Development and System-Level Implementation of Novel Damping Devices

Nikoo Hazaveh, Geoff Rodgers, Stefano Pampanin, Geoff Chase.

Key Aspects of the 2017 Flagship 4 Project:

- **Further develop of the quadrant-specific damping device**
  - Additional configurations to produce different damping behaviour
  - New silicone fluids (previously simple oil) to produce different force-velocity profiles
  - Analytically assess the influence of these configurations on structural performance
  - Undertake multi-level structural modelling to better understand/interpret the shake table testing recently completed at the University of Auckland

- **Integration of Damping Devices into a Large-Scale Shake-Table Test.**
  - Ideally, the viscous damping device will be incorporated into the QuakeCoRE-ILEE testing at Tongji next year.

- **Working with practitioners to better understand system-level interactions and detailing for incorporation of devices into field structures**

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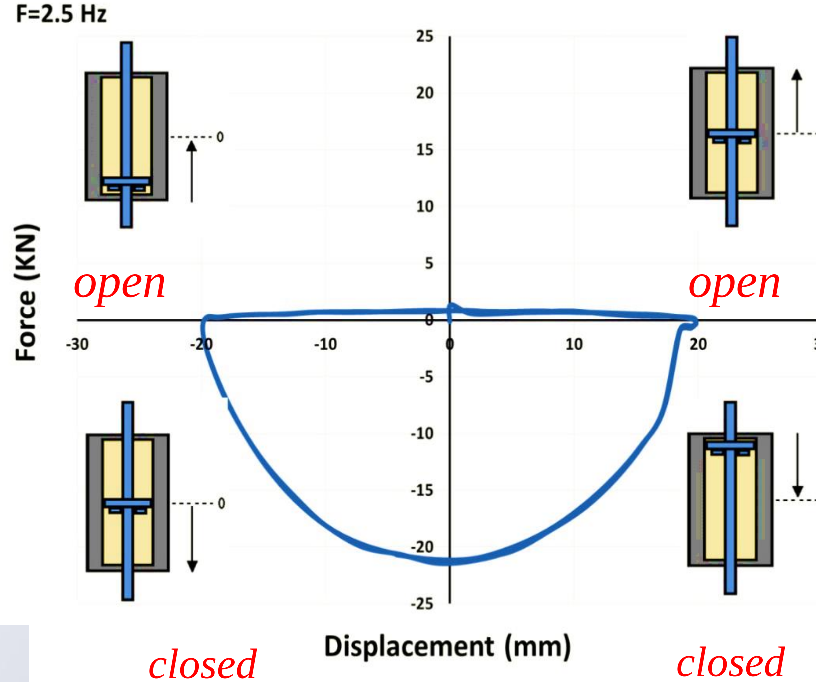
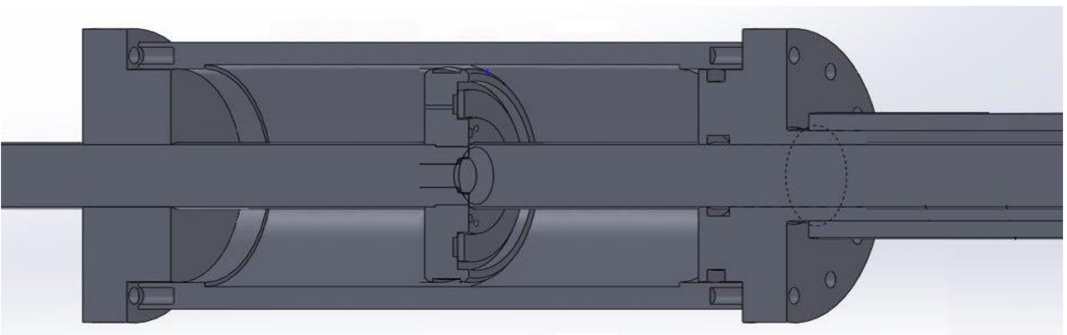
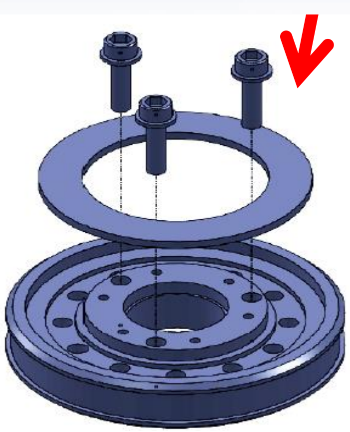
Customisable viscous damping behavior to modify the overall structural response for any given application







One way valves enables selection of when damping forces are provided to the structure, enabling the customisation of the overall structural hysteretic response.

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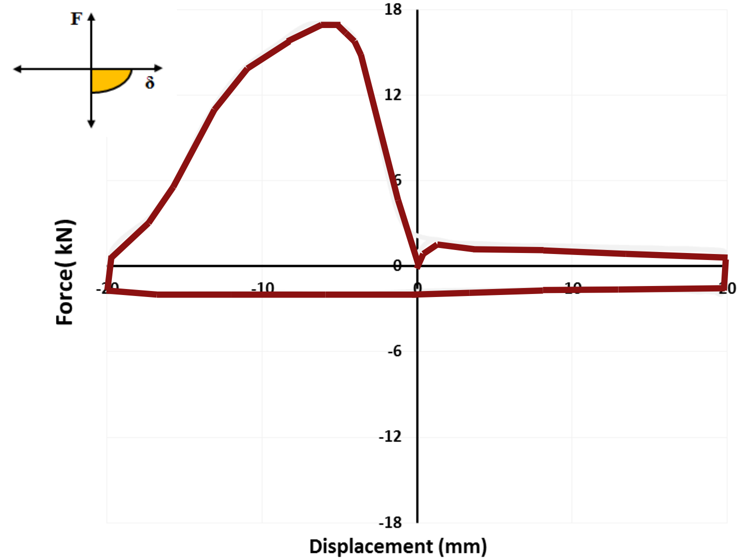

