NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

November 7, 2008

MATERIALS LABORATORY STUDY   Report No. 08-118

A. ACCIDENT

Place : Minneapolis, Minnesota
Date : August 1, 2007
Vehicle : I-35W Bridge
NTSB No. : HWY07MH024
Investigator : Mark Bagnard

B. TOPICS ADDRESSED

Calculation of the differential temperature on the east and west trusses as a result of the position of the sun on the day of the accident.

C. DETAILS OF THE STUDY

Following the gusset plate failure and near collapse of the Grand River bridge (LAK-90-2342 R) in Ohio on May 24, 1996, data were obtained from temperature sensors and strain gages placed on the main trusses of that bridge. The instrumentation and the data are described in a presentation attached as Appendix A. Temperature data were measured on September 4-5, 1996, showing that the exposed faces of the trusses reached temperatures above ambient as a result of solar heating. The Grand River bridge was aligned at approximately 45 degrees from North, and the data showed that the Southeast truss heated more quickly, reaching a peak temperature about 14 °F above ambient at about 1:30 pm, after which it began to cool. The Northwest truss began to heat up later in the day and reached a peak temperature about 11 °F above ambient at about 6 pm. The data from September 4, 1996 are shown in figure 1.

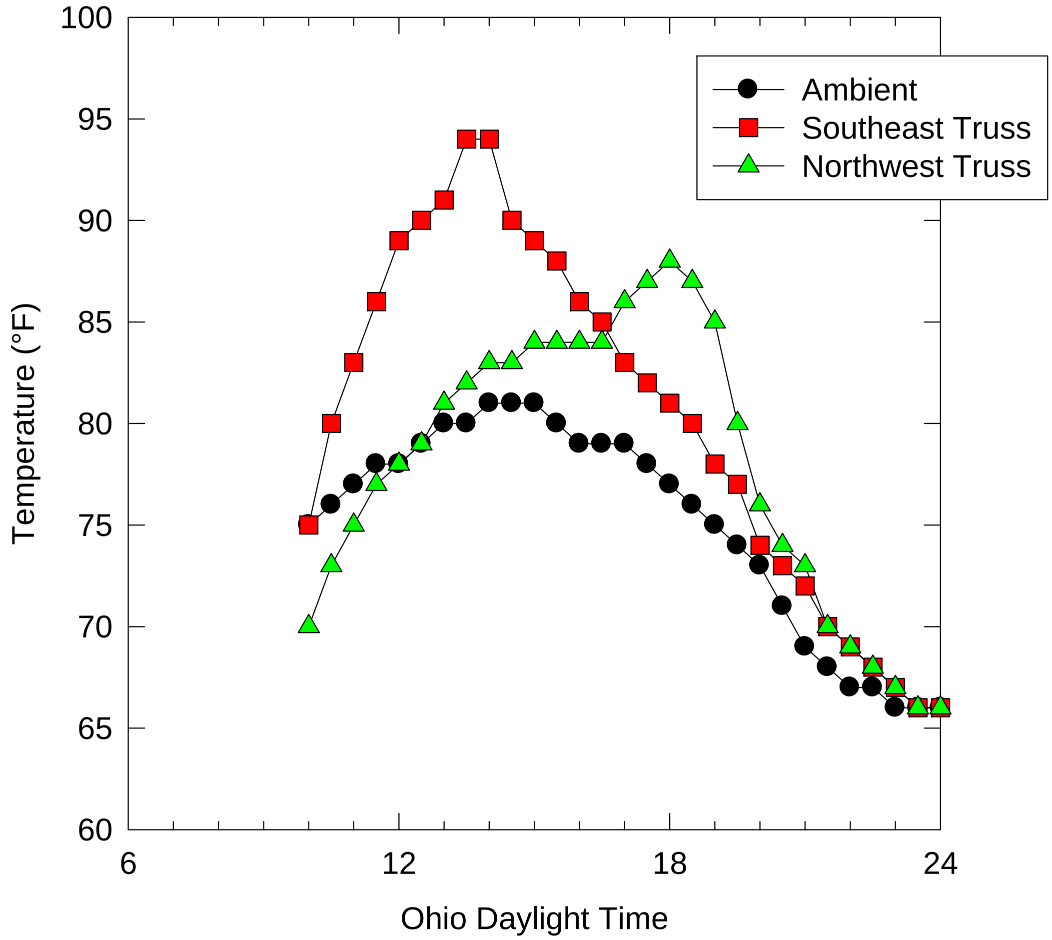


Figure 1. Temperature data from Ohio bridge LAK-90-2342 R taken on September 4, 1996.

The orientation of the Grand River bridge at about 45 degrees from north was such that the sun would have been aligned along the bridge at about 3:30 pm. When the ambient temperature was subtracted from the temperature data from the two trusses, the temperature profiles from the two trusses had more nearly symmetric shapes relative to the temperature at 3:30 pm, as shown in Figure 2.

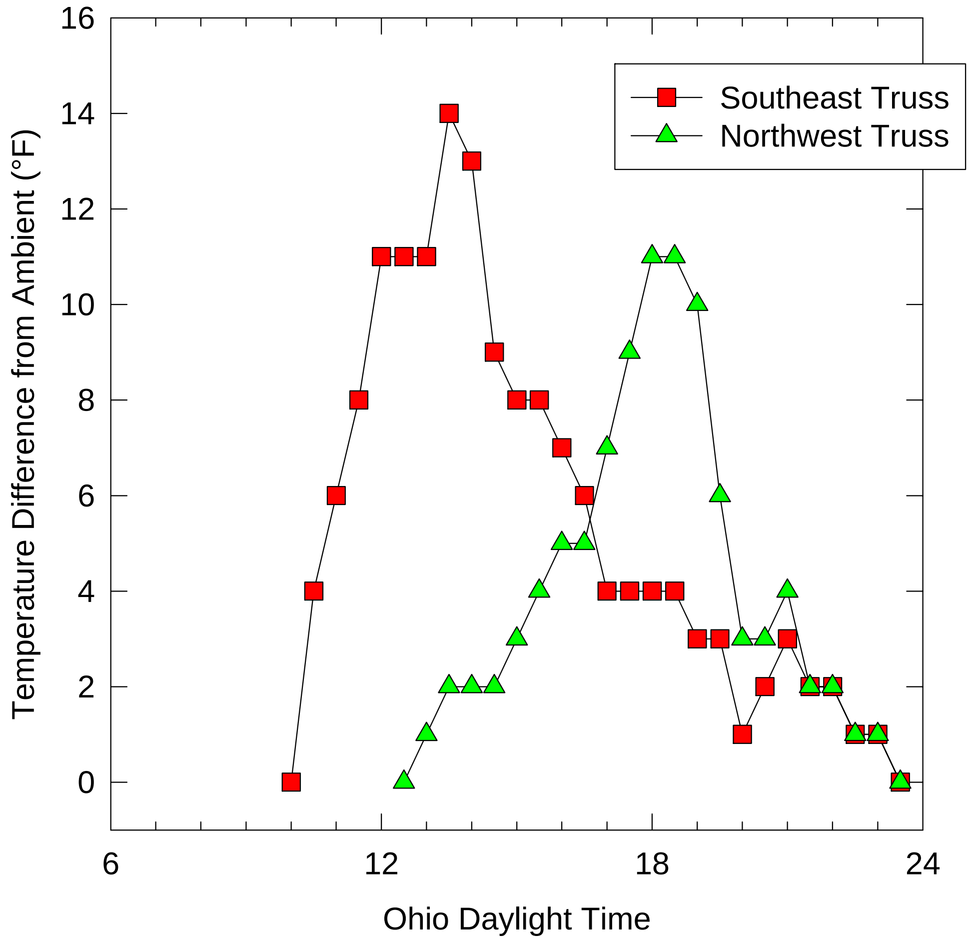


Figure 2. Temperature data from the two trusses after subtracting the ambient temperature.

The degree of symmetry is shown in Figure 3, where the temperature data from the Northwest truss has been reordered from last to first, then shifted to align the reordered data from the Northwest truss with the data from the Southeast truss at the time of 3:30 pm. It would be expected that the peak for the Southeast truss would be somewhat higher, as the sun did not begin to heat the Northwest truss until somewhat late in the day.

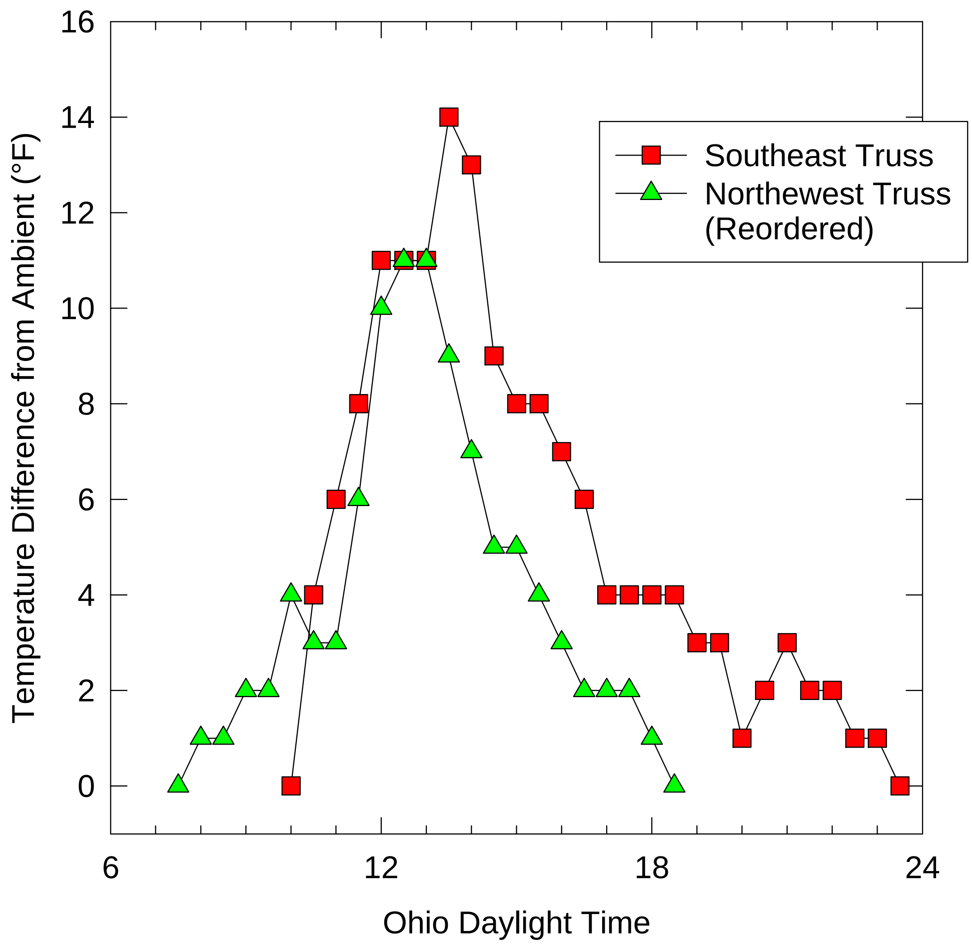


Figure 3. Temperature data from the two trusses after subtracting the ambient temperature, reordering the data from the Northwest truss from last to first, and then realigning the data to 3:30 pm.

The I-35W bridge was aligned at about 16 degrees from north, making it more nearly directly north and south than the Grand River bridge. Sun position data from the United States Naval Observatory shows that the sun would have been aligned with the bridge at about 2 pm (Daylight time) on August 1, 2007. Assuming that the temperature profiles on the two I-35W trusses would have been more symmetric around the 2 pm time, the two sets of data in Figure 3 were averaged together. The result was then smoothed using a 3-point averaging filter, and the peak difference from ambient rescaled to 14 °F. The time scale for the temperature change was also expanded to account for the longer day on August 1 compared to September

4 (14.5 hours versus 13 hours). The estimated temperature profiles for the two trusses are shown in Figure 4.

