HAL
open science

Implementation and Comparison of Contact Models within PIRAT for Nuclear Reactivity Control Systems

M. Bonney, M. Zabiego

To cite this version:

M. Bonney, M. Zabiego. Implementation and Comparison of Contact Models within PIRAT for Nuclear Reactivity Control Systems. TriboMechaDynamics 2019, Jul 2019, Houston, United States. cea-02614152

HAL Id: cea-02614152

https://cea.hal.science/cea-02614152v1

Submitted on 20 May 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

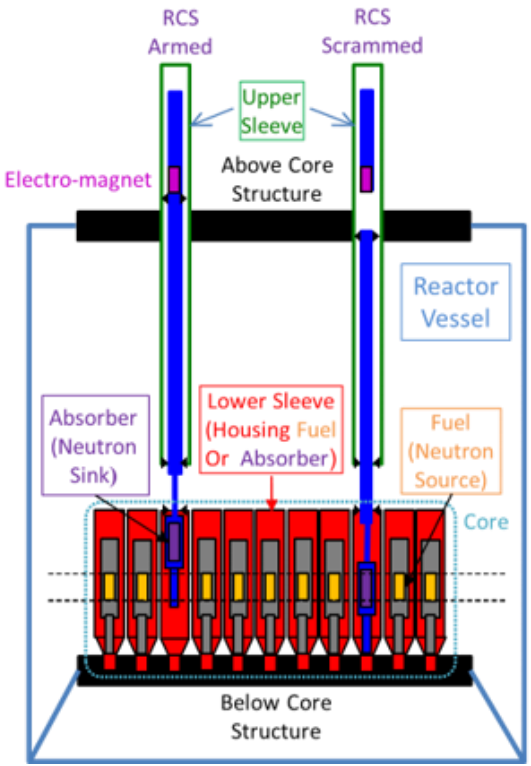
Implementation and Comparison of Contact Models within PIRAT for Nuclear Reactivity Control Systems

Matthew Bonney
and Maxime Zabiégo
CEA Cadarache, France
CEA/DEN/CAD/DEC/SESC/LECIM

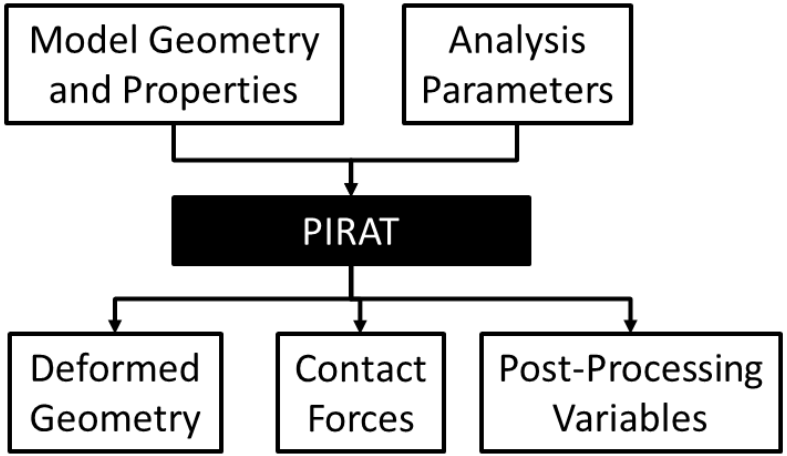
July 31 2019

Background

- CEA is focused on the development of next generation nuclear reactors
- Current development for Reactivity Control Systems (RCS)
  - Main use: Control output of reactor
- Exhibit difficult case of forced excitation and multi-body interactions with frictional contacts
- Desire: a simplified tool for early design phase simulations for safety during seismic event
  - Easy to modify/adjust test system

