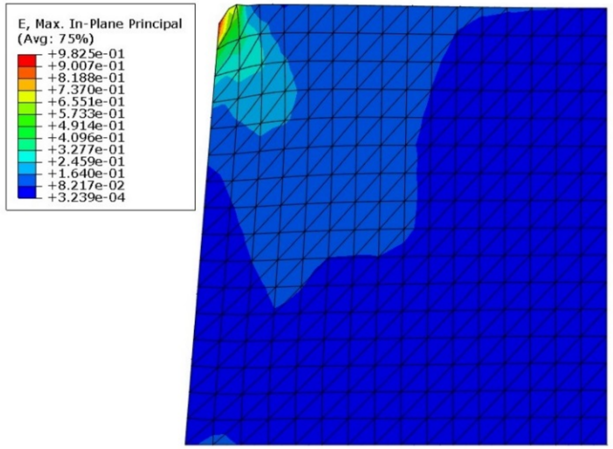
- Capture the physical model test in *n* images
- Log *n* sets of load-displacement data corresponding to each image
- Discretise each image into *p* patches each of which provide shear strain increment $\Delta\gamma$
- Strain can be calculated from displacement field using Constant Strain Triangle elements

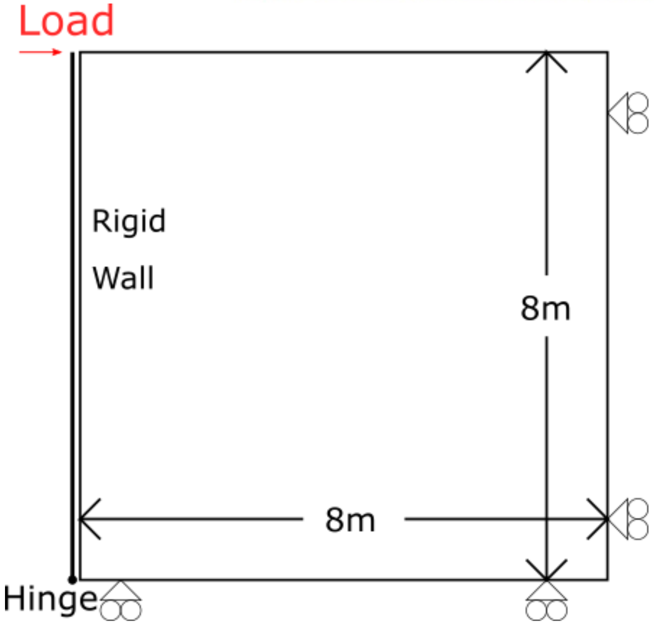


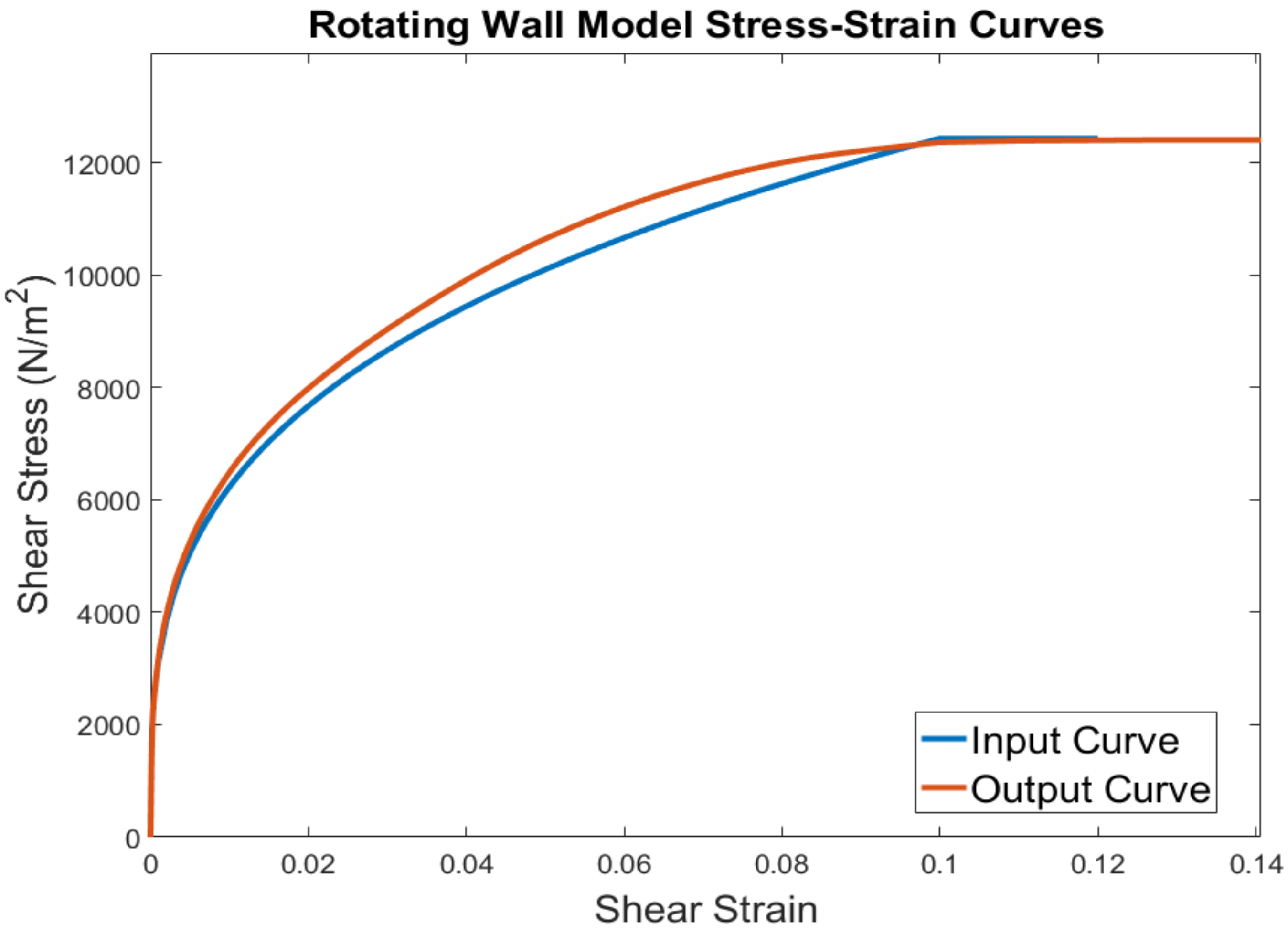
Methodology: General Procedure

- External work W_{ext} for each image can be computed from the load-displacement data
- Shear strain at each (discretised) point in the image can be determined from the displacement field
- Internal work W_{int} can be computed by integrating the shear strains with the shear stresses found via the (unknown) soil response
- Find the response that minimises rms of (W_{ext} - W_{int}) across *all* image data (typical solve time ~ 1-5 mins).

Validation: Rotating wall FEA, “Segment” approach







Physical Model Testing

- A suite of physical model tests carried out in order to obtain high quality image and loading data
- 1g footing tests with 20mm and 40mm footings
- GeoPIV-RG used to obtain imaging data
- 1g strain based actuator used at a rate ensuring undrained conditions
- Supplementary testing (triaxial, shear vane) taken to provide comparison data
- Methodology works well for artificial datasets – goal is to find robustness when dealing with real data

