Influence of Cross-Tie Geometry and Details on Mitigation of Wind-Induced Vibrations

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Federal Highway Administration

Wind Induced Vibration of Cable Stay Bridges Workshop
St. Louis, MO, April 25-27, 2006

Introduction

- Wind-induced stay cable vibrations risk premature damage and failure of the cables
- Cross-ties accepted as a viable solution
- Influence of cross-tie geometry and details on mitigation effectiveness not well known

Objective

To investigate,

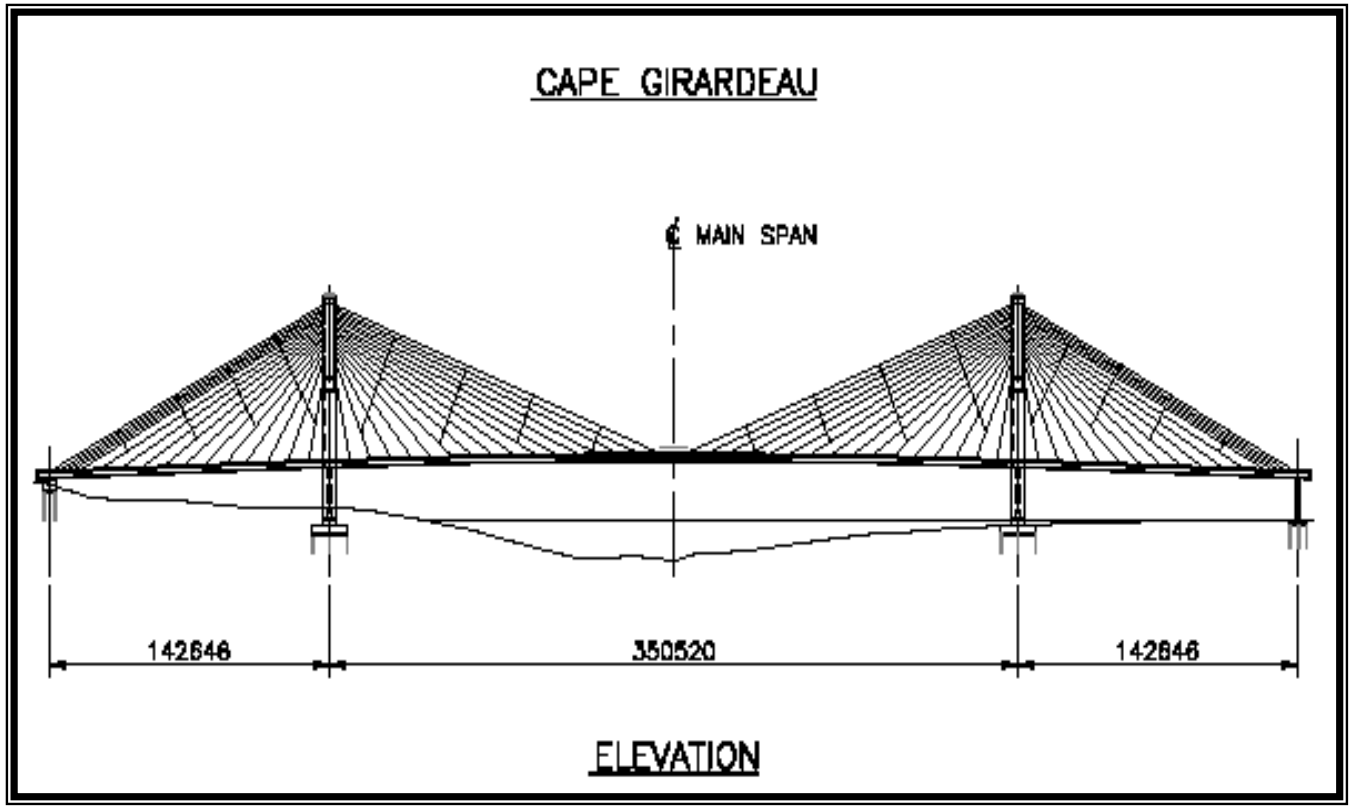
via finite element simulations,

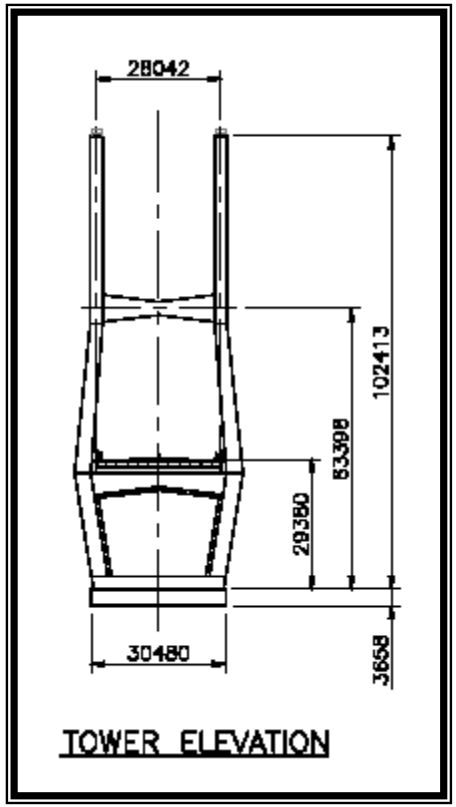
the influence of cross-tie geometry

and details on mitigation of wind-induced stay cable vibrations

Bill Emerson Memorial Bridge

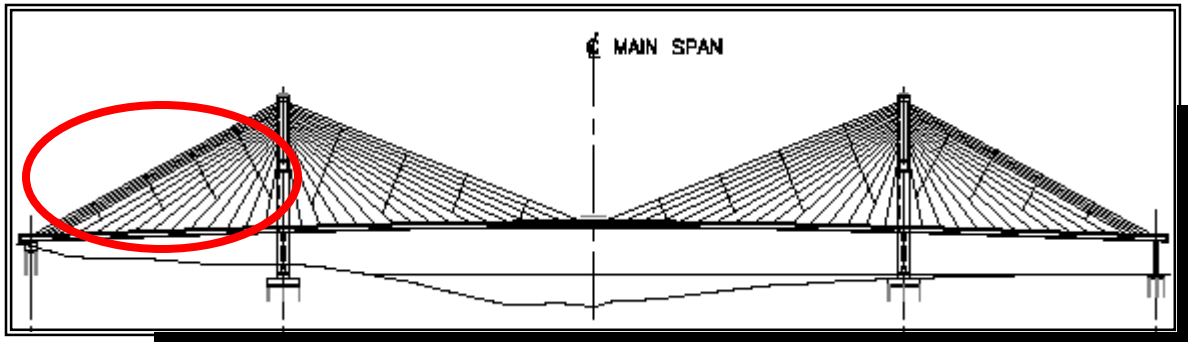
Bill Emerson Memorial Bridge

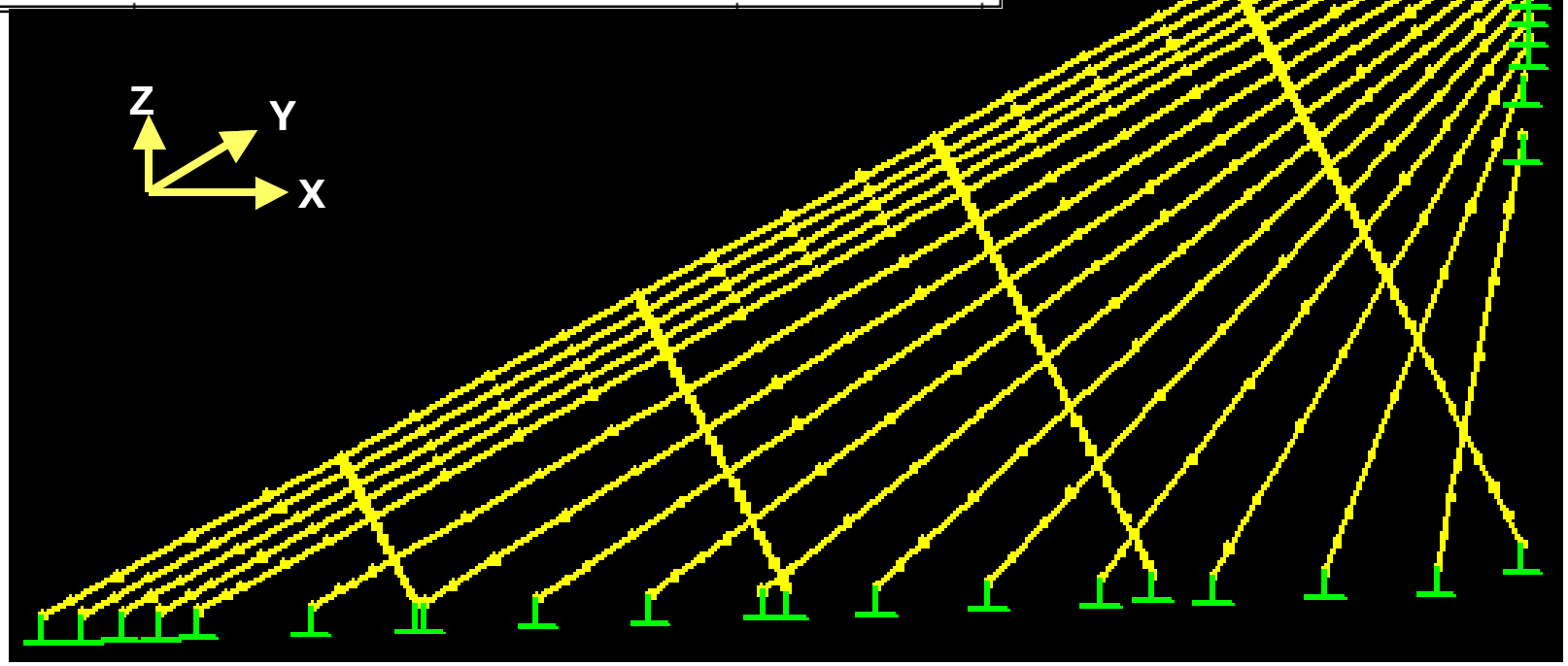




(128 Stays, Main Span: 350m, H-Shaped Tower)

Finite Element Model

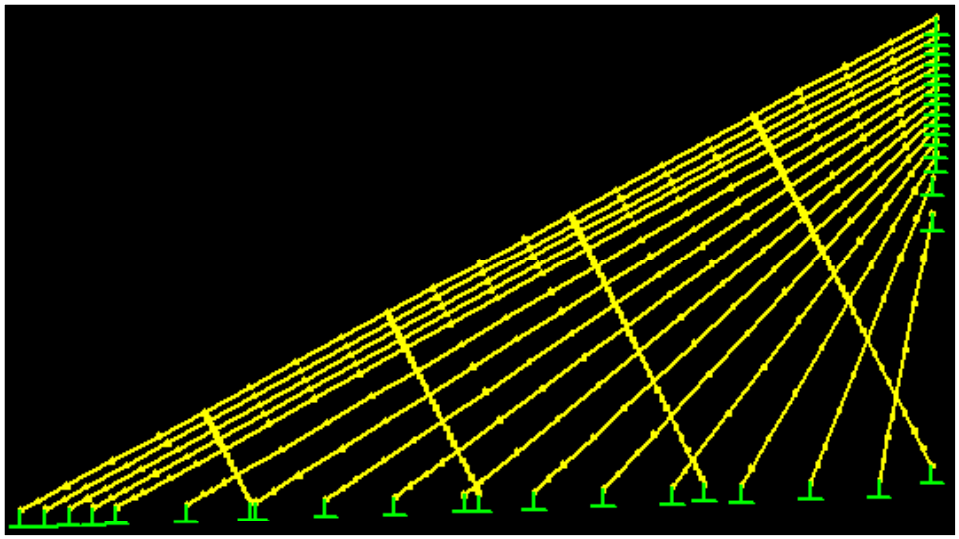




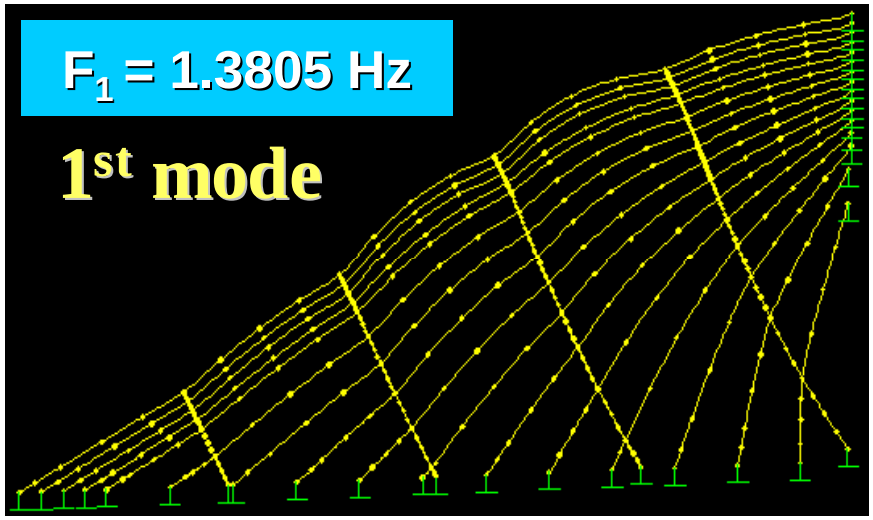
Free-Vibration Analysis :

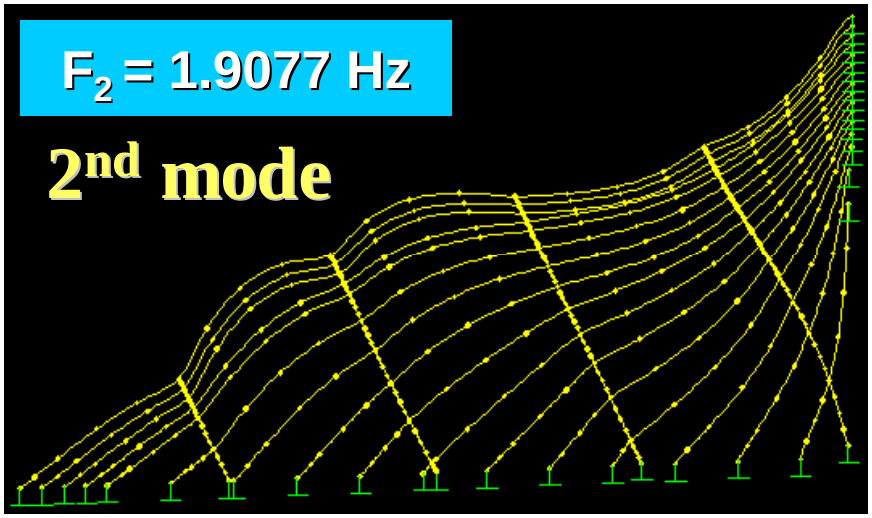
Natural Frequencies and Mode Shapes

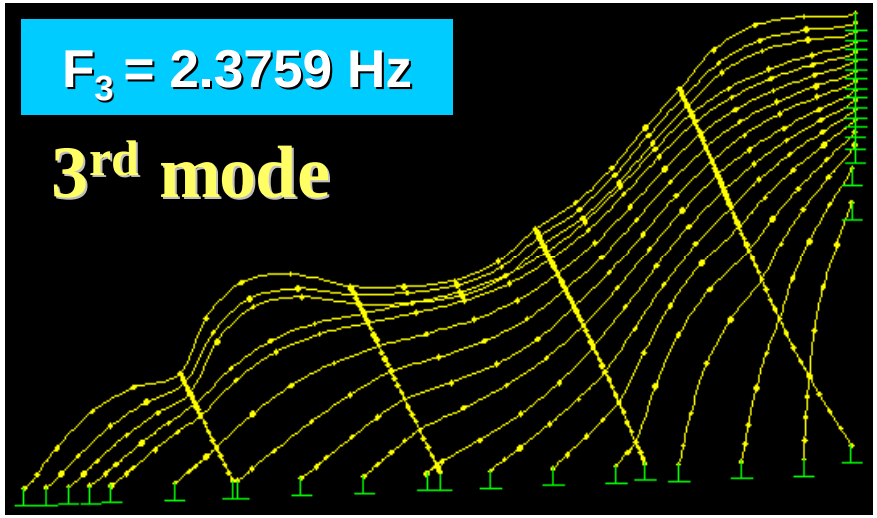
(In-plane Vibration)

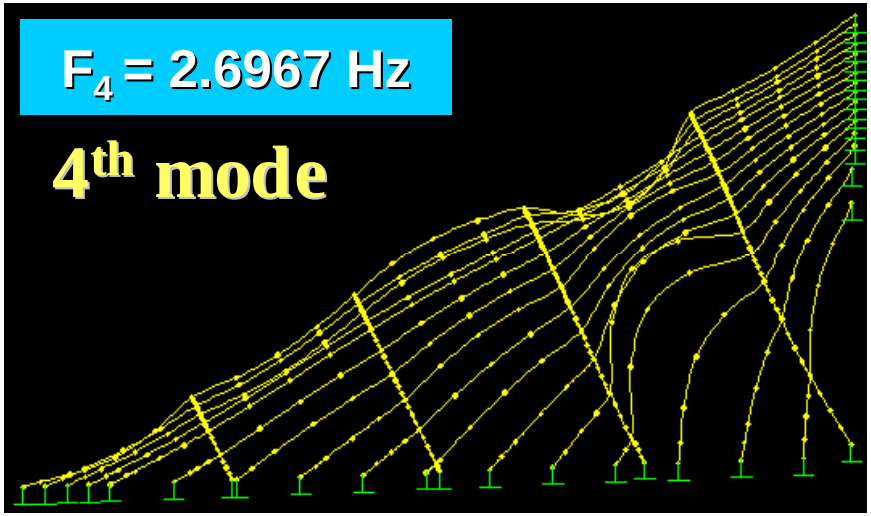


Vibration Mode Shapes (1)

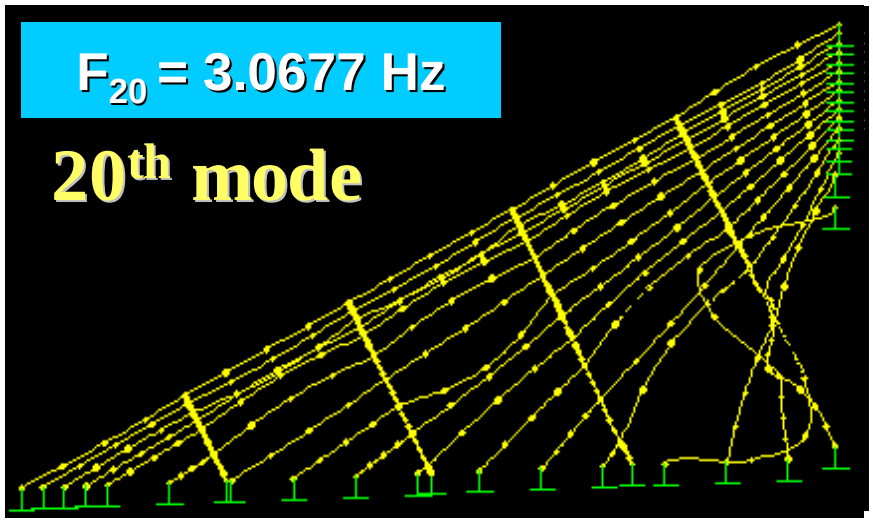


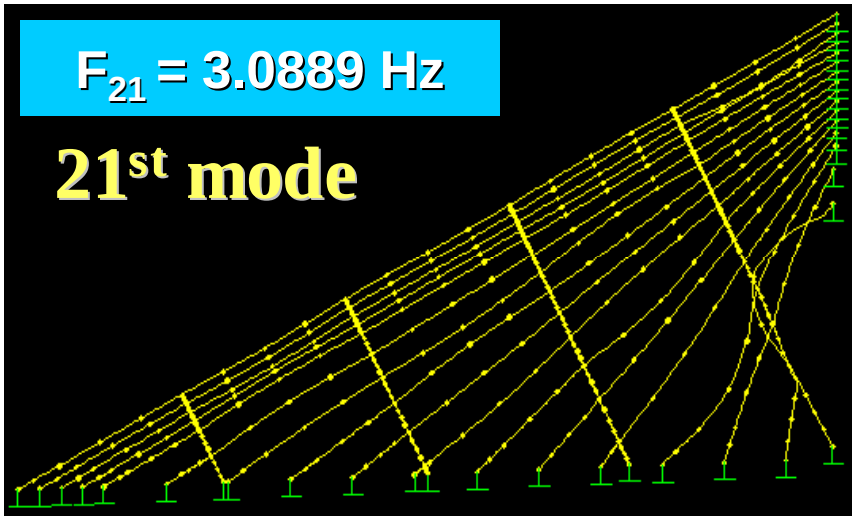


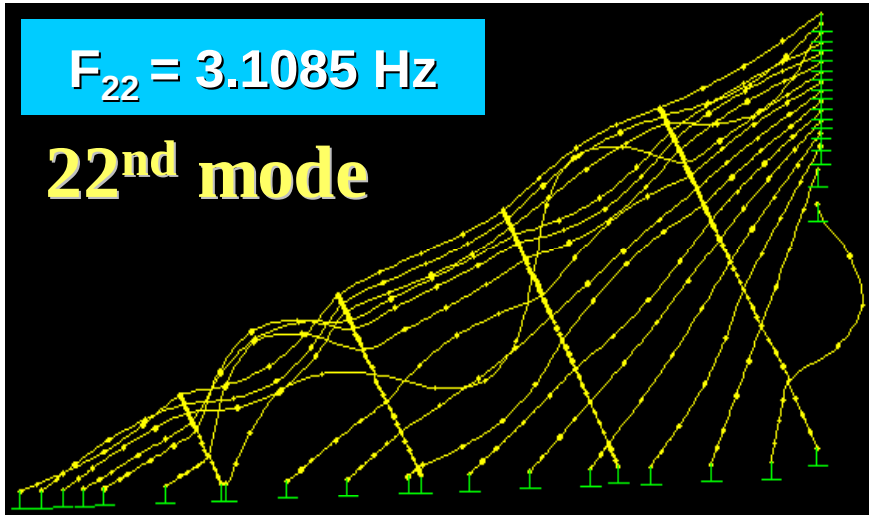


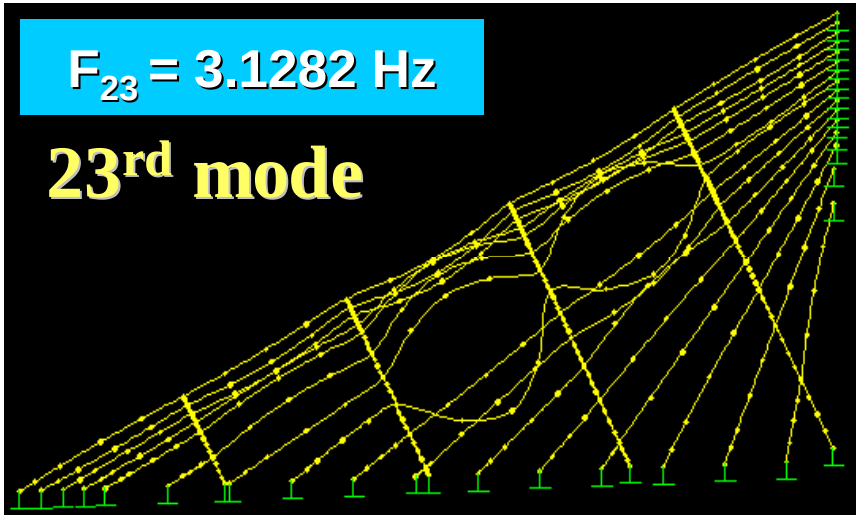


Vibration Mode Shapes (2)

