Post-Tensioning Web Cracking

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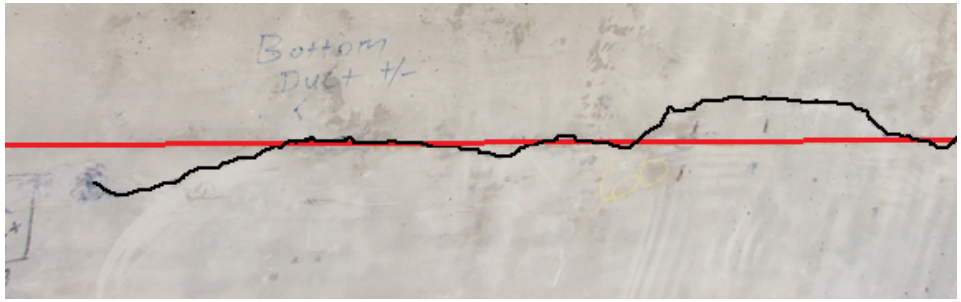
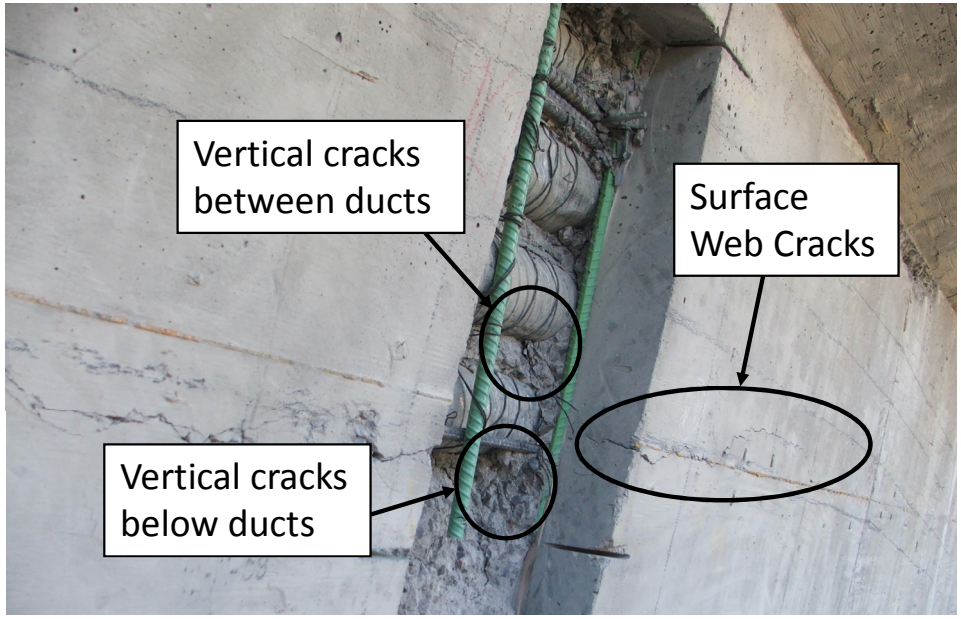
Problem Statement

- Nevada Department of Transportation (NDOT) getting cracks in the concrete box girder web of current bridges
- Cracks formed during post-tensioning and air pressure testing
- Air pressure test ducts to ensure no deficiencies for grouting purposes; Air pressure performed after post-tensioning
- Web cracks can ultimately lead to delamination and corrosion of post-tensioning materials
- Goal: eliminate web cracking in a cost effective manner

Problem Statement





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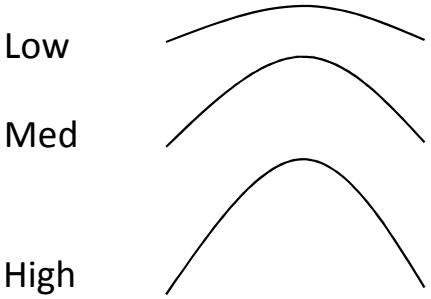
Scope of Research

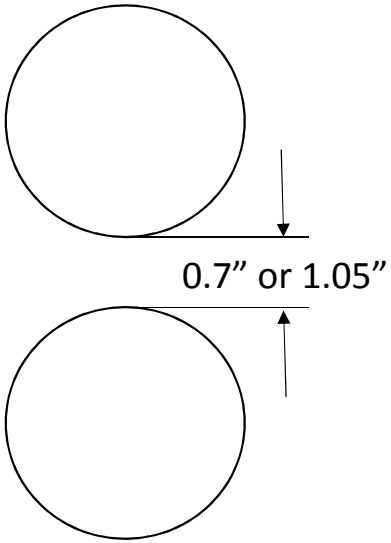
- Experimental testing of 6 large-scale beams
  - Modeled after NDOT as-built bridges
  - 0.7 scale of NDOT bridges
- Finite element models using Atena 3D software
  - Preliminary models used to determine experimental testing configurations
  - Parametric study on curvature, duct tie spacing, location of ducts and number of ducts

Experimental Research

- Total of 6 large-scale beams
- Split into two groups of 3 beams



		Curvature	Duct Spacing	Duct Ties
Round A	C1	Low	0.7"	No
	C2	Medium	0.7"	No
	C3	High	0.7"	No
Round B	C4	Medium	1.05"	No
	C5	Medium	1.05"	17.5" O.C.
	C6	Medium	1.05"	7.0" O.C.



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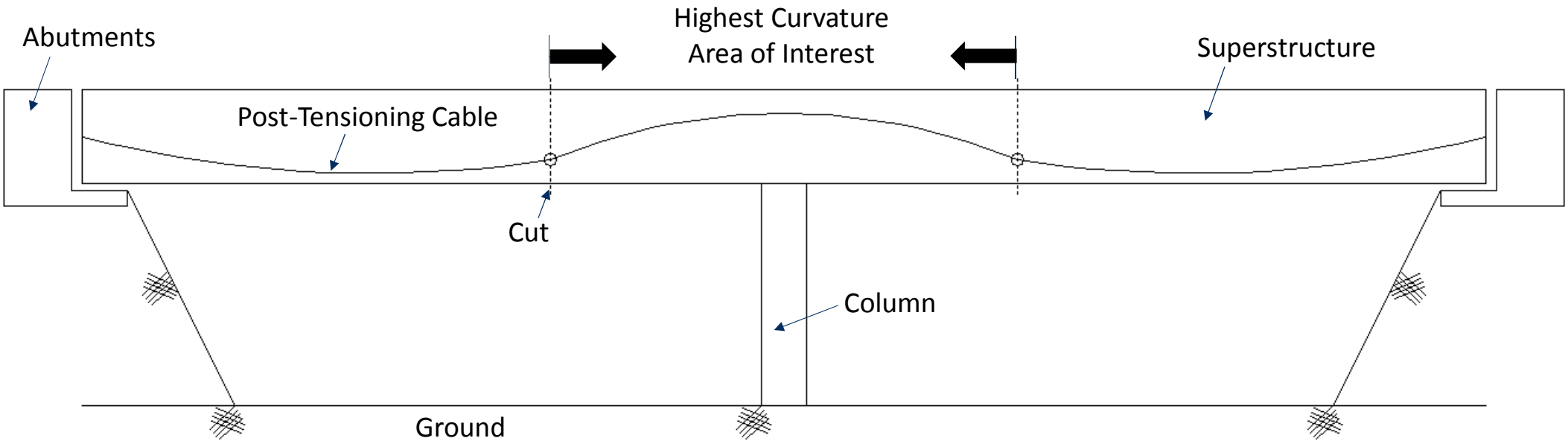
Experimental Research



