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Technologies to manage risk for infrastructure

I-91 Springfield Viaduct Structural Life Extension

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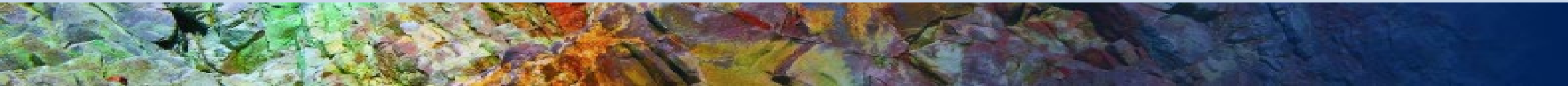
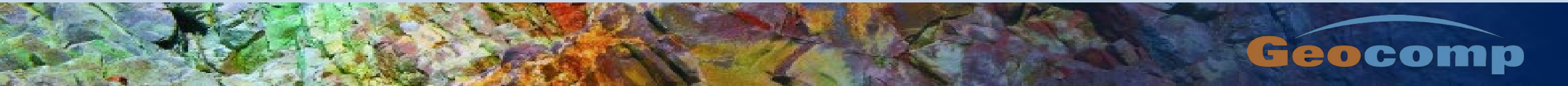


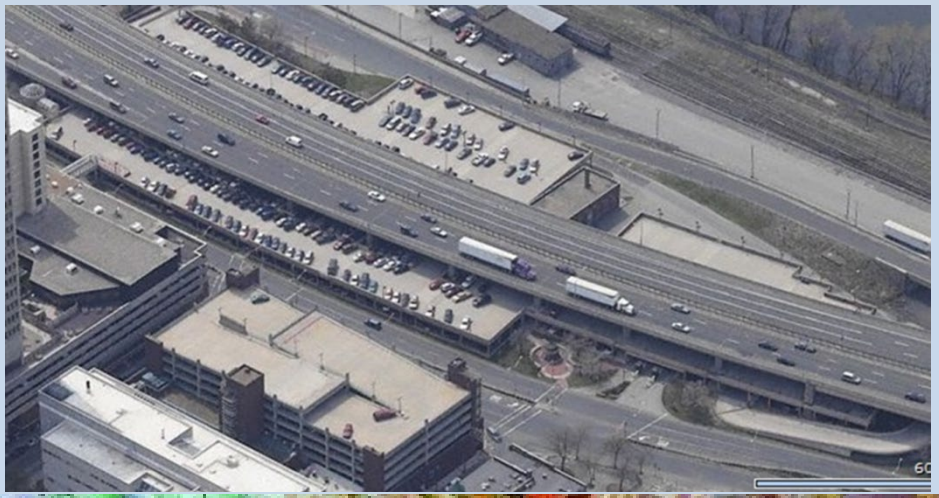
Presentation Outline

- I-91 Springfield Viaduct
- The Problem
- CME Investigation
- Instrumentation Plan / SHMS
- Dynamic Response Data Analysis
- Results / Conclusions
- Q&A



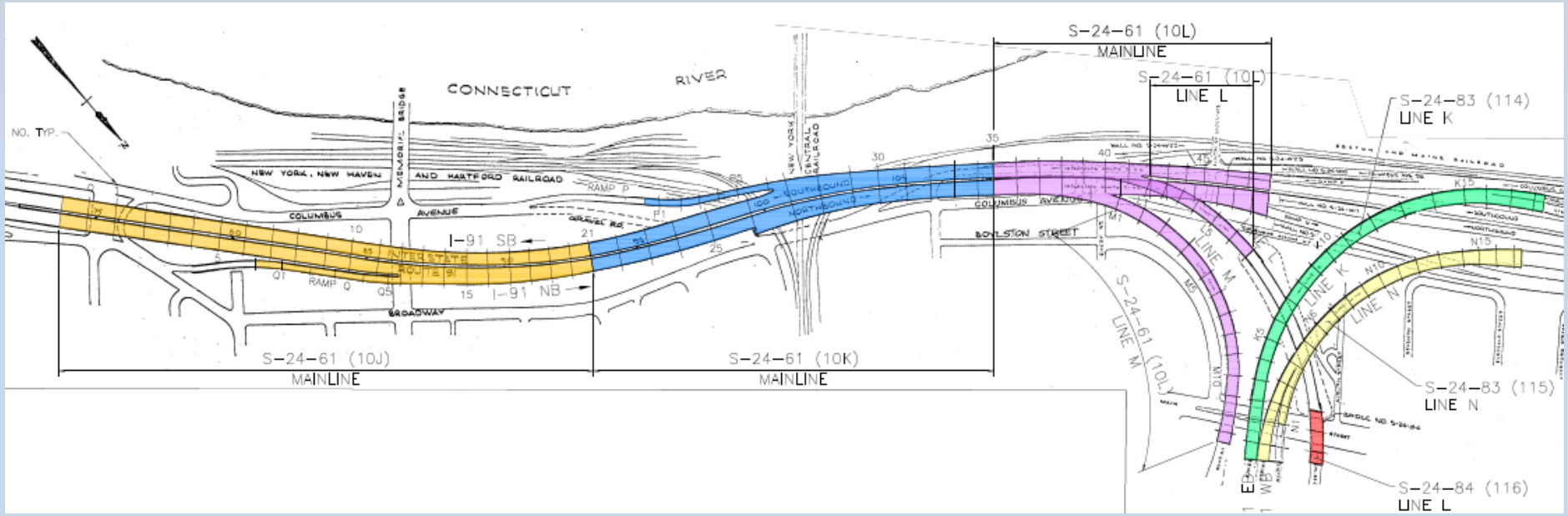
I-91 Springfield Viaduct

- Built in 1960's. Located in Springfield, MA
- Critical part of Interstate Highway System serving western MA and CT
- 3 Lanes per direction, Traffic Volumes:
  - 72,000 vehicles on weekdays
  - 54,000 vehicles on weekends



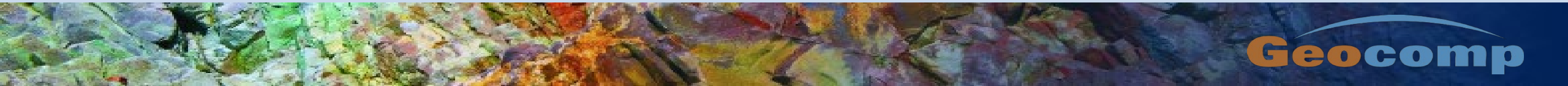
I-91 Springfield Viaduct

- I-91 NB+I-291 EBR 67 spans, 321,000 SF of bridge deck
- I-91 SB+I-291 WBR 62 spans, 293,000 SF of bridge deck
- Approximately 4,400 feet in length



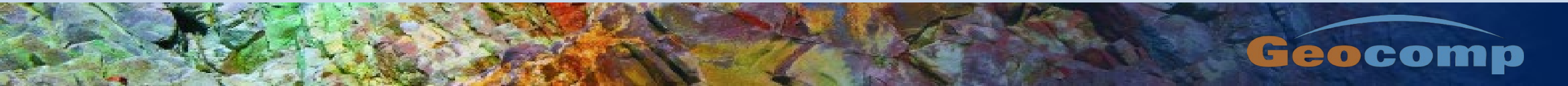
The Problem

- MassDOT annual maintenance cost $2M and increasing
- Need for bridge deck replacement due to poor condition
- Full replacement or relocation would take too long to put in place
- Two parking structures exist within bridge limits
- Estimated full superstructure replacement $800M
- Investigate Structural Life Extension (CME/Geocomp)



Investigation by CME Associates

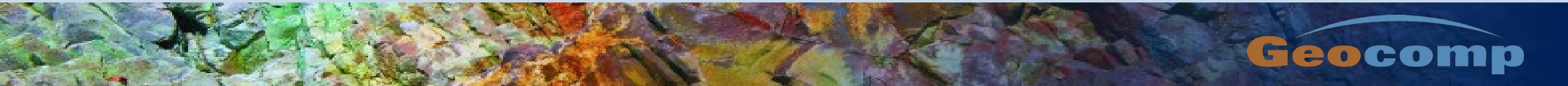
- Satisfactory substructure condition
- Viable full deck replacement with precast panels from structural capacity standpoint
- Calculate stresses and compare with infinite fatigue life thresholds listed in in the AASHTO LFRD Bridge Design Specifications
- Fatigue investigation (can we save the superstructure/mitigate the repairs)



Investigation by CME Associates

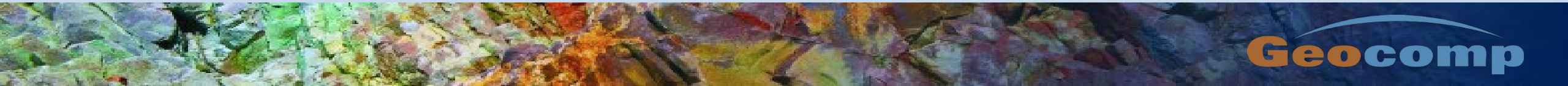
- 85 spans contain girders with partial length cover plates (766 total girders w/ plates)
  - Infinite Fatigue Life Threshold Limit: **2.6 ksi**
  - Calculated Fatigue I Stress: **3.4 ksi**
- Virtually every span contains fracture critical cap girders
- Bending stress in bottom flange of cap girders
  - Infinite Fatigue Life Threshold Limit: **12.0 ksi**
  - Calculated Fatigue I Stress: **9.1 ksi**

How to retrofit or verify?



