Bridge Health Monitoring Past, Present and Future

Bridge Engineering Center
Iowa State University

Bridge Health Monitoring

- Measurement and evaluation of bridge performance
  - Destructive and nondestructive (NDE) measurements
  - Continuous or single day monitoring
  - Remote or on site monitoring

Health Monitoring Objective

- Identify damage or deterioration
- Provide quantitative data for:
  - Assessing extent of damage/deterioration
  - Evaluating structural performance
  - Developing remedy (repair, strengthening)
  - Improving design/construction procedure
  - Bridge management

Structural Health Monitoring at ISU -- Short-term Monitoring

- Safe load carrying capacity (rating)
- Development of design procedures
- Identify damage
- Validate design procedure and identify damage
- Assess damage and evaluate remedy

Structural Health Monitoring at ISU -- Long-term Monitoring

- Smart structure technology – WIS DOT
- Fracture critical bridge monitoring – IHRB
- Innovative bridge long-term performance assessment – FHWA/Iowa DOT

Hoan Bridge in Wisconsin

Learning from failures!

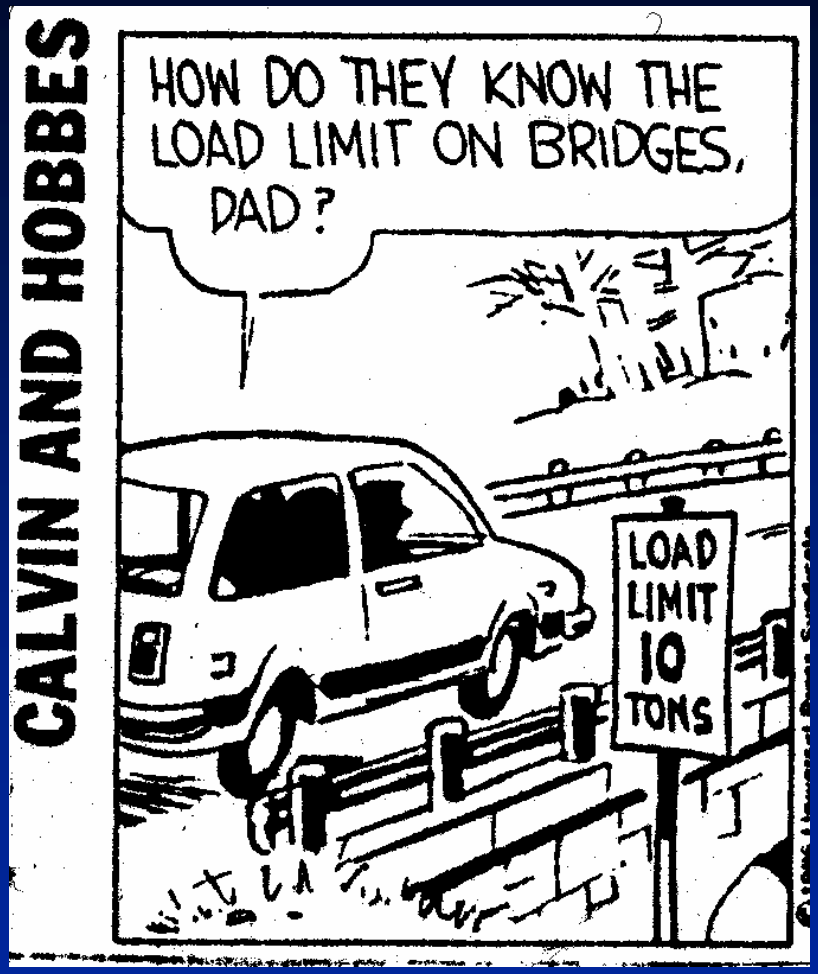
- December 15, 1967 - collapse of the Silver Bridge
- 46 fatalities
- Eyebar/pin failure

Learning from failures!

- 1968 - National Bridge Inspection Program initiated
- Inspect, rate, and inventory all highway bridges
- Visual Inspection – predominant NDE technique

Bridge Load Rating

NDE??


CALVIN AND HOBBES
HOW DO THEY KNOW THE LOAD LIMIT ON BRIDGES, DAD?
LOAD LIMIT 10 TONS


THEY DRIVE BIGGER AND BIGGER TRUCKS OVER THE BRIDGE UNTIL IT BREAKS.

NDE??


THEN THEY WEIGH THE LAST TRUCK AND REBUILD THE BRIDGE.
WATTERSON

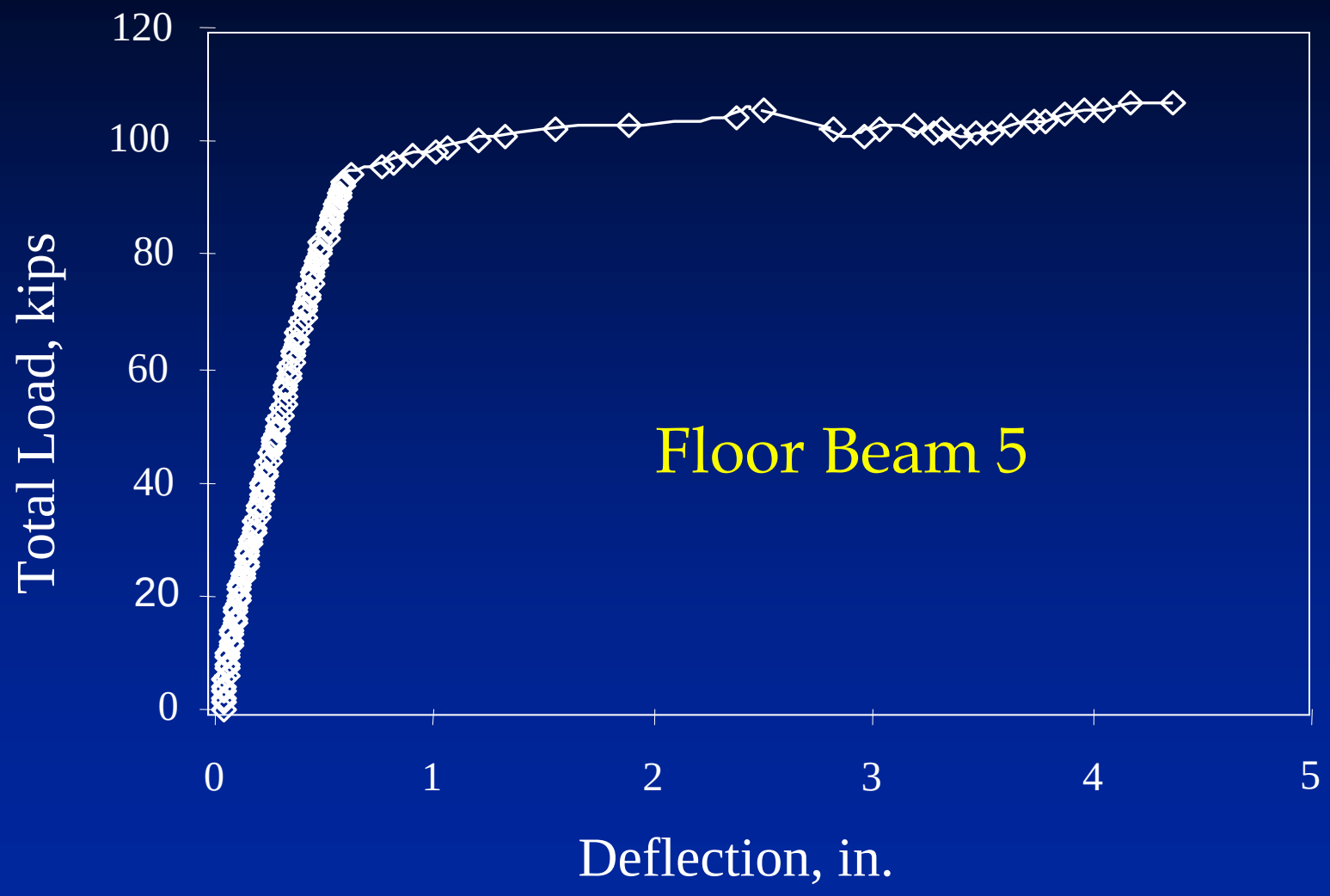

OH. I SHOULD'VE GUESSED.
DEAR, IF YOU DON'T KNOW THE ANSWER, JUST TELL HIM!
12-18

Historic Concrete Bridges

Marsh Arch Bridges

Load Increment	Total load (kips)	
	Bridge 1	Bridge 2
1	26.0	26.2
2	36.0	36.5
3	52.0	53.6

Laboratory Results



Bridge 1 Rating Summary

Element	HS20 Rating Vehicle	
	AASHTO LRFD (RF)	Modified Rating (RF)
Slab	0.94	--
Beams	1.18	2.87
Hangers	2.19	5.47
Arches	4.14	2.11

RF (Rating Factor)

