Modeling Moving Systems with RELAP5-3D

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Outline

- Background
  - Purpose
  - Refresher on moving problem theory
- Quantitative Verification
  - Translation Verification Problem
  - Calculation of Acceleration
  - Resultant Body Force
- Qualitative Assessment
  - Rotational
  - Translation
- Conclusions

Purpose

- Demonstrate ability to simulate moving systems with RELAP5-3D
- Demonstrate quantitative verification of code calculated accelerations due to translational displacement
- Demonstrate quantitative verification of code calculated pressure change due to acceleration
- Qualitative assessment of simple U-tube like geometry under rotational and translational motion
- Show similarity in results from rotational and translational sample problems

Modeling moving systems

- Moving system theory and input presented by Dr. Messina last year
- Only momentum equations are modified to account for system motion
  - Thermal energy equations do not include potential or mechanical energy
- System motion is accounted for with an additional body force term
  - Modifies the apparent acceleration due to gravity
- User can input system motion as rotation or translation of (or about) the metacenter
  - Motion can be input using functional forms or tables

Quantitative Verification

- Independent calculation of the body accelerations in 3-dimensions
  - Translational accelerations are separable
  - Each direction of body motion can be aligned with streamwise direction
- Independent calculation of resultant pressure difference due to accelerations
  - Calculation of pressure change from acceleration is independent of type of motion causing the acceleration
  - Verification for translation is valid for rotation

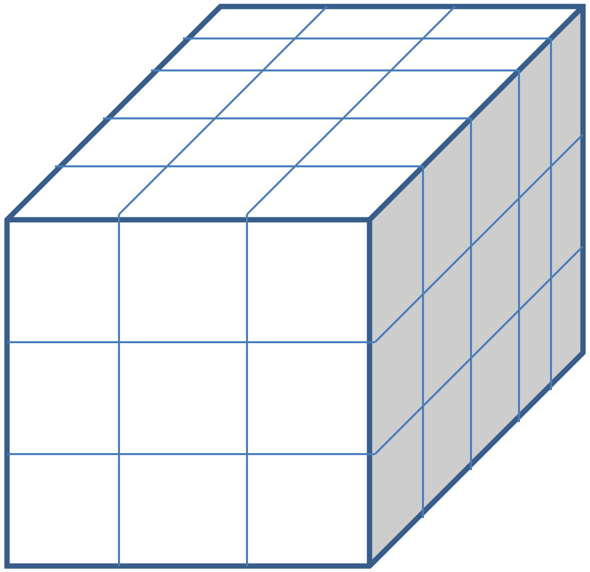
Translation Verification

- Interconnected rectangular prism
  - 3x3 square array of pipes
  - Each pipe is 5 volumes long
  - Multiple junctions used for transverse connections
- Sinusoidal forcing functions applied in each direction

$$\mathrm{x(t)} = 38.1m\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$

$$\mathrm{y(t)} = 152.4m\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$

$$\mathrm{z(t)} = 72.6m\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$



Translation Verification

- Verification of accelerations
  - Analytic solution by taking second derivative of displacement with respect to time

$$a_x(t) = \frac{d^2x}{dt^2} = -\frac{4\pi^2}{(10.0s)^2}(38.1m)\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$

