A HYBRID IMPULSIVE SCHEME FOR FASTER THAN REAL-TIME VEHICLE LOADS PREDICTION

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Summary

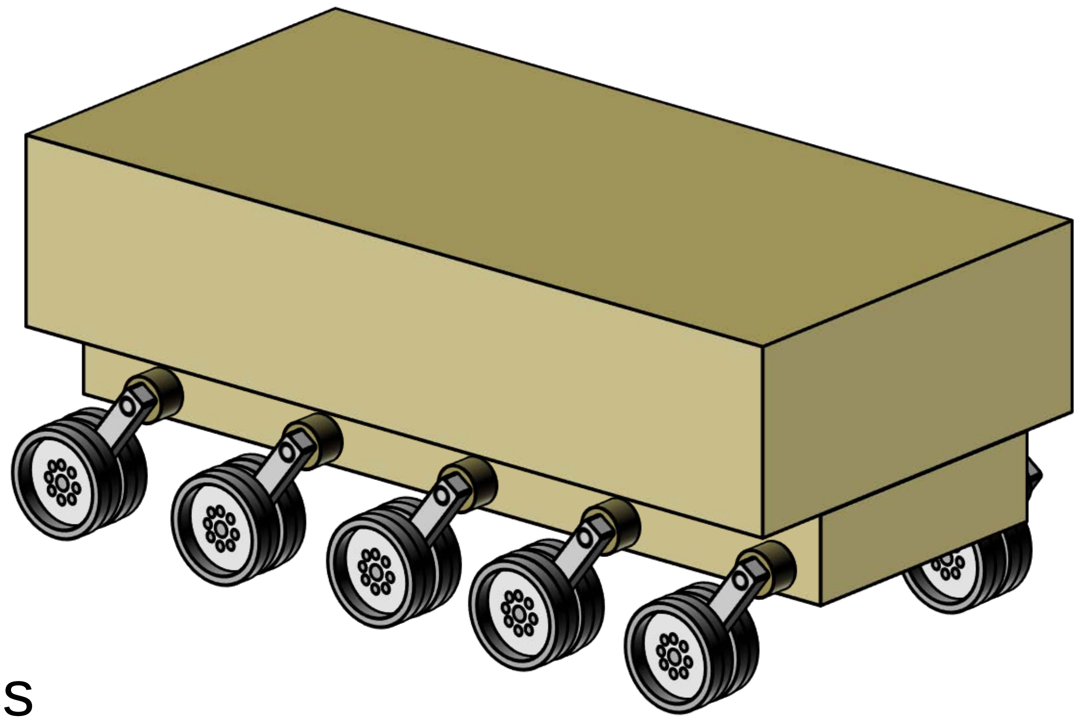
- A simple real-time model
- Real-time model results
  - Case 1 : Accuracy
  - Case 2 : Stability
- Numerical Temporal Integration
- Hybrid Step Method
  - Theory
  - Generalized Momentum and Impact Solution
  - Finite Time Impulse Results
- Conclusion

A Simple Real-time Model

Important features:

- Nonlinear System
  - Hull orientation
  - Road-arm rotations
- Ground Contact
  - Becker law
  - Constant SA
- Jounce Bumper
  - Exponential stiffness

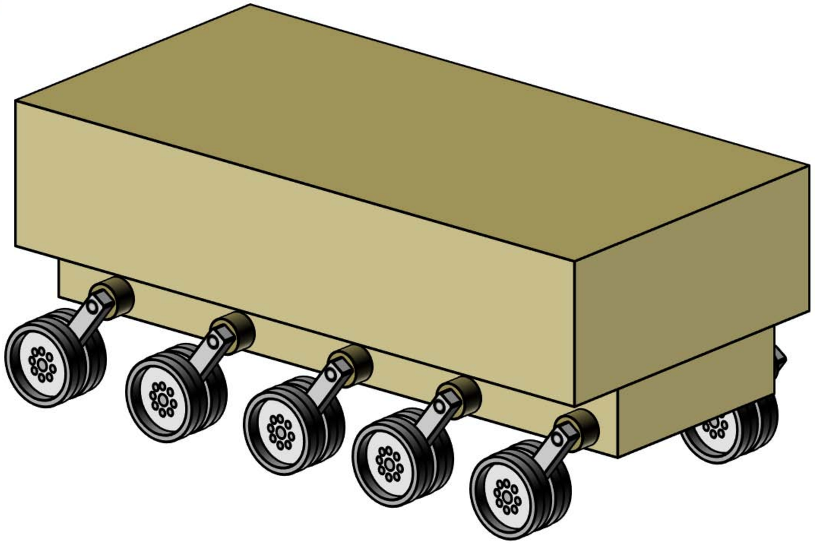
Tracked Vehicle



A Simple Real-time Model

Simplifying assumptions:

- Track loop "ignored"
  - Road wheels rotate in unison
  - Specified L/R track speeds
- Ground contact
  - "Spherical" wheels
  - Single point look-up
    - smooth terrain
    - curvature^{-1} >> RW radius.



Tracked Vehicle

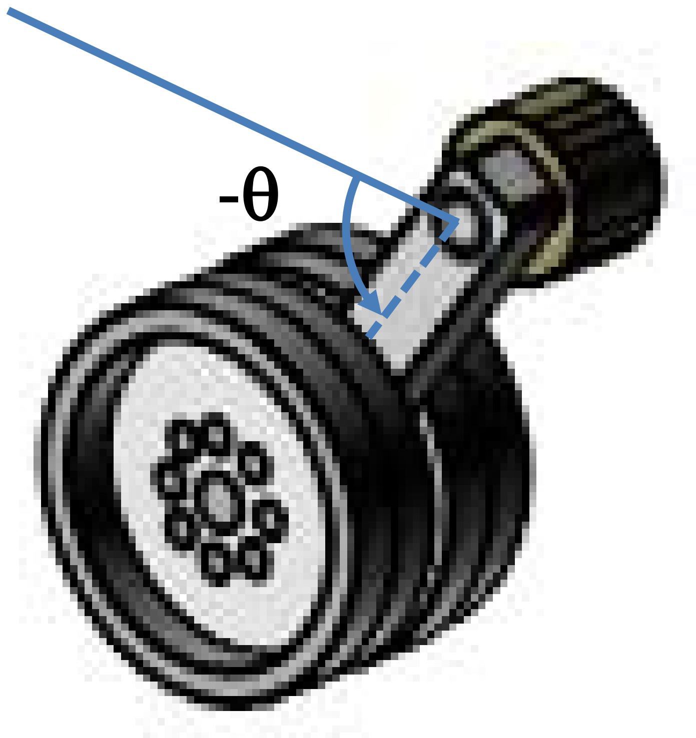
Force Elements:

$$M_{suspension} = k(\theta - \ell) + c\dot{\theta} + k(e^{(40s)} - 1)$$

$$p = \left(\frac{k_c}{b} + k_\phi\right) z^n$$

$$F_{long} = -F_{normal} c_{soil} (v_{long} - v_{track})$$

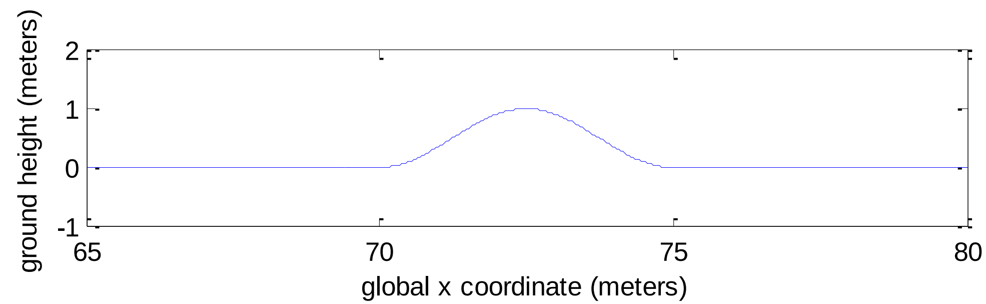
$$F_{lat} = -F_{normal} c_{soil} v_{lat}$$



A Simple Real-time Model

Terrain:

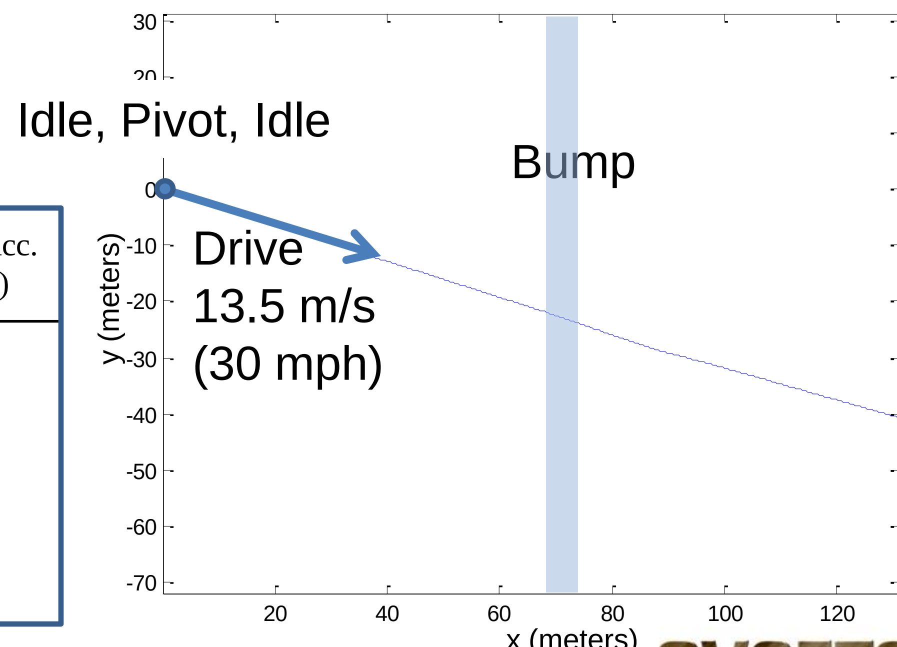
- Scalable bump
- Height, wavelength



Maneuver:

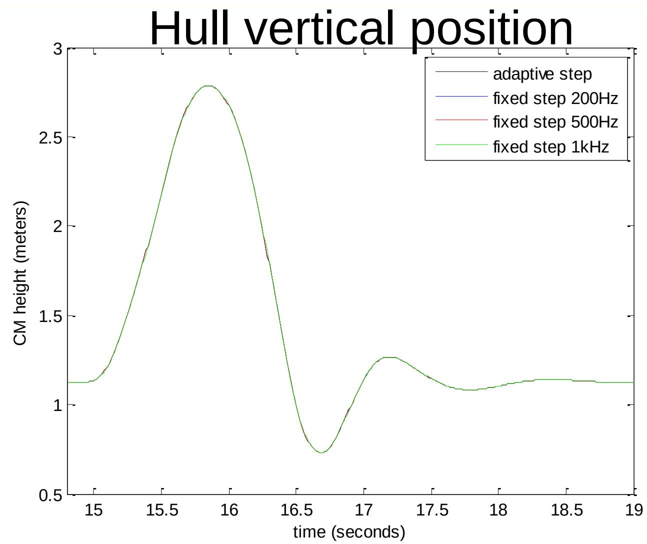
- Track speeds

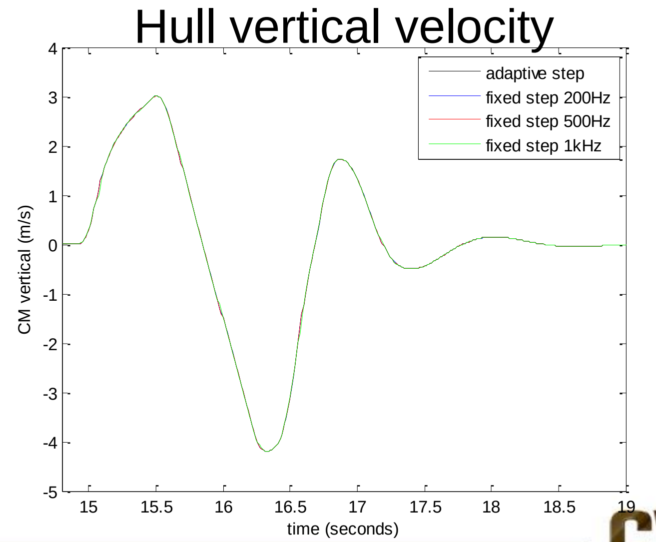
Time (sec)	Left speed (m/s)	Right speed (m/s)	Left Acc. (m/s^2)	Right Acc. (m/s^2)
0	0	0	0	0
3	0	0	0.5	-0.5
4	0.5	-0.5	0	0
5	0.5	-0.5	-0.5	0.5
6	0	0	0	0
7	0	0	2.7	2.7
12	13.5	13.5	0	0