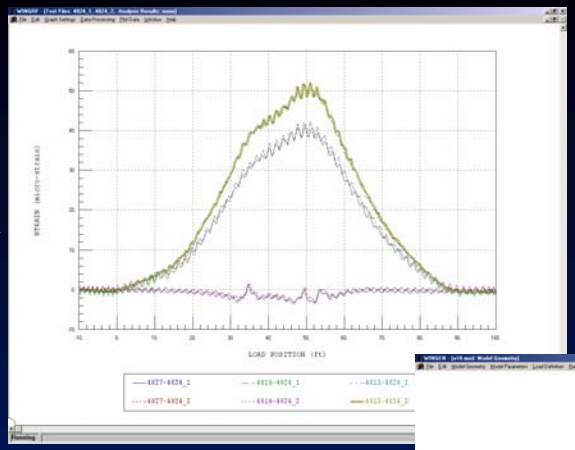
< 1 is NG

≥ 1 is OK

Hardwired strain gages

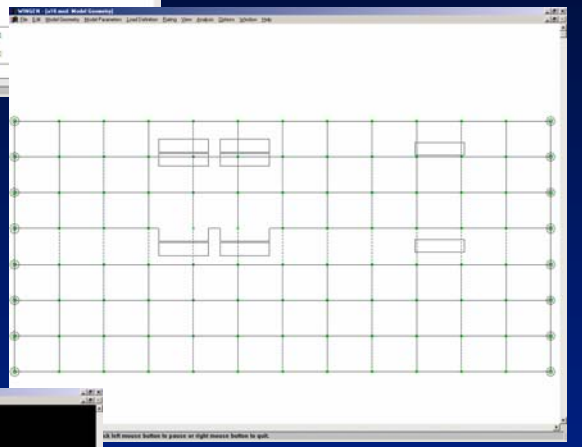
Wireless truck position indicator

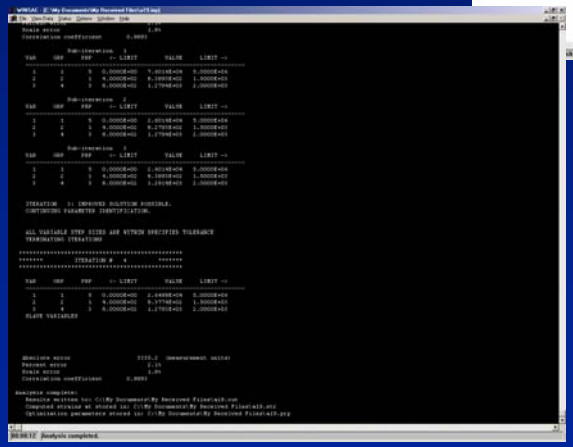
Accurate Assessment



Engineering based data interpretation

Structural modeling

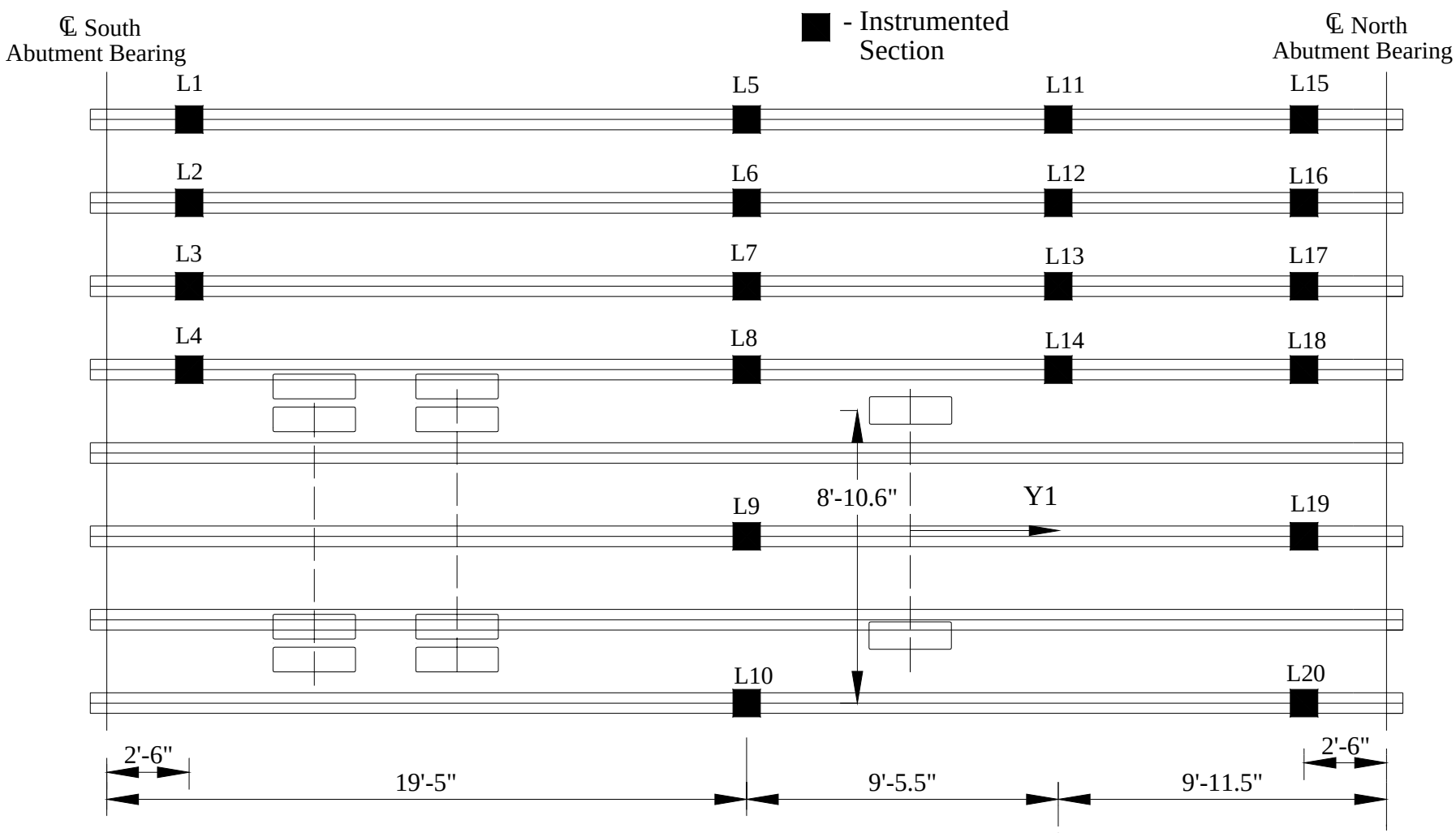




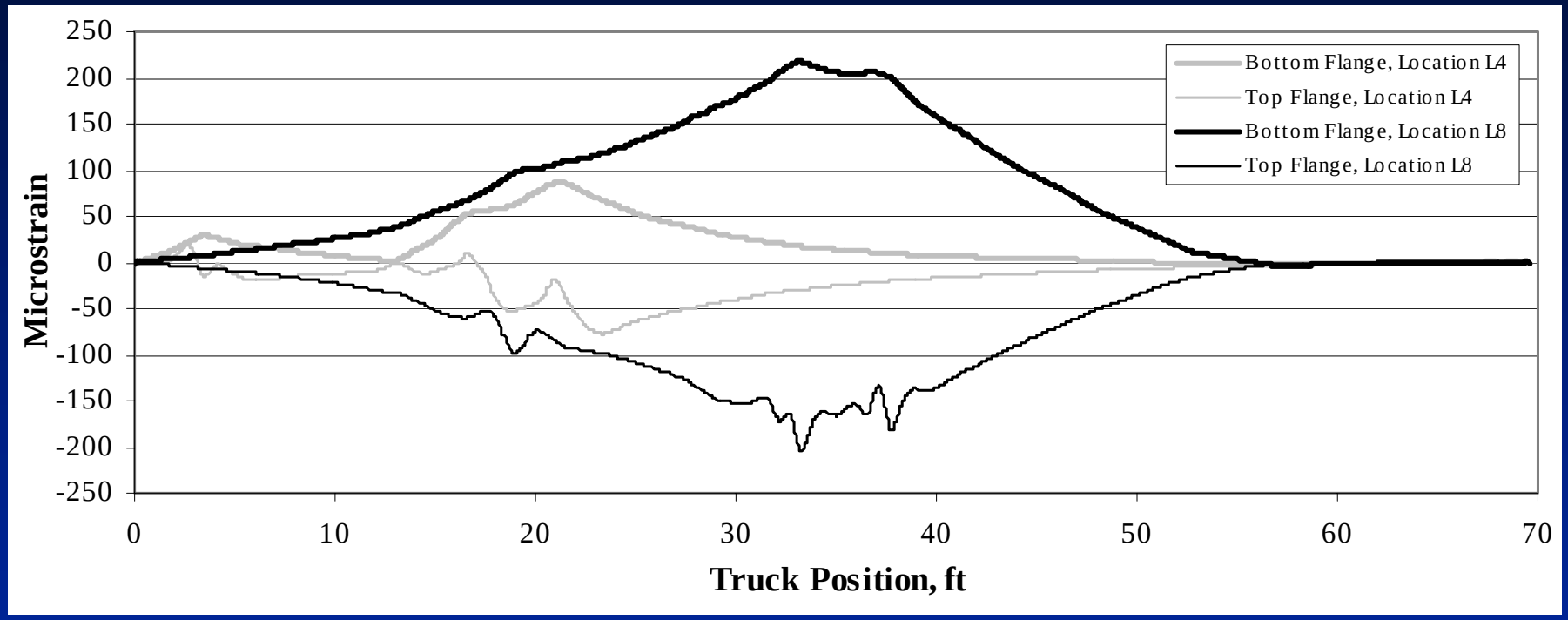
Model analysis and optimization with field collected data

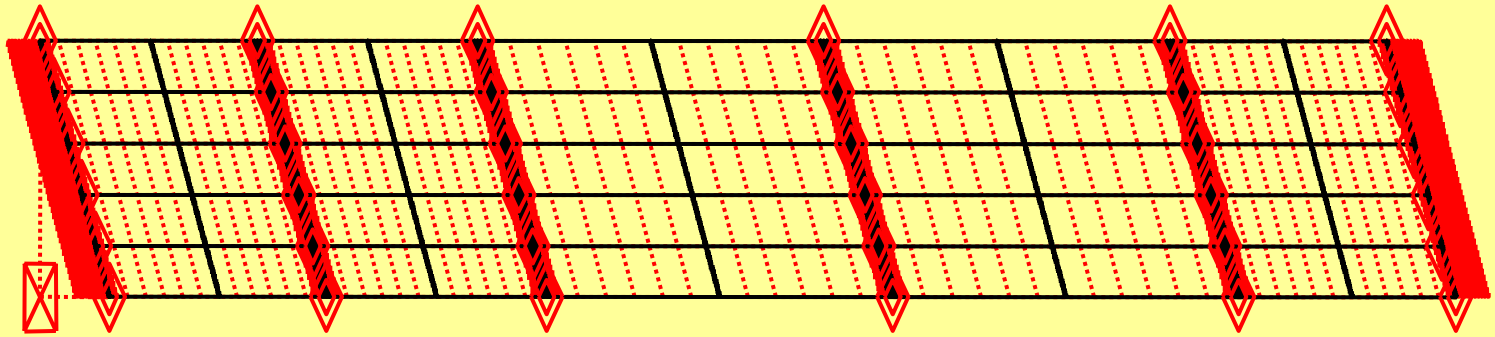
Diagnostic Testing of a Bridge

- Boone County Bridge #11 on L Road
- 38 ft - 10 in. single span
- Eight girders with timber deck
- Damaged exterior girder

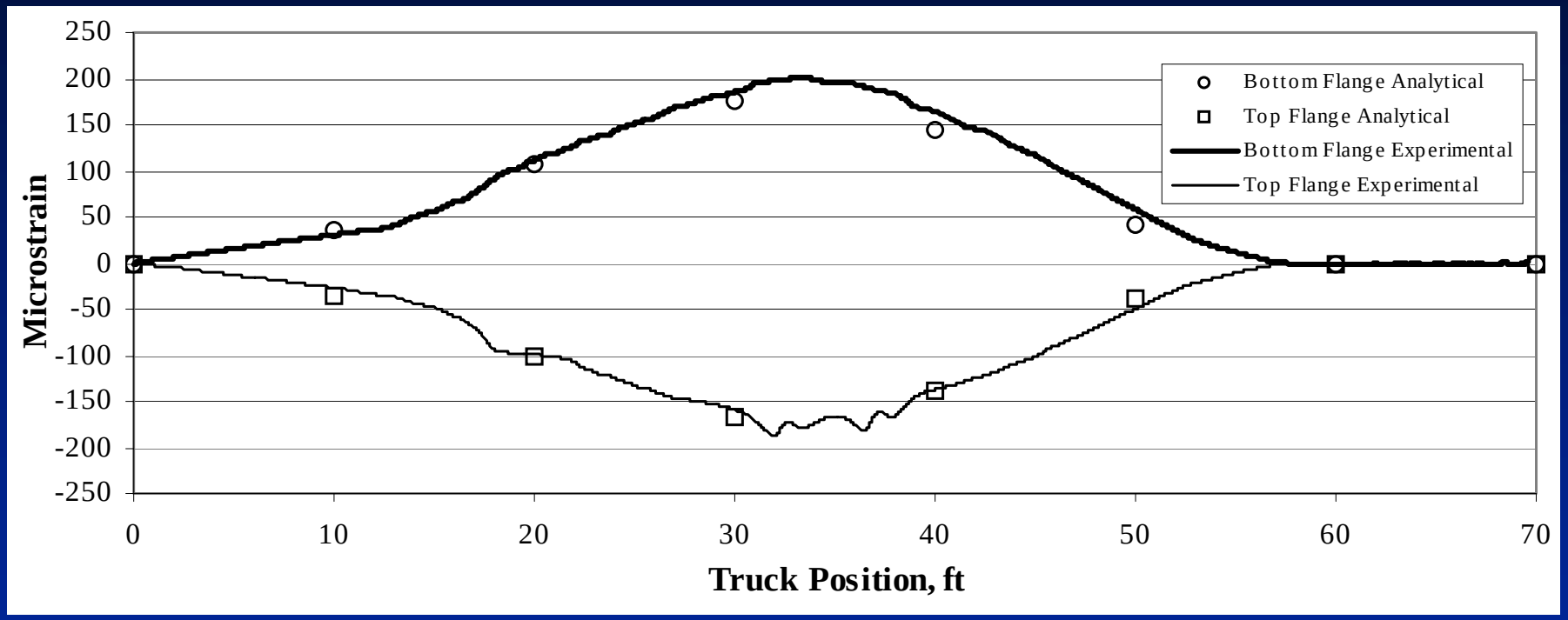

℄ South
Abutment Bearing
- Instrumented
Section
℄ North
Abutment Bearing
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17
L18
L19
L20
8'-10.6"
Y1
2'-6"
19'-5"
9'-5.5"
9'-11.5"
2'-6"

Test Results-Minimal End Restraint





Typical Modeling Results



Bridge Rating Summary

All Bridge Elements	HS20 Rating Vehicle	
	AASHTO Calculations (RF)	Load Test Results (RF)
Bending	0.92	1.31

RF (Rating Factor)

< 1 is NG

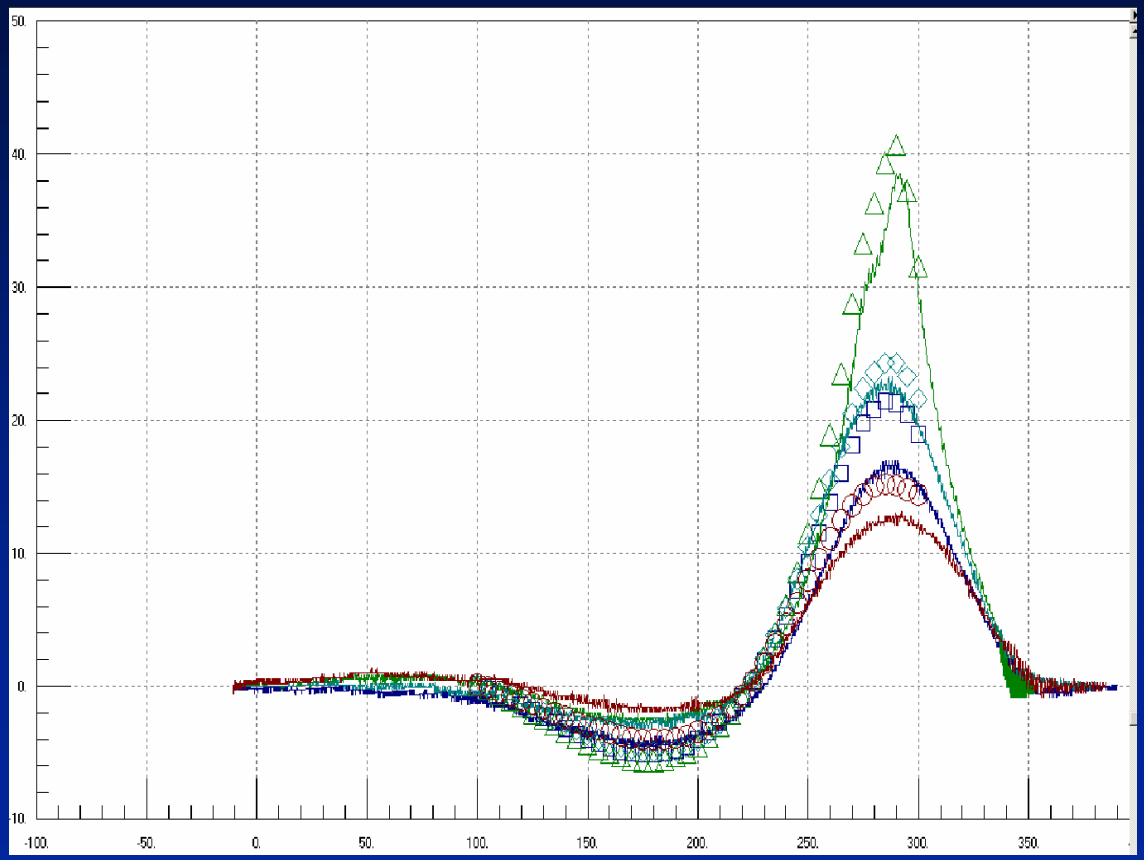
≥ 1 is OK

Superload Evaluation

- Six pre-stressed concrete girder lines
- Critical span ~ 122 ft.
- 40 ft. roadway carrying two lanes of traffic

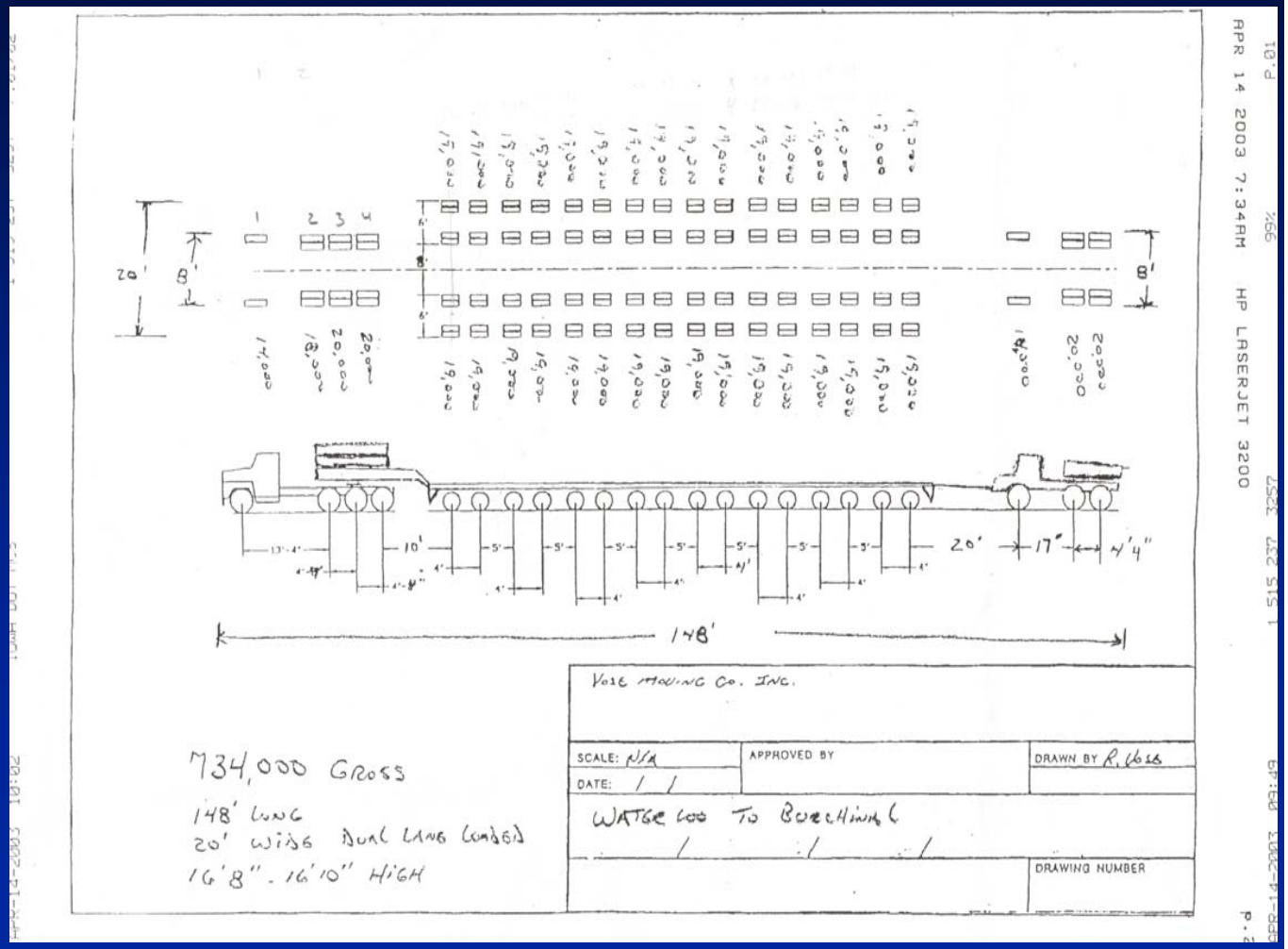
Preliminary testing (2 dump trucks)

