Effectiveness of Using Dampers on Cables and Cross-Ties Between Cables

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Wind Induced Vibration of Cable Stay Bridges Workshop
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Introduction

- External dampers and crossties are frequently specified for mitigation of wind-induced stay-cable vibrations
- Various types of dampers are used separately or in combination with crossties
- Behavior and mitigation effectiveness of damper/crosstie combinations are not well established

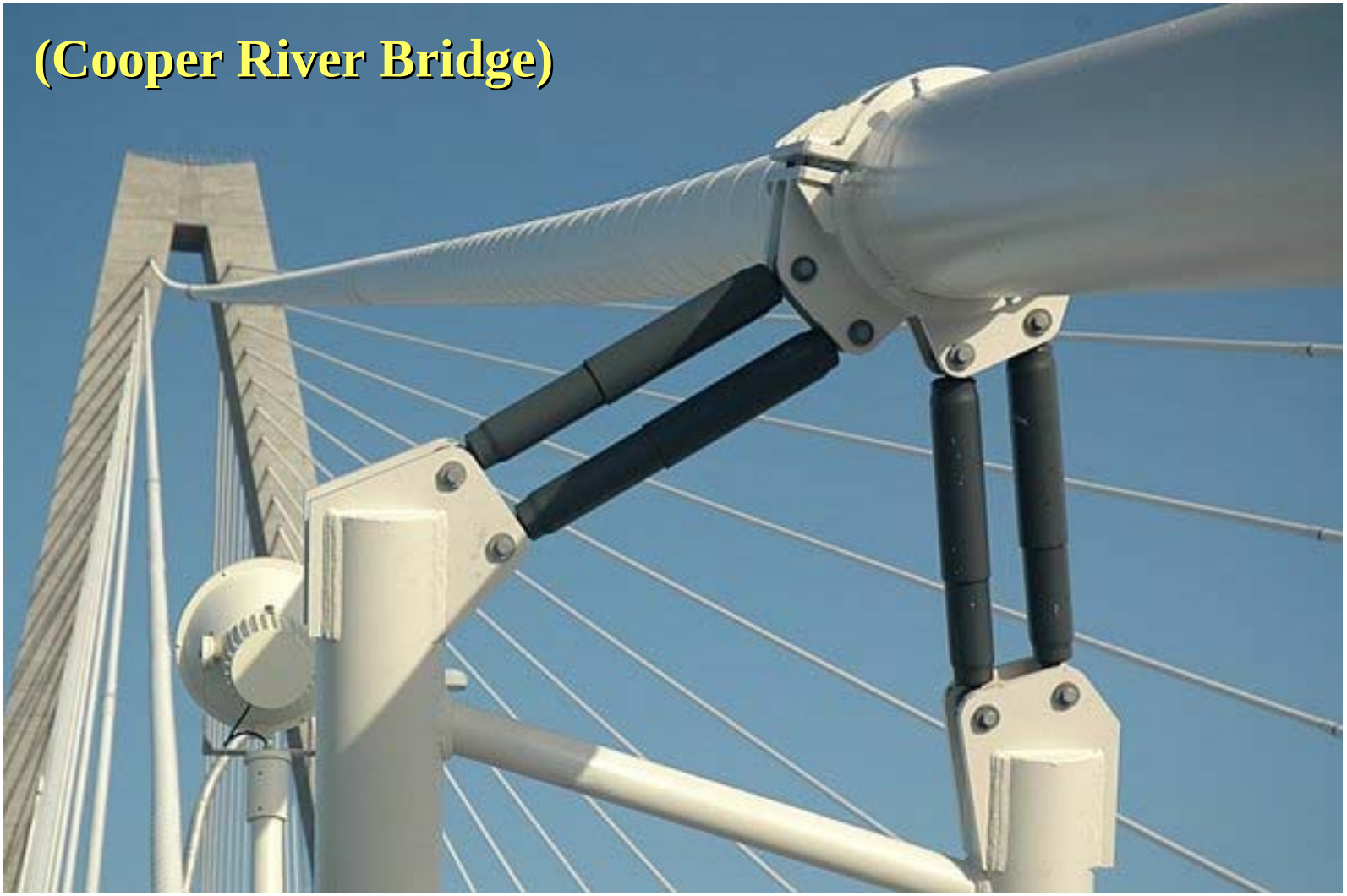
Objective

To assess quantitatively, via finite element simulations, the effectiveness of alternative strategies, involving external dampers and crossties, for mitigation of stay cable vibrations

