Load Testing After Strengthening Of A Pre-stressed Double Tee Beam That Had Failed In Shear

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Introduction

- Fountain Square Garage is located at the Reston Town Center in Reston, Virginia.
- The roof floor framing consists of precast, pre-stressed concrete double tees (DT) supported by precast concrete girders and columns.
- Following a heavy snow storm, a landscape contractor had piled up all the snow on the roof on two DT beams showing signs of imminent shear failure.

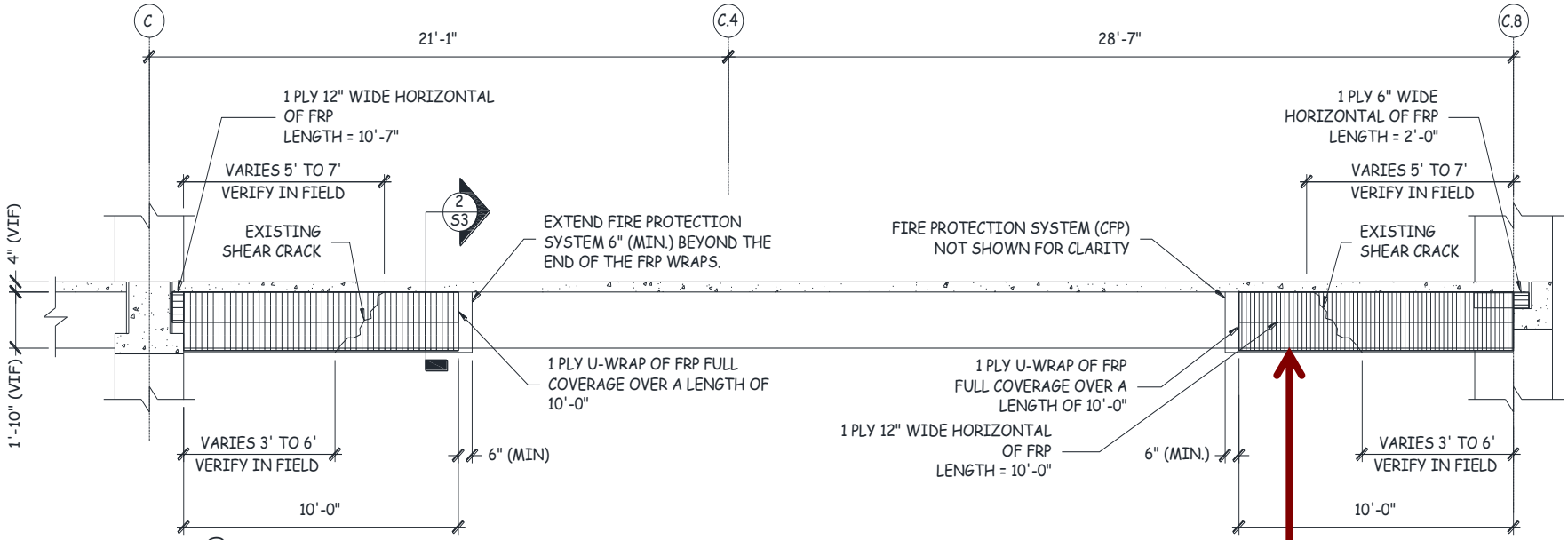
Existing Conditions

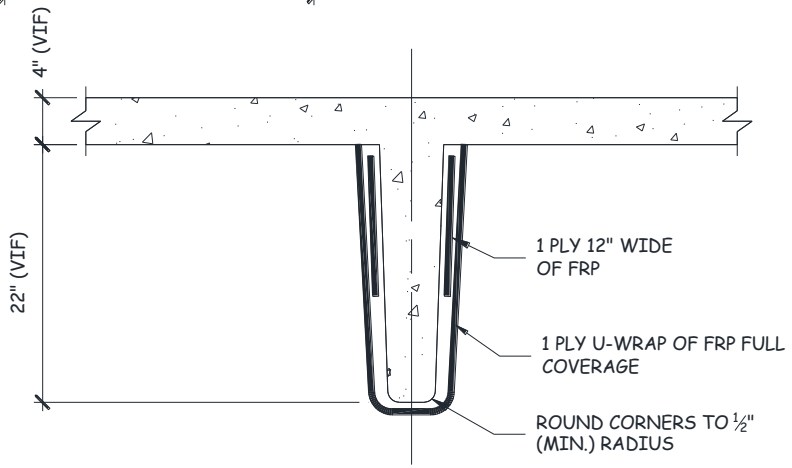
FRP Strengthening Details

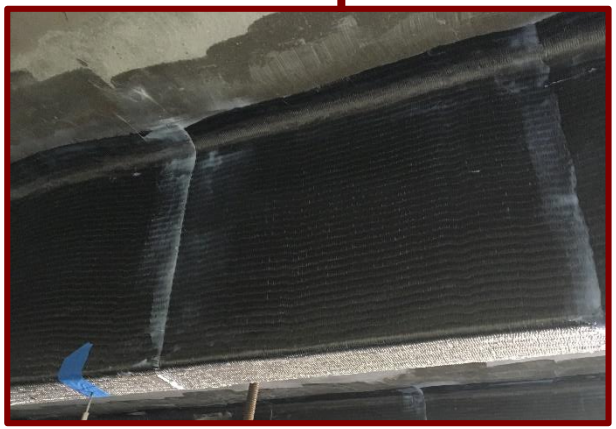
Strengthening procedure:

1. Restore structural integrity of the DT beams (epoxy injection/form and pump delaminated concrete)
2. Strengthen damaged DT beams with FRP U-Wrap designed as RC member (PT contribution considered as zero)

FRP Strengthening Details







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Testing Objectives

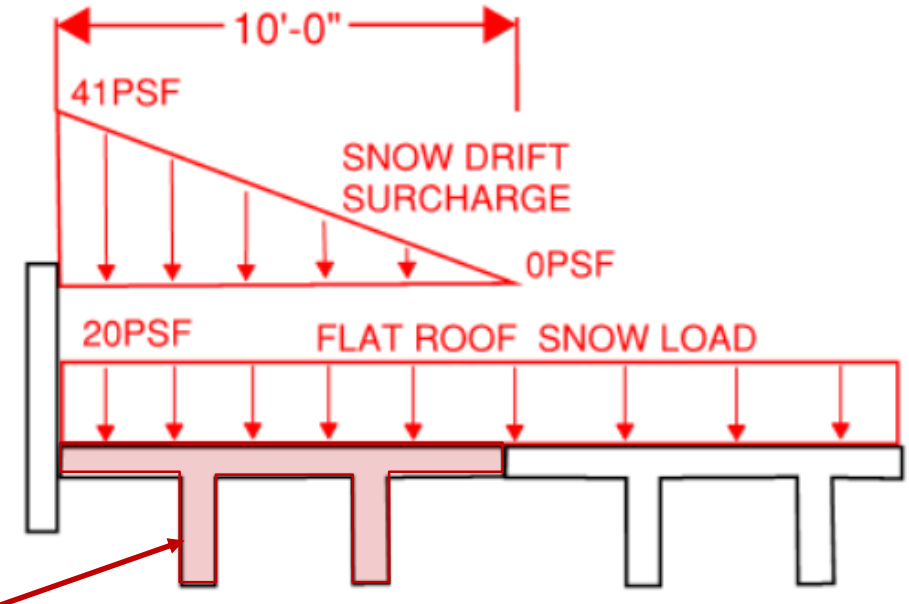
- Load testing was performed on the most damaged DT beam after FRP was installed.
- The objective of the load test was to confirm the shear capacity of the repaired DT beam.

