Damping by branching
A bio-inspiration from trees

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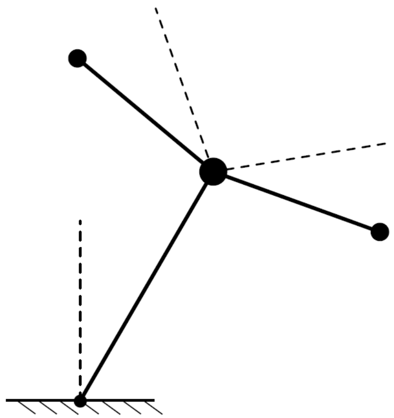

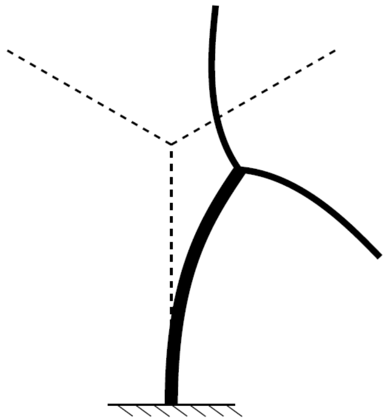

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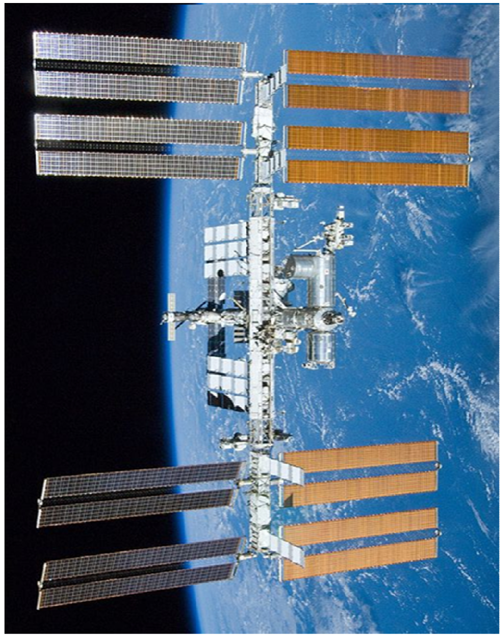
Recently published in the journal of
Bioinspiration & Biomimetics - IOP

DGA

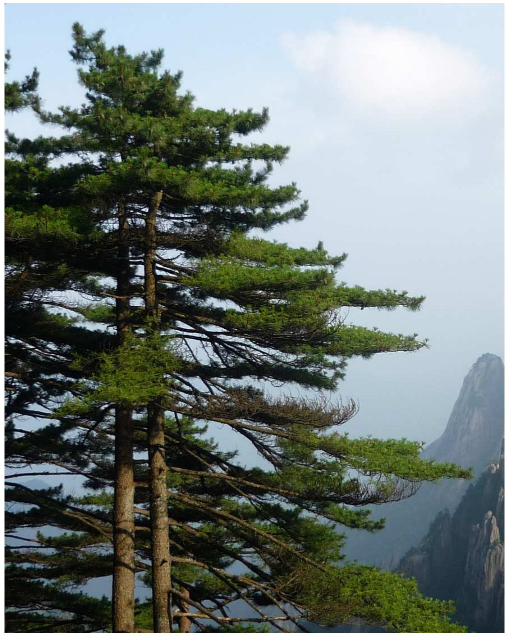
Large-amplitude vibrations



ISS

Damping

?



Trees

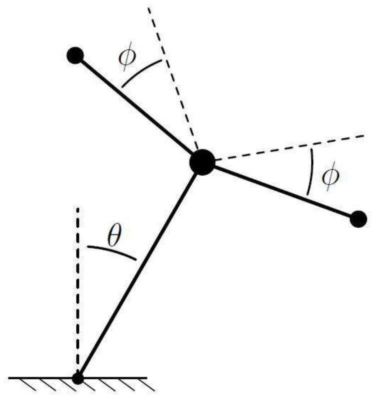
“**branching** [...] **damps** natural frequencies of **vibration**”

K. J. **Niklas** (1992) - Plant Biomechanics

Branching?

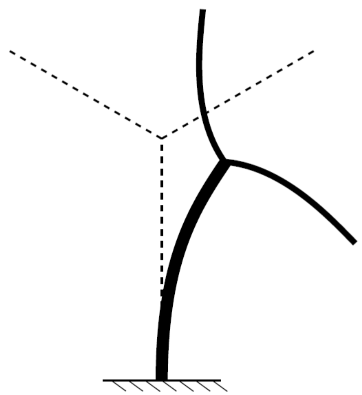
I – Lumped-parameter branched model

- Conservative dynamics
- Damping

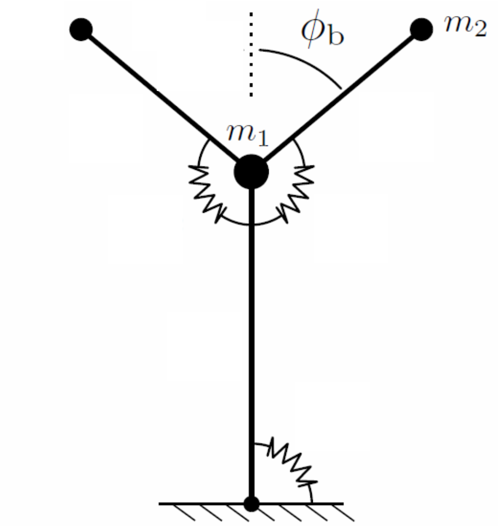


II – Flexible-beam model

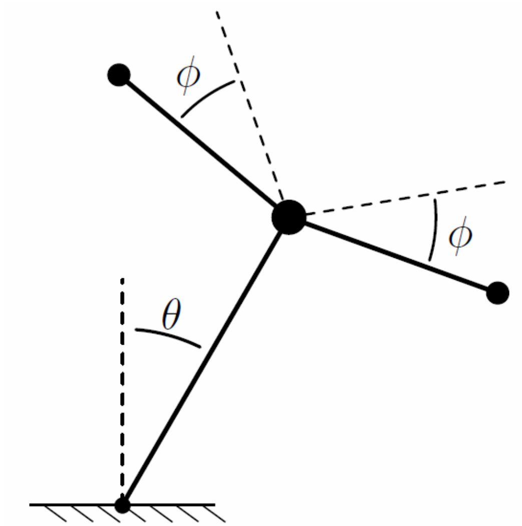
- CASTEM
- 'Pasapas' procedure with Newmark scheme



