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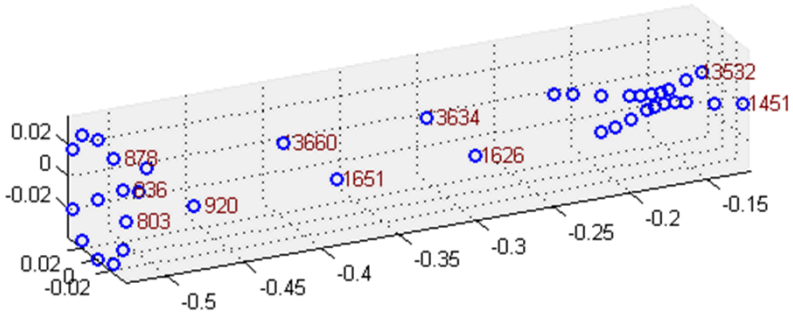

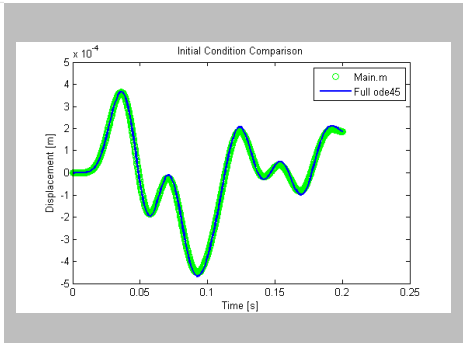

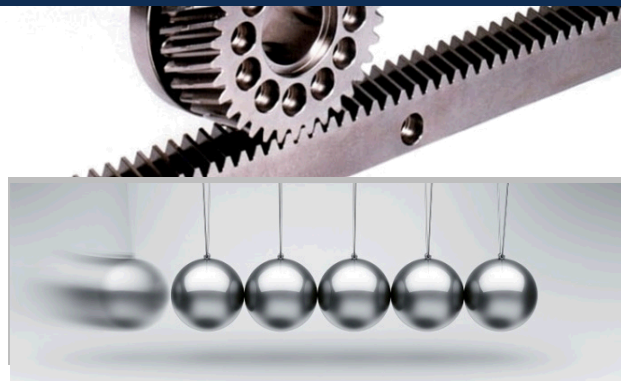

Interface Contact Simulator

Student Presentation

Bob Lacayo

TIM Sept 18, 2014

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Who is Bob Lacayo?

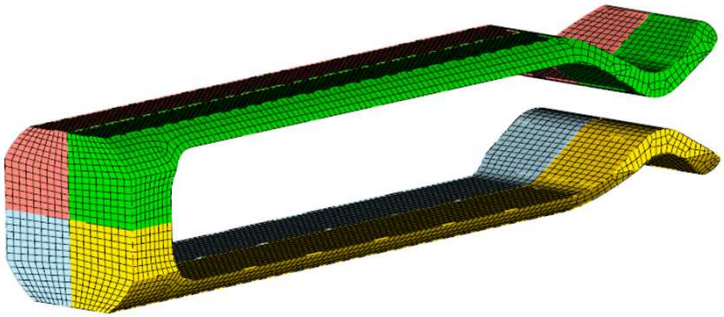
Bachelor of Science in Engineering Mechanics – 2014

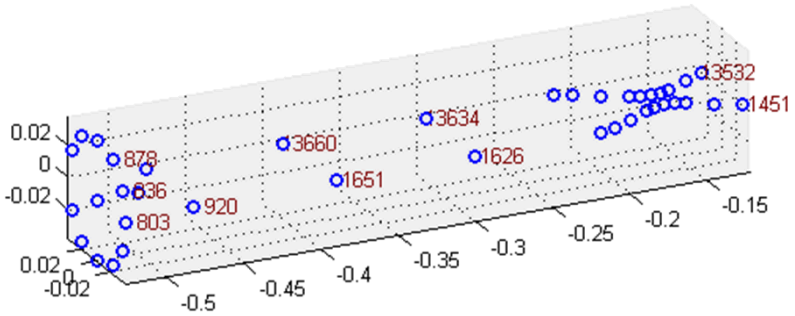
Academic Interest: Structural Dynamics

Undergraduate Intern at SNL
Supervisor: Matt Brake

Internship Project: Develop an Interfacial Contact Simulator in MATLAB

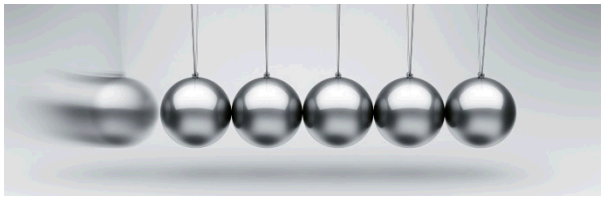
General multi-body FE transient solver that simulates elastic response of structures with localized interactions.