Experimental vs. Analytical



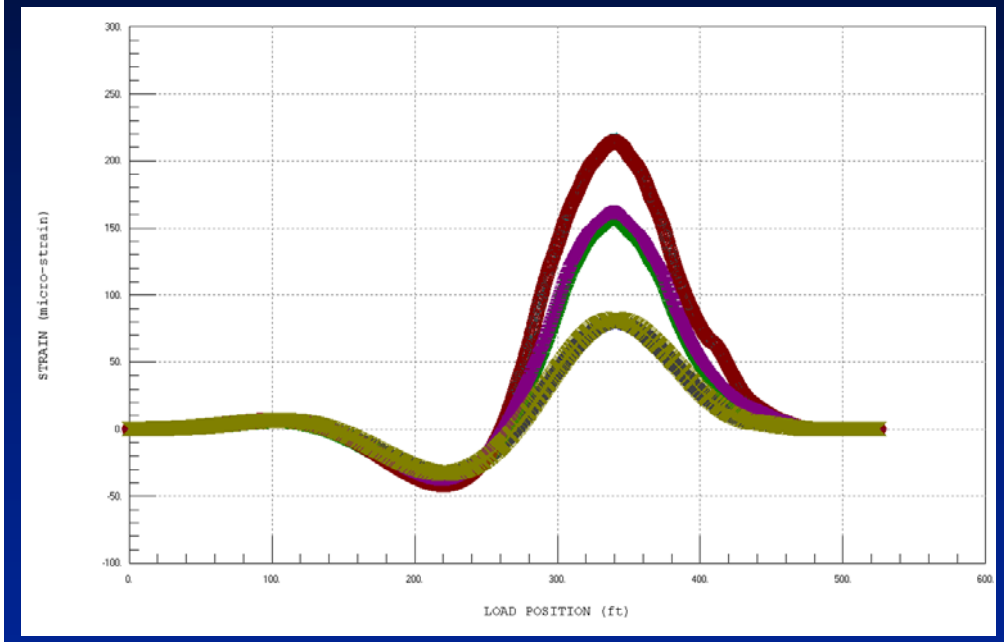
Analysis with Superload

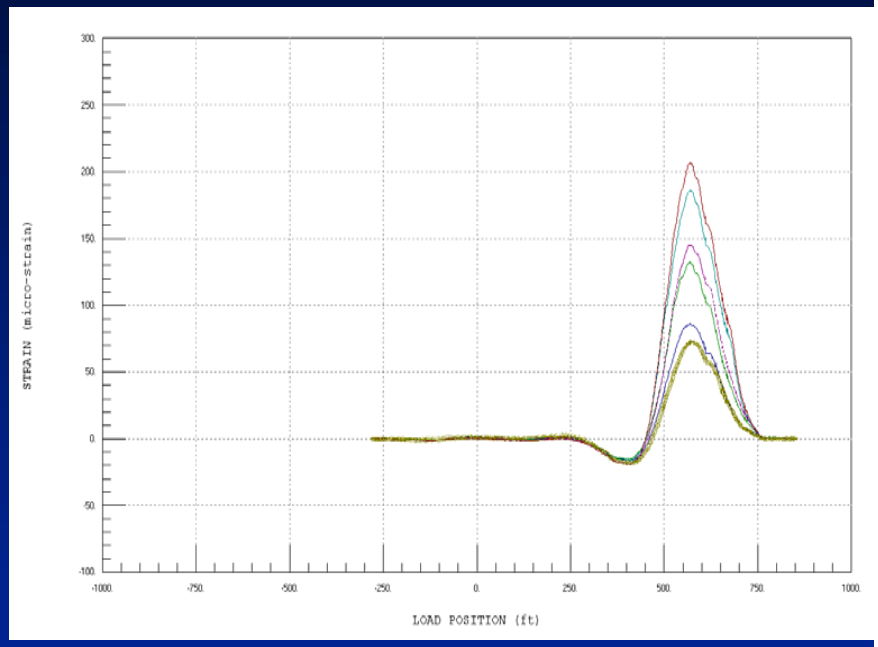
- Optimized model used to predict bridge behavior to anticipated load
- Determined to be acceptable