Lumped-parameter model

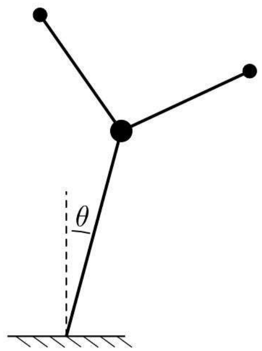


Geometry

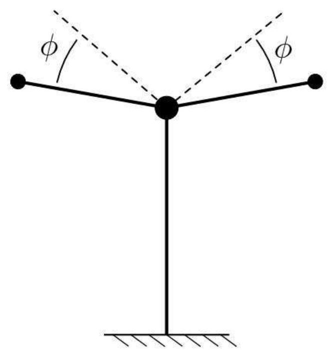


Motion

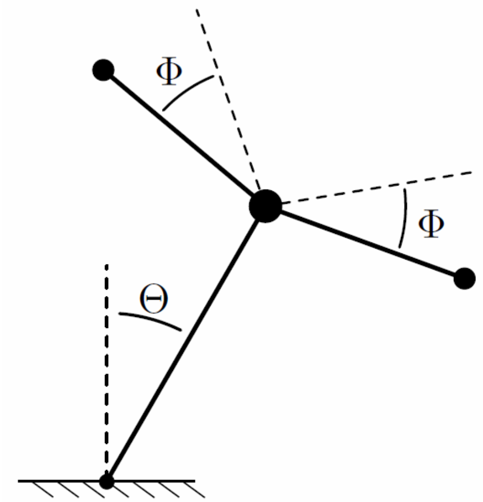
Trunk mode



Branch mode



Equations



- Branching angle ϕ_{b}

- Frequency ratio $\Omega = \dfrac{\omega_{\mathrm{Branch}}}{\omega_{\mathrm{Trunk}}}$

- Mass ratio $\Gamma = \dfrac{\gamma_{\mathrm{Branch}}}{\gamma_{\mathrm{Trunk}}}$

$$\ddot{\Theta} + \quad \Theta = 2\Gamma\left[\dot{\Theta}\dot{\Phi}\sin(\phi_{\mathrm{b}}+\Phi) - \ddot{\Theta}\left(\cos(\phi_{\mathrm{b}}+\Phi) - \cos\phi_{\mathrm{b}}\right)\right]$$