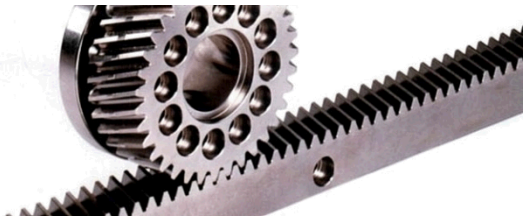


- Friction

- Impact



- Rolling



- And More!

How is This Simulator Different from Other Dynamics Software?

- Uses Matt Brake's IMEX integrator toolbox.
- Includes augmented modes to improve integrator convergence. Not implemented.
  - Discontinuous Basis Functions?
  - Lagrange Multipliers?
  - Nonlinear Normal Modes?
- Uses model reduction methods to speed computation.
- Can specify *any* interface model.

How is This Simulator Different from Other Dynamics Software?

Readily available MATLAB code to do structural dynamics using

low-performance machines.

How Does the Process Work?

Geometry

- Create mesh geometry. (CUBIT)
- Develop system matrices. (SIERRA S/D)

Model Reduction

- Reduce system using Craig-Bampton Method. (SIERRA S/D)

Simulation

- Specify loads, BCs, ICs, and interface models.
- Assemble global matrices and integrate.

Time Response

Model Reduction Using Craig-Bampton Method

For $j = 1..N$ bodies:

$$\begin{bmatrix} M_{ii} & M_{ib} \\ M_{bi} & M_{bb} \end{bmatrix}^{(j)} \begin{Bmatrix} \ddot{u}_i \\ \ddot{u}_b \end{Bmatrix}^{(j)} + \begin{bmatrix} K_{ii} & K_{ib} \\ K_{bi} & K_{bb} \end{bmatrix}^{(j)} \begin{Bmatrix} u_i \\ u_b \end{Bmatrix}^{(j)} = \begin{Bmatrix} 0 \\ f_b \end{Bmatrix}^{(j)}$$

Define fixed interface modes and constraint modes:

$$\left(K_{ii}^{(j)} - \lambda_k^{(j)} M_{ii}^{(j)}\right) \phi_k^{(j)} = 0 \qquad \text{keep } k = 1..n \text{ modes}$$

$$\Psi_{ib}^{(j)} = -K_{ii}^{-1} K_{ib}$$

Define Craig-Bampton transformation matrix:

$$\widehat{\Psi}_{CB}^{(j)} = \begin{bmatrix} \Phi_{ik}^{(j)} & \Psi_{ib}^{(j)} \\ 0 & I \end{bmatrix} \qquad u^{(j)} = \widehat{\Psi}_{CB}^{(j)} p^{(j)}$$

Transform equations of motion

$$\widehat{M}^{(j)} \ddot{p}^{(j)} + \widehat{K}^{(j)} p^{(j)} = \widehat{\Psi}_{CB}^{\mathrm{T}} f^{(j)} = f^{(j)}$$

Assemble Global Matrices

$$\widehat{D} = \begin{bmatrix} \widehat{D}^{(1)} & & 0 \\ & \ddots & \\ 0 & & \widehat{D}^{(N)} \end{bmatrix} \qquad f = \begin{Bmatrix} f^{(1)} \\ \vdots \\ f^{(N)} \end{Bmatrix}$$

Add coupling terms to global stiffness matrix at interface DoFs.