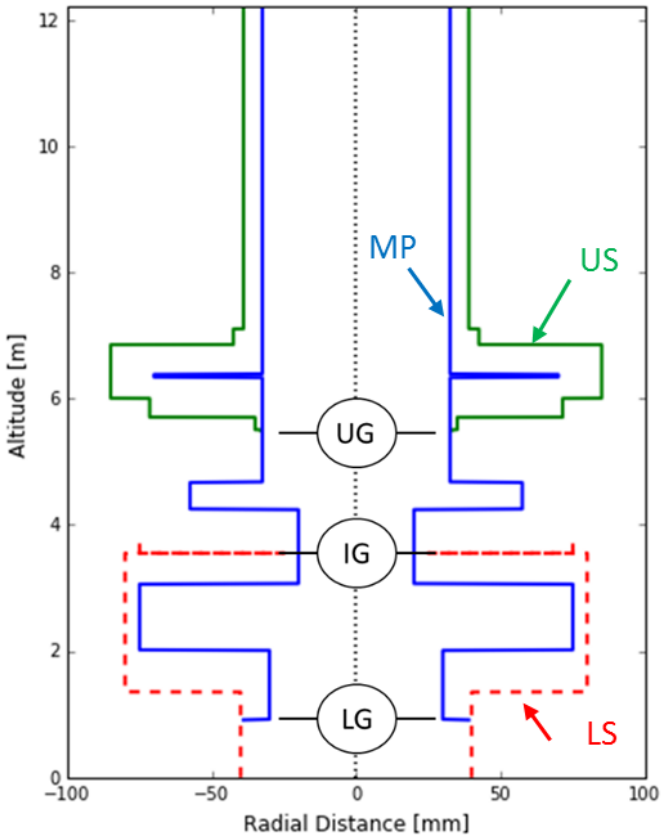


- To study these systems, PIRAT (Python Implementation for Reliability Assessment Tools) is currently being developed
- Based on 3 main tools:
  - StaBI – Statically enforced boundary
  - DEBSE – Dynamically enforced boundary (Focus of this work)
  - SIKI – Kinetic insertion to measure drop-time
- Uses analytical (continuous) modeling approaches
  - Opposed to FE



Types of Systems

- RCSs control the output of the reactor
  - Primarily during earthquake
- Comprised of 3 main subsystems
  - Mobile Part (MP) containing the absorbing material
  - Lower Sleeve (LS) that enforces the dynamic excitation caused by the core
  - Upper Sleeve (US) that is more rigid than MP but has relatively free movement
- To study these systems, the Model System Configuration (MSC) system is used
  - Modeled after past French fast reactors



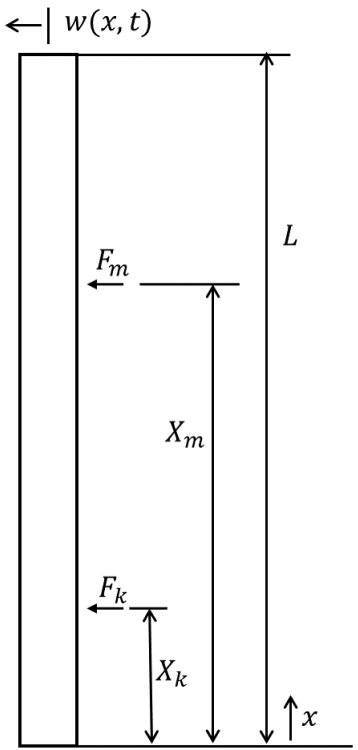
- Based on Euler-Bernoulli beam segments

$$EI\frac{\partial^4 w(x,t)}{\partial x^4} + cI\frac{\partial^5 w(x,t)}{\partial x^4 \partial t} + \rho A\frac{\partial^2 w(x,t)}{\partial t^2} = \sum^{N_k} F_k(t)\delta(x - x_k) + \sum^{N_m} F_m(t)\delta(x - x_m)$$

- Treat contact as externally applied, point-force
  - k for contact with LS and m for contact with US
- Contact forces and deformation relationship described by contact models (focus of this work)
- Due to excitation (fixed displacement), simple BC with change of CS is used to simplify analysis

$$w(x,t) = \phi_0(t)D_0(x) + \phi_L(t)D_L(x) + \sum^{N} \psi_n(x)q_n(t)$$

- Same type of analysis for US, assumed to be cantilever



- 2 models considered
- Both are regulation based and depend on relative penetration of MP and the sleeves

$$\Delta_i^b = \left(\frac{p_r + |p_r|}{2}\right)^b - \left(\frac{|p_l| - p_l}{2}\right)^b = \begin{cases} + & Contact\ on\ Right \\ - & Contact\ on\ Left \\ 0 & No\ Contact \end{cases}$$

- First model: a mass-less, two-stage linear spring with a gap

$$F_i = K_c \Delta_i + \frac{K_m}{2} \begin{cases} (p_r - g_i) + |p_r - g_i| & if\ p_r \geq g_i \\ (p_l + g_i) - |p_l + g_i| & if\ p_l \leq -g_i \\ 0 & else \end{cases}$$