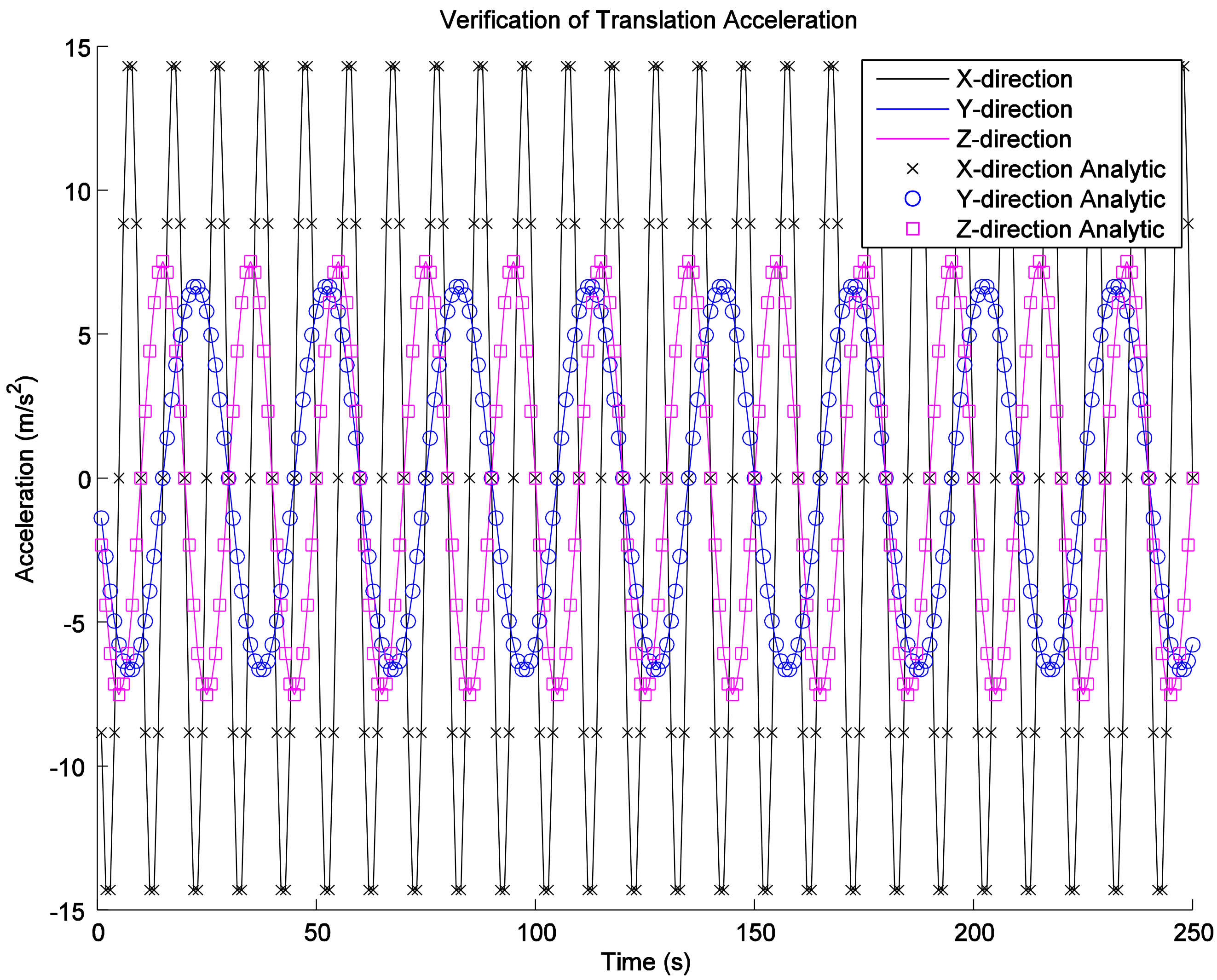
$$a_y(t) = \frac{d^2y}{dt^2} = -\frac{4\pi^2}{(10.0s)^2}(152.4m)\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$

$$a_z(t) = \frac{d^2z}{dt^2} = -\frac{4\pi^2}{(10.0s)^2}(72.6m)\ \sin\left(2\pi\left[\frac{t}{10.0s}\right]\right)$$

