Overview of Research Program Under Pooled-Fund Study SPR-3(078)

H.R. Bosch
Director, FHWA Aerodynamics Laboratory

2nd Workshop on Wind-Induced Vibrations of Cable-Stayed Bridges

St. Louis, MO

April 25-27, 2006

Study Goals

- Establish state of knowledge regarding vibrations
- Identify details of U.S. bridges
- Determine status of bridge performance
- Advance understanding of problem
- Provide guidelines for enhanced design

Study Objectives

- To establish the state of knowledge
- To synthesize all information available
- To develop guidelines for design

Study Scope

- Review of all existing information
  - *investigations, studies, remedial measures*
- Collection of detailed information
  - *designs, specifications, site conditions*
- Performance of special studies
  - *analytical, experimental, full scale*
- Evaluation of concepts
  - *existing and new*
- Development of guidelines

State Sponsors

State	Cable-Stay Bridges
Missouri	**Cape Girardeau**
Virginia	James River
Georgia	Talmadge, Sidney Lanier
Kentucky	Maysville, Owensboro
Florida	Dames Point, Sunshine Skyway
Alabama	Cochrane
Louisiana	Luling-Destrehan, St. Francisville
Texas	Veterans Memorial, Fred Hartman
Mississippi	US82
Illinois	Quincy, Clark
Iowa	Burlington
South Carolina	Cooper River

Key Team Members

JOHNS HOPKINS UNIVERSITY

RWDI CONSULTING ENGINEERS & SCIENTISTS

HNTB

BUCKLAND & TAYLOR LTD. Bridge Engineering

National Research Council Canada

uOttawa University of Ottawa

U.S. Department of Transportation Federal Highway Administration
AERODYNAMICS LABORATORY

HNTB Contract Research

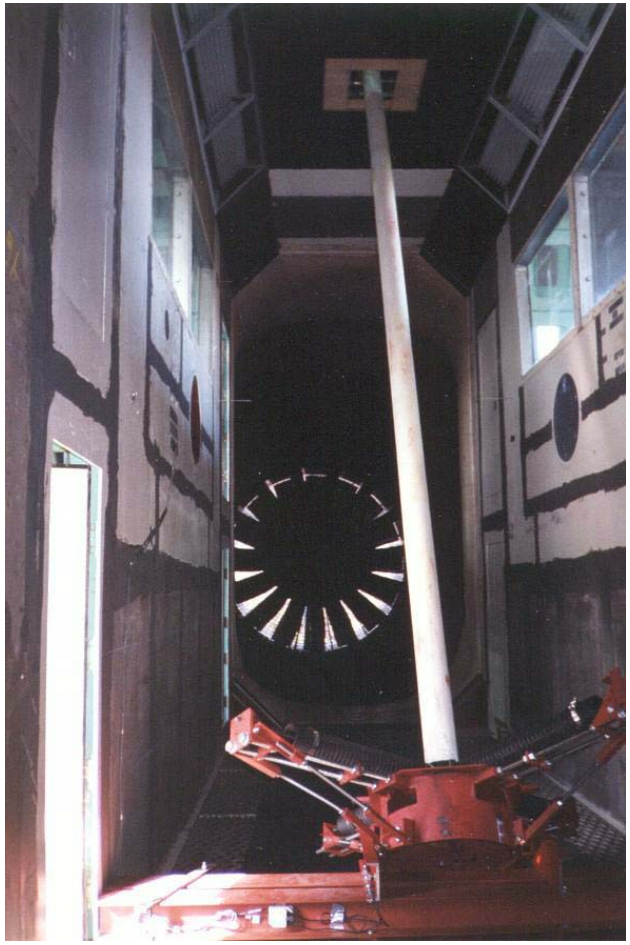
- Wind Tunnel Testing (NRC, UO, RWDI)
  - Dynamic Cable Response
  - 3-D Wind Pressures
- Dampers on Cables (JHU)
- Cross-Ties on Cables (JHU)
- Database Development (HNTB, JHU)
- Draft Guidelines Development (HNTB, B&T)

