ACTIVE VALVE CONTROL FOR CONTROLLED ENERGY RELEASE IN NON-LINEAR SEMI-ACTIVE DEVICES

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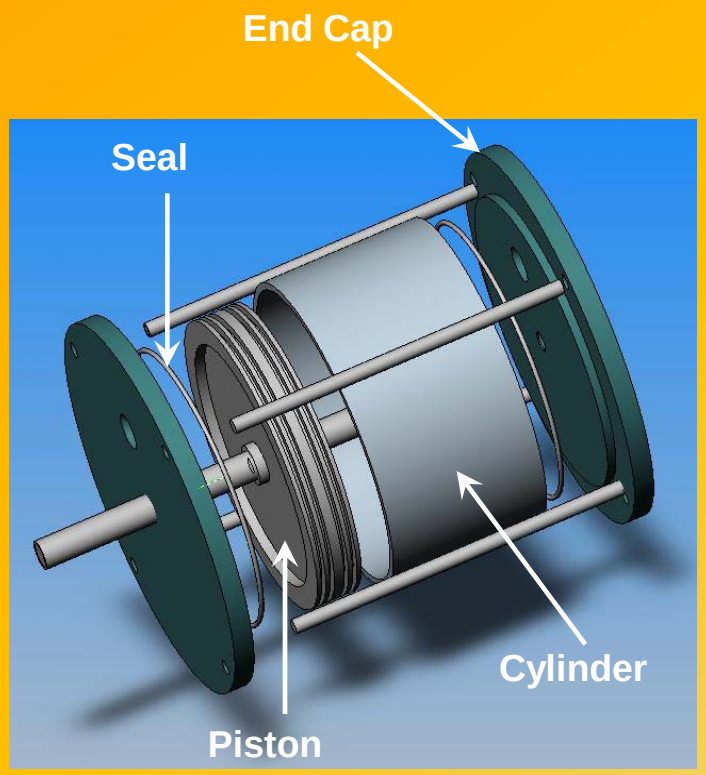
Motivation

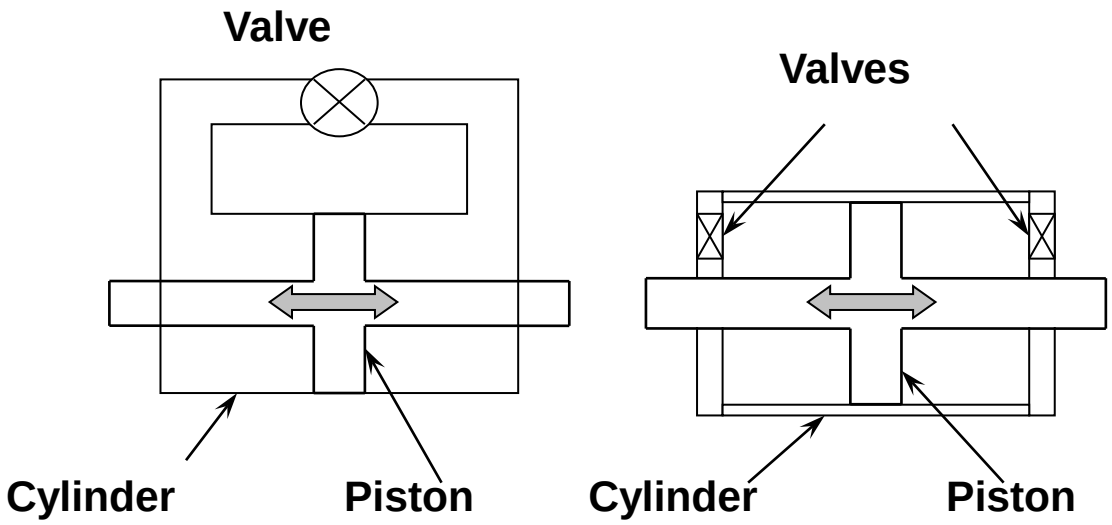
- *A main goal of a structure in a seismic event is to dissipate energy in a repeatable fashion*
- *Preferably in large amounts*
- *A diamond shaped resetable (Semi-Active) device has been shown to break existing compromises between reducing base shear and increasing dissipated energy with these devices*
- *<u>HOWEVER</u>, these solutions rely on an ideal linear shape for the device hysteresis loop → From a highly nonlinear device!*
- *This presentation presents a unique active valve control that provides this ideal, linearised shape using highly accurate, validated nonlinear device models* *[Mulligan et al, 2008; 2010]*

Re-Shaping Hysteretic Behaviour Using Semi-Active Resetable Devices

Double-acting piston with controlled dissipation enables customisation of structural hysteresis

