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A Physics-Based Link Model for Tree Vibrations

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Tropical storm Irene – August 29th 2011 (767,000 power outages)
Largest in Connecticut history – BY FAR

Just about two months after Irene…

Arboricultural questions

- Pruning trees- affecting tree stability?
- Reduces "sail" but what about ability to dissipate wind forces?

A dynamic system

Vibration frequency and damping important dynamical properties (de Langre 2008)

Although fundamental mode considered most important, other modes are of interest & help understand how wind energy is dissipated.

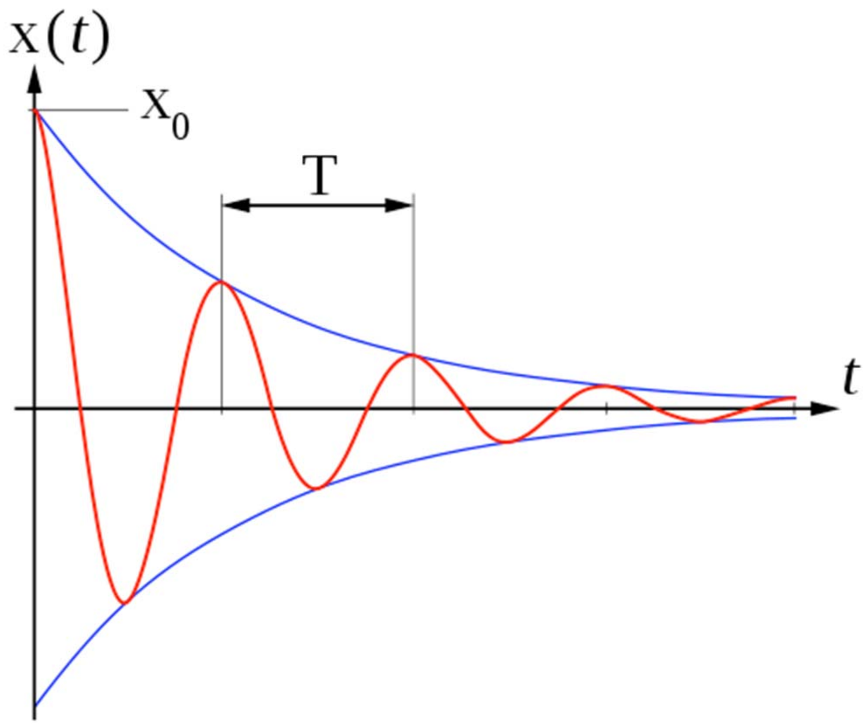
Determining Tree Vibration

Many studies manually induce motion (Mayer 1987, Moore & Mcquire 2005, Sellier & Fourcaud 2005 **and others**) but a few use wind loading and include the presence of neighbors.

Sellier and co-workers 2005,2006,2008,2009 (measurements and FEM) & Rodriguez et al. 2009

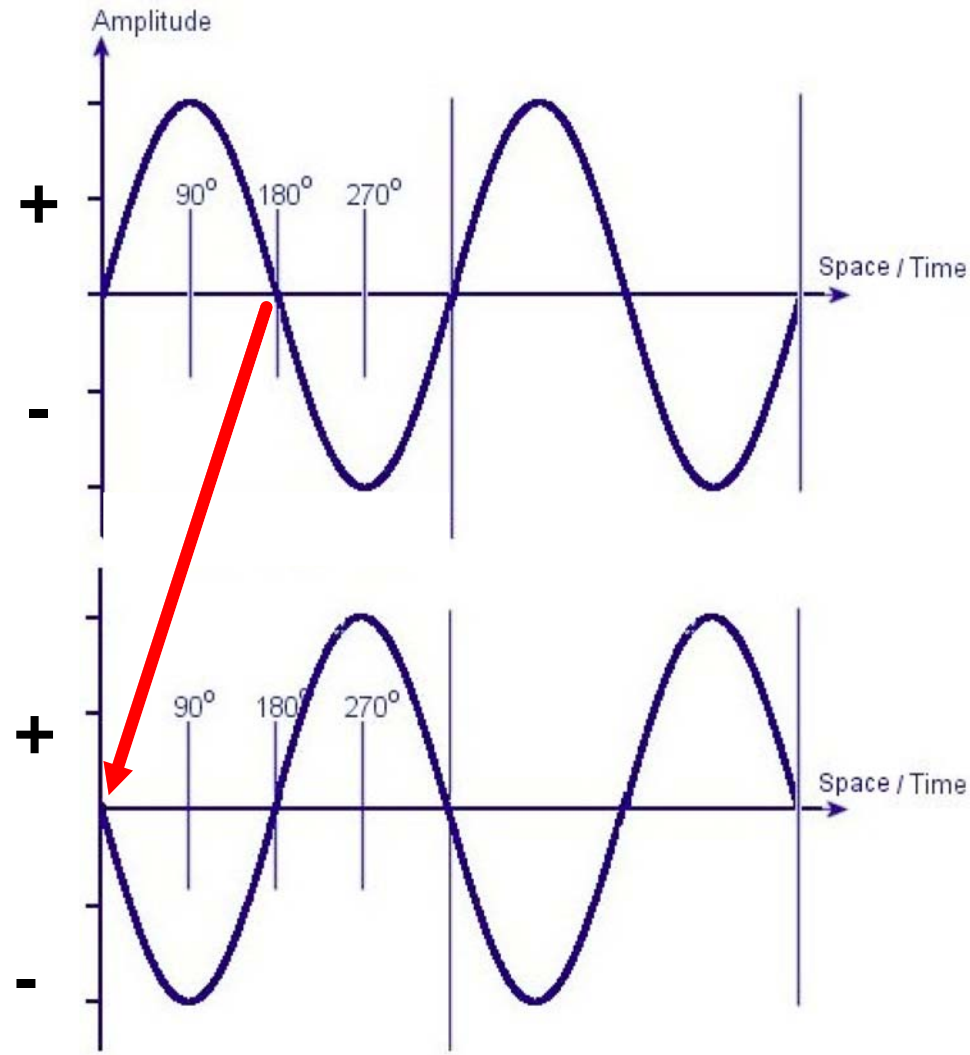
Damping

- Causes energy to dissipate
- Sources of damping:
  - viscoelastic (internal)
  - aerodynamic drag (leaves)
  - collisions with neighbors
  - **mass damping (branches)**



