Monitoring of I-235 Pedestrian Bridges

Presentation to University of Iowa Civil Engineering Students

September 29, 2005

Iowa Department of Transportation

BRIDGE ENGINEERING CENTER

Bridge Location & I-235 Corridor

I-235 Reconstruction

- 70 Bridges reconstructed or replaced
- $400 million total construction cost

Pedestrian Bridges

- 1st bridge completed January 2004
- Two similar bridges constructed 2005

Gateway to the City of Des Moines

Quick Facts

- Gateway to the City
- Arch spans ranging from 70 m to 80 m
  - 80 m @ Botanical (88.5 m total bridge)
  - 80 m @ 40th Street (83.2 m total bridge)
  - 70 m @ 44th Street (78.5 m total bridge)

Quick Facts

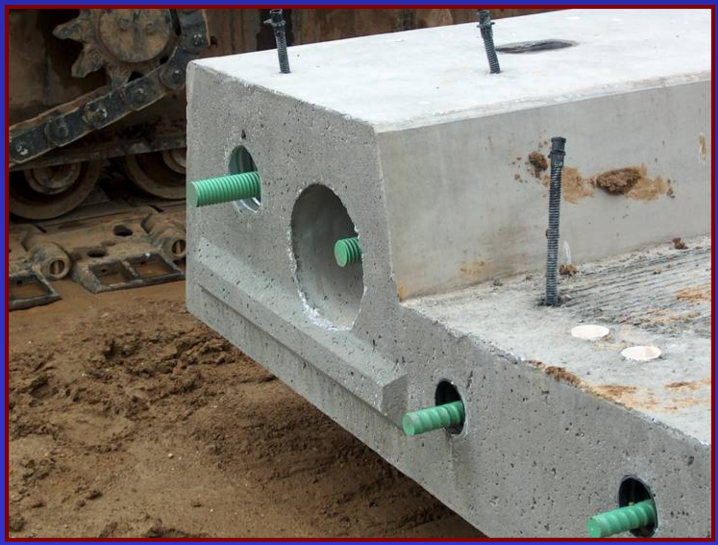
- Gateway to the City
- Spans ranging from 70 m to 80 m
- Drilled shafts and pile foundations
  - 4 - 1680 mm drilled shafts @ Botanical
  - 67 - HP 310x79 piles @ 40th Street
  - 78 - HP 310x79 piles @ 44th Street

Quick Facts

- Gateway to the City
- Spans ranging from 74 m to 80 m
- Drilled shafts and pile foundations
- Steel box arch ribs
  - 500 mm x 700 mm at crown
  - 750 mm x 1250 mm at base

Quick Facts

- Gateway to the City
- Spans ranging from 74 m to 80 m
- Drilled shafts and pile foundations
- Steel box arch ribs
- Precast/post-tensioned deck segments



Quick Facts

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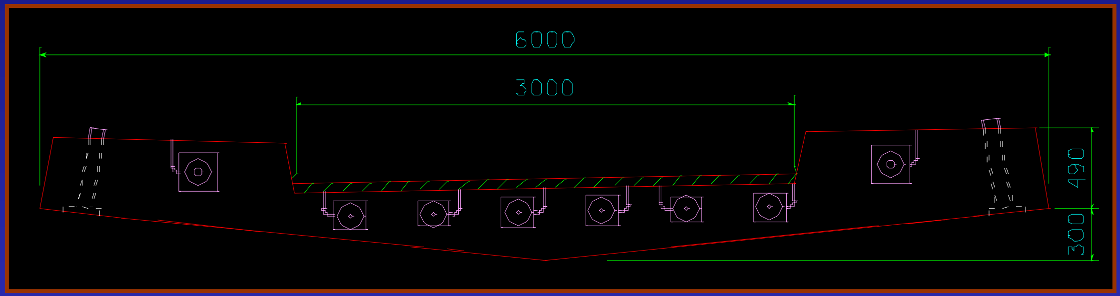
- Spans ranging from 74 m to 80 m
- Drilled shafts and pile foundations
- Steel box arch ribs
- Precast/post-tensioned deck segments
- **Dywidag hangers**

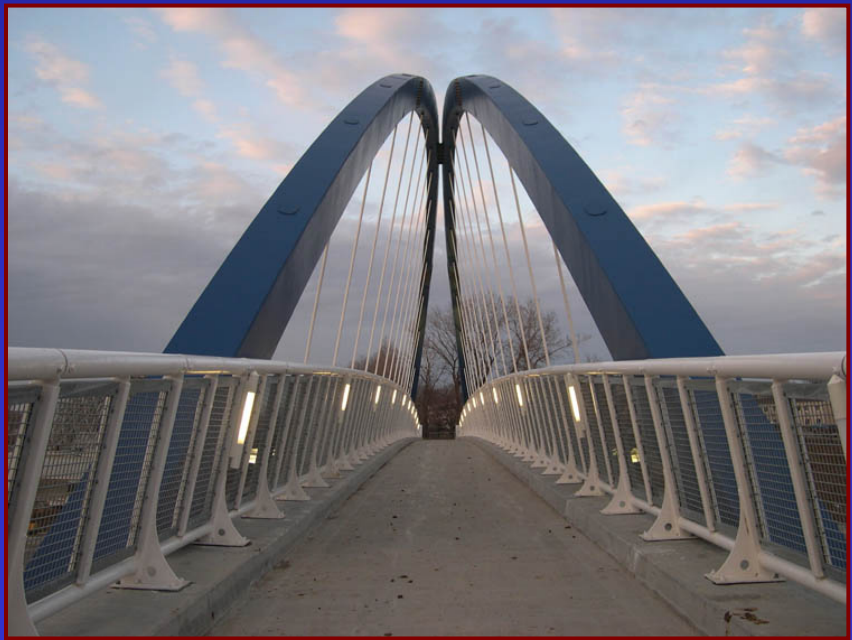
Quick Facts - precast deck panels

- 6.0 m width x 4.2 m length
- 3.0 m wide walking surface



Pedestrian Concerns

- Safety
  - Higher guardrails over traffic area



Pedestrian Concerns

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  - Open environment – no hidden corners
  - Well-lit at night

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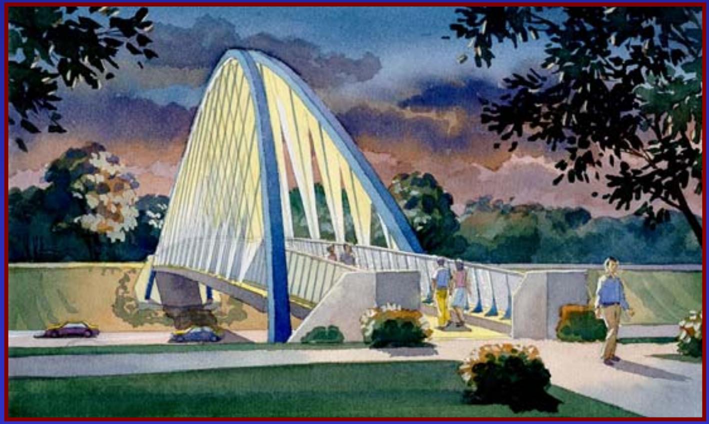

Pedestrian Concerns

- Safety:
  - Higher guardrails over traffic area
  - Open environment – no hidden corners
  - Well-lit at night
  - Minimize temptation of vandalism

Pedestrian Concerns

- Comfort
  - Vibration from wind and vehicular traffic

Pedestrian Concerns – RWDI Studies

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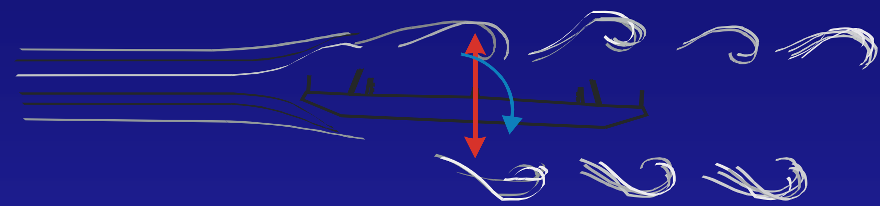
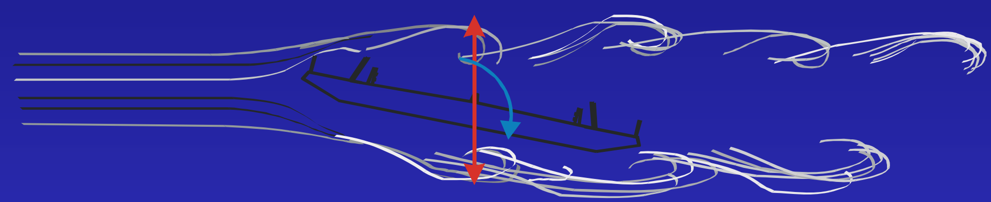
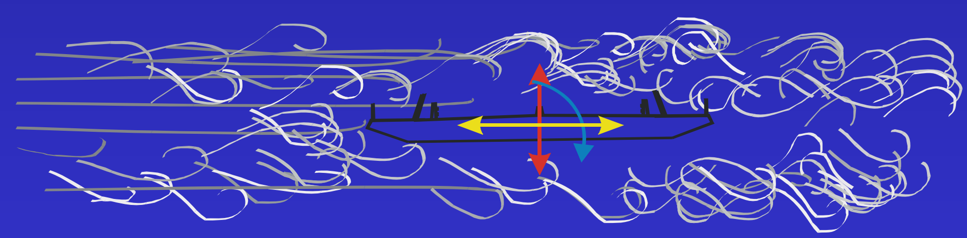
Pedestrian Concerns



