Selecting potentially critical sloshing loads on an LNG cargo containment system

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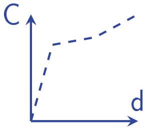
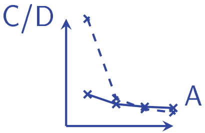
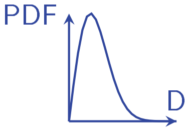
CCS assessment



Structural capacity using FEA



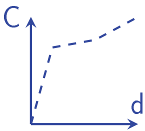
Apply calibration based on operational experience



Hydrodynamic loads using small scale (1:20-1:40) model tests

Details: Gervaise, De Sèze, and Maillard 2009

CCS assessment



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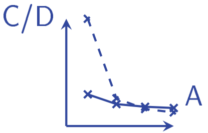

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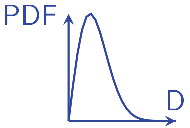


Hydrodynamic loads using small scale (1:20-1:40) model tests

Details: Gervaise, De Sèze, and Maillard 2009

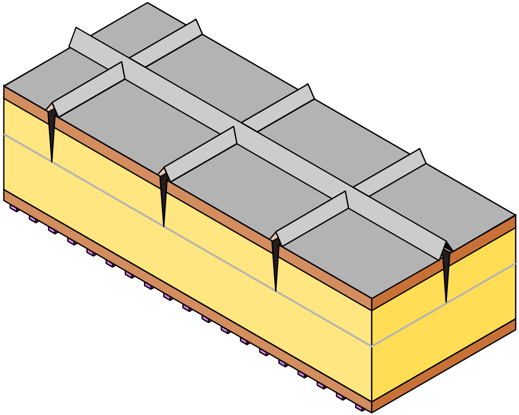
This could be improved if we know what the structure feels.

Demands critical load selection

Compared to failure analysis:

- Easy to arrange
- Quick to judge
- Pessimistic

Background

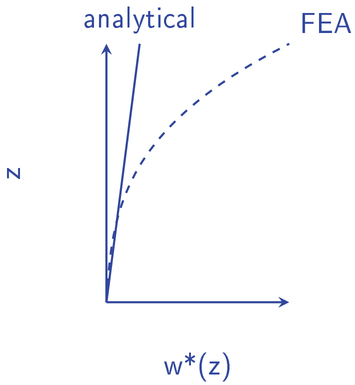


Sketch of the Mk III cargo containment system (CCS) as designed by GTT

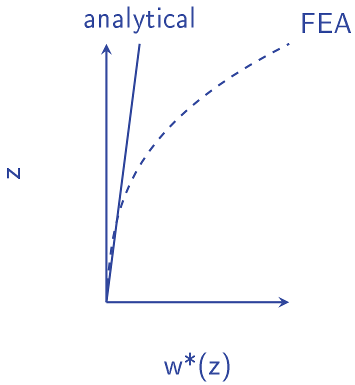
Simplified response model

- Sandwich theory (Carlsson and Kardomateas 2011)
- Beam on elastic foundation (Hetenyi 1946)
- Beam on elastic foundation with shear (Das 2011)

Linear analytical model



Linear analytical model

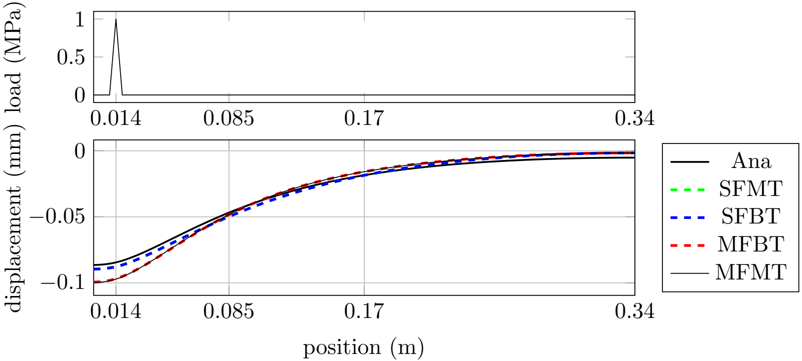


$$\underbrace{(\rho_p A_p + \frac{1}{3}\rho_f h_f^2)\frac{\partial^2 w(x,t)}{\partial t^2}}_{\text{inertia}} + \underbrace{E_p I_p \frac{\partial^4 w(x,t)}{\partial x^4}}_{\text{beam bending}}$$

$$\underbrace{-\frac{E_f h_f}{6(1+\nu_f)}\frac{\partial^2 w(x,t)}{\partial x^2} + \frac{E_f}{h_f(1-\nu_f^2)} w(x,t)}_{\text{foundation shear and compression}} = p(x,t)$$

