

Structural Response of Truss Bridges to Wind

**Iron & Steel Preservation Conference & Workshop
Purdue University
West Lafayette, Indiana
May 18 – 20, 2016**

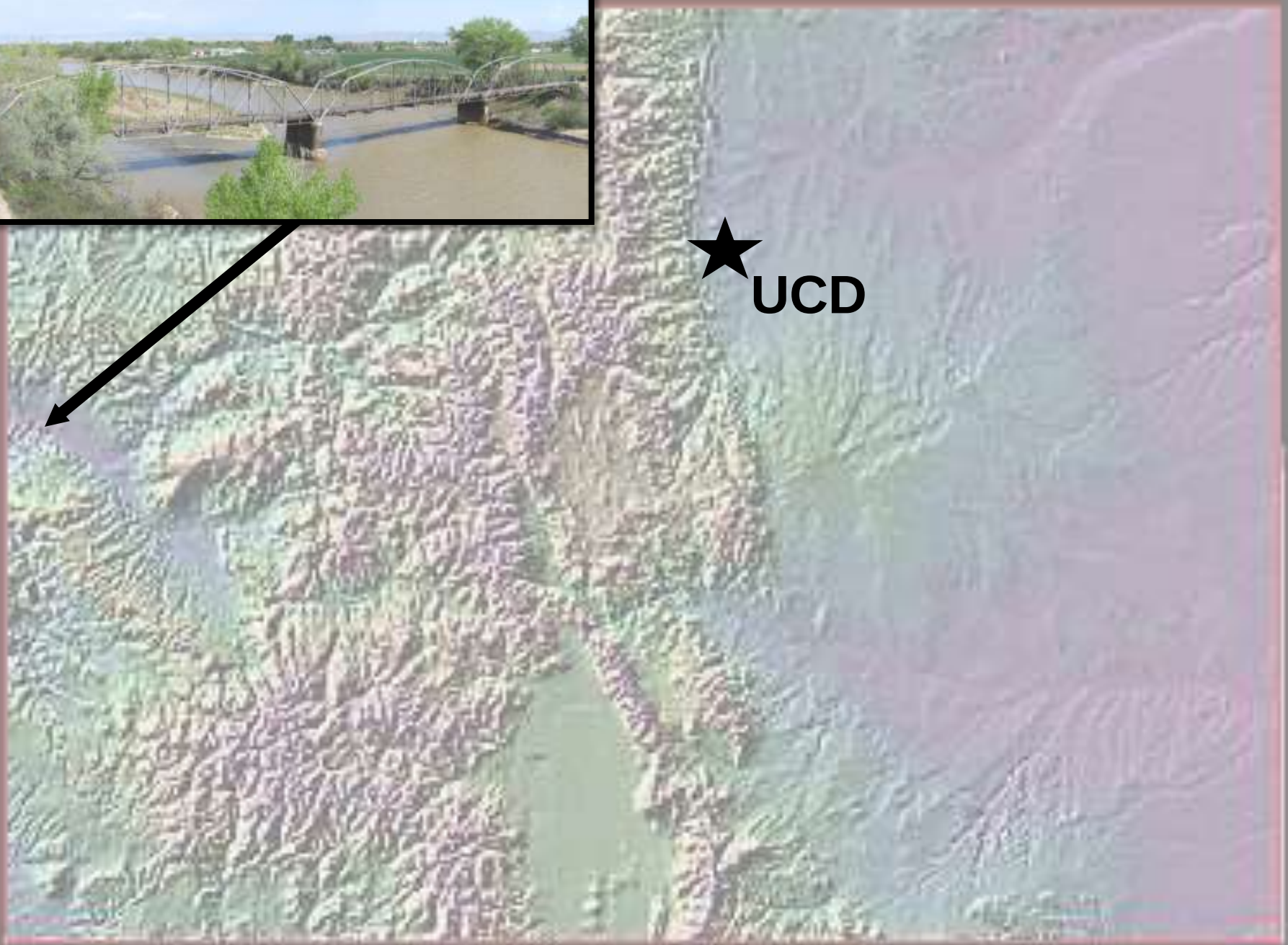
**Frederick R. Rutz, PE, SE, PhD
University of Colorado Denver
J.R. Harris & Company**



Fruita Bridge over Colorado River



★ UCD



Wind Pressure Recommendations (psf)

	<u>60'</u>	<u>100'</u>	<u>150'</u>	<u>200'</u>	<u>1000'</u>	<u>1500'</u>
1881, Smith	30	30	30	30	30	
1884, Waddell	40	40	35	30	30	30
1898, Waddell	40	40	40			25
1905, Cooper	50	30	30	30		
1916, Waddell	35	35	35	35	25	

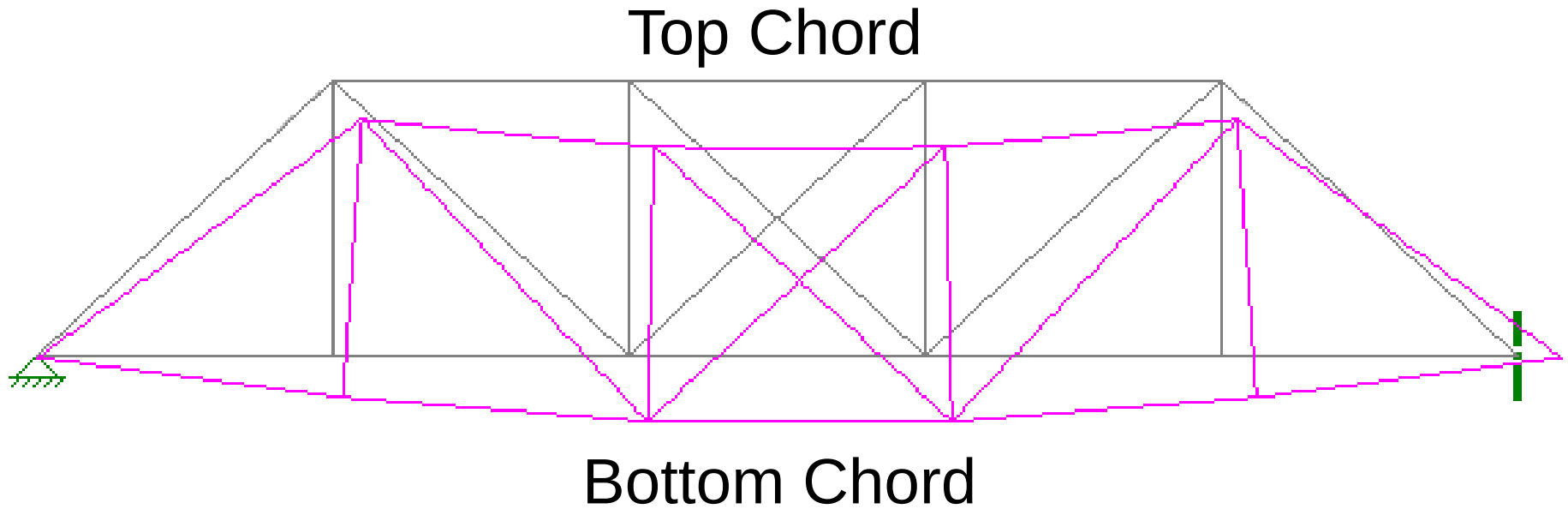


7TH HISTORIC BRIDGES CONFERENCE

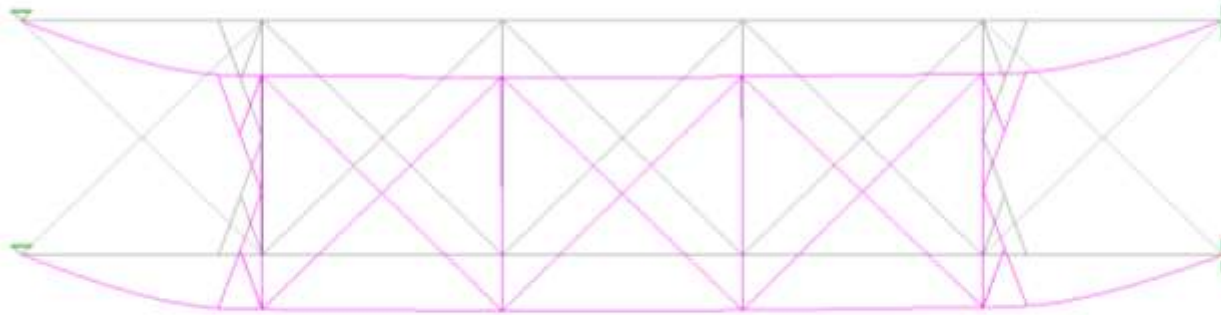


**Dr. Frank Hatfield
Historic Metals Workshop
LCC, 2010**

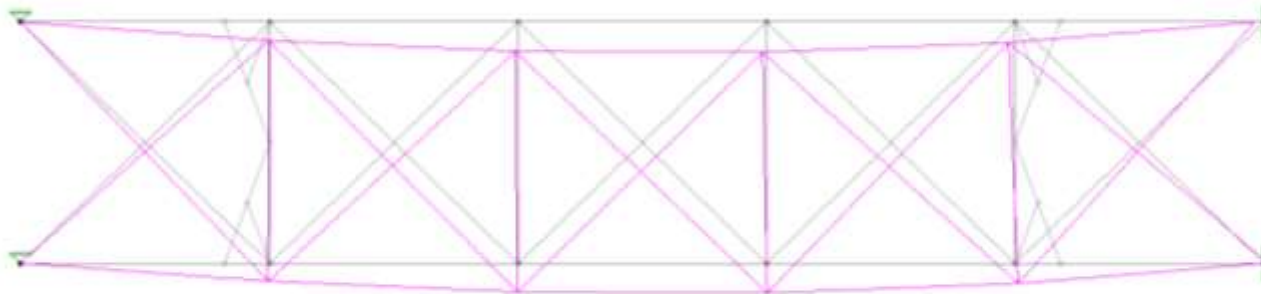
**7th Historic Bridges Conference
Cleveland, OH, 2001**



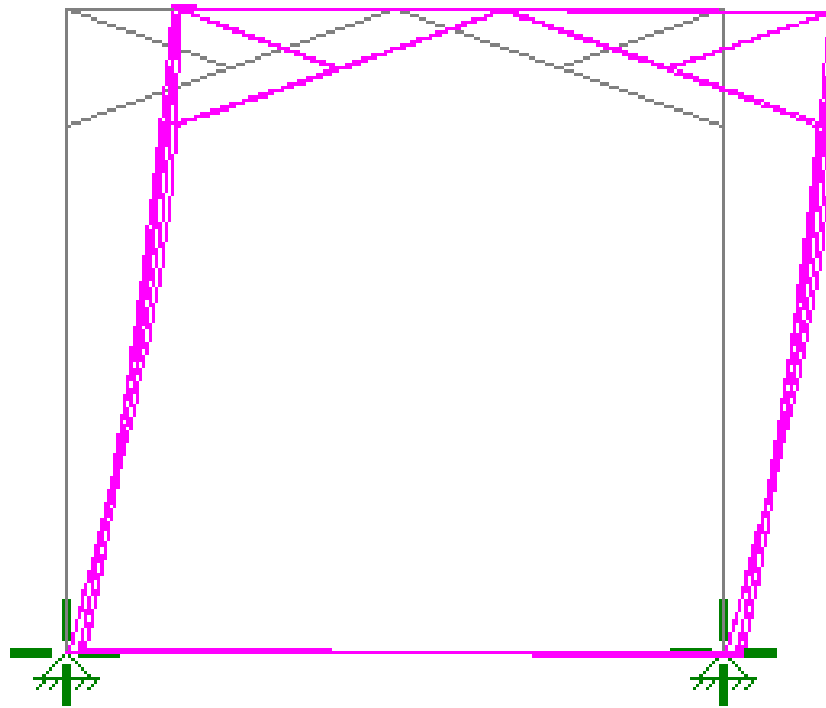
Vertical deflection of skeleton structure
under gravity loads



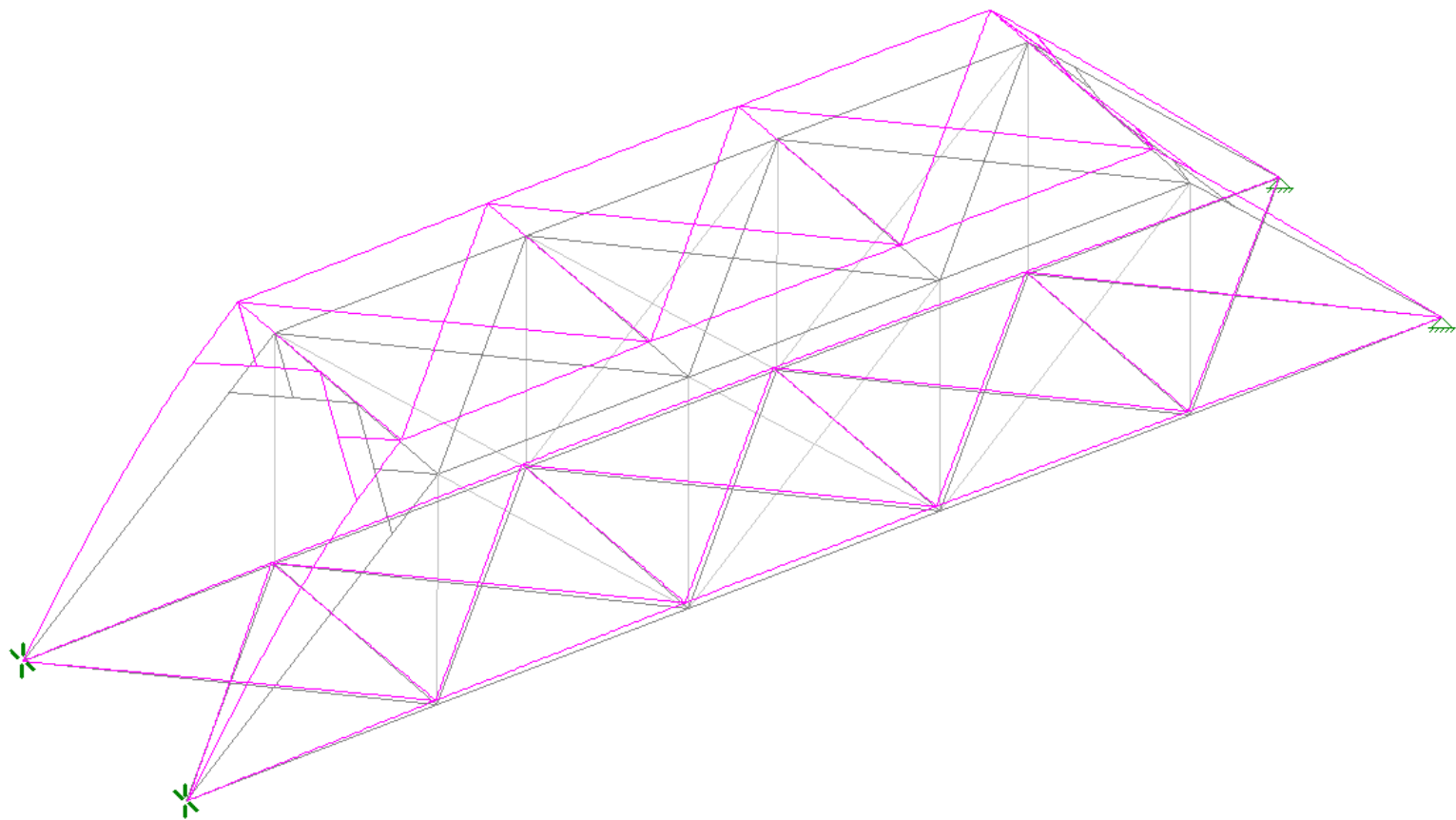
Lateral Deflection in Plane of Top Chord