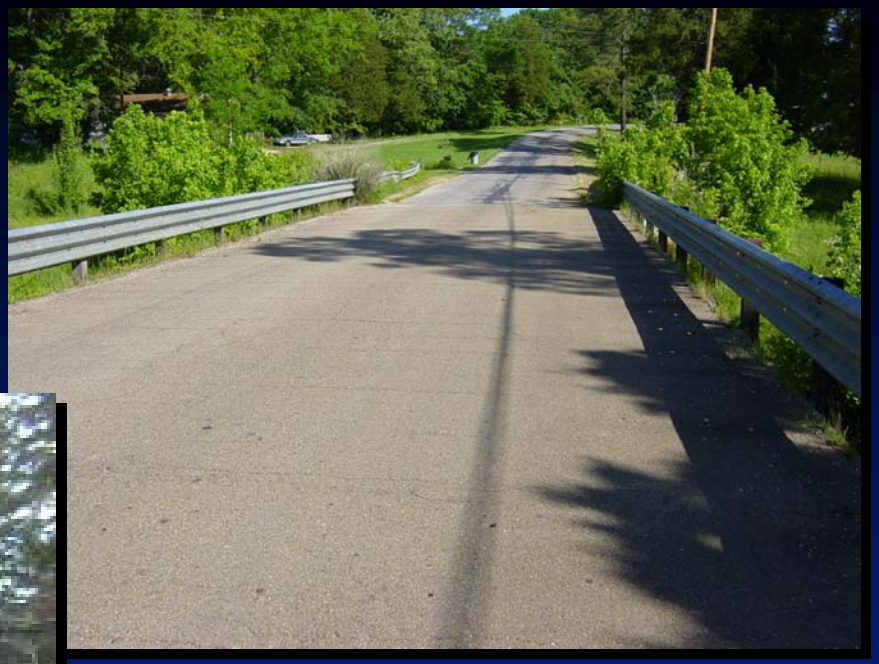
Monitoring During Passage

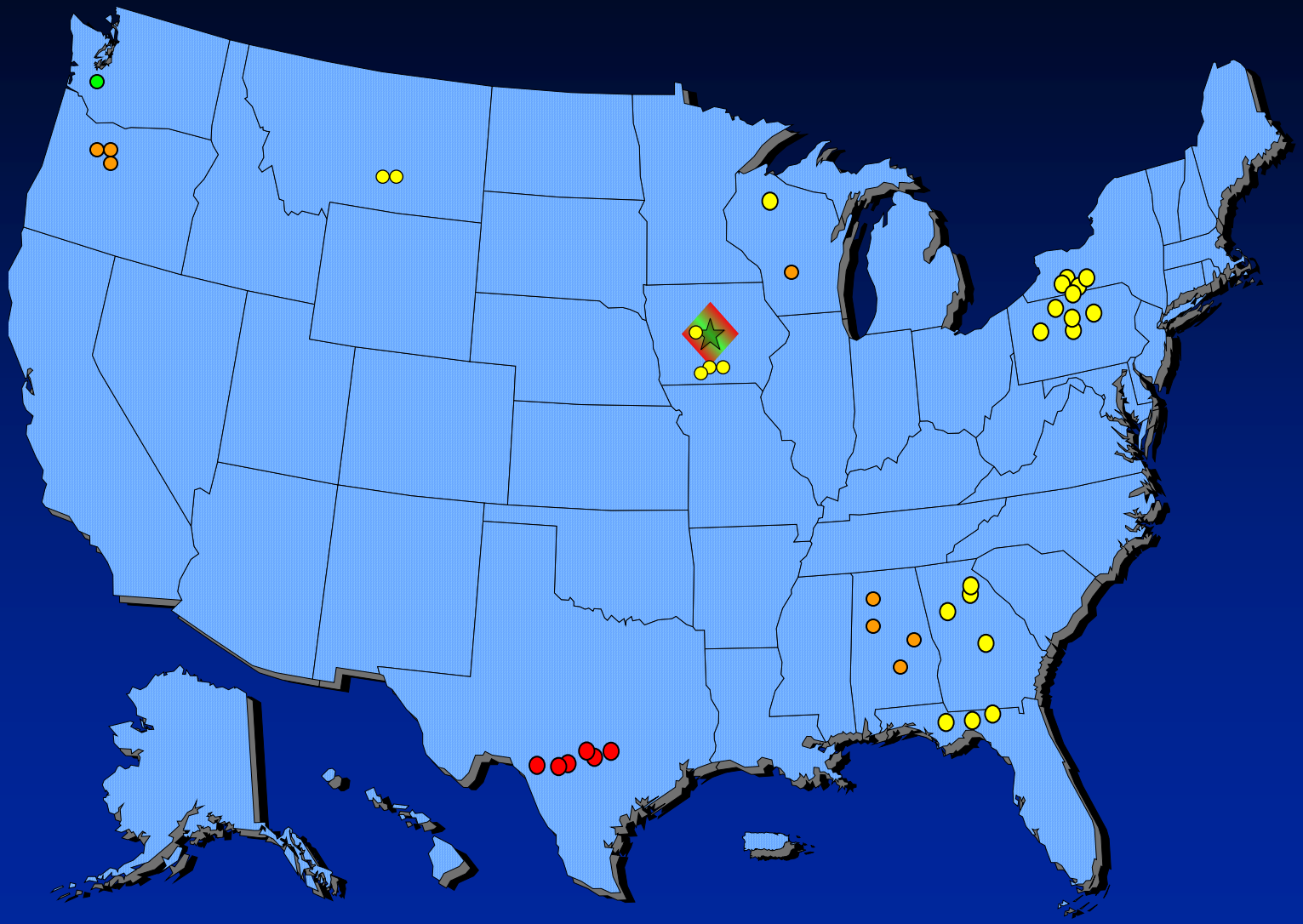
Accuracy of Prediction



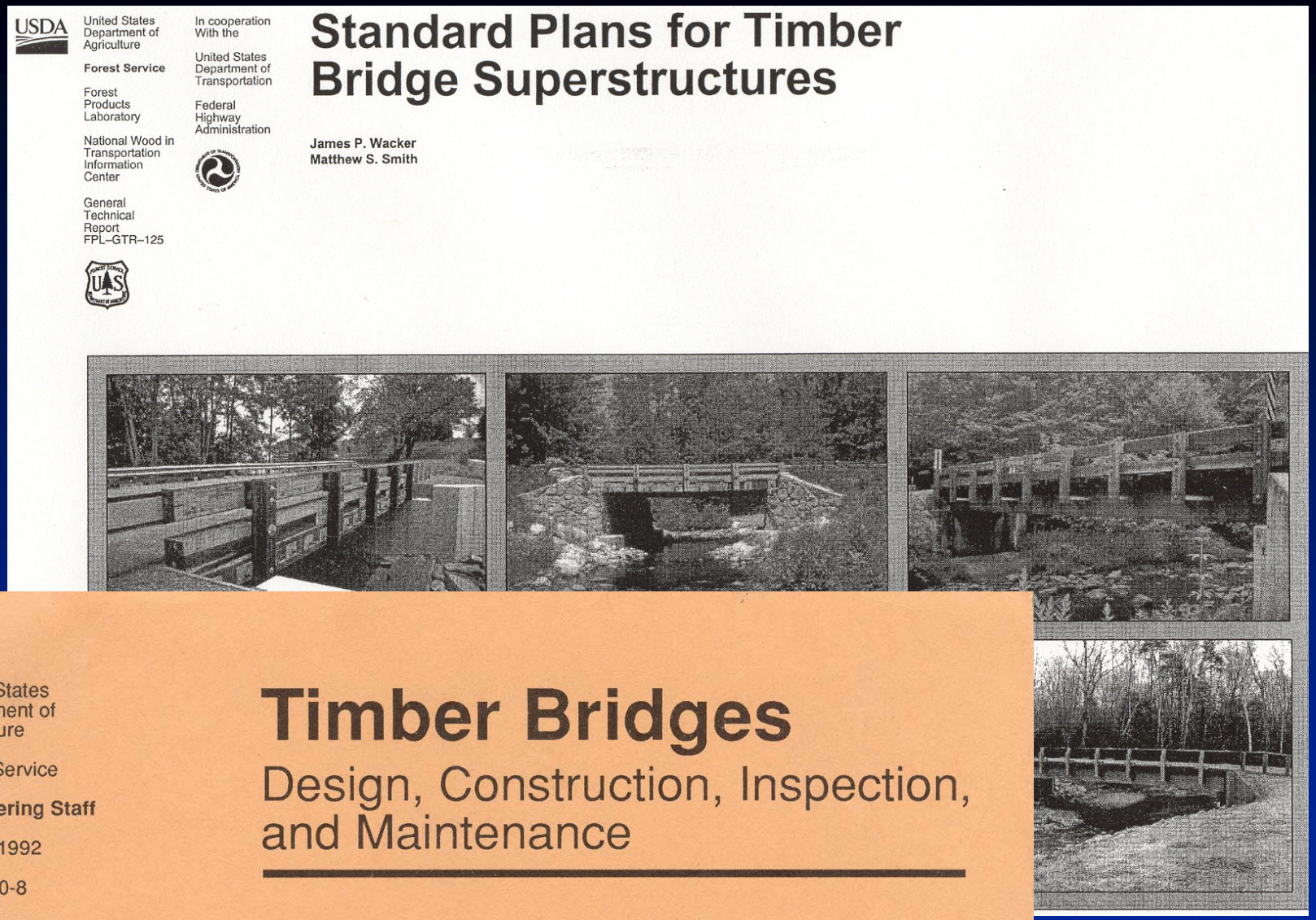


Development of Design Procedures






BRIDGE
LIMITED TO
ONE TRUCK



USDA

United States Department of Agriculture

Forest Service

Forest Products Laboratory

National Wood in Transportation Information Center

General Technical Report FPL–GTR–125

In cooperation With the

United States Department of Transportation

Federal Highway Administration

Standard Plans for Timber Bridge Superstructures

James P. Wacker
Matthew S. Smith

United States Department of Agriculture

Forest Service

Engineering Staff

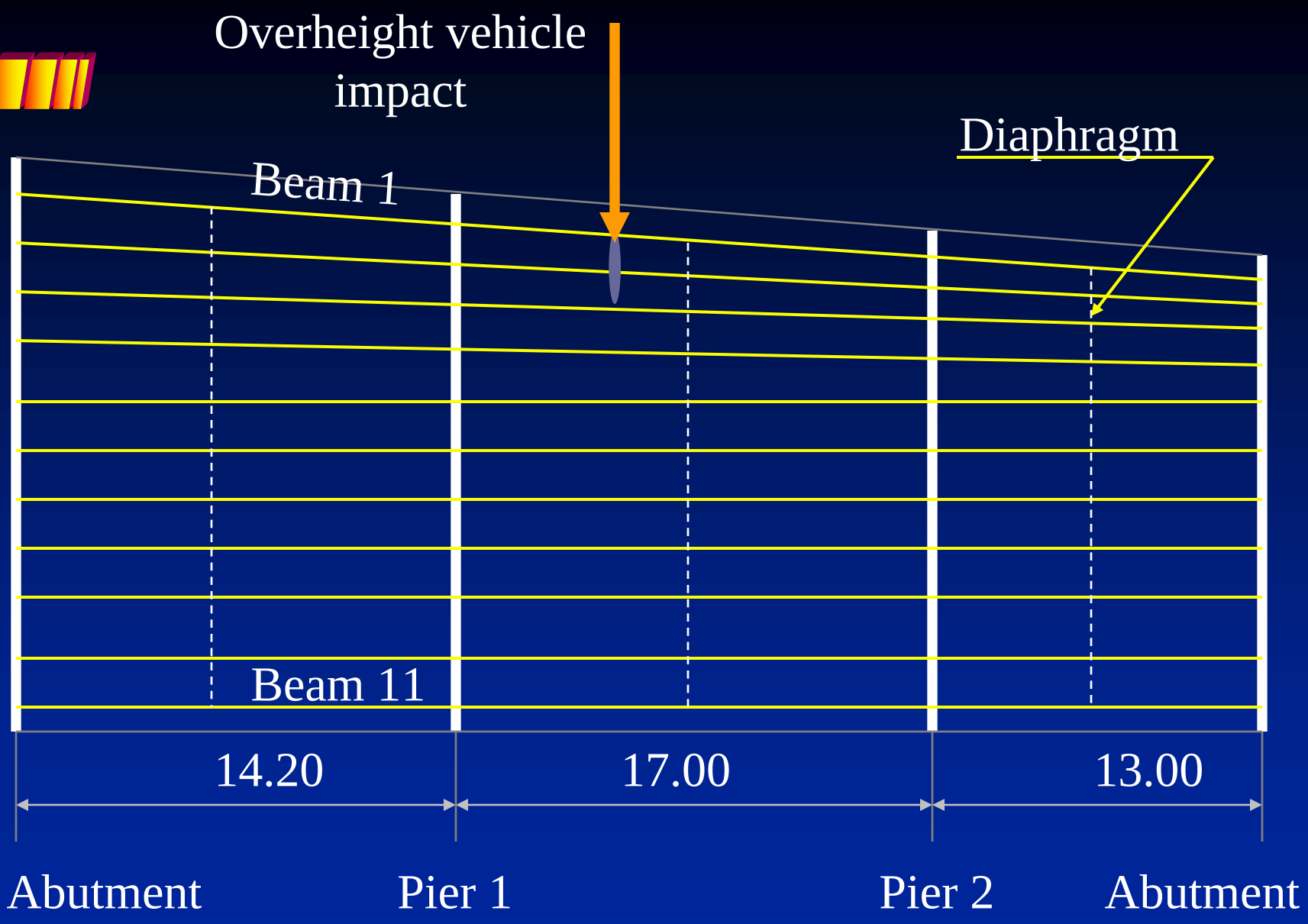
August 1992

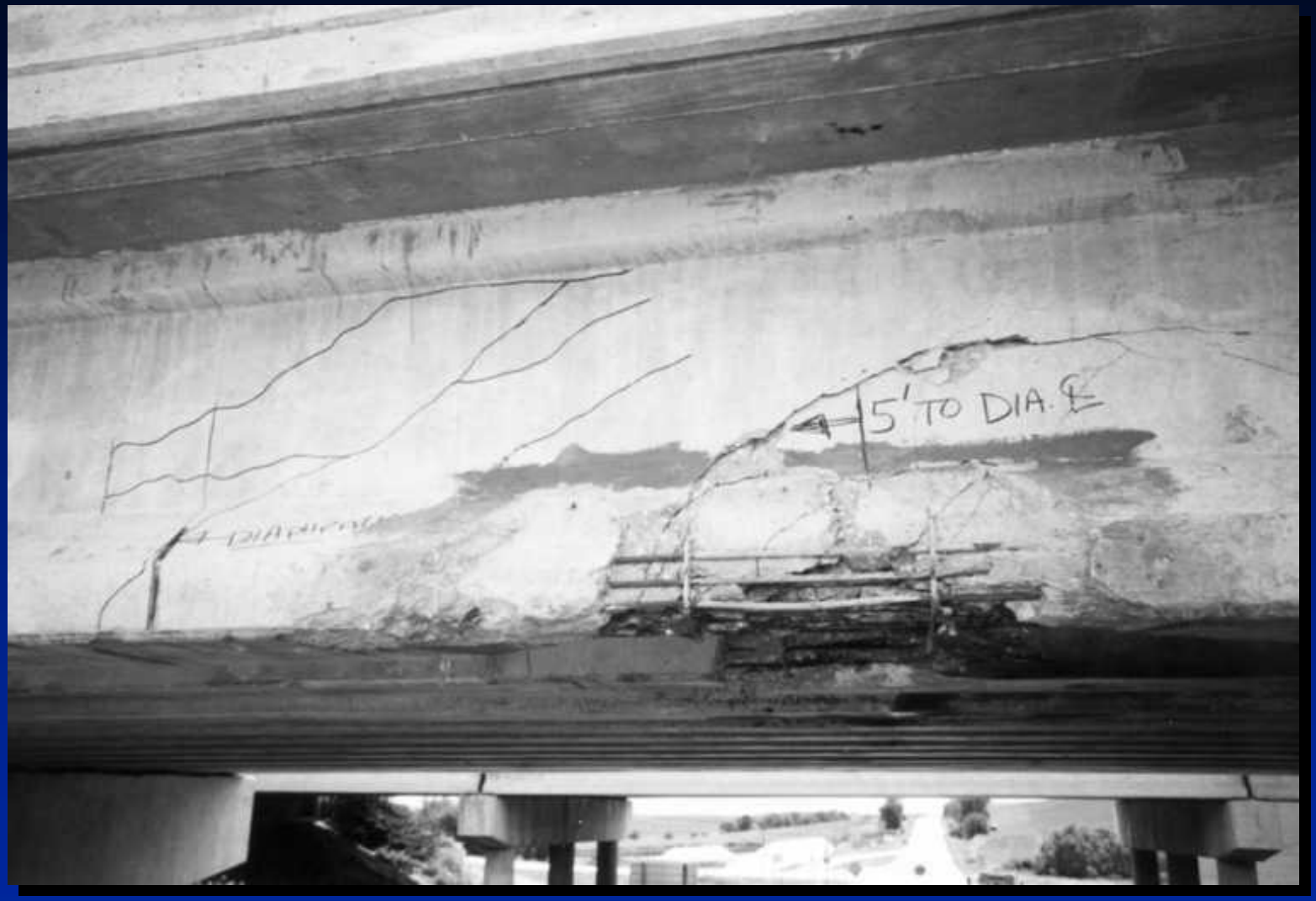
EM 7700-8

Timber Bridges

Design, Construction, Inspection, and Maintenance

Identification of Damage


Overheight vehicle impact
Diaphragm
Beam 1
Beam 11
14.20
17.00
13.00
Abutment
Pier 1
Pier 2
Abutment

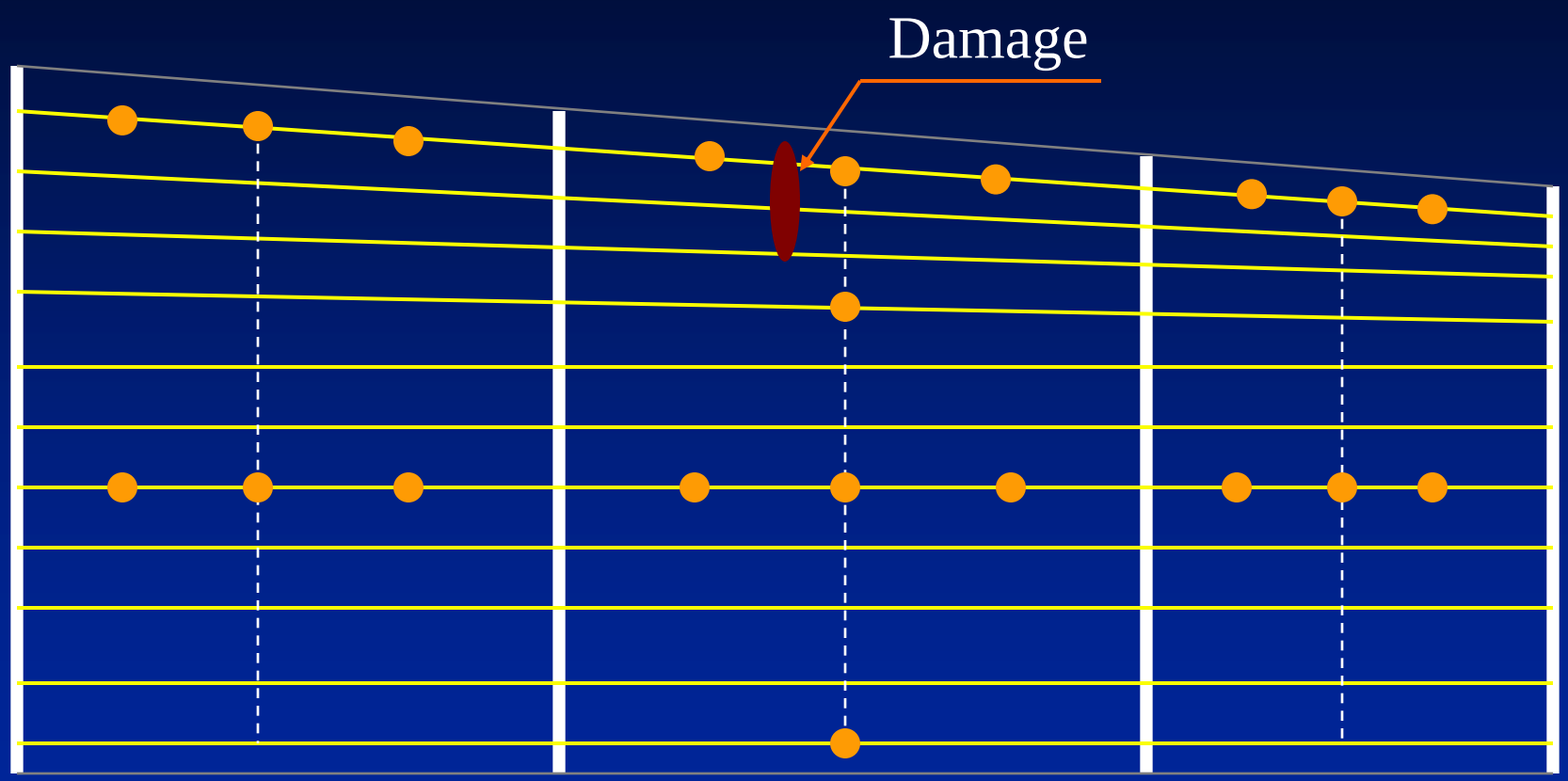

5' TO DIA. ℄

Static Load Test

Collected Data

- Deflections
- Exposed strand strains

Accelerometer Locations



Frequencies

Mode	Span	DAMAGED	INTACT	Ratio
First bending	Intermediate	6.42	6.78	95%
First torsional	Intermediate	6.77	6.90	98%
First bending	14.20 meter	8.02	8.08	99%
First torsional	14.20 meter	8.20	8.28	99%