Mass Damping

- Phase relationships
  - Out of phase: Amplitudes cancel
  - In phase: amplitudes combine



Completely out of phase

Study Site

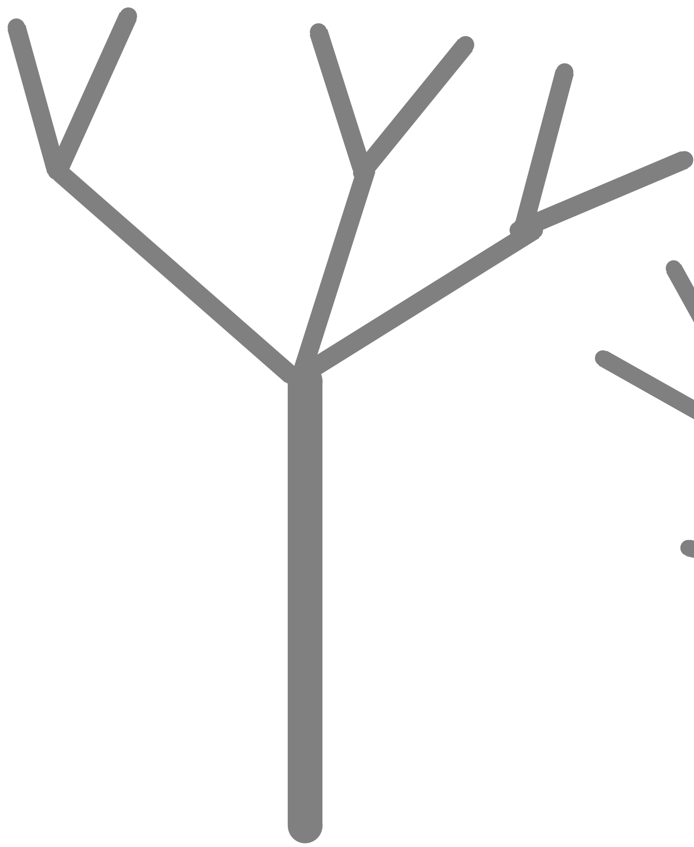
- Davey Tree Research Farm, Shalersville, OH
- ISA Tree Biomechanics Week
  - August 23- 27, 2010
- Investigation began on August 24, 2010

TREE FUND
Tree Research & Education Endowment Fund

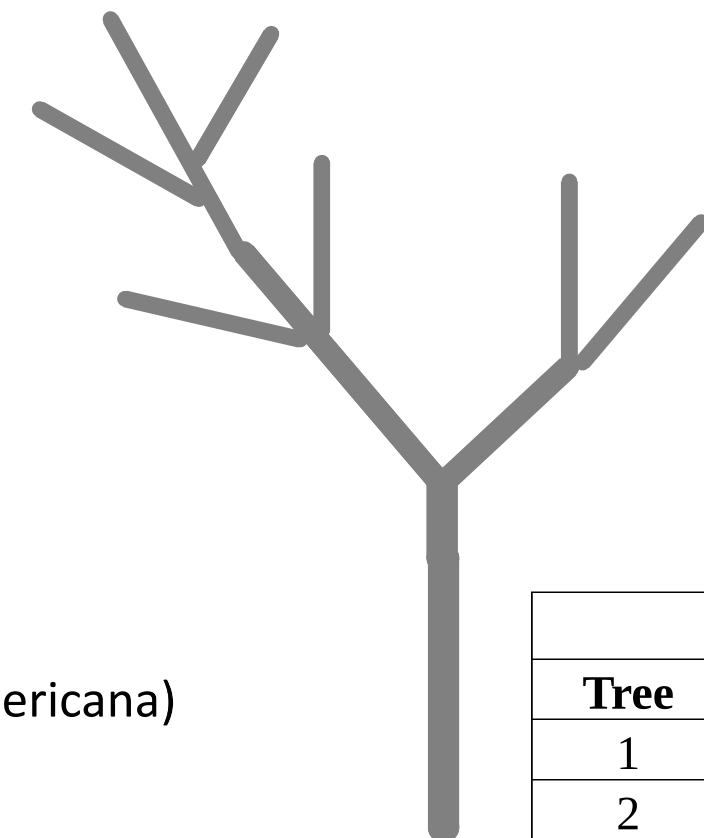
ISA
International Society of Arboriculture