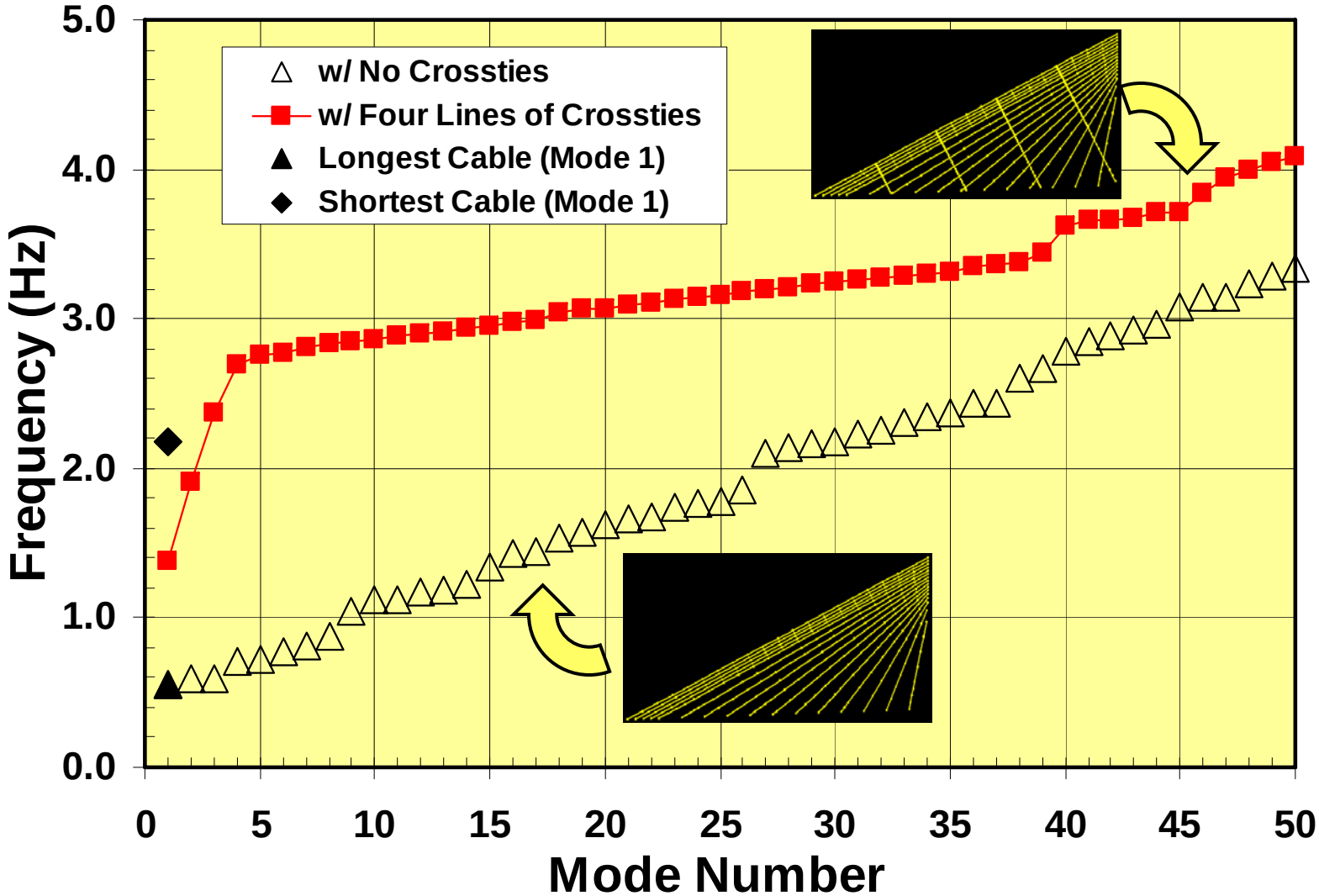




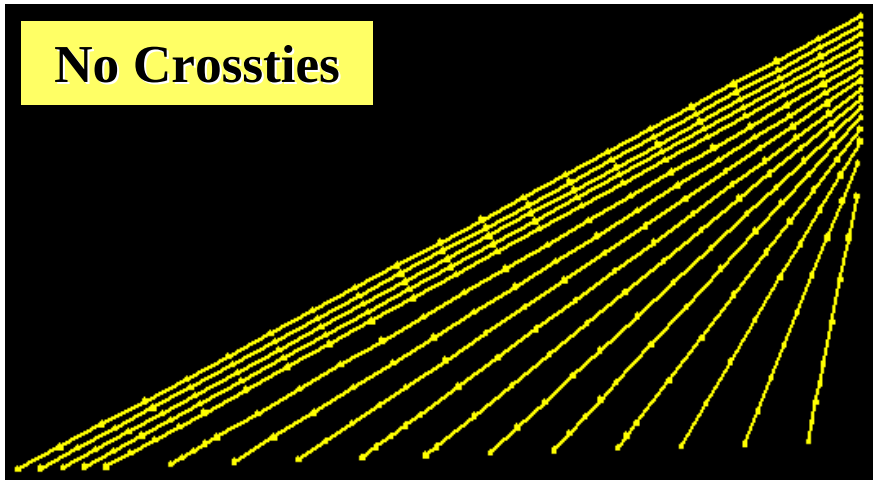


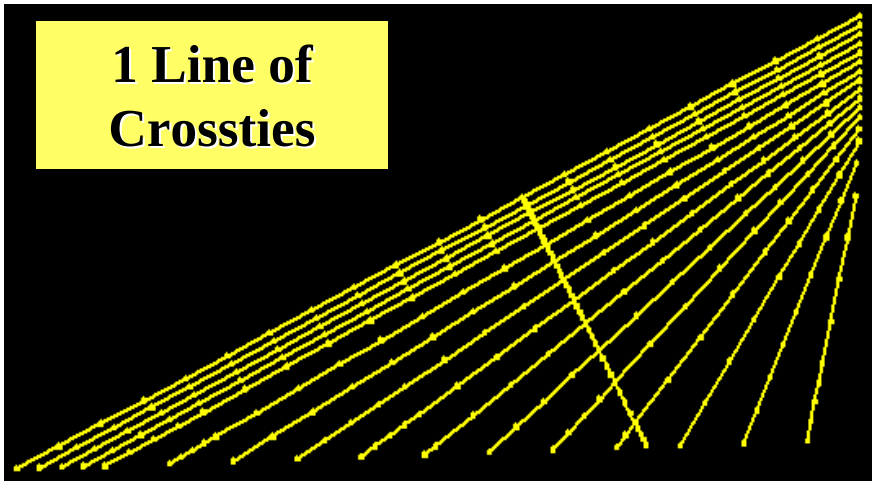


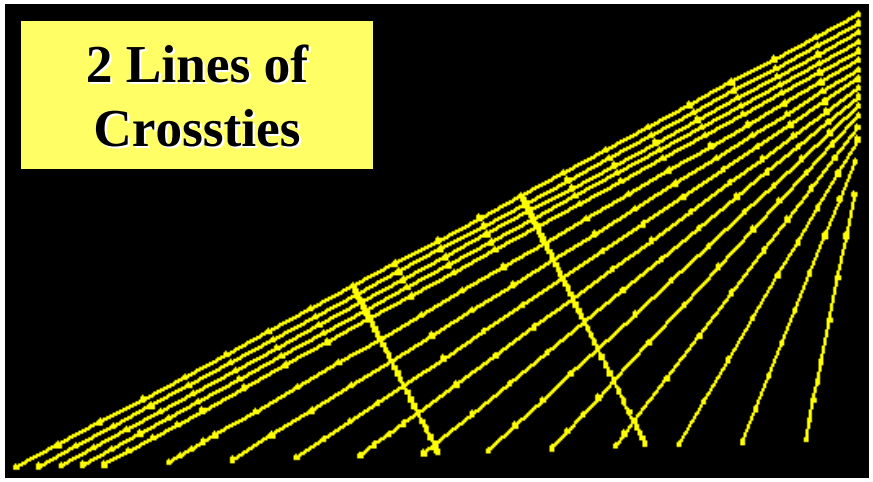
Mode-Frequency Evolution

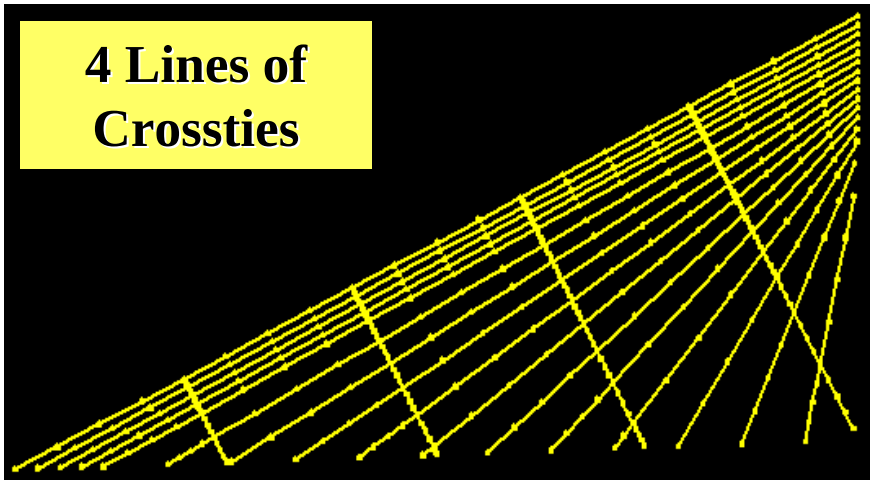


Cross-tying Schemes Analyzed

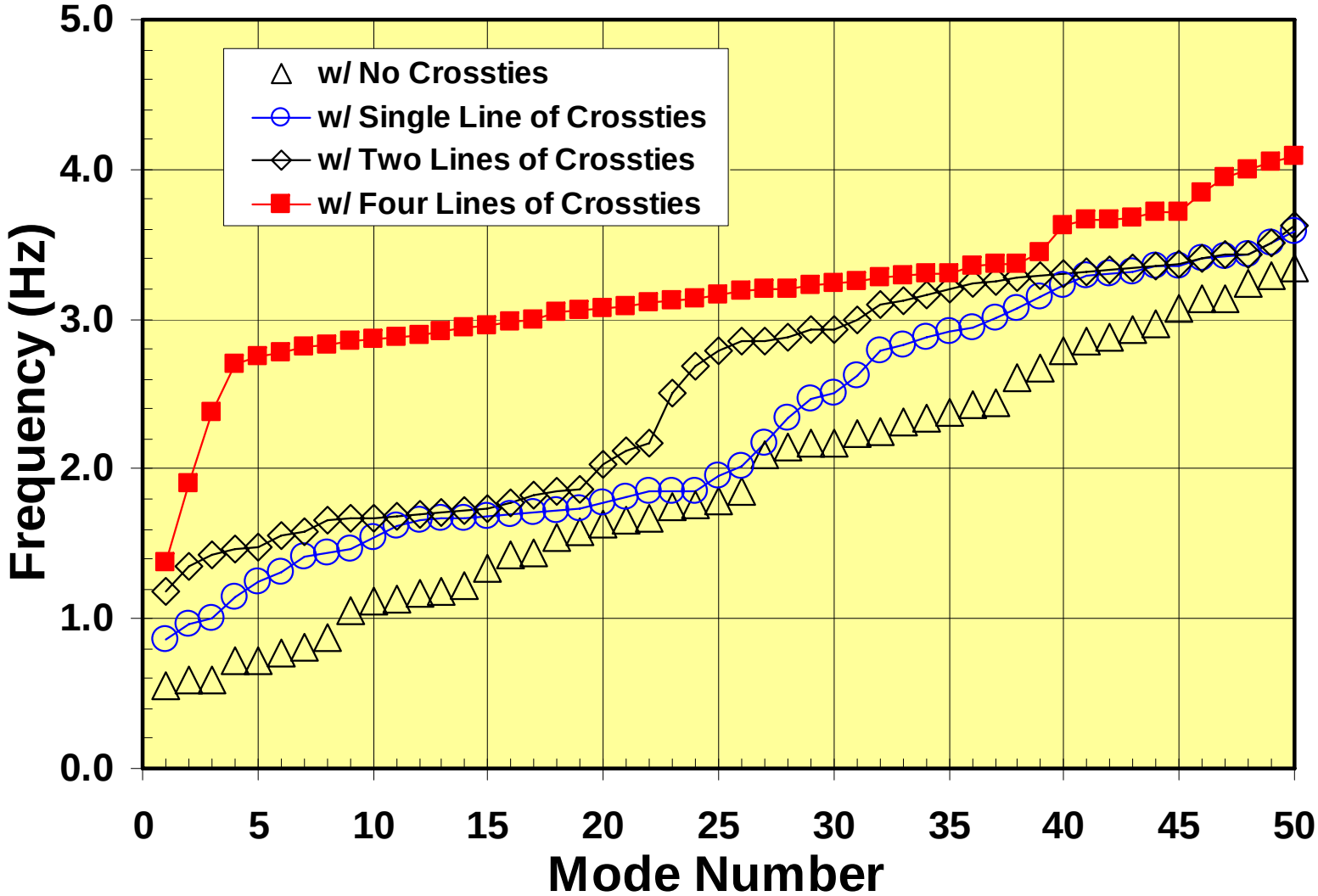




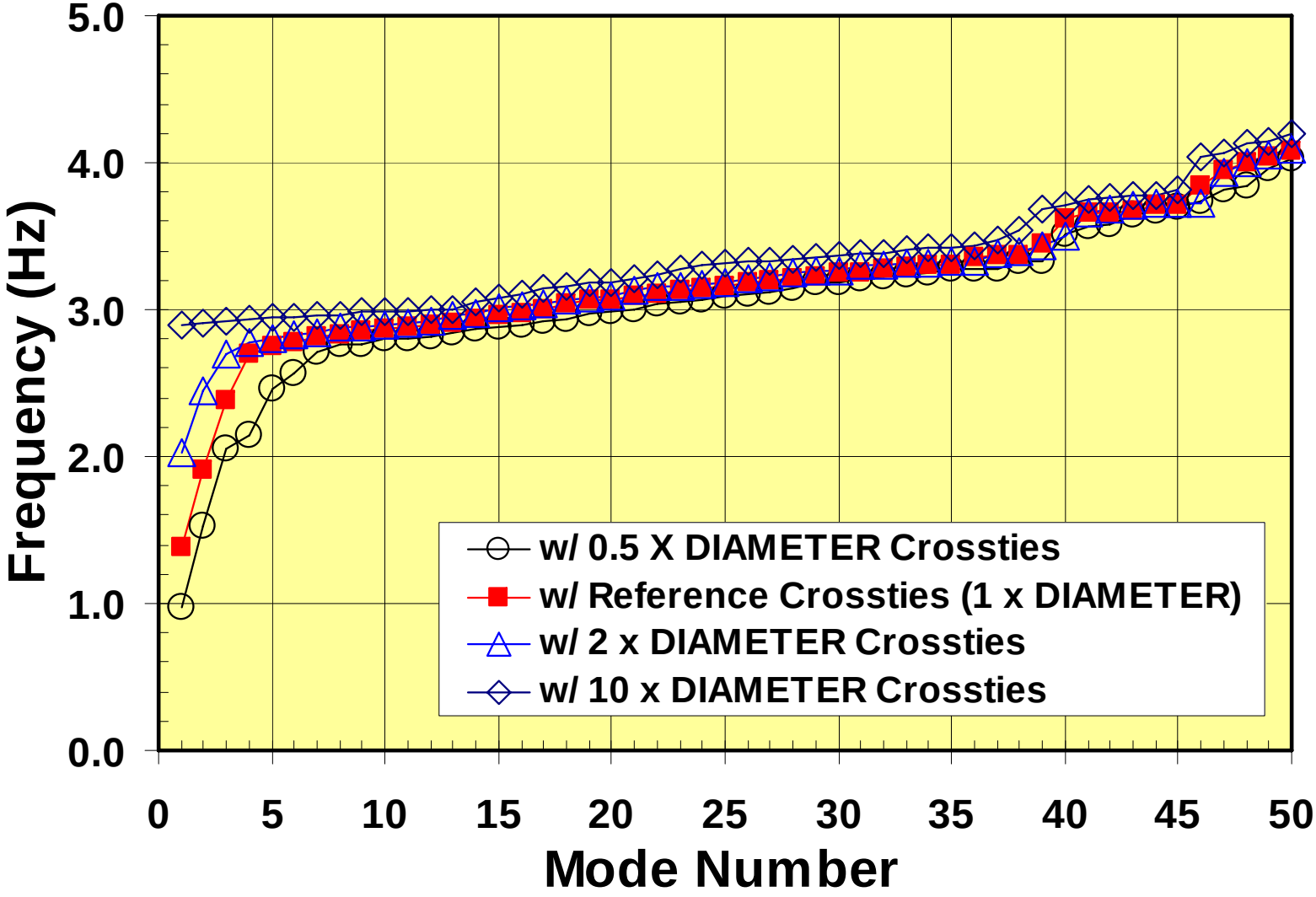




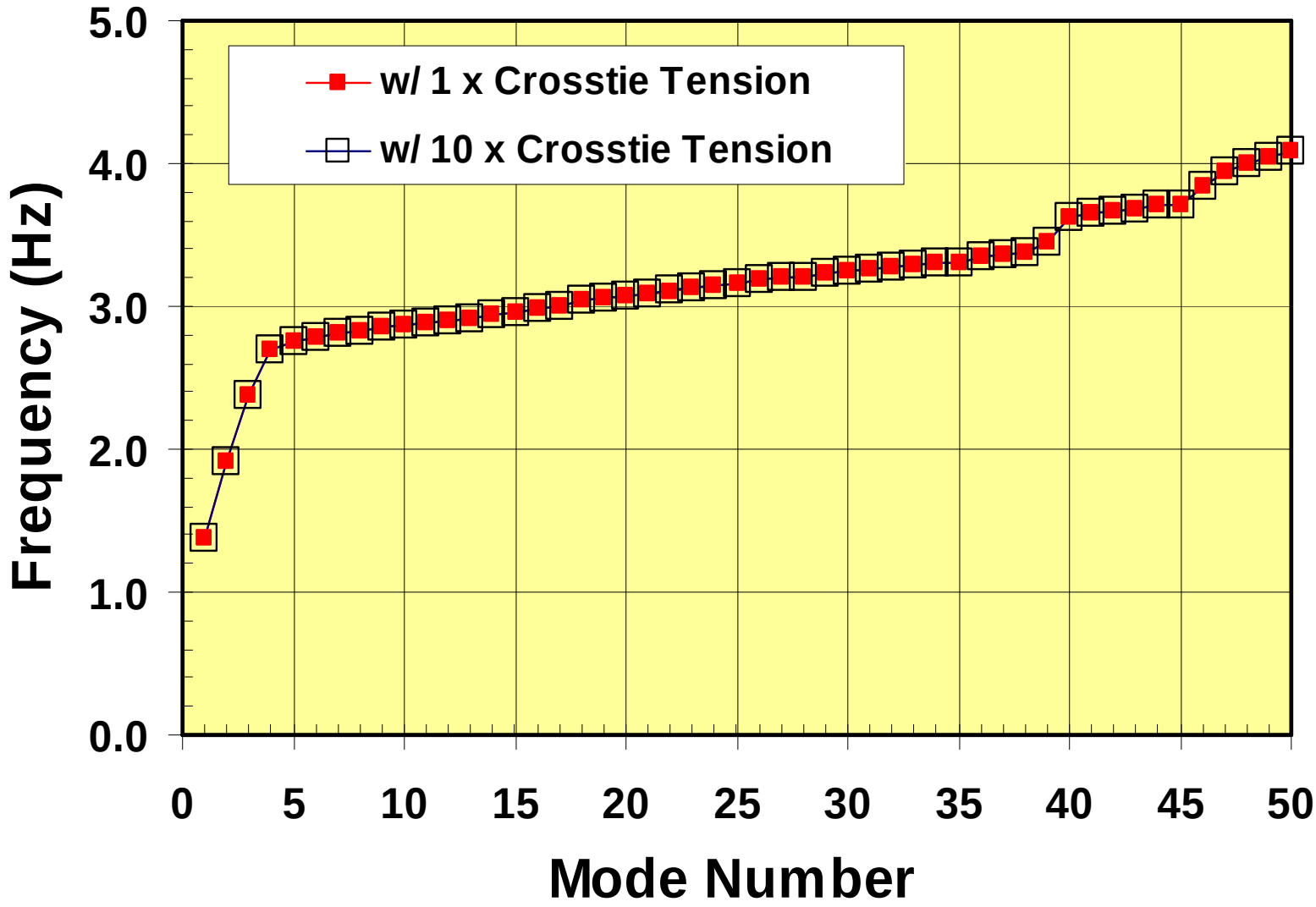
Influence of Crosstie Quantity



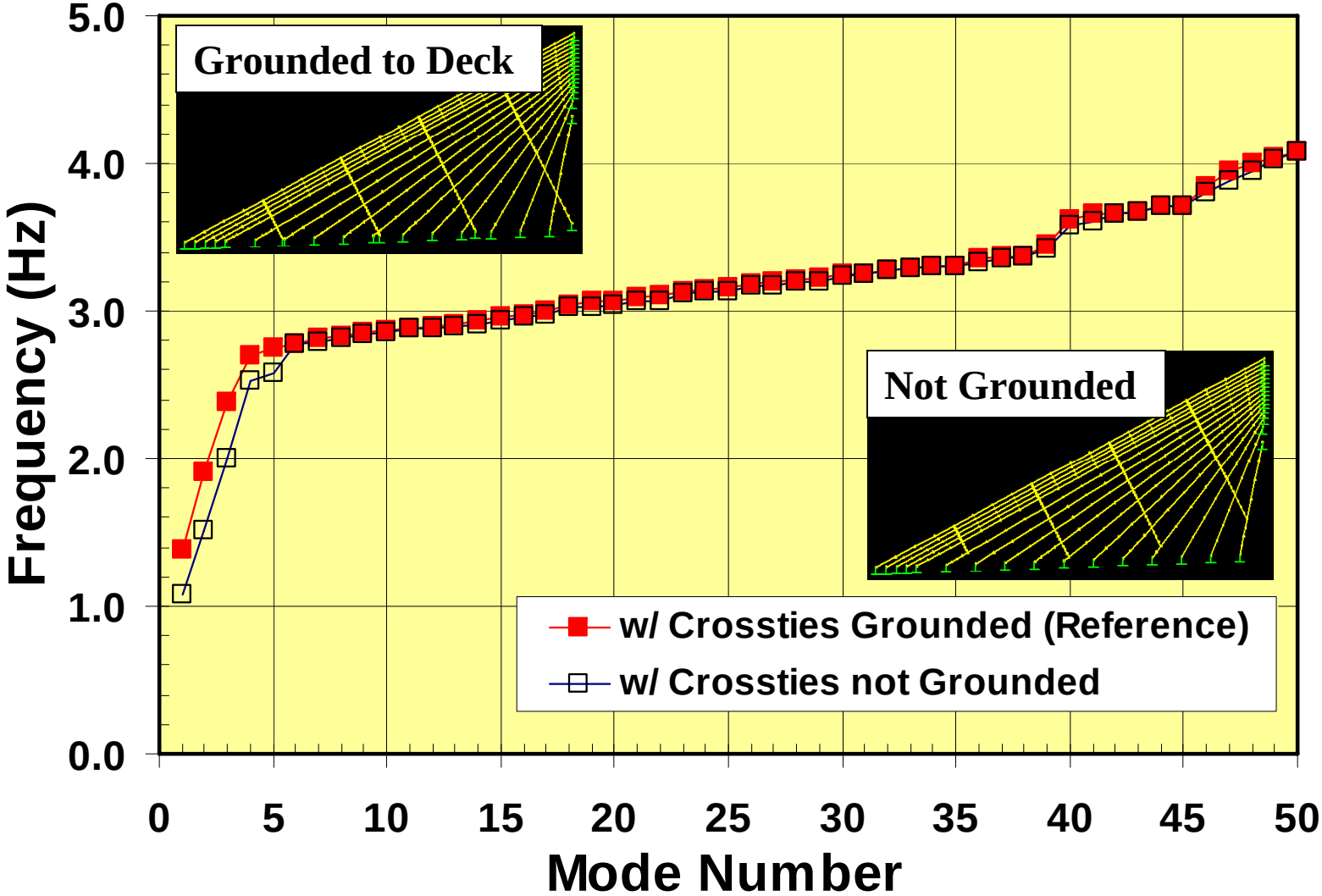
Influence of Crosstie Stiffness



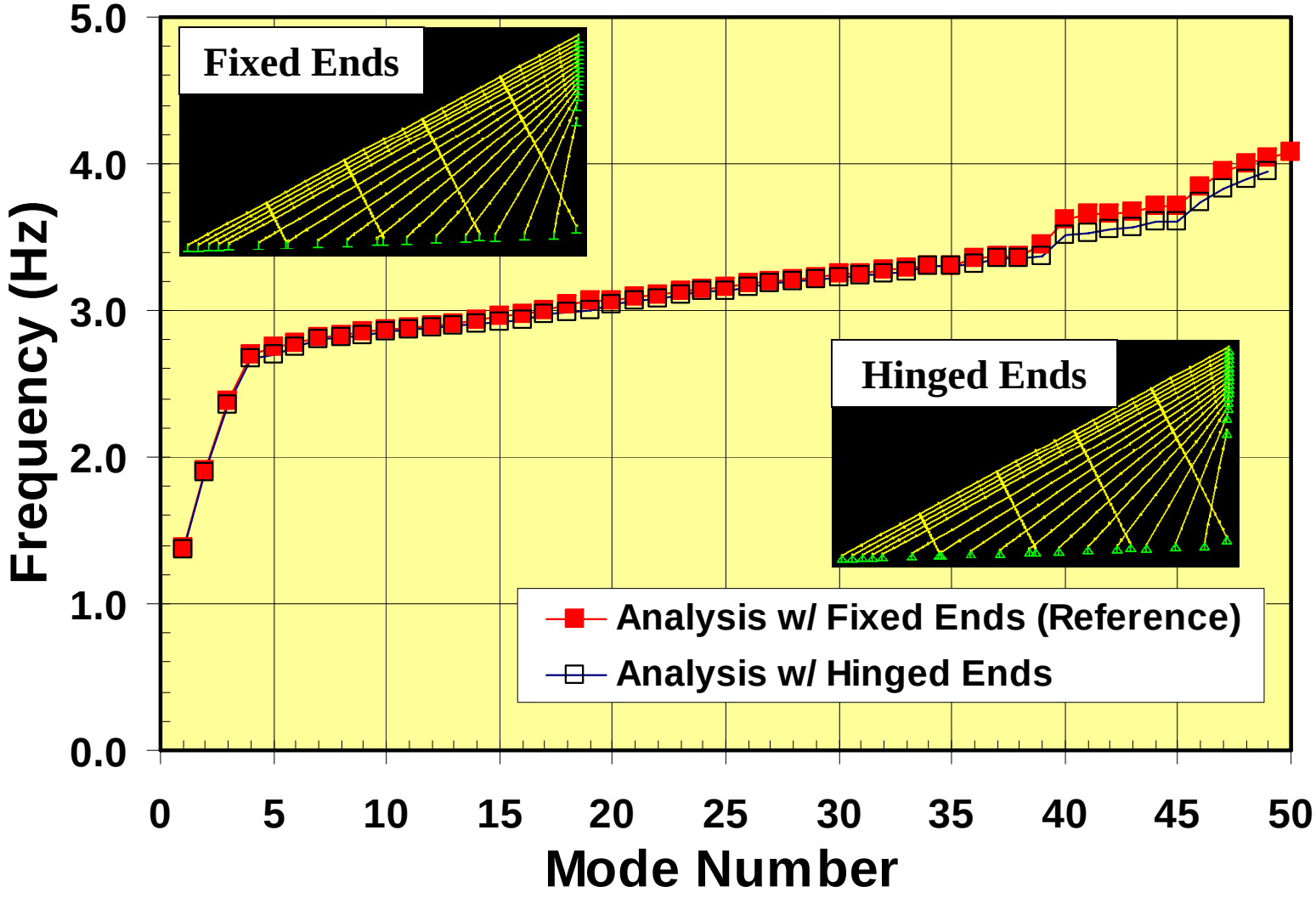
