DECK-INDUCED STAY CABLE VIBRATIONS: FIELD OBSERVATIONS AND ANALYTICAL MODEL

Ming-Yi Liu
Sinotech Engineering Consultants, Inc., Taipei, Taiwan
Delong Zuo
Johns Hopkins University, Baltimore, MD, USA
Nicholas P. Jones
Johns Hopkins University, Baltimore, MD, USA

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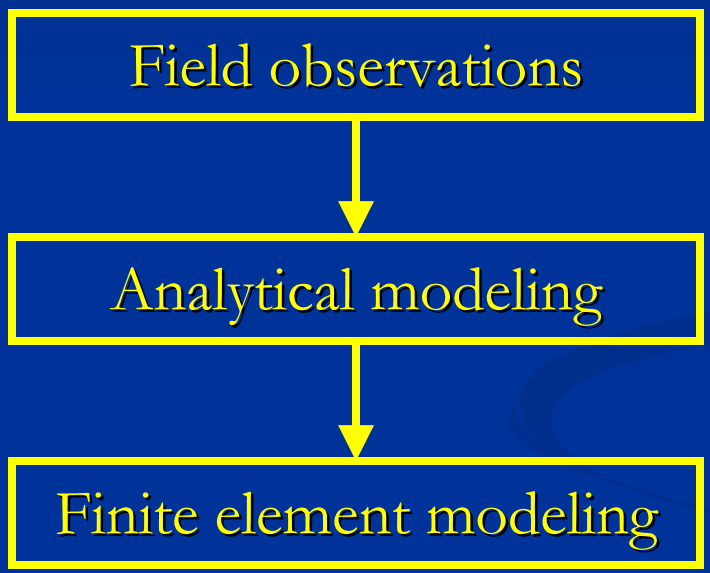
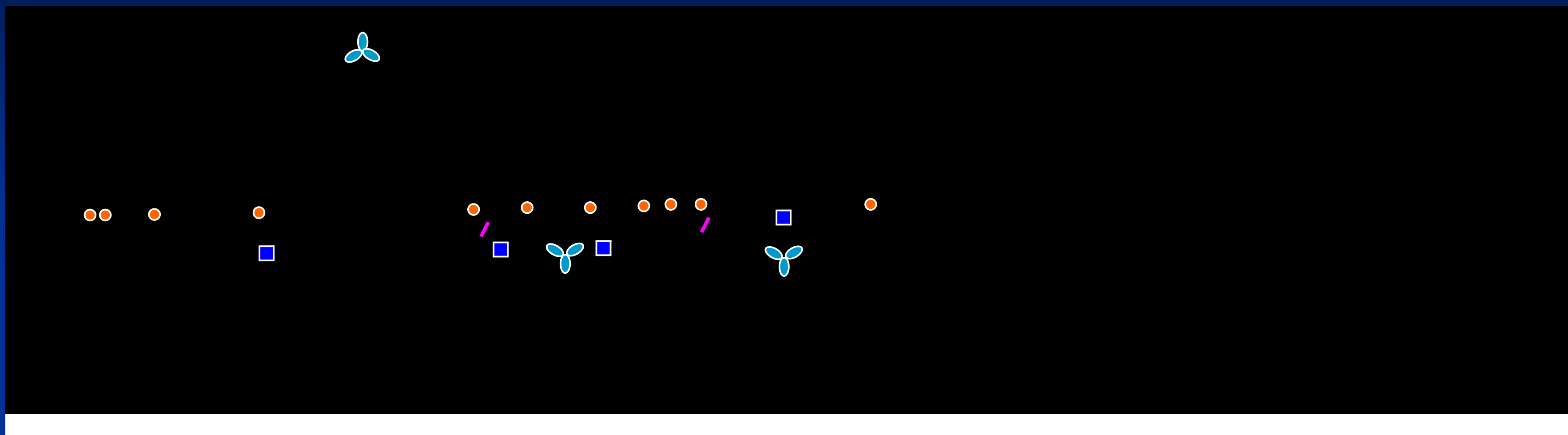
Scope


Field observations
Analytical modeling
Finite element modeling

The Fred Hartman Bridge

- Over the Houston ship channel in Houston, Texas, USA
- 384 m main span, 54 m clearance
- Twin-deck, each 24 m wide and 2.87 m high
- Double-diamond shaped towers
- 192 cables (59 m to 198 m long) in four inclined planes

Full-Scale Measurement System



- Major measurement
  - Acceleration
    - Displacement
    - Damper force
  - Acceleration
  - Wind
    - Rainfall
- Sampling rate = 40 Hz
- Low-pass filtered at 10 Hz
- Five-minute records

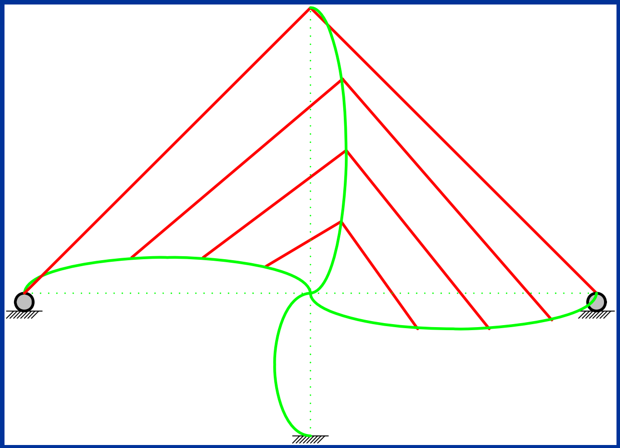
Anemometer
Bi-axial accelerometer
Uni-axial accelerometer

Observed Types of Vibration

- (Kármán-) Vortex-induced vibration (VIV)
- Rain-wind induced vibration (RWIV)
- Large-amplitude dry cable vibration
- Vibration induced by deck oscillation
- Vibrations not categorized