DAVEY

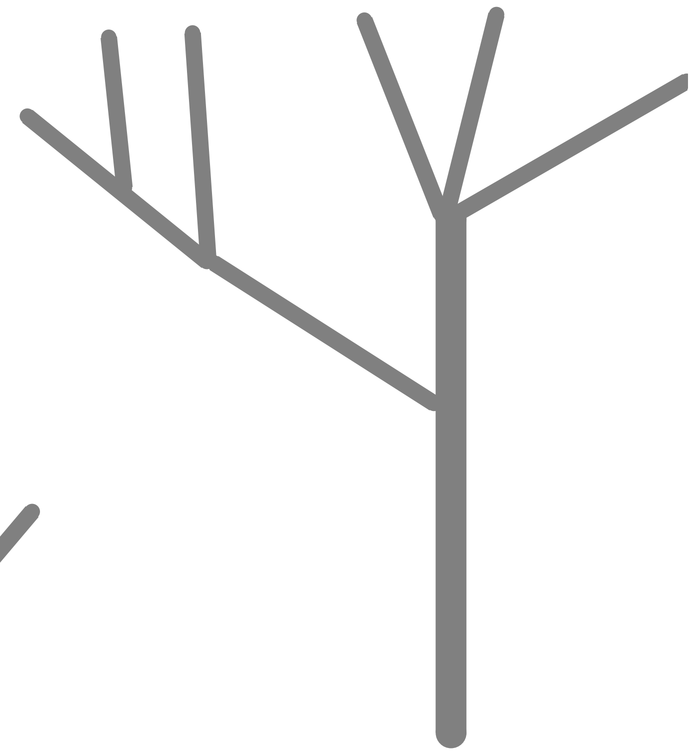
Tree 1



Tree 2



Tree 3



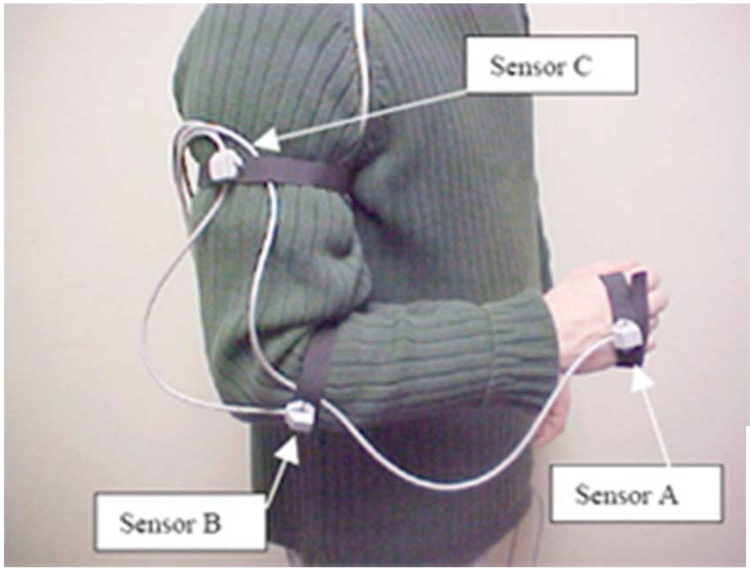
White ash (Fraxinus americana)

Tree Measurements		
Tree	**Height (m)**	**DBH (cm)**
1	17.6	26.4
2	17.2	26.2
3	19.5	26.8

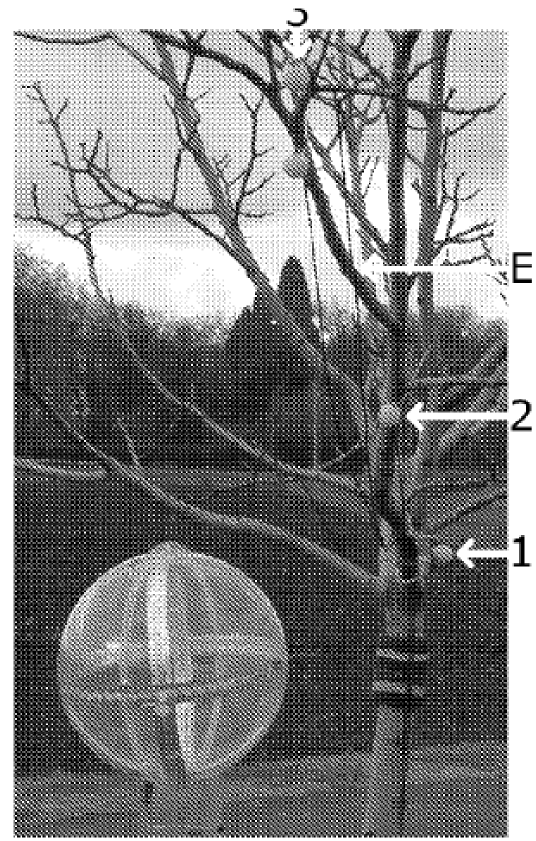
3D Motion Capture

- Polhemus LIBERTY Motion Tracking System
- Emits electromagnetic field (sphere), radius 15 ft (4.5m)
- Motion recorded at 240 times per second

POLHEMUS
INNOVATION IN MOTION™



To predict human motion



RODRIGUEZ, M., MOULIA, B and de LANGRE, E. 2009. Experimental investigations of a walnut tree multimodal dynamics. 2nd International Conference Wind Effects on Trees, 13-16 Oct. 2009, Freiburg, Germany.

Pruning tests were hand loaded (wind uncooperative)

- Pull and release tests
  - 4 pulley system, (quadrupled force)
  - Rope attached to first notch in the tree
- Pruning Treatments- removed mass
  - **No Prune**- tree crown intact
  - **Prune 1**- approximately 1/3 of crown mass removed
  - **Prune 2**- approximately 1/3 crown mass removed