Vortex-Induced Oscillations



Flutter

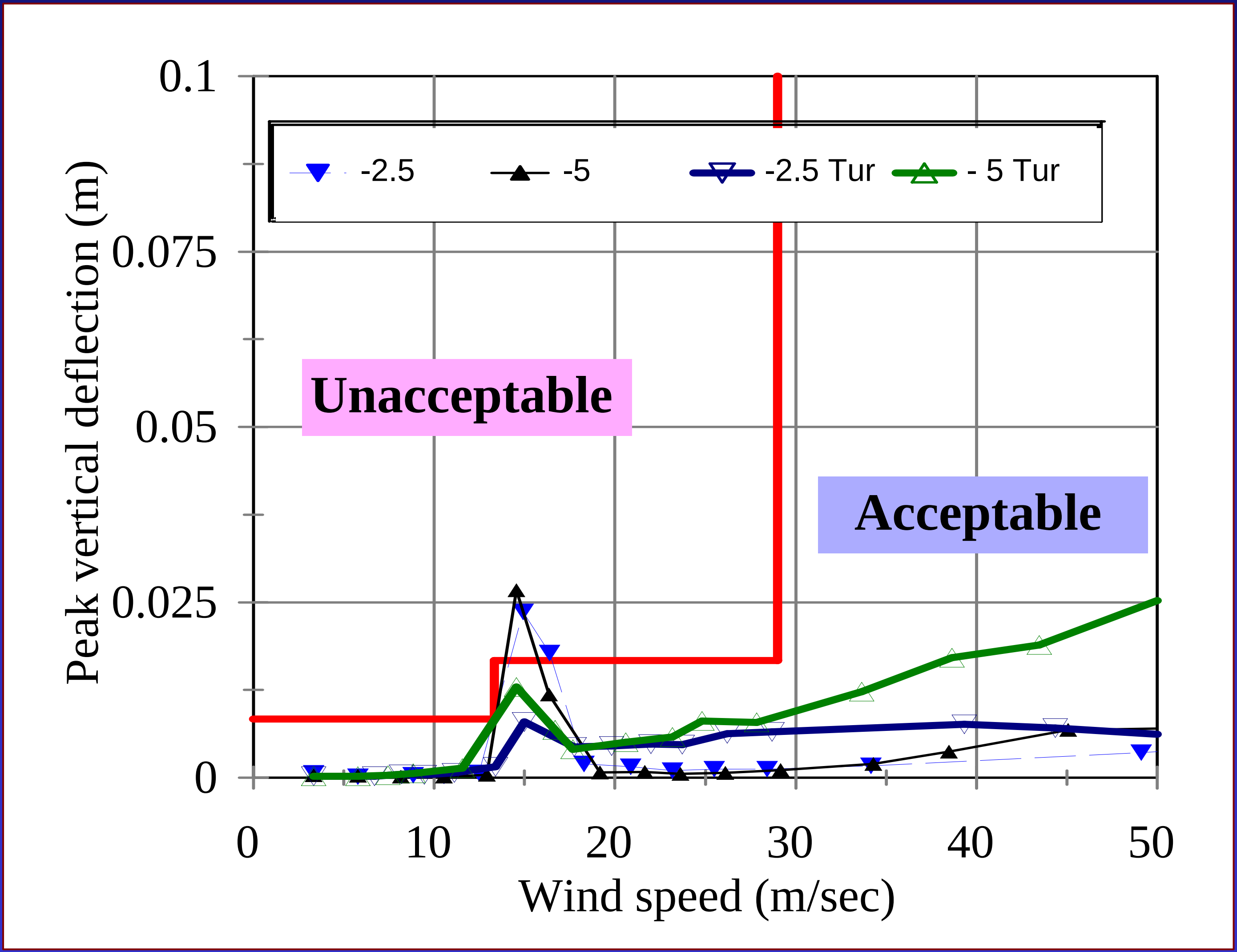


Turbulence-Induced Buffeting

Wind-Induced Instability and Response Phenomena of Bridge Decks

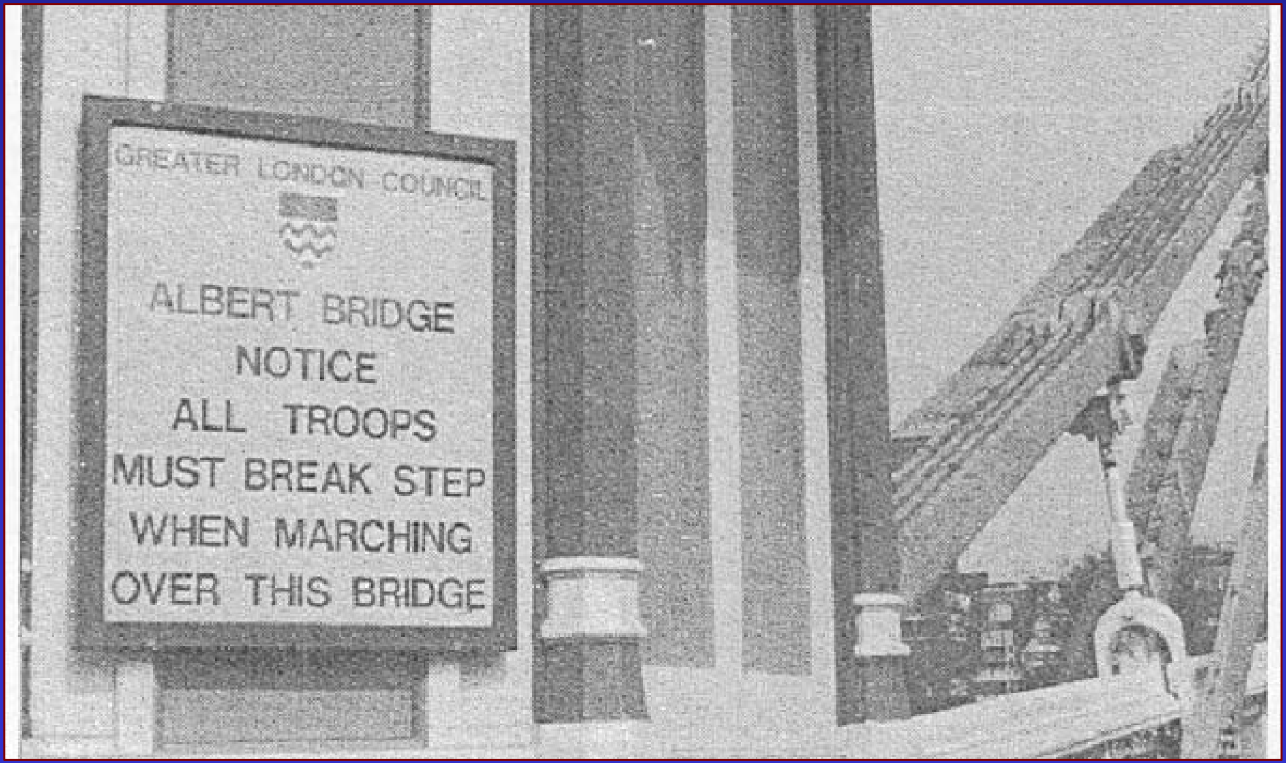
Rowan Williams Davies & Irwin Inc., 650 Woodlawn Road West, Guelph, Ontario, CANADA N1K 1B8
tel: (519) 823-1311, fax: (519) 823-1316, e-mail: sts@rwdi.com

Pedestrian Concerns



Pedestrian Concerns

- **Comfort:**
  - **Vibration from wind and vehicular traffic**
  - **Vibration from pedestrian traffic**



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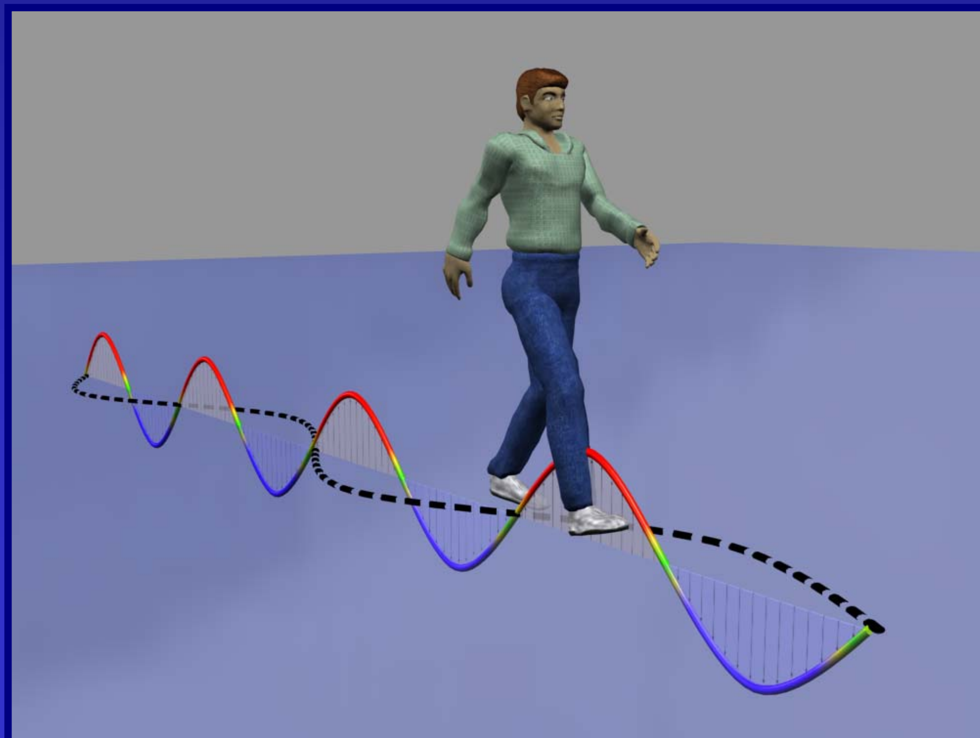
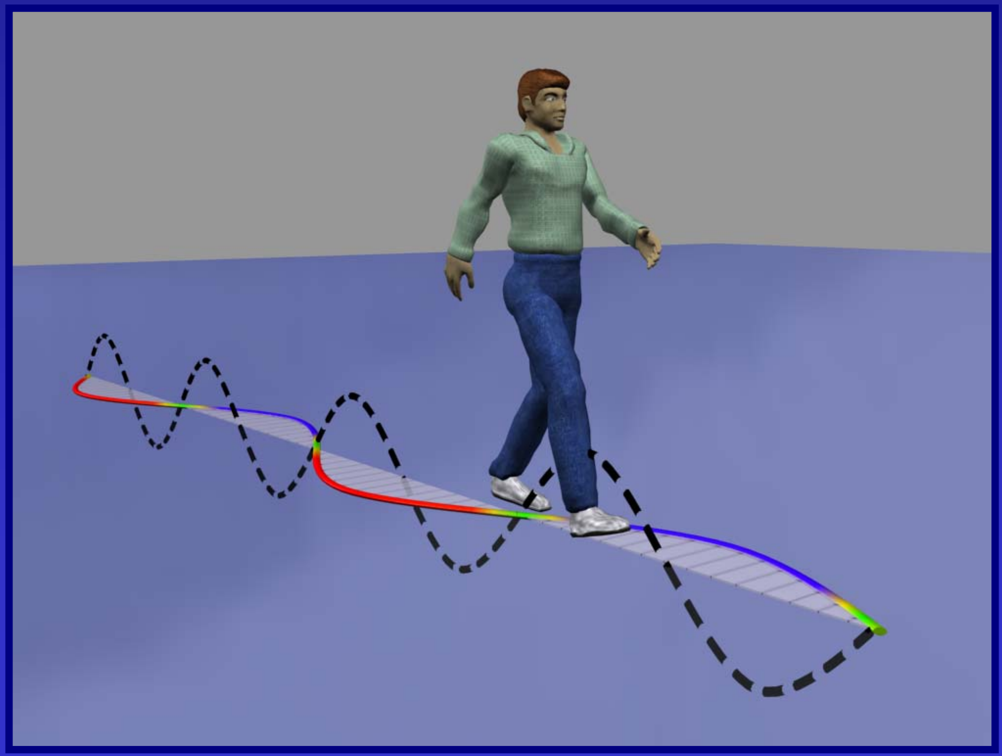


Pedestrian Concerns

- Comfort:
  - Vibration from wind and vehicular traffic
  - Vibration from pedestrian traffic
  - Lateral sway



Pedestrian Concerns

- **Comfort:**
  - **Vibration from wind and vehicular traffic**
  - **Vibration from pedestrian traffic**
  - **Lateral sway**