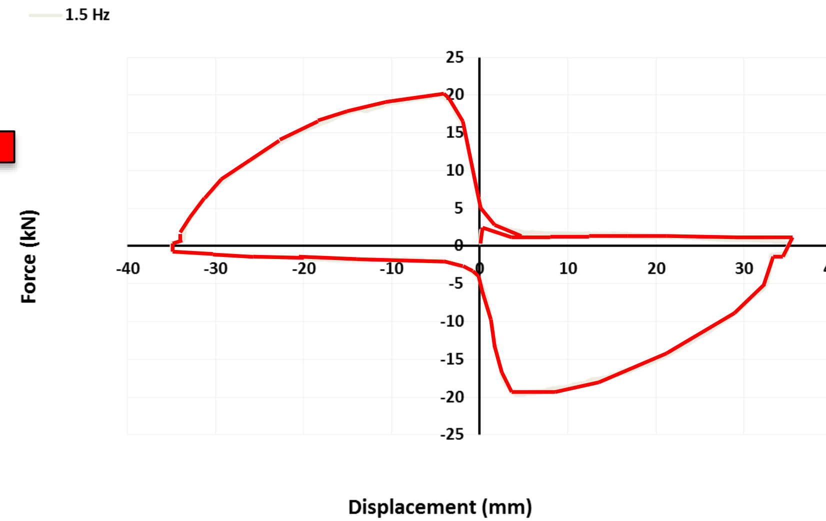

Large-Scale Testing (15 tonne structure) on the University of Auckland Shake-Table

Any individual quadrant or any combination of two or more quadrants can be included in the response

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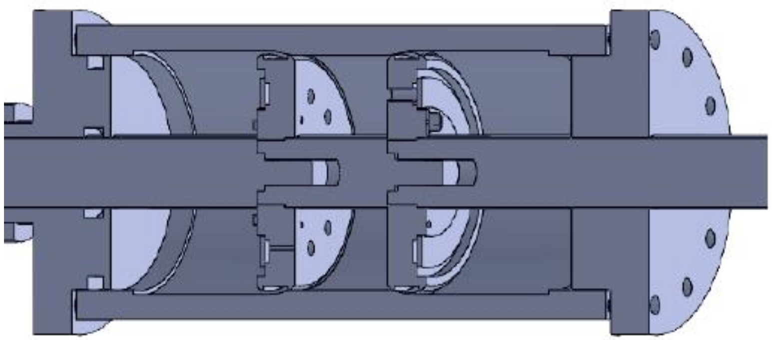
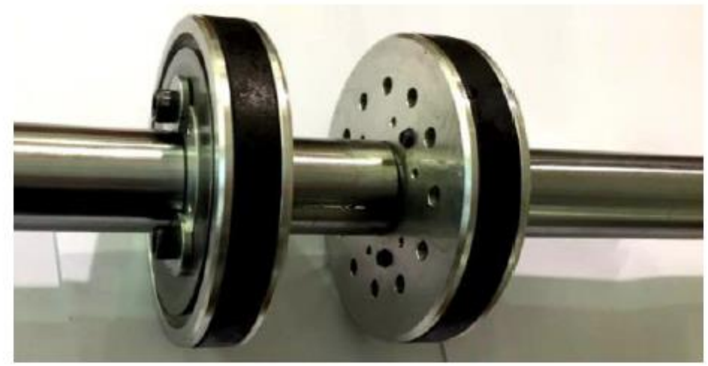
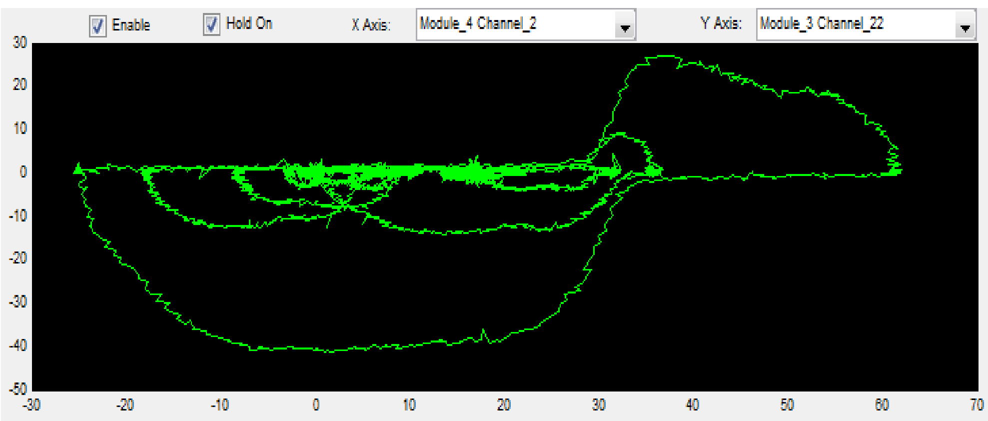
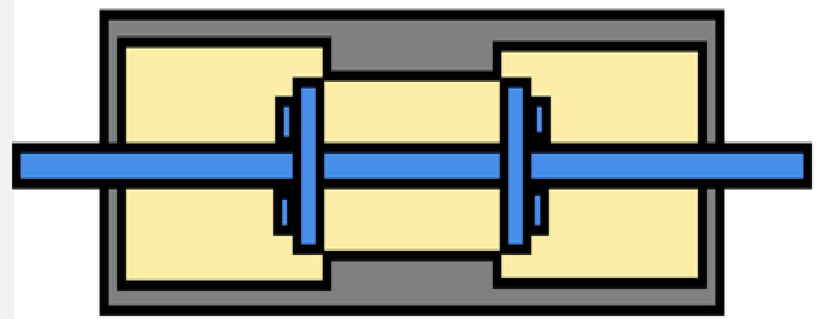
Additional configurations to produce different damping behaviour