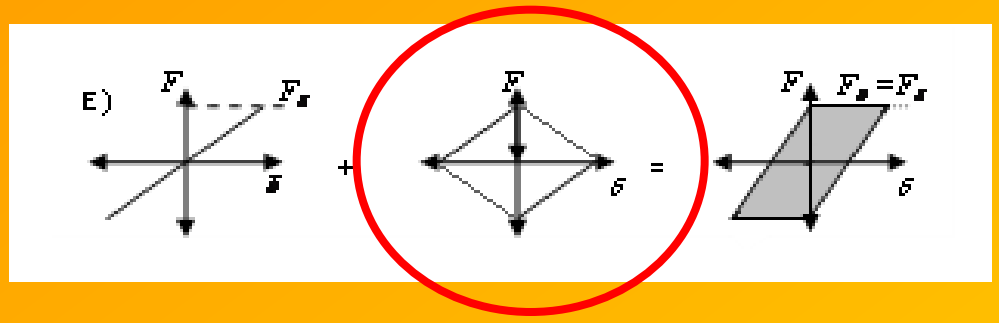


Device Design



Independent two chamber design allows broader range of control laws

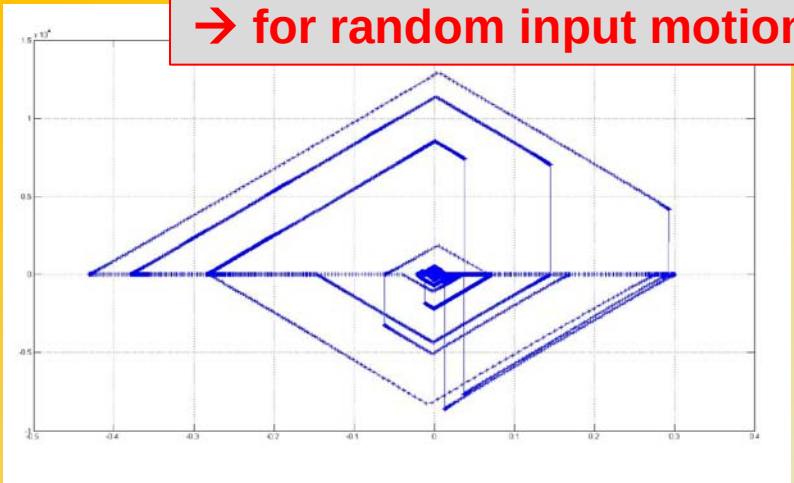
A Diamond-Shaped Solution



- **Increased** energy dissipation
- **No increase** to base shear
- **Reduced** displacement

- Meets all goals

Ideal Device Model Loop
→ for random input motion



- **Problem: How to get this ideal linear behaviour from a nonlinear device**

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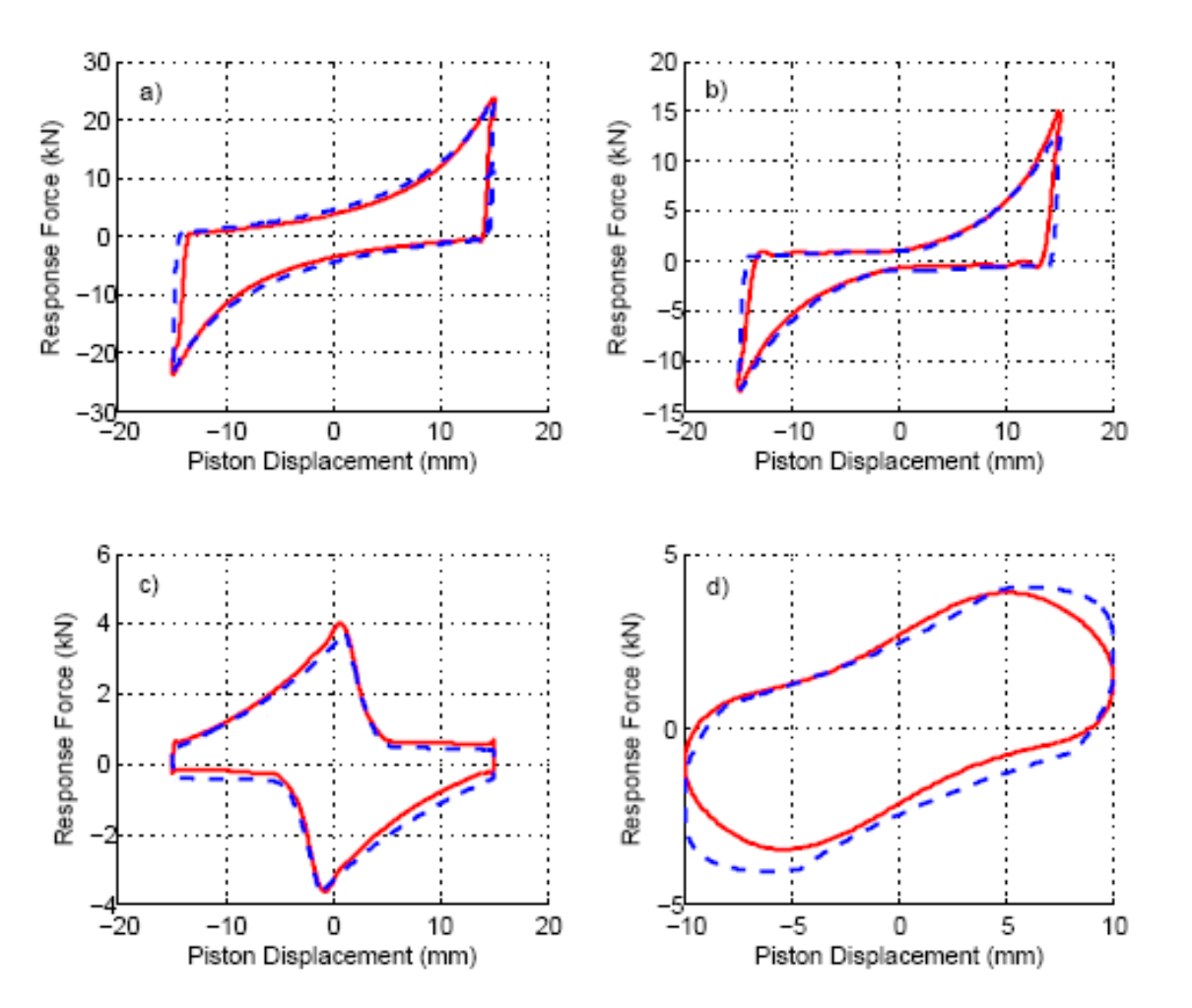
The Problem = Nonlinear Devices