$$\ddot{\Phi} + \Omega^2\Phi = -\dot{\Theta}^2\sin(\phi_{\mathrm{b}}+\Phi)$$

Geometric nonlinearities

Method

Initial energy

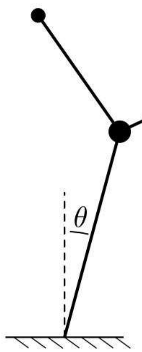
E_0

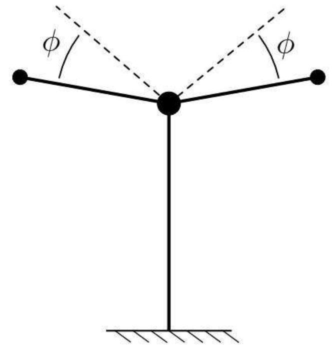
Trunk mode

Energy exchanges

Geometric nonlinearities

Branch mode



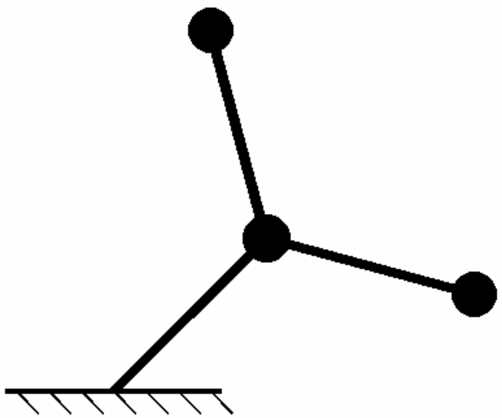


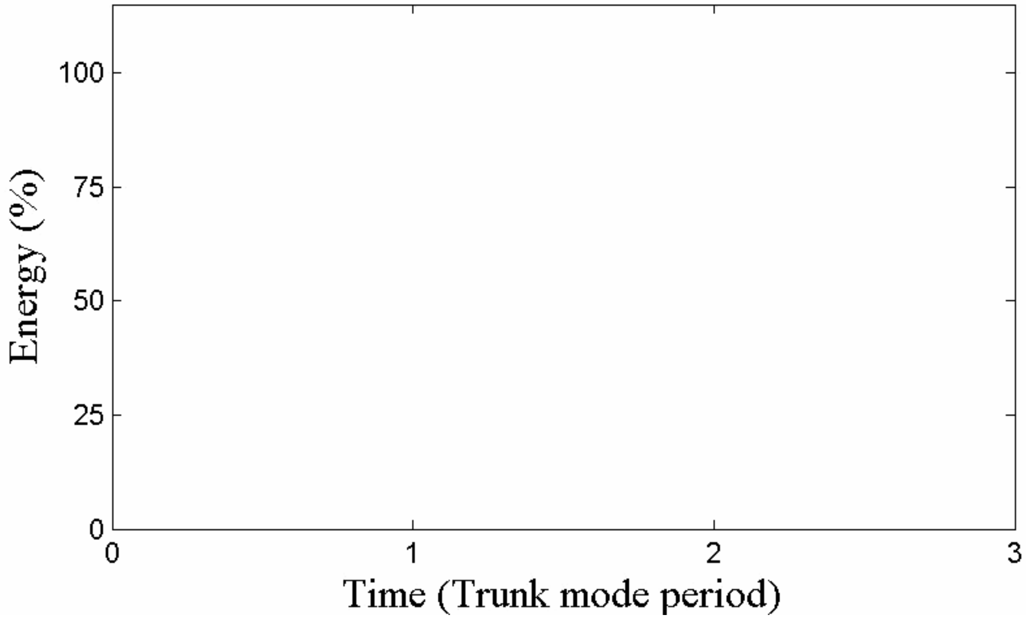
Free dynamics

Numerical and analytical analyses