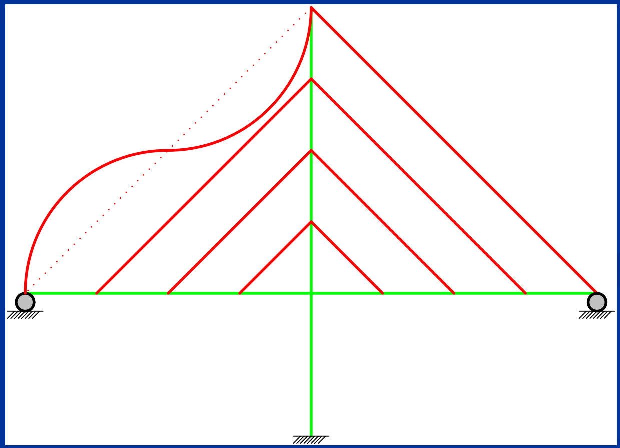
Mode Shapes

Global motion



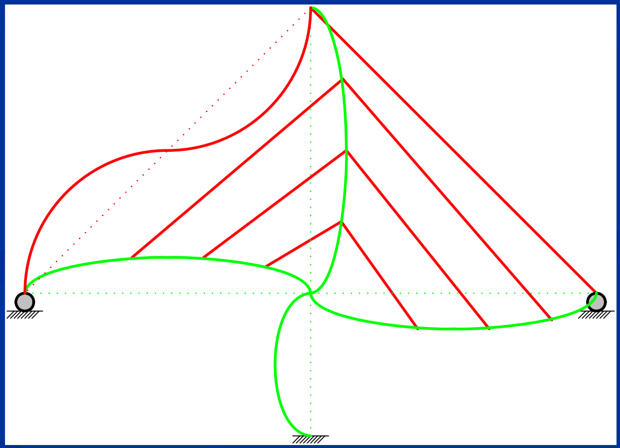
Deck / Tower vibration

Local motion



Cable vibration

Coupled motion



Deck / Tower vibration
+
Cable vibration

Natural Frequencies

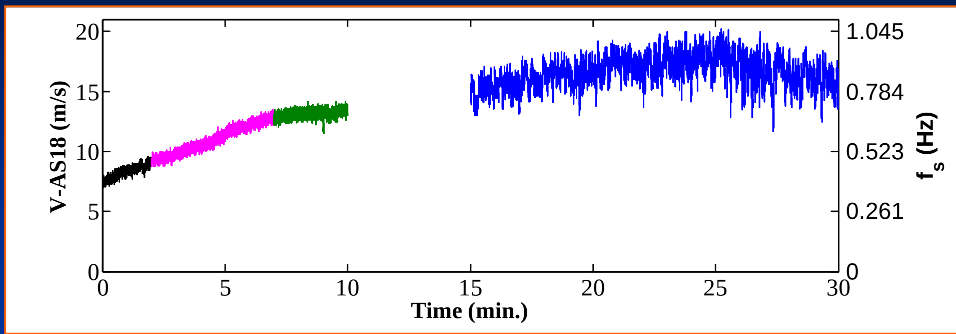
- Deck Modes (Ozkan 2003)

Mode	Frequency (Hz)	Phasing	Description of Mode
1	0.287	I	1st Vertical
2	0.301	O	1st Vertical
3	0.372	I	2nd Vertical
4	0.385	O	2nd Vertical
5	0.413	I	1st Lateral
6	0.432	O	1st Lateral
7	0.570	I	3rd Vertical
8	0.588	O	3rd Vertical
9	0.686	I	1st Torsional
10	0.688	O	1st Torsional
11	0.665	I	4th Vertical
12	0.668	O	4th Vertical
13	0.715	I	5th Vertical
14	0.720	O	5th Vertical
15	0.786	I	6th Vertical
16	0.790	O	6th Vertical

- Fundamental Stay Mode

Stay	AS24	AS16
Frequency	0.570	1.248

Response of Bridge Deck

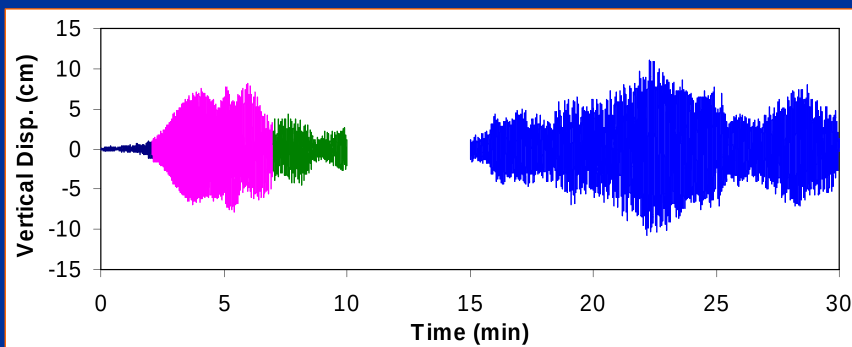


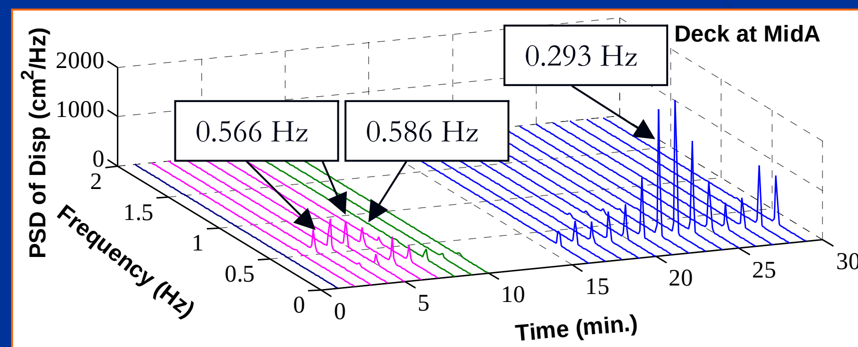
$$f_s = \frac{VS}{D}$$

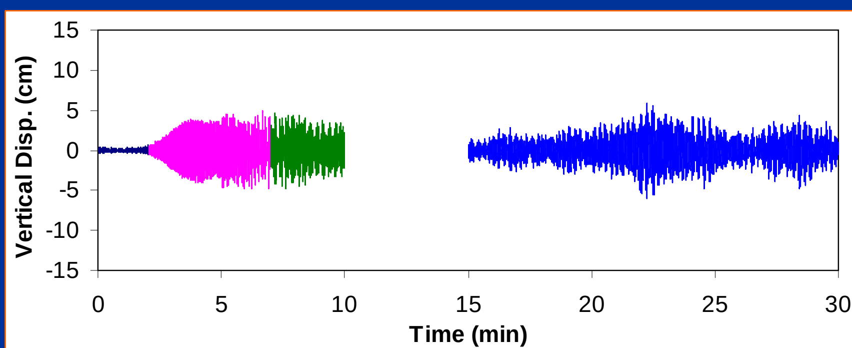
V : Wind speed perpendicular to deck axis