Lateral Deflection in Plane of Bottom Chord

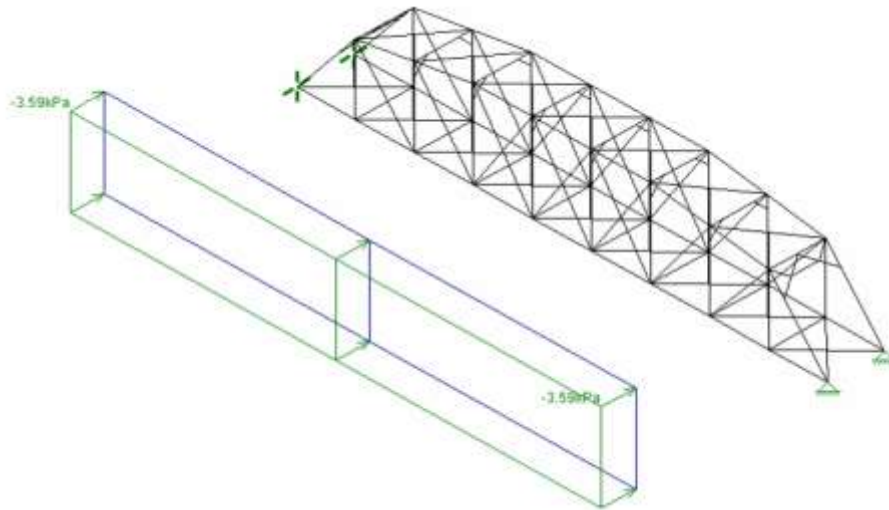


Lateral deflection of skeleton structure
under wind pressure





WIND LOAD



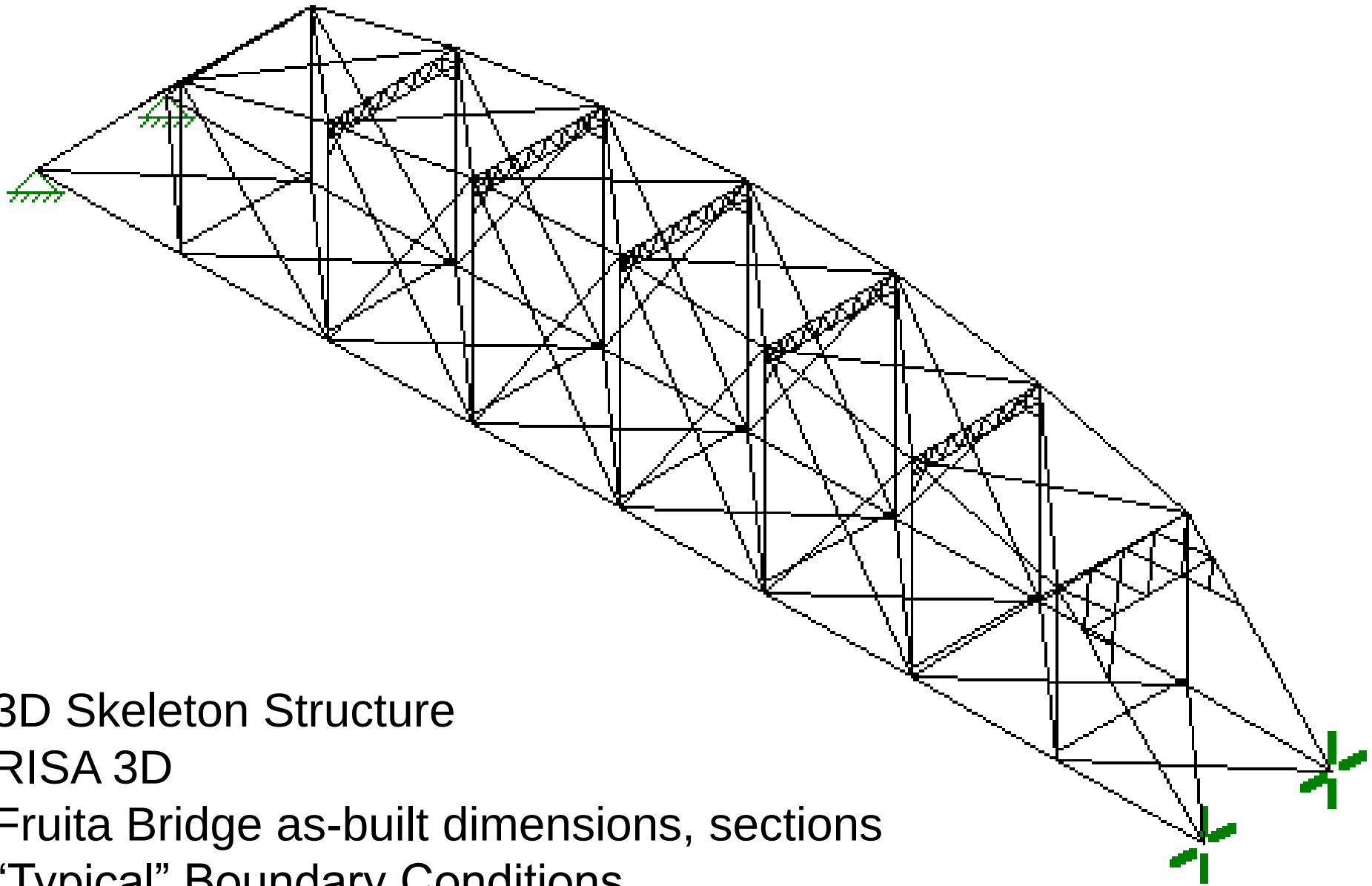
AASHTO Wind Criteria -75 psf

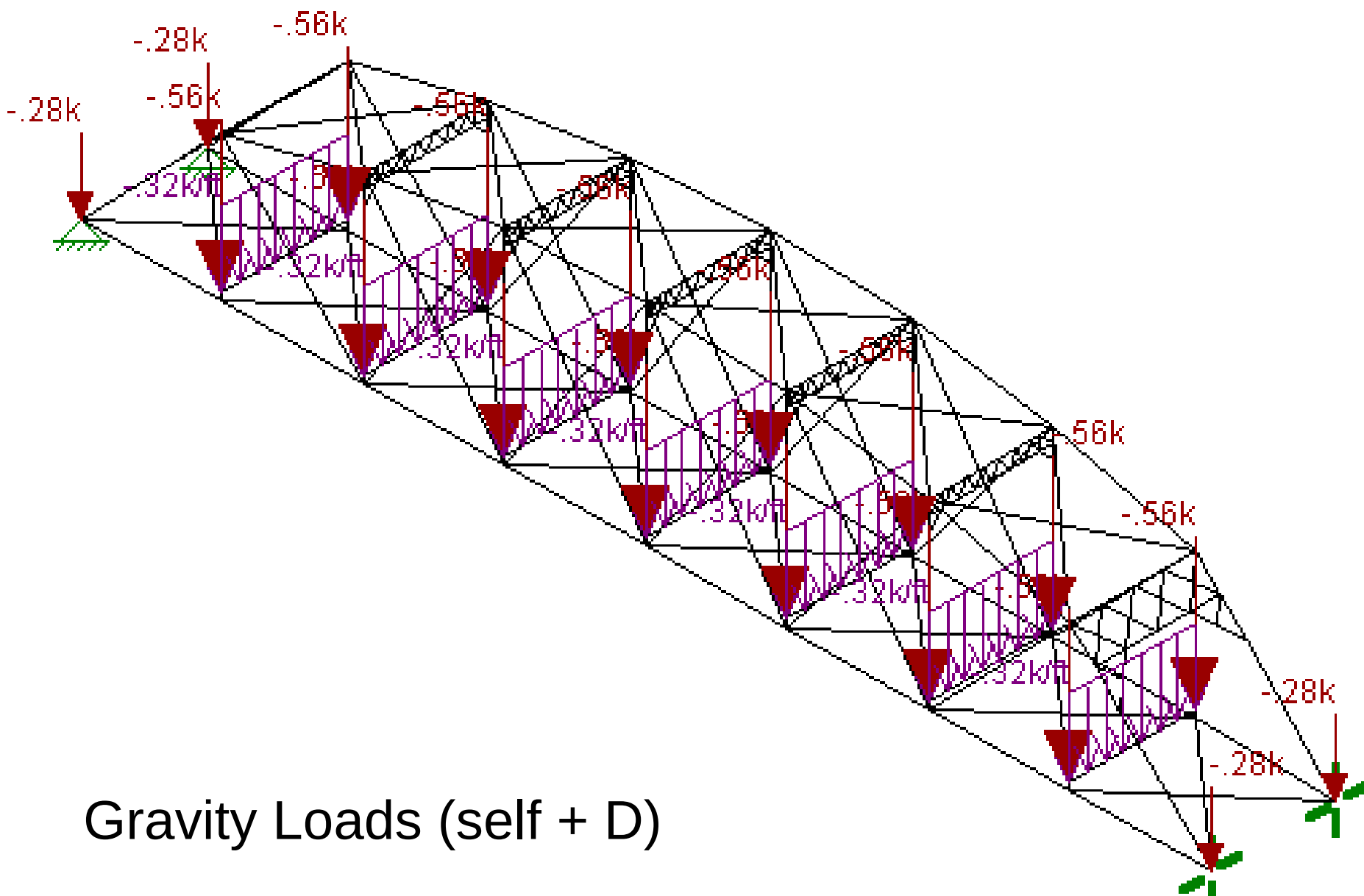
Early 20th Century designers used 30 to 40 psf

Applied to both windward and leeward members



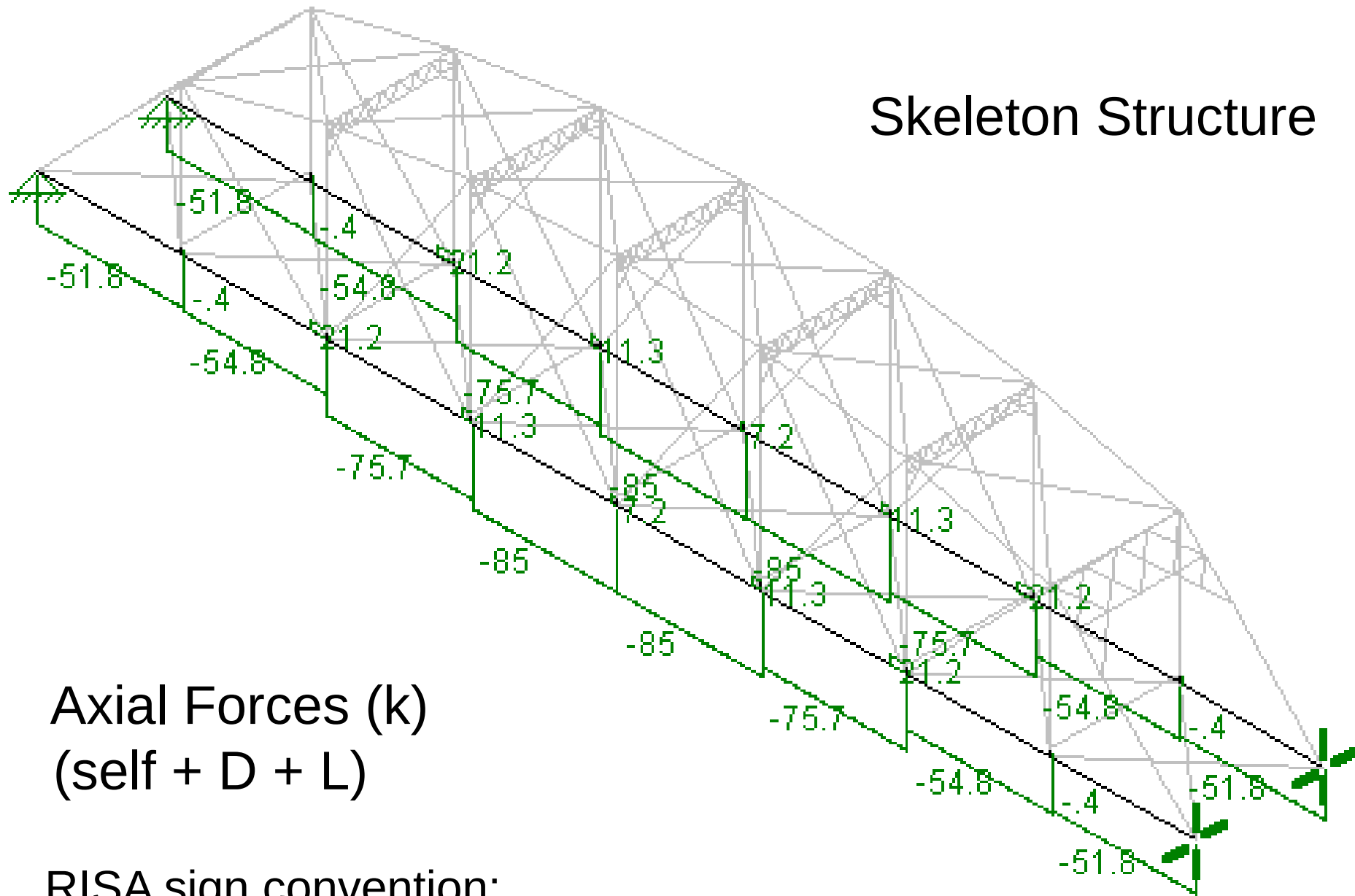
MODELING & ANALYSIS





Gravity Loads (self + D)

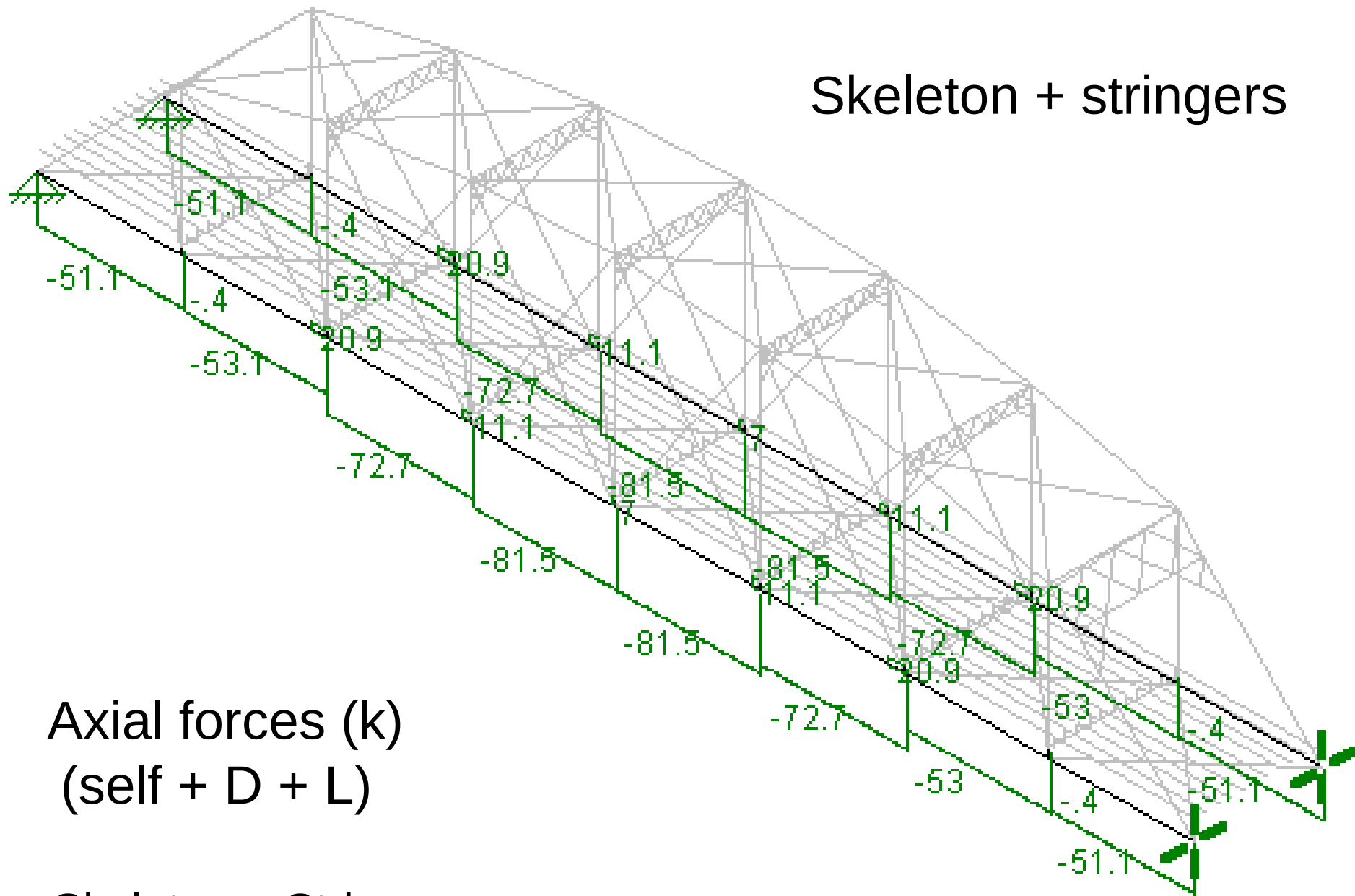
Skeleton Structure



Axial Forces (k)
(self + D + L)

RISA sign convention:
- = tension
+ = compression

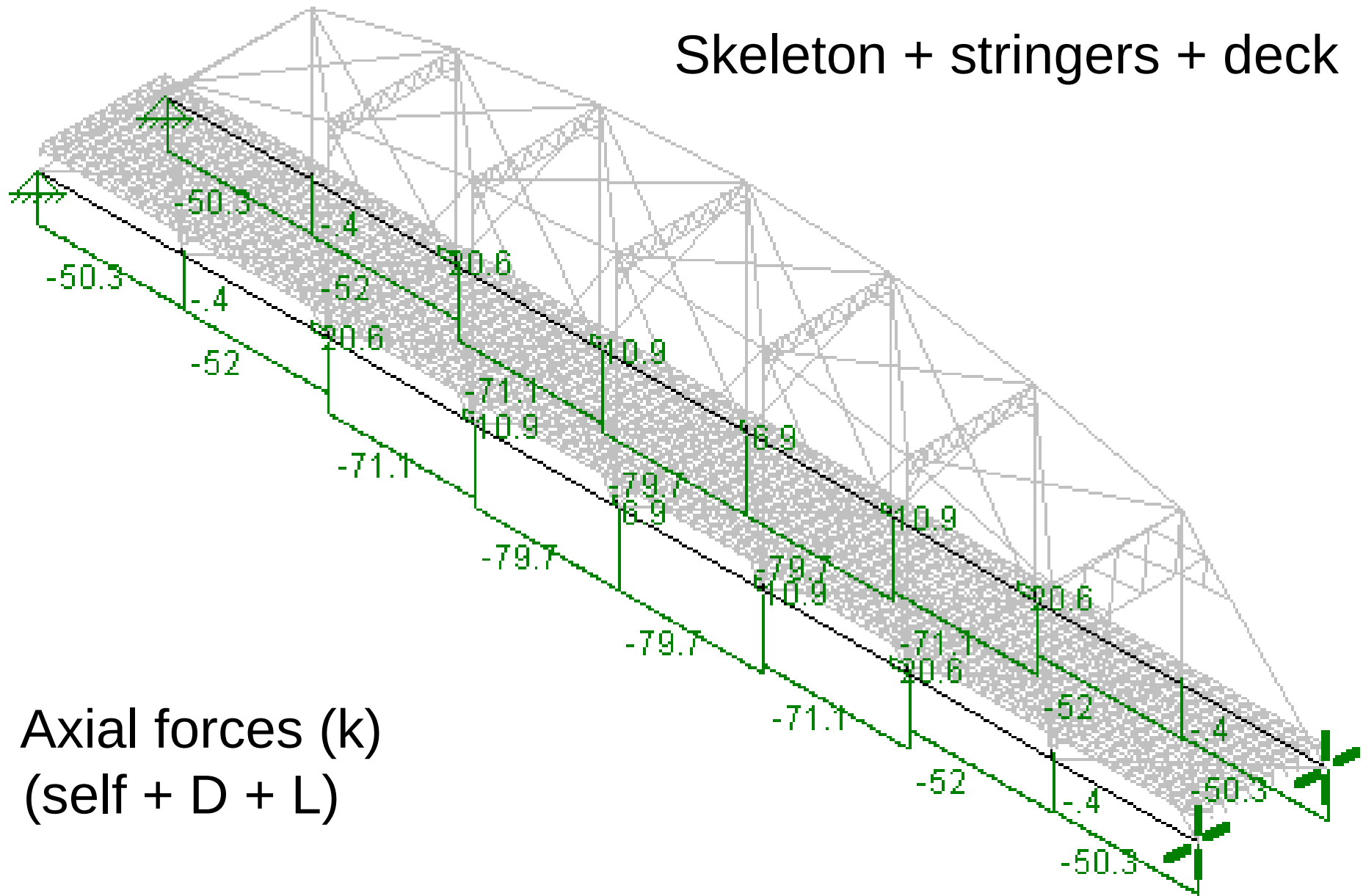
Skeleton + stringers



Axial forces (k)
(self + D + L)

Skeleton + Stringers

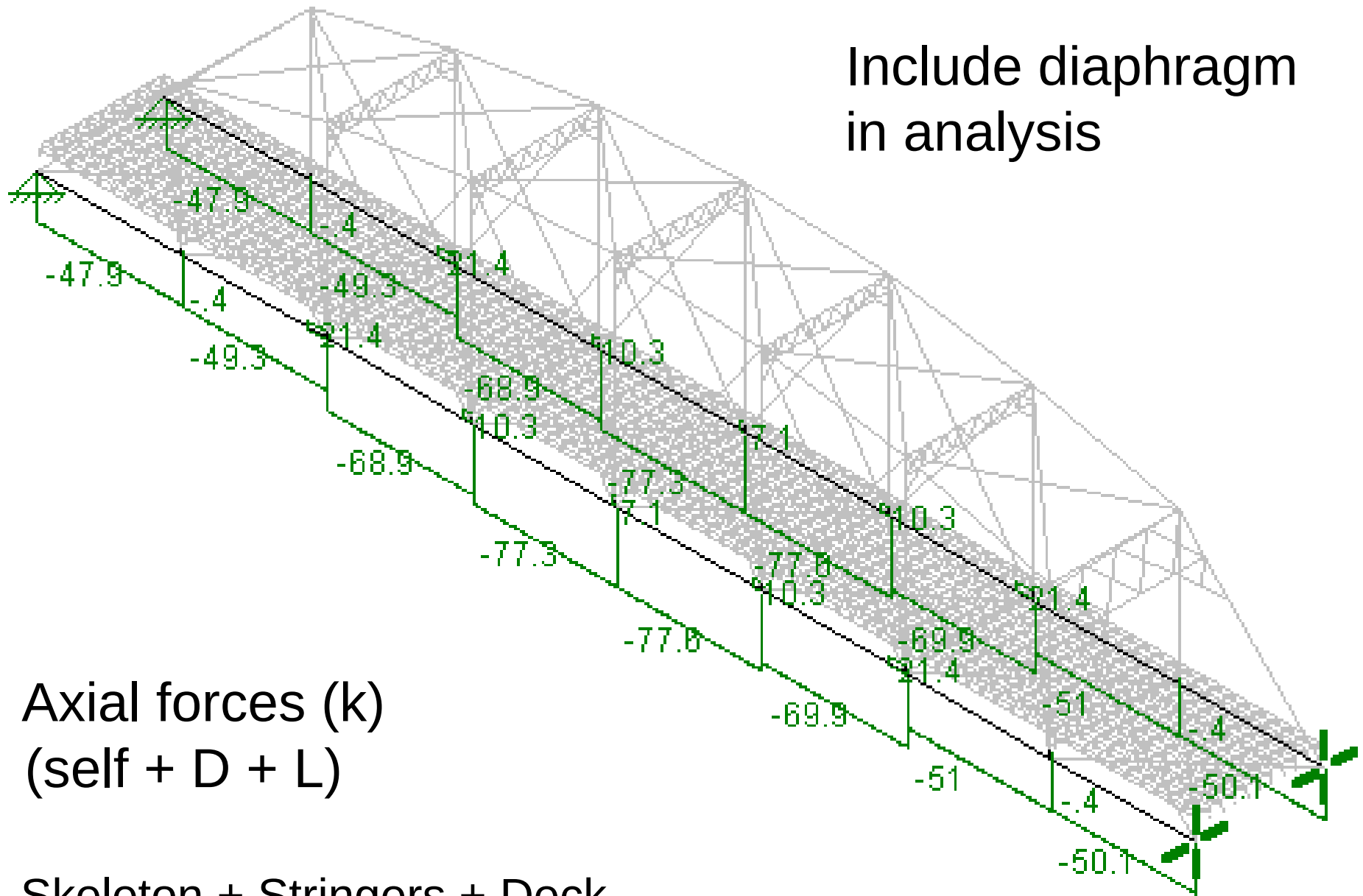
Skeleton + stringers + deck



Axial forces (k)
(self + D + L)