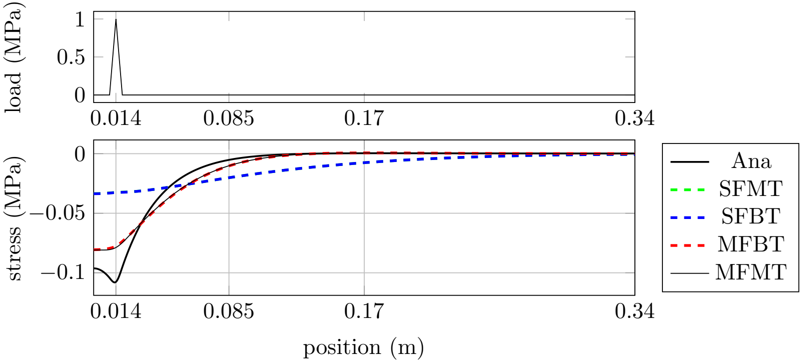
Coefficients using Finlayson 1972

Analytical model



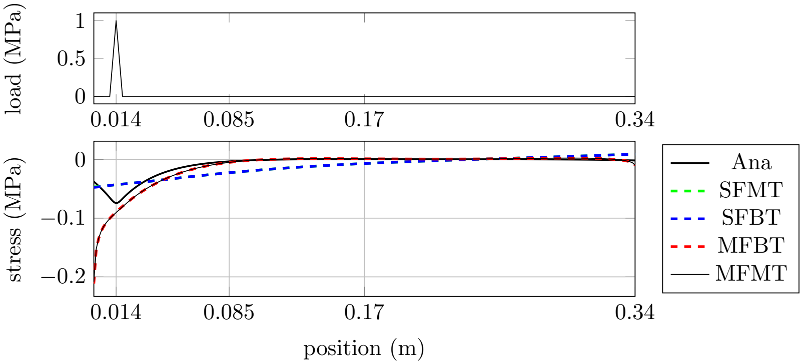
Indentation at top (sliding)

Analytical model



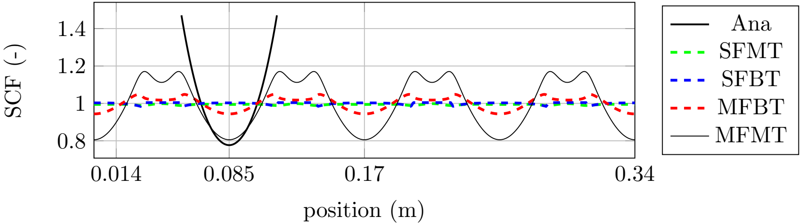
Stress at top (sliding)

Analytical model



Stress at top (free) – edge shear force?

Analytical model



Stress concentration factor at mastic

Solution procedure

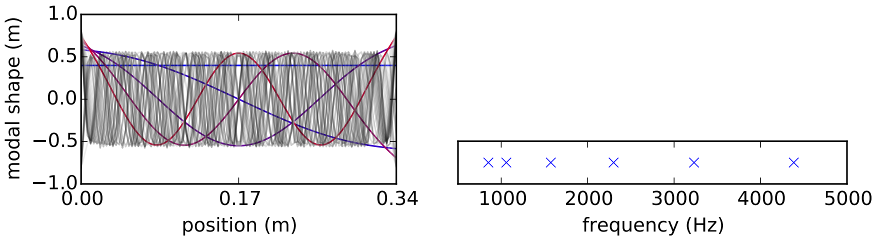
1. Vibration modes and frequencies
2. Integrate vibration over time, for each mode
3. Reconstruct deformation to obtain stresses

$$\sigma_z(x, z = h) = \left(\frac{E_f}{h_f\left(1-\nu_f^2\right)}\right) \cdot w - \left(\frac{E_f h_f}{6(1+\nu_f)}\right) \cdot \left(\frac{\partial^2 w}{\partial x^2}\right)$$

$$\sigma_z(x, z = 0) = \left(\frac{E_f}{h_f\left(1-\nu_f^2\right)}\right) \cdot w$$