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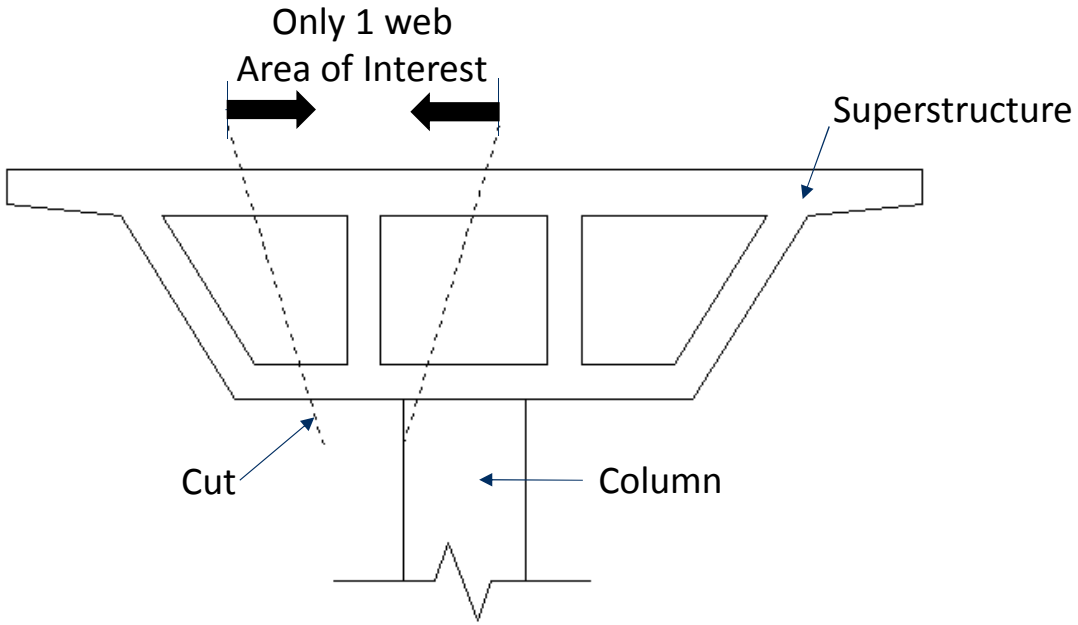
Experimental Research



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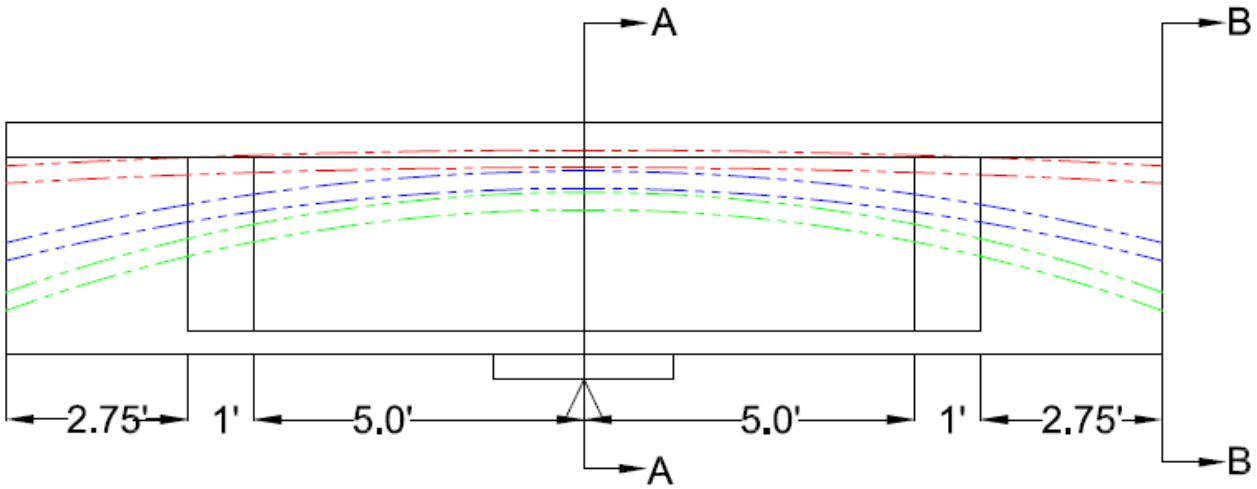
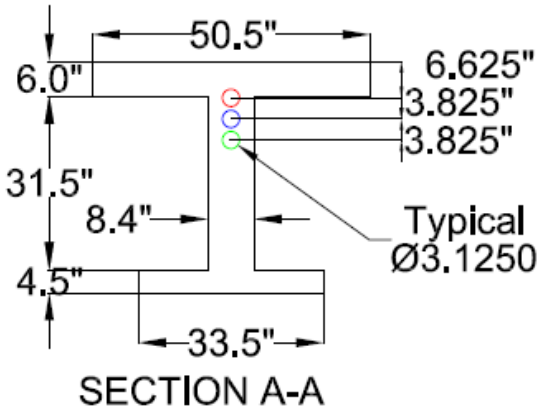
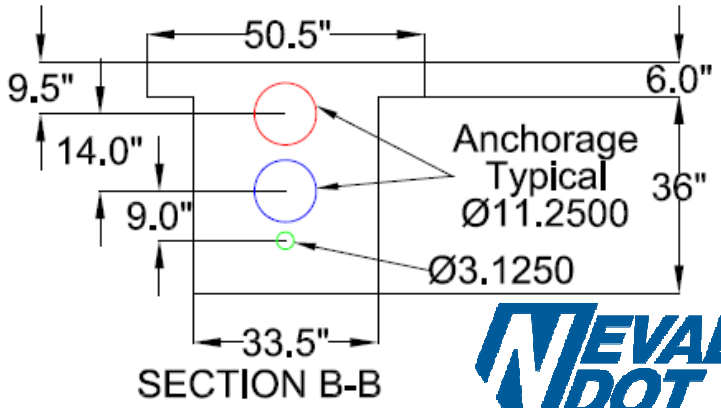
Experimental Beams





*Total of 3 ducts but only top 2 ducts had post-tensioning tendons. The bottom duct (empty one) was used to have 2 areas between ducts.



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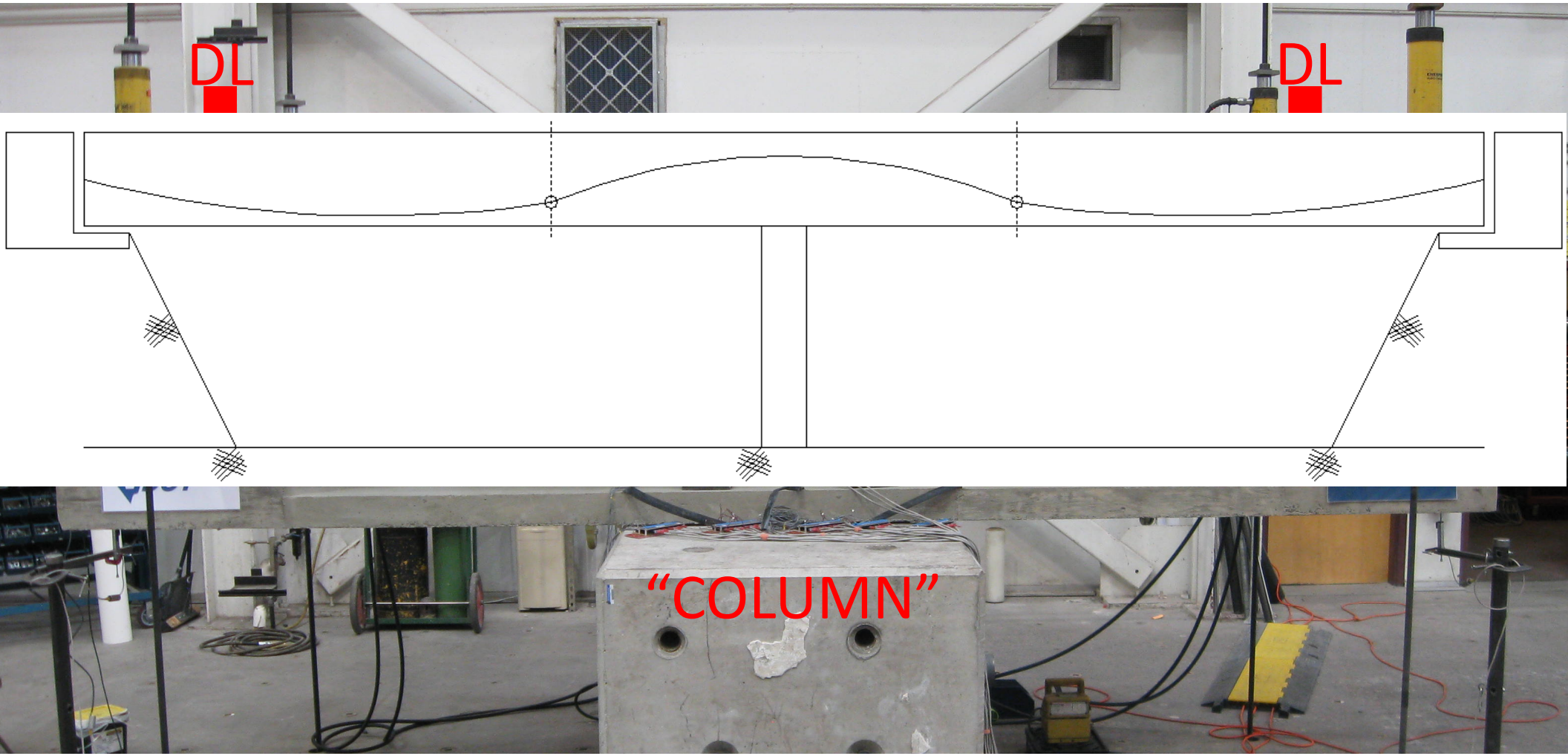
Experimental Setup