- Typical device control laws yield <u>nonlinear</u> hysteresis loops:



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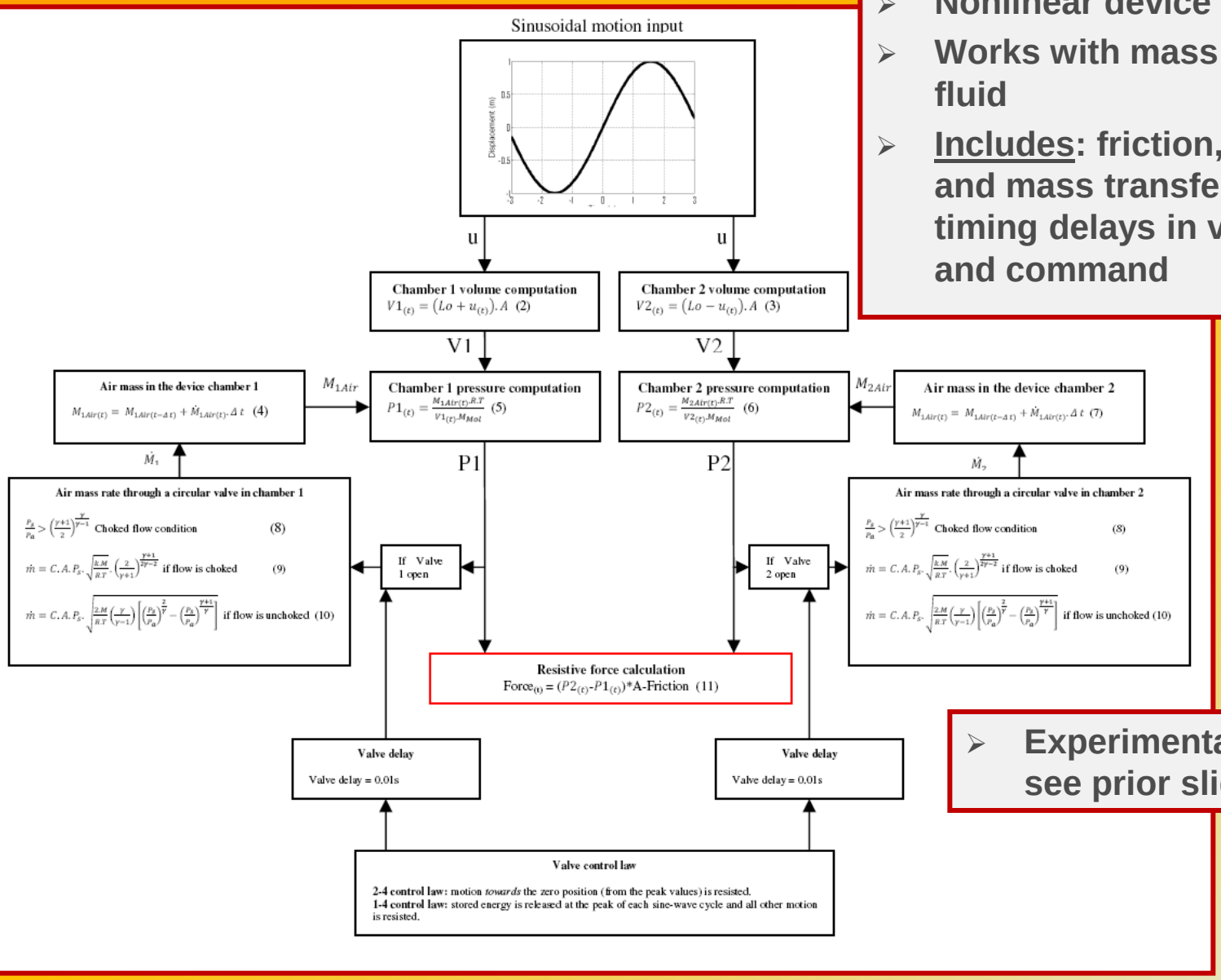
How Nonlinear? … Very