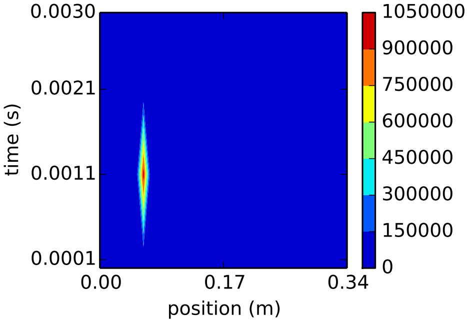
Response to a single load

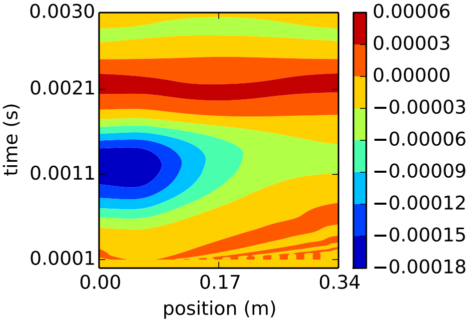
Vibration modes and frequencies



First five modes are colored, rest in grey, total 31 modes

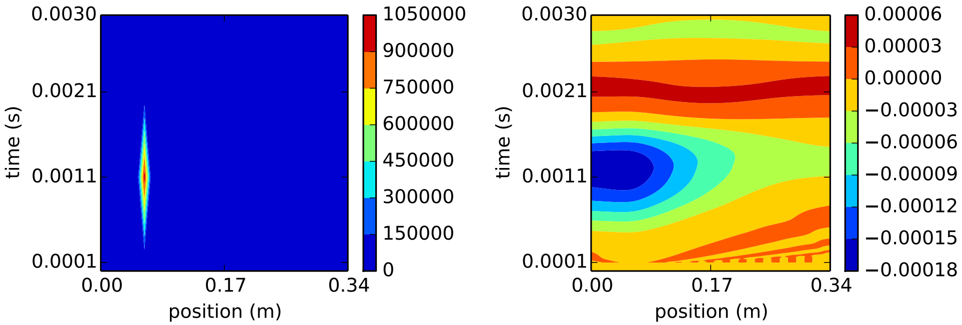
Displacement





Load (Pa) and displacement (m)

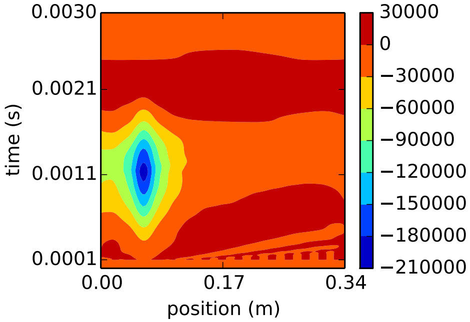
Displacement

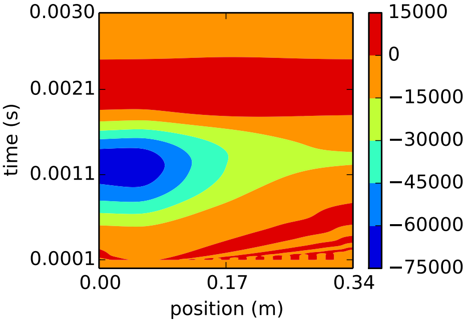


Load (Pa) and displacement (m)

A local load induces a not-so-local response

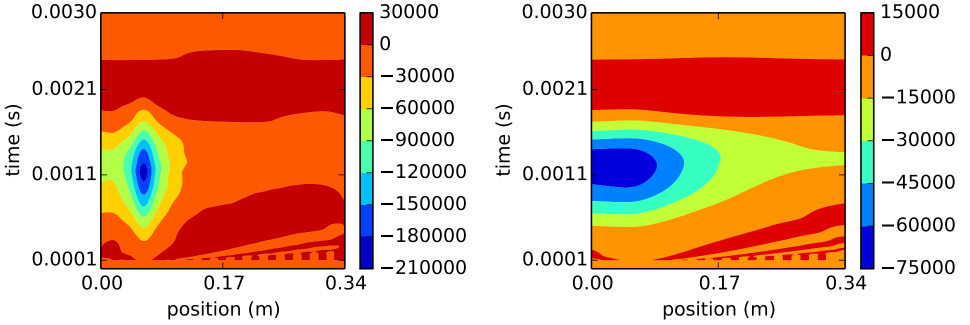
Stresses





Top and bottom stress (Pa)