Modal energy exchanges

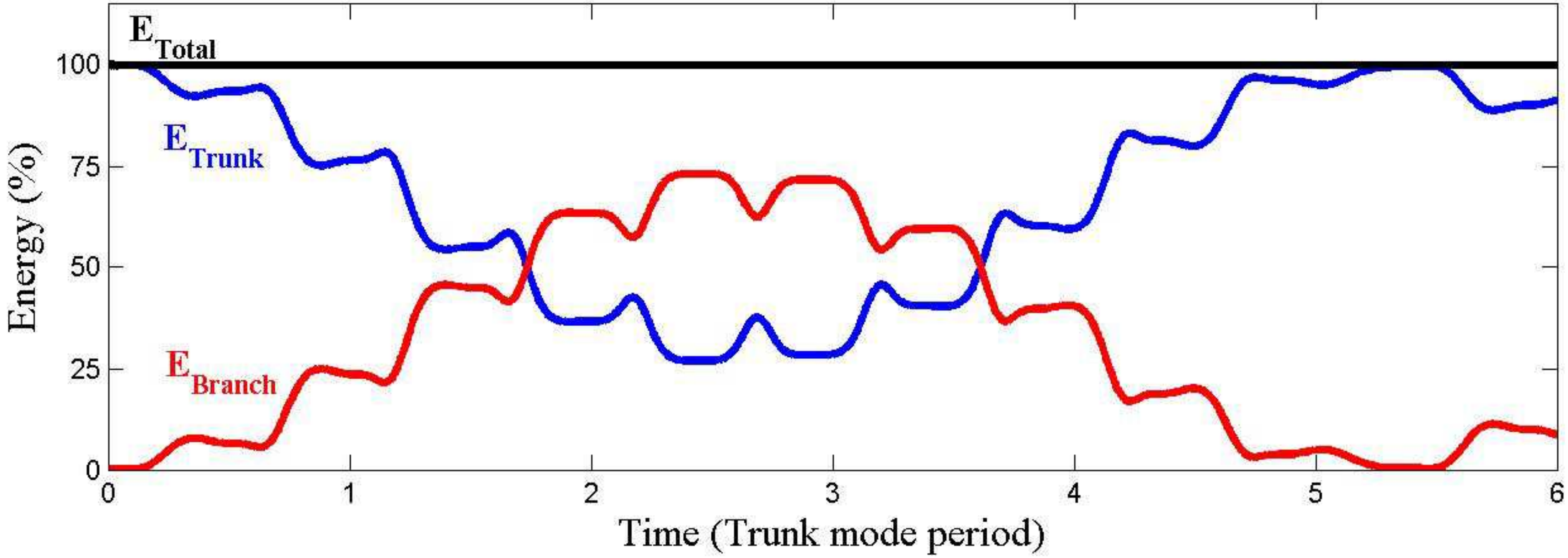
A typical example





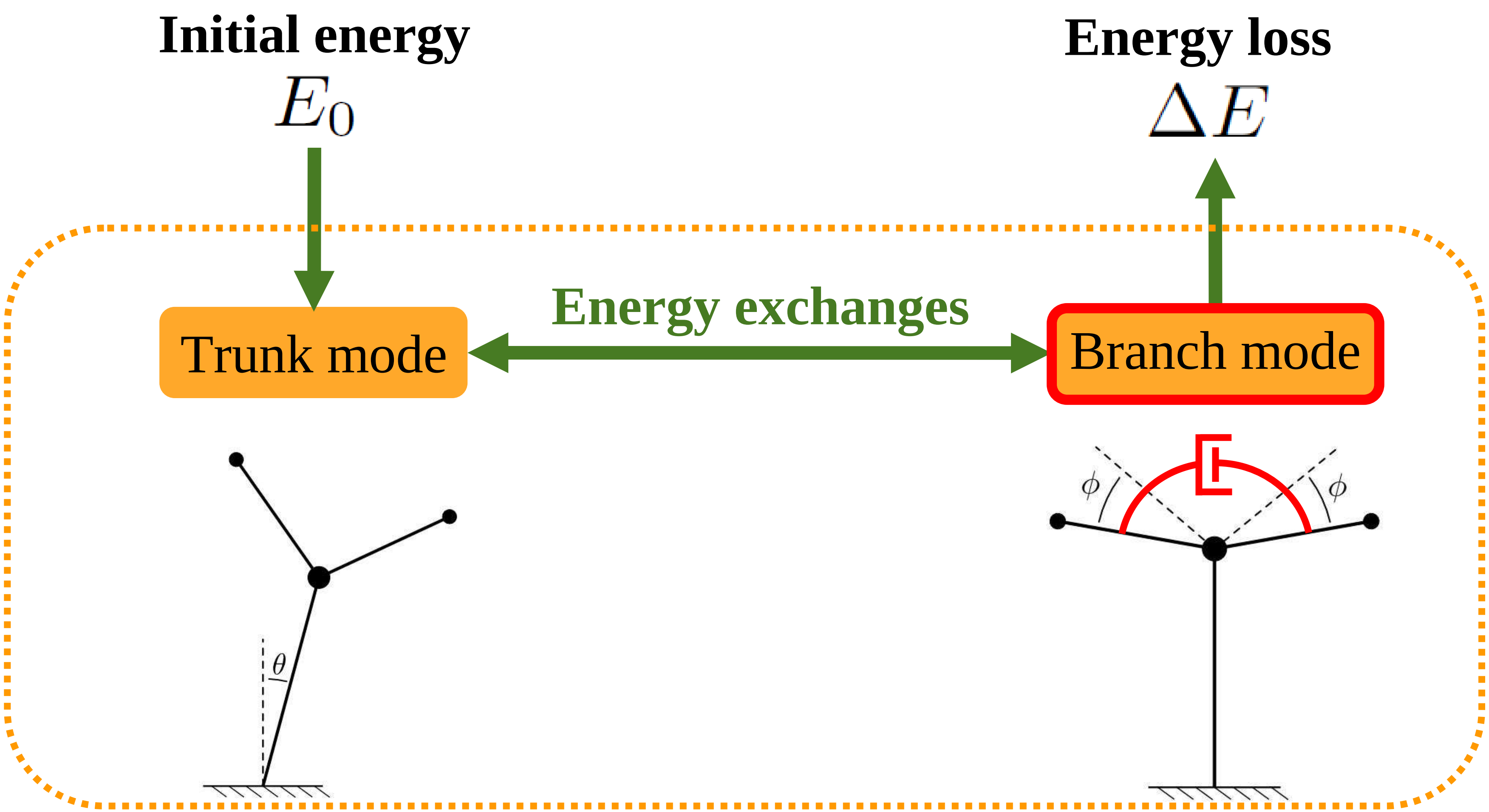
Modal energy exchanges

A typical example

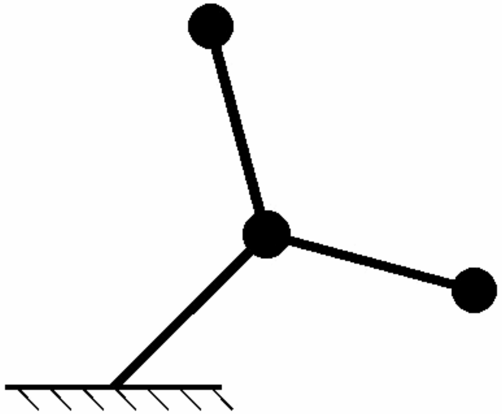


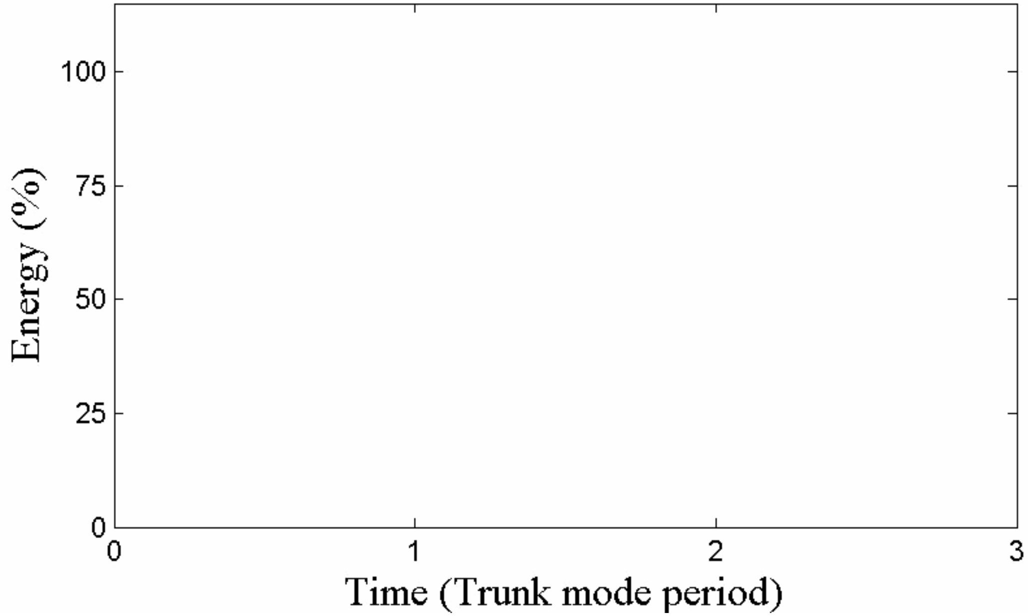
Conservative energy exchanges

Damping


Initial energy
E_0
Energy loss
ΔE
Energy exchanges
Trunk mode
Branch mode
θ
ϕ
ϕ

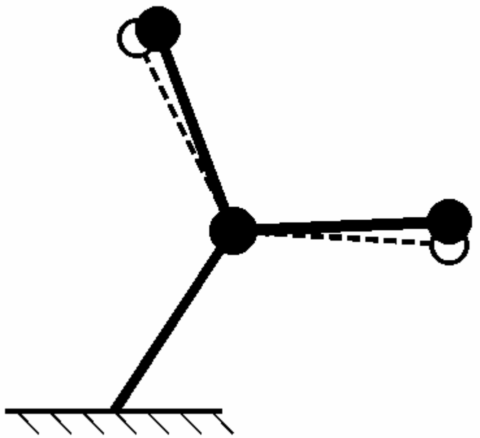
