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TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Guidelines for Adjacent Precast Concrete Box Beam Bridge Systems

September 20, 2023

3:00 – 4:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

This webinar will share recent research on ways to prevent leakage in joints of adjacent box girder bridges. Presenters will share details of analytical and experimental evaluations of joints to provide load transfer while preventing leakage. Presenters will also make recommendations on joint material and surface preparation.

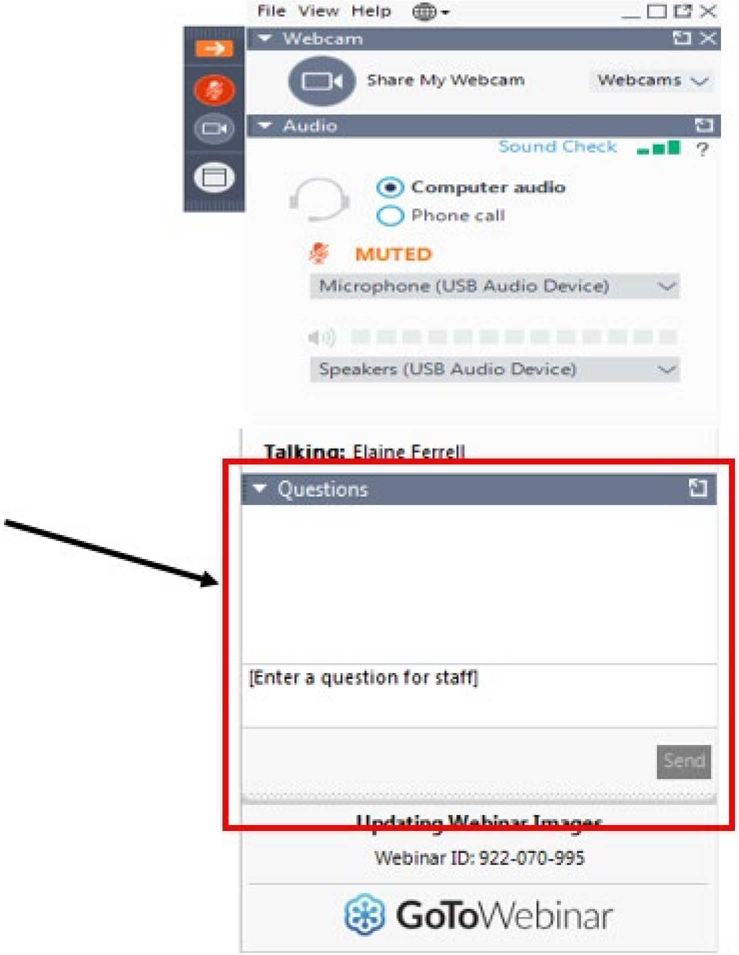
Learning Objectives

At the end of this webinar, you will be able to:

- Evaluate options and provide details for a more crack resistant joint
- Modify specifications on joint material and surface preparation to create a more crack resistant joint

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today’s presenters

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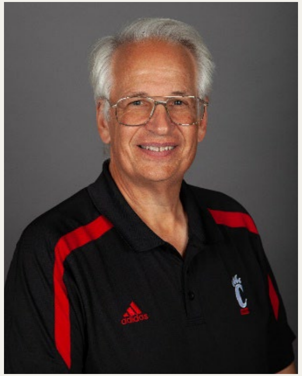

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NCHRP

Project Number 12-95A

Proposed AASHTO Guidelines for Adjacent Precast Concrete Box Beam Bridge Systems

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September 20, 2023

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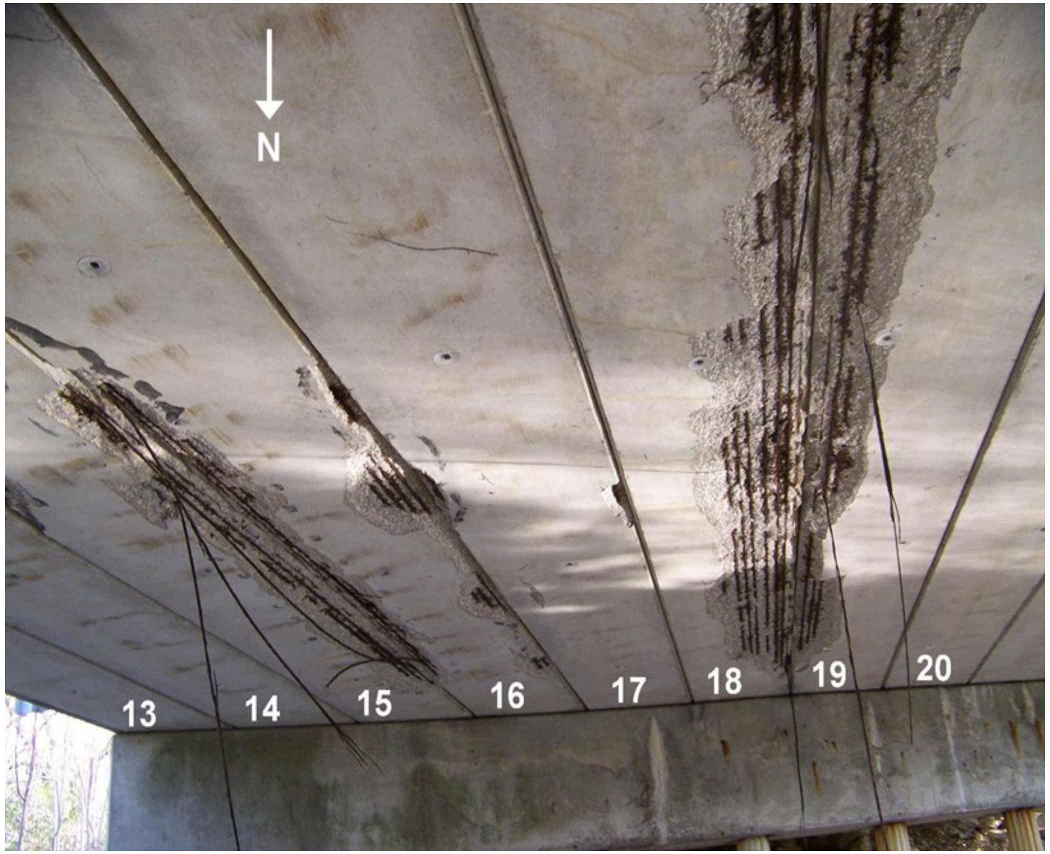
STATEMENT OF THE PROBLEM



A typical adjacent box girder bridge damaged by leaking joints.

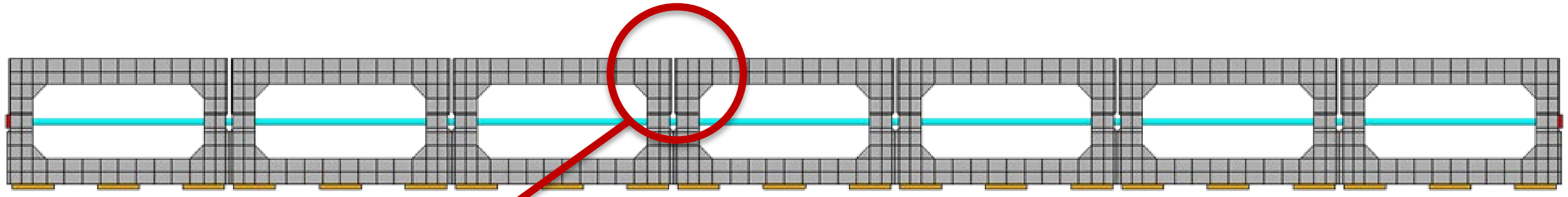
STATEMENT OF THE PROBLEM

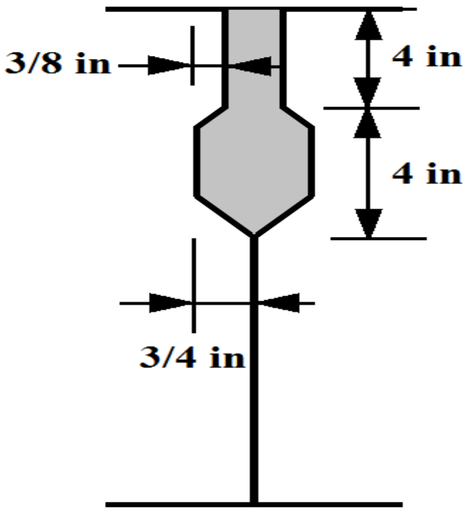
The problem of cracking in the shear keys needs to be addressed.

Cracking leads to leakage and leakage of chloride laden water eventually damages the girders.

Severe cracking may also prevent load transfer between girders.

Box Girder Joint Testing





Type III Shear Key

This is a typical joint, or shear key, in an adjacent box girder bridge. The actual size varies from state to state, but the important factors is that they are near the TOP of the girder and are filled with a cementitious material.

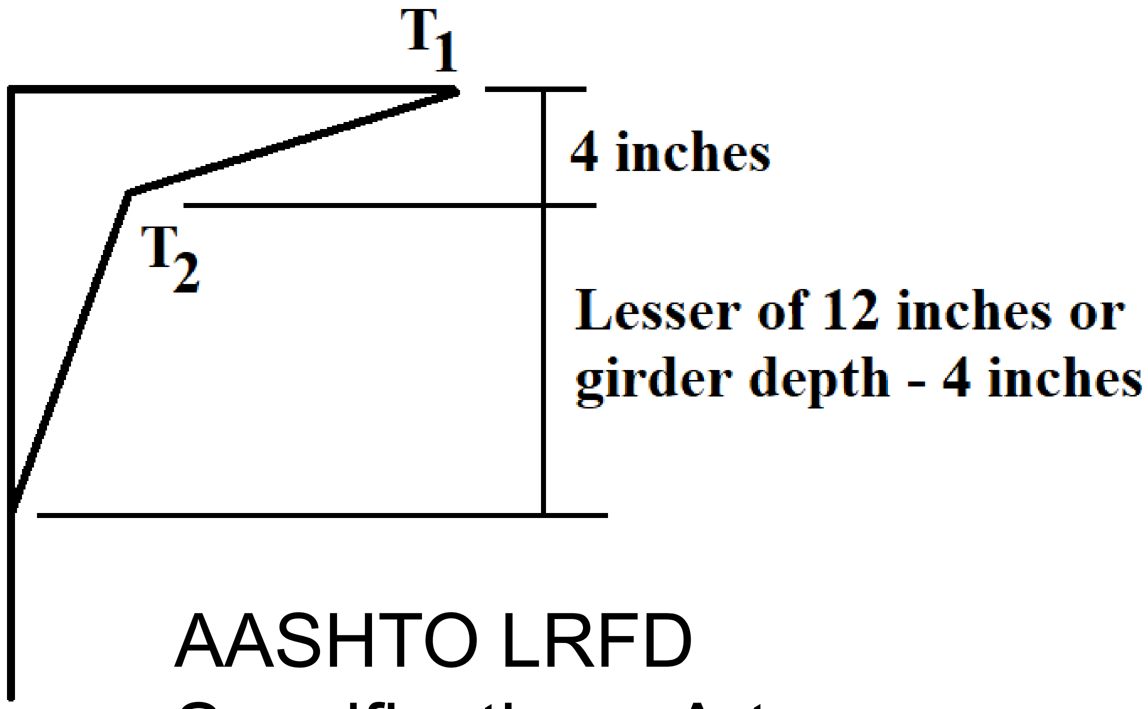
CAUSES OF CRACKING

Numerous studies have looked at cracking in shear keys.

They all point to one cause: TEMPERATURE!

Live load appears to propagate temperature cracks but not cause them.

CAUSES OF CRACKING



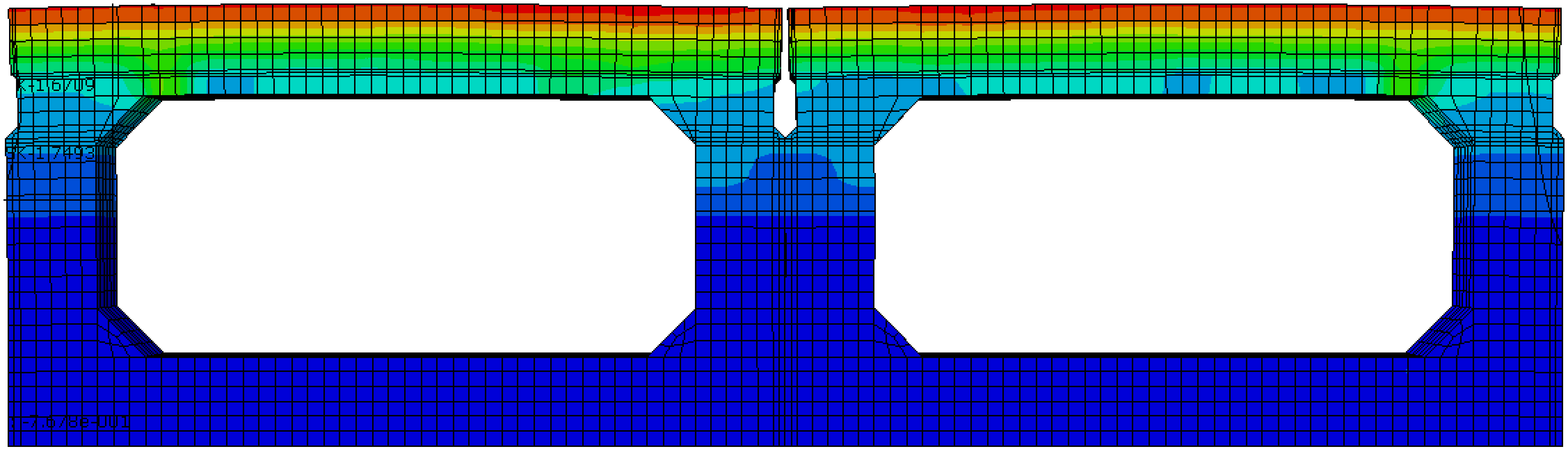
This is the AASHTO temperature gradient. The difference between T_1 and T_2 is 29° F to 40° F, depending on the zone.

It occurs over the top 4 inches!

AASHTO LRFD Specifications, Art 3.12.3.

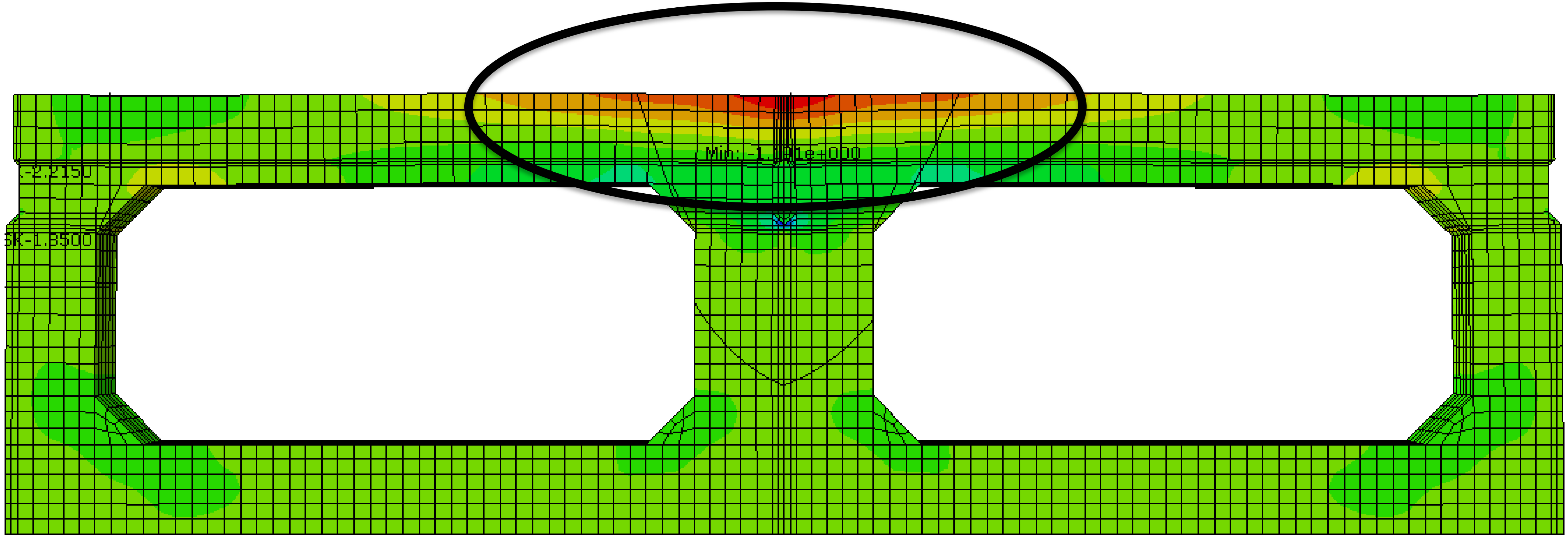
Zone	T_1 (°F)	T_2 (°F)	ΔT (°F)
1	54	14	40
2	46	12	34
3	41	11	30
4	38	9	29

CAUSES OF CRACKING



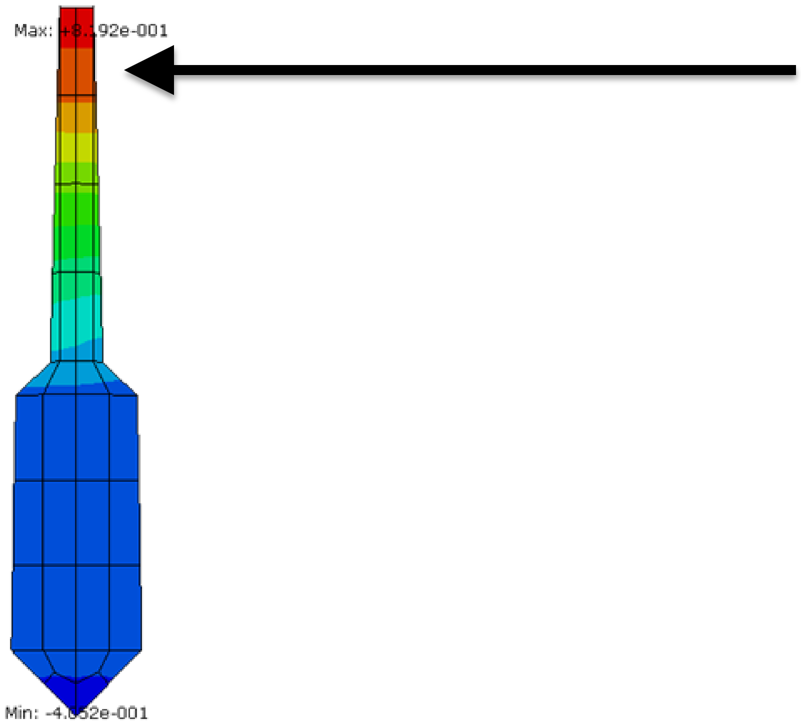
This shows a simulation of two box girders where the tops have been heated by solar radiation. The tops of the girders expand. The shaded sides and bottoms do not expand. The shear key is often cast when the girders are in this condition.

CAUSES OF CRACKING



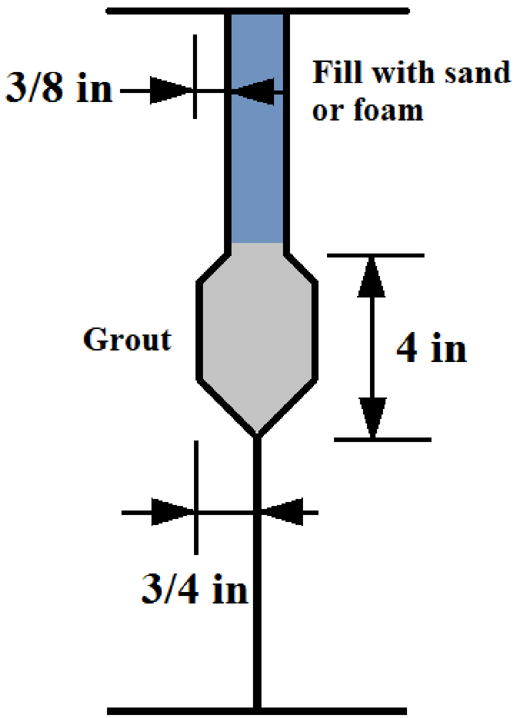
This shows a simulation of what happens when the girders cool after casting the shear key. The tops of the girders contract putting tensile stress on shear key.