Influence of Crosstie Pre-Tension



Influence of Crosstie Grounding

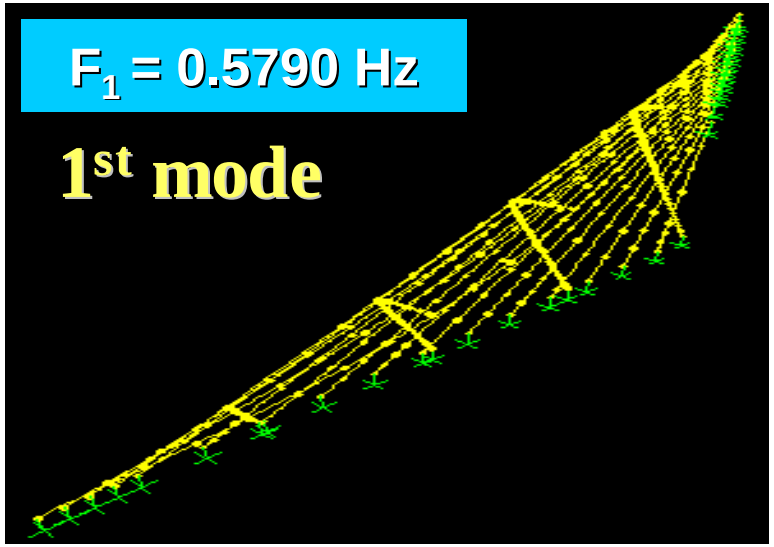


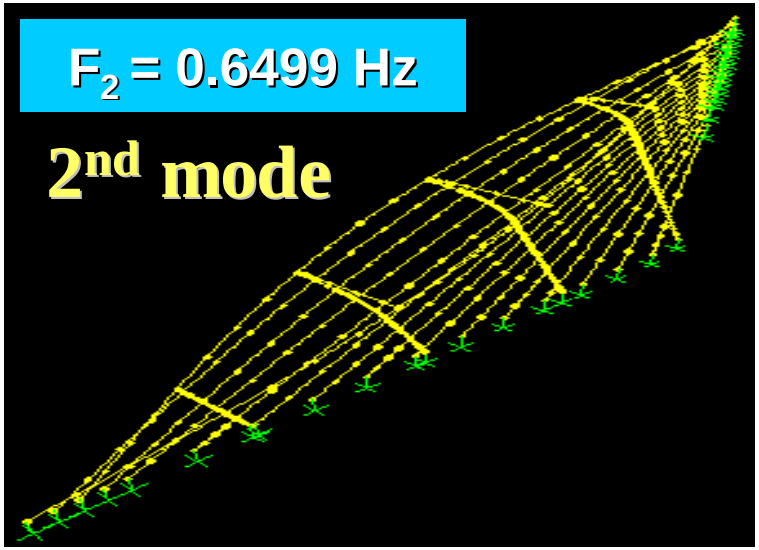
Influence of Cable End Conditions

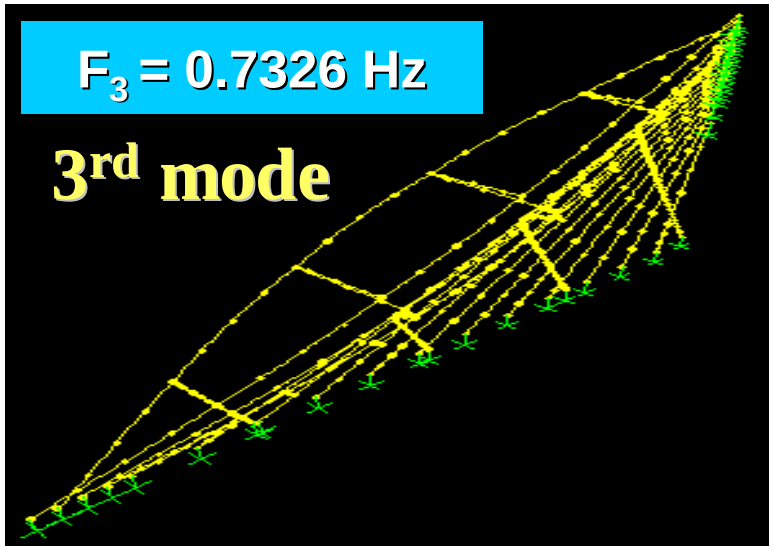


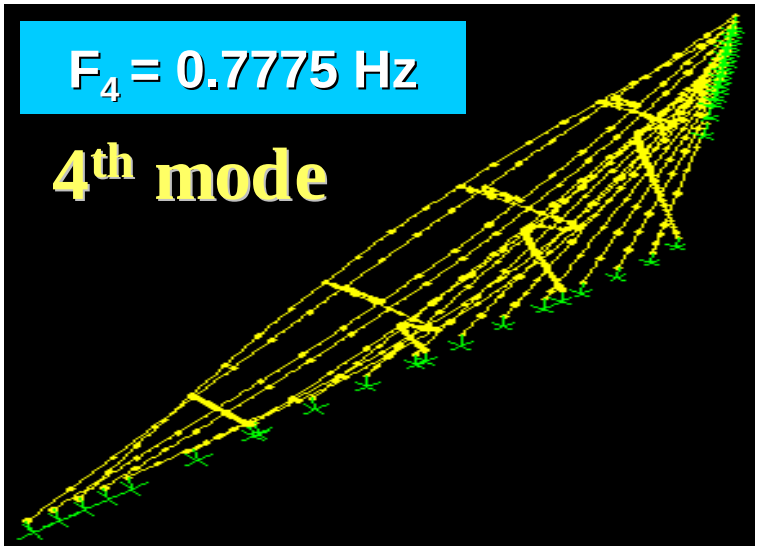
Transverse (out-of-plane) Vibration

- Mode Shapes and Frequencies -



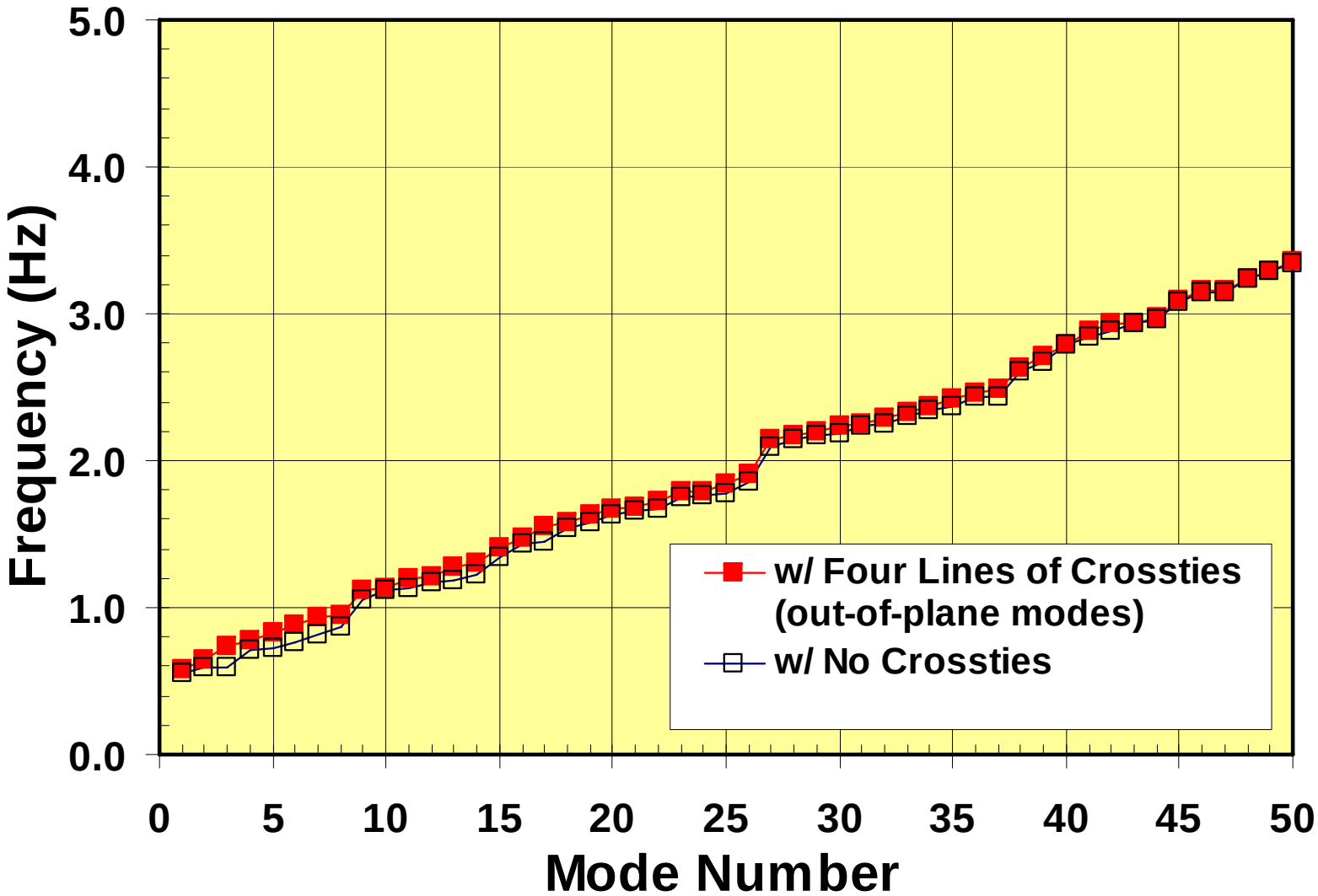






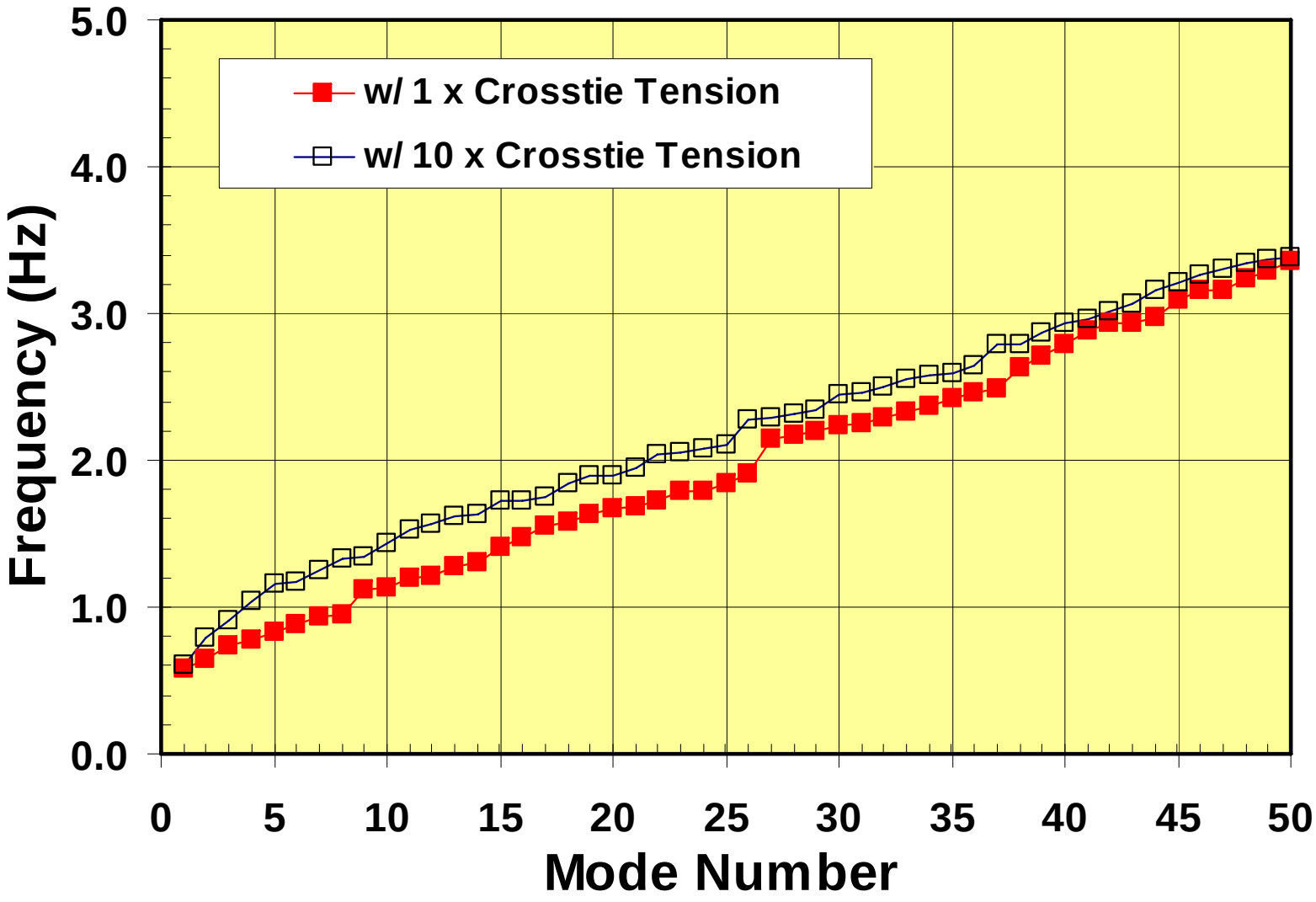
Mode-Frequency Evolution

(Transverse Vibration)



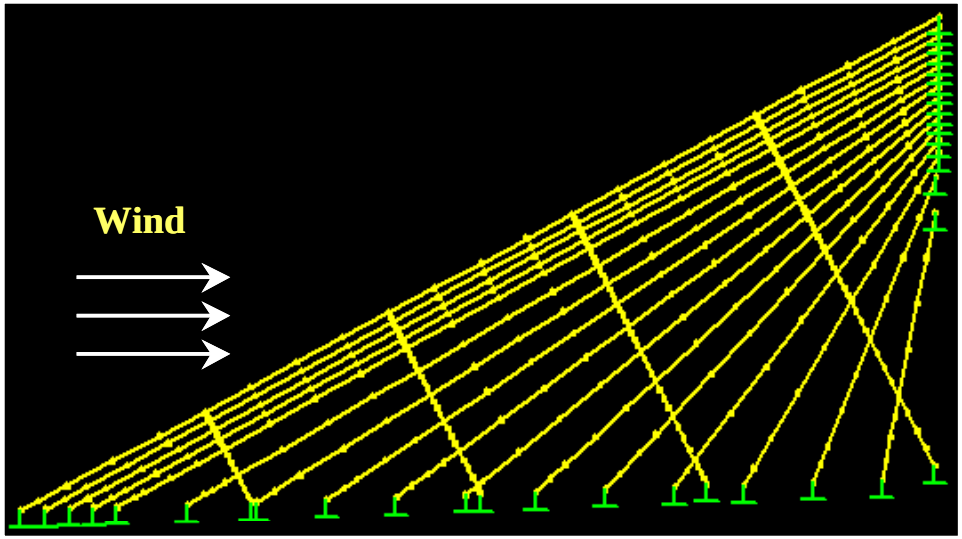
Influence of Cross-tie Pre-Tension

(Transverse Vibration)