Wind Tunnel Tests

NRC Canada Jet Propulsion Wind Tunnel

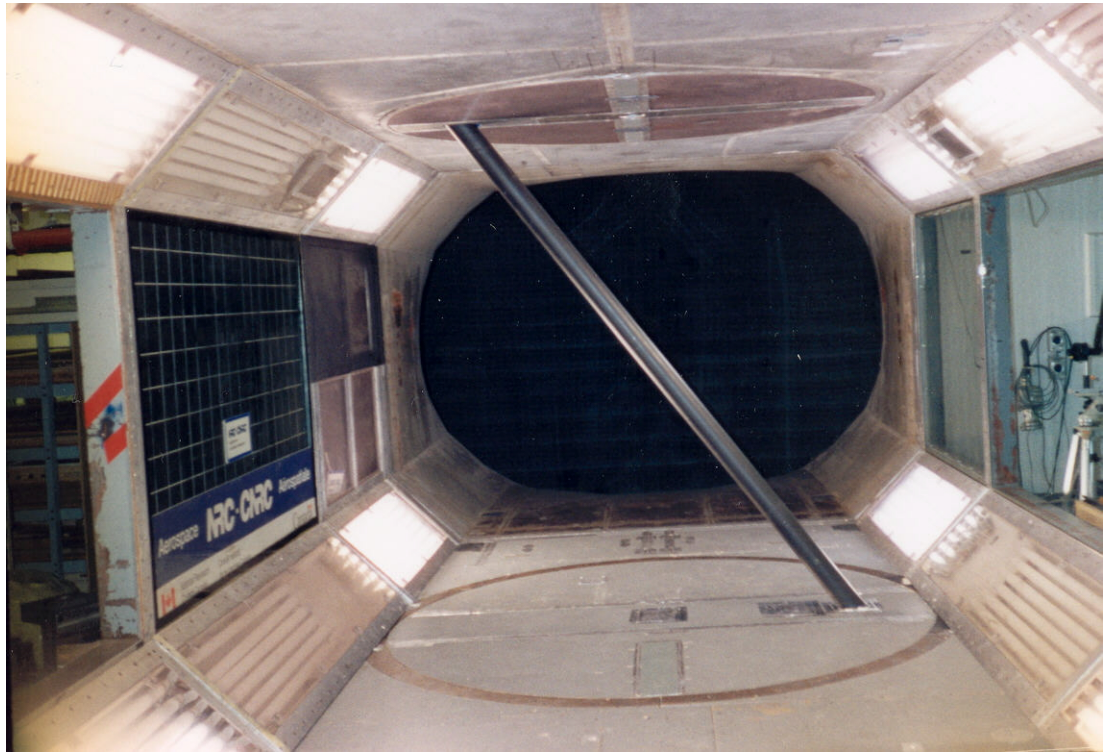
Wind Tunnel Tests

Cable Set Up in JP Wind Tunnel for Dynamic Testing



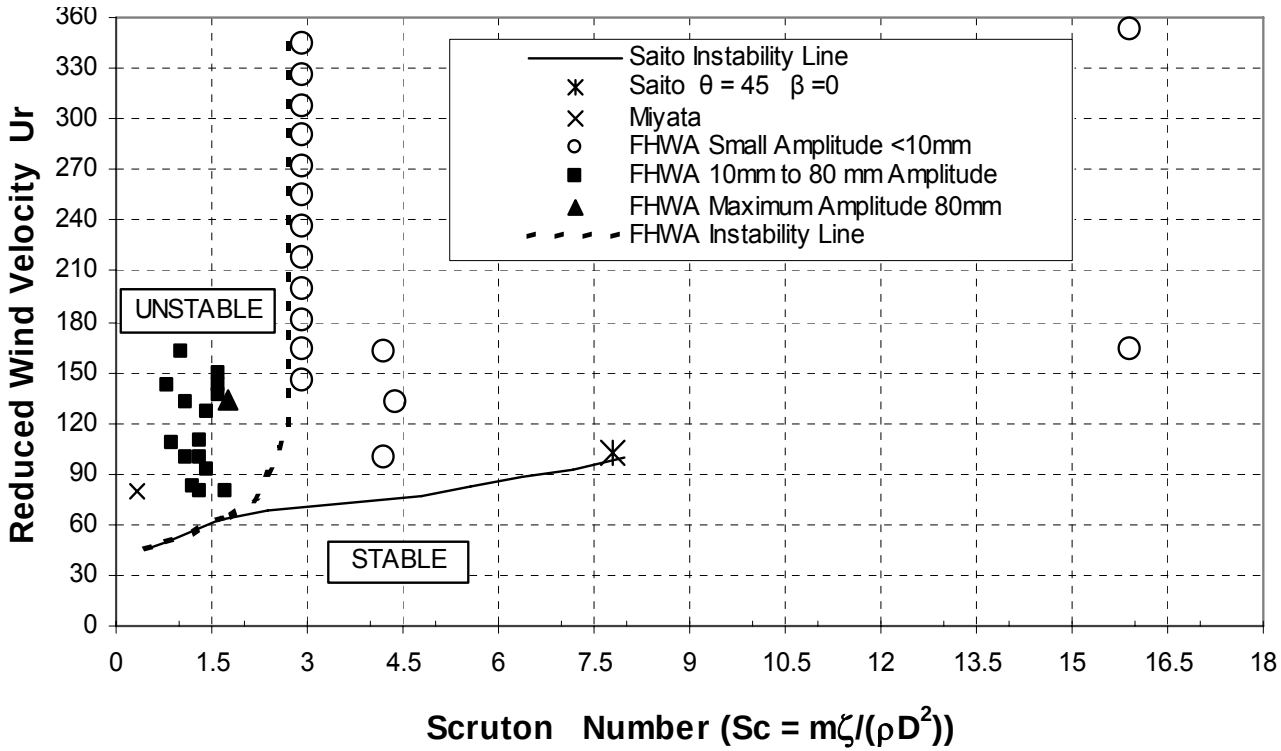
Wind Tunnel Tests

NRC Canada Wind Tunnel – 3-D Pressure Measurements



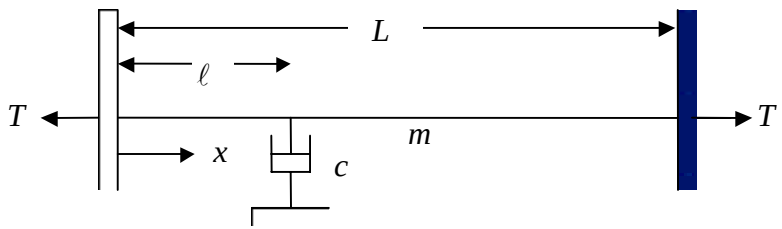
Wind Tunnel Tests

Comparison of wind velocity-damping relation of inclined dry cable



Damper Model (Phase Equation)

Taut cable with linear damper

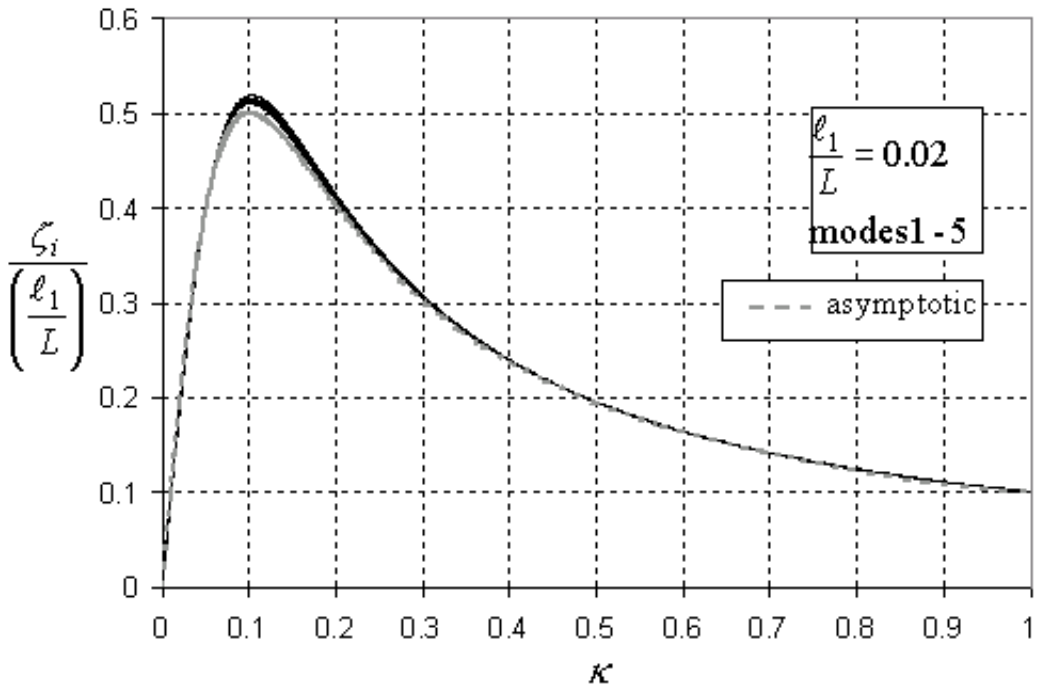


$$\frac{\zeta_i}{(\ell / L)} \cong \frac{\pi^2 \kappa}{(\pi^2 \kappa)^2 + 1} \quad ; \quad \kappa \equiv \frac{c}{mL\,\omega_{o1}} i \frac{\ell}{L}$$

i	= mode of vibration
c	= damping coefficient
m	= mass per unit length
ω_{o1}	= fundamental circular frequency
ℓ/L	= normalized damper location