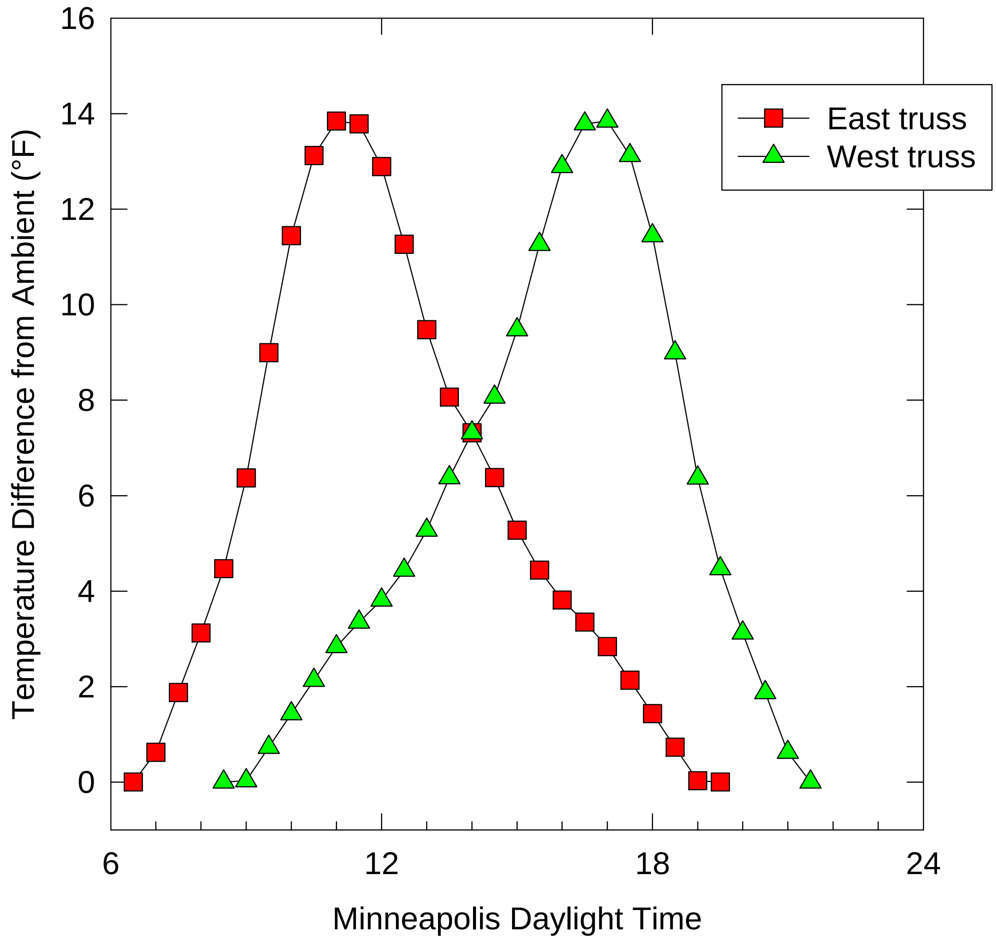


Figure 4. Estimated temperature deviation from ambient for the East and West trusses of the I-35W bridge on August 1, 2007.

The temperature data from the weather station on the University of Minnesota campus was interpolated to half-hour increments and smoothed with a 3-point averaging filter. Figure 5 shows the result of adding the data from Figure 4 to the ambient temperature from the University.

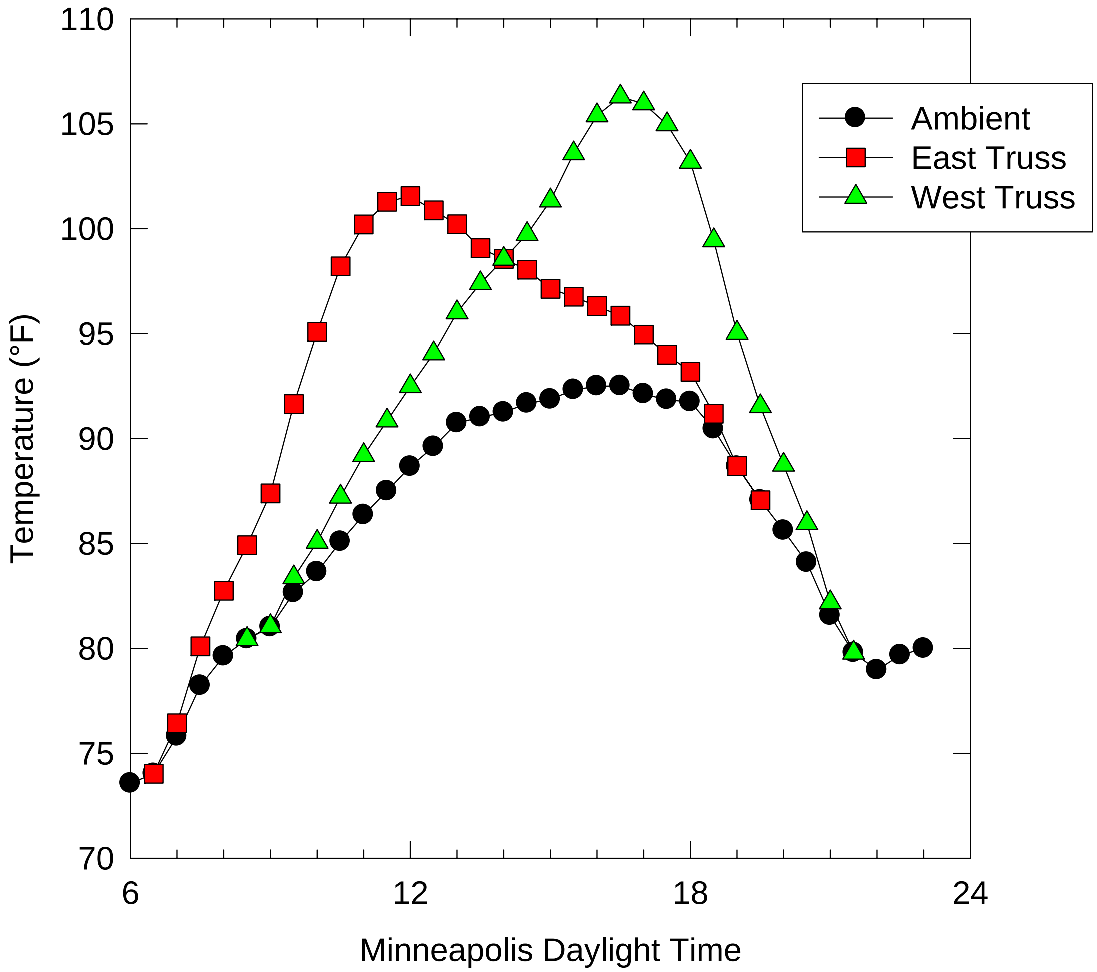


Figure 5. Ambient temperature data plus estimated temperatures in the East and West trusses of the I-35W bridge on August 1, 2007.

All of the data shown in the figures are tabulated below. The results provide an estimate that at 6 pm on August 1, 2007, the east truss was about 1.5 °F above ambient and the west truss was 11.5 °F above ambient.

Carl R. Schultheisz
Materials Research Engineer

Table 1. Temperature data from LAK-90-2342 R			
Time	Ambient temperature (°F)	Southeast truss (°F)	Northwest truss (°F)
10.0	75	75	70
10.5	76	80	73
11.0	77	83	75
11.5	78	86	77
12.0	78	89	78
12.5	79	90	79
13.0	80	91	81
13.5	80	94	82
14.0	81	94	83
14.5	81	90	83
15.0	81	89	84
15.5	80	88	84
16.0	79	86	84
16.5	79	85	84
17.0	79	83	86
17.5	78	82	87
18.0	77	81	88
18.5	76	80	87
19.0	75	78	85
19.5	74	77	80
20.0	73	74	76
20.5	71	73	74
21.0	69	72	73
21.5	68	70	70
22.0	67	69	69
22.5	67	68	68
23.0	66	67	67
23.5	66	66	66
24.0	66	66	66

Table 2. Temperature difference from ambient for LAK-90-2342 R			
Time	Southeast truss (°F)	Northwest truss (°F)	Northwest (reordered)
7.5			0
8.0			1
8.5			1
9.0			2
9.5			2
10.0	0		4
10.5	4		3
11.0	6		3
11.5	8		6
12.0	11		10
12.5	11	0	11
13.0	11	1	11
13.5	14	2	9
14.0	13	2	7
14.5	9	2	5
15.0	8	3	5
15.5	8	4	4
16.0	7	5	3
16.5	6	5	2
17.0	4	7	2
17.5	4	9	2
18.0	4	11	1
18.5	4	11	0
19.0	3	10	
19.5	3	6	
20.0	1	3	
20.5	2	3	
21.0	3	4	
21.5	2	2	
22.0	2	2	
22.5	1	1	
23.0	1	1	
23.5	0	0	

Table 3. Temperature deviations from ambient as constructed for the East and West trusses of the I-35W bridge on August 1, 2007.

Time	East truss (°F)	West truss (°F)
6.5	0	
7.0	0.62	
7.5	1.87	
8.0	3.12	
8.5	4.47	0
9.0	6.37	0.03
9.5	8.99	0.73
10.0	11.44	1.43
10.5	13.12	2.13
11.0	13.84	2.84
11.5	13.78	3.35
12.0	12.89	3.81
12.5	11.26	4.44
13.0	9.48	5.27
13.5	8.06	6.38
14.0	7.31	7.31
14.5	6.38	8.06
15.0	5.27	9.48
15.5	4.44	11.26
16.0	3.81	12.89
16.5	3.35	13.78
17.0	2.84	13.84
17.5	2.13	13.12
18.0	1.43	11.44
18.5	0.73	8.99
19.0	0.03	6.37
19.5	0	4.47
20.0		3.12
20.5		1.87
21.0		0.62
21.5		0

Table 4. Ambient temperature data and calculated differential temperatures for the two trusses for the I-35W bridge on August 1, 2007

Time	Ambient temperature (°F)	East truss (°F)	West truss (°F)
6.0	73.57		
6.5	74.02	74.02	
7.0	75.81	76.43	
7.5	78.22	80.09	
8.0	79.62	82.74	
8.5	80.44	84.91	80.44
9.0	81.01	87.38	81.04
9.5	82.64	91.64	83.37
10.0	83.63	95.08	85.07
10.5	85.08	98.21	87.22
11.0	86.36	100.2	89.19
11.5	87.5	101.28	90.85
12.0	88.66	101.55	92.47
12.5	89.6	100.86	94.04
13.0	90.73	100.2	96
13.5	91.01	99.07	97.39
14.0	91.24	98.56	98.56
14.5	91.67	98.05	99.73
15.0	91.86	97.13	101.34
15.5	92.32	96.76	103.58
16.0	92.49	96.31	105.38
16.5	92.5	95.85	106.28
17.0	92.11	94.95	105.95
17.5	91.84	93.98	104.96
18.0	91.74	93.17	103.18
18.5	90.44	91.17	99.44
19.0	88.66	88.69	95.03
19.5	87.05	87.05	91.52
20.0	85.61		88.74
20.5	84.08		85.96
21.0	81.55		82.18
21.5	79.79		79.79
22.0	78.96		

Appendix A
Presentation showing the instrumentation and data from the Grand River bridge