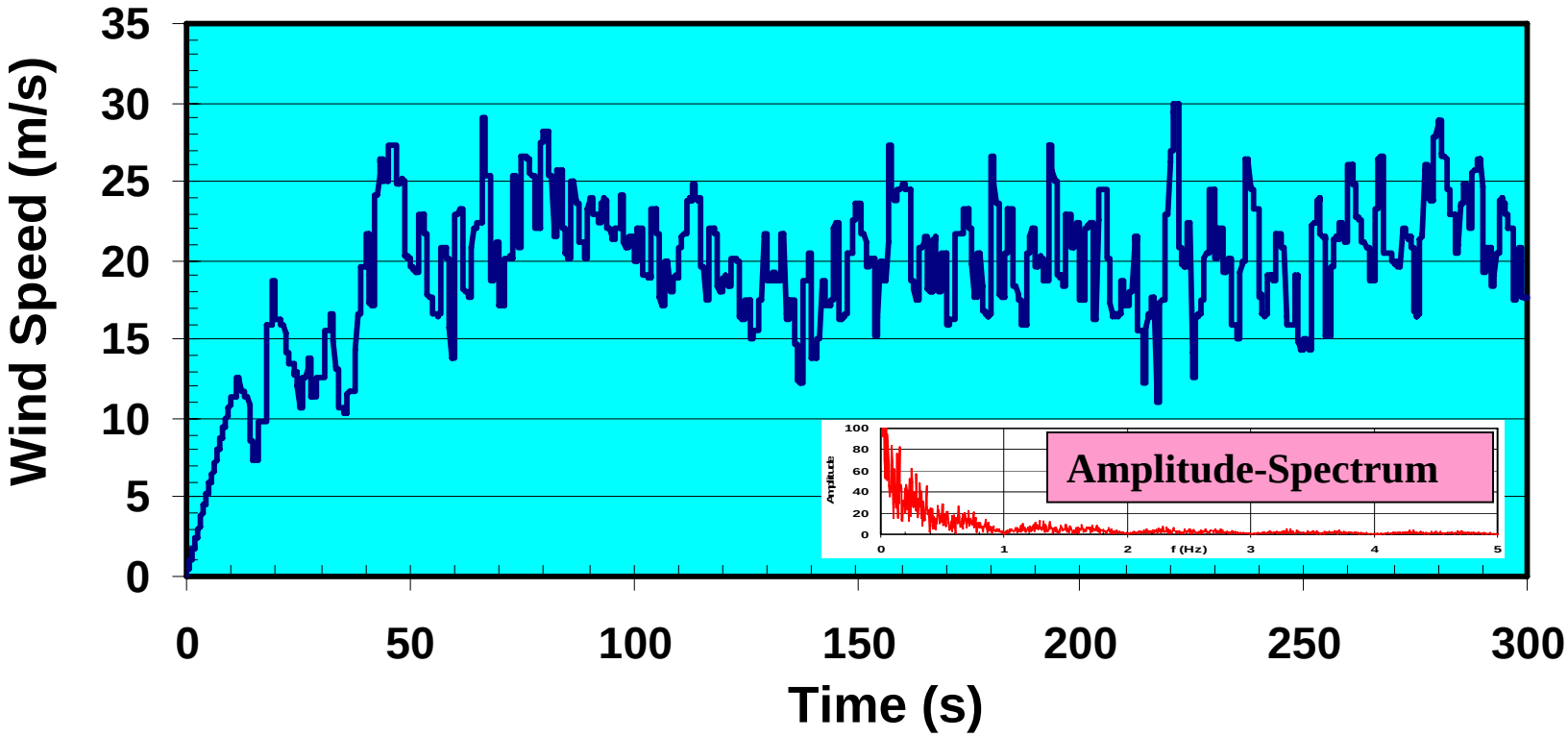
Time-History Analysis

under Transient Wind Loads

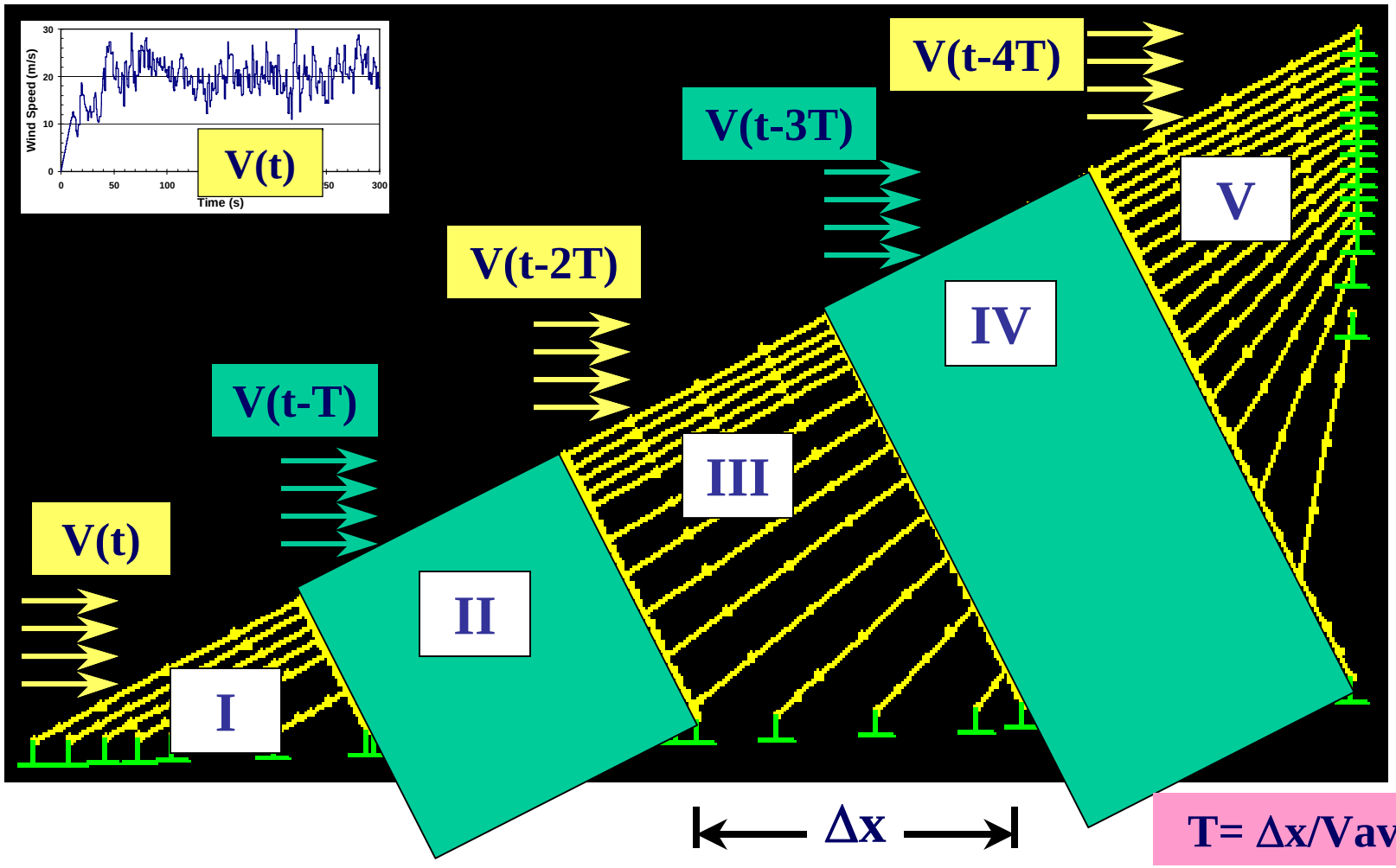


Wind Profile Used

- **Based on 5-min wind speed record**
- **Upscaled to 3-s peak gust speed of 30 m/s**
- **Drag formula used (Cd=1.2)**

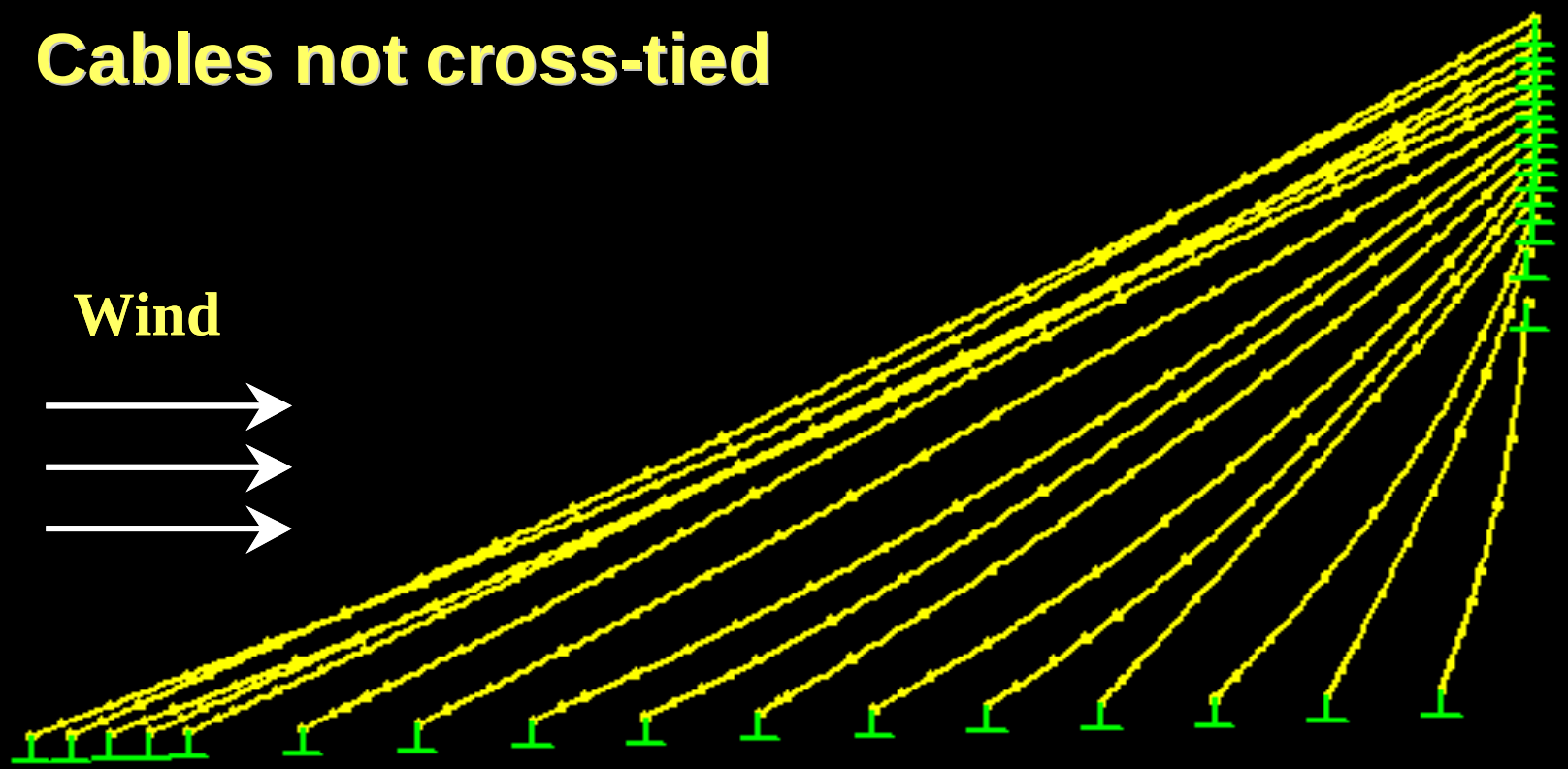


Sequential Wind Loading



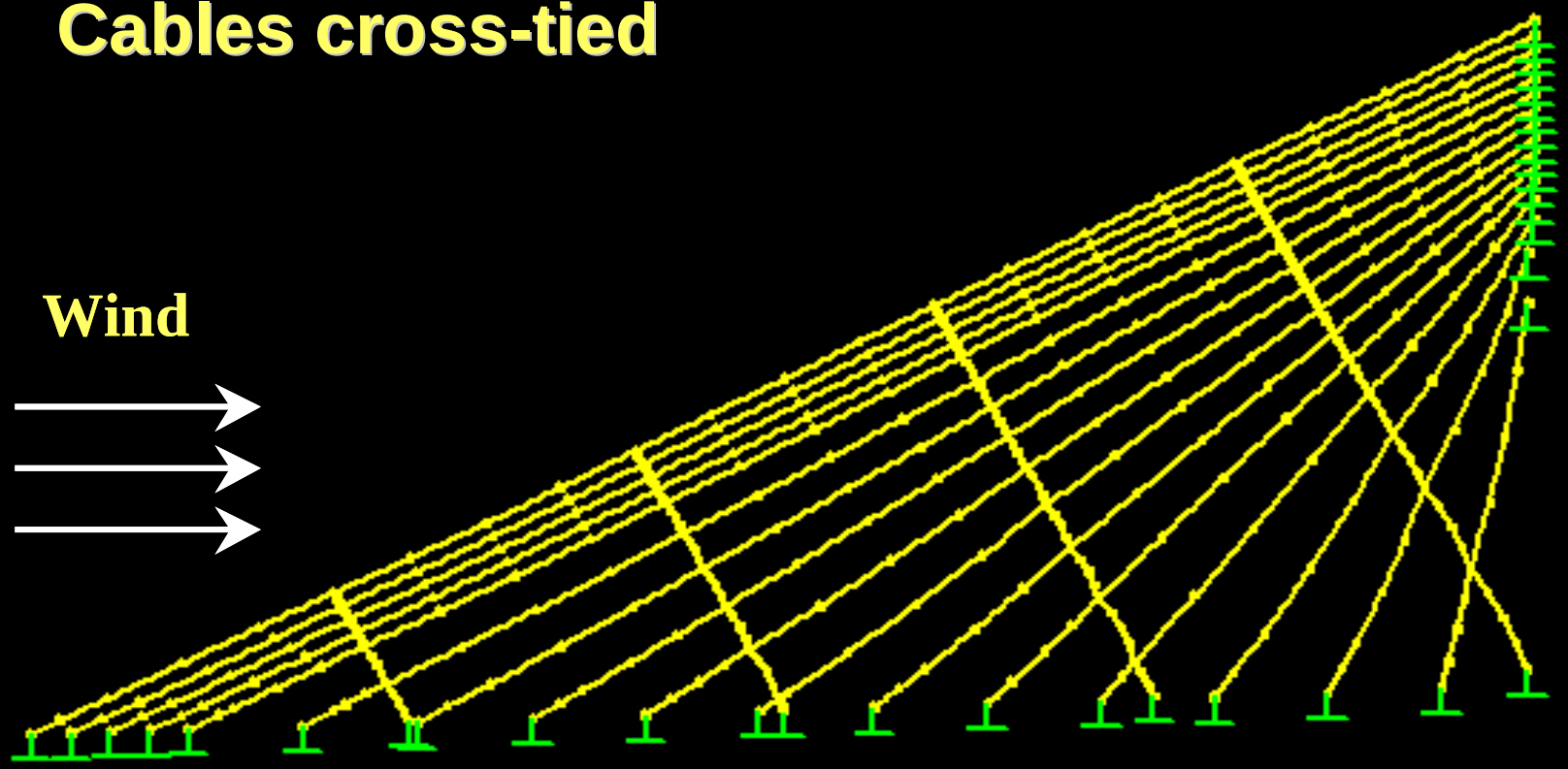
$T = \Delta x / V_{avg}$

Finite Element Simulation (1)



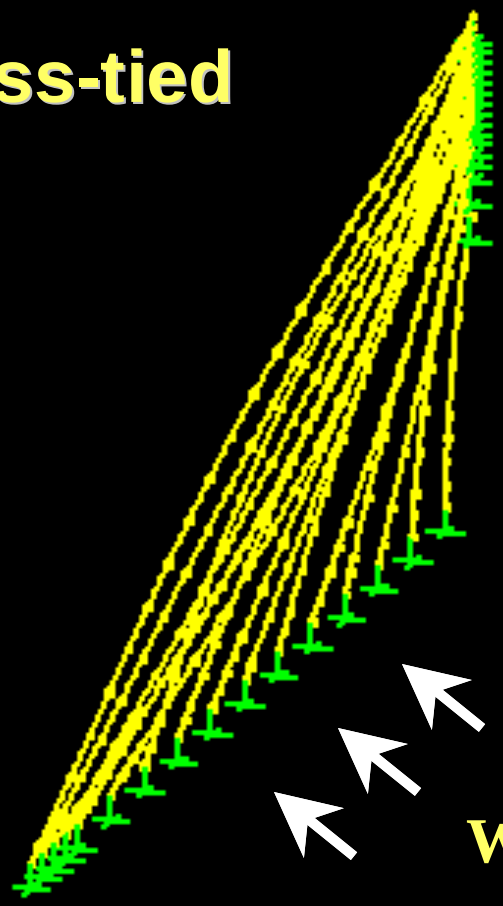
Finite Element Simulation (2)

Cables cross-tied



Finite Element Simulation (3)

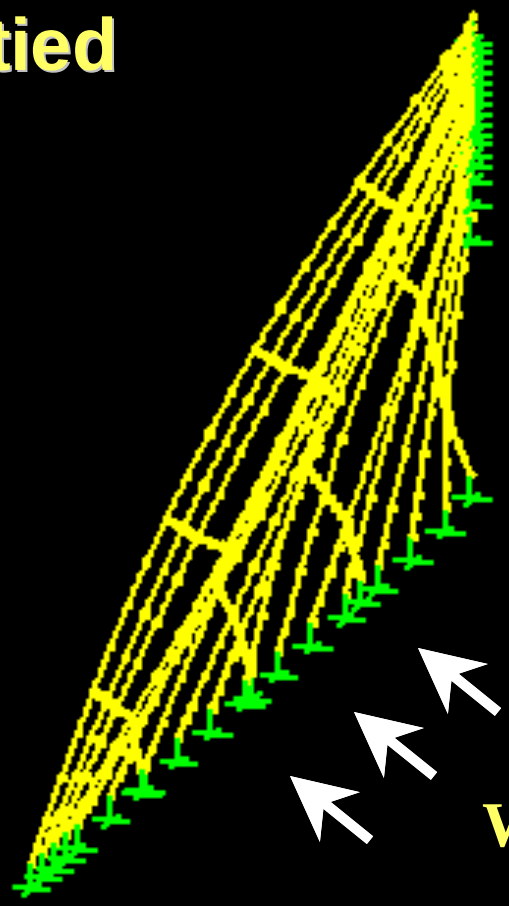
Cables not cross-tied



Wind (transverse)

Finite Element Simulation (4)

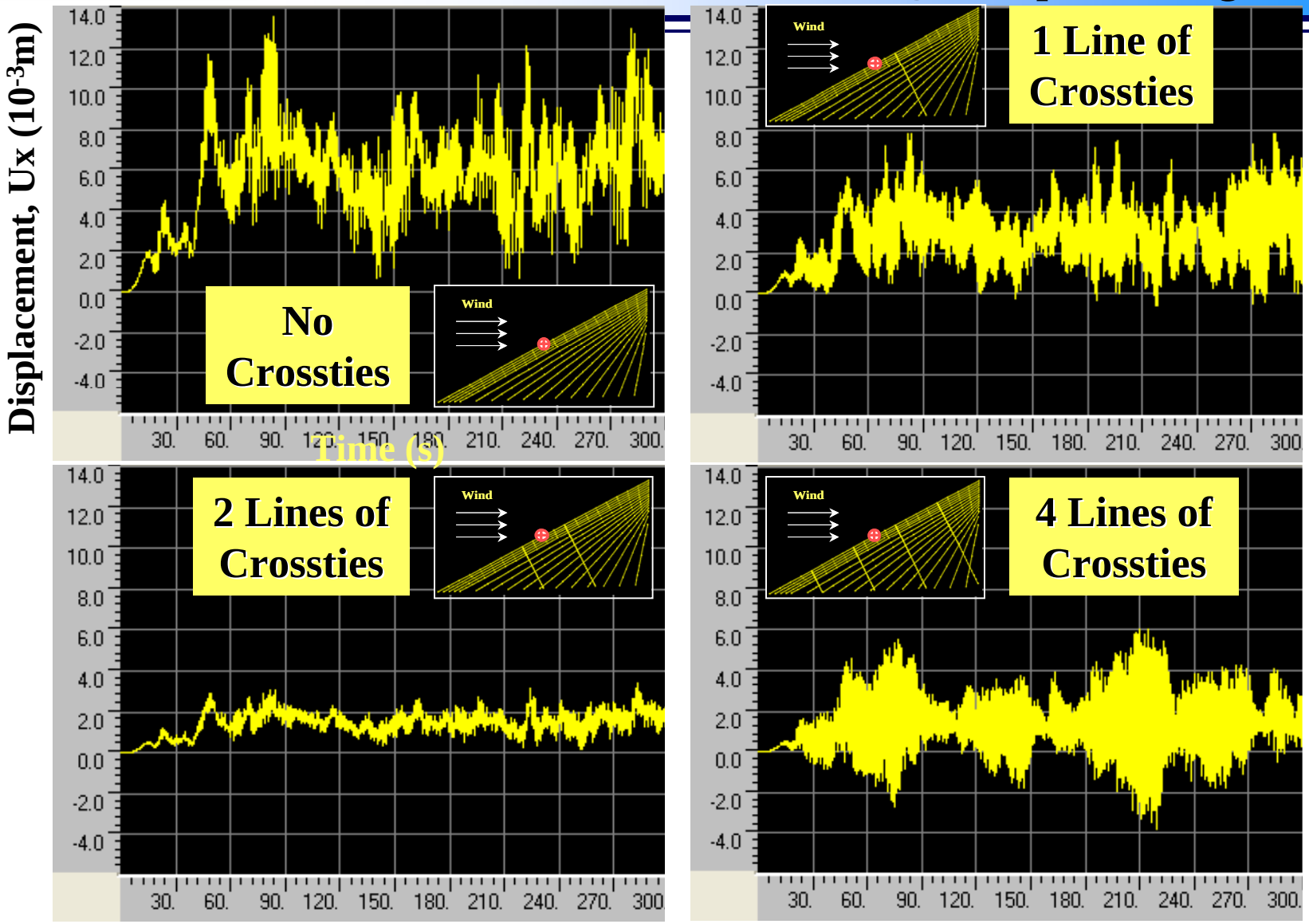
Cables cross-tied



Wind (transverse)