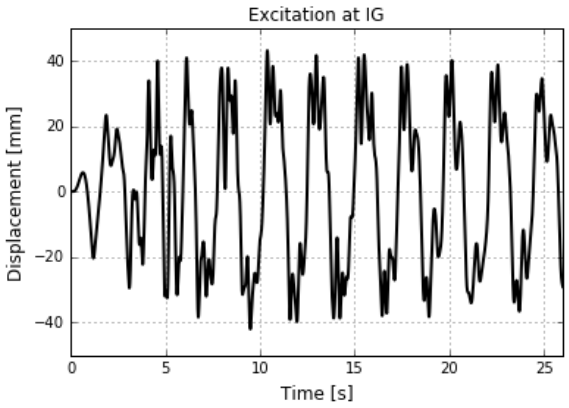
- Second model: Lankarani and Nikravesh (L&N) contact model

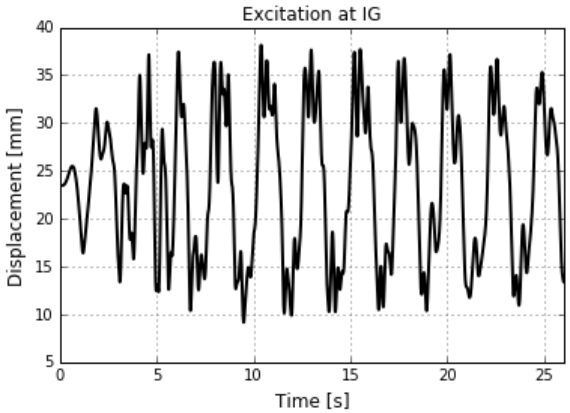
$$F_i = \frac{4}{3}\pi E_i^* \sqrt{R_i^*}\, L_i \Delta_i^b \qquad b \in [1.0, 1.5]$$

- Both characterize different aspects and simplifications for these types of systems

Simulation Results

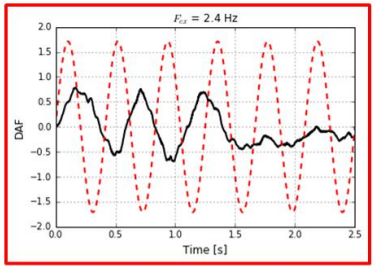
- 3 types of excitations considered
  - Nearly same maximum displacement of excitation locations
  - Safe Shutdown Earthquake (SSE) magnitude
- 1st – Stepped-Sine excitation
  - Easier to understand interactions
  - Adjust applied frequency
  - Identify resonance behavior
- 2nd /3rd – Realistic excitations
  - Generated from whole-core simulations
  - Reactor is not expected to restart
    - Focus on early time

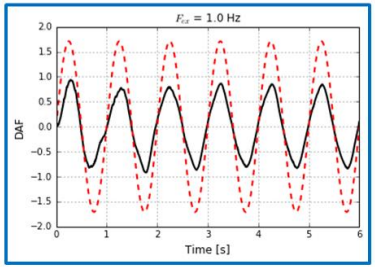


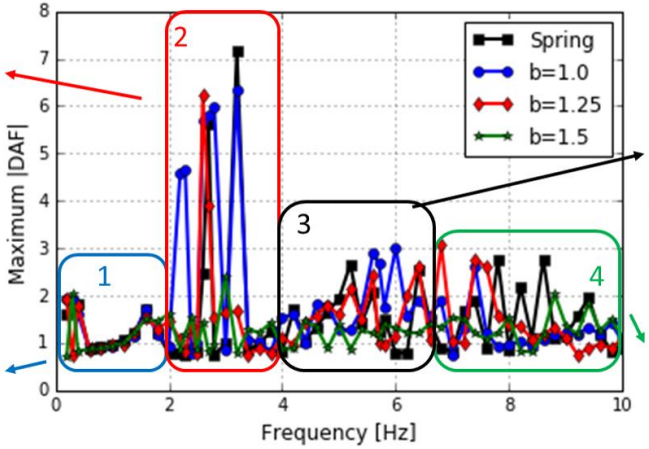


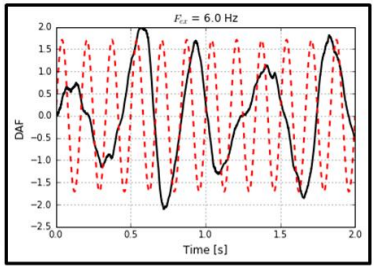
First Results – Stepped Sine Excitation

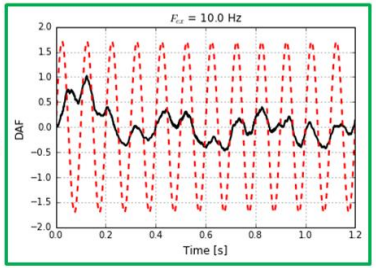
- The first result is for LS motion via Sine wave with variable frequency
- Plot shows maximum displacement magnitude of Upper Guide (UG) normalized to static deformation estimate – Dynamic Amplification Factor (DAF)
- Shows 4 distinct regions based on frequency