- Nonlinear device model and flow
- Works with mass flows of working fluid
- <u>Includes</u>: friction, nonlinear heat and mass transfer, valve size, and timing delays in valve opening and command



- Experimentally validated – see prior slide figure

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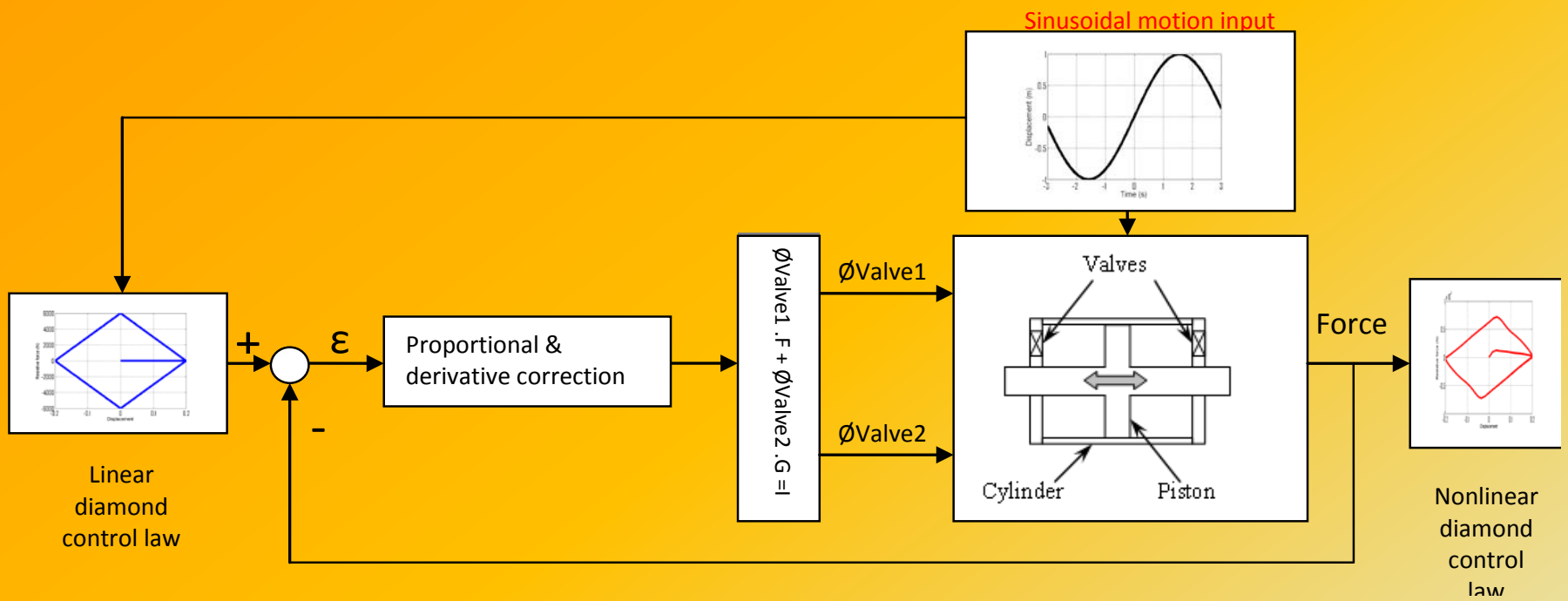
Solution: Active Valve Control



- **Feedback loop sets desired shape**
- **PD control used to set valve diameter as control input**
- **Tested with sinusoidal input motions (for clarity)**