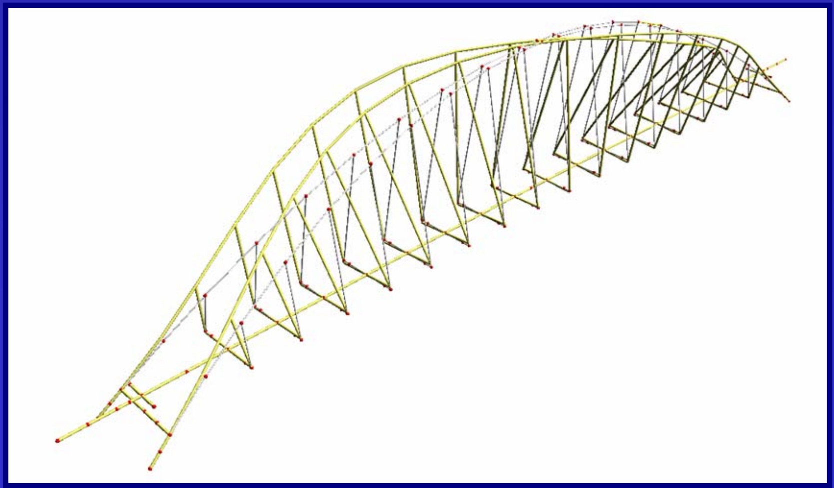
Pedestrian Concerns

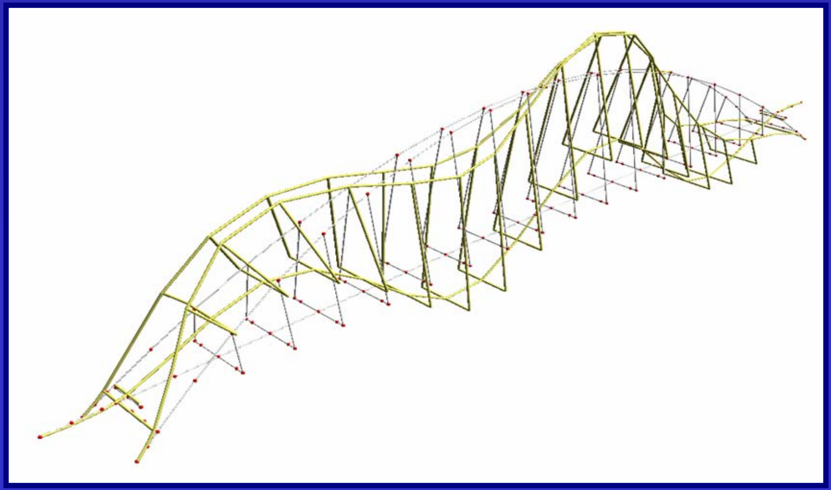
Walking

- Vertical = 1.50 Hz to 3.00 Hz
- Horizontal = 0.75 Hz to 1.50 Hz

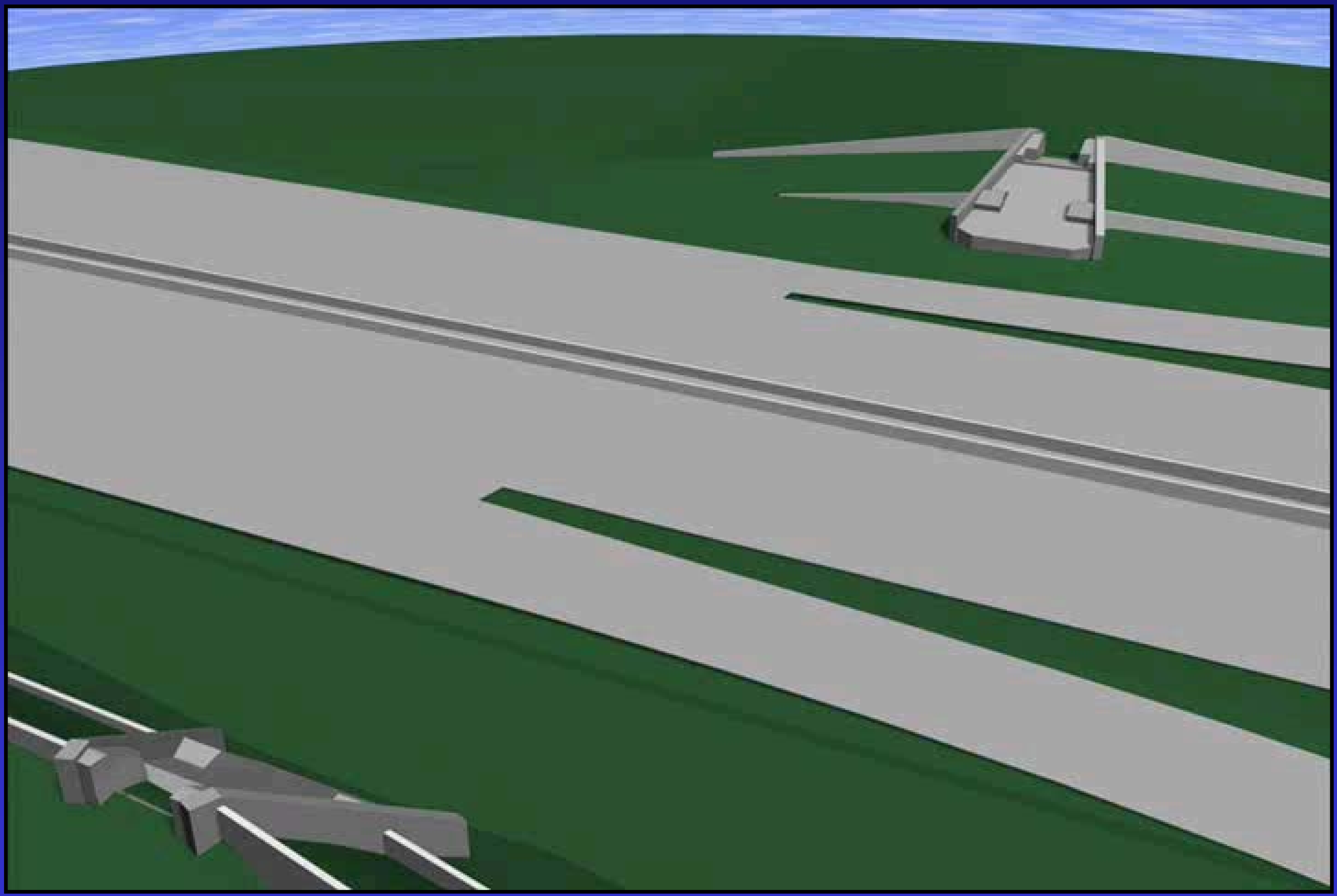
Running

- Vertical = 2.00 Hz to 4.00 Hz
- Horizontal = 1.00 Hz to 2.00 Hz



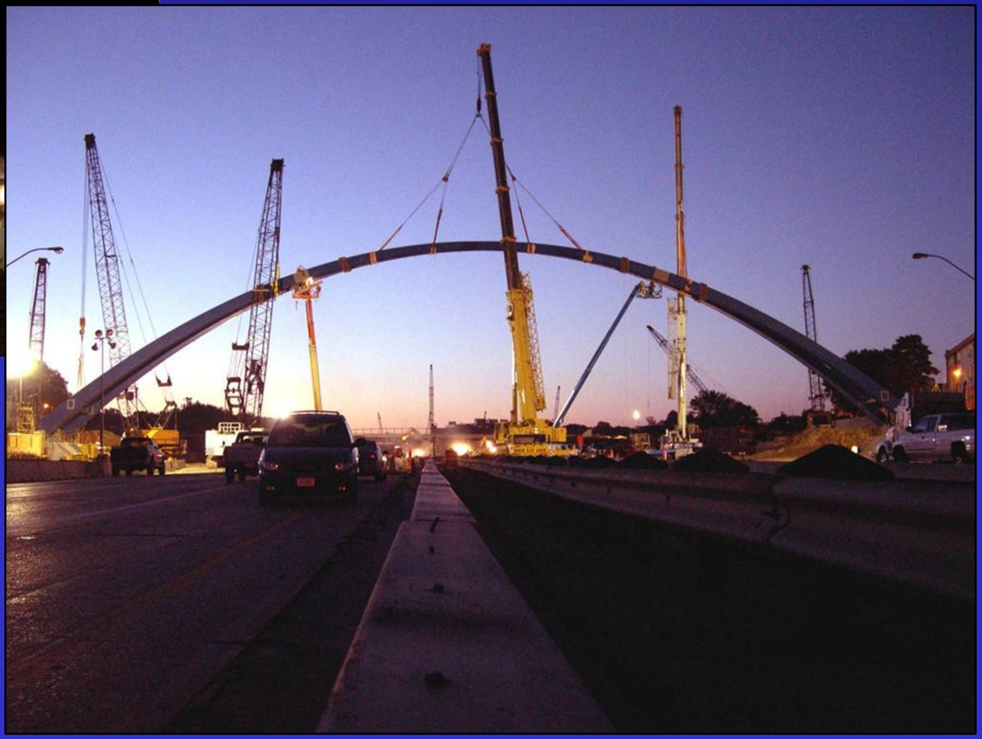


Construction Animation



Steel Erection

Steel Erection

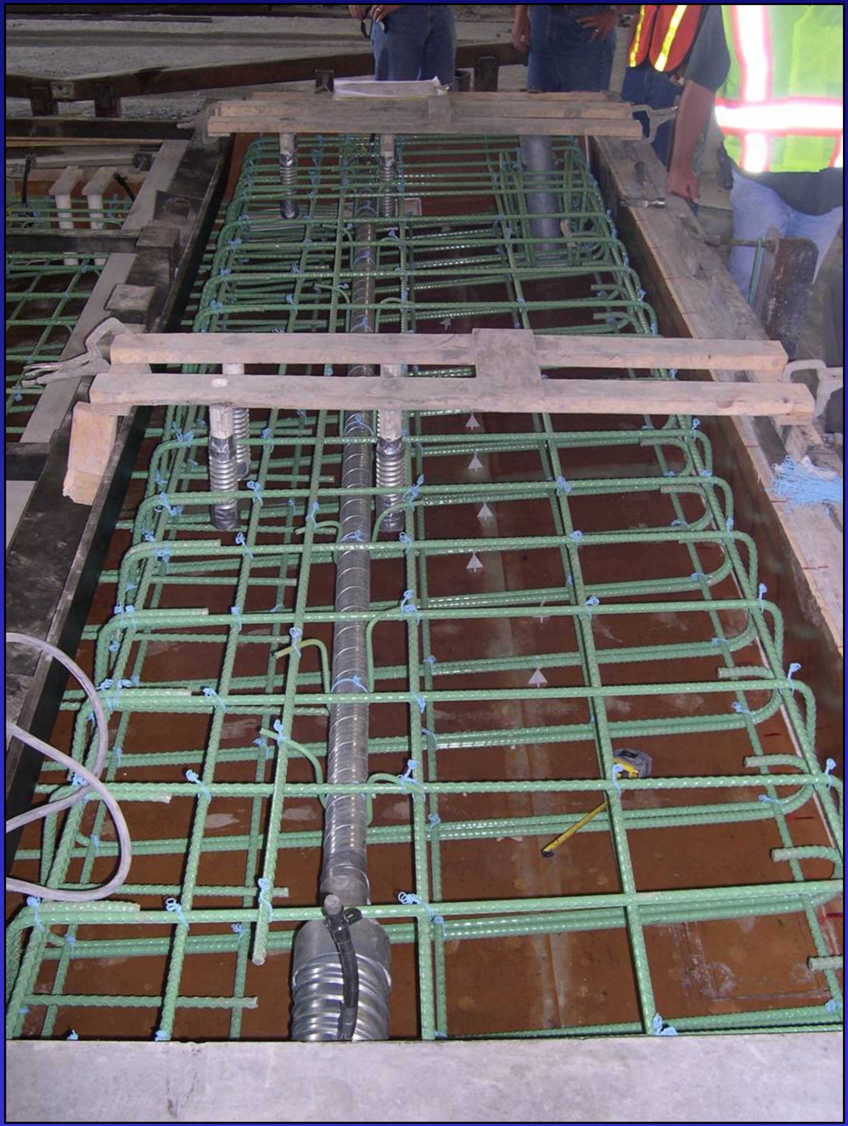


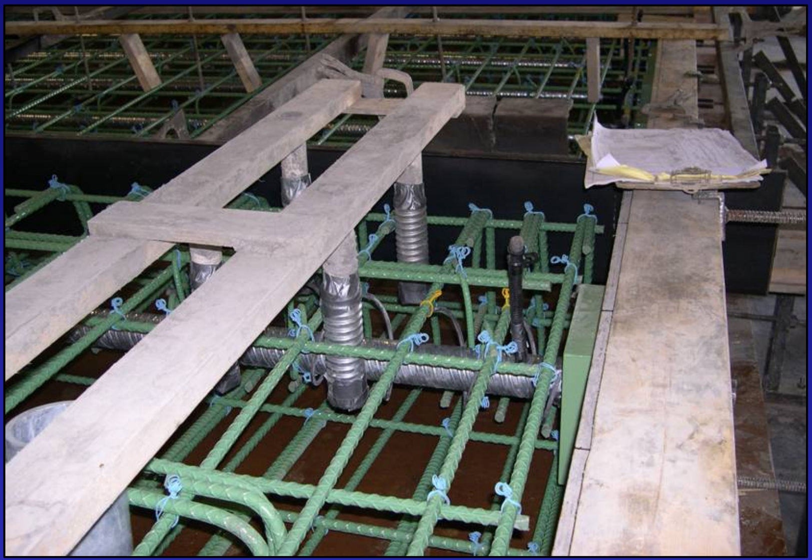
Self-Consolidating Concrete

- Admixtures provide <u>temporary</u> flowability
- Measure "spread" rather than "slump"