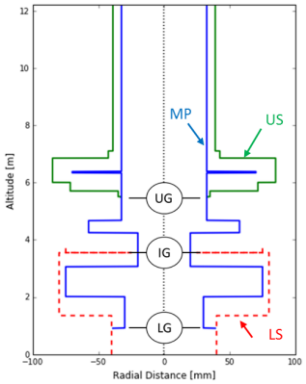




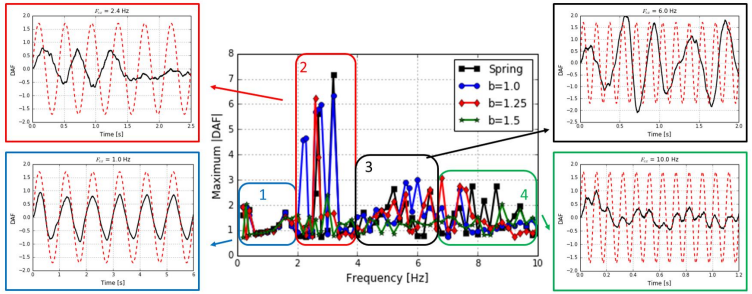


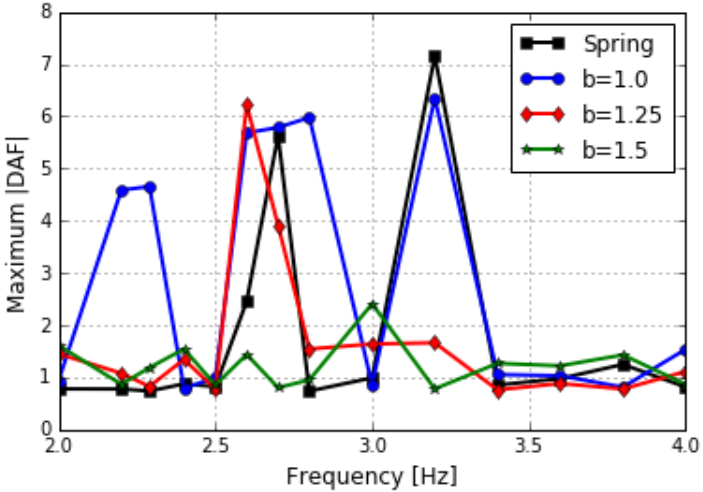




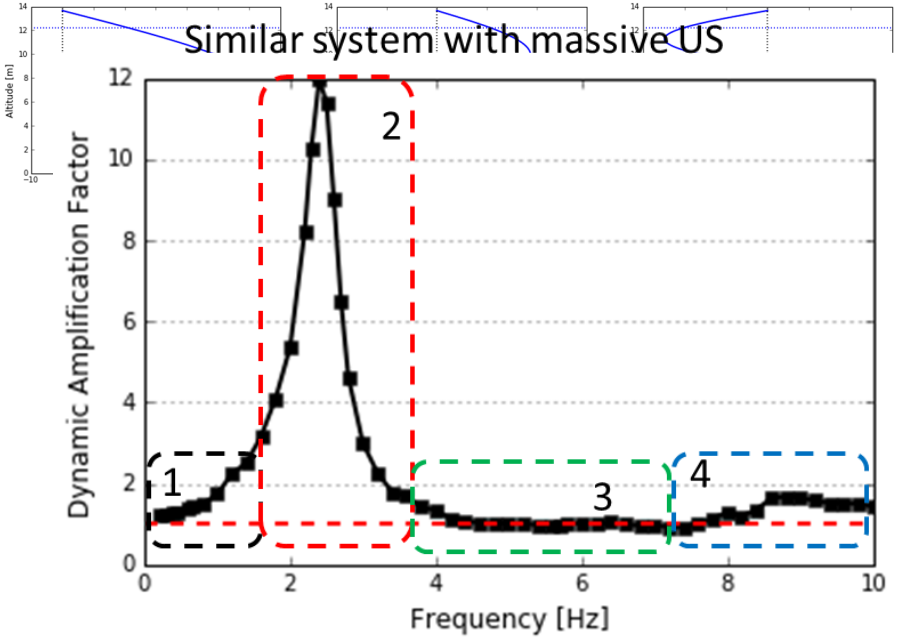


- Low frequency region
  - Nearly identical results
  - Some numerical issues at very low frequencies
- Resonant region
  - MP mode at 2.3 Hz and US mode at 2.1 Hz
  - Causes numerical instabilities
- Mid frequency region
  - Large variability
  - Response dominated by low frequency motion, not excitation
- High frequency region
  - Multi-mode response