Load Test Strengthening Beams

- The load test was designed to verify the shear performance of the repaired zone.
- All Loading was achieved using hydraulic jacks. Hydraulic jacks can remove the load quickly in the event of failure.
- Steel spreader beams and wood bearing pads used to transfer load to DT stems.

Loading on the structure

- Self-weight of the structure;
- Snow load consisting of a flat snow load of 20 psf and snow drift supercharge having a triangular distribution over a width of 10 ft and maximum value of 41 psf;
- Live load of 40 psf (parking).



Failed DT Beam

Load Test Magnitude

- ACI 437.2 considers two sets equations when determining the load test magnitude.
  1. Statically indeterminate - Eq. (4.2.2a) through (4.2.2c)

$$TLM = 1.3(D_W + D_S) \quad (4.2.2a)$$

$$TLM = 1.0D_W + 1.1D_S + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) \quad (4.2.2b)$$

$$TLM = 1.0D_W + 1.1D_S + 1.6(L_r \text{ or } S \text{ or } R) + 1.0L \quad (4.2.2c)$$

  2. Statically determined

$$TLM = 1.2(D_W + D_S) \quad (4.2.3a)$$

$$TLM = 1.0D_W + 1.1D_S + 1.4L + 0.4(L_r \text{ or } S \text{ or } R) \quad (4.2.3b)$$

$$TLM = 1.0D_W + 1.1D_S + 1.4(L_r \text{ or } S \text{ or } R) + 0.9L \quad (4.2.3c)$$

Load Test Magnitude

- If the deficiency in statically determinate members is not tension-controlled, then Eq. (4.2.2a) through (4.2.2c) shall be used to determine the TLM".

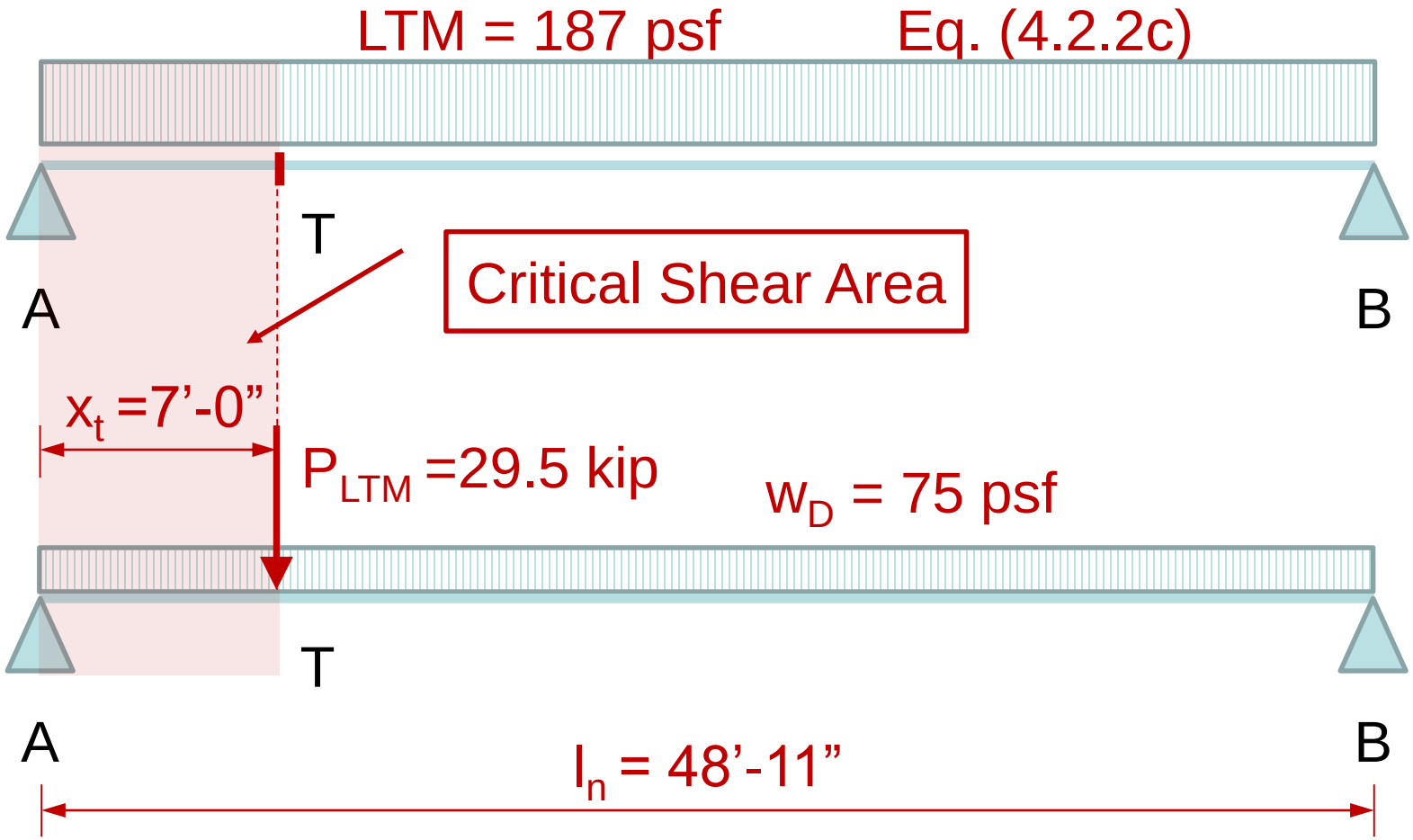
$$TLM = 1.3(D_W + D_S) \quad (4.2.2a)$$

$$TLM = 1.0D_W + 1.1D_S + 1.6L + 0.5(L_r \text{ or } S \text{ or } R) \quad (4.2.2b)$$

$$TLM = 1.0D_W + 1.1D_S + 1.6(L_r \text{ or } S \text{ or } R) + 1.0L = 187 \text{ psf} \quad (4.2.2c)$$