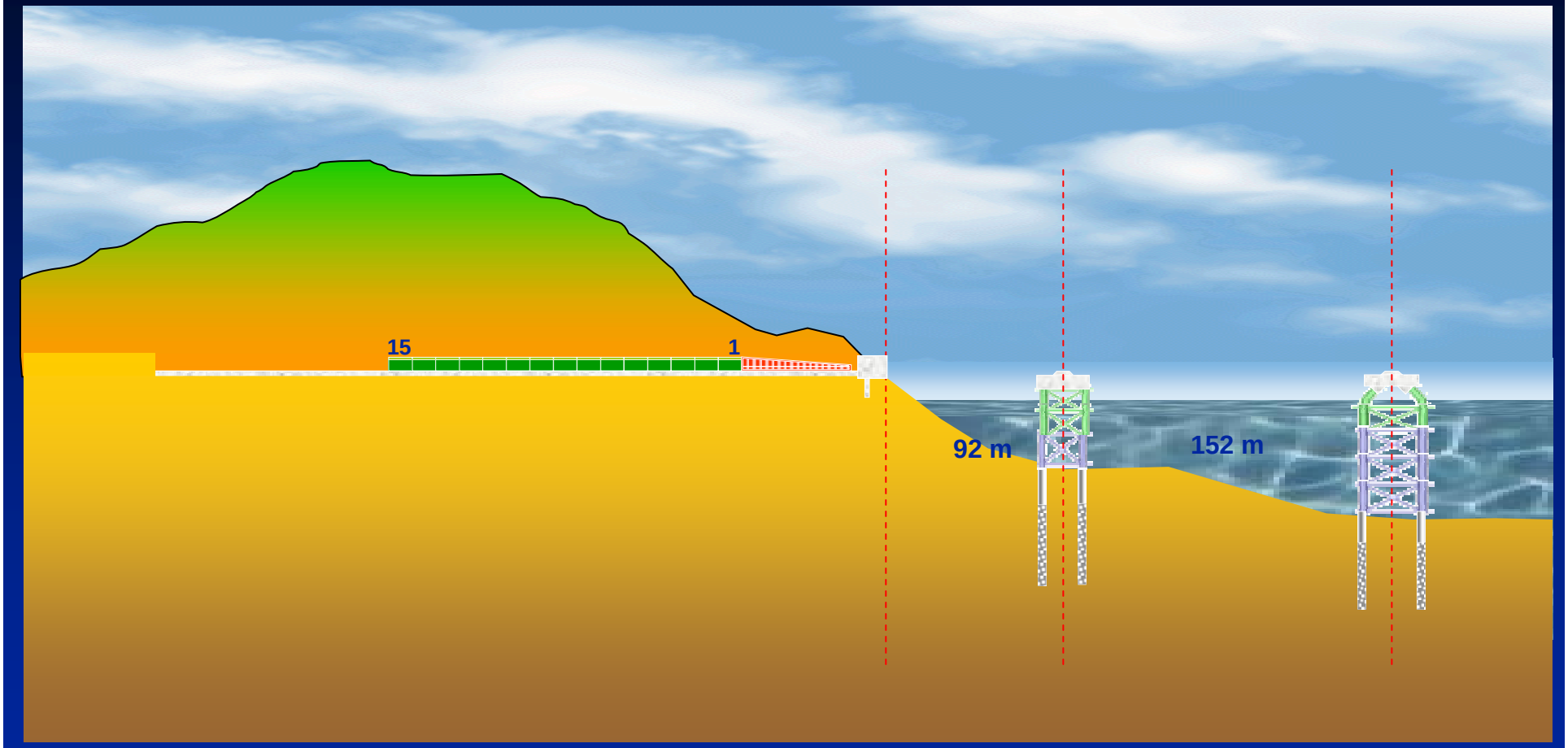
Mode Shape Correlation

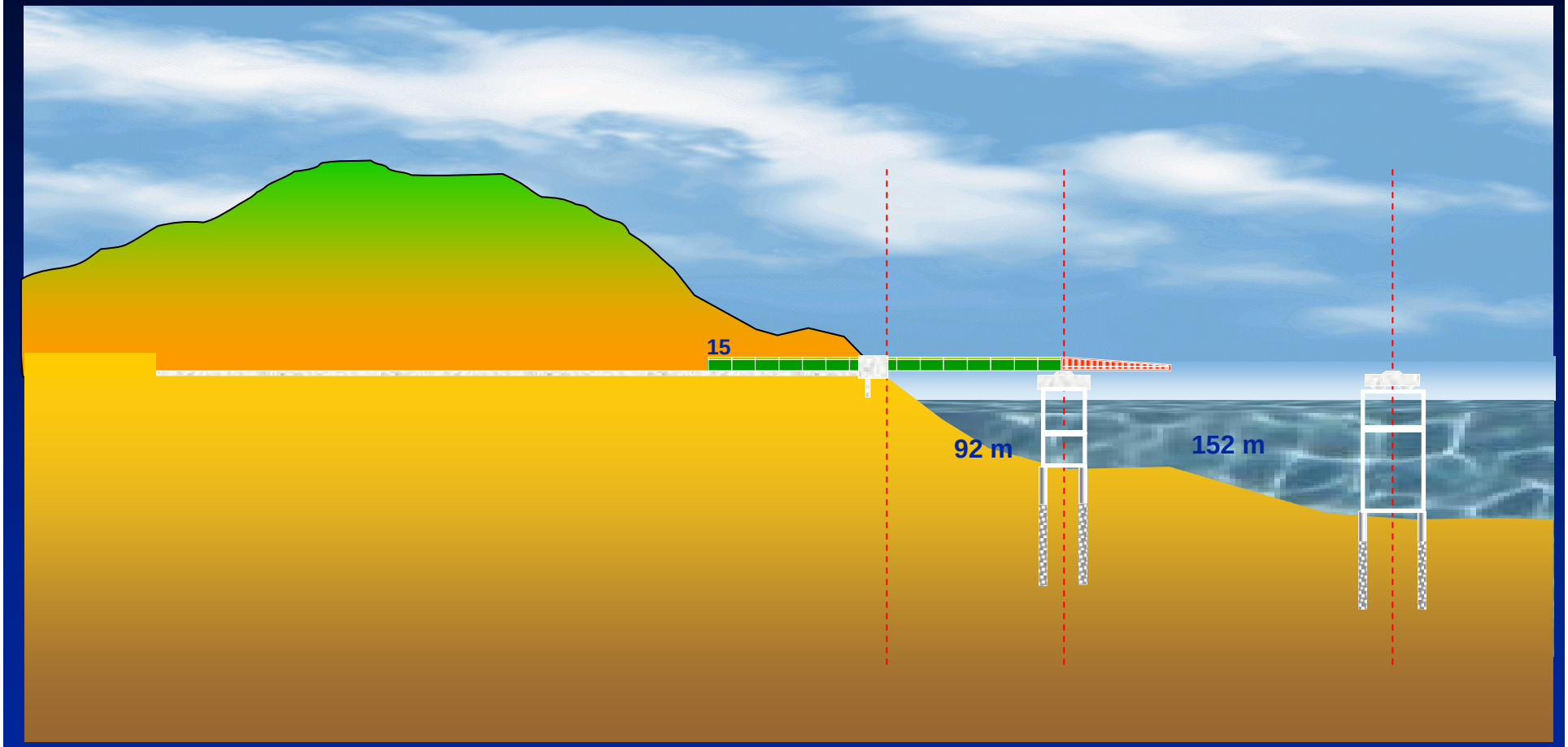
$$MAC(\{\phi_i^X\},\{\phi_j^Y\}) = \frac{(\{\phi_i^X\}^T\{\phi_j^Y\})^2}{(\{\phi_i^X\}^T\{\phi_i^X\})(\{\phi_j^Y\}^T\{\phi_j^Y\})}$$

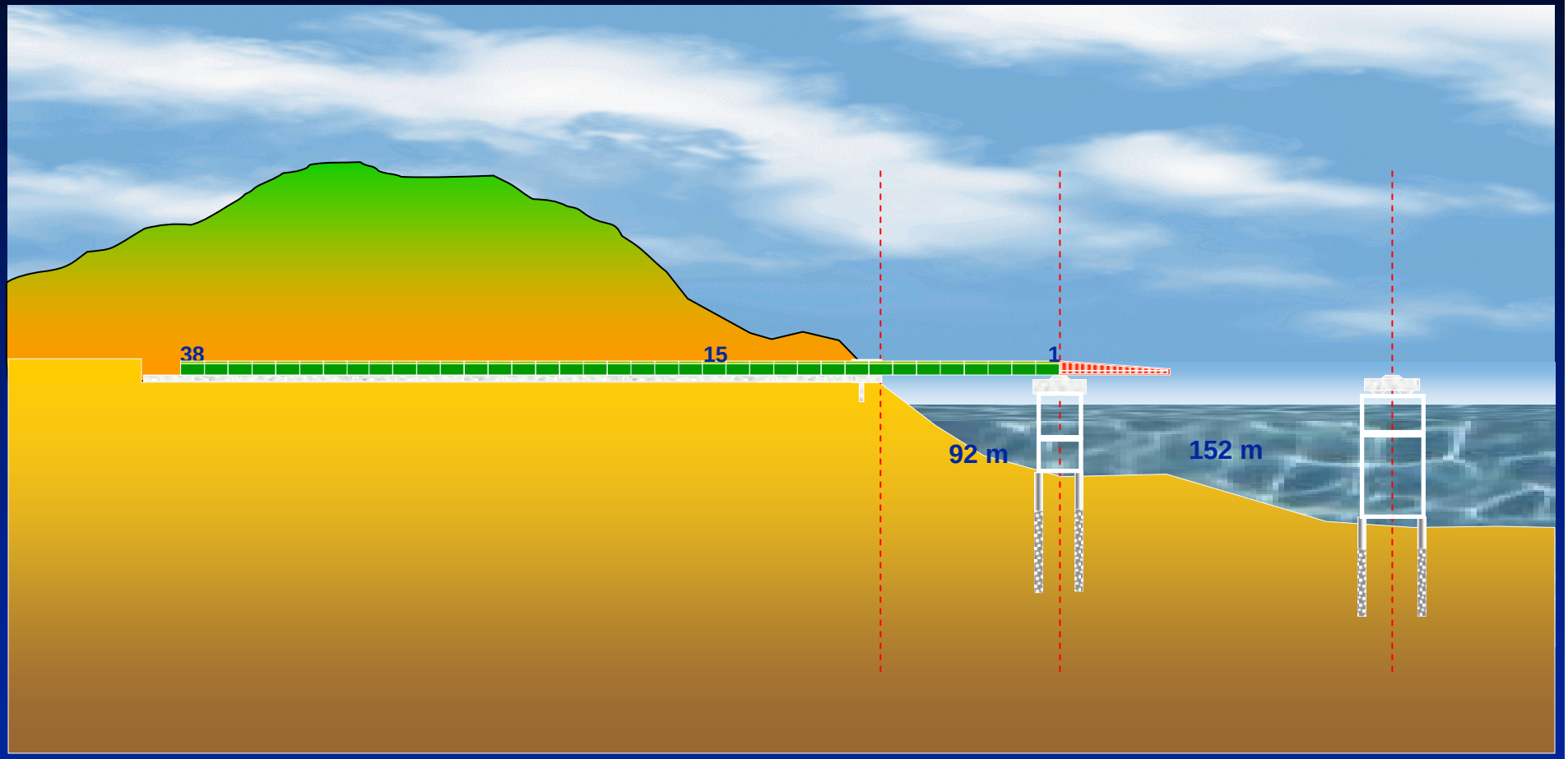
Mode	MAC
First bending	0.83
First torsional	0.34
First bending	0.99
First torsional	0.95
Bending longitudinal and transverse	0.94
First bending	0.99
First torsional	0.99
Bending longitudinal and transverse	0.95
Second bending	0.99
Second torsional	0.99