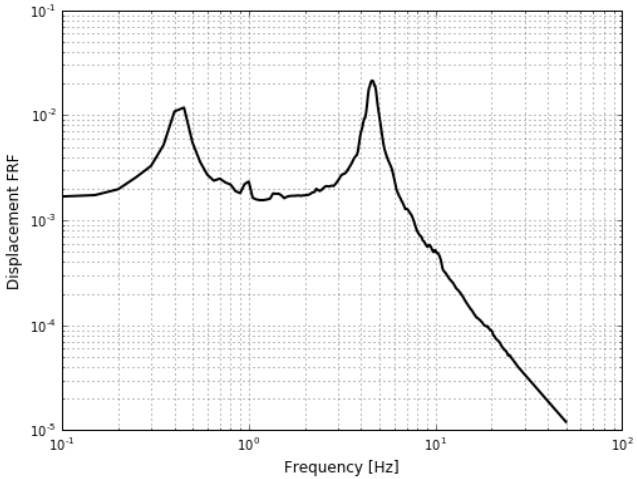


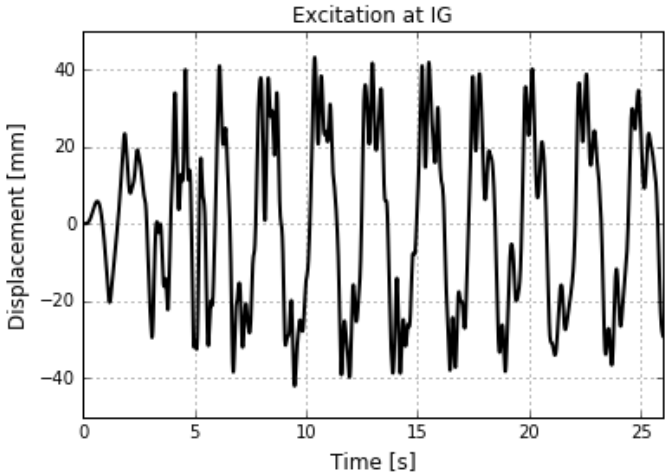
- 2 Aspects of resonance effects
  - Variability (partially due to numerical conditioning)
  - Increase in response
- Increase in response due to imposing large displacement at mode shape max
  - Large energy due to resonance, but fixed amount of energy in 2nd mode due to fixed displacements
  - Energy transferred to 1st mode where UG has large displacement



Realistic Excitation – BASILIQ excitation

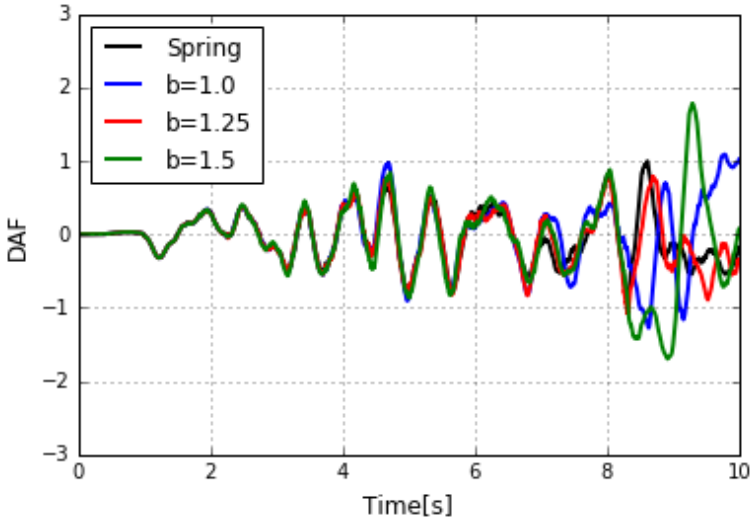
- To mimic more realistic excitation, response of whole core simulation of seismic event is used (From BASILIQ^{CAST3M} a CEA code)
- Uses dynamics of fuel rods, RCS, and core
- Based on realistic seismic spectrum to get deflection of LS