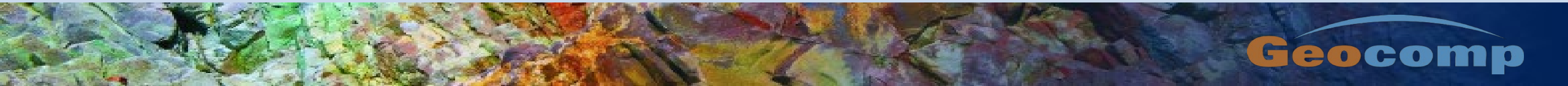
Superstructure Rehabilitation Options

- Girders with partial length cover plates:
  - Bolt splice plates for bottom flanges or Peening of cover plate welds
- Fracture critical steel cap girders:
  - Bolt angles between connection plate and bottom flange to eliminate out-of-plane distortion or attach connection plate to bottom flange with fillet welds
- Bending Stress in bottom flange of cap girders:
  - Install cover plates on bottom flanges of cap girders or install post-tensioning systems as redundant load path systems, or make cap girders composite with concrete deck

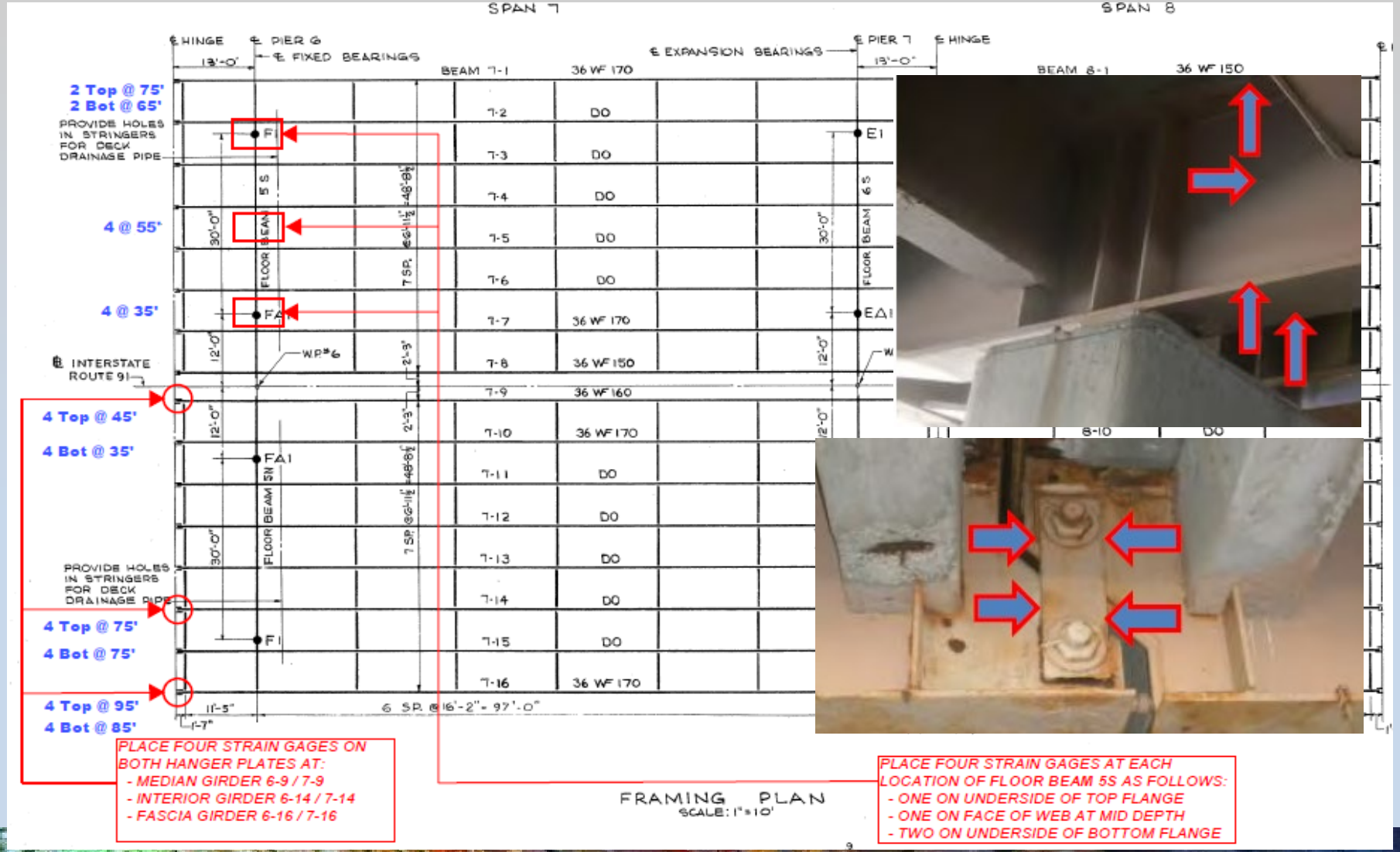


OR, Use Structural Health Monitoring System utilizing Strain gages for Counting Stress Cycles

- Fatigue Life Investigation
- ASTM Standard E1049
- Breaks counting method into logical, loop steps
- Algorithm to process large volumes of data
- Fully automated process for daily analysis of incoming data
- Output provides frequency distribution of stress cycles



Instrumentation Plan
Hanger Plates and Floor Beams



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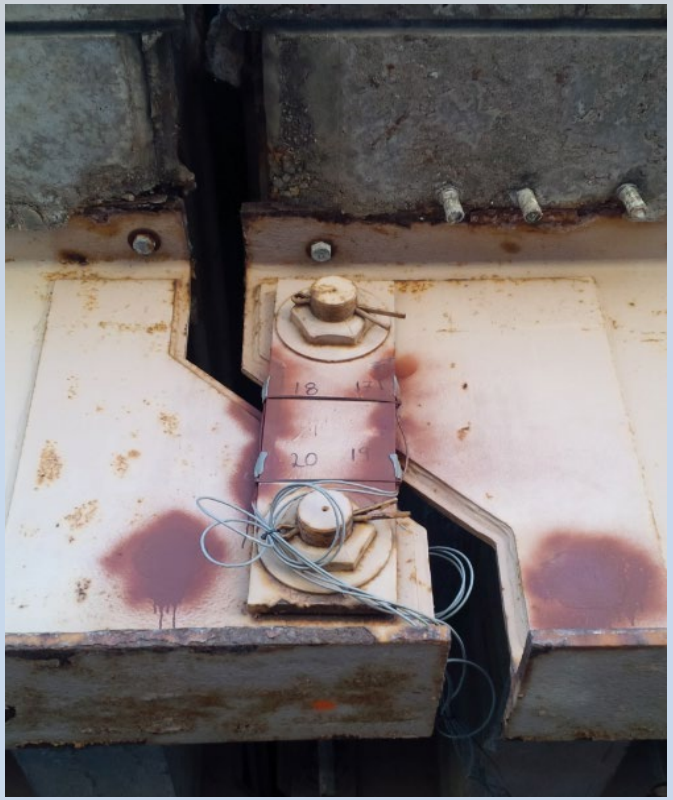
Installation of Strain Gages
Hanger Plates

Spot weldable strain gages on Hangar Plates to measure stresses induced by frozen or corroded pins.