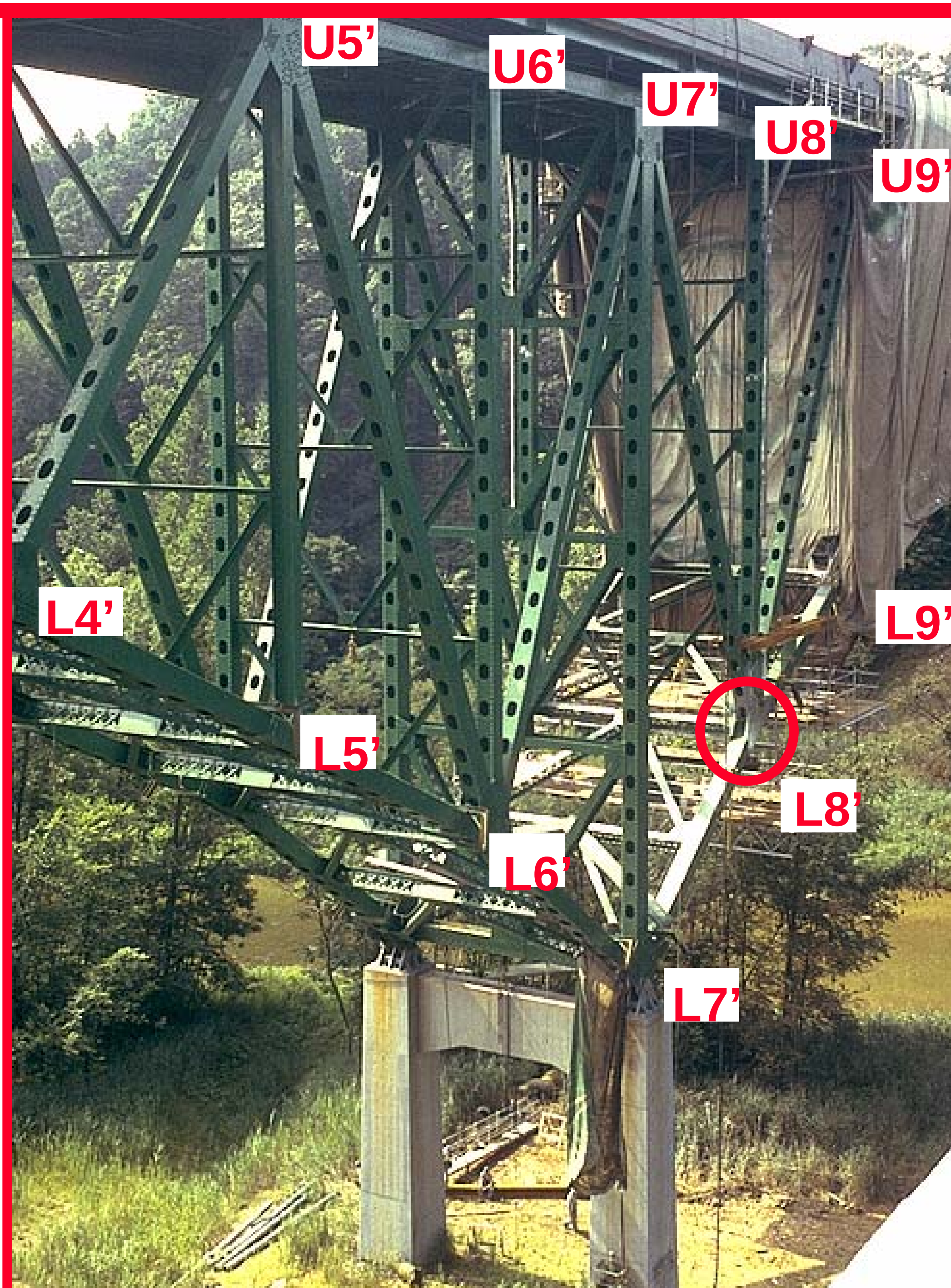
Case School Of Engineering

Art Huckelbridge
Dept. of Civil Engineering
Rick Snyder
Bridge Weighing Systems

Instrumentation and Repair Monitoring of LAK-90-2342 R Over the Grand River Lake County, Ohio

July - October, 1996

Case Western Reserve University



Twin bridges No. LAK-90-2342 L&R each carry two lanes of Interstate Route 90 vehicular traffic over the Grand River about 30 miles east of Cleveland at mile post 209.7. The structures were built in 1960. End spans 1 and 5 consist of reinforced concrete deck on simple span, parallel steel girders. Spans 2,3 and 4 consist of reinforced concrete deck on stringers and floorbeams, carried by two lines of arched cantilevered deck trusses. The spans are about 75, 208, 297, 208 and 75 feet. Span 3 includes a 178 foot suspended span. The trusses are on chords of a 0^{o} - 28' horizontal curve.

On May 24, 1996 the truss connection at joint L8' at the east end of the eastbound structure failed in the north and south trusses. The gusset plates supporting the verticals and compression diagonals buckled and allowed the member ends to drop about 3 inches and move laterally about 3 inches. The damaged members were in the truss cantilever supporting the center suspended span. The bridge was closed to traffic.

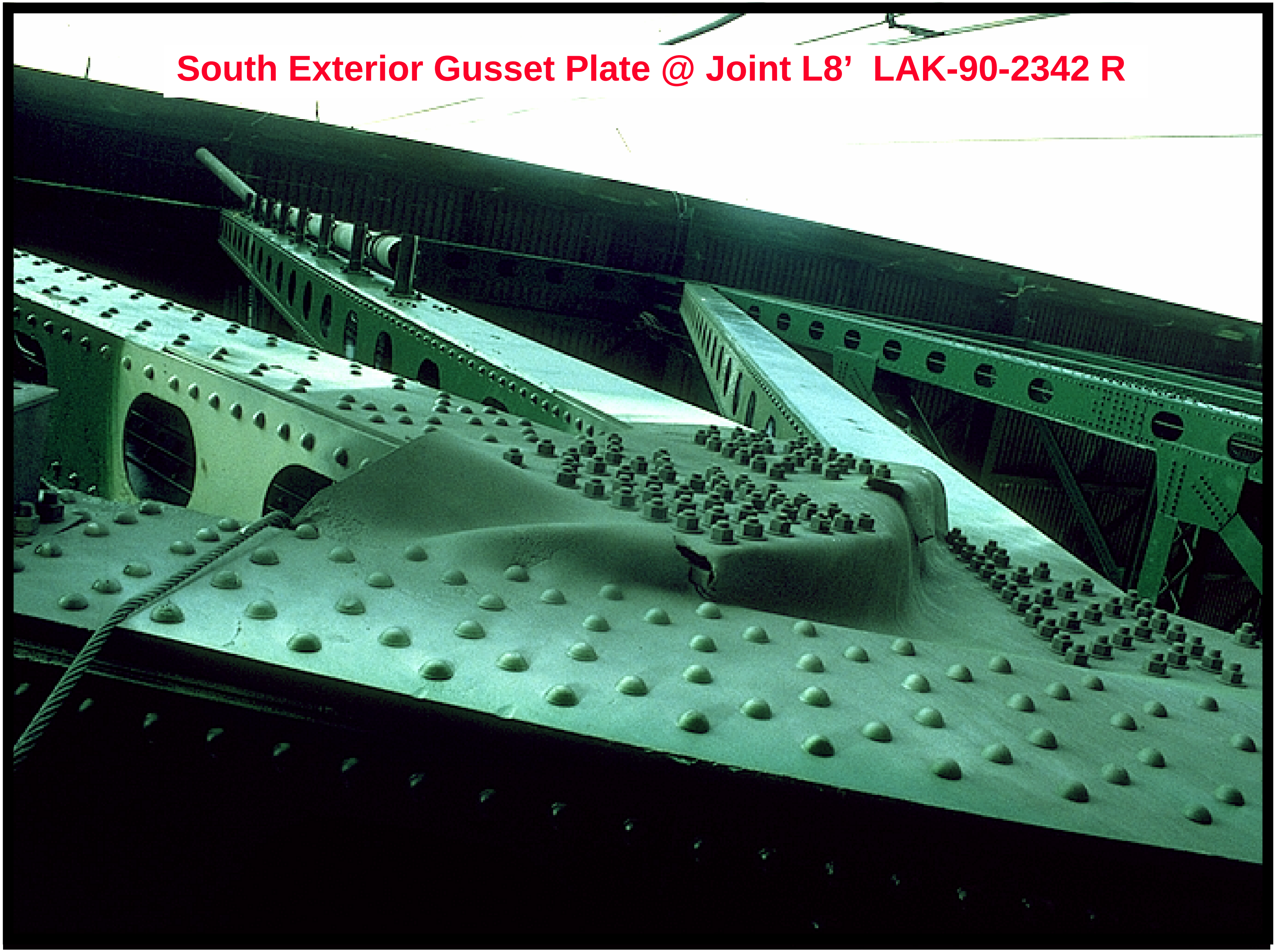
At the time of failure a contractor was painting the structural steel of the bridge. The work began earlier in May and was progressing from the east end of the bridge toward the west end of the bridge. On the day of the failure the contractor had a line of trucks and equipment on the right shoulder of the bridge, the right lane was closed to traffic, and traffic was being maintained in the left lane.

All other gusset plates similar to L8' in the twin bridges have been strengthened with the addition of stiffening angles bolted to the plates. The failed truss connections at joint L8' of the eastbound structure have been lifted, realigned and reconstructed. Temporary support (rods) were removed (from between joints L8' and U7') on October 14 (and 16), 1996.

Excerpts from a 10/21/96 discussion on the LAK-90-2342 R bridge, authored by Dean Palmer, P.E. ,of Richland Engineering Ltd., engineering consultants for the repair/retrofit of LAK-90-2342 R.


I90 Eastbound
Location of Damaged Gusset Plates

North Exterior Gusset Plate @ Joint L8’ LAK-90-2342 R


South Exterior Gusset Plate @ Joint L8’ LAK-90-2342 R

LAK-90-2342 R

View of Failed Joints @ L8’ Taken From Catwalk Below U9’

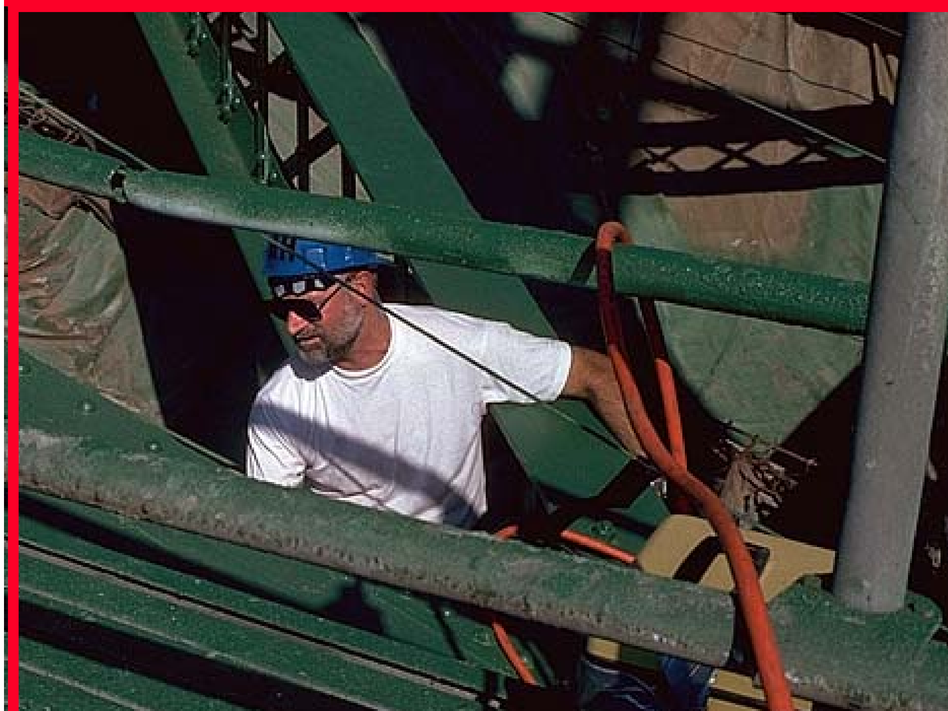
As part of the repair/retrofit process, all 5 main structural members connecting to joint L8' , in both the north and south trusses , were instrumented with strain gages. Each member had 4 strain gages, positioned near each of its corners, at a section near the midspan of the member. In addition to these 40 strain gages on the main members, each of 8 post-tensioned rods, anchored at joint U7' and running down to joint L8' (in order to provide supplemental support in each of the trusses) were also instrumented with strain gages prior to the tensioning operations.

Three temperature sensors were also installed. One sensor was located on the deck to monitor ambient air temperatures. One sensor was placed against an exposed face of the south truss and covered by insulation, in order to monitor steel temperatures on the south truss. A third sensor was similarly located and covered on the north truss.

All instrument readings were continually recorded at five minute intervals for the duration of the repair activity. Background thermal stress data, recorded prior to actual repair operations, served as a database to "correct for temperature" during subsequent repair and jacking operations. Daily 5 AM readings (when thermal gradients throughout the structure were minimized) provided a "running record" of the state of the structure, and of the impact of the various repair operations upon the stress distribution in the structure.