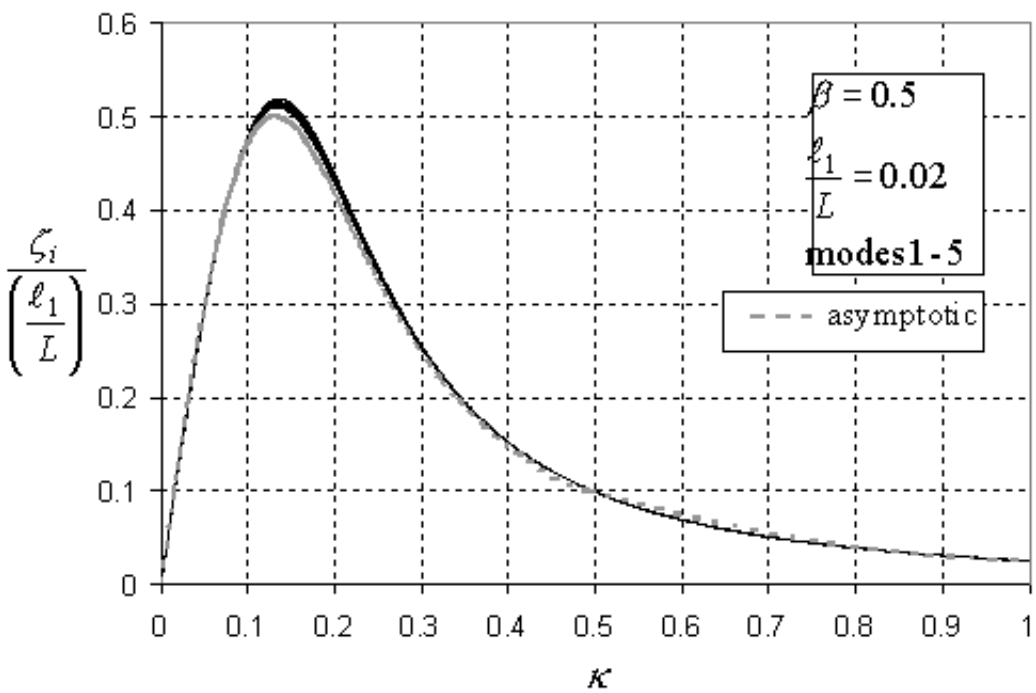
"Universal" Damping Curve

Normalized Damping Ratio versus Normalized Damper Coefficient: Linear Damper



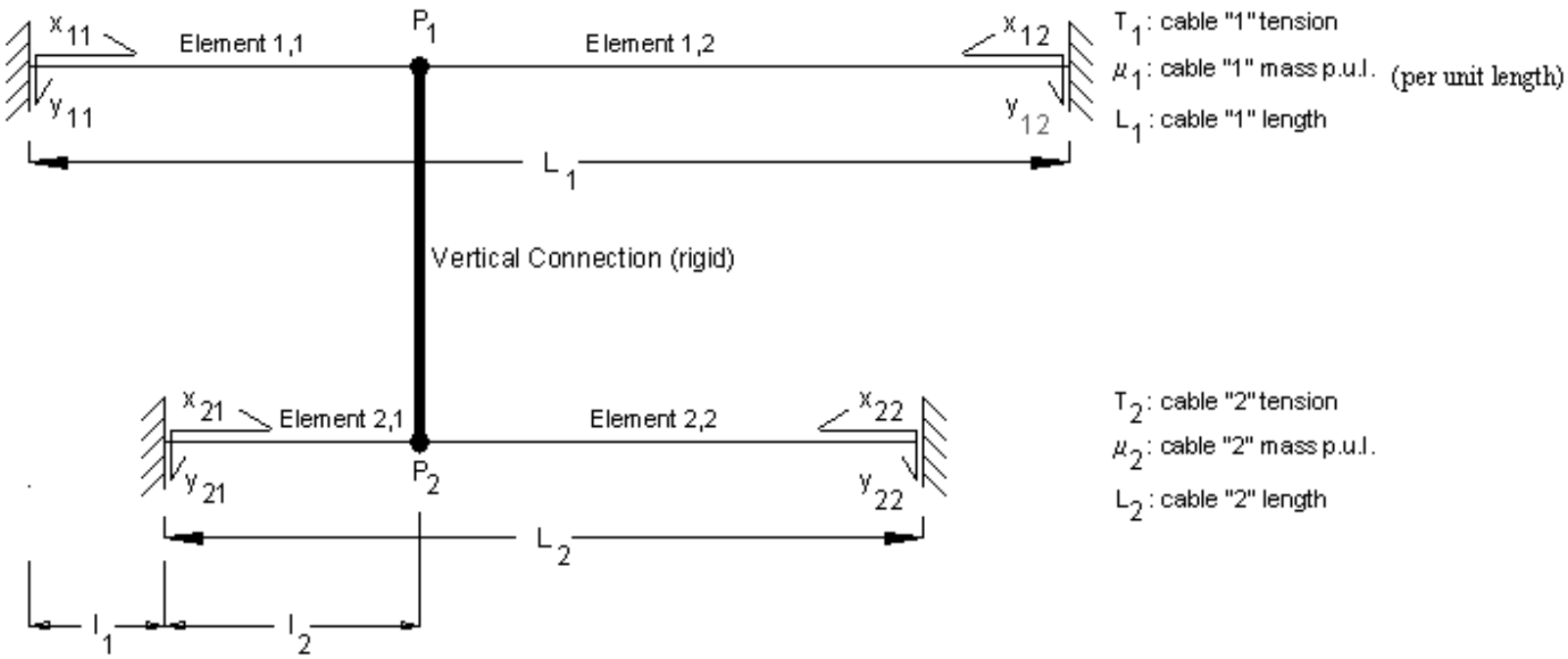
"Universal" Damping Curve

Normalized Damping Ratio versus Normalized Damper Coefficient: β=0.5
Non-Linear Damper