48 SG total on
6 hanger sets

- 24 on NB
- 24 on SB



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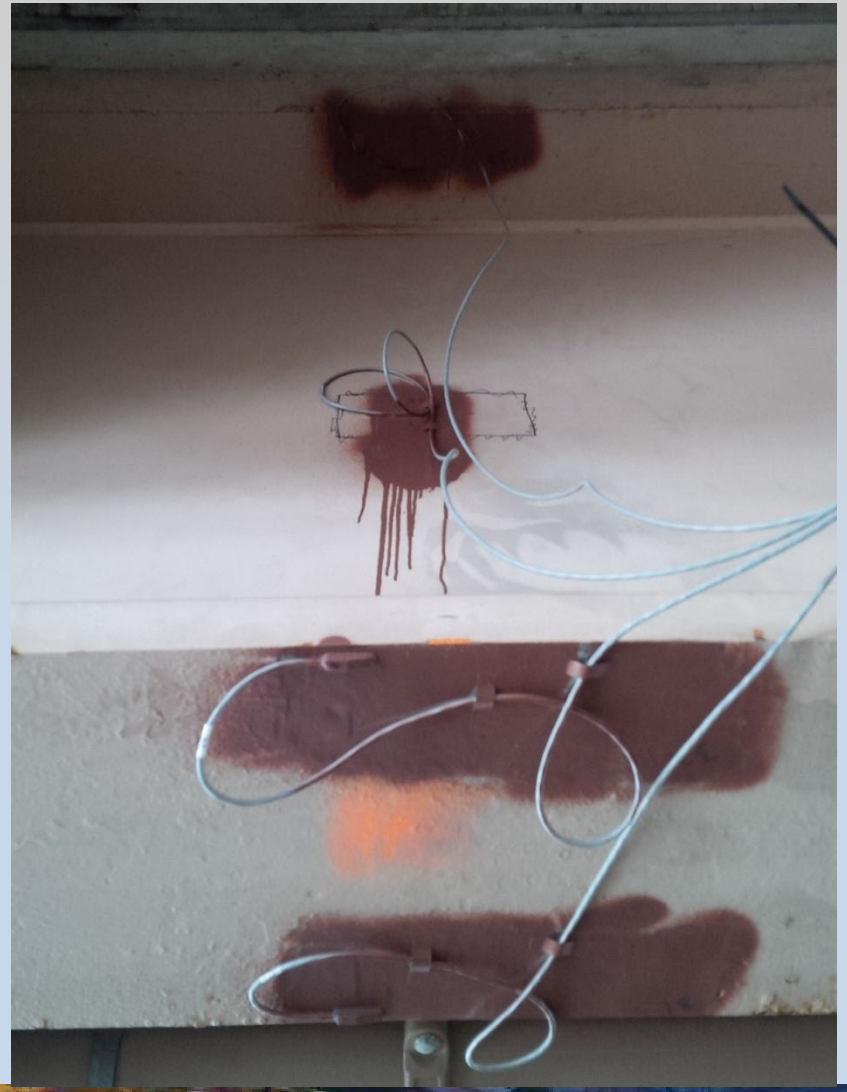
Installation of Strain Gages
Floor Beams

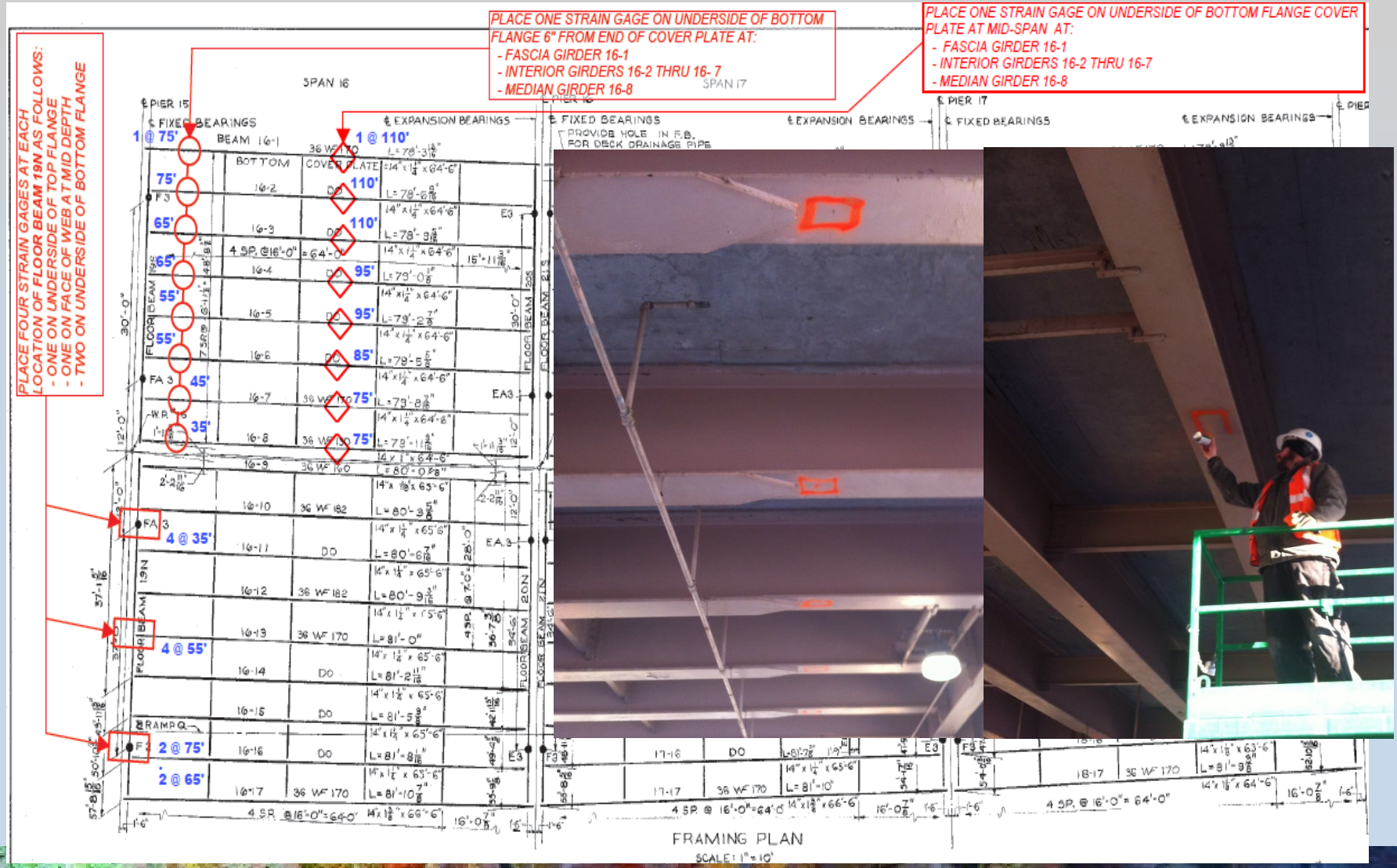
Spot weldable strain gages on floor beams to determine normal and out of plane bending.

36 SG Total on 3 floor beams

- 24 SG on SB
- 12 SG on NB



Instrumentation Plan
Girders



Installation of Strain Gages Girders

Spot weldable SG on girders with partial length cover plates to determine remaining fatigue life of girders