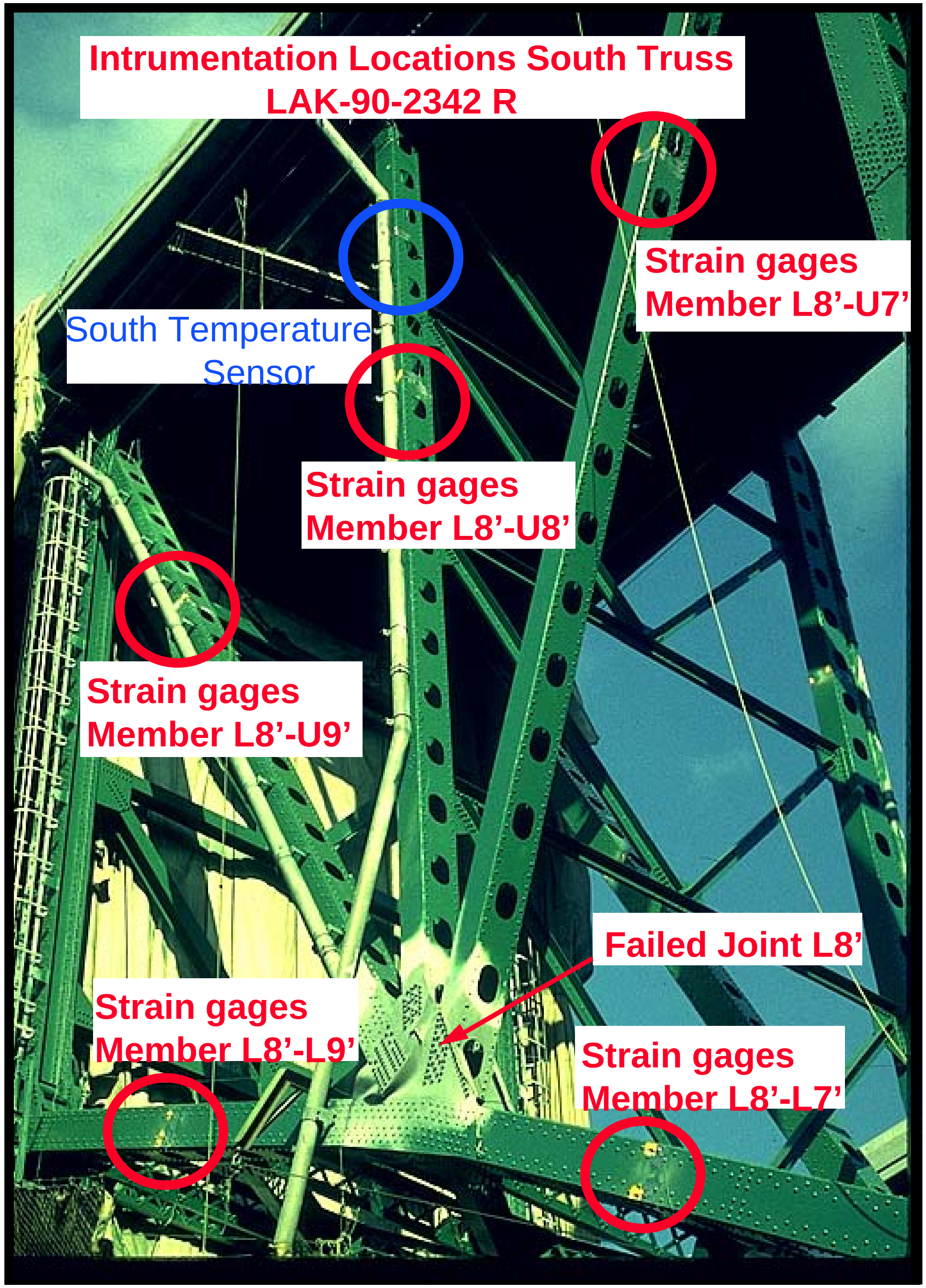
Prior to reopening of the structure, a "live load" test of the structure was carried out, utilizing an ODOT dump truck loaded to just over 50,000 lbs. "Influence lines" for each of the instrumented main members in the repaired section were obtained for each traffic lane of the bridge.

Strain Gage Installation
LAK-90-2342 R

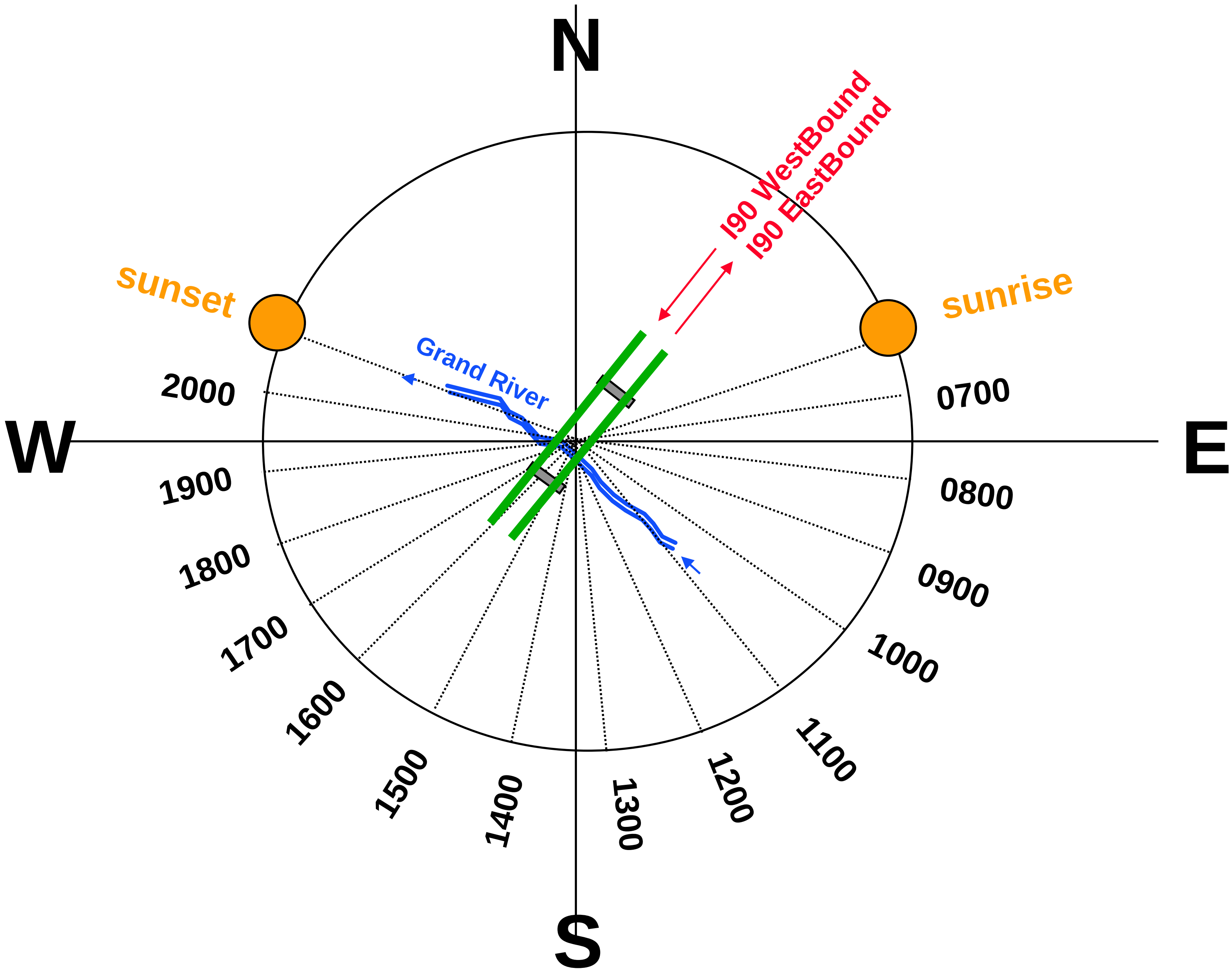


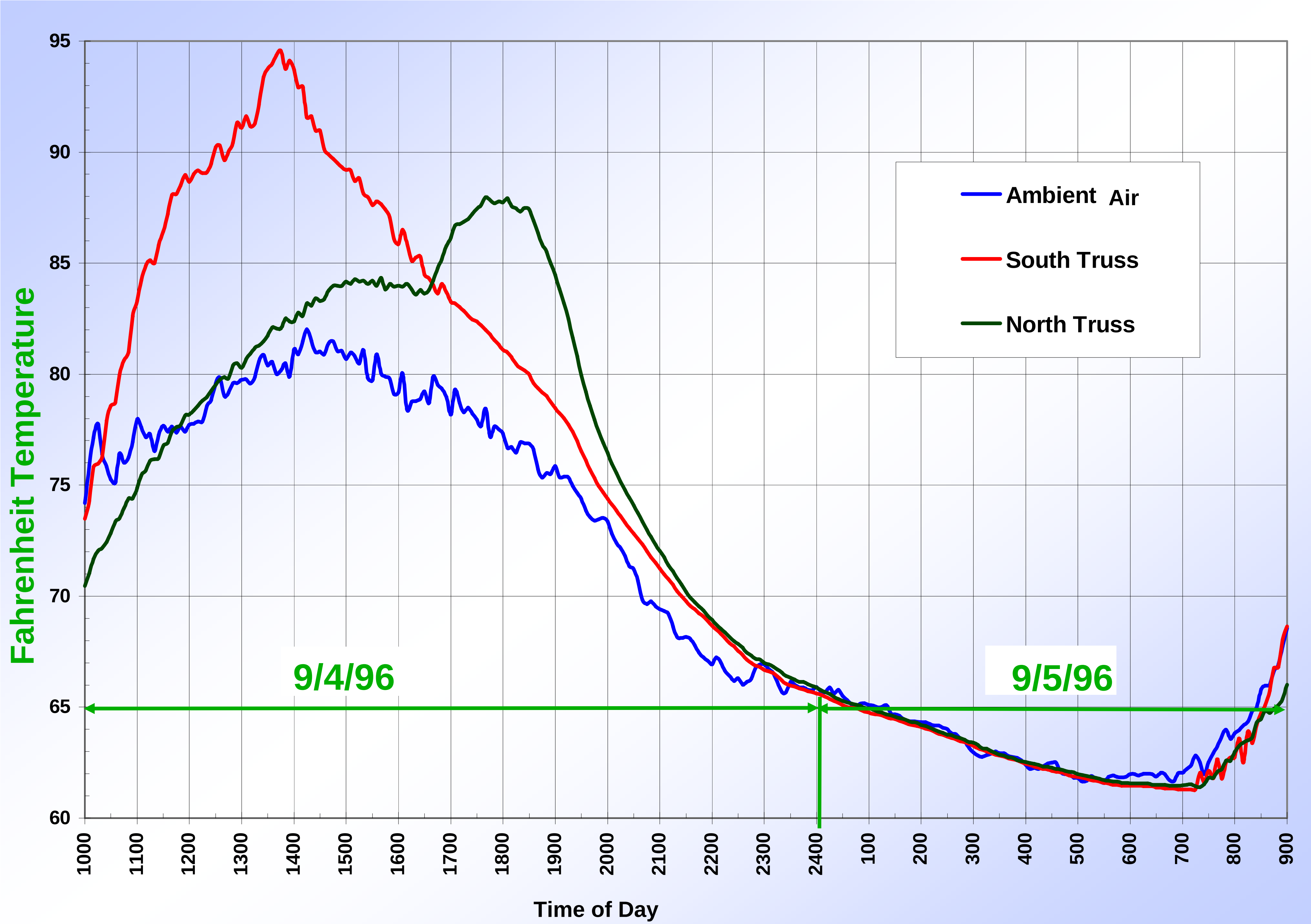

Strain Gages
L8'-U7' LAK-90-2343 R


Strain Gages
L8'-L7' LAK-90-2343 R

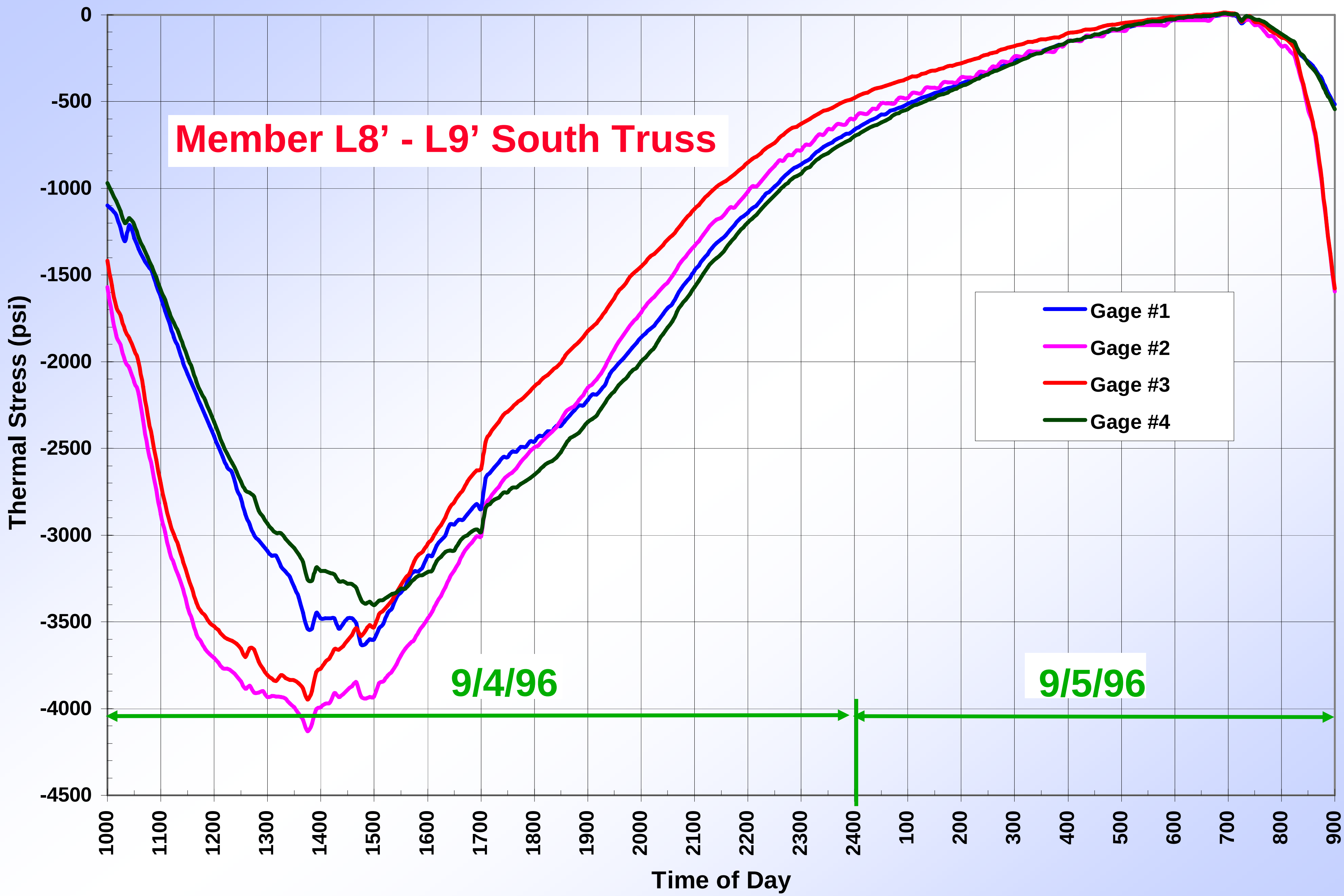

Intrumentation Locations South Truss
LAK-90-2342 R
Strain gages
Member L8’-U7’
South Temperature
Sensor
Strain gages
Member L8’-U8’
Strain gages
Member L8’-U9’
Failed Joint L8’
Strain gages
Member L8’-L9’
Strain gages
Member L8’-L7’

