Live Load Testing and Long Term Monitoring of the Varina-Enon Bridge

Marc Maguire – Utah State University
Carin Roberts-Wollmann – Virginia Tech
Tommy Cousins – Clemson University

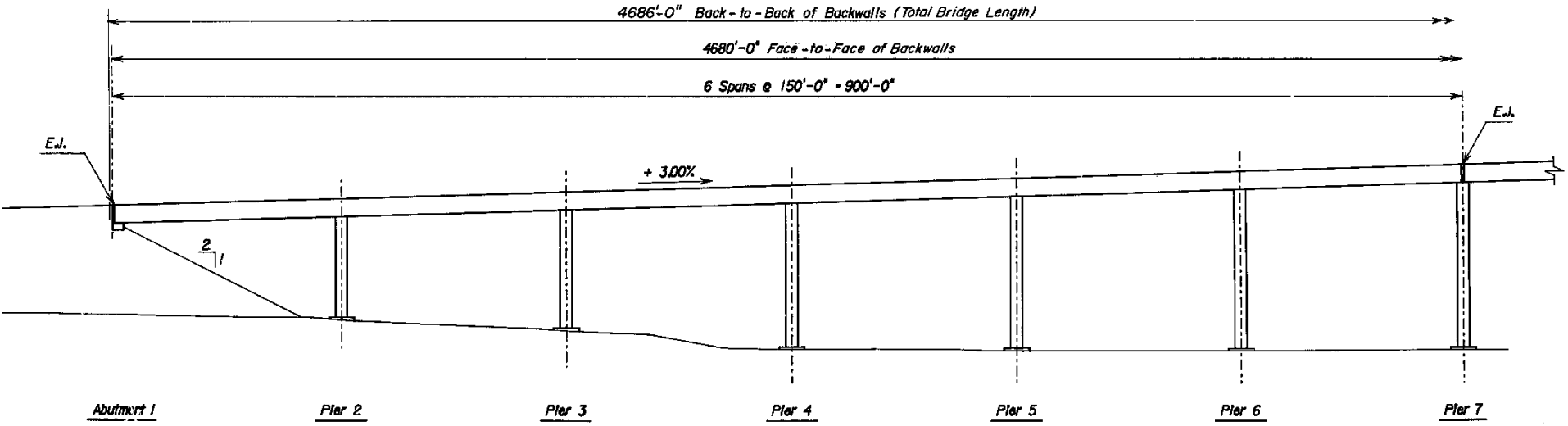
Fall 2015 ACI Convention

Outline

- Varina-Enon Bridge and observed distress
- Live load test results and comparison to simple models
- Long term monitoring system and one year of data

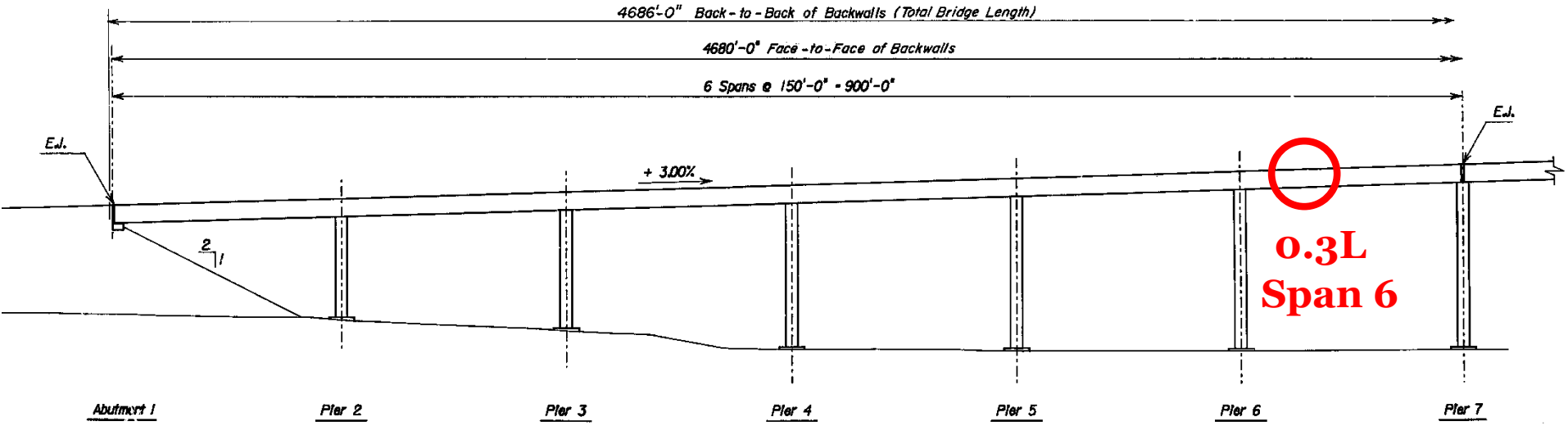
Designed by Figg and Mueller
Designed in 1985
Opened to traffic in 1990

Varina-Enon Approach Structure



- Northbound, Southern-most Approach Structure Unit
  - Six – 150 ft Spans
  - Externally Post-Tensioned
  - Distress noted by inspectors Summer 2012

Varina-Enon Approach Structure



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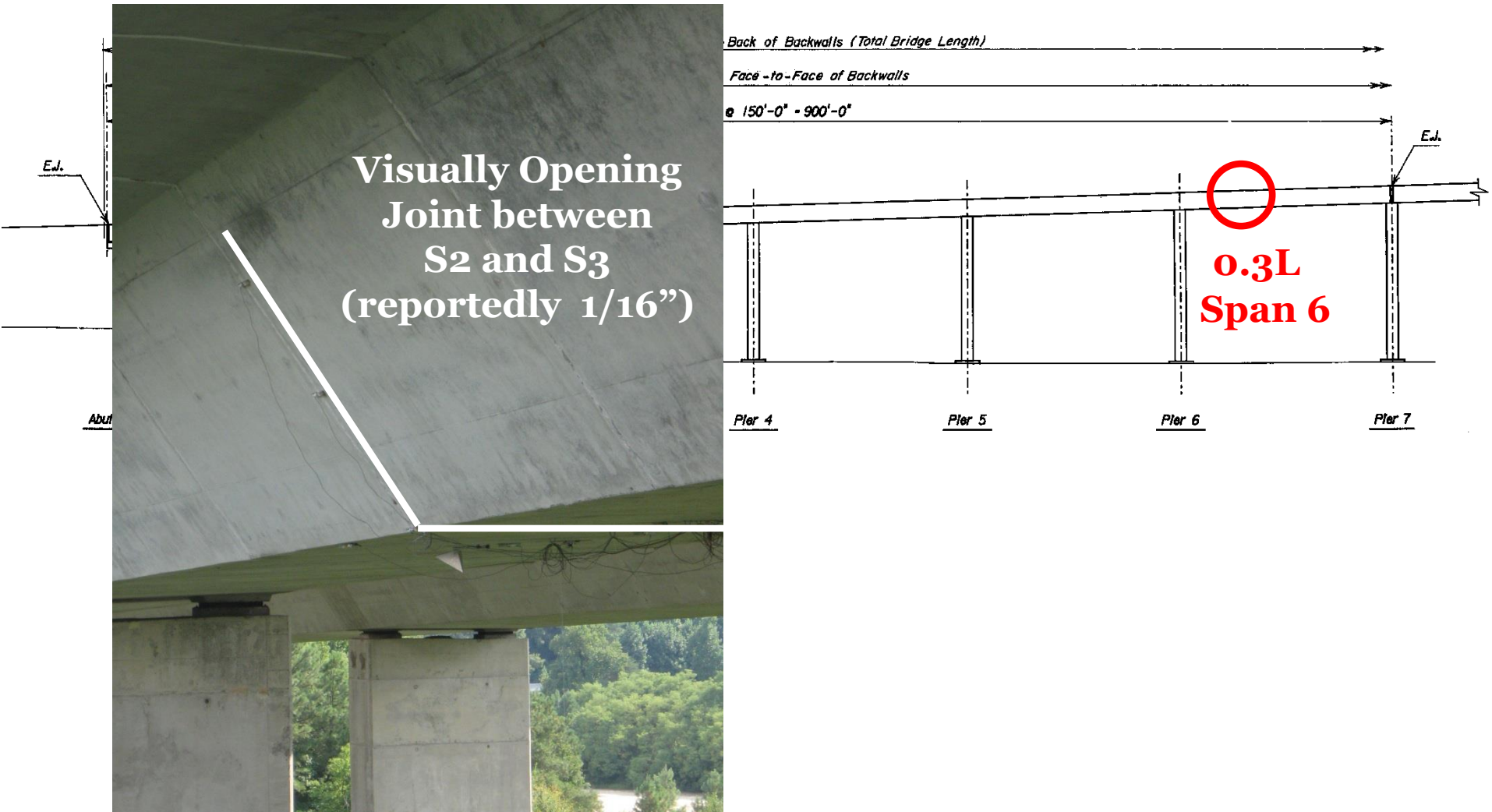