Case 1:

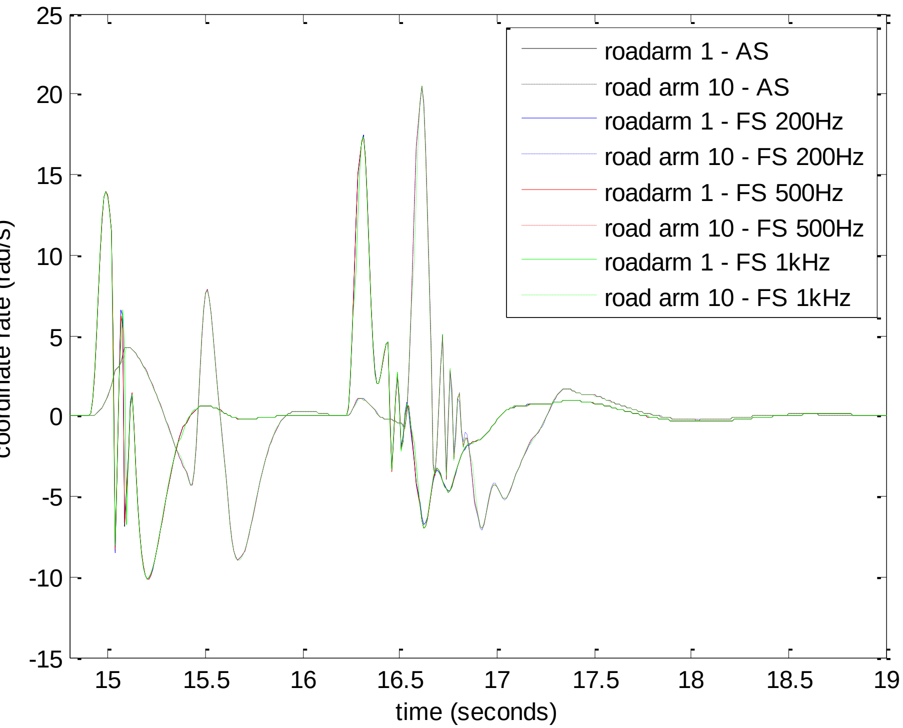
- Model integrated with error control (AS) and at 200 Hz, 500Hz, and 1kHz
- Bump height and wavelength <1, 5>m
- Trajectories are indistinguishable.



