Do We Need Better Suspension Element Models ?

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Simple Answer

Yes !

Multi-Body Simulations

- Regardless of formulation, all vehicle-track MBS codes fundamentally use the same modeling approach
- Lumped masses
  - Rigid body
  - … or flexible body
- Connected by suspension elements
  - Constraints or joints
  - Springs, dampers, etc.
- Plus specialized wheel/rail elements
  - Hertzian contact, non-Hertzian contact, etc.

Suspension Elements

- Do we correctly represent actual suspension behavior ?
- Example issues
  - Faulty assumptions
  - Quasi-static stiffness versus dynamic stiffness
  - Damping or hysteresis
  - Small amplitude versus large amplitude response
  - On-axis versus off-axis behavior
  - Interaction between on-axis and off-axis inputs
  - Real components versus design idealizations
- Are the errors important ?

Examples

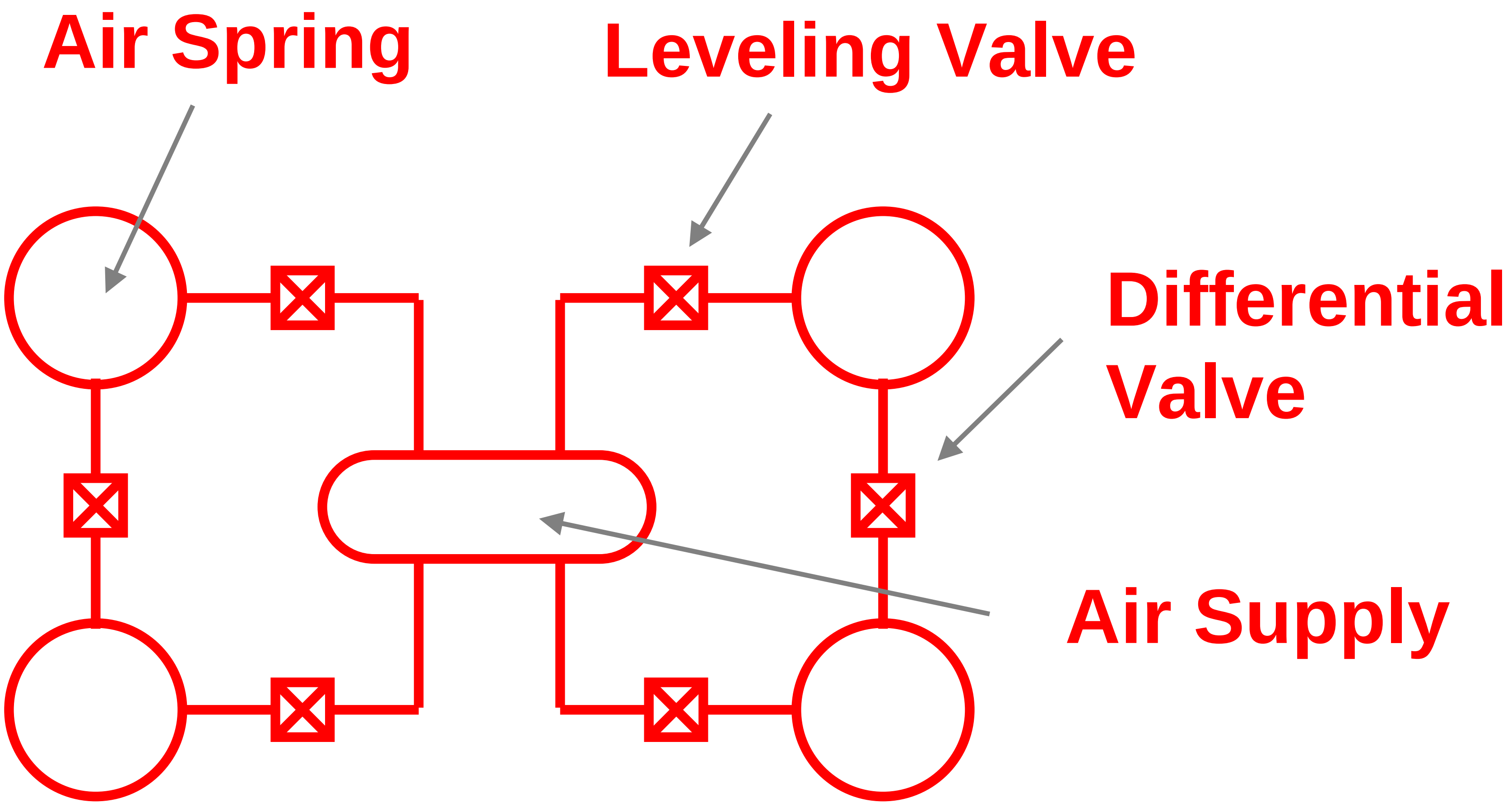
- Air spring − secondary suspension component for most modern passenger cars
  - Interaction between interconnected air springs
- Friction wedge − critical suspension element for three-piece freight car truck (bogie)
  - Vertical response … OK
  - Lateral response … sometimes
  - Vertical, lateral, plus warp … no clue
- Shear spring − interaction between on-axis and off-axis behavior (coil spring or rubber-metal pad as examples)
  - Coil spring shear stiffness as function of rotation angle

