

Effects of Anchor Wedge Dimensional Parameters on Post- Tensioning Strand Performance

Kevin Q. Walsh, Randy L. Dragnis,
Richard M. Estes, and Yahya C. Kurama

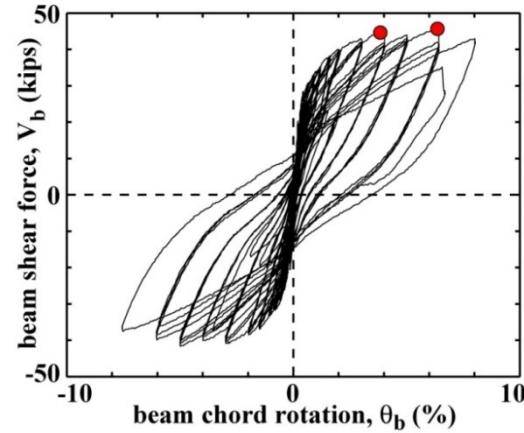
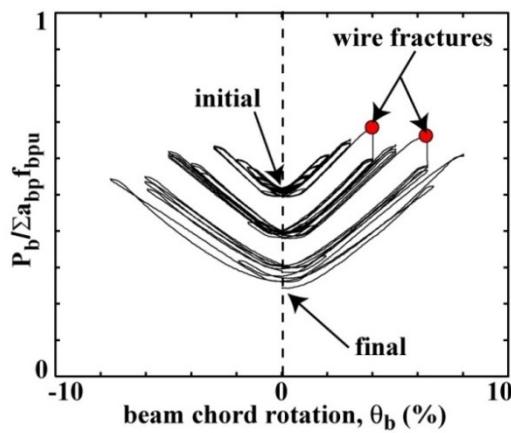
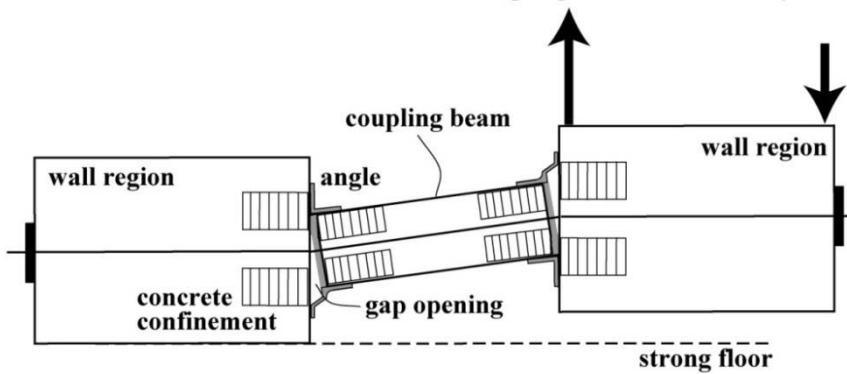
PTI Convention
Norfolk, Virginia
May 6, 2014



2002 – 2007

Brad Weldon PhD Research at ND

Unbonded Post-Tensioned Precast Coupling Beam Subassembly



2007 – 2009

Kevin Walsh MS Research at ND

- Questions:
 - How is PT strand/anchor performance affected by changes in anchorage configuration?
 - How is PT strand/anchor performance affected by changes in loading parameters?