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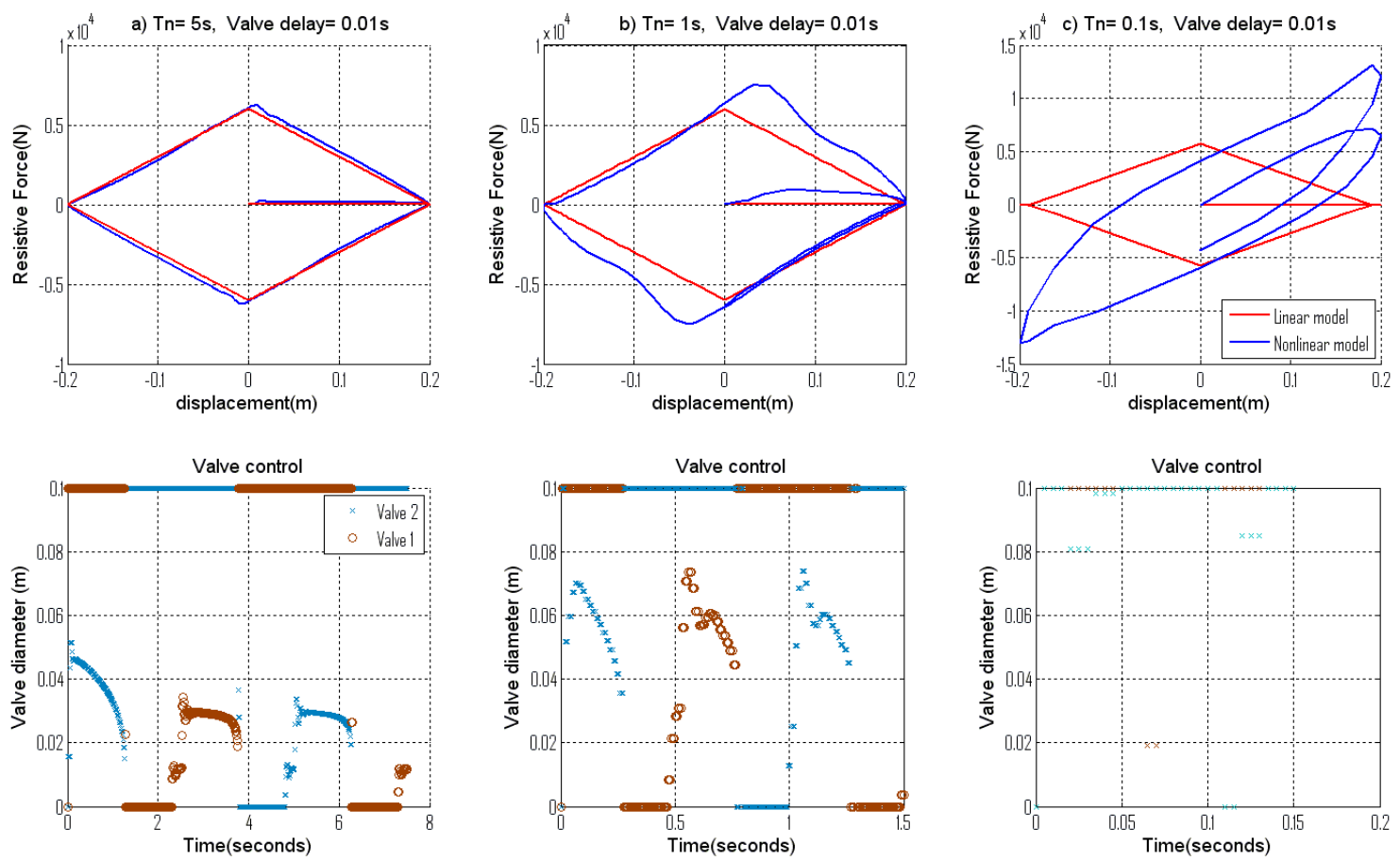
Results vs Structure Period



- As period shrinks the number of time steps to control shape per cycle declines significantly → Loss of control and inability to control shape
- At T = 0.1 sec with valve delay of 0.01 sec → Only 10 corrections are possible to control shape (100 for T = 1.0 sec and so on).

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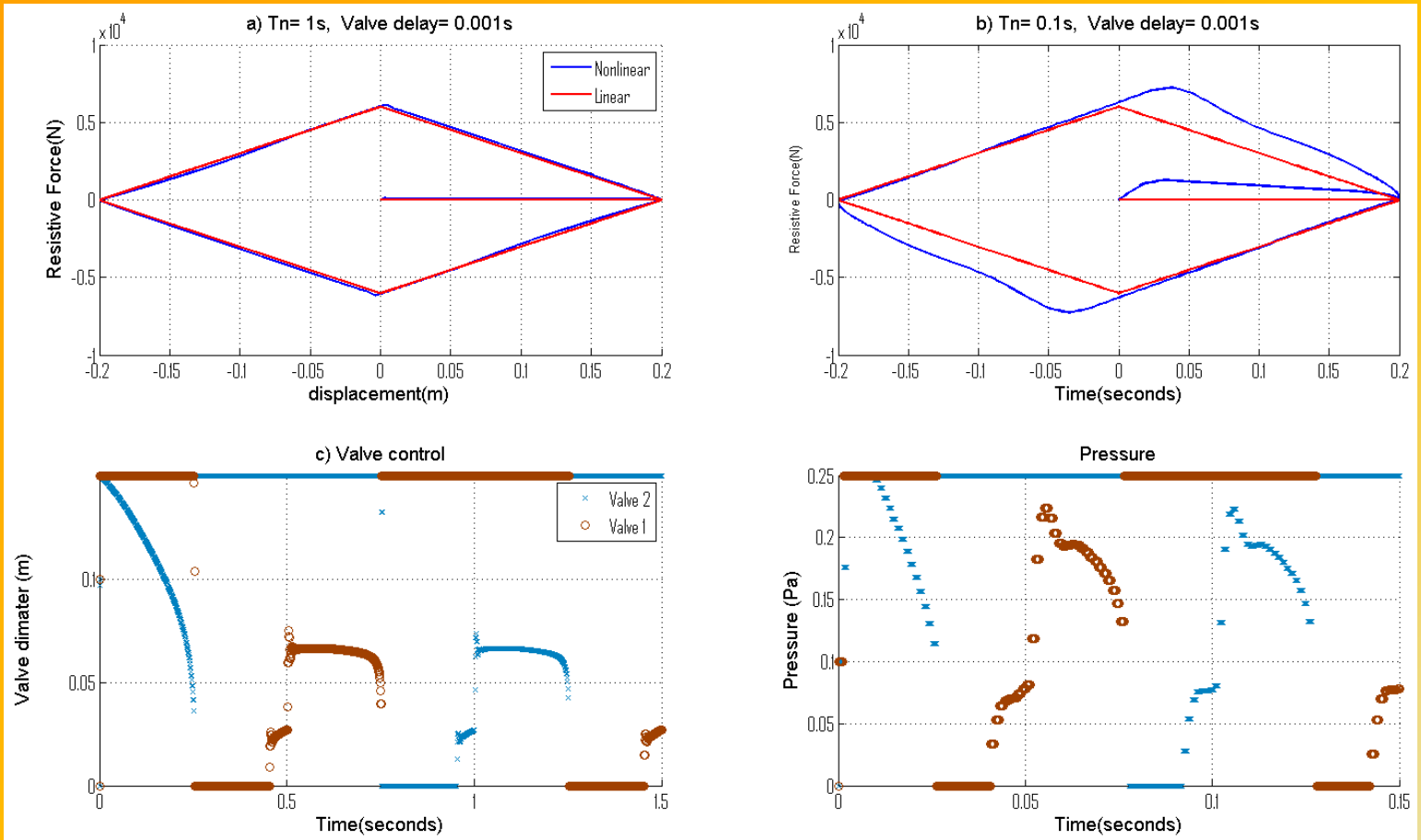
Results vs Valve Delay