Effective damping mechanism

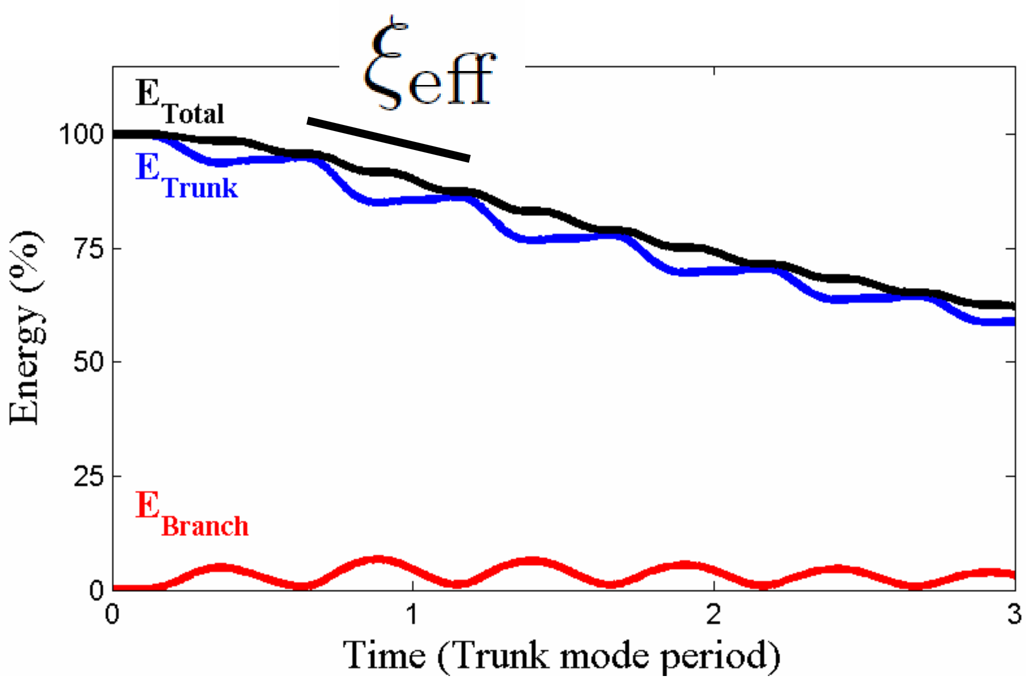




The structure is **effectively damped**

Effective damping mechanism

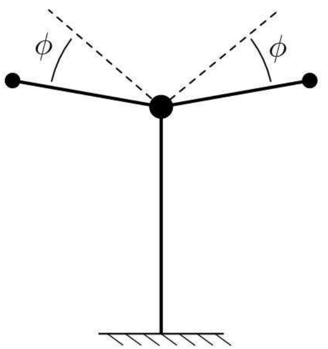




The structure is **effectively damped**

Analytical analysis

Small-angles approximation



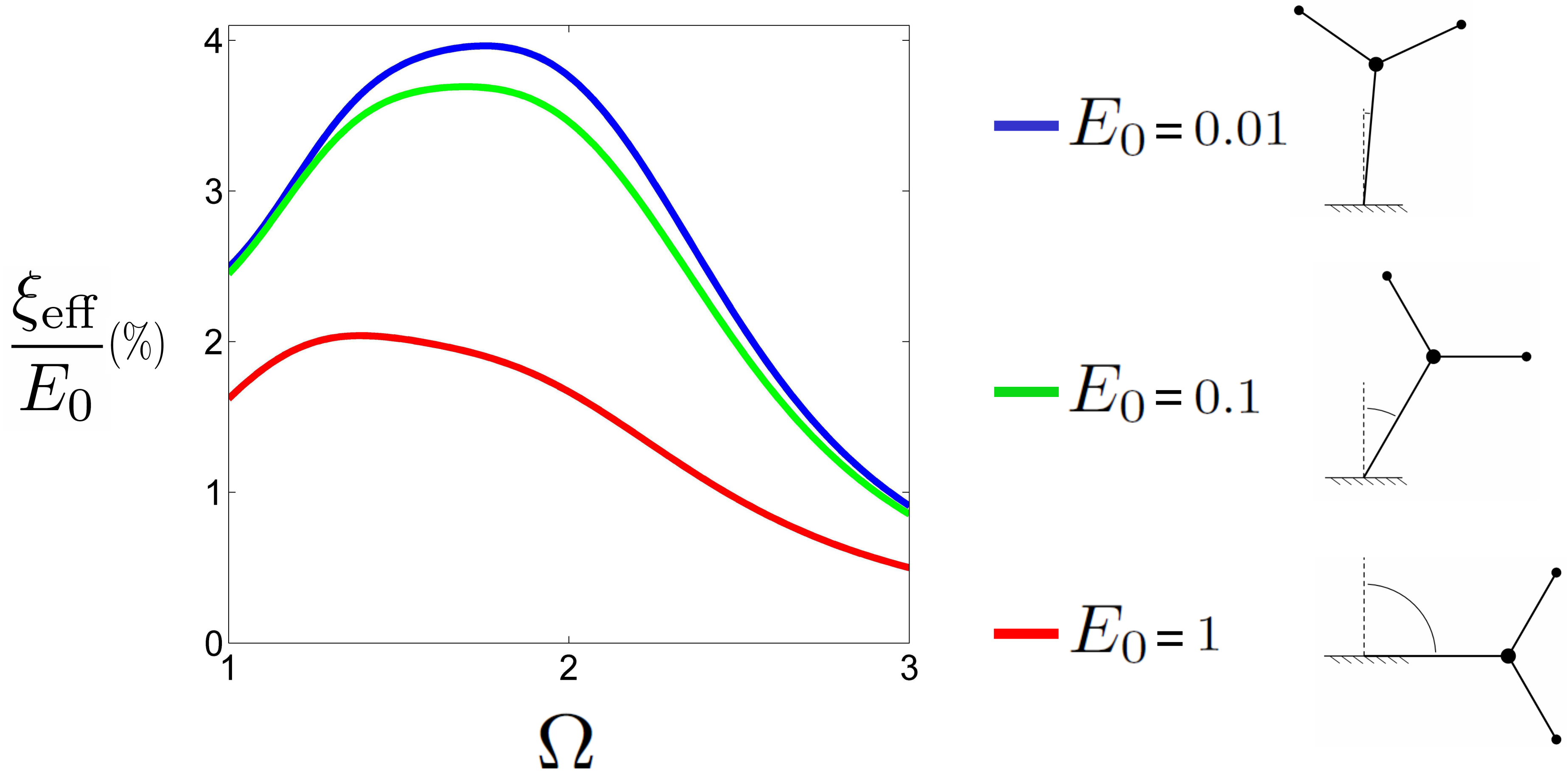
$$\ddot{\Phi} + \Omega^2 \Phi = E_0 \sin \phi_b (\cos 2\tau - 1)$$