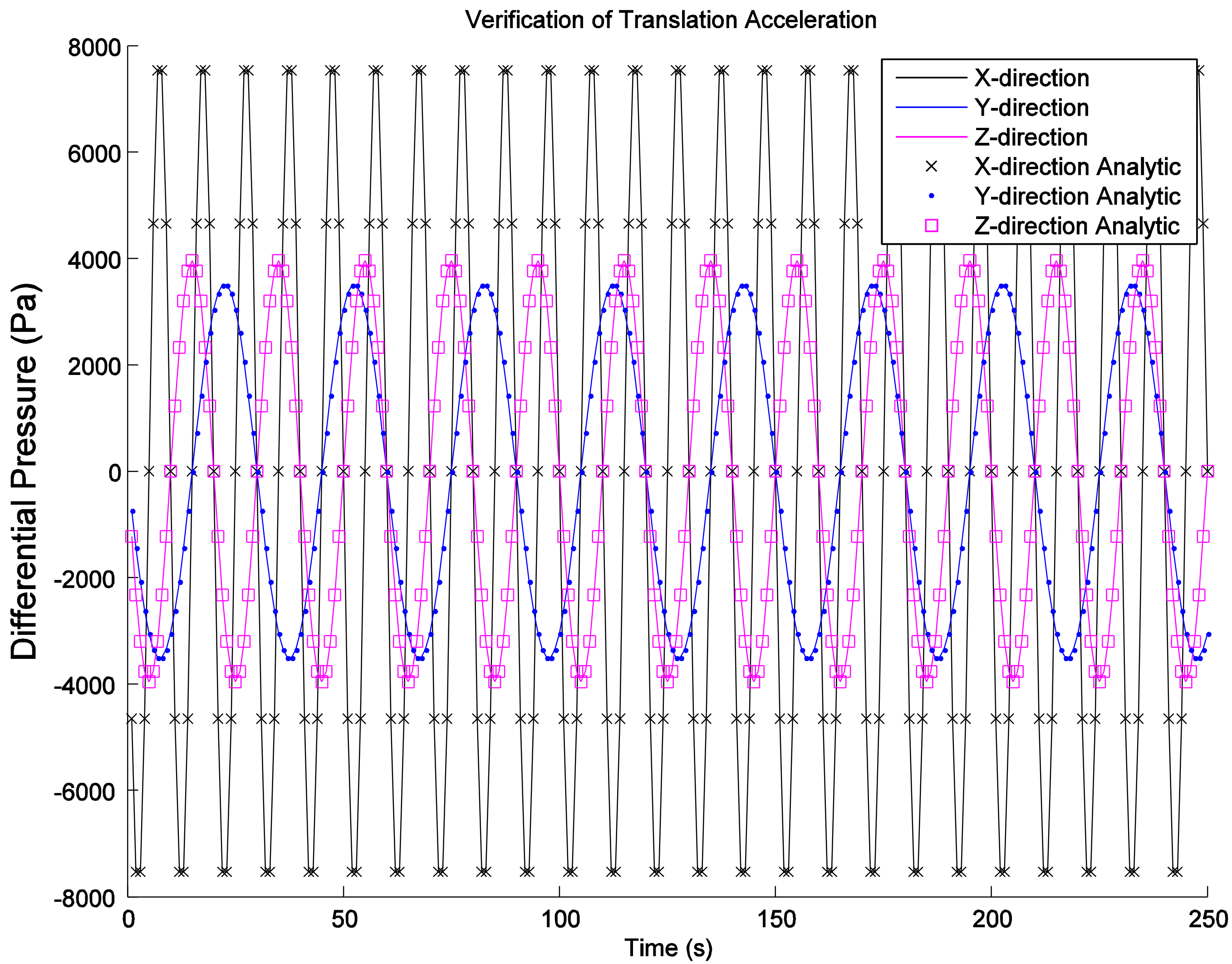
  - Pressure change due to acceleration is given as:

$$dp = \frac{1}{2}(\rho_K + \rho_L)\ a_{acc}\frac{1}{2}(L_K + L_L)$$

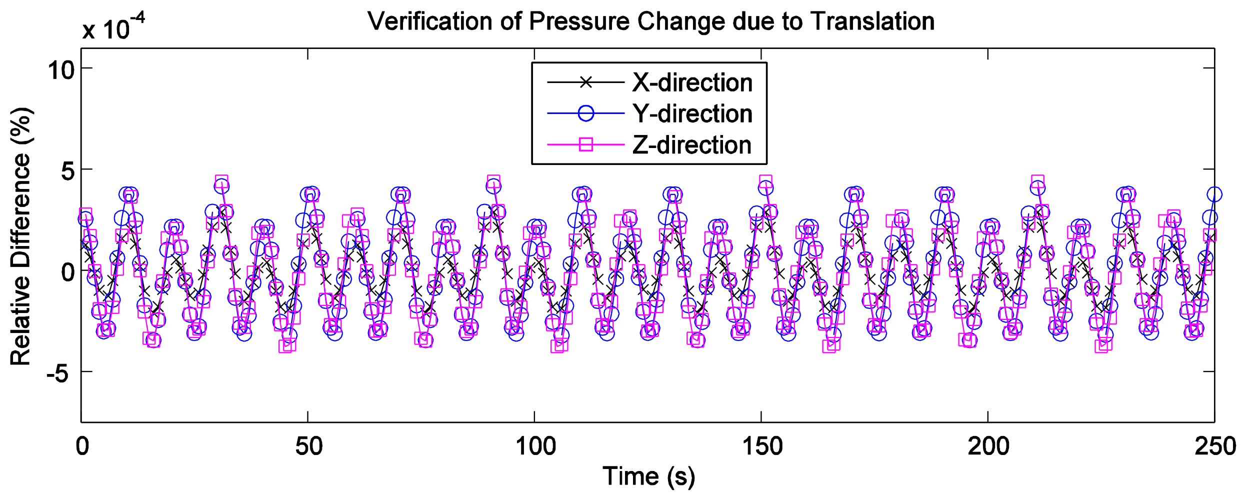
Translation Verification

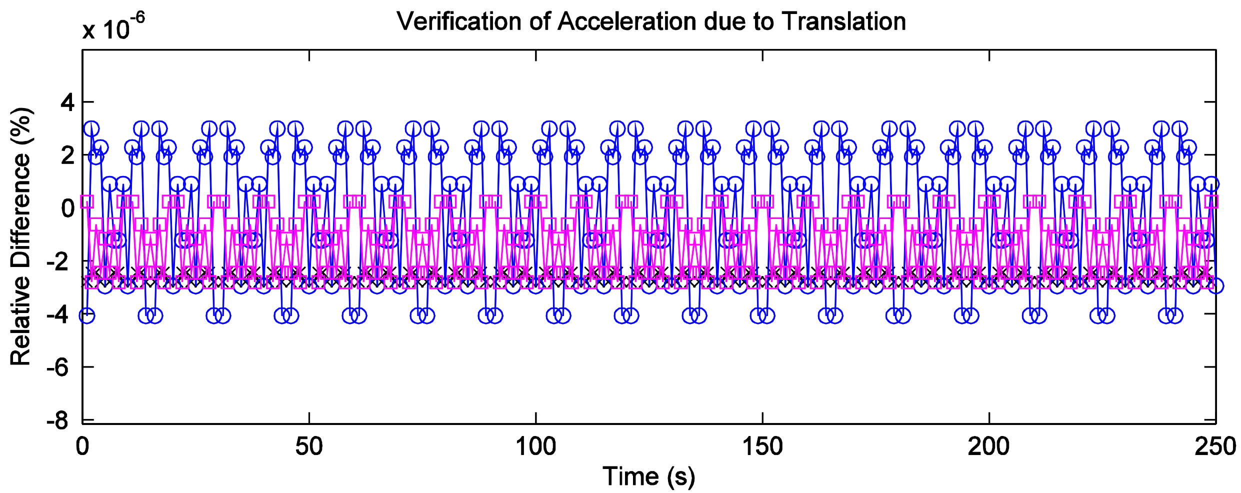


Translation Verification



Translation Verification

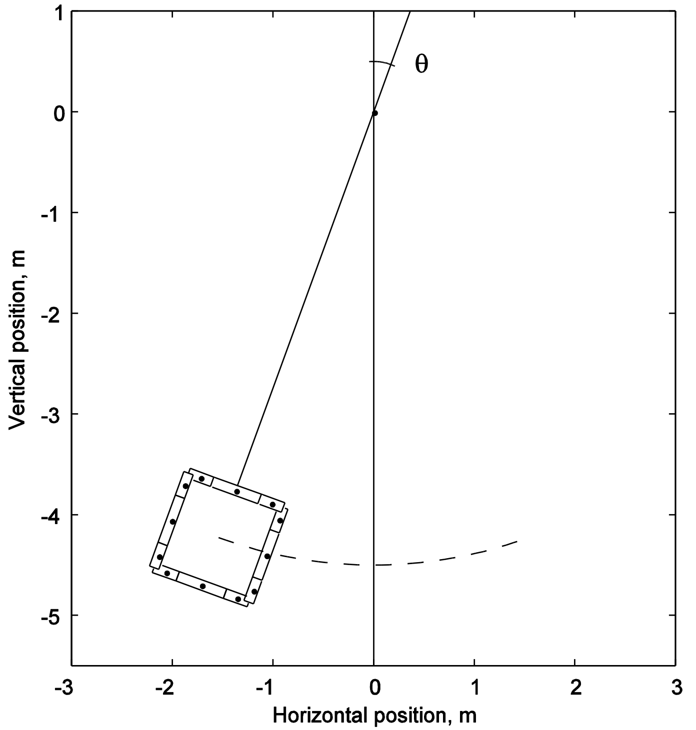