LAK-90-2342 R : Approximate Sun Orientation (August)

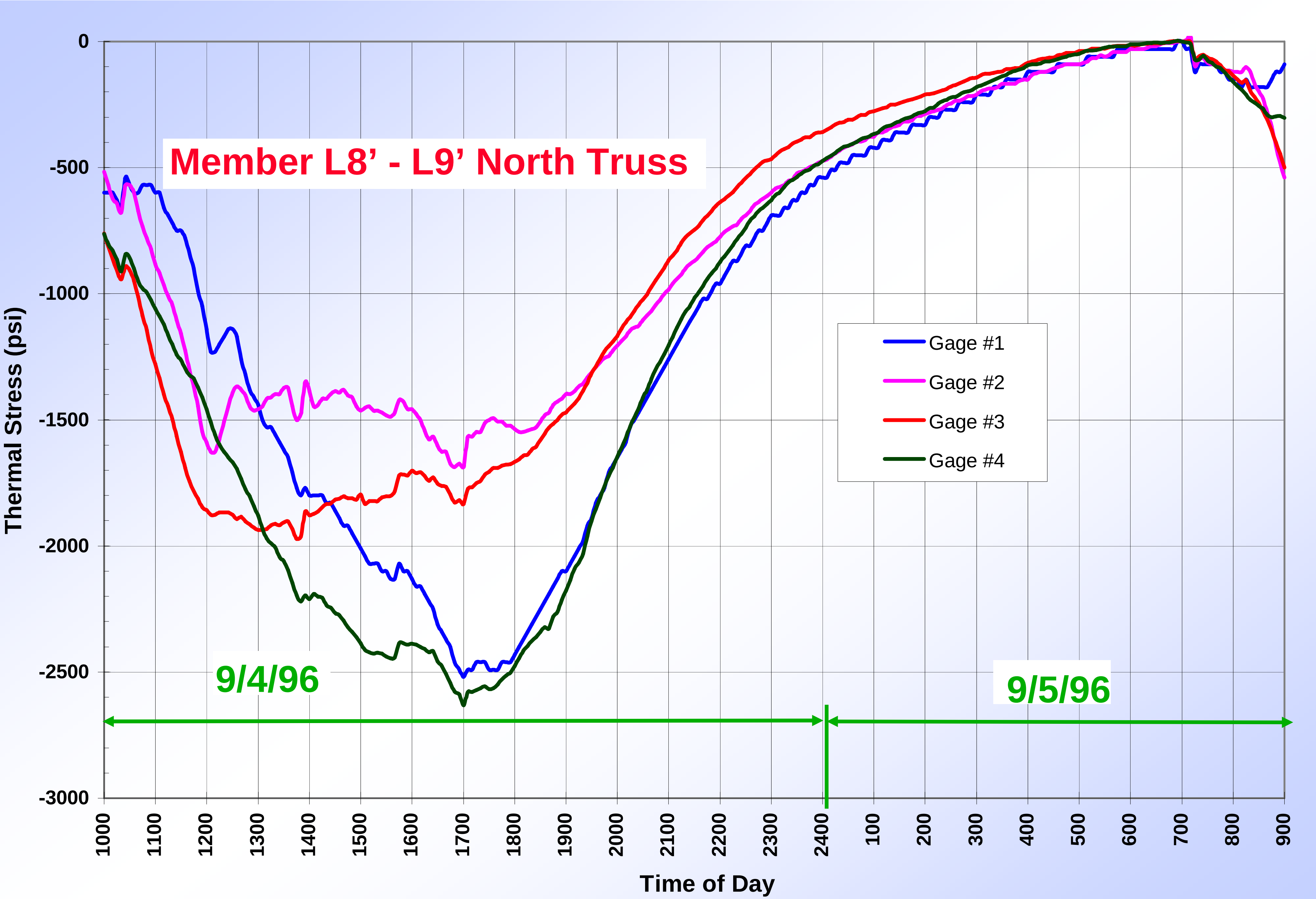




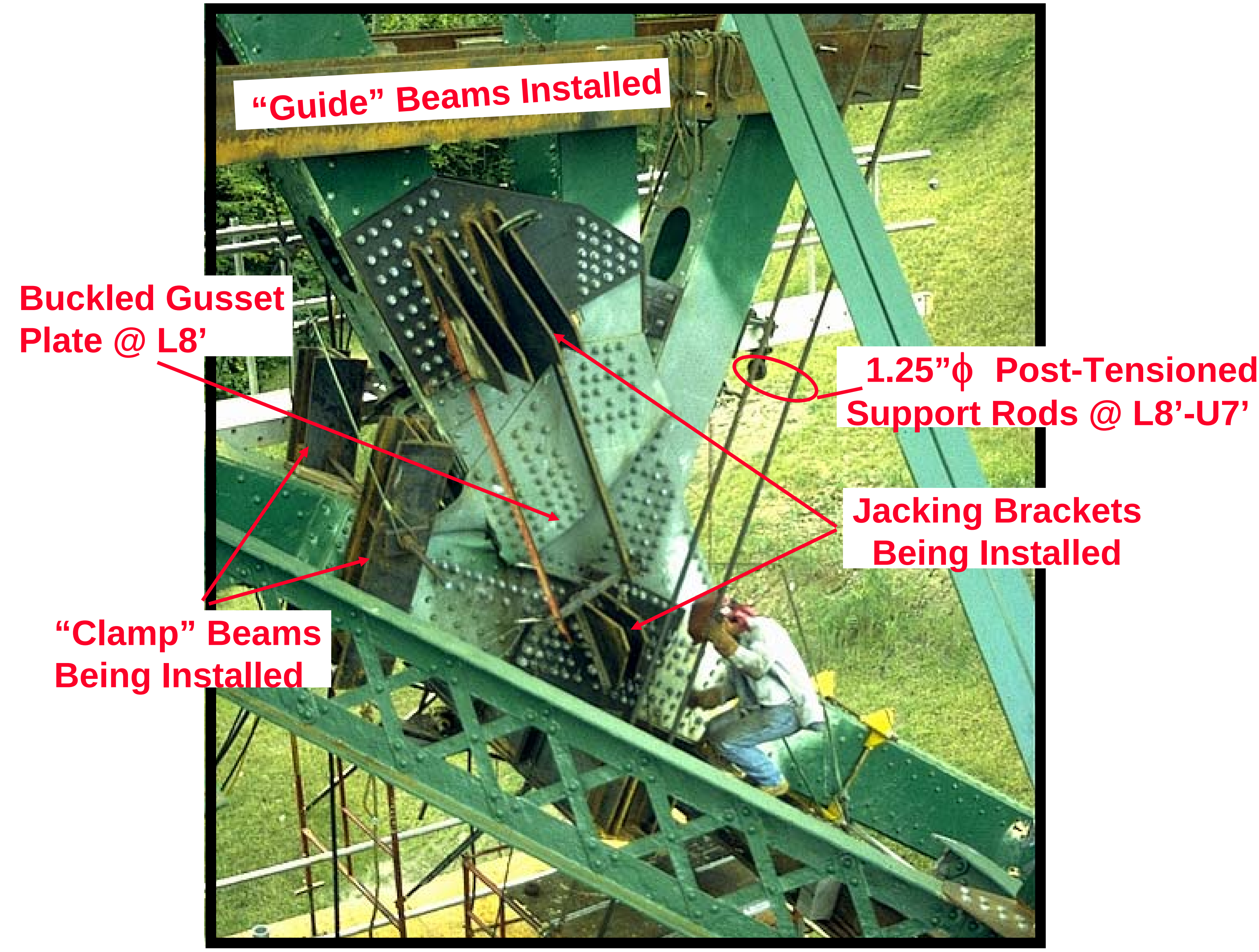
Typical Daily Temperature Fluctuations Measured on LAK-90-23242 R