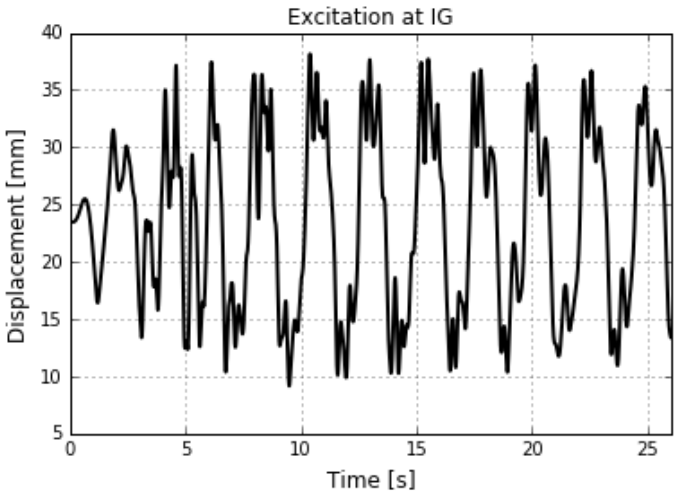
BASILIQ Excitation – Results

- For short-time (<8 seconds), little variability
- In general for this excitation only focused on short-time
  - Reactor is not expected to restart after this level of earthquake
- Within short-time, |DAF|<1 suggesting that static estimate might be conservative

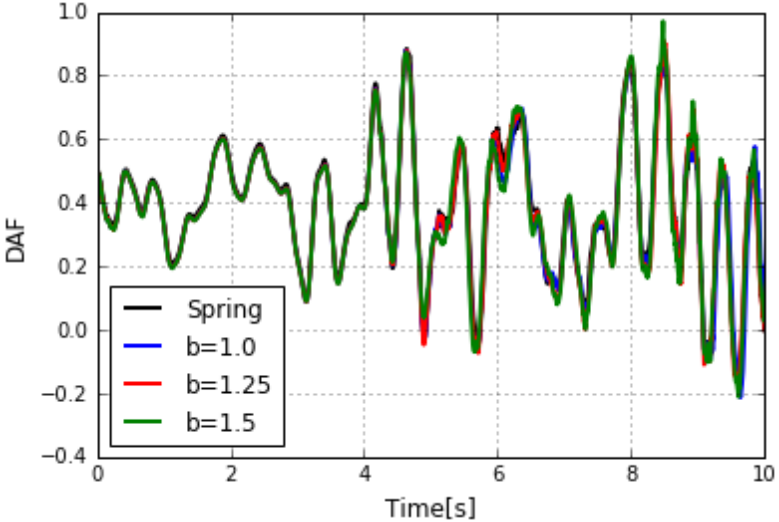


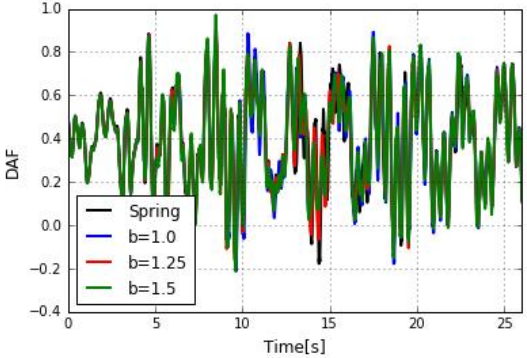
Realistic Excitation – Dynamic Excitation on Statically Deformed System

- In actuality, the deformation is comprised of several components, some static and some dynamic
- Static contributions:
  - Installation misalignment
  - Fabrication uncertainty
  - Irradiation
- Dynamic contributions:
  - Primarily seismic activity
- To simulate this, apply dynamic excitation to statically deformed system
- Nearly same maximum deformation



- Almost no variability in short time (<10 seconds)
- Largest DAF <1
- Some instances where IG is positive (at all times) and UG is negative
  - Induces large shear forces that hinder the safety function of RCS





Conclusions

- CEA is developing tools to study Reactivity Control Systems that consist of multiple sub-systems
- One of the most difficult aspects is the interaction between sub-systems
- For the dynamic tool DEBSE, 2 candidate contact models are compared
  - 2-stage spring, L&N contact model (with various exponential values)
- Both are implemented and can produce similar results
- Differences were noticed for both higher frequency (especially resonance range) sine excitation and parts of more realistic excitation
- Large dynamic excitations shows variability in contact models
- But for the scope of early design phase/excitations of interest, current modeling is sufficient
  - Just needs experimental validation

Thank you for your attention

Early Career Researchers Social

- Tonight at 6pm, Early Career Researcher Social
- At Valhalla Bar [6100 Main St, Houston, TX 77005]
  - Next to Engineering Building
- Meet other early career researchers (Grad-students, post-docs, entry professors/lecturers, etc.)
- Drinks & Food provided
  - Torchy's Tacos for food and Valhalla for drinks

FREE!!!