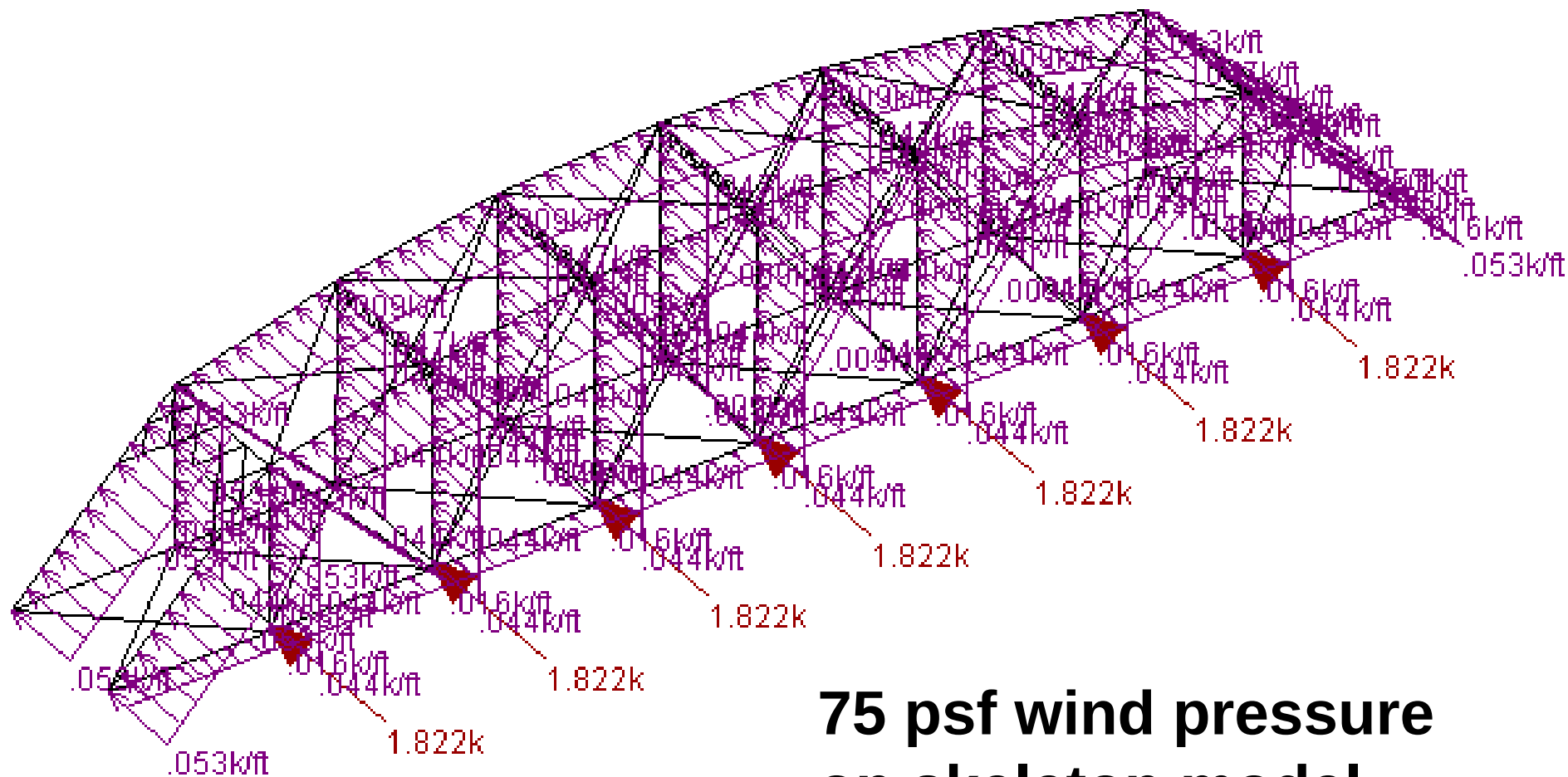
Skeleton + Stringers + Deck

Include diaphragm
in analysis

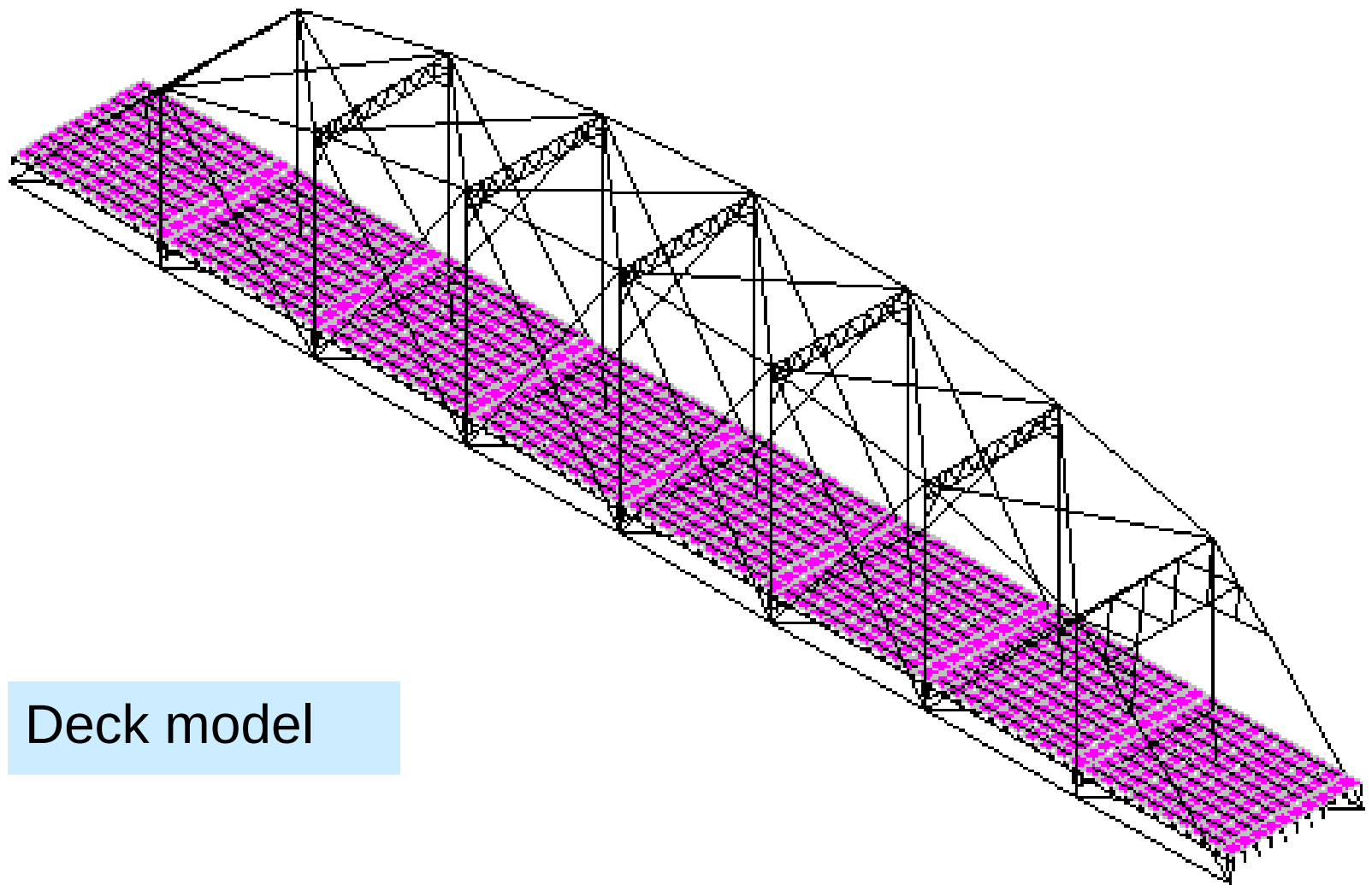


Axial forces (k)
(self + D + L)

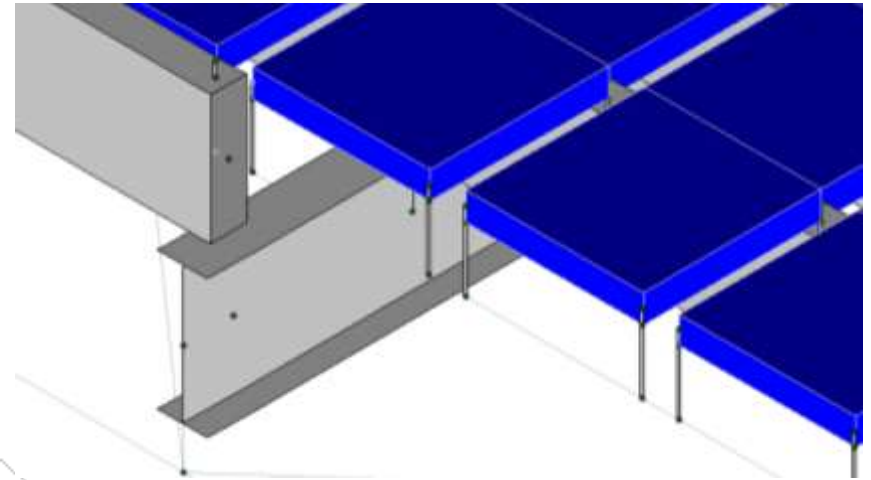
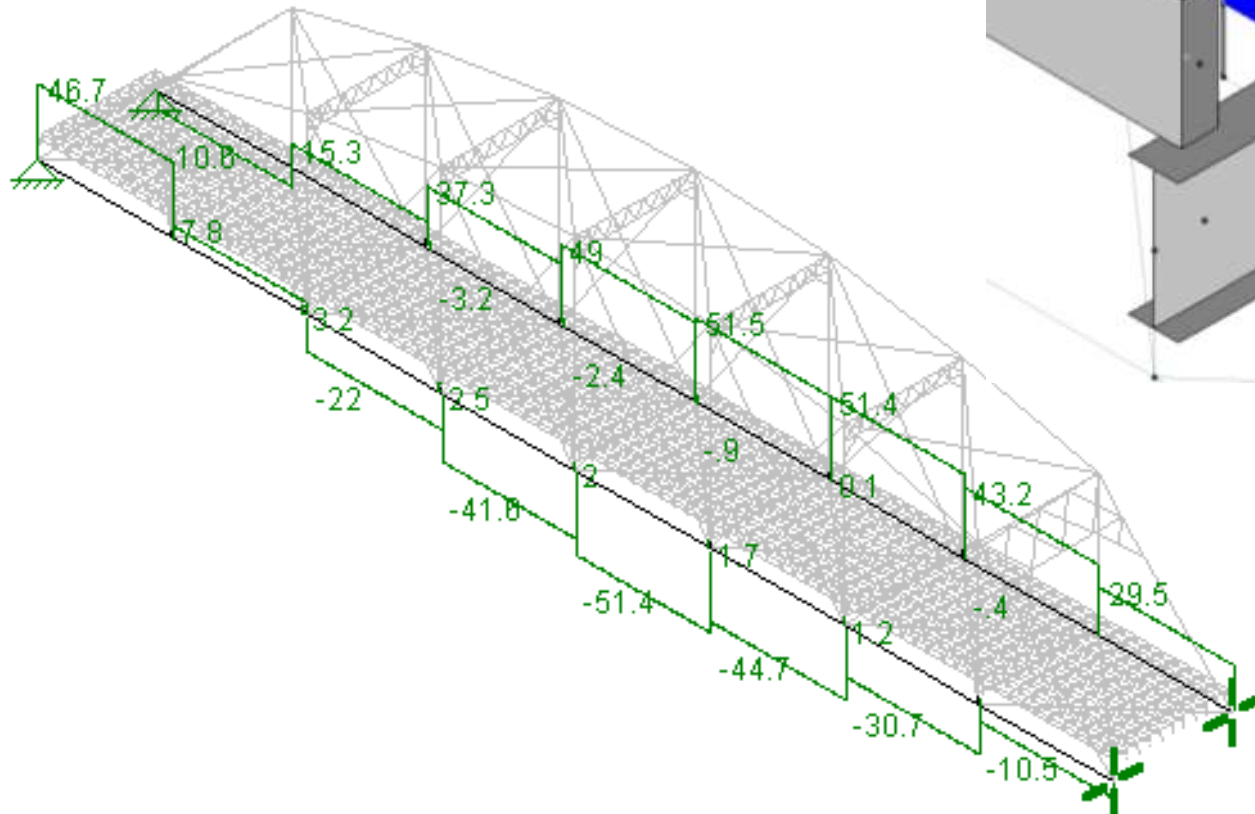
Skeleton + Stringers + Deck
+ Diaphragm



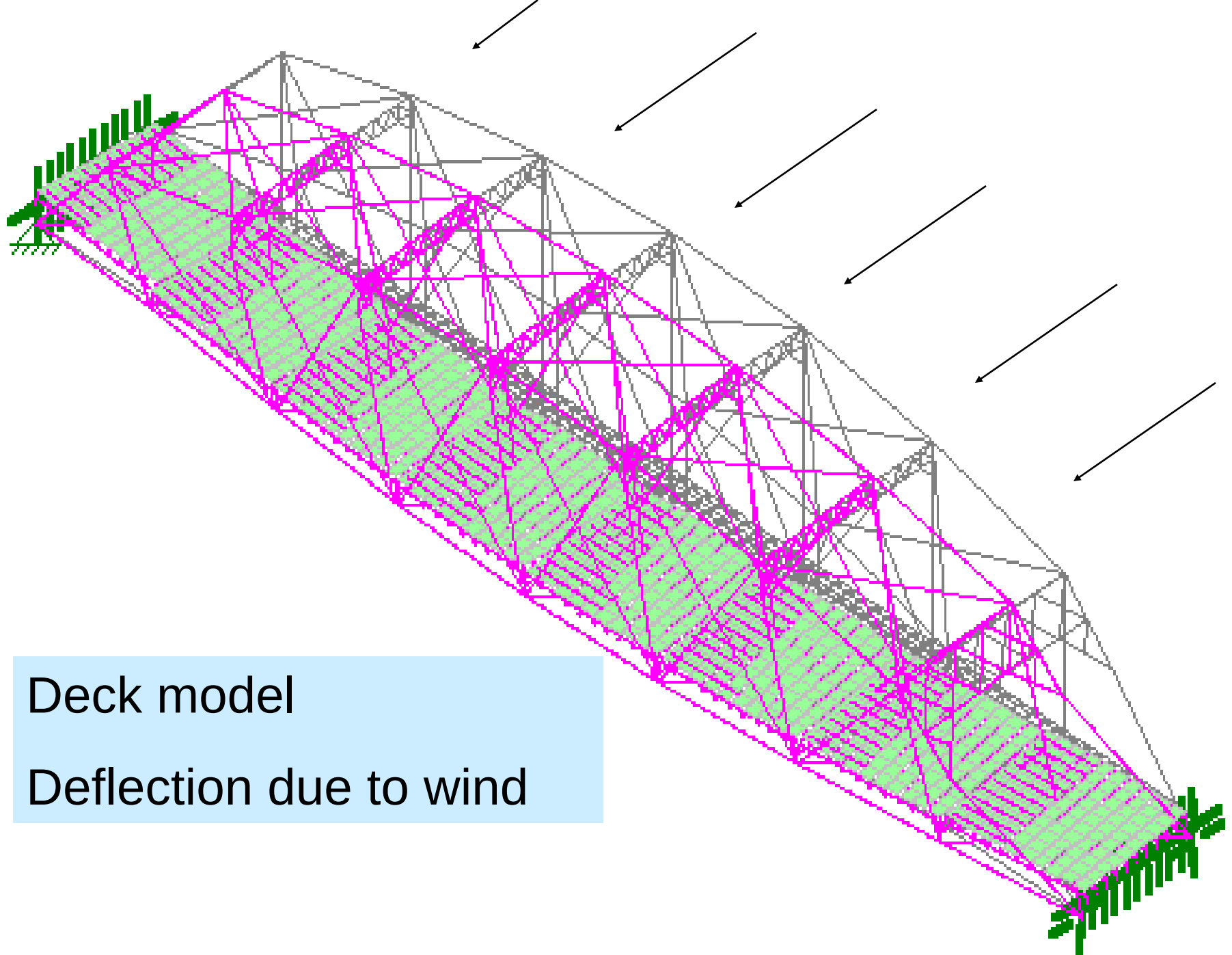
**75 psf wind pressure
on skeleton model**



Deck model

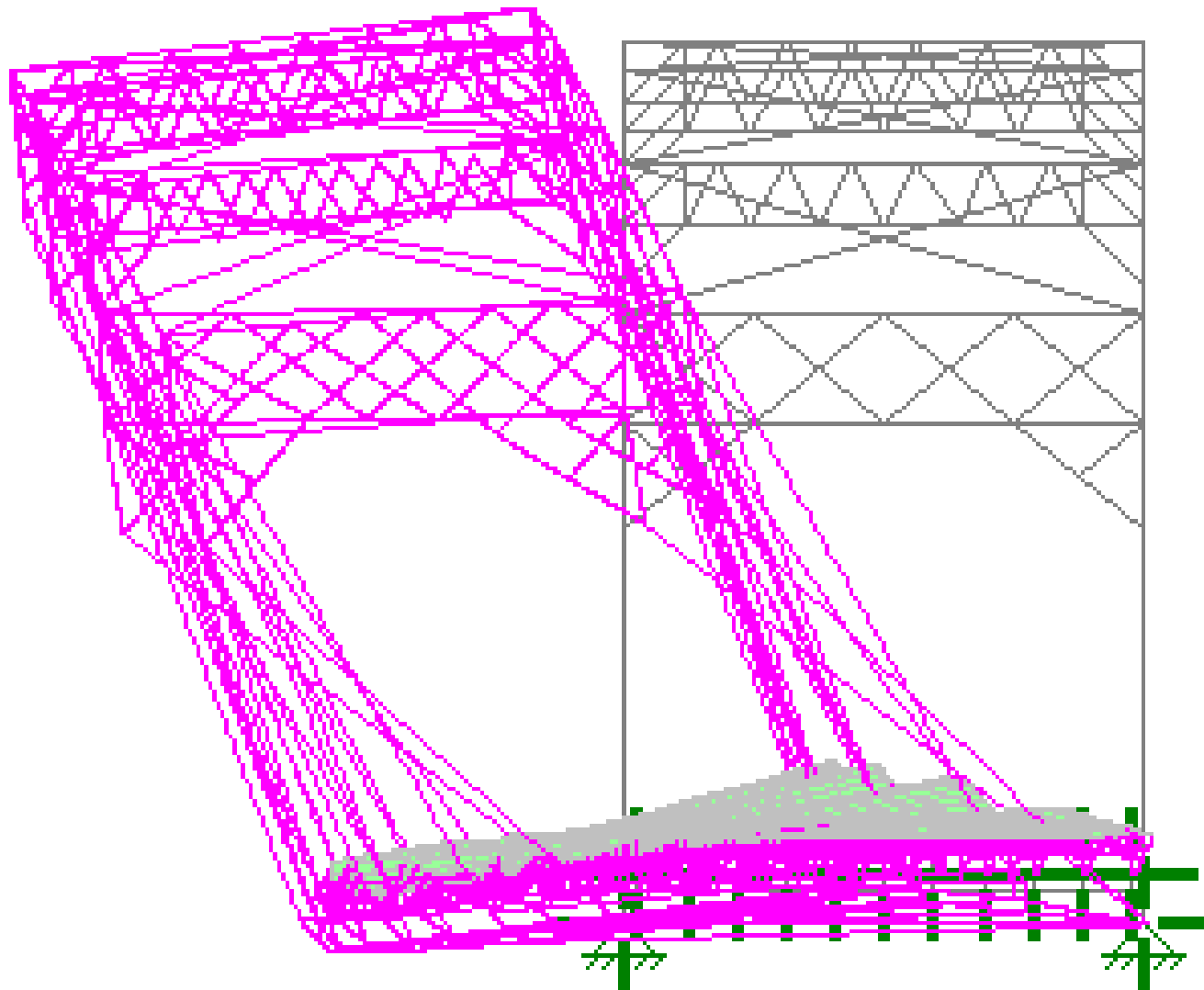


Deck model

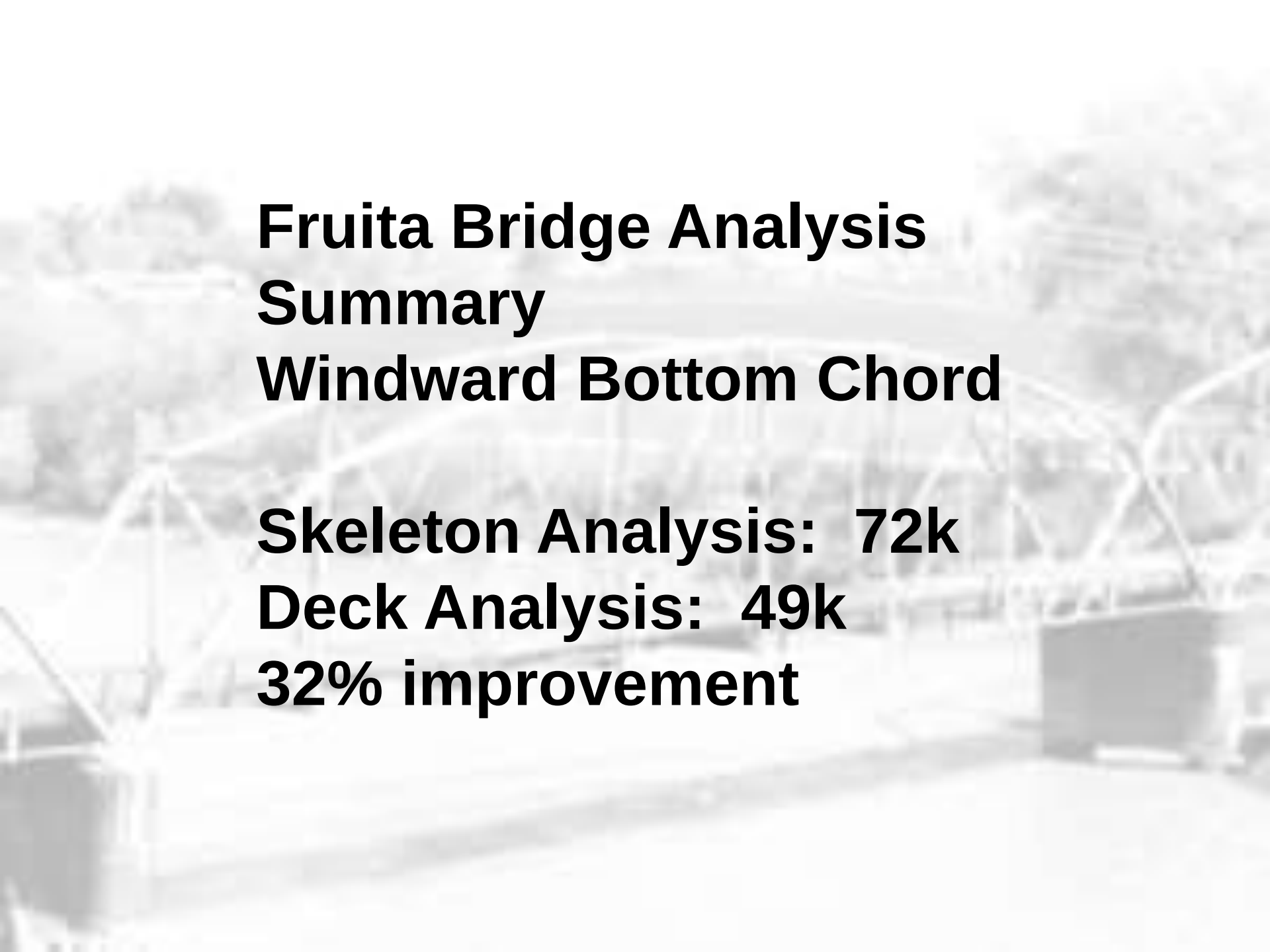


Deck model

Deflection due to wind



Deck model
Deflection due to wind

A grayscale photograph of the Fruita Bridge, a large steel truss bridge spanning a river. The bridge's intricate steel framework is visible, with multiple trusses supporting the deck. The river flows beneath the bridge, and the surrounding landscape includes trees and a small building on the right bank.