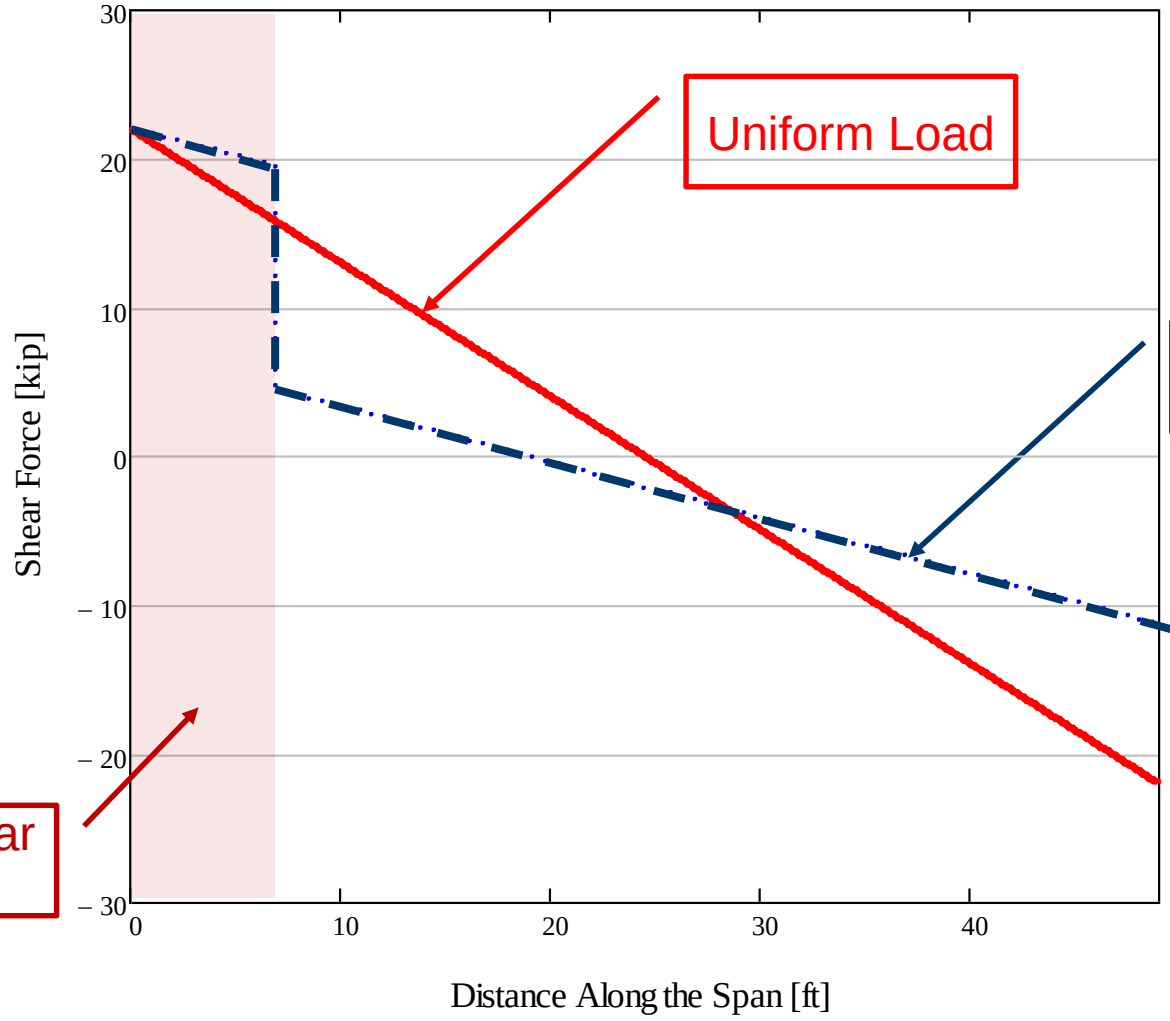
When testing to evaluate shear strength, the moment in the section will influence the shear strength of the section. Therefore, it is important to arrange the testing load that duplicate the suspected shear deficiency.

Determining Test Load Configurations



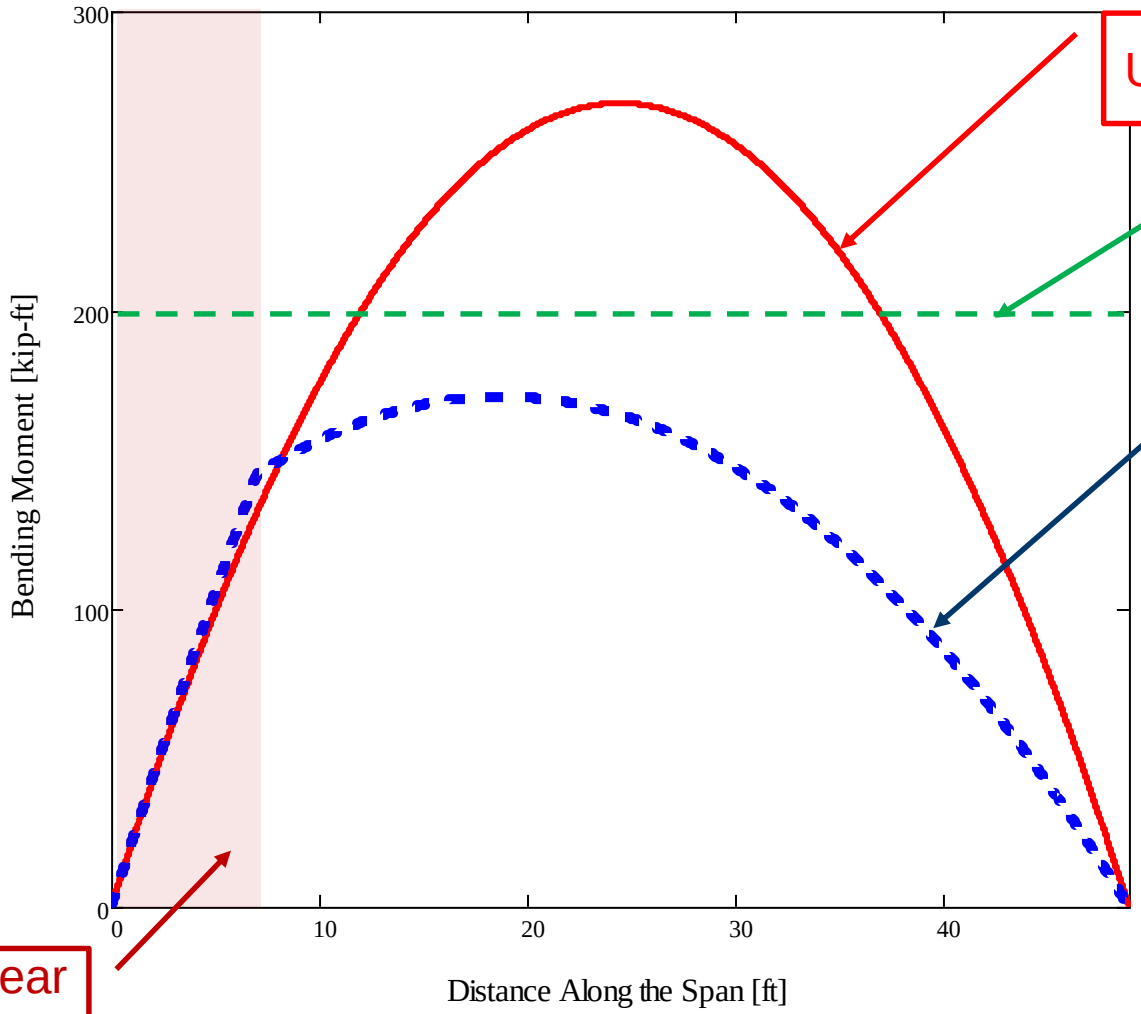
Equivalent Point Load

Shear Distribution LTM



Applied shear force 8 % higher than the one generated by uniformly distributed LTM at critical sections