Come hang out!

Extra-Slides

Extra Slide – Penetration Variables

$$\Delta_i^b = \left(\frac{p_r + |p_r|}{2}\right)^b - \left(\frac{|p_l| - p_l}{2}\right)^b = \begin{cases} + & Contact\ on\ Right \\ - & Contact\ on\ Left \\ 0 & No\ Contact \end{cases}$$

- $p_r > 0$ for contact on Right, and $p_l < 0$ for contact on Left
- Depends on US or LS
- For LS:

$$p_r = \phi_0(t)D_0(x_k) + \phi_L(t)D_L(x_k) + \sum^N \psi_n(x_k)q_n(t) - V_k(t) - \left(R_{LS}(x_k) - R_{MP}(x_k)\right)$$

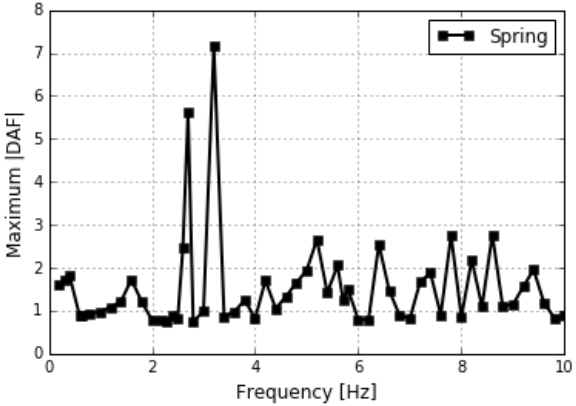
$$p_l = \phi_0(t)D_0(x_k) + \phi_L(t)D_L(x_k) + \sum^N \psi_n(x_k)q_n(t) - V_k(t) + \left(R_{LS}(x_k) - R_{MP}(x_k)\right)$$

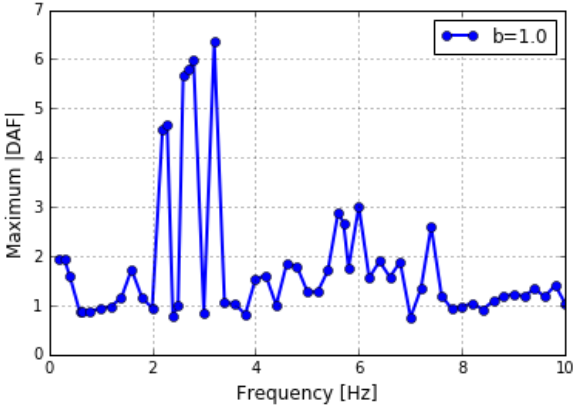
- For US:

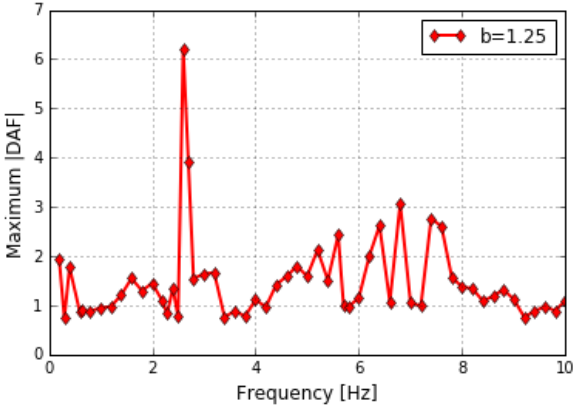
$$p_r = \phi_0(t)D_0(x_m) + \phi_L(t)D_L(x_m) + \sum^N \psi_n(x_m)q_n(t) - \sum^\Gamma \Psi_\gamma(z_m)Q_\gamma(t) - \left(R_{US}(z_m) - R_{MP}(x_m)\right)$$