SCC – Formwork is Critical

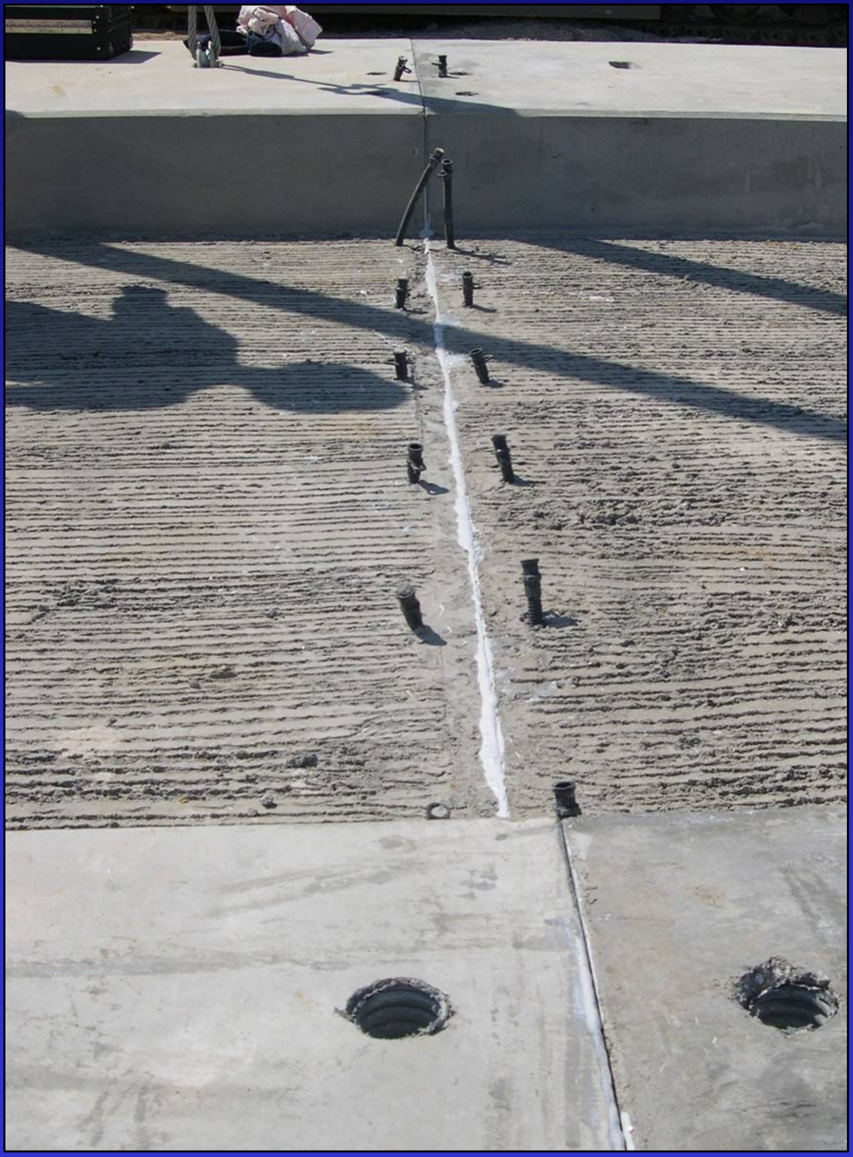
Precast Deck Panels



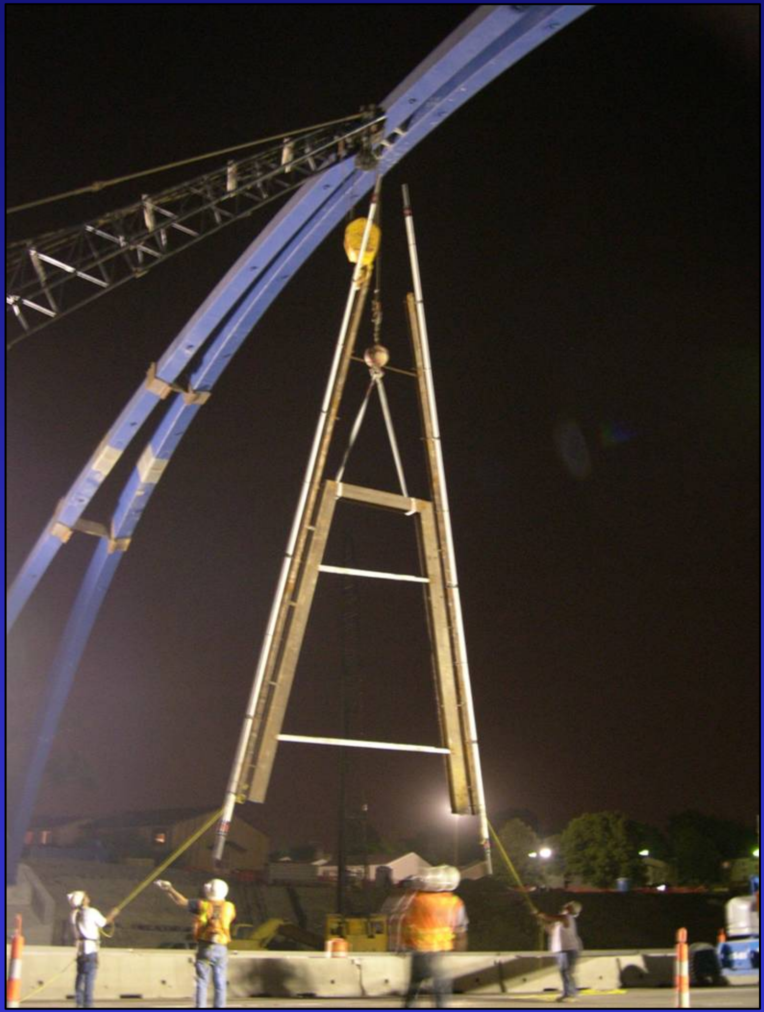


Precast Deck Panels – Match casting

Center Panels Stressed on the Ground



Hanger and Precast Panel Installation

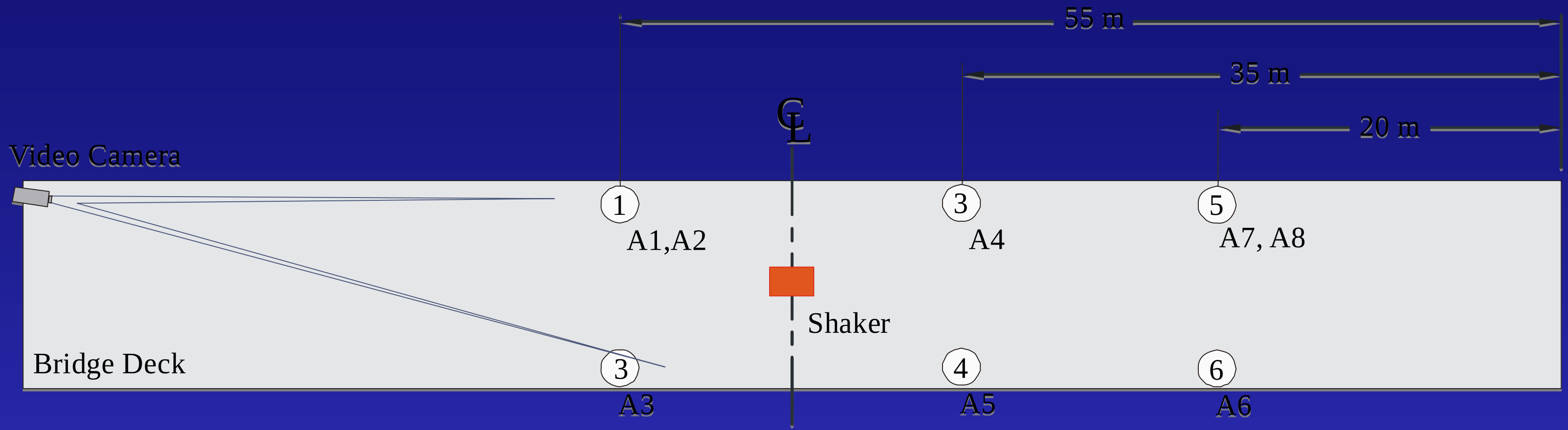


Post-tensioning of Deck Panels

Measure Elongation During PT stressing

Aesthetic Lighting

Field Testing of I-235 Pedestrian Bridge



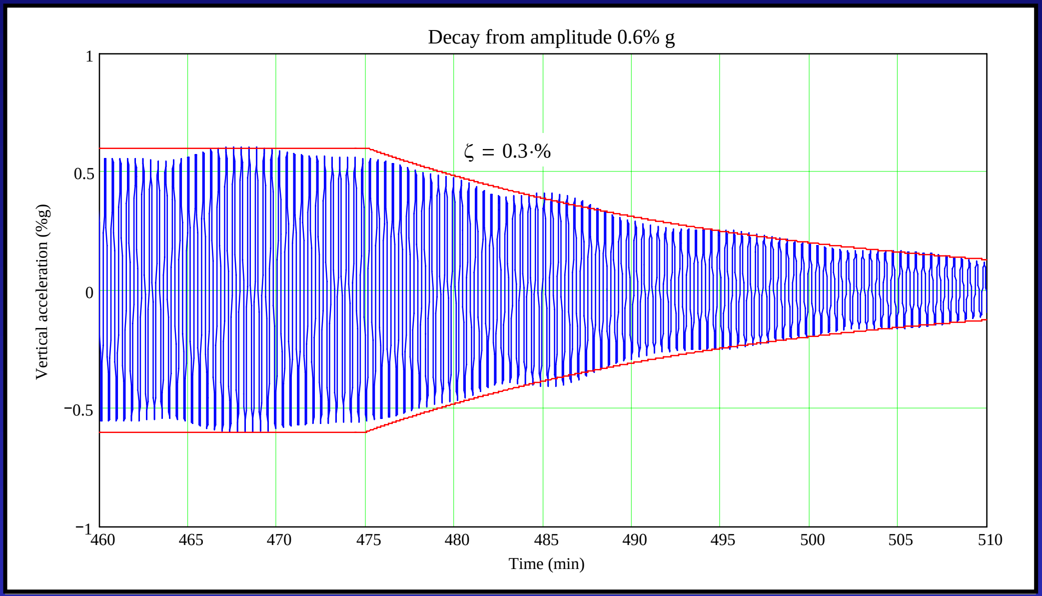
A1, 3, 4, 5, 6, 7 - Vertical Accelerometers
A2&8 - Lateral Accelerometers

True North

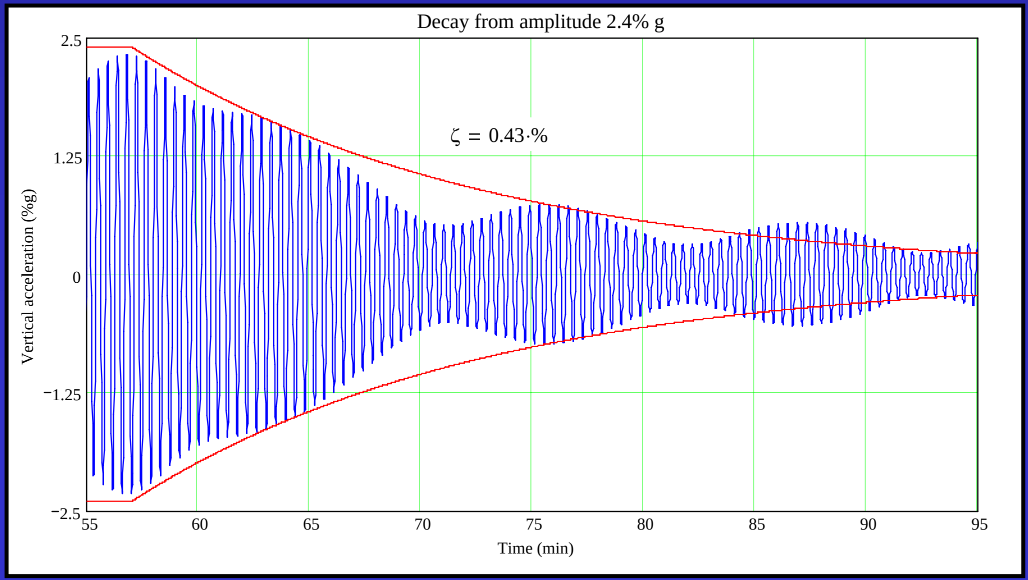
Pedestrian Concerns

- Field testing of Botanical Bridge
  - Mechanical shaker

Identification of Structural Damping



Test 8
forced excitation at 2.344 Hz

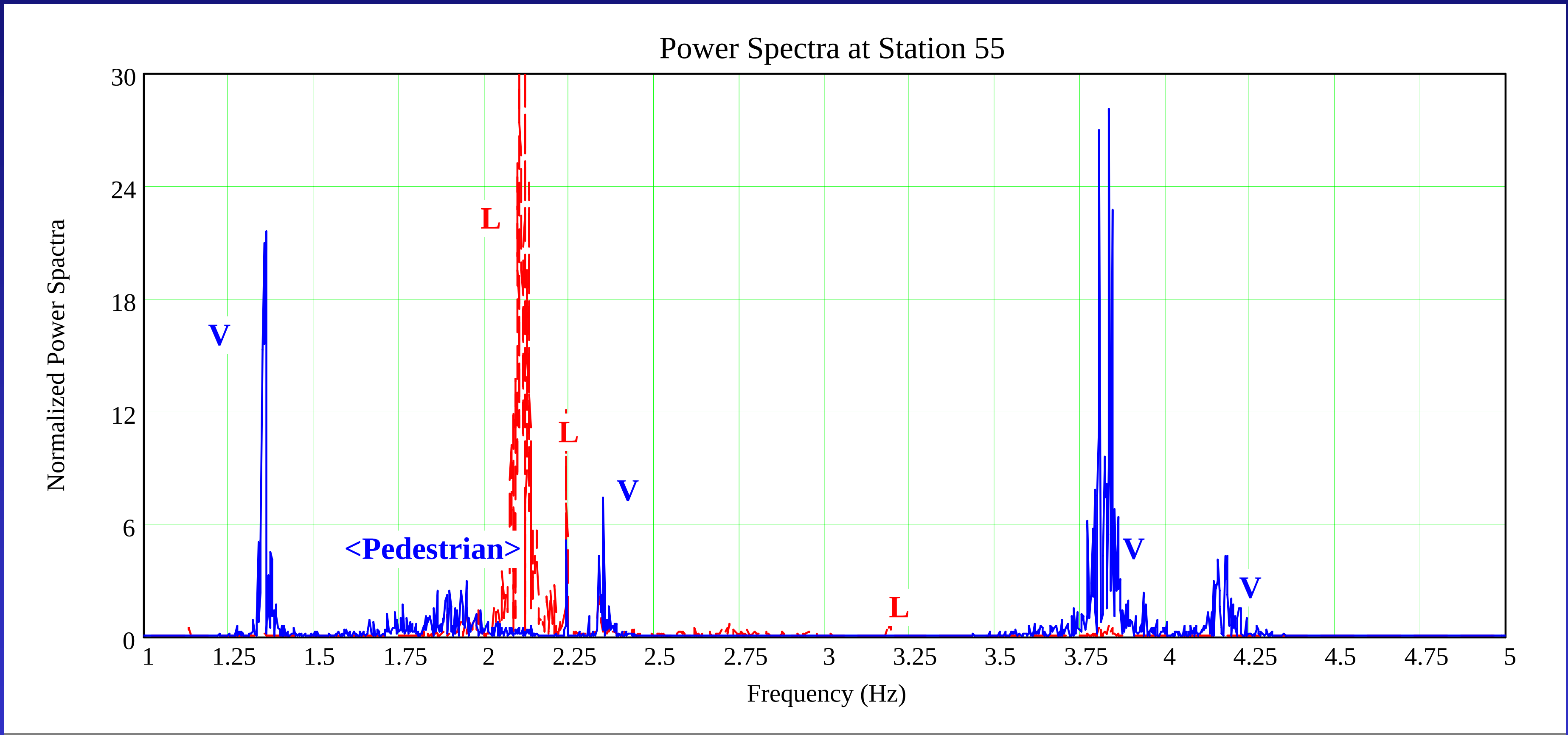


Test 26
forced excitation at 2.344 Hz