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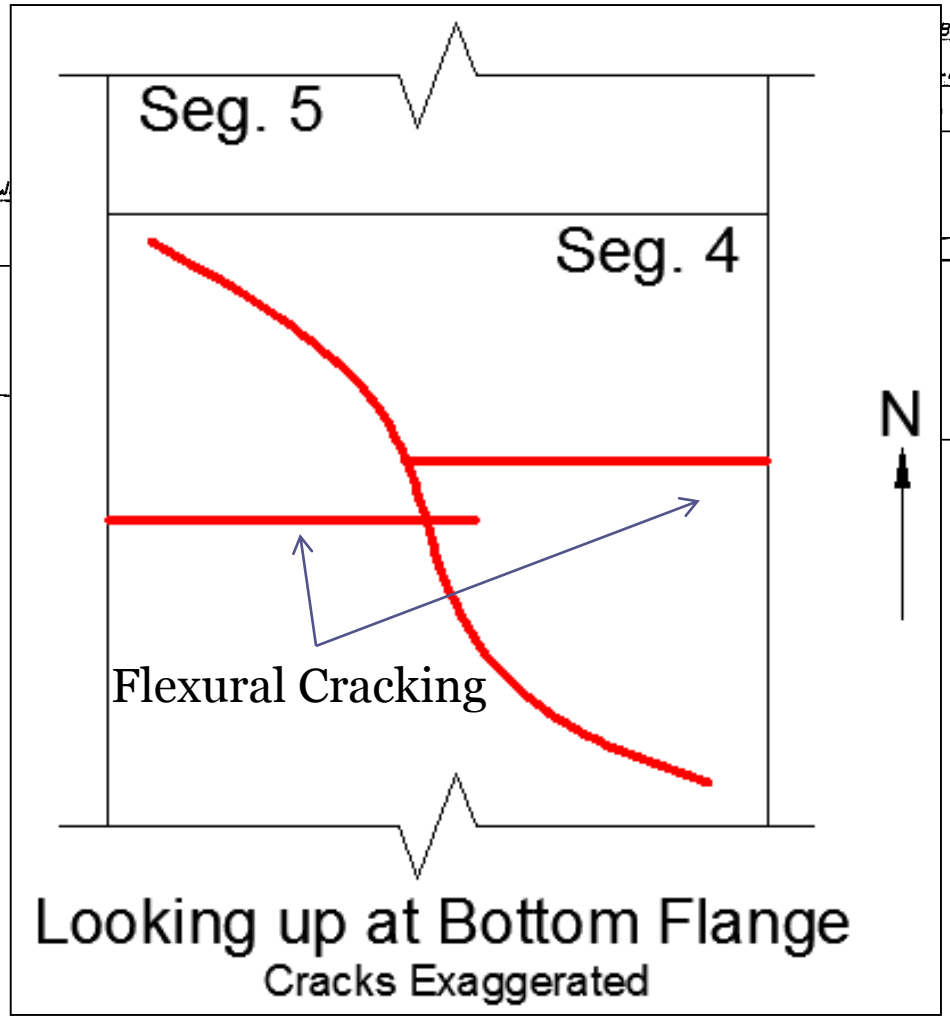
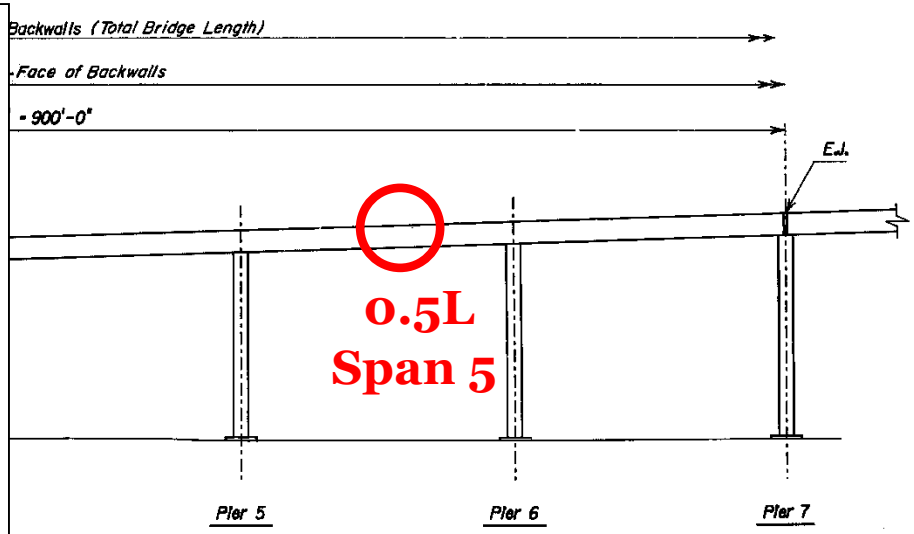
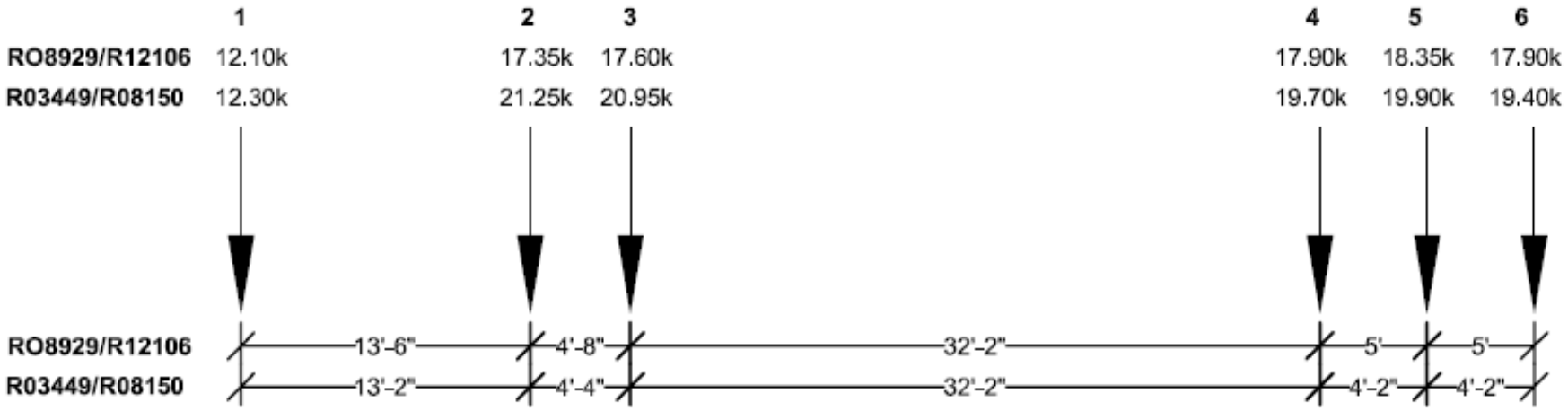


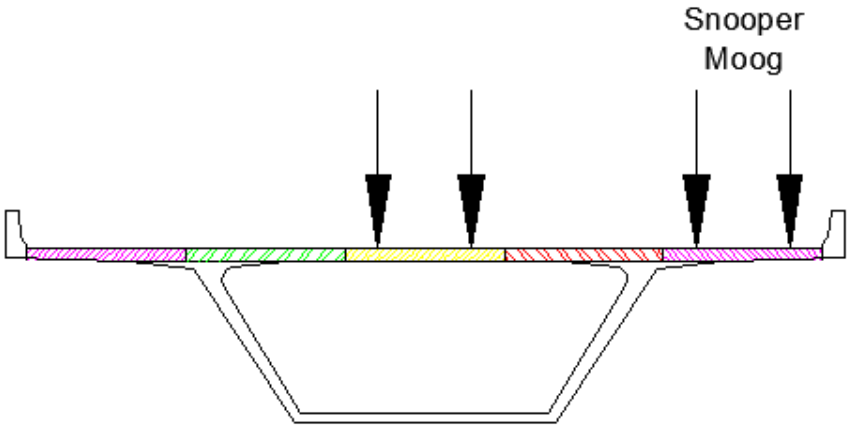


Live Load Test Performed August 2012

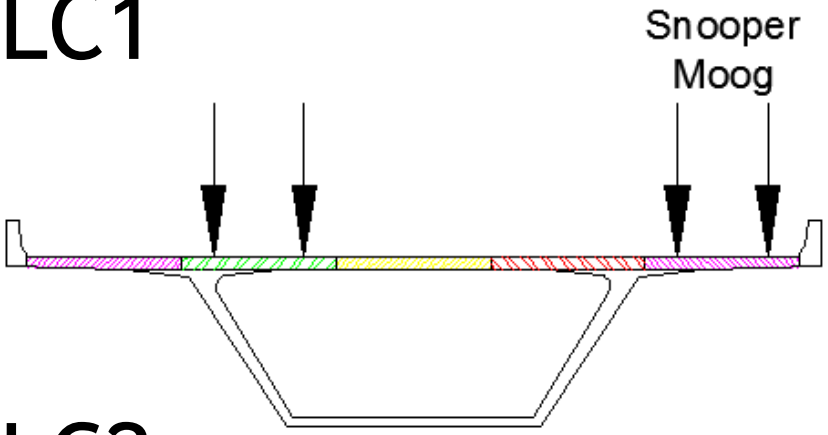
- Two Low Boy Tractor-Trailers
  - R12106 – 101.2 kips
  - R08150 – 113.5 kips