Typical Daily Thermal Stress Fluctuations Measured on LAK-90-23242 R

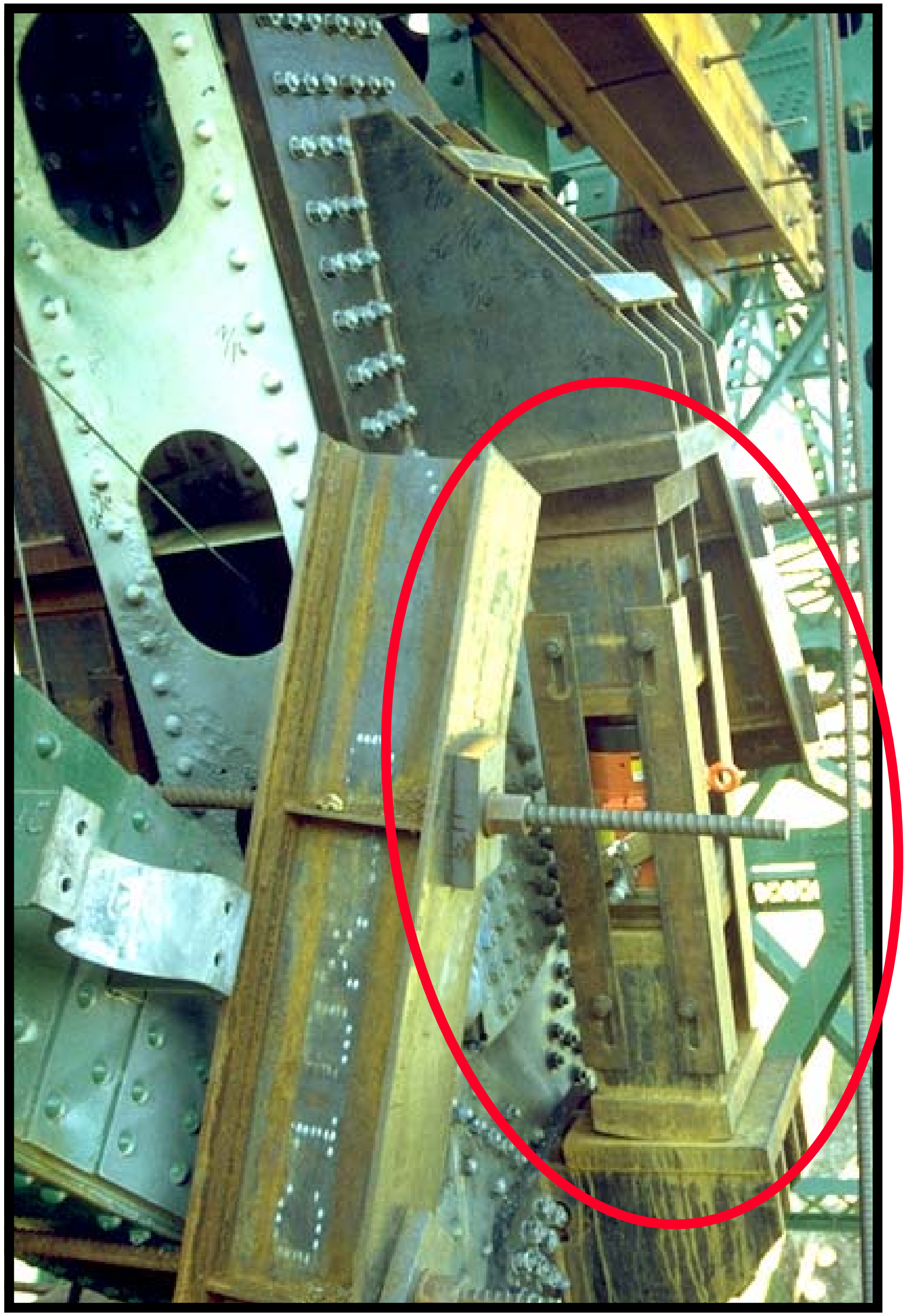


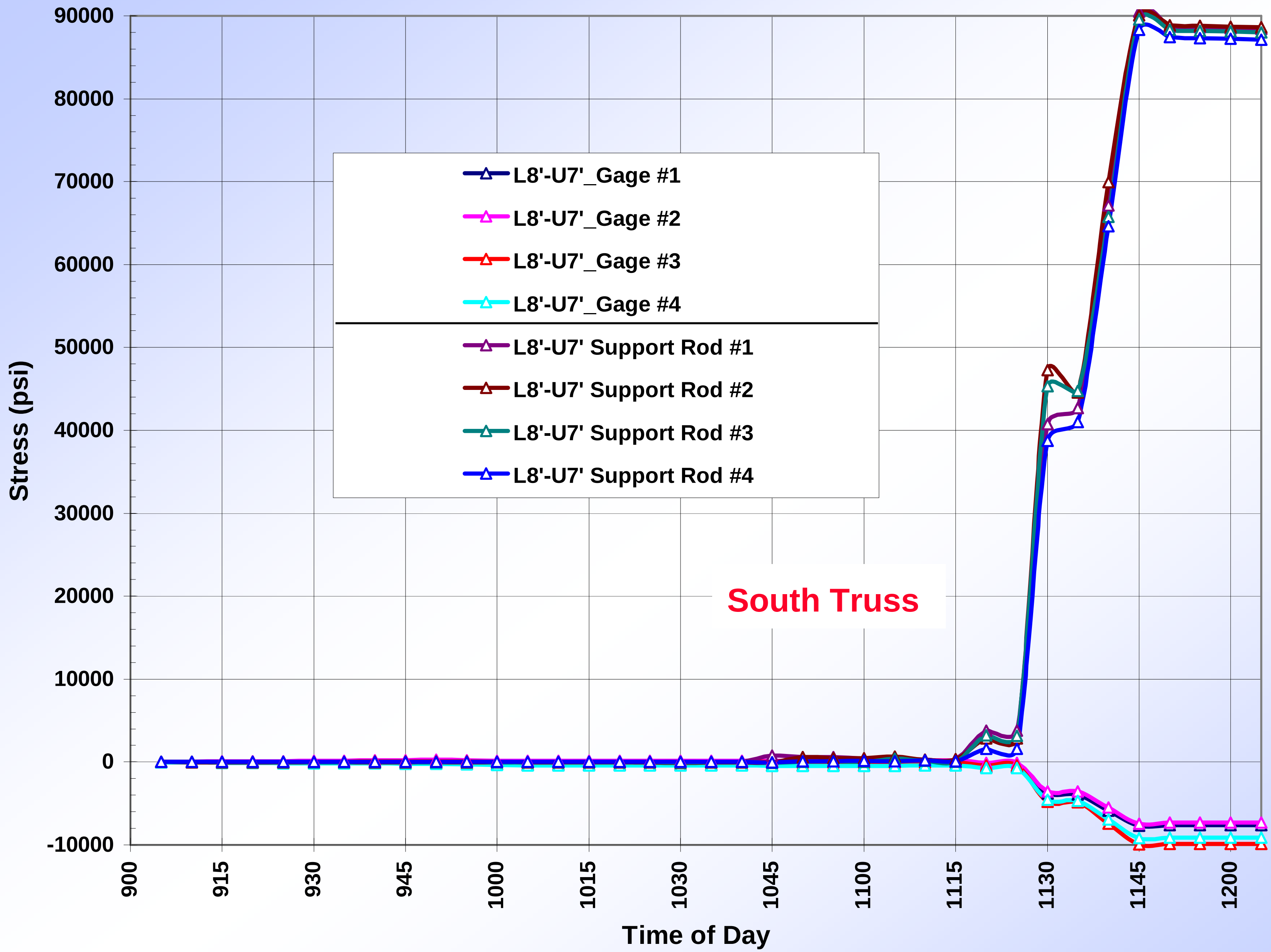
Typical Daily Thermal Stress Fluctuations Measured on LAK-90-23242 R



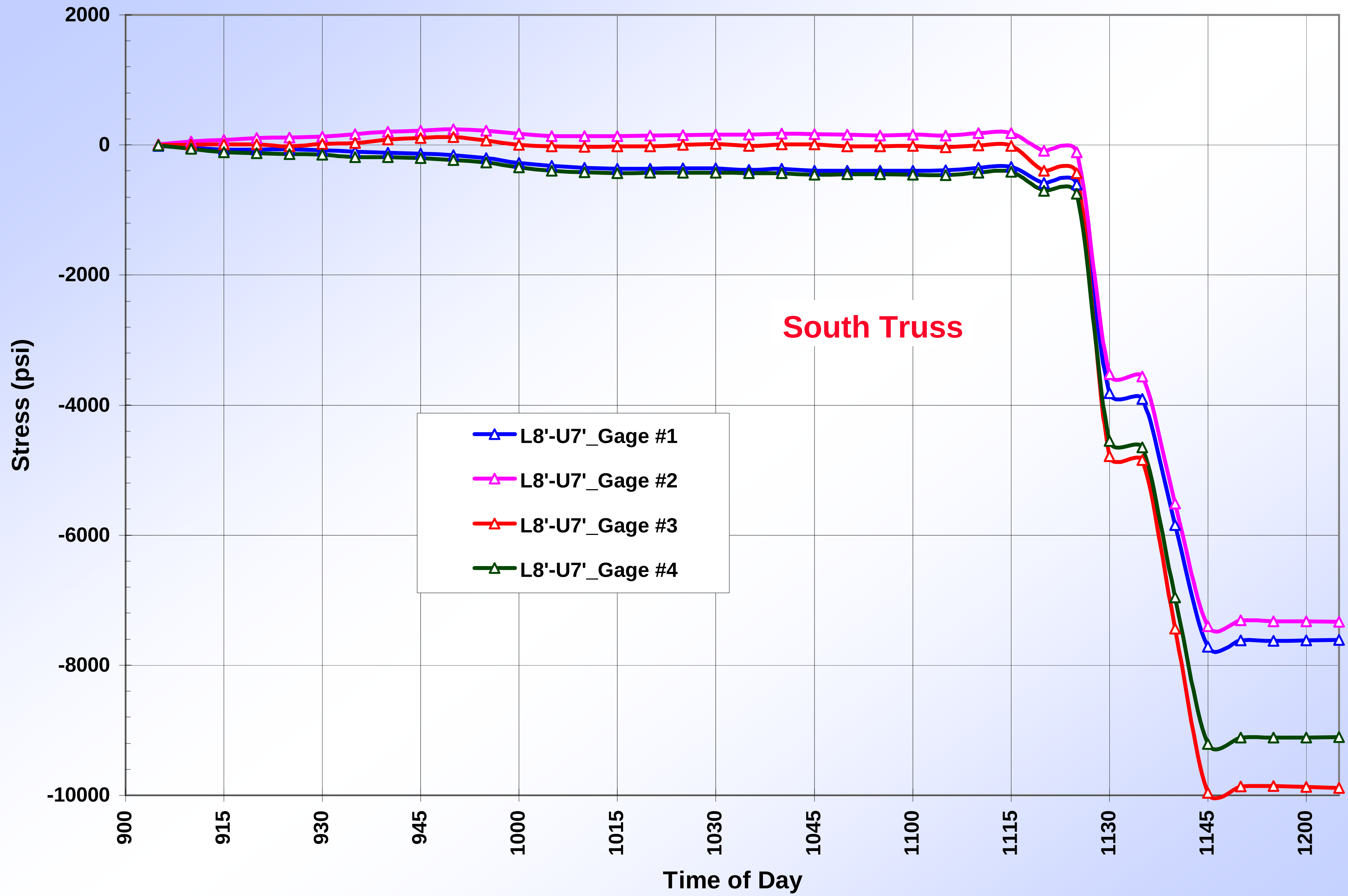
"Guide" Beams Installed
Buckled Gusset Plate @ L8'
1.25"ϕ Post-Tensioned Support Rods @ L8'-U7'
Jacking Brackets Being Installed
"Clamp" Beams Being Installed

South Exterior Jack in Place in Preparation to Raise Members L8’-U9’ & L8’-U8’