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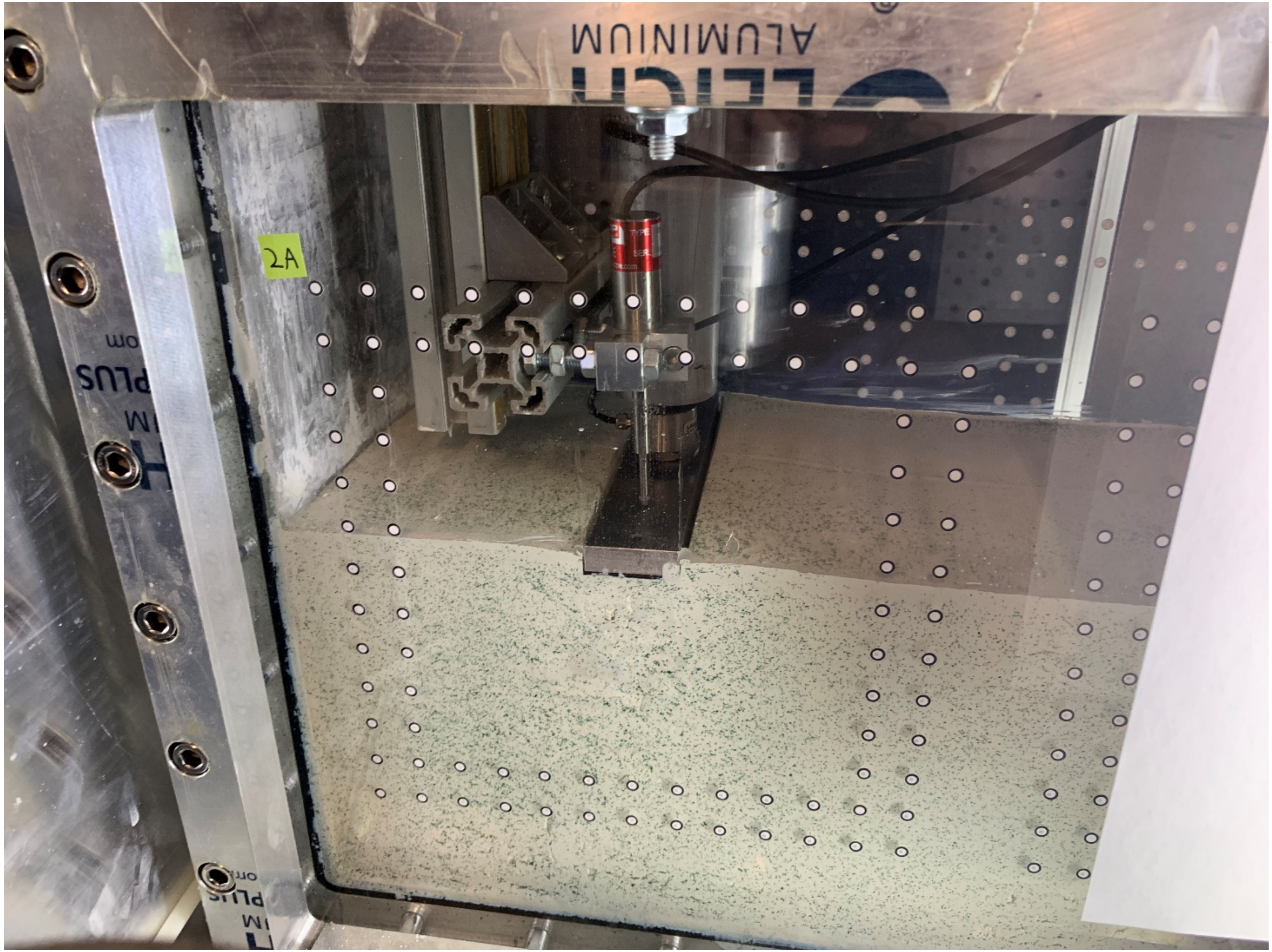

Physical Model Testing: Results

- Overall findings are that the methodology works but is not robust to flaws in the datasets.
- It is possible to use the methodology to recover stress-strain responses but care must be taken to ensure datasets are of sufficient quality.
- Flaws that cause some internal work to be "missing" such as poor PIV texture or movement outside area of interest cause stress-strain response to be higher and steeper.
- Some flaws such as random noise result in "extra" internal work, causing recovered response to be lower/shallower
- A subset of collected data will be presented to illustrate these points.