Fruita Bridge Analysis Summary Windward Bottom Chord

**Skeleton Analysis: 72k
Deck Analysis: 49k
32% improvement**

Field Testing

A large, arched, open-frame structure, possibly a greenhouse or tunnel, is set up in an outdoor field. The structure is made of metal poles and plastic or fabric covering. It is surrounded by trees and a grassy area. The text "Field Testing" is overlaid in the center.

Fruita Bridge Fruita, CO

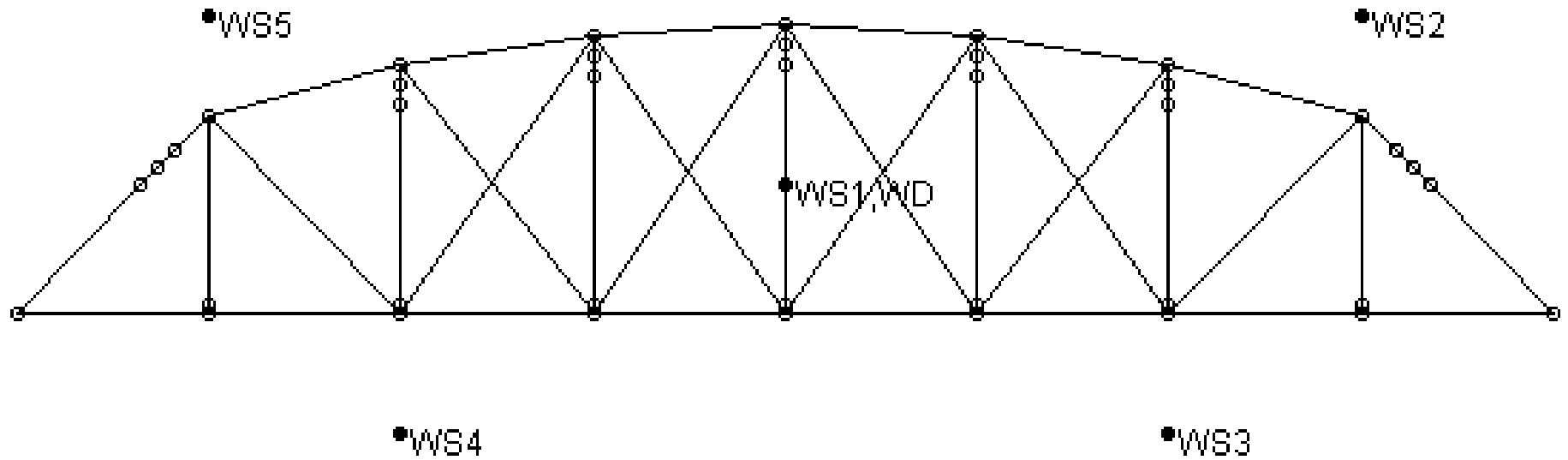
1907



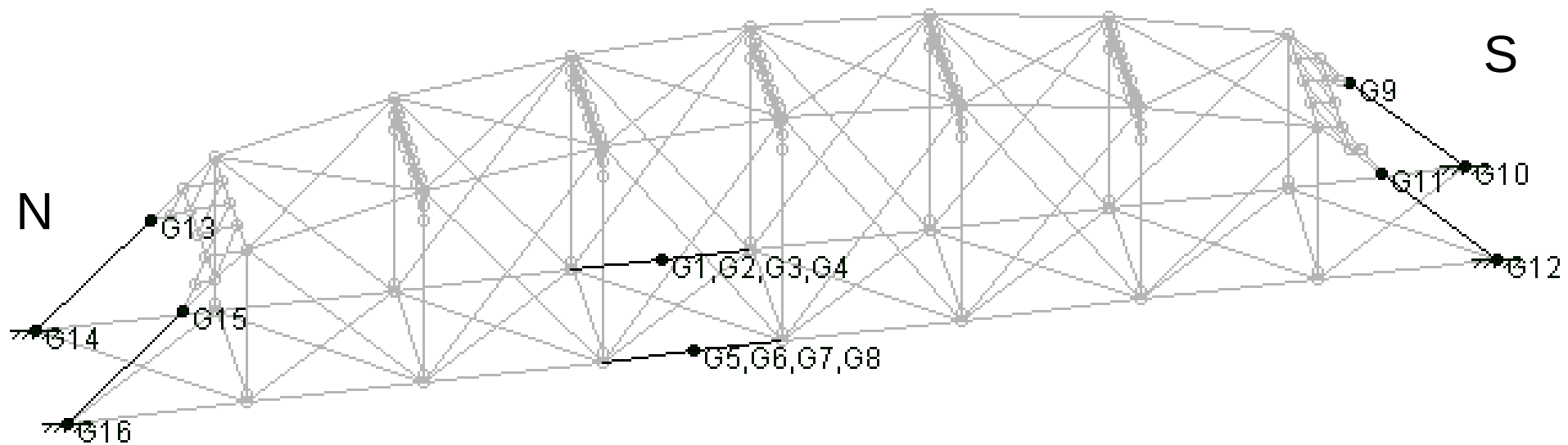
Fruita Bridge Deck



Fruita Bridge Underside



Locations:
Anemometer and wind direction sensor



Strain transducer locations

Wind Direction Vane & Anemometer



Anemometer and Wind Speed Sensor



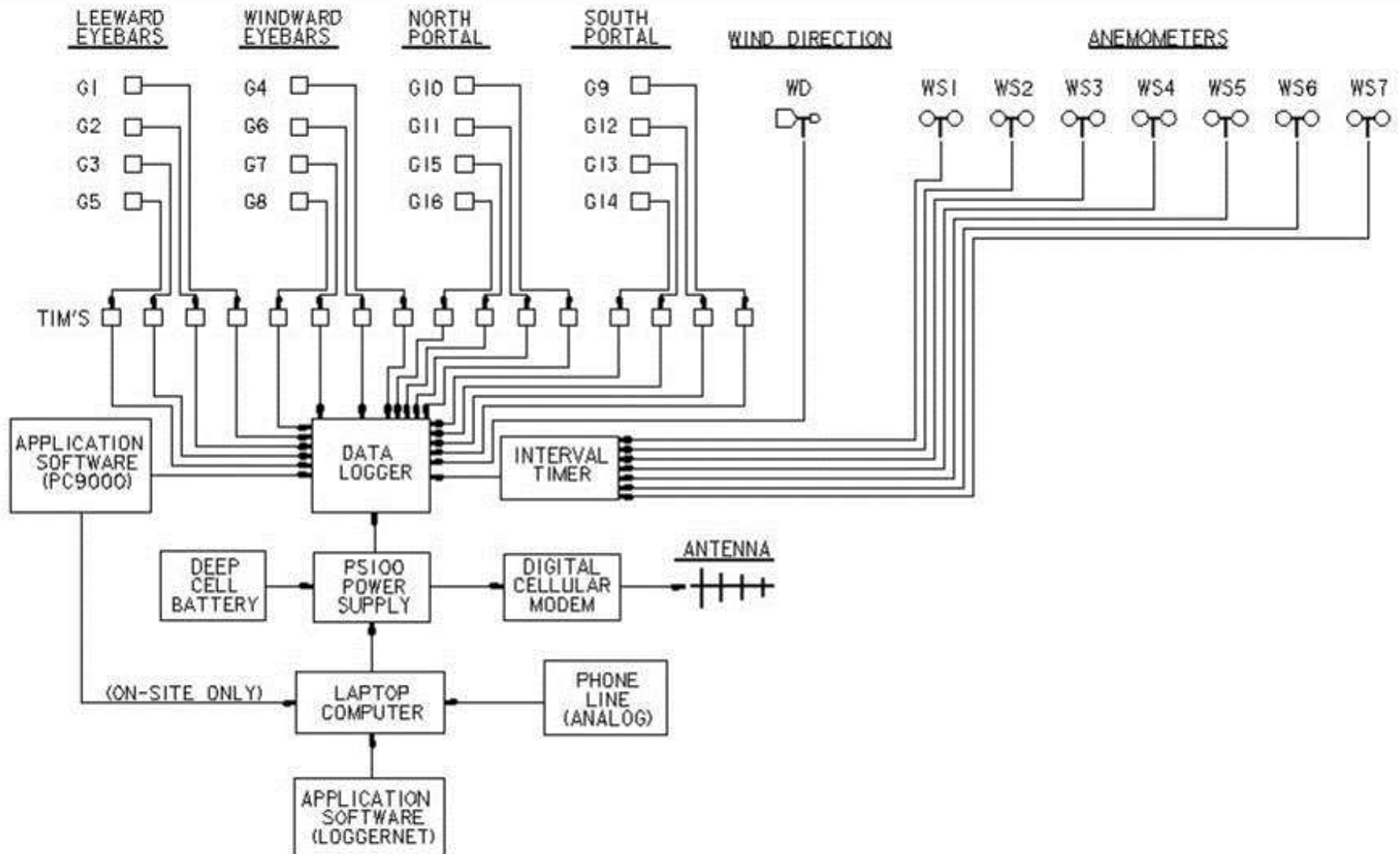
Clamp-on Strain Transducer



Strain Transducers



Field Instrumentation System



Data Logger – CR5000