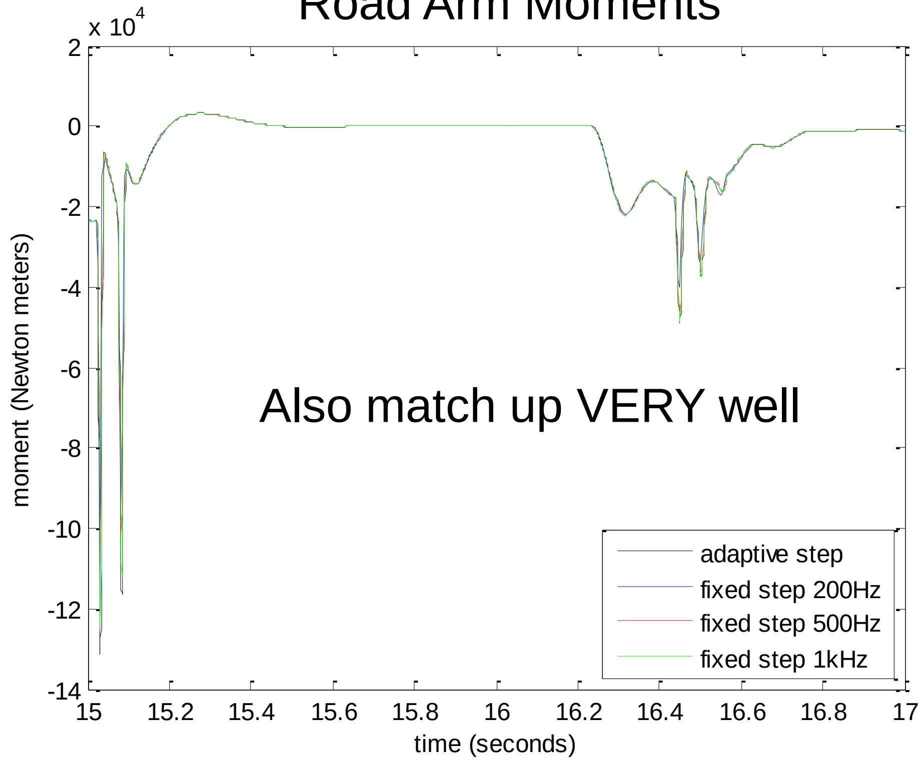


Results : Case 1

Road Arm Rates

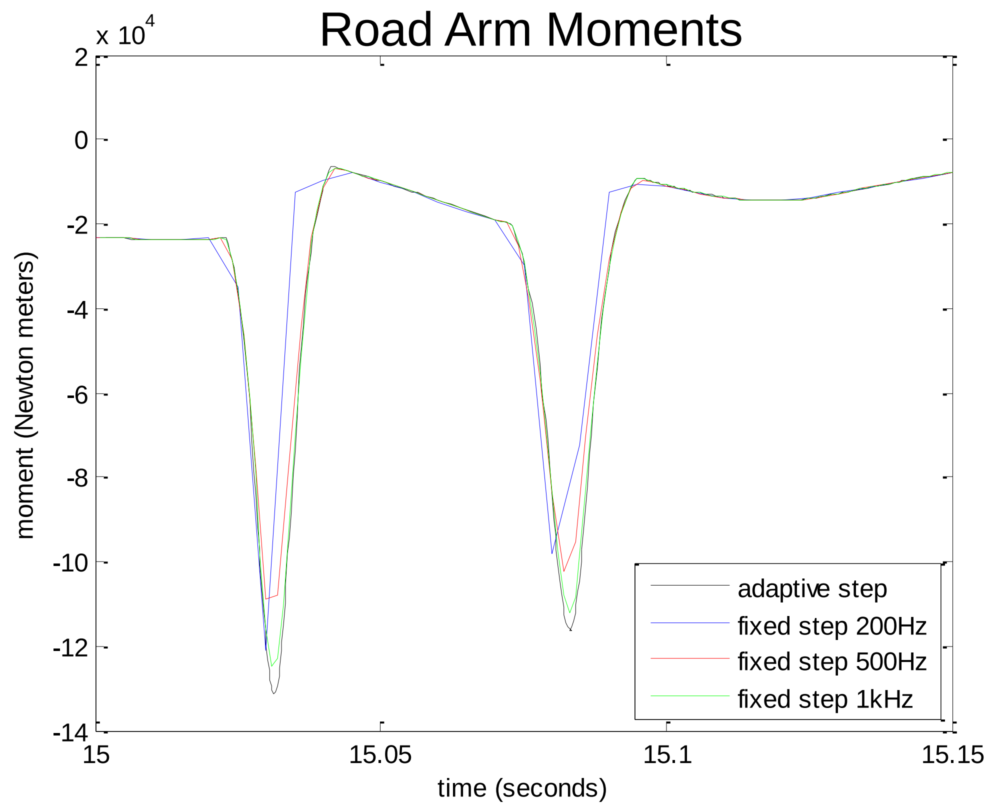


Road Arm Moments



Results : Case 1

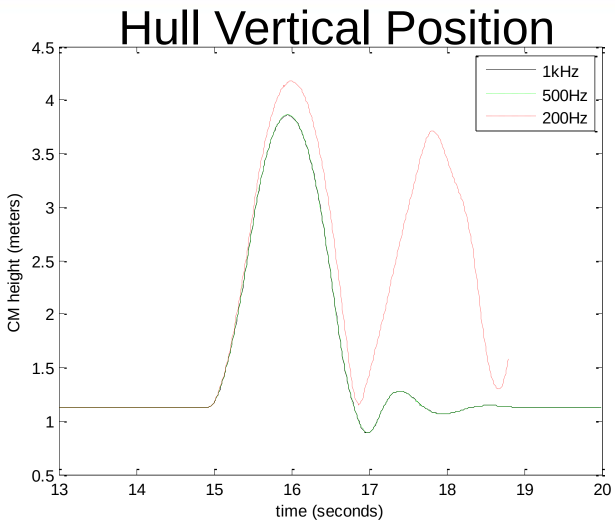
- Peak Loads
  - AS **-1.31×10^5 Nm**
  - 200Hz -1.21×10^5 Nm
  - 500Hz -1.09×10^5 Nm
  - 1kHz -1.25×10^5 Nm
- Results vary chaotically
  - 8%
  - **17%**
  - 5%
- Aliasing also contributes.

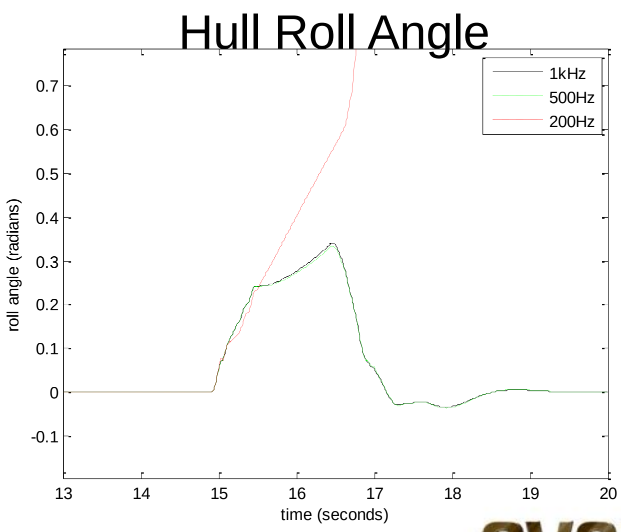


Results : Case 2

Case 2:

- Again model integrated with error control (AS) and at 200 Hz, 500Hz, and 1kHz
- Bump height and wavelength **<1, 2>m**
- Initial terrain assumption violated!
- **Results are unstable**.





Numerical Temporal Integration

- Runge-Kutta family of explicit integrators
  - Forward Euler, RK3, RK4, ode23, ode45, Dormand-Prince, etc.
- Basics
  - Approximate: $y(t_0+h)$ where $y' = f(t,y)$
  - Taylor Series Expansion:

$$y(t_0+h) = y(t_0) + hy'(t_0) + \tfrac{h^2}{2}y''(t_0) + O(h^3)$$