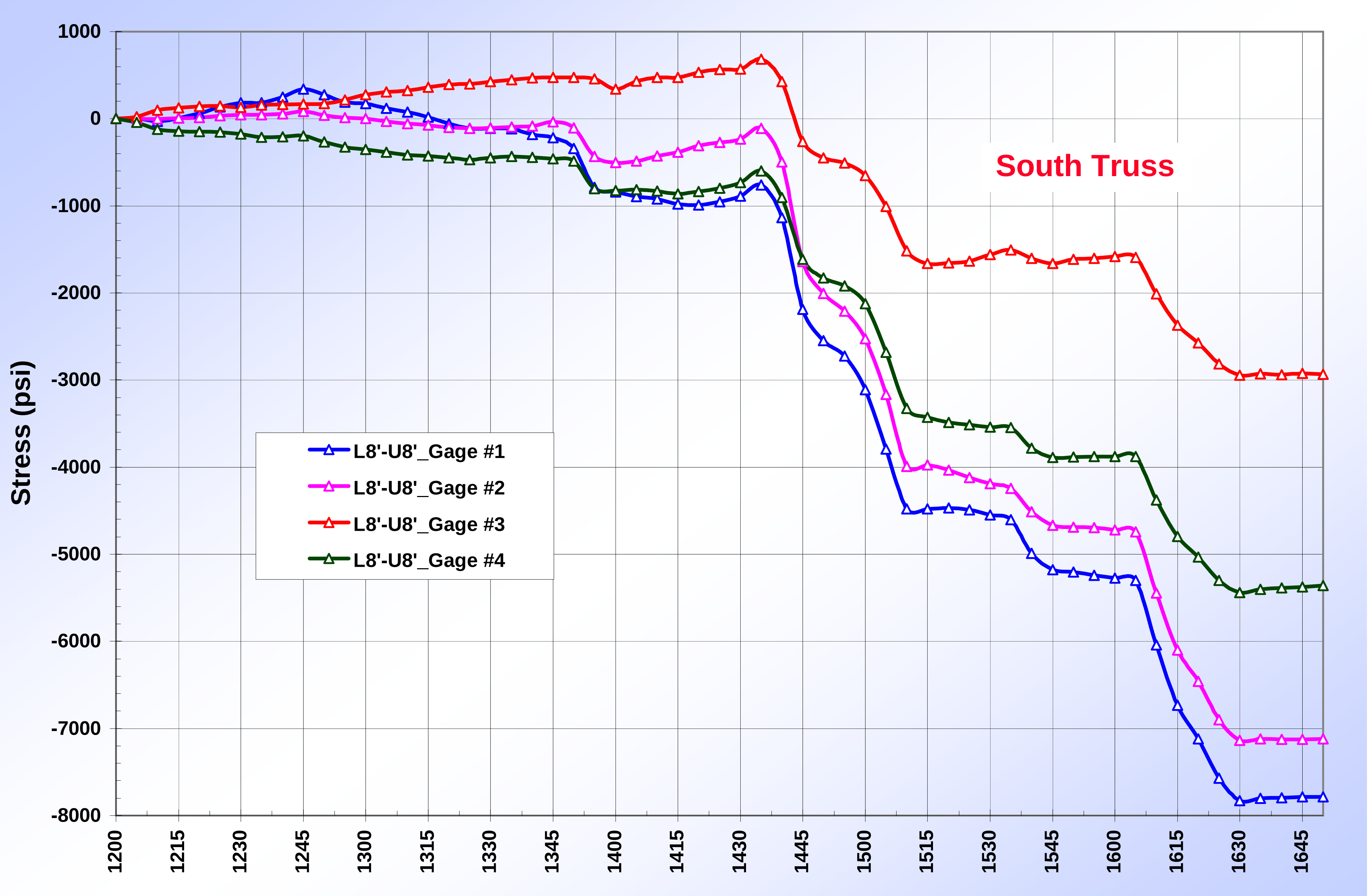




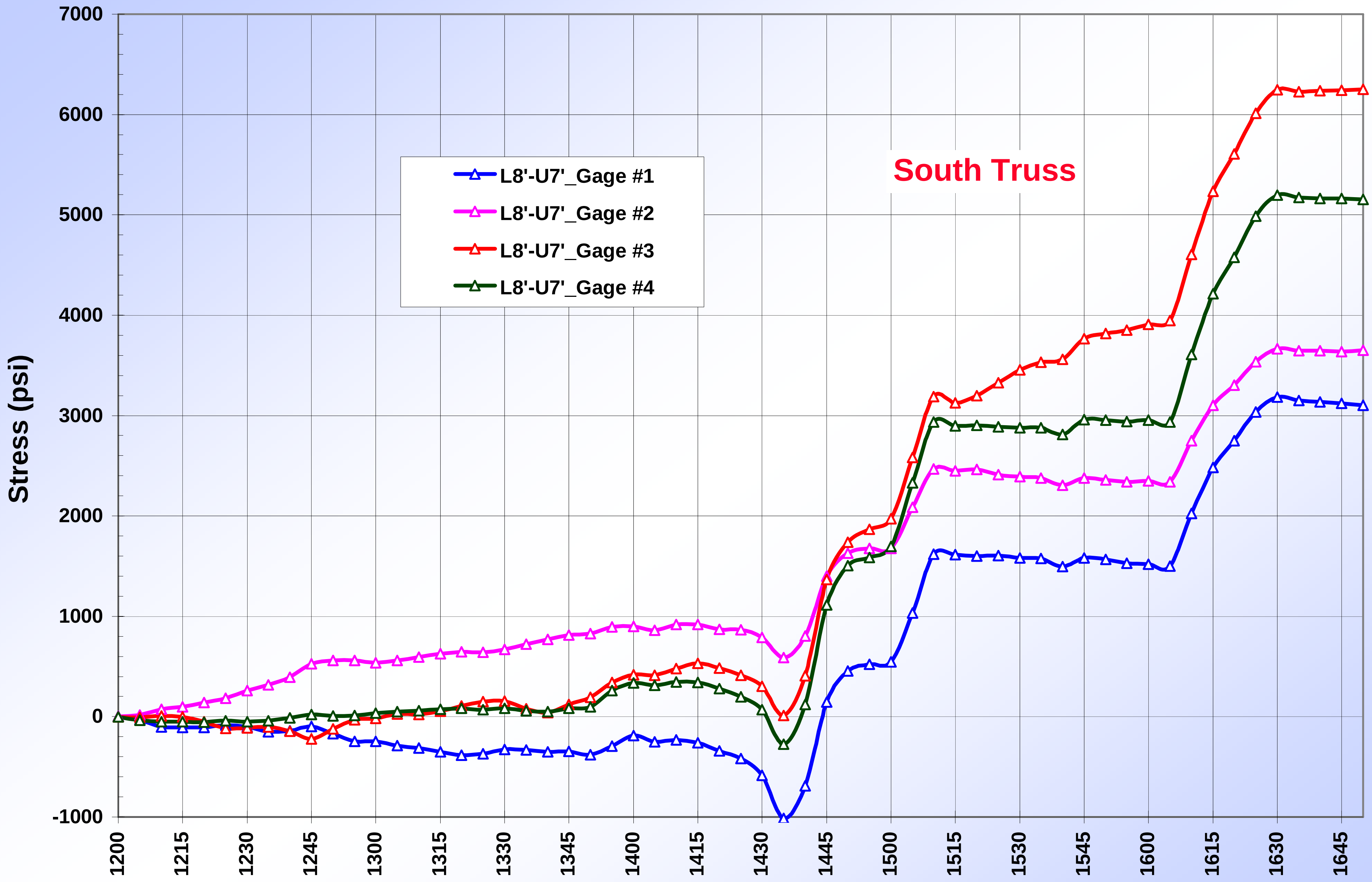
Real Time Monitoring on Morning of 9/16/96 During Tensioning of South Truss Support Rods at Member L8’-U7’



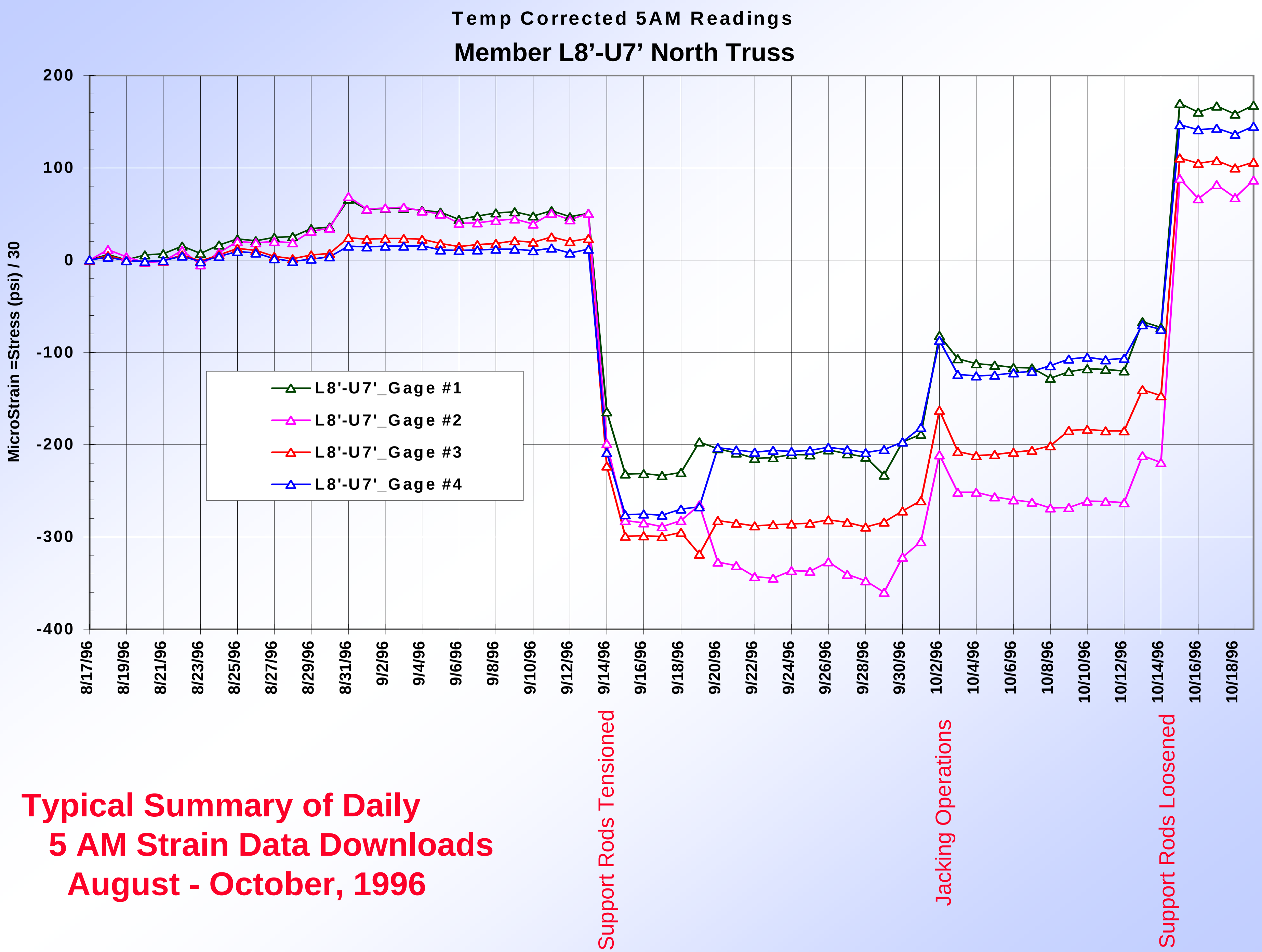
Real Time Monitoring on Morning of 9/16/96 During Tensioning of South Truss Support Rods at Member L8'-U7'



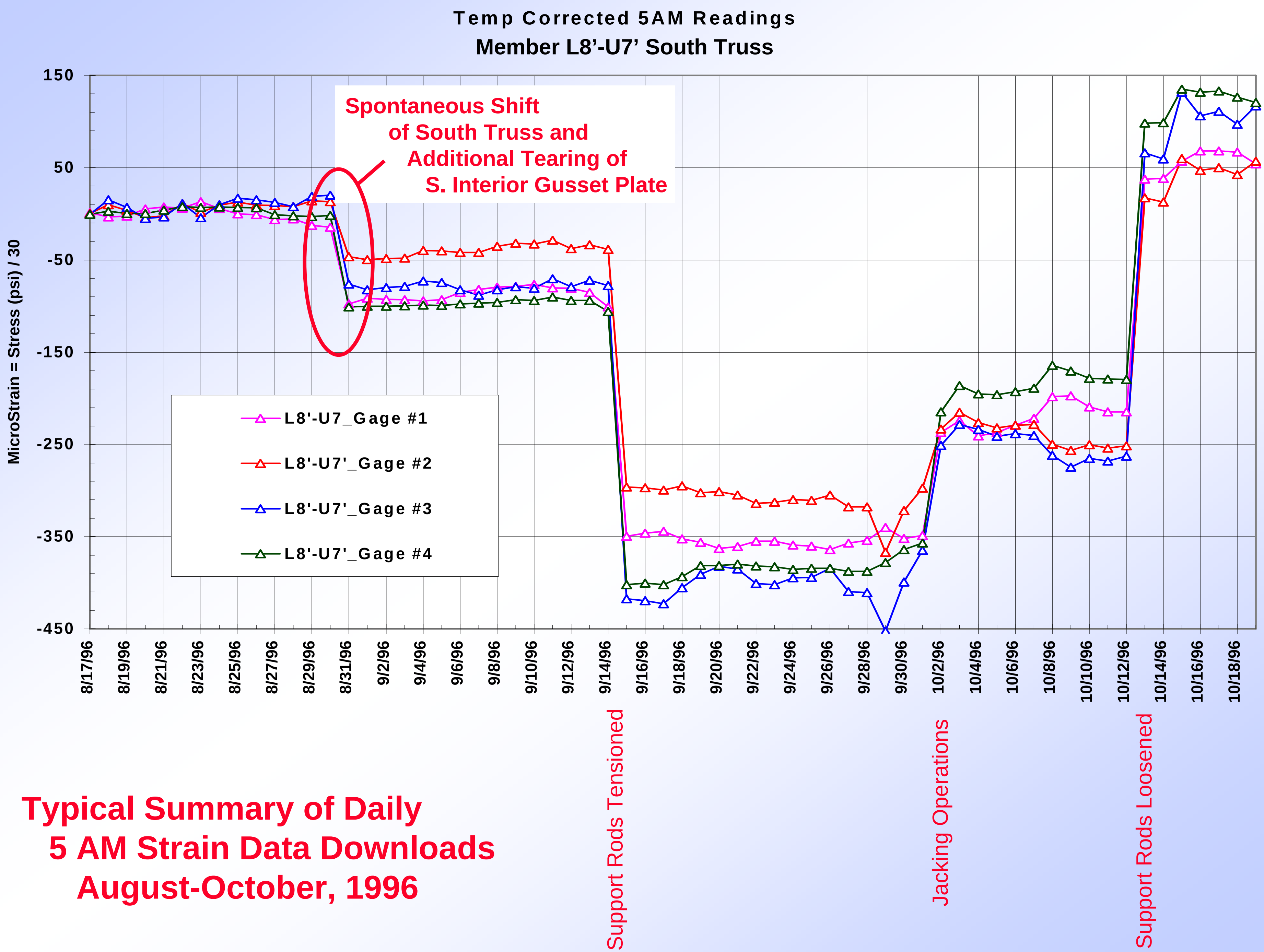
Real Time Monitoring on 10/1/96 During Jacking Operations to Raise Members L8’U9’ and L8’-U8’