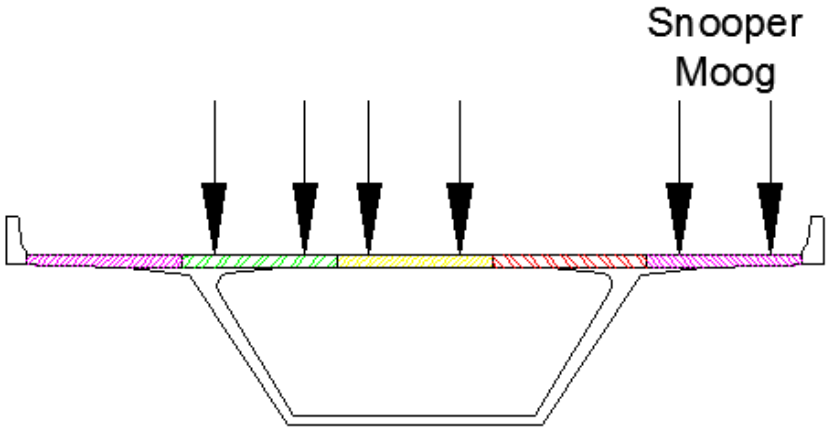
Three Truck Crossing Paths



LC1

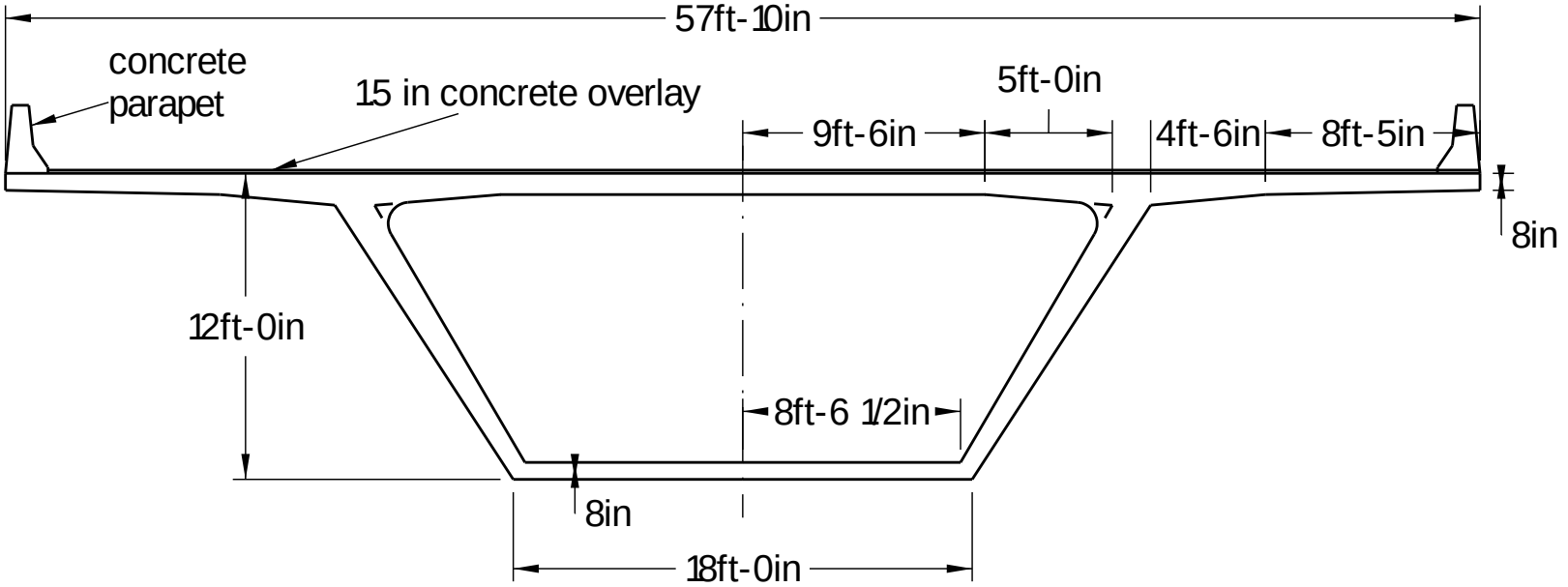


LC2



LC3

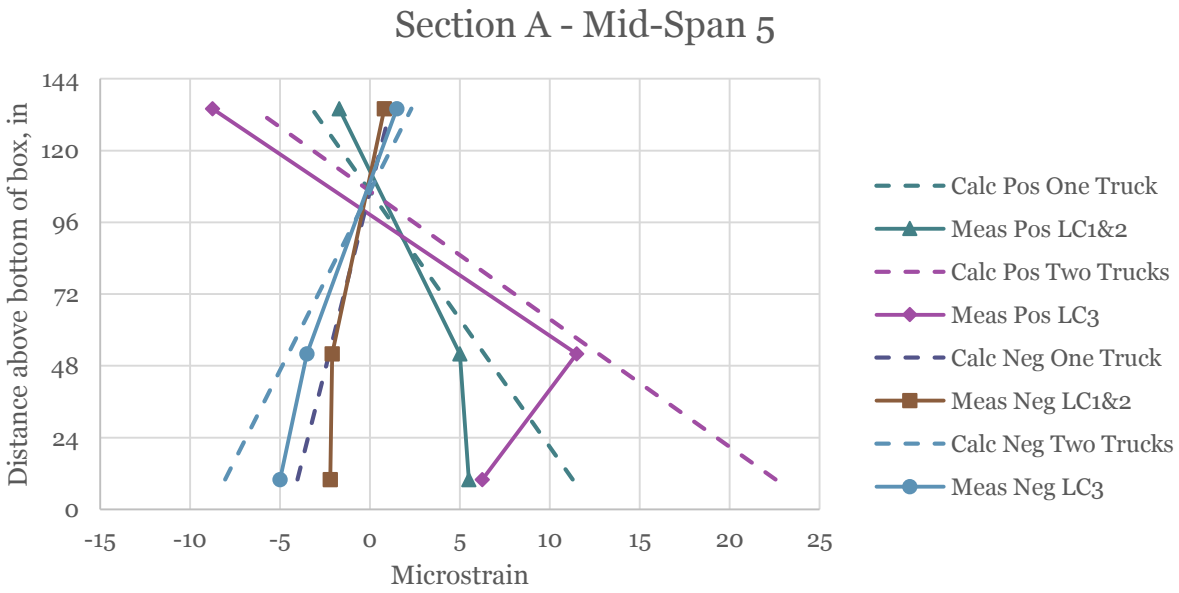
Simplified Beam Line Analysis

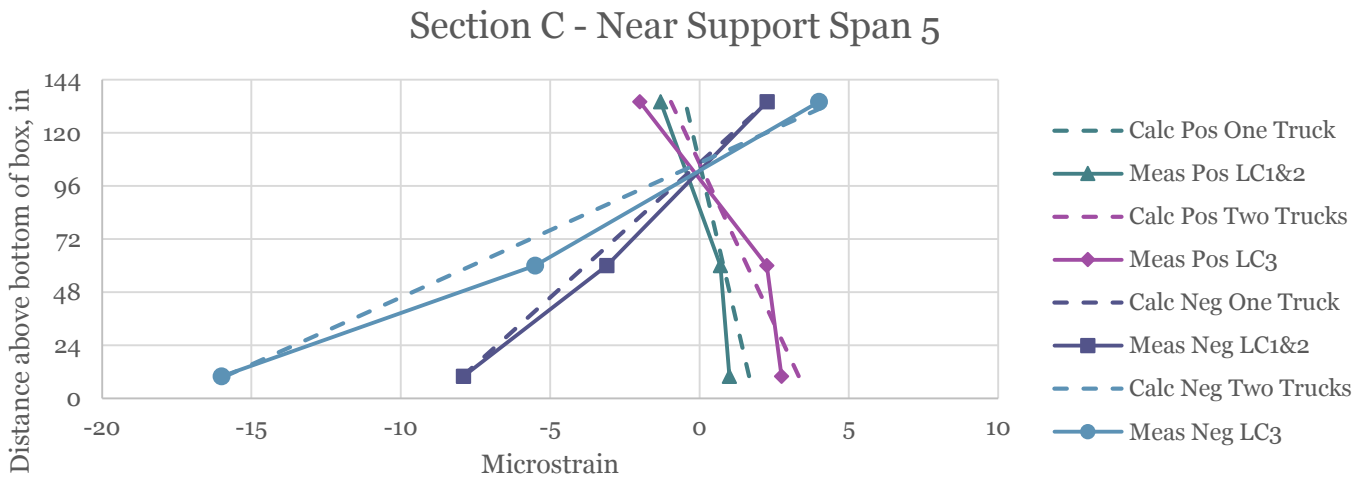


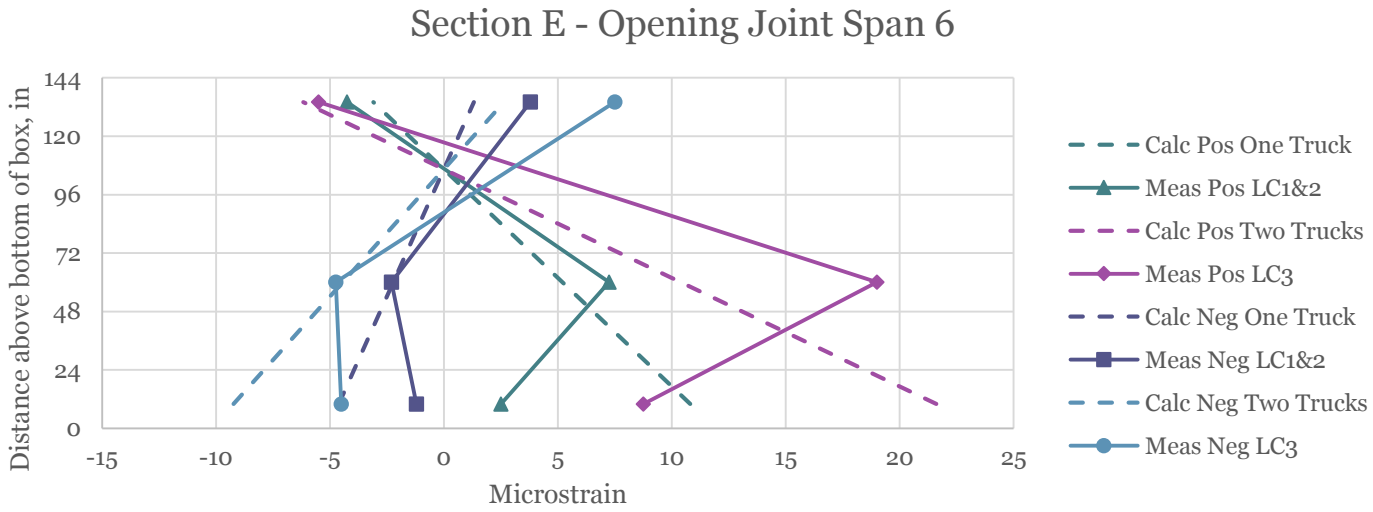
	Concrete Box Only	Concrete Box plus Overlay, Barrier, Rebar and Tendons
Area	12630 in^2	14730 in^2
Moment of Inertia	33,853,000 in^4	39,771,000 in^4
Centroid (from bottom)	101.9 in	106.4 in

Comparisons to Tests

	LC1		LC2		LC3	
	LC1-1	LC1-2	LC2-1	LC2-2	LC3-1	LC3-2
Measured Deflection, in	0.030	0.030	0.035	0.034	0.062	0.062
Calculated Deflection, in	0.031		0.031		0.062	



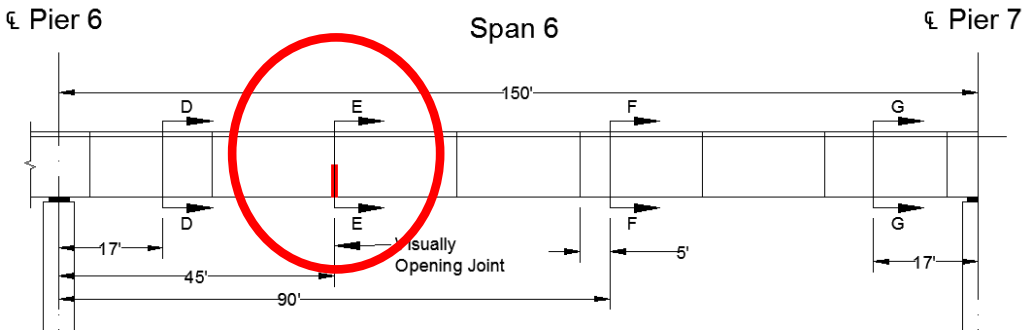

Section C - Near Support Span 5
Distance above bottom of box, in
144
120
96
72
48
24
0
-20
-15
-10
-5
0
5
10
Microstrain
Calc Pos One Truck
Meas Pos LC1&2
Calc Pos Two Trucks
Meas Pos LC3
Calc Neg One Truck
Meas Neg LC1&2
Calc Neg Two Trucks
Meas Neg LC3


Section E - Opening Joint Span 6
Distance above bottom of box, in
144
120
96
72
48
24
0
-15
-10
-5
0
5
10
15
20
25
Microstrain
Calc Pos One Truck
Meas Pos LC1&2
Calc Pos Two Trucks
Meas Pos LC3
Calc Neg One Truck
Meas Neg LC1&2
Calc Neg Two Trucks
Meas Neg LC3

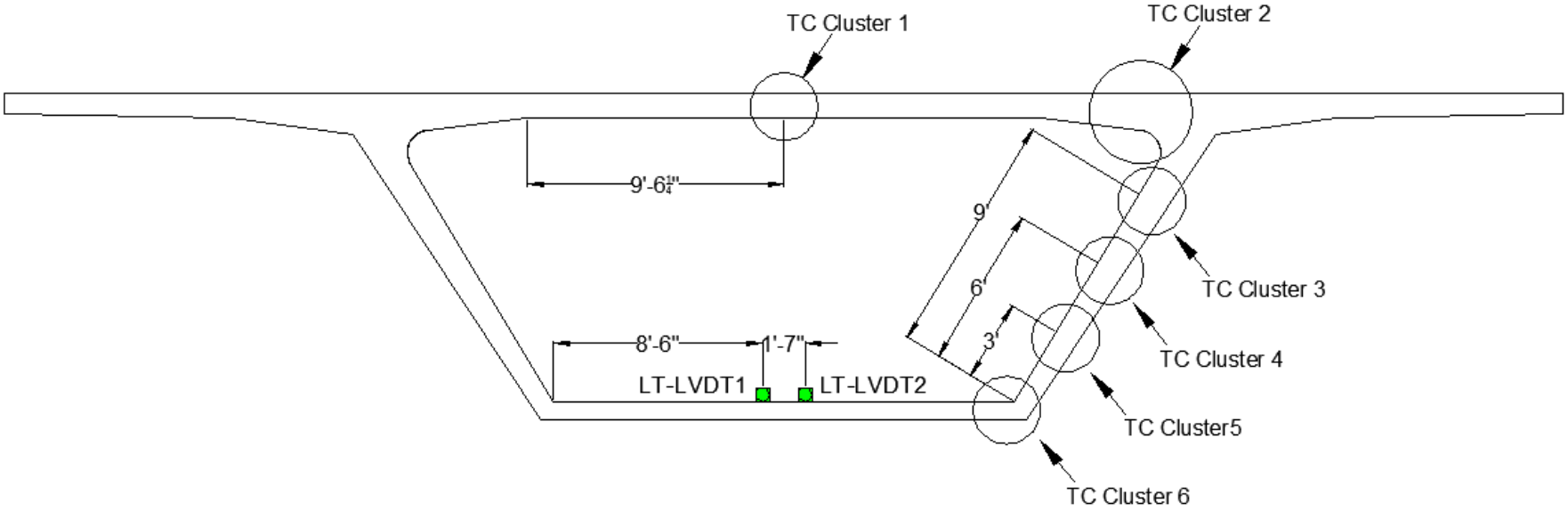
Recap

- Visual estimate of joint opening prior to load test was 1/16 in. under traffic
  - Opening was observed on June 29, 2012
  - High temperature according to NOAA at the airport was 103 degrees F
- Joint opening measured during load tests was 1/64 in. under load
  - Test was performed on August 21, 2012
  - Heaviest test vehicle 113.5 kips (rear three axles 60k)
  - Temperature at test time was mid 80s F