Apply Boundary Conditions:

$$\begin{bmatrix} \widehat{M}_{ff} & \widehat{M}_{fc} \\ \widehat{M}_{cf} & \widehat{M}_{cc} \end{bmatrix} \begin{Bmatrix} \ddot{p}_f \\ \ddot{p}_c \end{Bmatrix} + \begin{bmatrix} \widehat{K}_{ff} & \widehat{K}_{fc} \\ \widehat{K}_{cf} & \widehat{K}_{cc} \end{bmatrix} \begin{Bmatrix} p_f \\ p_c \end{Bmatrix} = \begin{Bmatrix} f_f \\ f_c \end{Bmatrix}$$

p_c is known…

$$\widehat{M}_{ff}\ddot{p}_f + \widehat{K}_{ff}p_f = f_f - \widehat{M}_{fc}\ddot{p}_c - \widehat{K}_{fc}p_c = \hat{f}$$

Transform into Eigen Space

$$\widehat{M}_{ff}\ddot{p}_f + \widehat{K}_{ff}p_f = \hat{f}$$

Define free modes:

$$\left(\widehat{K}_{ff} - \lambda_r \widehat{M}_{ff}\right)\phi_r = 0$$

Augment Φ_r with additional interface modes

Not Implemented

Define modal transformation:

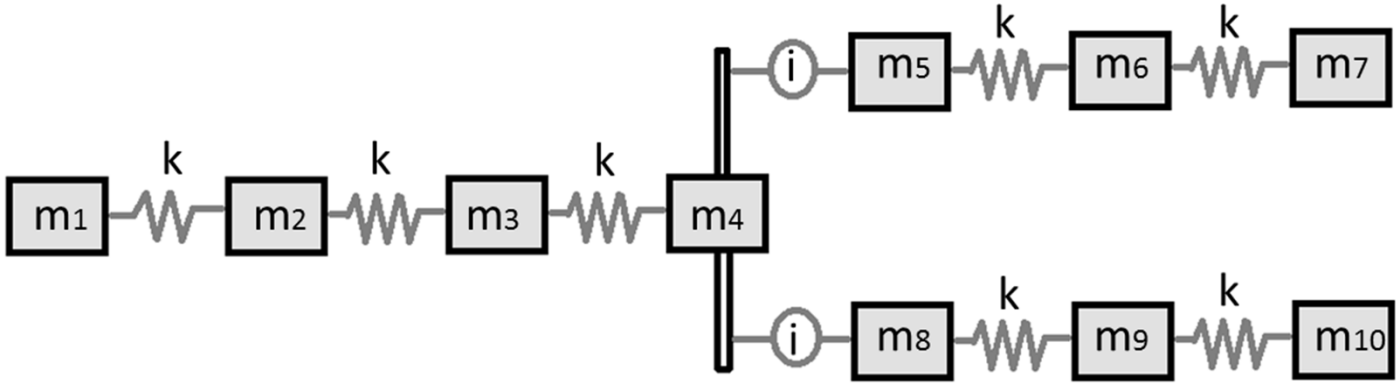
$$p_f = \Phi_r \eta$$

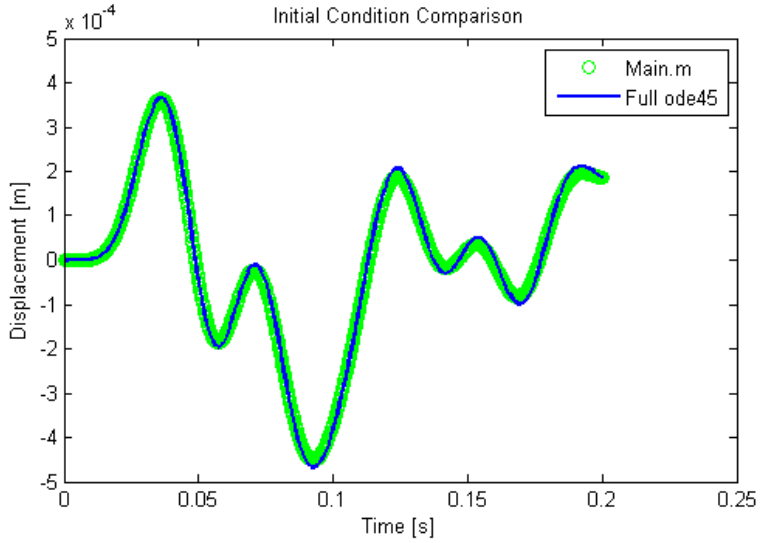
Transform equations of motion

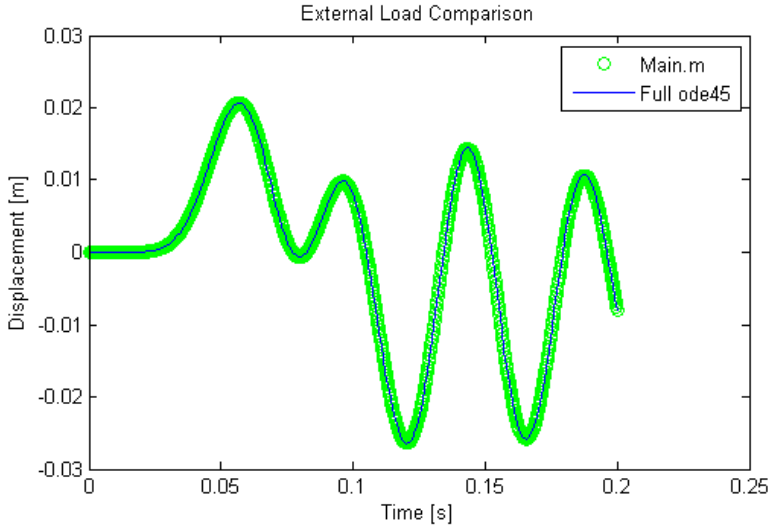
$$\widetilde{M}\ddot{\eta} + \widetilde{K}\eta = \Phi_r^T \hat{f}$$

Send equations into integrator with ICs and interface models.

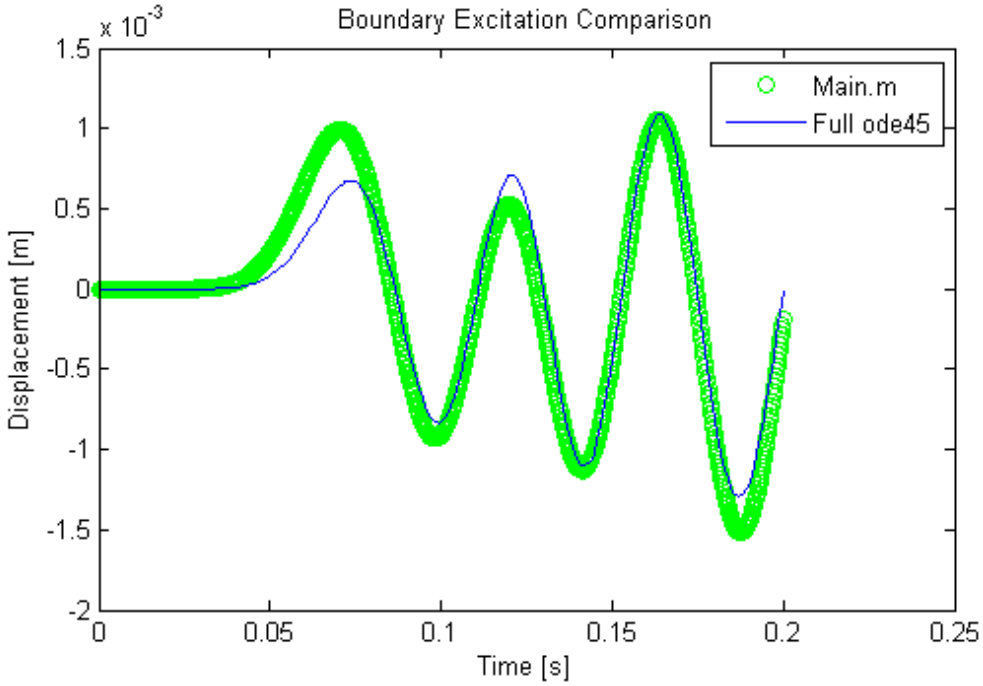
Testing the Code







Testing the Code



Assumption:

$$p_{BC} = \begin{Bmatrix} 0 \\ u_{BC}(t) \end{Bmatrix}$$

WRONG!

Except when $u_{BC} = 0$

Non-zero

$$\begin{Bmatrix} 0 \\ u_{BC} \end{Bmatrix} = \hat{\Psi}_{CB} p_{BC} \rightarrow p_{BC} = \hat{\Psi}_{CB}^{-1} \begin{Bmatrix} 0 \\ u_{BC} \end{Bmatrix} = \begin{Bmatrix} p_{k,BC} \\ u_{BC} \end{Bmatrix}$$

Possible Solution: Apply BCs Before Reducing System

BCs can be specified in SIERRA S/D

- Cannot retrieve boundary effective forces

Use MATLAB

- Require original system matrices
- Memory problems with large matrices

Next Steps

- Tweaks and Debugging
- Sandia FE Dynamics Projects
- Develop a GUI
- Create Documentation.

¿Preguntas?

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