CAUSES OF CRACKING



This shows the stresses in the shear key.   The top of the key is under a high level of tension due to contraction of both the tops of the girders and shear key material itself. This often exceeds either the tensile or bond strength of the material, resulting in cracking.

A POSSIBLE SOLUTION



Mid-depth Shear Key

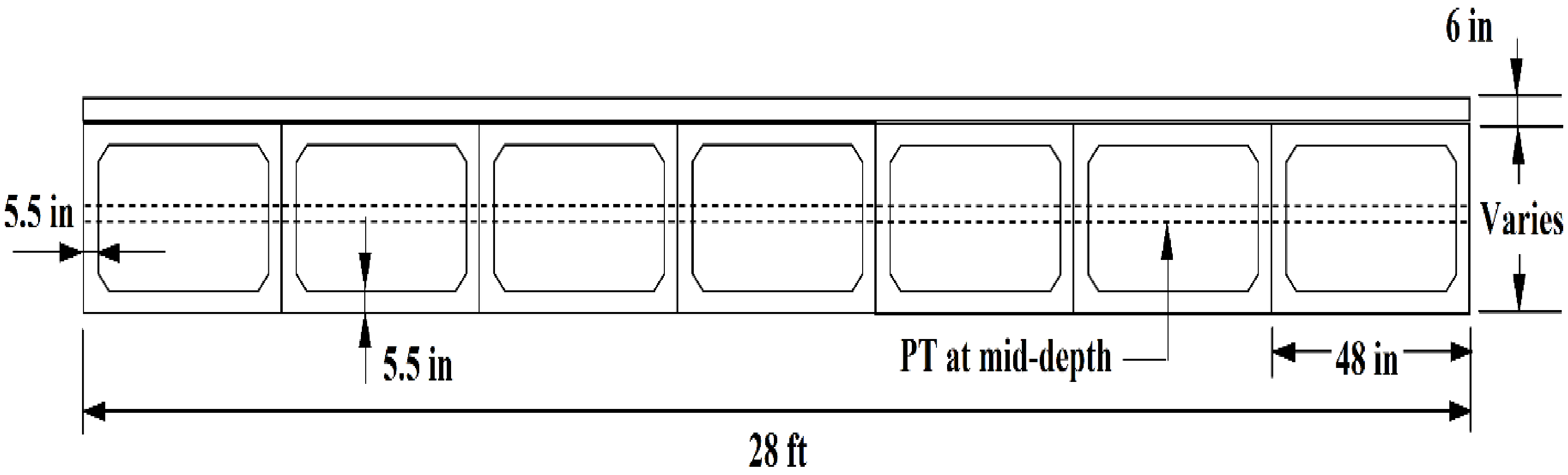
Huckelbridge et al. (1997) suggested that a mid-depth shear key with an ungrouted throat would be better. Load testing indicated that this configuration had lower stresses

Miller, et al. (1999) tested the mid-depth shear key and found very little cracking due to temperature. It was not known at the time, but this is likely due to the shear key being placed a the point where temperature movements are minimum.

A POSSIBLE SOLUTION

Ohio Department of Transportation (ODOT) built a 120 foot long, adjacent box girder bridge using high performance concrete and the mid-depth shear key (Greuel, et al, 2000). The shear keys used non-shrink grout, except at the construction joint which used magnesium-phosphate grout. After almost 20 years, the only leakage is at the construction joint. That damage has been there since construction and is likely due to traffic load applied before the grout had completely set.

ANALYTICAL STUDIES



Typical Cross Section

ANALYTICAL STUDIES

Material Properties:

Girder Concrete:

Compressive Strength:	6 ksi
Modulus of Elasticity:	4500 ksi
Poisson Ratio:	0.2
Tensile Strength	590 psi
Coefficent of Thermal Exp:	5.5×10^{6} /^{o}F

Deck Concrete:

Compressive Strength:	4.5 ksi
Modulus of Elasticity:	3800 ksi
Poisson Ratio:	0.2
Tensile Strength	500 psi
Coefficent of Thermal Exp:	5.5×10^{6} /^{o}F

ANALYTICAL STUDIES

Suggested Material Properties:

Grout:

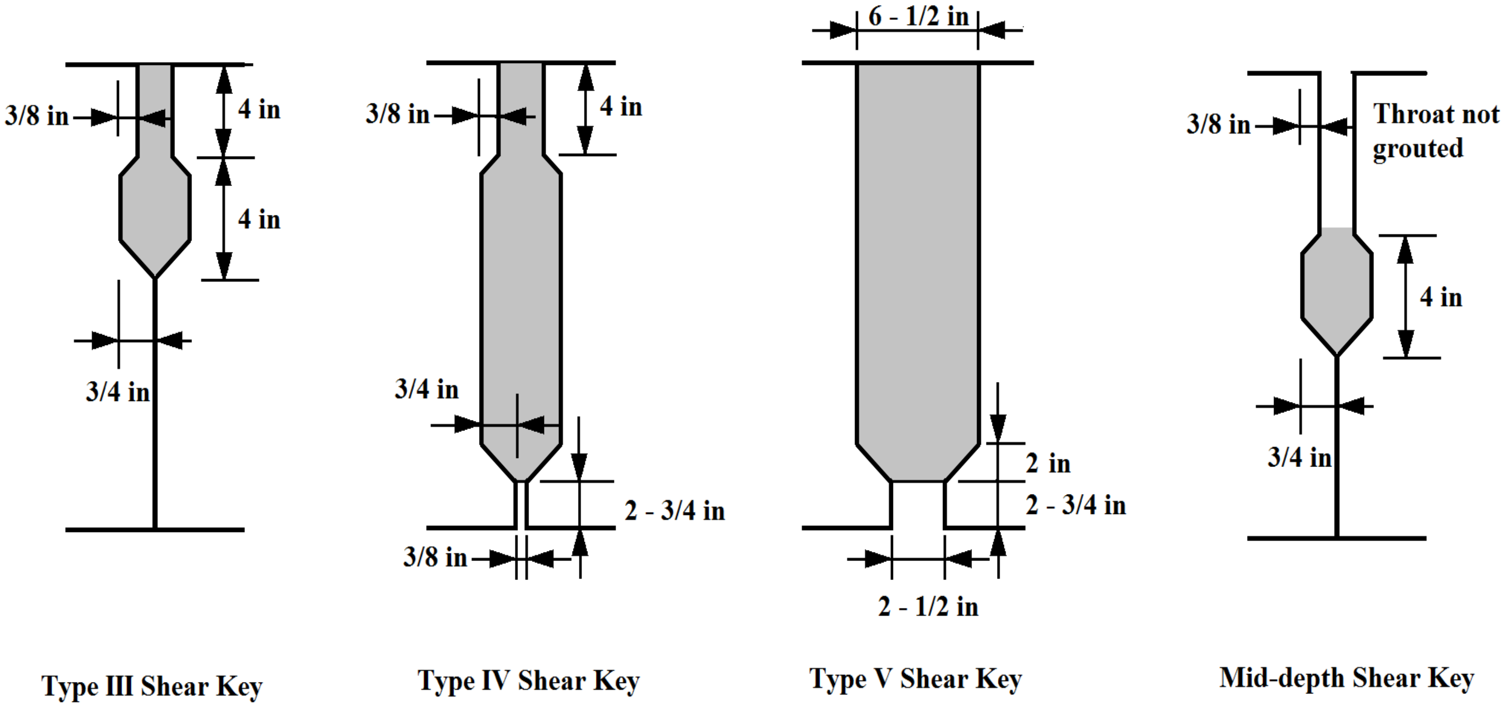
Compressive Strength:	3 ksi @ one day; 8 ksi at 28 days
Modulus of Elasticity:	3000 ksi
Poisson Ratio:	0.2
Tensile Strength	600 psi
Coefficent of Thermal Exp:	5.5×10^{6} /^{o}F (assumed same as concrete)
Shrinkage:	None (non-shrink assumed)

Grout Properties were determined as typical properties of non-shrink grout materials listed on the Ohio Department of Transportation Approved Product list in flowable condition.

Steel:

Modulus of Elasticity:	29000 ksi
Coefficient of Thermal Exp:	6×10^{-6} /^{o}F

ANALYTICAL STUDIES



SHEAR KEY CONFIGURATIONS EXAMINED

ANALYTICAL STUDIES

Bridge Models:

Four different bridges were modeled:
A 45-foot span using a 27 inch deep girder.
A 60-foot span using a 27 inch deep girder.
A 60-foot span using a 42 inch deep girder.
An 80-foot span using a 42 inch deep girder.

This examines the effect of depth and the effect of span on the shear keys.

The spans and girder depths were justified based on information obtained on span/depth ratios from various state DOTs.

Both composite and non-composite bridges were modeled.
Skews of 0^o and 30^o were modeled.

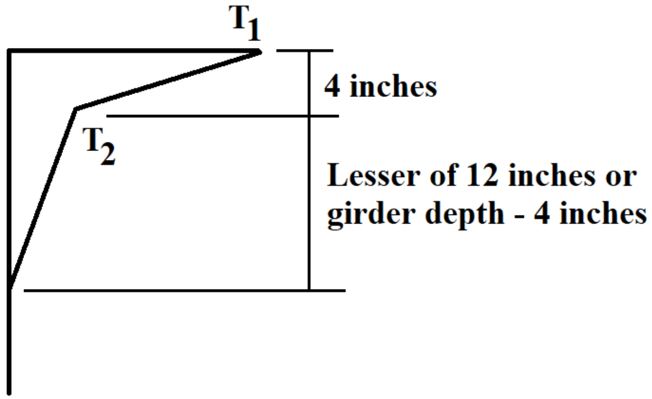
ANALYTICAL STUDIES

Procedure

- Model the bridge in the FEM program.
  - The shear keys were modeled.
  - Any deck was modeled.
    - Concrete decks were modeled as elements
    - Asphalt decks were not modeled but the deck weight was added.
  - The deck and shear keys were “turned off” during the initial heating phase so the shear keys and deck follow any subsequent temperature movement.

ANALYTICAL STUDIES

- The AASHTO temperature gradient was applied to the girders.
  - The provisions of Article 3.12.3 were used.
    - The worst case of Solar Radiation Zone 1 was used; $T_1 = 54^oF$ and $T_2 = 14^oF$ for a $\Delta T = 40^oF$.
- This caused the top of the boxes to expand.



ANALYTICAL STUDIES

Procedure (con’t)

- The shear keys and deck were turned on.
- The bridge was allowed to “cool” by removing the temperature gradient.
- Stresses at the interface were checked.

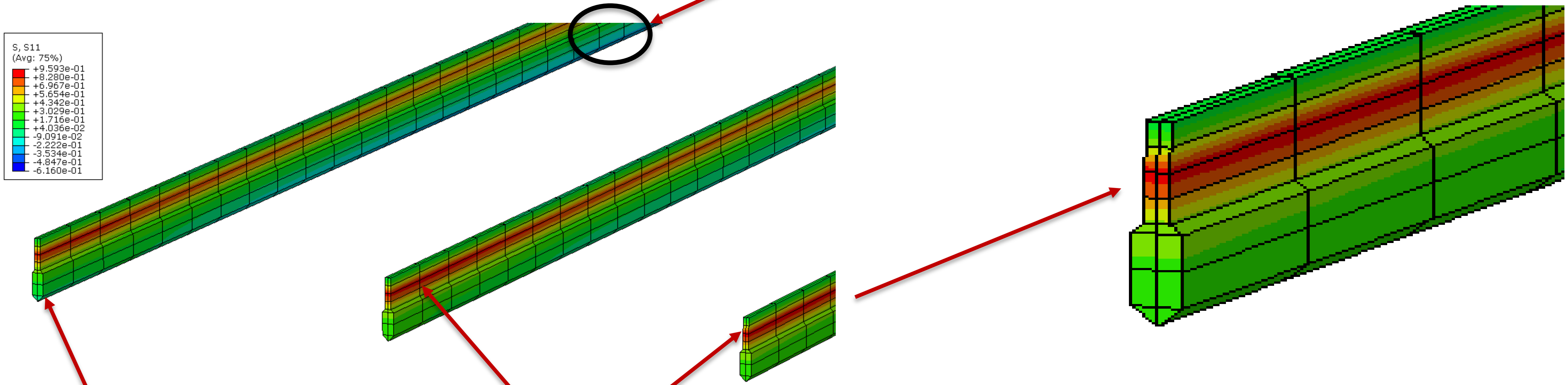
ANALYTICAL STUDIES

- Initial models had pinned ends. This was just to verify models.
- Actual analysis used bearing pads on ends.
  - One end had two bearing pads
  - The other end had one bearing pad
  - This is done in some states and allowed evaluation of both one and two pad configurations.
- Bearing pads do restrain lateral movement which increases stresses at the end, but there was no difference seen between one and two pads.

RESULTS

“Standard” Type III Shear Key

Compression at bottom near mid-span.



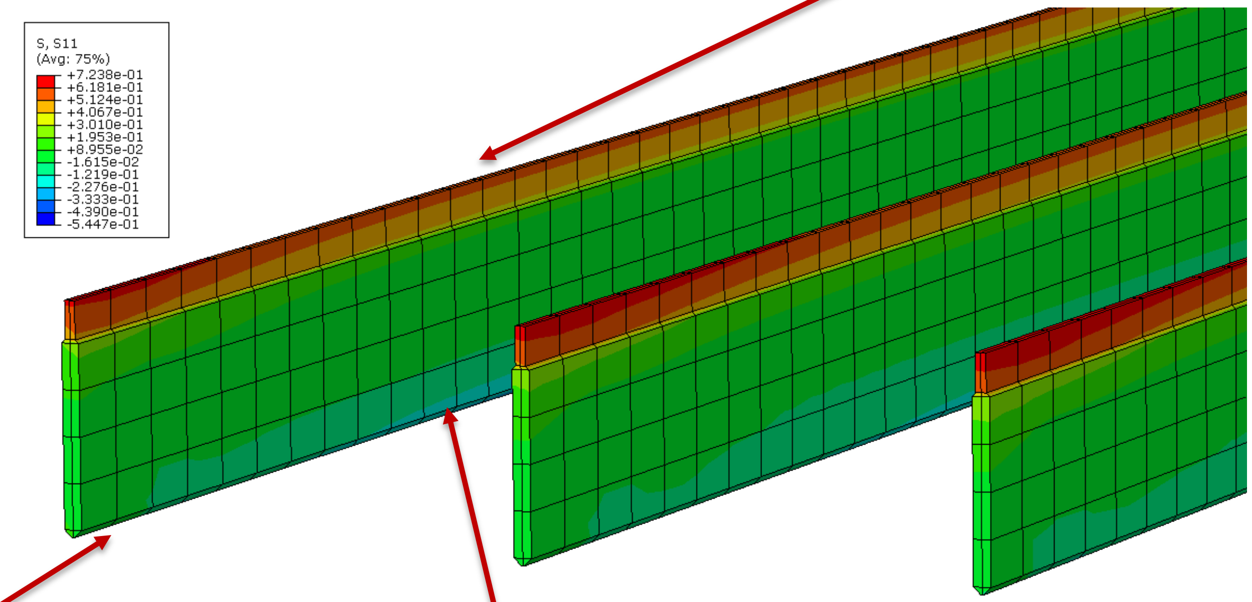
Higher stresses at end.
Agrees with field tests.
Attributed to bearing pad restraint.

Very high tensile stress in the “throat” of the key.
Approximately 900 psi

RESULTS

Type IV Full Depth Shear Key

Very high tensile stress in the "throat" of the key. Approximately 725 psi



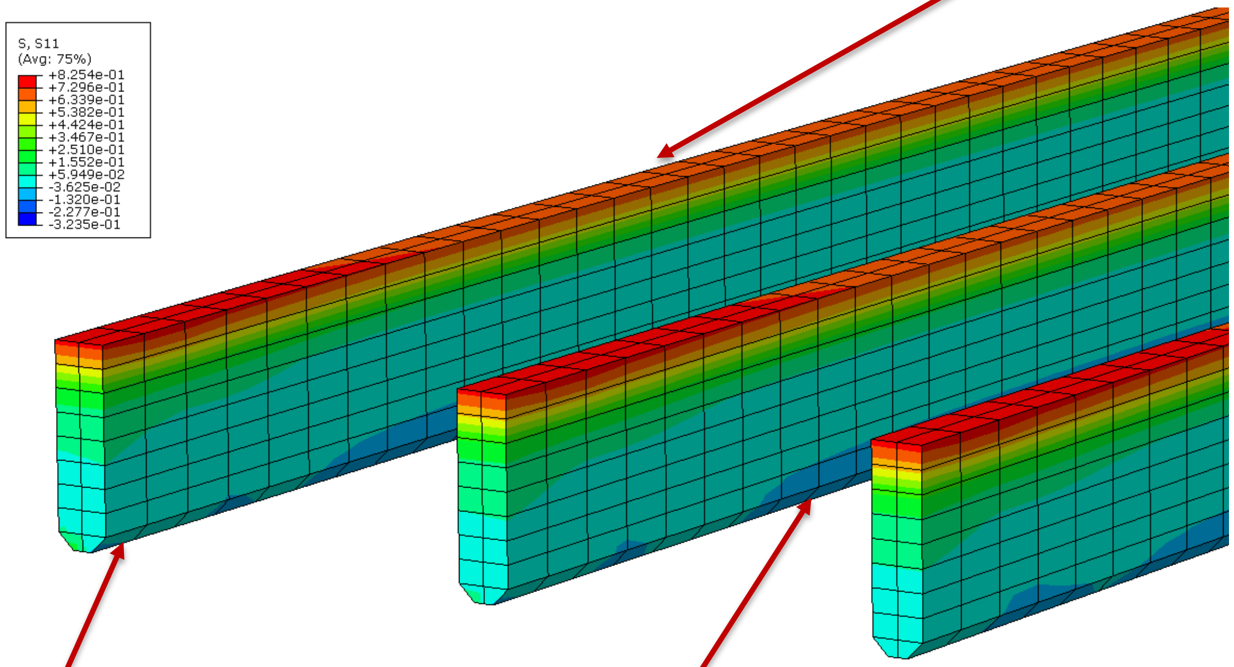
Over most of the shear key stress is less than 100 psi tension.

Higher stresses at end. Agrees with field tests. Attributed to bearing pad restraint.

Compression at bottom near mid-span.

RESULTS

Type V Full Depth Shear Key



Very high tensile stress in the "throat" of the key. Approximately 825 psi

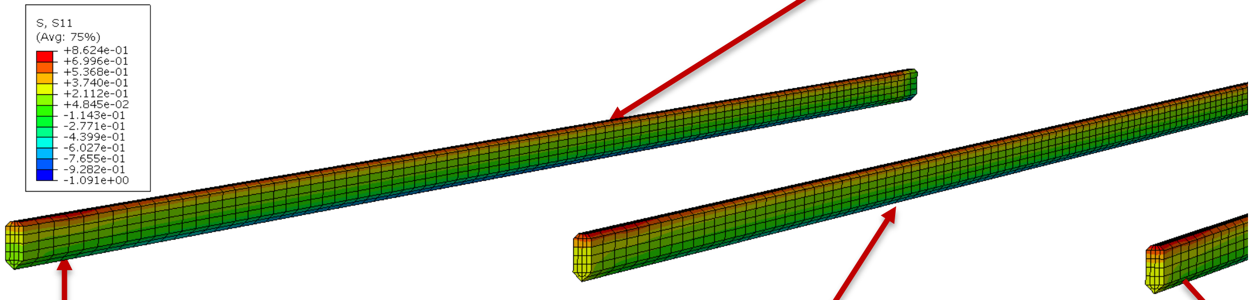
Overall most of the shear key stress is compressive.