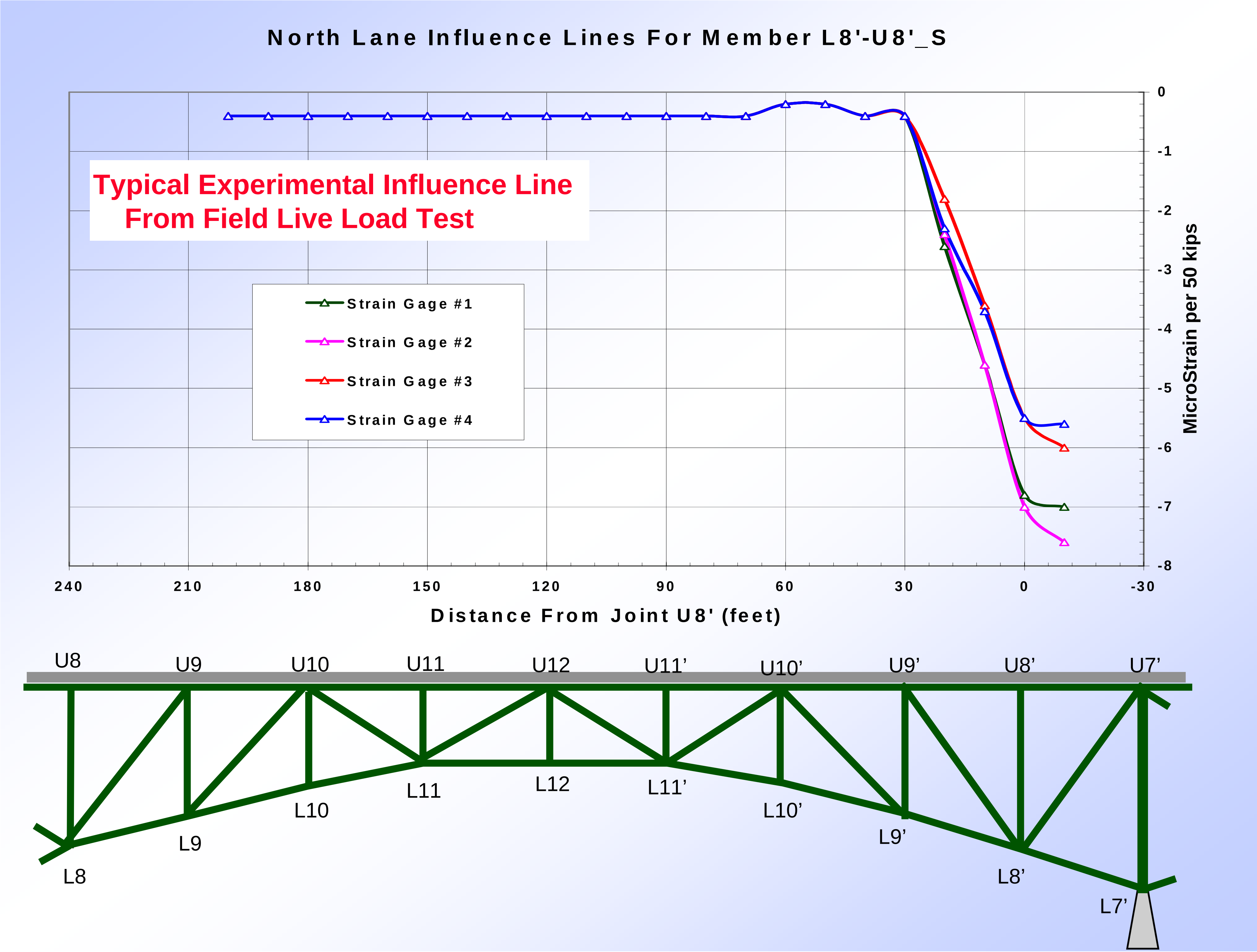
Real Time Monitoring on 10/1/96 During Jacking Operations
to Raise Members L8'U9' and L8'-U8'

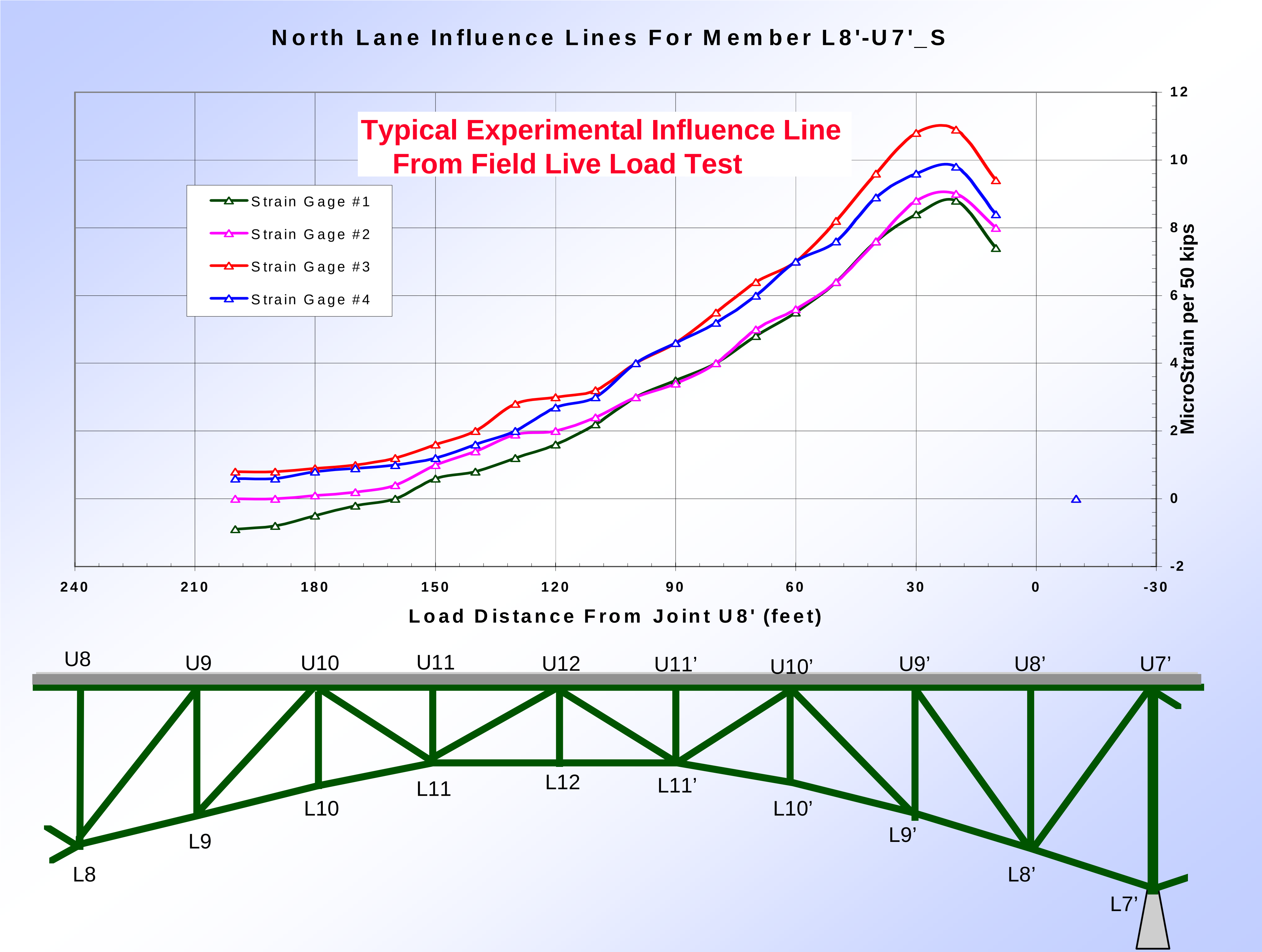


Typical Summary of Daily
5 AM Strain Data Downloads
August - October, 1996



Typical Summary of Daily
5 AM Strain Data Downloads
August-October, 1996


North Lane Influence Lines For Member L8'-U8'_S
Typical Experimental Influence Line
From Field Live Load Test
Strain Gage #1
Strain Gage #2
Strain Gage #3
Strain Gage #4
0
-1
-2
-3
-4
-5
-6
-7
-8
MicroStrain per 50 kips
240
210
180
150
120
90
60
30
0
-30
Distance From Joint U8' (feet)
U8
U9
U10
U11
U12
U11'
U10'
U9'
U8'
U7'
L8
L9
L10
L11
L12
L11'
L10'
L9'
L8'
L7'


North Lane Influence Lines For Member L8'-U7'_S
Typical Experimental Influence Line
From Field Live Load Test
Strain Gage #1
Strain Gage #2
Strain Gage #3
Strain Gage #4
MicroStrain per 50 kips
Load Distance From Joint U8' (feet)
240
210
180
150
120
90
60
30
0
-30
12
10
8
6
4
2
0
-2
U8
U9
U10
U11
U12
U11'
U10'
U9'
U8'
U7'
L8
L9
L10
L11
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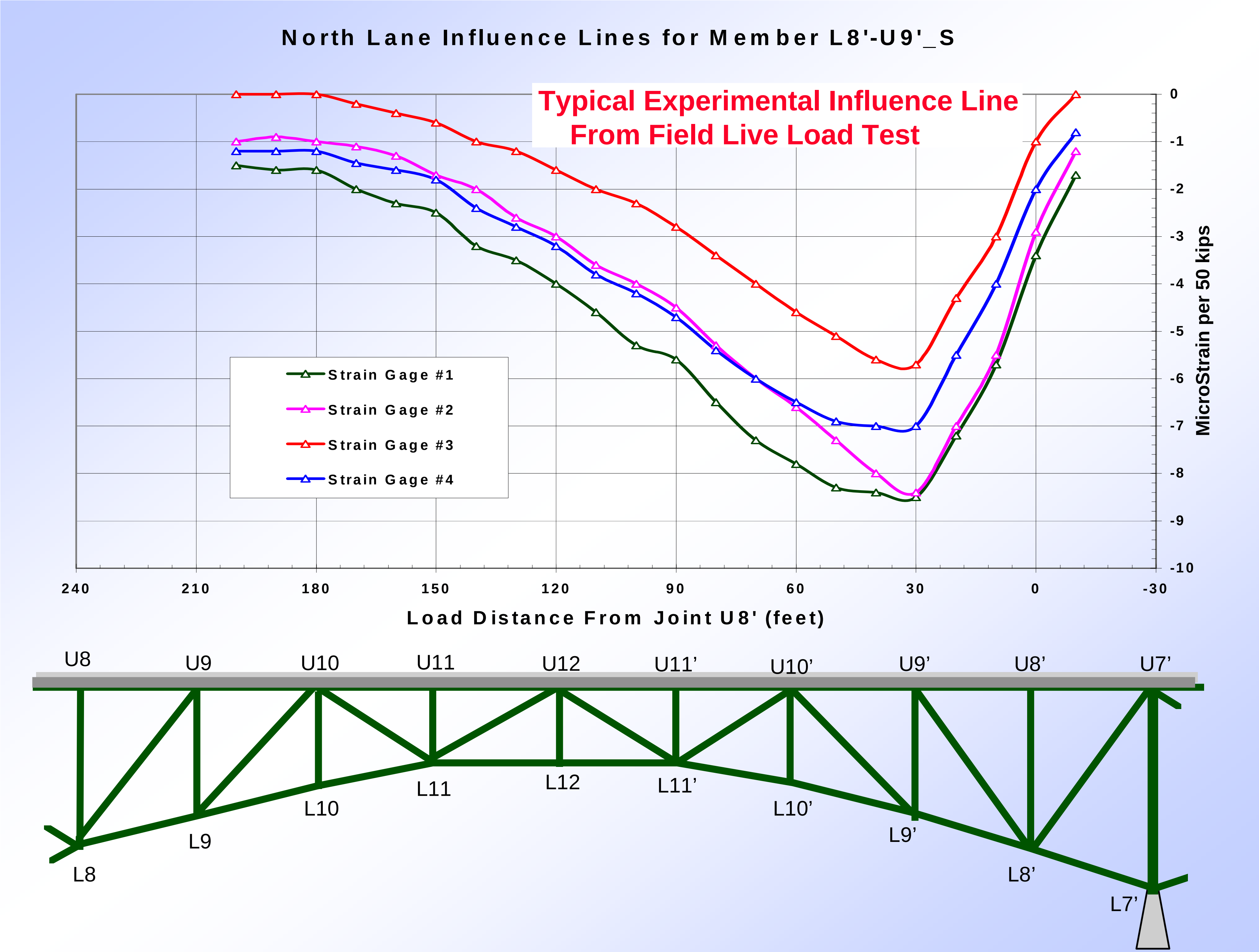
L11'
L10'
L9'
L8'
L7'


North Lane Influence Lines for Member L8'-U9'_S
Typical Experimental Influence Line
From Field Live Load Test
Strain Gage #1
Strain Gage #2
Strain Gage #3
Strain Gage #4
MicroStrain per 50 kips
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
240
210
180
150
120
90
60
30
0
-30
Load Distance From Joint U8' (feet)
U8
U9
U10
U11
U12
U11'
U10'
U9'
U8'
U7'
L8
L9
L10
L11
L12
L11'
L10'
L9'
L8'
L7'