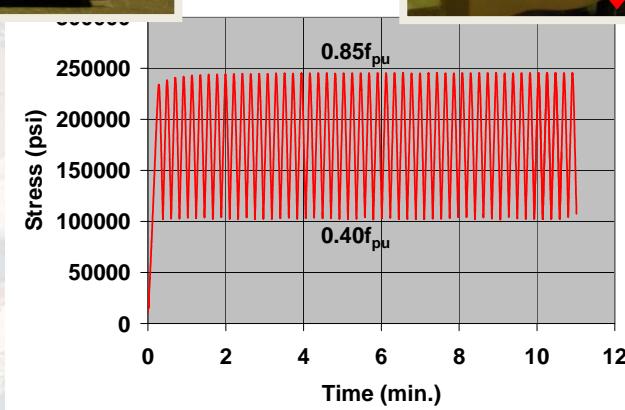
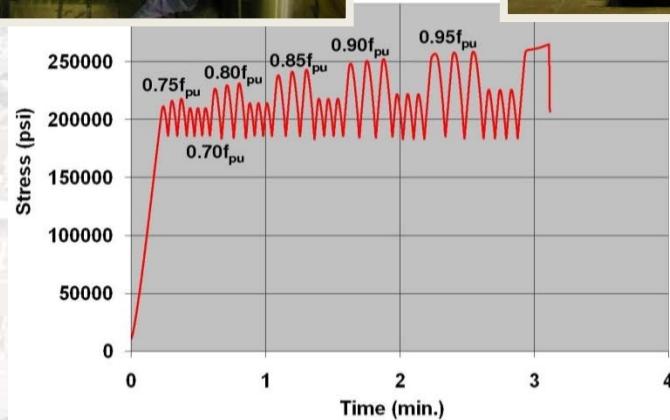
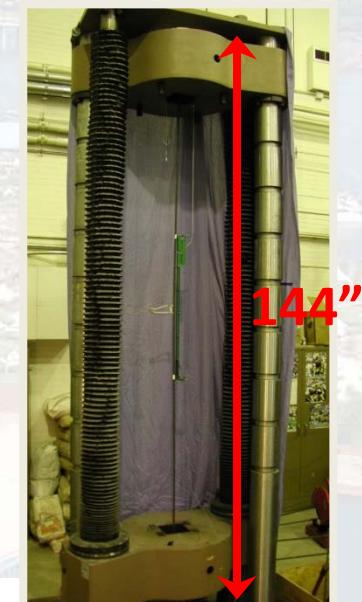
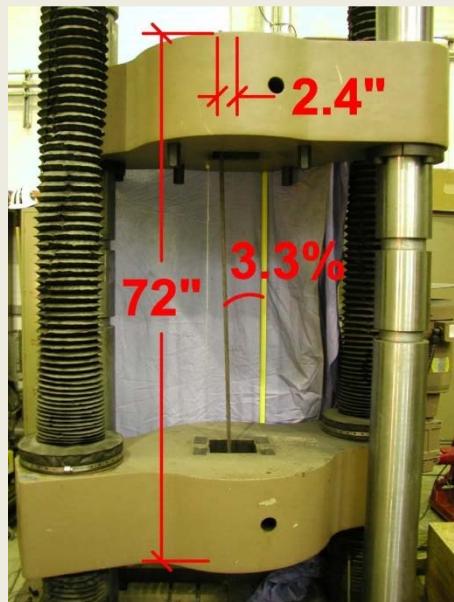
2007 – 2009

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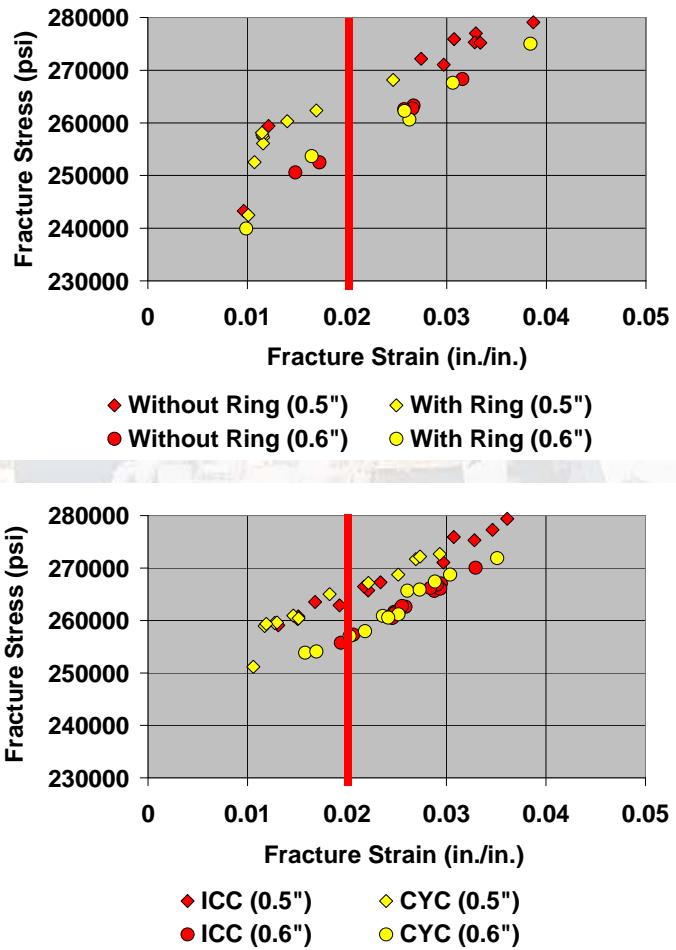
2007 – 2009