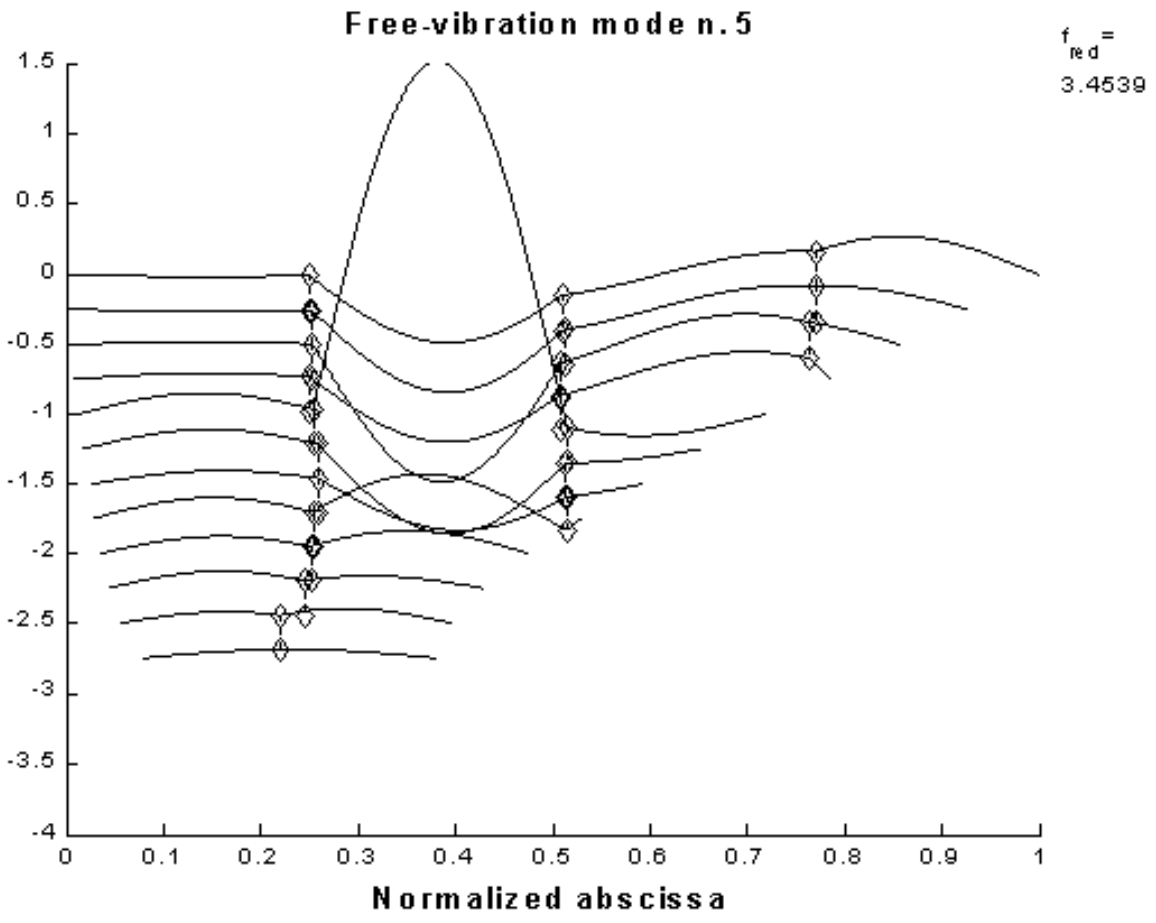
Cable Network Analysis

General problem formulation



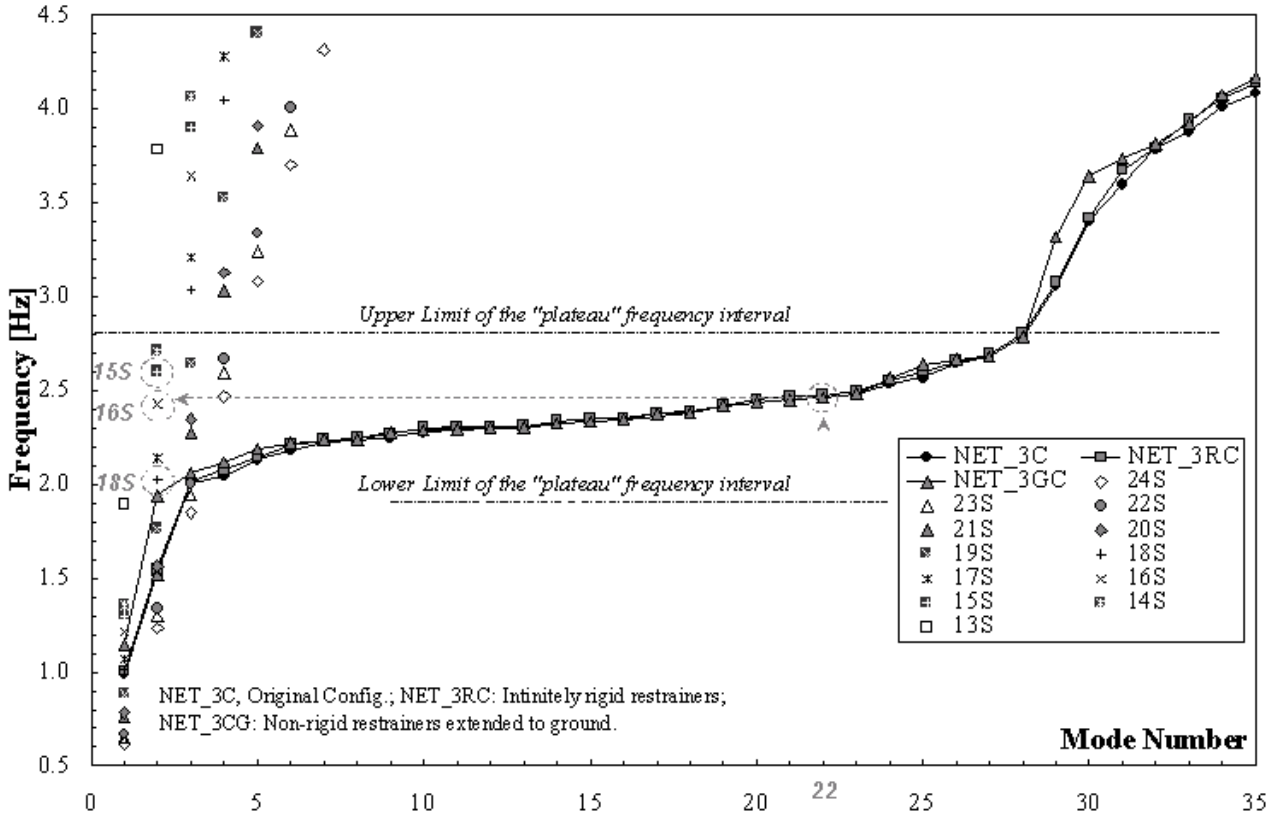
Cable Network Vibration Modes

Eigenfunctions of the network equivalent to Fred Hartman Bridge; mode 5



Cable Network Frequency Evolution

Comparative analysis of network vibration characteristics and individual-cable behavior; Fred Hartman Bridge