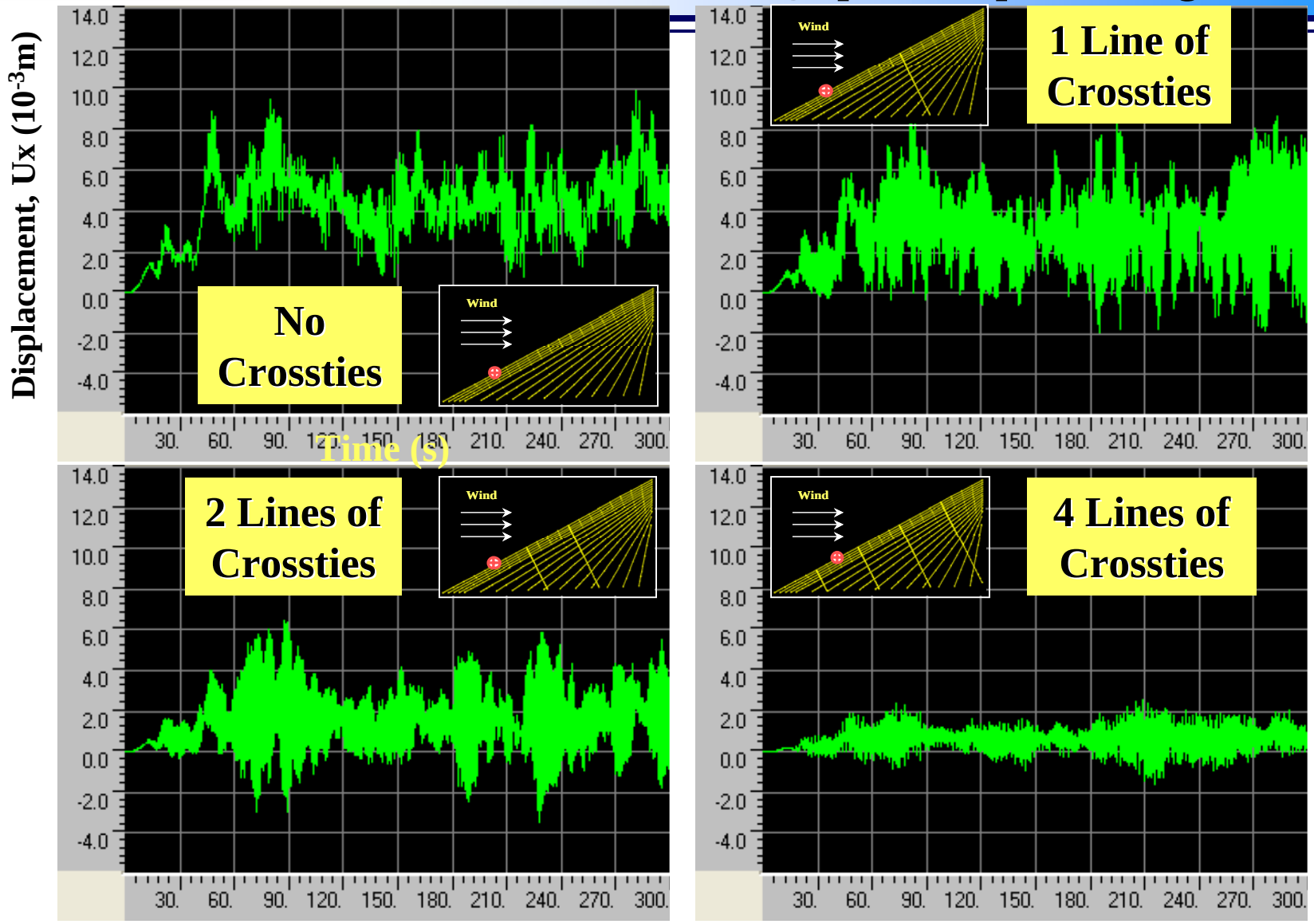
Sample Displacement Profile (1)

@ midspan of longest cable



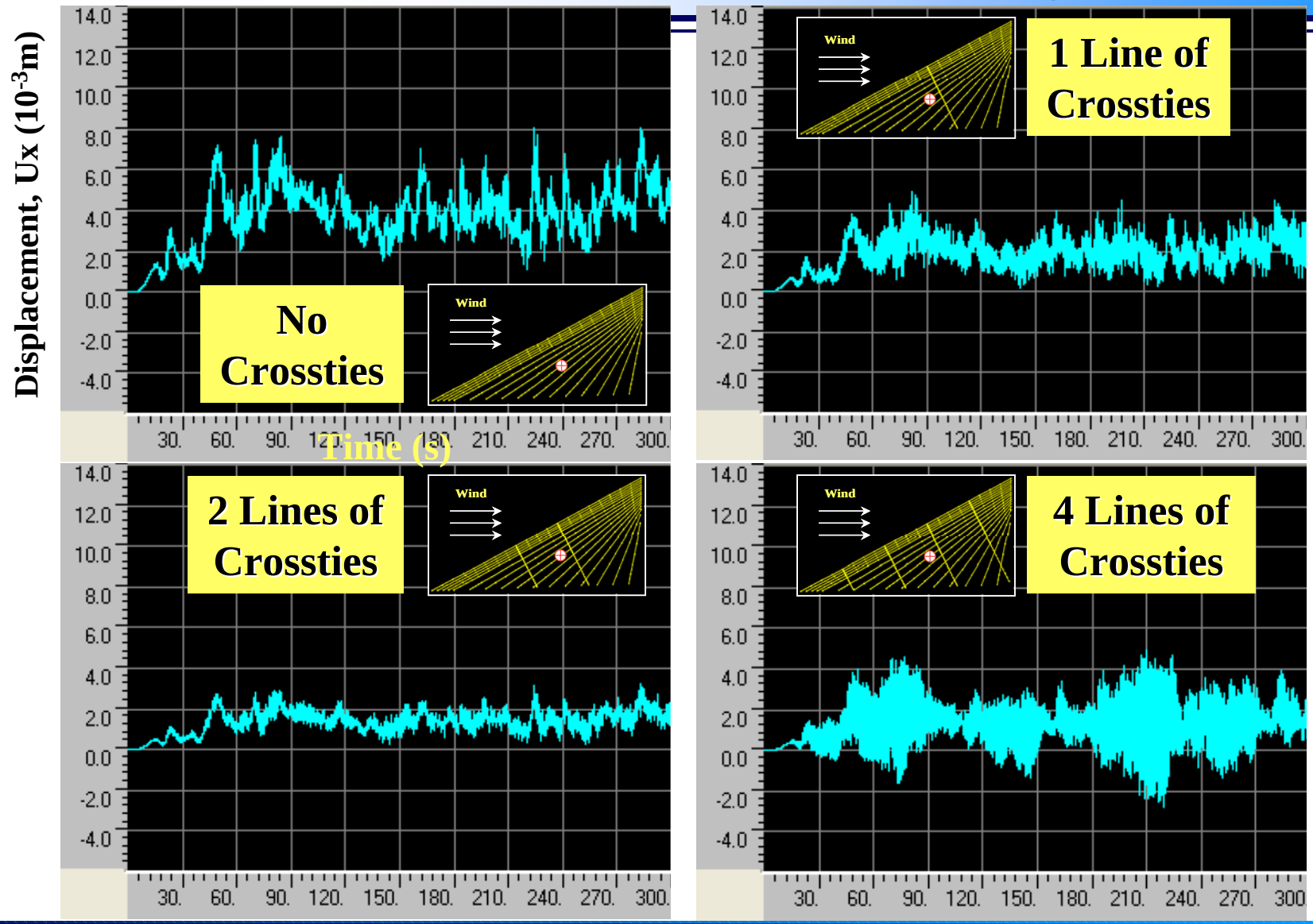
Sample Displacement Profile (2)

@ quarter-span of longest cable



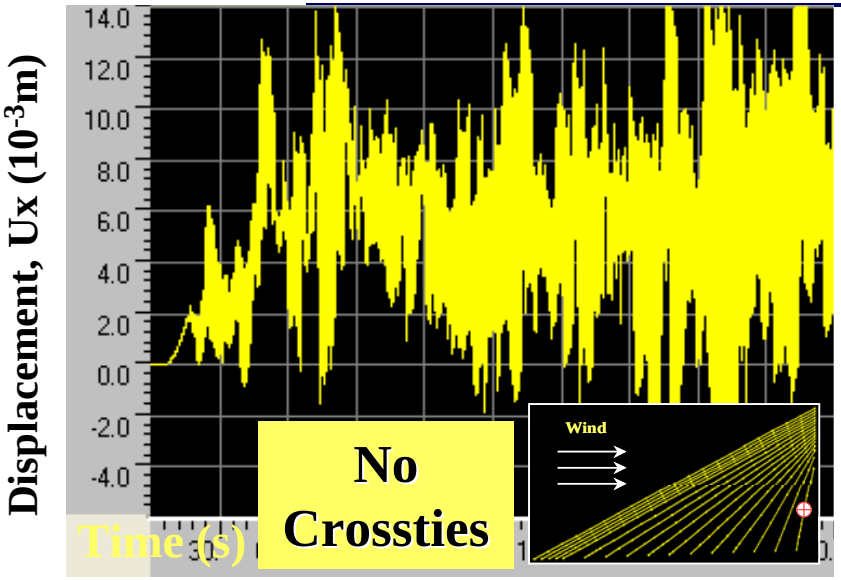
Sample Displacement Profile (3)

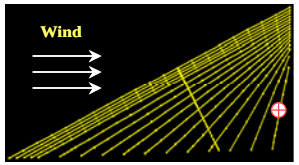
@ network center



Sample Displacement Profile (4)

@ midspan of shortest cable

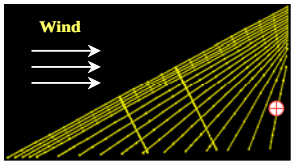




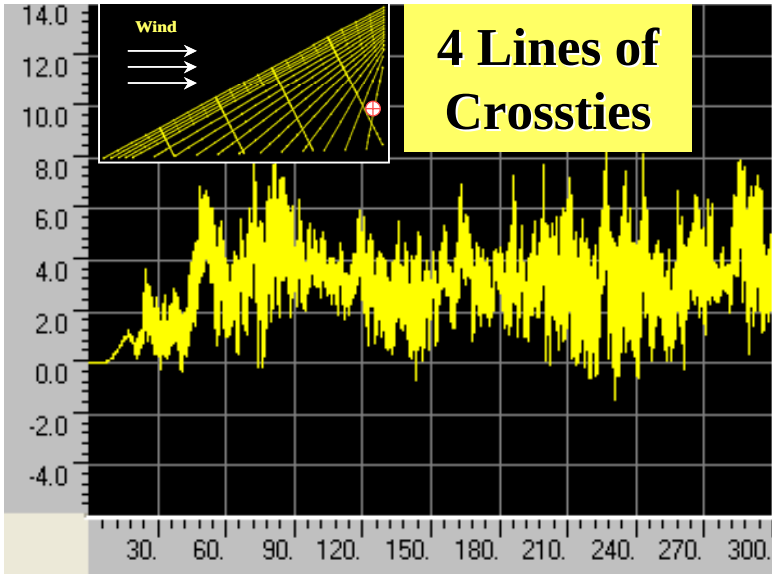
1 Line of Crossties

(Same as Left)

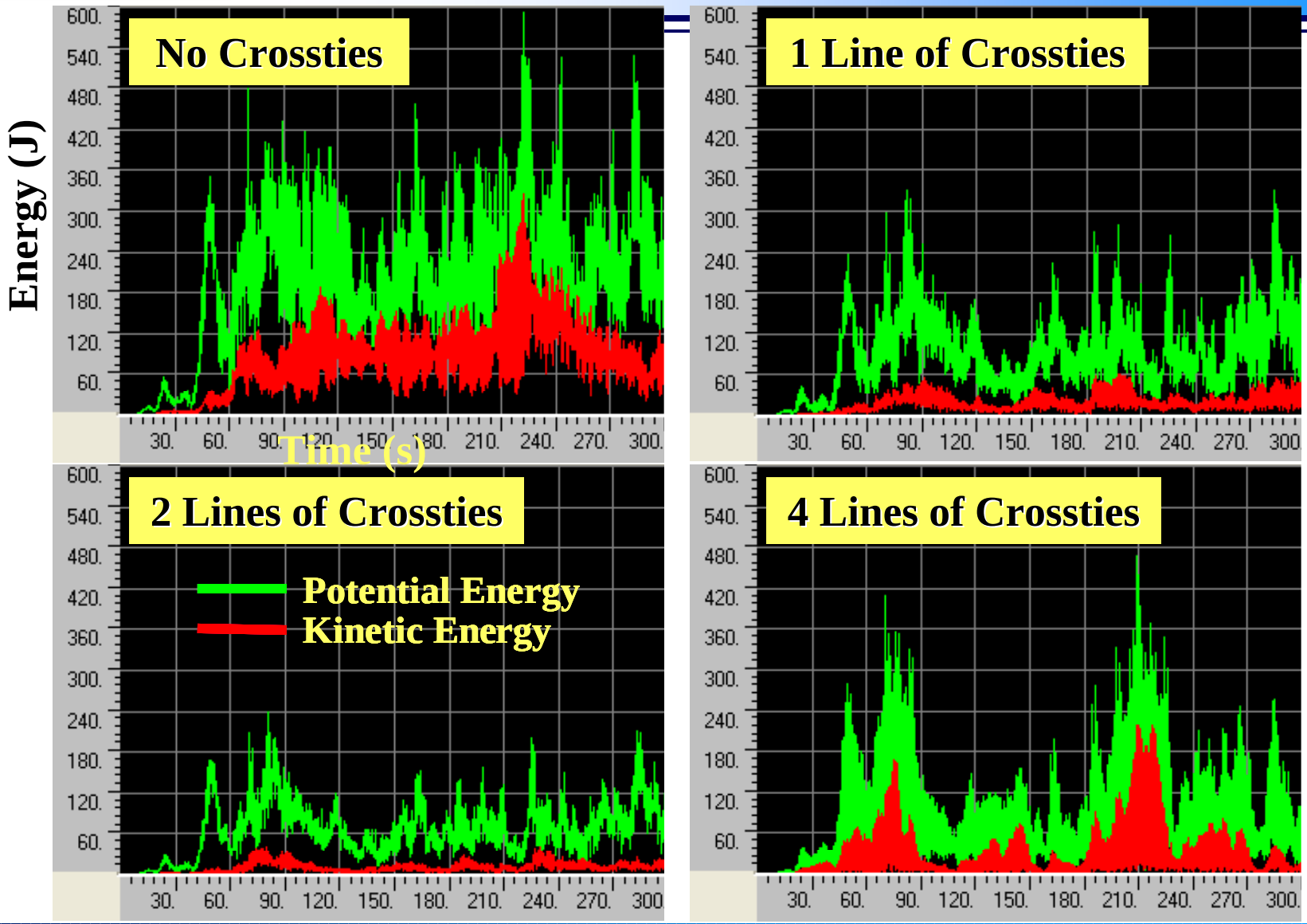
2 Lines of Crossties



(Same as Above)

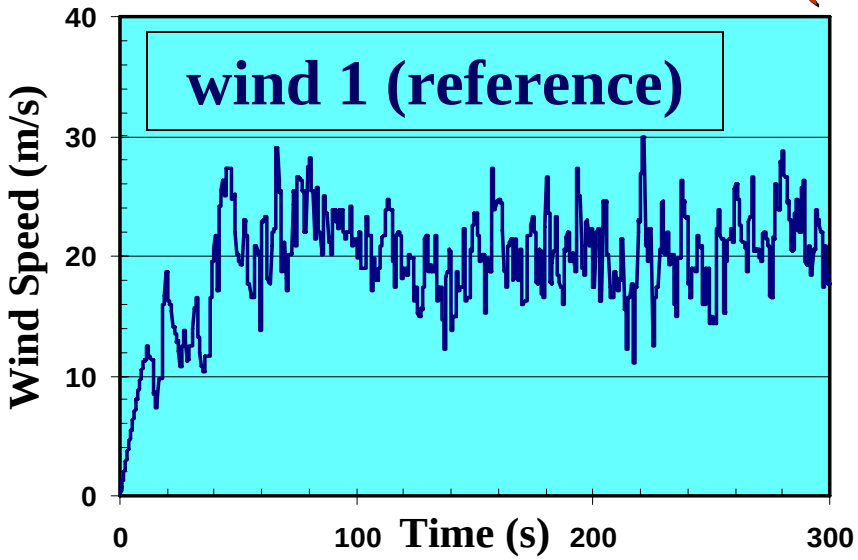


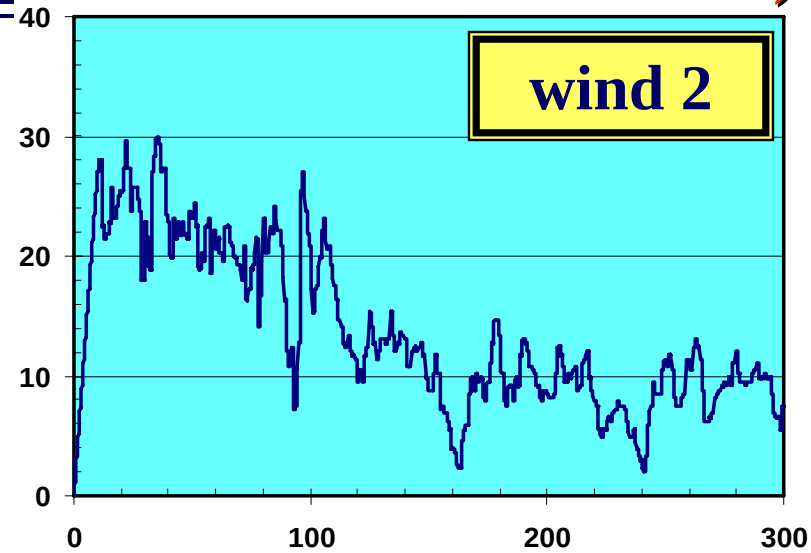
Energy Evolution of the cable system

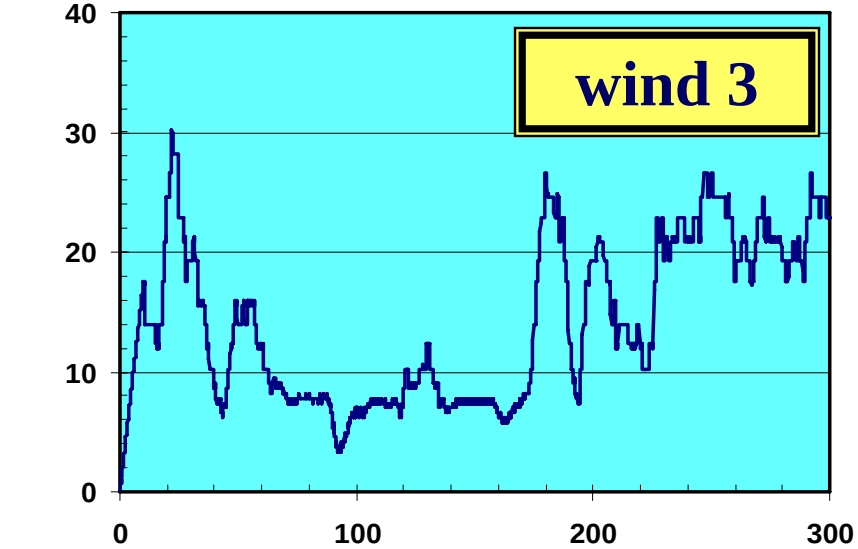


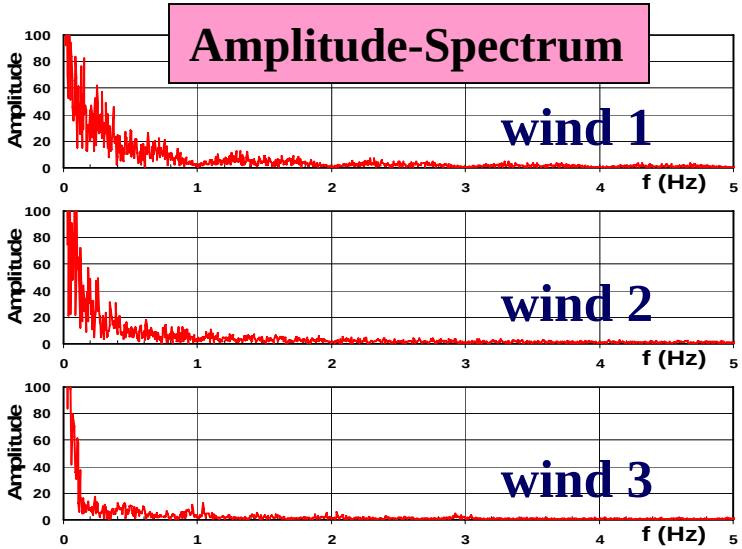
Other Wind Profiles Tested (1)

(based on measured wind records)