32 SG total on 16 girders

- 16 on girder mid span
- 16 at cover plate end

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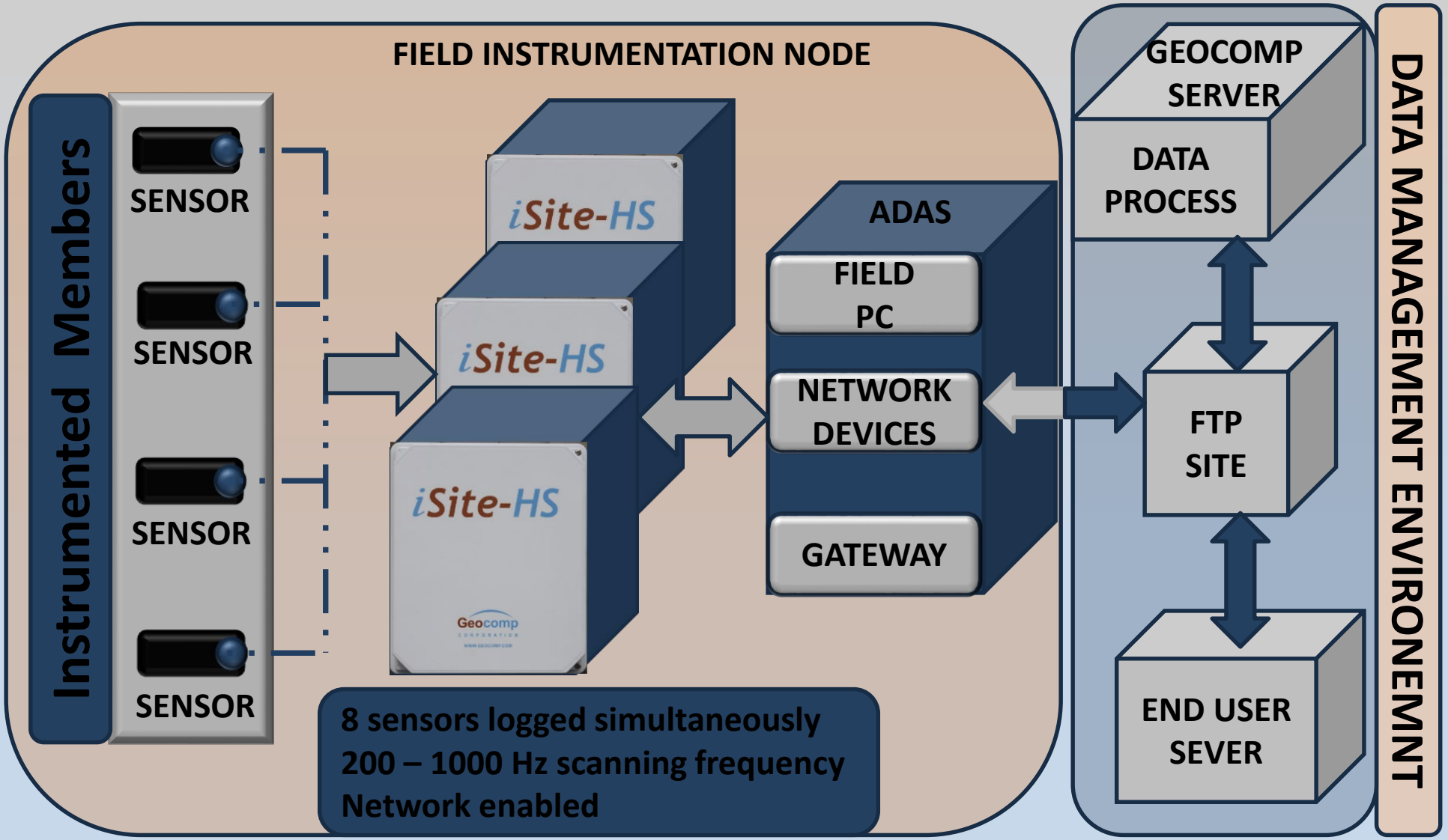
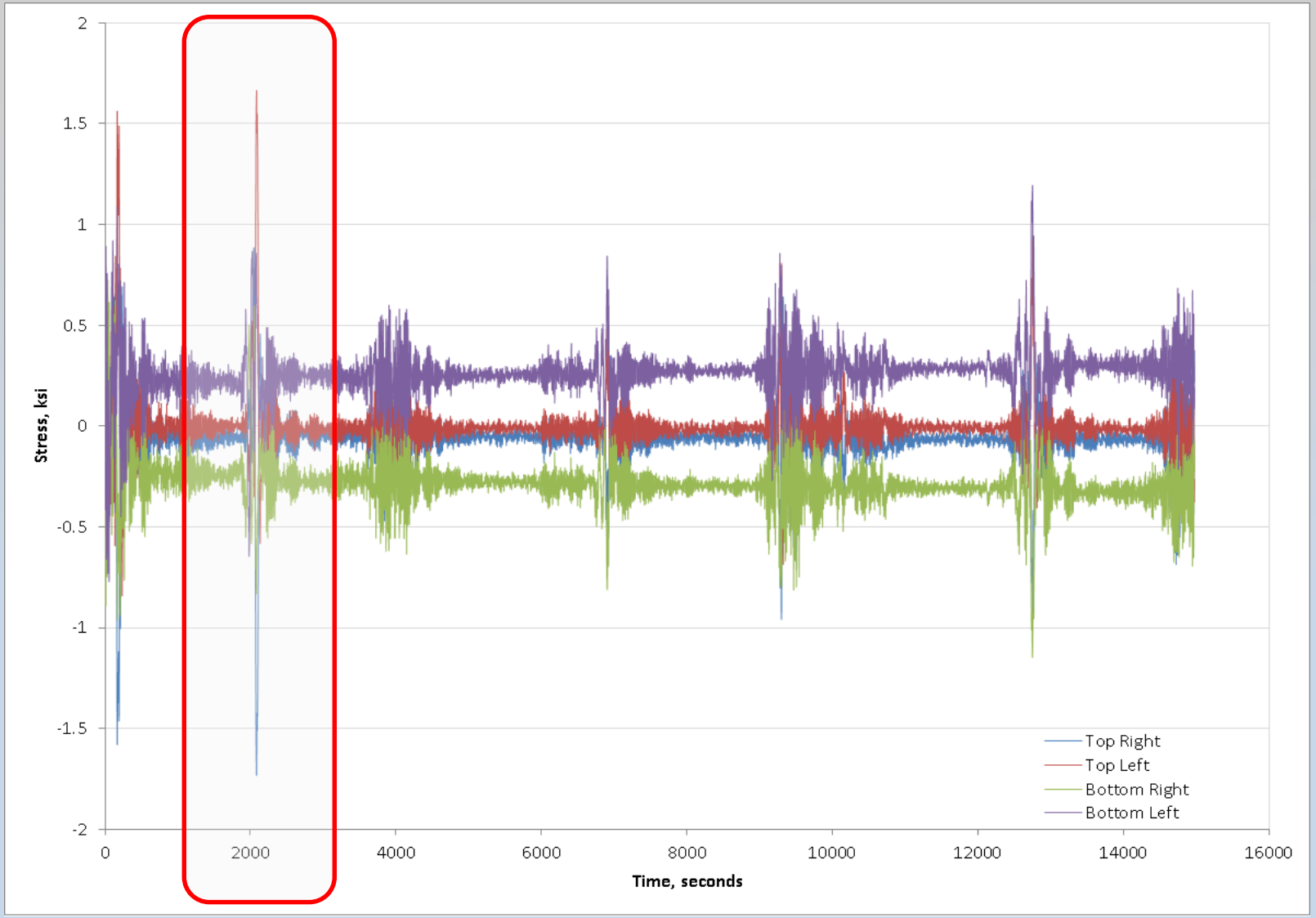
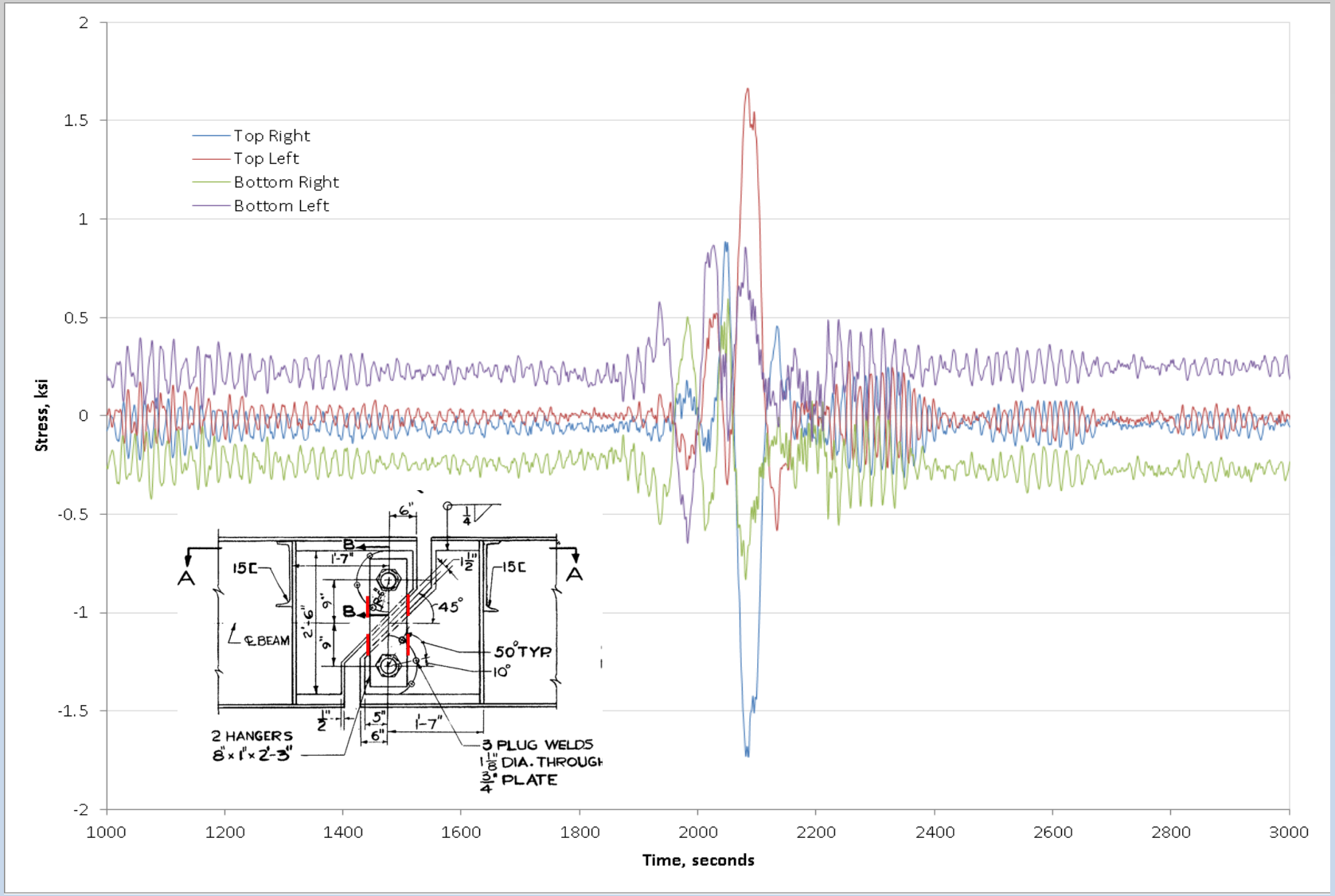
Structural Health Monitoring System