plus 5 jumping individuals

Pedestrian Concerns

- Field testing of Botanical Bridge
  - Mechanical shaker
  - Human response

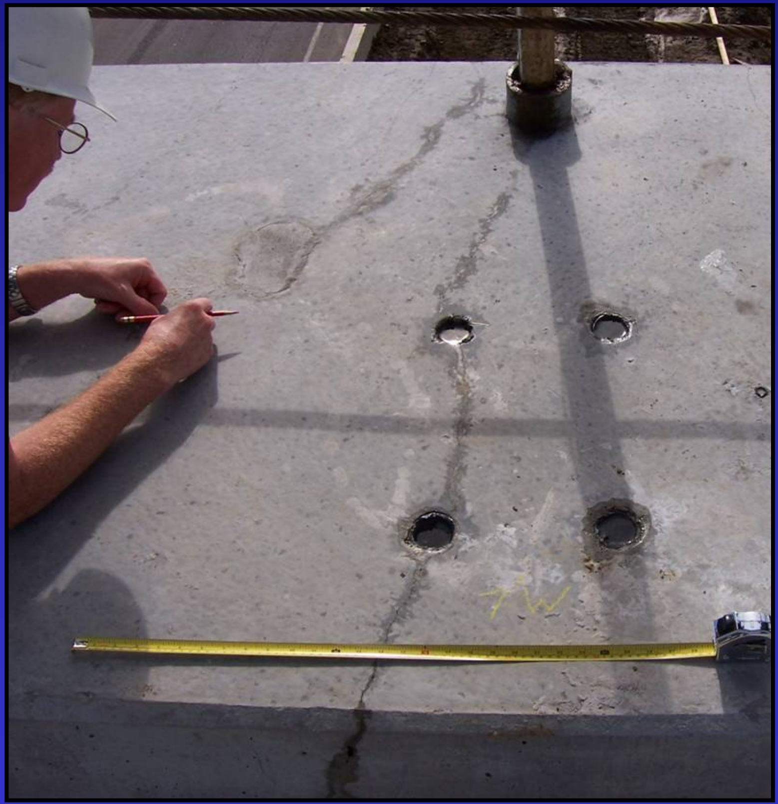
Identification of Modes



Power spectra from walking of 33 individuals
Test 35 - low pass filtered at 20 Hz

Concrete Panel Cracking

Minor cracking of panels occurred during 2003 construction



Construction Monitoring – 2005

Unequal loading of hanger rods considered most likely cause of panel cracking

ISU Bridge Engineering Center hired to perform monitoring during construction of 2005 bridges

Goals of monitoring:

- Short term – eliminate panel overstresses during construction
- Long term – monitor redistribution of loads in hangers (concrete creep)

Instrumentation and Monitoring

Fiber optic sensors (FOS) can be used to monitor:

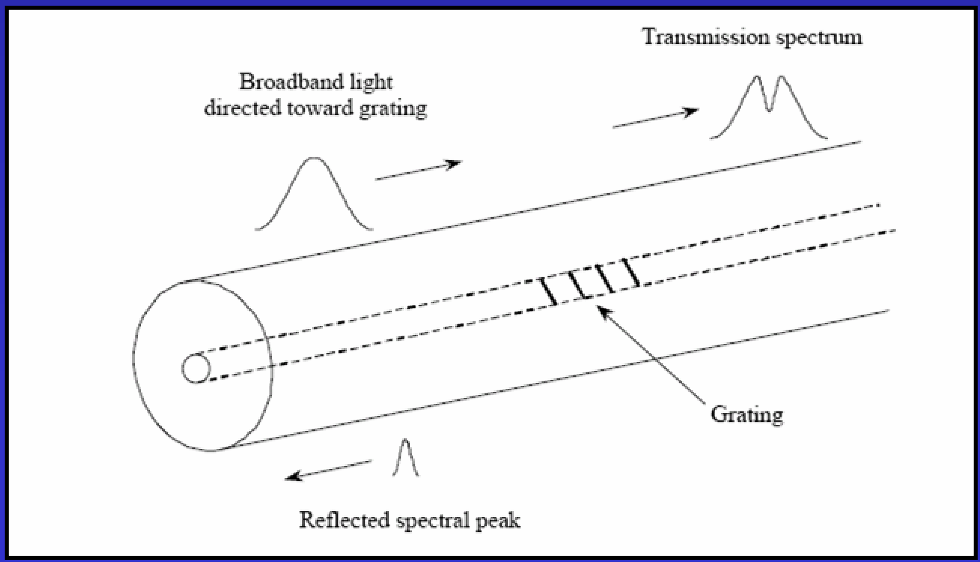
- Temperature
- Moisture/humidity
- Pressure
- Strain

ISU Bridge Engineering Center has used FOS for a number of projects over past few years

Fiber Optic Strain Sensors

Fiber Bragg Gratings (FBG)

- Introduced 1995
- FBG reflects very narrow band of wavelengths – all others pass through
- Any change in strain/temperature causes proportional shift in reflected spectrum



Fiber Optic Sensors

Advantages:

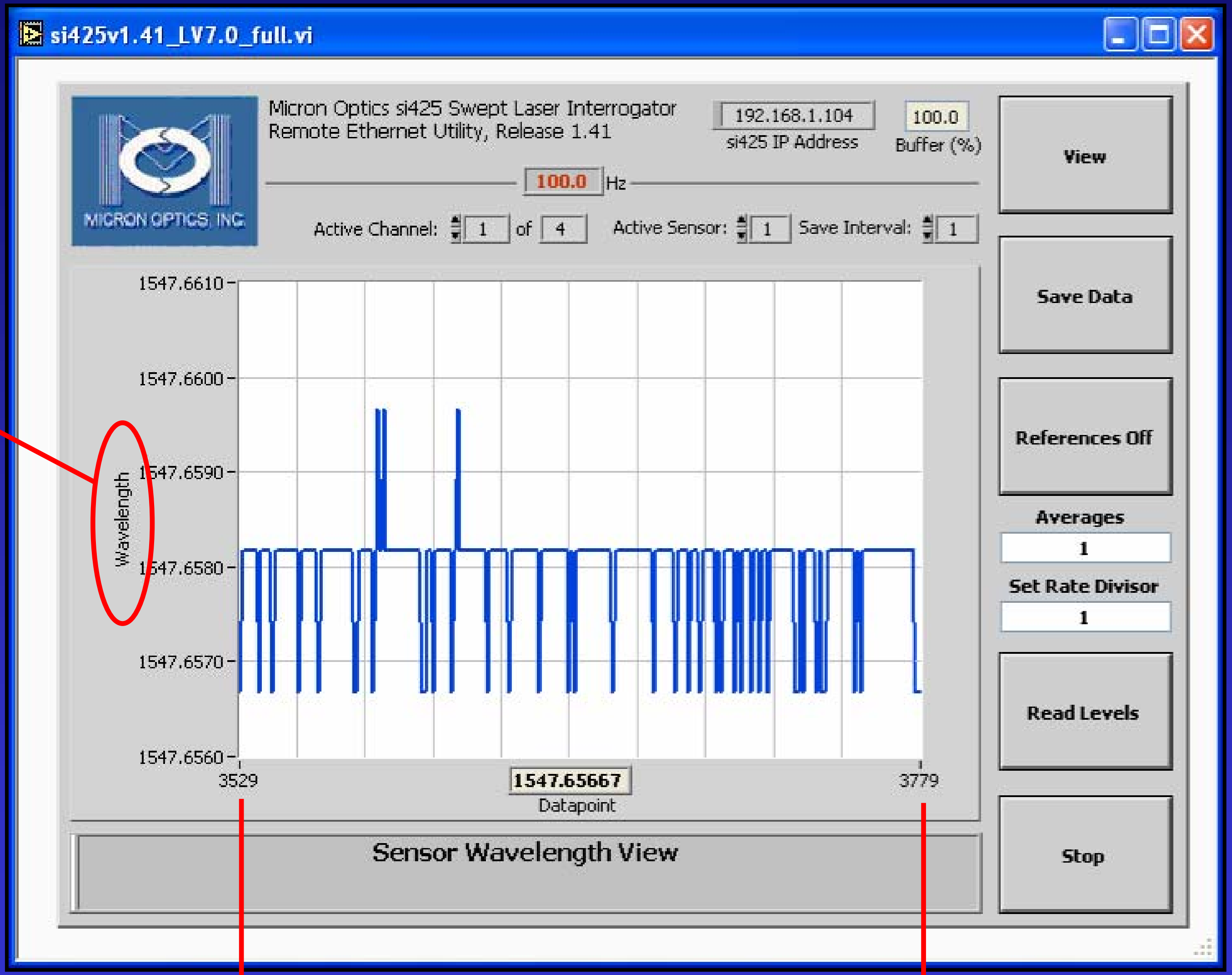
- No drift during long term monitoring
- Very durable when embedded or installed on completed structure
- Low signal loss with long lead lengths.
- Can be serially multiplexed

Disadvantages:

- Expensive compared to convention strain sensors
- Delicate and easily damaged during construction

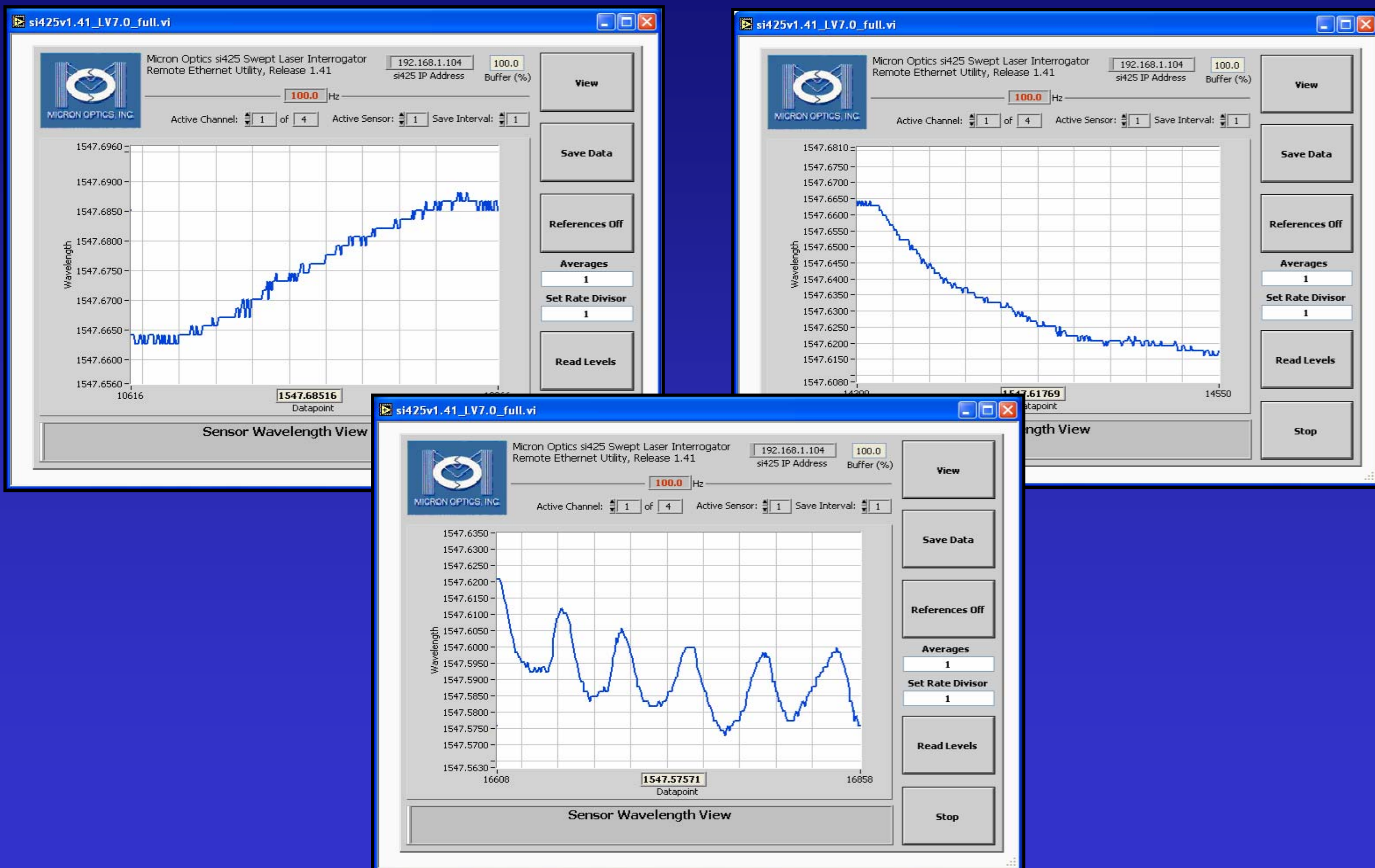
Fiber Optic Strain Sensor – data collected

Reflected Wavelength



250 points = 2.5 seconds

Fiber Optic Sensors – sample data collected



Fiber Optic Sensors - Installation

Fiber Optic Sensors – Handling in Field

Problems with FOS survivability

Original intent of monitoring:

- Connect sensors in series to simultaneously read multiple λ
- Each quadrant of bridge separated
- Monitor load in each hanger as each subsequent panel installed

Damage during construction prevented series connections and required individual readings at each stage