Moment Distribution LTM



Uniform Load

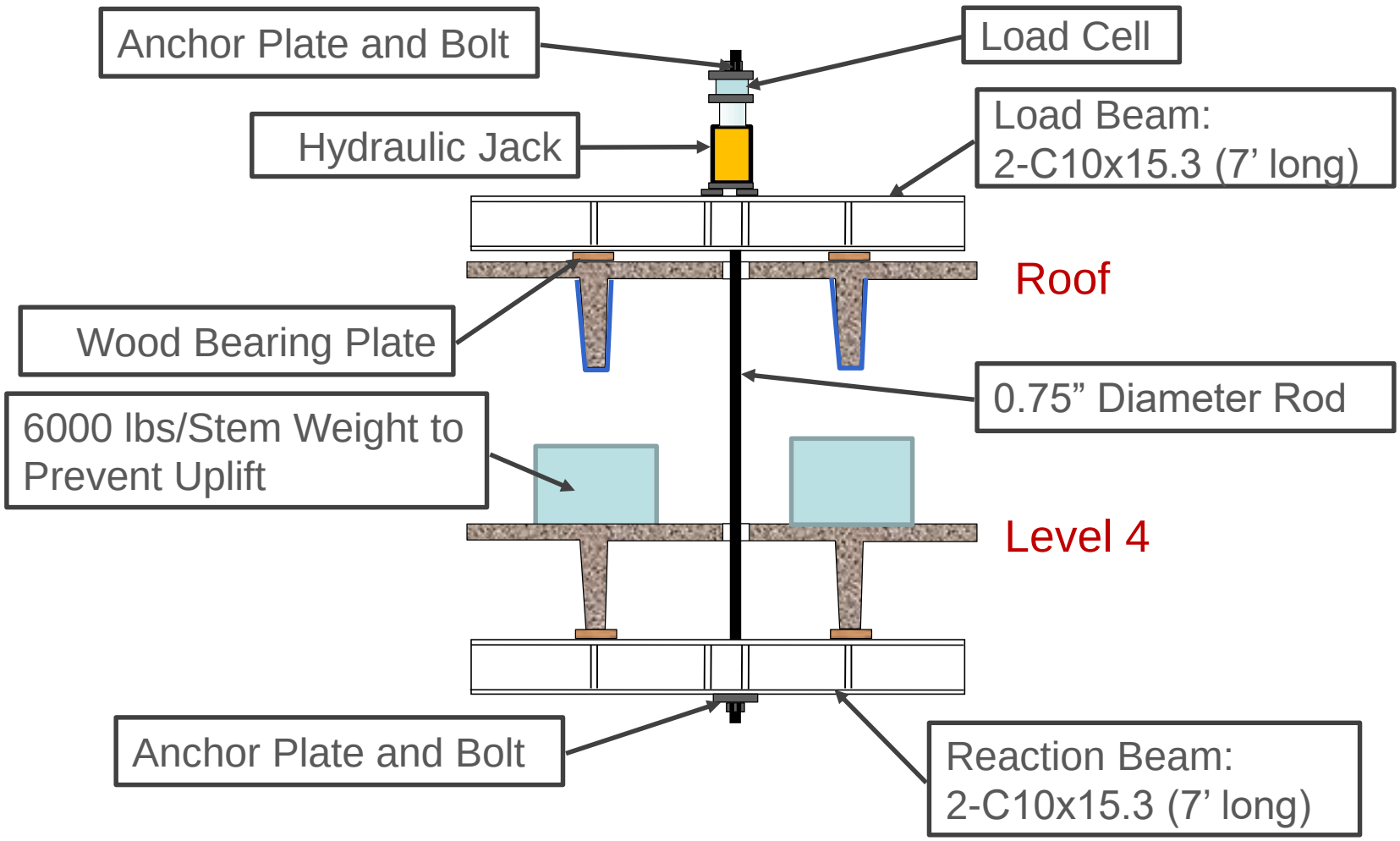
Cracking Moment

Concentrated Load

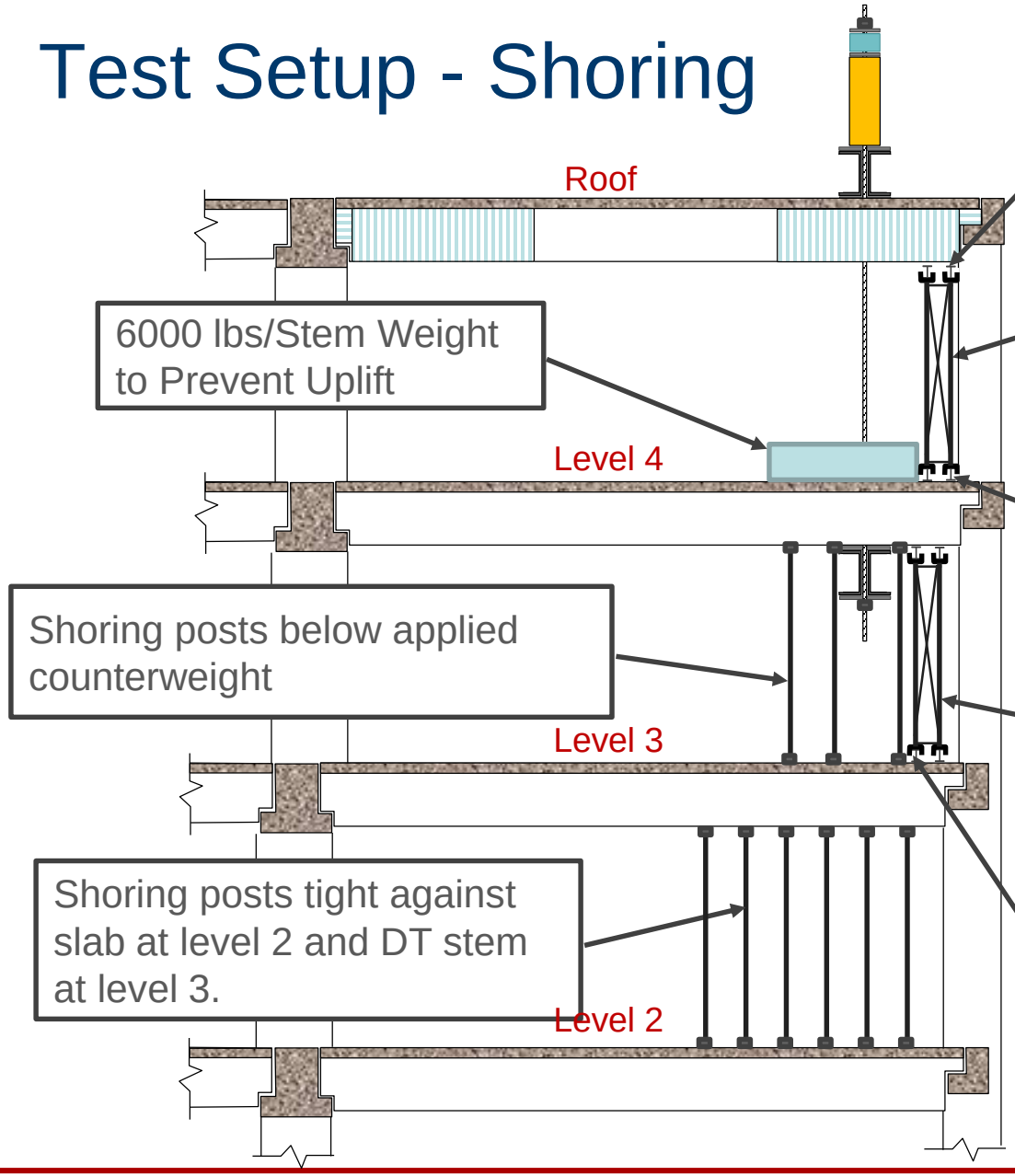
Critical Shear Area

Bending moment applied 6.6% higher than the one generated by uniformly distributed LTM at critical sections

Load Test Set Up



Test Setup - Shoring



6000 lbs/Stem Weight to Prevent Uplift

Shoring posts below applied counterweight

Shoring posts tight against slab at level 2 and DT stem at level 3.