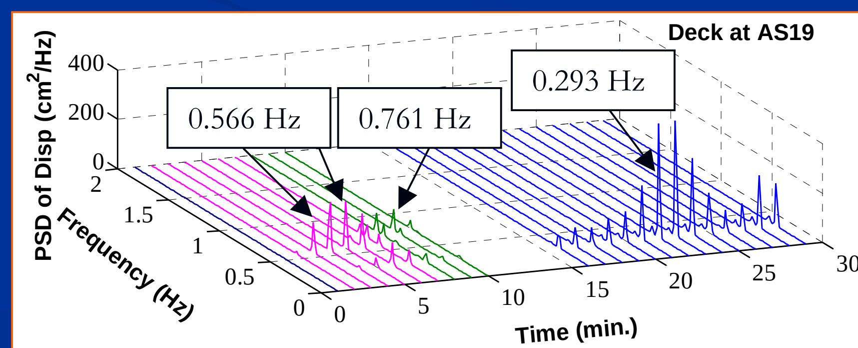
$S = 0.15$: Strouhal number according to wind tunnel tests (Mehedy Mashnad)

D : Height of bridge deck

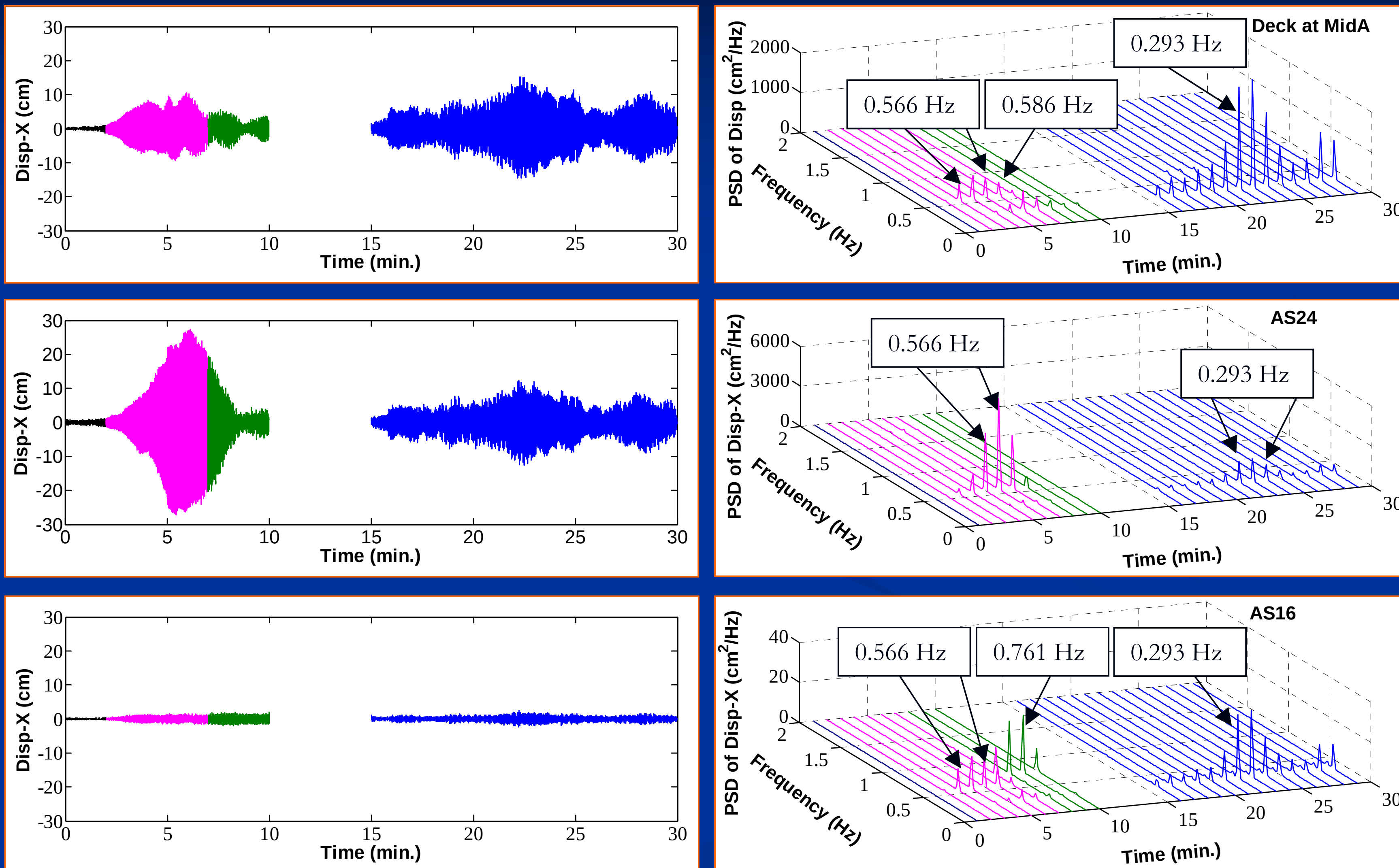




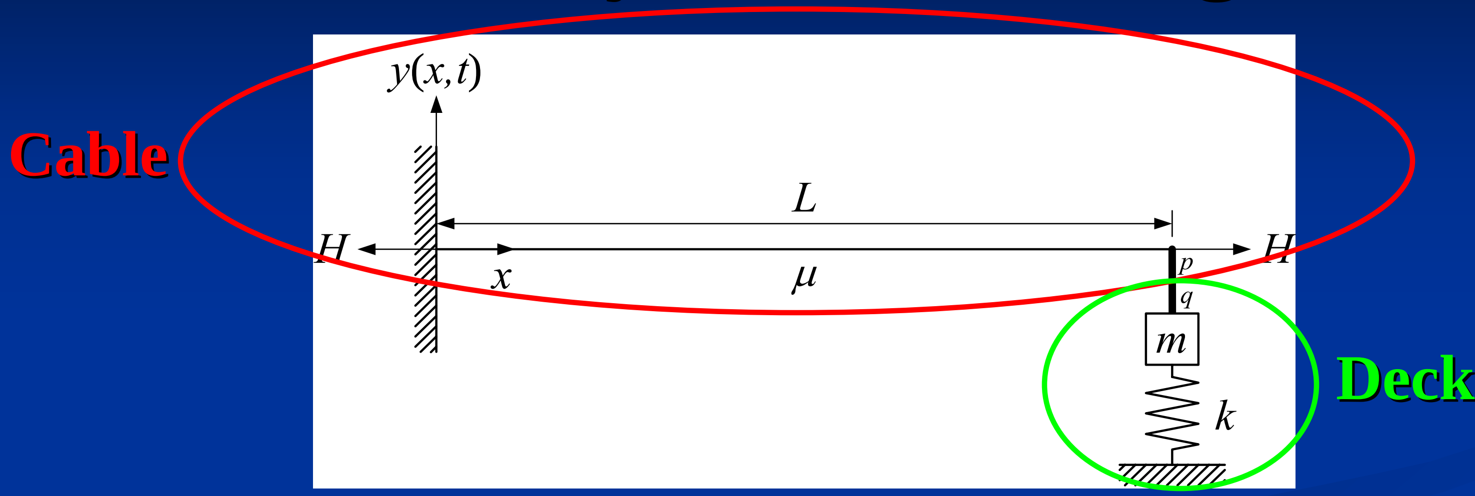




Response of Bridge Deck



Analytical Modeling



- Wave equation

$$c^2 \frac{\partial^2 y(x,t)}{\partial x^2} = \frac{\partial^2 y(x,t)}{\partial t^2}$$

- Boundary conditions

$$y(0,t); \quad H\frac{\partial y(L,t)}{\partial x} = m\frac{\partial^2 y(L,t)}{\partial t^2} + ky(L,t)$$