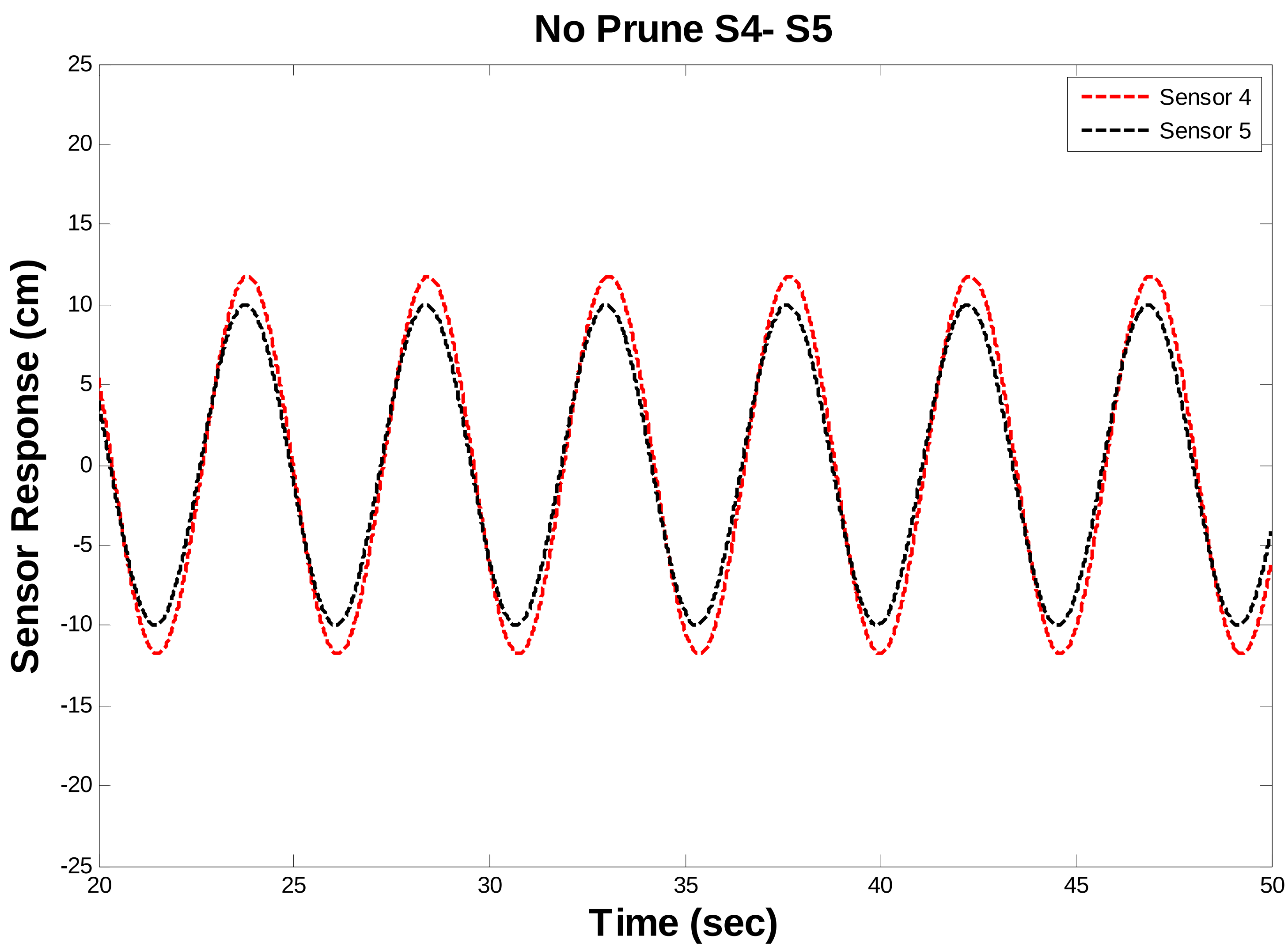
Mean Freq (Hz) Across All Sensors & Pruning Treatments

	TREE 1	TREE 2	TREE 3
No Prune (n=24)	0.19 (0.005)	0.21(0.004)	0.21 (0.009)
Prune 1 (n=16)	0.21 (0.005)	0.22 (0.009)	0.22 (0.008)
Prune 2 (n=8)	0.21 (0.011)	0.22 (0.008)	0.24 (0.005)

Phase Angle

- Used Least Mean Squares method to generate a signal that mimicked the actual branch sway signals recorded (Matlab)
- Input parameters required for the function
  - $Y(t) = A * \sin(\omega (t) - \varphi)$
  - A and φ based on time series
  - ω based on FFT results (0.2 Hz)

No observed Phase Shift



Phase Shift

	Mean Phase Shifts (°) Across Pruning Treatments		
	No Prune	**Prune 1**	**Prune 2**
	Tree 1		
S4 - S5	1.0	0.8	2.2
	Tree 2		
S5- S6	8.2	8.4	4.9
	Tree 3		
S2 - S4	3.2	8.9	1.4

Pruning experiment

- No change in frequency
- No change in phase shift
- No evidence of mass damping

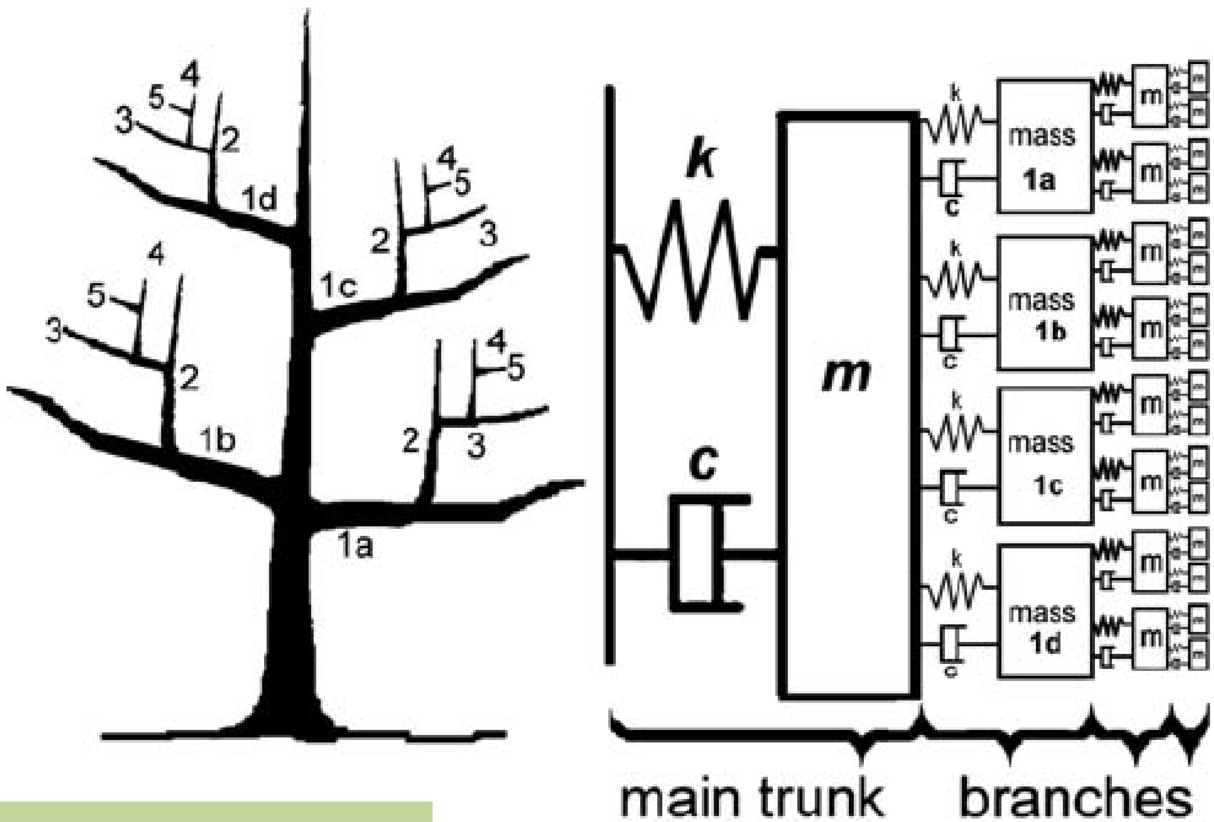
Large amount of:

- Aerodynamic Drag
- Collisions with neighbors

- So experiment indicates heavily damped system.