Round A Designs

		Curvature	Duct Spacing	Duct Ties
Round A	C1	Low	0.7"	No
	C2	Medium	0.7"	No
	C3	High	0.7"	No

Experimental Loading Protocol

1.	**Apply Dead Load**
2.	**50 psi air pressure middle and top (in order)**
3.	**0.15fpu stress of middle duct**
4.	**0.15fpu stress of top duct**
5.	**0.45fpu stress of middle duct**
6.	**0.45fpu stress of top duct**
7.	**0.75fpu stress of middle duct**
8.	**0.75fpu stress of top duct**
9.	**50 psi air pressure middle and top (in order)**
10.	75 psi air pressure middle and top (in order)
11	100 psi air pressure middle and top (in order)
12.	125 psi air pressure middle and top (in order)
13.	0.85fpu stress of middle duct
14.	0.85fpu stress of top duct
15.	50 psi air pressure middle and top (in order)
16.	75 psi air pressure middle and top (in order)
17.	100 psi air pressure middle and top (in order)
18.	125 psi air pressure middle and top (in order)

Round A Results

- **Configuration 1:** no surface web cracking occurred; no cracking between ducts
- **Configuration 2:** surface web cracking (0.75fpuB); cracking between ducts
- **Configuration 3:** surface web cracking (0.75fpuB minor/50psiB major); cracking between ducts

Can conclude that radius of curvature is a factor on web cracking. The higher the curvature (smaller radius), the more web cracking.

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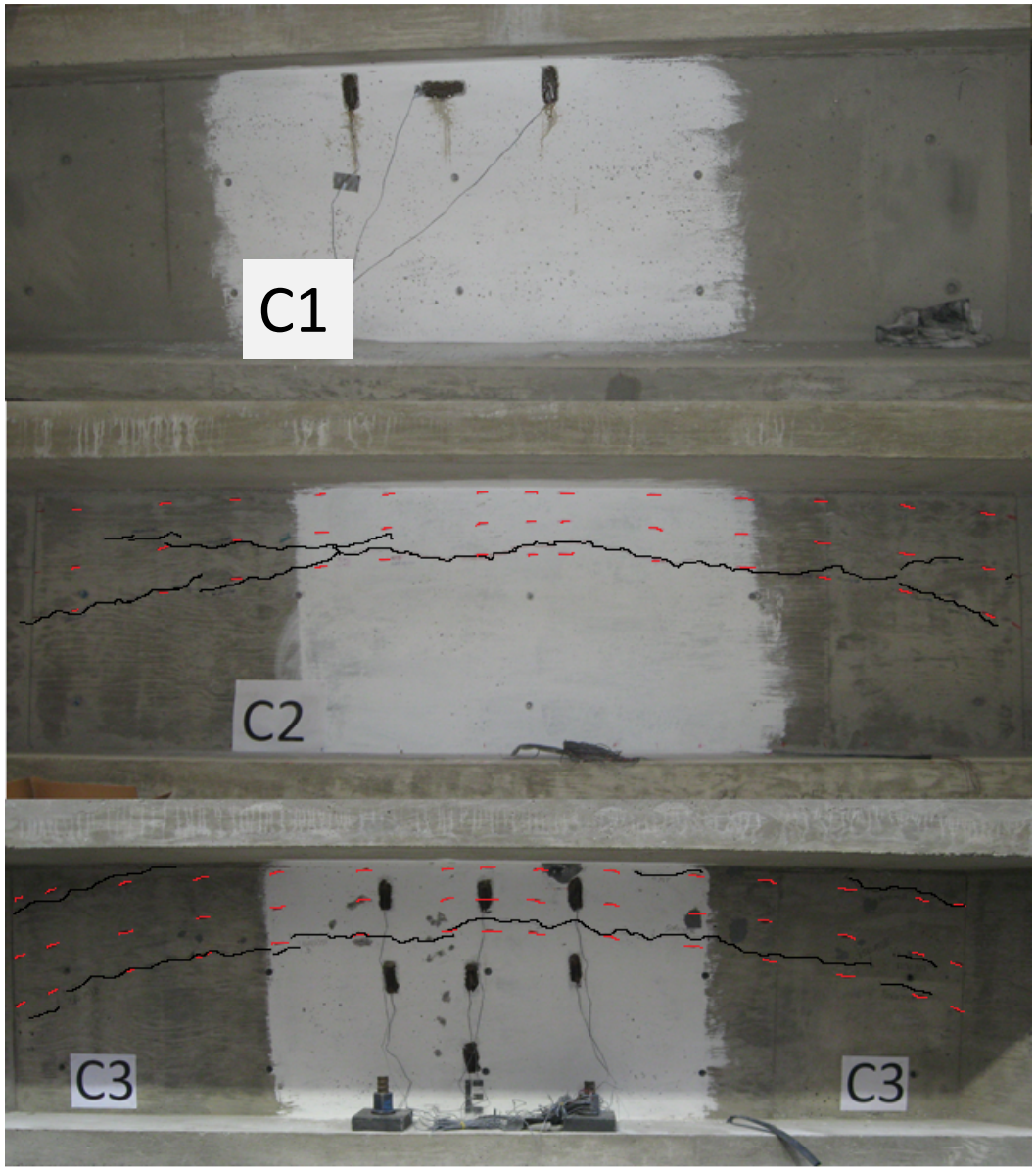
Reminder

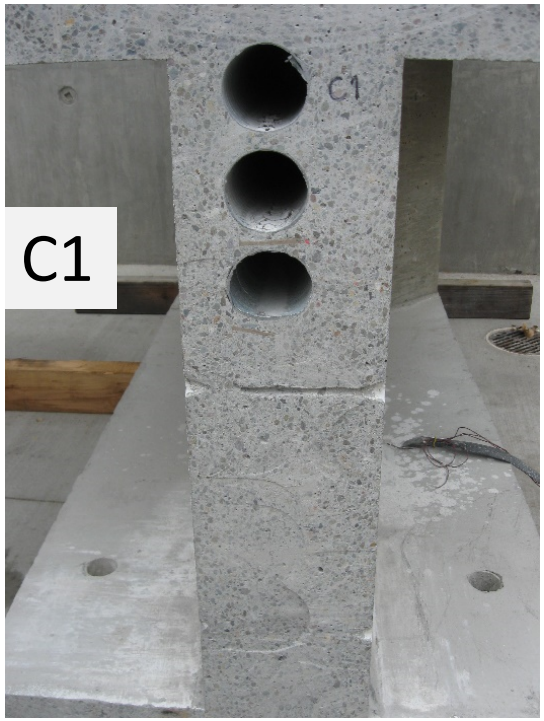
-Configuration 1: Low curvature, 0.7” spacing, no duct ties