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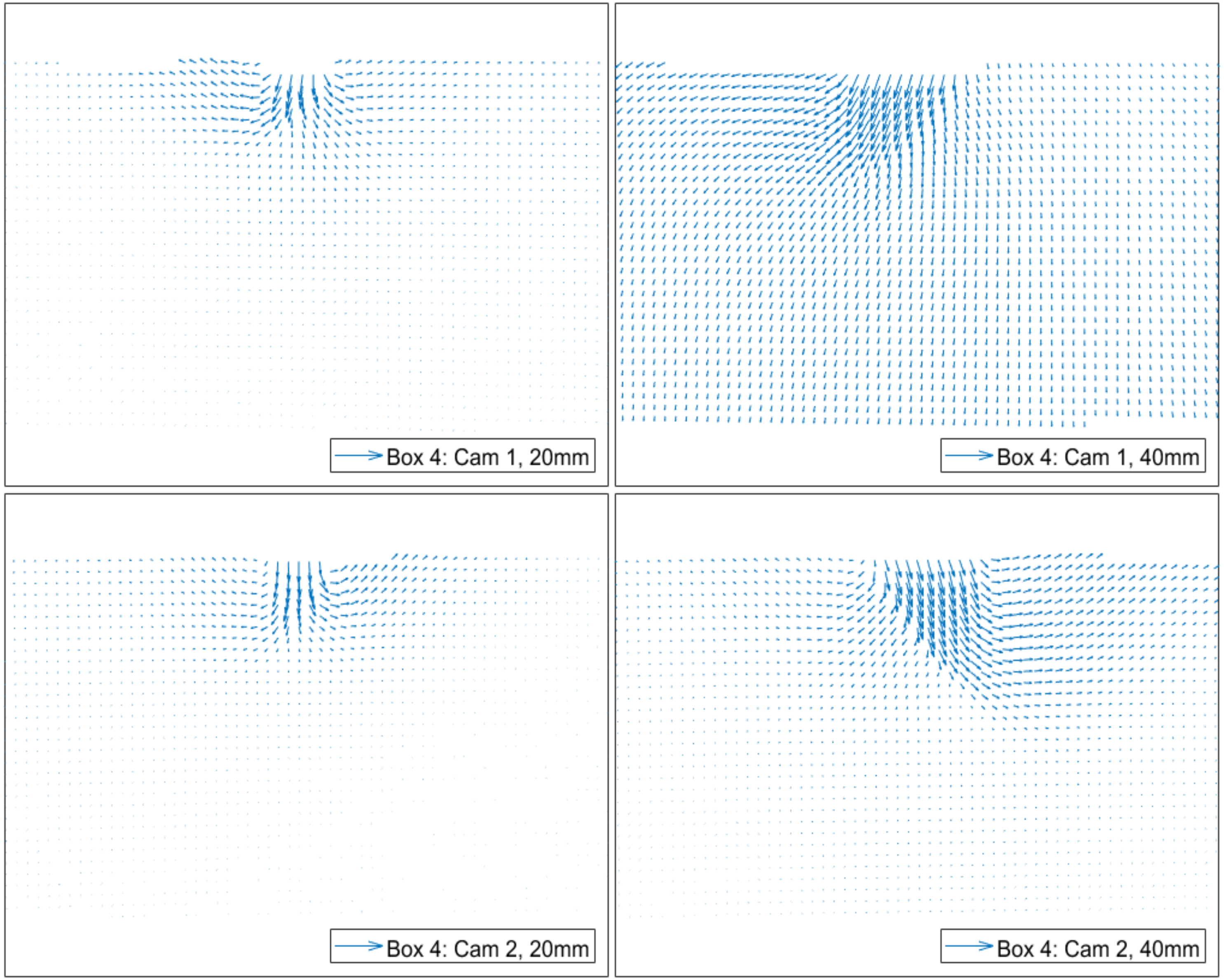
Dataset 4