- Modeling tree motion as a mechanical system conceptualized by James (2006)

Dynamic Structural Model (James et al., 2006)

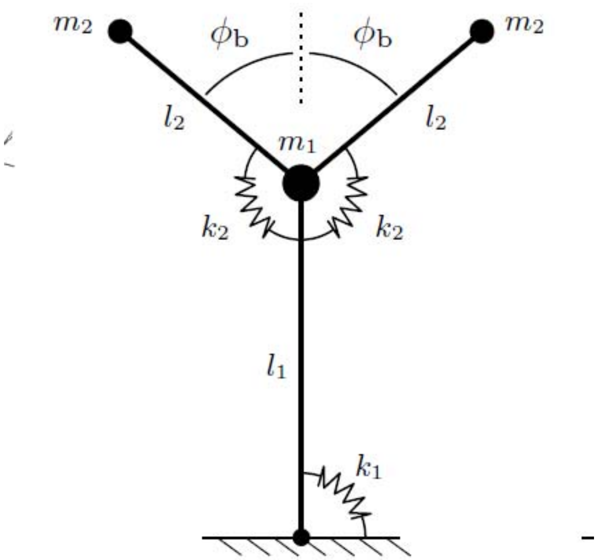


Lumped mass and springs

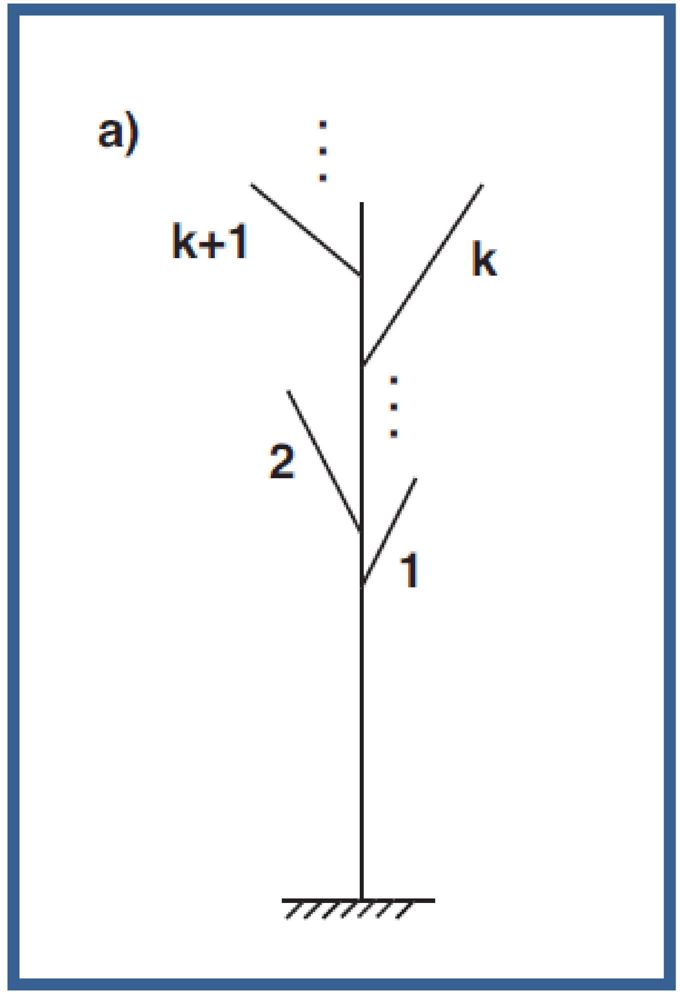
k= spring constant, a property of the wood related to stiffness
c= damping factor
m= mass

A Physics-Based Link Model for Tree Vibrations

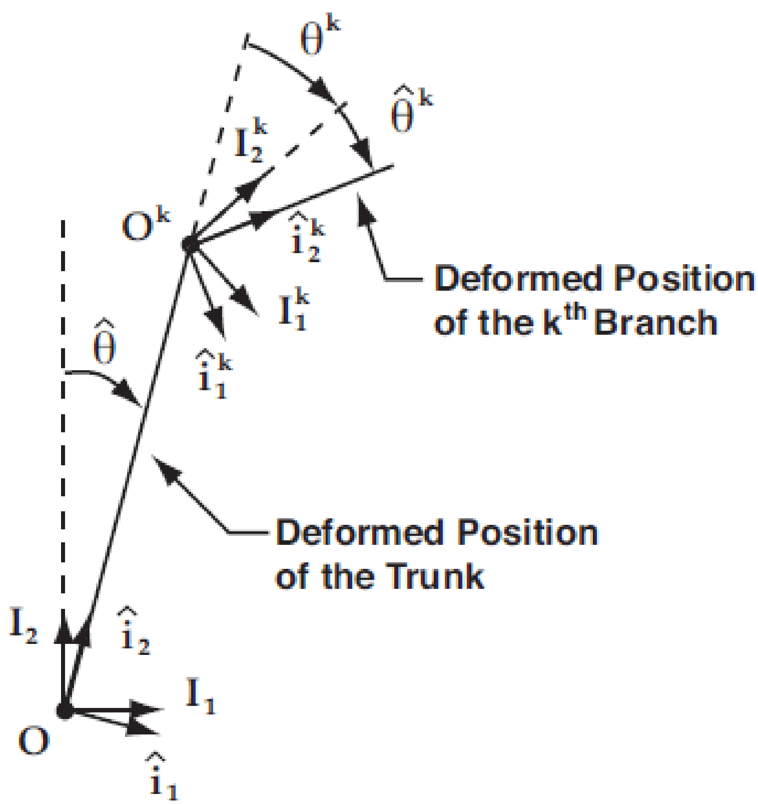
-asymmetric branch links to multi-link model (Kerzenmacher and Gardiner (1998) and Theckes et al. 2011