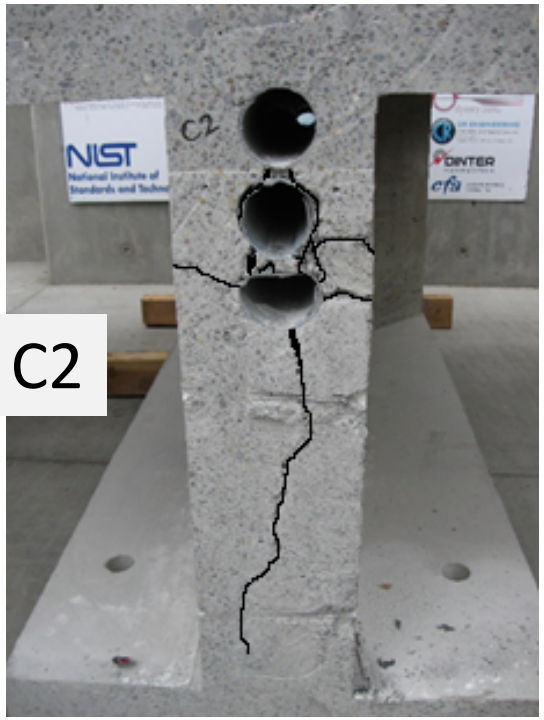
-Configuration 2: Med. curvature, 0.7” spacing, no duct ties

-Configuration 3: High curvature, 0.7” spacing, no duct ties



*NOTE: Cracks shown not representative of true crack width





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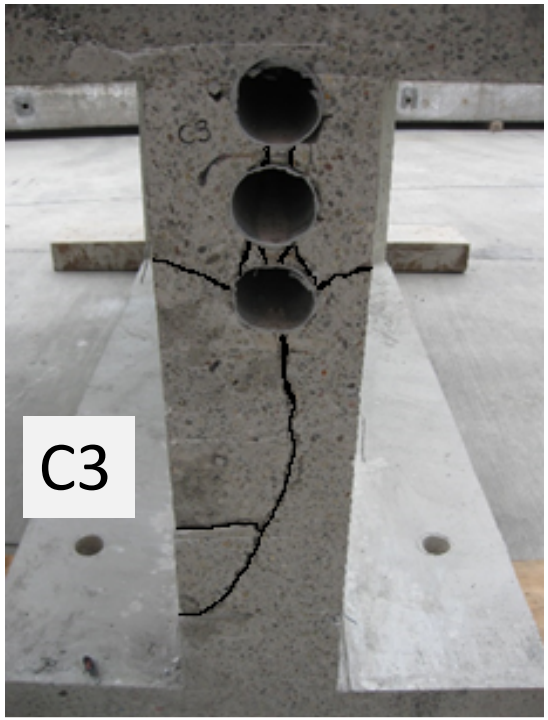

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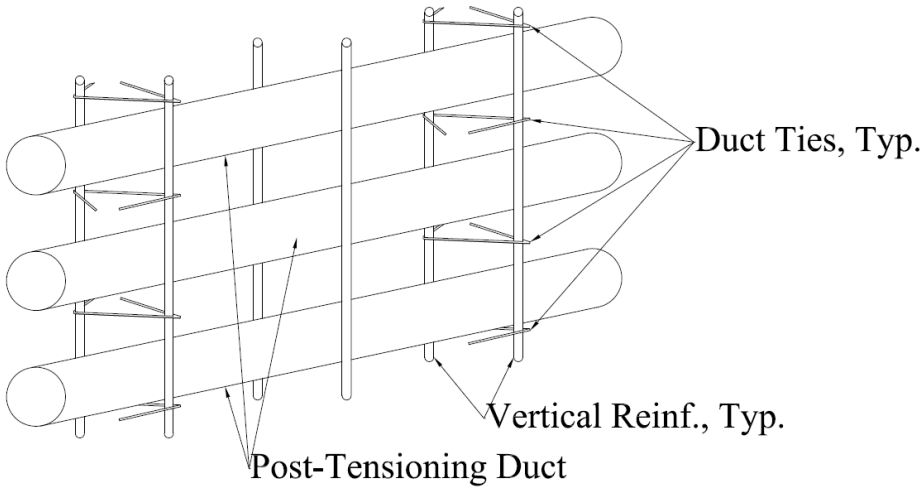
Round B Preliminary Analysis

- ~~Web thickness~~
  - ~~25% increase in width ➡ NO decrease in web cracking~~
- Spacing between post-tensioning ducts
  - 0.7” ➡ 1.05” (50% increase) ➡ Decrease in cracking
- Adding duct tie reinforcement between ducts
  - 1 tie on both sides of duct; note: only 1 tie between duct ➡ Decrease in cracking
- Spacing of duct tie reinforcement
  - Determine best spacing increment (17.5” & 7.0”)

Round B Designs

		Curvature	Duct Spacing	Duct Ties
Round A	C1	Low	0.7"	No
	C2	Medium	0.7"	No
	C3	High	0.7"	No
Round B	**C4**	**Medium**	**1.05"**	**No**
	C5	**Medium**	**1.05"**	**17.5" O.C.**
	C6	**Medium**	**1.05"**	**7.0" O.C.**



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Round B Results

- **Configuration 4:** less surface cracking than C2 (100psiB – 0.75fpu)
- **Configuration 5:** less surface cracking than C4 (75psiB – 0.75fpu minor/100psiB major), reinforcement helped reduce cracking
- **Configuration 6:** the best performance of round B with minimal cracks (125psiB – 0.75fpu)

Can conclude that increased duct spacing and inclusion of duct ties decreases web cracking.

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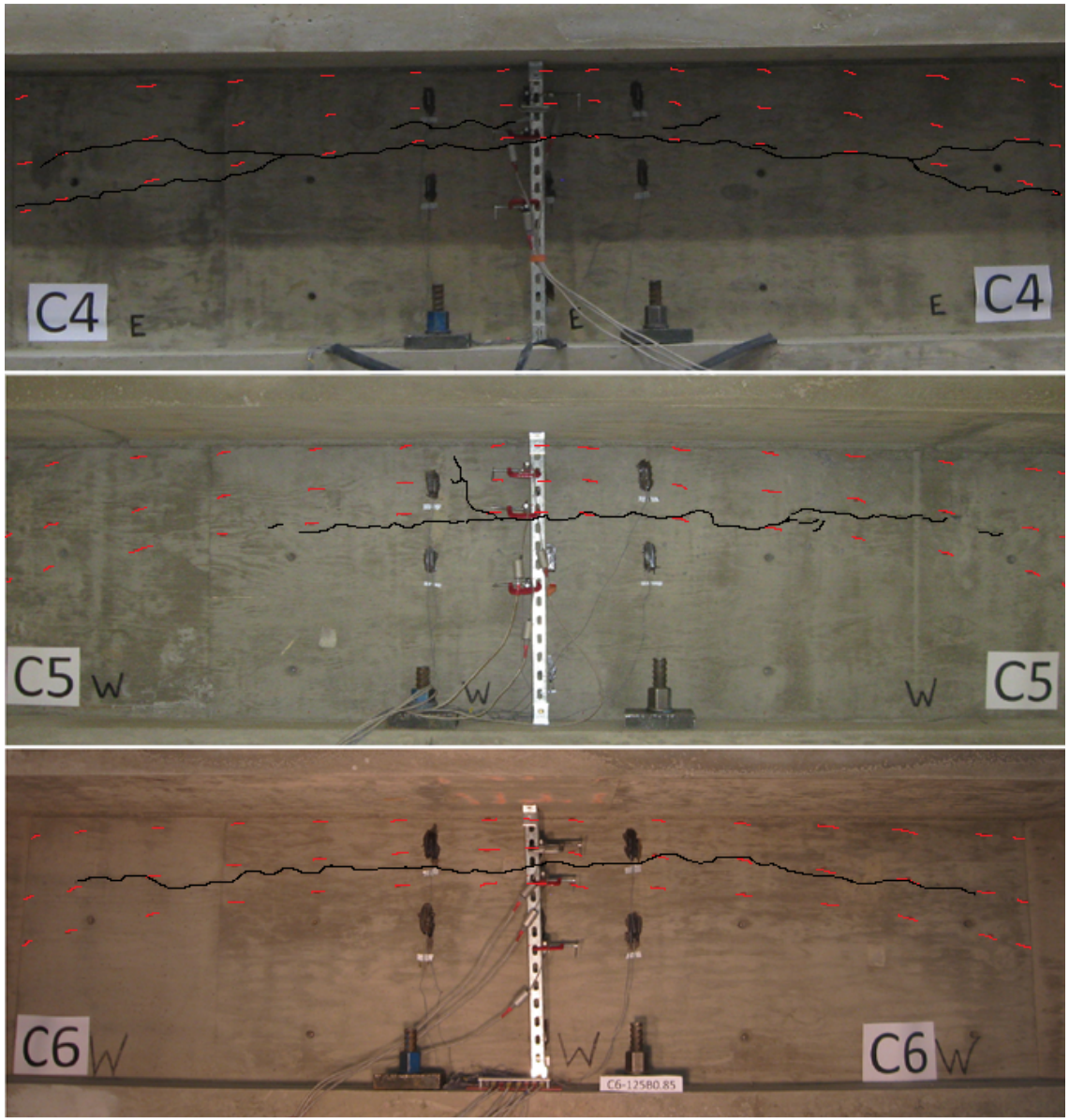
Reminder