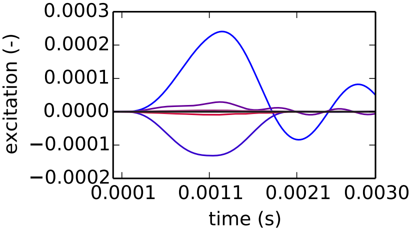
Stresses



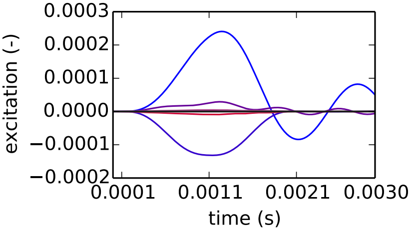
Top and bottom stress (Pa)

Response at the top is more concentrated and therefore higher than at the bottom.

Time integral of modes



Time integral of modes



Only three modes (seem to) contribute to the response.

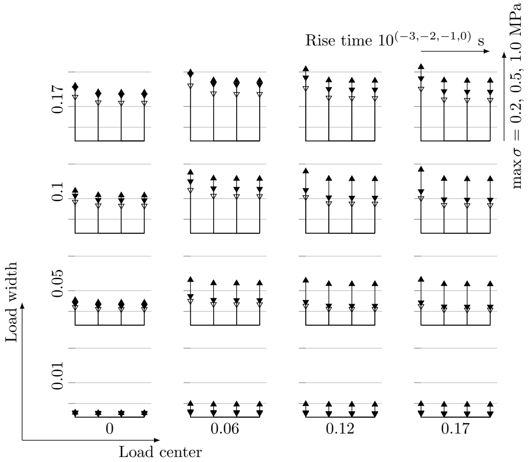
Systematic study

Load cases

All combinations of:

- Location [0, 0.06, 0.12, 0.17] m from side
- Width [0.01, 0.05, 0.10, 0.17] m build up (triangular)
- Time [0.001, 0.01, 0.1, 1] s rise time

Results: maximum top and bottom stress



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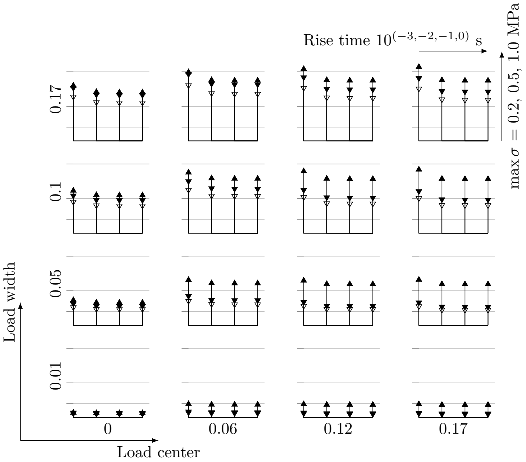
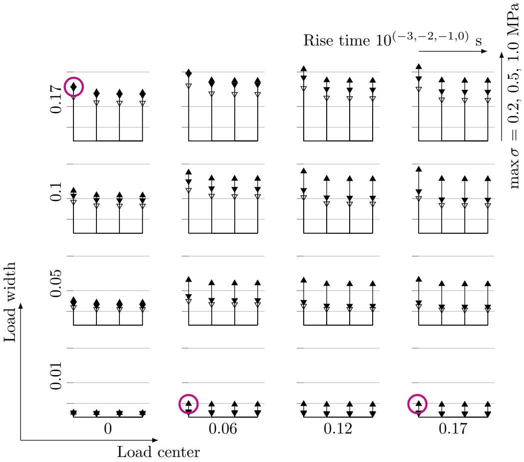


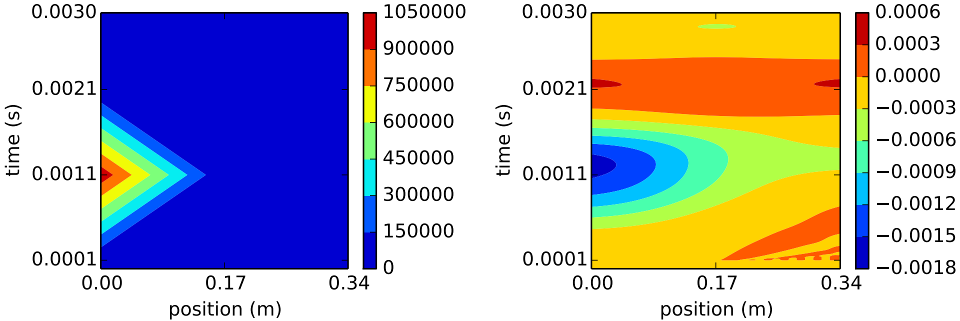
- Load width is most important
- Load center is not important
- Rise time could be important