Air Spring

- Typically consists of air spring, auxiliary reservoir, safety spring, and leveling valve
- Air spring is flexible, while reservoir is rigid
- SIMPACK®, VAMPIRE®, and VI-Rail® have stand-alone vertical and lateral models with varying degrees of complexity
- Roughly comparable model can be created in NUCARS® by combining element types and adding masses to represent inertial effects
- Modeling generally ignores leveling valve

Reality is More Complicated

- Four-point leveling system (for example)



System Components

- Air springs
  - Non-linearities
  - Skirts to control shear stiffness as function of direction
- Reservoirs
- Connecting lines
- Leveling valves
  - Geometry, dead-band, and delay effects
- Differential valves
  - May be pressure-dependent
- Orifices
  - Pressure-dependent and direction of flow dependent

Modeling Solutions

- More detailed models are available
  - Work of Docquier at Université Catholique de Louvain (Belgium) involving co-simulation between SIMPACK® and Simulink®
- Interface with Simulink® creates flexible approach but typically not available to industry

- Proposed solution is extended element library to allow modeling of individual components
- System architecture defined through block diagram

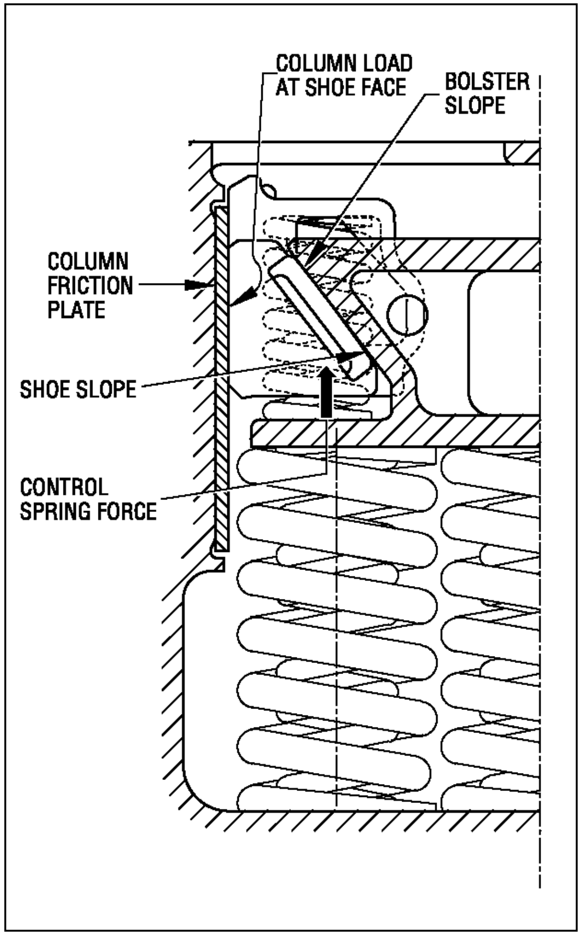
Friction Wedges

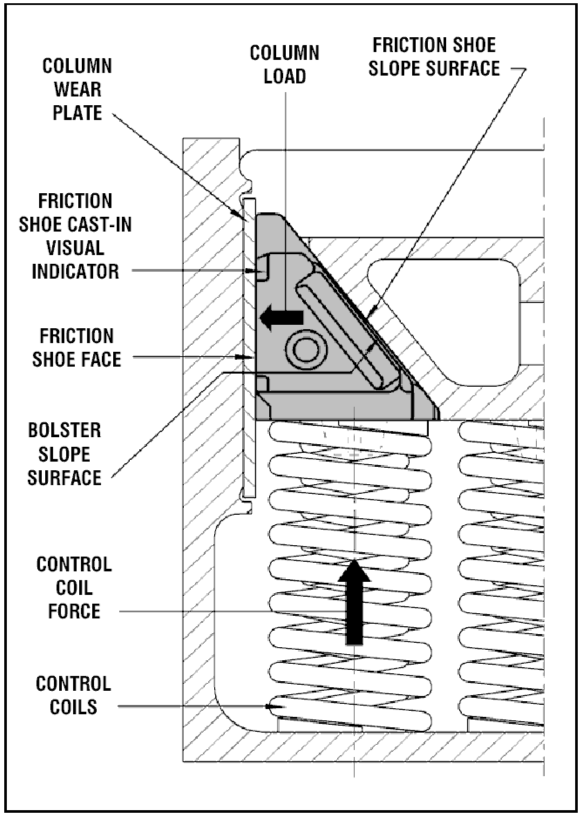
- Primary damping component for three-piece freight car truck
- Integral to all aspects of vehicle response

Photographs courtesy of A. Stucki Company

Damping Design

- Wedge moves with bolster and bears on side frame columns
  - Constant column damping
  - Variable column damping

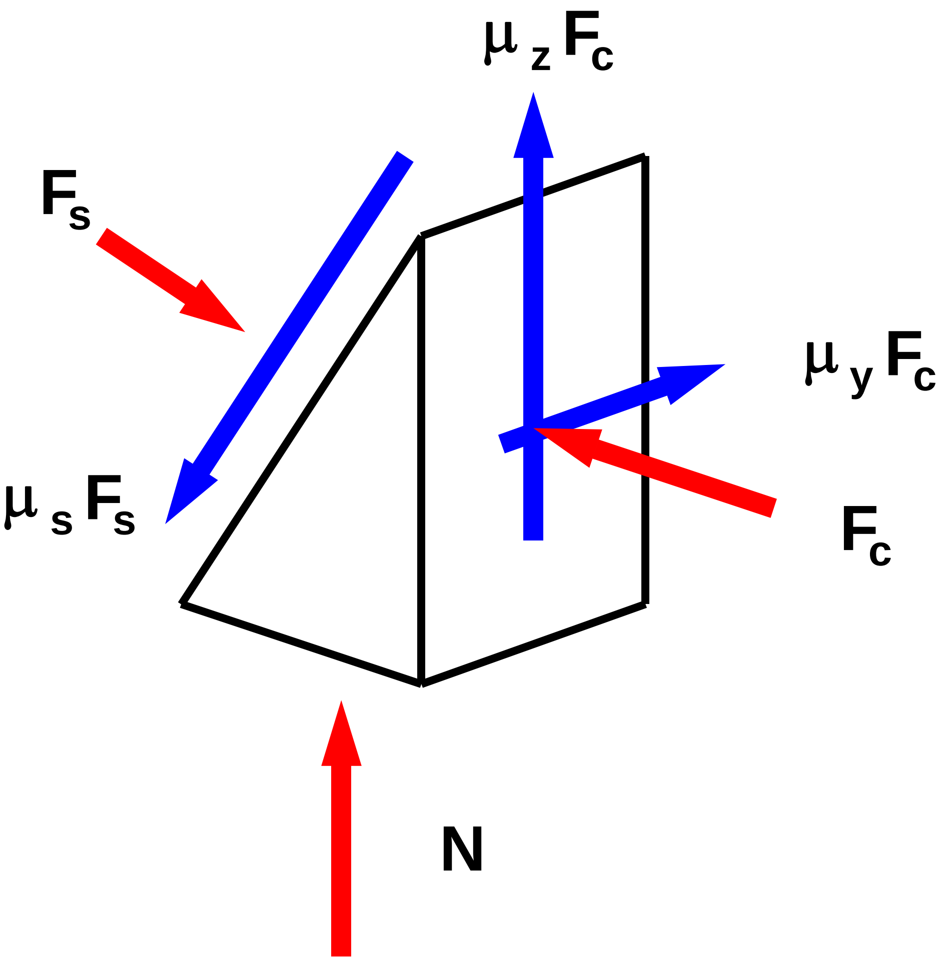




Original figures courtesy of ASF-Keystone, Inc.