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Component	Publication	Required Strength (ksi)	Required Strain at Ultimate Load
Strand/Anchor System	ACI 318-08 Section 18.21.1	$0.95f_{nominal}$	2.0%
Strand/Anchor System	ACI 423.7-07 Section 2.6	$0.95f_{actual}$	2.0%
Strand/Anchor System	ACI 423.3R-05 Section 4.1	$0.95f_{actual}$	2.0%
Strand/Anchor System	PTI-2000 Section 2.2.1	$0.95f_{actual}$	2.0%

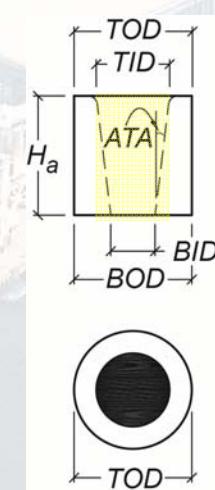
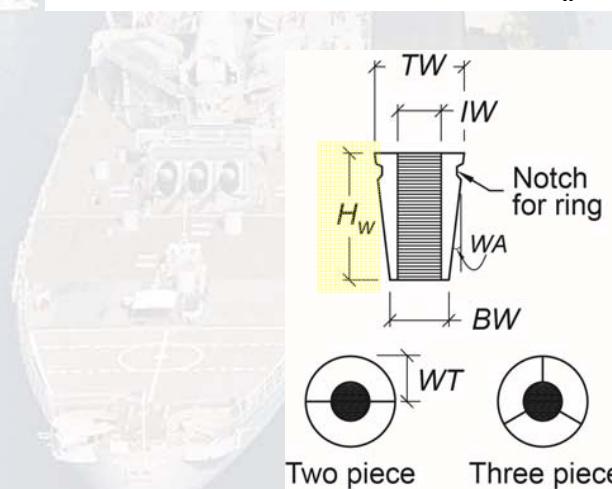
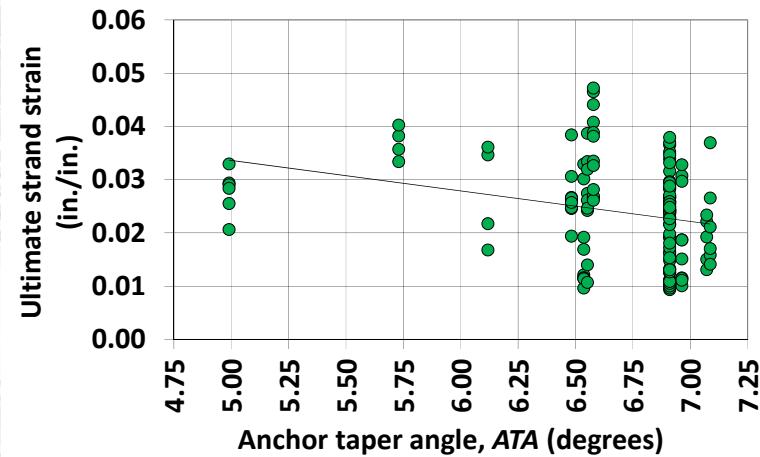
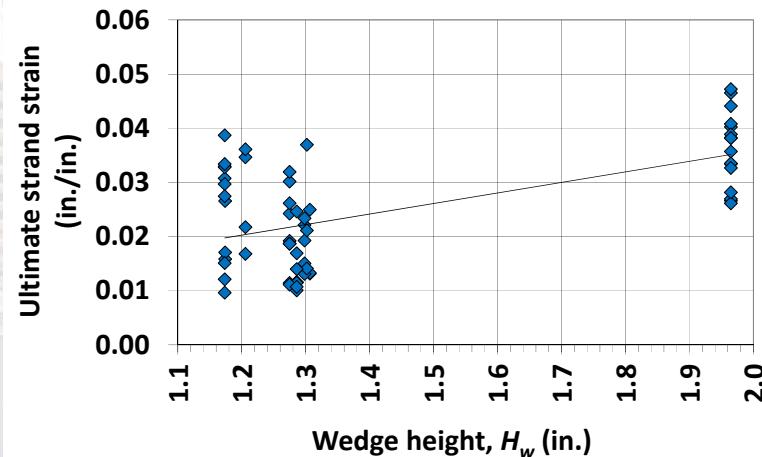
2007 – 2009