Results: maximum top and bottom stress



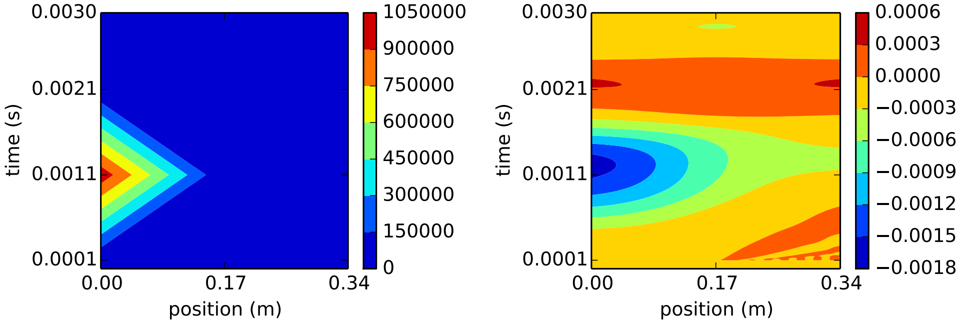
- Load width is most important
- Load center is not important
- Rise time could be important

Displacement (loc: 0 m, width: 0.17 m, time: 0.001 s)



Load (Pa) and displacement (m)

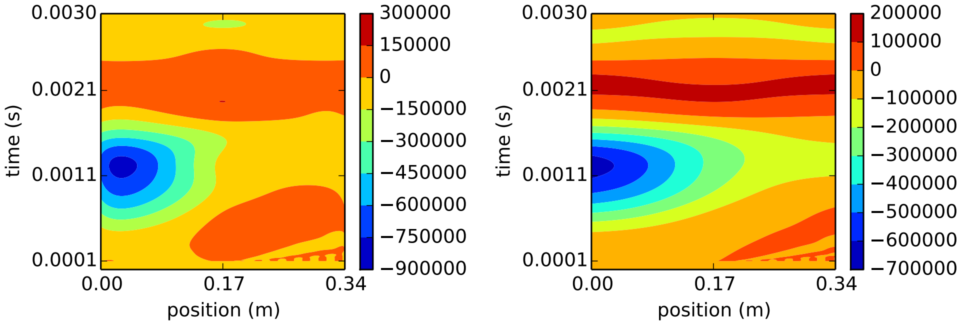
Displacement (loc: 0 m, width: 0.17 m, time: 0.001 s)



Load (Pa) and displacement (m)

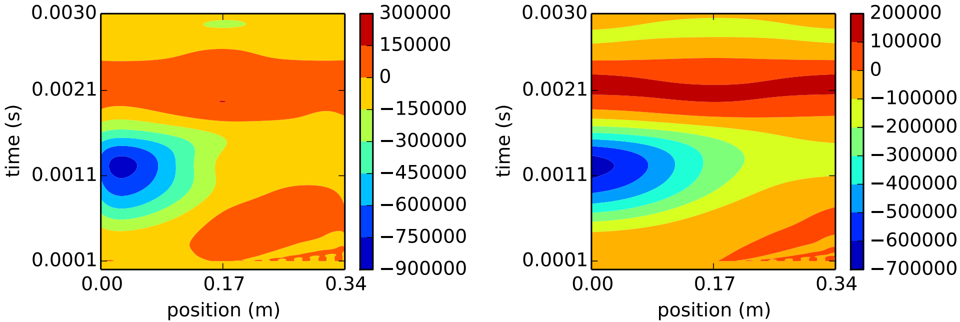
A relatively wide load (half width) excites response over entire width.