Gap between element being tested and shoring tower.

Shoring tower One tower per stem being tested.

Shoring towers on W8 Beams spanning between the two stems being tested.

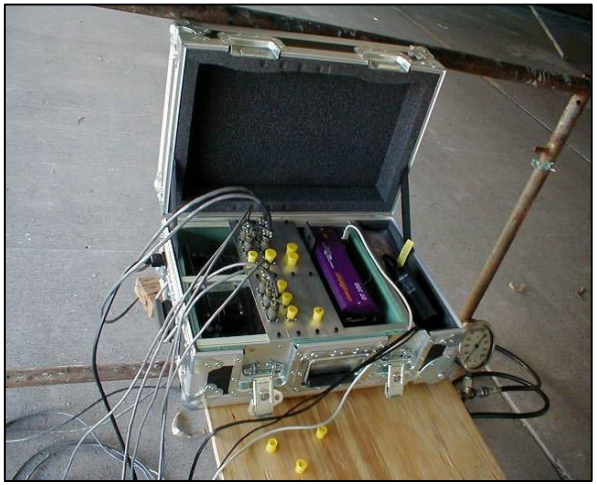
Shoring tower installed tight against level 3 and DT stem at level 4.

Install shoring towers on W8 Beams spanning between the two stems being tested

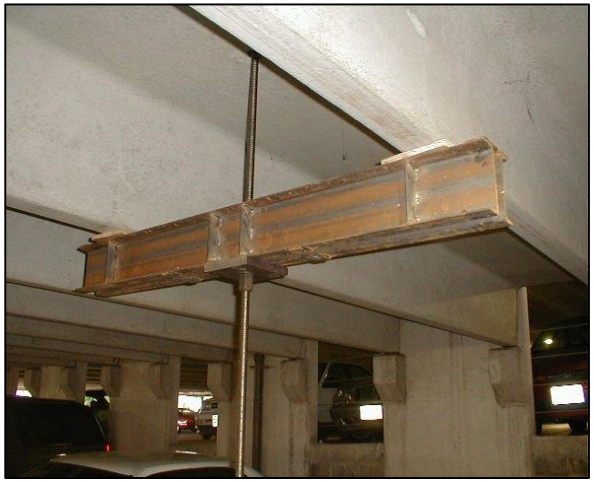
Load Test Equipment

Load Cell and Jack

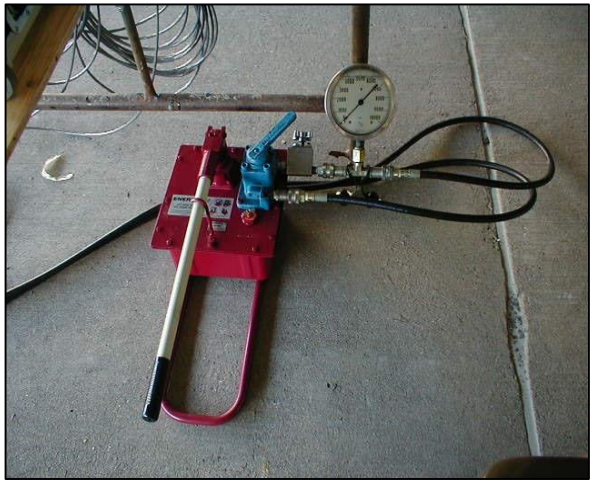
Steel Spreader Beam with High Strength Williams Bar