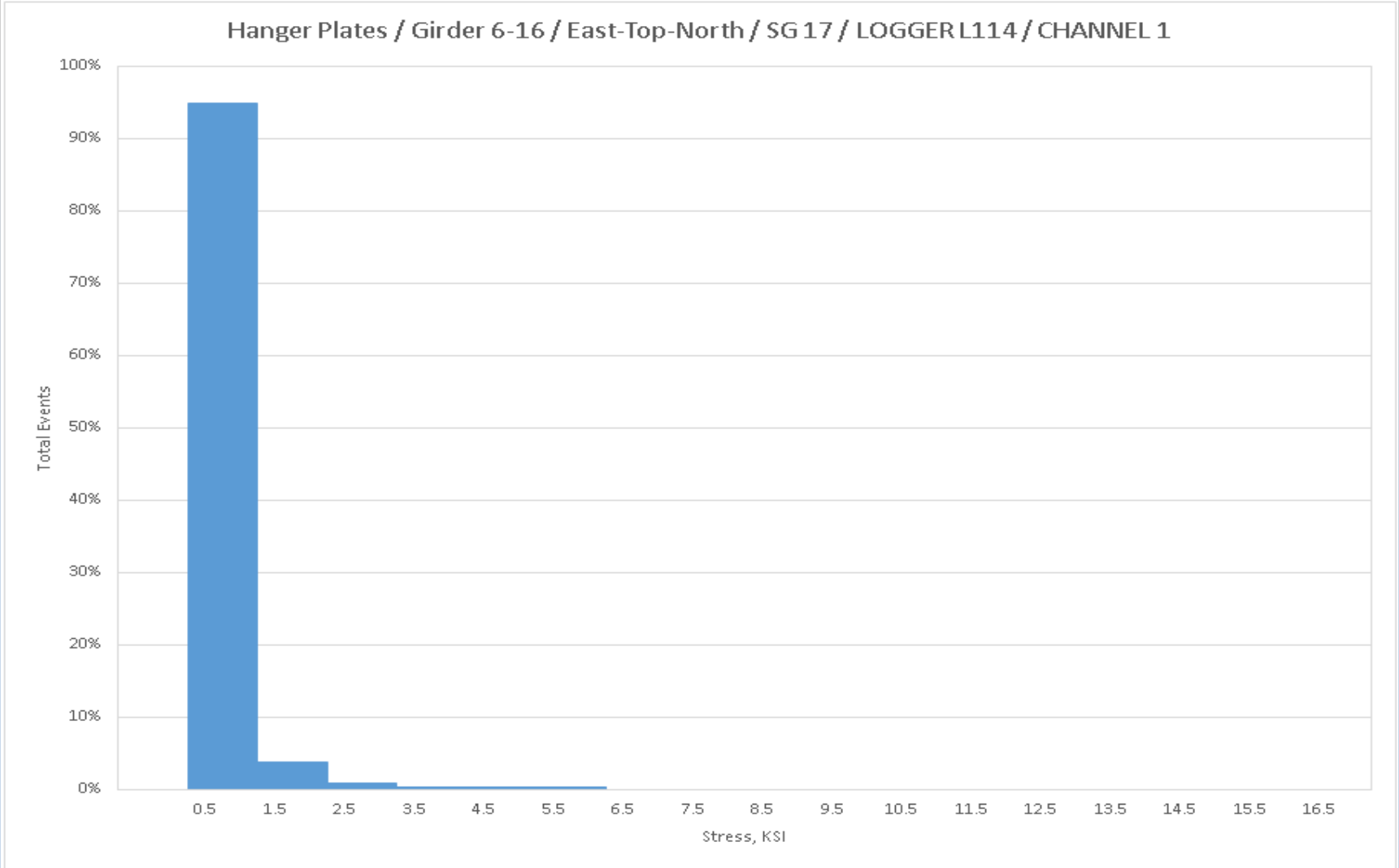
Hanger Plate / Girder 6-16 (5 min)