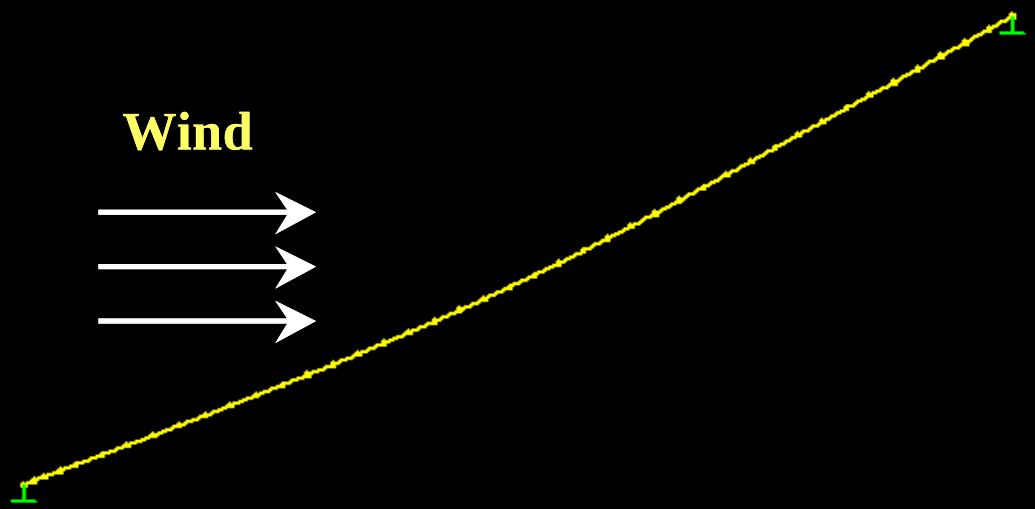
Cooper River Bridge

Stay Cables with Dampers

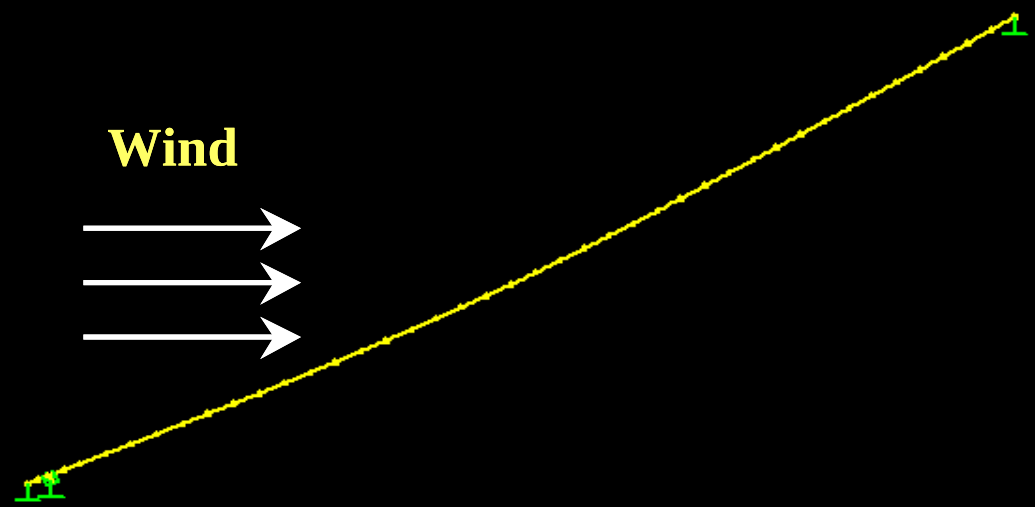
External Viscous Dampers



Finite Element Simulation



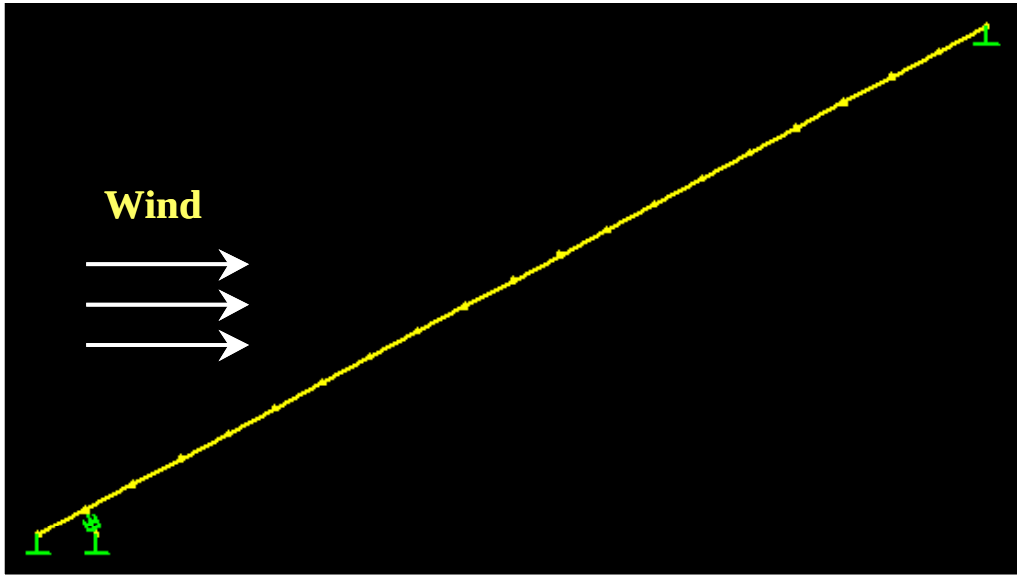
← A cable without a damper



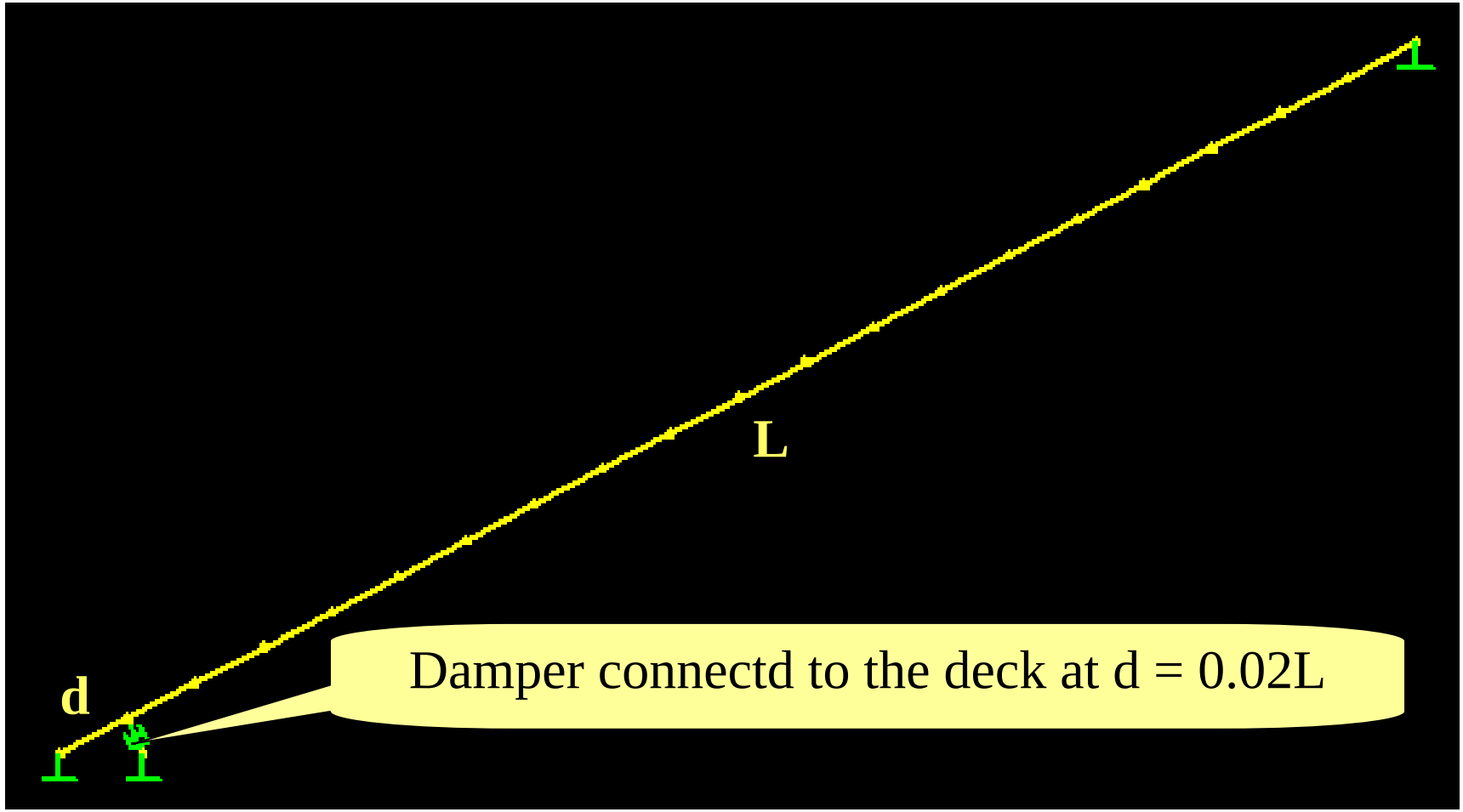
A cable with a damper →

Single Cables

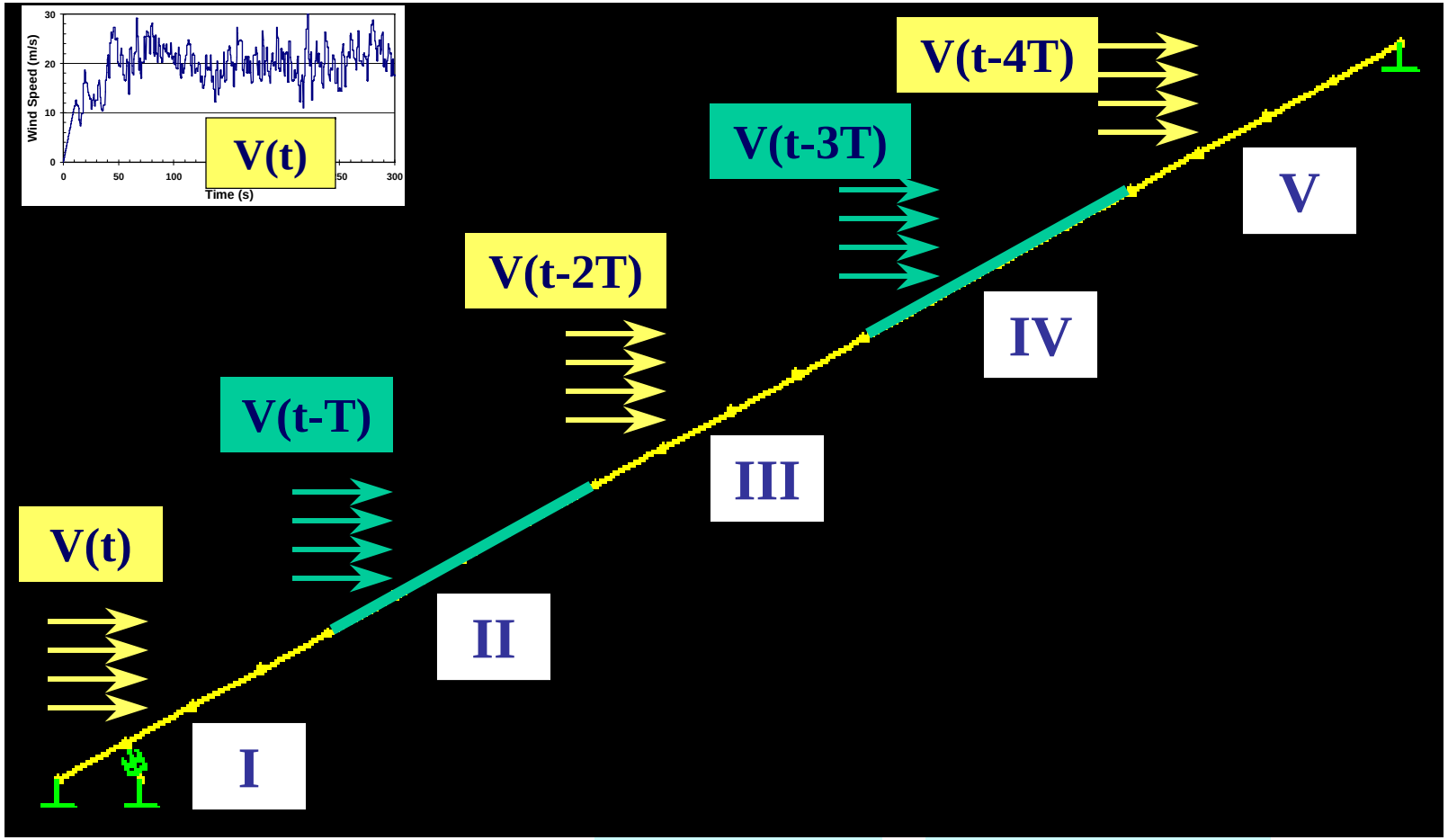
with a Viscous Damper



Single Cable with a Viscous Damper



Wind Loading Scheme

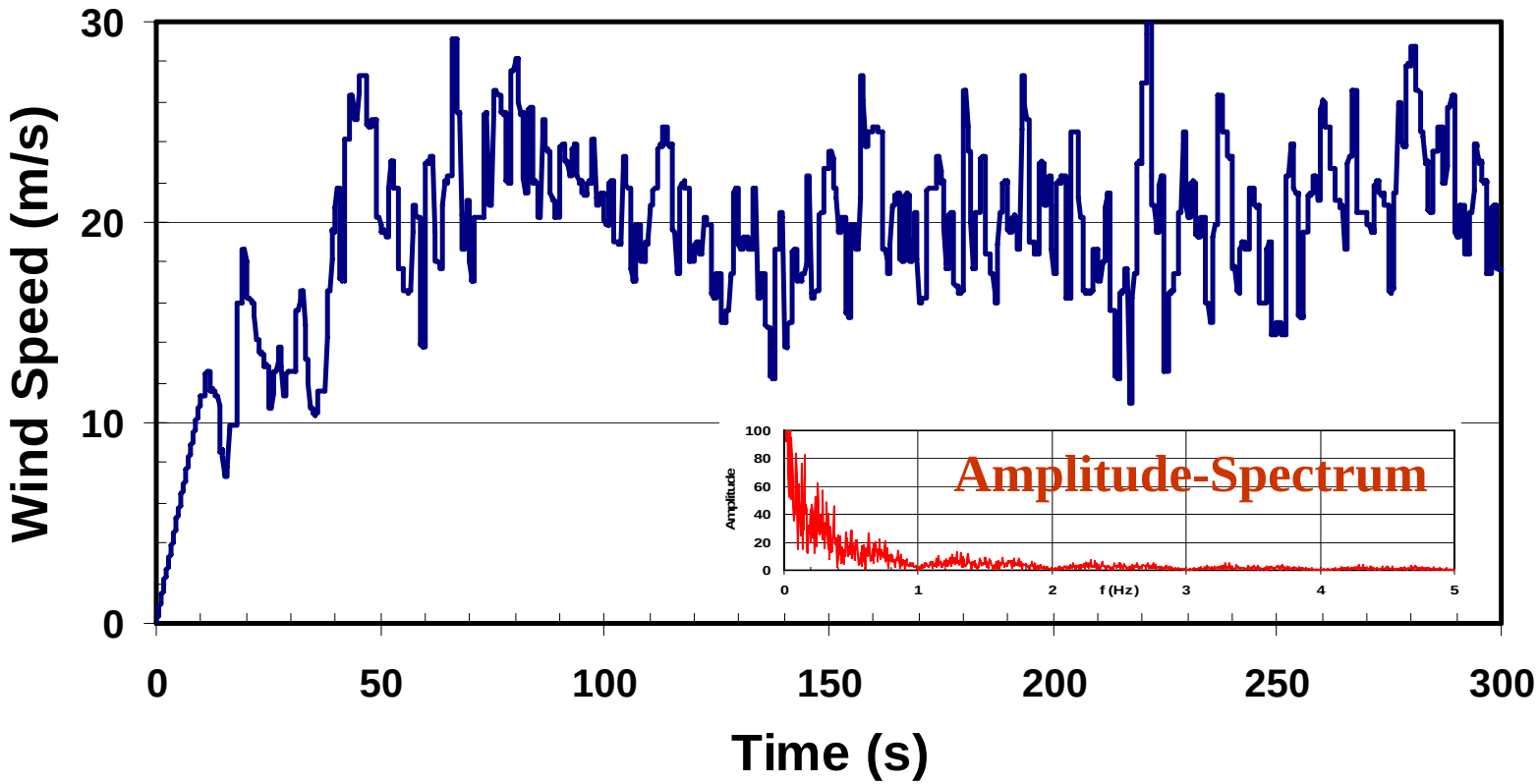


Δx

$T = \Delta x / V_{avg}$

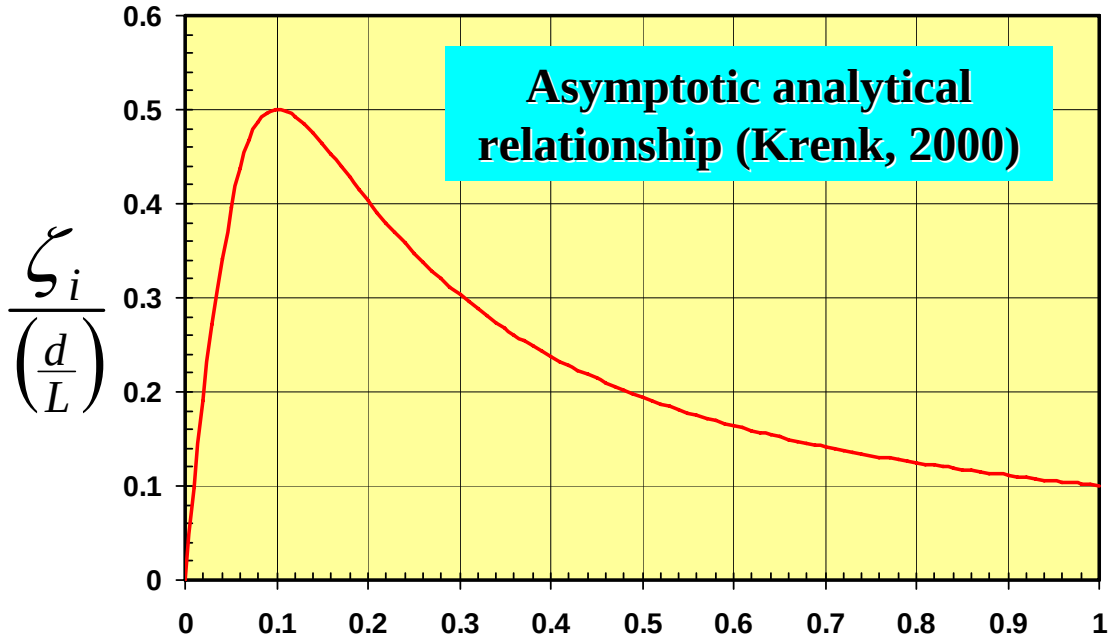
Wind Profile Used

- **Based on 5-min wind speed record**
- **Scaled up to 3-s peak gust speed of 30 m/s**
- **Drag force formula used**



Determination of Damper Coefficient, C

"Universal" Damping Curve