Data Acquisition Unit



Reaction Beam



Hydraulic Pump

Load Test Equipment

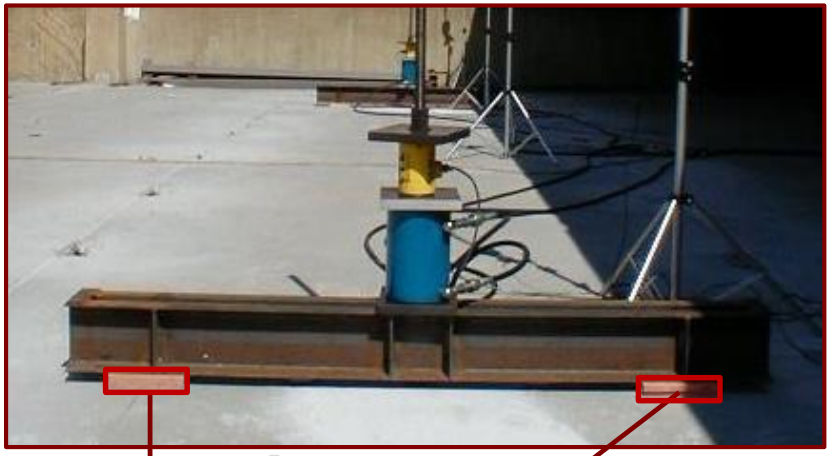
6000 lbs./Stem Weight to Prevent Uplift

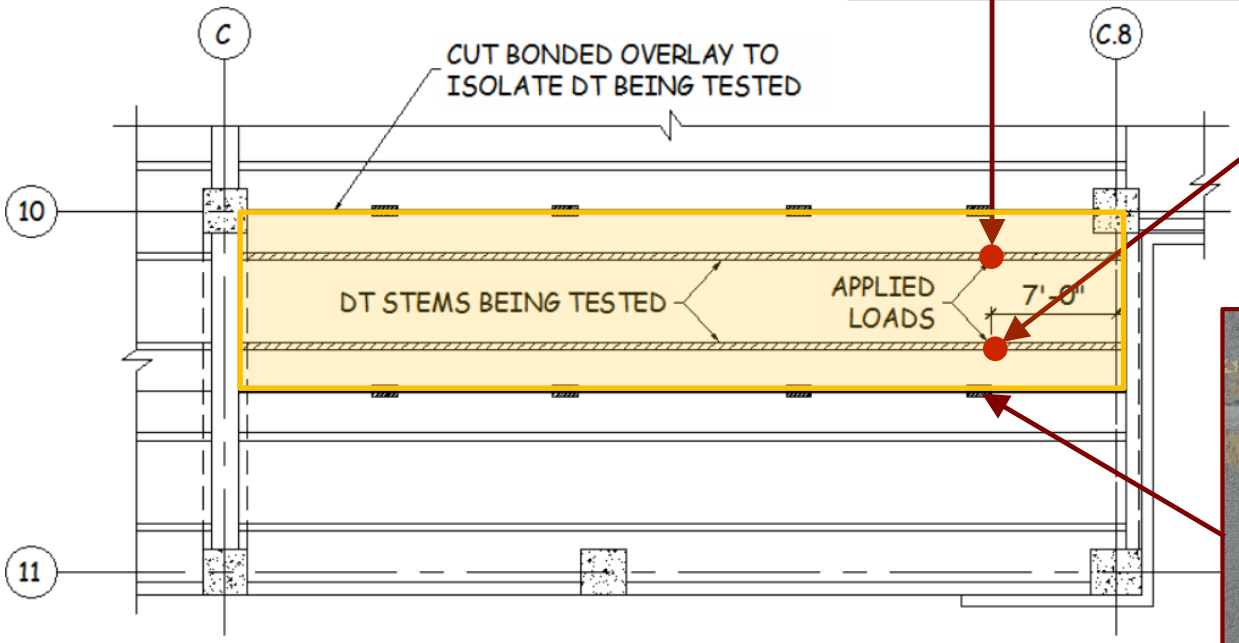
3 TO 6 kip Capacity Shoring Posts

Dial Gages at Underside of DT Beams

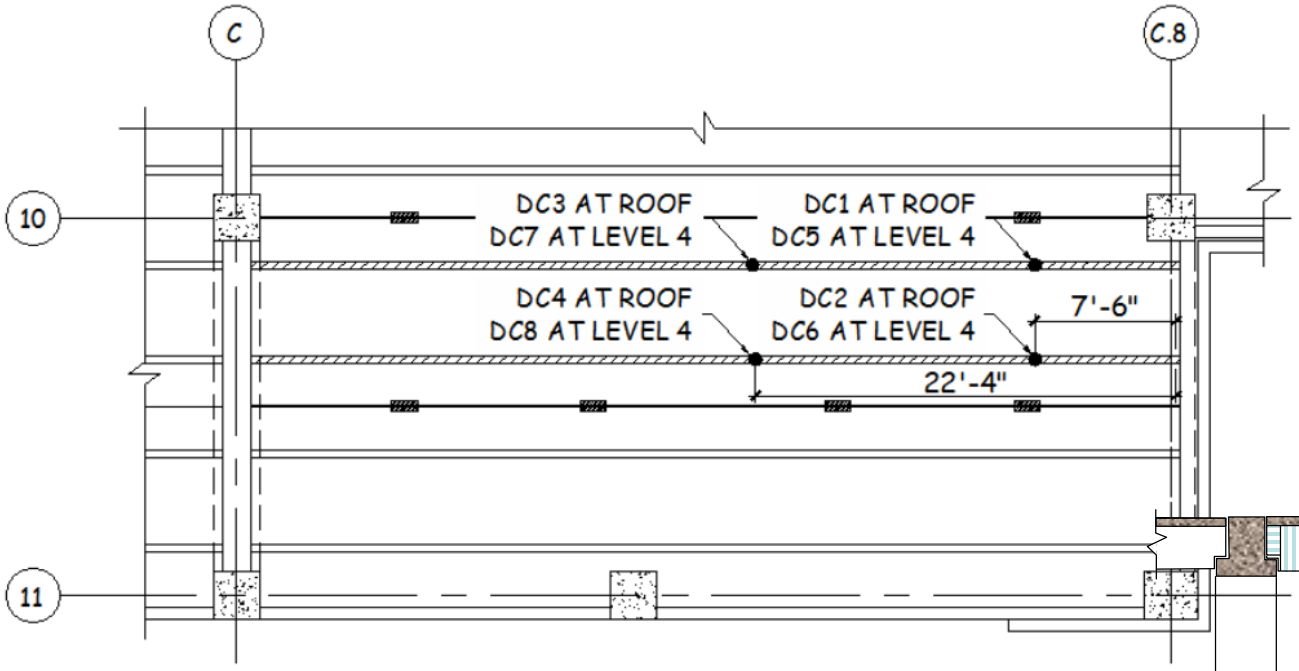
Applied Loads

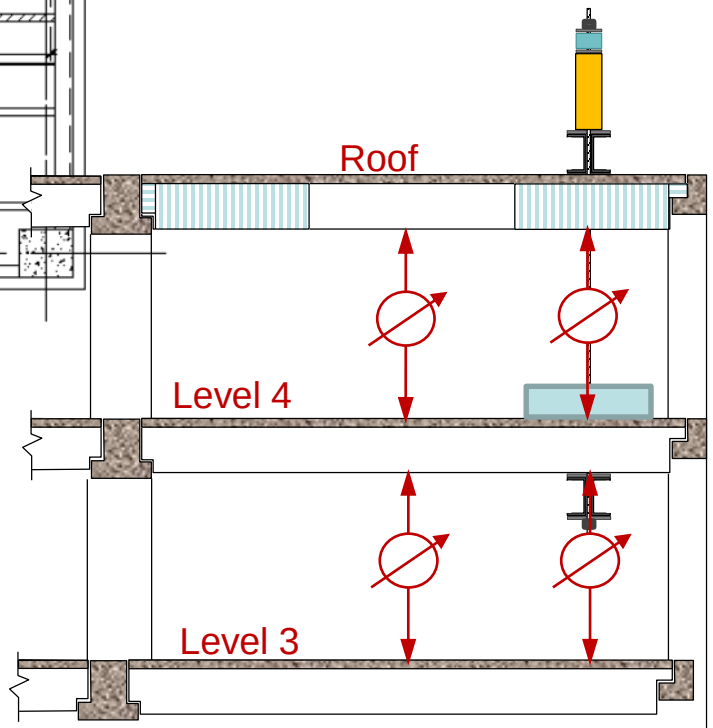
Tested DT beam was disconnected from the remaining structure