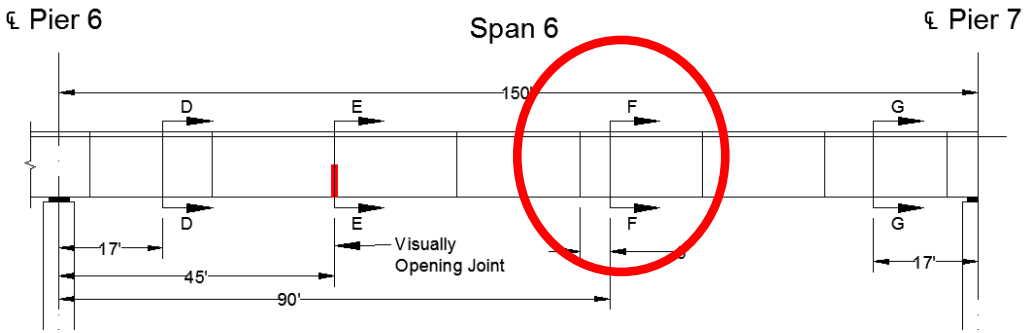
Long Term



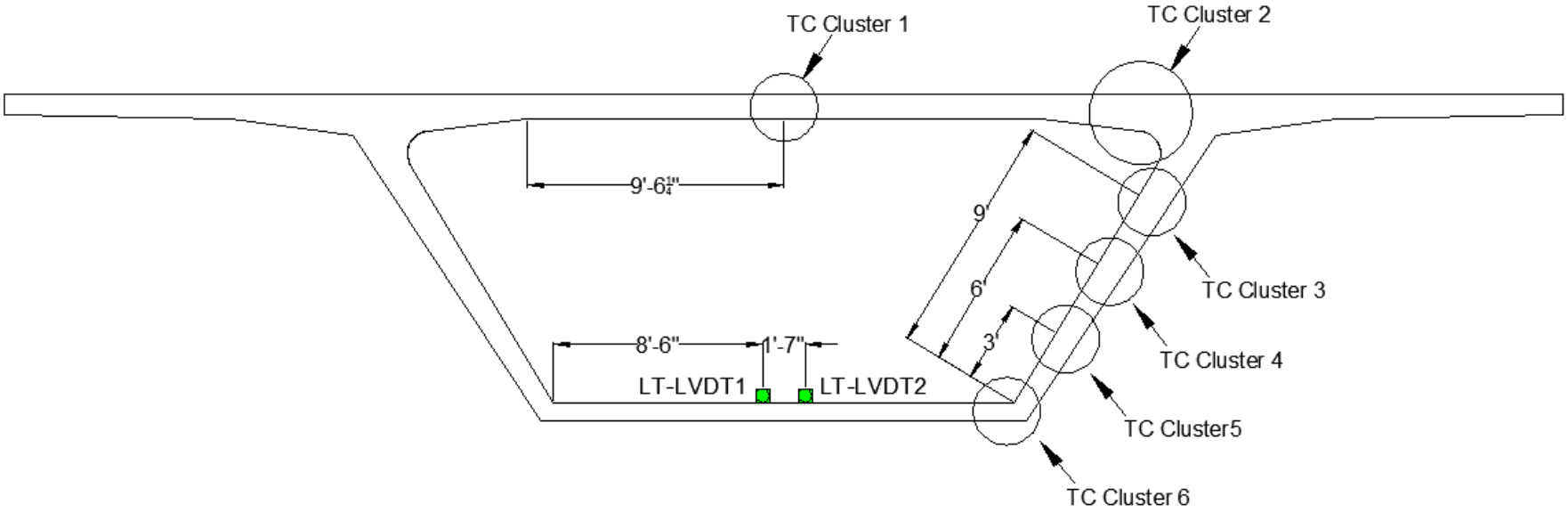
- S2/S3 Joint
  - 2 LVDTs monitoring crack opening
  - 1 Strain transducer next to crack
  - 24 Thermocouples measuring thermal gradient

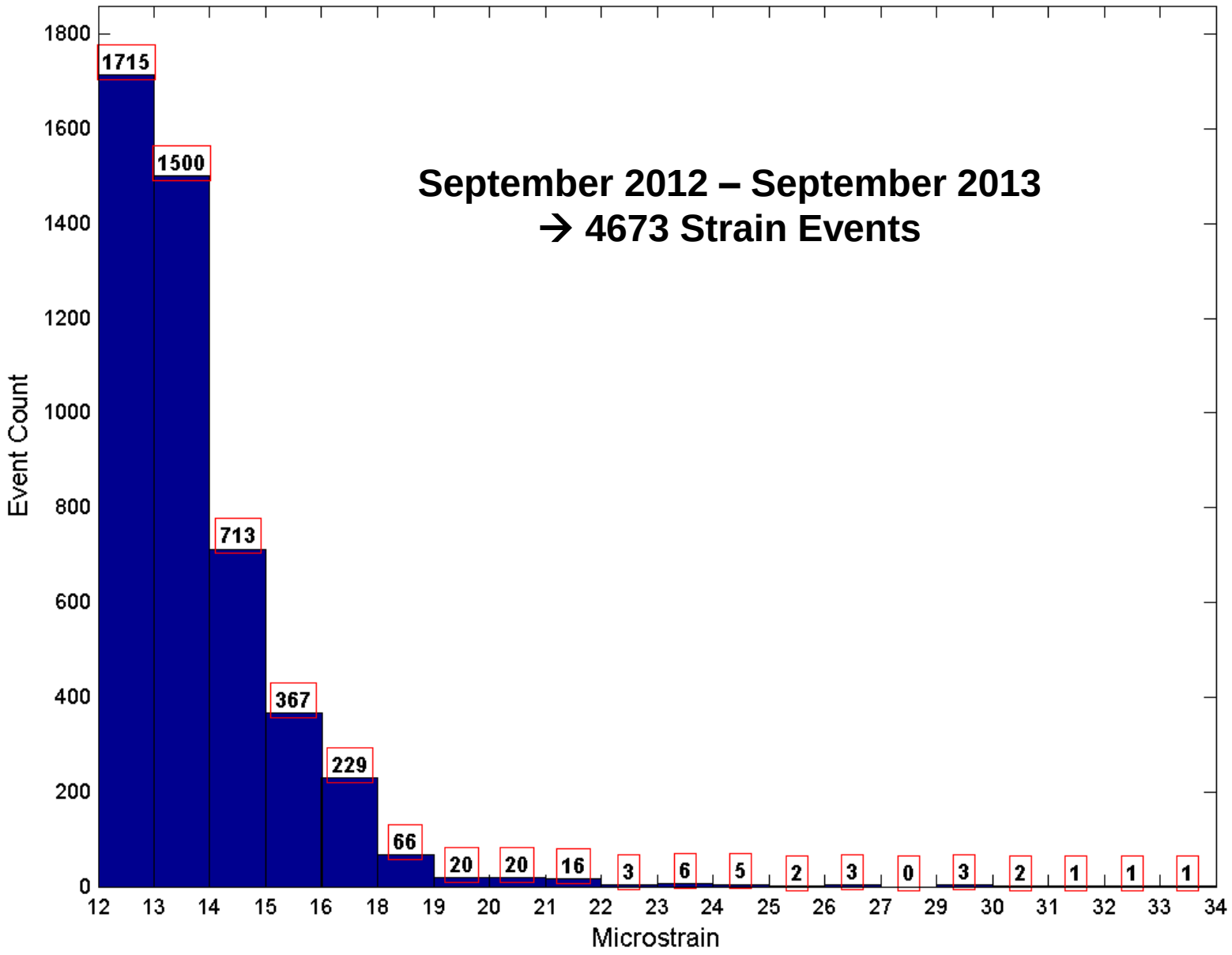


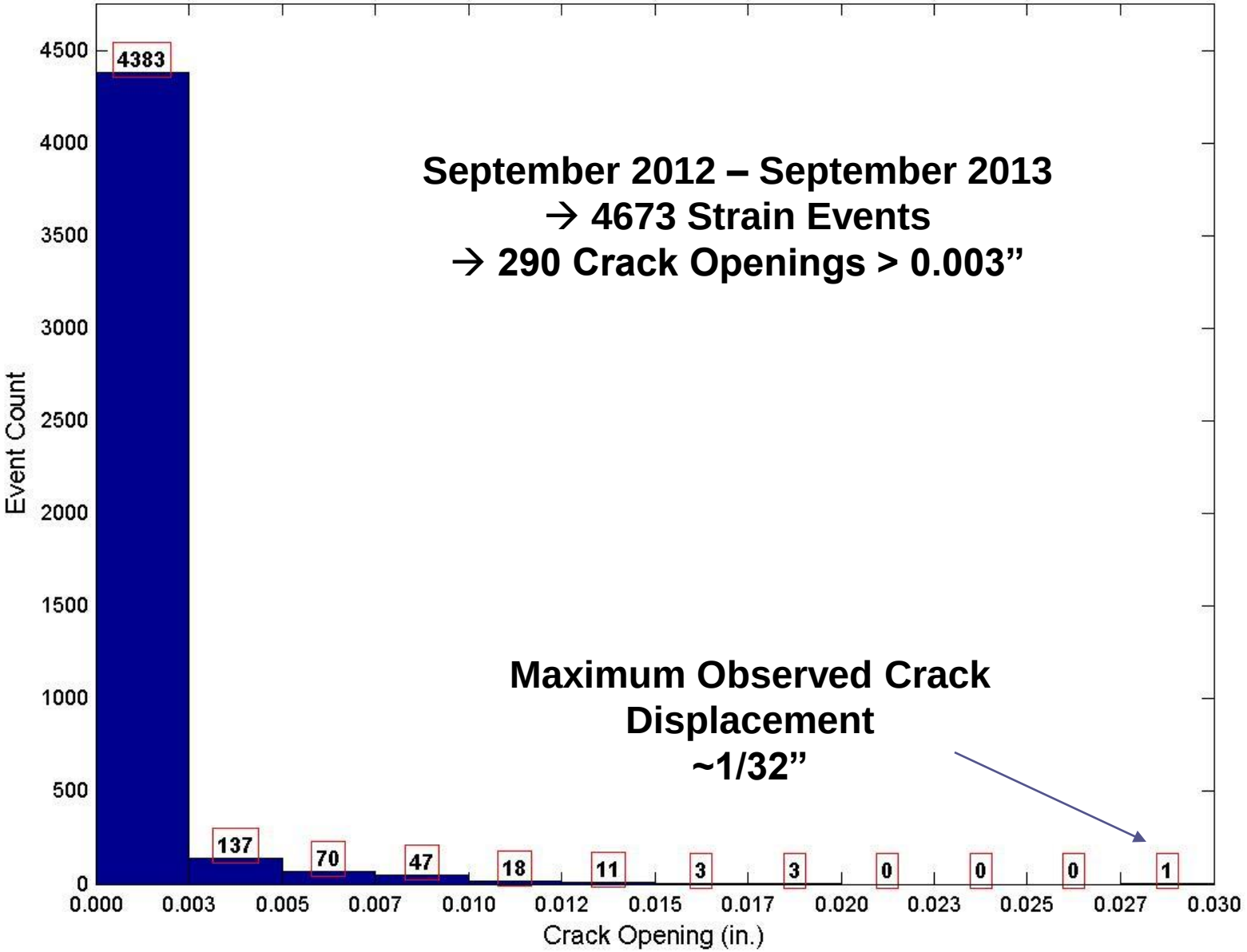
Long Term



- 0.4L
  - Single strain transducer at 0.4L from bridge end
  - Used to trigger events, trigger set at 12 με