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- Additional question:
 - How can strand/anchor performance be reliably improved?

2007 – 2009

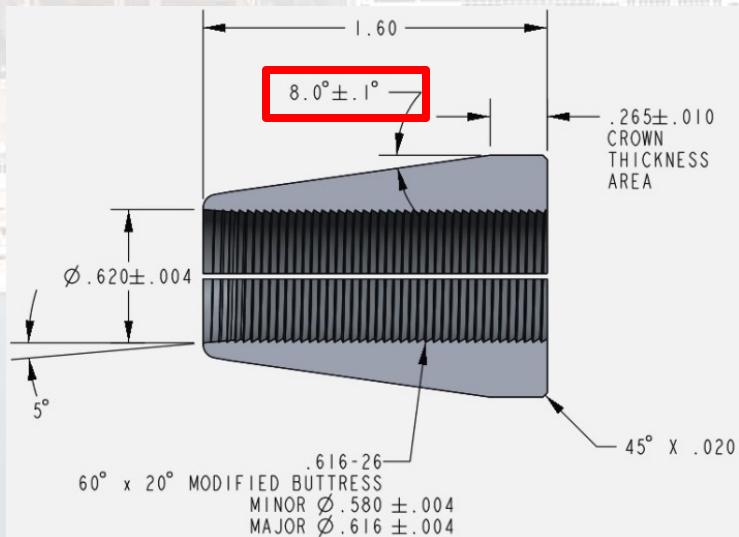
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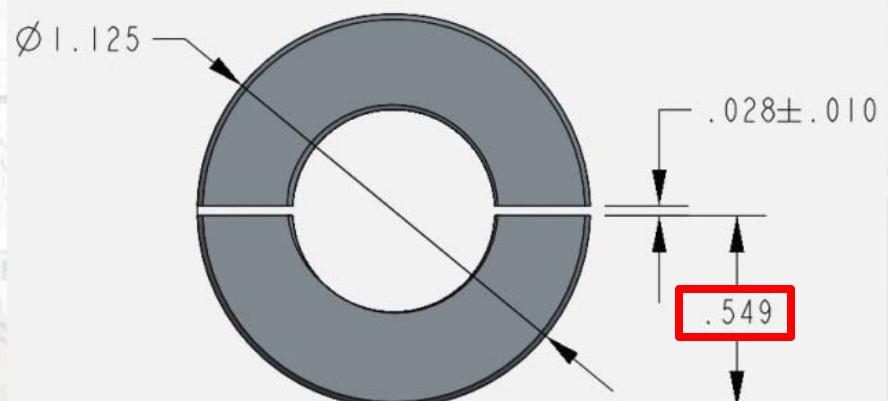
2010 - 2013