Database Development

- Stay Cable Vibration References
- U.S. Cable-Stayed Bridges
- Fred Hartman Full-Scale Measurements
- Veteran's Memorial Full-Scale Measurements

Draft Guidelines Development

- General Statement
- Mitigation of Rain/Wind Mechanism (Aerodynamic Surface)
- Additional Mitigation (External Damping, Cross-Ties)
- Minimum Scruton Number
- External Dampers
- Cross-Ties
- User-Tolerance Limits

FHWA Lab Research

- Full-Scale Measurements (FHWA)
  - Zakim, Emerson, C&D Canal, Luling
- Full-Scale Measurements (JHU Task Order)
  - Sunshine Skyway
- Cable Network Analysis
  - Mass-Damping & Dynamic Properties
  - Finite Element Analysis
- Guidelines Document Development
- Database Enhancement
  - Cable-Stayed Bridge Database
  - Stay Cable Reference Database
- Deployment of Wind Instruments on Emerson Bridge

Full Scale Measurements

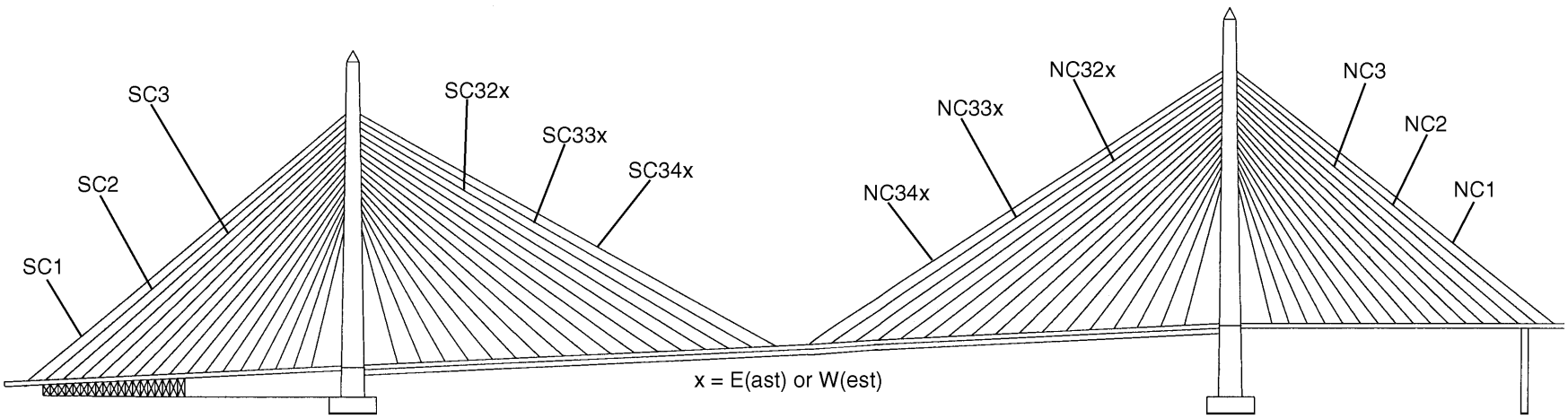
- Zakim – Boston, MA (18 cables tested)
  - Phase I – Cable Only
  - Phase II – Cable and Damper
  - Phase III – Cable, Damper, and Cross-Tie

- C&D Canal – St. Georges, DE (3 cables tested)
  - Phase I – Forced Vibration, In-Service Configuration
  - Phase II – Short-Term Monitoring (24 months)

- Cape Girardeau, MO (35 cables tested)
  - Phase I – Ungrouted Cable
  - Phase II – Grouted Cable
  - Phase III – Grouted Cable with Single Cross-Tie