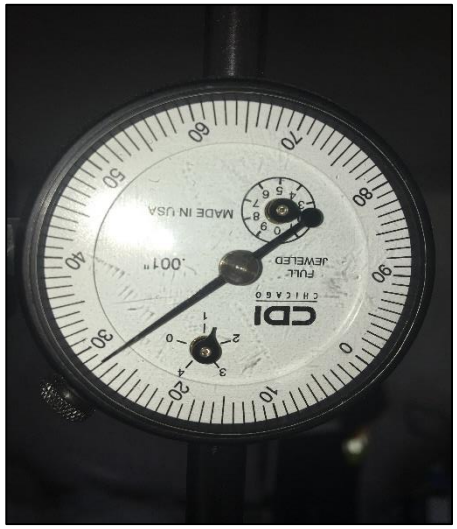
Deflection Measurements





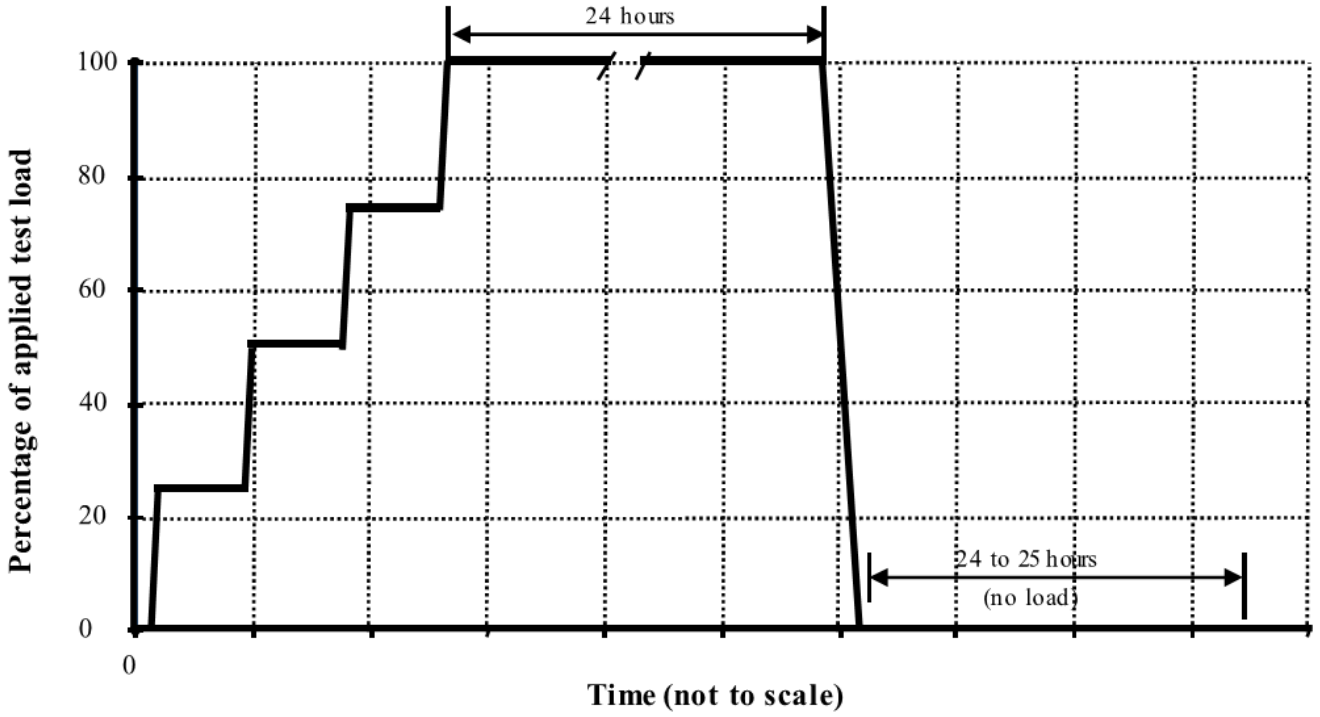
Deflection of the roof obtained as the difference of the deflection measured at level 4 and deflection measured at level 3

Deflection Measurements



What is the maximum expected deflection? $\cong 0.2\ in.$
Dial gages with 0.001 in. resolution are adequate

Loading Protocol



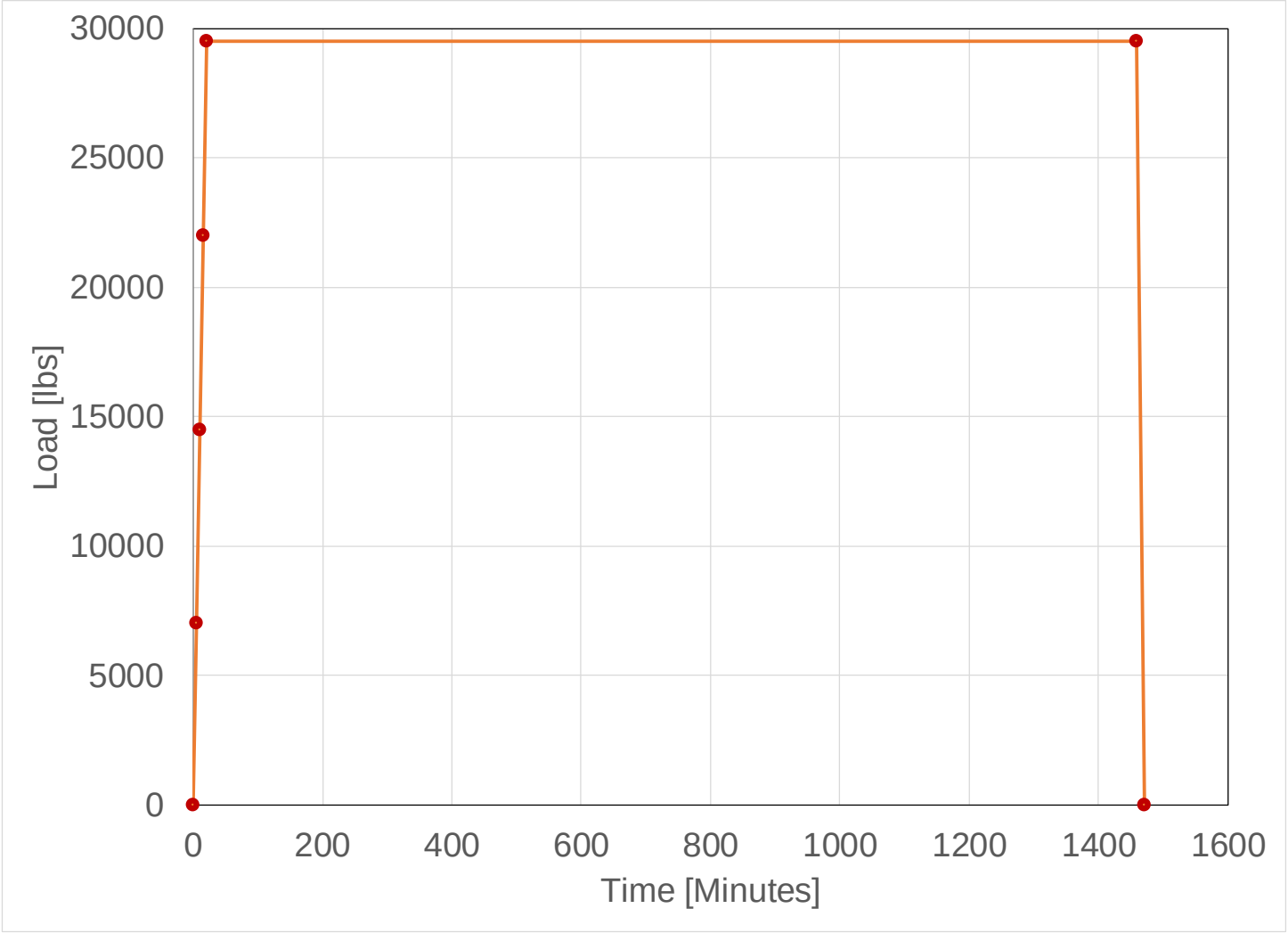
Test Load shall be applied in not less than 4 approximately equal increments

Test Load applied for 24h and final response within 24h test load has been removed

Testing Protocol and Test Magnitudes

Load Step	Min. Time per Step	Load Applied at Each Point (kips)	Total Applied Test Load (kips)
1	-	0.3	0.6*
2	5 min	3.5	7
3	5 min	7.25	14.5
4	5 min	11	22
5	24 hours	14.75	29.5
6	-	0.3	0.6*
* Weight of equipment			

Load - Time


30000
25000
20000
15000
10000
5000
0
Load [lbs]
0
200
400
600
800
1000
1200
1400
1600
Time [Minutes]