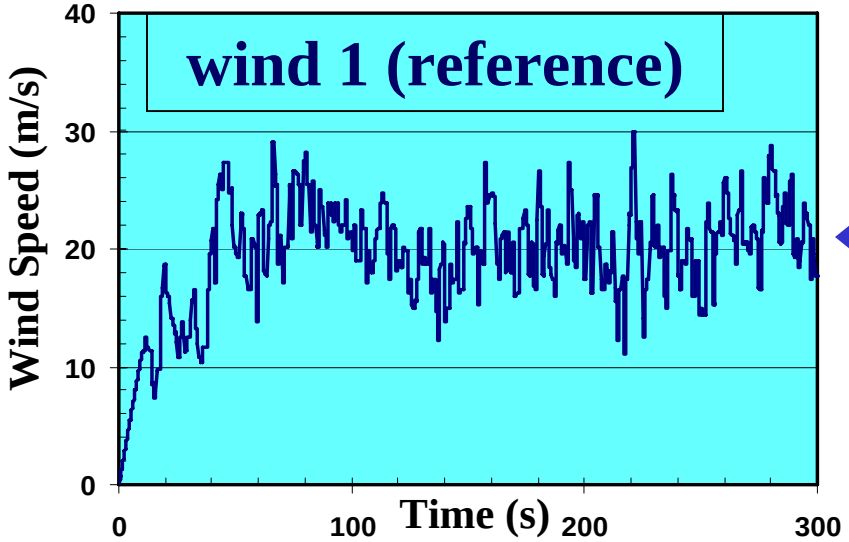




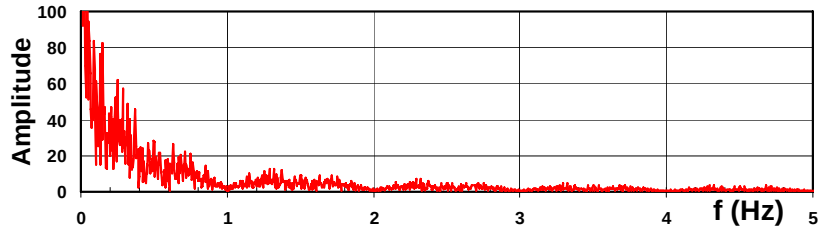


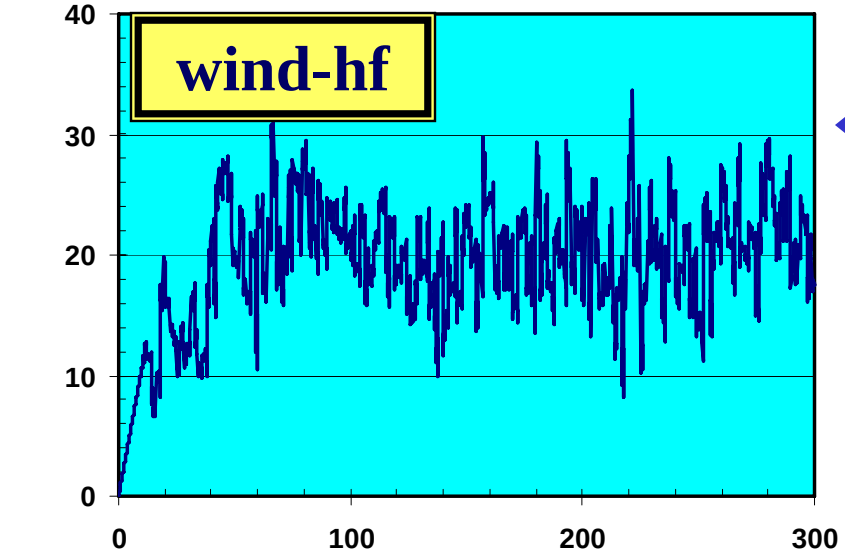
Other Wind Profiles Tested (2)

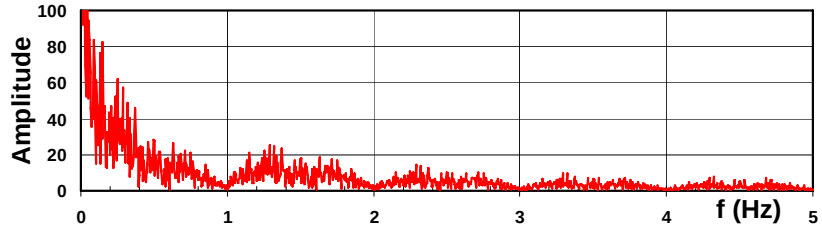
(An artificial profile to test vulnerability to high-frequency wind components)



Amplitude-Spectrum





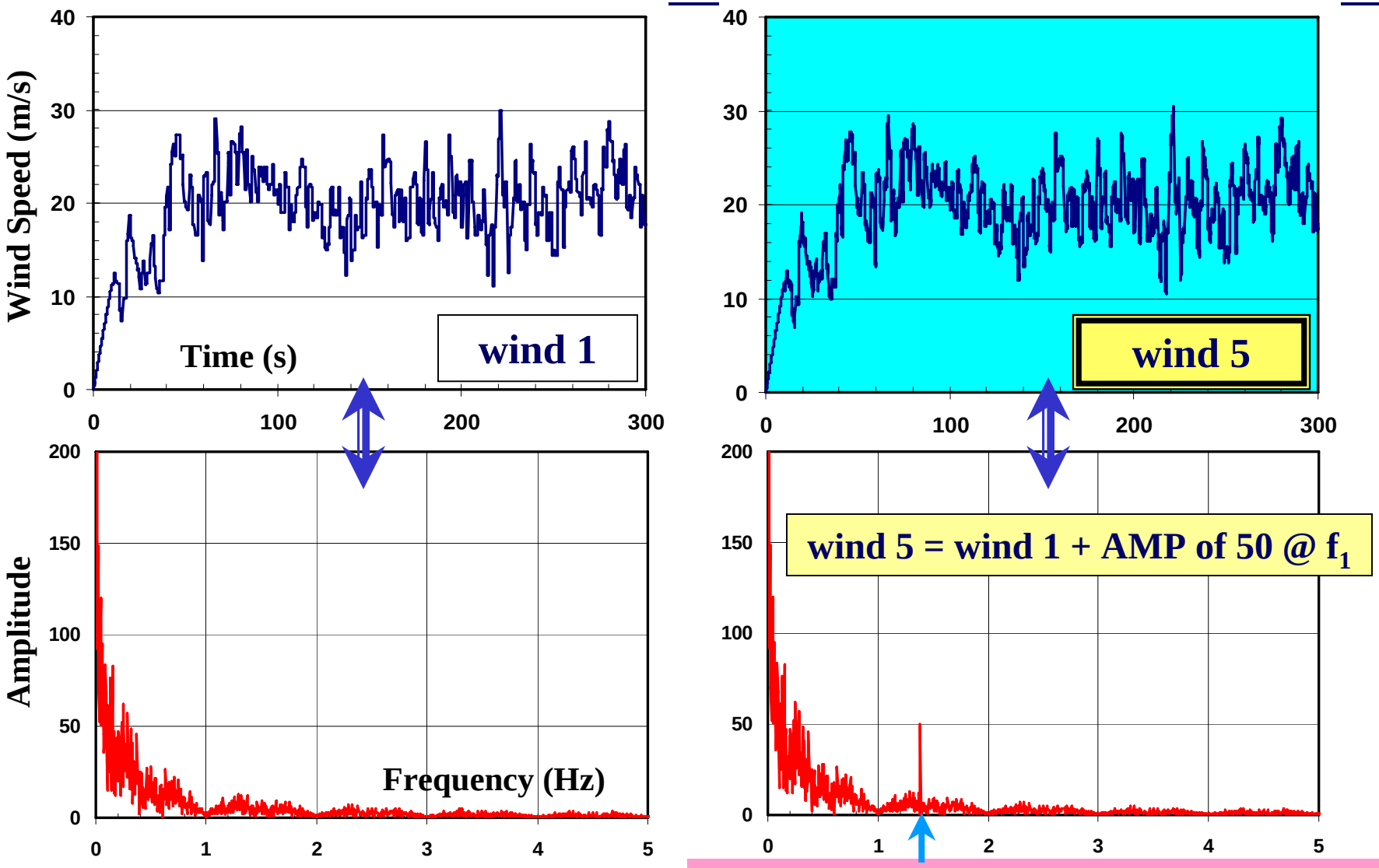


"wind-hf" = "wind-1" with 2 x Amplitude for f > 1 Hz

(high-frequency components doubled)

Other Wind Profiles Tested (3)

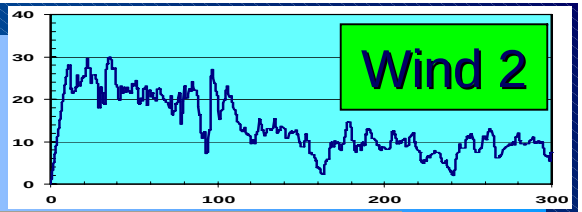
(An artificial profile to test vulnerability to resonant wind load)