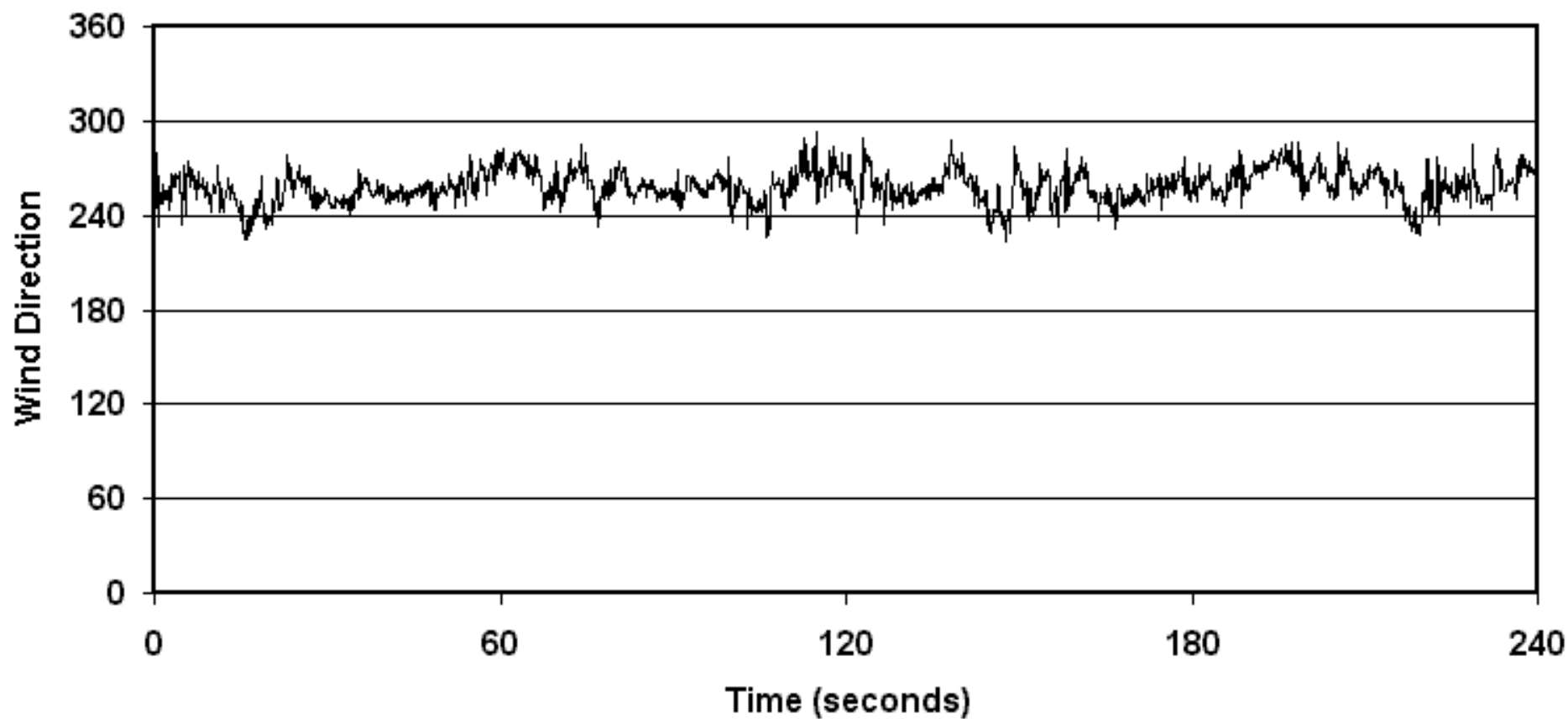






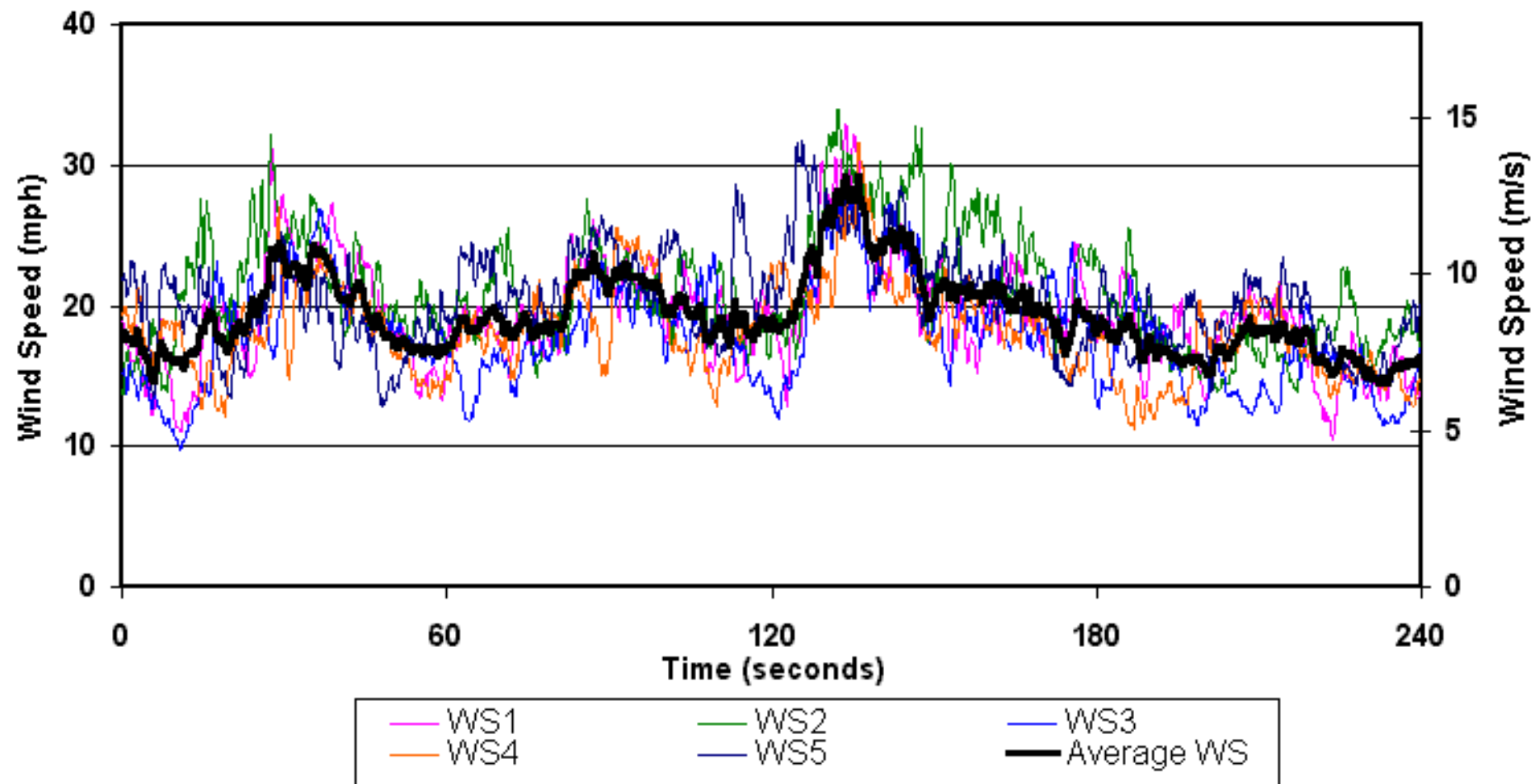


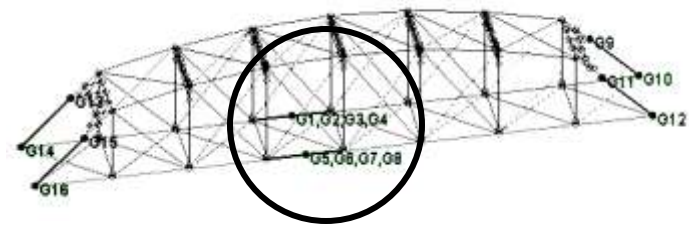
WIND DIRECTION
Fruita Bridge 4/26/04



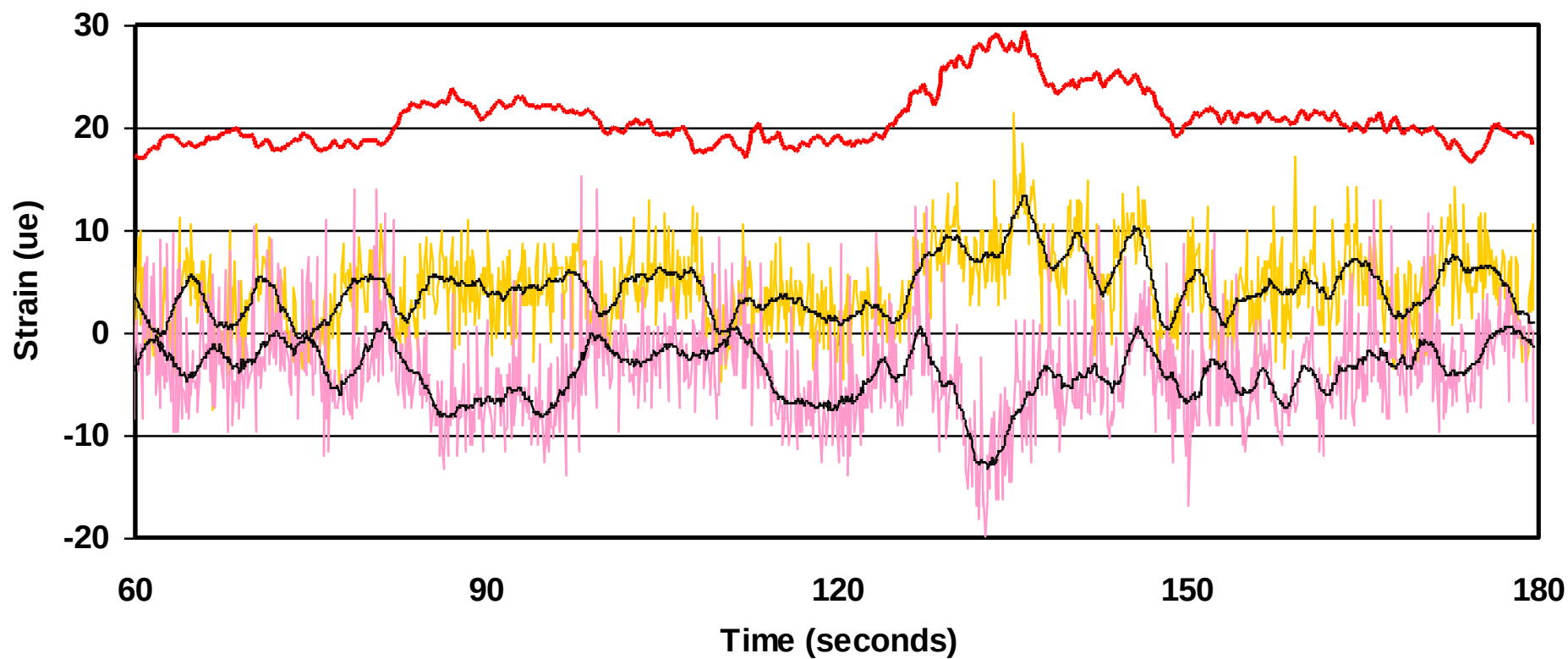


WIND SPEED
Fruita Bridge 4/26/04

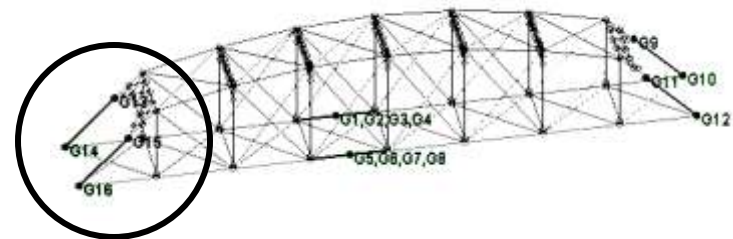
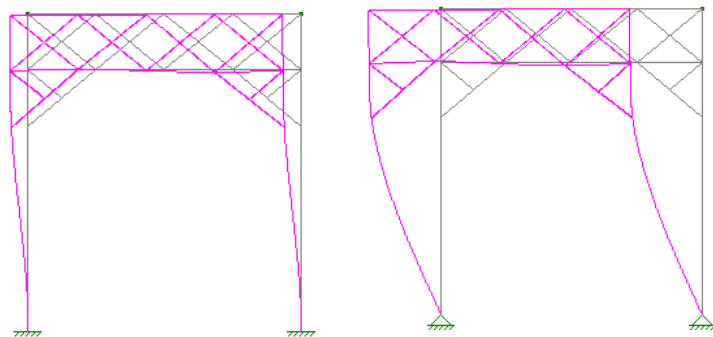




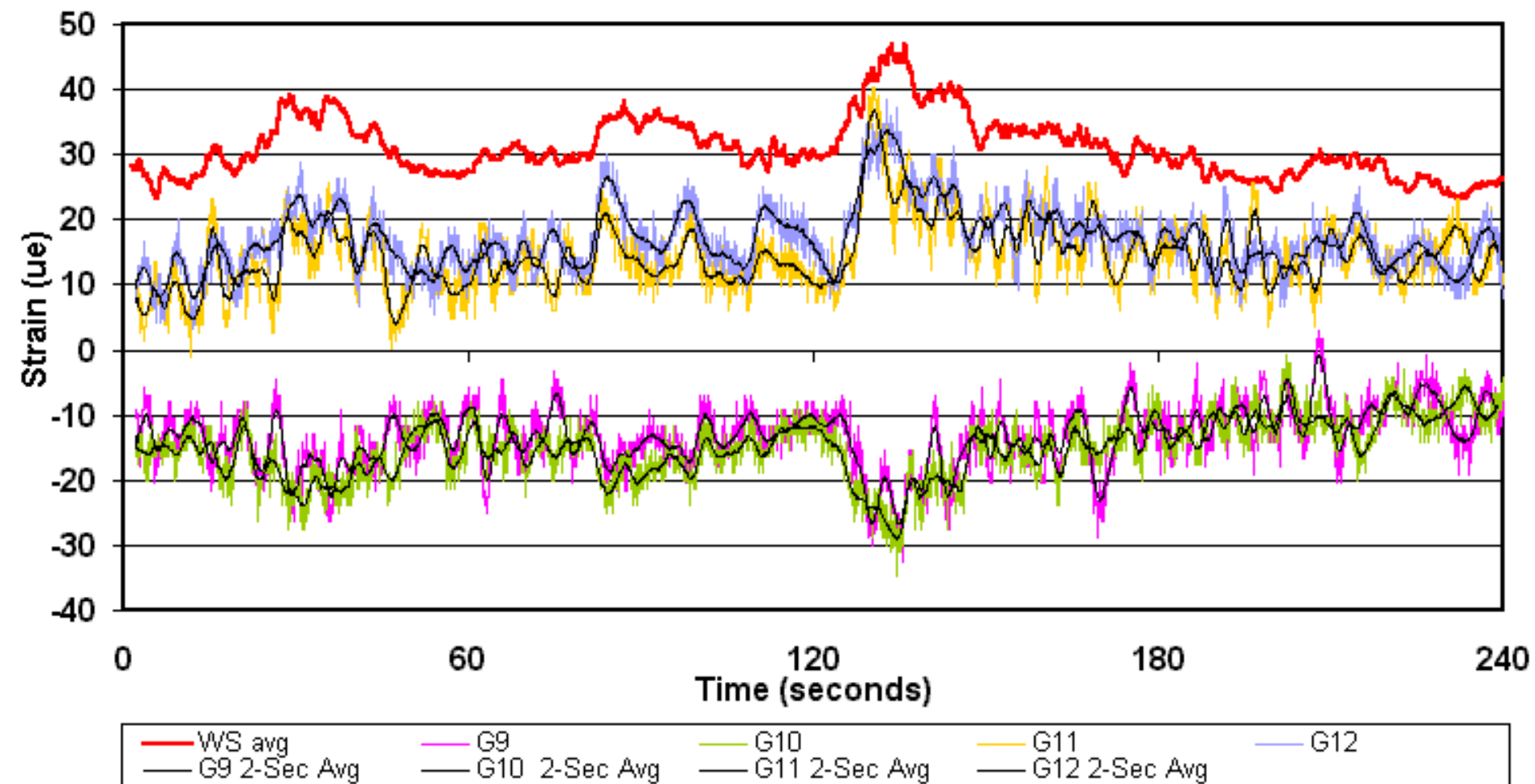
BOTTOM CHORDS **Fruita Bridge 4/26/04**



— WS avg — Leeward Strain — Windward Strain — Leeward - filtered — Windward - filtered

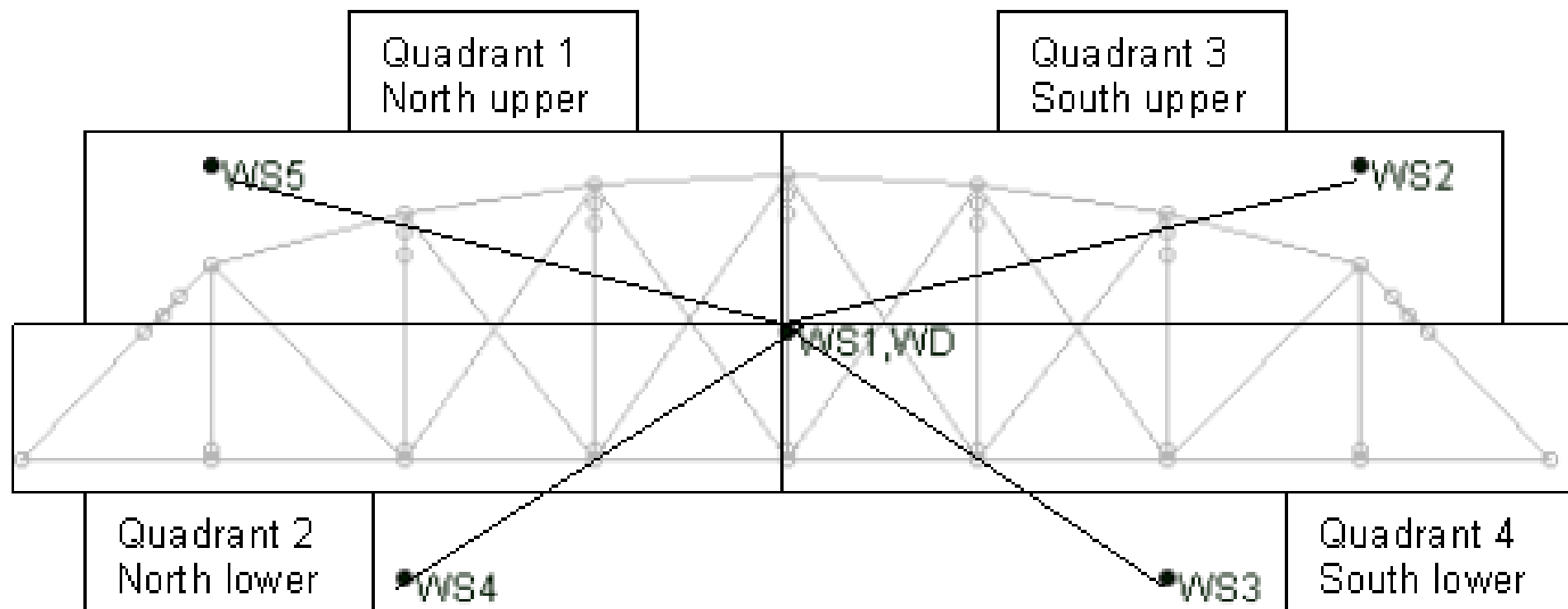


SOUTH PORTAL
Fruita Bridge 4/26/04

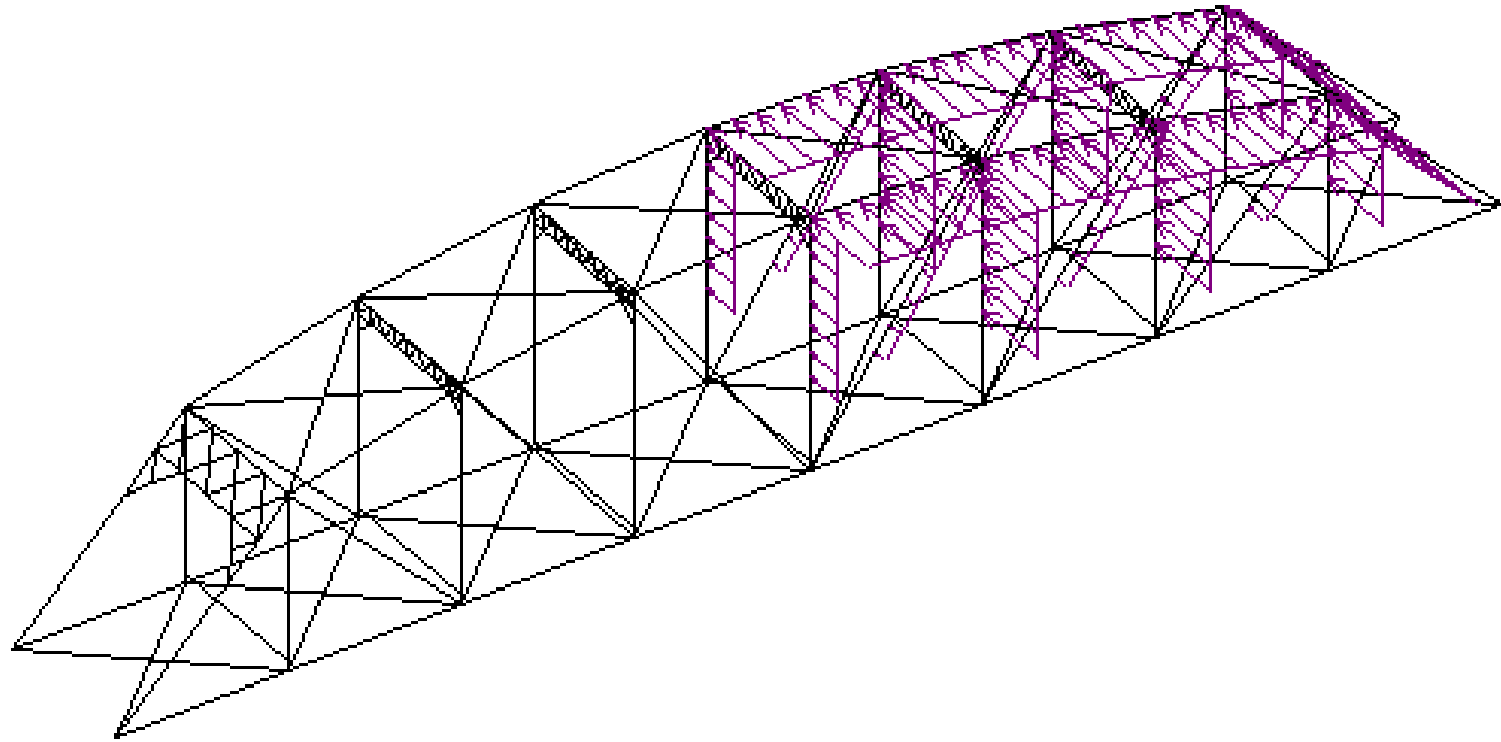


Discussion





Wind Pressure by Quadrants



Wind pressure applied to upper south quadrant

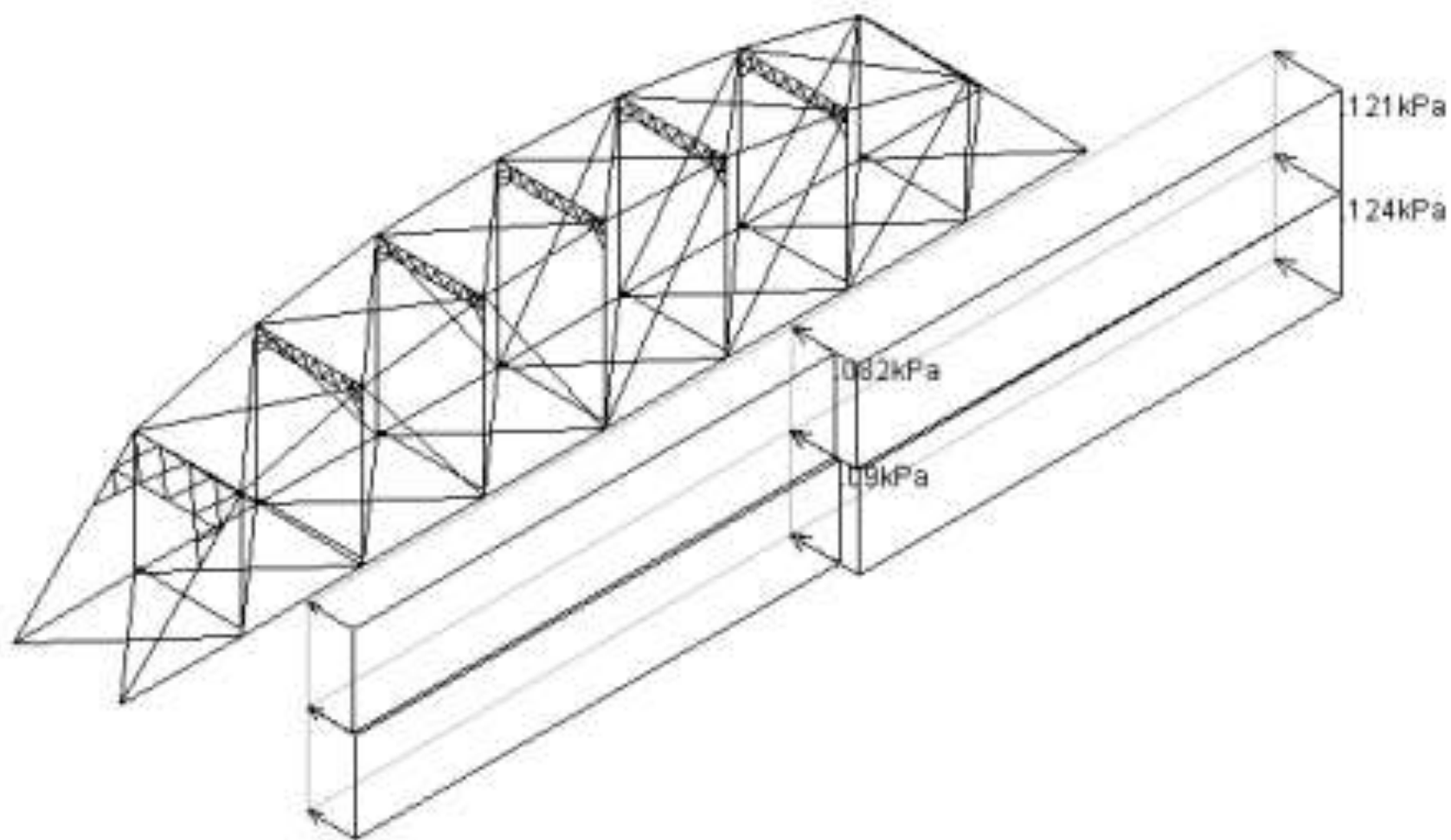
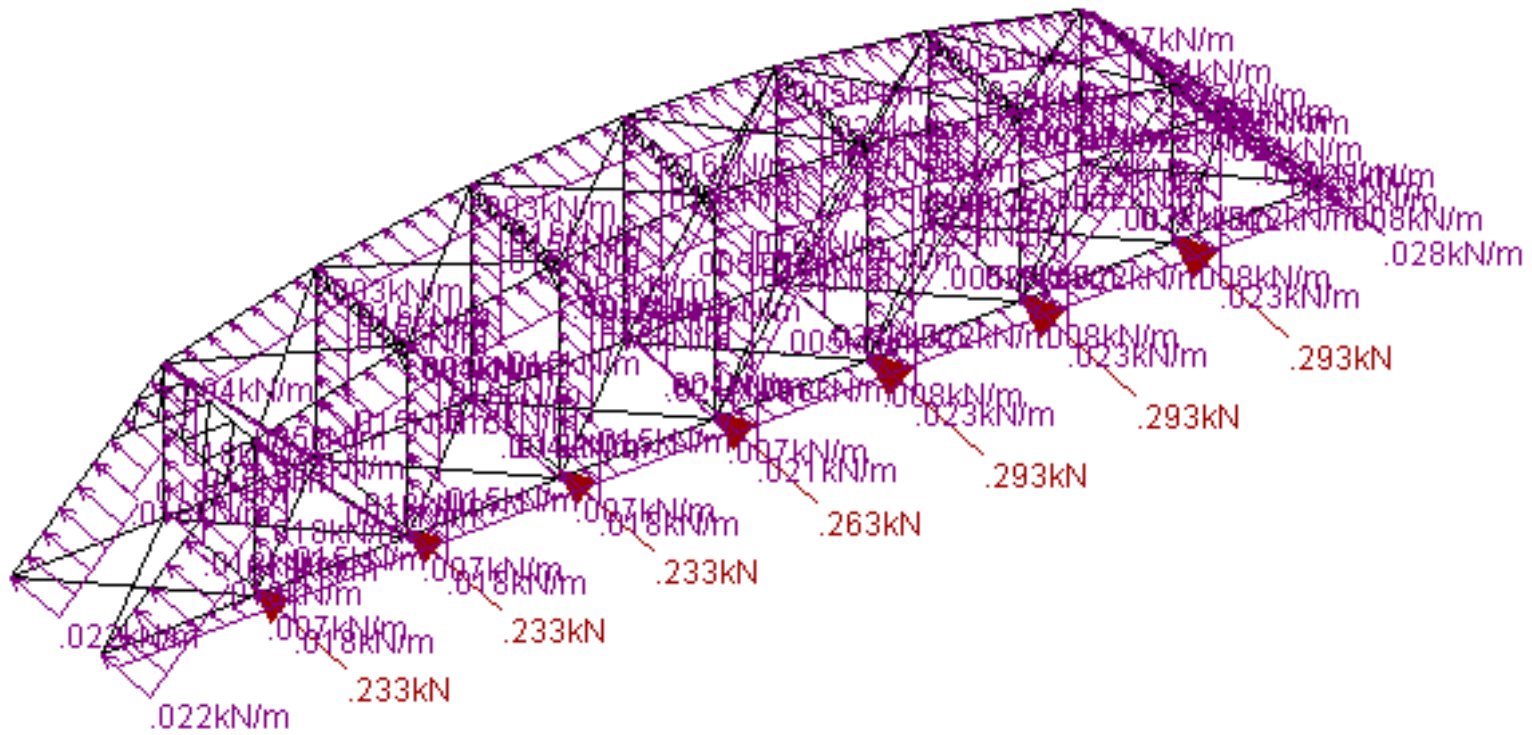
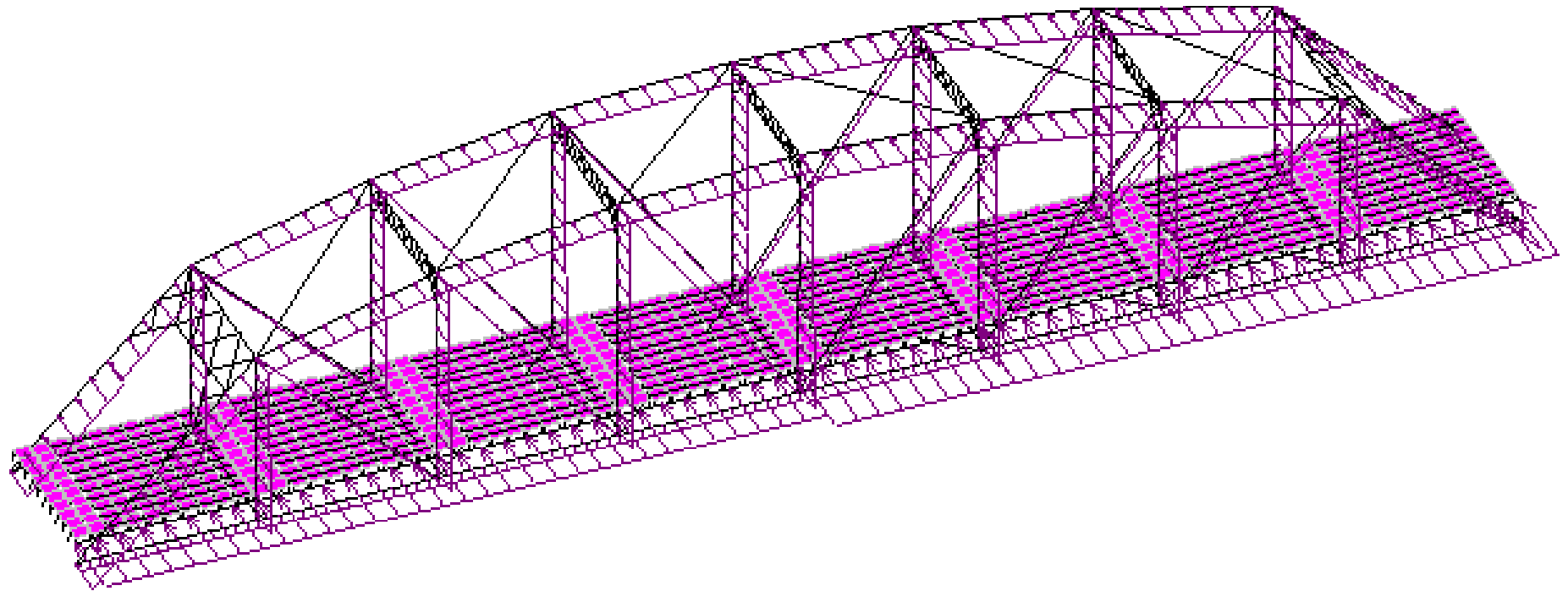