$$\kappa \equiv \frac{C}{mL\omega_1} i \left(\frac{d}{L}\right)$$

C: damper coefficient

L: cable length

d: damper distance from the deck

m: cable mass/length

ω_1: first-mode natural frequency

ζ: modal damping ratio

i : mode number

At optimum,
ζ_i/(d/L) = 0.5 and κ = 0.1

$$C_{i,opt} = \frac{0.1 m L \omega_1}{(i)(d/L)}$$

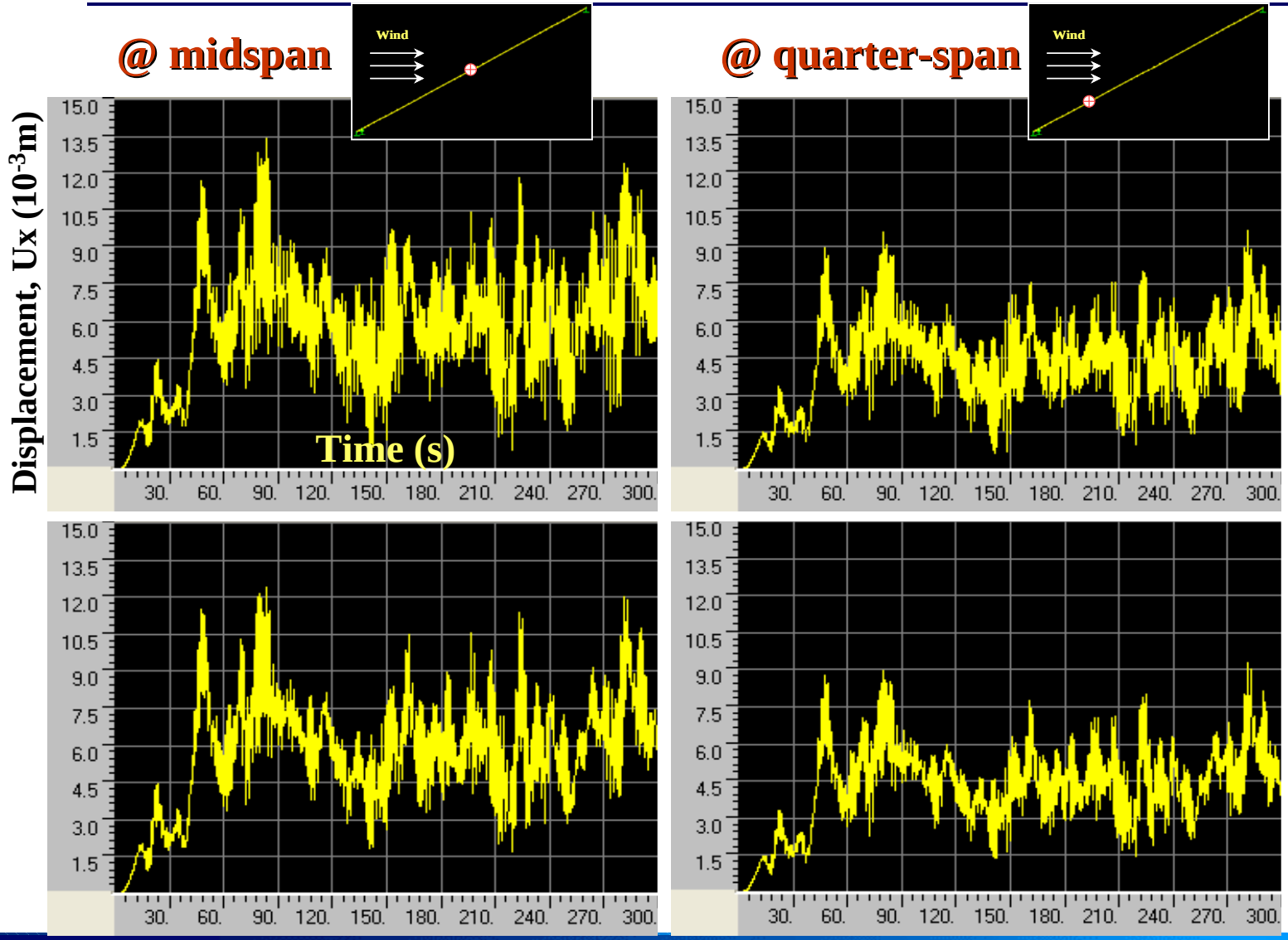
$$\zeta_i = 0.5 \frac{d}{L}$$

(ζ_i = 1% for d/L=0.02)

Sample Displacement Profiles

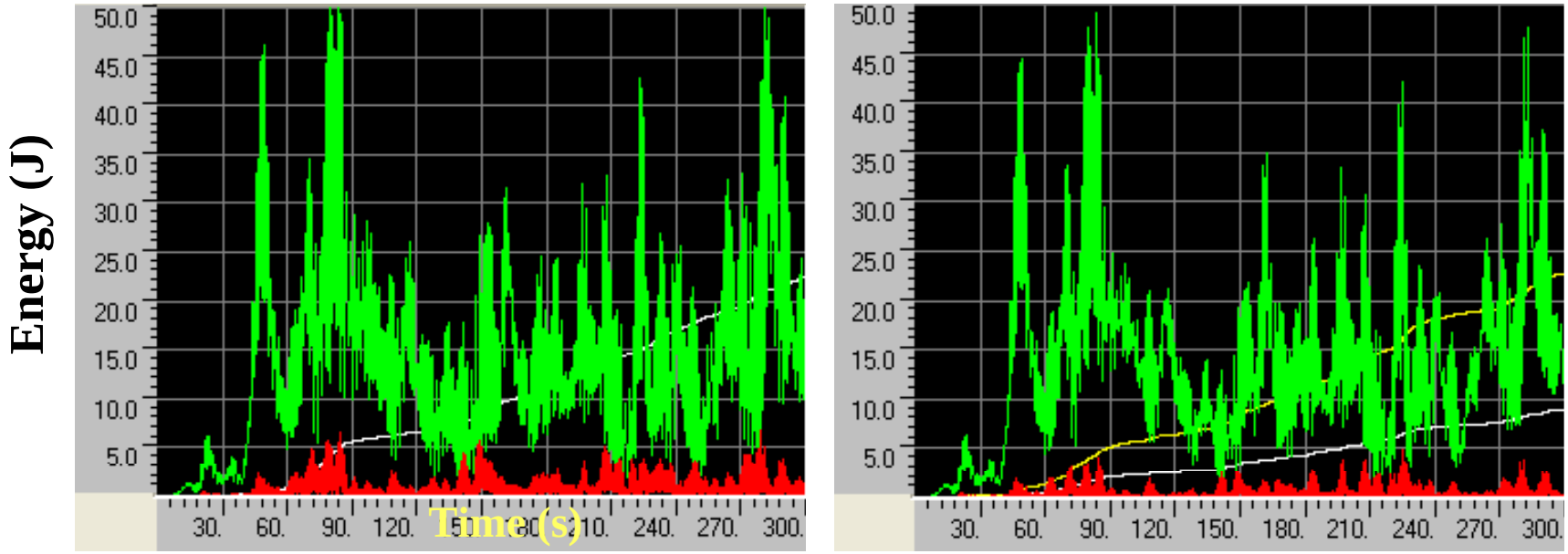
No Damper →

With Damper →



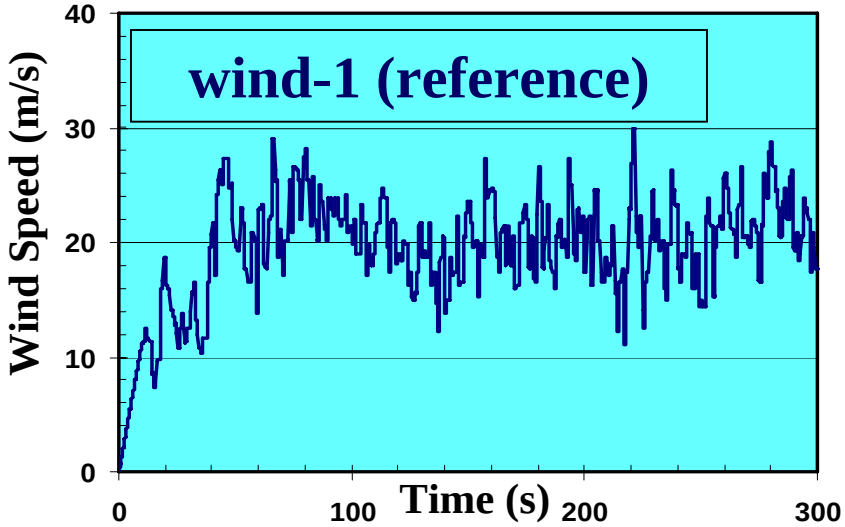
Energy Evolution

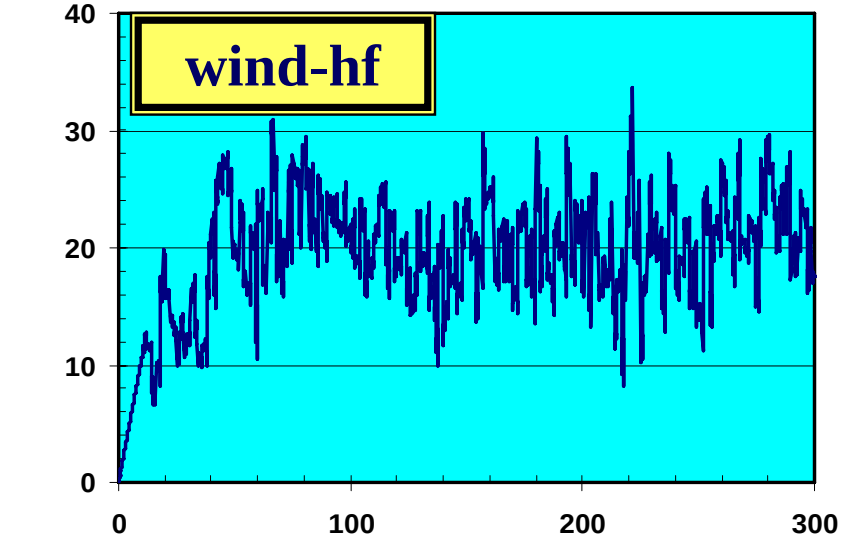
No Damper | **With Damper**



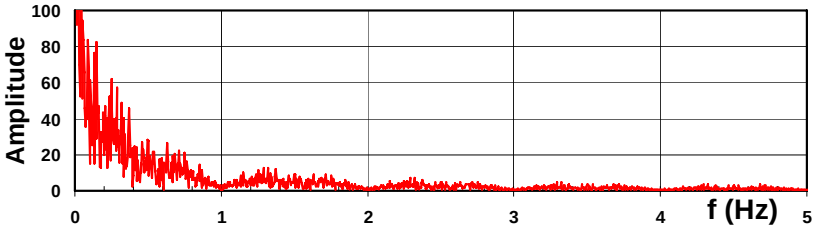
- Potential Energy
- Kinetic Energy
- Dissipation via Modal Damping
- Dissipation via Damper