- Similar to changing period. Reduced valve delay provides more cycles to make corrections and achieve good control
- Valve delay and Tn trade off in design
- Realistic valve delays depend on valve size

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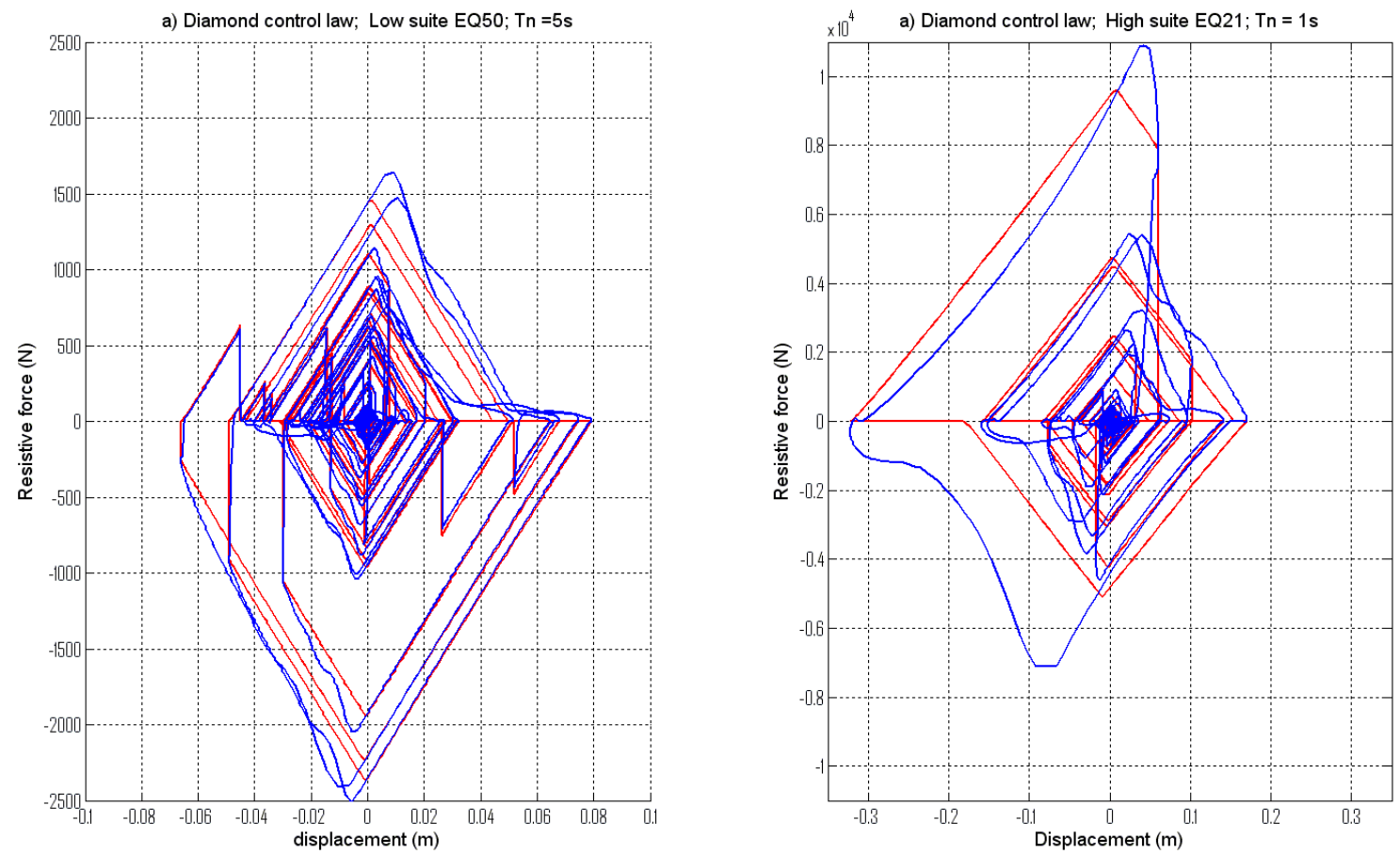
Results – Realistic Input