1:2 Internal resonance

$$\Omega = 2$$

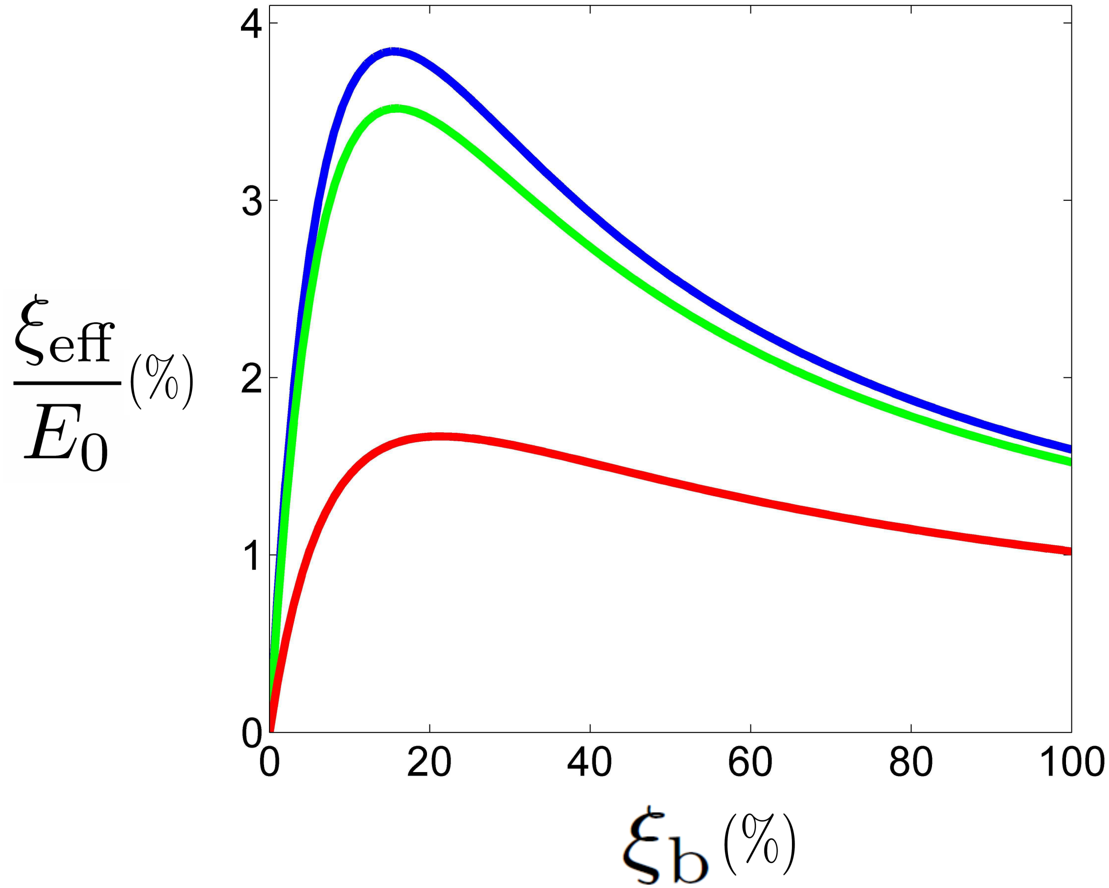
Parameter dependency

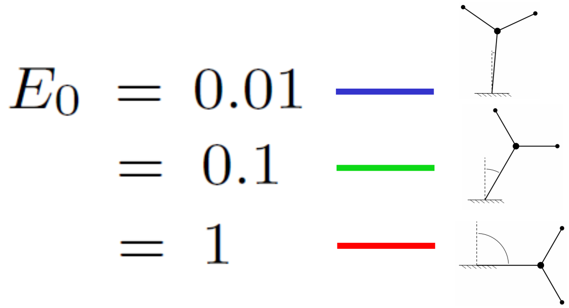
Frequency ratio

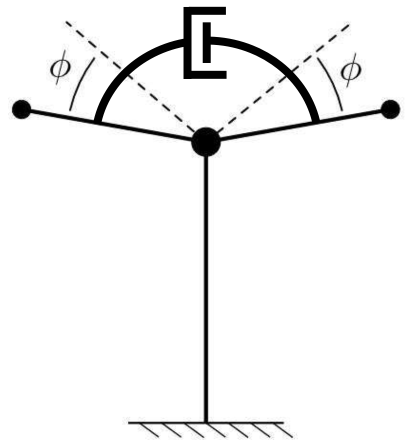


Parameter dependency

Branch mode damping

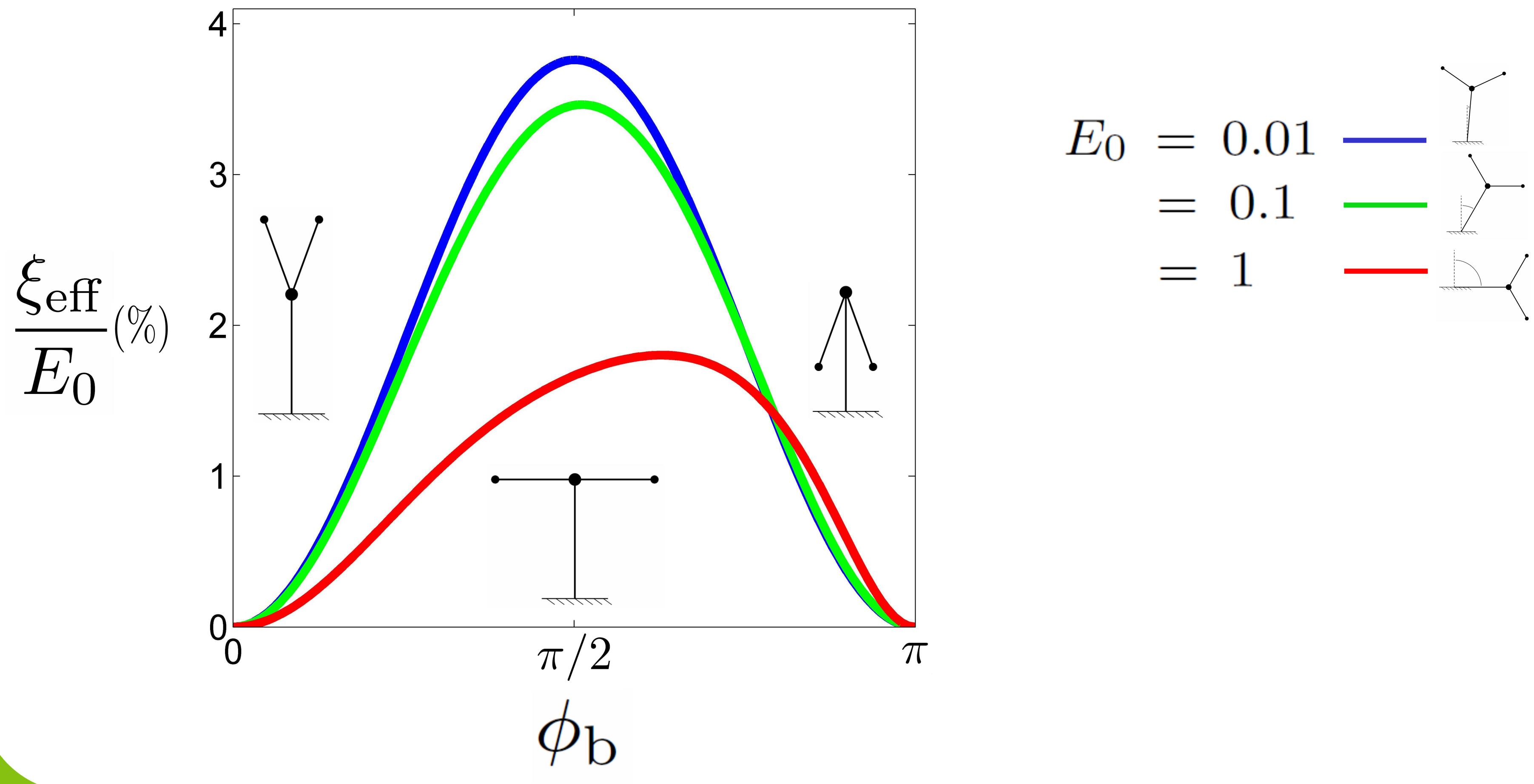






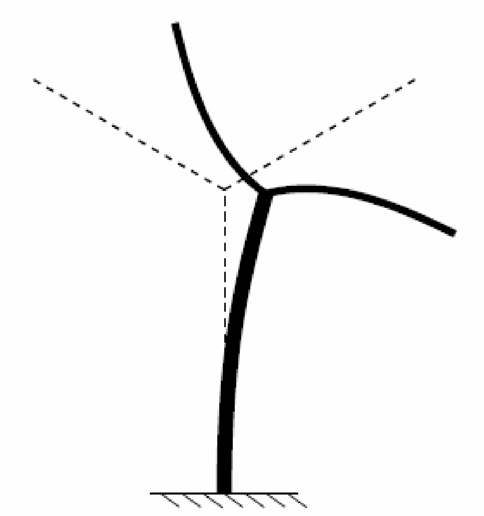
Parameter dependency

Branching angle

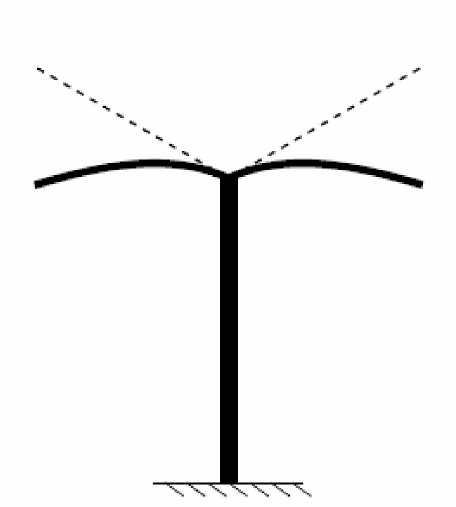


Flexible-beam model in CASTEM

Modal analysis



Trunk mode



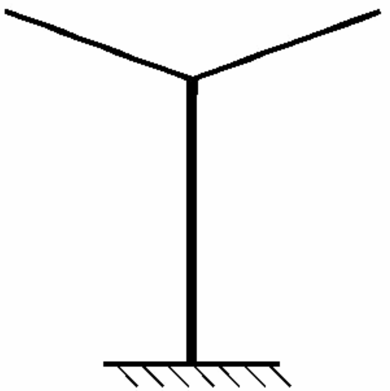
Branch mode

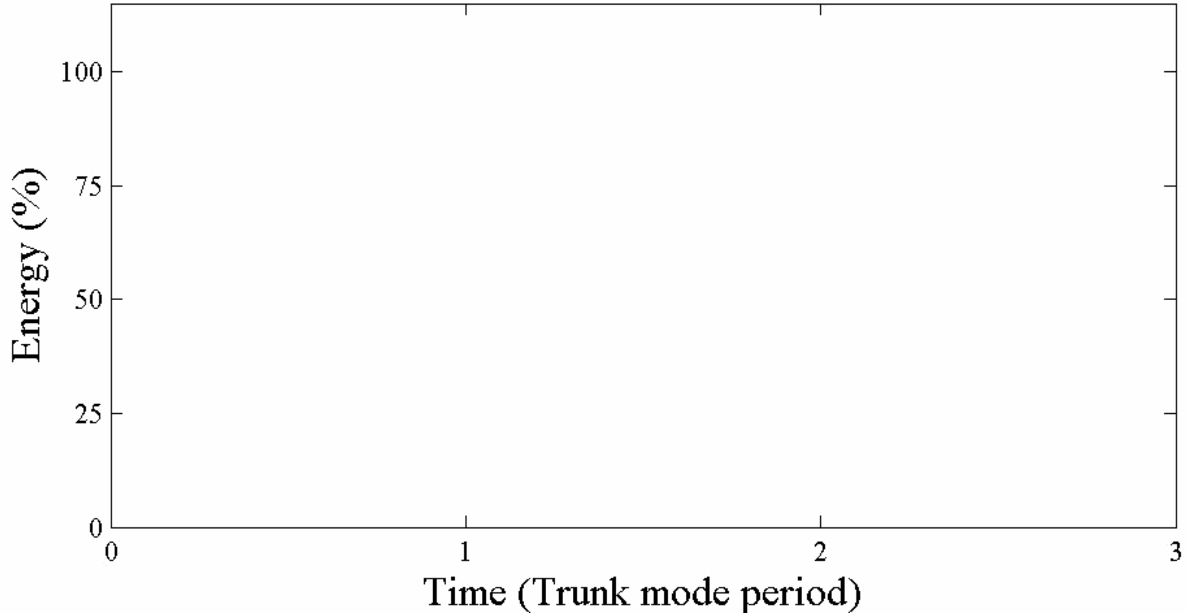
Full dynamics!