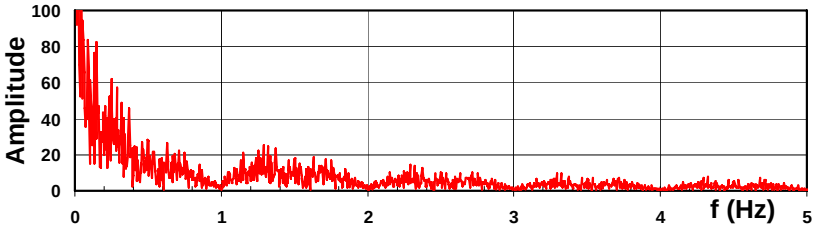
Artificial Wind Profile, "wind-hf"





Amplitude-Spectrum





"wind-hf" = "wind-1" with 2 x Amplitude for f > 1 Hz

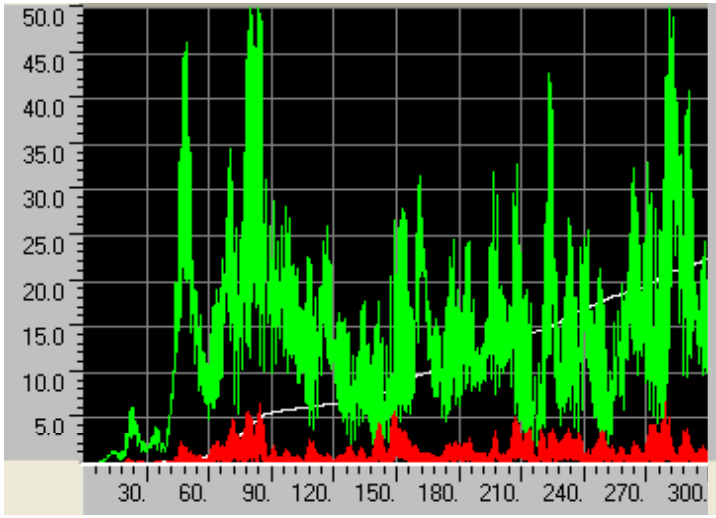
(high-frequency components doubled)

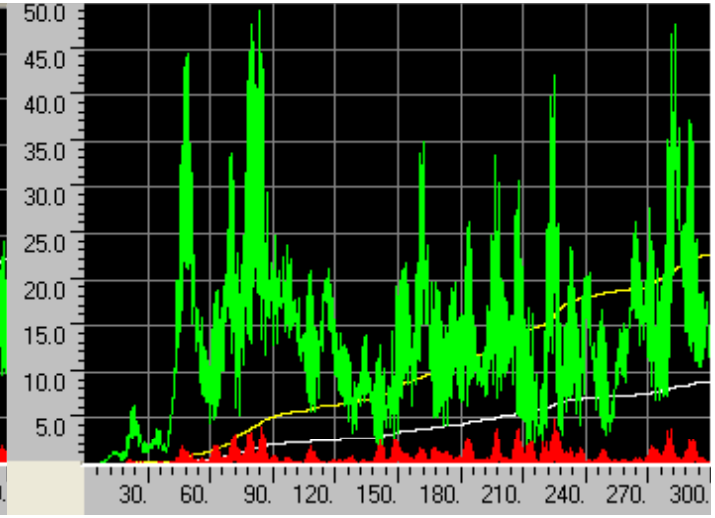
Energy Evolution

- Potential Energy
- Kinetic Energy
- Dissipation via Modal Damping
- Dissipation via Damper

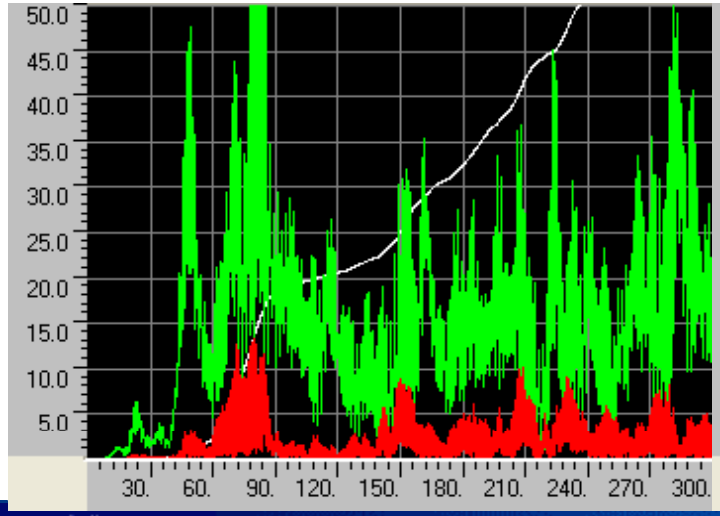
No Damper | **With Damper**

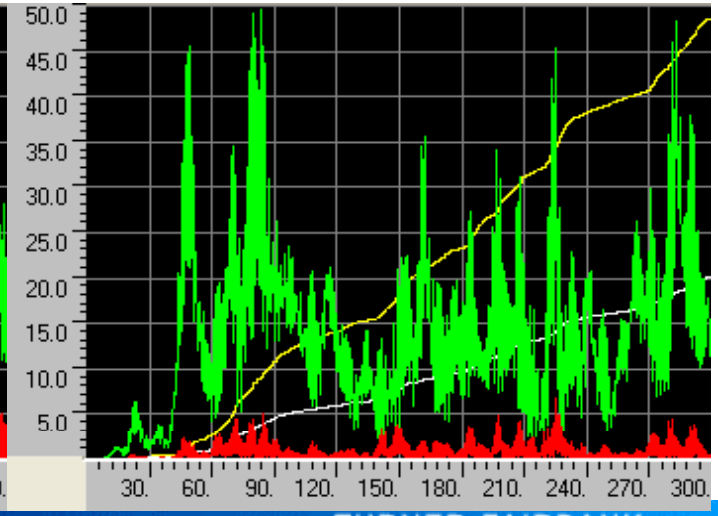
wind-1 →





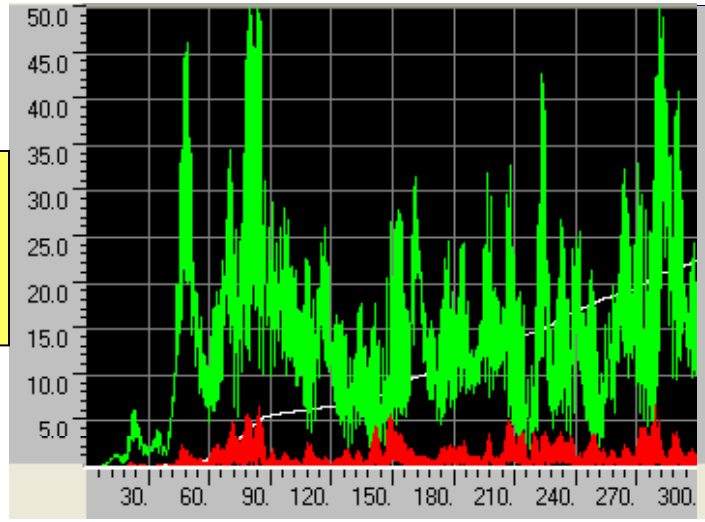
wind-hf →

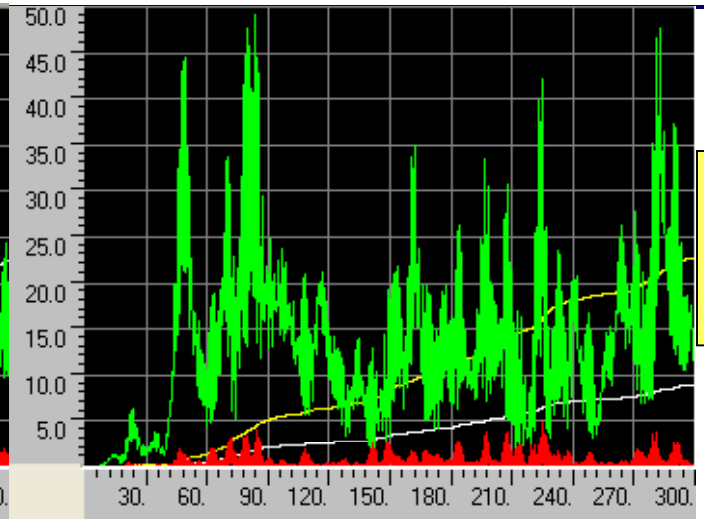




Influence of Damper Coefficient, C

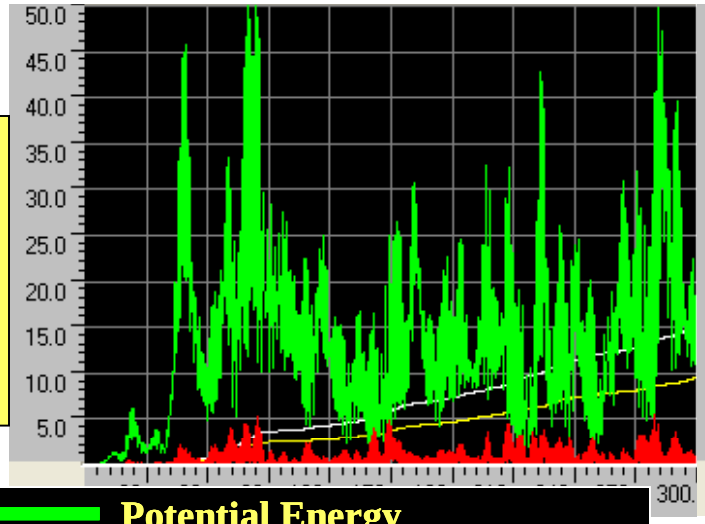
No Damper →

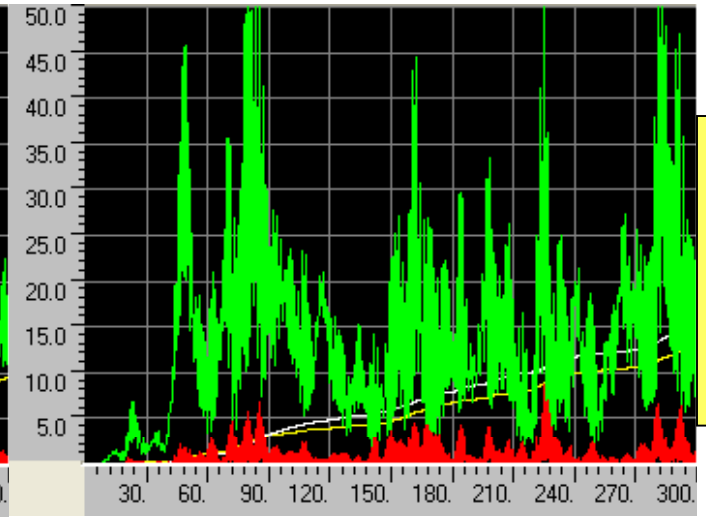




Optimal (Copt) ←

Less than Optimal (0.1Copt) →





Larger than Optimal (10Copt) ←

- Potential Energy
- Kinetic Energy
- Dissipation via Modal Damping
- Dissipation via Damper

Copt = 412 kN-s/m for a Cable with L=157m, D=0.273m, T=4537kN, f_1=0.549Hz, d/L=0.02

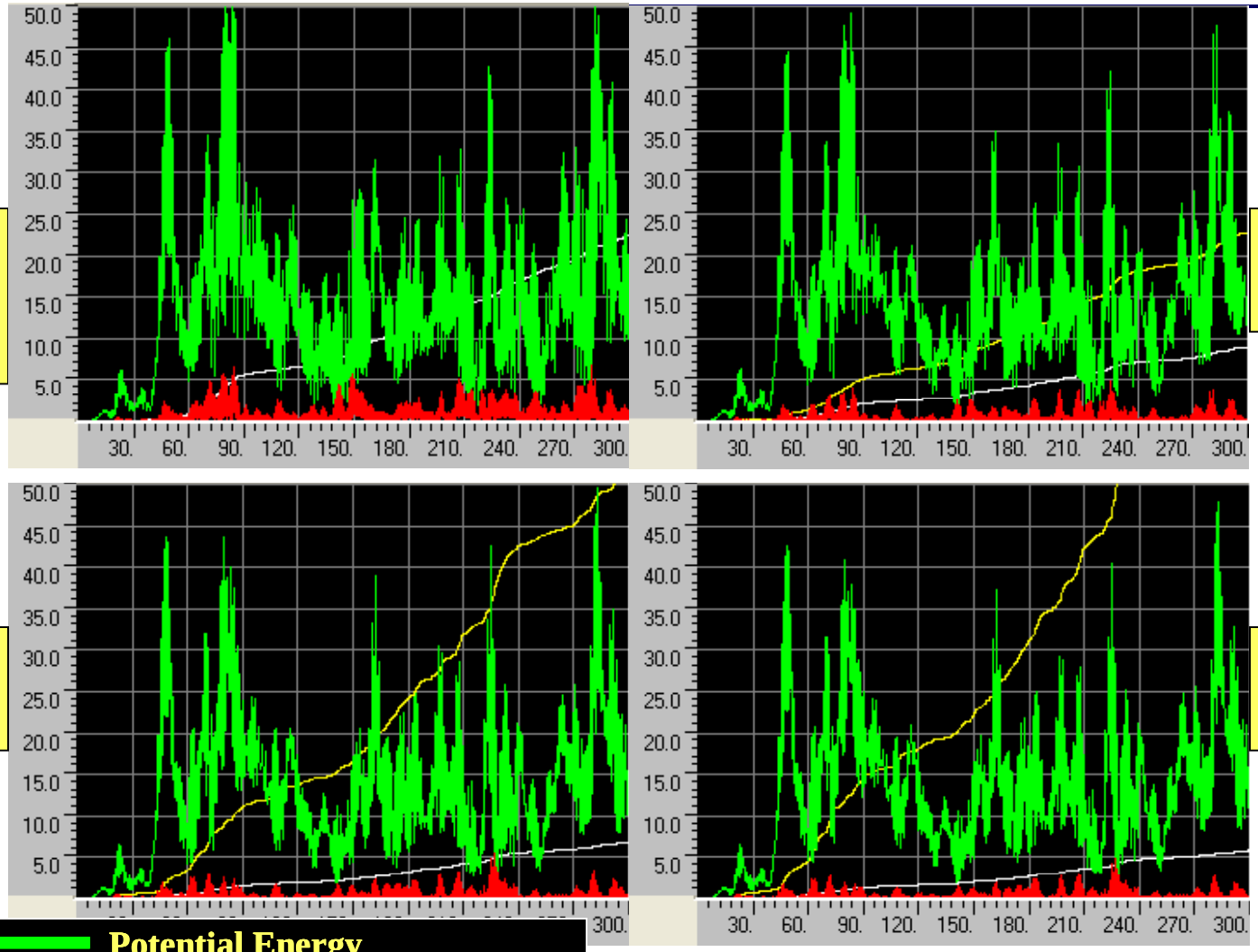
Influence of Damper Location, d/L

No Damper →

d/L=0.02 ←

d/L=0.05 →

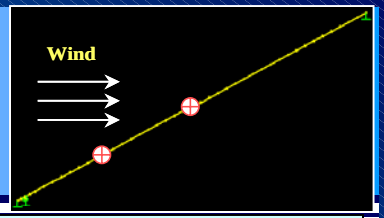
d/L=0.1 ←



- Potential Energy
- Kinetic Energy
- Dissipation via Modal Damping
- Dissipation via Damper

Power Spectral Analysis

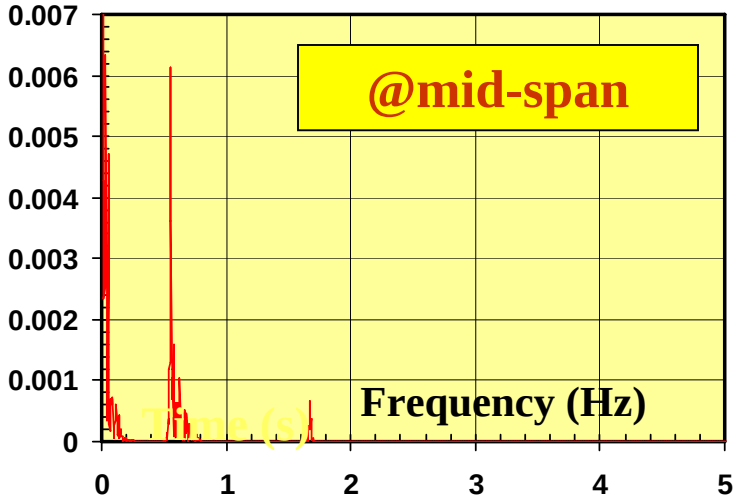
of displacements @ mid- and quarter-span

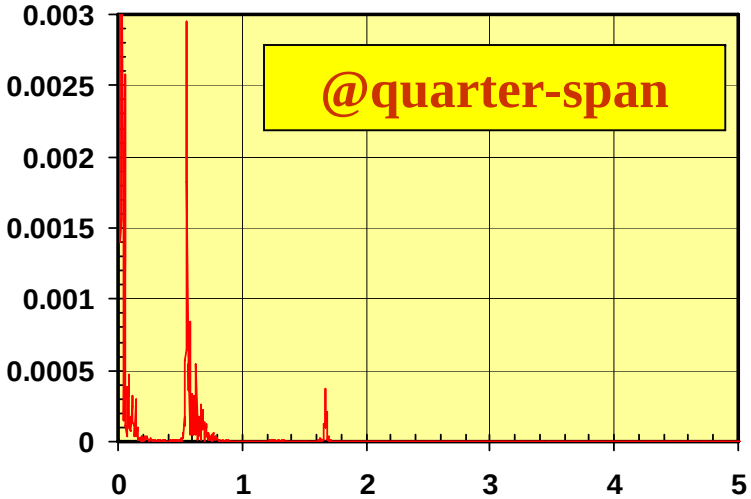


under wind-1 (reference)