Figure 9.6. Wind pressure applied to the four quadrants for analysis. North is to the left.



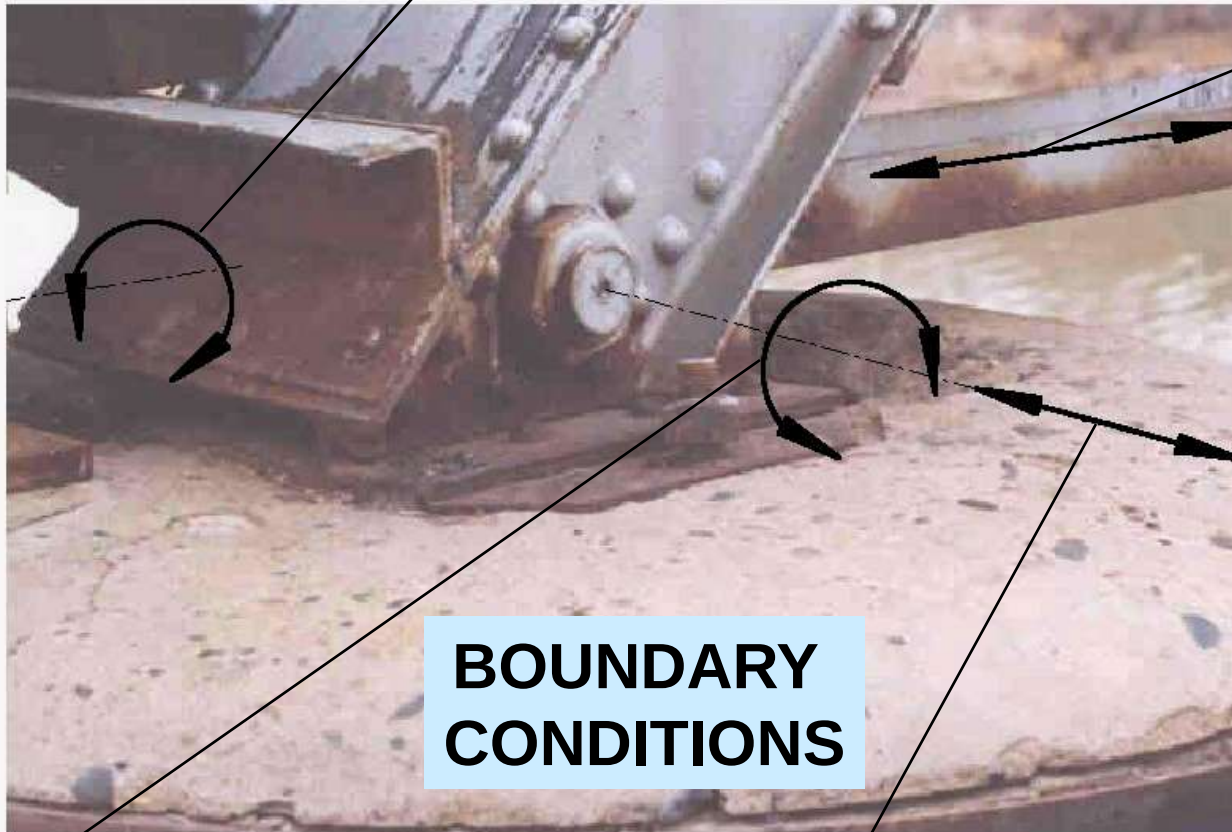
- Wind pressure applied to all quadrants
- Skeleton model



- Wind pressure applied to all quadrants
- Deck model

**Restrained rotation
about axis of bottom
chord**

**Translation in direction of
bottom chord released for
roller; restrained for anchor**



**Rotation about pin
released**

**Translation
restrained**



Fruita Bridge Verification Summary

Comparison of total calculated forces to total measured forces

Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-1.37 kN (-0.31 kips)	-1.44 kN (-0.32 kips)	5% (Excellent)
Leeward Bottom Chord	2.09 kN (0.46 kips)	2.95 kN (0.66 kips)	41% (Good)

RESULTS

- **Excellent correlations for the windward bottom chord.**
- **Good correlations in the leeward bottom chords.**
- **Altered boundary conditions:**
 - **Dirt, rusted rollers.**
 - **Limit rotation/ partial fixity.**



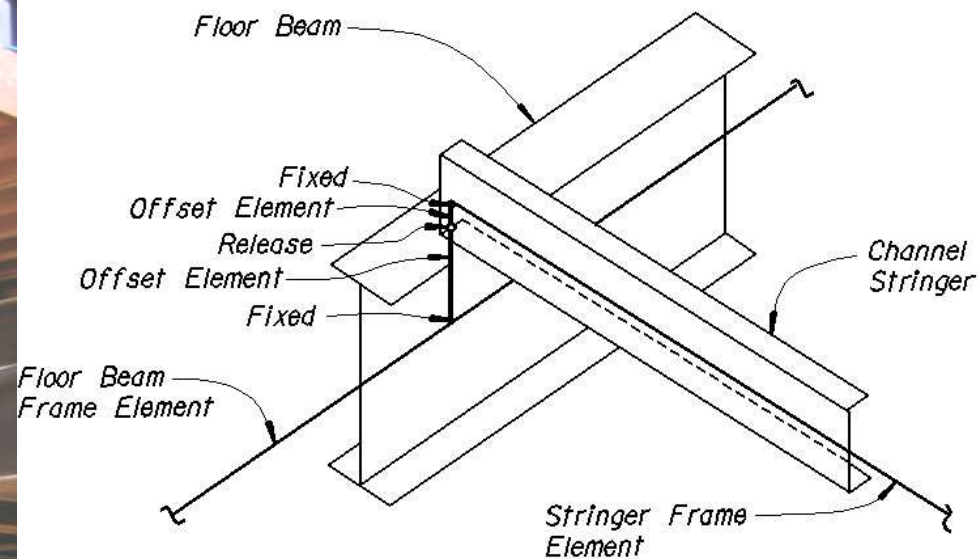
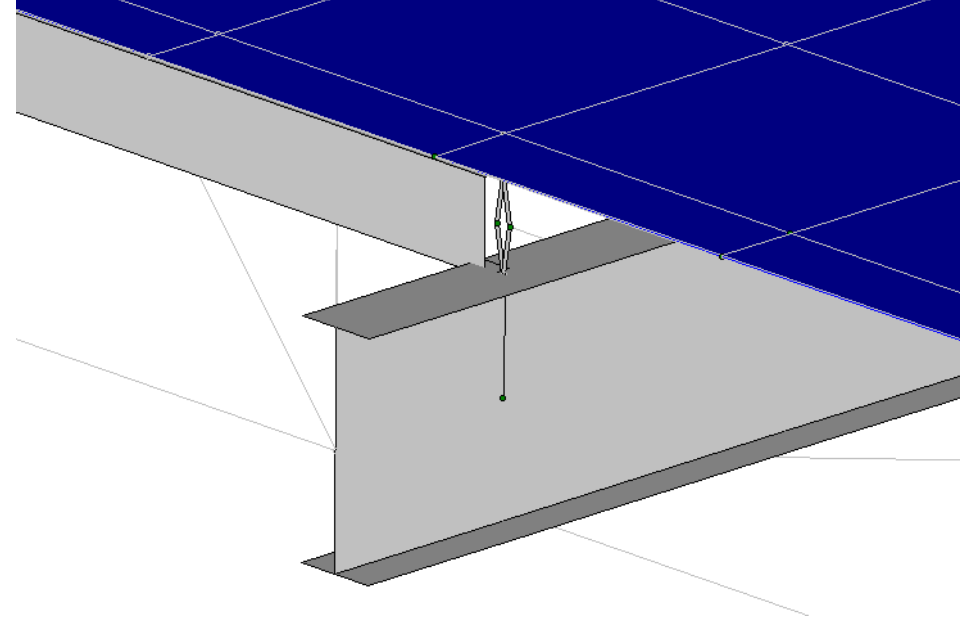
★
UCD





**Prowers Bridge
Bent County, CO**

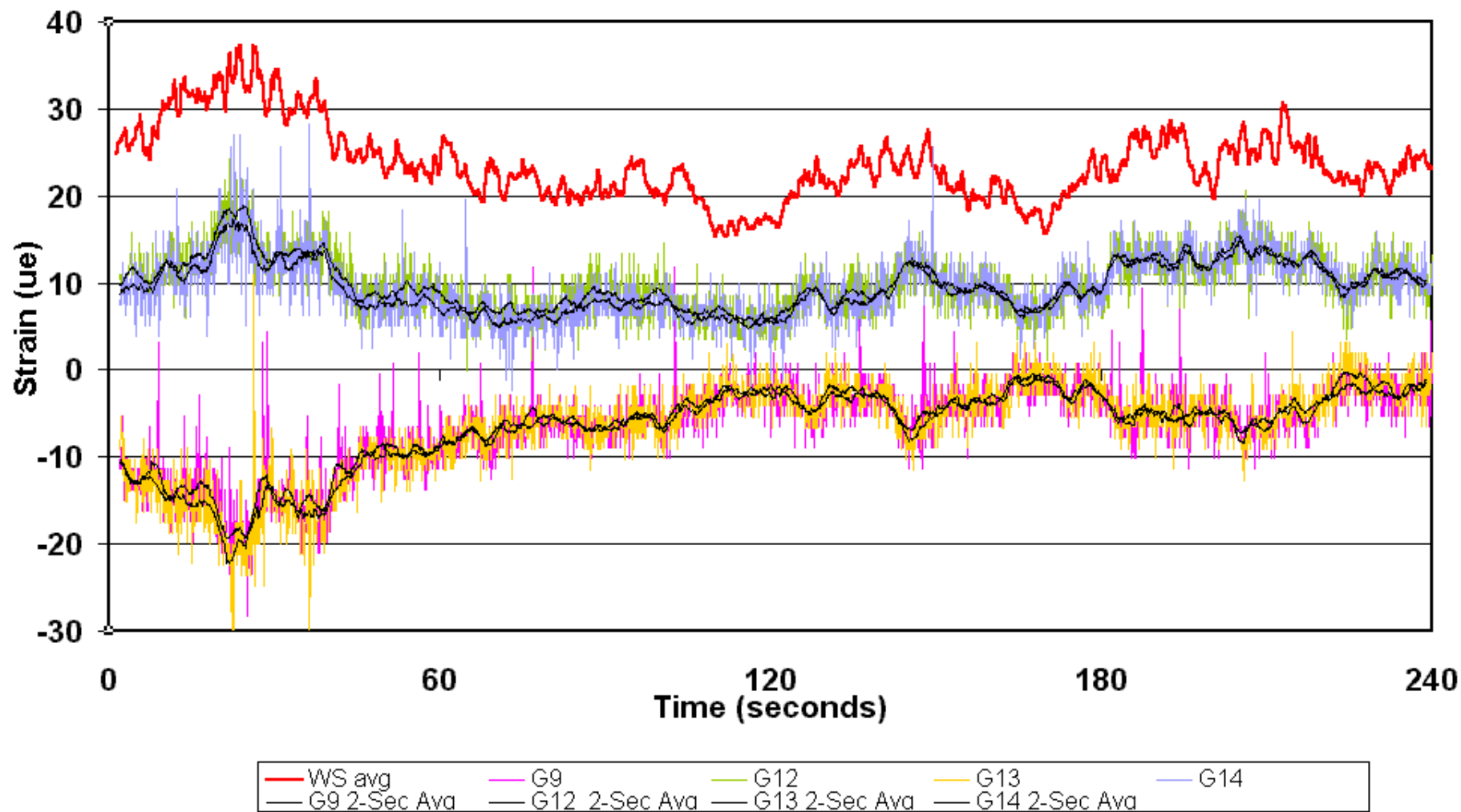
1909

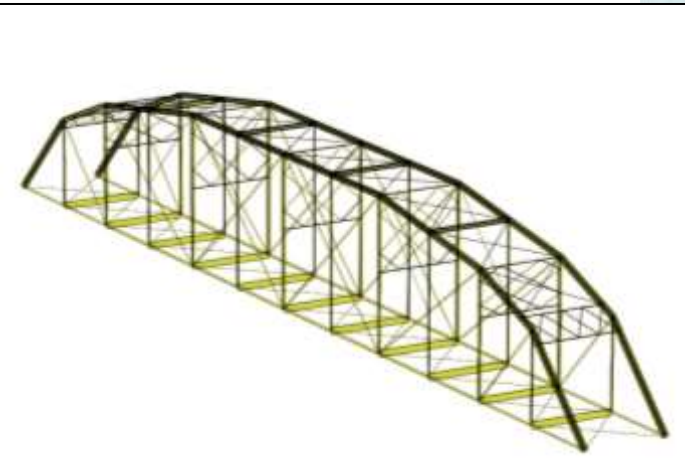


Prowers Bridge: Deck modeling considerations



SOUTH PORTAL
Prowers Bridge **04/04/05**



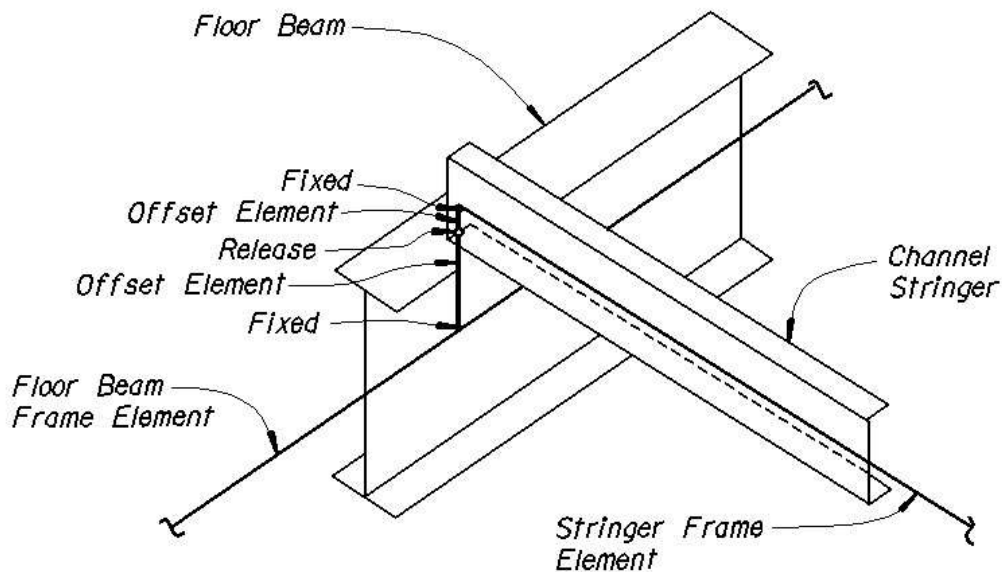


**Rifle Bridge
Rifle, Colorado**

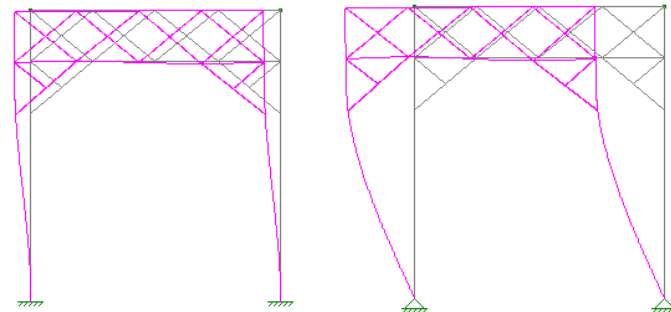


DECK TYPE- PROWERS AND RIFLE BRIDGES

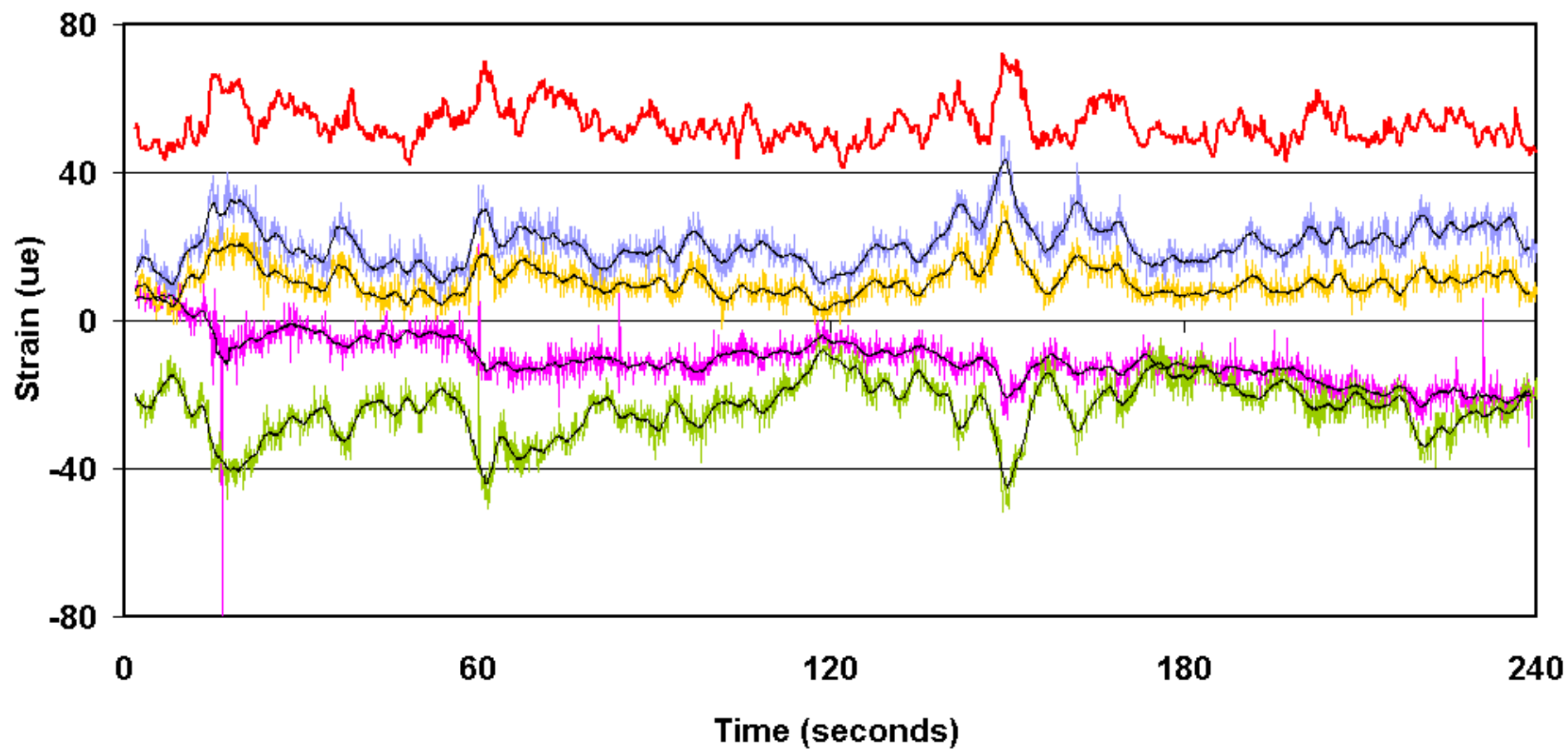
**Asphalt pavement
on corrugated metal deck
over steel stringers**