$$y(t_0+h) = y(t_0) + hf + \tfrac{h^2}{2}\frac{df}{dt} + O(h^3)$$

$$\frac{df}{dt} = \frac{\partial f}{\partial y}\frac{dy}{dt} + \frac{\partial f}{\partial t}\frac{dt}{dt} = f_y f + f_t$$

$$y(t_0+h) = y(t_0) + hf + \tfrac{h^2}{2}(f_t + f_y f) + O(h^3)$$

- Taylor Series Expansion:

$$y(t_0+h)=y(t_0)+hf+\tfrac{h^2}{2}(f_t+f_y f)+O(h^3)$$

- Function Evaluations:

$$k_1=f(t_0,y_0)=f$$

$$k_2=f(t_0+ha_2,y_0+hb_{21}k_1)=f+ha_2 f_t+hb_{21}f_y f+O(h^3)$$

- Assembly:

$$y(t_0+h)=y(t_0)+hw_1k_1+hw_2k_2+O(h^3)$$

$$y(t_0+h)=y(t_0)+h(w_1+w_2)f+h^2w_2a_2 f_t+h^2w_2b_{21}f_y f+O(h^3)$$

- Constraints defining second order methods:

$$w_1+w_2=1 \qquad w_2a_2=w_2b_{21}=\tfrac{1}{2}$$

Numerical Temporal Integration

MODELING AND SIMULATION, TESTING AND VALIDATION

Second order methods

$$\begin{array}{c|cc} 0 & & \\ \alpha & \alpha & \\ \hline & 1-\frac{1}{2\alpha} & \frac{1}{2\alpha} \end{array}$$