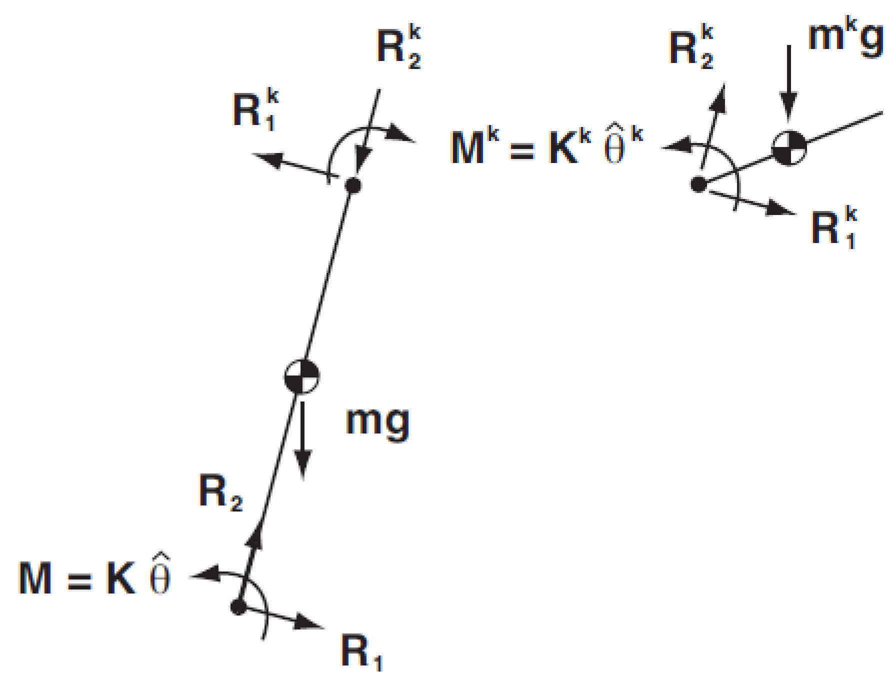
Theckes et al 2011 – Y shaped spring mass model



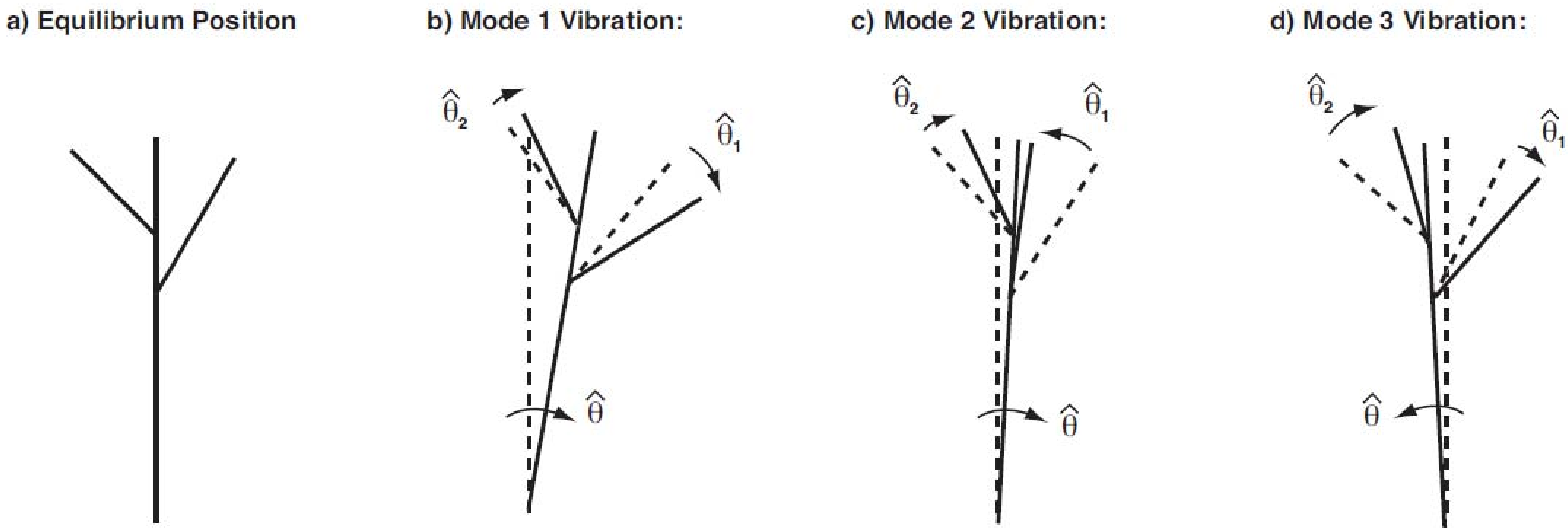
the deformed trunk and kth branch as well as the four coordinate systems describing the system