Higher stresses at end. Agrees with field tests. Attributed to bearing pad restraint.

Compression at bottom near mid-span.

RESULTS

Mid-Depth Shear Key

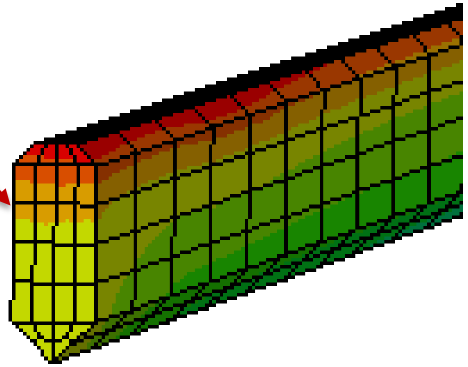


Very high tensile stress at the top of the key but then it drops off rapidly.

Over most of the shear key stress is less than 100 psi tensile.

Higher stresses at end. Agrees with field tests. Attributed to bearing pad restraint.

Compression at bottom near mid-span.

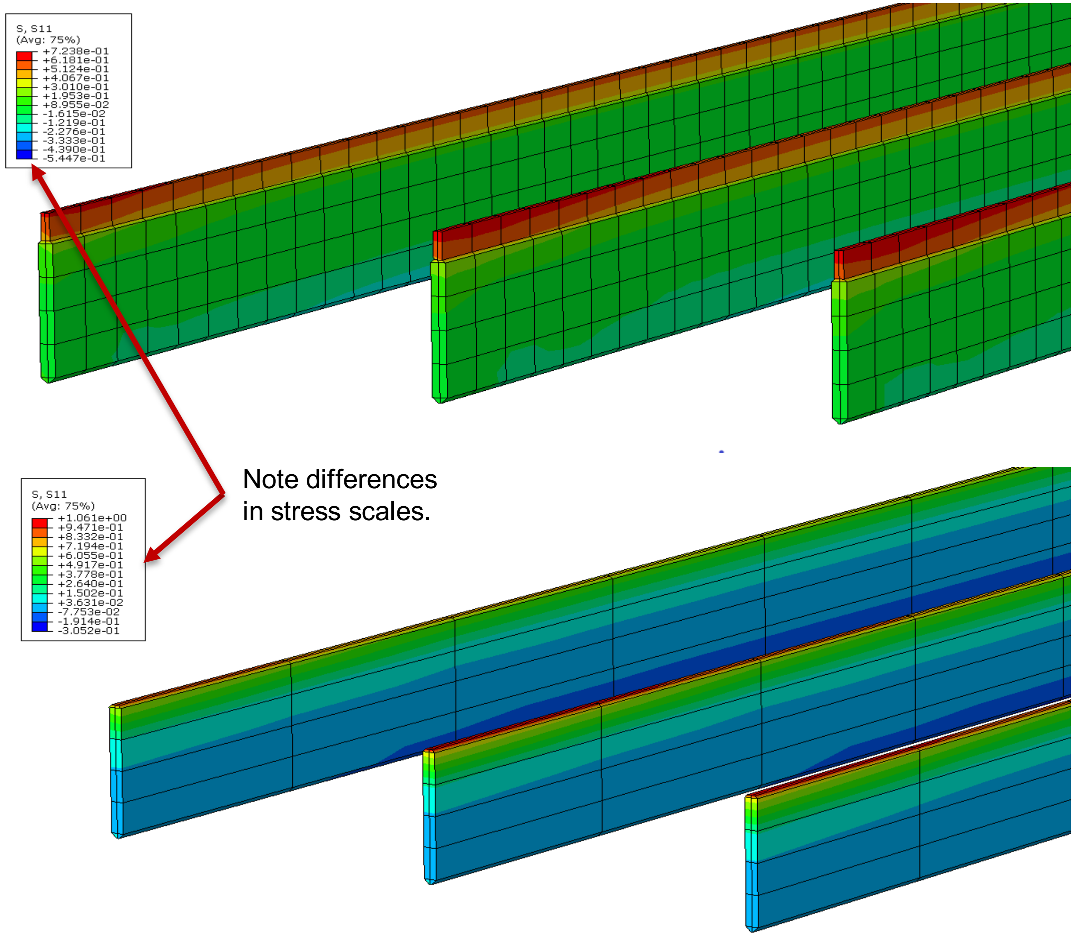


RESULTS

Effect of removing grout over the top 4 inches Type IV shear key:

Grouted throat.

Ungrouted throat.



Differences:

Almost no tension at top.

More compression over the depth of shear key.

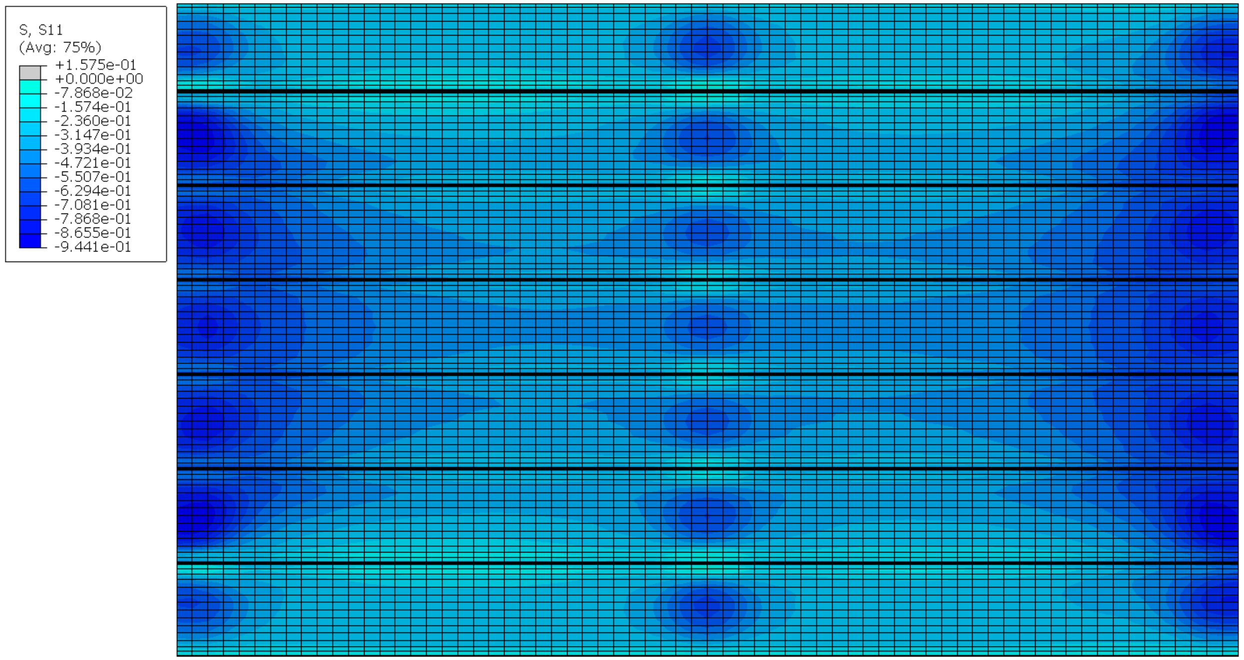
RESULTS

- All shear keys have high tensile stresses near the top, between 800 and 1000 psi.
- Removing the grout in the top 4 inches (area of maximum temperature gradient) greatly decreases the stress.
- Bearing pads restraint increases stresses at the ends.
- There is no clear effect of span, girder depth or skew.
- There is no clear difference between asphalt or concrete decks.

POST TENSIONING ANALYSIS

- Was done to see if post-tensioning decreases stresses in the shear keys.
  - Load transfer was not considered.
- Girders, shear keys and deck are modeled.
- Shear keys and deck are turned off.
- Girders are "heated" with the gradient temperature.
- Shear keys and deck are turned on.
- Cross section is post-tensioned.
- Girders are cooled by removing gradient.

RESULTS – PT ONLY

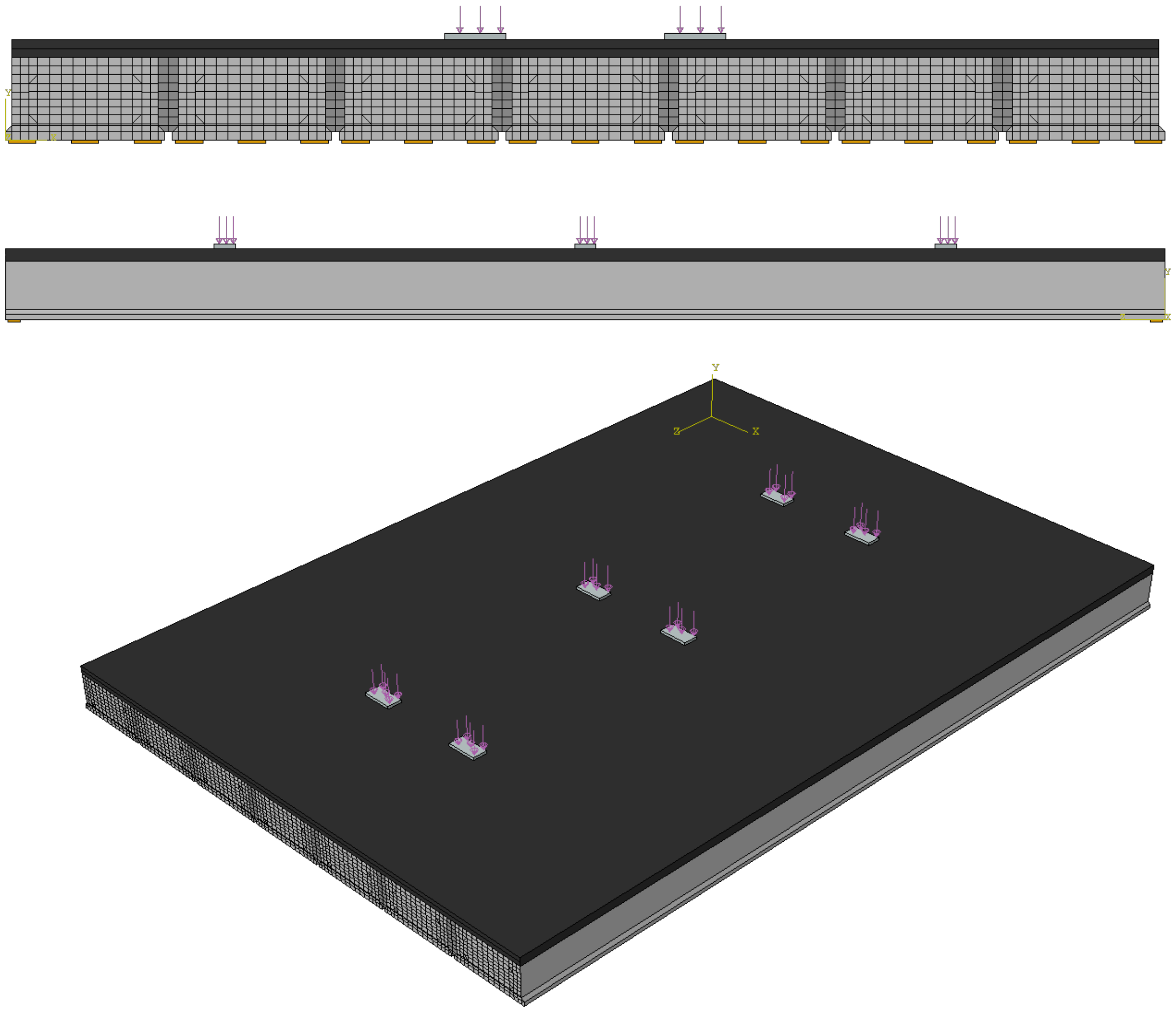


Typical result for a post-tensioned structure with end and midspan post-tensioning.

RESULTS

- Results show that PT is effective in compressing the joints near the points of post-tensioning but the stress falls off rapidly away from the PT point.
- This is consistent with previous analyses, lab measurements and field measurements.
- In some cases, tensile stresses are created in the girders and the shear keys.

LIVE LOAD ANALYSIS



HI-93 LOADING

Transverse, longitudinal and 3-D view shown.

Load placed to maximize key stress.

LIVE LOAD ANALYSIS

- Live Load stresses are very low.
- This is consistent with the literature.
- LL will not likely crack the shear keys but, acting with temperature, may propagate existing cracks.

CONCLUSIONS

- Temperature cracks the shear keys.
- Highest stresses are near the top. Removing the grout at the top reduces stresses.
- Type IV and V shear keys are very effective if the throat is not grouted. The mid-depth shear key is also effective.
- There is no discernable effect of span, skew or girder depth.

CONCLUSIONS

- Post-tensioning may aid in load transfer; however, post-tensioning does not prevent cracking in the joints.
- Reinforced joints were examined (but omitted here for time).
  - Reinforcing may control cracking but does not prevent cracking.
  - Reinforcing will transfer load.
- Live Load stresses are very low.
  - LL won't crack the keys but may help propagate temperature cracks.

LOAD TRANSFER

- Currently, shear keys are assumed to transfer load.
- Steinberg, et al. (2011) showed that untensioned lateral rods transfer load. Russell (2009) noted in his synthesis that other researchers reported this.
- Graybeal (2017) and then later Semendary et al. (2017a,b) showed that reinforced joints made with Ultra High Performance Concrete transfer load.
- Lateral post-tensioning will not stop cracking of the shear keys, but will transfer load.

WAYS TO IMPROVE SHEAR KEYS

- Move the shear key out of the area of maximum temperature movements (top 4 inches).
- Make the shear key deeper so there is more bond area.
- Roughen the sides of the girders to improve bond between the girder and the grout.
- Use a better bonding grout.
- Prewet the girder sides to improve bond.

NCHRP 12-95A

Experimental Phase

EXPERIMENTAL OBJECTIVES

- Determine the bond strength of various shear key materials to various substrate conditions.
- Test two full scale specimens.
  - A full depth Type IV shear key where the top 4 inches is not grouted.
  - A full depth Type V shear key where the top 4 inches is not grouted.
  - Test under temperature and live loads.

Bond strength testing of keyway material

- To establish the standards for:
  - strength of keyway material
  - bond strength of keyway and girder material
  - surface preparation requirements for the keyways
- Use ASTM C1583 Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)
- Tests performed on three panels (with different surface finishes) and finally on the sides of the girders.

Shear Key Materials

- Sika 212
  - Non-shrink grout
- Masterflow 928
  - Non-shrink grout
- Masterflow 4316
  - High bond non-shrink grout
- Small aggregate concrete

ASTM C1583 Standard Test Method

- Grout material was placed on a substrate. In this case the grout layer was 1.5 inches thick = shear key width.
- A 2 inch diameter core was taken through the grout and at least 0.5 inches into the substrate.
- A 2 inch diameter disk was epoxied to the core.
- Tensile load was applied to the disk to try to separate the grout from the substrate.

ASTM C1583 Standard Test Method

- Four Possible outcomes:
  - The grout fractures (good test)
  - The substrate fractures (good test)
  - The bond fails (good test)
  - The epoxy fails (unusable test)
- Testing was repeated until at least 3 tests with the same failure mode were obtained.

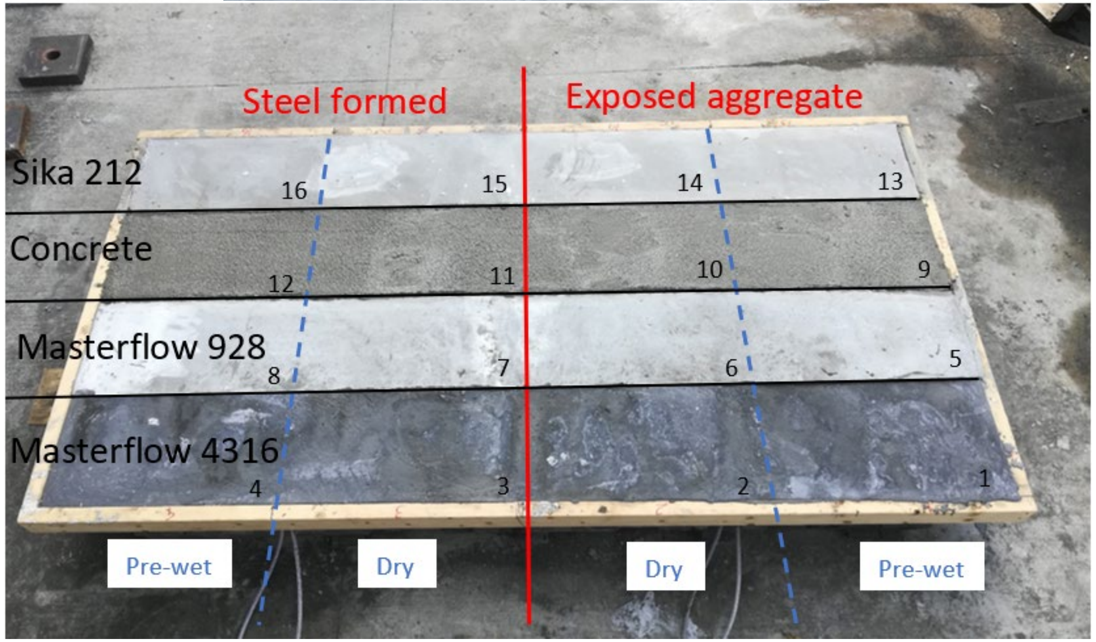
Test panel I

- Surface finishes: steel formed and round aggregate
- Grout materials: Sika 212, Masterflow 928, Masterflow 4316, small aggregate concrete
- Surface prep: Light sandblasting followed by prewetting of half the portion

Test panel I

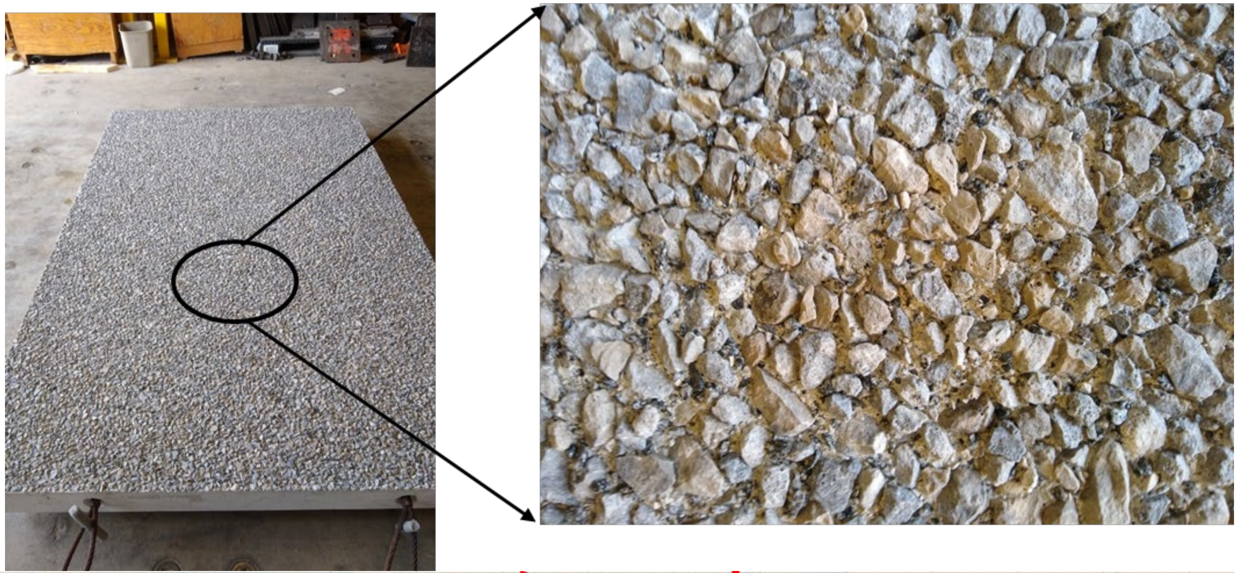
Observations:

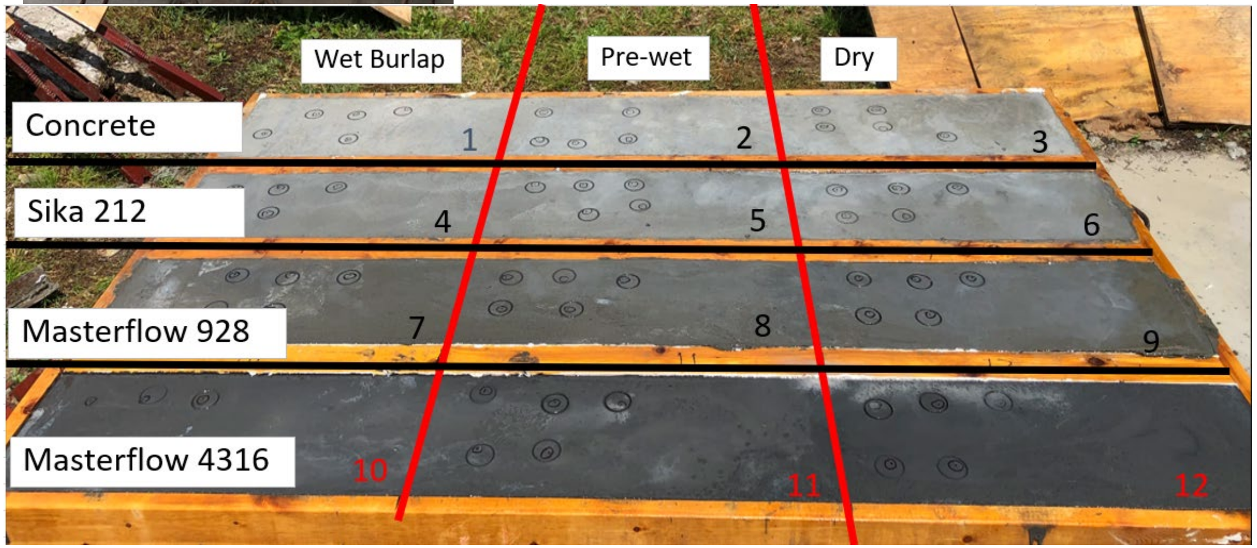
- Masterflow 4316 performed the best and failed in substrate
- Remaining materials performed about the same
- Exposed aggregate surface performed better than the steel formed
- All surfaces showed strength of at least 200 psi with most above 300 psi



Test panel II

- Surface finishes: crushed exposed aggregate
- Grout materials: Sika 212, Masterflow 928, Masterflow 4316, small aggregate concrete
- Surface prep: Light sandblasting
  - Dry surface
  - Prewet surface
  - Applied wet burlap for 24 hours

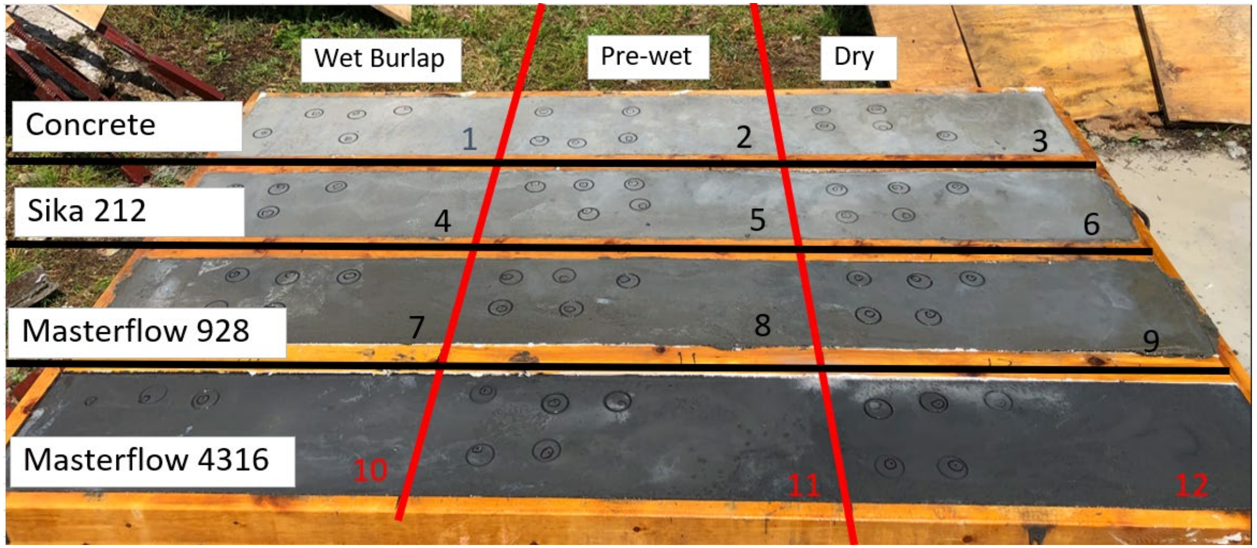




Test panel II

Observations:

- Masterflow 4318 again performed the best
- No significant difference when compared to round aggregate
- Prewetting the surface increased the strength in most cases
- Using burlap had no significant impact on the strength



Test panel III – Made with Full Size Specimens

- Surface finish: Sandblast to International Concrete Repair Institute Concrete Surface Profile-3

- Grout materials:
  - Sika 212, Masterflow 4316
  - small aggregate concrete

- Surface prep: Light sandblasting followed by prewetting

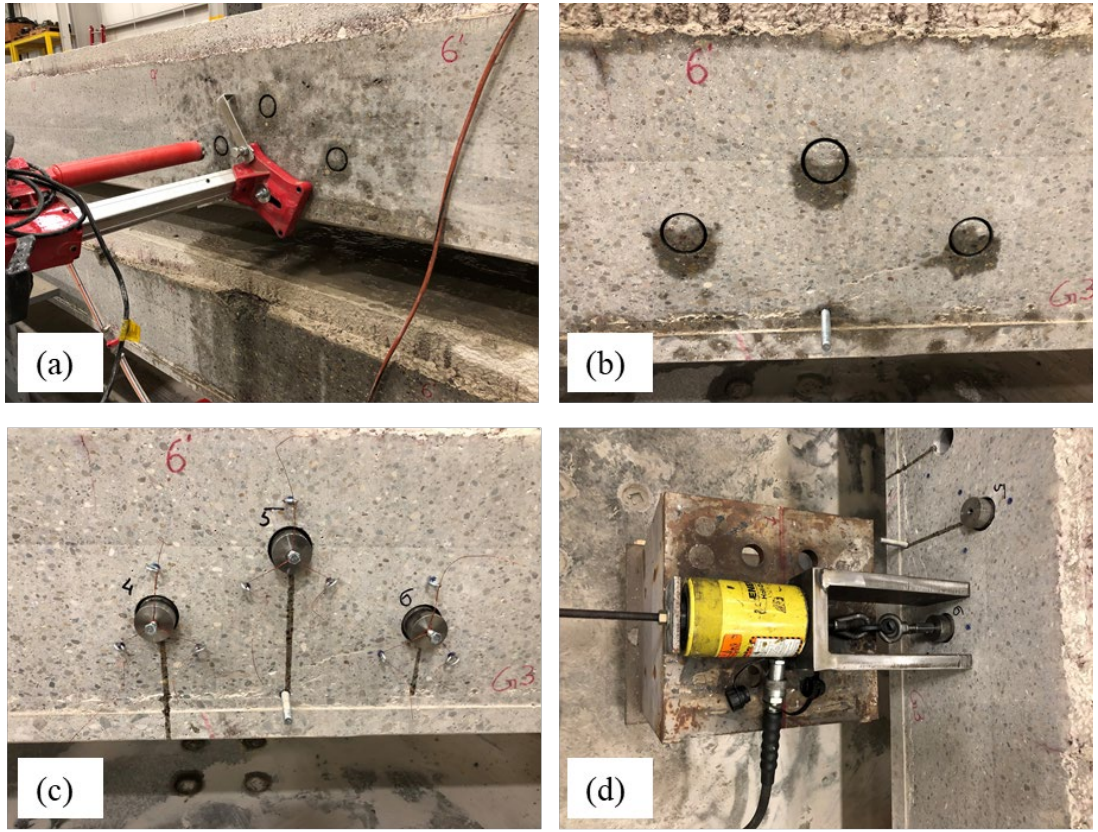
Test panel III

Observations:

- Masterflow 4316 again failed in substrate indicating sufficient bond strength even on CSP-3 to 4 surface
- SIKA 212 performed poorly, but there were problems with the grout (discussed later)
- Concrete failed at unexpectedly low bond strengths, but the mix started to set before placing on the panel (discussed later).

Girder sides

- Surface finishes: CSP-3 to 4 surface
- Grout materials:
  - Sika 212(used in Type IV shear key)
  - small aggregate concrete (used in Type V shear key)
- Surface prep: Light sandblasting followed by prewetting



Girder Sides

Observations:

- Concrete:
  - Average failure strength for concrete increased from 136 psi on panel to 306 psi on the girder surface
  - Failure was in the bond for both the cases
  - This verifies the RT's suspicion that the low failure strengths in the original pull off tests was due to concrete setting before casting the panel.
- Sika 212:
  - Strength increased from 268 psi on panel to 464 psi on girder surface
  - Mode of failure changed from grout failure to bond failure.
  - This indicates that for a good quality Sika grout, the performance is adequate.

Pull off test summary

- All the materials and surface conditions had a pull off strength of at least 200 psi and most were above 300 psi. De la Varga et al. (2016) suggested that a strength of 150 psi was needed, and all the grouts and all the conditions met this minimum
- Higher bonding grout performed the best and is recommended; however, other grouts also showed satisfactory performance and could be used
- Any surface roughened to CSP-4 or more is recommended
- For roughened surface, prewetting of the girder surface is highly recommended

Full Scale System Testing

It included:

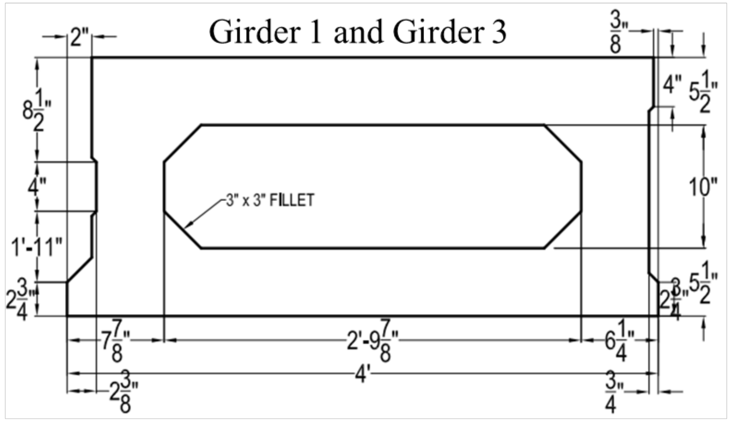
1. Plant monitoring of individual girders to establish thermal stresses experienced by the girders at the plant to simulate field conditions.

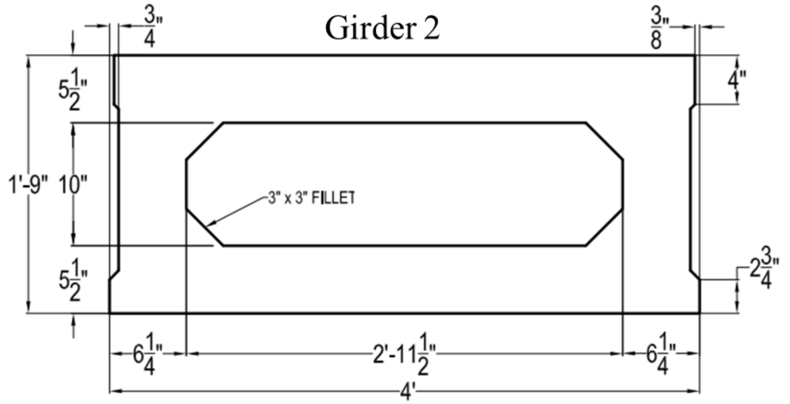
2. A system test on three girders forming two Type IV shear key joints cast with two different grouts and subjected to thermal and live loading.

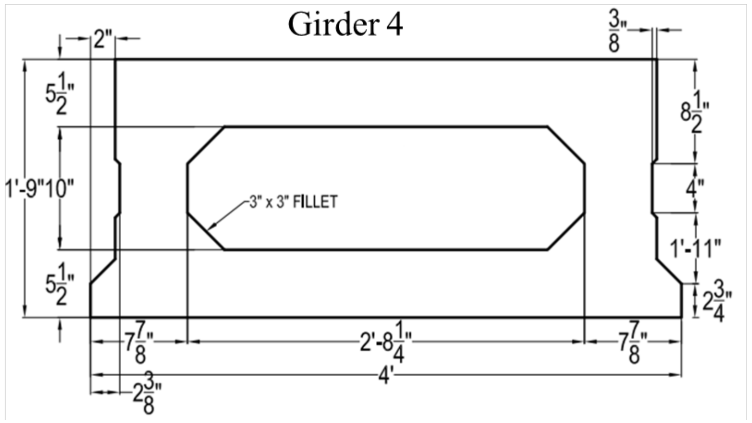
3. A system test on three girders forming two Type V shear key joints cast with small aggregate concrete and subjected to thermal and live loading.

Test Girder

- 4 feet wide; 21 inch deep; 36 feet long girders used for testing
- Designed according to AASHTO LRFD Specifications
- Girder 1 and Girder 3 had Type IV shear key on one face and Type V shear key on the other
- Girder 2 and Girder 4 had Type IV and Type V shear keys, respectively, on both faces

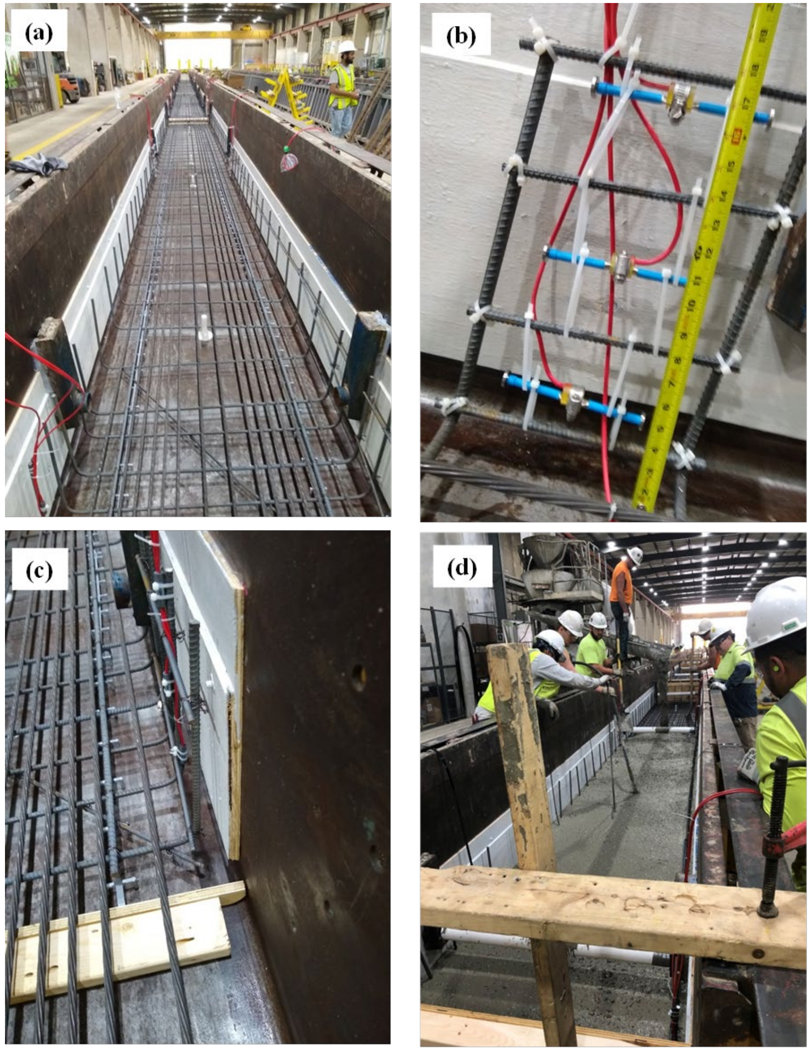


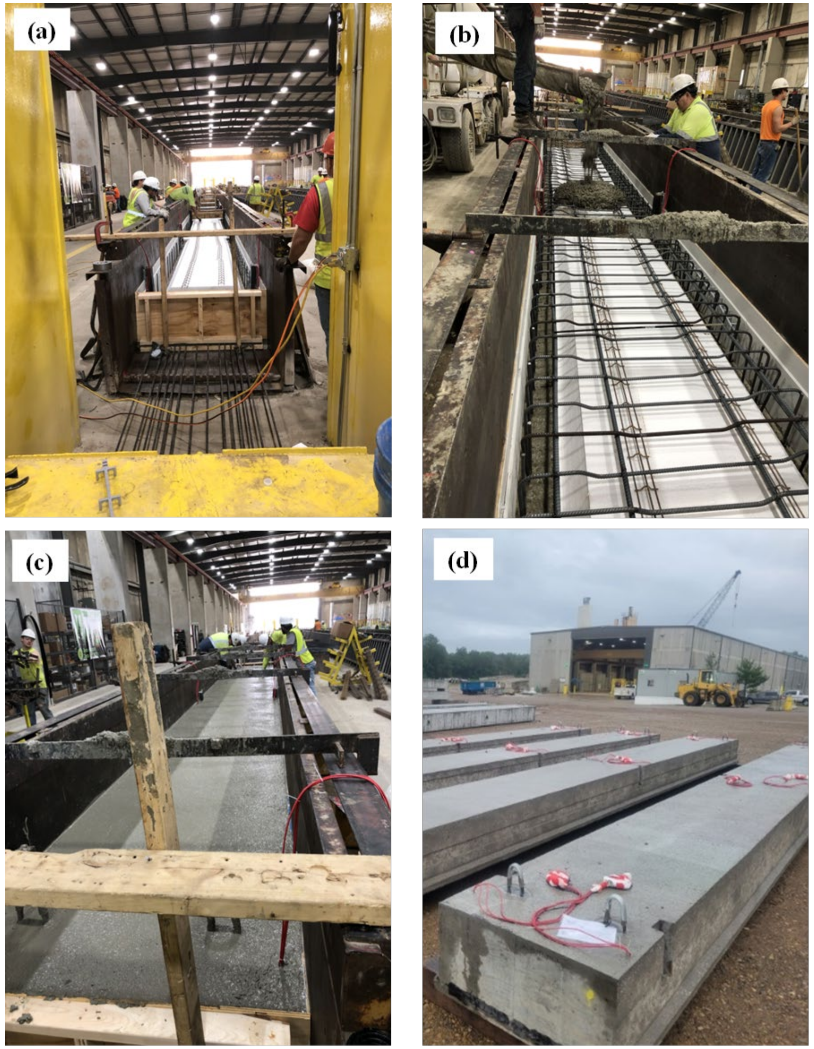




Girder Fabrication

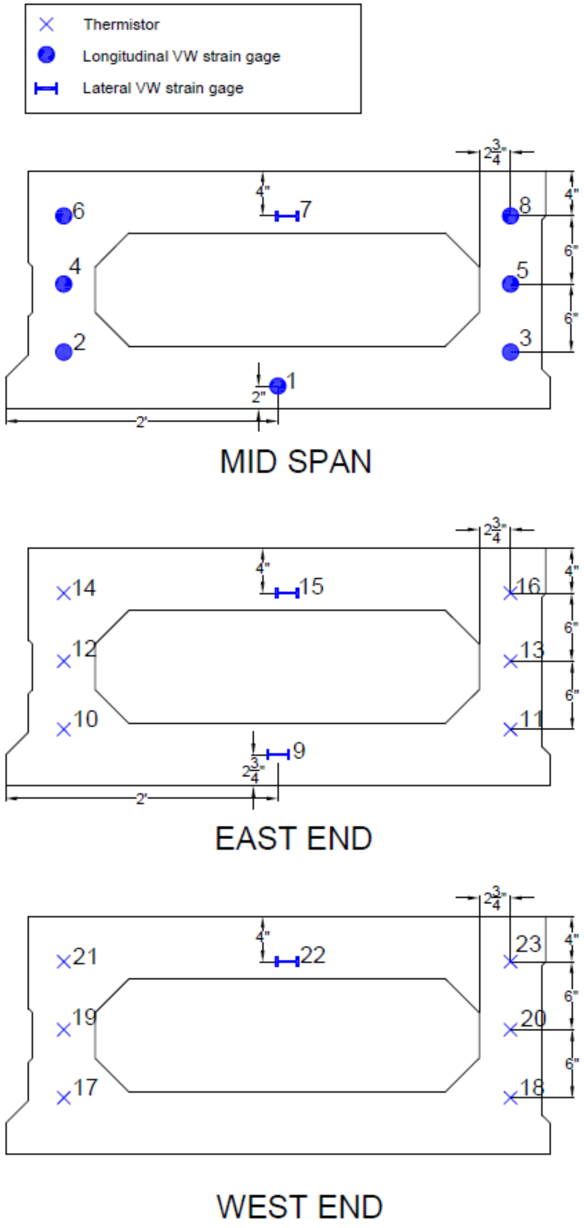
- Girders were fabricated at the Prestress Services plant in Mount Vernon, Ohio
- Instruments were installed during fabrication