1-3 damping device as tested on the Auckland shake-table (the opposite diagonal to the 2-4 device)



1-3 device has demonstrated potential to re-centre a structure with a residual drift (due to resistance away from centre)

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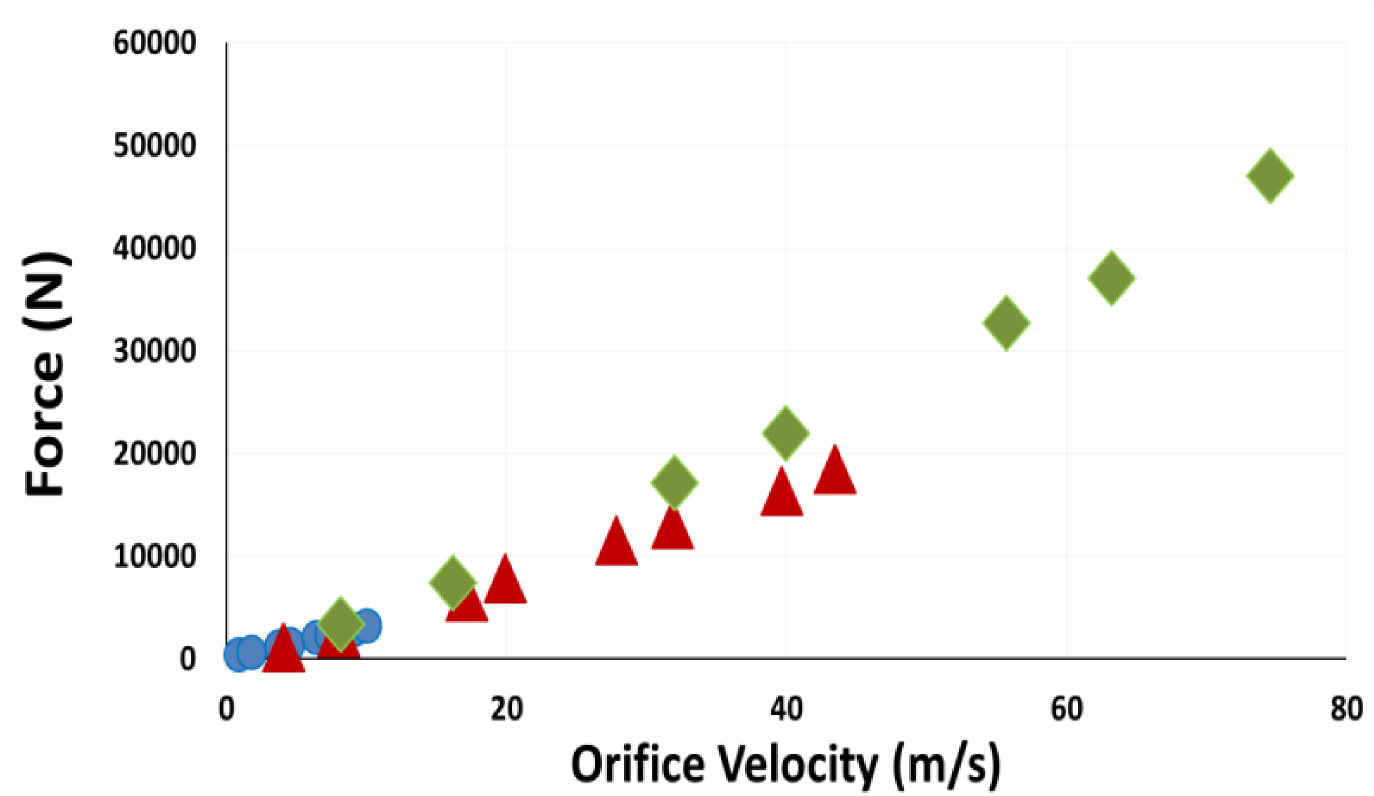
New silicone fluids to decrease temperature dependence and (hopefully) create a non-linear velocity response

Initially, using basic oil with Newtonian behaviour:



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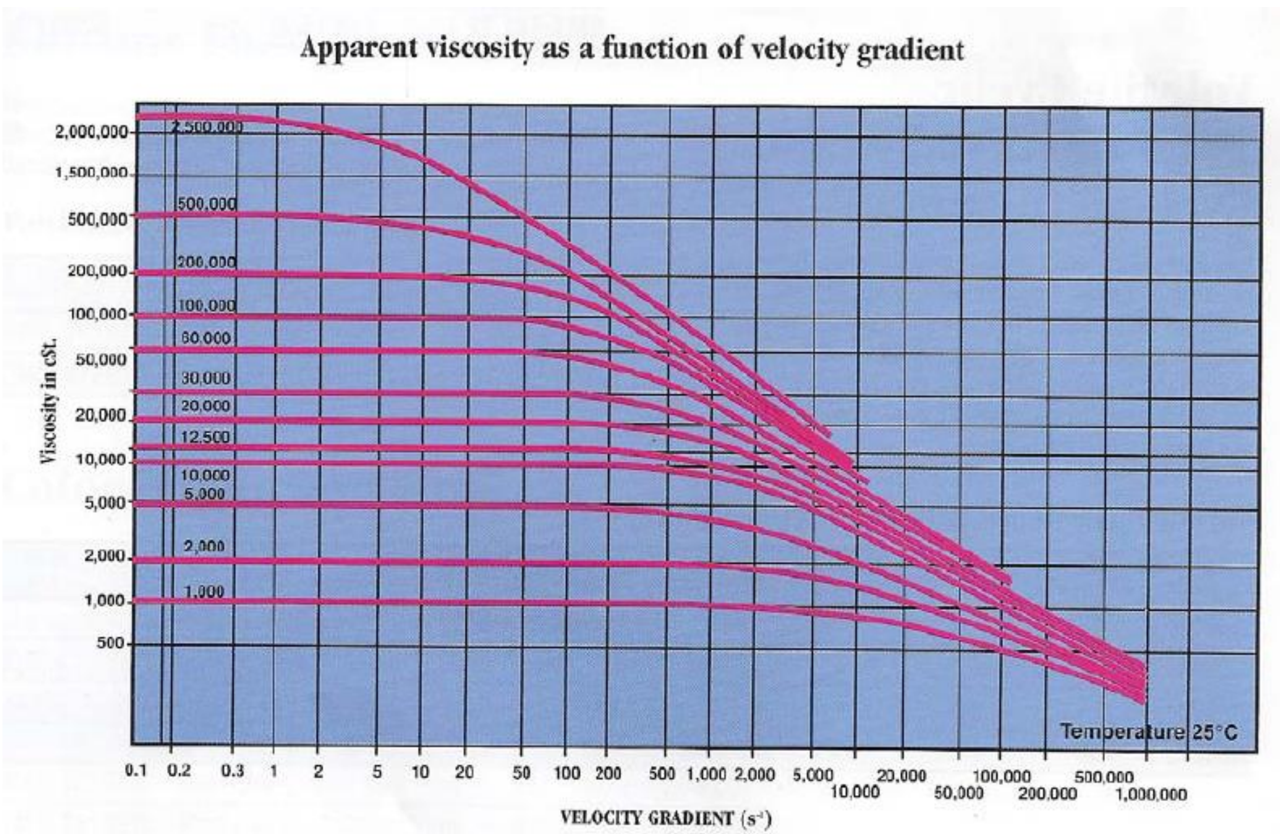
High molecular weight silicone fluids exhibit a reduction in viscosity as the velocity gradient/shear rate within the fluid increases (Non-Newtonian behavior).