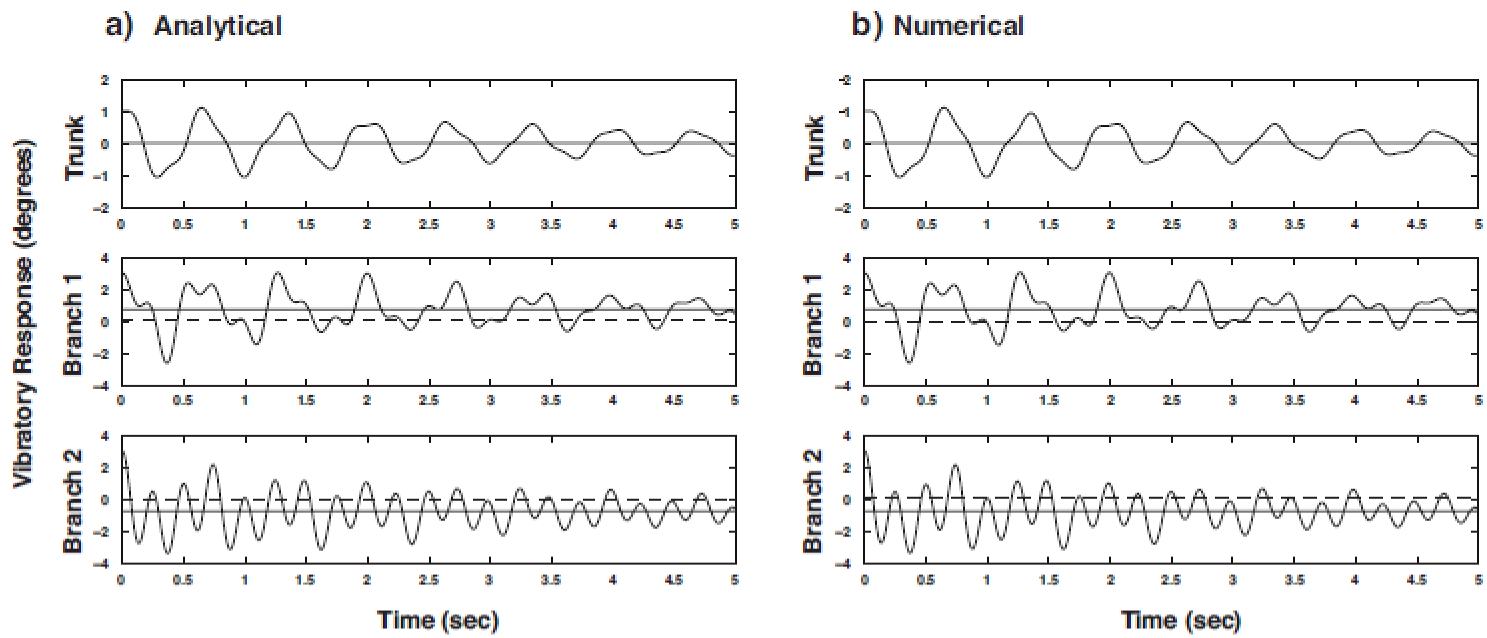


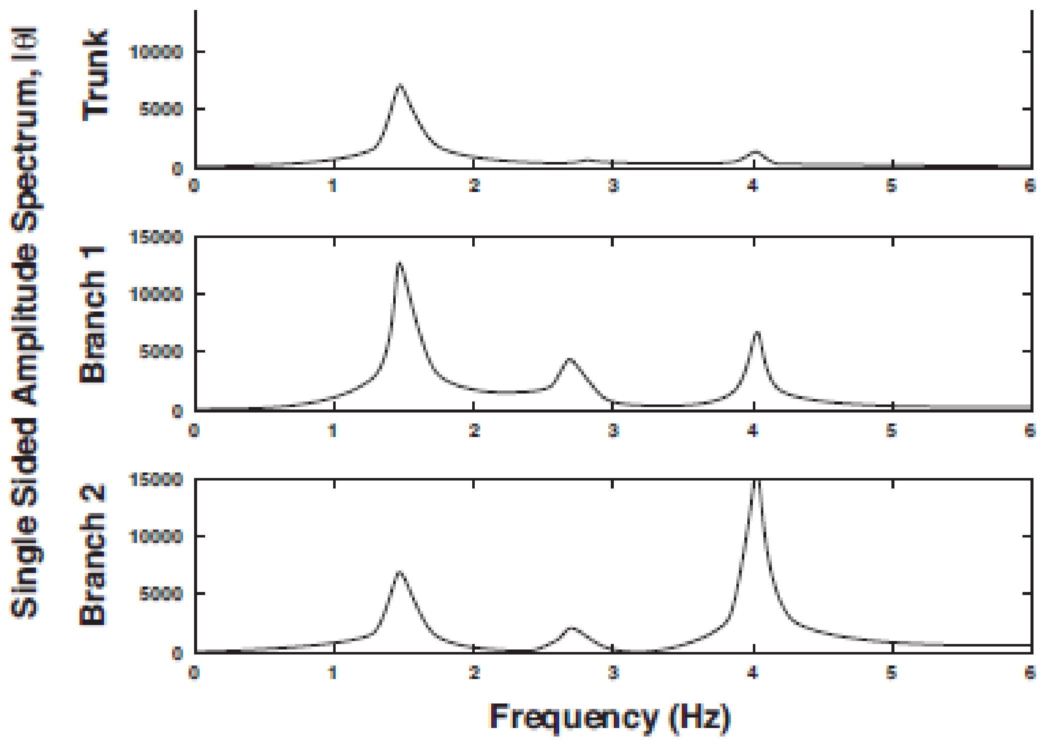
the free body diagram of the trunk and the kth branch



Asymmetric Two Branch Case (N = 2)