Girder Fabri

- VW gages and Thermistors installed at the midspan and each end of the girder
- These gages were used to obtain the strain and temperature profile of the girders



Girder Fabrication

- Specifications asked for an exposed aggregate finish on the shear key surface
- Unfortunately, the desired exposed aggregate surface was not obtained.
- The contractor sandblasted the surface.
- The girder ended up having a CSP-3 to CSP-4 roughness

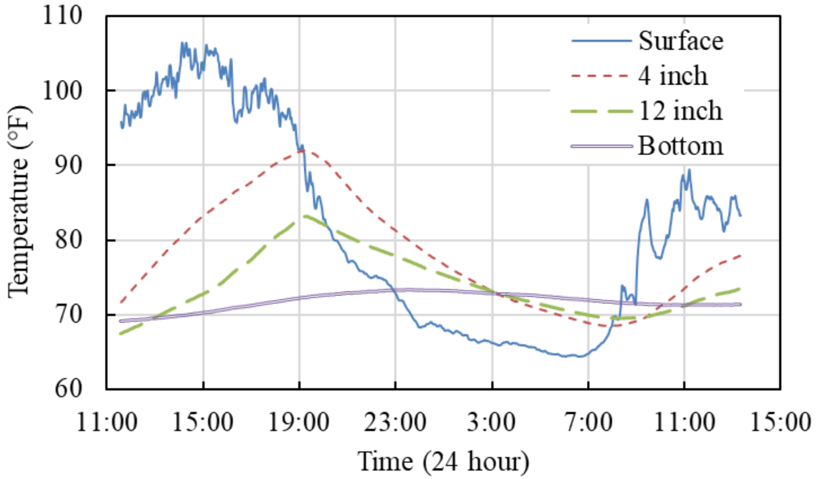
Filed Monitoring of the Girders

- While girders were in prestressing yard, they were monitored for temperature profiles along their depth
- Embedded instruments were connected to a data acquisition system and monitored for 24 hours
- For most of the day during monitoring, one face of the girder was shaded from the sunlight while the other was directly exposed.

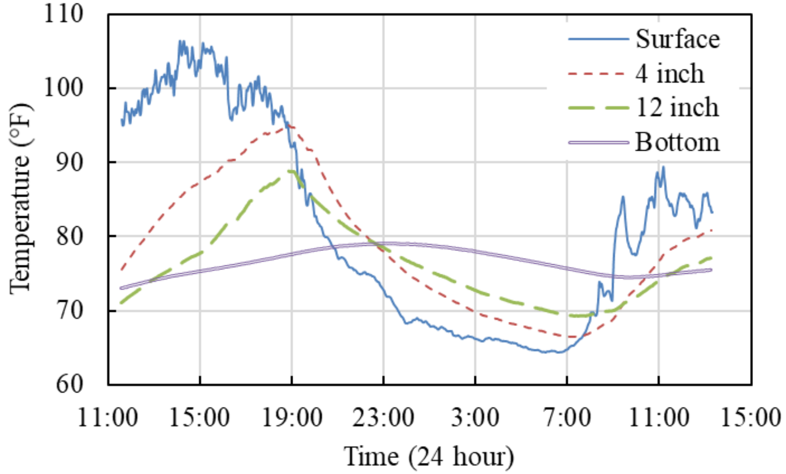
Field Monitoring: Temperature variation

SHADED FACE

(a)

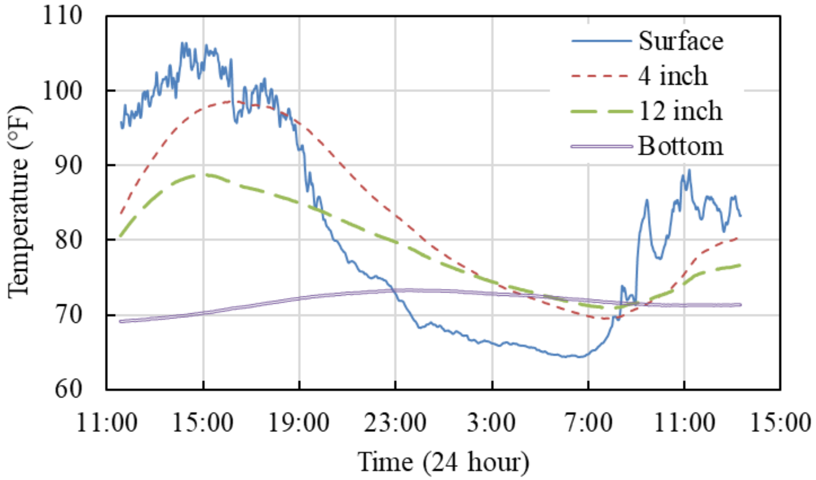


(a)



EXPOSED FACE

(b)



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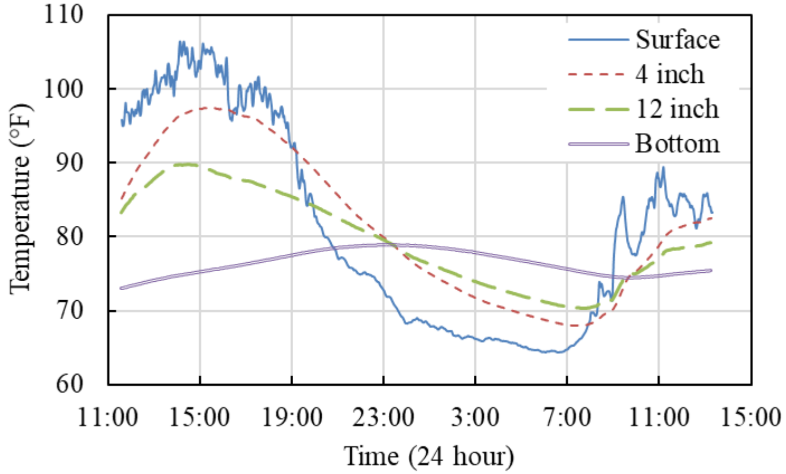
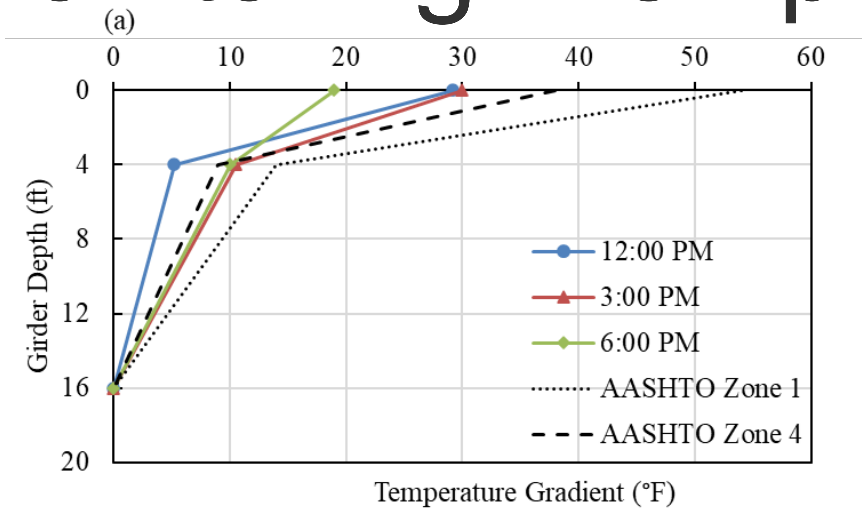


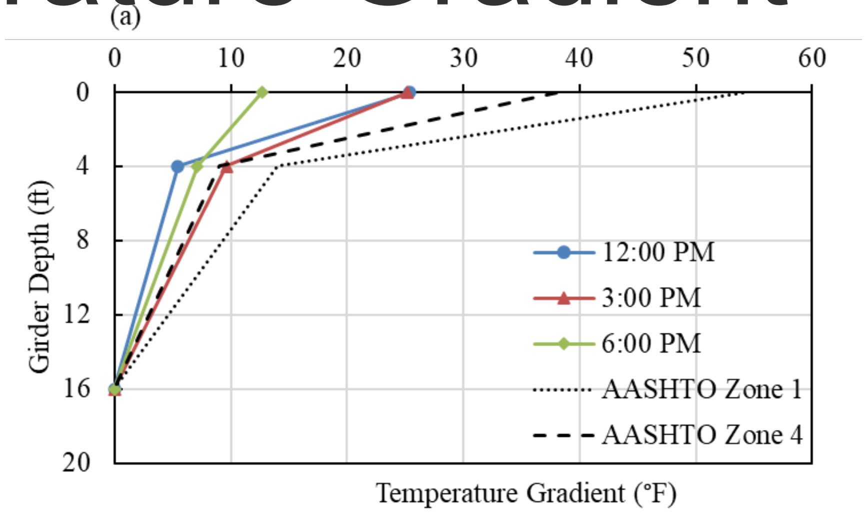
MIDSPAN

ENDSPAN

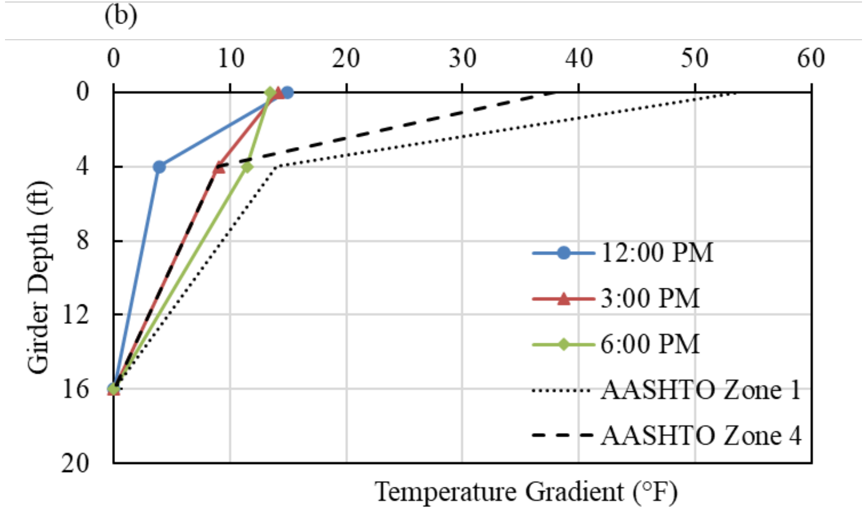
Field Monitoring: Temperature Gradient

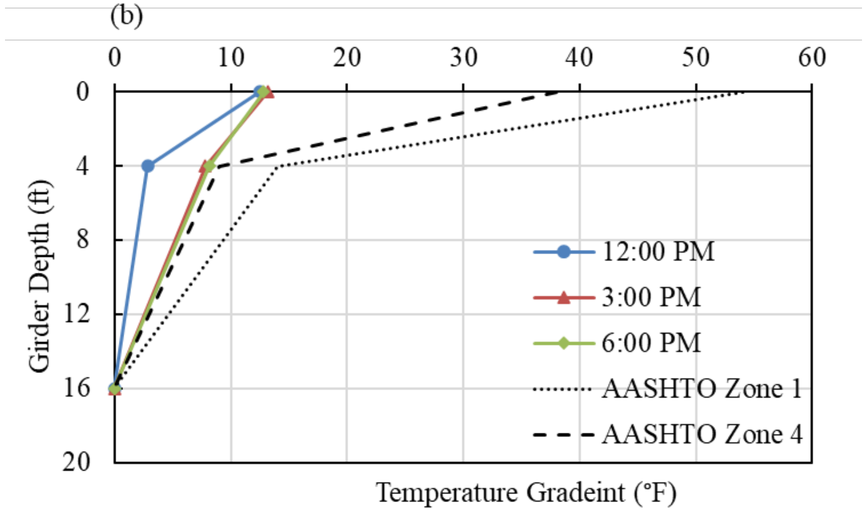
SHADED FACE





EXPOSED FACE





MIDSPAN

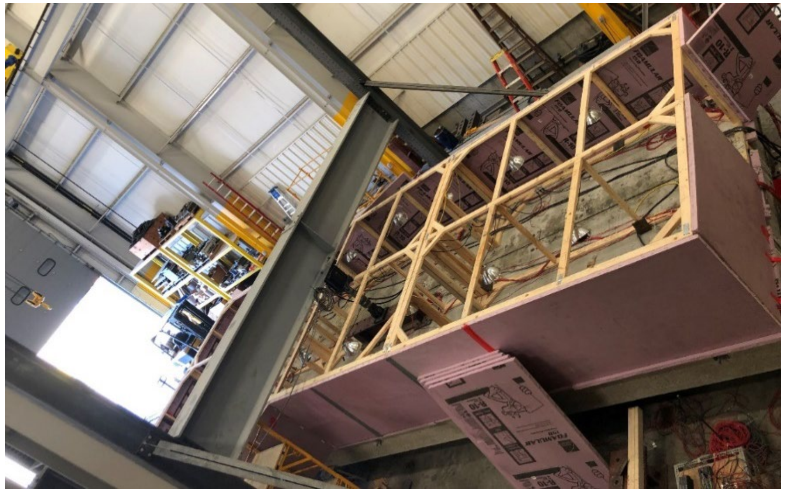
ENDSPAN

Field Monitoring: Summary

- For face shadowed from direct sunlight, the peak temperature inside the girder occurred several hours later than the peak temperature on the surface
- Temperature gradient observed in the field is comparable to the gradient suggested by AASHTO
- Temperature gradient is more severe on the face shadowed from sunlight than on the face exposed to sunlight
- Temperature gradient is more severe at the midspan than at the end of the girder. This is likely due to the fact that the end of the girder is a solid diaphragm and not hollow.
- Peak gradient occurs at around 3 pm

Type IV shear key test

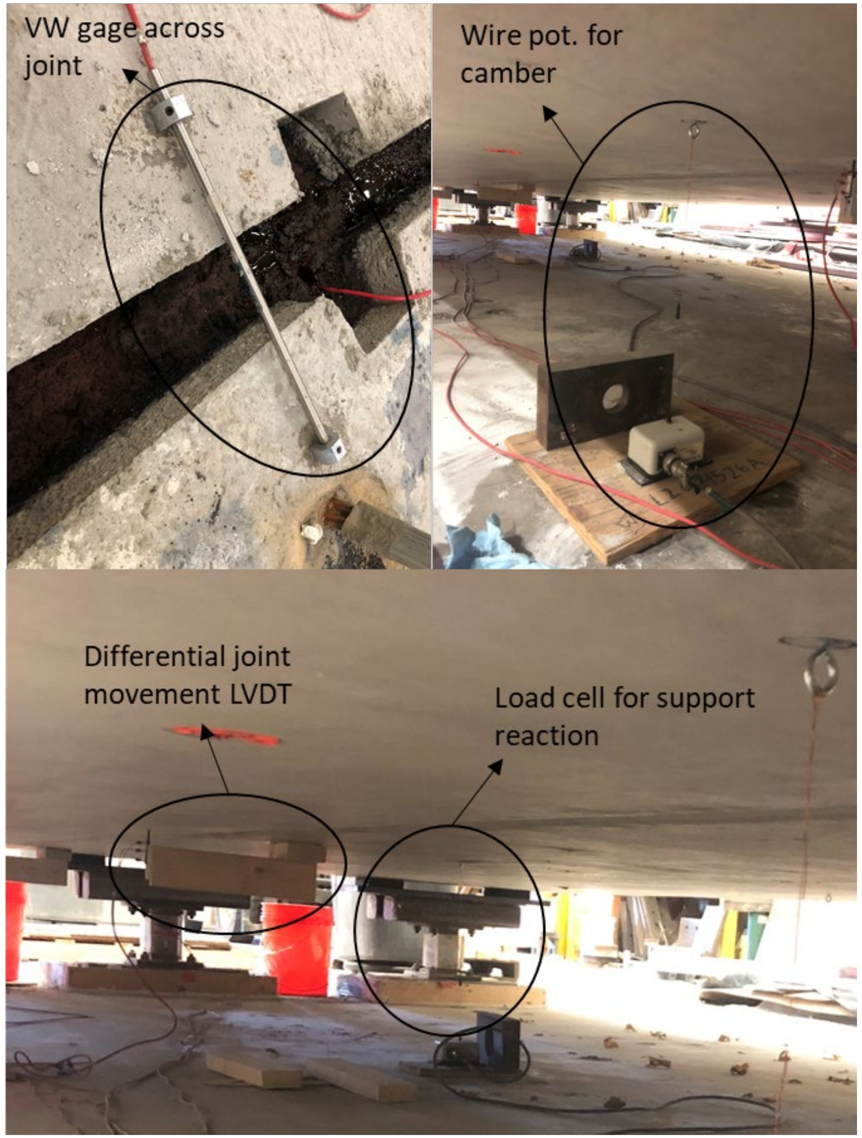
- Girders assembled on lab floor and "heat box" was built to apply temperature load
- Heaters, lamps and fans were used to heat the top of the girder
- VW gages and thermistors embedded during fabrication were monitored to measure temperature profiles



Method suggested by Liu and Phares (2019)