-Configuration 4: Med. Curvature, 1.05” spacing, no duct ties

-Configuration 5: Med. Curvature, 1.05” spacing, duct ties at 17.5”

-Configuration 6: Med. Curvature, 1.05” spacing, duct ties at 7.0”



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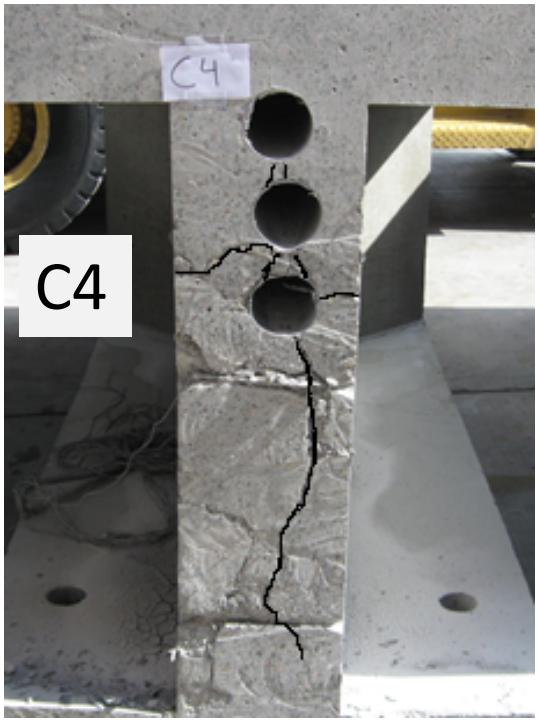

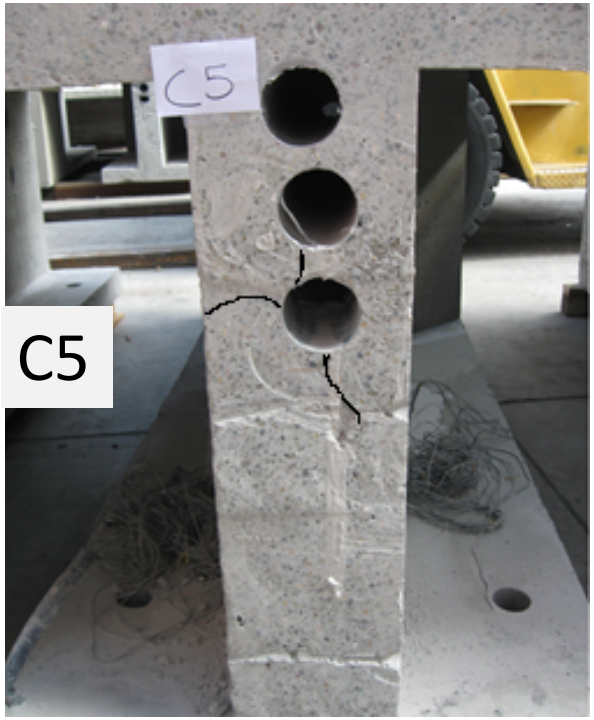

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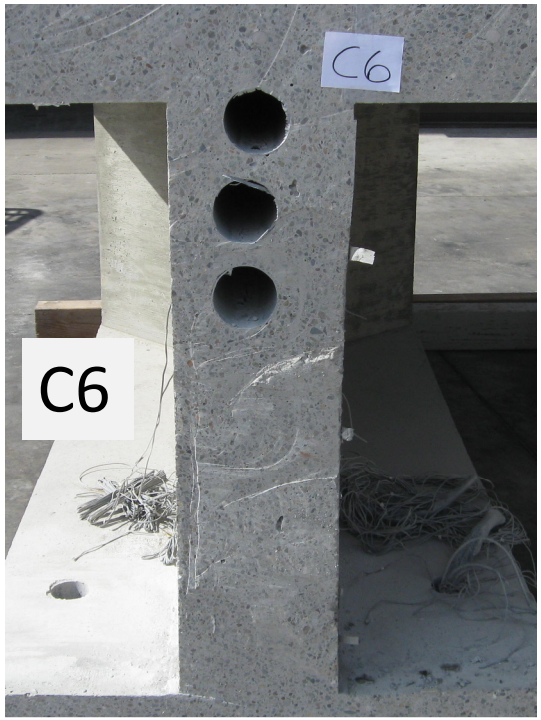

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Experimental Testing Conclusions

- Keeping curvature of PT ducts low minimizes web cracking.
- Increasing spacing between ducts decreases the amount of cracks.
- Inclusion of duct tie reinforcement between PT ducts decreases cracks even more than just increasing spacing.
- Air pressure testing causes the damage.

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Parametric Study

- Studying effects of:
  - Curvature
  - Duct tie reinforcement spacing
  - Location of ducts in the web (top of the web, middle of the web, bottom of the web)
  - Number of ducts (2, 3, 4)
- All models are 0.7 scale

Parametric Study

# of Ducts	Equivalent Curvature Loads, kip/ft.	Effective Full Scale Radius, ft.	Reinforcement Spacing, in.	Duct Location on Web	Loading
2	19.12	57.85	N, 17.5, 3.5	Top	0.80fpu + 100psi
3	19.12	57.85	N, 17.5, 3.5	Top	0.80fpu + 100psi
4	19.12	57.85	N, 17.5, 3.5	Top	0.80fpu + 100psi
3	19.12	57.85	N	Top	0.80fpu + 100psi
	19.12	57.85	N	Middle	0.80fpu + 100psi
	19.12	57.85	N	Bottom	0.80fpu + 100psi
3	11.75 (C1)	91.59	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	19.12 (C2)	57.85	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	22.6 (0.5C2+0.5C3)	49.41	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	26.1 (C3)	43.17	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	29.7 (C3+)	38.29	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi

Note: Overstressed to 0.80fpu and over air pressured to 100psi for unexpected errors during construction