The result is a non-linear force-velocity profile for the device.



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Computational Modelling of Fluid Flow in Viscous Dampers

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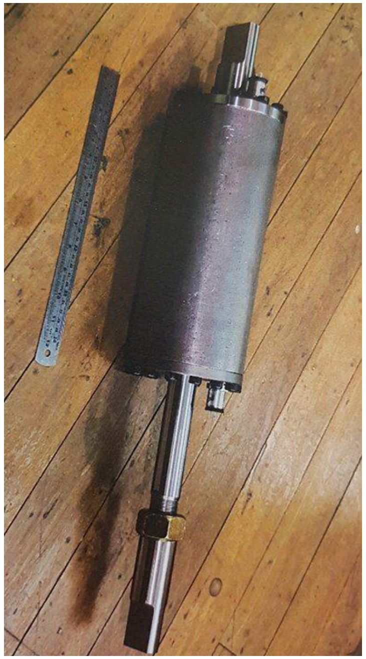

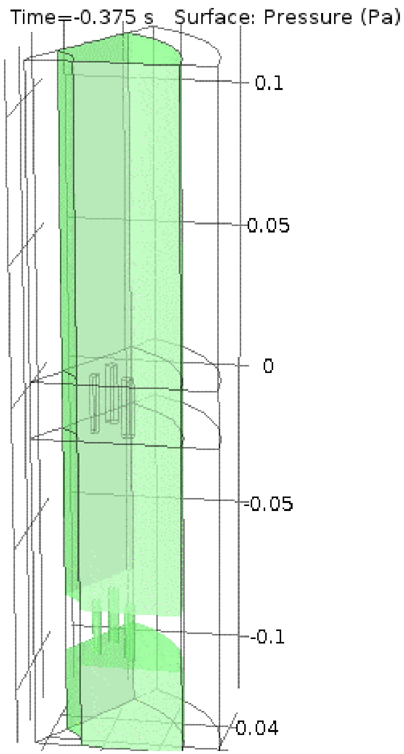

- PROJECT AIM:
  - Establish models of the current device and working fluids
  - Extend these validated models to use silicone fluids with non-Newtonian behavior
  - Provide recommendations for future viscous damper designs

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Computational Modelling of Fluid Flow in Viscous Dampers

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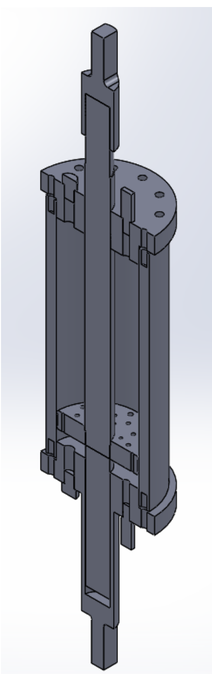
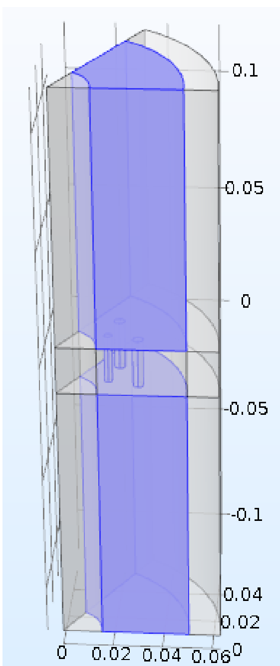
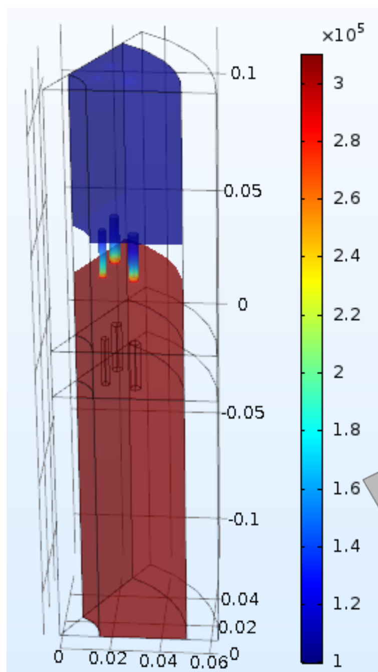
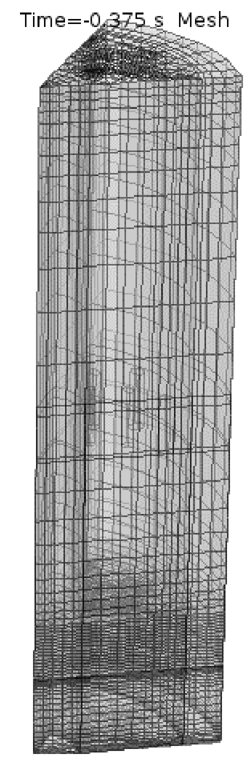
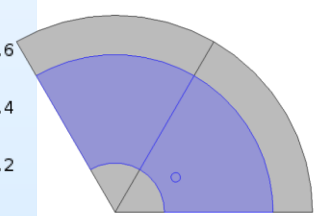
- Model built in COMSOL
- Symmetry exploited by using a wedge of cylinder
- Dynamic mesh
- Pressure and velocity fields solved using Navier-Stokes equations
- Model results compared to experimental data