Third order method

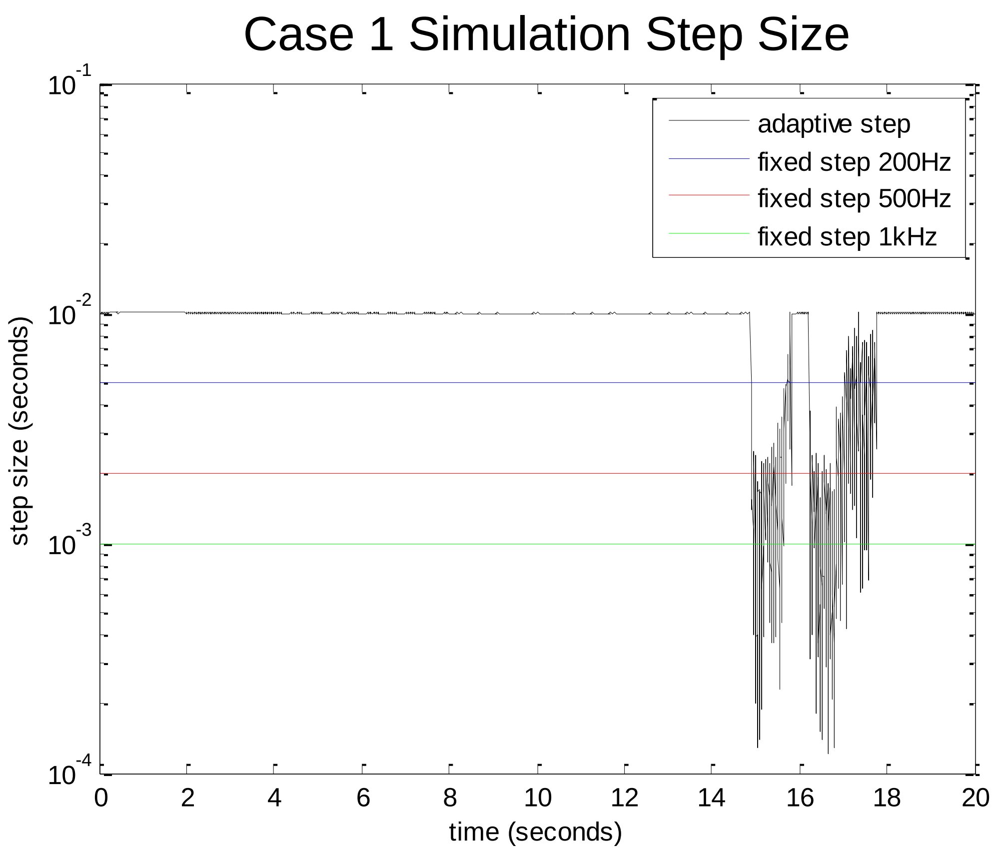
$$\begin{array}{c|ccc} 0 & & & \\ \frac{1}{2} & \frac{1}{2} & & \\ 1 & -1 & 2 & \\ \hline & \frac{1}{6} & \frac{2}{3} & \frac{1}{6} \end{array}$$

An embedded second order method with α=1/2

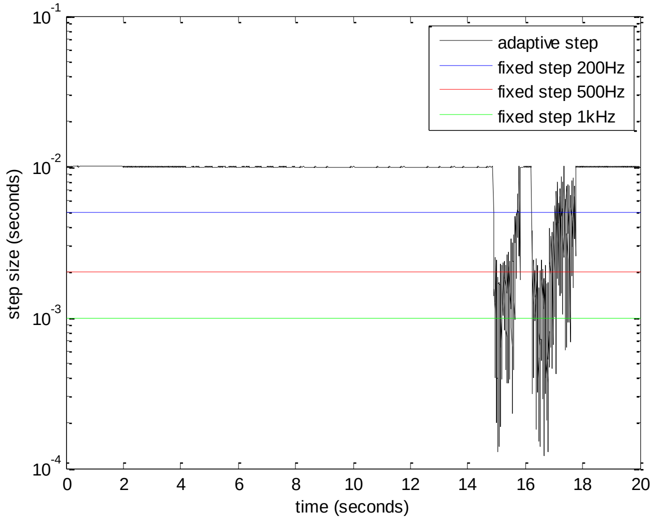
Subtraction of two methods approx. error within step.

Error is a state vector difference.

- Application
  - Fixed step
  - Adaptive step



Hybrid Step Method



Description:

- Use a fixed step integration method.
- Monitor error at each DoF.
- Error exceeding tolerance indicates the system is too stiff to integrate accurately.
- Substitute impulsive event response in zero time.
- Continue integrating.

- Determine accurate loads independently from initial conditions for impulsive event.

- Generalized Momentum and Impact Solutions:

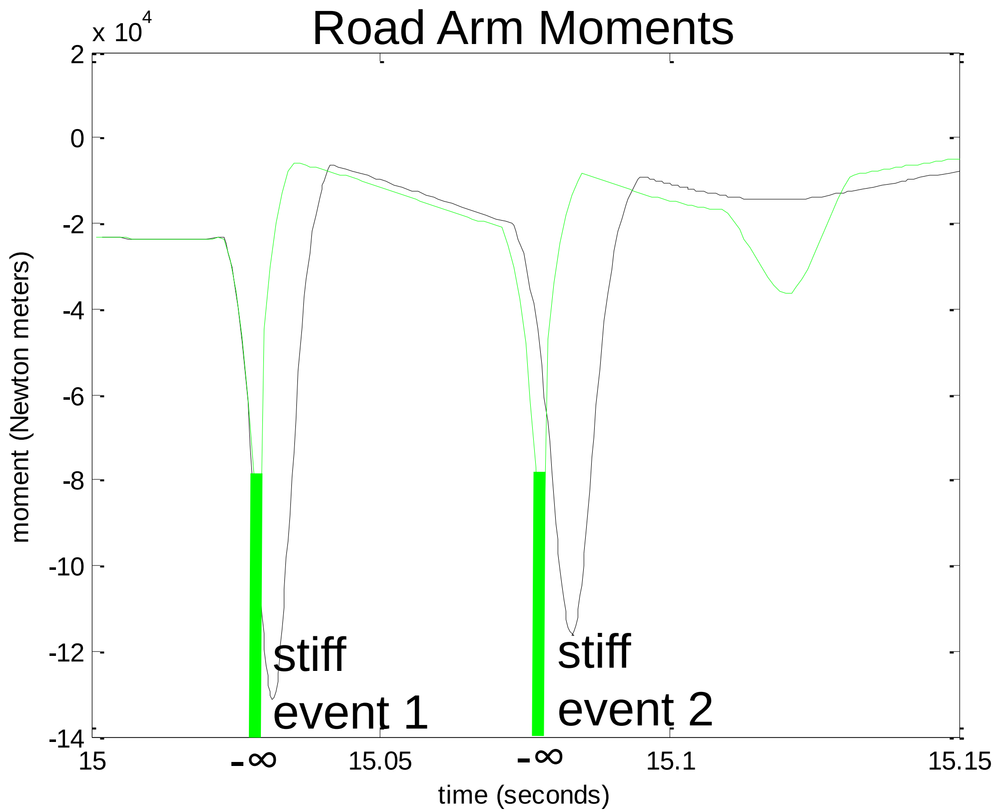
$$\sum_i \left(m_i v_i^{+} \cdot \frac{\partial v_i}{\partial u_r} + I_i \cdot \omega_i^{+} \cdot \frac{\partial \omega_i}{\partial u_r} \right) - F_c \Delta t \cdot \frac{\partial v_c}{\partial u_r} =$$