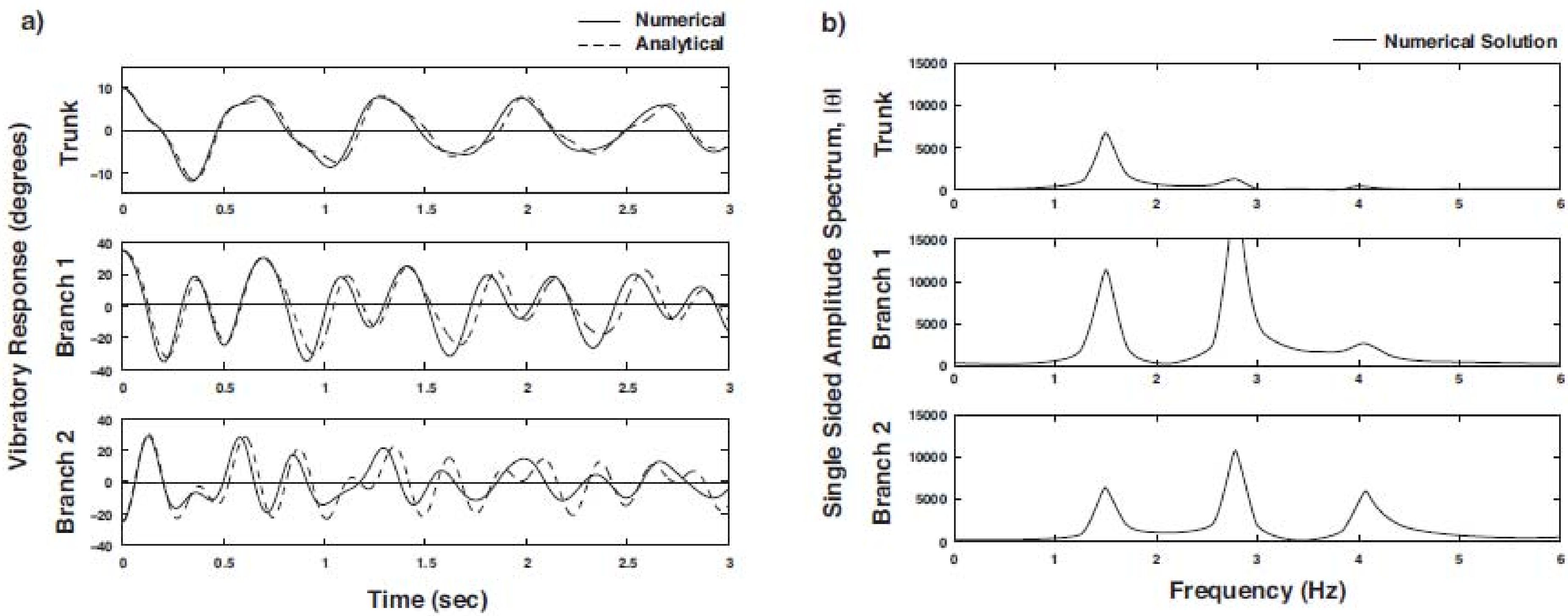






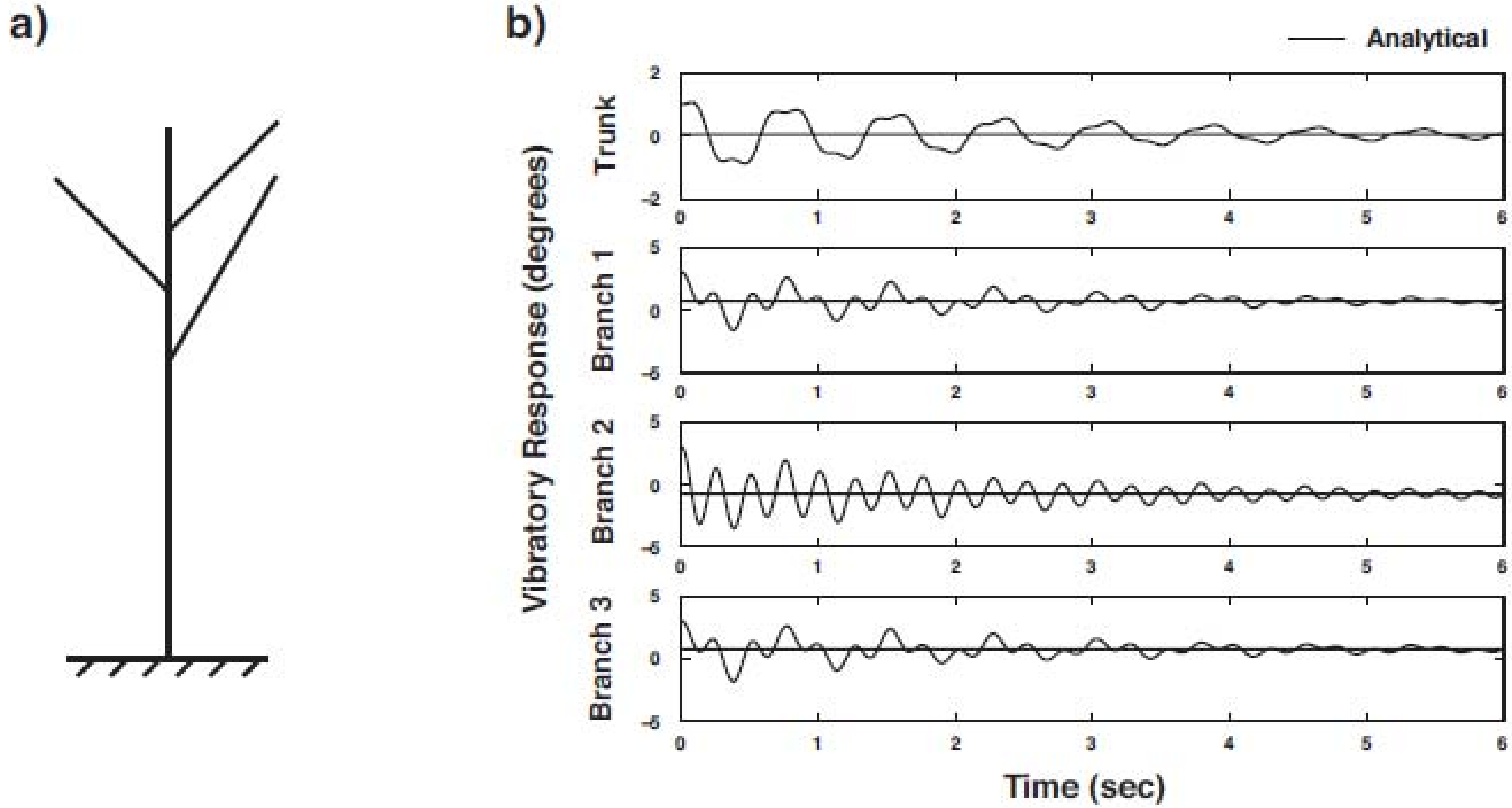
Small amplitude response for asymmetric 2-branch case

Large amplitude response for asymmetric 2-branch case



Analytical solution breaks down – spectra based on numerical solution

Small amplitude response for asymmetric 3-branch case



Conclusions

Strengths of this approach are that it correctly incorporates the necessary physics, it is easy to implement and interpret, and it is computationally fast.

Still needs third dimension but promising for further exploration into more complex architectures.

Oh yes, and need to add wind.

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Questions ?