Parametric Study: Duct Location

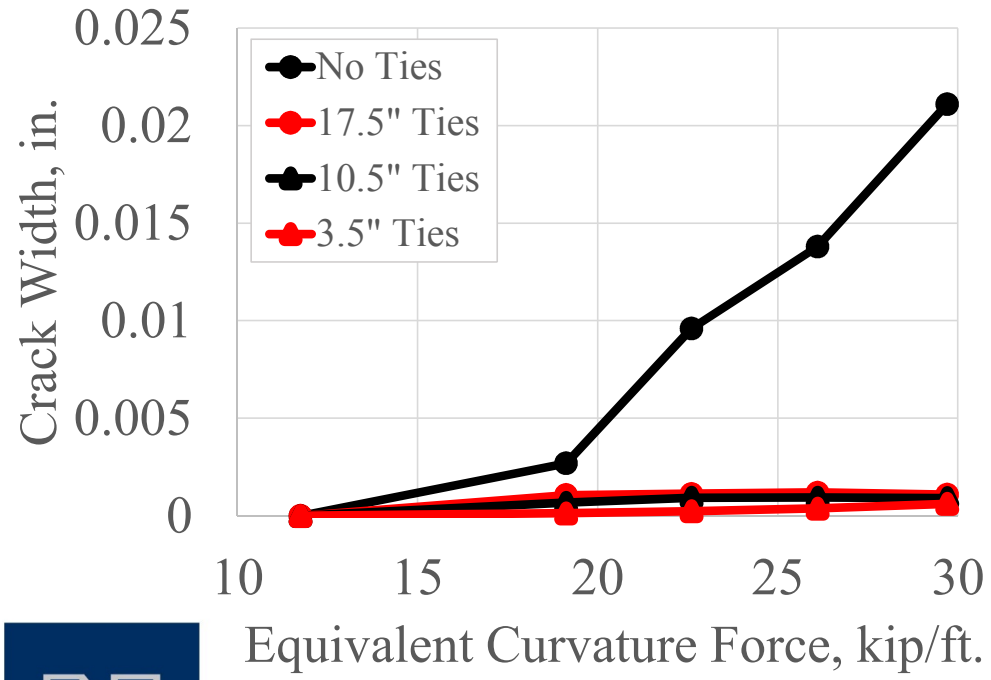
- Locations of ducts:
  - Top of web
  - Middle of web
  - Bottom of web
- Can conclude location of ducts in the web **does not** affect performance.

Parametric Study: Curvature & Duct Ties

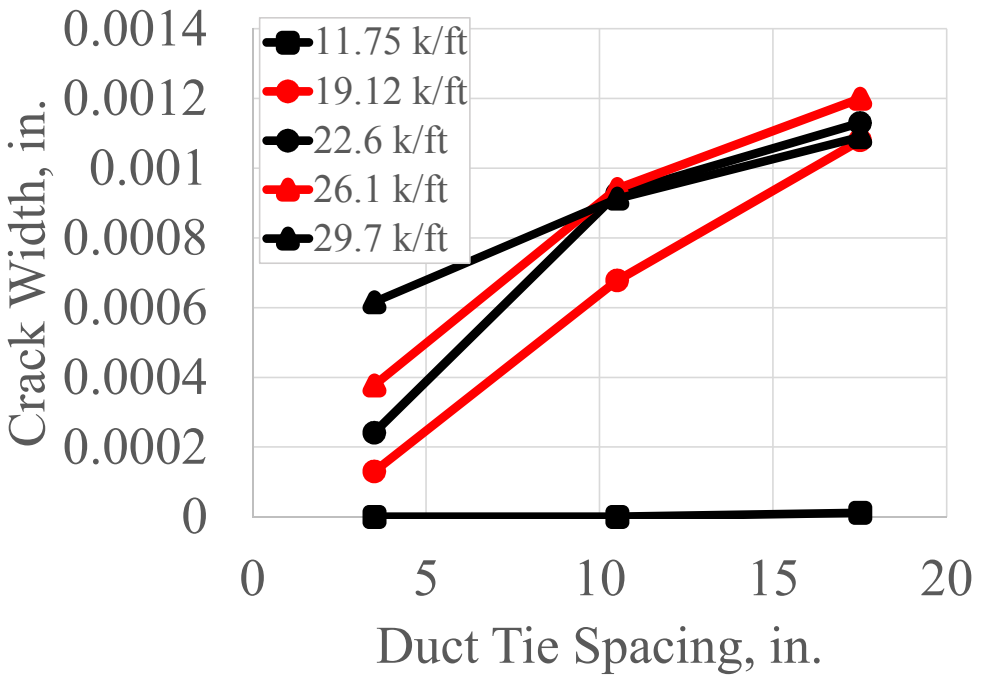
# of Ducts	Equivalent Curvature Loads, kip/ft.	Reinforcement Spacing, in.	Duct Location on Web	Loading
3	11.75 (C1)	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	19.12 (C2)	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	22.6 (0.5C2+0.5C3)	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	26.1 (C3)	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi
	29.7 (C3+)	N, 17.5, 10.5, 3.5	Top	0.80fpu + 100psi

Parametric Study: Curvature & Duct Ties

Crack Width vs. Duct Curvature



Crack Width vs. Duct Tie Spacing



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*Crack width between middle and bottom ducts.

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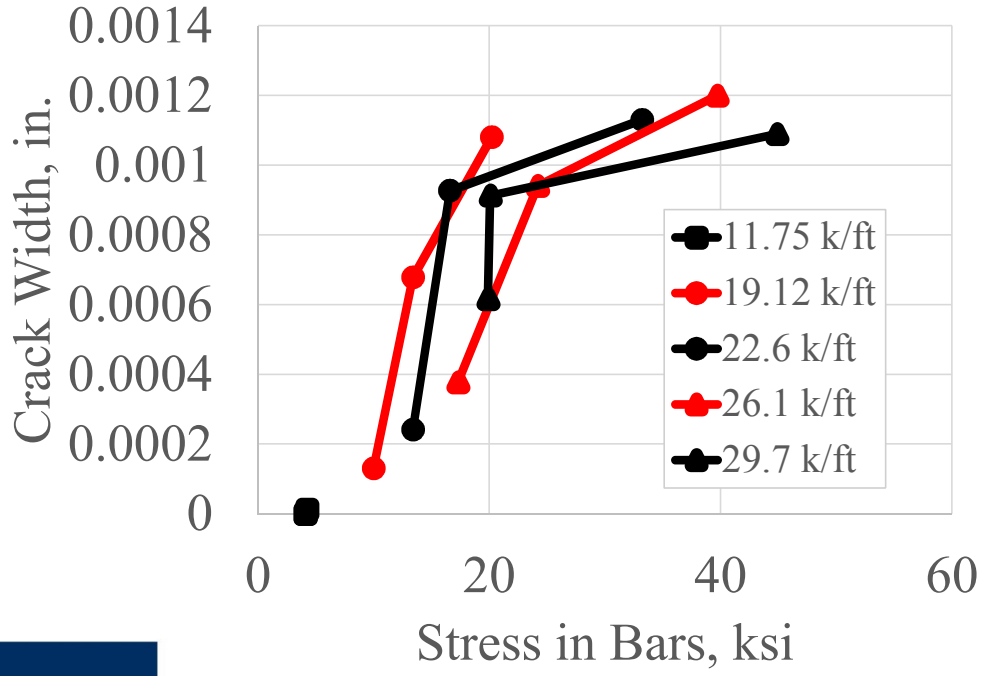
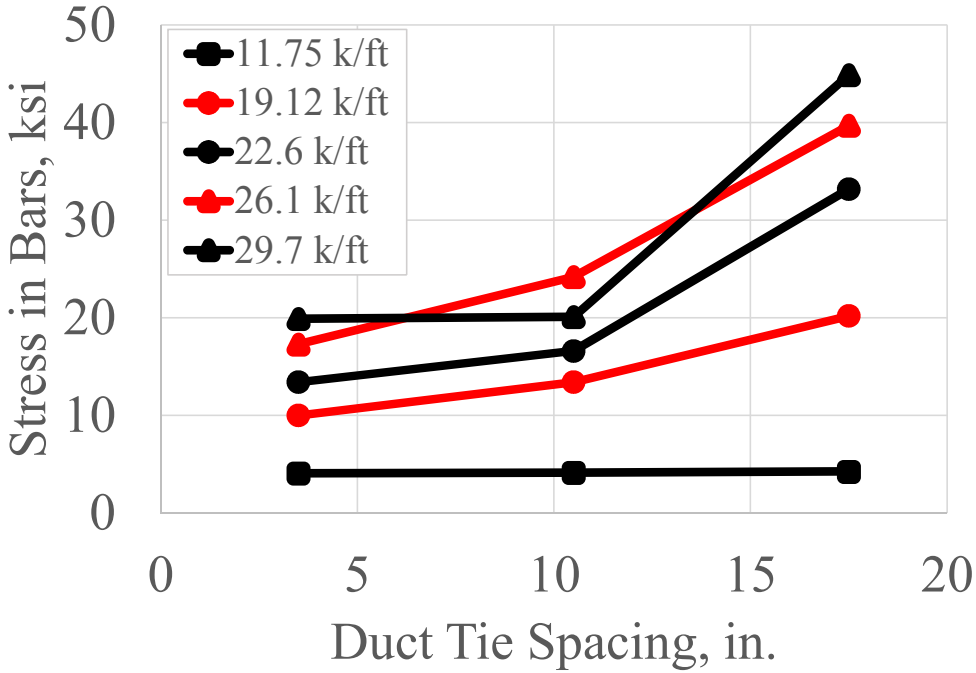
Parametric Study: Curvature & Duct Ties