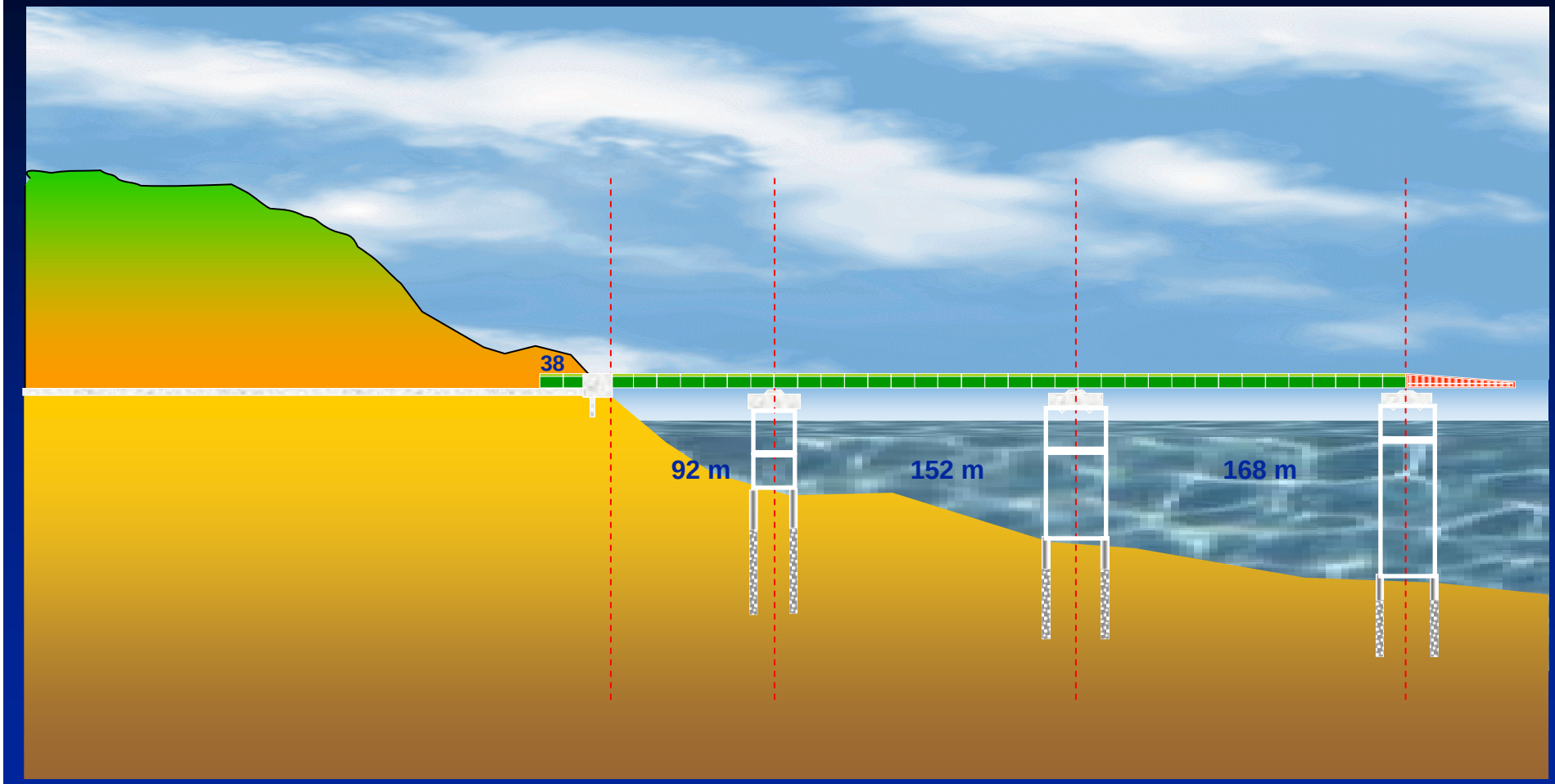
Validate Design and Identify Damage

Bridge Launching




15
92 m
152 m

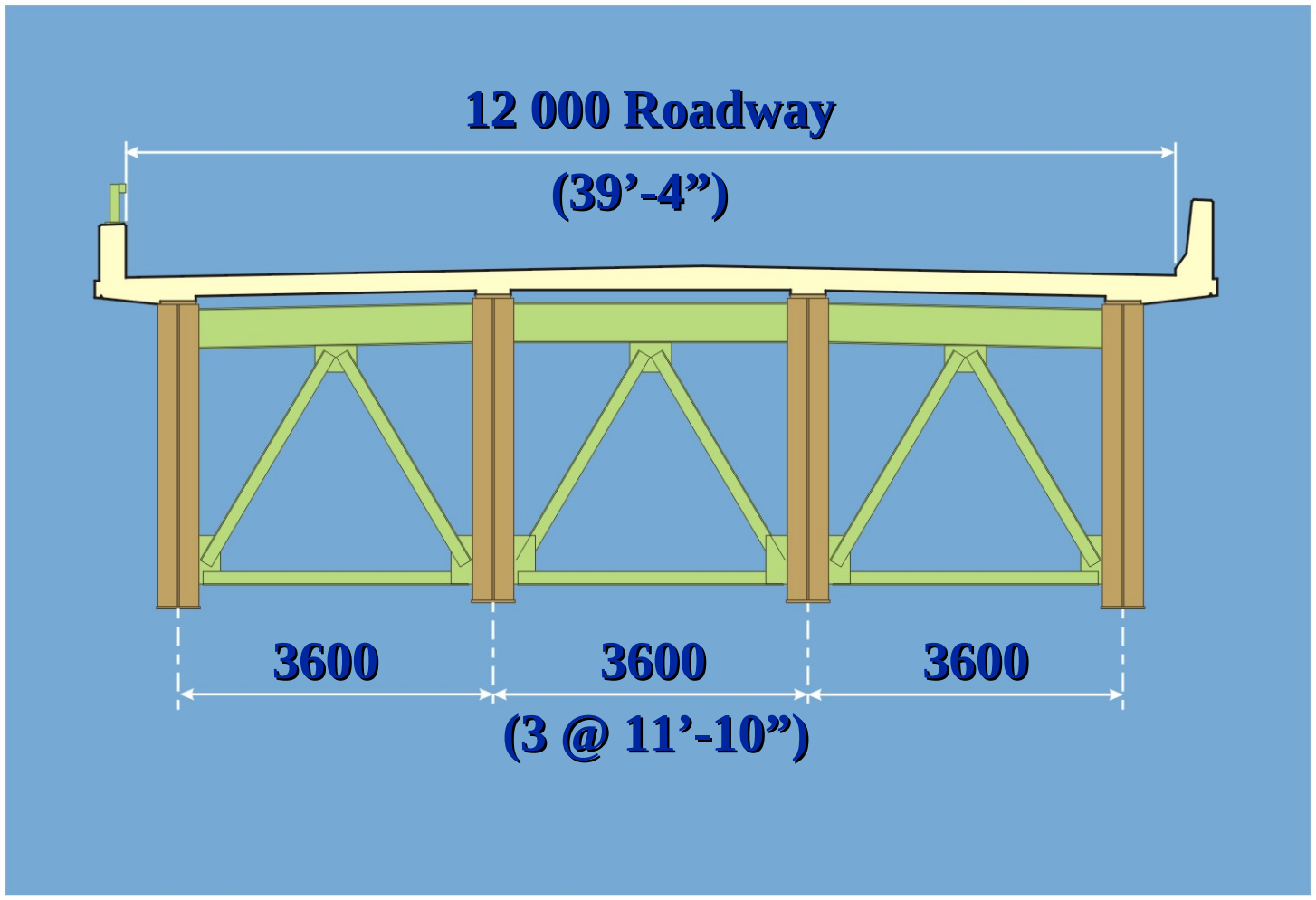

38
15
1
92 m
152 m


38
92 m
152 m
168 m

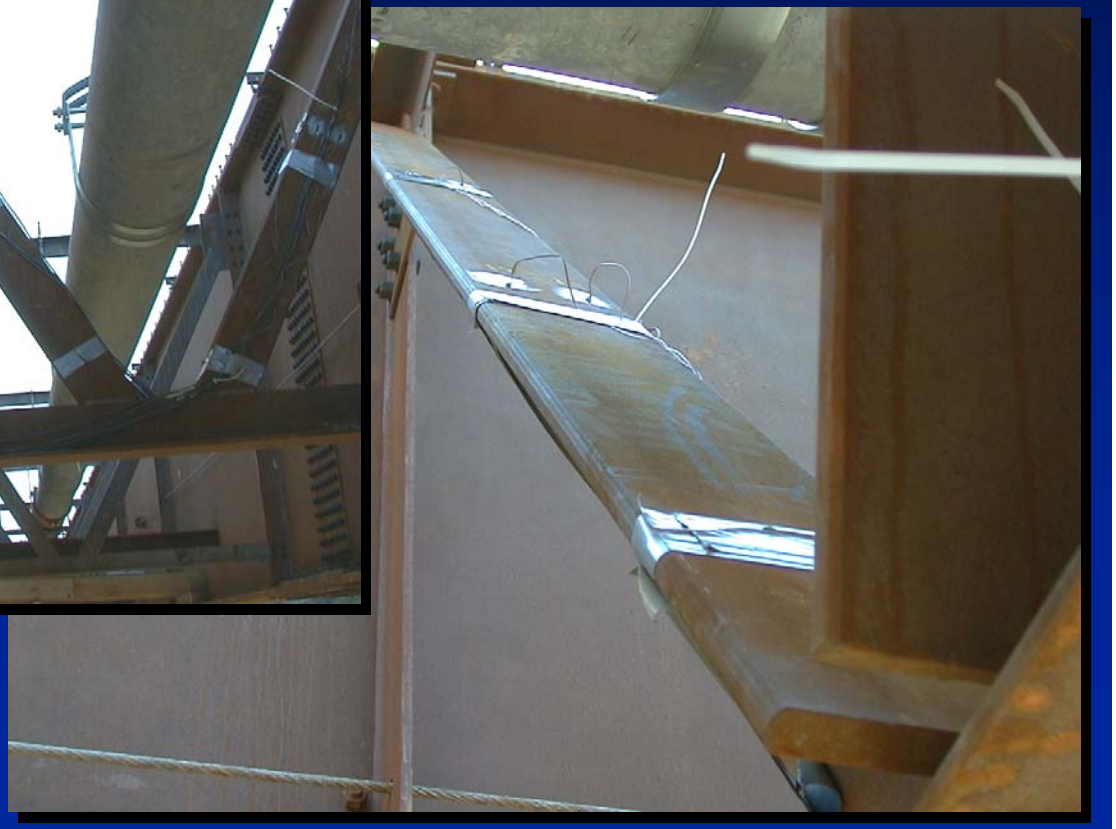
Launching is Serious Business

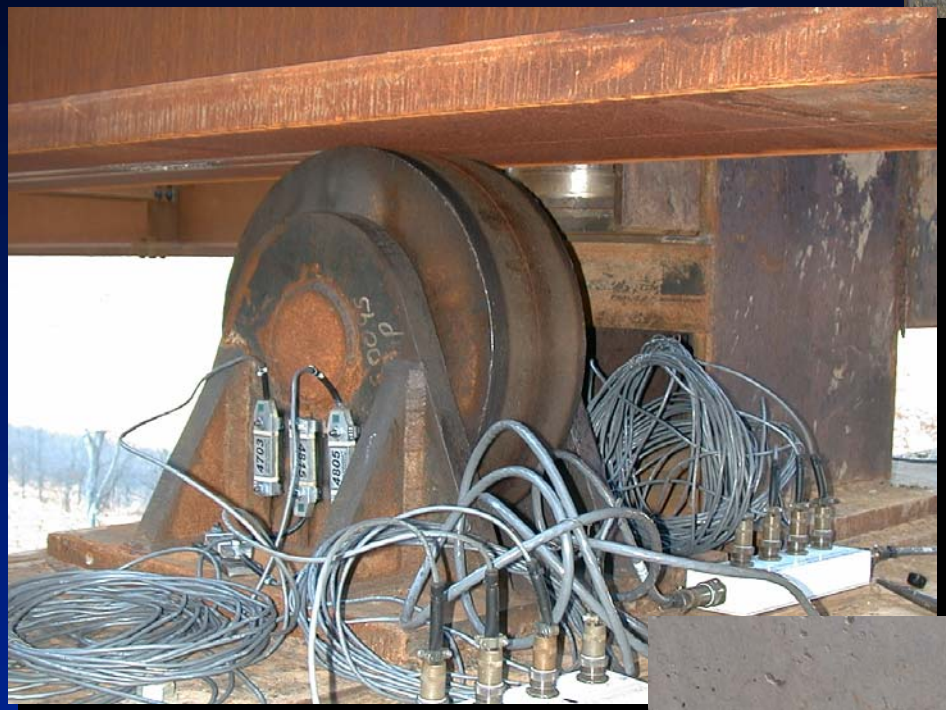
Launching Pit Excavated at East Abutment

Roadway Section (each deck)