- Natural frequency

$$f = \frac{c\left(4\pi^2 m f^2 - k\right)}{2\pi H}\tan\left(\frac{2\pi f L}{c}\right)$$

- Mode shape

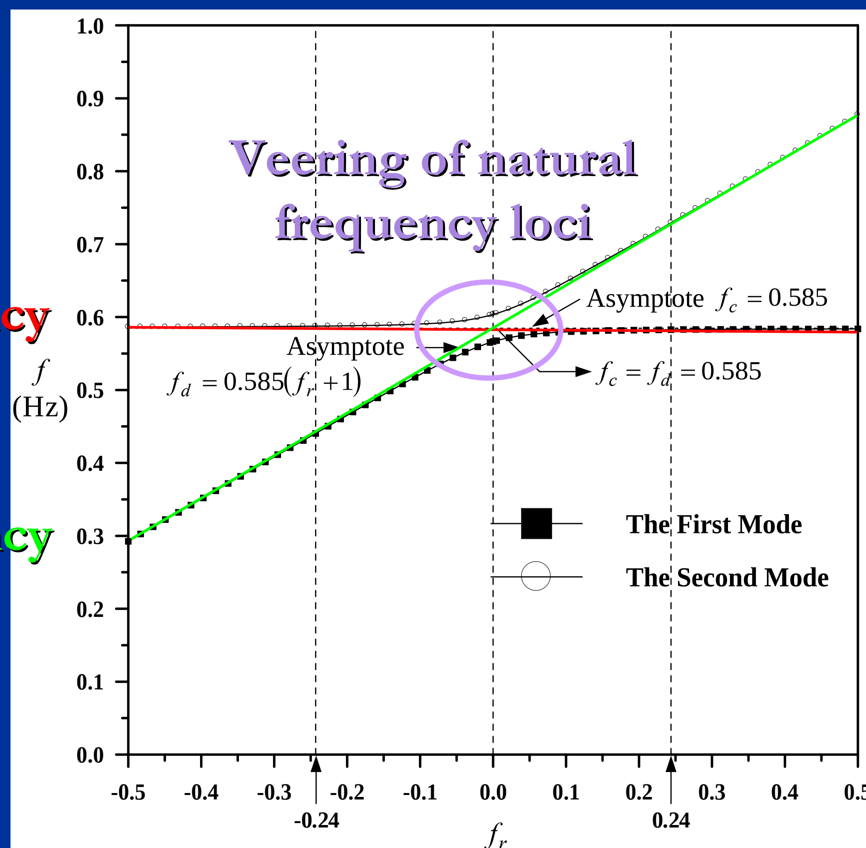
$$Y(x) = A\sin\left(\frac{2\pi f x}{c}\right)$$

Natural Frequency Loci of System

	Parameters	Natural frequency	Relative frequency
Cable	L = 199.8; μ = 76.0 kg/m; H = 4150 kN	f_c = 0.585 Hz	$f_r = (f_d - f_c) / f_c$
Deck	m = 7.59 x 10^5 kg; k = 2564 – 23072 kN/m	f_d = 0.293 – 0.878 Hz	