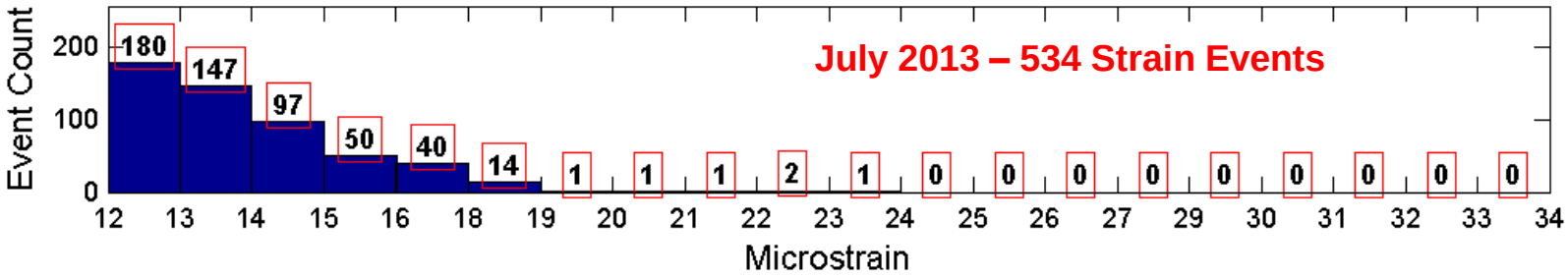


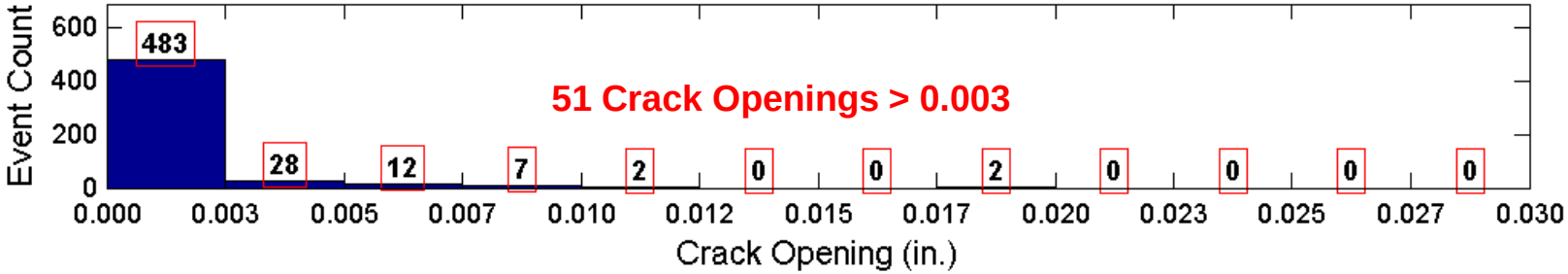

September 2012 – September 2013
→ 4673 Strain Events
Event Count
Microstrain
1800
1600
1400
1200
1000
800
600
400
200
0
12 13 14 15 16 18 19 20 21 22 23 24 25 26 27 29 30 31 32 33 34
1715
1500
713
367
229
66
20
20
16
3
6
5
2
3
0
3
2
1
1
1

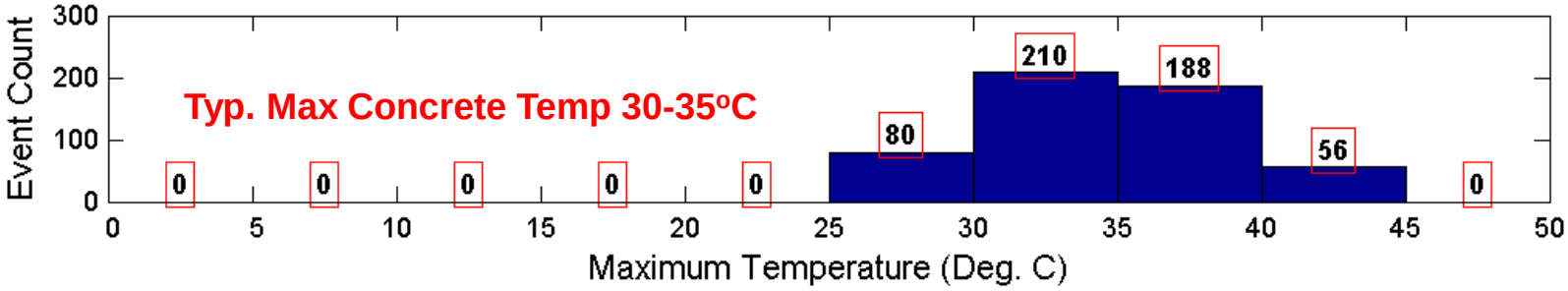

September 2012 – September 2013
→ 4673 Strain Events
→ 290 Crack Openings > 0.003”
Maximum Observed Crack Displacement
~1/32”
Event Count
Crack Opening (in.)
4383
137
70
47
18
11
3
3
0
0
0
1
0.000
0.003
0.005
0.007
0.010
0.012
0.015
0.017
0.020
0.023
0.025
0.027
0.030
0
500
1000
1500
2000
2500
3000
3500
4000
4500

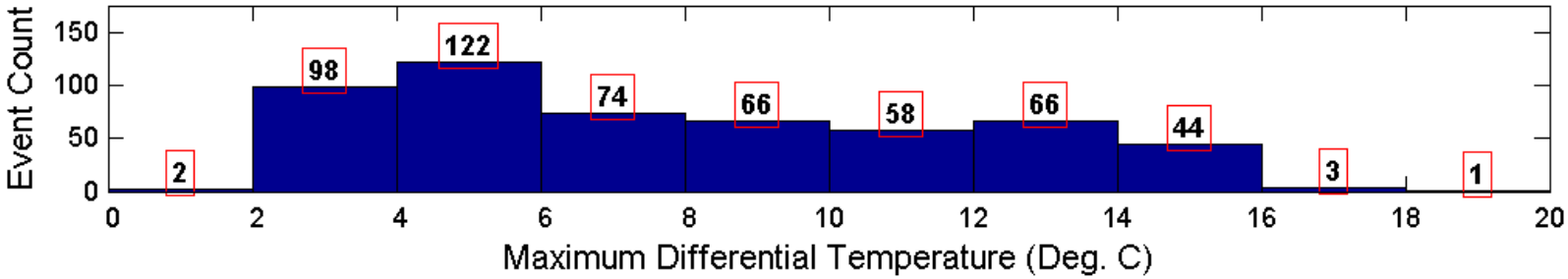
Influence of Temperature

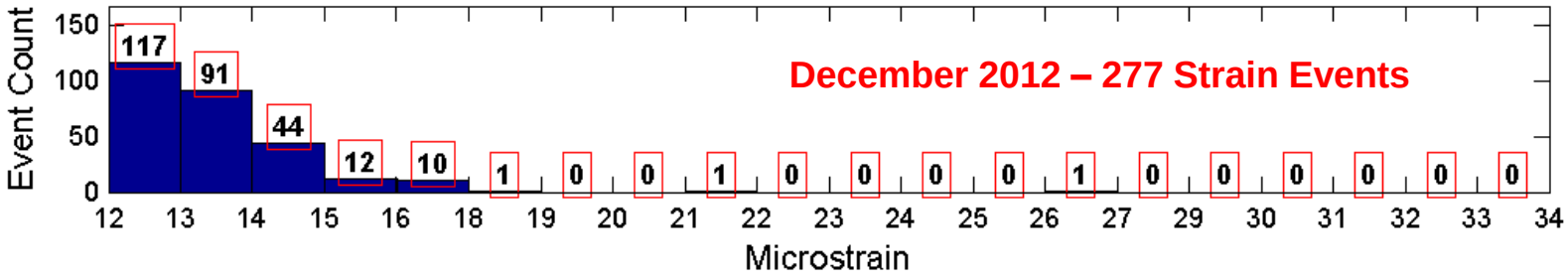
- Positive thermal gradients induce bottom slab tension at critical joint location
- Compare warm month and cold month data to investigate
- AASHTO Design Thermal Gradient is 41°F (23°C) non-linear
- Actual design gradient, with live load, was 9°F (5°C) linear

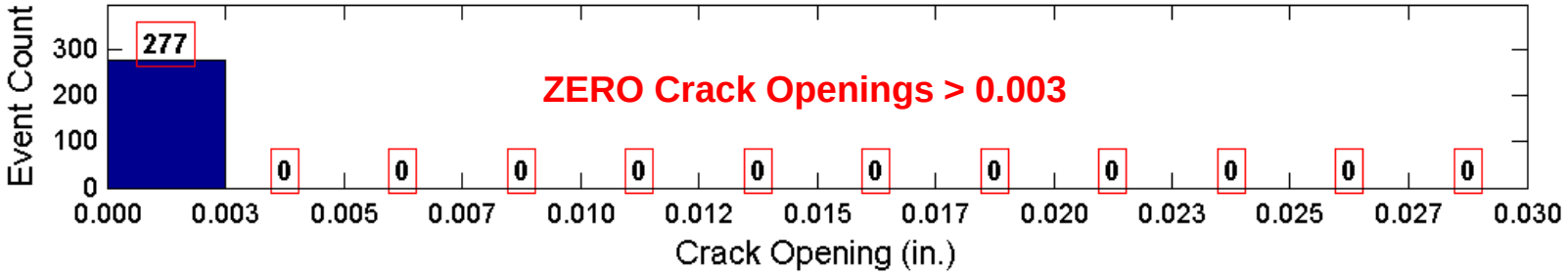

July 2013 – 534 Strain Events
Event Count
Microstrain
180
147
97
50
40
14
1
1
1
2
1
0
0
0
0
0
0
0
0
0

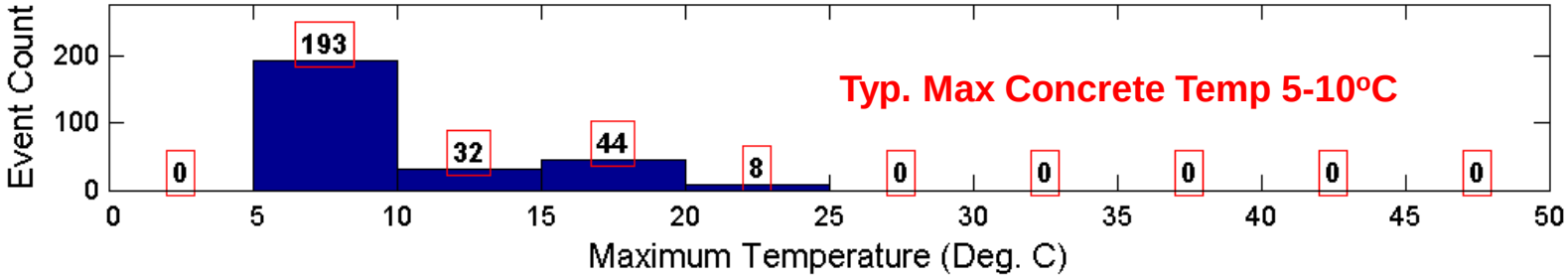

51 Crack Openings > 0.003
Event Count
Crack Opening (in.)
483
28
12
7
2
0
0
2
0
0
0
0

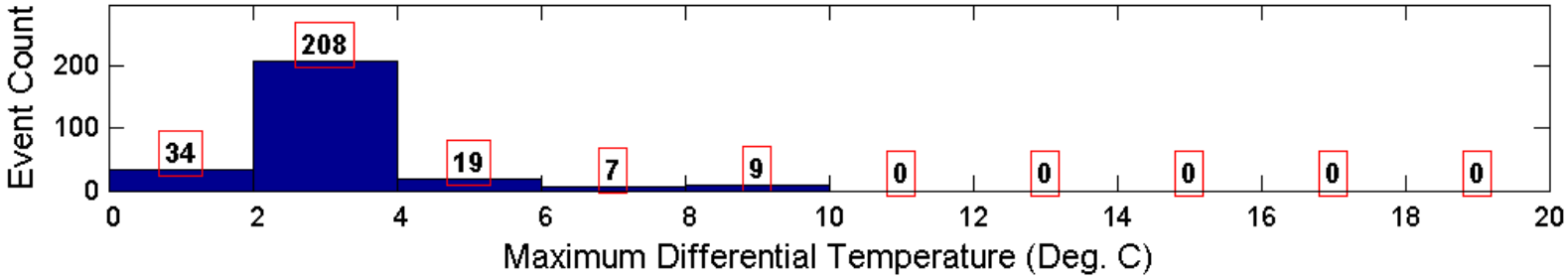

Typ. Max Concrete Temp 30-35ºC
Event Count
Maximum Temperature (Deg. C)
0
0
0
0
0
80
210
188
56
0