- SDOF spectral analysis case wtih Tn = 5s and 1s (left / right)
- Actual system close to ideal linear except for 1-2 cycles at faster period
- Valve delay = 0.01s

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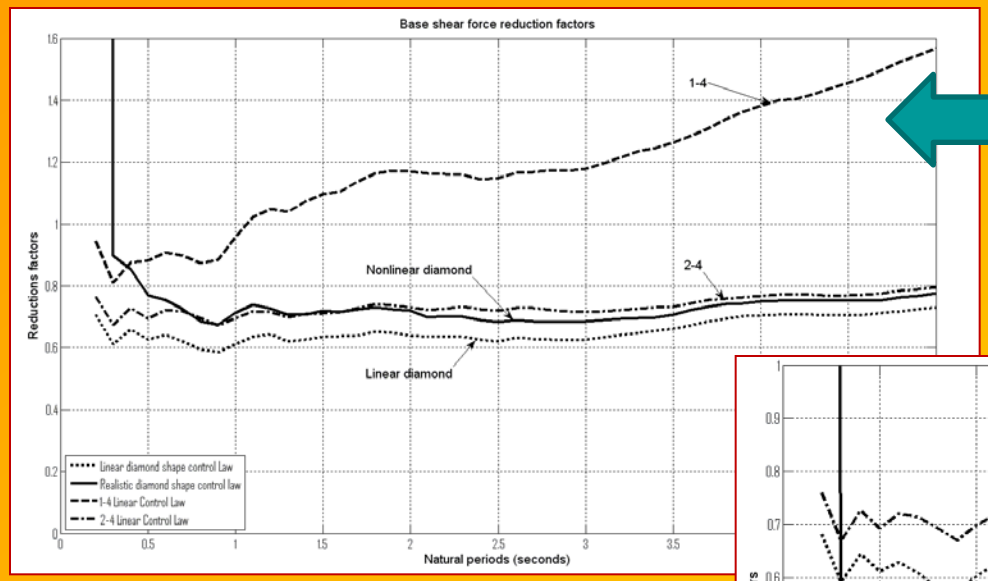
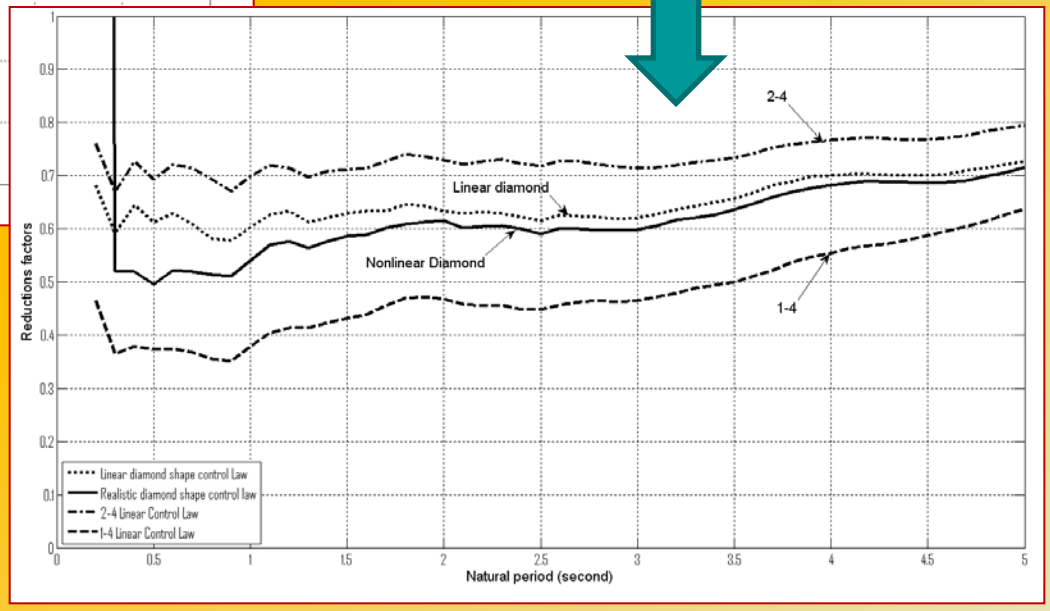
Results – Spectral Analysis



Structural Force (and displacement)

Base Shear Force



→ **Repeat of plots from first presentation comparing to 1-4 and 2-4 devices**

- **Spectral analysis across all 3 SAC suites with valve delay of 0.01s**
- **Ideal versus Nonlinear → Did we achieve the outcome of matching the linear, ideal case (robust over 60 ground motions)??**
- **At low Tn, valve delay → Tn and not a good match. OK after Tn = 1.0-1.5s**

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“Local” Conclusions

- Diamond shape active valve controlled resetable devices offer some significant potential for specific, high value applications
- Active valve control implemented using a validated, highly nonlinear model of semi-active devices
- Basic PD control can yield a highly linear, ideal device outcome for both sinusoidal and random earthquake (response) inputs
- Valve delay and natural period (Tn) must be considered in valve selection for obtaining desirable results
  - Tradeoff leads to selecting (e.g.) one large valve versus several smaller but faster valves to yield same total orifice area
- Spectral analysis shows the models and approach are robust over a wide range of periods and ground motions

So, ... From these 2 talks ...