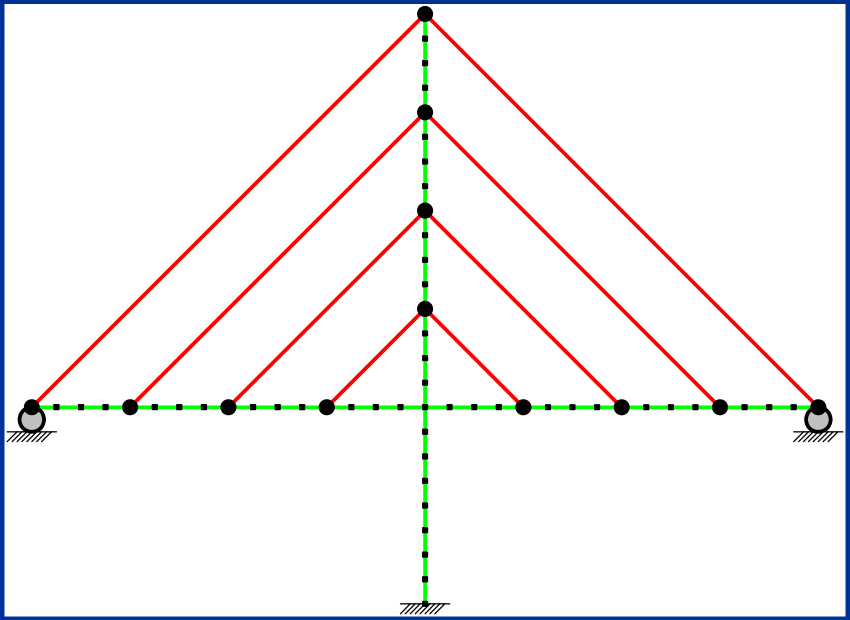
Pure cable frequency

Pure deck frequency

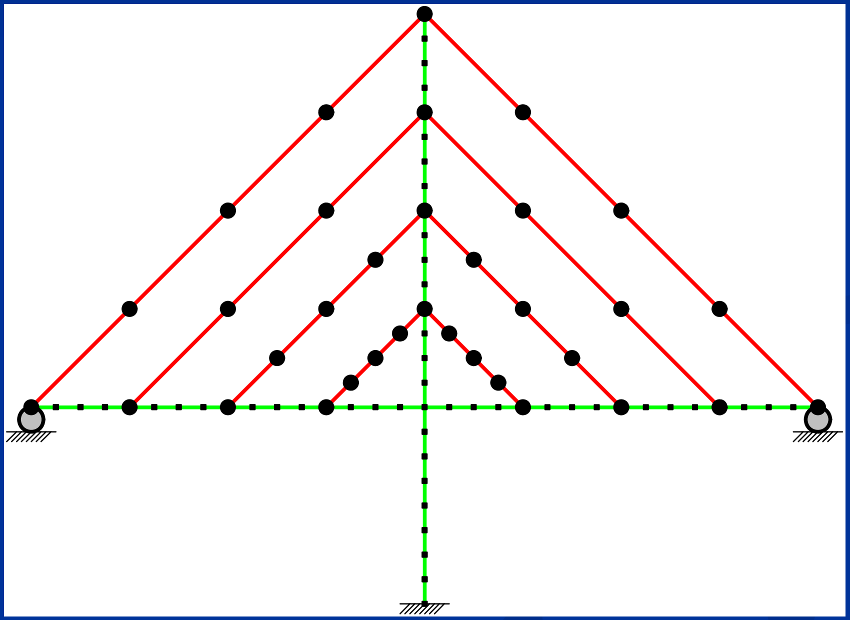


Finite Element Modeling

OECS
(one-element cable system)



MECS
(multi-element cable system)

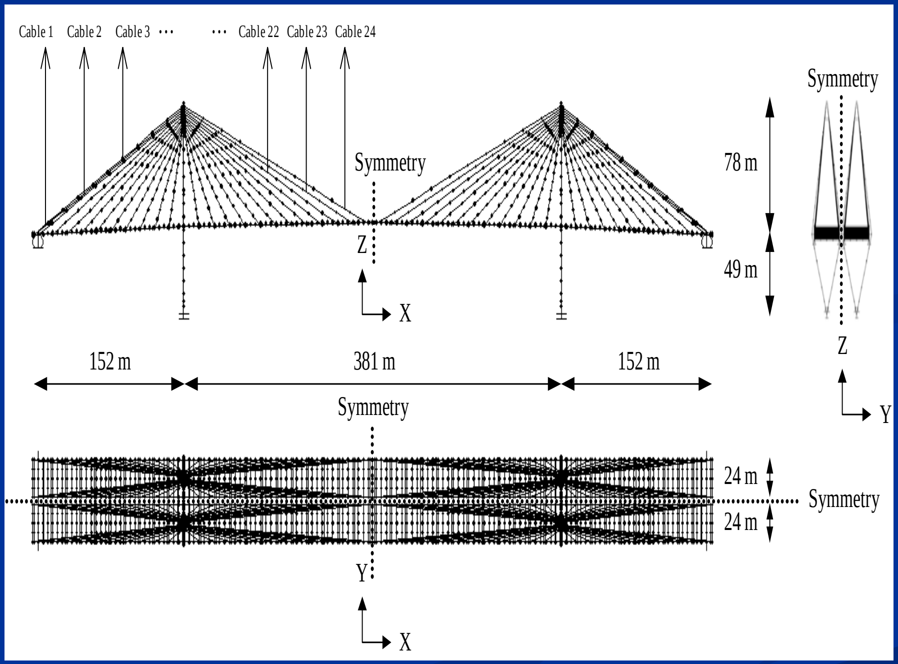


Deck / Tower (beam elements)
Cable (truss elements)