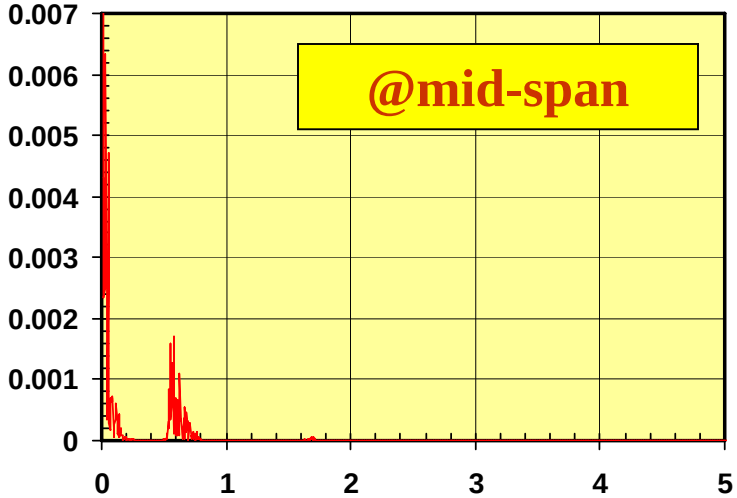
Power Spectral Density

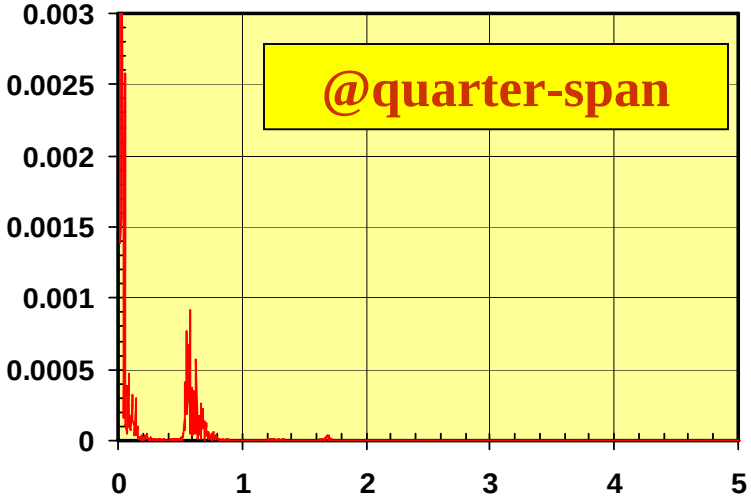
No Damper →





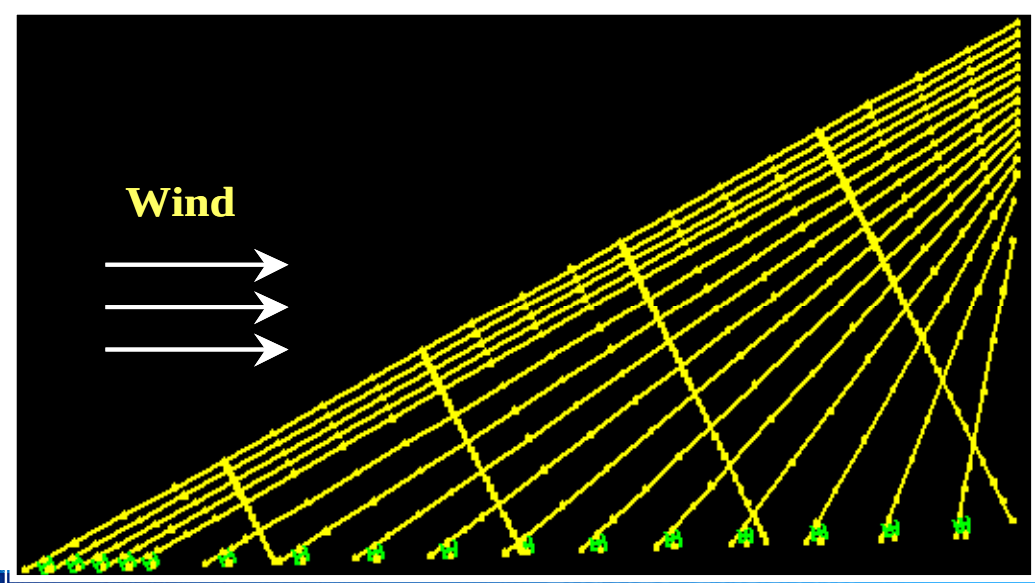
With Damper →



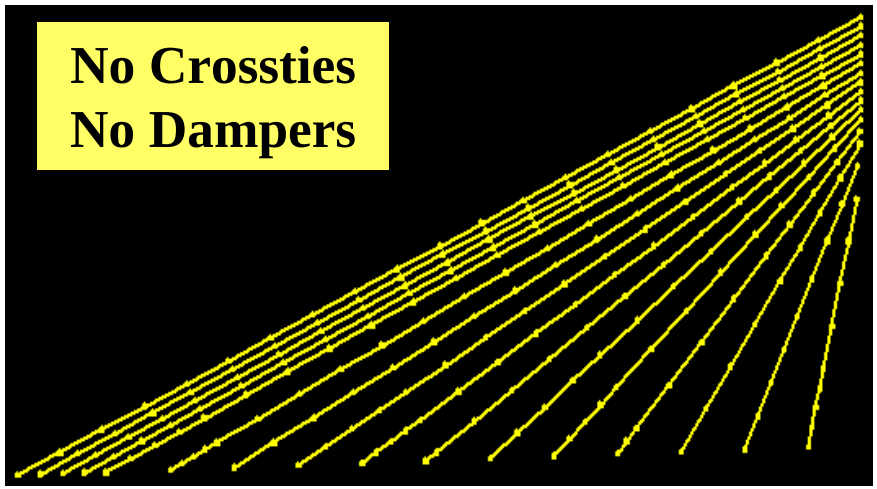


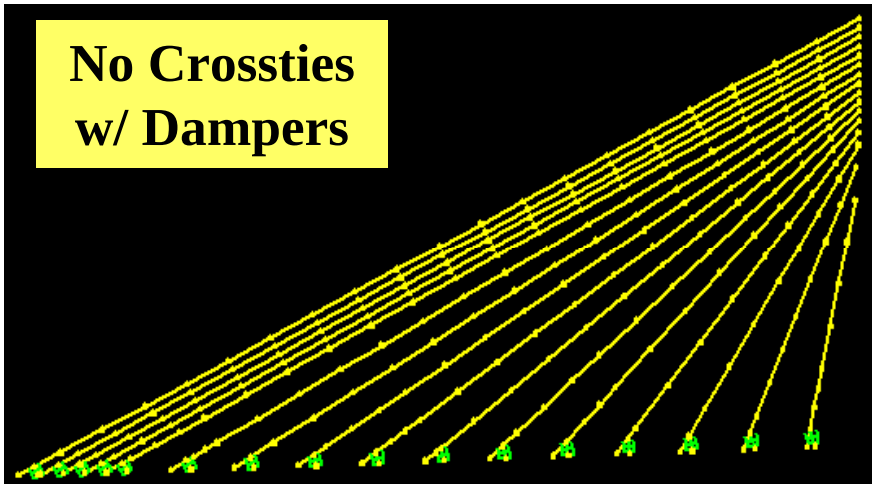
Stay Cable Systems

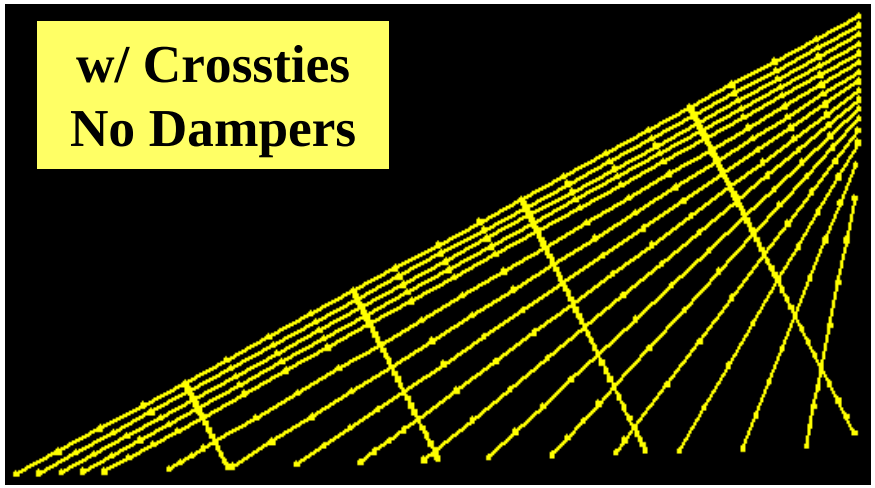
with Dampers and Crossties

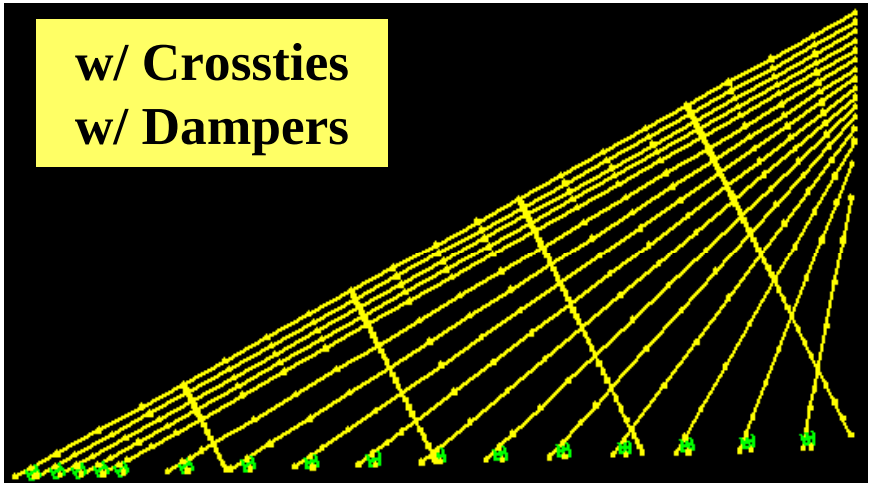


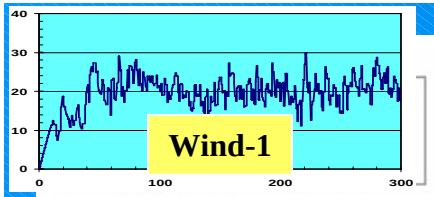
Cable Systems with Crossties / Dampers





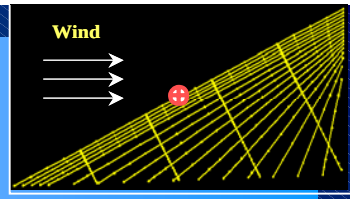


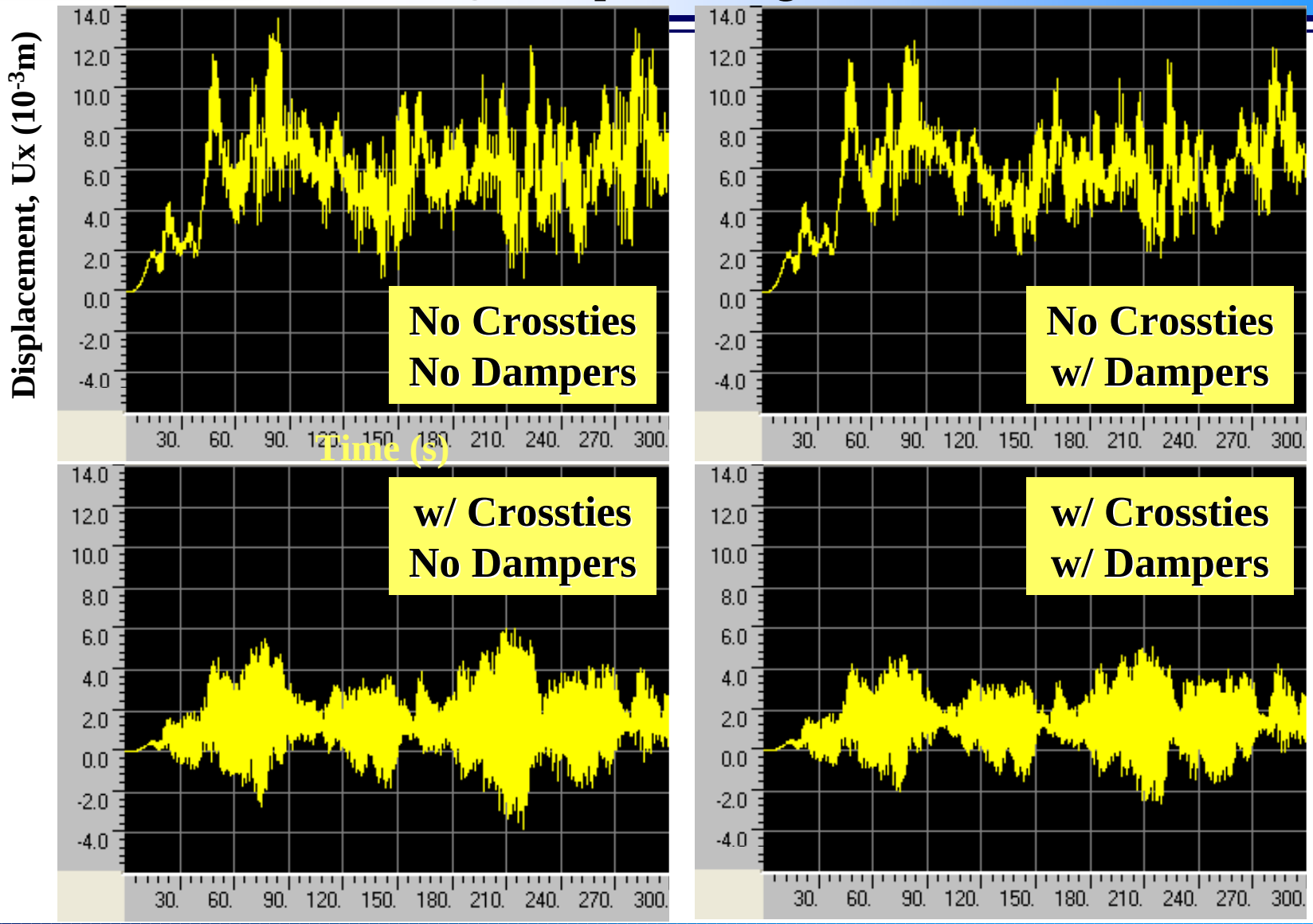


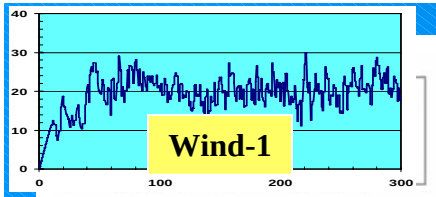


Sample Displacement Profile (1)