Wedge Effect

- Wedge angle and combined friction forces on slope and column faces define wedge response
- Wedge may or may not lock dependent in column face toe-in or toe-out

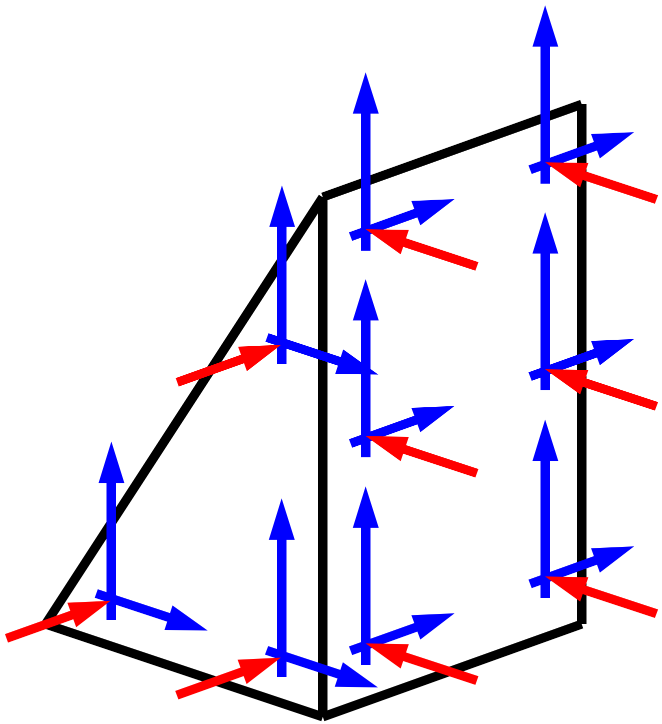


Modeling Options

- NUCARS® (in particular) and VAMPIRE® both contain wedge models
- VI-Rail® includes constant and variable column damping models in Freight Toolkit
- Considerable research over past years regarding “better” wedge model
- Limited progress on implementation of improved models in commercial codes