Fiber Optic Sensors - Protection

Survivability of Fiber Optic Sensors

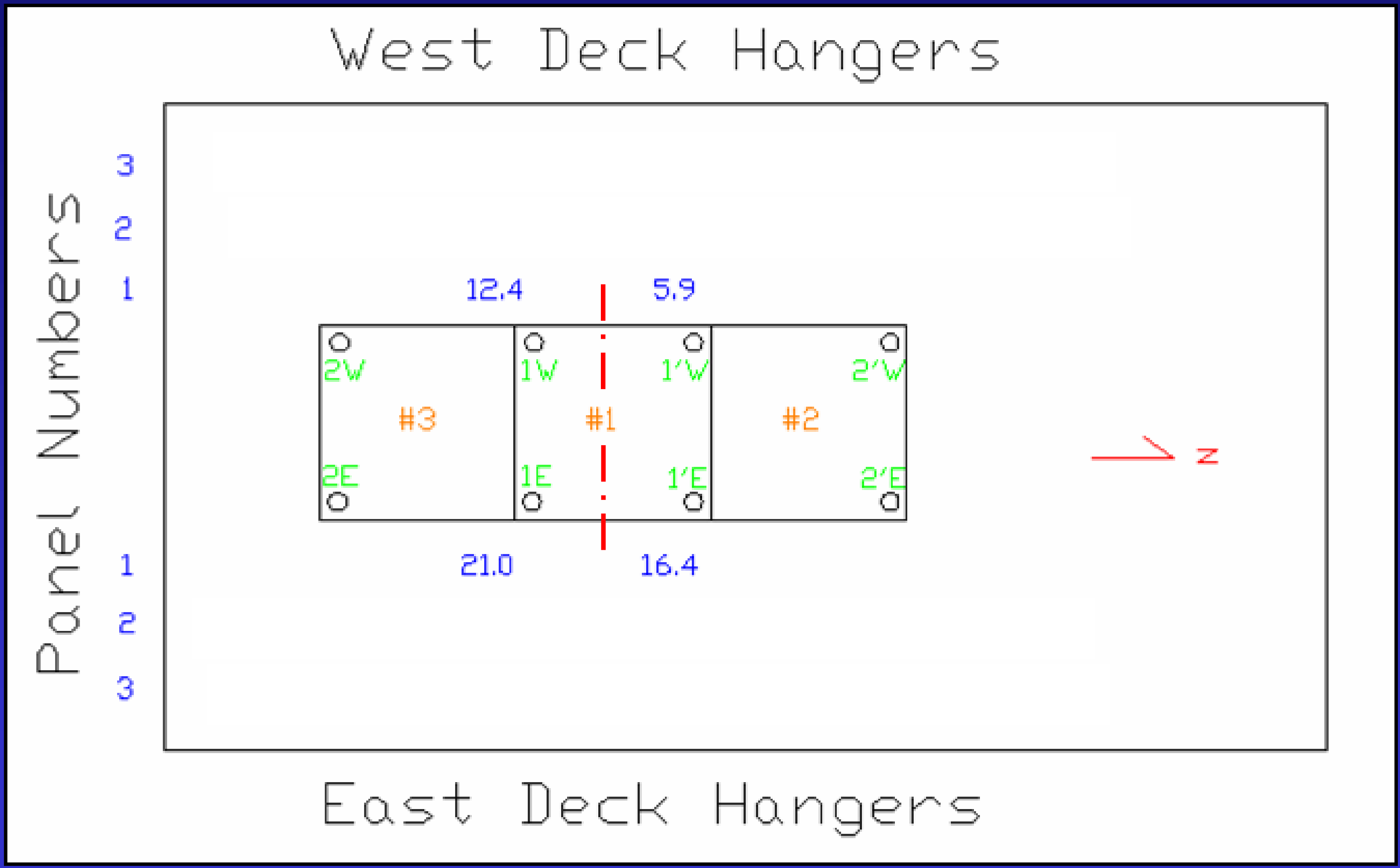
First bridge – 44th Street:

- Total of 28 hangers installed
- Only 13 were usable after construction

Second bridge – 44th Street:

- Total of 36 hangers installed
- Total of 31 hangers working after construction

Fiber Optic Strain Sensor Results



Long term monitoring of hanger loads

Natural frequency monitoring - hanger loads

Hanger assumed to be uniform beam subjected to axial load with:

- Distributed mass and elasticity properties
- Length, L
- Area, A
- Flexural rigidity, EI
- Mass density, ρ

$$T = \rho A \left(\frac{L}{n\pi} \left[\omega_n - (\beta_n L)^2 \sqrt{\frac{EI}{\rho A L^4}} \right] \right)^2$$

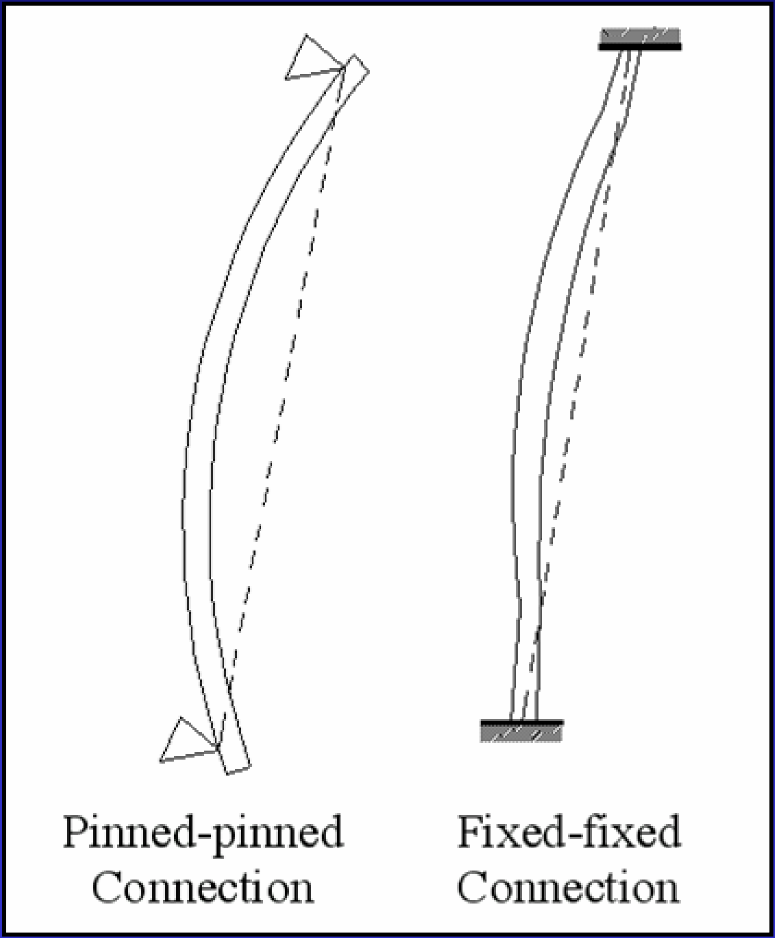
Other Modeling Considerations

Which section properties are "correct" :

- Steel rod alone?
- Steel rod with grout?
- Grout composite w/ rod?

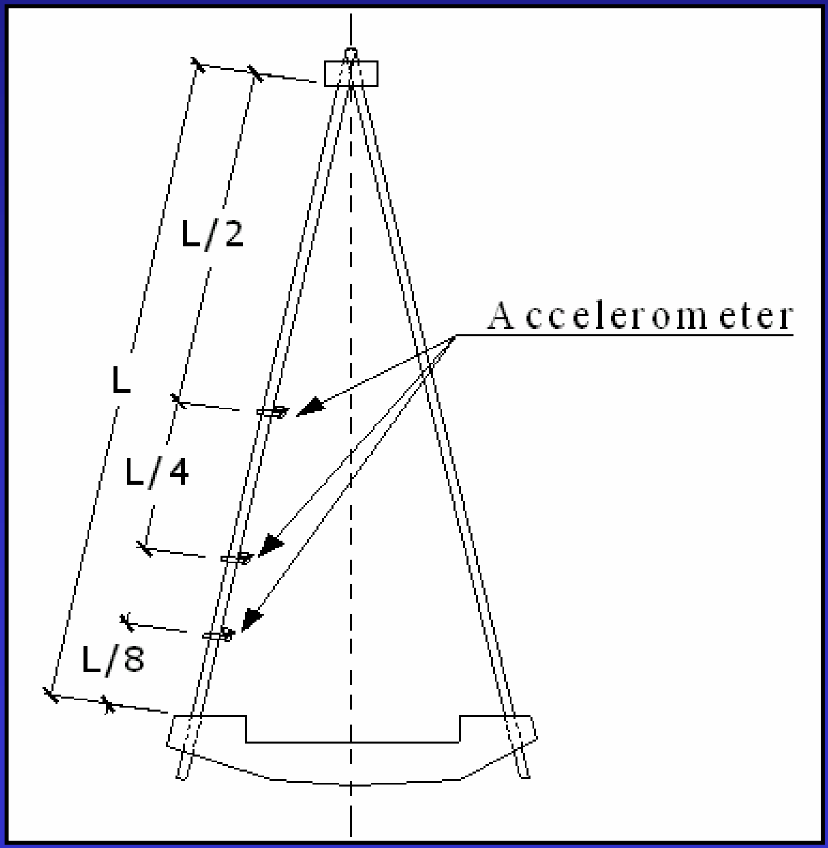
Natural frequencies for simple span beams, $\beta_1 L$:

- Pinned-pinned = 3.141
- Fixed-fixed = 4.730

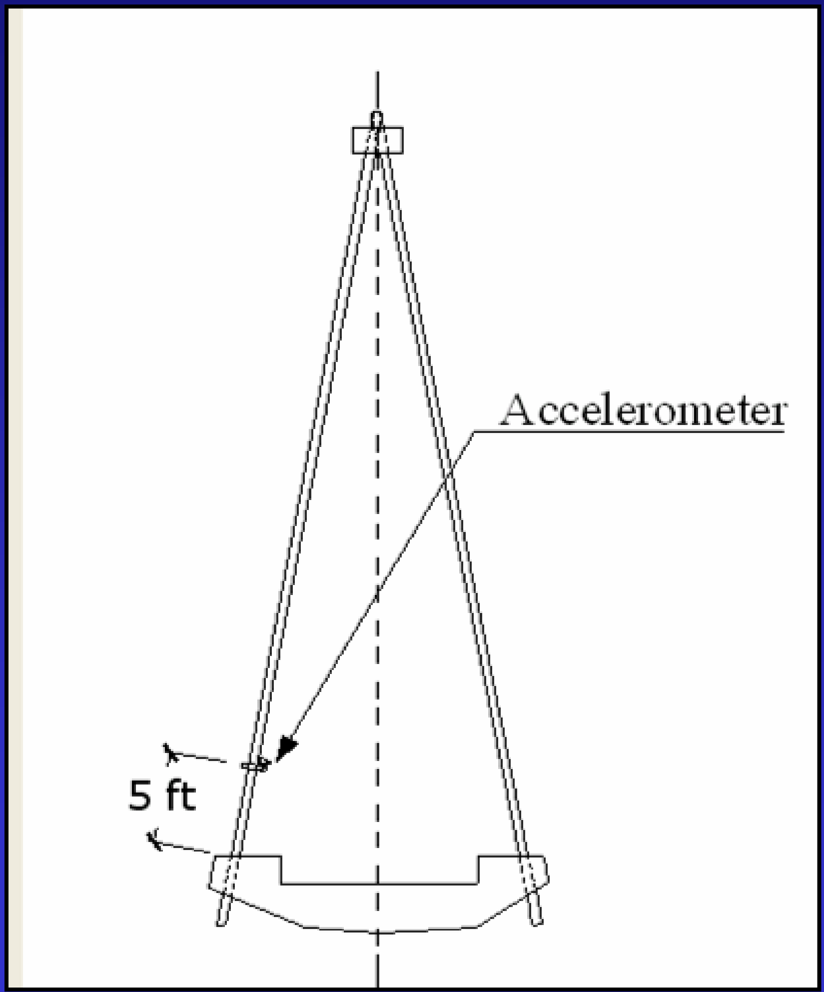


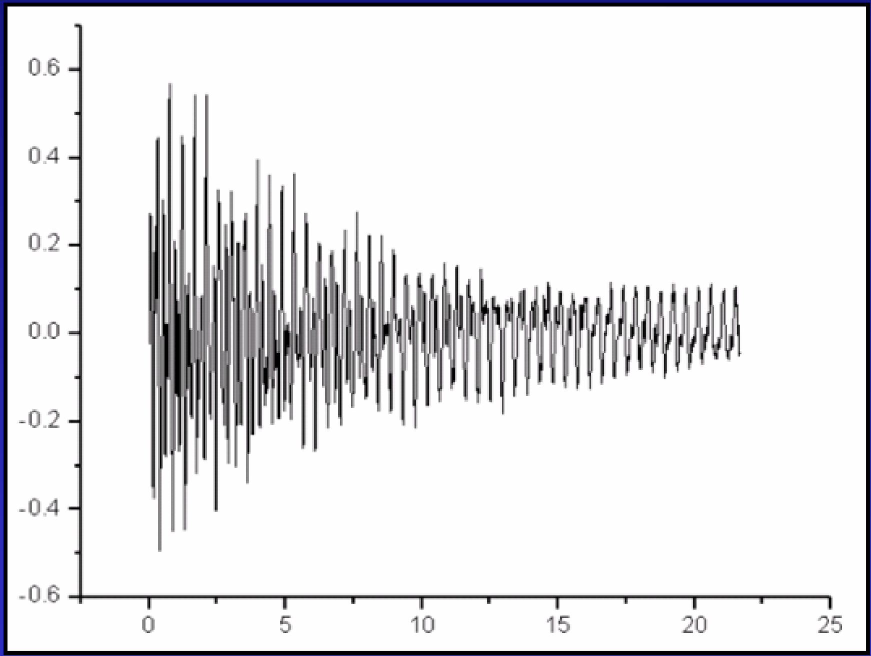
Vibration Testing of Hanger Rods

Initial testing included varying the position of the accelerometer to ensure identical ω_n measured



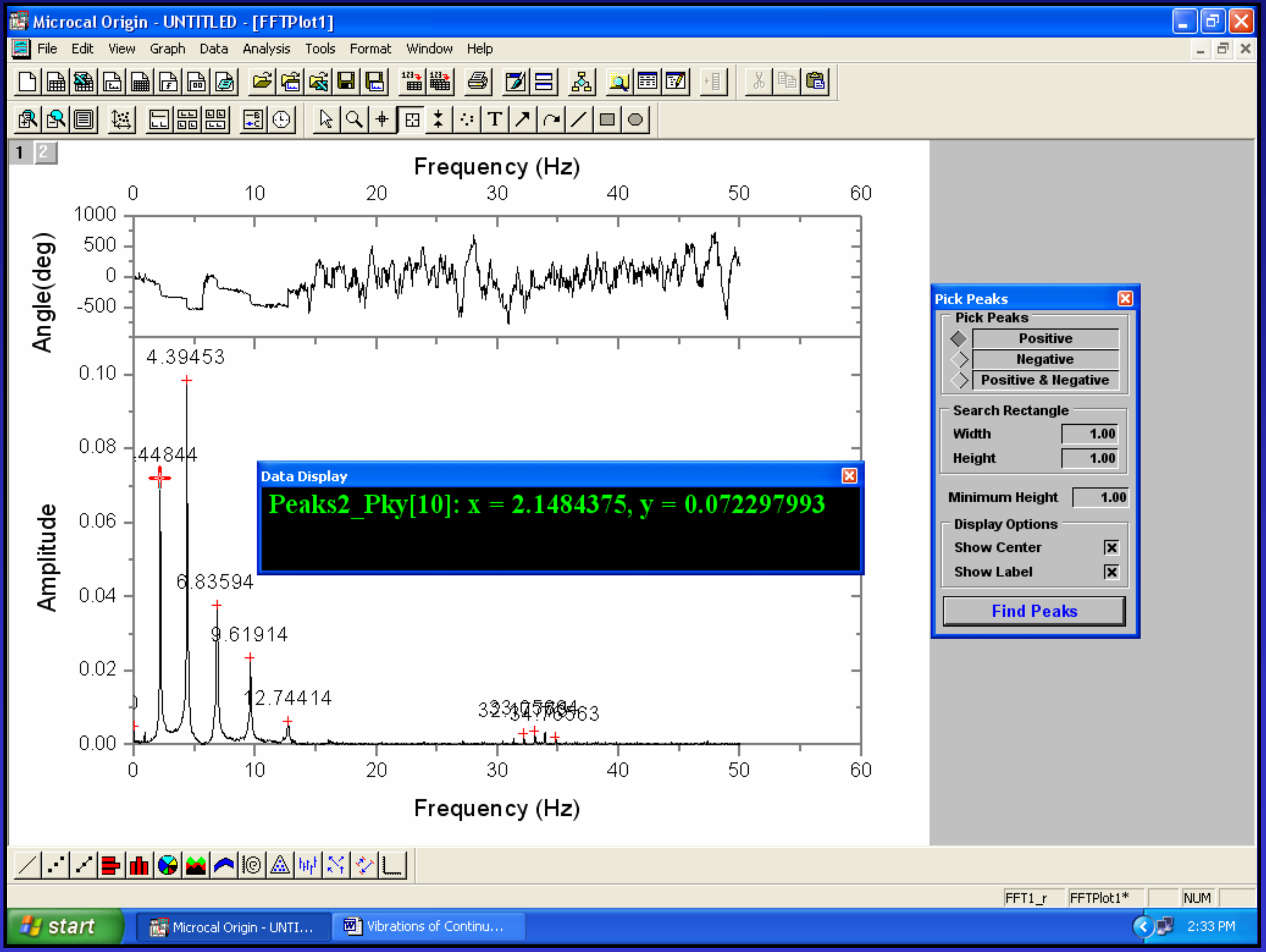
Free vibration of hanger rods





Each hanger excited and allowed to vibrate for 10-15 seconds

Calculation of Natural Frequencies

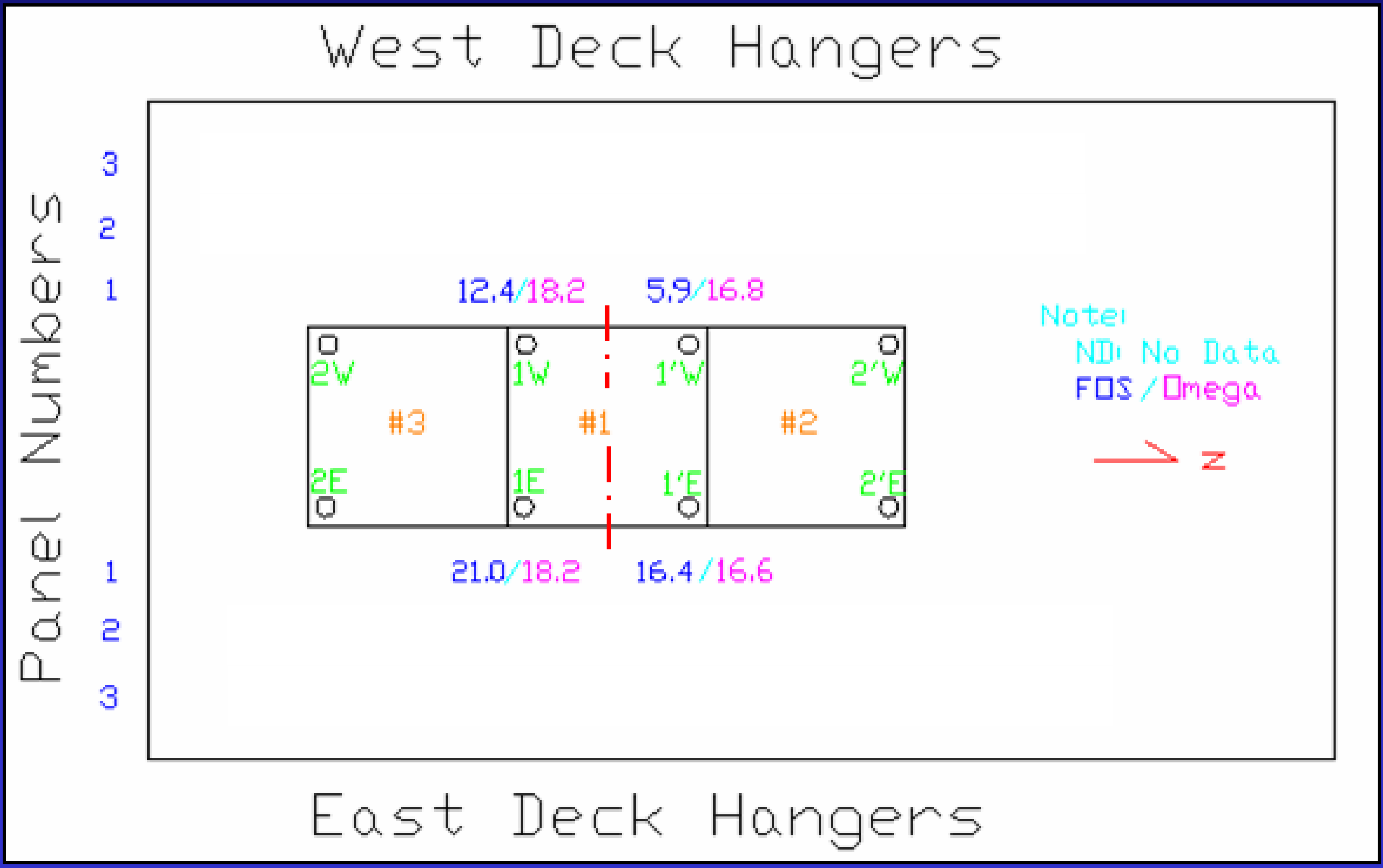


Estimated hanger loads – end conditions

Hanger	West Arch	
	Pinned – Pinned (kips)	Fixed – Fixed (kips)
9	-----	-----
8	30.8	17.7
7	31.3	21.9
6	35.6	27.5
5	32.5	25.8
4	33.4	27.4
3	27.7	22.5
2	25.6	20.9
1	36.2	30.7

Not computed

Comparison of FOS and dynamics results



Adjustment of Hanger Loads

Recall that deck must be constructed to match the profile grade as precast

On the shortest hanger rods, a change in length of 1/8” changes force by approx. 40 kips

Adjusted Hanger Loads

Hanger	West Arch	
	Before Adjustment (Pinned-Pinned) (kips)	After Adjustment (Pinned-Pinned) (kips)
8	6.0	30.8
7	27.8	31.3
6	49.6	35.6
5	52.3	32.5
4	33.1	33.4
3	5.6	27.7
2	23.2	25.6
1	83.9	36.2

Conclusions

- Hanger loads are much more uniform than in 2003 bridge construction
- Visual inspection indicates fewer cracks in precast concrete panels
- BEC will return to 2005 bridges in six months to a year to monitor changes in hanger loads due to creep, etc.
- Use of fiber optic strain sensors during construction is difficult due to survivability concerns
- It is possible to use vibration records to monitor loads of axial members which also provide flexural stiffness

Questions ?

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