Stresses (loc: 0 m, width: 0.17 m, time: 0.001 s)



Top and bottom stress (Pa)

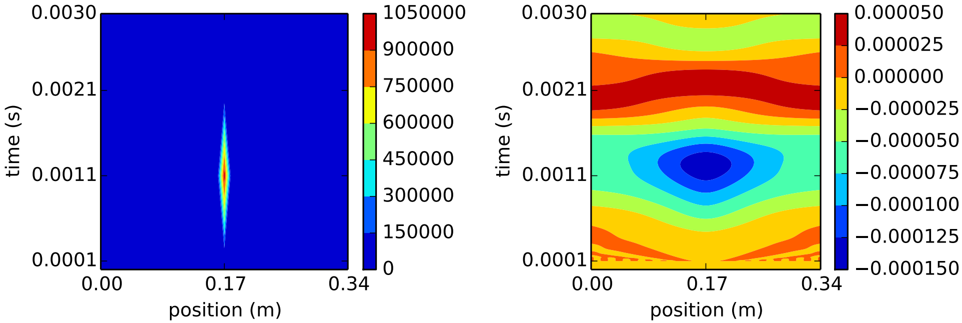
Stresses (loc: 0 m, width: 0.17 m, time: 0.001 s)



Top and bottom stress (Pa)

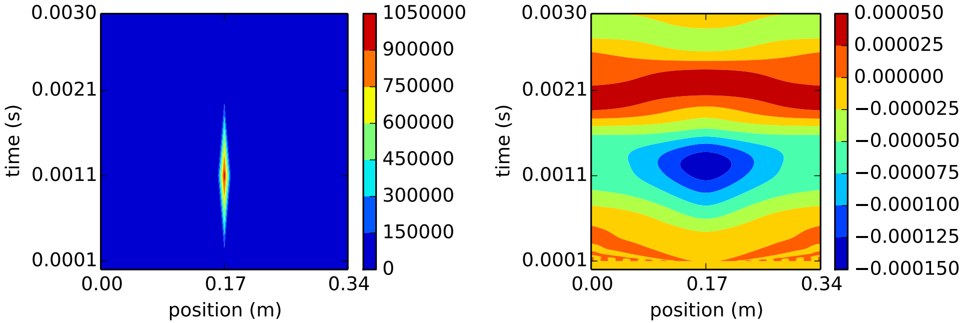
Maximum top stress is localized not at the edge, due to curvature.

Displacement (loc: 0.17 m, width: 0.01 m, time: 0.001 s)



Load (Pa) and displacement (m)

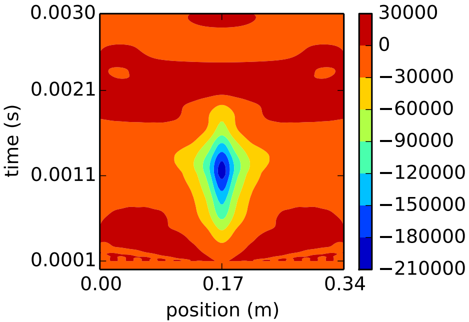
Displacement (loc: 0.17 m, width: 0.01 m, time: 0.001 s)

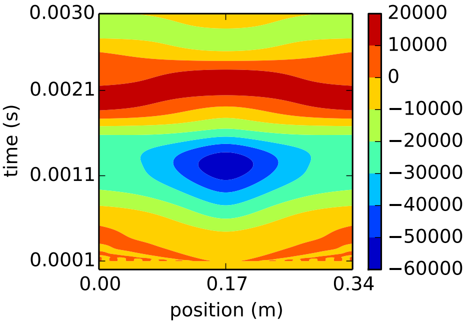


Load (Pa) and displacement (m)

A concentrated center load excites response mostly in two point bending.

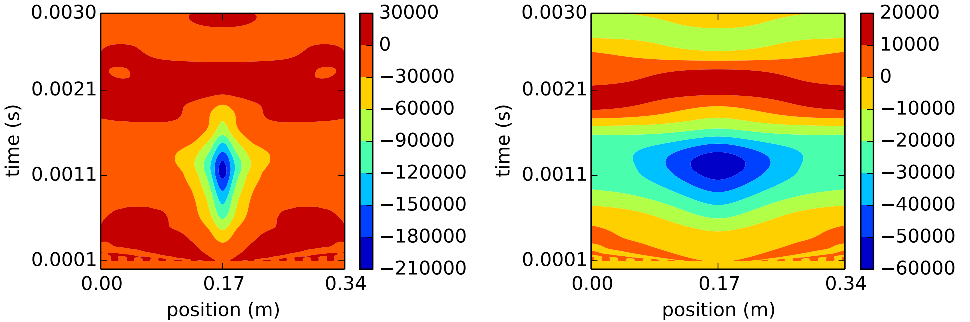
Stresses (loc: 0.17 m, width: 0.01 m, time: 0.001 s)