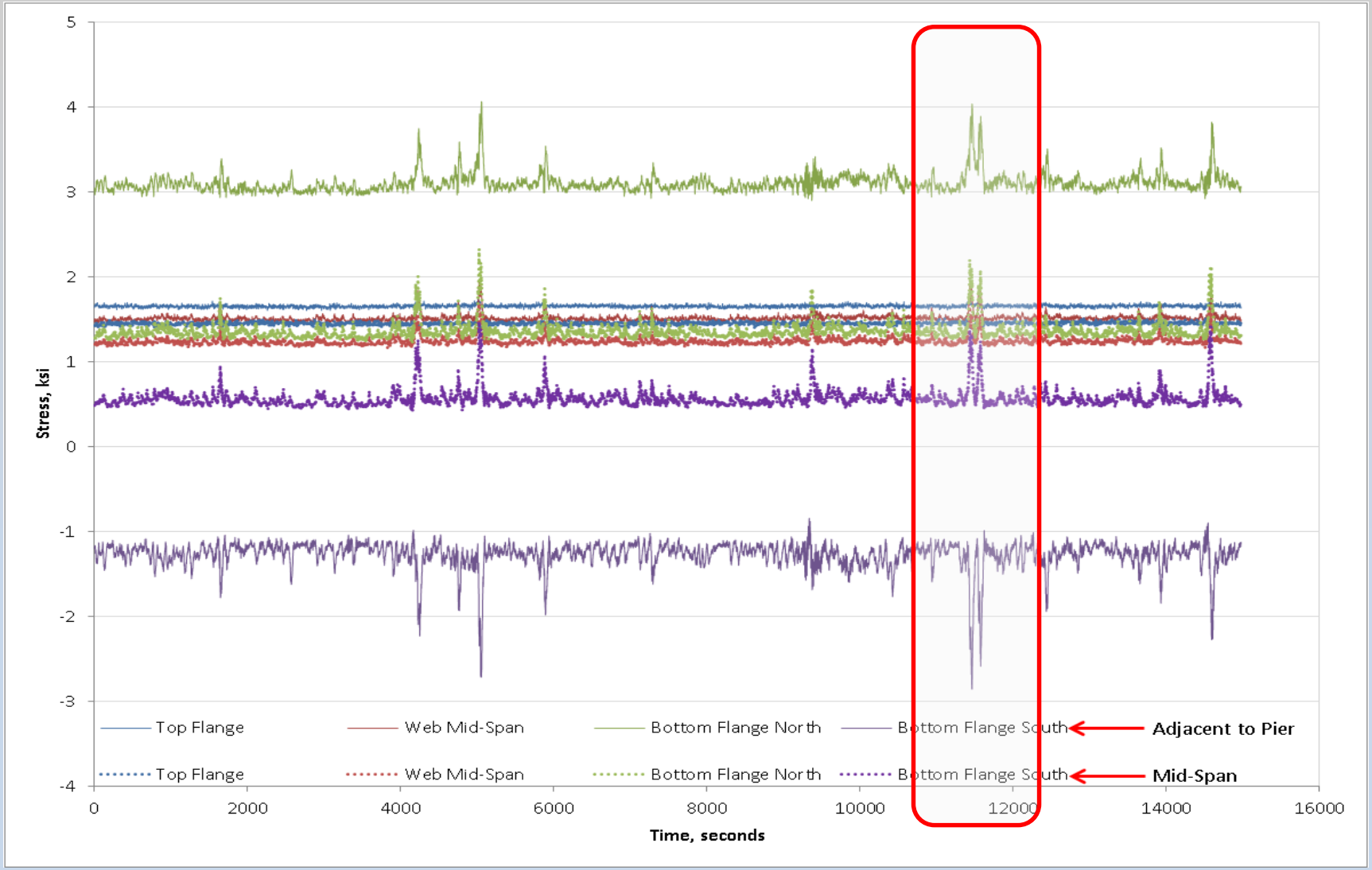
Hanger Plate/Girder 6-16



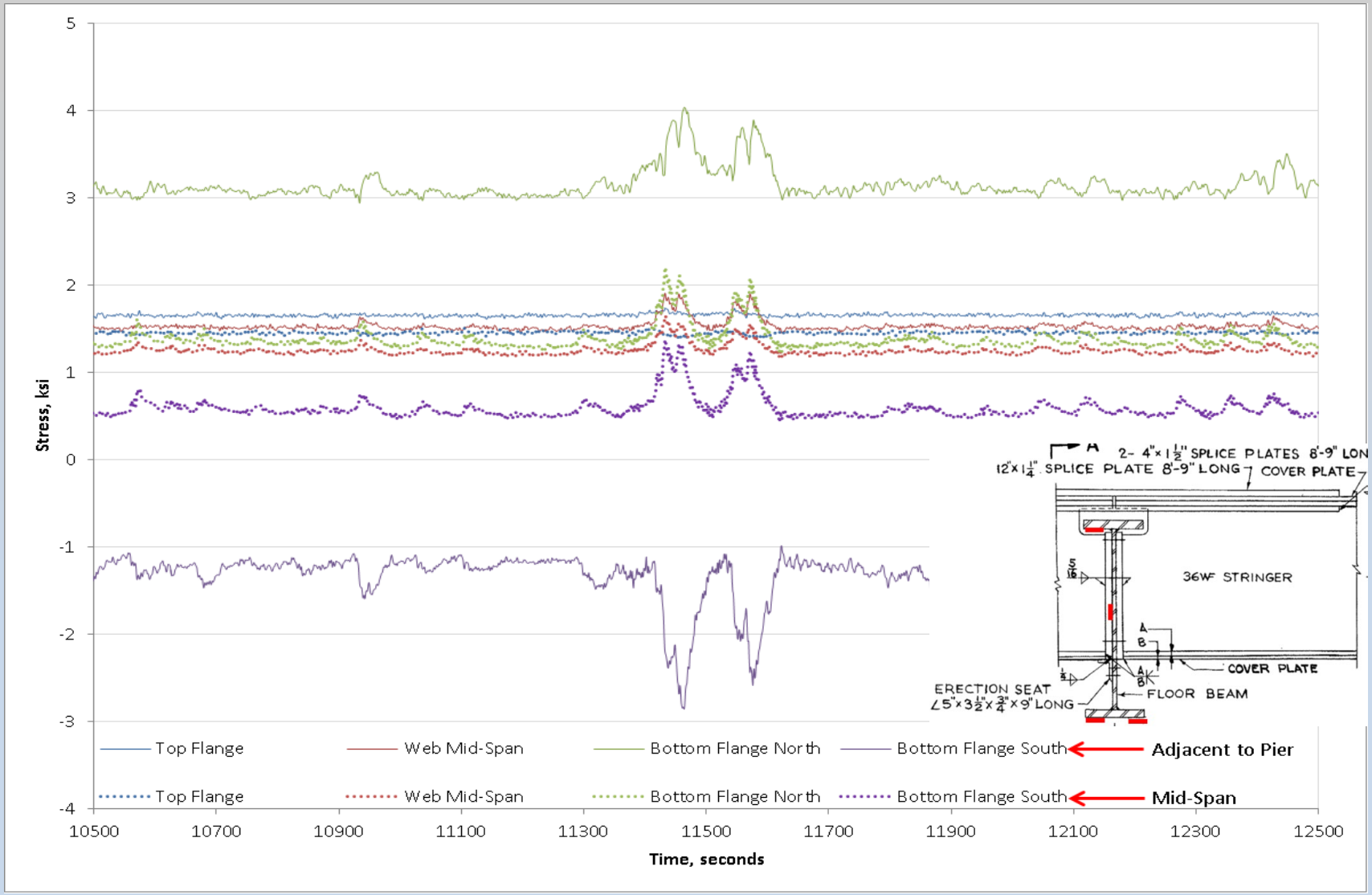
Rainflow Analysis – Stress Range Count



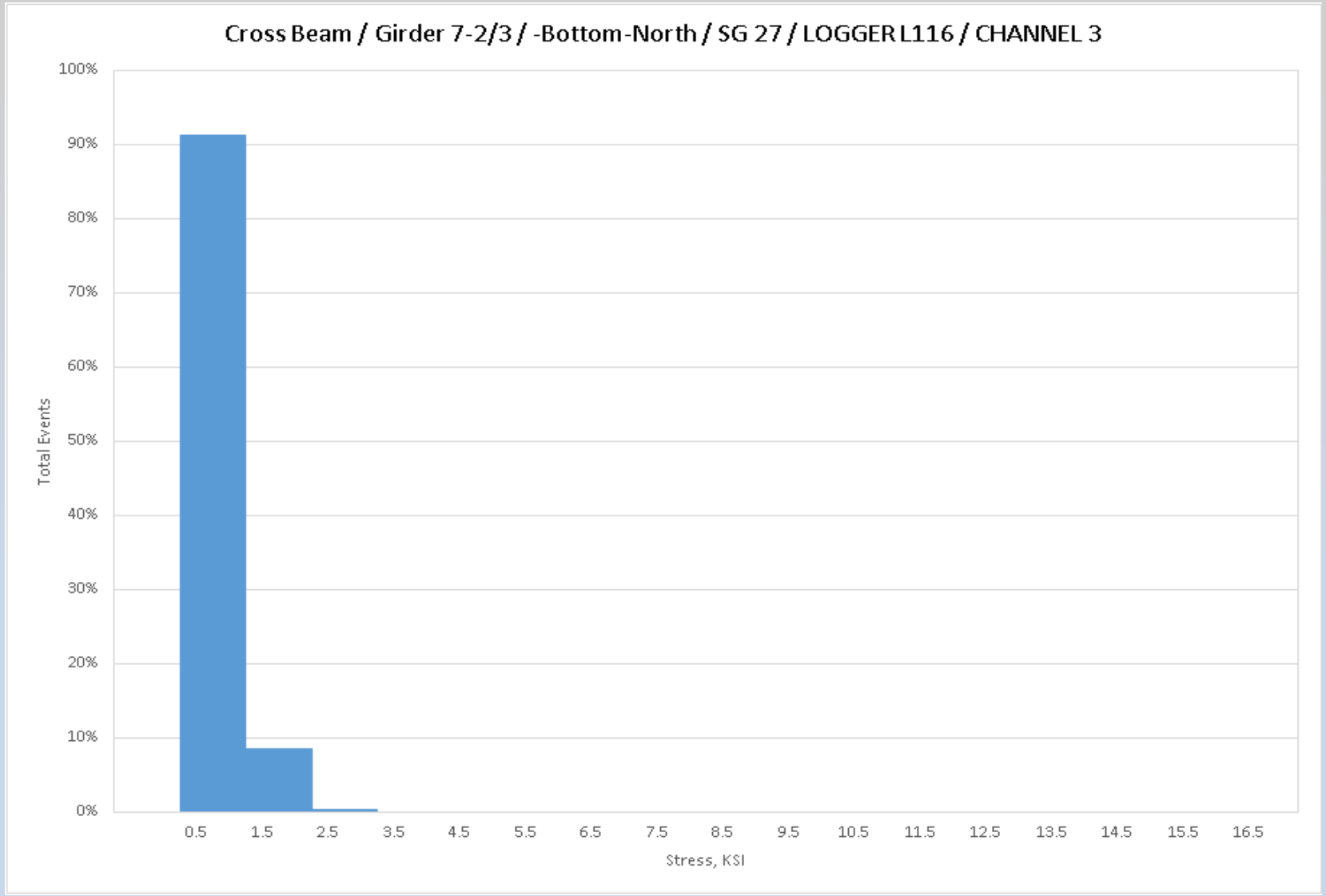
Floor Beam @ Pier 15 NB (5 min)