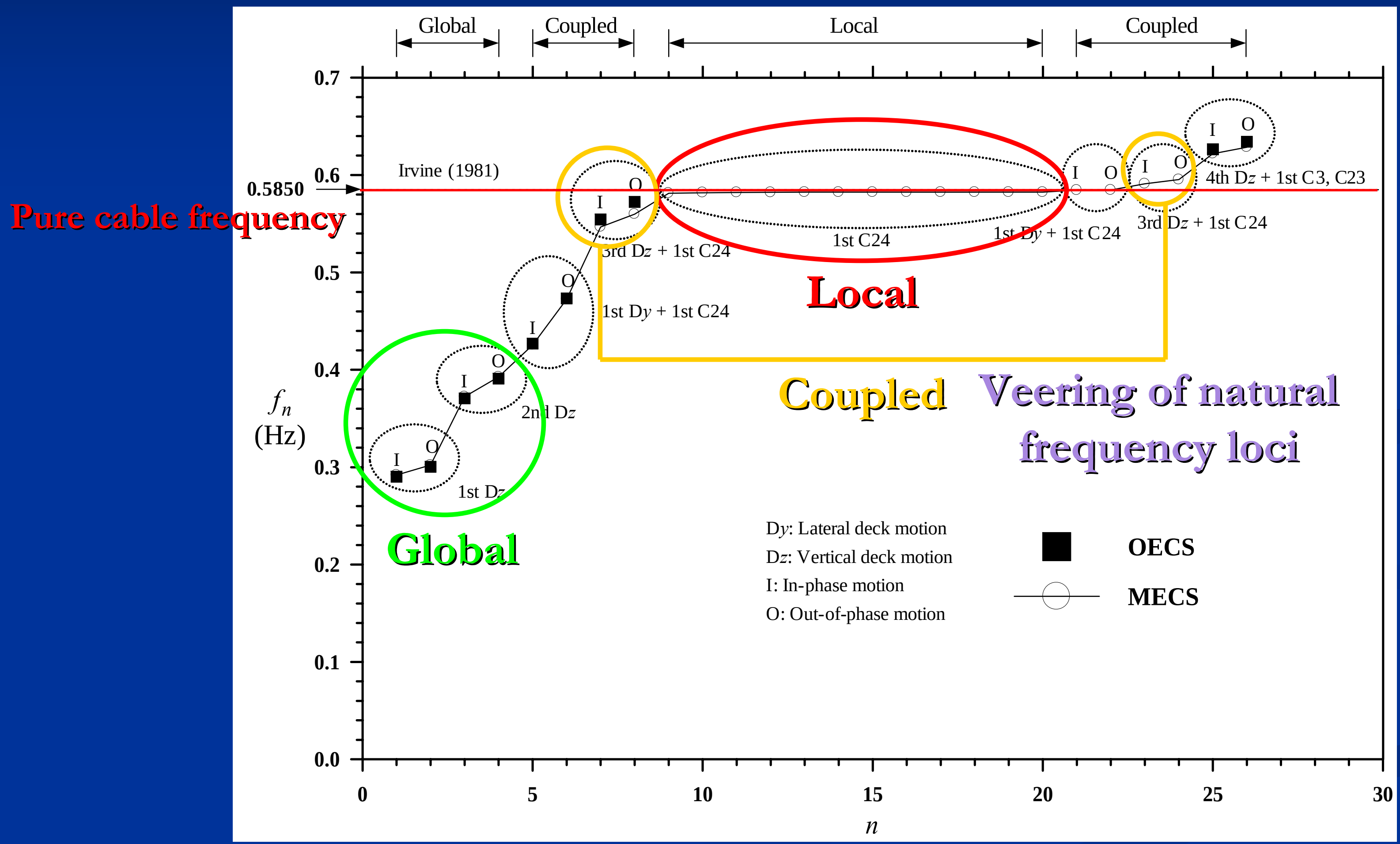
Fred Hartman Bridge

Prototype

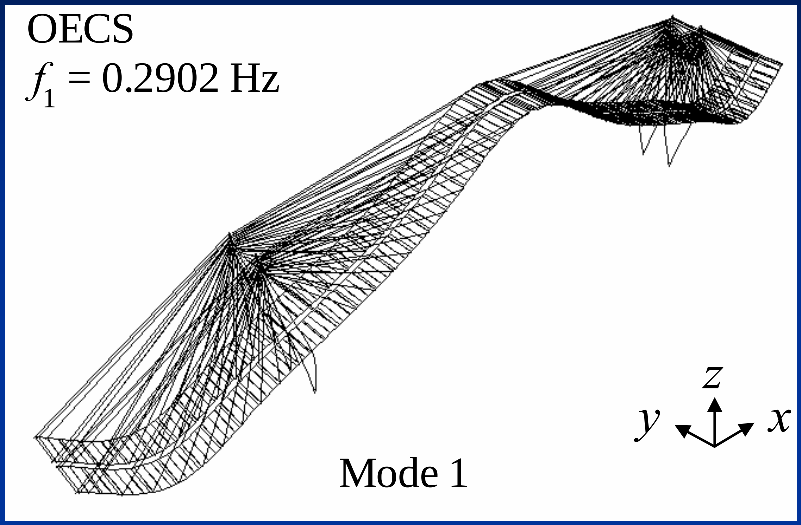
Finite element modeling

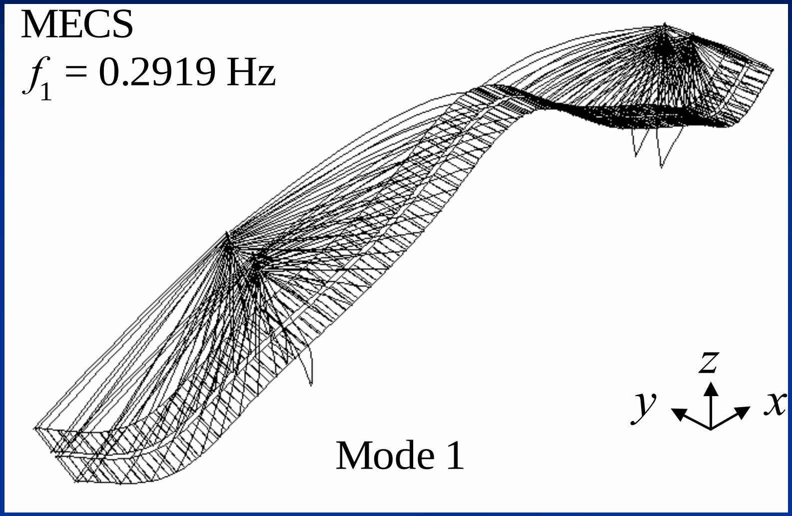


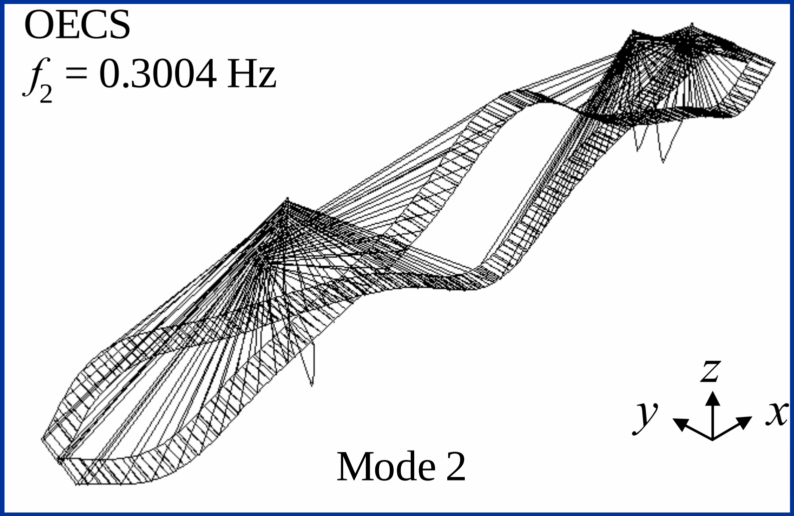
Natural Frequency Loci of Bridge

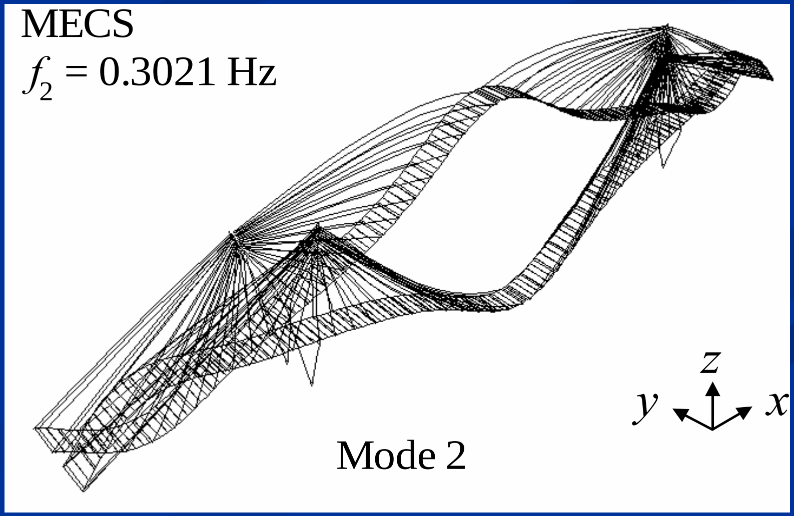


Global Motions

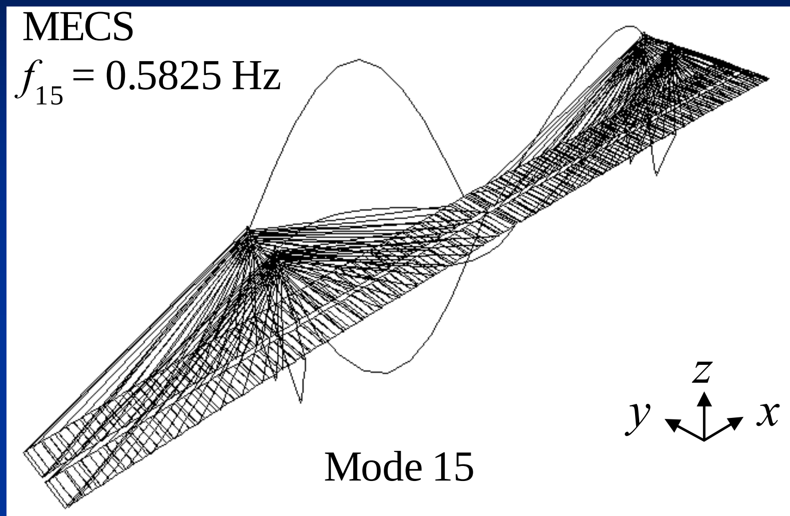


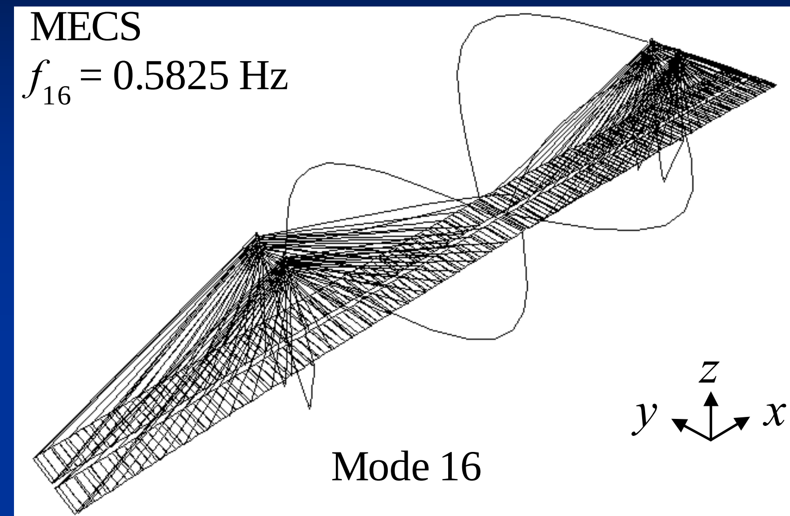


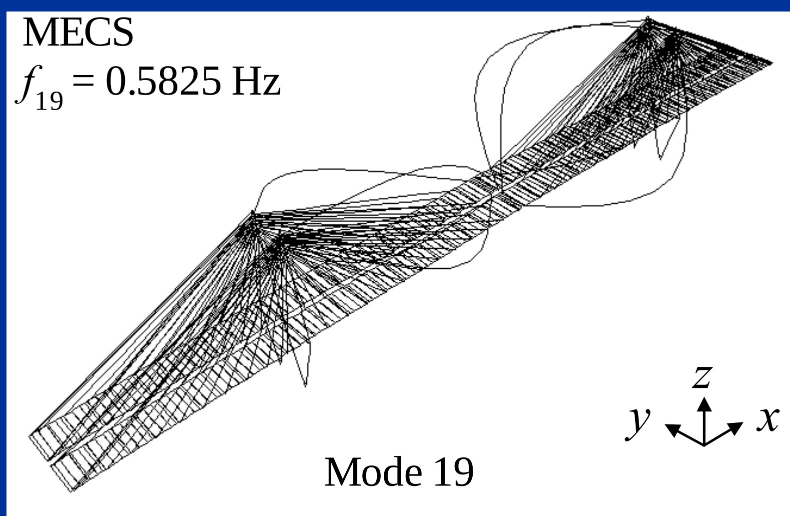


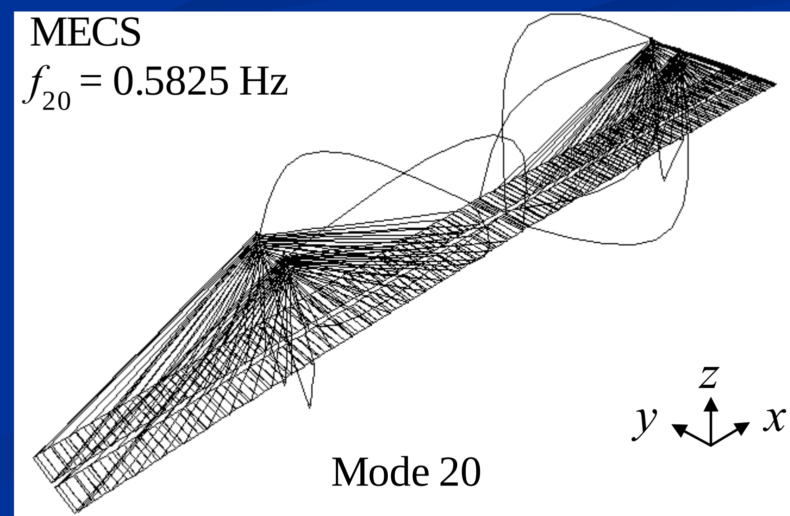