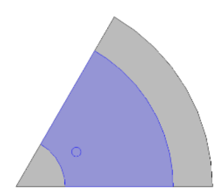


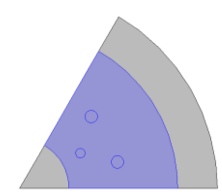


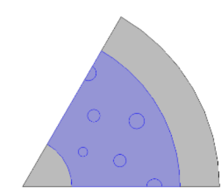





3 open orifices


6 open orifices


18 open orifices


30 open orifices

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Computational Modelling of Fluid Flow in Viscous Dampers

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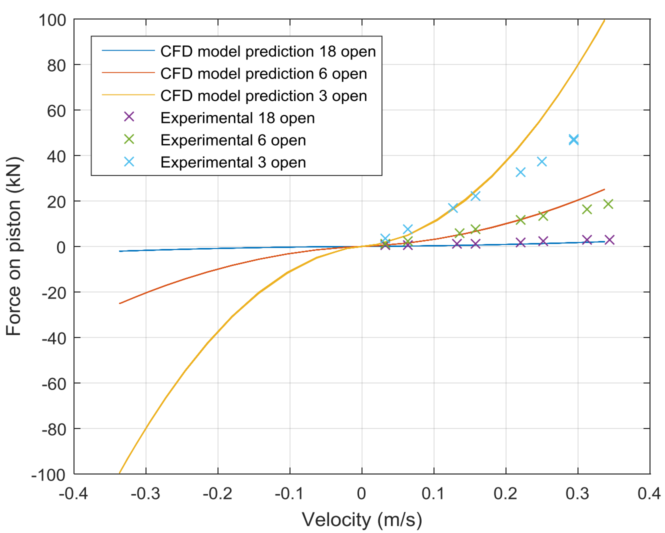
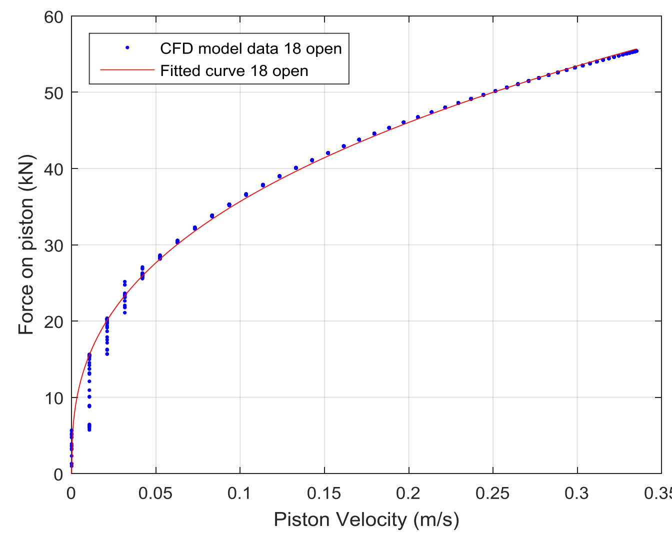
- Agreement between model and experimental for piston velocities < 0.15 m/s
- Model predicts silicone fluids of 2,500,000cSt kinematic viscosity (2.5 m^2/s) will produce desired force response
- Recommended fluids: 100,000cSt - 2,500,000cSt



$$F = CV^n$$

- n = 1 for Newtonian fluid
- n = 0.2 – 0.4 for desired non-Newtonian behaviour
- n = 0.368 for graph on left



FUTURE WORK:

- Experimental testing with silicone fluids
- Developing CFD model to accurately predict behaviour at higher velocities

Computational Modelling of MDOF Structure

- Auckland Shake Table testing represents a specific structure and those specific results have limited usefulness
- We (or really Nikoo) developed a MDOF model of the structure in OpenSEES to capture the experimental results, validate a structure and device computational model, and enable the results to be used more broadly (such as in the design/response prediction of other structures with a range of possible viscous damping configurations)