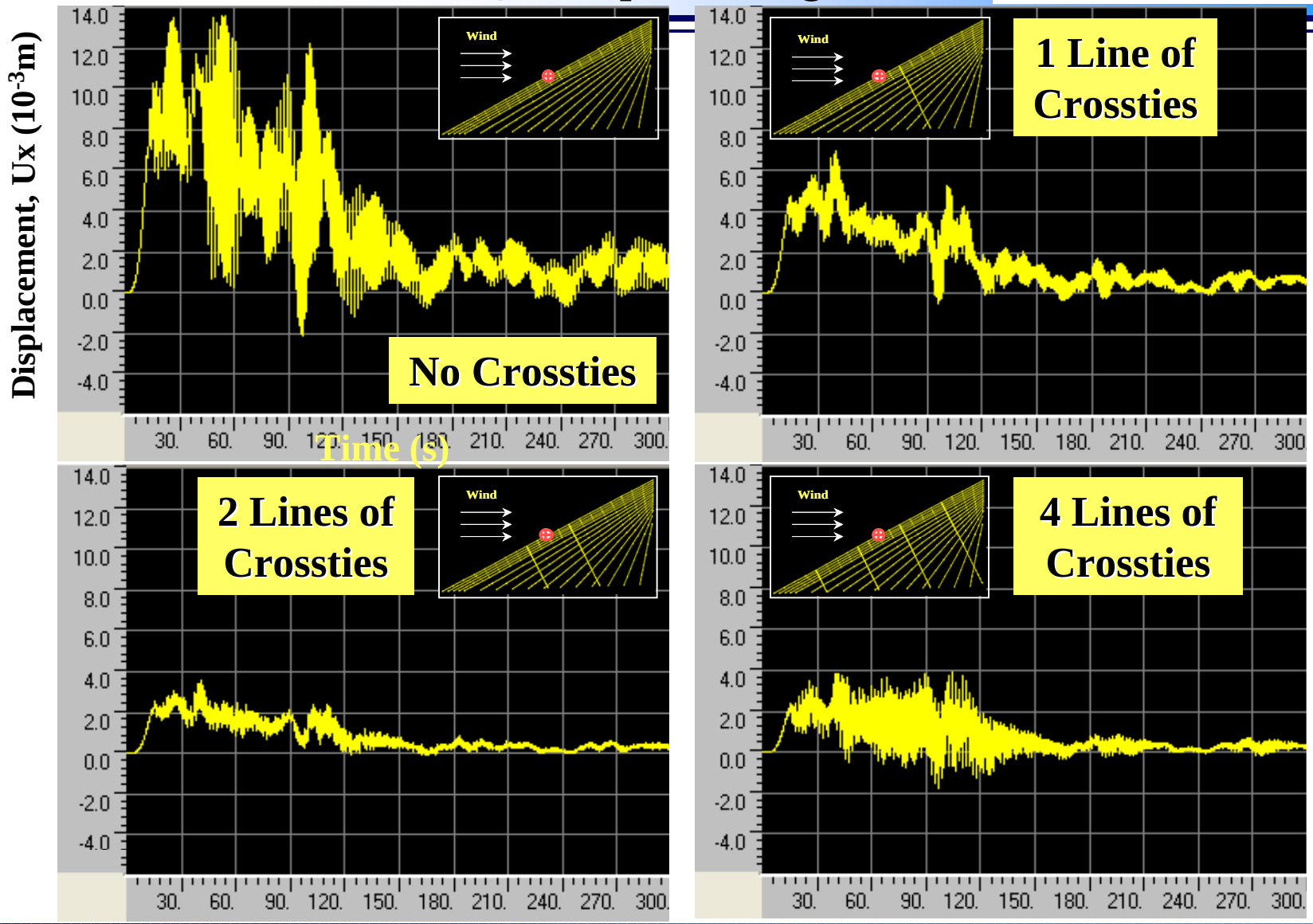


f_1=1.38 Hz : Network's 1st mode frequency

Displacement

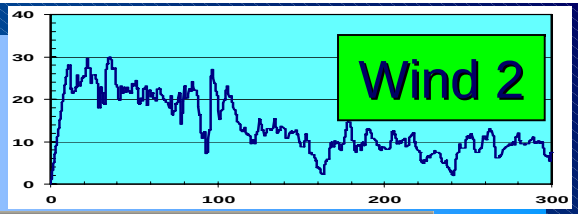
@ midspan of longest cable

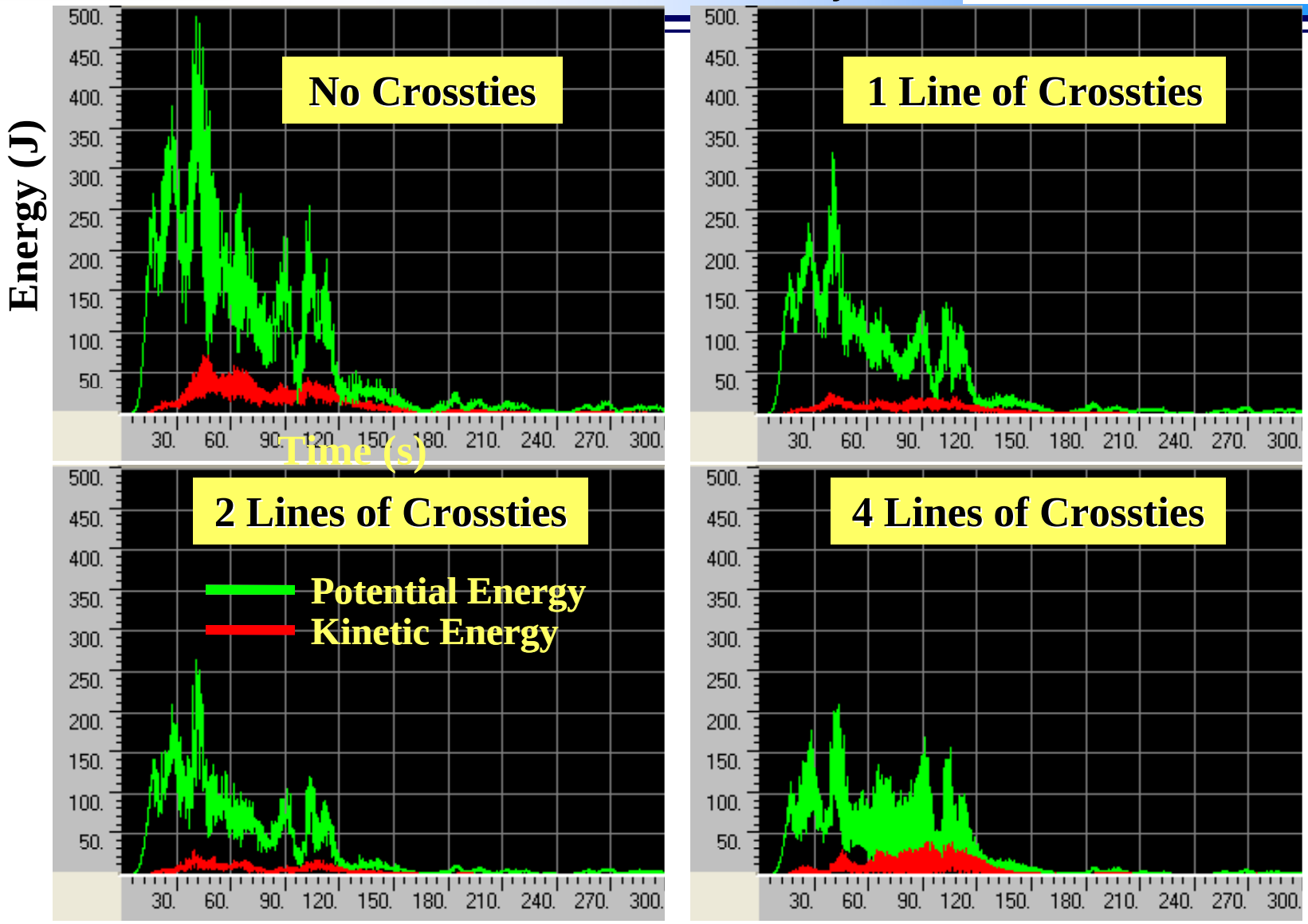




Energy Evolution

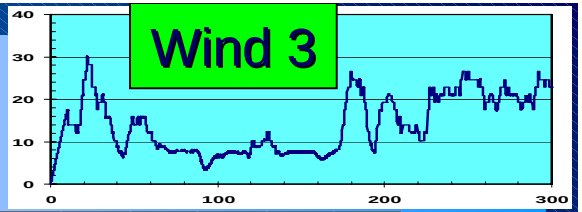
of the cable system

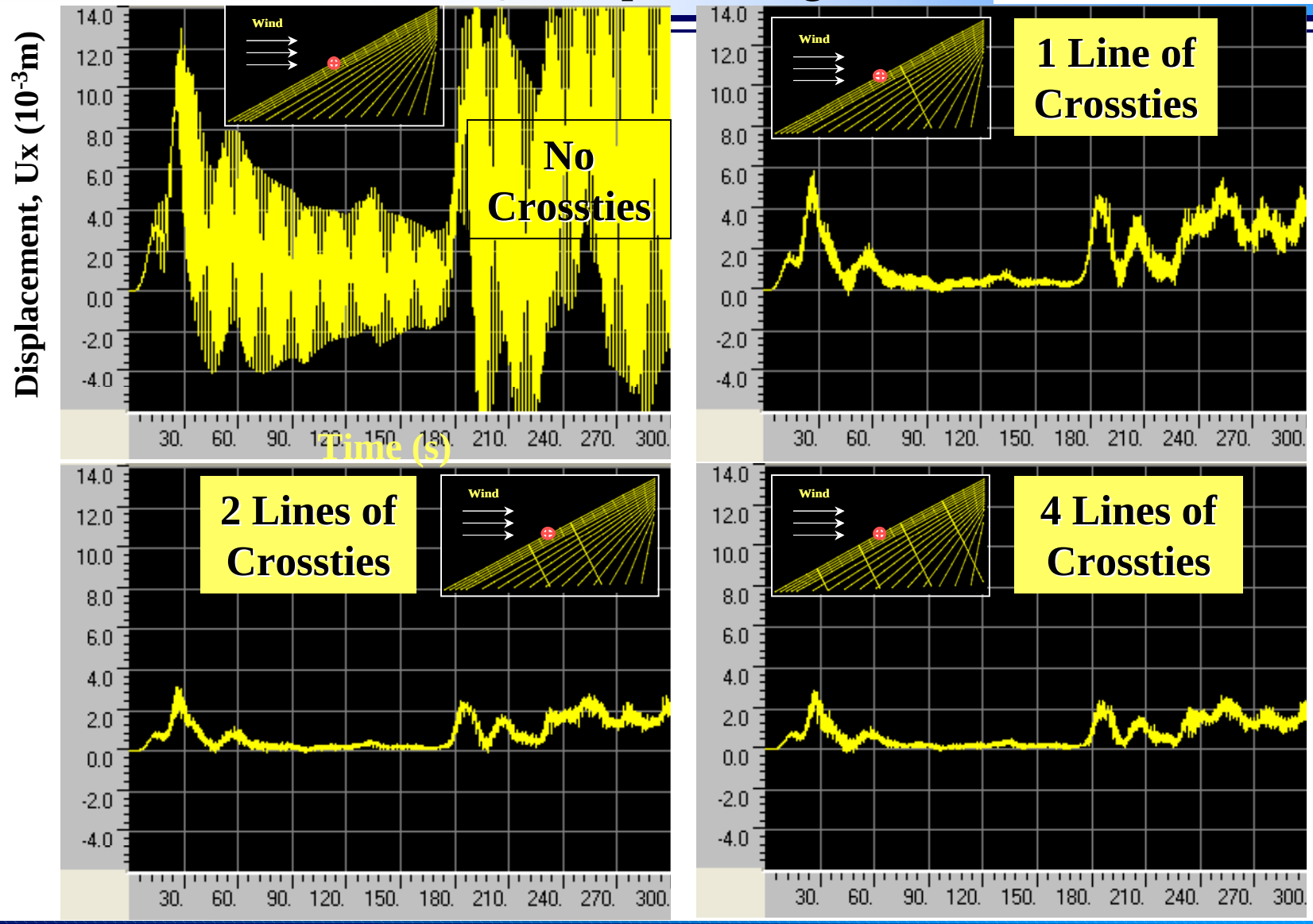




Displacement

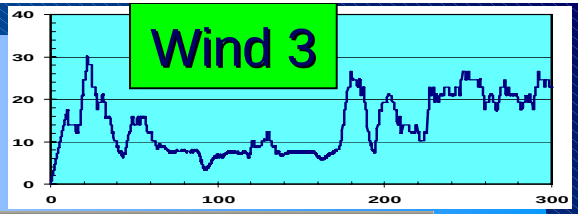
@ midspan of longest cable

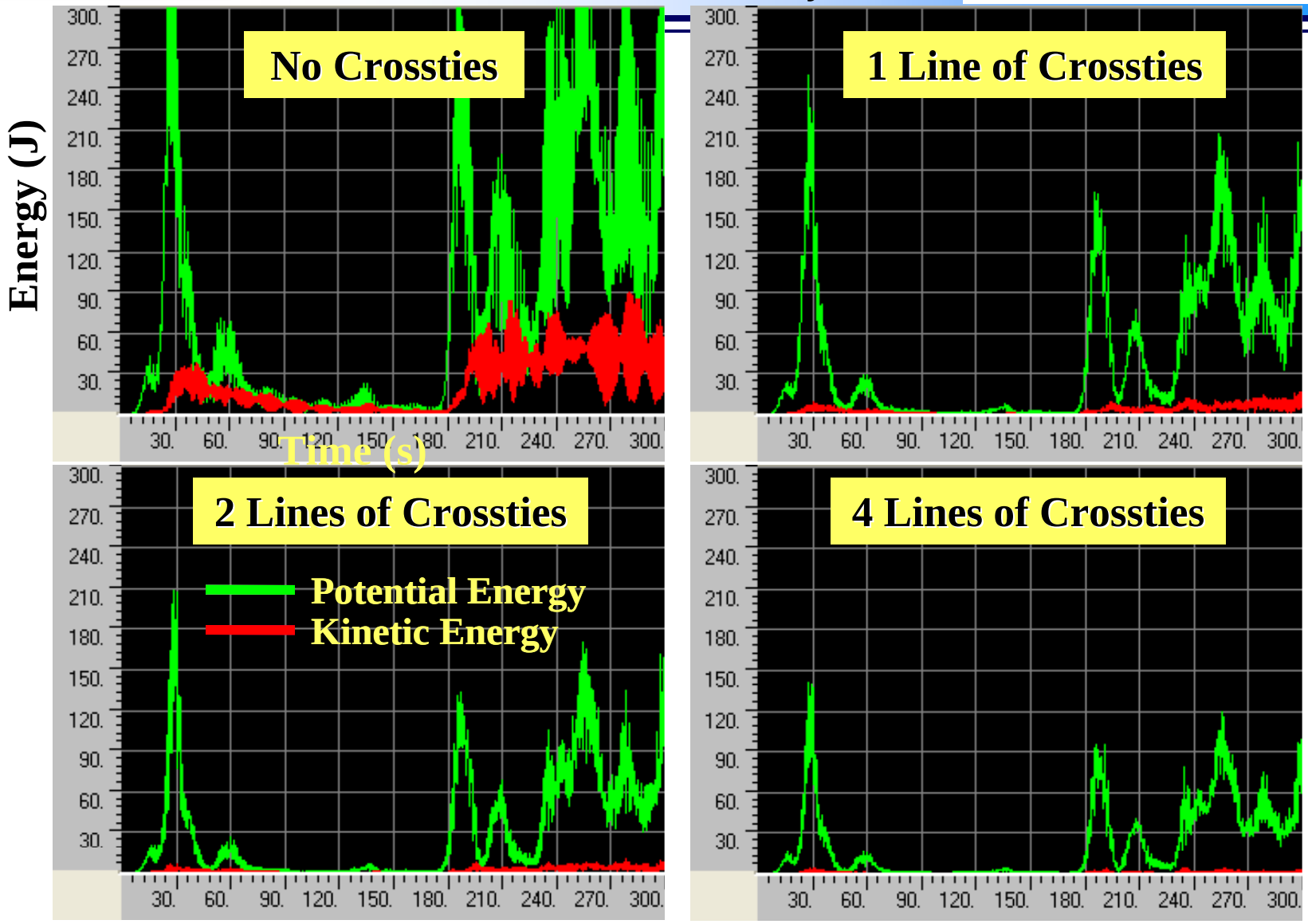




Energy Evolution

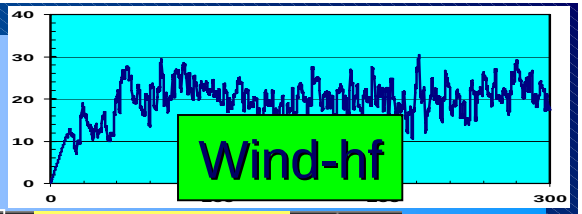
of the cable system

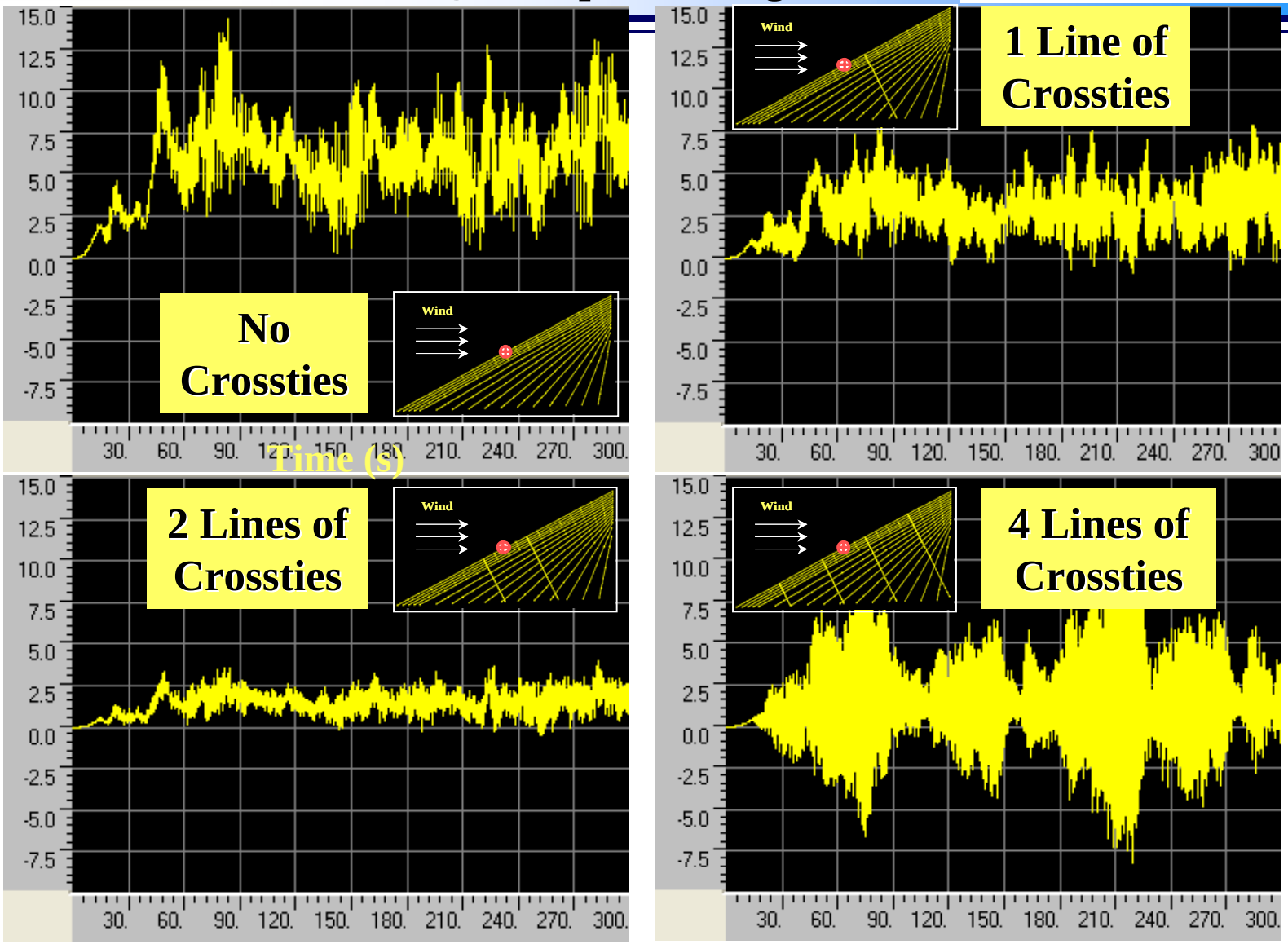




Displacement

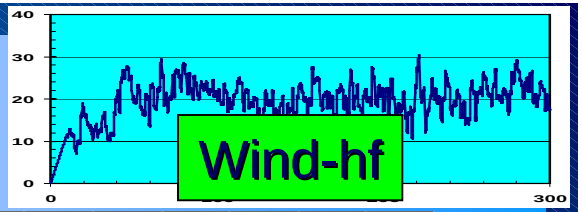
@ midspan of longest cable

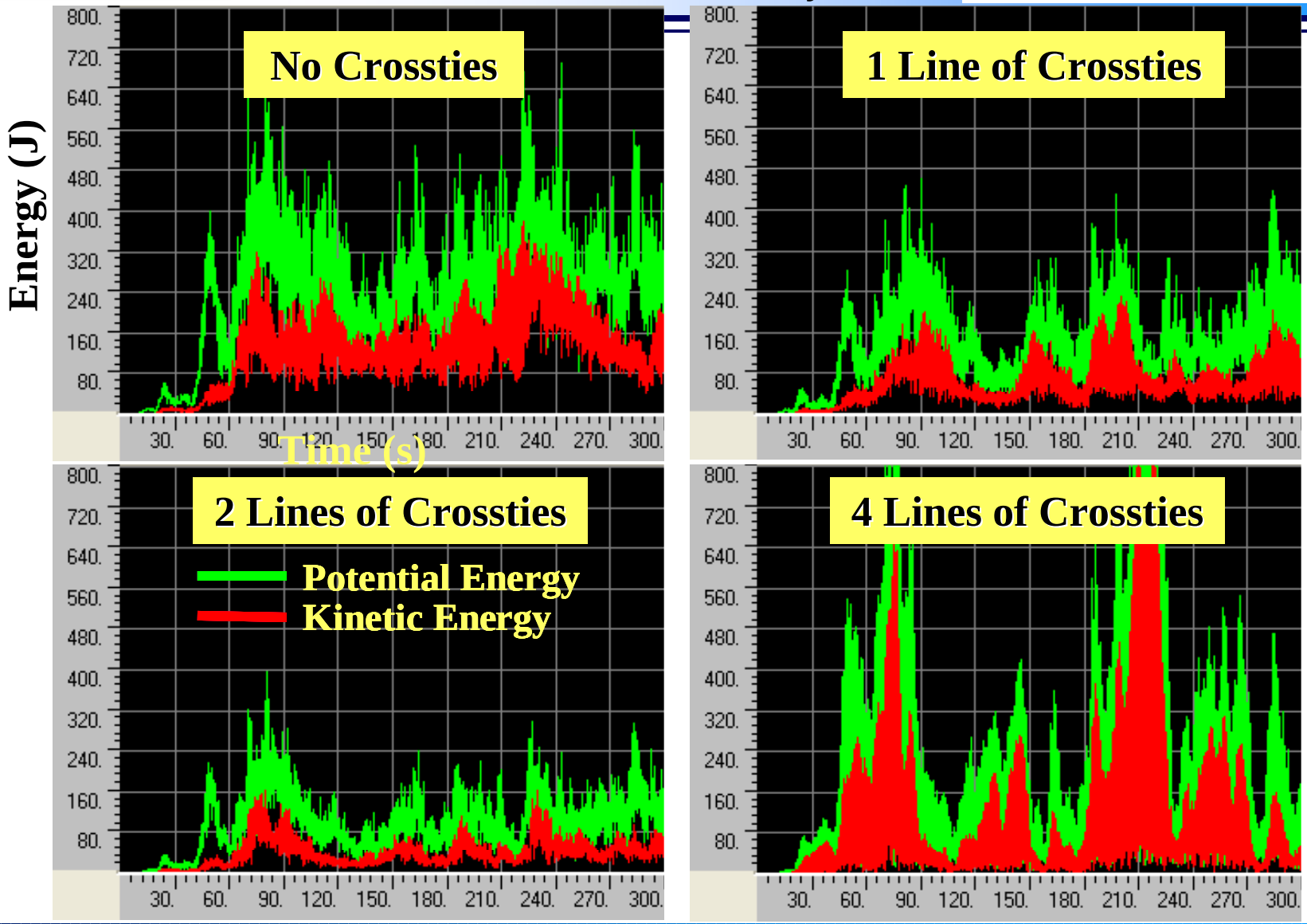




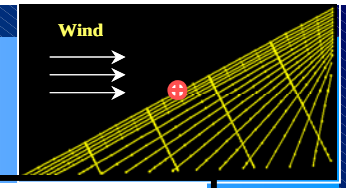
Energy Evolution

of the cable system

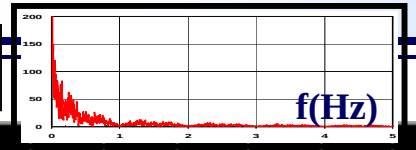




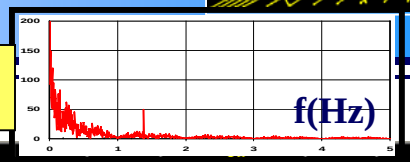
Response to "wind-5"

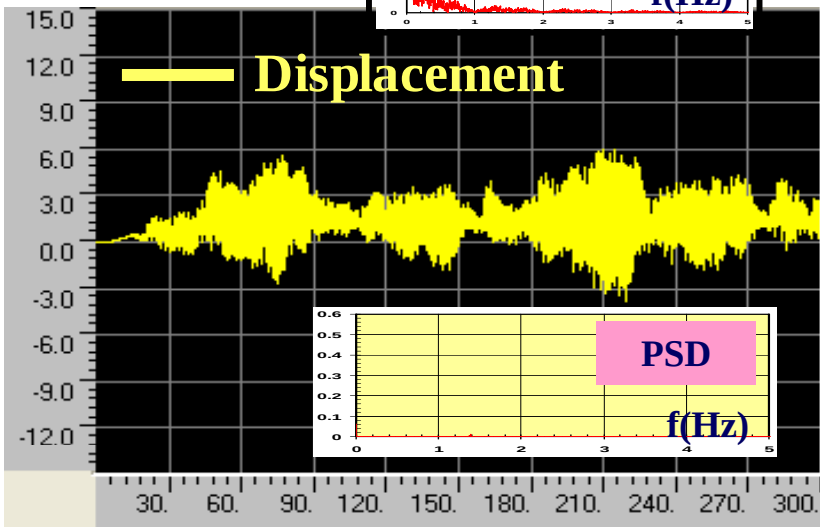


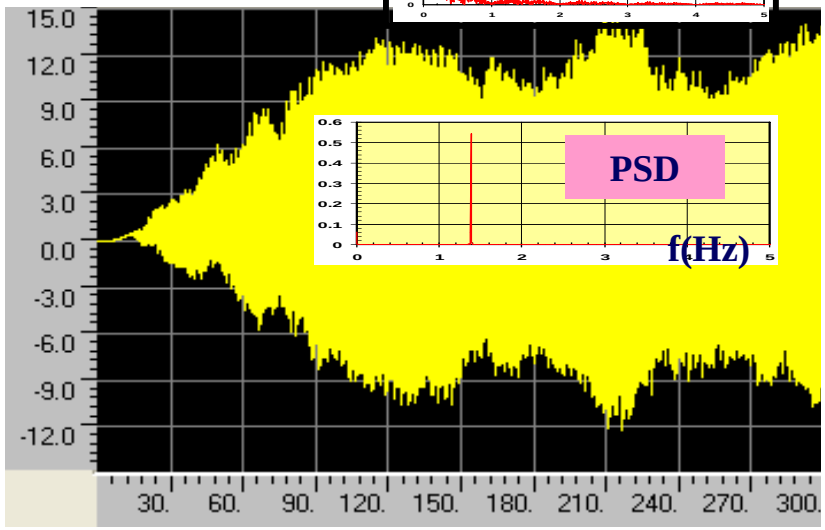
wind 1 (ref)

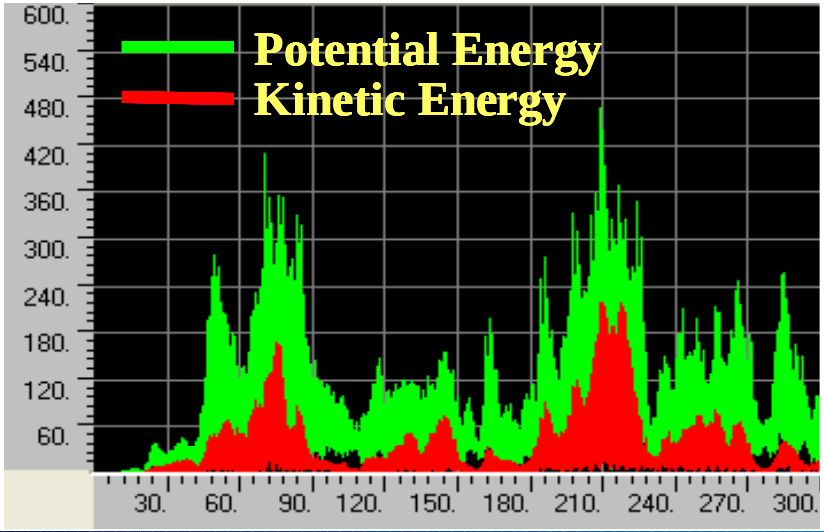


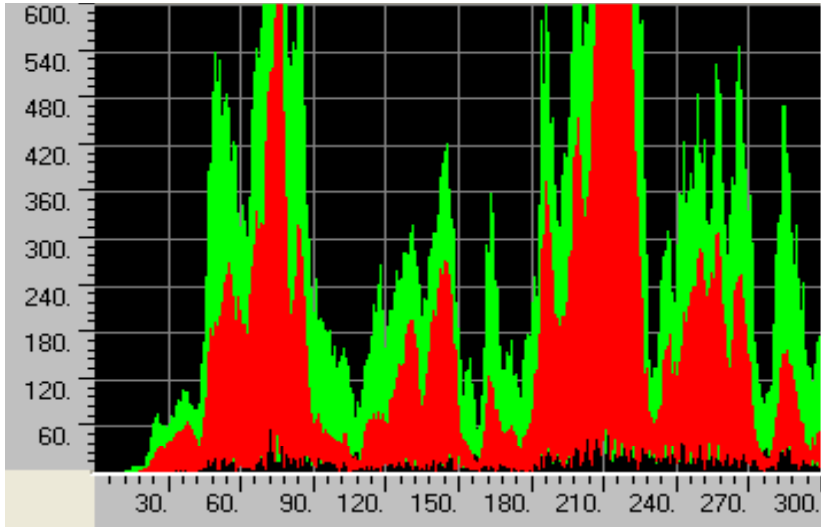
wind 5







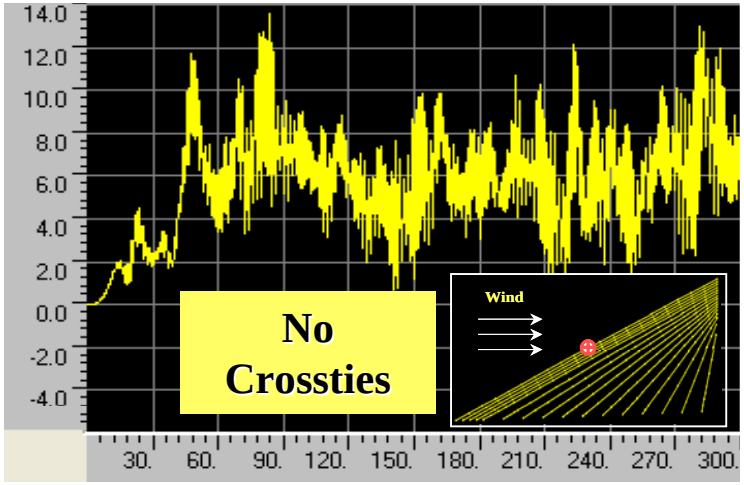


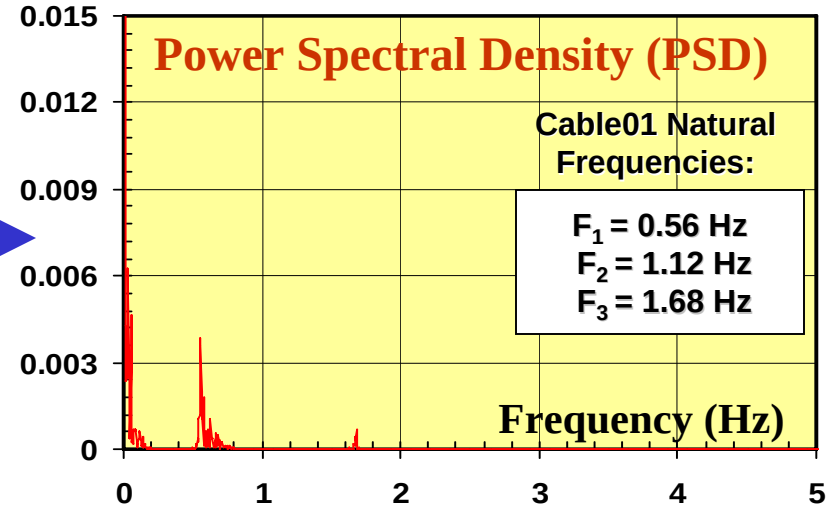


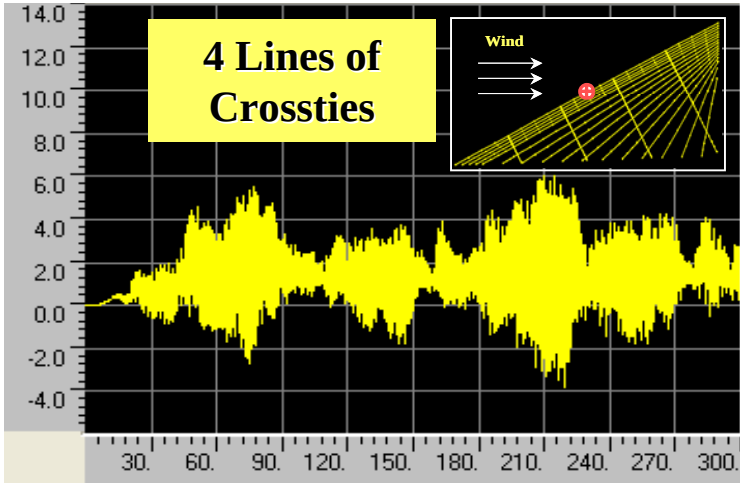
modal damping ratio used = 0.003

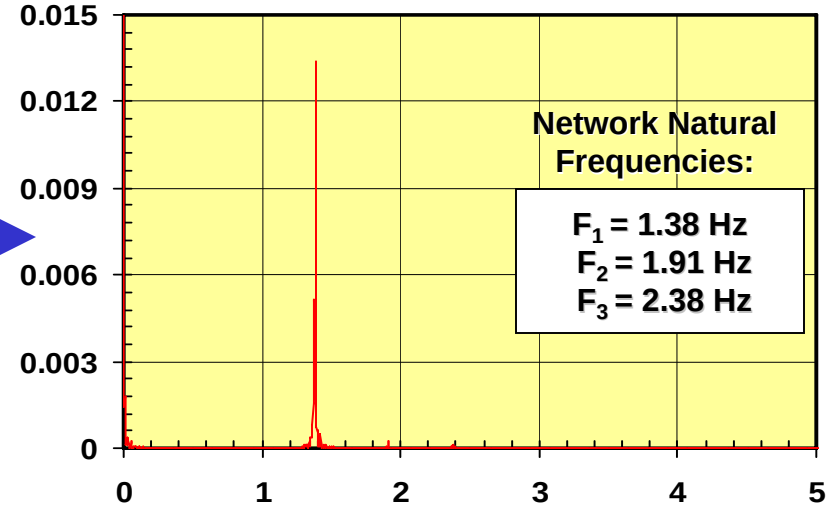
Spectral Analysis (1)