Crack Width vs. Bar Stress



Bar Stress vs. Duct Tie Spacing



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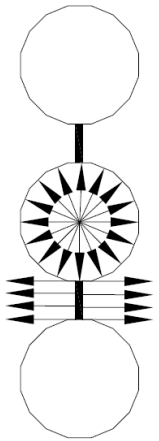
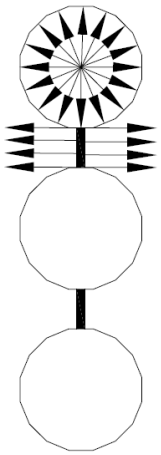
Parametric Study: Artificial Crack Model

- Previous models did not allow air to transfer into the crack.
- No air pressure on the crack so an artificial crack was created between ducts .
- Applied pressure to artificial crack equivalent to air pressure.





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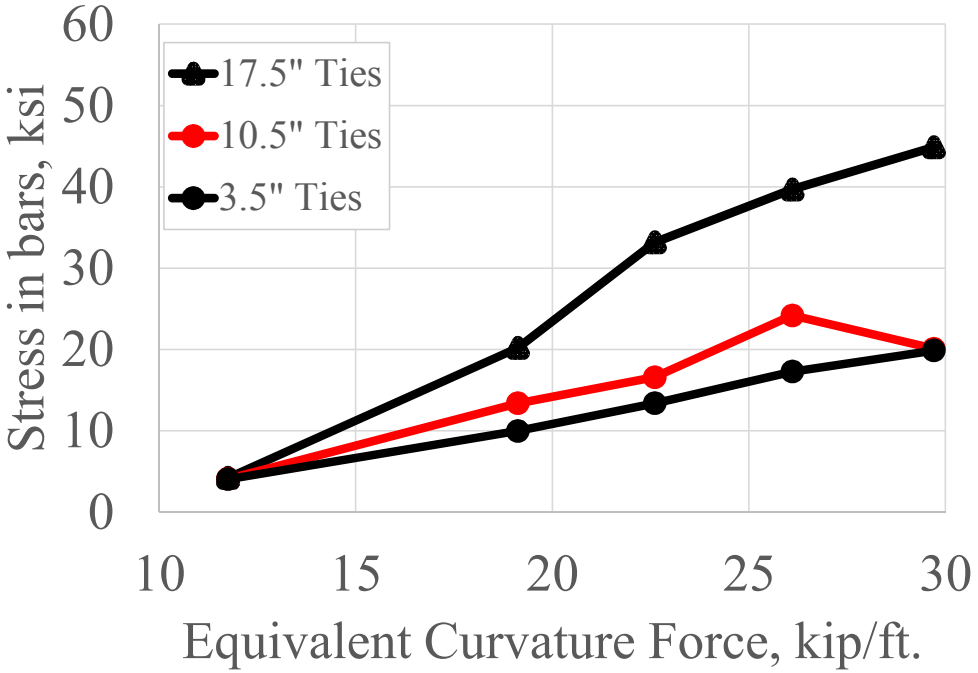
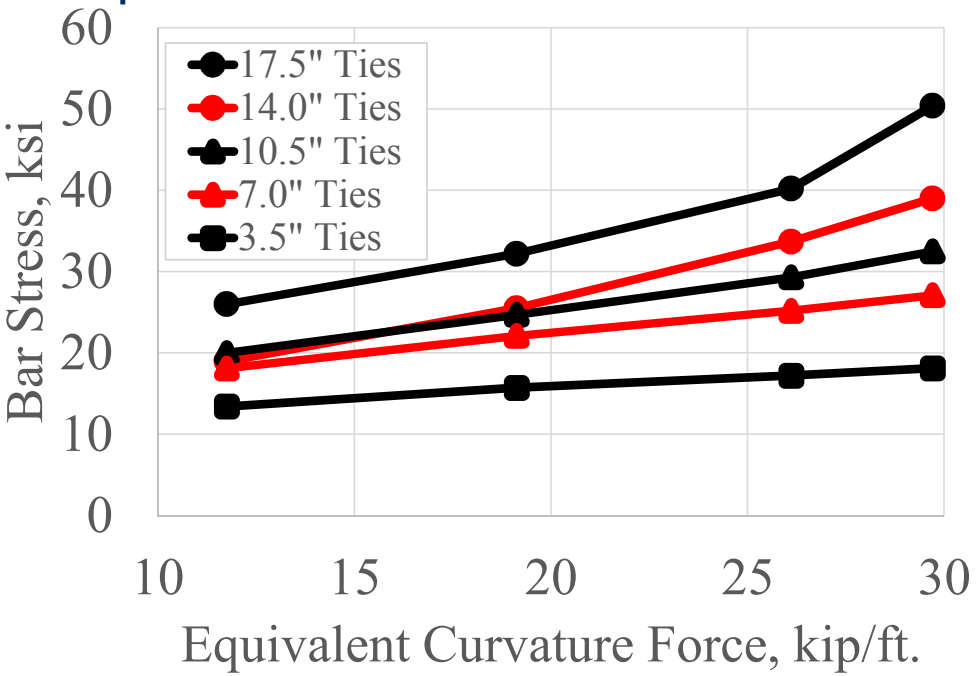
Parametric Study: Curvature & Duct Ties

Bar Stress nearest center span with **NO** air pressure on crack



Artificial Crack Model: Bar Stress nearest center span **WITH** air pressure on crack



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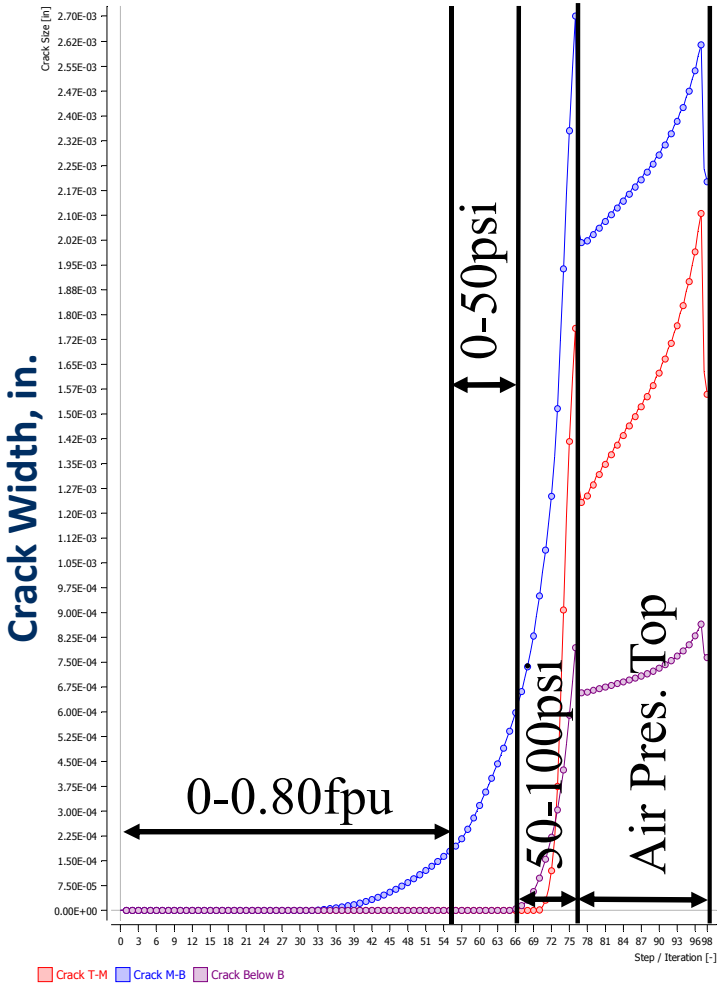
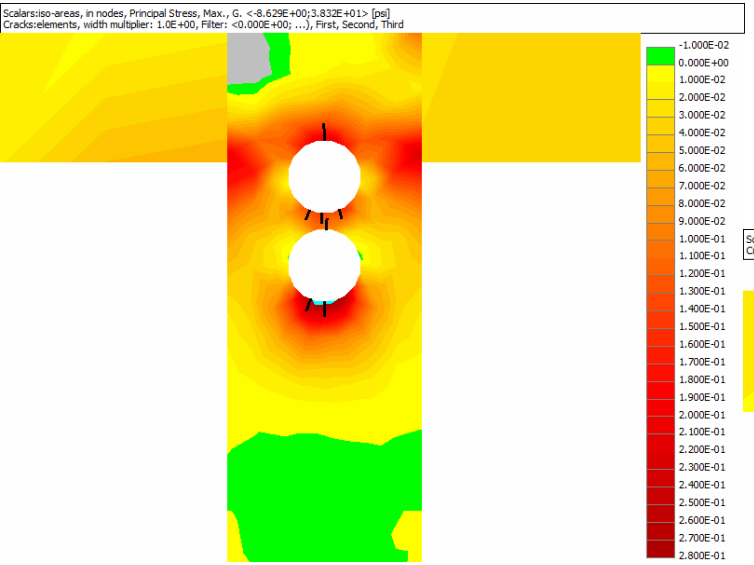
Parametric Study: Air Pressure