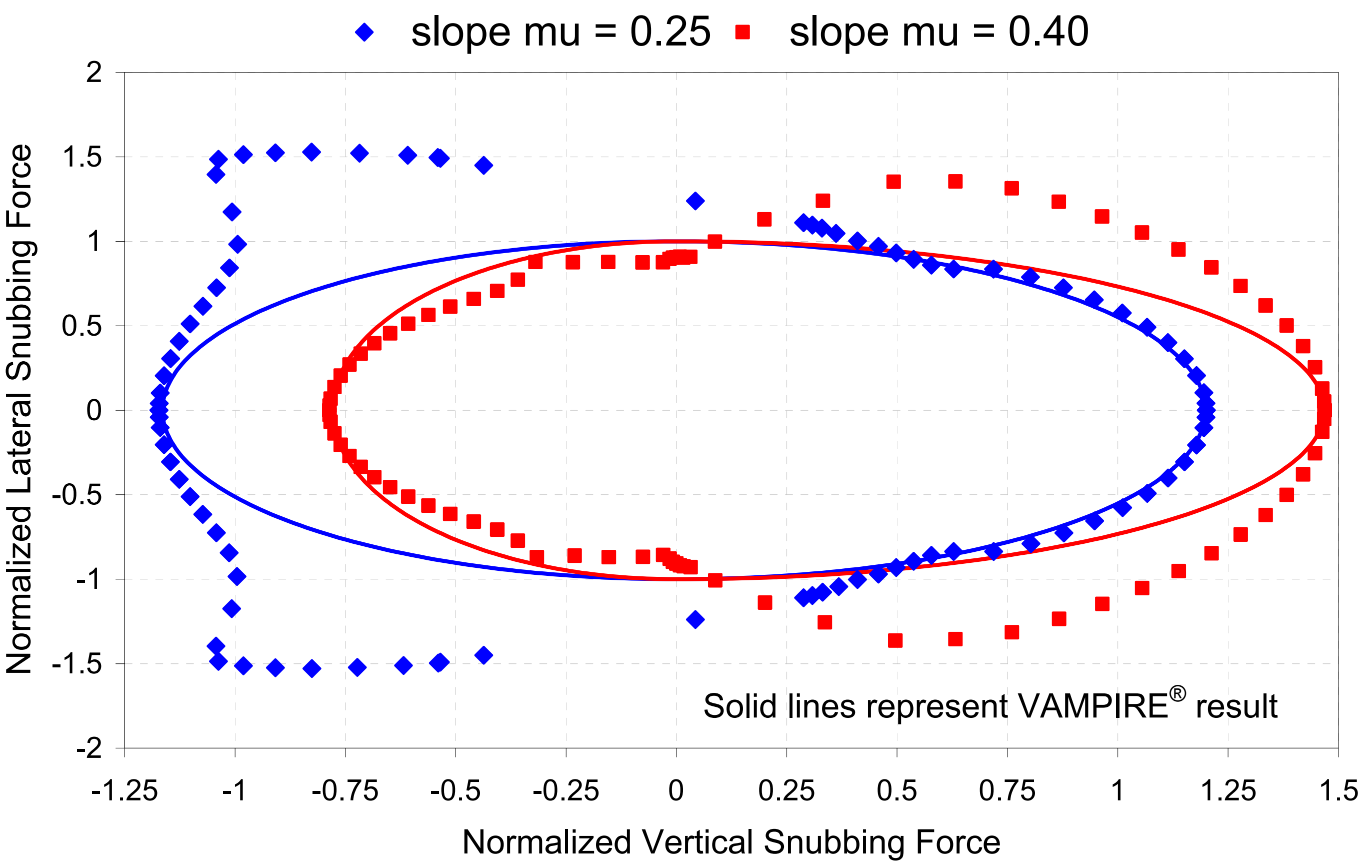
Improved Model

- Wedge element with mass
- Contact surfaces represented through grid of contact elements with normal stiffness and tangential friction
  - Explicit model of wedge geometry (width depth, height)
  - Ability to represent amount of column toe-out or toe-in
  - Modeling of normal and tangential pressure distributions on wedge faces
  - Explicit modeling of friction on wedge faces (including stick and slip)
  - Possibility of side wall contact



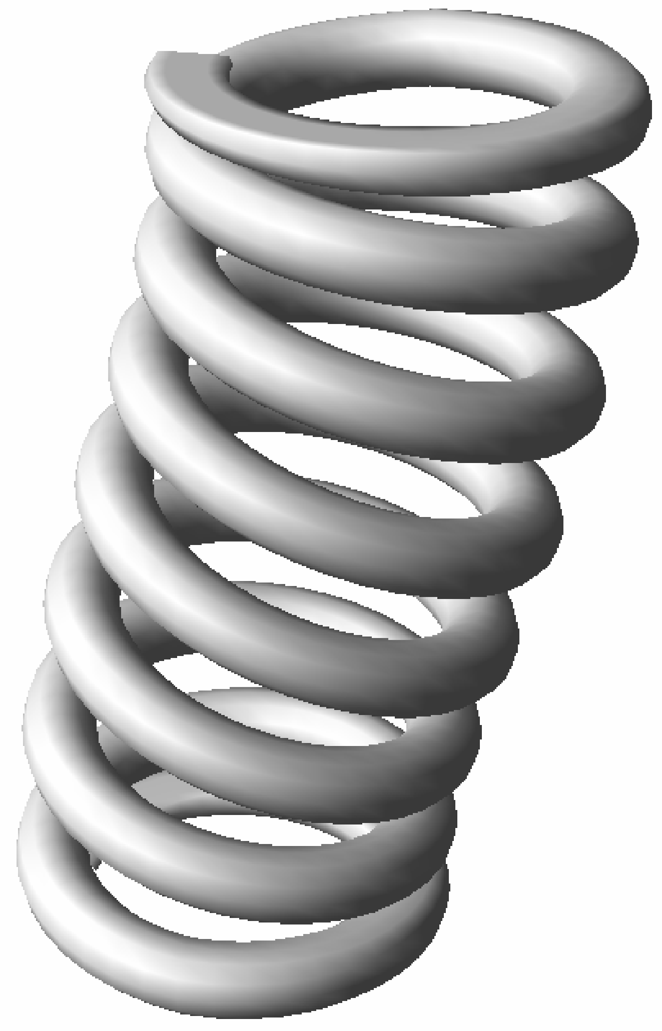
Test Results

- Vertical versus lateral sliding with column face friction of 0.4 and slope face friction of 0.25 or 0.4