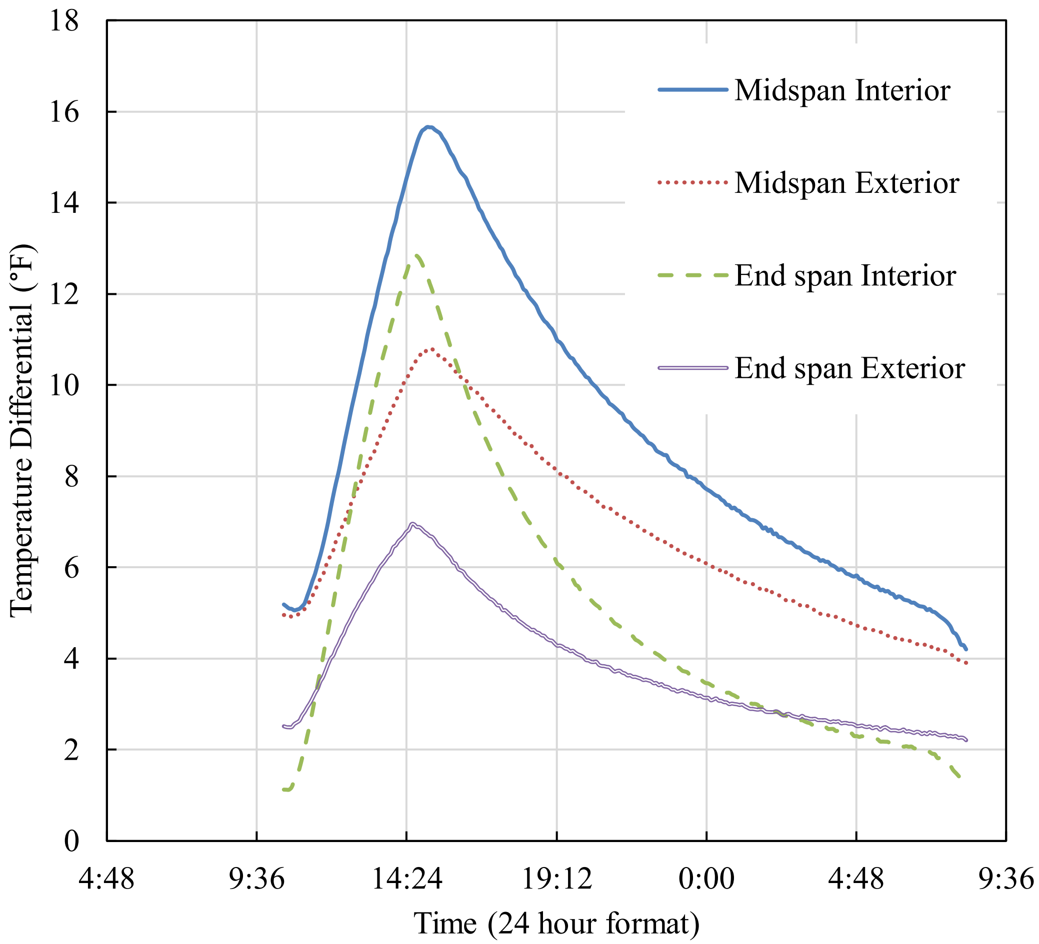
Type IV shear key test

- Instruments were also installed to measure the camber, strain across the joints, differential joint movement, and support reactions
- Tasks performed:
  - Thermal loading before grouting
  - Grouting the shear keys
  - 30 thermal cycles
  - 100 k live load cycles
  - Dye penetration test
  - Joint cutting and inspection



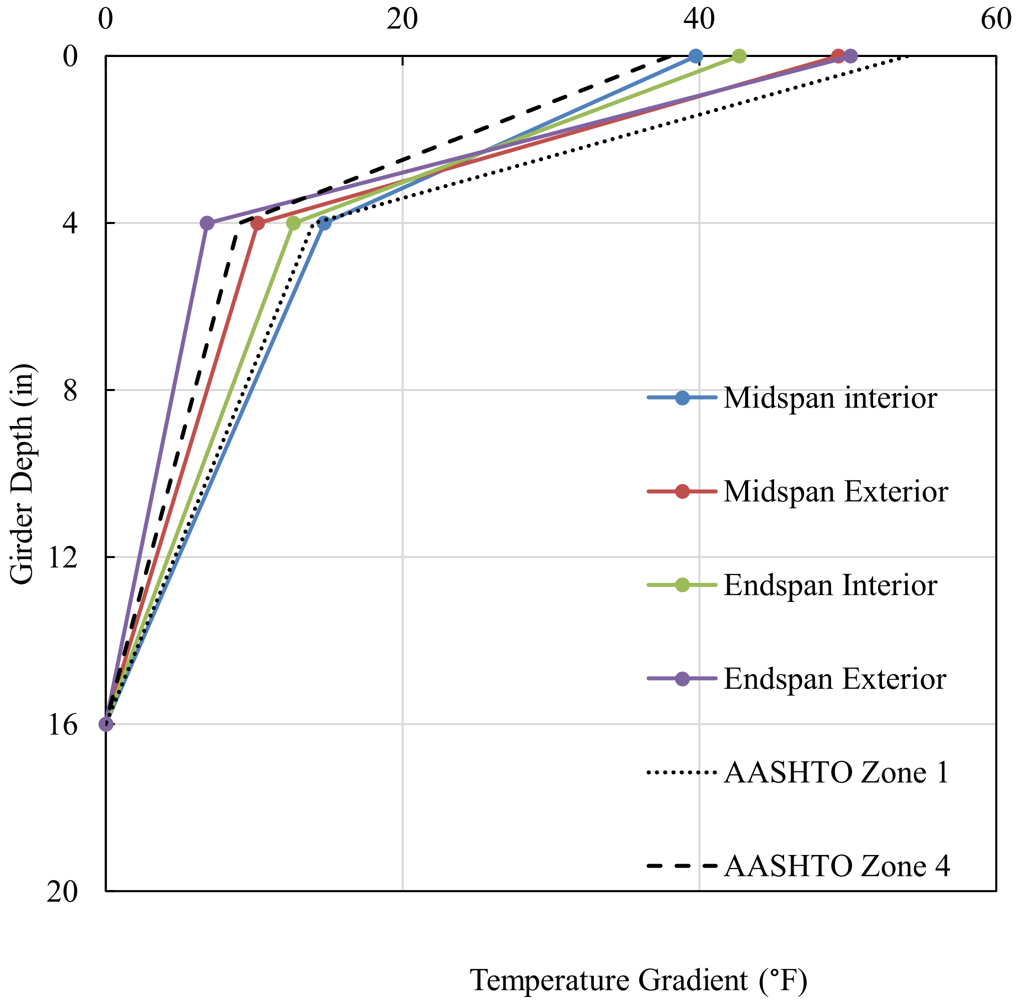
Type IV shear key: Thermal loading before grouting

- The girders were heated until the temperature gradient between four inches and sixteen inches below the girder surface (T_2) reached approximately 14 °F, and then were allowed to cool until the gradient fell at least below 4 °F
- Graph shows the temperature differential at a depth of 4 inches from the surface
- Just like in the field, midspan interior experiences the highest gradient



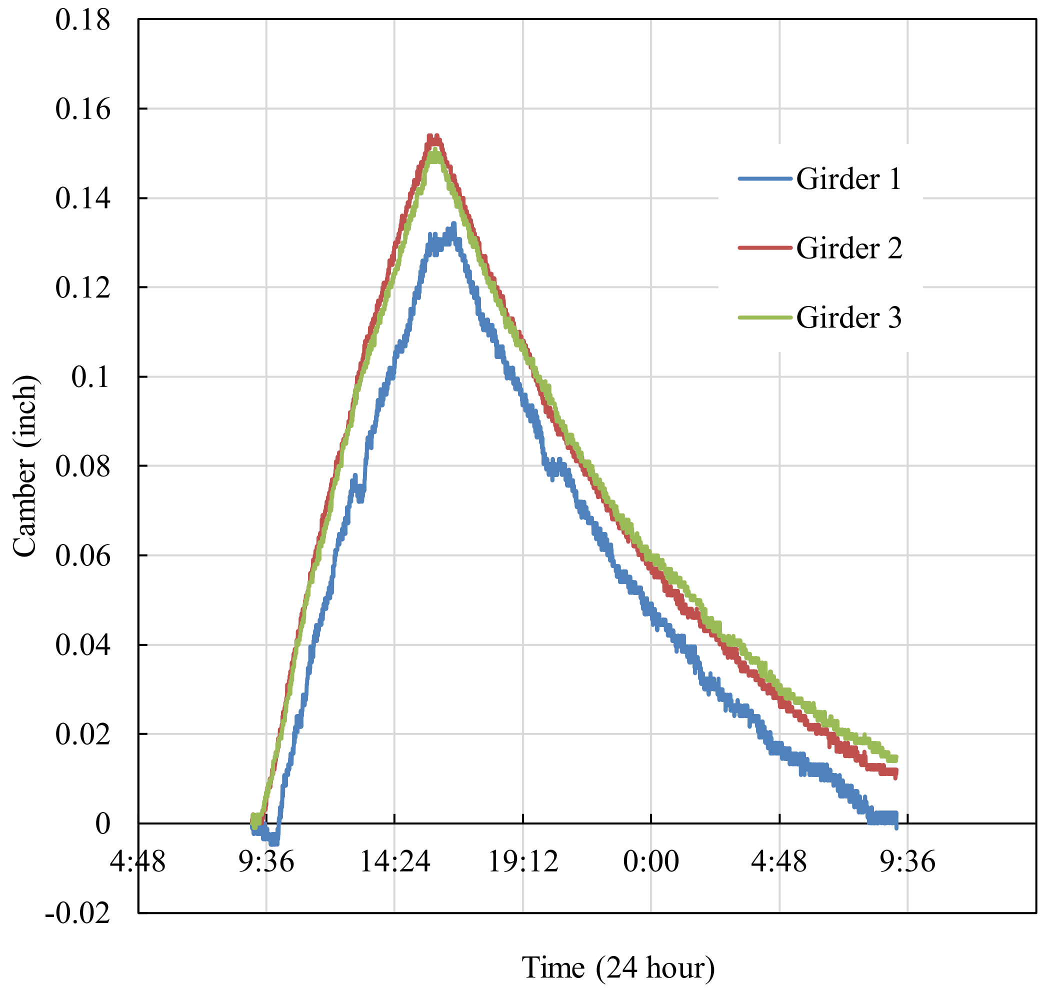
Type IV shear key: Thermal loading before grouting

- Graph shows the temperature gradient through girder depth at various locations.
- Well within the AASHTO gradient band and similar to field observations



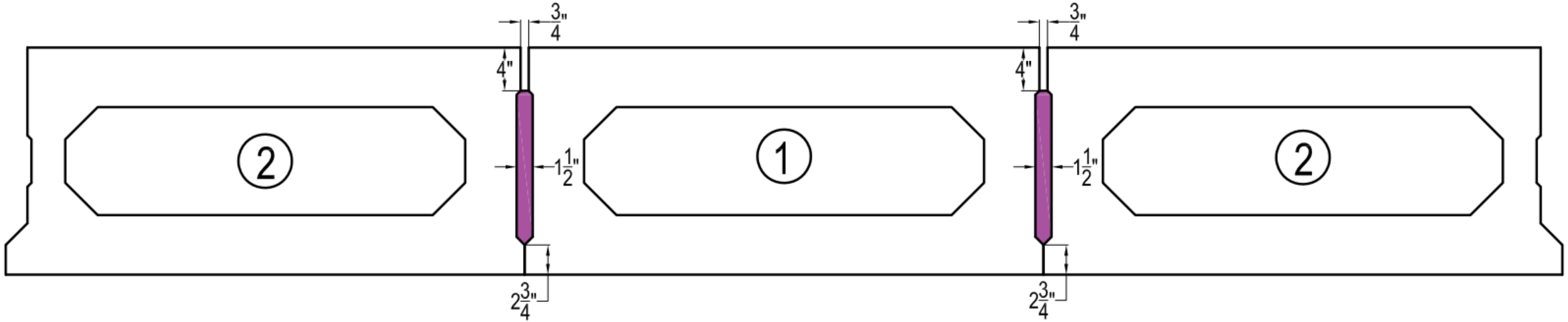
Type IV shear key: Thermal loading before grouting

- Graph shows the camber of the girder during heat cycle
- Camber increases with temperature and drops down on cooling



Type IV shear key: Grouting

- Prior to casting the shear keys, the girders were heated to simulate field conditions
- Sika 212 was used in one joint and Masterflow 4316 was used in one joint.
- Grout was not placed in the top 4 inches of the shear keys.
- After grouting the girders were heated again to increase T_2 to 14^o F.
- The girders were then allowed to cool overnight
- The process was repeated for 30 cycles.



Type IV shear key: Grouting

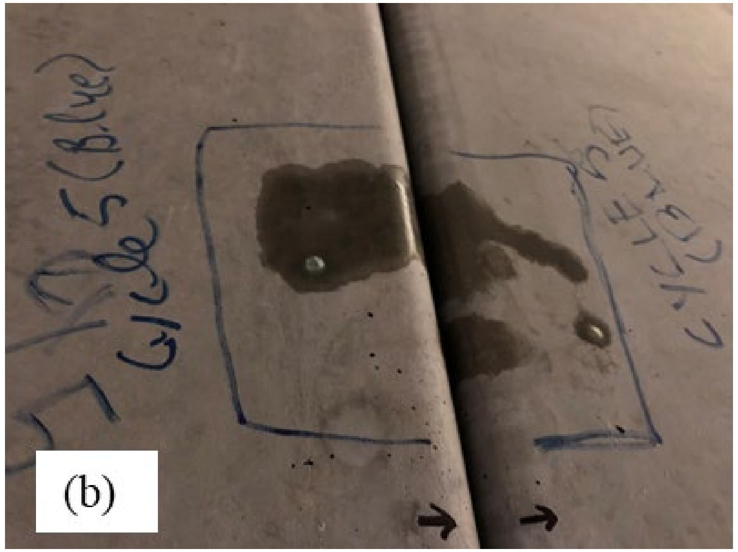
- The joint with the Masterflow 4316 was grouted without incident.
- Half the joint with the Sika 212 was grouted without incident.
- After grouting half the joint with Sika 212, it was found the remaining grout had been exposed to moisture. Since it was too late to do anything, the remainder of the joint was cast with the poor quality grout.

Type IV shear key: Thermal load and flooding after grouting

- From the day after grouting, thermal loading was applied to the girder system
- A total of 30 thermal cycles were applied to the system
- Joints were flooded with different colors of dyed water after 1st , 5th, 15th , and 30th cycle to look for leakage.
  - The dye will indicate where any cracking occurred. The color indicates when it occurred.

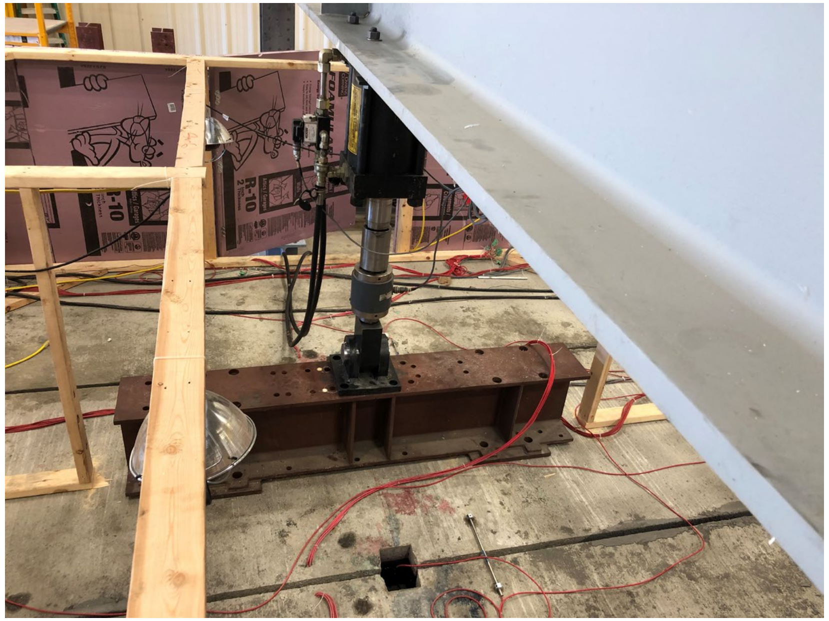
Type IV shear key: Thermal load and flooding after grouting

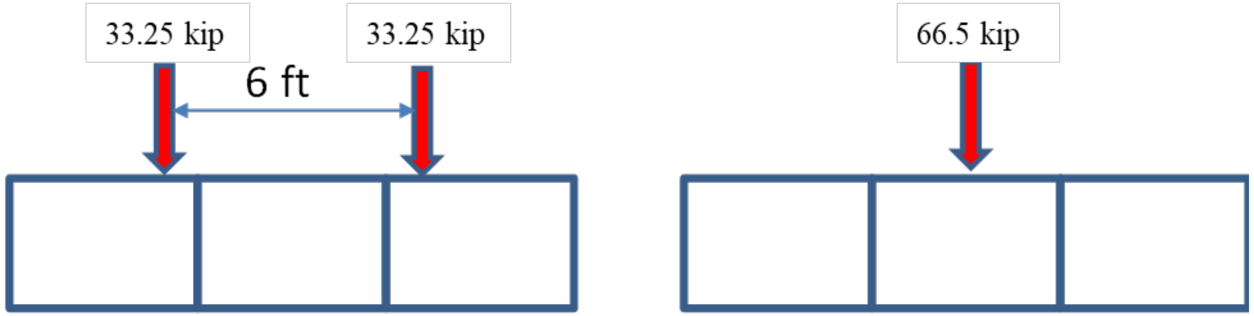
- Masterflow 4316 joint showed no signs of leakage during any dye test
- Sika 212 joint showed leakage in part of the joint that was done using the poor quality grout



Type IV shear key: Live Load

- The live loading consisted of a cyclic load between 0 kip and 66.5 kip applied at a frequency of 2 Hz for a total 100,000 cycles
- This load represents a tandem load of two, 25 kip loads plus a 33% impact
- Static load of 66.5 kip was applied after 0, 5000, 10000, 25000, 50000, and 100000 cycles to find any deterioration of joints
  – the instruments do not respond fast enough to read them under cyclic load



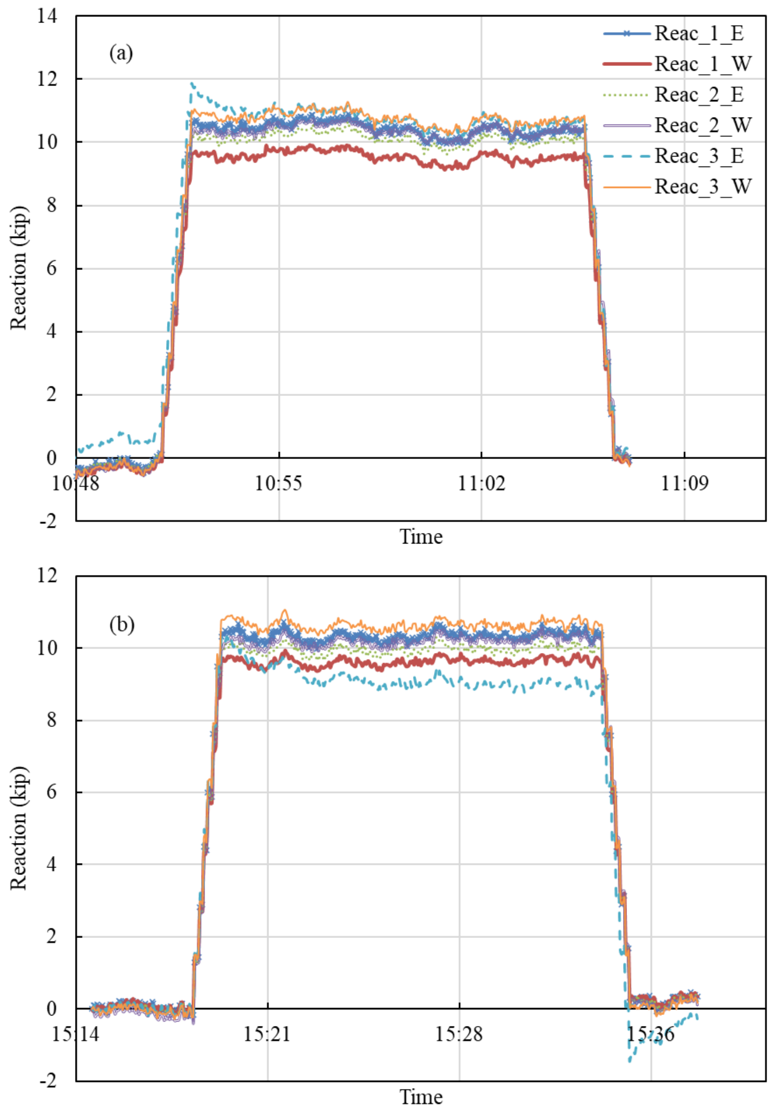


(a) Tandem Load

(b) Actual Load

Type IV shear key: Live Load

- Graph shows the support reactions during static load at the start and end of live loading
- The load applied at the center distributed almost equally to all six support points indicating complete load transfer
- Load distribution before and after live load testing showed no change. That indicates no degradation of joints due to live load