@ midspan of longest cable

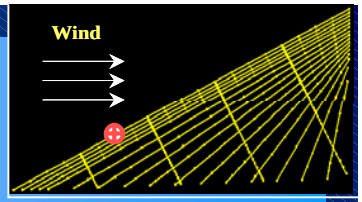


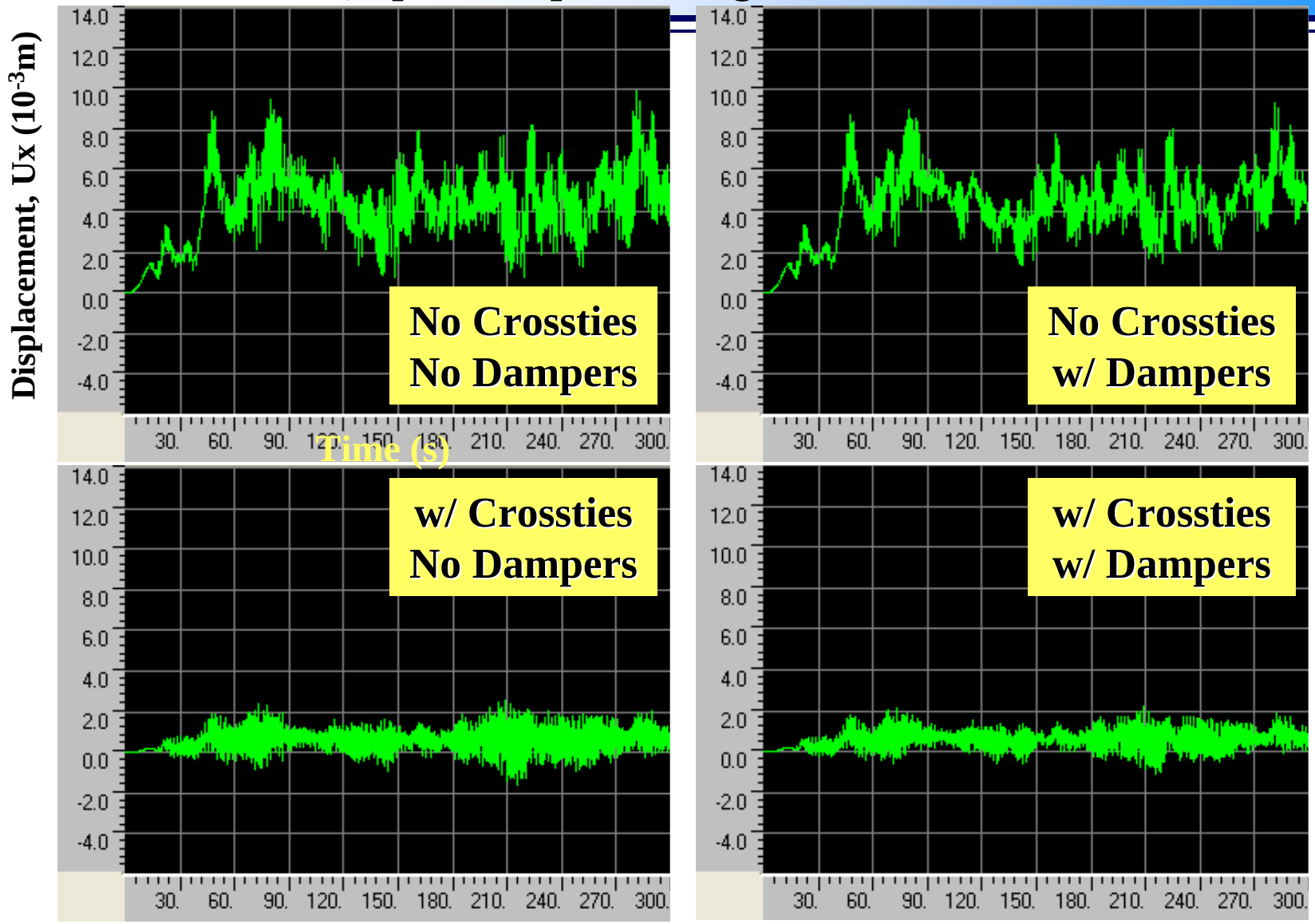


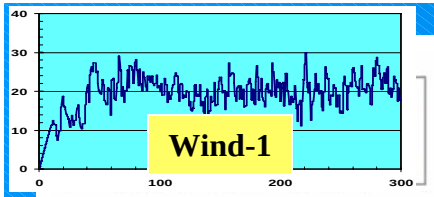


Sample Displacement Profile (2)

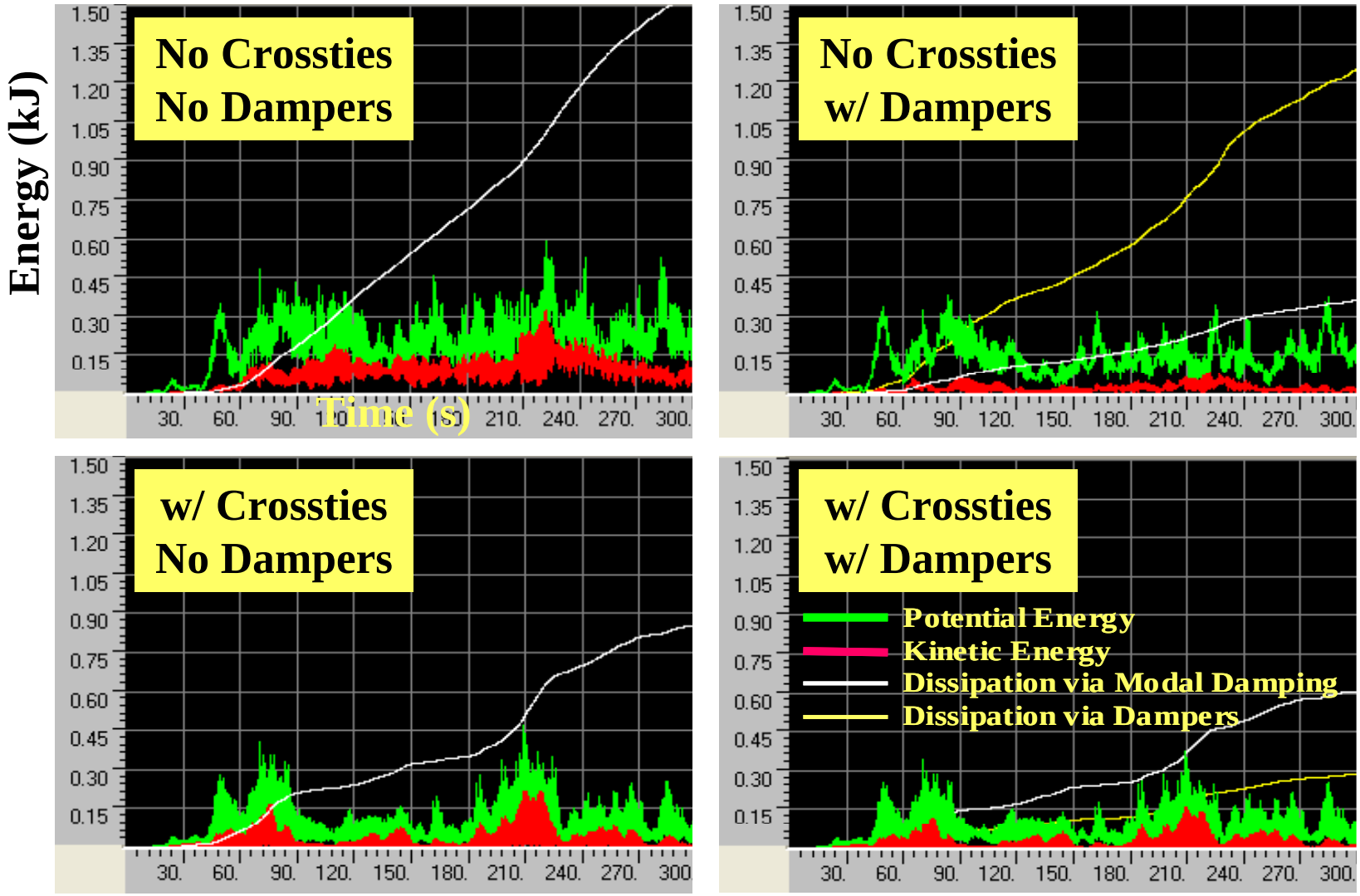
@ quarter-span of longest cable

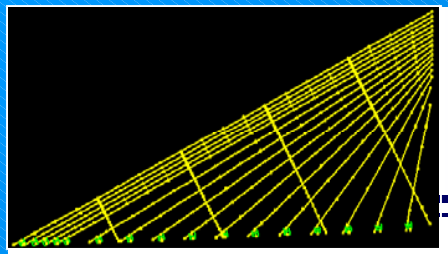






Energy Evolution of the system





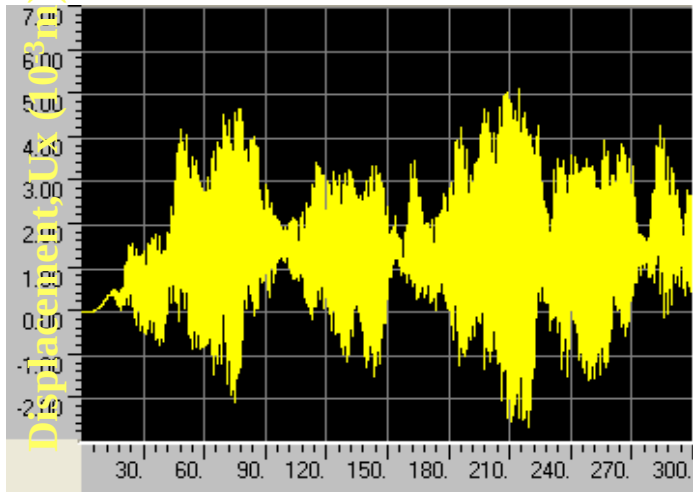
Influence of Damper Coefficient (1)

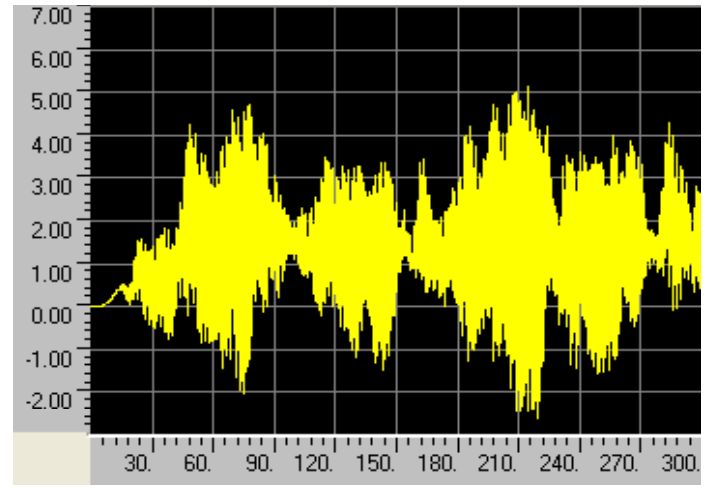
How to determine C-values for Networked Cables ?

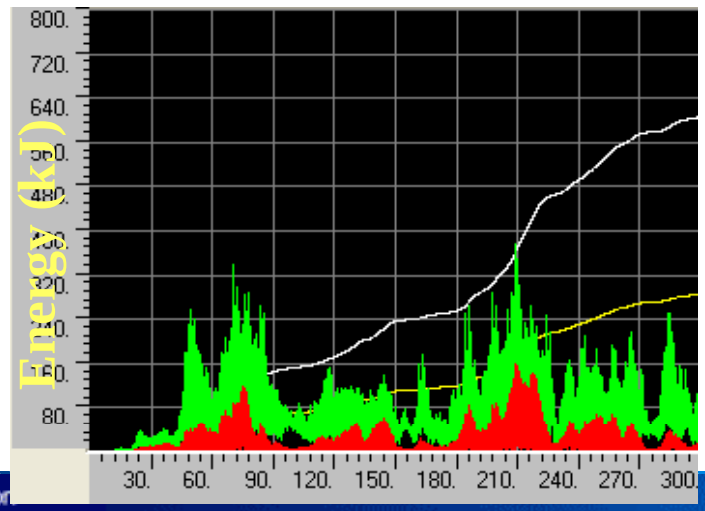
$$C_{i,opt} = \frac{0.1 m L \omega_1}{(i)(d/L)}$$

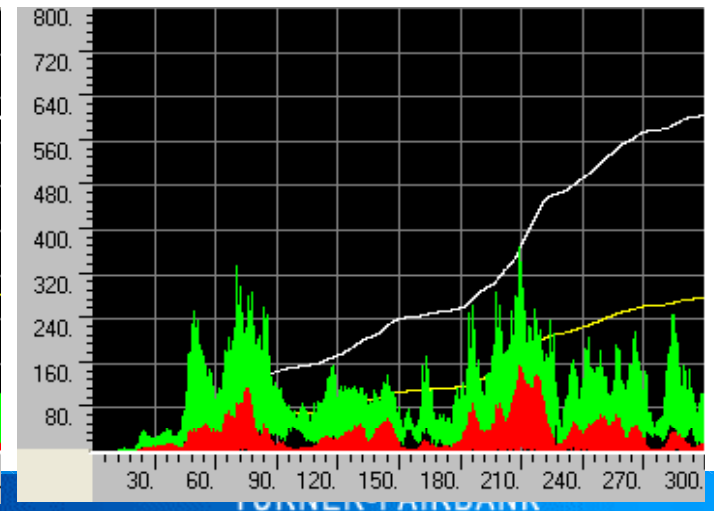
Trial 1: "C-Individual"
(based on individual cable's ω_1)

Trial 2: "C-System"
(based on system's ω_1)

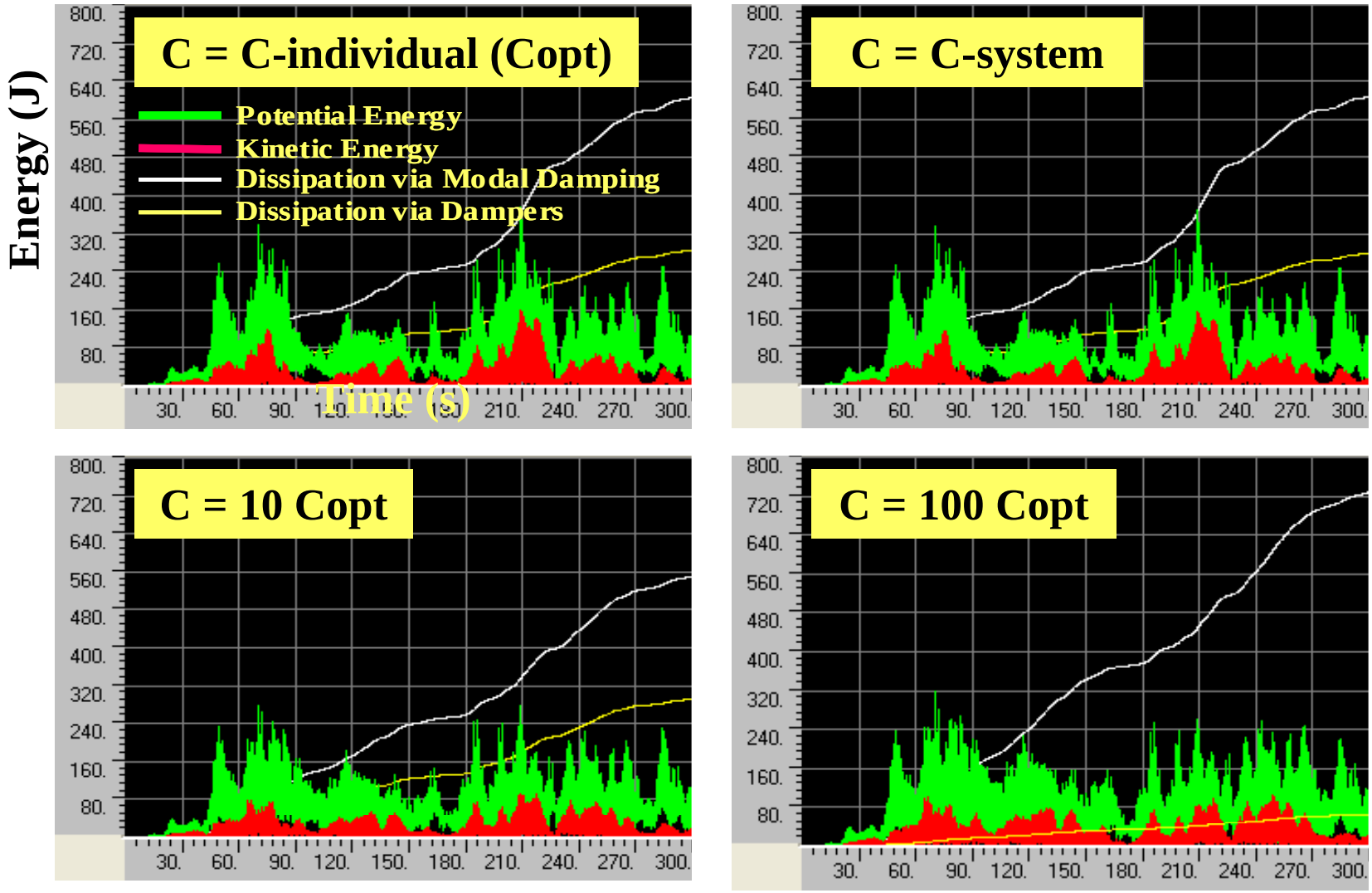




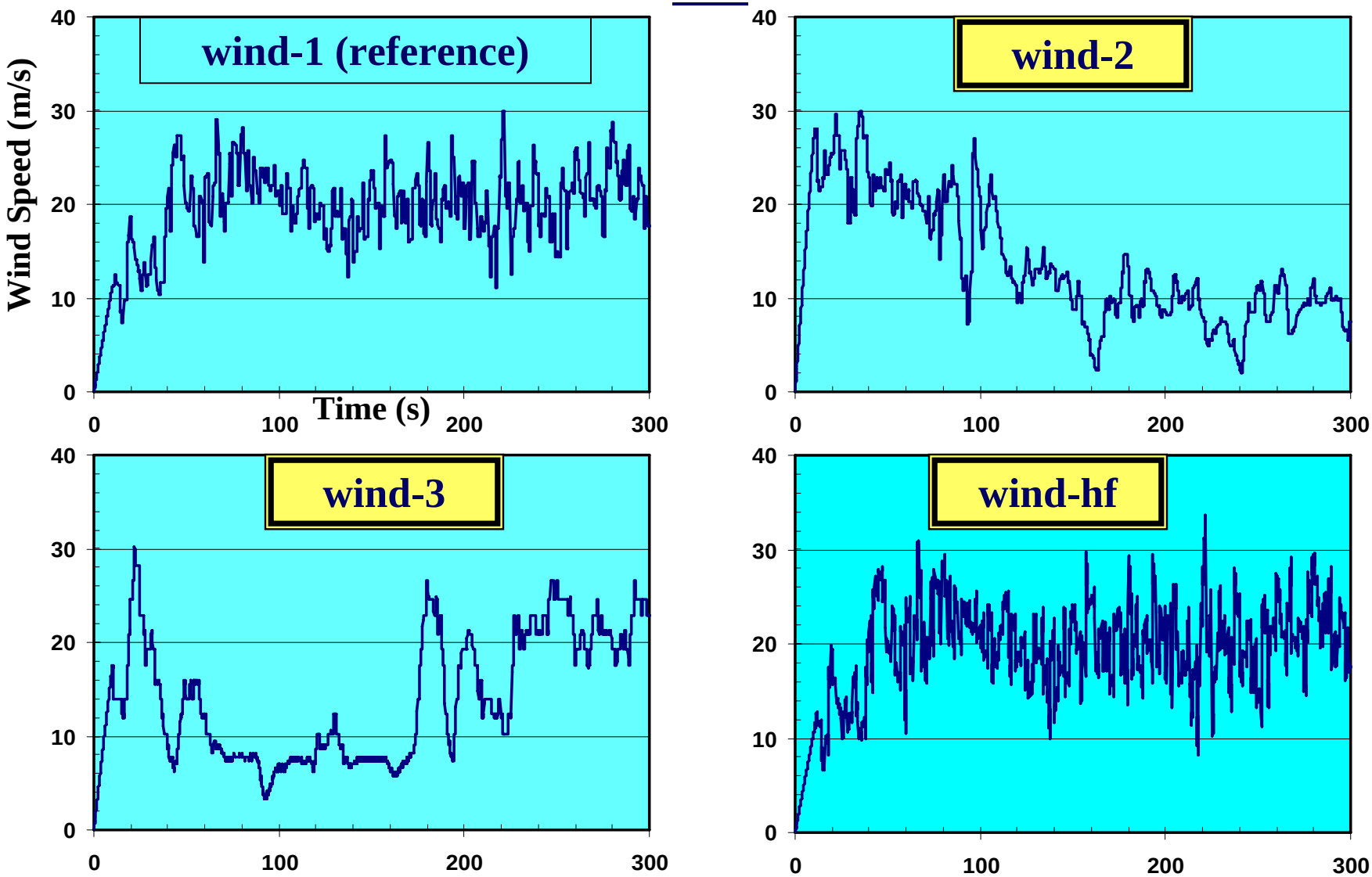


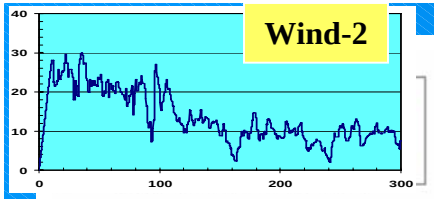


Influence of Damper Coefficient (2)