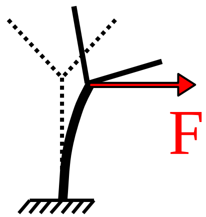
Other modes

Large-amplitudes computations

'Pasapas' procedure



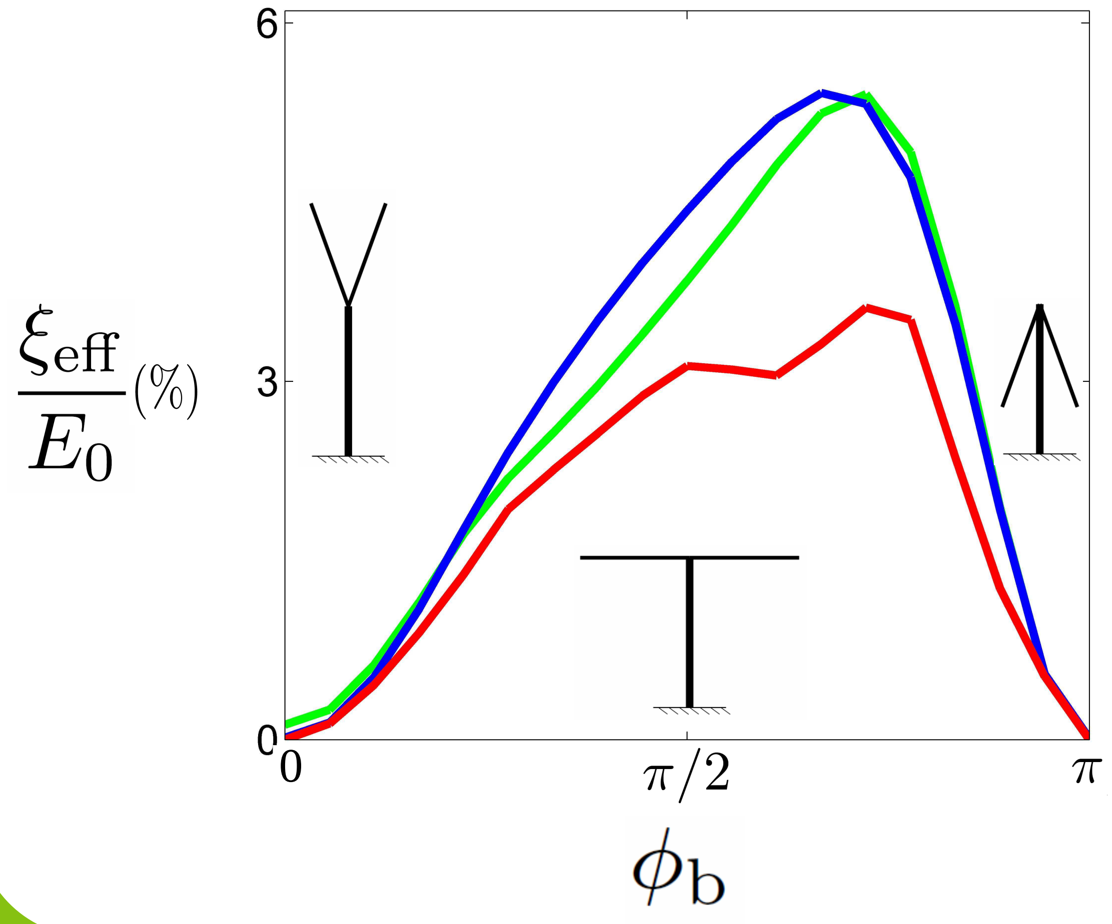




Pull & Release

Parameter dependency

Branching angle

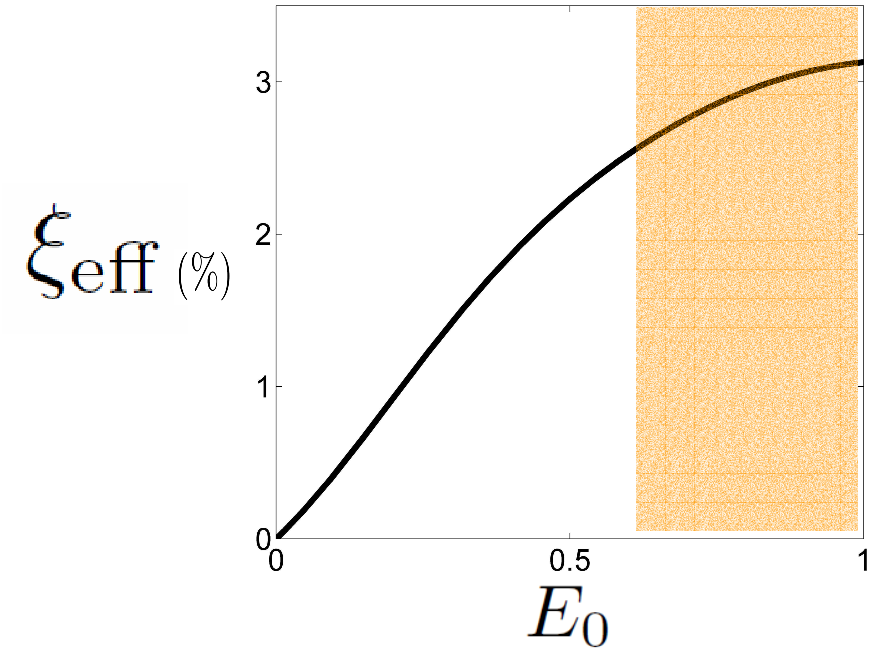


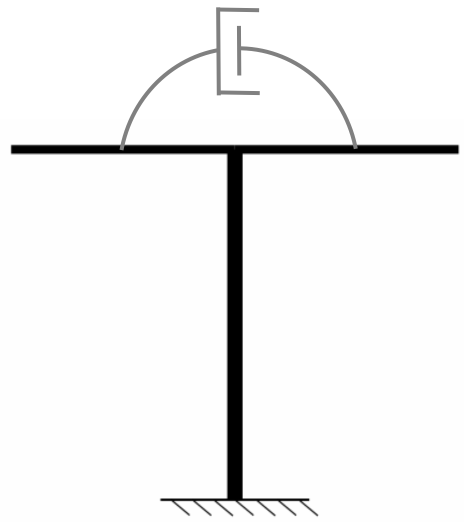
$E_0 = 0.01$
$= 0.1$
$= 1$

Same basic mechanism

Damping by branching

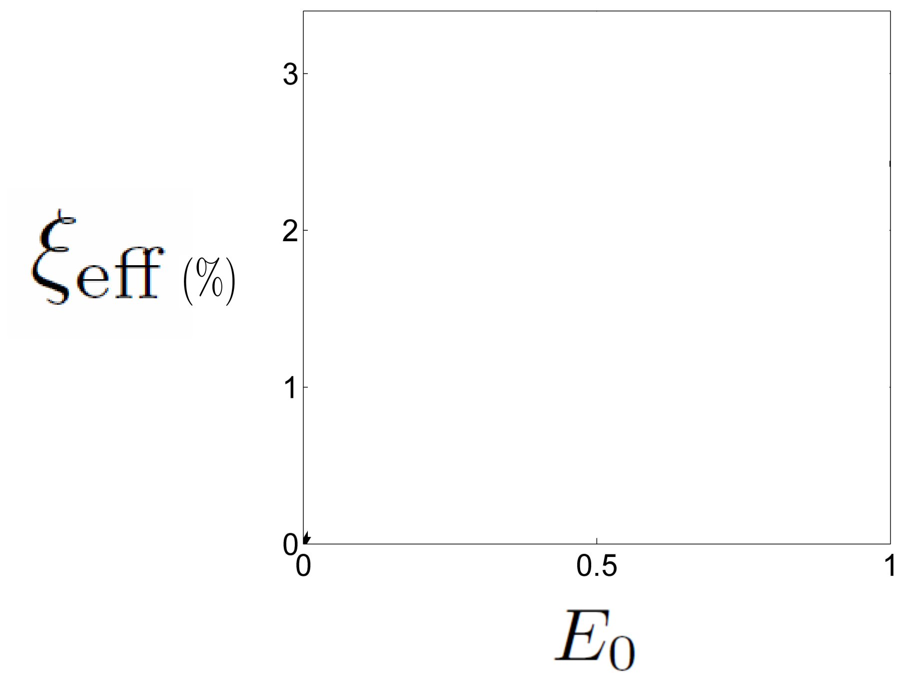
Increases with the energy

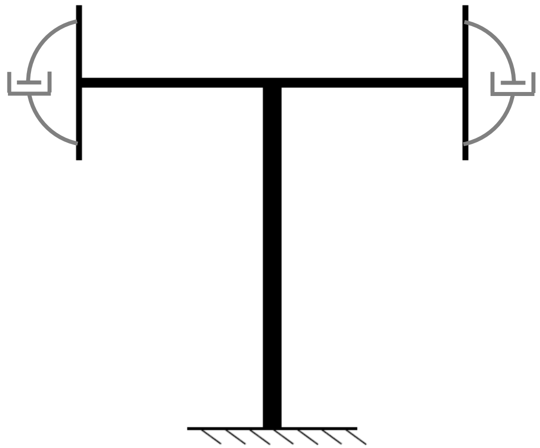