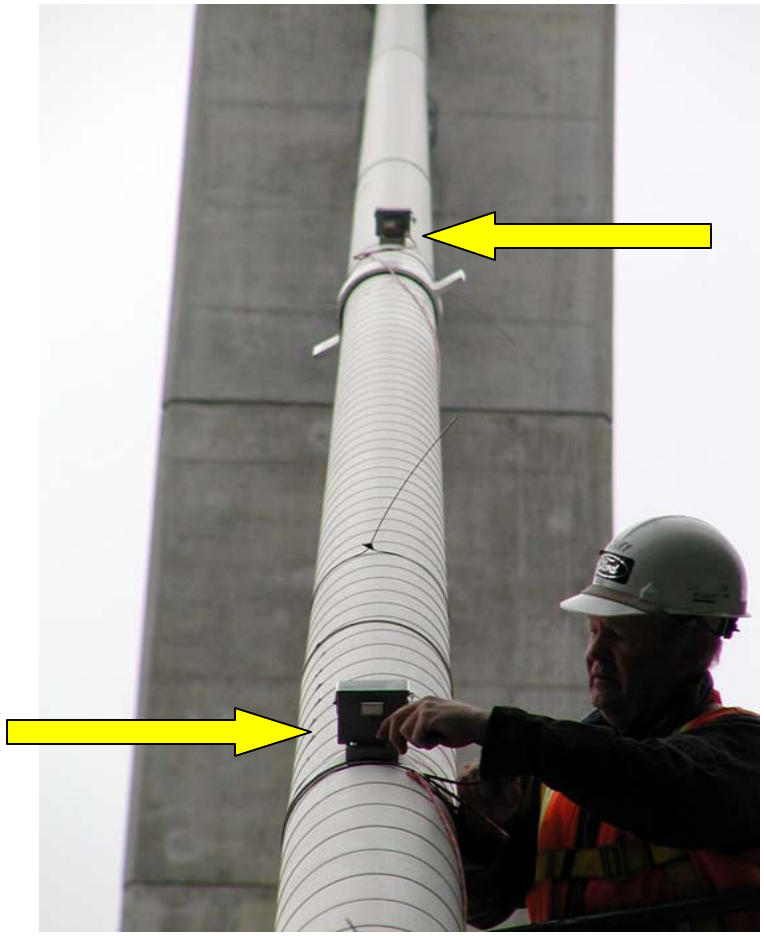
FHWA Field Tests – Boston, MA

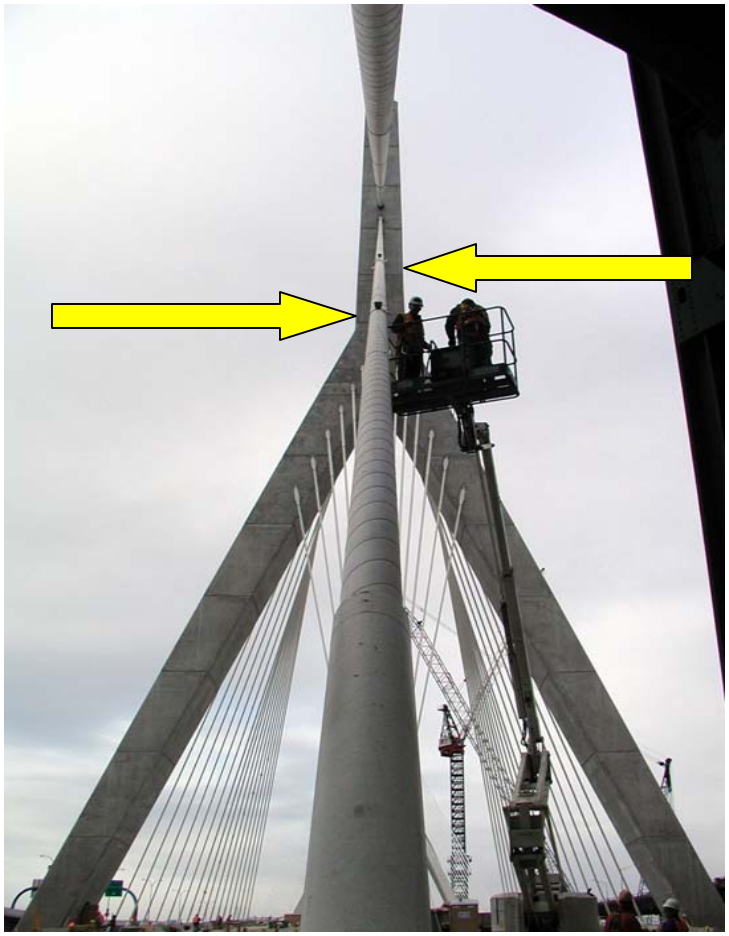
Charles River - Bridge Cables Tested



FHWA Field Tests – Boston, MA

Charles River Bridge – Sensor Placement



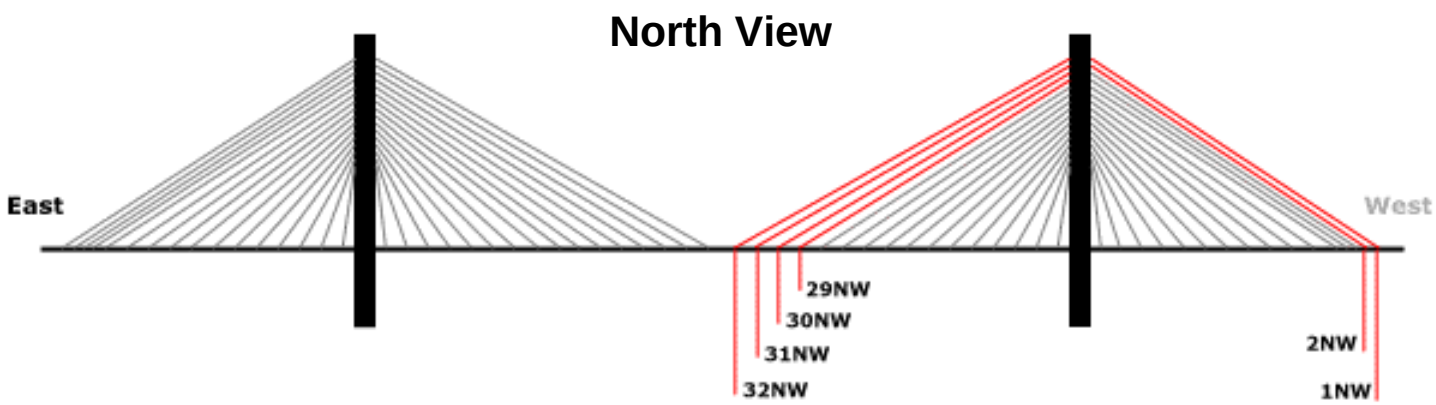


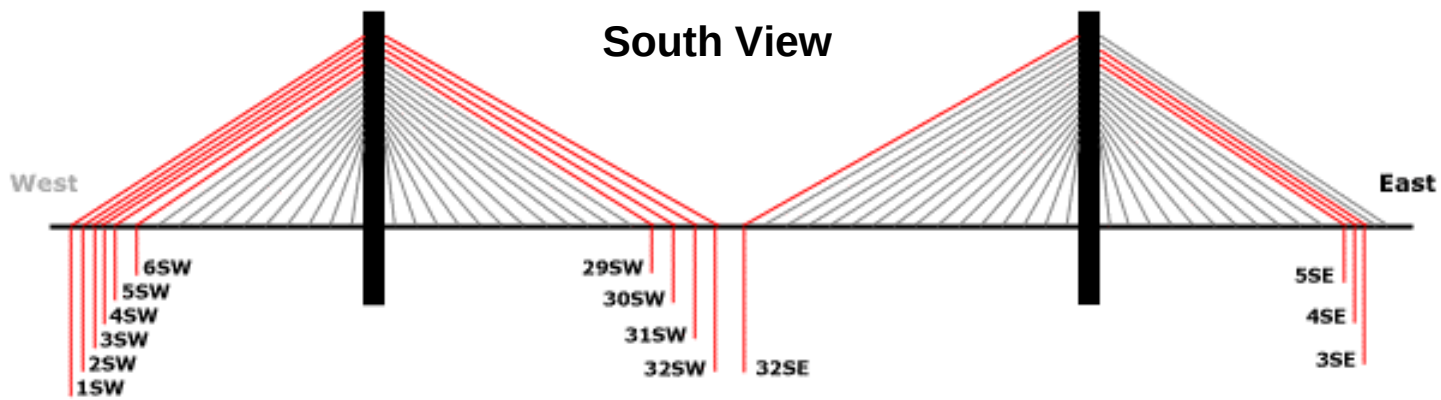
FHWA Field Tests – Boston, MA

Charles River Bridge – Cable Vibration Simulation

FHWA Field Tests – Cape Girardeau, MO

Cape Girardeau - Bridge Cables Tested (Phase I)