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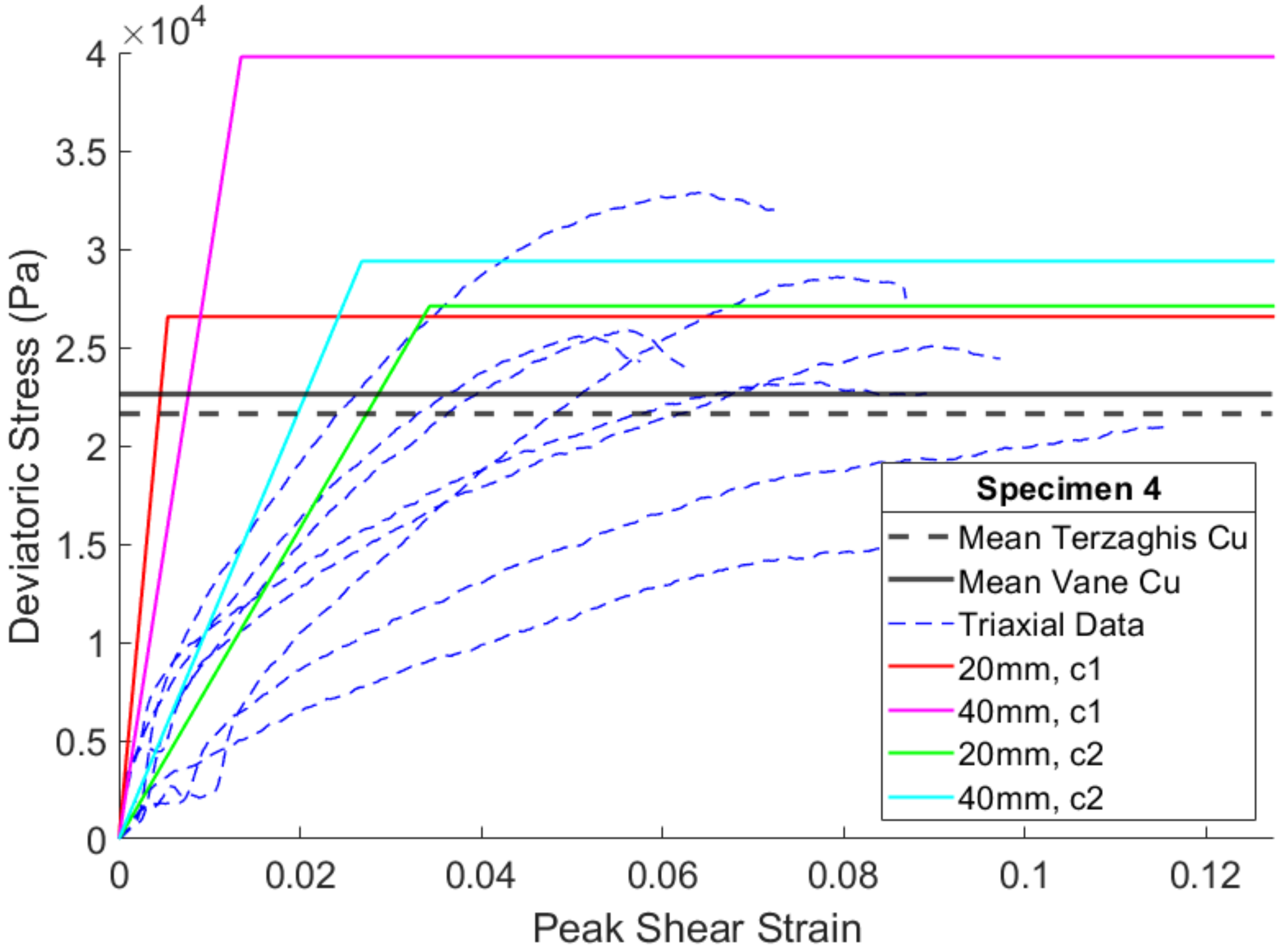
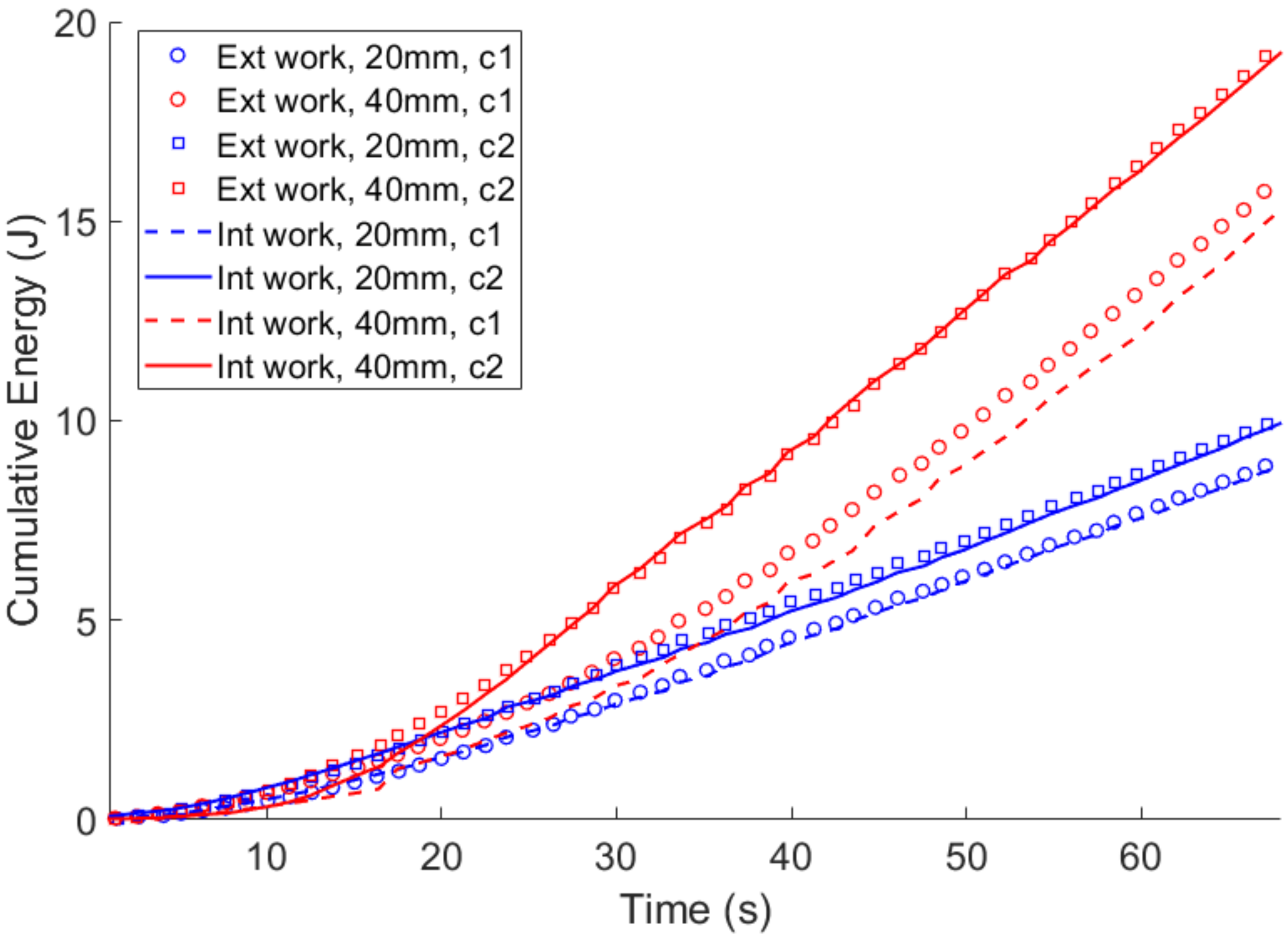


Dataset 4



Cumulative Energy (J)
Time (s)
Ext work, 20mm, c1
Ext work, 40mm, c1
Ext work, 20mm, c2
Ext work, 40mm, c2
Int work, 20mm, c1
Int work, 20mm, c2
Int work, 40mm, c1
Int work, 40mm, c2
0
5
10
15
20
10
20
30
40
50
60

Conclusions

- Methodology shows promise, working well for “perfect” artificial datasets and some “real” datasets but is not robust to flaws or omission in the available data.
- It is possible that this could be solved through software changes but experimental design is likely the best means to ensure successful recovery of stress-strain response.
- Detailed recommendations for designing experiments to utilise the methodology can be found in my thesis.
- Key point is to ensure **All** internal work is counted.

End of Presentation

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