Qualitative Assessment

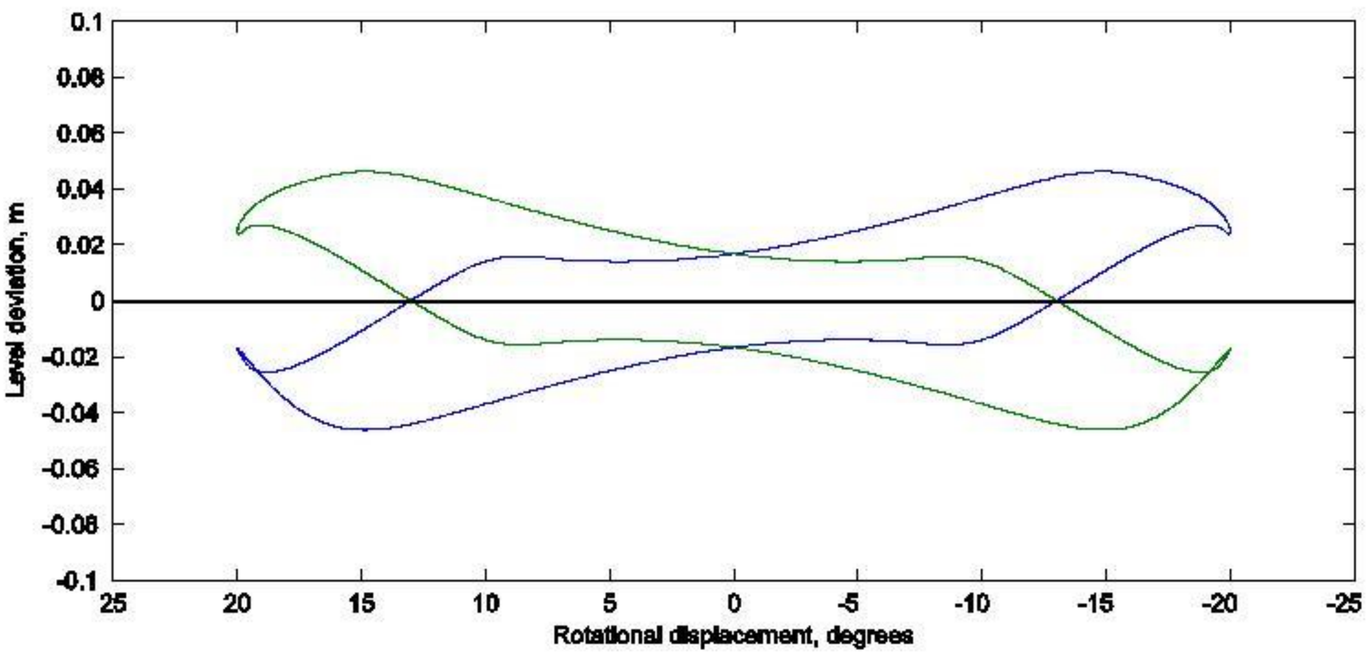
- Rotational Sample Problem
  - One pipe component and one single junction
  - Formed into a square
  - Equilibrium level at midpoint of vertical legs
  - Top leg of square is 4 meters below center of rotation
  - Rotates according to:

$$\theta(t) = 20^\circ \sin\left(2\pi\left(\frac{t}{10s}\right)\right)$$

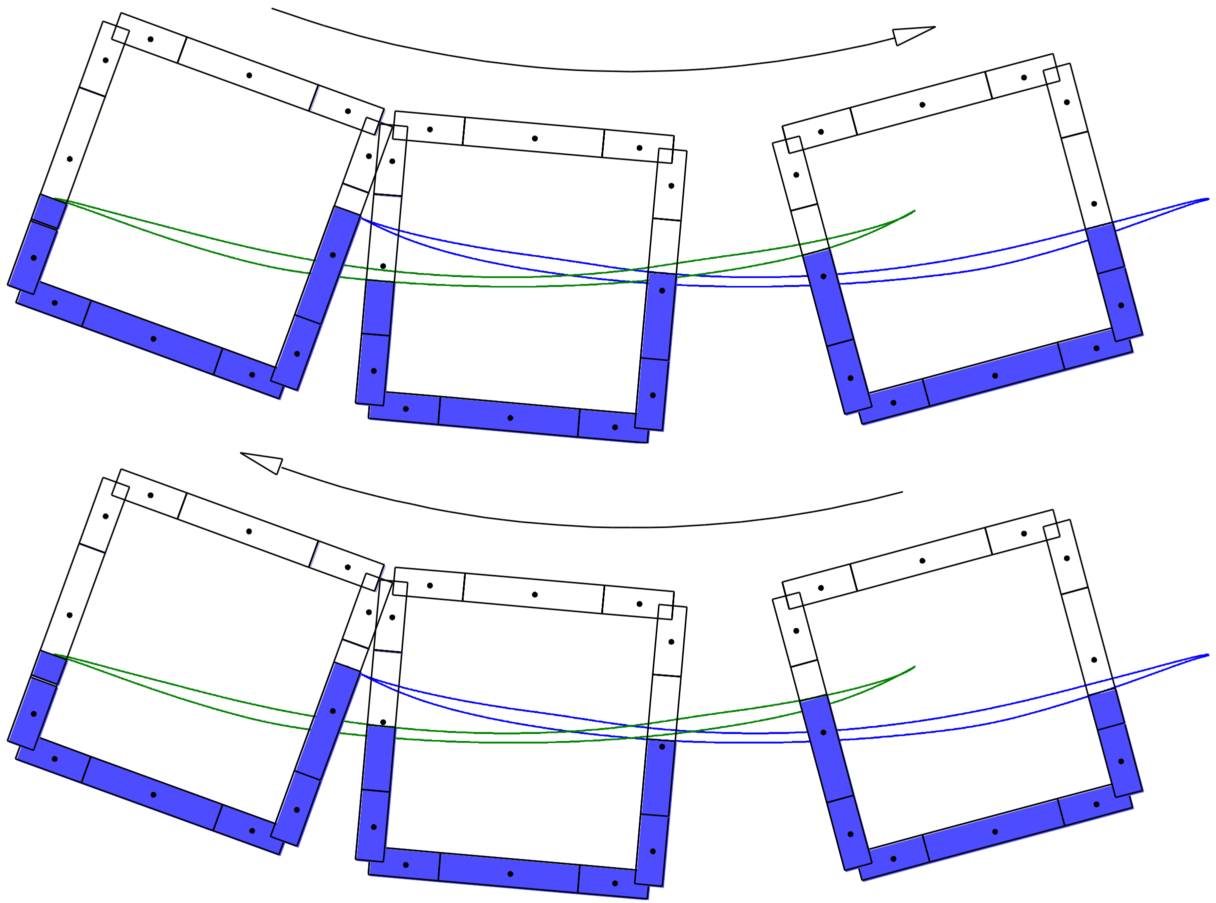


Rotational Sample Results

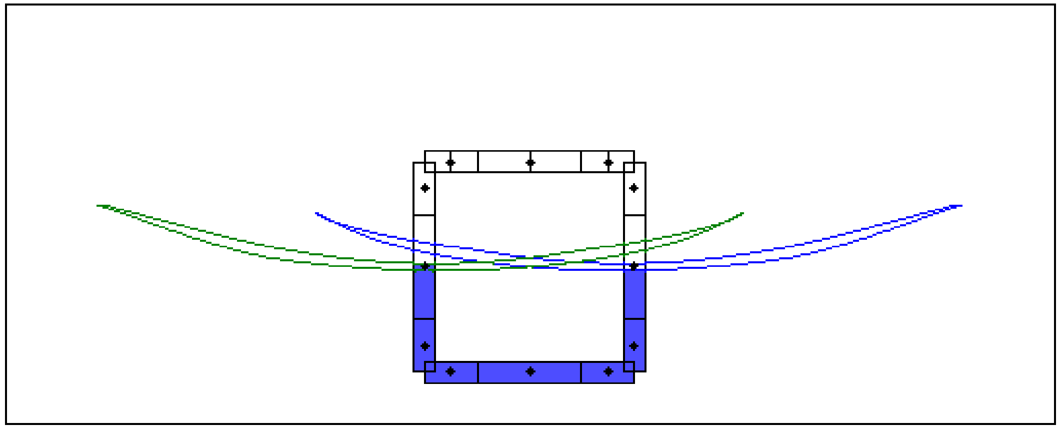
- Figure shows difference between collapsed level for middle vertical volume in the right (blue) and left (green) legs
- Deviation from zero is due to inertial effects
- Figure shows hysteresis effects