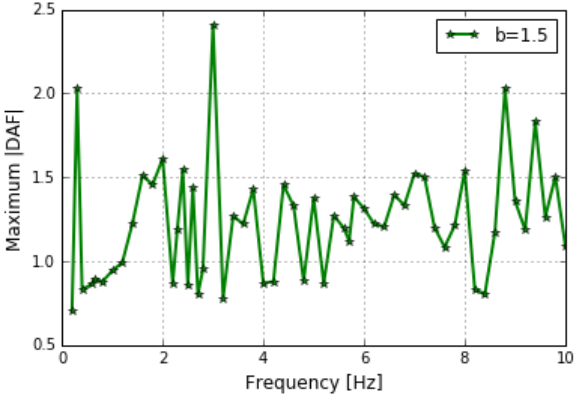
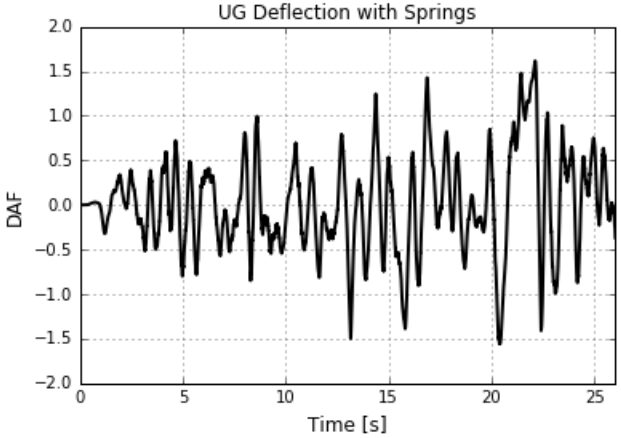
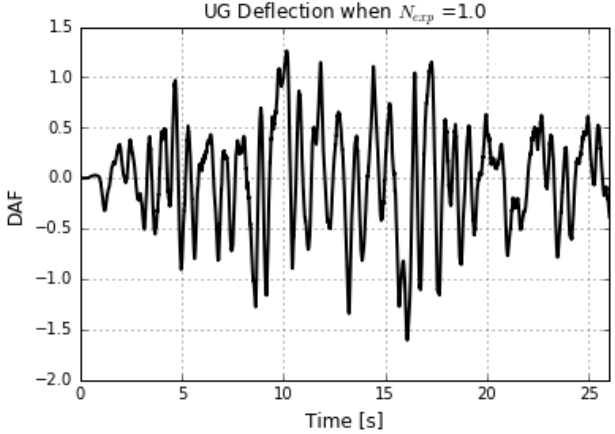
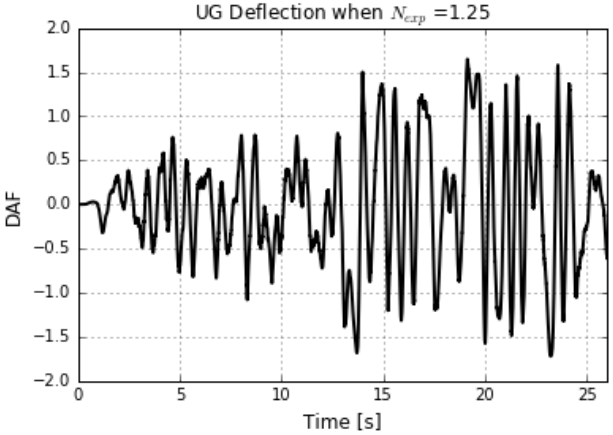
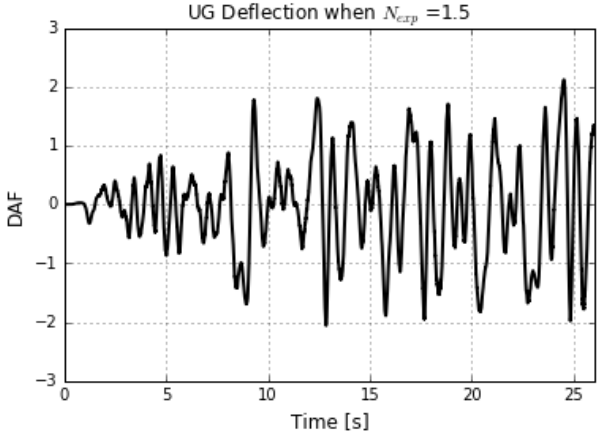
$$p_l = \phi_0(t)D_0(x_m) + \phi_L(t)D_L(x_m) + \sum^N \psi_n(x_m)q_n(t) - \sum^\Gamma \Psi_\gamma(z_m)Q_\gamma(t) + \left(R_{US}(z_m) - R_{MP}(x_m)\right)$$

Extra Slide – Stepped-Sine DAF









Extra Slide – Separate Time Histories