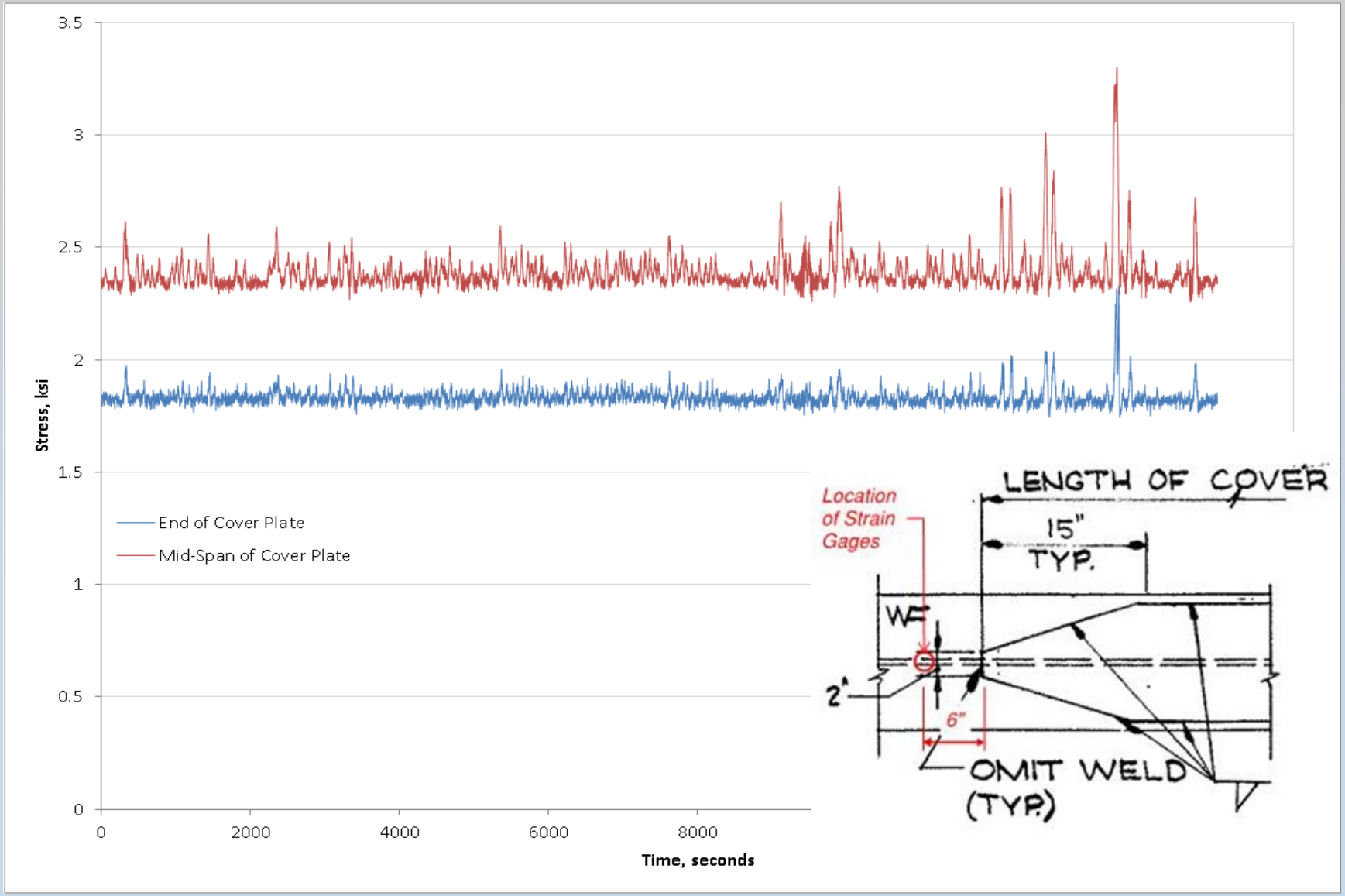
Floor Beam @ Pier 15 NB



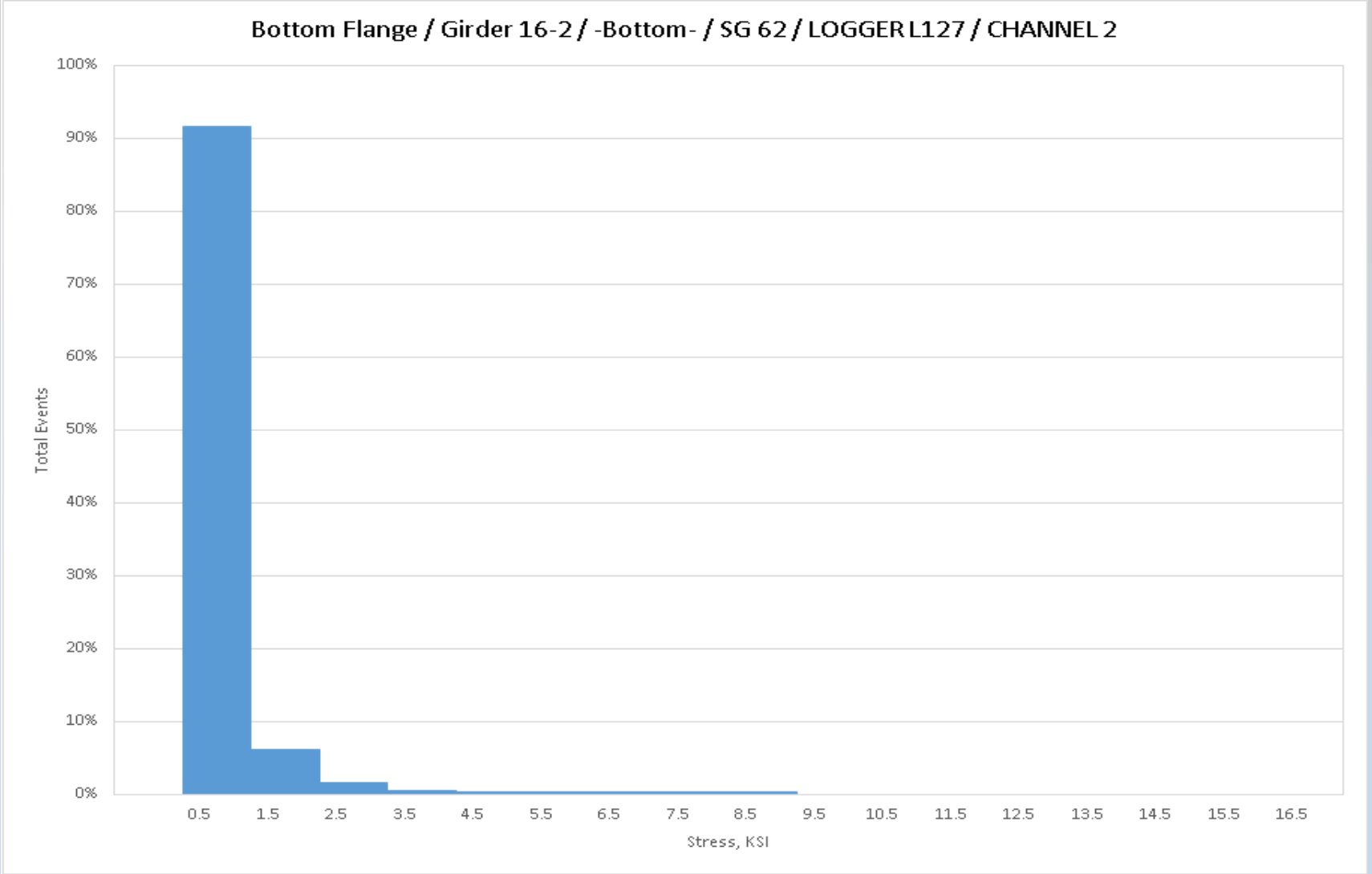
Rainflow Analysis – Stress Range Count



Girder with Partial Length Cover Plate (5 min)



Rainflow Analysis – Stress Range Count



Rainflow Analysis – Stress Range Calculations

- Use Miner's rule

$$Sr_{miner} = (\sum fi * Sri^3)^{1/3}$$

Where:

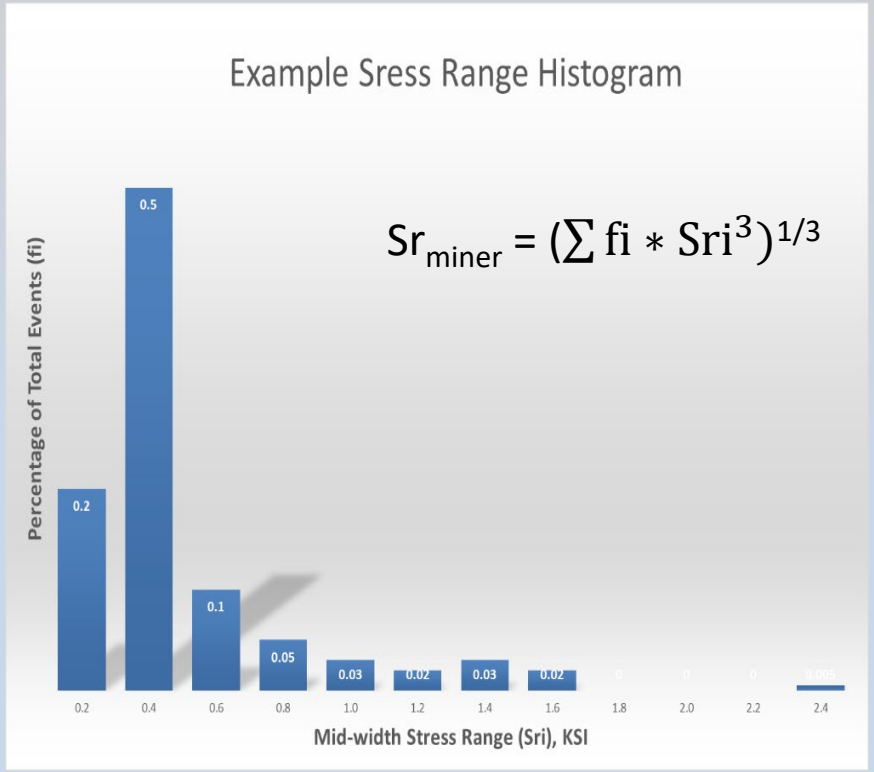
Sr_{miner} = Constant Effective Stress Range

fi = fraction of stress ranges within an interval (percentage of total stress ranges)

Sri = mid-width stress range of the interval

Rainflow Analysis – Stress Range Calculations

- Use Miner's rule example

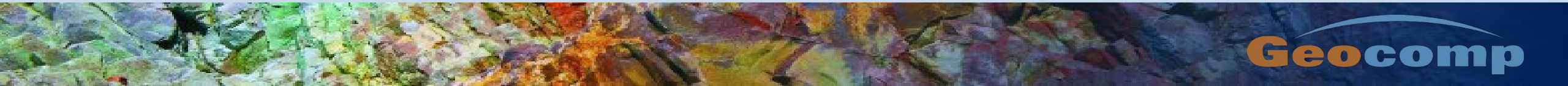


Mid-width stress Range	Percentage of Total	(fi*Sri^3)
0.2	20	0.0016
0.4	50	0.032
0.6	10	0.0216
0.8	5	0.0256
1	3	0.03
1.2	2	0.03456
1.4	3	0.08232
1.6	2	0.08192
1.8	0	0
2	0	0
2.2	0	0
2.4	0.5	0.06912
	Sr miner=	0.37872

Conclusions

- All of the locations gaged resulted in a CESR that was less than the specified infinite fatigue life thresholds listed in the AASHTO LRFD Bridge Design Specifications.

Location	Infinite Constant Effective Stress Range Threshold	Maximum CESR
Hanger Plates	4.5 ksi (Category E)	1.78 ksi
Cap Girders	12.0 ksi (Category C')	0.821 ksi
Cover Plate Stringers	2.6 ksi (Category E')	1.19 ksi



Conclusions

Thermal effects in Pin and Hangers

- Gaged over a 7 day period
- Large stress variations were measured (20+ ksi)
- Cause of stresses:
  - Stresses are bending stress
  - Conclusion: Frozen Pins

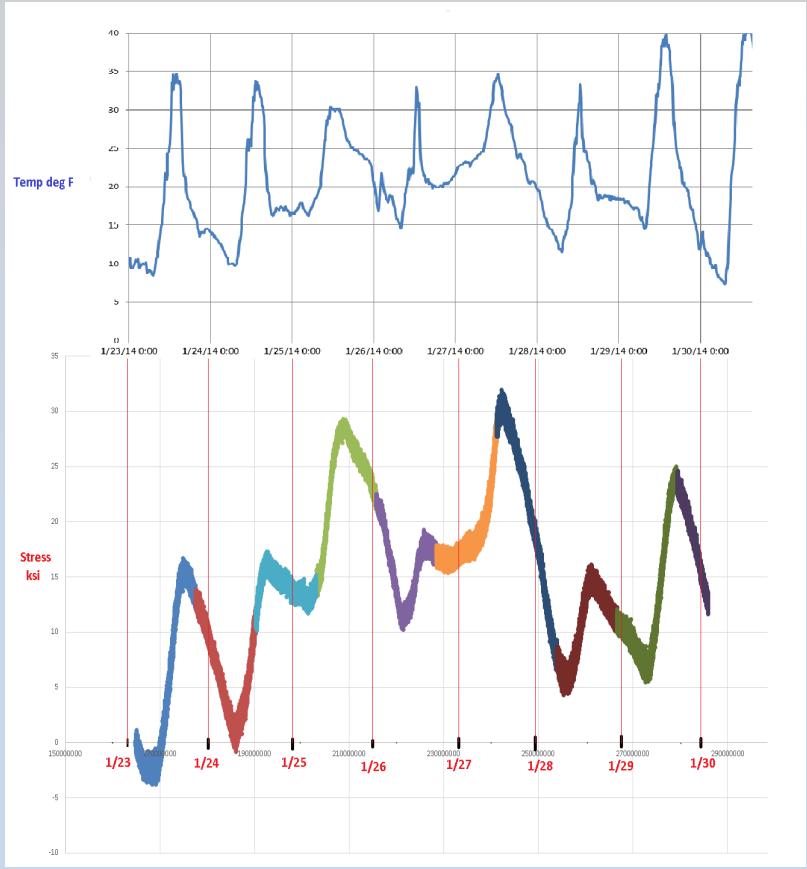
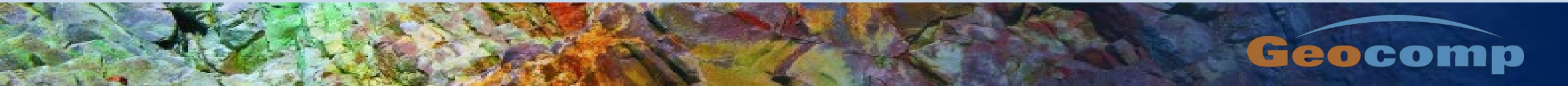


Figure 3-1 Thermal Stresses in Hanger Plates

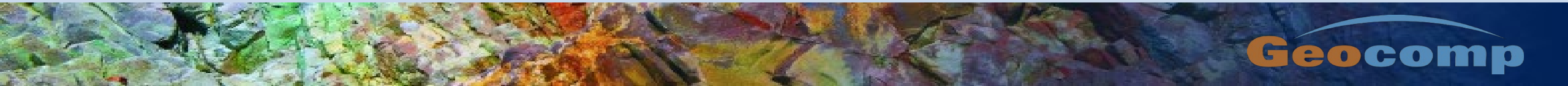
Results of SHM Program

- Concluded that CESR at all locations gaged were less than infinite fatigue life thresholds specified by AASHTO LRFD Bridge Design Specifications
- Determined service life of steel structure could be extended at least 30 more years
- Eliminated the need to replace the entire bridge and made the proposed deck replacement project viable



Results of SHM Program (ctd)

- SHM program removed conservatism inherent to AASHTO's fatigue life formulation
- Confirmed concerns about corroded, frozen pin-hanger assemblies by revealing thermal effects over 7-day period
- Eliminated potential load posting or repairs to the bridge through accurate determination of live load distribution
- **Reduced cost of rehabilitation from estimated $800M to $260M by implementing a $180K SHM program**



Acknowledgment

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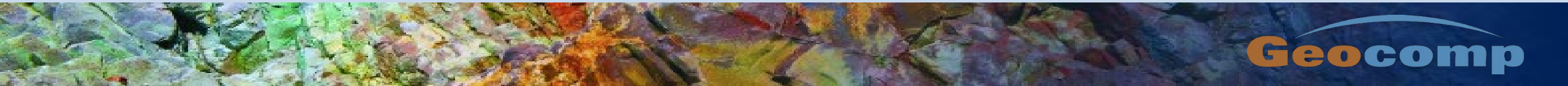

Questions?

Thank you!