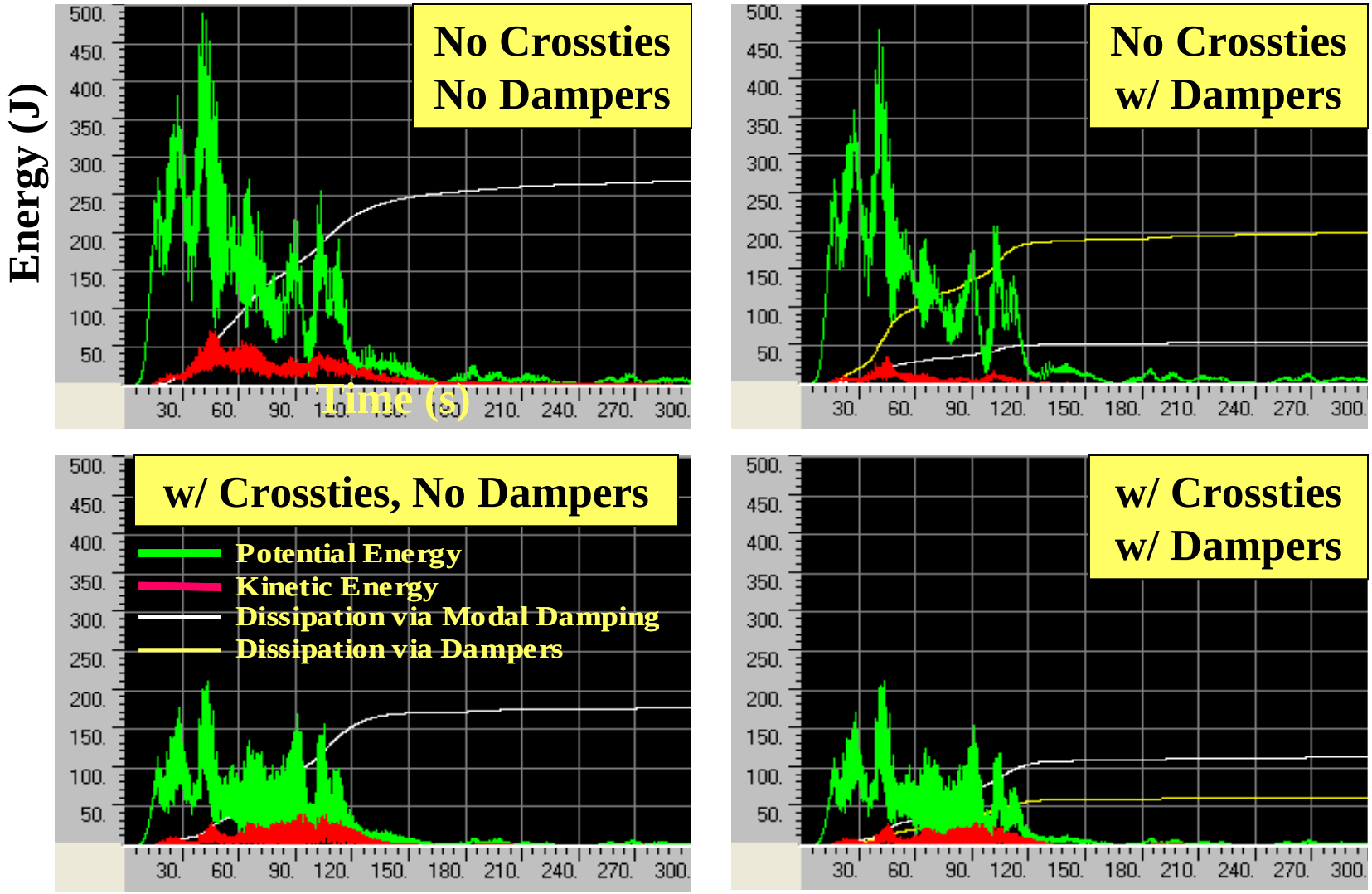


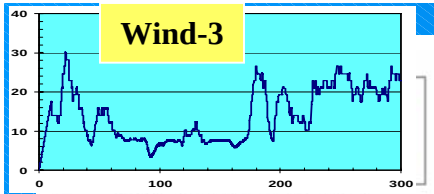
Other Wind Profiles Tested



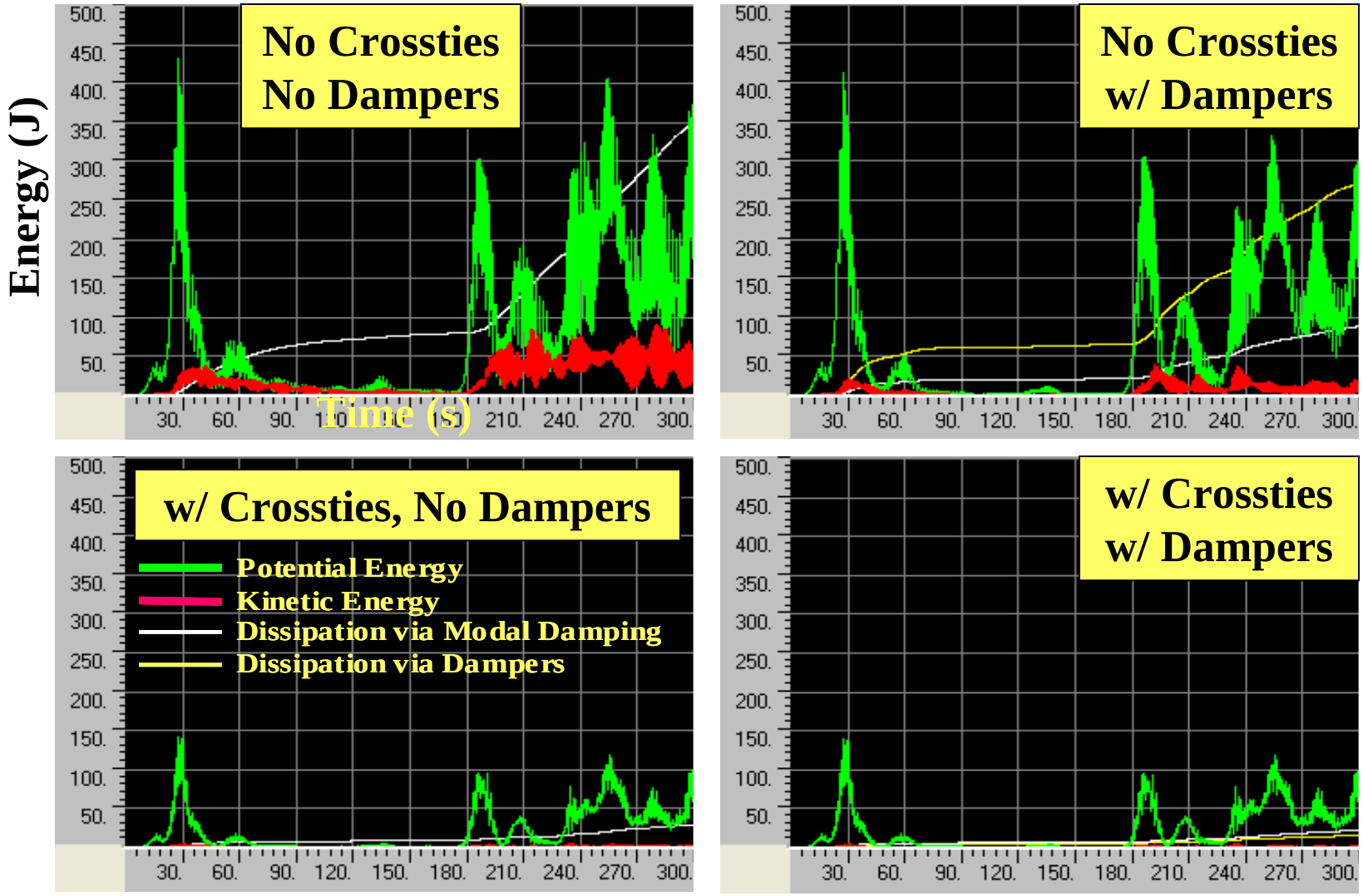


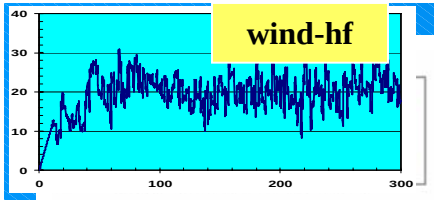
Response to wind-2



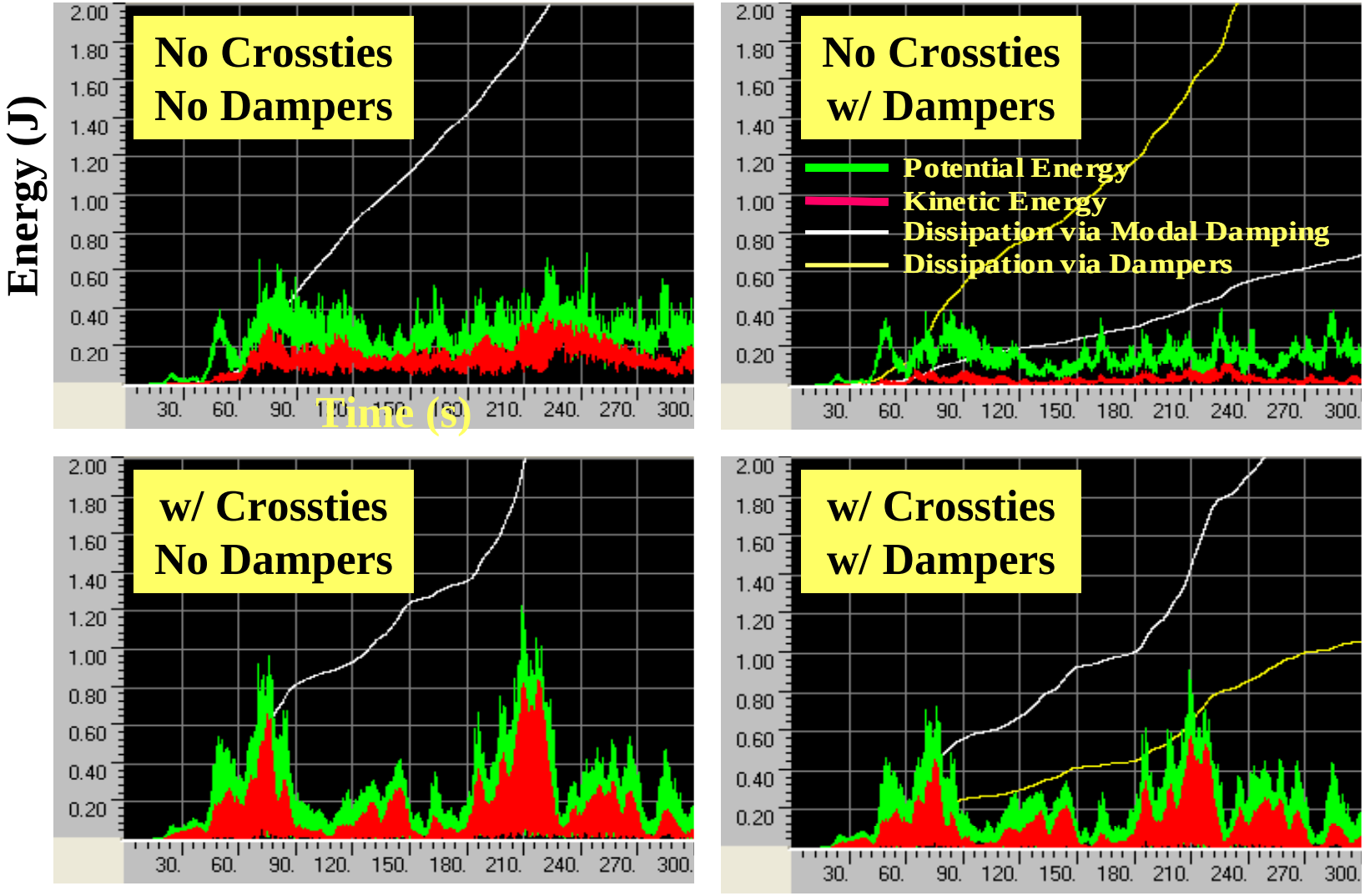


Response to wind-3



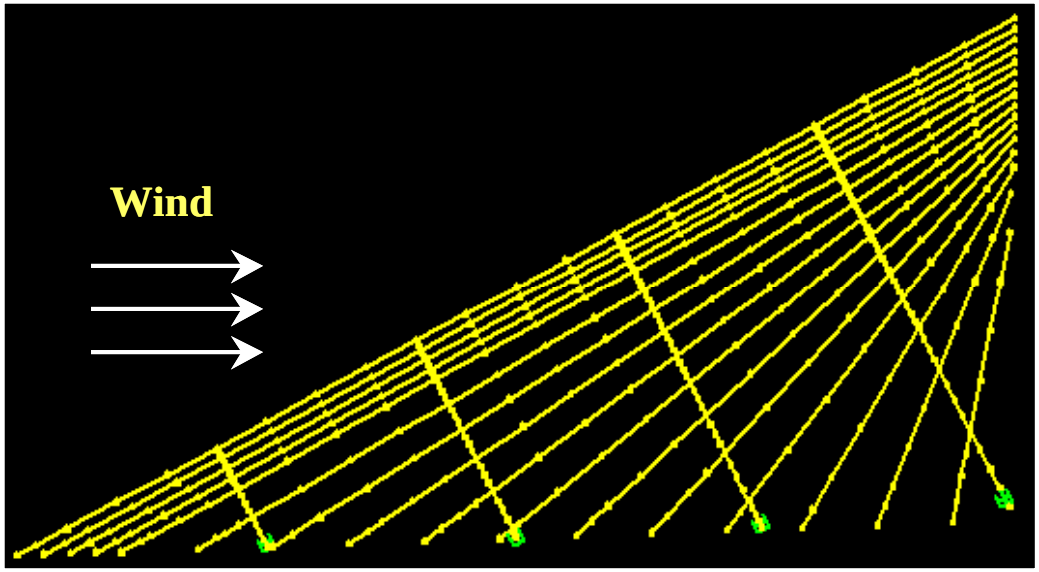


Response to wind-hf

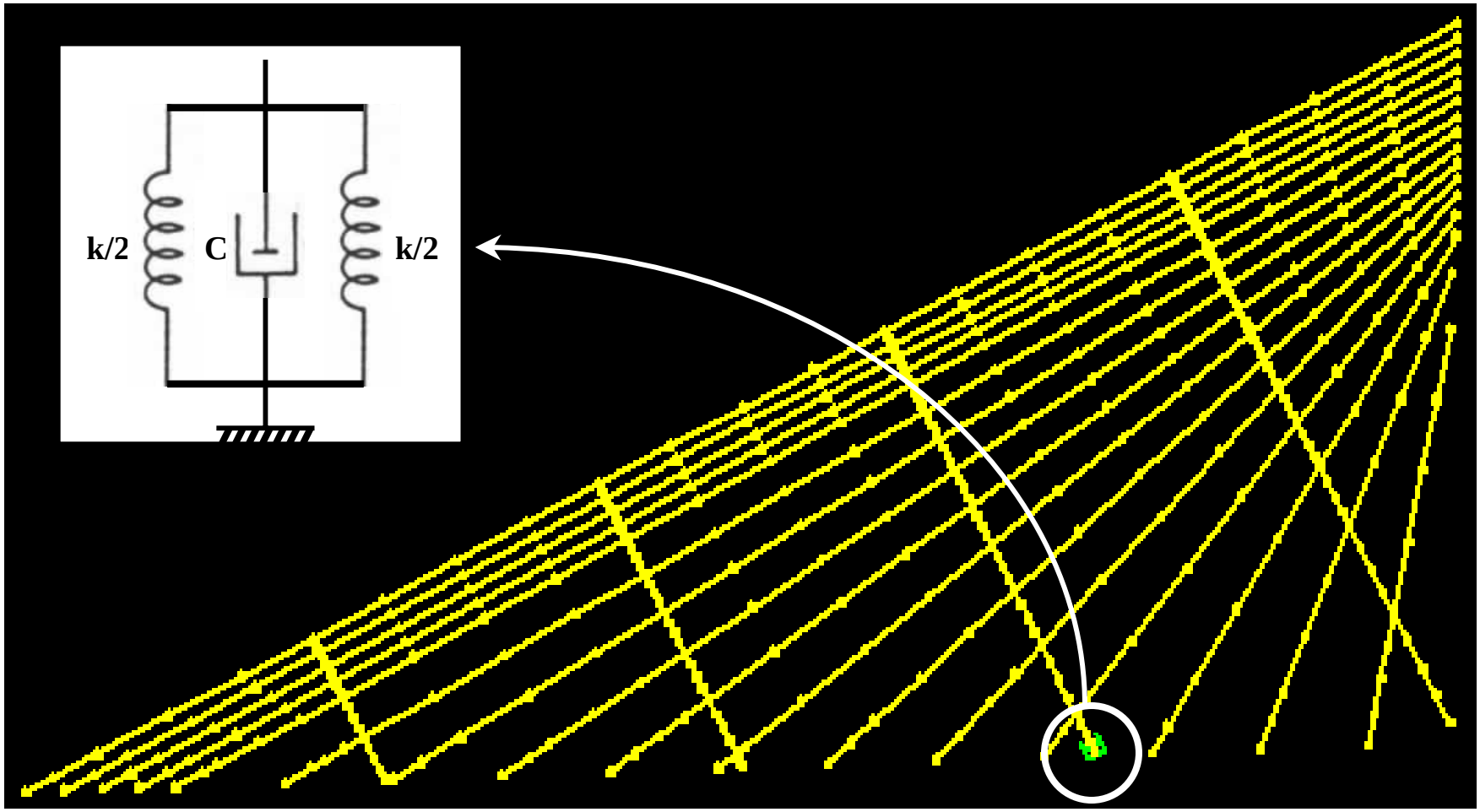


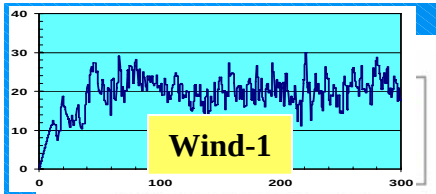
Cross-tied Cable Networks

with Dampers at Crosstie Anchorages

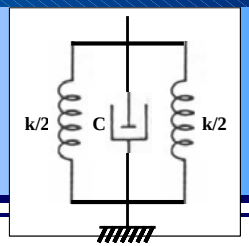


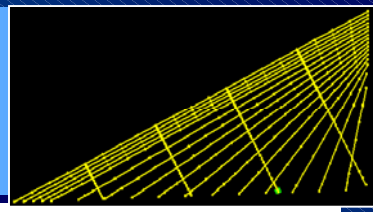
Cable Network with a Single Damper

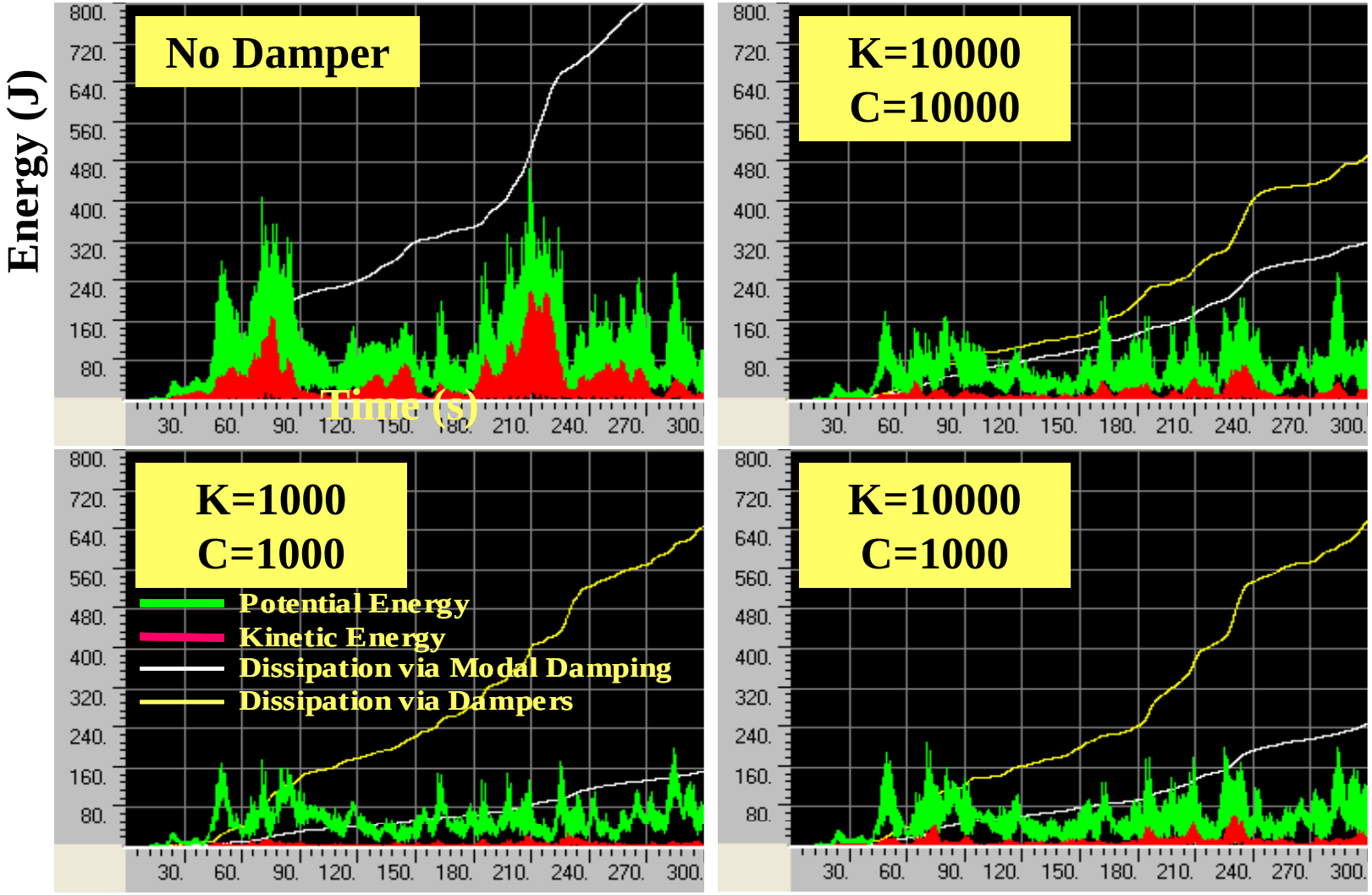




Energy Evolution

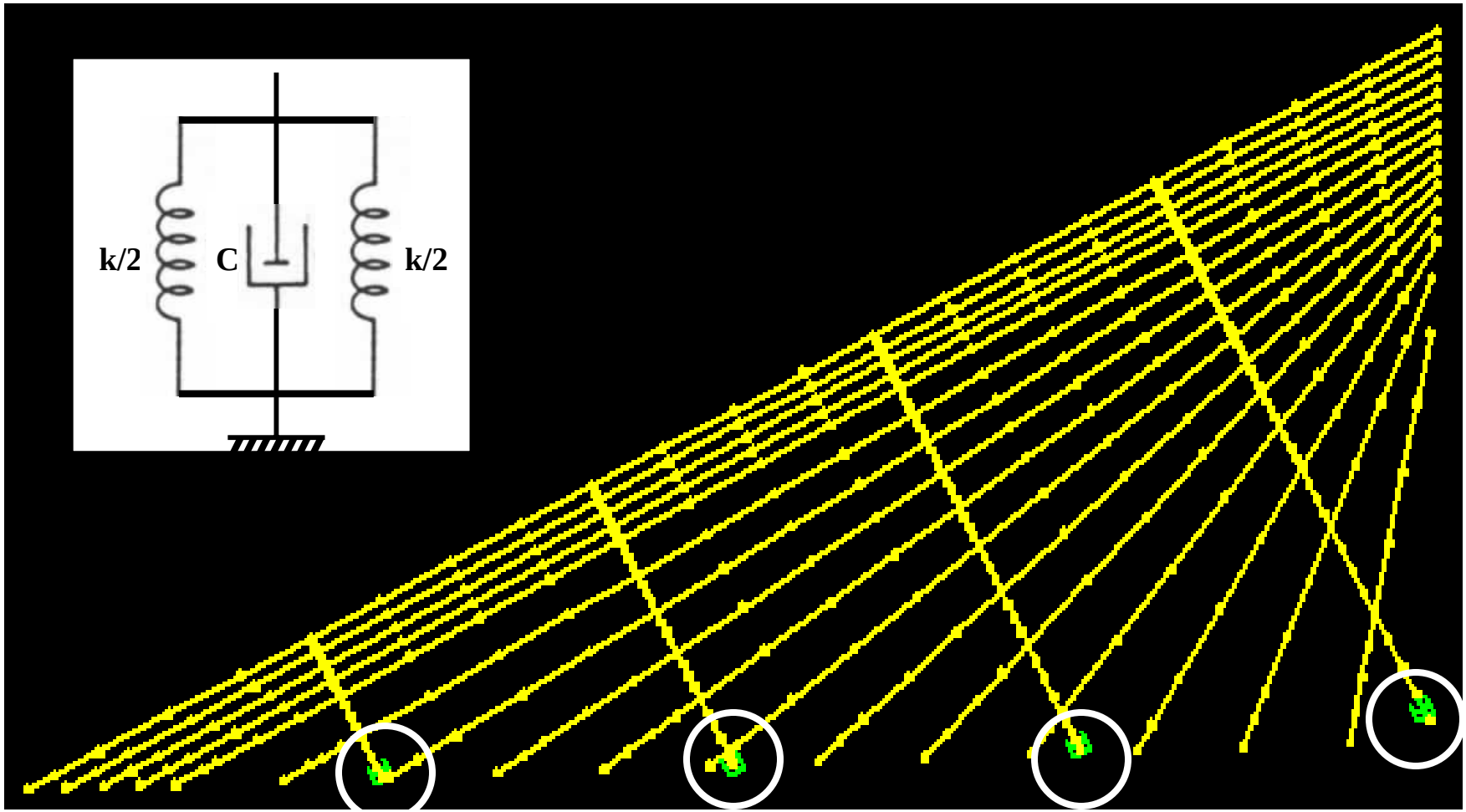


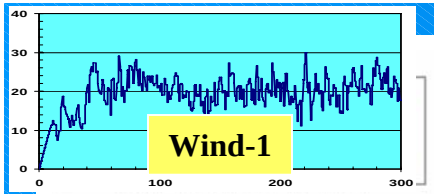




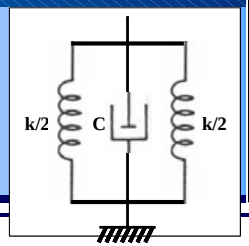
(units: kN-m-s)