Event Count
Maximum Differential Temperature (Deg. C)
2
98
122
74
66
58
66
44
3
1

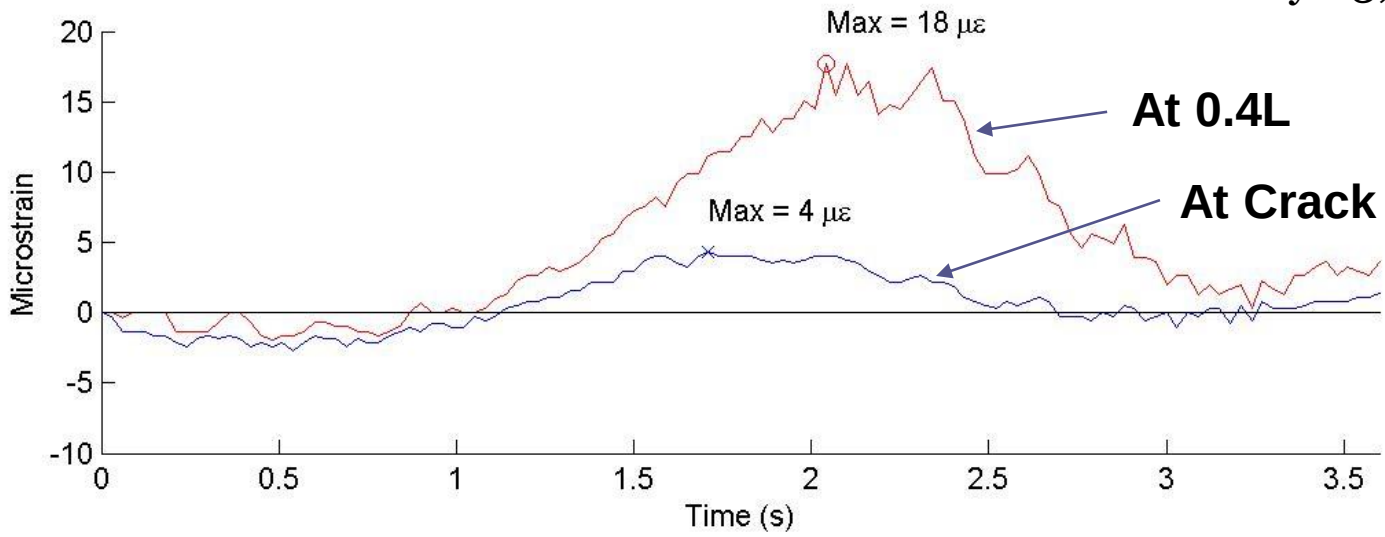

Event Count
150
100
50
0
117
91
44
12
10
1
0
0
1
0
0
0
0
1
0
0
0
0
0
0
12
13
14
15
16
18
19
20
21
22
23
24
25
26
27
29
30
31
32
33
34
Microstrain
December 2012 – 277 Strain Events

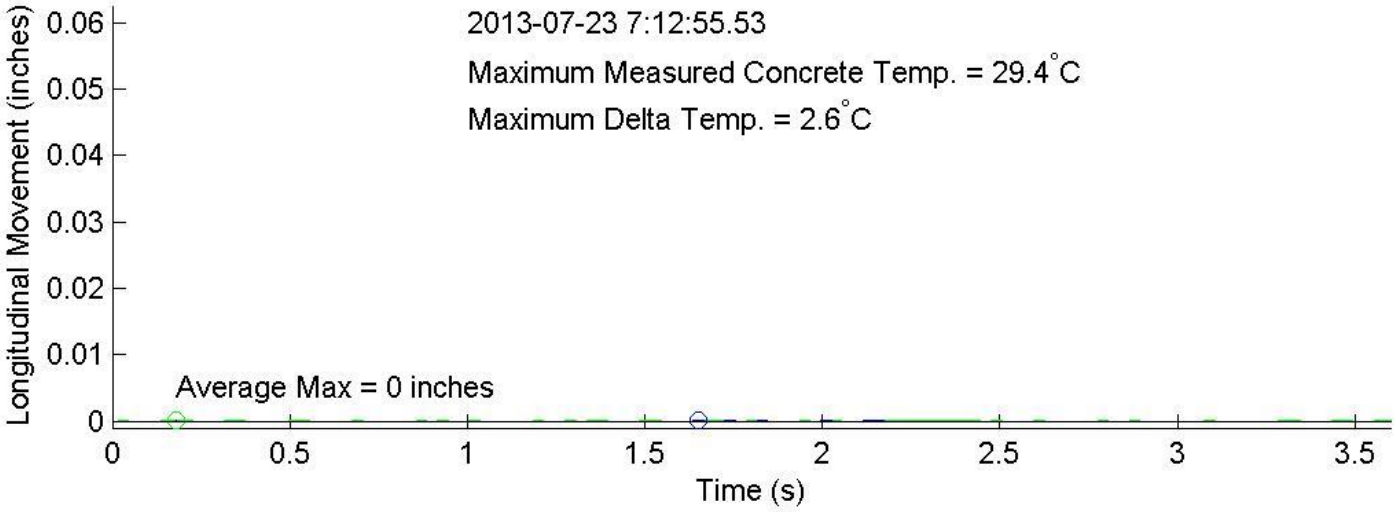

Event Count
300
200
100
0
277
0
0
0
0
0
0
0
0
0
0
0
0.000
0.003
0.005
0.007
0.010
0.012
0.015
0.017
0.020
0.023
0.025
0.027
0.030
Crack Opening (in.)
ZERO Crack Openings > 0.003


Event Count
200
100
0
0
193
32
44
8
0
0
0
0
0
0
5
10
15
20
25
30
35
40
45
50
Maximum Temperature (Deg. C)
Typ. Max Concrete Temp 5-10ºC

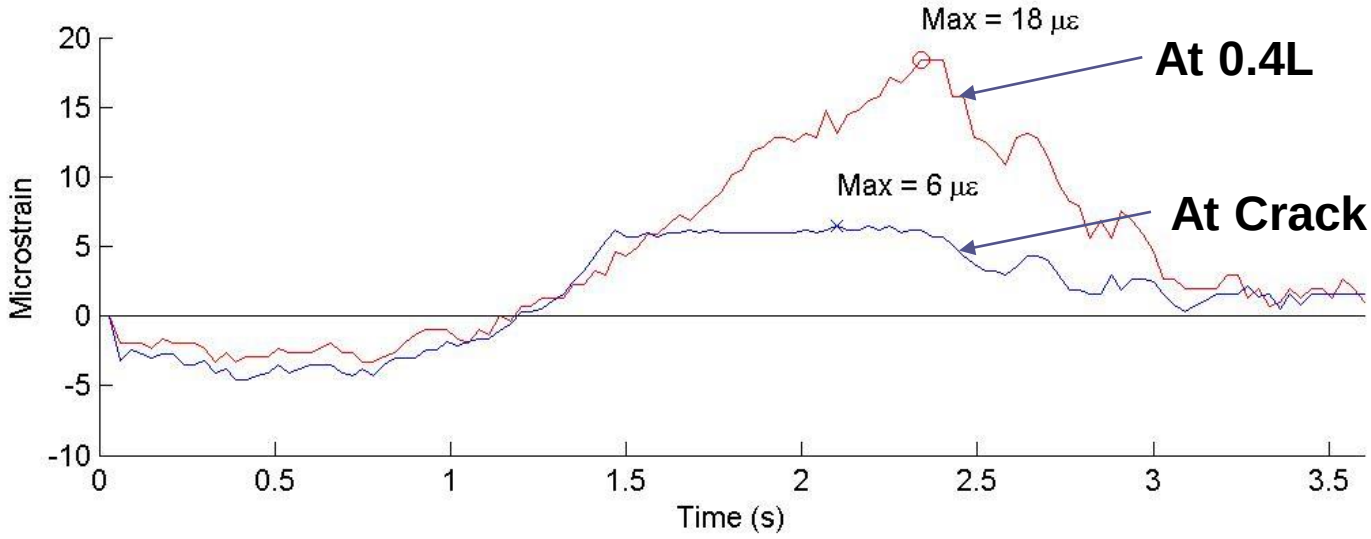

Event Count
200
100
0
34
208
19
7
9
0
0
0
0
0
0
2
4
6
8
10
12
14
16
18
20
Maximum Differential Temperature (Deg. C)

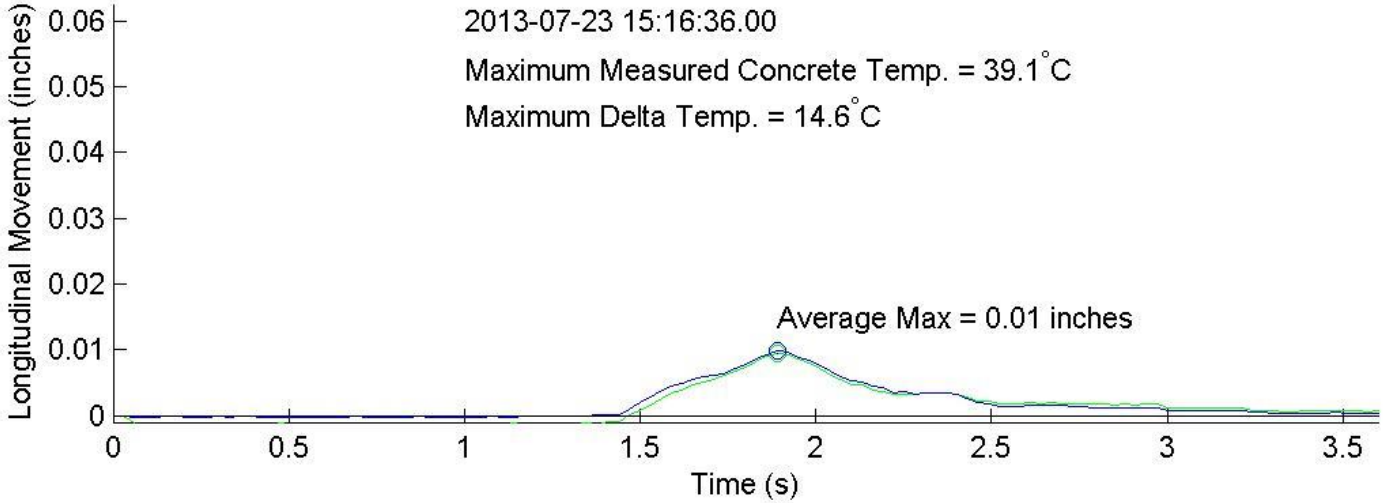
July 23, 7am, 2.6°C diff.