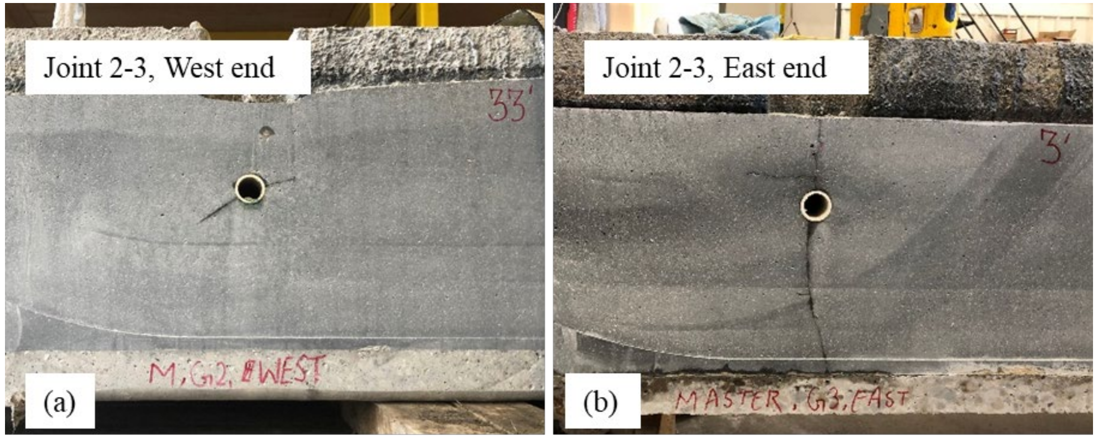


Type IV Shear Key: Joint cutting and inspection

- After testing was complete, joints were cut and visually inspected
- Delamination sounding device was used to check for delamination

Masterflow 4316 Joint:

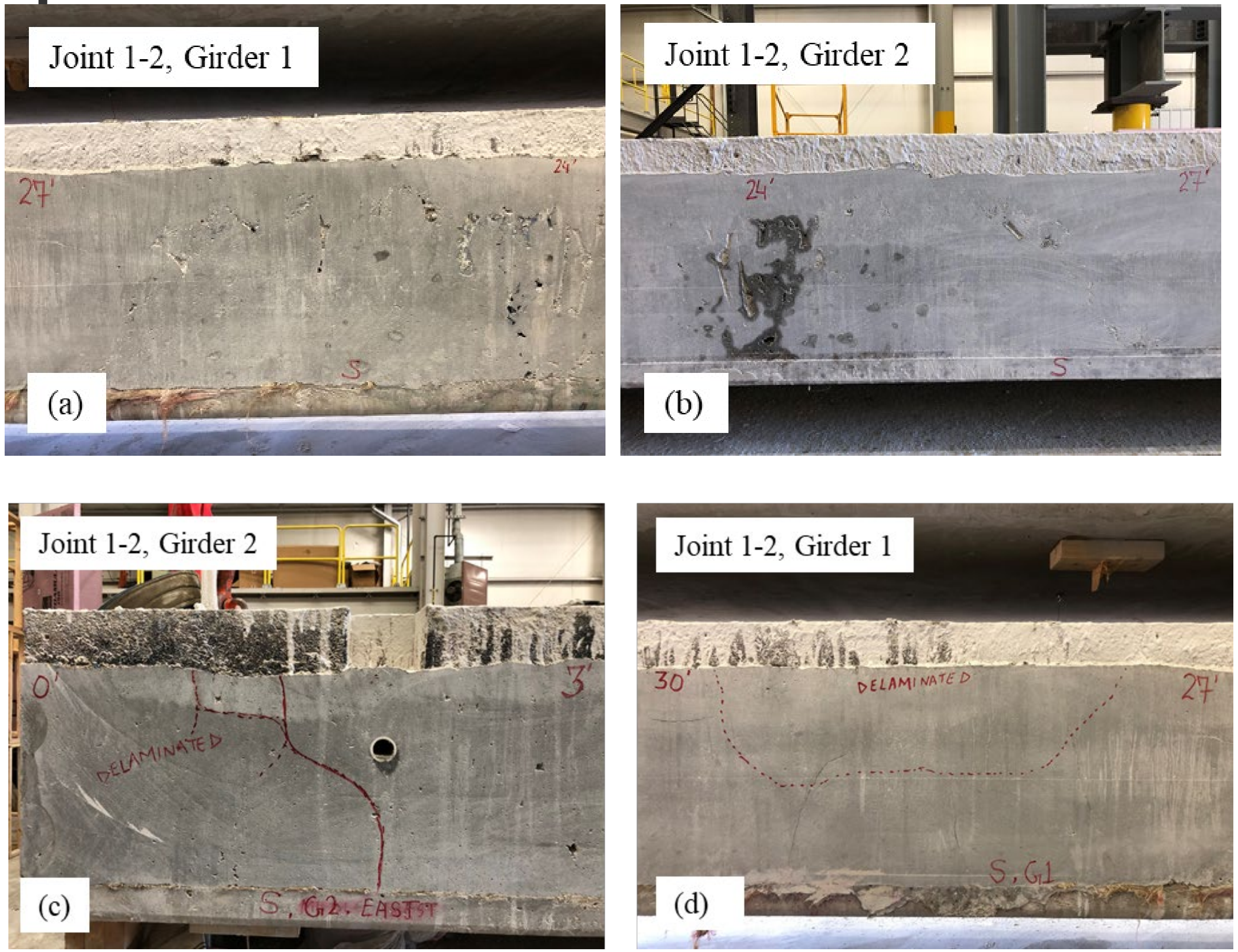
- Cracking at the tie rod locations
- No delamination
- No through cracks



Type IV Shear Key: Joint cutting and inspection

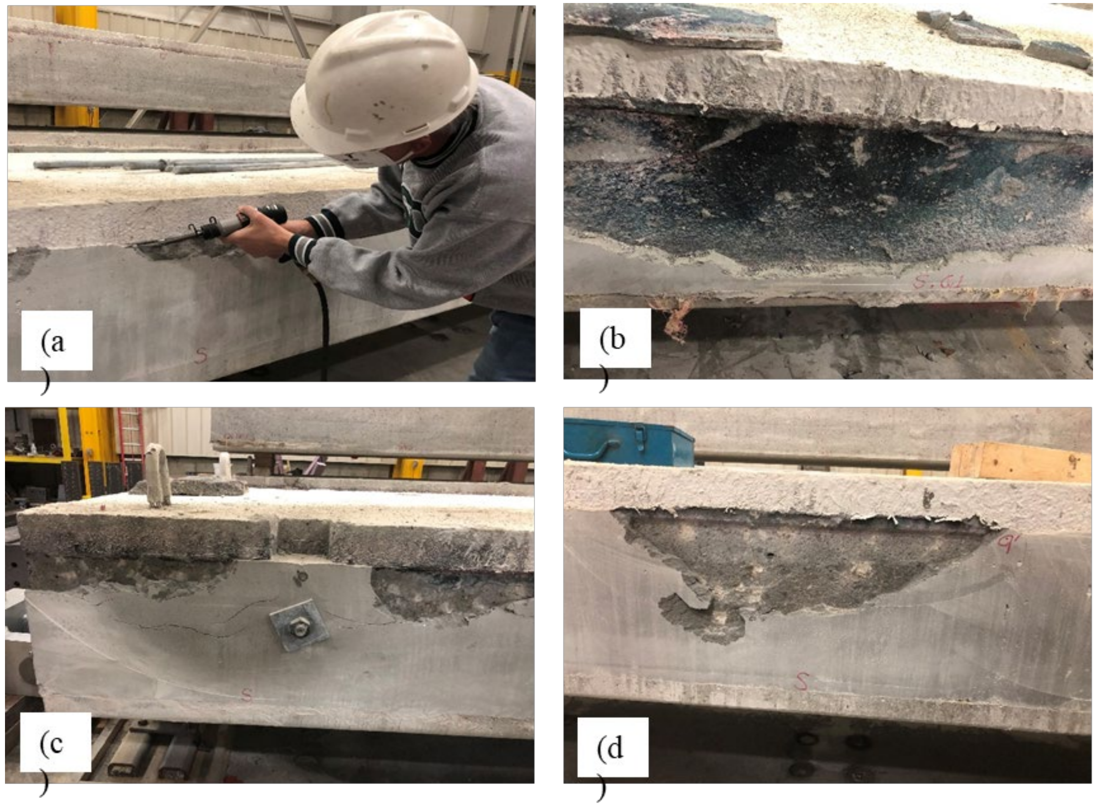
Sika 212 joint:

- Severe cracking was found in the one half of the joint that had poor quality grout that leaked during dye tests
- Delaminated surface was found both at the end and near midspan in the region where grout was of poor quality.
- The area with good quality grout was sound.



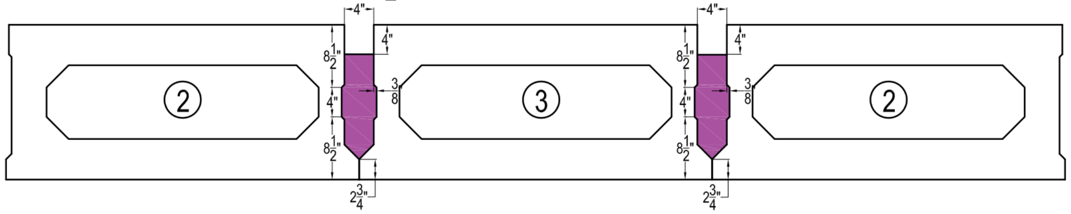
Type IV Shear Key: Joint cutting and inspection

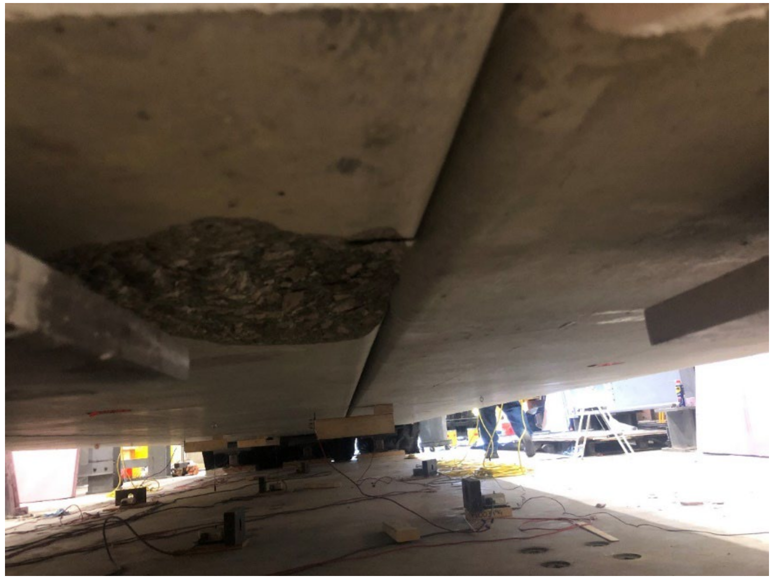
- Grout was removed to reveal the girder surface using a chipping hammer.
- Masterflow 4316 grout had a very strong bond with the girder surface.
- Sika 212 could be removed
  - Dye pattern was observed under delaminated surfaces
  - Dye was not found on the surface where no delamination was observed during sound test



Type V shear key

- After Type IV testing was complete, girders were cut and assembled into Type V configuration
- Instrumentation and testing procedure was similar to Type IV shear key
- The only difference was the shear key material used (concrete instead of grout)
- Concrete on the bottom of the girder spalled when tightening the lateral tie rods



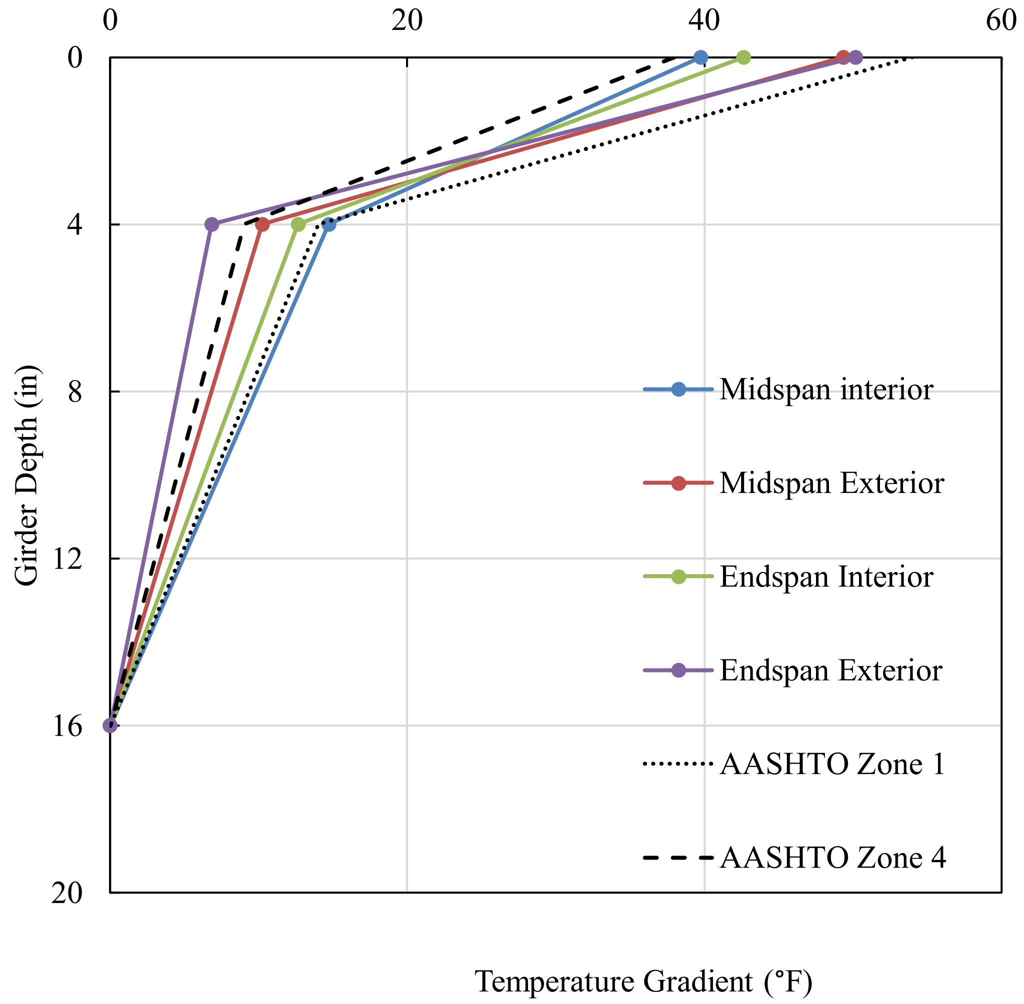


Type V shear key: Grouting

- Small aggregate concrete was used in both the joints
- Just like before, the girders were heated before grouting
- Sides of the girder were prewet and a ready-mix concrete was placed into the joints
- After completing the first joint, the mix started to lose slump and had to be re-dosed with the HRWR
- After casting, the girders were reheated to restore the lost gradient
- Thermal cycles were applied from the following day

Type V shear key: Thermal load before grouting

- Graph shows the gradient through the depth of the girder
- Similar to the previous test.

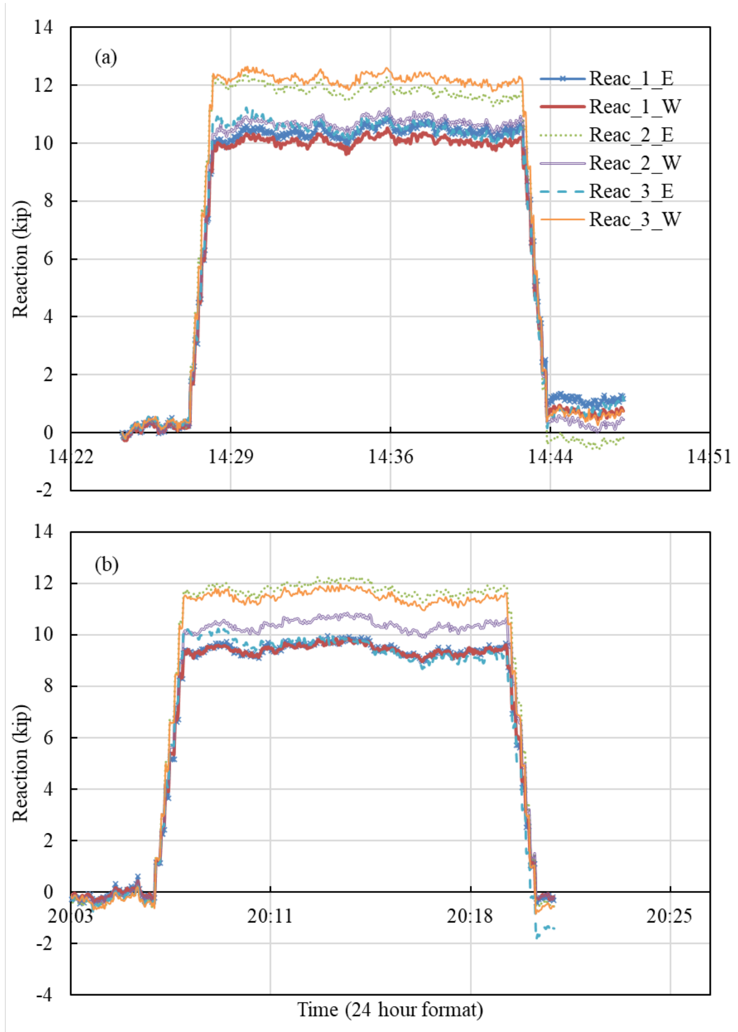


Type V shear key: Thermal load and flooding after grouting

- A total of 30 thermal cycles were applied to the system
- Joints were flooded with dyed water after 1st , 5th , 15th , and 30th cycle to look for leakage