**Asphalt pavement
only used in model if
in decent condition**



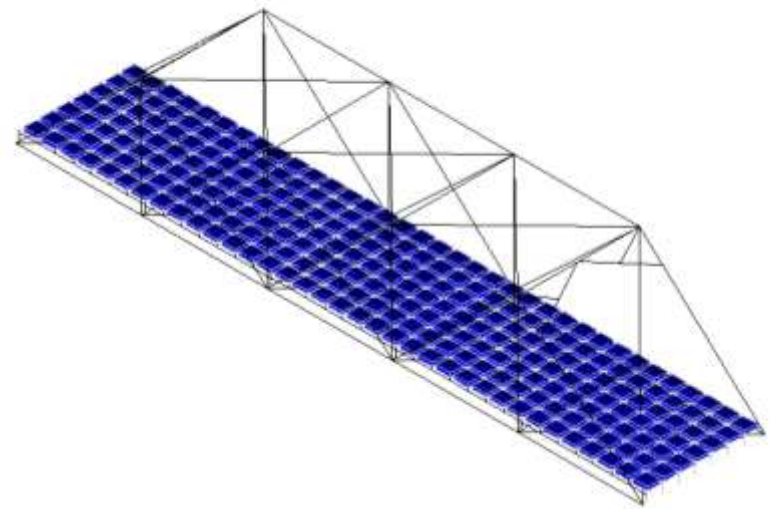
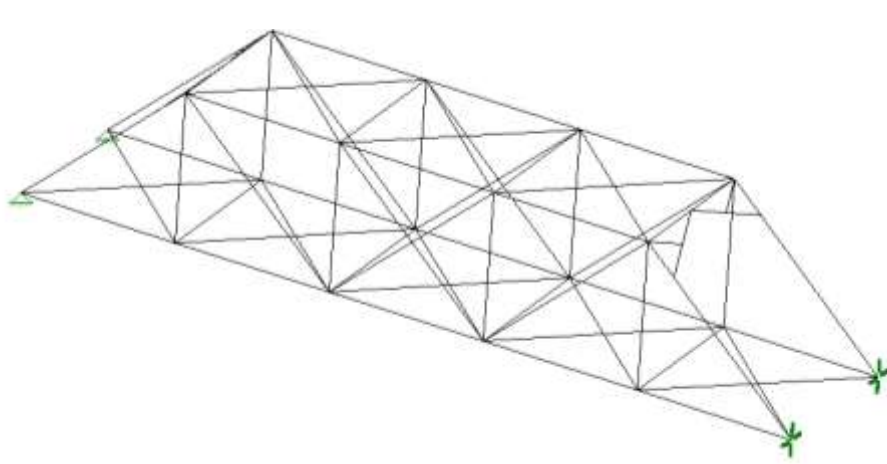
NORTH PORTAL
Rifle Bridge **7/03/05**



Rifle Bridge Findings

- **Non-symmetry in the structure:**
 - Outboard sidewalk (leeward side).
- **Disconnected connection:**
 - Skelton assumed connected.
 - Verification deck modeled it removed.
- **Bearing conditions could not be verified.**





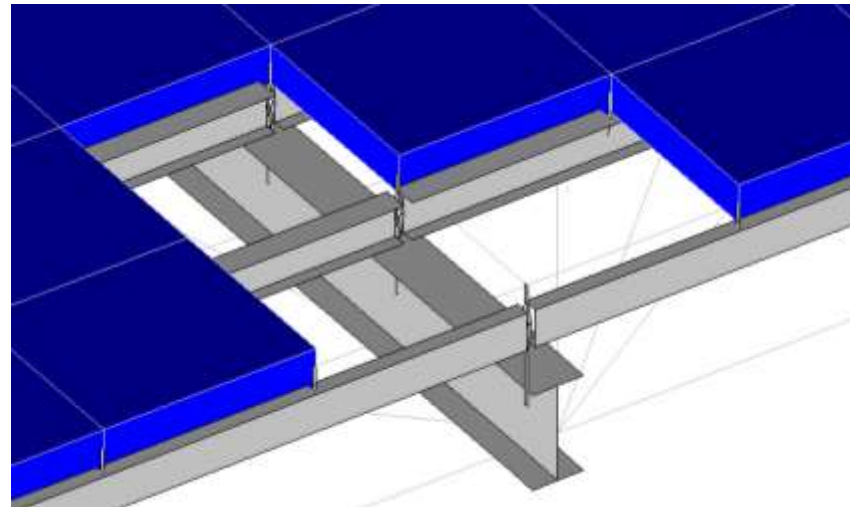
Blue River Bridge, Summit County, Colorado

DECK TYPE – BLUE RIVER BRIDGE

**Running boards over
wood deck on steel stringers**

**Orthogonal deck timbers were
well spiked together,
providing a stiffer deck than
the Fruita Bridge**

**Modeled as plate elements
with single properties**





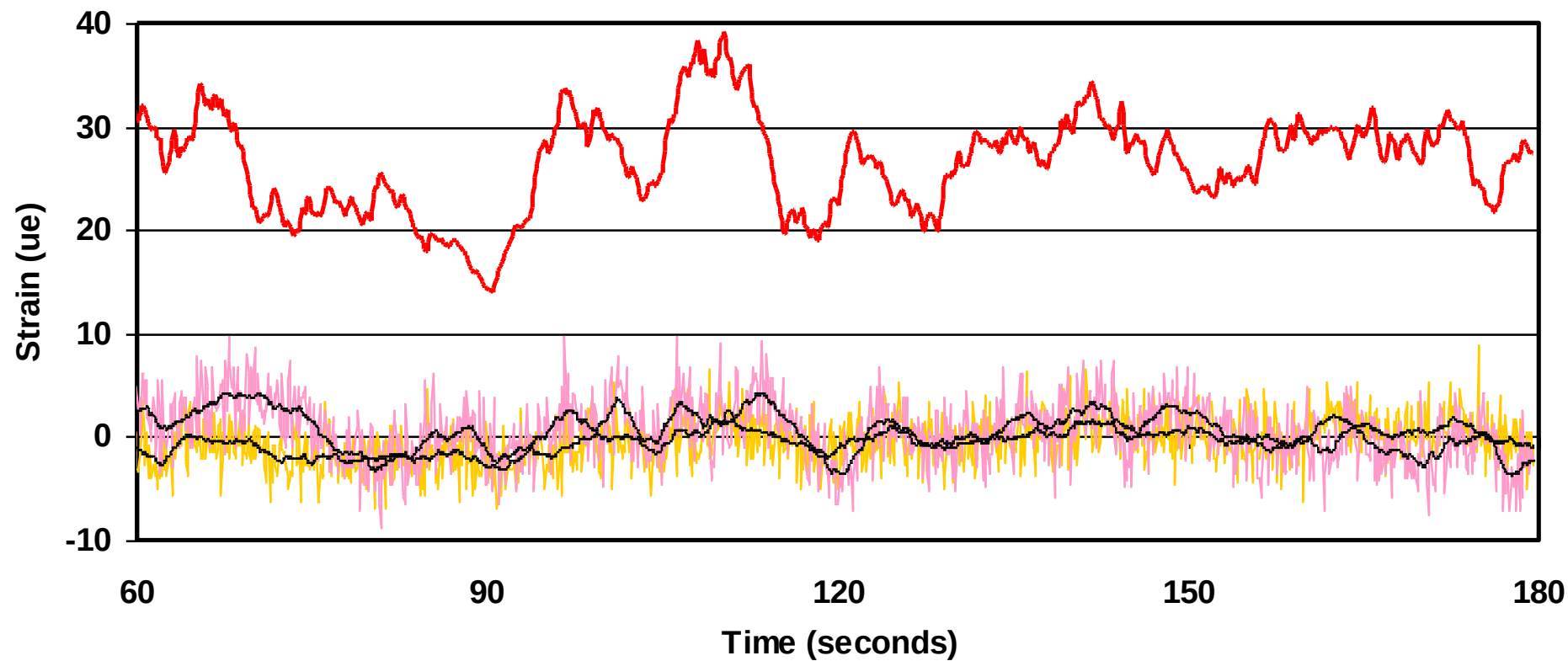
Blue River Bridge: Deck modeling considerations

Security Box





BOTTOM CHORDS
Blue River Bridge **4/20/05**



— WS avg — Leeward Strain — Windward Strain — Leeward - filtered — Windward - filtered

Blue River Bridge Conclusion

- **Buried bearings/
Frozen and rusted.**
- **Analysis were treated
as fixed boundary
conditions.**
- **May be acting as an
arch.**





**1886 5th Street Bridge
Grand Junction, Colorado**



**San Miguel Bridge
Uravan, Colorado**

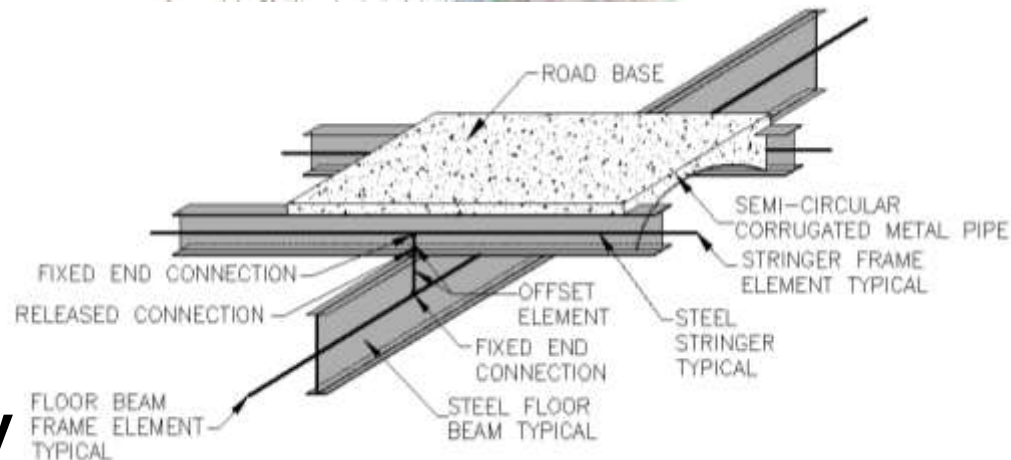


DECK TYPE – SAN MIGUEL BRIDGE



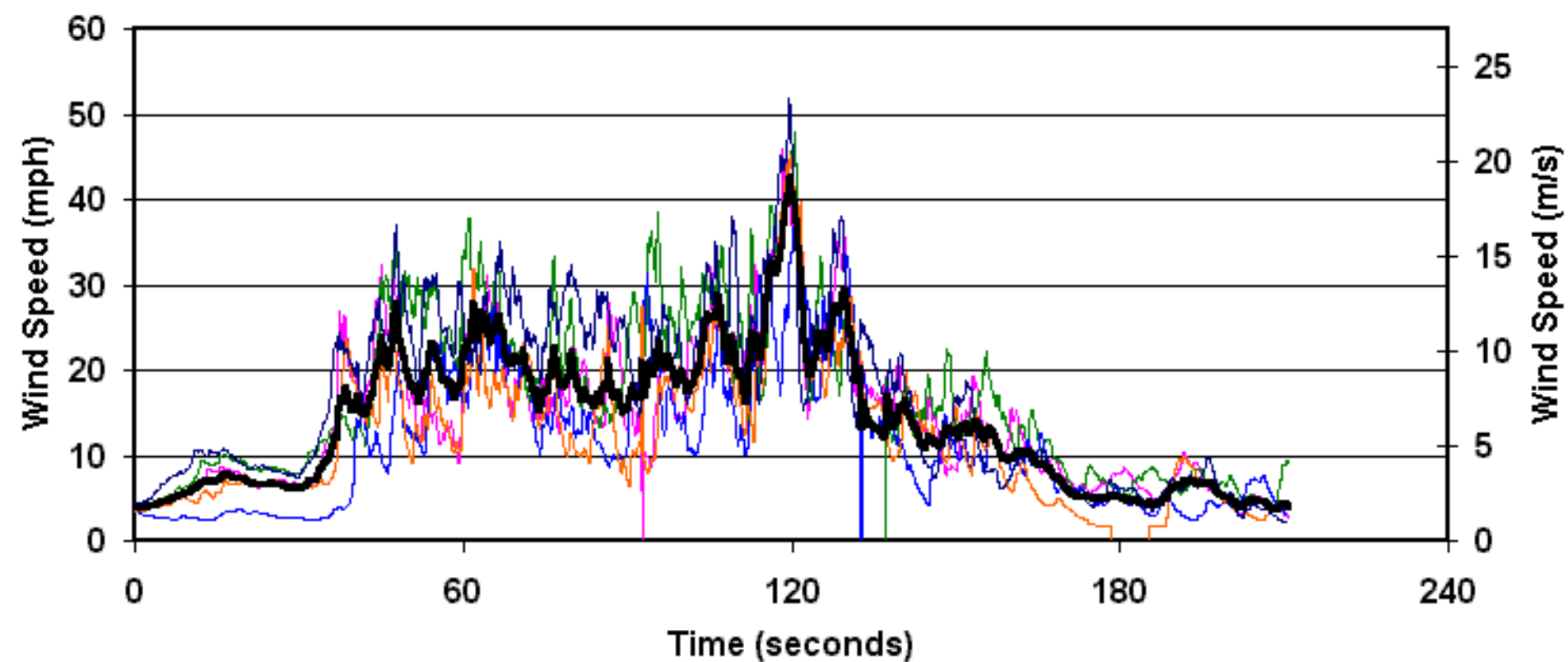
Gravel over ½ sections of corrugated metal pipe on steel stringers

Retrofitted in 1964 for heavy truck traffic





WIND SPEED
San Miguel Bridge 6/15/2005



WS1 WS2 WS3 WS4 WS5 Average WS

Correlations Results Investigations

- **Modified boundary conditions:**
 - Due to rust, dirt and debris
- **Hidden elements:**
 - Pinned or fixed connections and deck attachments.
 - Differ moments along deck.
- **Stiffness:**
 - Gravel to sand mixture vary.
- **Diagonal wind pressure.**



SUMMARY: DECK TYPES

- Wood deck over timber stringers
- Asphalt on corrugated metal deck over steel stringers
- Running boards over wood deck on steel stringers
- Gravel over $\frac{1}{2}$ sections of corrugated metal pipe on steel stringers



Fruita Bridge Verification Summary

Comparison of total calculated forces to total measured forces

Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-1.37 kN (-0.31 kips)	-1.44 kN (-0.32 kips)	5% (Excellent)
Leeward Bottom Chord	2.09 kN (0.46 kips)	2.95 kN (0.66 kips)	41% (Good)



Prowers Bridge Verification Summary

Comparison of total calculated forces to total measured forces

Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-2.71 kN (-0.61 kips)	-3.11 kN (-0.70 kips)	14% (Excellent)
Leeward Bottom Chord	2.74 kN (0.62 kips)	3.10 kN (0.70 kips)	13% (Excellent)



Rifle Bridge Verification

Summary Comparison of total calculated forces to total measured forces in kN (kips)

Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-7.34 kN (-1.65 kips)	-8.41 kN (0.05 kips)	14% (Excellent)
Leeward Bottom Chord	4.3 kN (1 kips)	16.8 kN (3.78 kips)	88% (Weak)



Blue River Bridge Verification Summary Comparison of total calculated forces to total measured forces

Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-0.44 kN (-0.1 kips)	-0.54 kN (-0.122 kips)	23% (Good)
Leeward Bottom Chord	1.44 kN (0.32 kips)	0.78 kN (0.18 kips)	45% (Good)



San Miguel River Bridge

Verification Summary

Comparison of total calculated forces to total measured forces

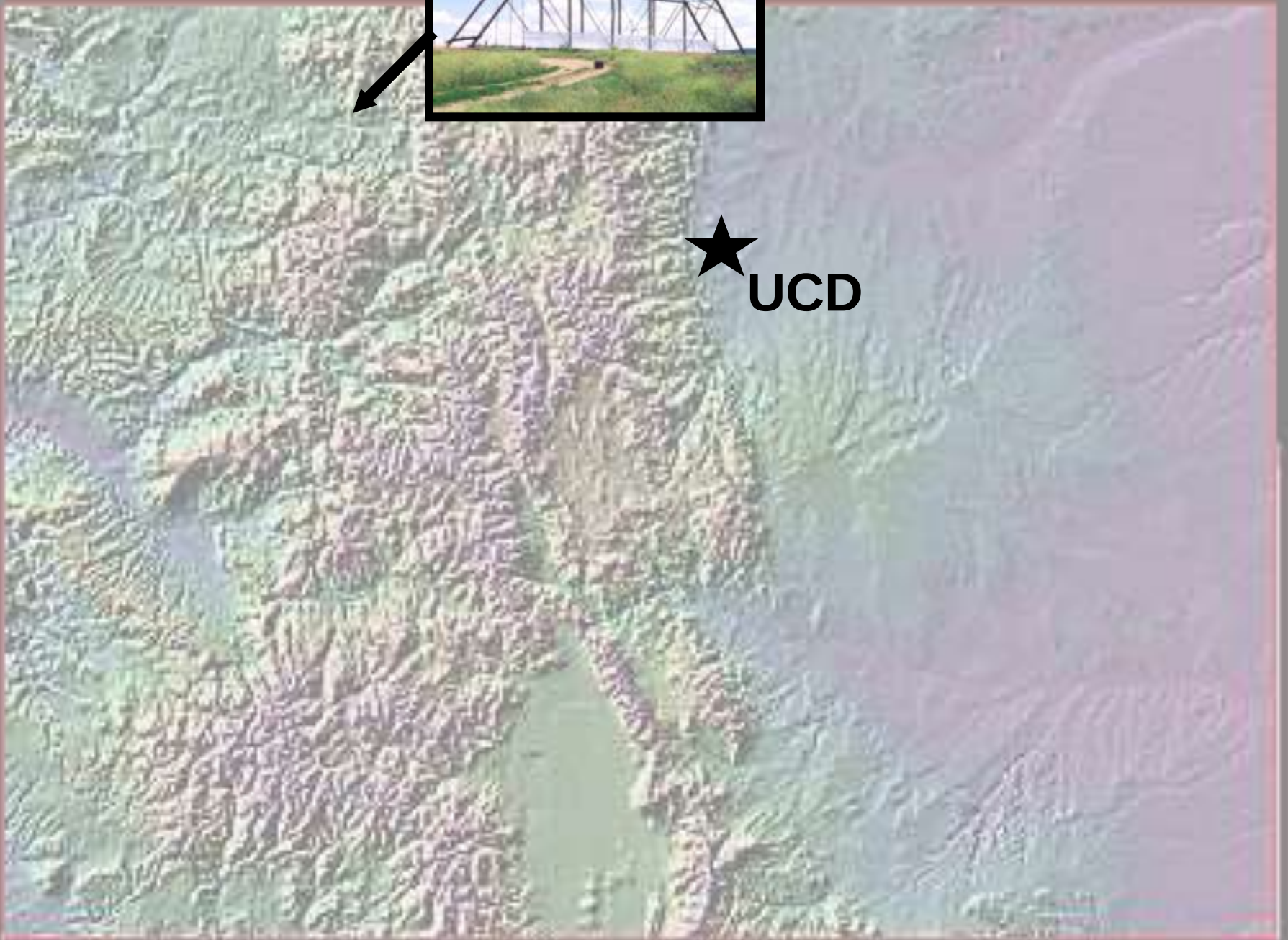
Member	Calculated Force (Deck Model)	Measured Force (Field Data)	Correlation: % Difference
Windward Bottom Chord	-1.5 kN (-0.3 kips)	0.22 kN (0.05 kips)	114% (Weak)
Leeward Bottom Chord	4.3 kN (1 kips)	9.61 kN (2.16 kips)	55% (Fair)

Summary – Analysis Results

Bridge	Skeleton	Deck	% Reduction
Fruita	71.9k	49.0k	32%
Prowers	51.0k	34.2k	33%
Blue River	13.3k	11.2k	16%
San Miguel	49.9 k	23.7k	53%
Rifle	127k	77k	40%



★ UCD





1983

**Four Mile Bridge, July 2004 Relocated in 1993 to
top of hill, Selby Ranch, near Steamboat Springs, CO**









UCD



SUMMARY

Most surviving truss bridges are Pratt trusses

Rehab into pedestrian bridge for preservation

19th century design wind pressure lower than current
Deck and restraint at portal base are ways to increase resistance

With deck, forces in bottom chords are lower

Moments in portal frames unaffected by deck

Rotational restraint at base of portal frame increases portal resistance

CONCLUSIONS

Deck stiffens and strengthens a truss bridge laterally.