- **We can use resetable devices to further optimise hysteresis loops and maximise trade**
- **Accomplished by using active valve control to effectively "linearise" these devices**
- **When they act like a linear ideal device they are easily analysed, BUT also ideal (maximum) energy dissipaters**
- **But, could we do this passively by design alone for 1-4 and 2-4 devices that don't need active valve control?**

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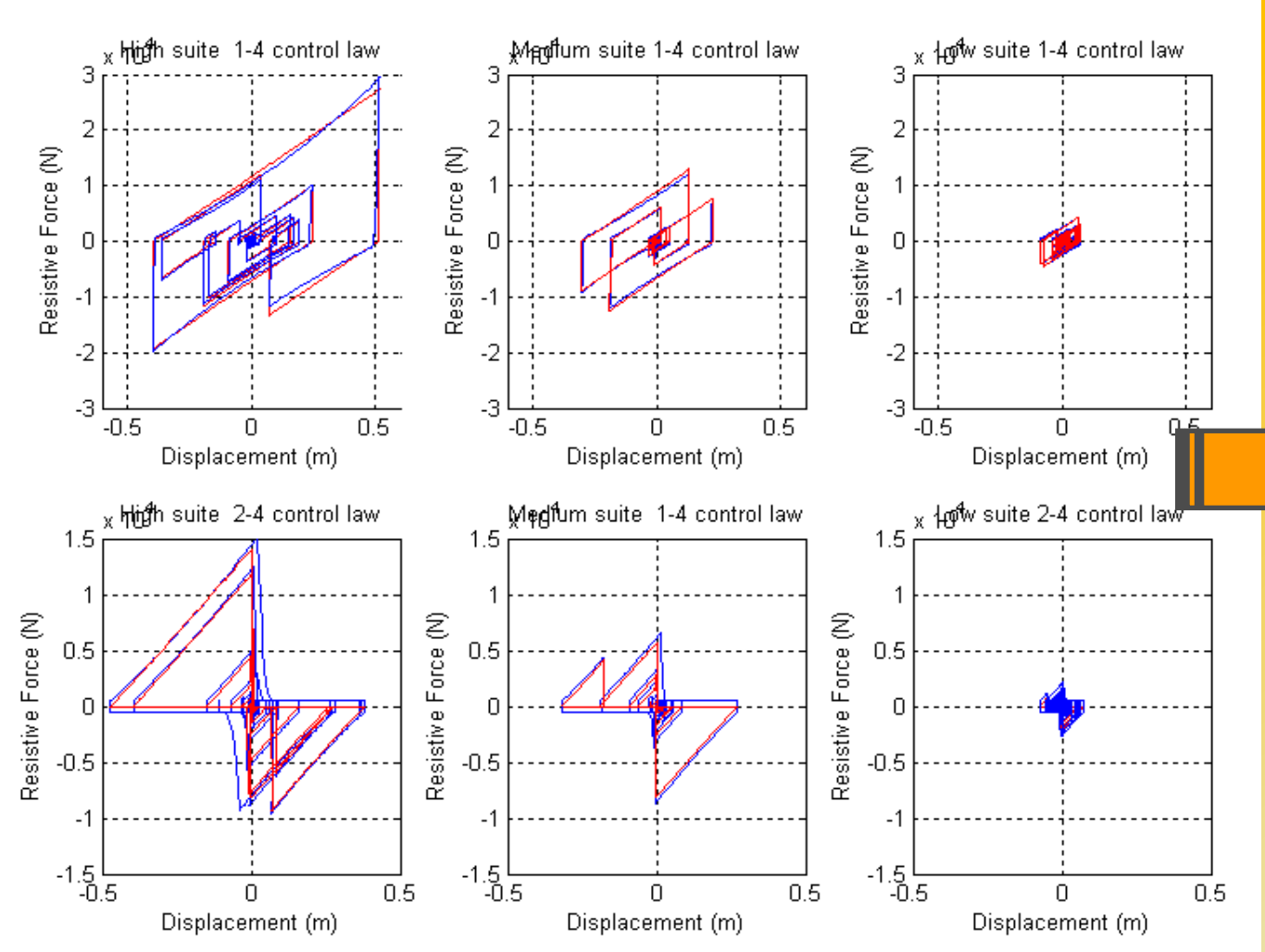
The Real End ... OR What's to come

- **But, could we do this passively by design alone for 1-4 and 2-4 devices that don't need active valve control?**



YES

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