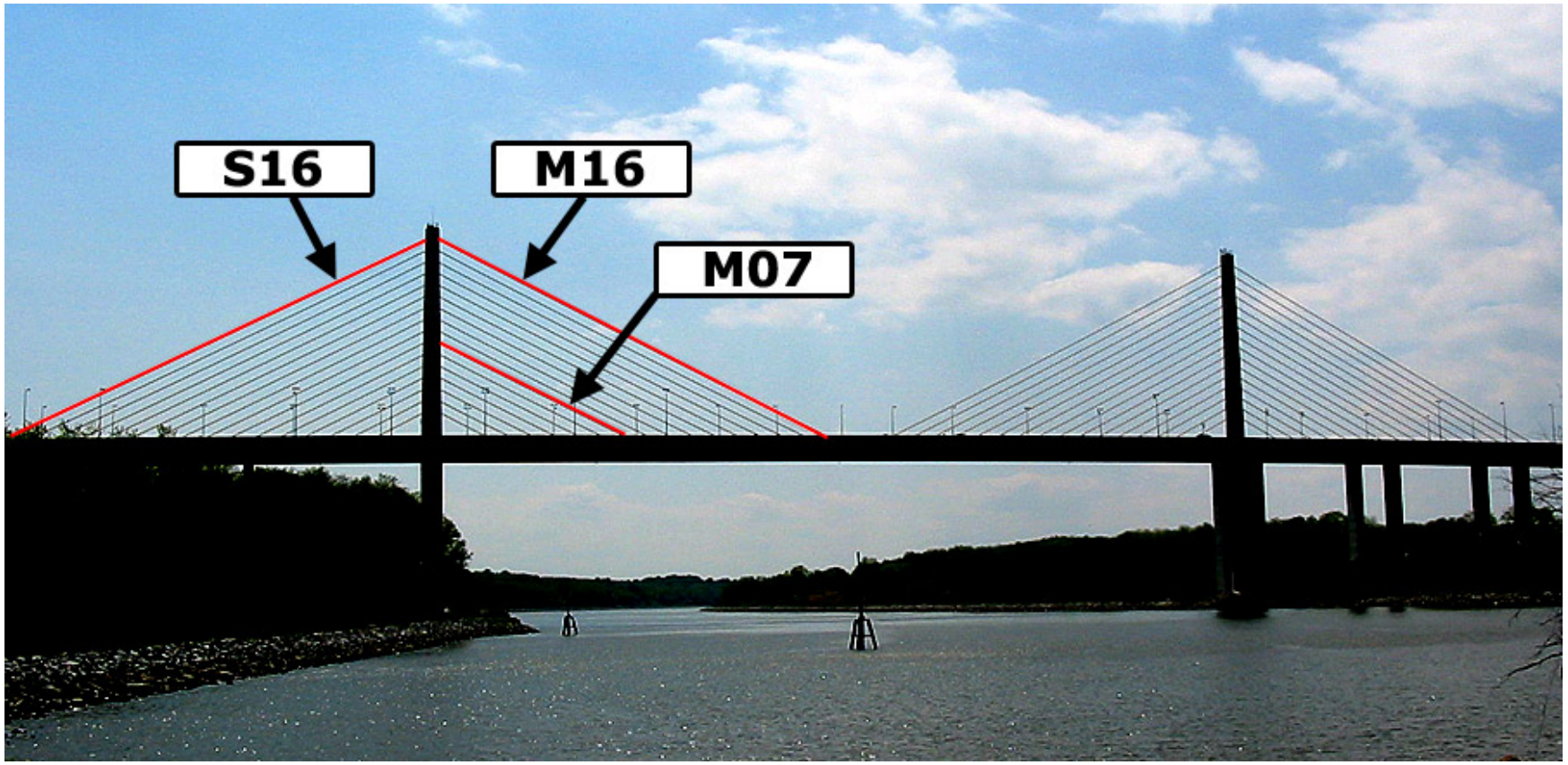
FHWA Field Tests – Cape Girardeau, MO

Cape Girardeau Bridge – Experimental Setup

Installation Detail and Portable Data Acquisition System

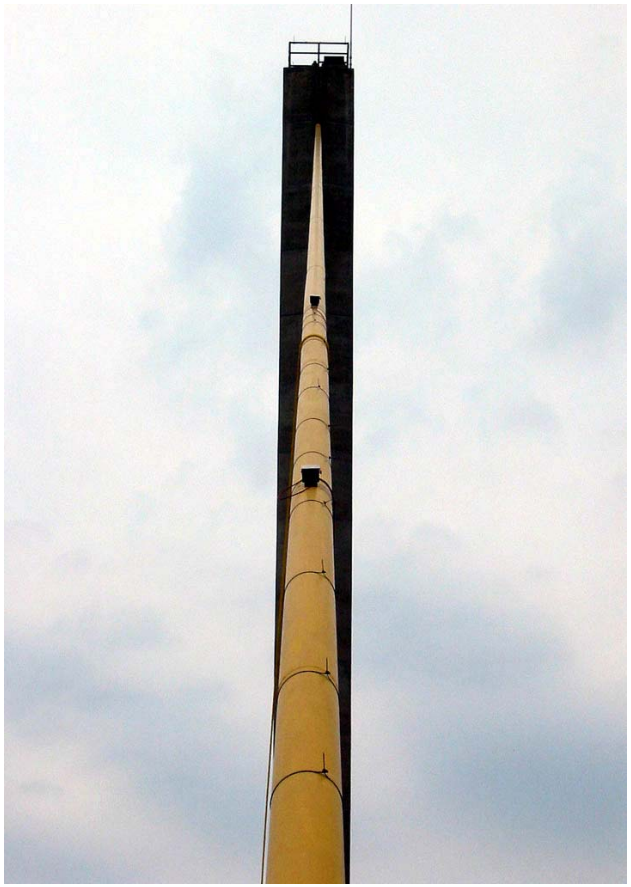
FHWA Field Tests – St. Georges, DE

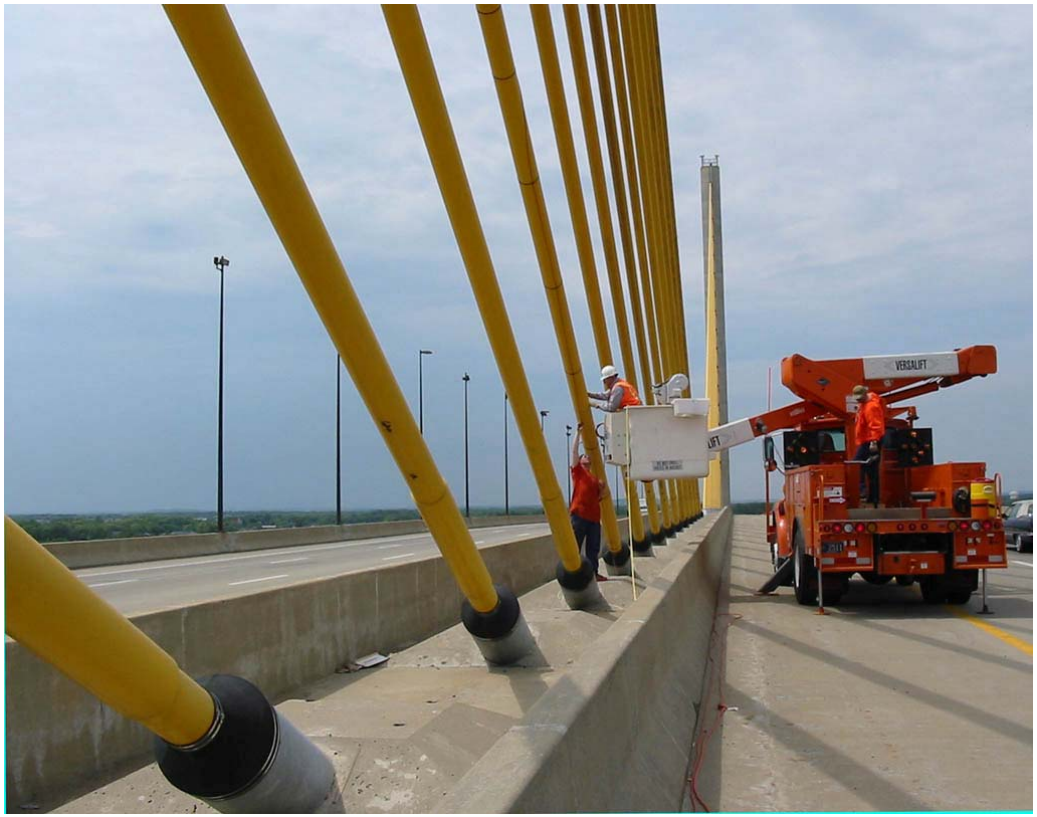
C&D Canal - Bridge Cables Tested



FHWA Field Tests – St. Georges, DE

C&D Canal Bridge – Sensor Placement





Evaluation of Stay Cables and Cable Systems

Research Tasks

- Update databases of cable properties
  - Size, geometry, static and dynamic details
- Collect information on mitigation features
- Collect information on performance
- Assess effectiveness of actual and alternative cross-tie and damper deployments.
- Evaluate impact of combining mitigation features.
  - Dampers, cross-ties

Evaluation of Stay Cables and Cable Systems

Task Status

- Databases have been updated
- Finite element model of Fred Hartman completed and compared with JHU work
- Finite element model of Emerson mostly completed
  - Evaluated actual and alternative cross-tie configurations
  - Evaluated cable network without ties
  - Evaluated network with dampers and no ties
  - Evaluated netowrk with dampers and ties
- Modeled and measured dynamic properties are being compared

Development of Guidelines Document for Cable Vibration Mitigation

Research Tasks

- Review results of HNTB contract
- Review available recent information on mitigation of cable vibrations
- Review structure and format of similar guideline documents
- Develop new draft design guideline document
- Present drafts of new document to committee and revise as necessary