Acceptance Criteria

- The maximum and residual deflection shall satisfy

$$\Delta_{Test} \leq \Delta_{Max} = \frac{l_t}{180} = 3.3\ in.$$

$$\Delta_{r,max} \leq \frac{\Delta_{Test}}{4}$$

Does Not Governs
Limit for re-testing

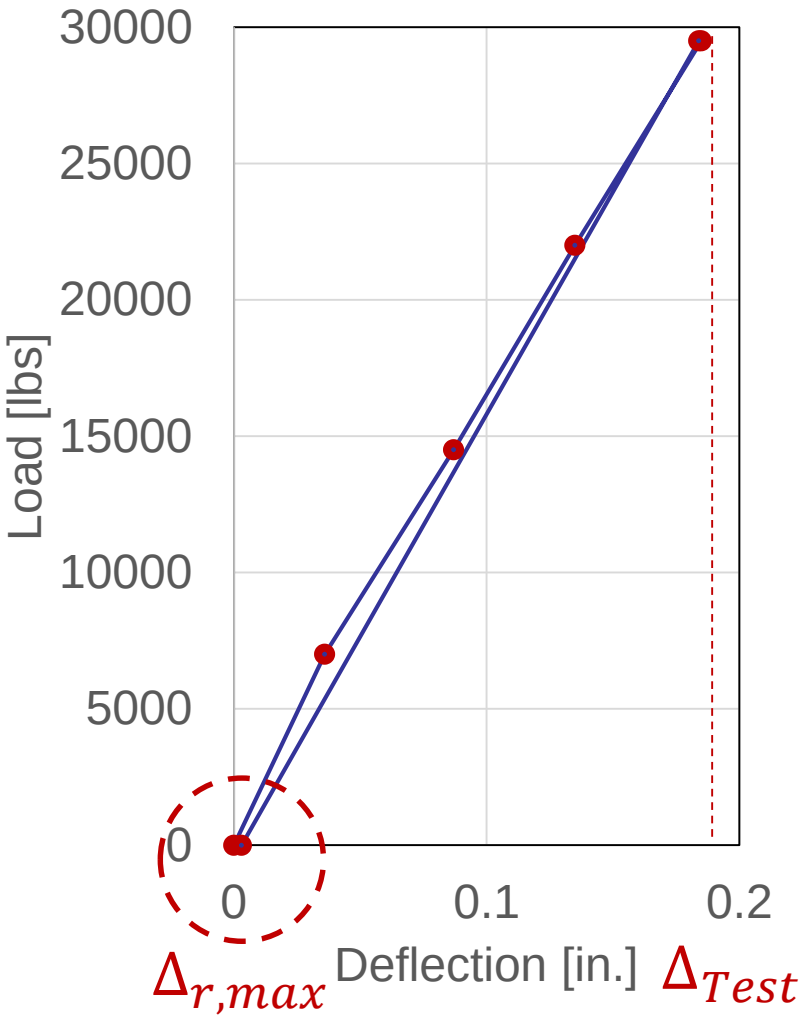
where:

l_t= span of the member under test

Δ_{Test}= measured max deflection

$\Delta_{r,max}$= measured residual deflection

Test Results – Load Deflection

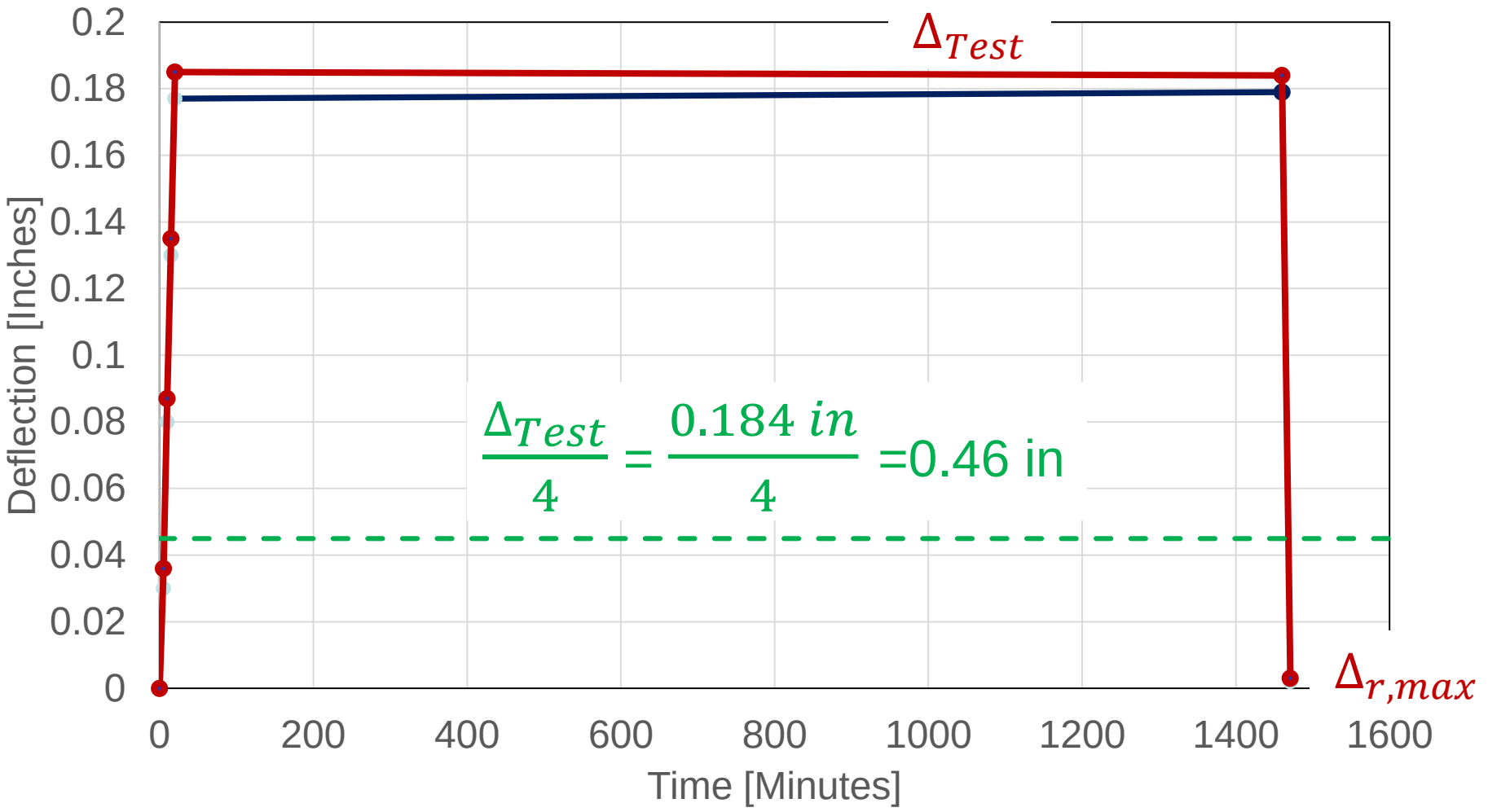


$$\Delta_{Test} = 0.184\ in \leq \Delta_{Max} = 3.3\ in.$$

$$\frac{\Delta_{Test}}{4} = \frac{0.184\ in}{4} = 0.046 \text{ in}$$

$$\Delta_{r,max} = 0.003\ in \leq 0.046 \text{ in (PASS)}$$

Test Results – Deflection Time



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Conclusions

- The monotonic load testing was used to verify the shear capacity of a double tee beam failed in shear.
- The load test was designed to verify the shear performance of only the repaired zone. The remaining portion of the beams was below cracking.
- The structure met the acceptance criteria of ACI 437.2 and stayed elastic during the load test.
- Is a deflection criteria meaningful when testing for shear or would a pass/fail criteria be more feasible?

Thank You

Any Questions?