Top and bottom stress (Pa)

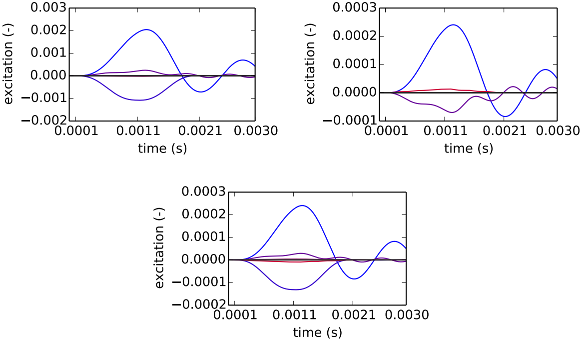
Stresses (loc: 0.17 m, width: 0.01 m, time: 0.001 s)



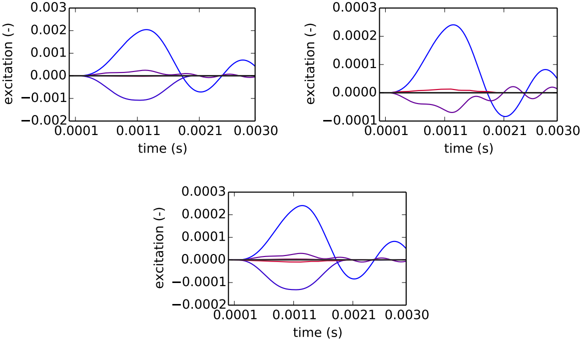
Top and bottom stress (Pa)

Top stresses are highly local, but small compared to loading.

Comparison of modal excitation



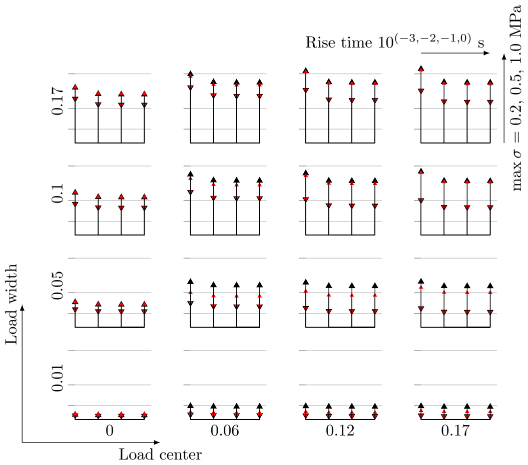
Comparison of modal excitation



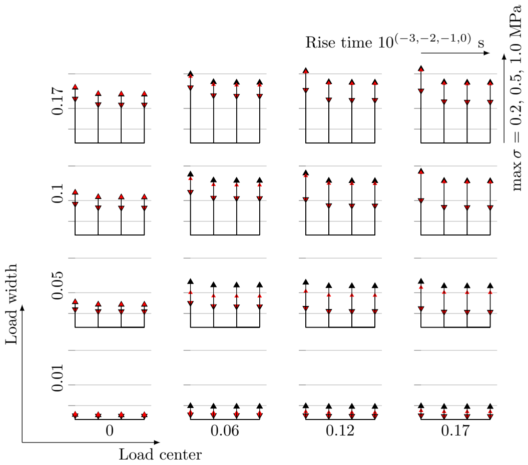
Only three modes (seem to) contribute to the response.

Alternative solution

Results using first five modes



Results using first five modes



- Five modes are enough for global loads
- Difference for local loads a difference (25%) is observed

Closing

Conclusion

In this case:

- Response is dominated by first five vibration modes
- Stress levels require the higher modes, although these modes behave statically
- Ranking of importance of load parameters
  1. load width
  2. rise time
  3. impact location

Conclusion

In this case:

- Response is dominated by first five vibration modes
- Stress levels require the higher modes, although these modes behave statically
- Ranking of importance of load parameters
    1. load width
    2. rise time
    3. impact location
- This model can be used for 'first estimate' of importance

Remarks

- Added mass and damping
- Stiffness and strength gradient due to temperature
- Linear superposition of thermal stress, ship global bending
- Bottom: stress concentration by mastic
- Center: stress concentration by groove
- Top: stress concentration peel

References I

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Das, B. (2011). *Geotechnical Engineering Handbook*. J. Ross Publishing Inc.

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Thank you