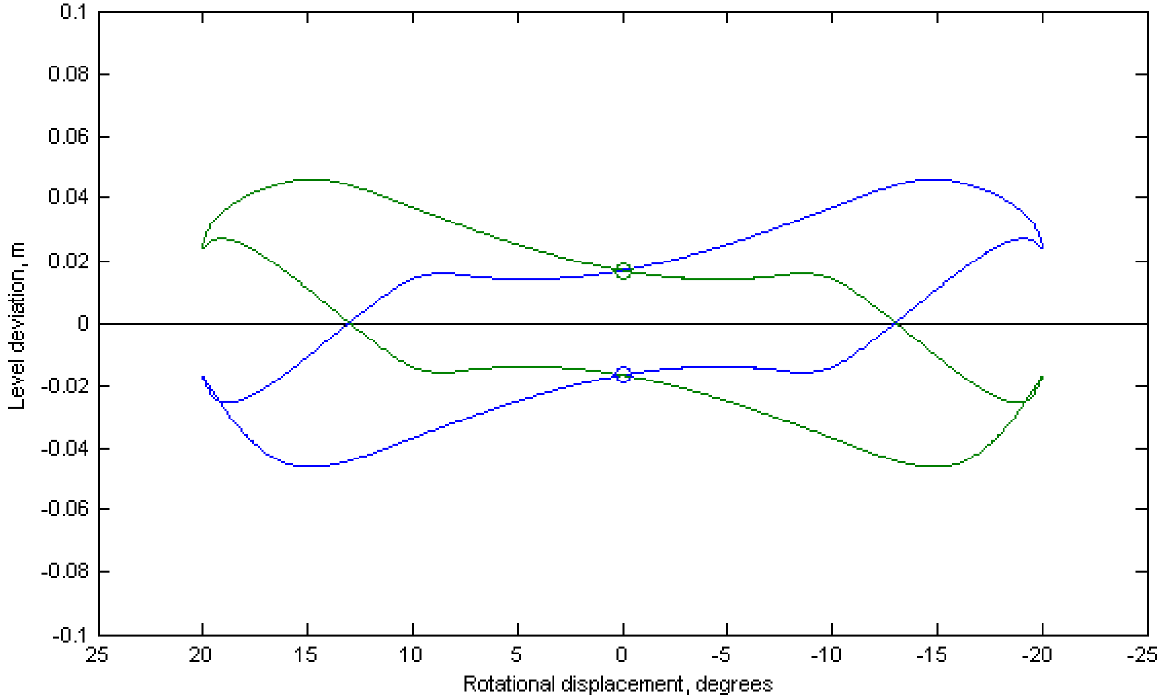


Rotational Sample Results



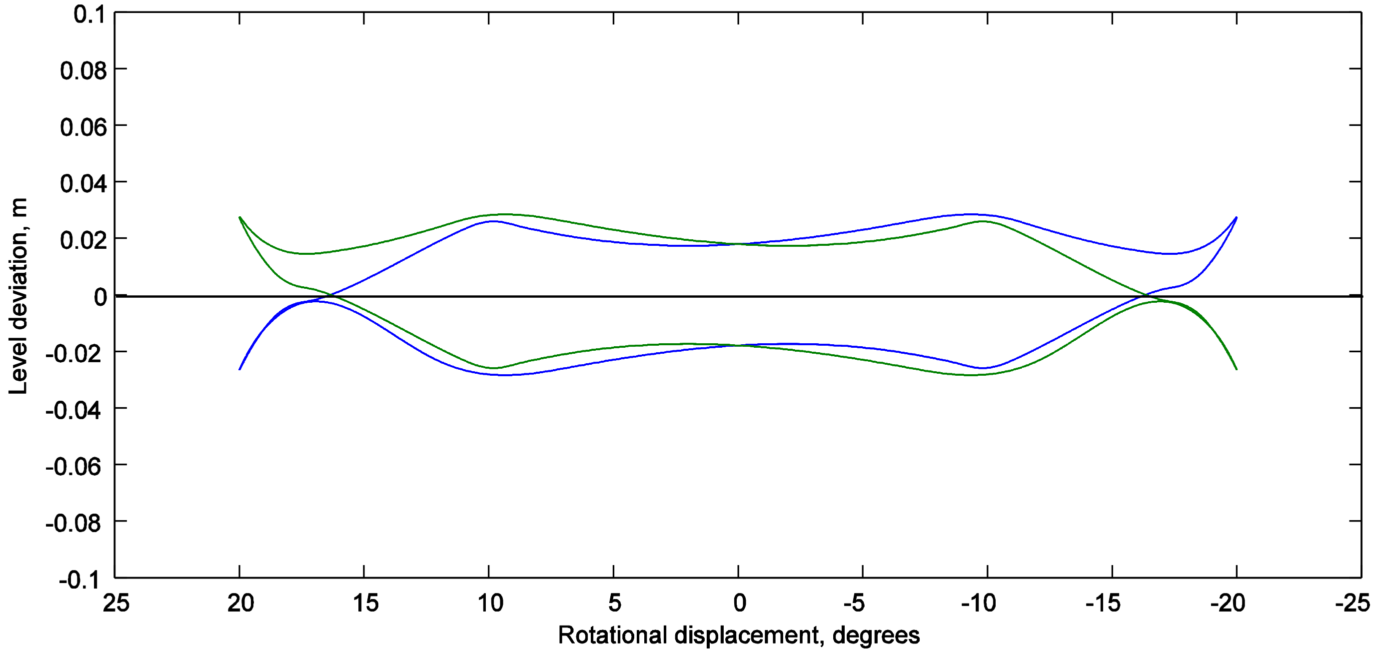
Rotational Sample Results





Rotational Sample Results

- Sensitivity to increased gravity
  - Gravitational constant doubled
  - Deviation from equilibrium is reduced
  - Increased gravity trying to maintain same level