$$\sum_i \left(m_i v_i^{-} \cdot \frac{\partial v_i}{\partial u_r} + I_i \cdot \omega_i^{-} \cdot \frac{\partial \omega_i}{\partial u_r} \right)$$

$$v_c^{+} \cdot \hat{n} = -\varepsilon v_c^{-} \cdot \hat{n}$$

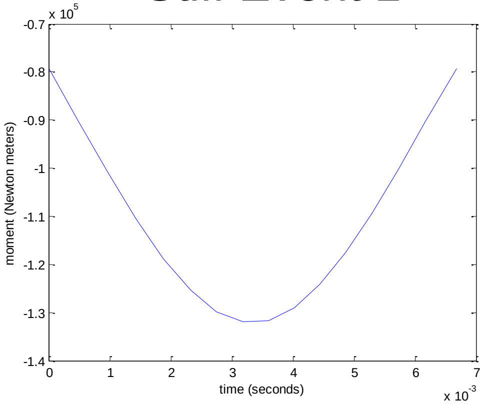
DESIRED Loads Method

Hybrid Impulsive Load Time History

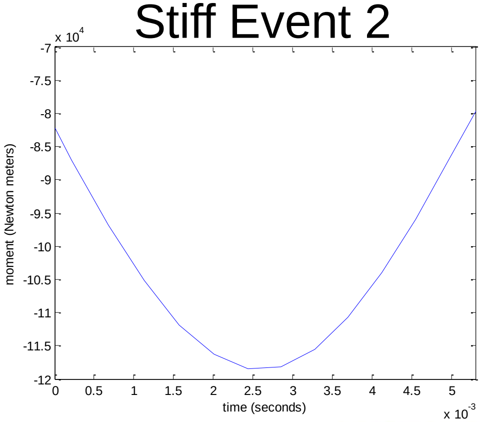


External Integration

Stiff Event 1



Stiff Event 2



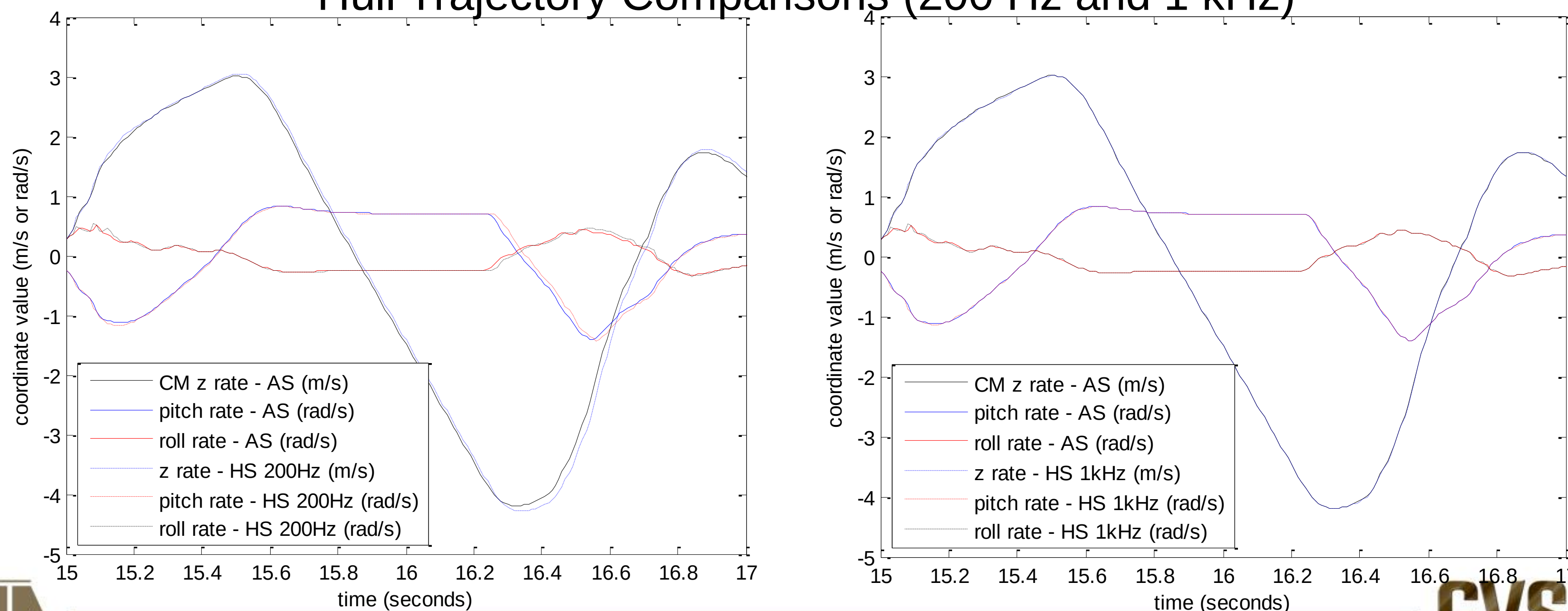
Didn't quite get there

Hybrid Step Method

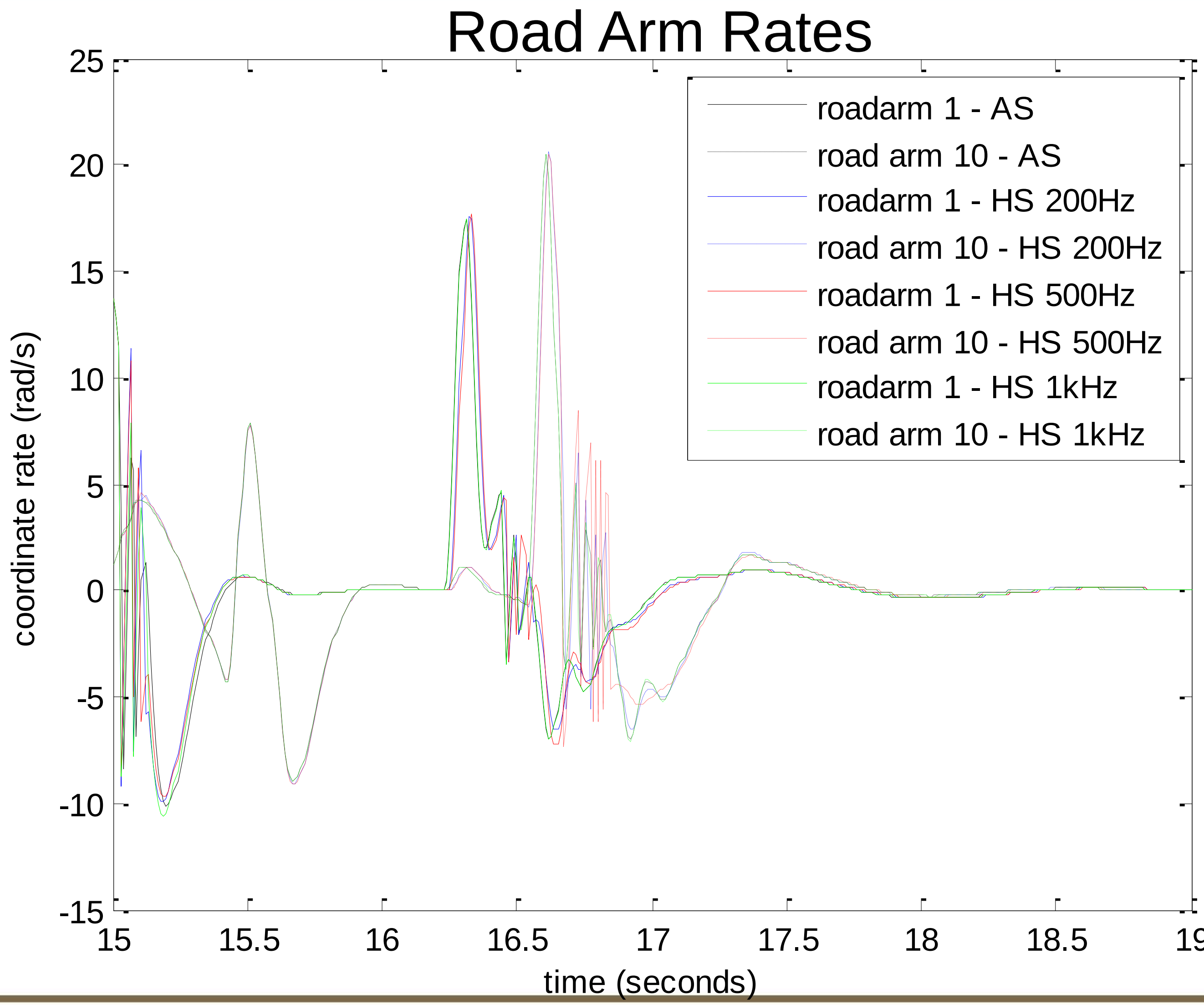
Applied Finite Time Impulses

- A compromise, in some sense a more “general” solution.
  - Modeling the design intent of a component throughout a stiff region with prescribed motion constraint.
  - Peak loads reconstructed using initial conditions for impulse.

Hull Trajectory Comparisons (200 Hz and 1 kHz)