Local Motions

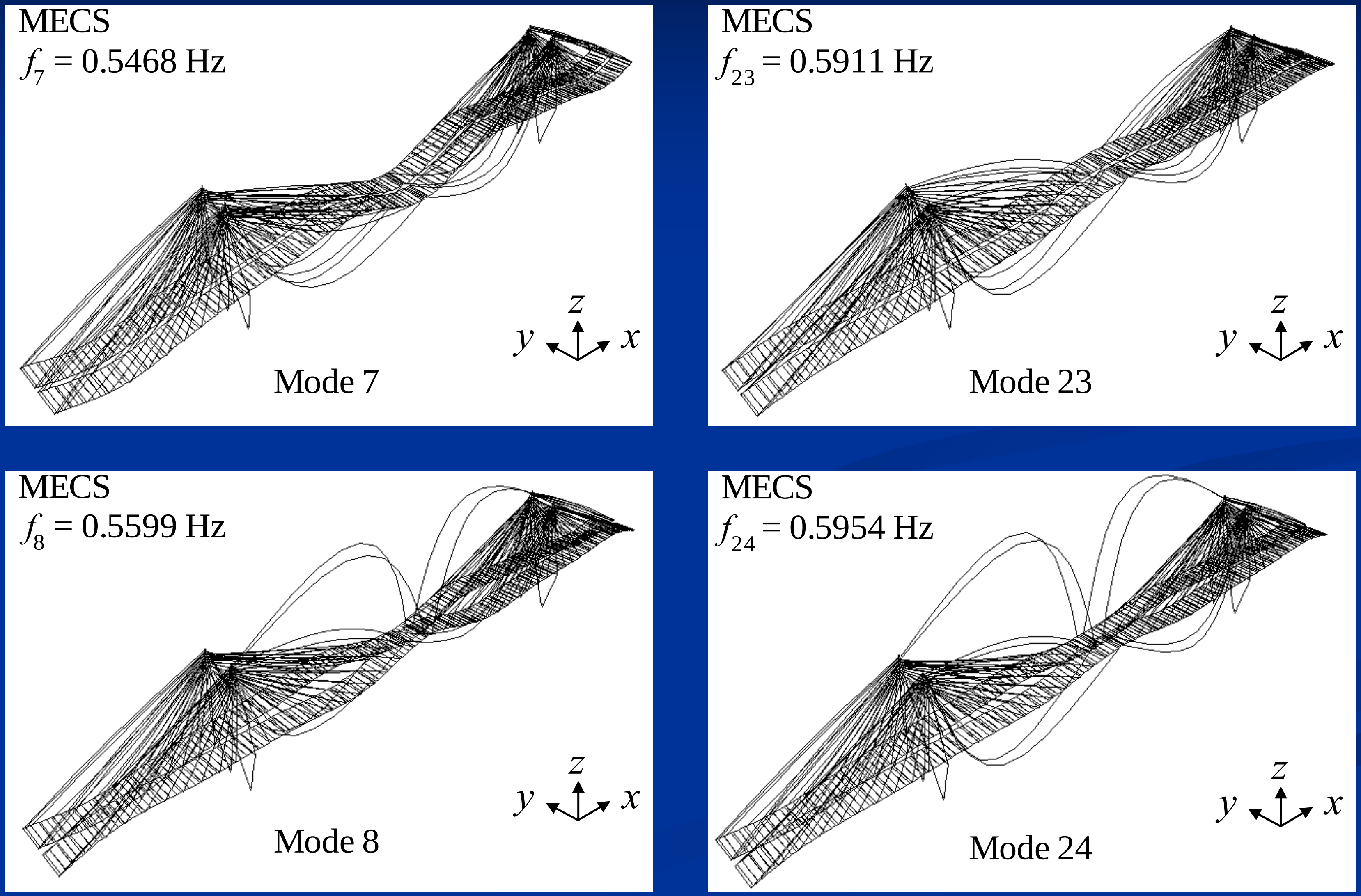






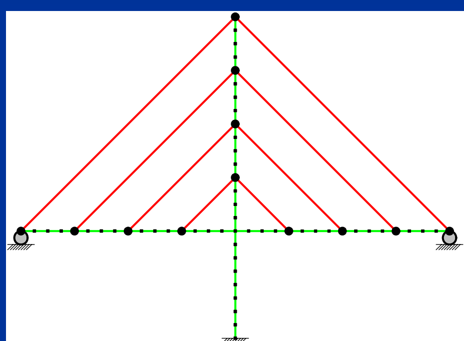


Coupled Motions



Summary

OECS + Cable-deck system $\overset{?}{\Leftrightarrow}$ MECS



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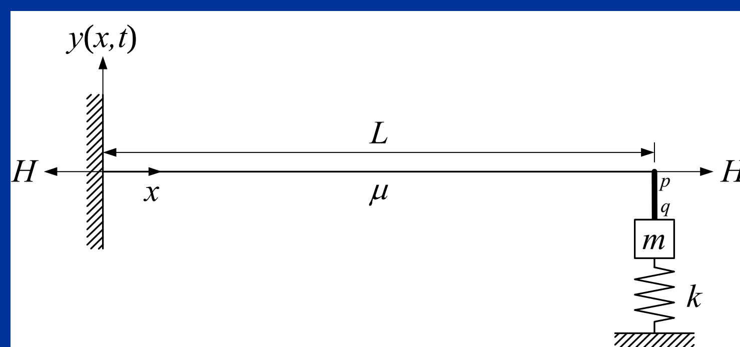
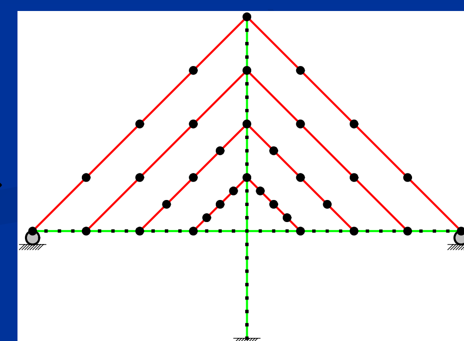


$\overset{?}{\Leftrightarrow}$



Conclusions

- Large-amplitude stay cable vibration induced by deck oscillation have been observed in the field
- Analytical modeling revealed that coupled motions of deck and stay cables are associated with the veering of natural frequency loci
- Three-dimensional finite element models verified that coupled motion and natural frequency curve veering are exhibited in real structures
- An OECS model with linear vibration theory for a cable based on the presented model would reasonably evaluate coupled motions for engineering applications, offering a more efficient approach than a MECS model