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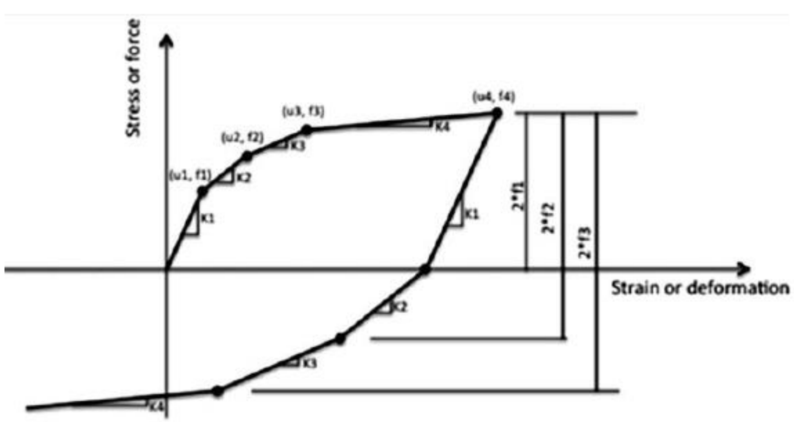
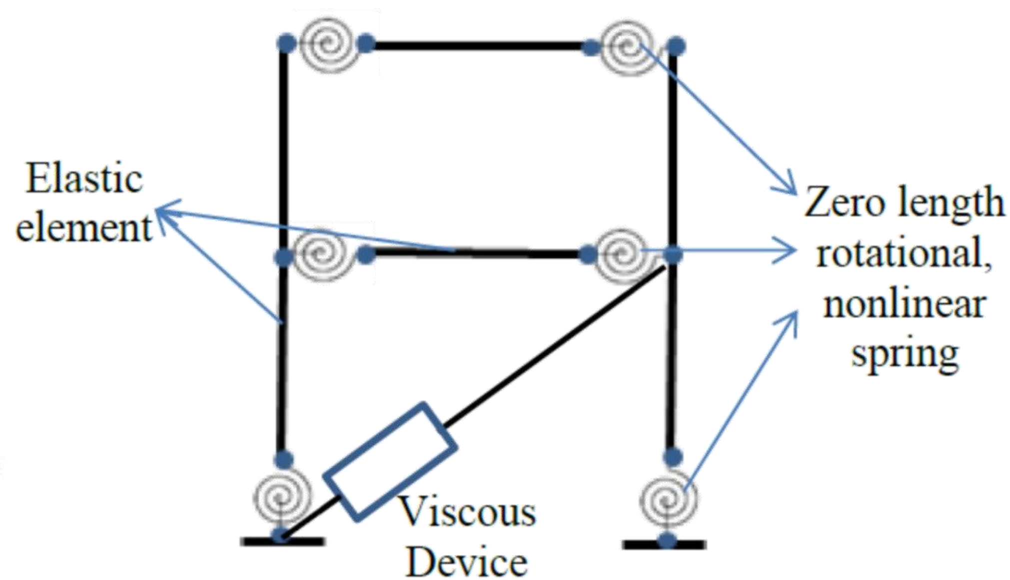
Computational Modelling of MDOF Structure

- Structural Model
  - Nonlinear spring elements to capture the sliding friction connection behaviour
  - Different viscous damper element models to capture the displacement and direction dependent models

    (as well as traditional viscous dampers)





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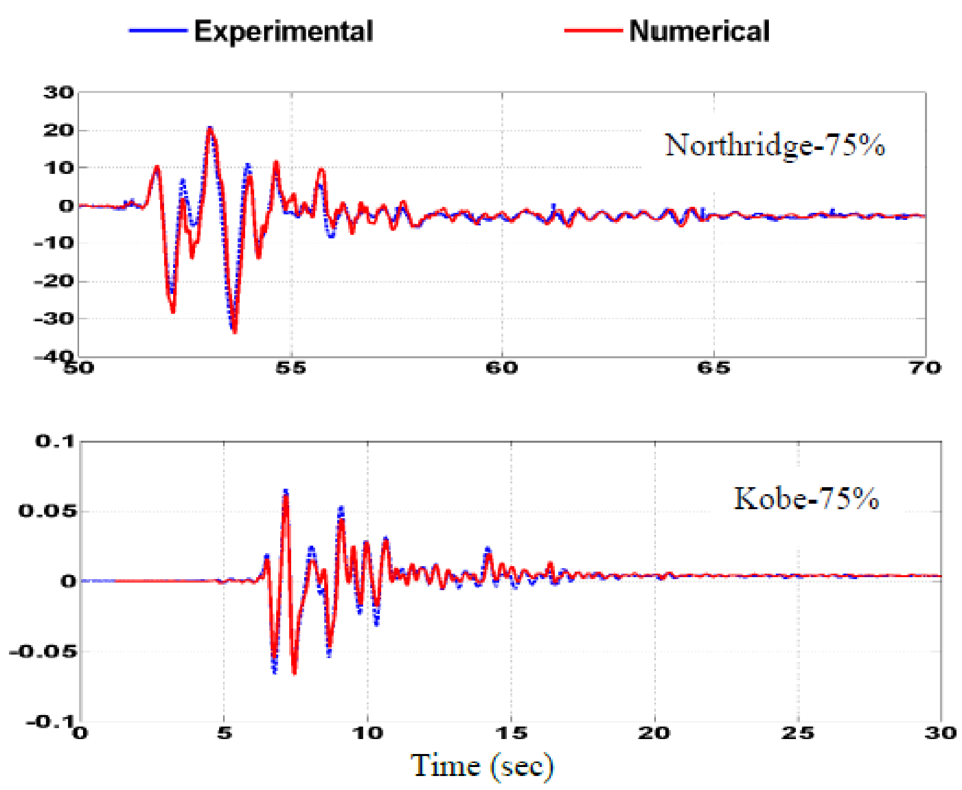
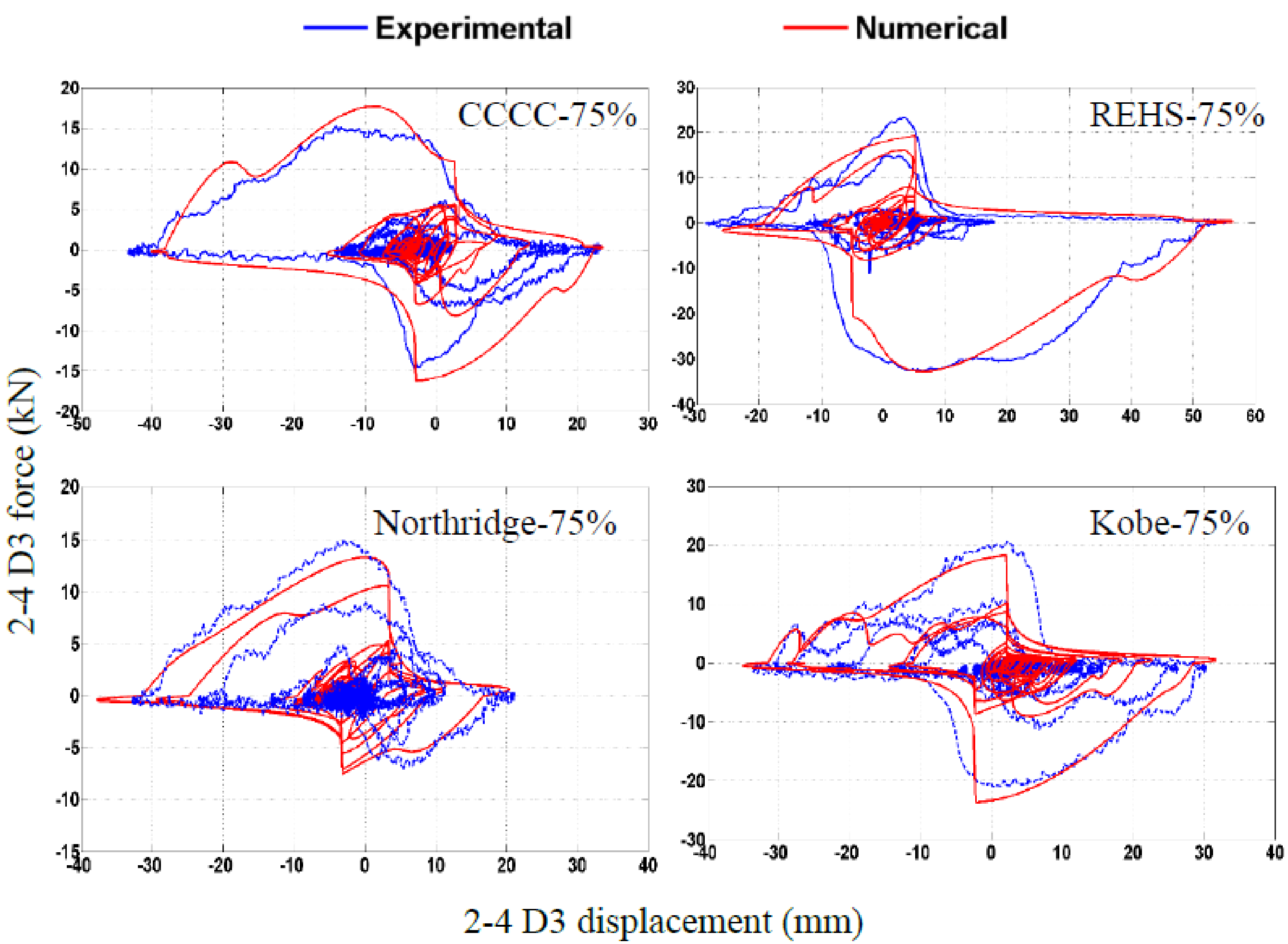
Structural response to earthquake input loading