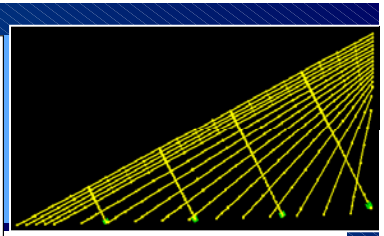
Cable Network with Four Dampers

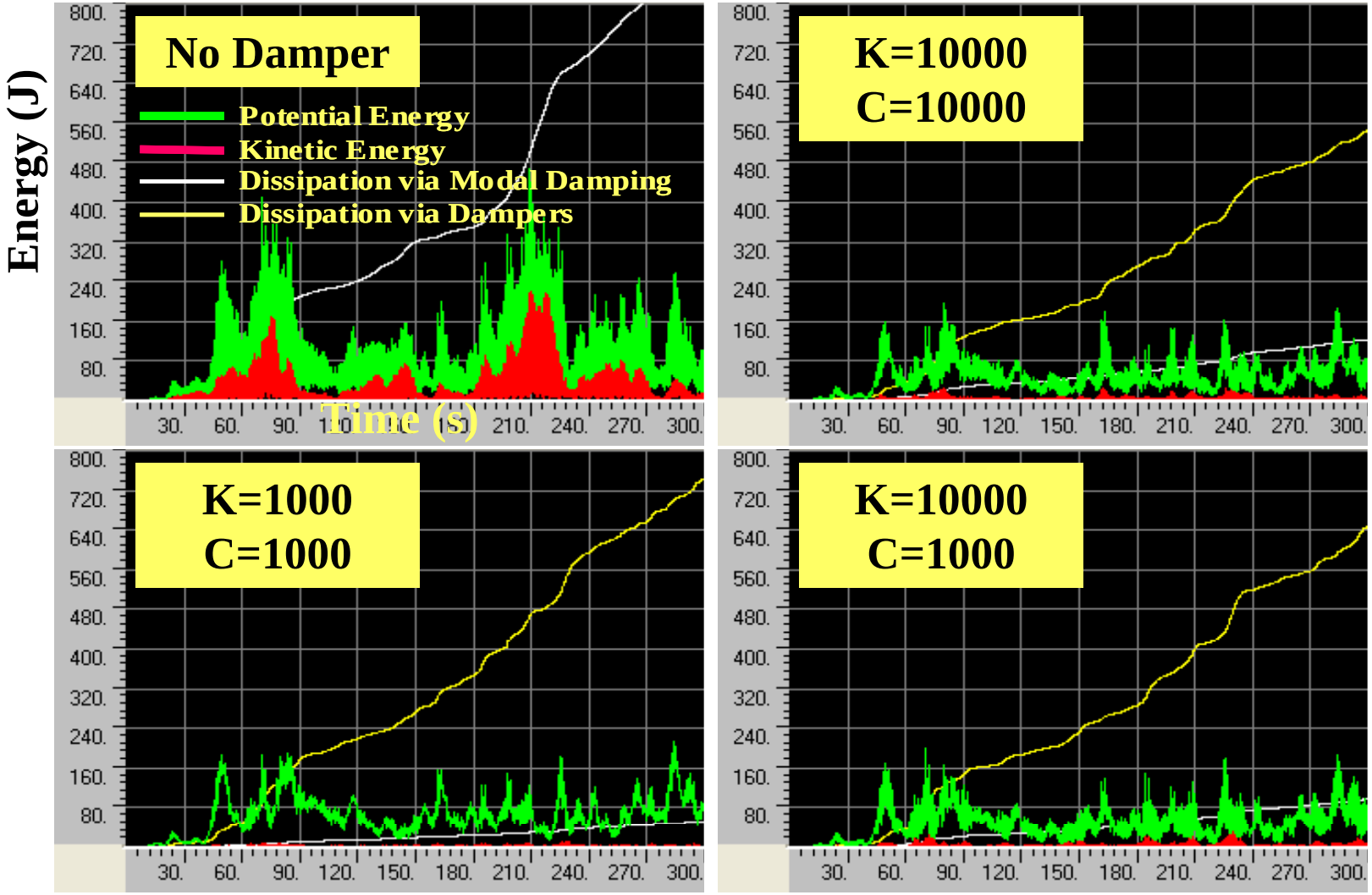




Energy Evolution

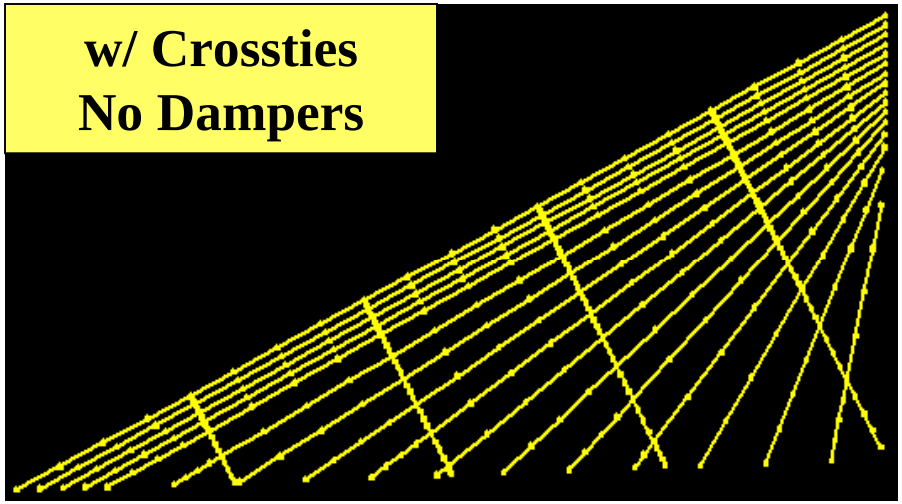




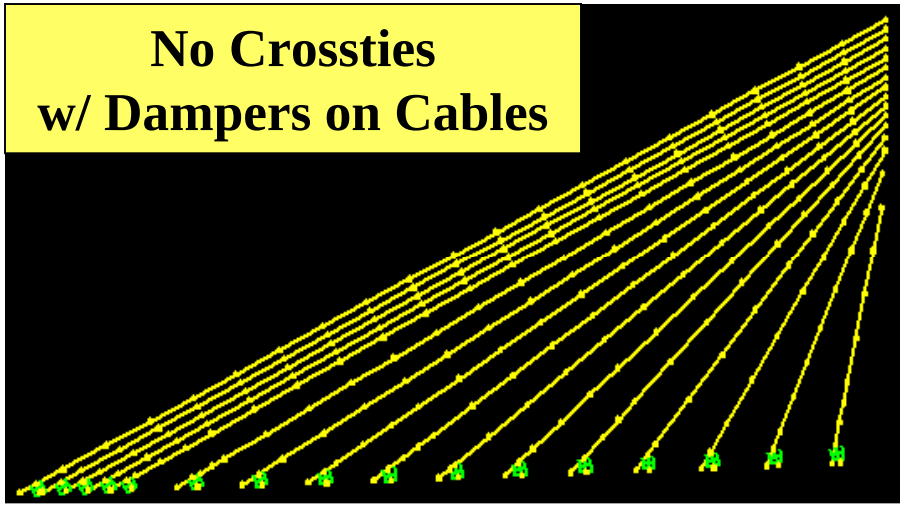


Comparison of Strategies

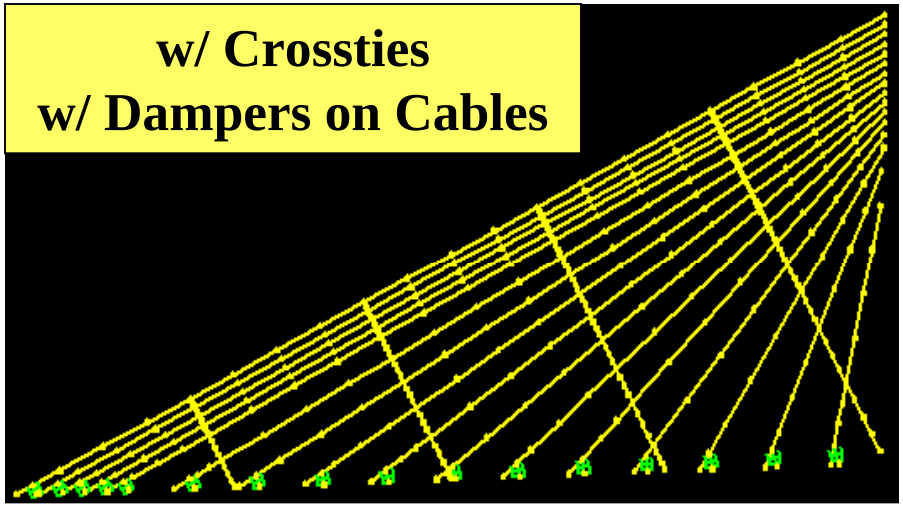
w/ Crossties
No Dampers



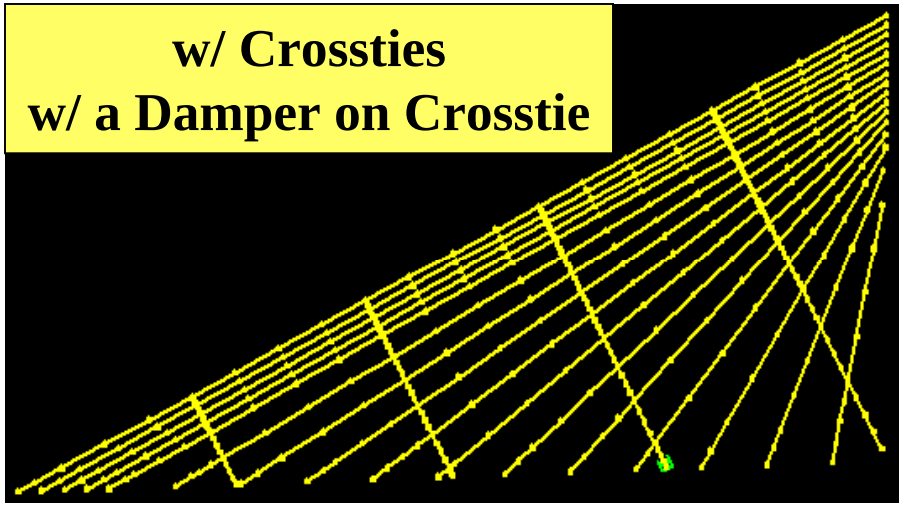
No Crossties
w/ Dampers on Cables



w/ Crossties
w/ Dampers on Cables

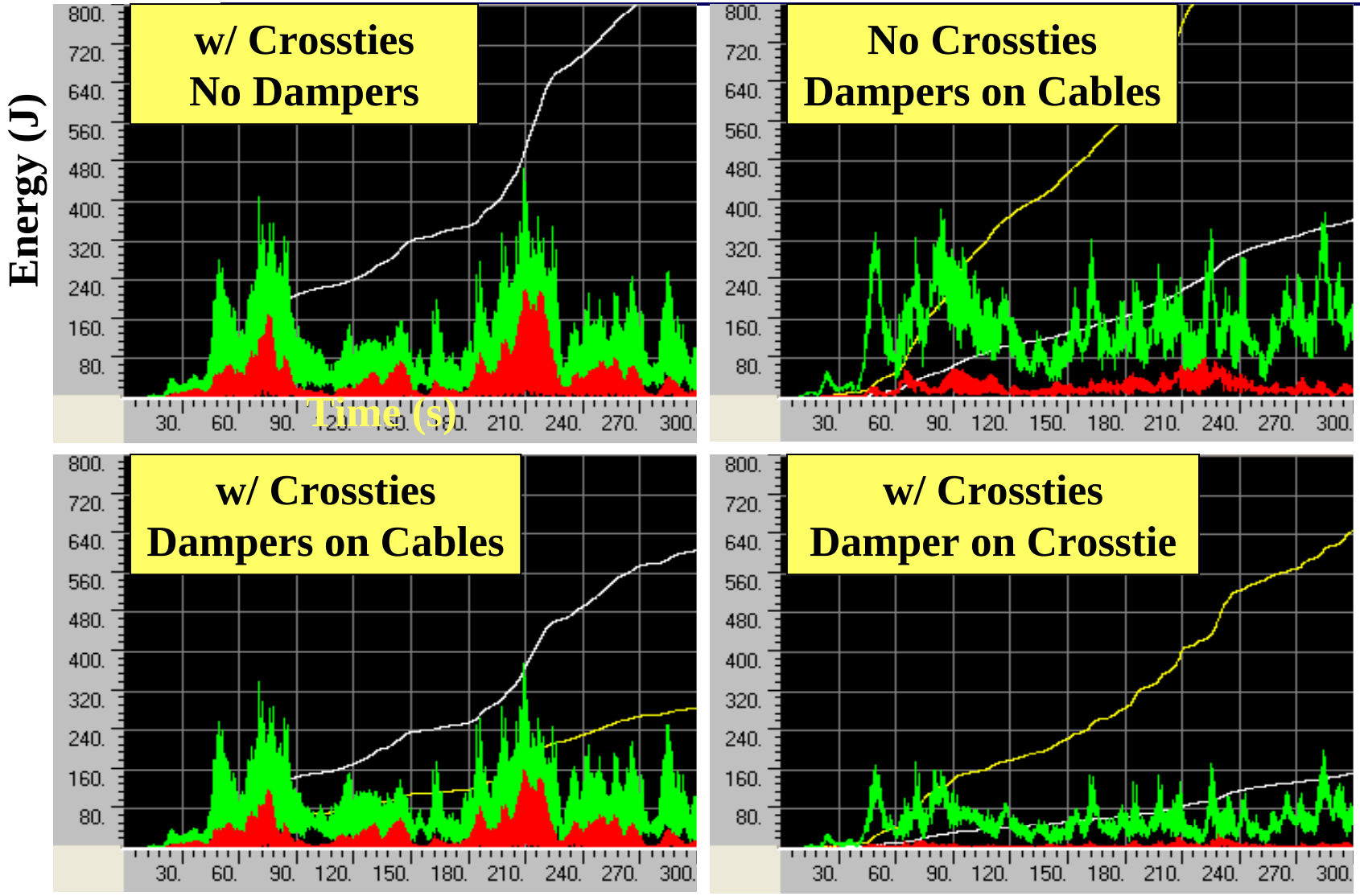


w/ Crossties
w/ a Damper on Crosstie



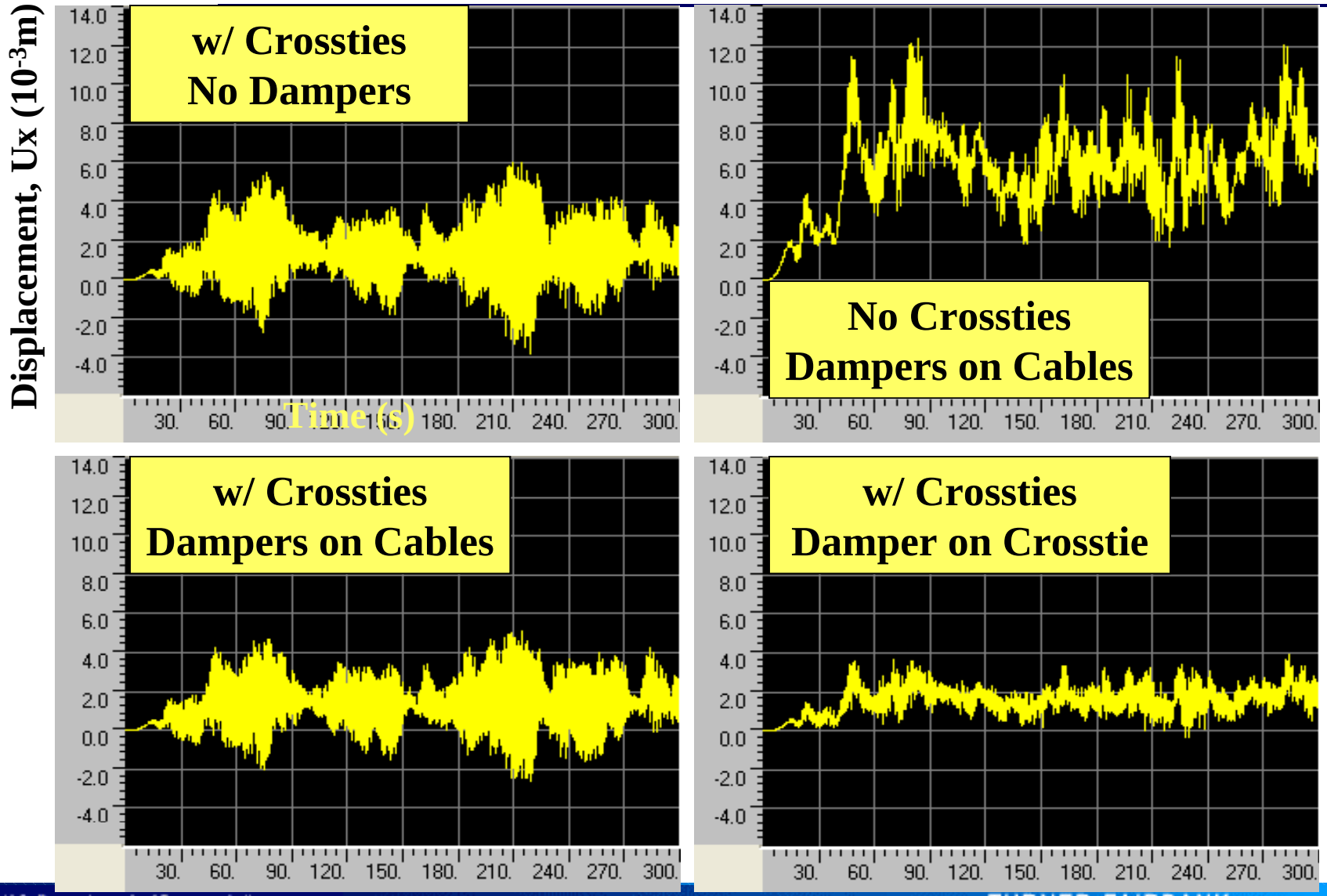
Comparison of Performance (1)

Energy evolution of the system



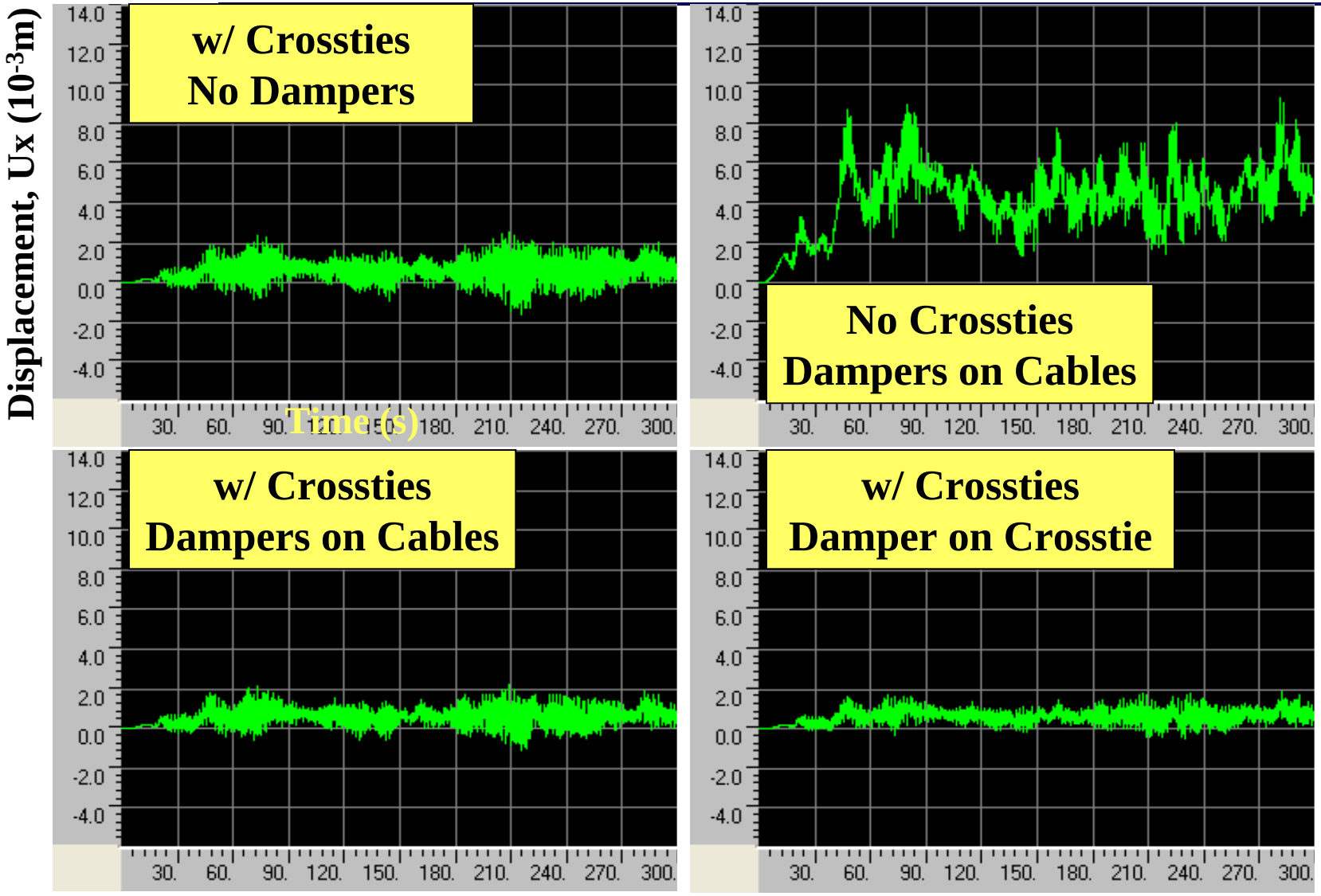
Comparison of Performance (2)

Dispalcement @ mid-span of longest cable



Comparison of Performance (3)

Dispalcement @ quarter-span of longest cable



Conclusions (1)

- External dampers are efficient in reducing cable vibrations, lowering the potential and kinetic energy of a cable system via inelasitc dissipation
- Viscous dampers are sensitive to the rate of motion and are efficient in dealing with cable vibrations induced by highly turbulent winds
- Combined use of cable dampers and crossties is not necessarily better than their independent use, its efficacy depending on the configuration of crossties and the nature of winds

Conclusions (2)

- The optimal coefficients for dampers on cables networked with crossties cannot be determined from consideration of dynamics of a single cable
- Dampers installed at crosstie connections to the deck dissipate energy very efficiently, constituting a good mitigation alternative
- Dampers are effective in mitigation of transverse as well as in-plane cable vibrations

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http://www.tfhrc.gov/aerodynamics/