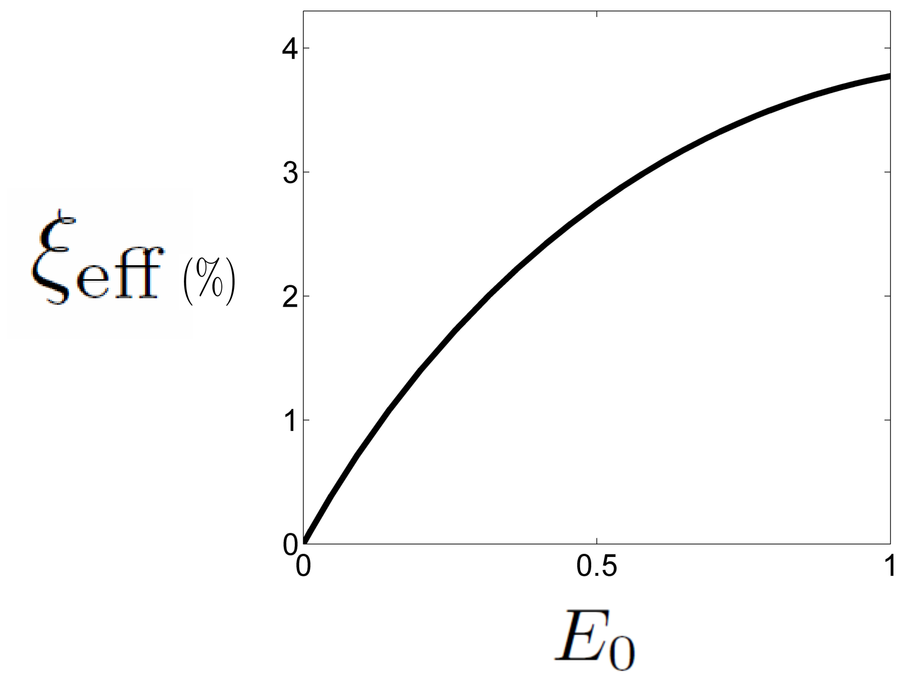
About **30%** of the initial energy is dissipated for large initial amplitudes after only one period

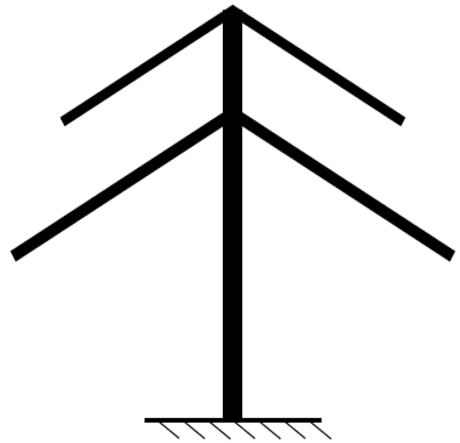
Needs few ingredients





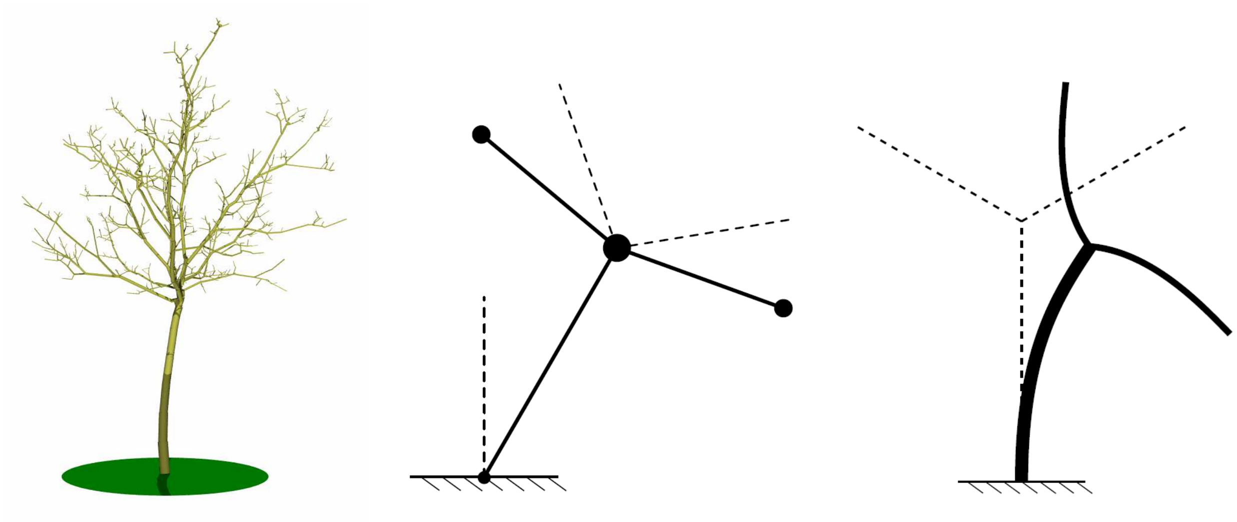
Branch as you wish





Damping by branching

A new hint for the design of slender and flexible structures



A robust bio-inspired mechanism to damp large-amplitude motions

Based on a 1:2 internal resonance