Device response to earthquake input loading



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Computational Modelling of MDOF Structure

- Main Outcomes
  - Captured the key response behaviour of the shake table testing, to enable results to be used more widely than just for those specific tests and give confidence in modelling and design methods
  - Development of damping reduction factors for atypical viscous damping configurations (1-3 and 2-4) and benchmarking against the current methods for conventional viscous dampers
  - Currently, the damping reduction factors for the new configurations have only been based on simple Newtonian (linear) viscous fluids. Extension of these to Non-Newtonian (non-linear) viscous damper fluids will be part of future work on this project.
  - Work to include a range of dampers into the QuakeCoRE-ILEE shake table test

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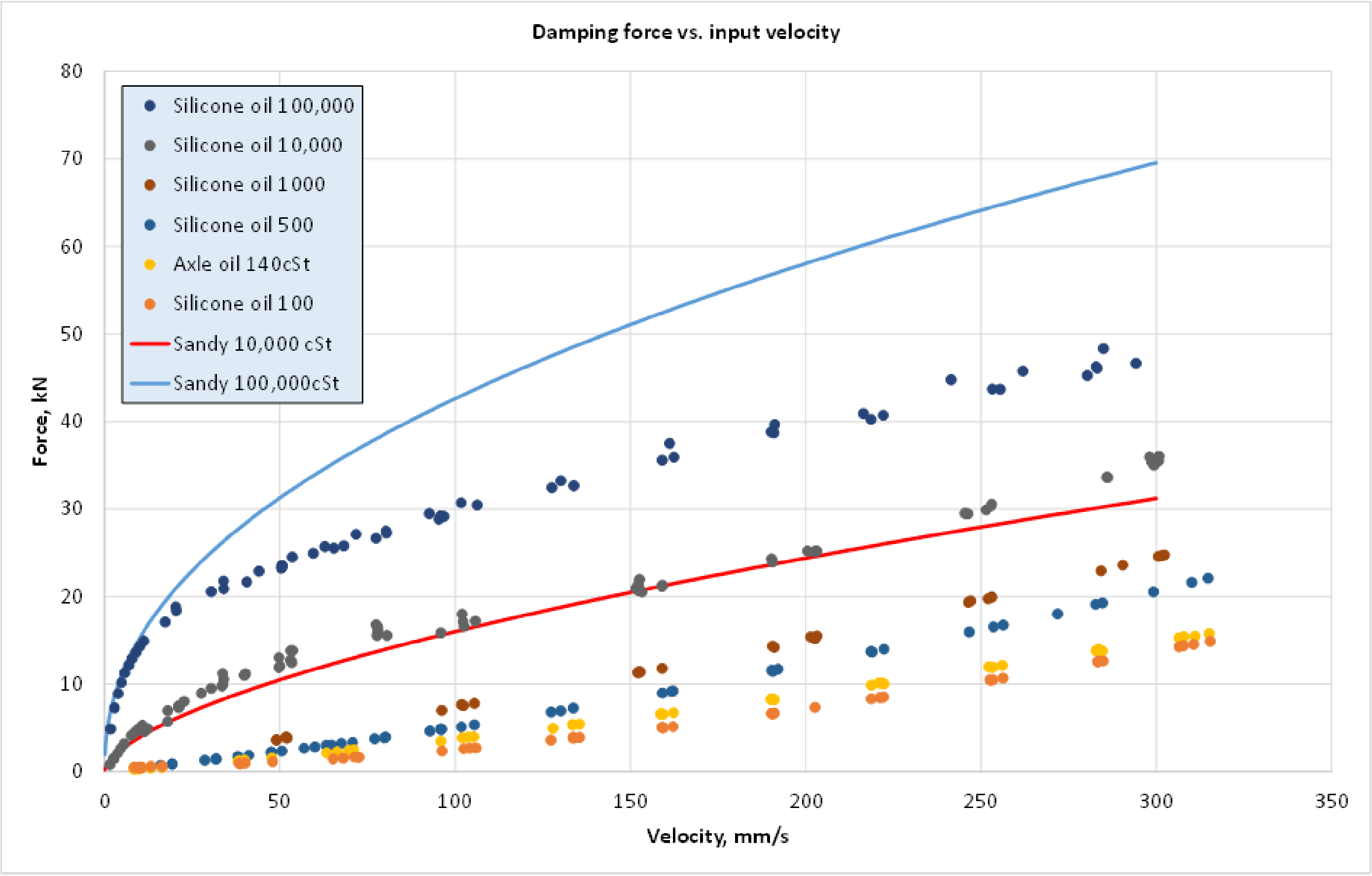
Computational Fluid Dynamic Modelling