With deck, bottom chord forces are lower.

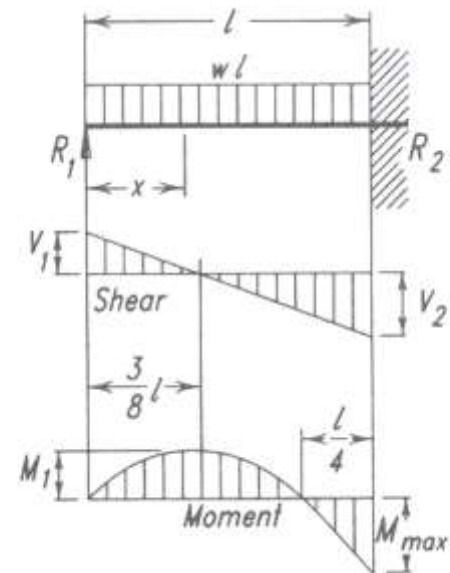
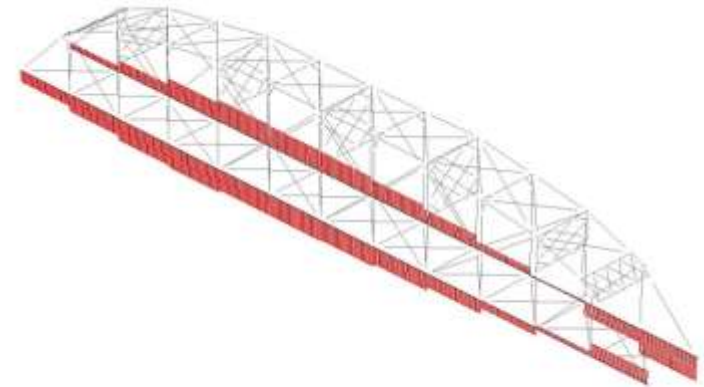
Desirable to restrain portal frame bases from rotation about the axis of bottom chords.

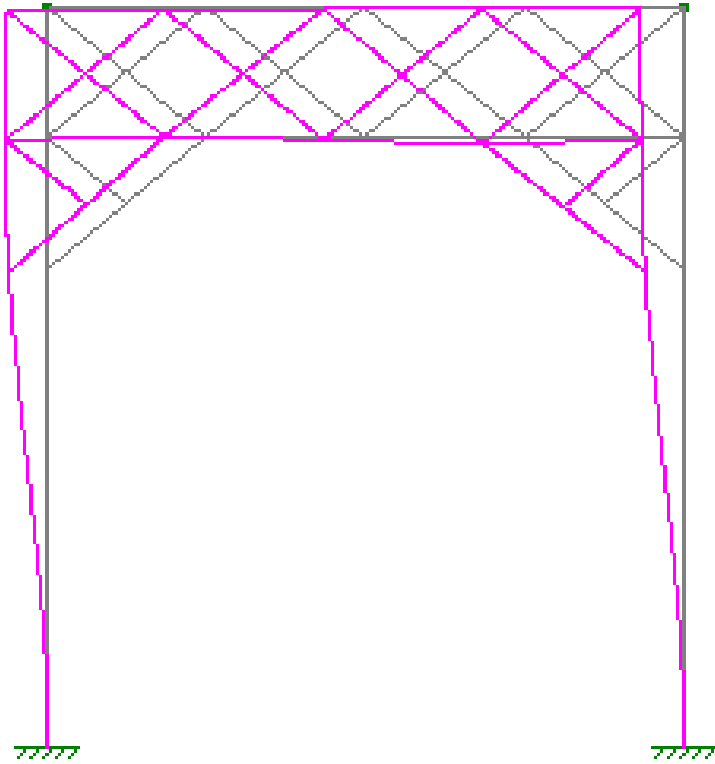
3D analysis is more accurate than 2D.

PROPPED CANTILEVER

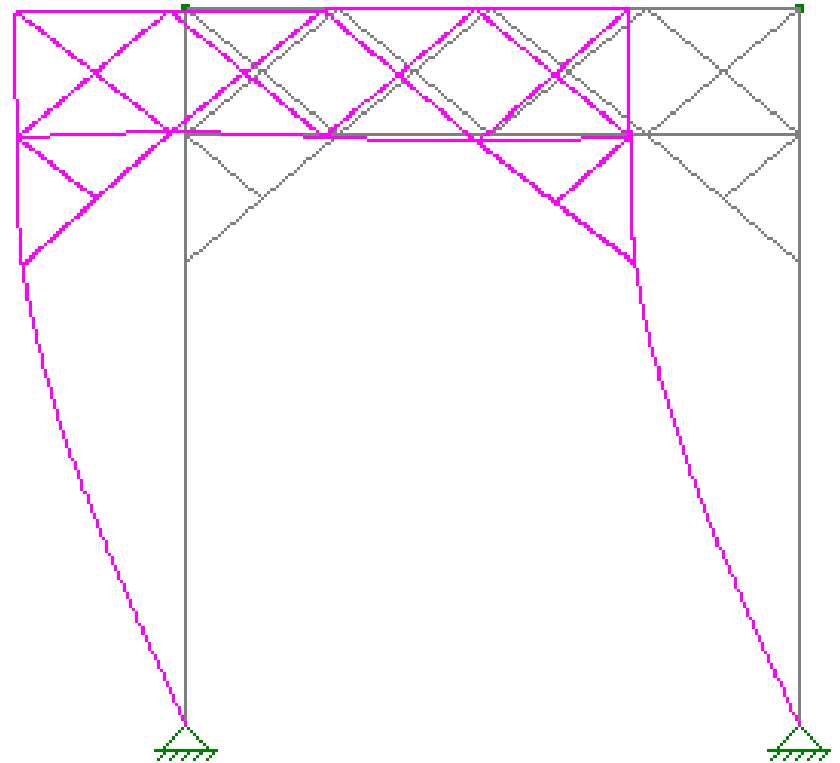
Sign reversal near anchored ends of bridge

Due to restraint against translation one end (acts as fixed support), and roller opposite end (acts as pinned support)





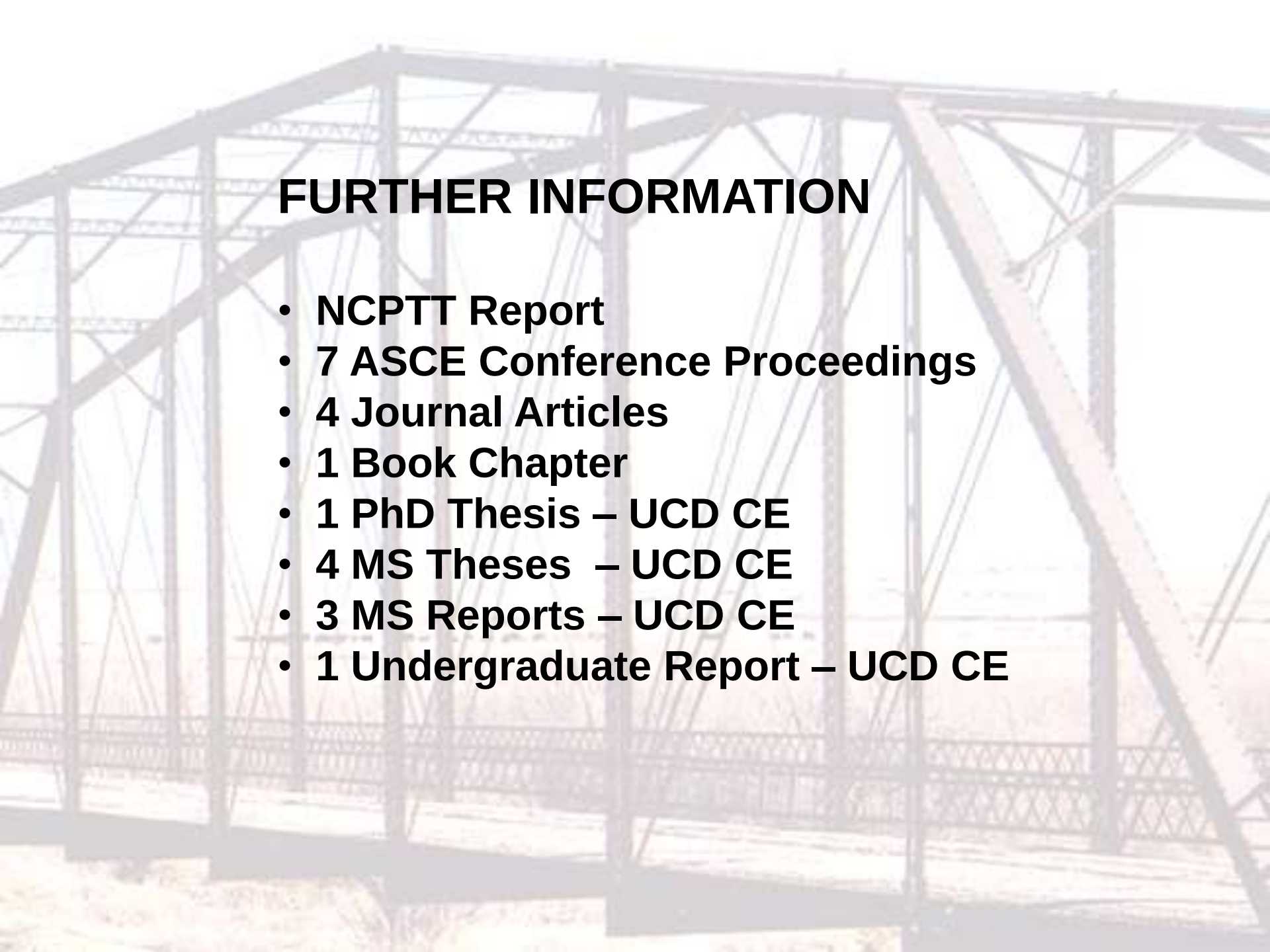
**Portal with fixed ends
Used by Waddell, 1916**



**Portal with end rotation
Used by Ketchum, 1908**

ACKNOWLEDGEMENTS

- **State Historical Fund of the Colorado Historical Society**
- **National Center for Preservation Technology and Training**
- **City of Fruita, Colorado**
- **Bent County, Colorado**
- **Summit County, Colorado**
- **Montrose County, Colorado**
- **Garfield County, Colorado**
- **Selbe Farms, Steamboat Springs, CO**
- **Civil Engineering Dept., University of Colorado at Denver**



FURTHER INFORMATION

- **NCPTT Report**
- **7 ASCE Conference Proceedings**
- **4 Journal Articles**
- **1 Book Chapter**
- **1 PhD Thesis – UCD CE**
- **4 MS Theses – UCD CE**
- **3 MS Reports – UCD CE**
- **1 Undergraduate Report – UCD CE**



Load Paths in Historic Truss Bridges | 2004-25

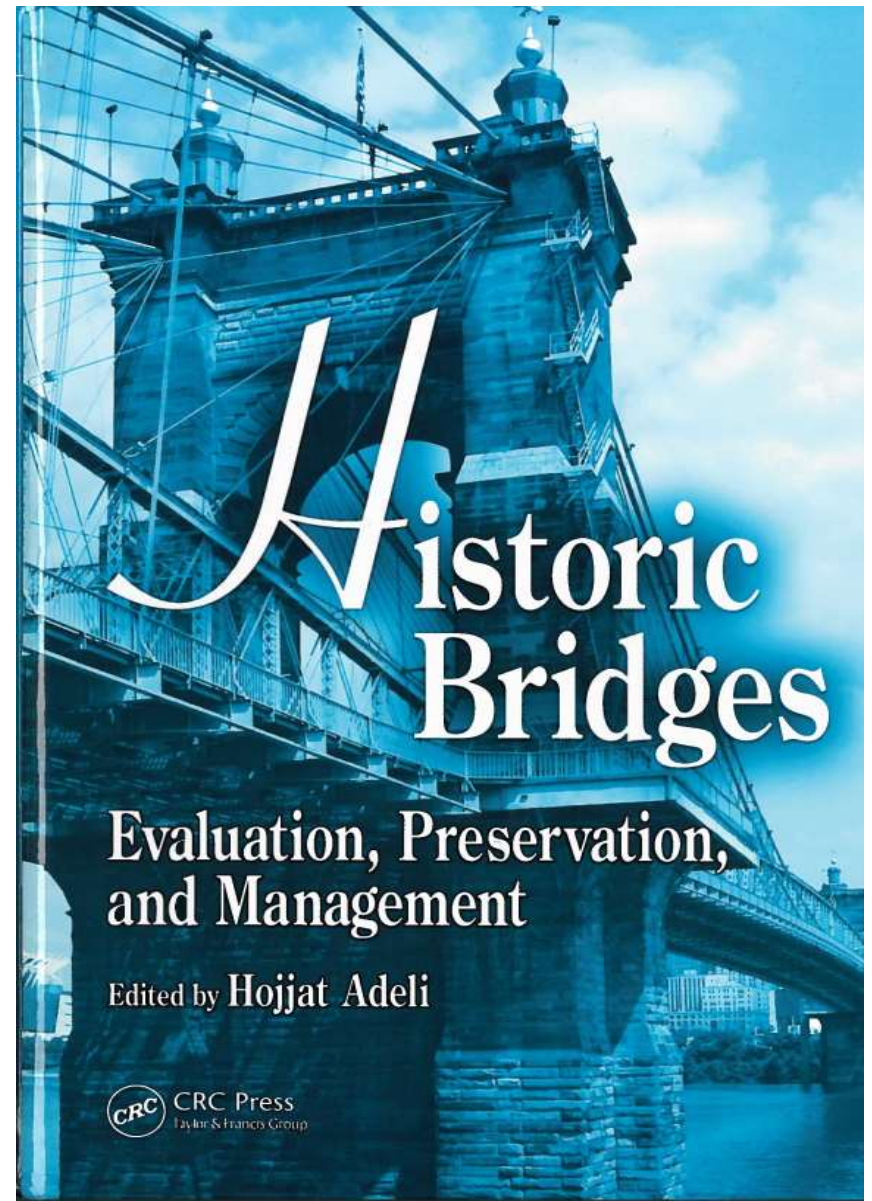
University of Colorado Denver



National Park Service
U.S. Department of the Interior

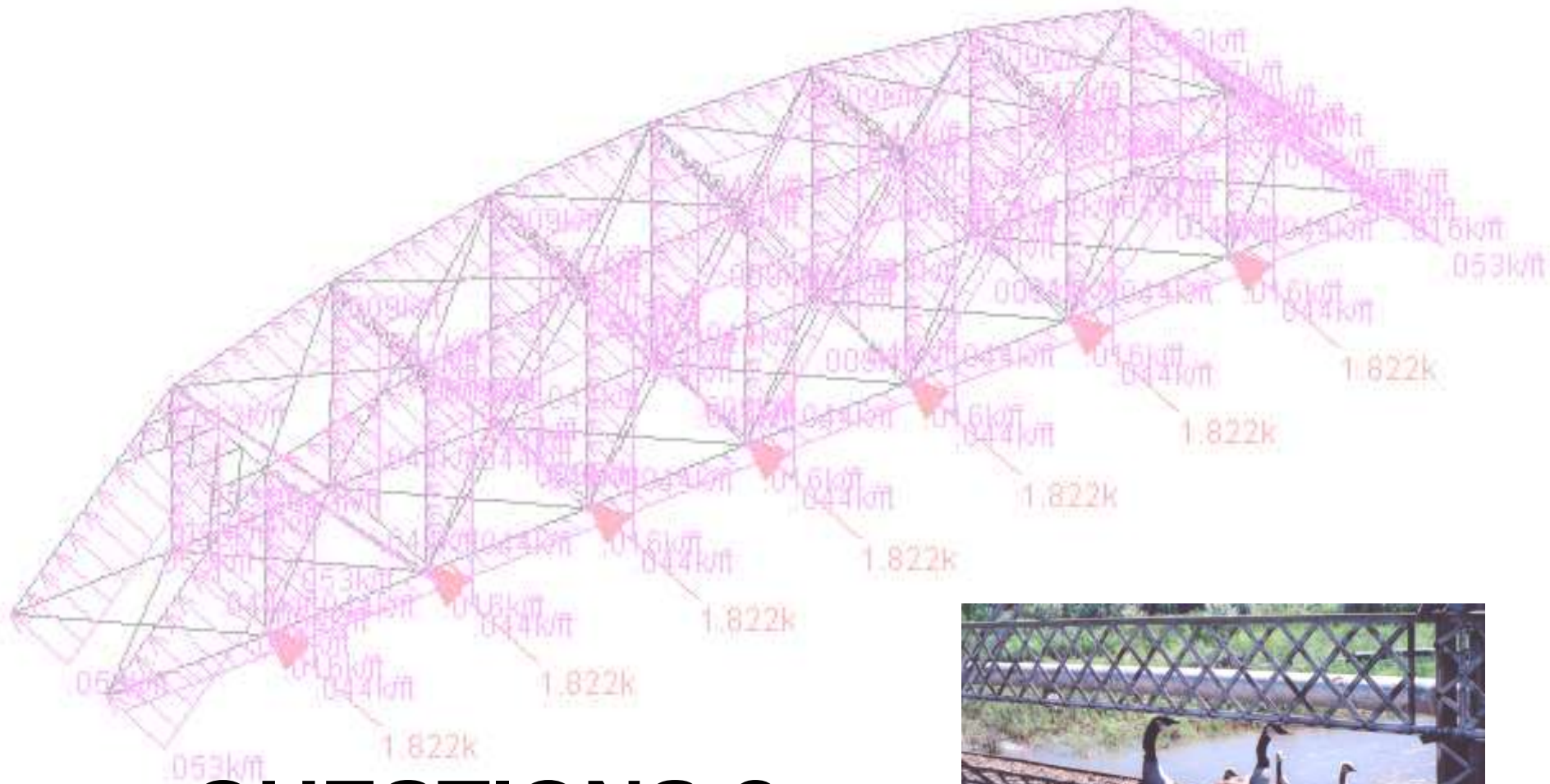


National Center for Preservation Technology and Training



A photograph of a yellow truss bridge spanning a river. The bridge has a complex lattice of yellow metal beams. In the background, there are mountains with patches of snow or light-colored rock. The river is blue and flows under the bridge. The text "Thank You" is overlaid in the center in a bold, black, sans-serif font.

Thank You



QUESTIONS ?