- 50-100 psi Air pressure drastically increased damage.
- C2 with no duct ties.

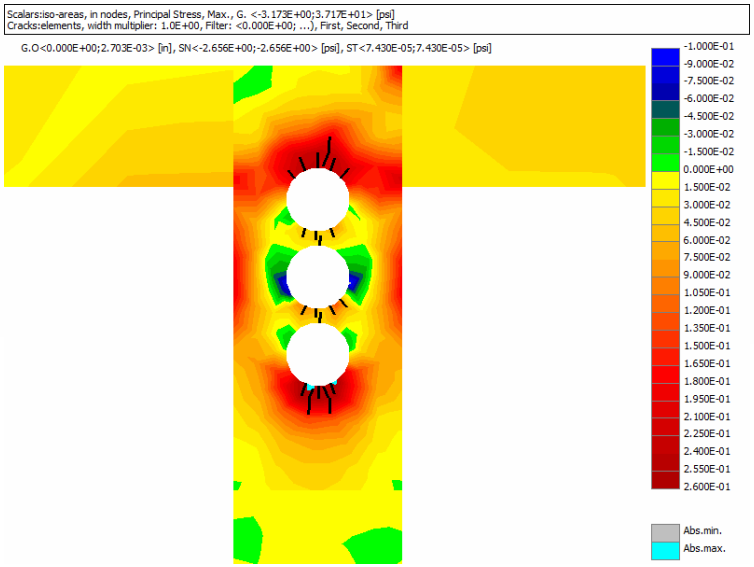


Parametric Study: No. of Ducts

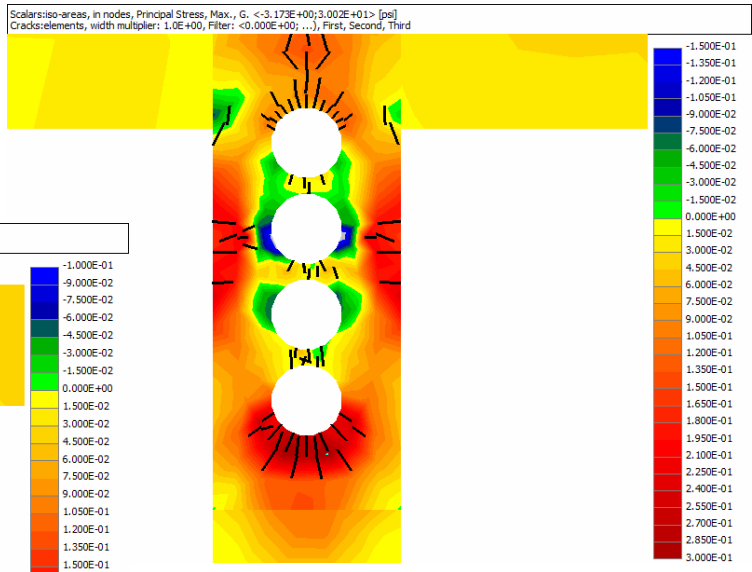
- **Principal stresses** after 0.80fpu and 100psi air pressure on TOP 2 ducts.



2 DUCTS



3 DUCTS



4 DUCTS

- Duct ties decrease damage for 2, 3, and 4 ducts.

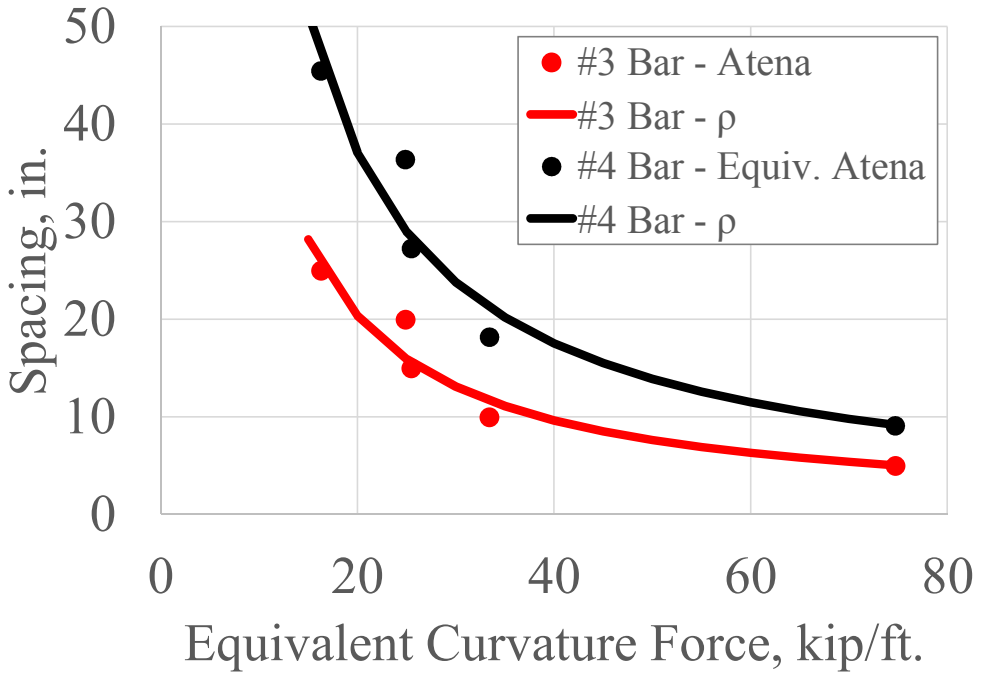
Parametric Study: Conclusions

- The duct location (top, middle, bottom) within the web does not have an effect on the overall performance and flow of forces.
- Simply including duct tie reinforcement decreases the web bulge and cracking between the ducts.
- Air pressure testing causes the damage.
- Number of ducts (2, 3, 4) does not affect overall stress within the section but does increase cracking. Revised design detail should cover all number of ducts.

Recommendations

- 1.5” PT duct spacing
- Inclusion of duct ties for curvatures > 15.0 kip/ft.

Full Scaled Model



Equations:

$$s = \frac{10{,}000A_s}{3w - 6}$$

s = required duct tie rein. spacing, in.

A_s = area of reinforcement, $in.^2$

w = equivalent curvature force, kip/ft.

Overall Conclusions

- Larger curvature equates to more damage.
- Duct tie design equation is sufficient for various curvatures, number of ducts, and location of ducts for reducing damage.
- Air pressure was primary cause for web cracking.
  - Limiting air pressure strictly to 50 psi will limit amount of cracking damage.
- Careful consideration during construction to ensure proper consolidation around PT ducts.

Questions?

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