Type V shear key: Live Load

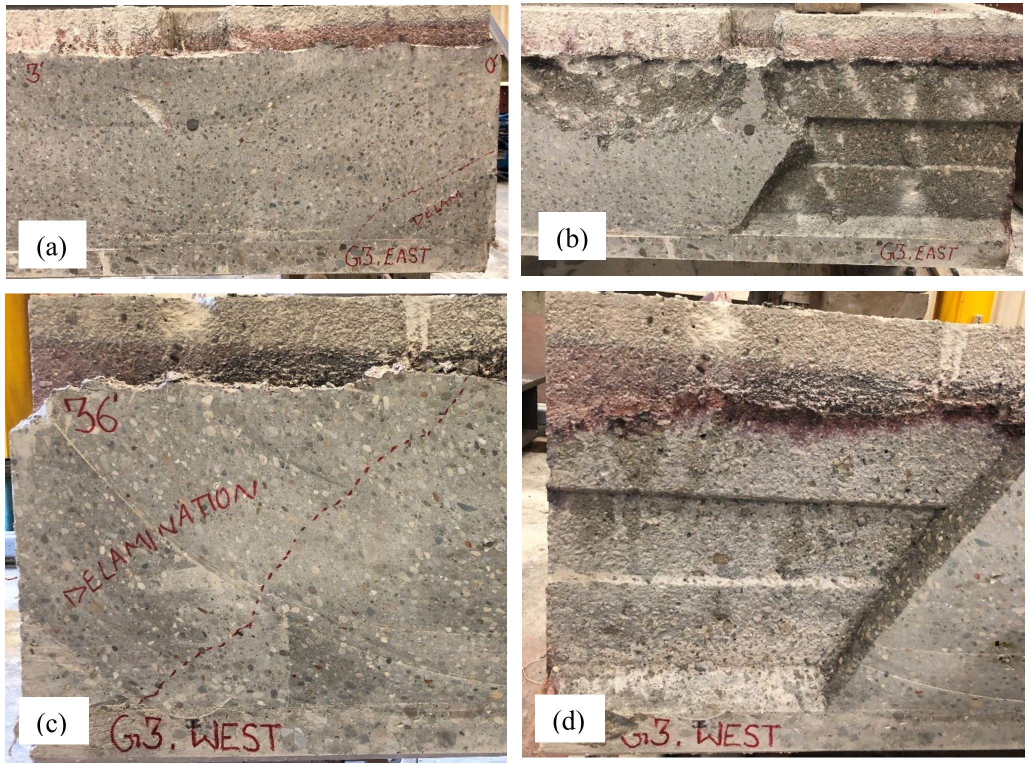
- Live load similar to Type IV shear key was repeated along with static tests
- Graph shows the support reactions during static load at the start and end of fatigue loading
- Again, the load distribution was almost equal and no change in distribution was observed before and after live load application



Type V Shear Key: Joint cutting and inspection

Joint poured first (without additional HWRA):

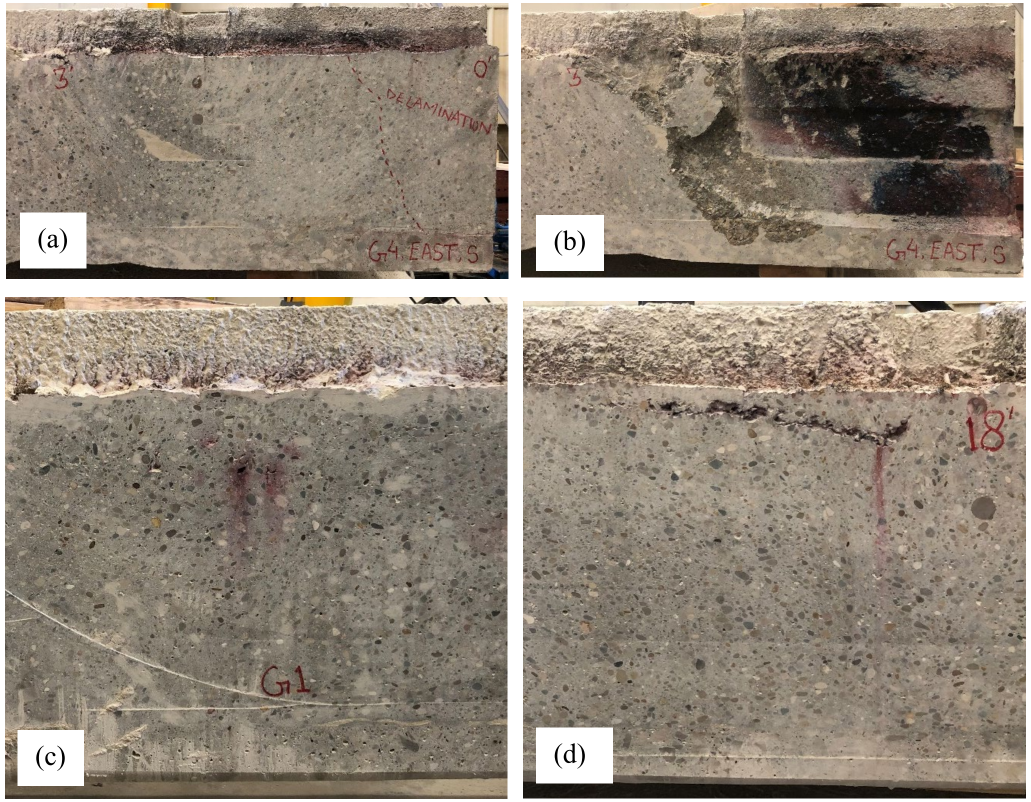
- No defects away from the ends
- Hammer soundig tests indicated some delamination at the ends
- Upon removing the grout, no dye was found at these potential delaminated locations
- These delamination might have occurred during joint cutting operation



Type V Shear Key: Joint cutting and inspection

Joint poured later (with additional HWRA):

- Some spots with bad compaction with dye impressions
- Delamination at the ends with dye under them
- Black dye suggests the delamination occurred during the early age after casting shear keys



Summary of Full-Scale testing

- Full depth shear keys where the top 4 inches are not grouted appear to be very effective in preventing leakage in the joints
- Not grouting the top 4 inches keeps the grout out of the area of severe thermal strains
- The surfaces of the girder must be roughened and prewet prior to placing the grout
- Use of concrete as fill material in the wider Type V shear key provided an acceptable performance. However, the tests performed here were short in duration (about 30 days). The effect of shrinkage of the concrete was not assessed.

Summary of Full-Scale testing

- The full depth shear keys appear to bind the boxes together and apparently caused them to behave as a single slab in the 3-girder test
- Use of the ASTM C1583 pull off test seems to be appropriate for assessing bond of the grout and substrate
- The AASHTO temperature gradients are consistent with field measurements for box girders and can be used to assess thermal movements in the joints

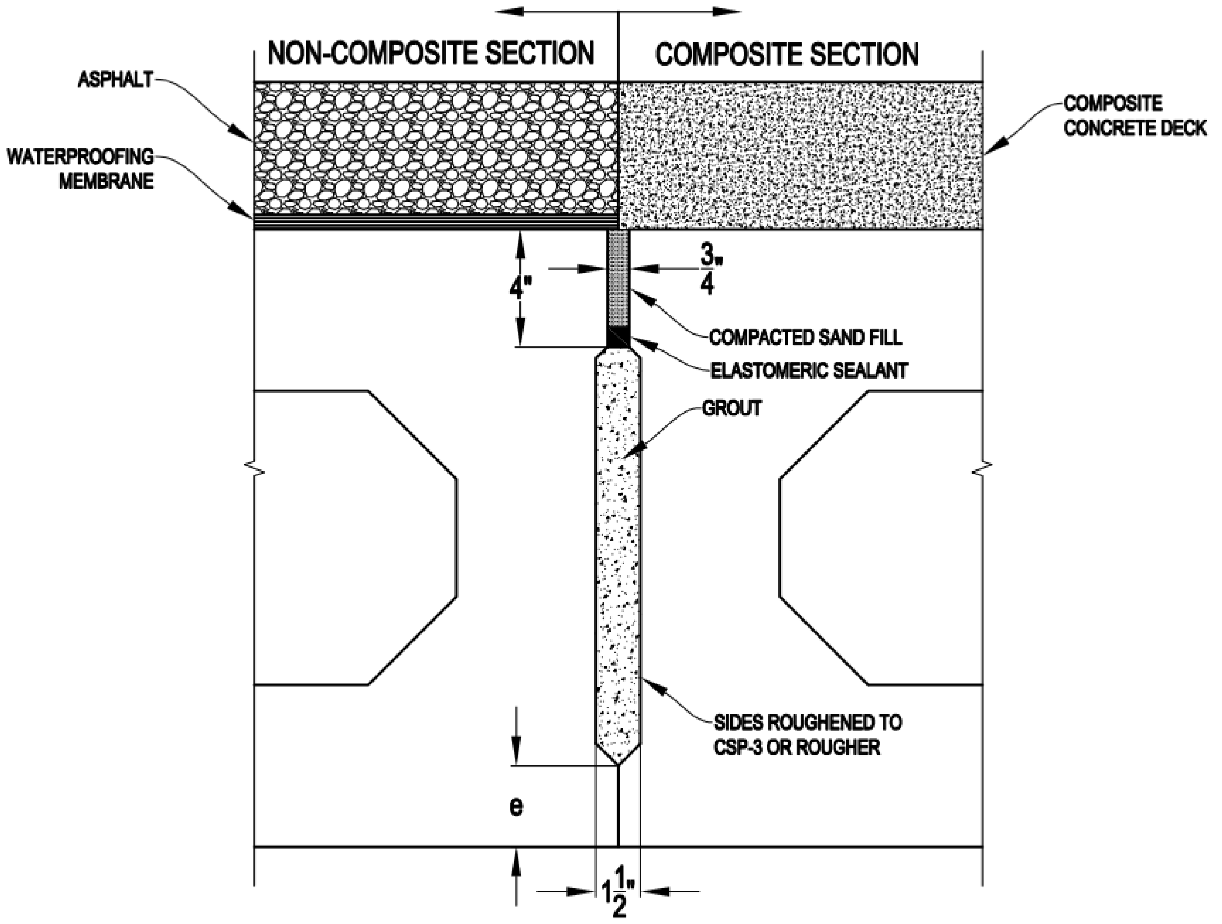
RECOMMENDATIONS

- Use a Type IV or V full depth shear key.
  - For deep girders it may not be necessary to make the shear key full depth, but the deeper the shear key, the more bond area available.
- Do not fill the top 4 inches with grout or concrete.
- Roughen the sides of the girders to at least CSP-4.
- Prewet the girder sides if recommended by the manufacturer of the grout.

RECOMMENDATIONS

- Use a grout with thermal properties similar to the concrete girders.
- Use a grout with a 7 day bond strength of at least 200 psi, but higher is better.

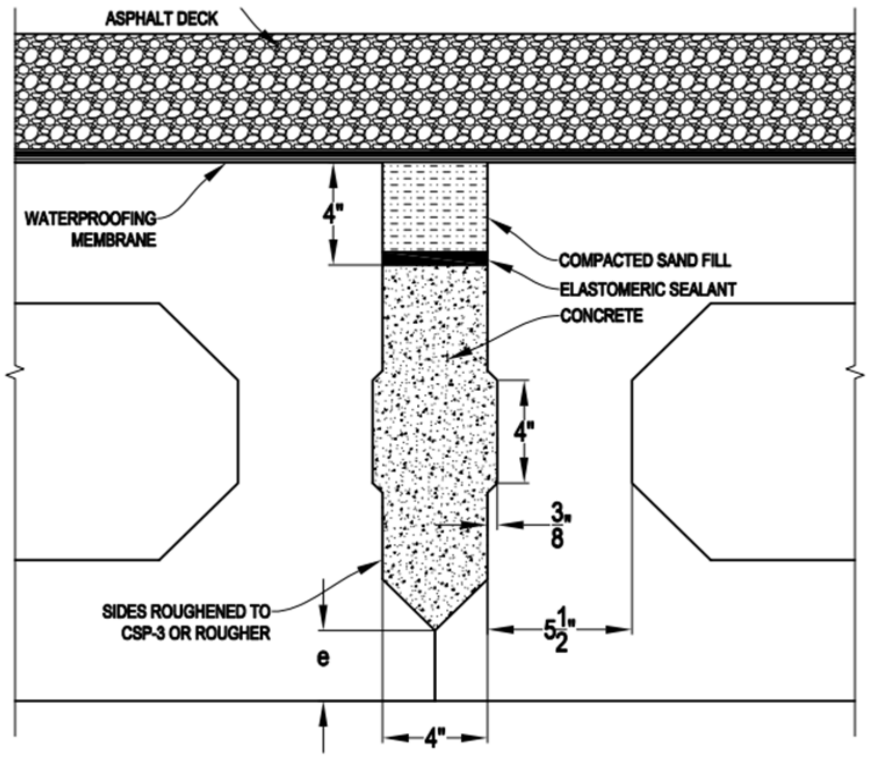
SUGGESTED DETAILS



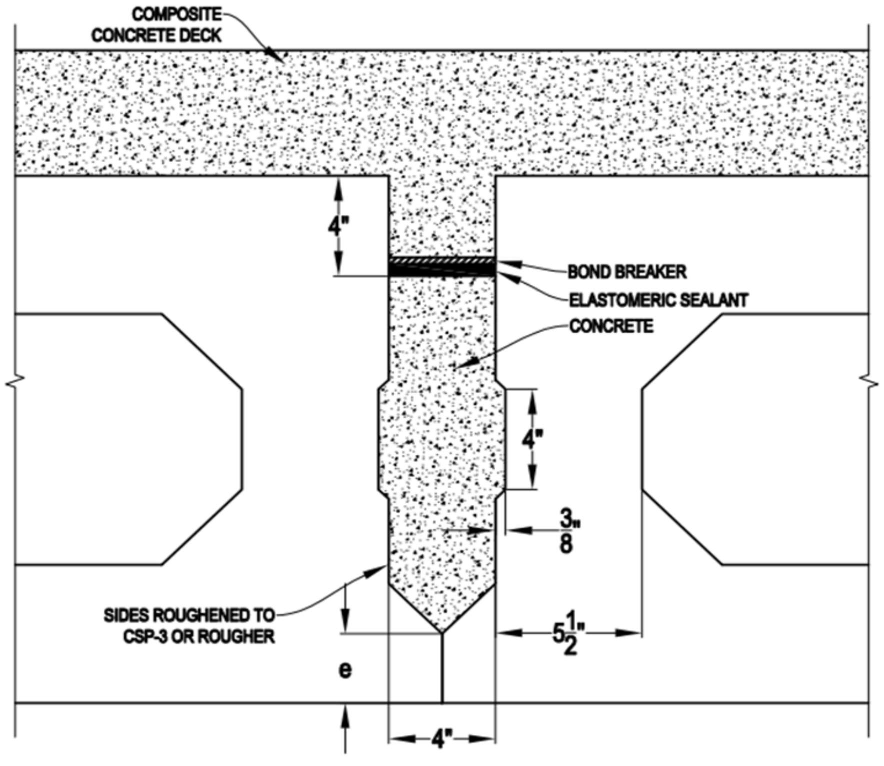
TYPE IV

e shall be taken as 1" for girder depths up to 15" and 2 3/4" for girder depths greater than 15"

SUGGESTED DETAILS



TYPE V NON-COMPOSITE SECTION



TYPE V COMPOSITE SECTION

e shall be taken as 1" for girder depths up to 15" and 2 $\frac{3}{4}$" for girder depths greater than 15"

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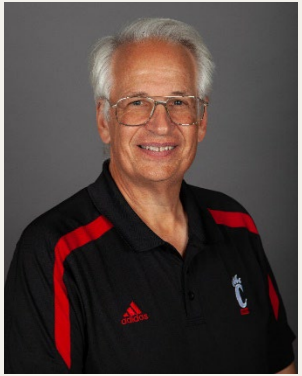

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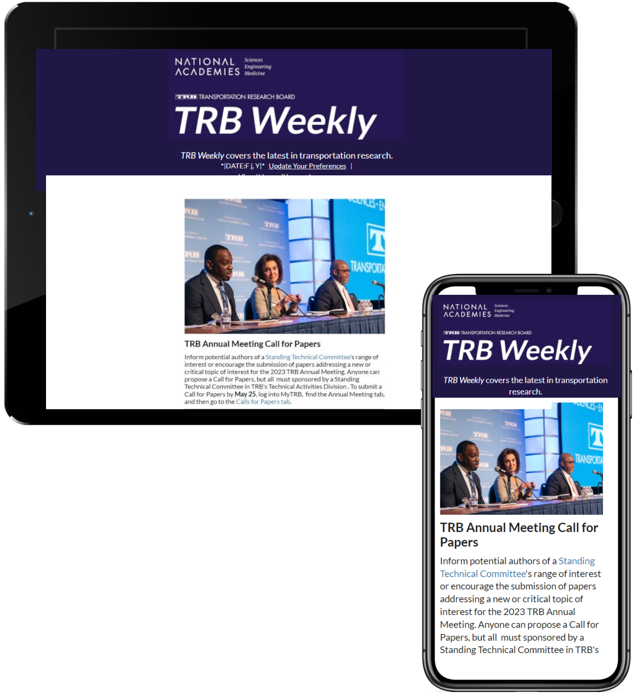

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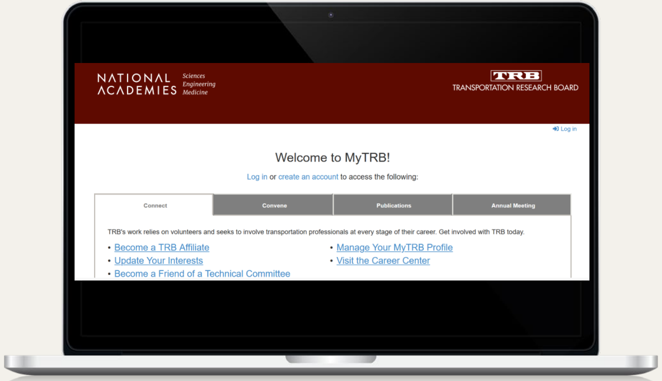

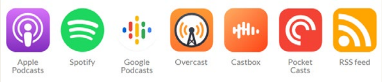

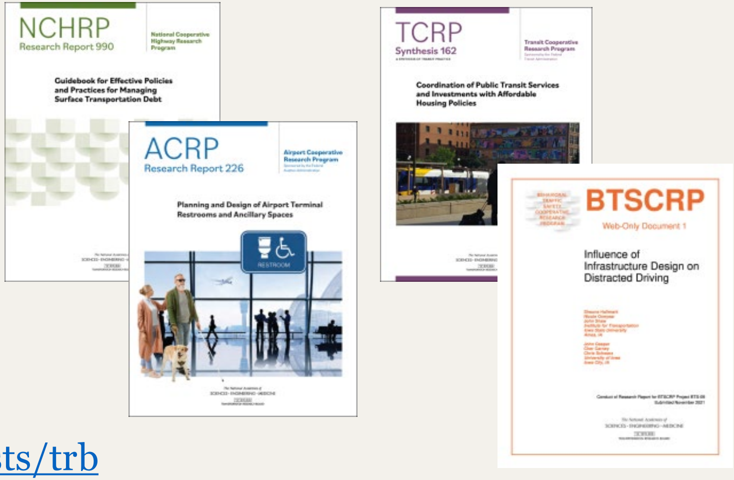

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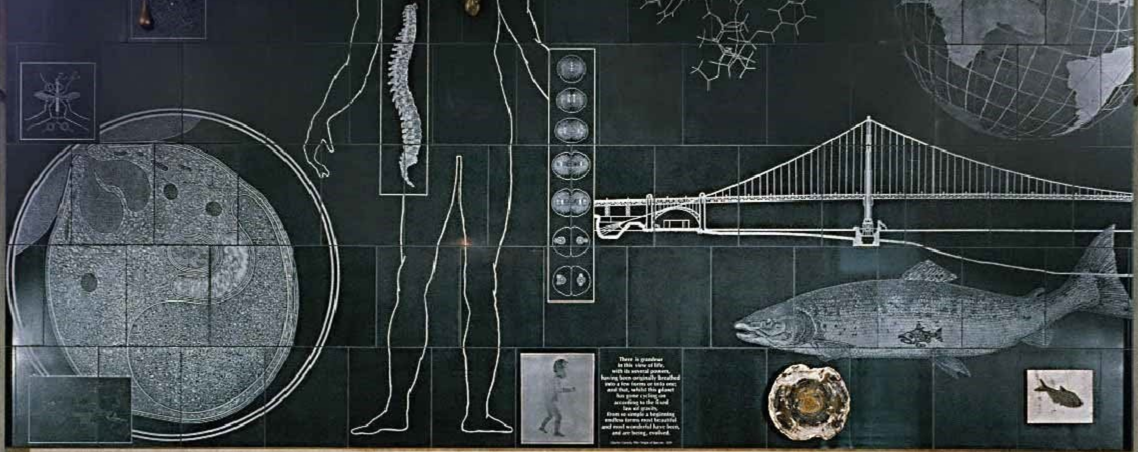

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