Shear Springs

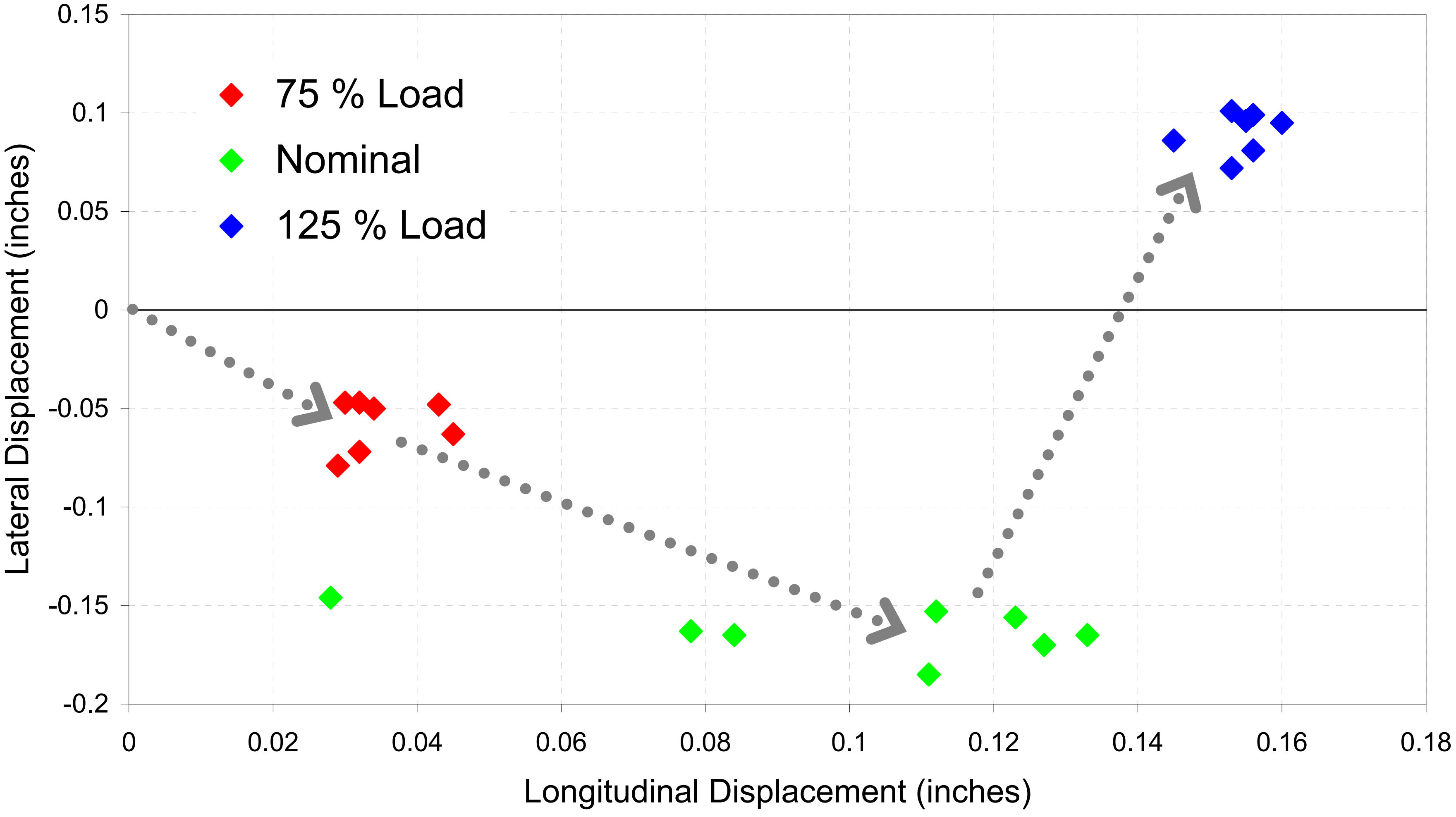
- Modeling of coil springs and rubber-metal sandwich springs
- Interaction between on-axis (vertical) and off-axis (shear response)
- SIMPACK®, VAMPIRE®, and VI-Rail® have models with varying degrees of complexity



Shear Springs

- Modeling challenges
  - Off axis forces under static loading
  - Changing shear stiffness as function of on-axis load
  - Variable shear stiffness as function of rotational position
  - Effect of spring support conditions

Off-Axis Forces



Effect of Rotation Angle