Database Enhancement

Background

- Databases products of HNTB Project
- Were hosted on JHU servers; when project ended, no server space
- Initiated plan to develop stand-alone databases
- Databases maintained by FHWA Aerodynamics Lab

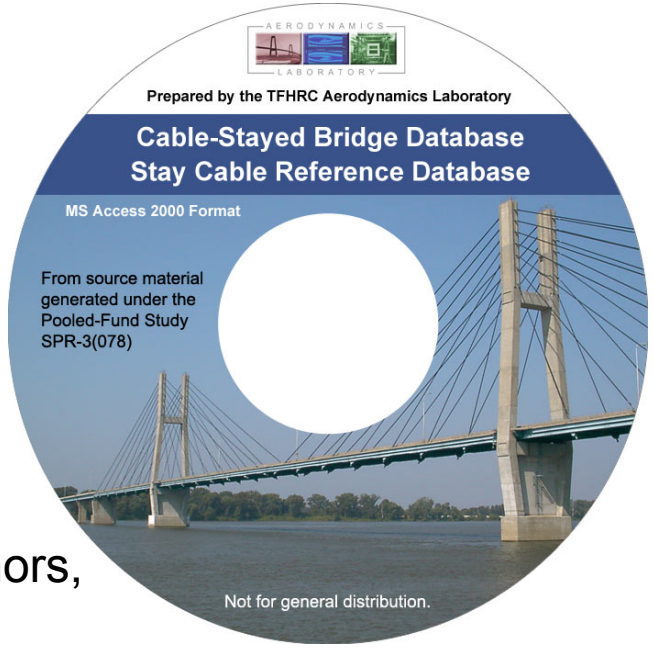
Description

- Stay Cable Reference Database – Reference library database containing bibliographic information about reports/documents used during HNTB project
- Cable-Stayed Bridge Database – Bridge and cable data for a number of cable-stayed bridges

Database Enhancement

Stay Cable Reference Database

- Designed new user interface to view/edit report information, author(s), abstracts, etc.
- Designed using Microsoft Access and Visual Basic for Applications (VBA)
- Developed search interface to allow users to search records by title, keyword(s), authors, etc.



Cable-Stayed Bridge Database

- Performed minor modifications to interface/code of pre-existing Microsoft Access database
- Primary modifications to correct problems with screen-sizing and application flow

Emerson Bridge Wind Instrumentation

Research Tasks

- Develop instrumentation plan for monitoring wind conditions and cable vibrations
- Select and procure instrumentation
- Assemble and bench test instrumentation
- Develop deployment plan for instrumentation
- Install and verify system at site

Emerson Bridge Wind Instrumentation

Task Status

- Instrumentation plan is complete
- Sensor cables installed during construction
- 70% of instrumentation has been purchased
- Deployment plan is 90% complete
- Sensor mounting fixtures have been designed