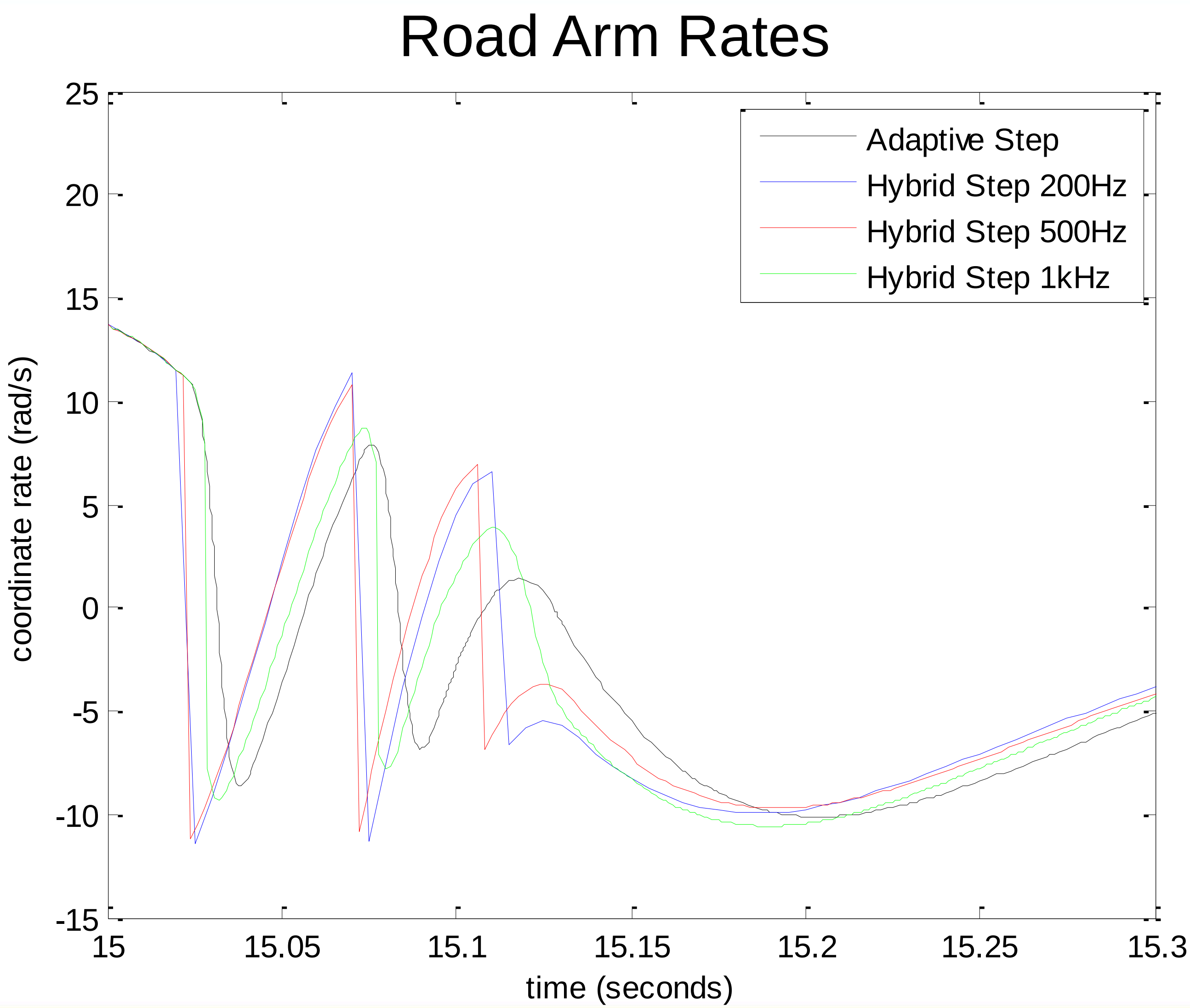


Hybrid Step Method



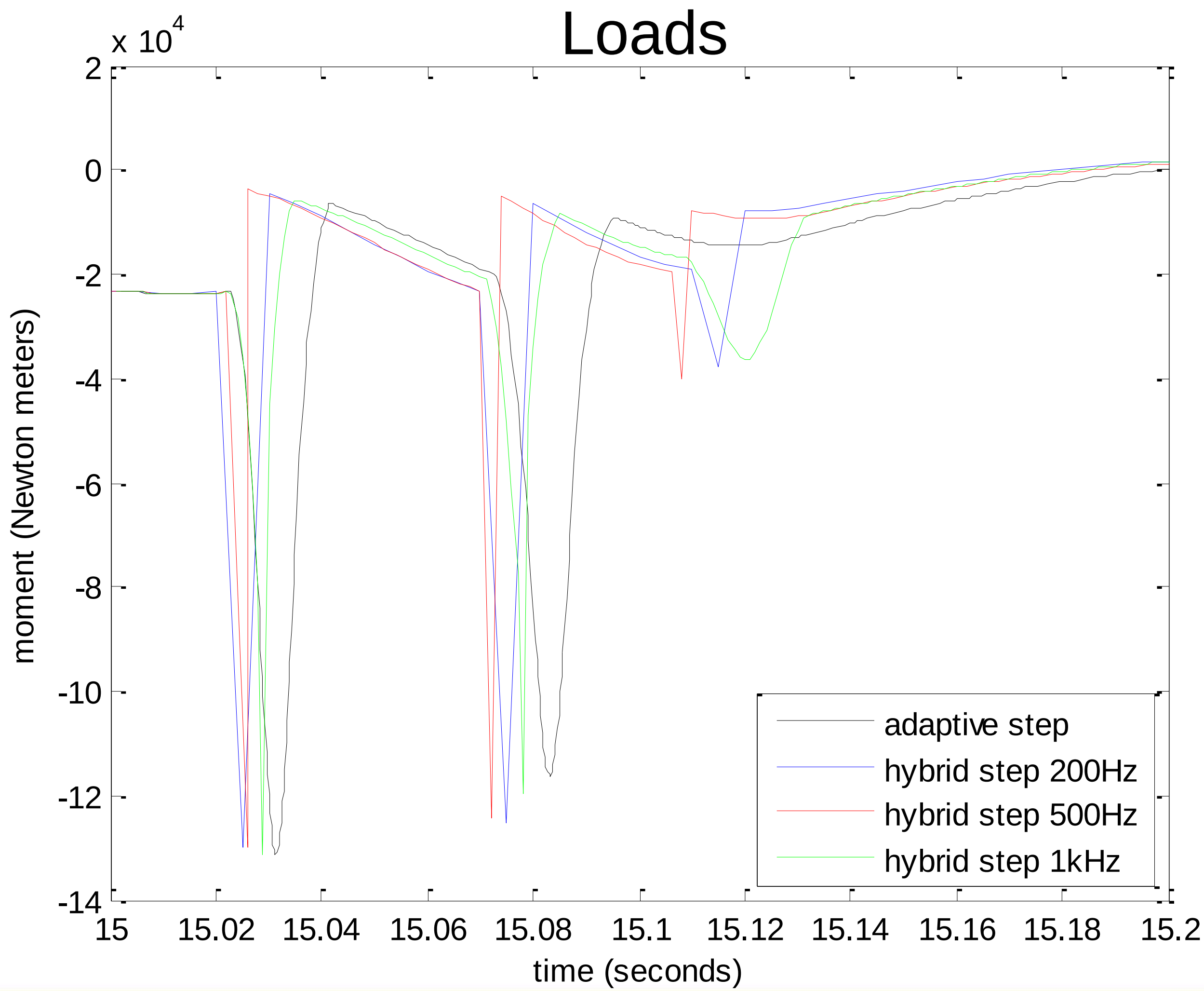
COR = 1
Better values needed

Hybrid Step Method



COR = 1
Better values needed

Hybrid Step Method



Conclusion

- A new method for rapid loads evaluation has been presented in combination with real-time requirements.
- Stiffness is identified dynamically rather than geometrically (no contact detection).
- Zero time events proved difficult and are the subject of on going work.
- Finite time impulses
  - Have broader/easier application.
  - Peak loads may be post processed off-line and independently.