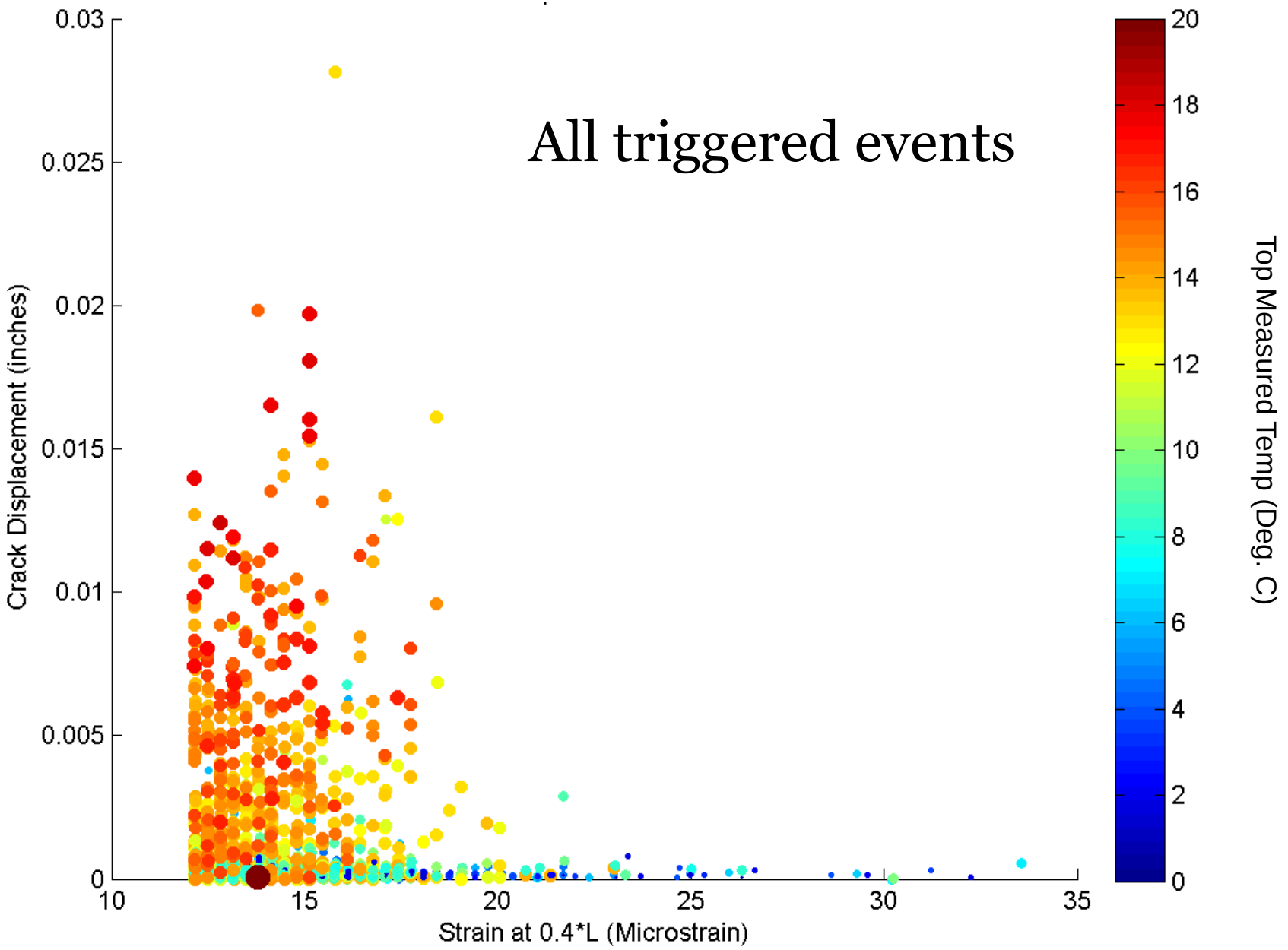


July 23, 3pm, 14.6°C diff.

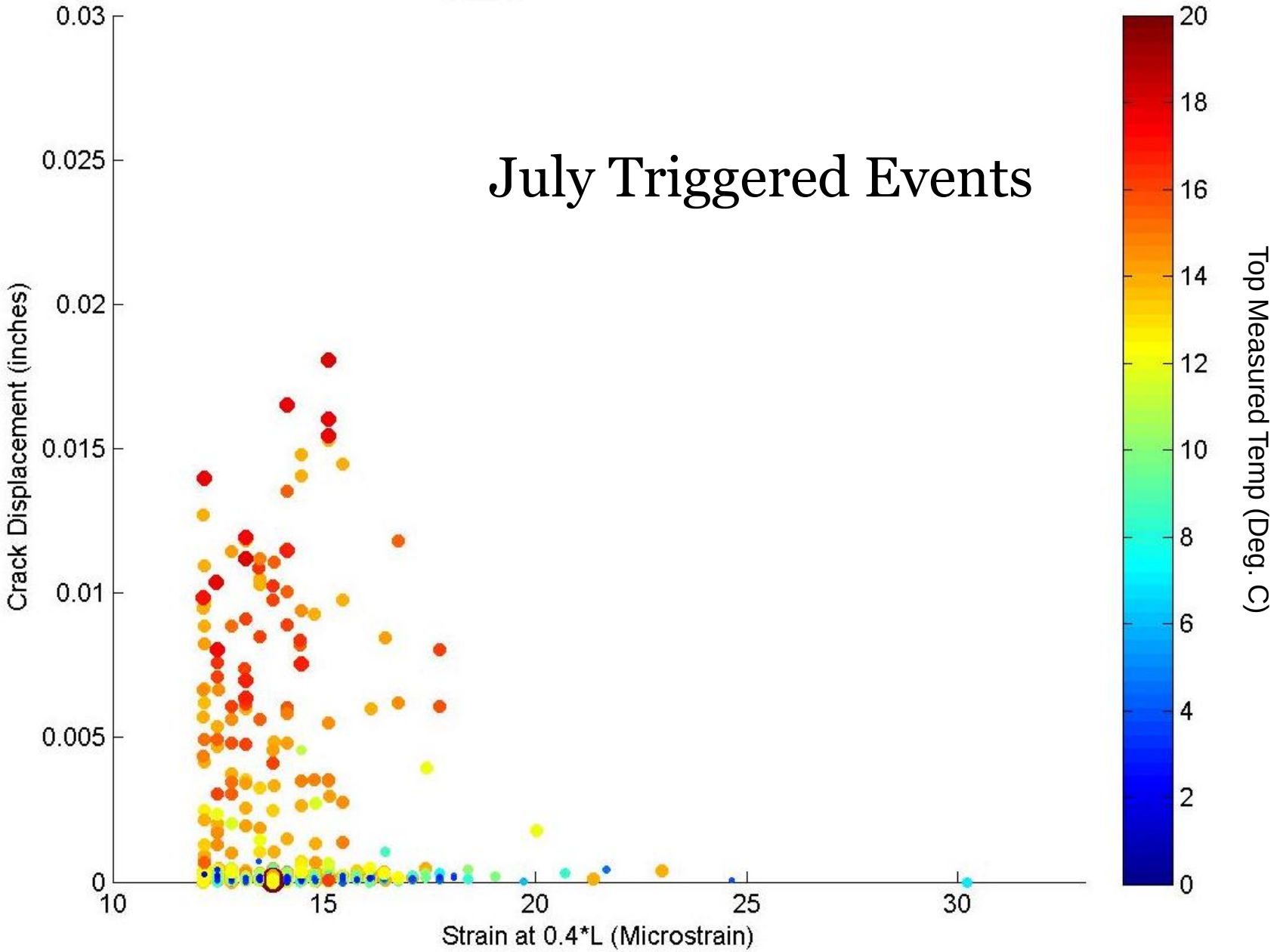




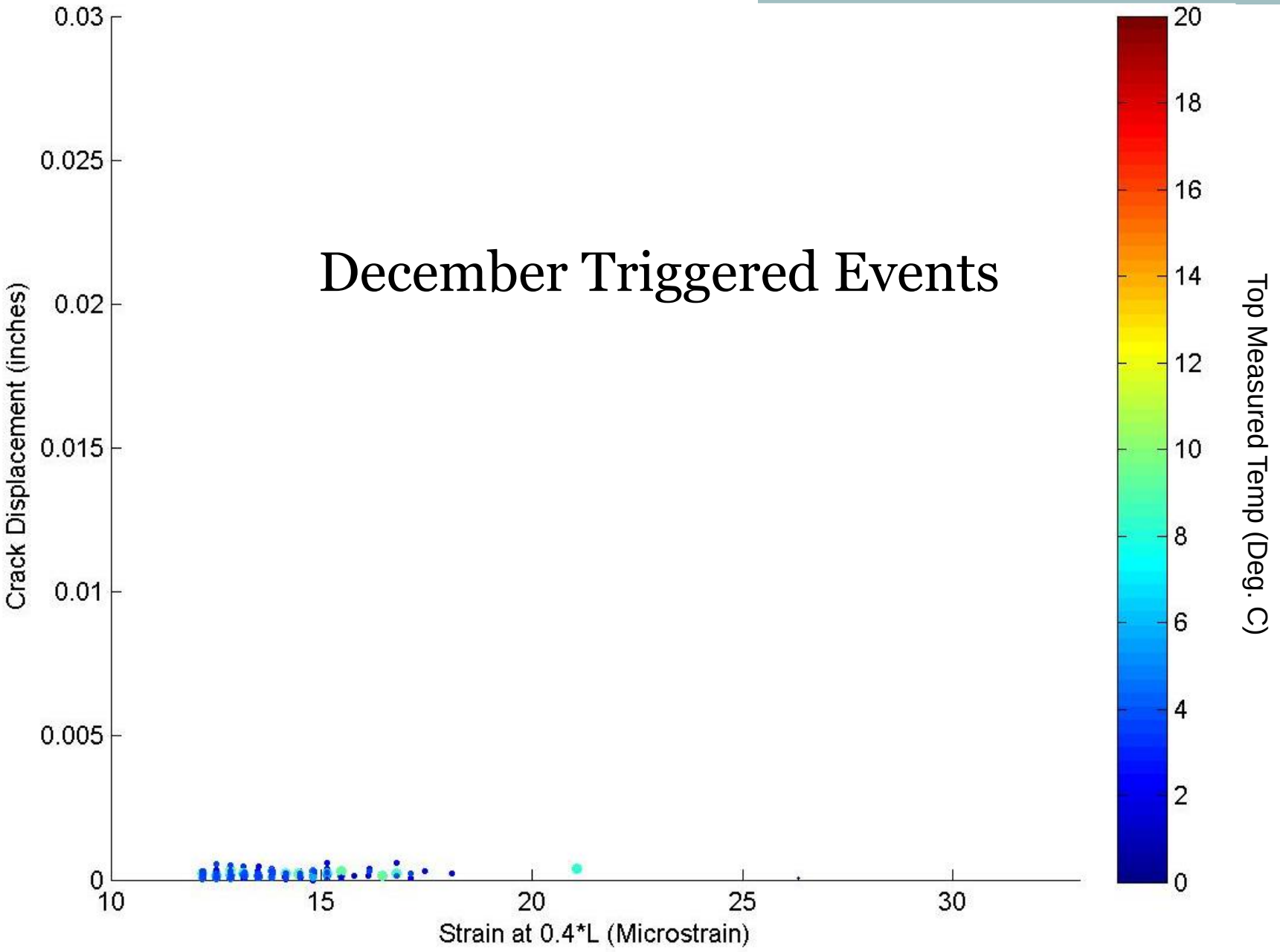
All triggered events



July Triggered Events



December Triggered Events



Simplified Long Term Analysis

Equation

$$M_f = M_{initial} e^{-\phi} + M_{final}(1 - e^{-\phi})$$

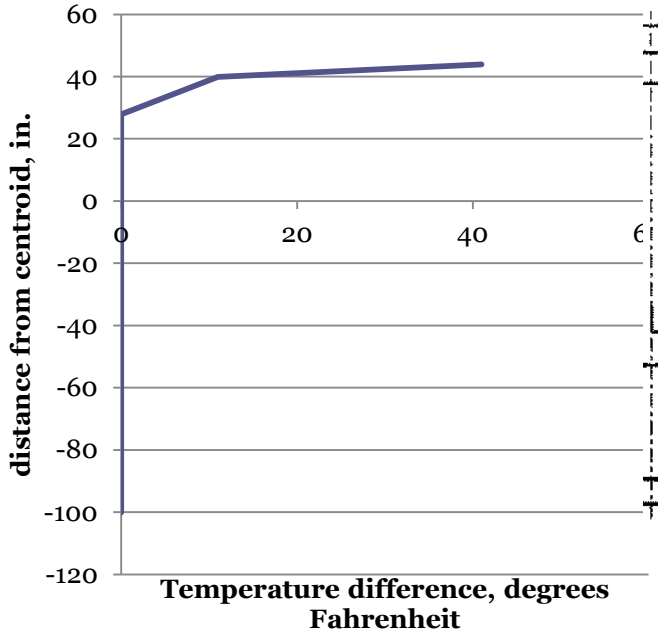
For $\phi = 0$ – no change in moment distribution