Translation Sample Problem

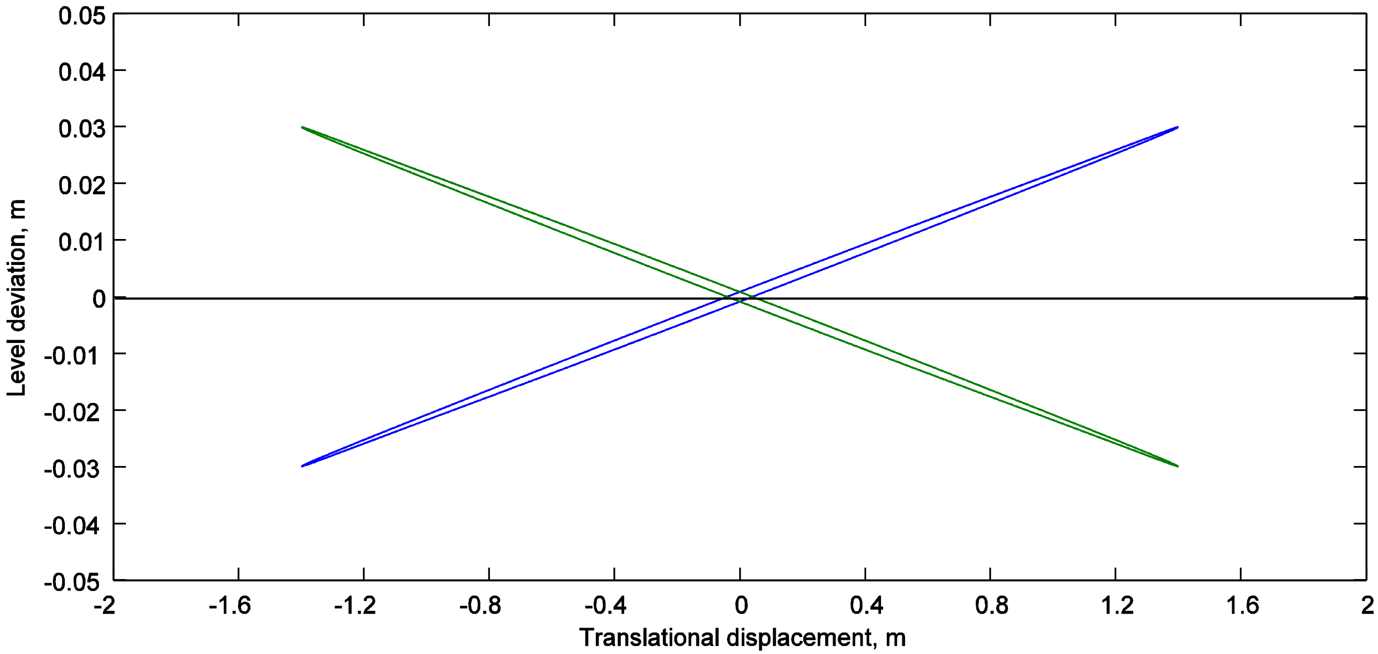
- Same geometry as rotational sample problem
  - One pipe and one single junction forming a square
  - Equilibrium level at midpoint of vertical legs
  - X-direction displacement according to:

$$x(t) = 1.4m \sin\left(2\pi\left(\frac{t}{10s}\right)\right)$$

  - Displacement function selected to maximize similarity with rotational sample problem
    - Amplitude of oscillations matches the arc length of the rotational problem
    - Same period as rotational sample problem

Translational Sample Results

- Hysteresis is greatly reduced
  - No vertical acceleration
- Deviation at extremes of oscillation compare well to rotational sample problem



Conclusions

- Quantitative verification of acceleration due to translational motion is demonstrated
- Quantitative verification of pressure change due to modified body force due to acceleration is demonstrated
- Qualitative assessment of simple geometry under rotational and translational motion is provided
  - Hysteresis effects are amplified by vertical component of acceleration in rotational problem
- Similarities in displacements in rotational and translational sample problems are shown