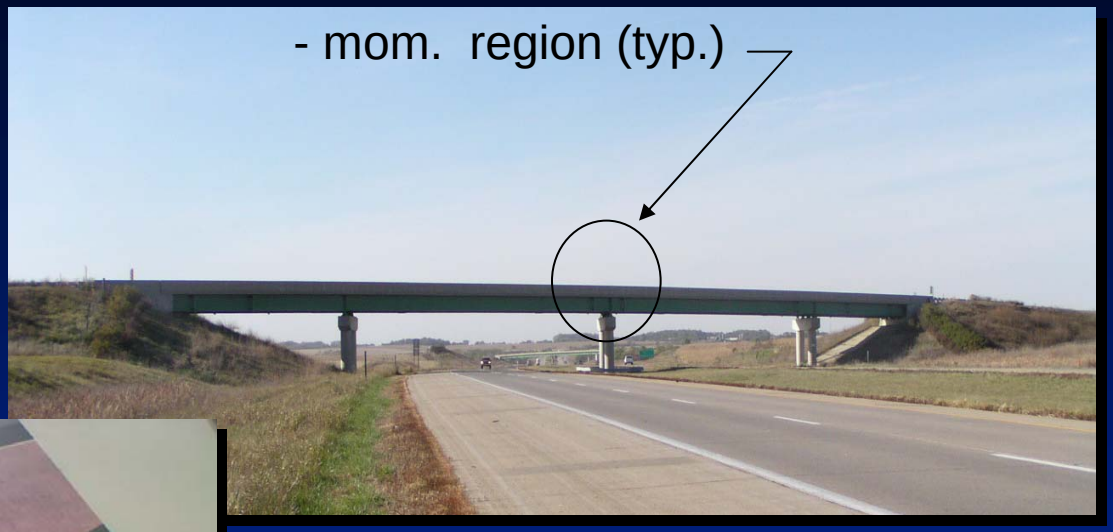
Girders Assembled in Launching Pit

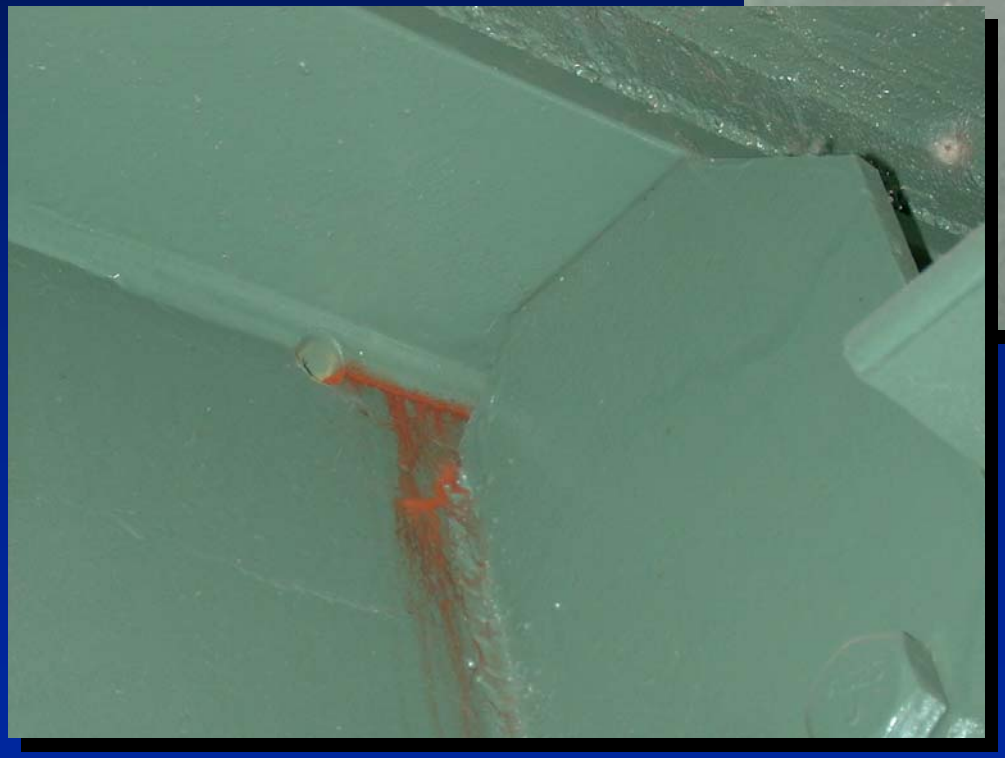


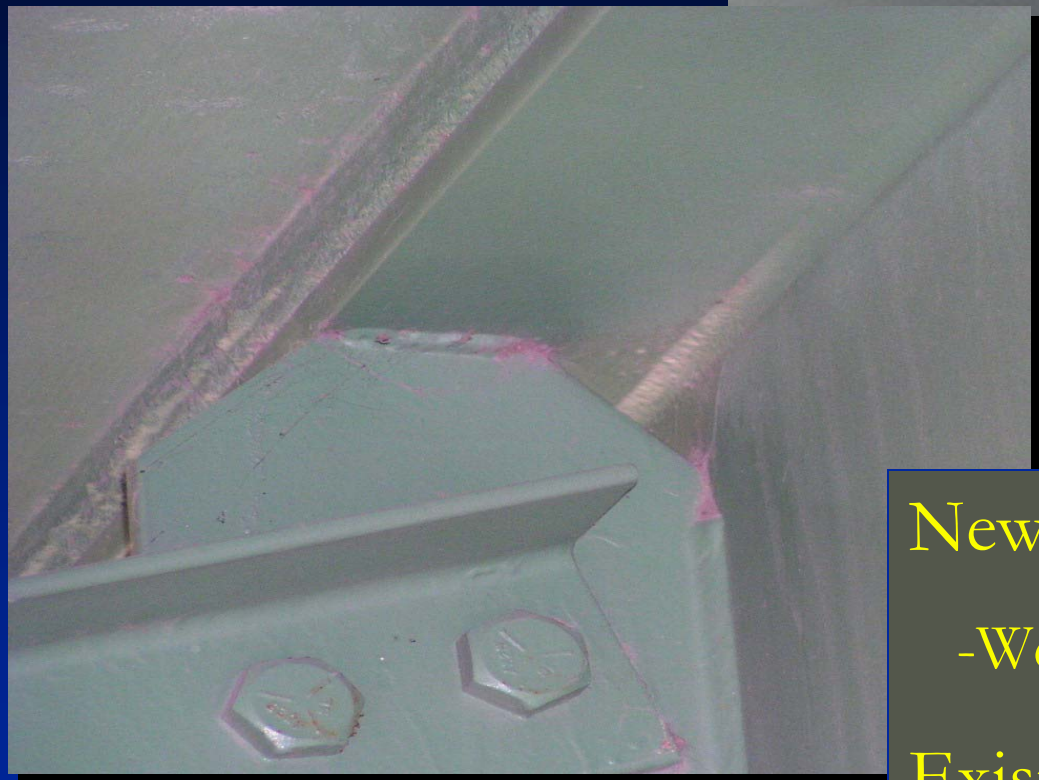

4807
4810
4805


4817
4815

Assess Damage and Evaluate Remedy







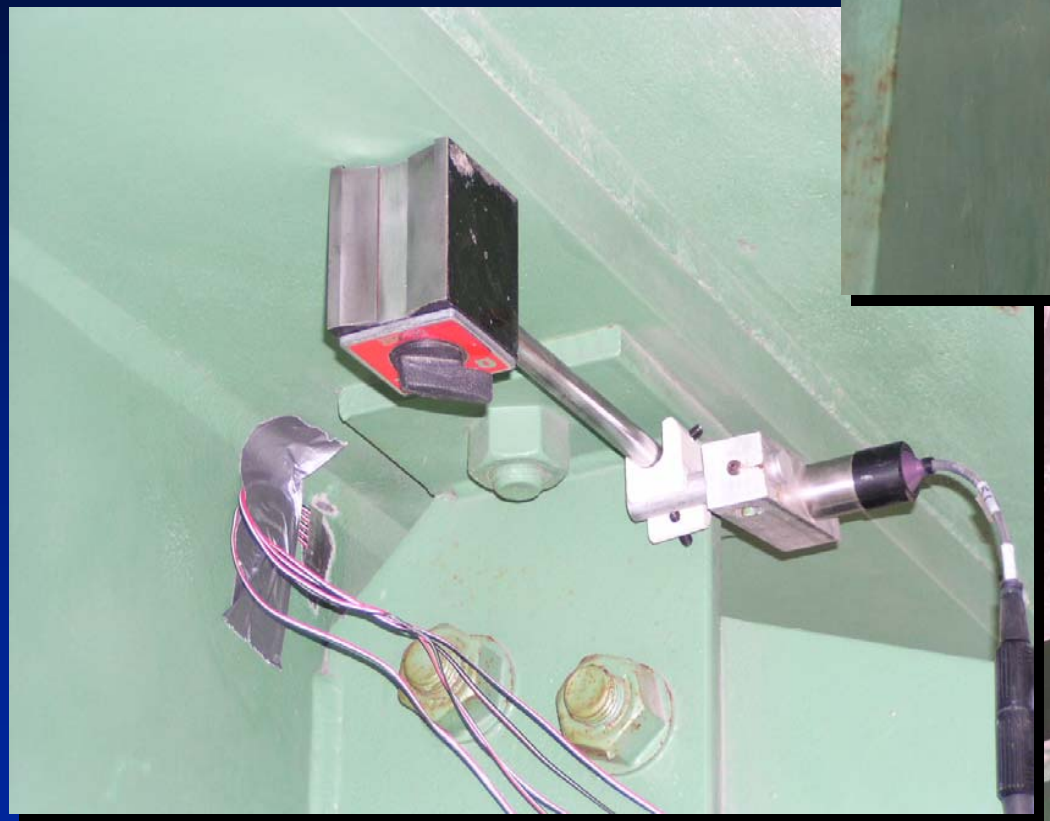
New Bridges

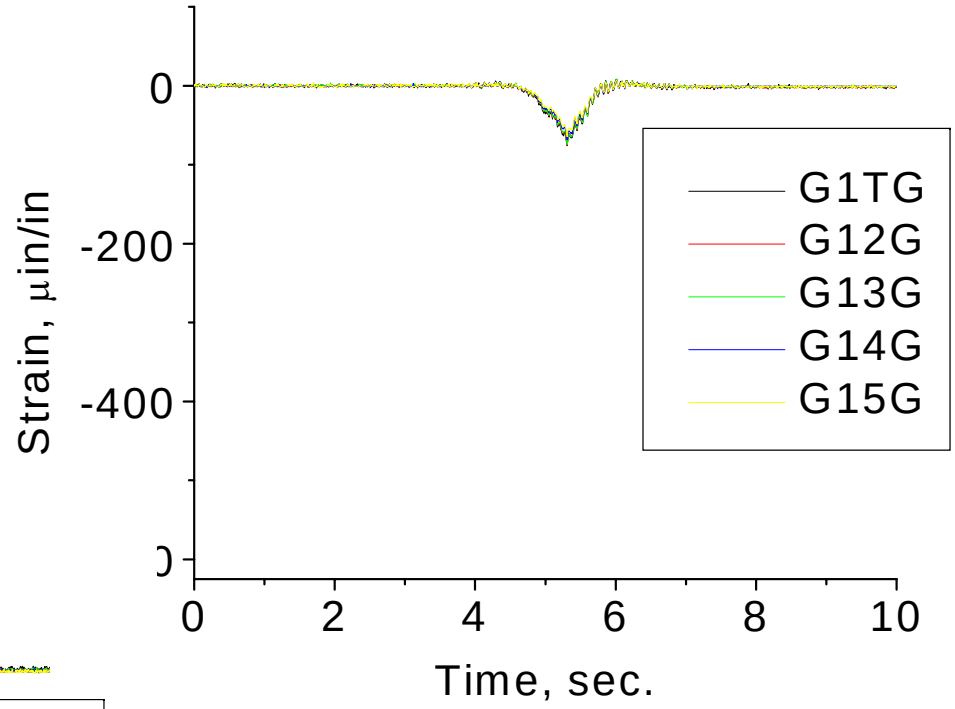
-Weld or bolt to top flange

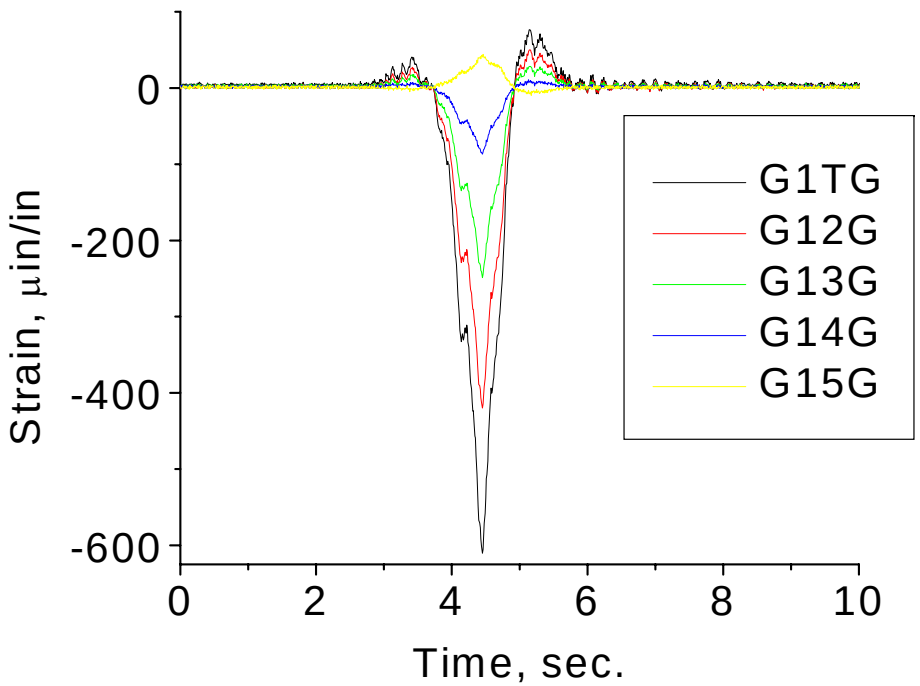
Existing Bridges

-Loosen Bolts in connection

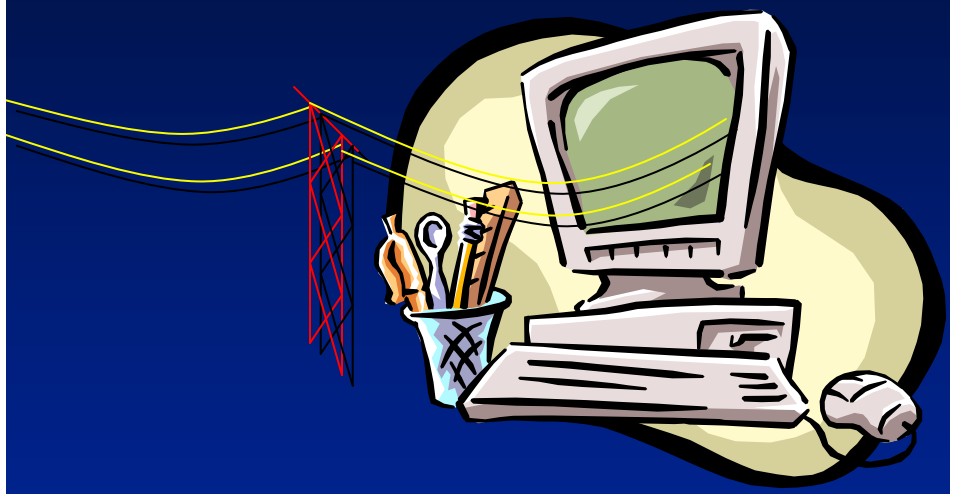

G2

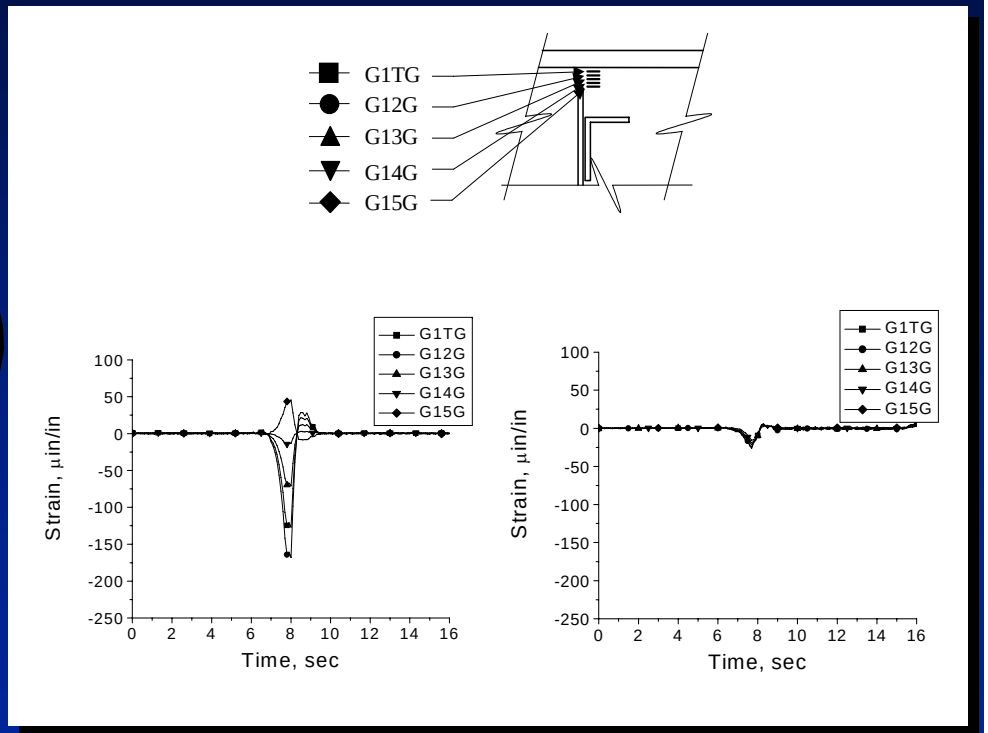


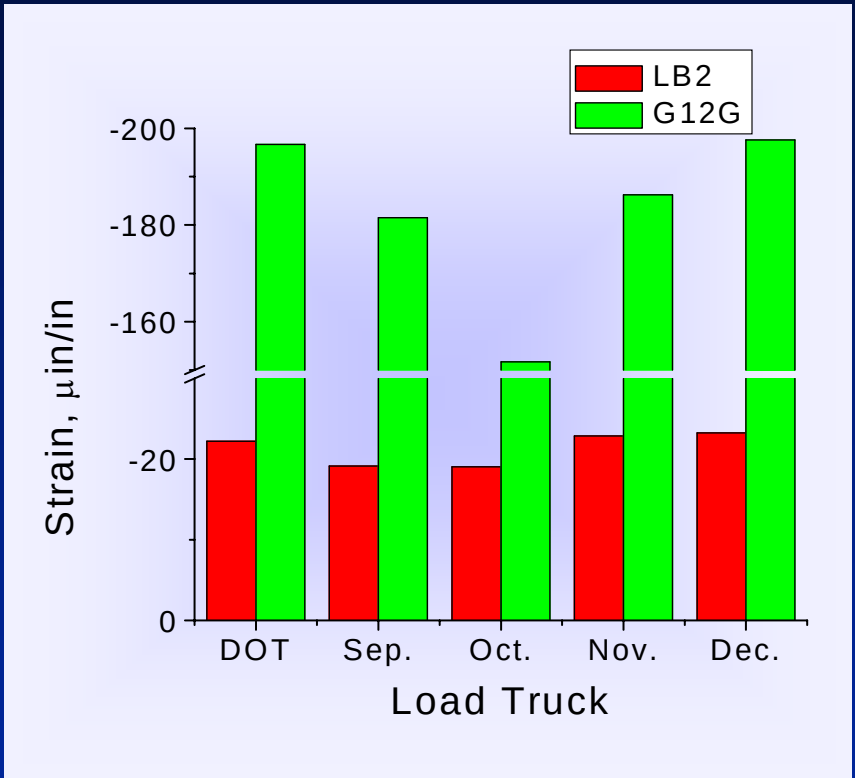

0
-200
-400
Strain, µin/in
0
2
4
6
8
10
Time, sec.
G1TG
G12G
G13G
G14G
G15G

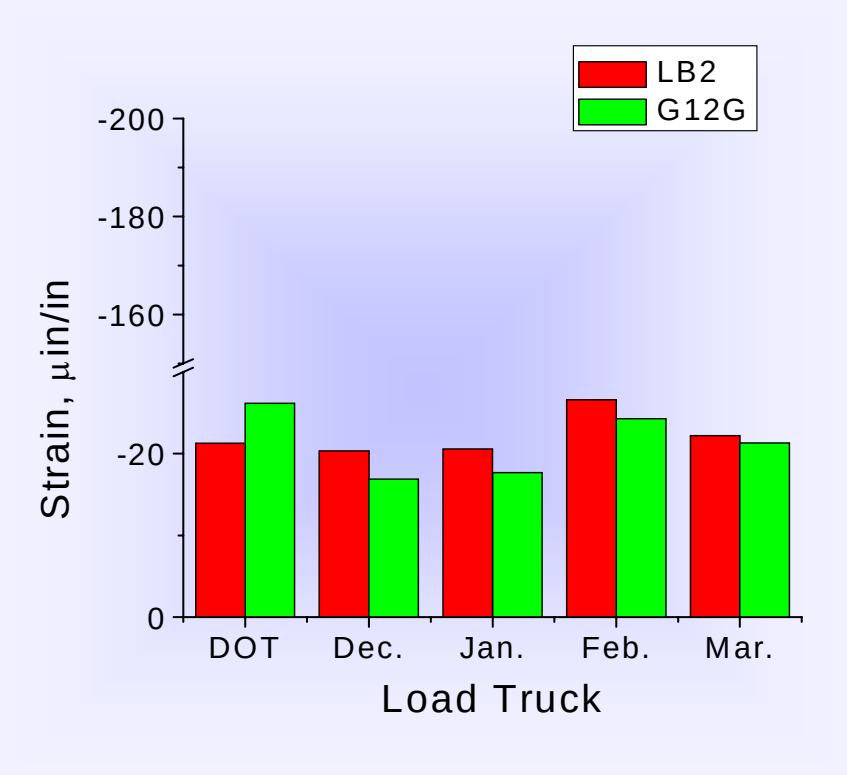

0
-200
-400
-600
Strain, µin/in
0
2
4
6
8
10
Time, sec.
G1TG
G12G
G13G
G14G
G15G

Remote Sensing-Performance

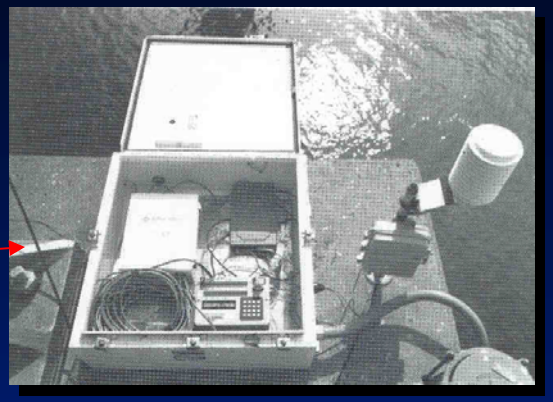


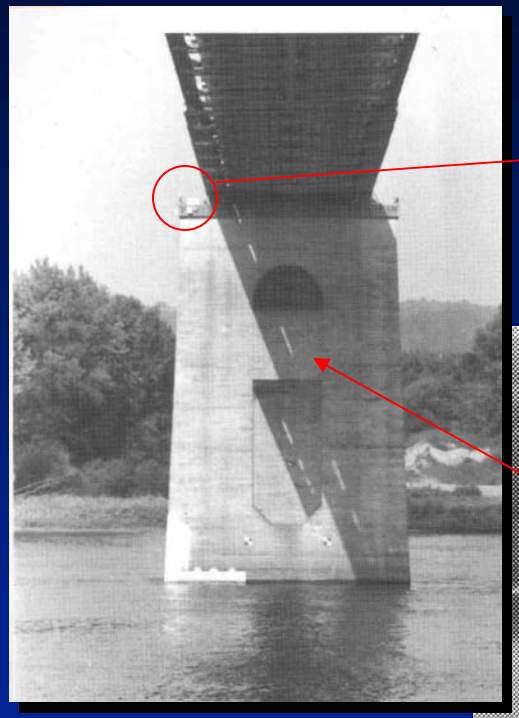

G1TG
G12G
G13G
G14G
G15G
Strain, µin/in
Time, sec
100
50
0
-50
-100
-150
-200
-250
0
2
4
6
8
10
12
14
16


LB2
G12G
-200
-180
-160
-20
0
Strain, µin/in
DOT
Sep.
Oct.
Nov.
Dec.
Load Truck

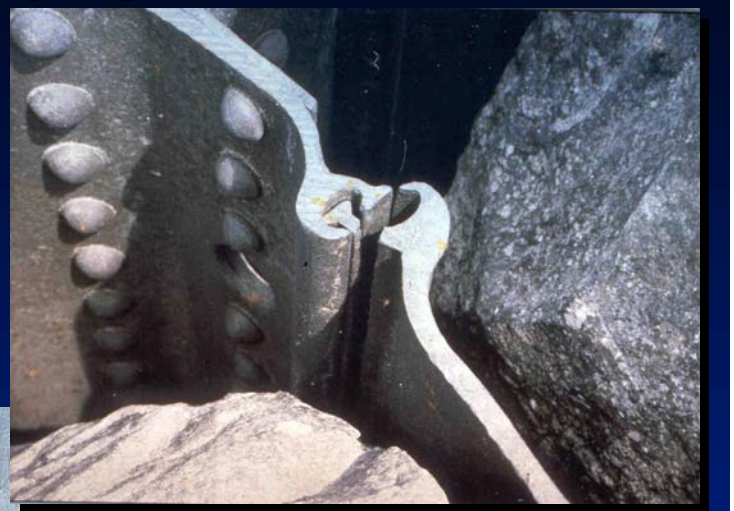

LB2
G12G
-200
-180
-160
-20
0
Strain, µin/in
DOT
Dec.
Jan.
Feb.
Mar.
Load Truck

Remote Sensing-Security





Remote Sensing-Health



SHM-What the Future Holds

The Future of SHM, at ISU, is Now

- Innovative sensors.
- Data handling techniques.
- Client-based information presentation.