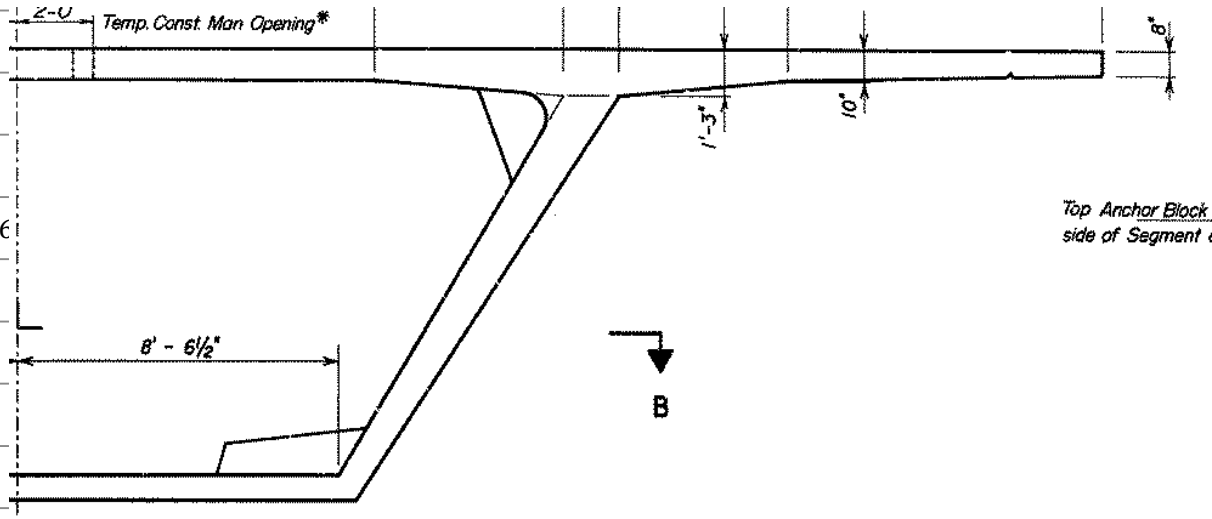
For $\phi = \infty$ - Creeps completely to final moment distribution

For $\phi = 2.5$ – Creeps over 90% toward final moment distribution

Analysis done for final system configuration (close enough)

Thermal Gradient

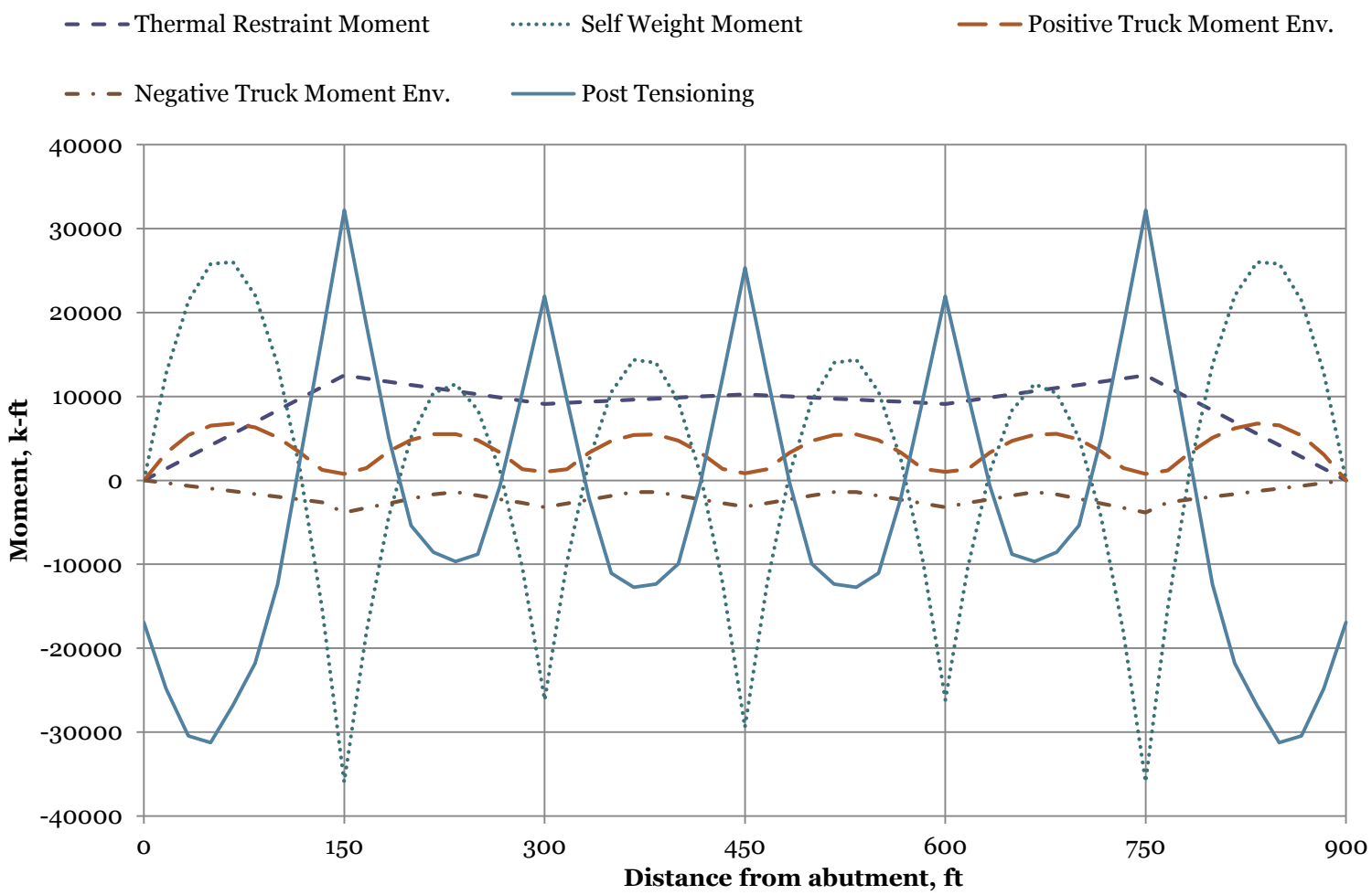




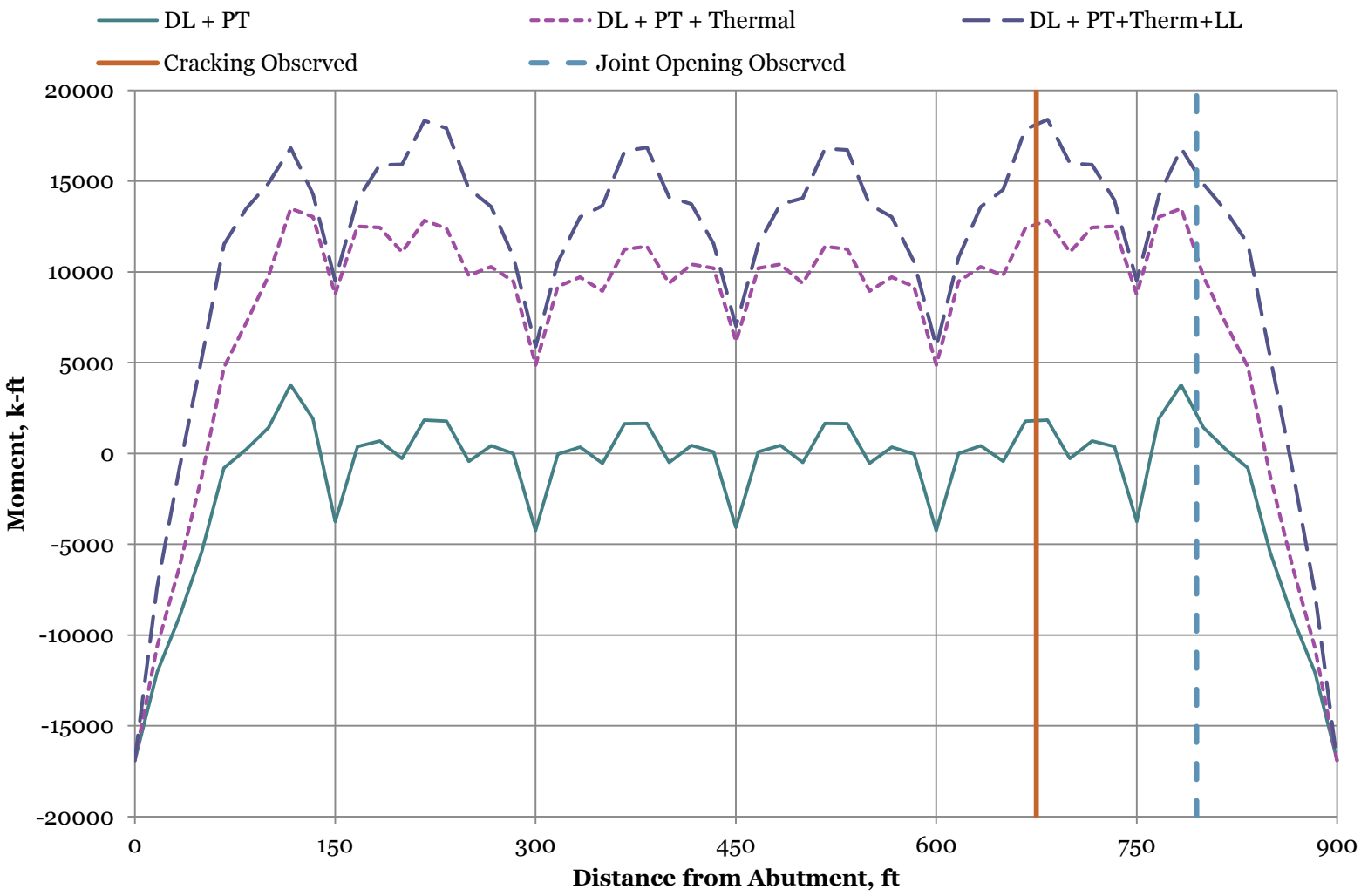
$$M_{thermal} = \int_{Y} E\alpha T(Y) b(Y) Y dY$$

Moment = 8727 k-ft

All Moments


Thermal Restraint Moment
Self Weight Moment
Positive Truck Moment Env.
Negative Truck Moment Env.
Post Tensioning
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
Moment, k-ft
0
150
300
450
600
750
900
Distance from abutment, ft

Summations


DL + PT
DL + PT + Thermal
DL + PT+Therm+LL
Cracking Observed
Joint Opening Observed
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
Moment, k-ft
0
150
300
450
600
750
900
Distance from Abutment, ft

Summary

- Maximum joint movement during load test:
  - 1/64 in.
  - Less than previously observed: 1/16 in.
- Maximum joint movement from ambient traffic over the past year:
  - 1/32 in.
- Thermal gradient is affecting severity and frequency of crack opening
- Monitoring is continuing and other locations will be investigated

Questions?