- Testing of Non-Newtonian fluids and comparison of experimental and fluid dynamics models



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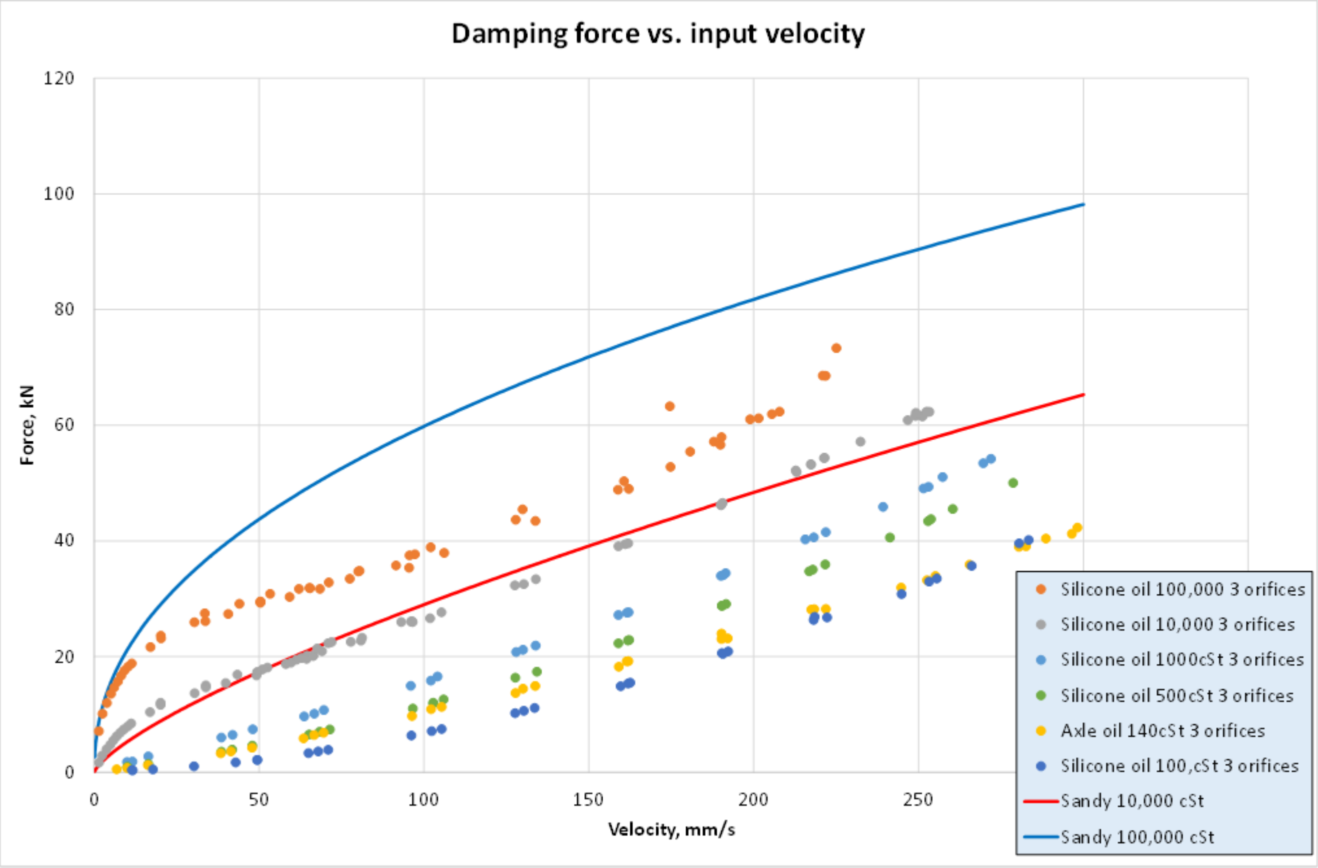

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Focus of Ongoing Work

- Extension of the multi-level analytical modelling to other similar structures and investigation of the influence of damper placement within structures
- Further work on CFD modelling to better understand internal reaction mechanisms (an extension to the project, not a core focus)
- Modelling work and development of a device for potential inclusion within the QuakeCoRE-ILEE tests at Tongji.
- Ongoing discussion with practitioners about system-level integration of energy dissipation/damping devices.