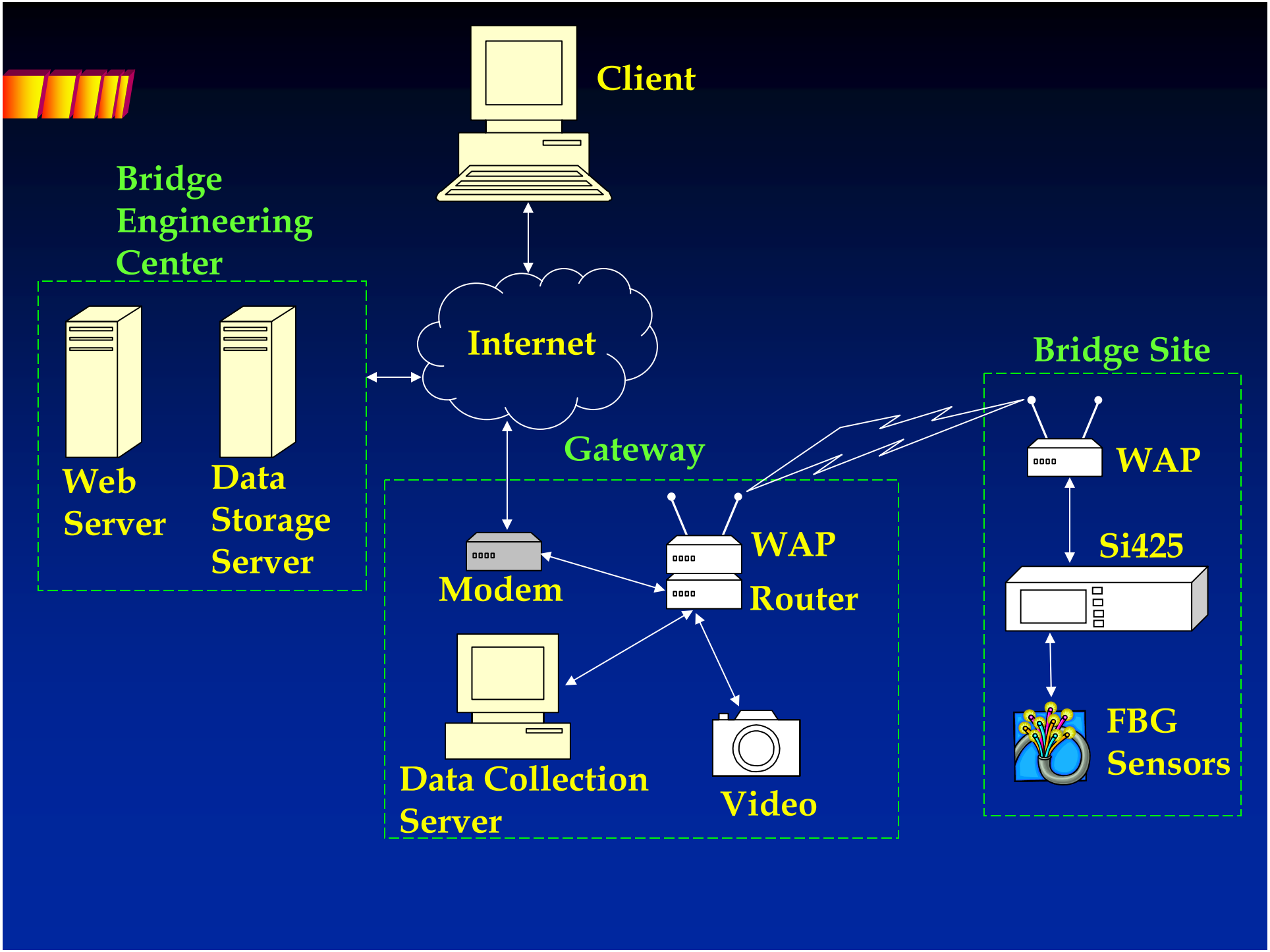
Health Monitoring of a High-Performance Steel Bridge

Health Monitoring of a High-Performance Steel Bridge

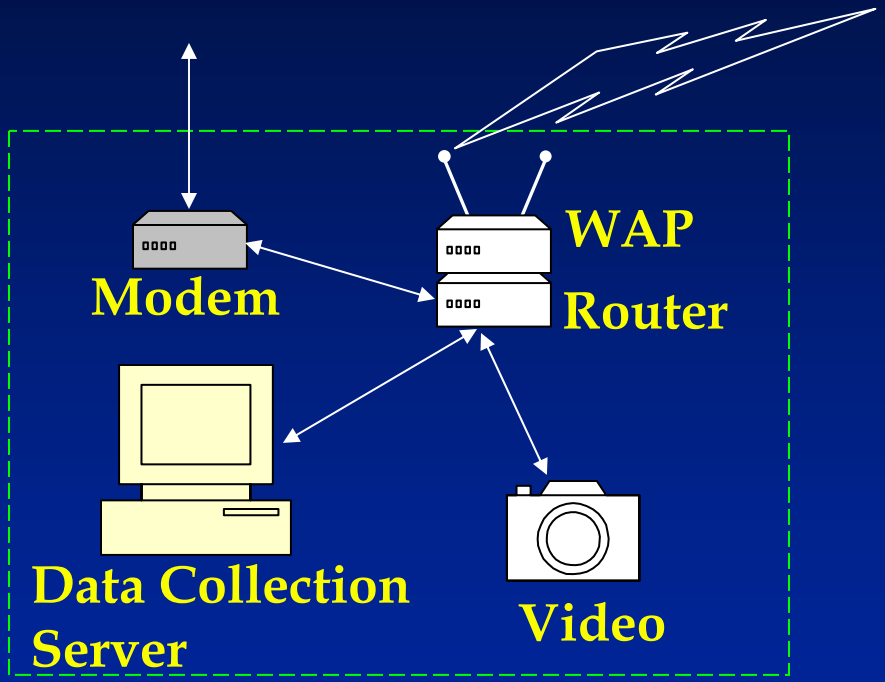
- Purpose of monitoring:
  - Assess long-term performance
    - » Changes with time.
    - » Structural characteristics.
  - Measure and quantify fatigue loadings.
  - Assess serviceability associated with "lighter" design.

East 12th Street Health-Monitoring System

- Components:
  - 30 FBG optical sensors.
  - Swept laser interrogator (Unix based).
  - Web server.
  - Data collection server (DCS).
  - Data storage server (DSS).
  - Video camera.
  - Wireless networking components.


Client
Bridge Engineering Center
Internet
Web Server
Data Storage Server
Gateway
Bridge Site
WAP
Si425
Modem
WAP
Router
Data Collection Server
Video
FBG Sensors

WAN/LAN Gateway



WAN/LAN Gateway

- Network
  - Standard DSL modem and line
    - » Port-forwards all port requests to router.
- Data Collection Server (DCS)
  - 700 MHz Pentium III Processor.
  - 256 MB RAM.
  - 8.0 GB Hard drive.
- Universal power supply
  - Backup power for up to 25 minutes.

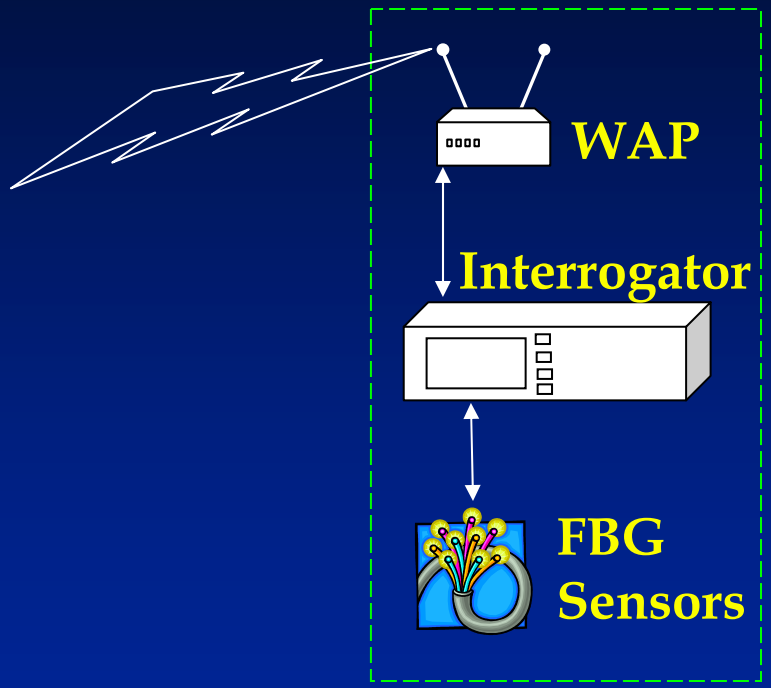
WAN/LAN Gateway

- Video Camera:
  - Canon Network Camera VB-C10/VB-C10R.
  - Adjustable video quality and frame rate.
  - 16x zoom lens.
  - Remote camera control utility.
  - Built-in web server and FTP server.

WAN/LAN Gateway

- Wireless Router and Access Points:
  - Linksys 2.4 GHz Wireless-802.11g Router
  - Linksys 2.4 GHz Wireless-802.11g Access Point
  - Data transfer rate = 54 Mbps
  - 128-bit WEP encryption, MAC or IP address filtering

Bridge Site System Components



Bridge Site System Components

- Swept laser interrogator
  - Simultaneously monitor up to 512 sensors
    - » 4 channels @ 128 sensors/channel.
  - Scan speeds up to 250 Hz.
  - Standard Ethernet port for access and control.
  - Built-in single-board computer and display.

Bridge Site System Components

- Fiber Bragg Grating (FBG) Sensors

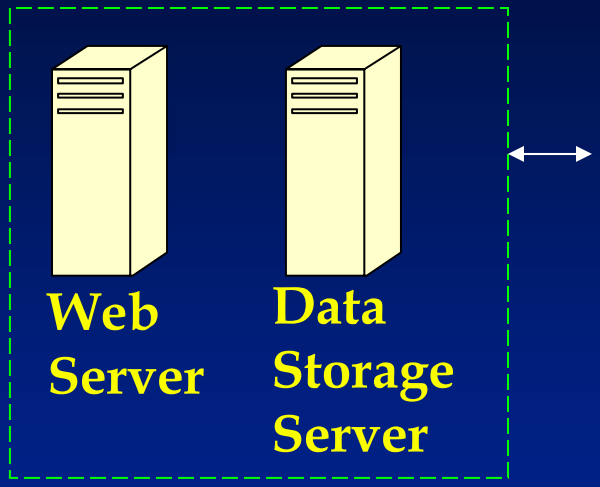
Bridge Site System Components

- Fiber Bragg Grating (FBG) Sensors
  - Immune to EMI/RF interference.
  - Measure wavelength shift.
  - Form part of the data transmission optical fiber.
  - Not electrically conductive.
  - Low signal loss with long lead lengths.
  - Can be serially multiplexed.

Bridge Site System Components

- Wireless Access Point.
- Universal power supply
  - Backup power for up to 100 minutes.
- Protective housing unit
  - Stores interrogator, WAP, and UPS.
  - Temperature controlled via thermostat, heaters, insulation, fans, etc.

BEC System Components



BEC System Components

- Web server.
- Data Storage Server (DSS)
  - 3.0 GHz processor.
  - 1.2 TB Hard drive (RAID 5).
  - 4.0 GB RAM.

File Transfer Protocol

- DCS saves strain data in 100 MB files
  - Generated ≈ 40 minutes.
- 100 MB files automatically compressed to 10 MB files.
- DSS automatically retrieves 10 MB files from DCS (≈ 6 minutes to transfer).
- DSS utility unzips and stitches files into larger, useful packets.

Web Portal

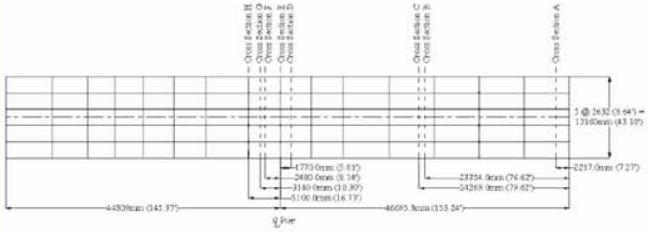
Structural Health Monitoring [I-235 and E. 12th Street Bridge, Des Moines, Iowa] - Microsoft Internet Explorer

File Edit View Favorites Tools Help

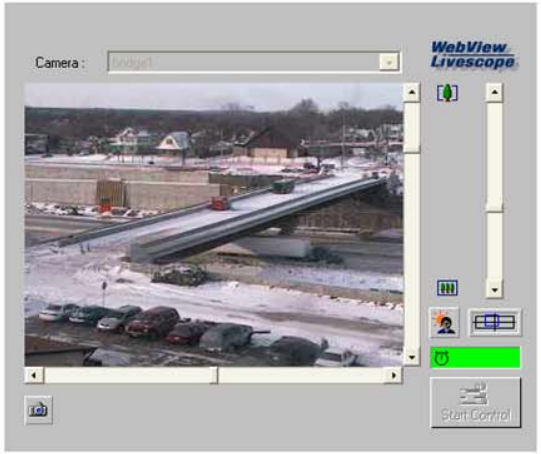
Address http://www.ctre.iastate.edu/nick/HPS.htm

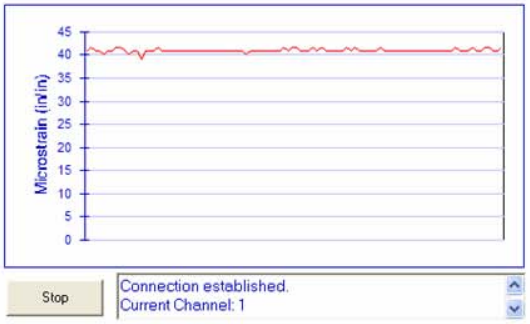
BRIDGE ENGINEERING CENTER

Timber Bridge Program | Structural Health Monitoring | Current Projects | Completed Projects | About BEC | Staff | Students | Related Links



[Sensor List | Overview]





Packet Analyses

- Stress cycle counting
  - Rain flow analysis.
- Autonomous separation of vehicle/environment induced strain.
- Formulation of temperature/strain relationships
  - Nonlinear, multivariate analysis.
- Estimation of transient load characteristics.
- Comparison with point-in-time controlled tests.

What We've Learned

- Standard DSL adequate for data transfer
  - Possible via compressed partial file transfer and stitching utility.
- Verified real-time WWW interactive video and strain display.
- Success with off-the-shelf wireless networking equipment.
- Testing has proven system stability.

Future Needs in SHM

- Power
- Cost
- Data
- Assessment

Power

- The Problem: Tied to a land-based power grid.
- The Solution: Alternative power sources.

Alternative Power Solutions

- Solar power.
- Batteries.
- Hydrogen fuel cells.
- Parasitic power sources
  - Bridge vibrations.
  - “Wind” from passing vehicles.
- ????

Cost

- Some DOTs are allocating up to 5% of the bridge cost to SHM (for "important" bridges).
- For a "typical" $250,000 bridge, this amounts to $12,500.
- Need: low-cost systems that utilize "off-the-shelf" technology where possible.

Data

- Transmission.
- Storage.
- Manipulation.

Data Transmission

- Two problems:
  - As the number of sensors increases, currently available solutions (DSL, dial-up) may not be acceptable.
  - Remote locations may not have accessibility to all currently available solutions.

Data Transmission

- The solutions:
  - Longer range (100's of miles) wireless.
  - Satellite.
  - Improved compression algorithms.

Data Storage

- Problem: Although HDD space is increasingly getting larger and less expensive, likely that large bridge needs would exceed technology.
- Solution:
  - Techniques for only retaining the “legacy” of the data.
  - ??

Data Manipulation

- The Problem: time
- The Solution: Develop computer based autonomous techniques that essentially "replace" the engineer from "touching" the data.

Answers

- Problem: "So what does the data mean?"
- Solution:
  - "Smart" Engineering solutions
    - » Neural networks.
    - » Fuzzy logic.
    - » Evolutionary programming.
    - » Artificial life.
    - » Data Mining.

Concluding Remarks

- SHM has been going on for many years.
- Only limits are those we imagine.
- However, must keep grounded by what our clients will use.