displacement @ midspan of longest cable



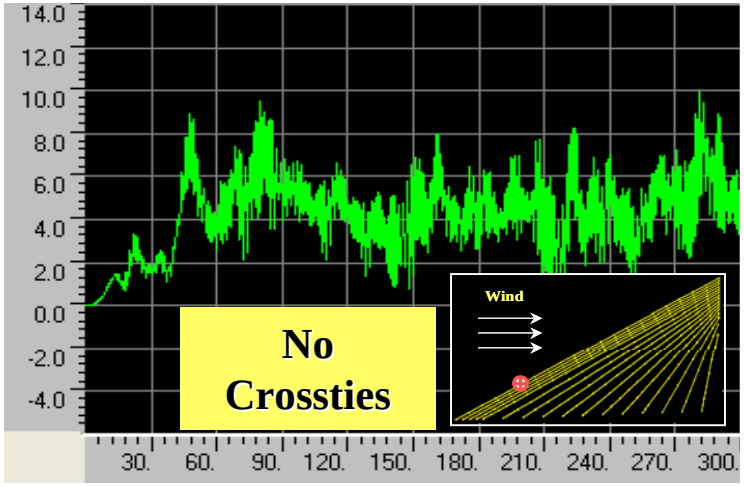


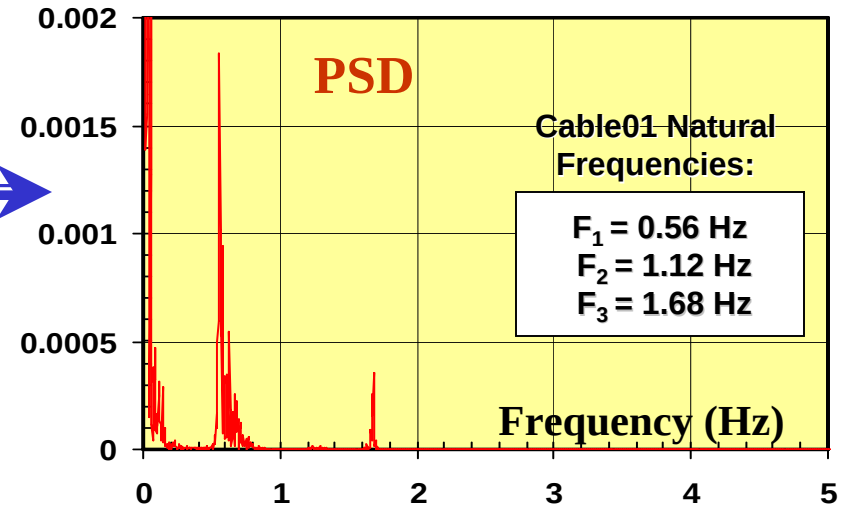


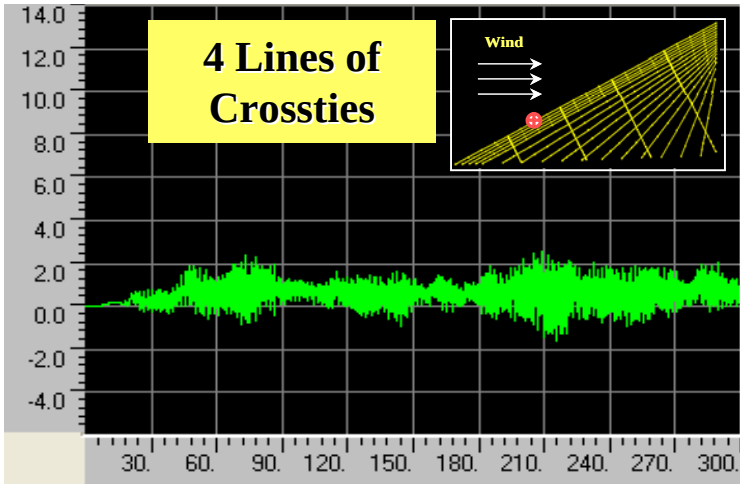


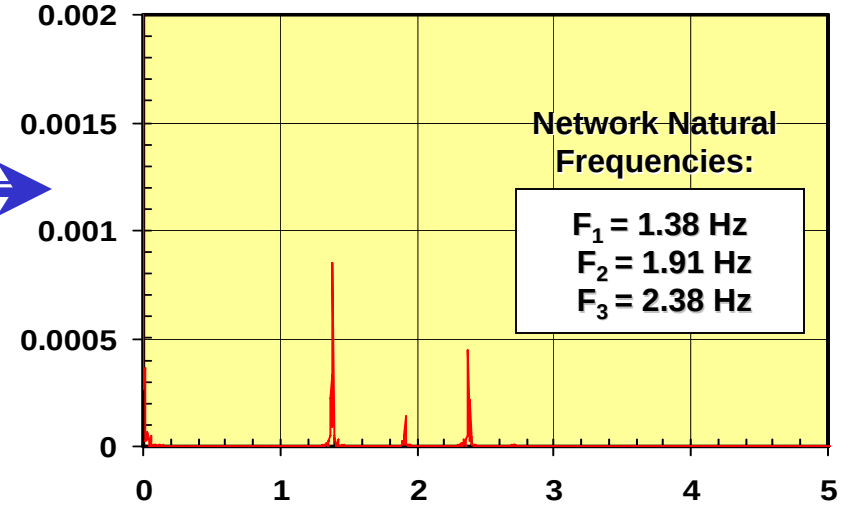
Spectral Analysis (2)

displacement @ quarter-span of longest cable

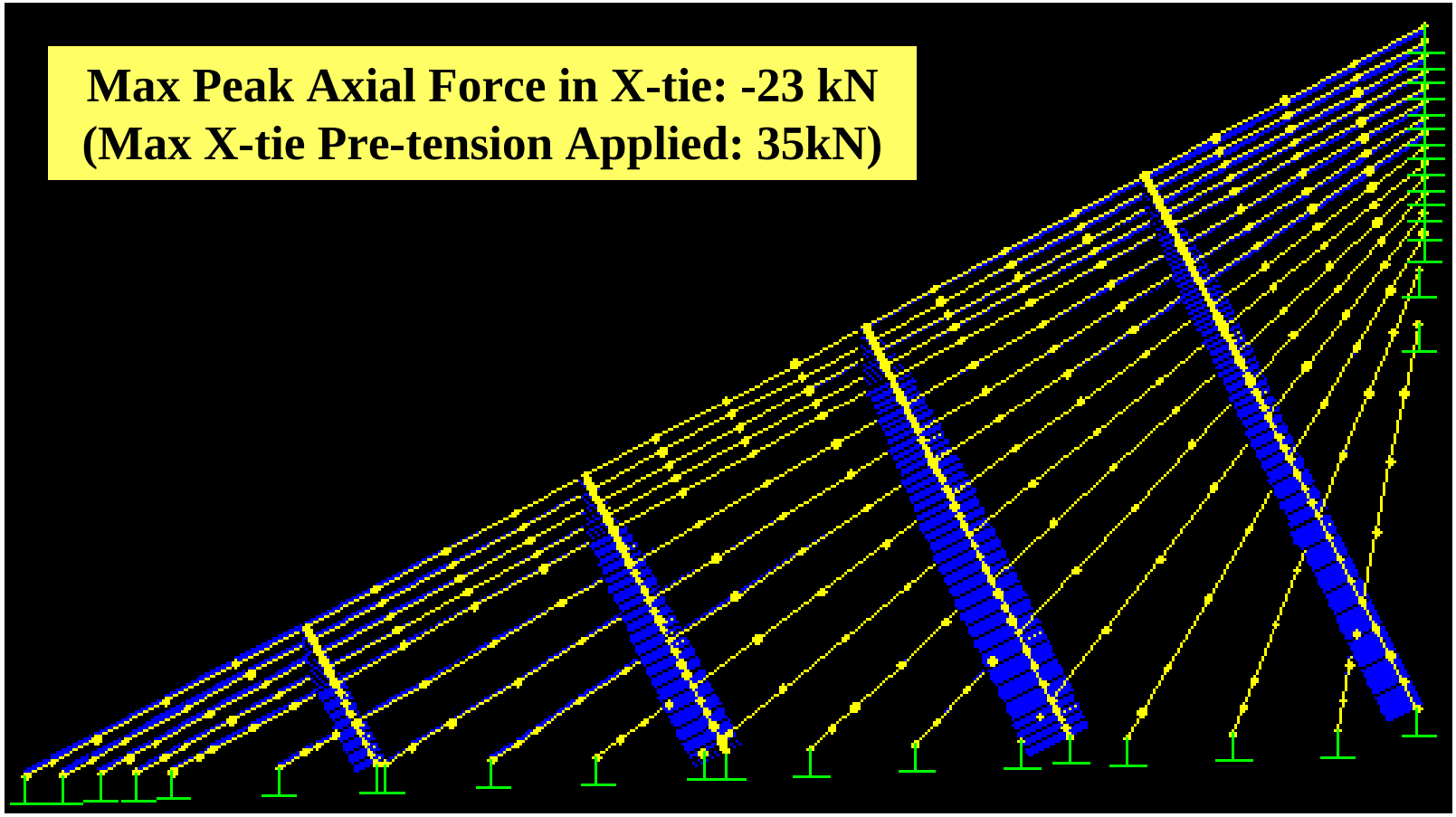




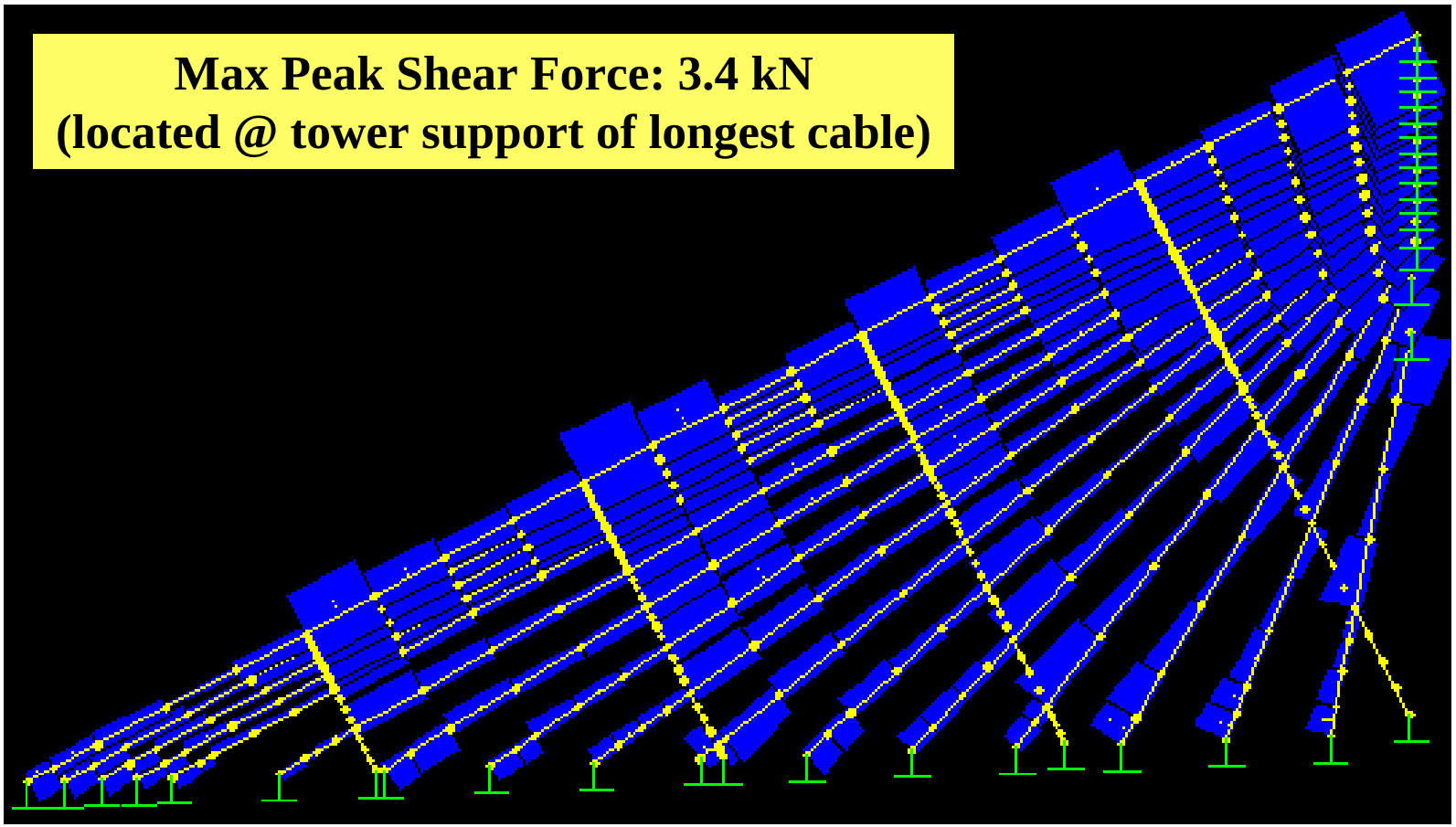




Peak Axial Forces



Peak Shear Forces



Conclusions

- Crossties are effective in reducing in-plane vibration of a stay-cable system by providing lateral constraints between cables
- Incorporation of crossties modify the oscillation properties of a cable system, and its mode-frequency evolution depends on the configuration of crossties
- Over-sized crossties make the system overly rigid, rendering the system vulnerable to high-frequency local vibration modes

Conclusions (cont'd)

- Crosstie grounding increases the natural frequencies of the system's global modes of vibration
- Increased crosstie pre-tension improves the transverse performance of a cable network, while the in-plane performance is insensitive to crosstie pre-tension
- Performance of a cross-tied network is sensitive to the frequency content of wind loading. Crossties are particularly effective in reducing low-frequency components of cable vibration

Conclusions (cont'd)

- Performance of a cross-tied network is not necessarily proportional to its quantity (or number of lines) of crossties. Excessive provision of crossties may cause adverse effect under highly turbulent winds
- Establishment of standard design winds appear imperative in the assessment and design of cross-tying systems for stay cables

Acknowledgments

This research has been supported by:

- Pooled Fund for Wind-Induced Vibration of Cable-Stayed Bridges (SPR-3-078)

  Participating States and Agencies: MO, AL, FL, GA, IA, IL, KY, LA, MS, SC, TX, VA, and FHWA

- FHWA Support Services for the Aerodynamics Laboratory (DTFH61-02-Z-00046)

U. S. Department of Transportation

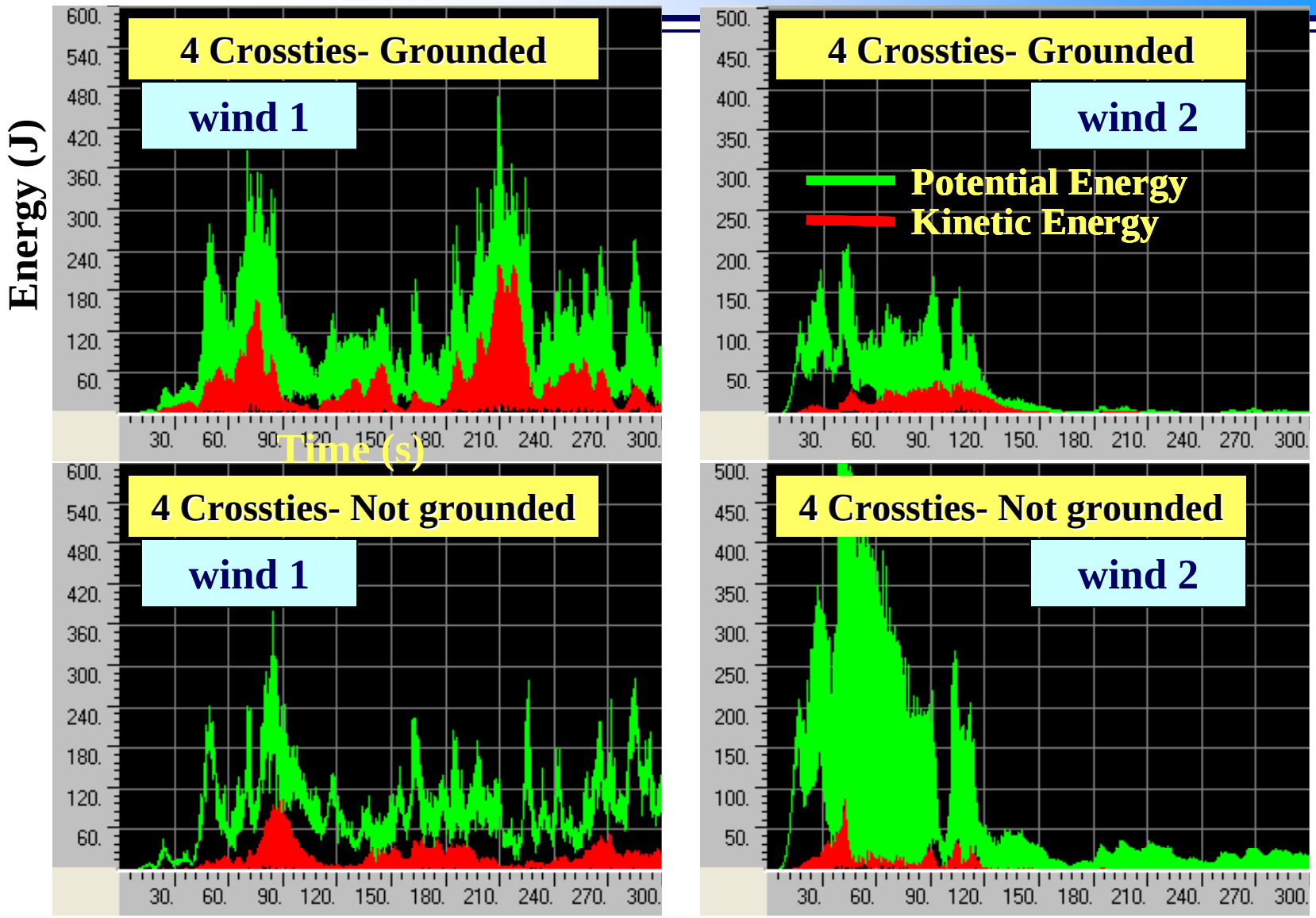
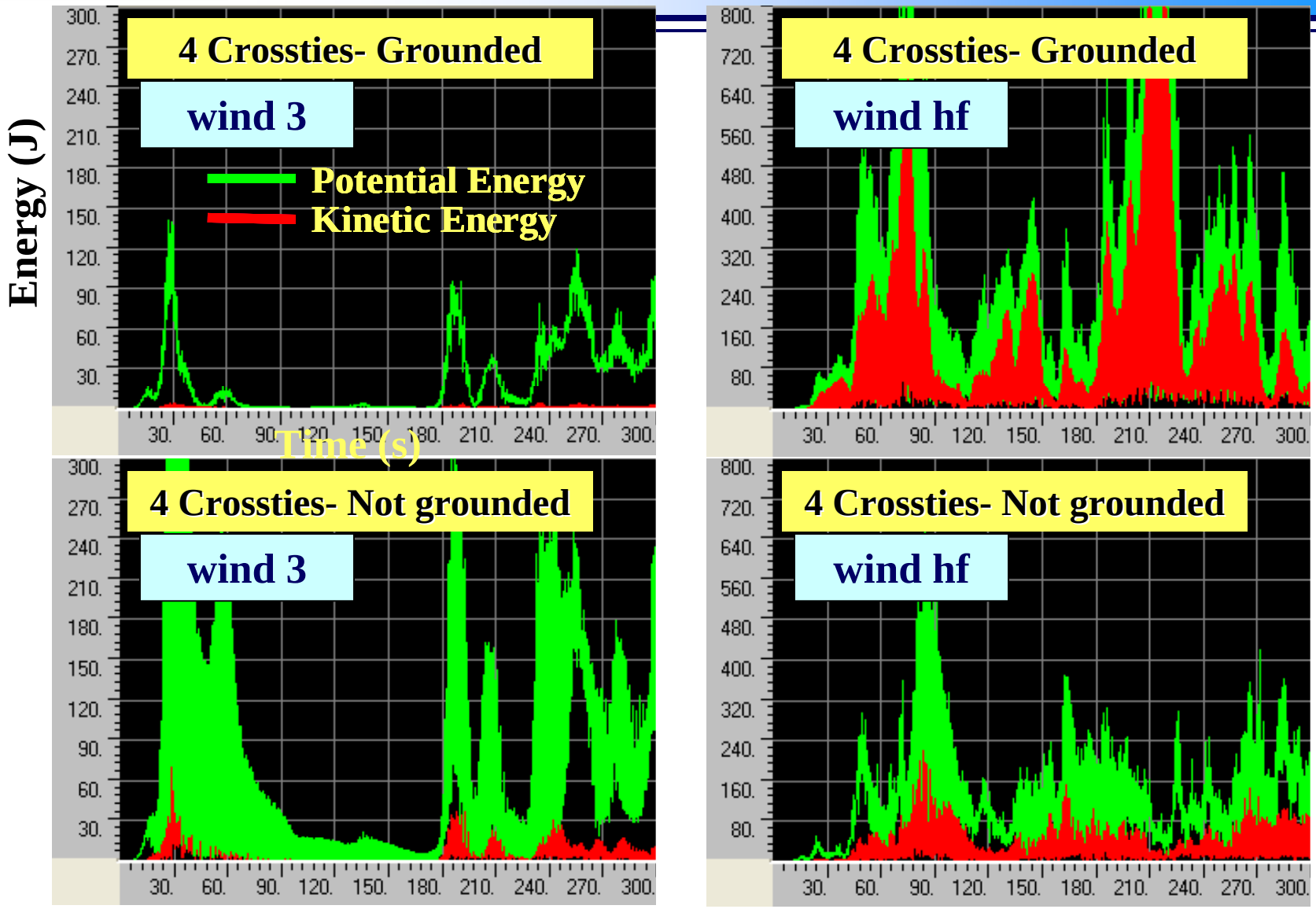
Federal Highway Administration

Turner-Fairbank Highway Research Center

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

Backups

Influence of Cross-tie Gounding (1)



Influence of Cross-ties Grounding (2)