Hayes Research at ND

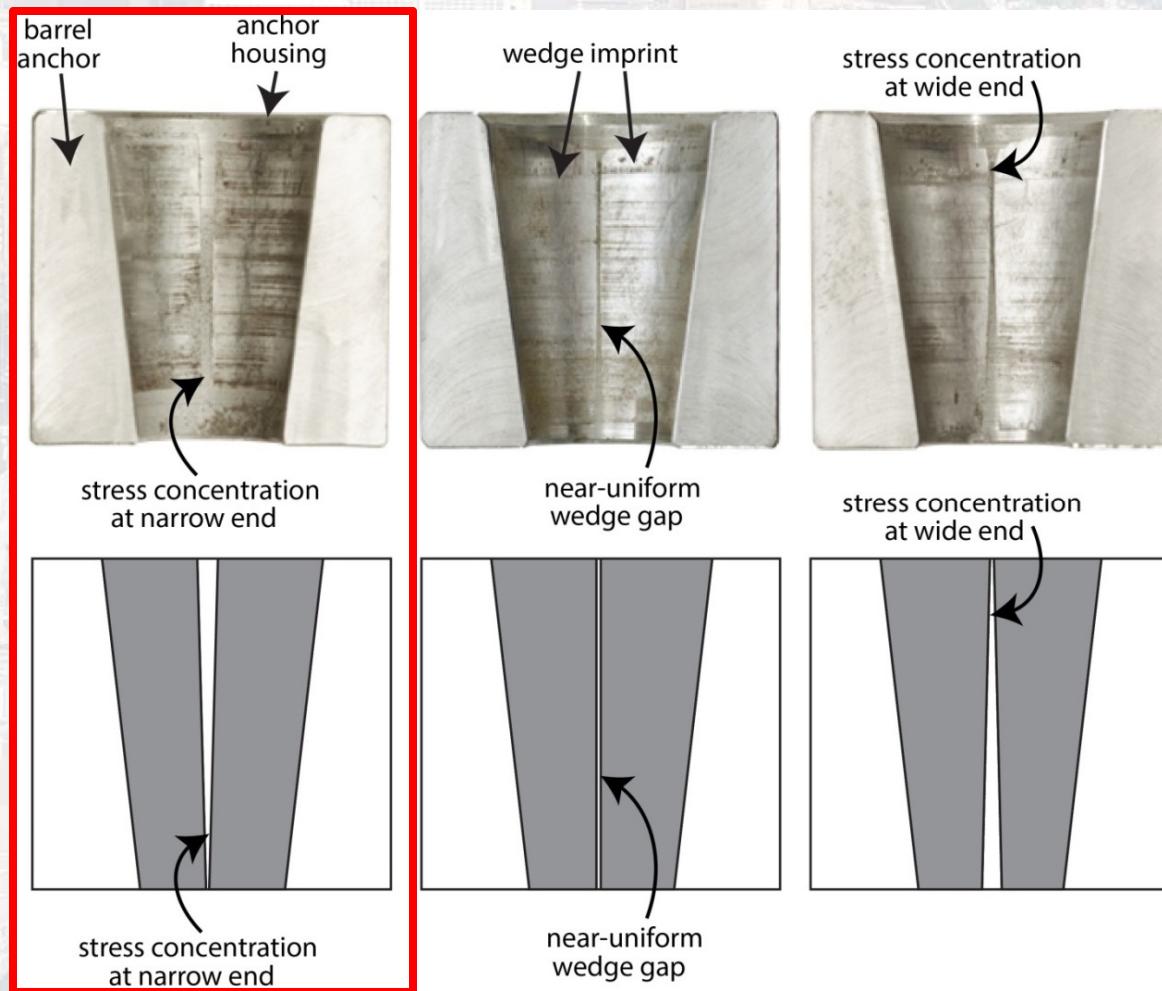
Wedge taper angle differential



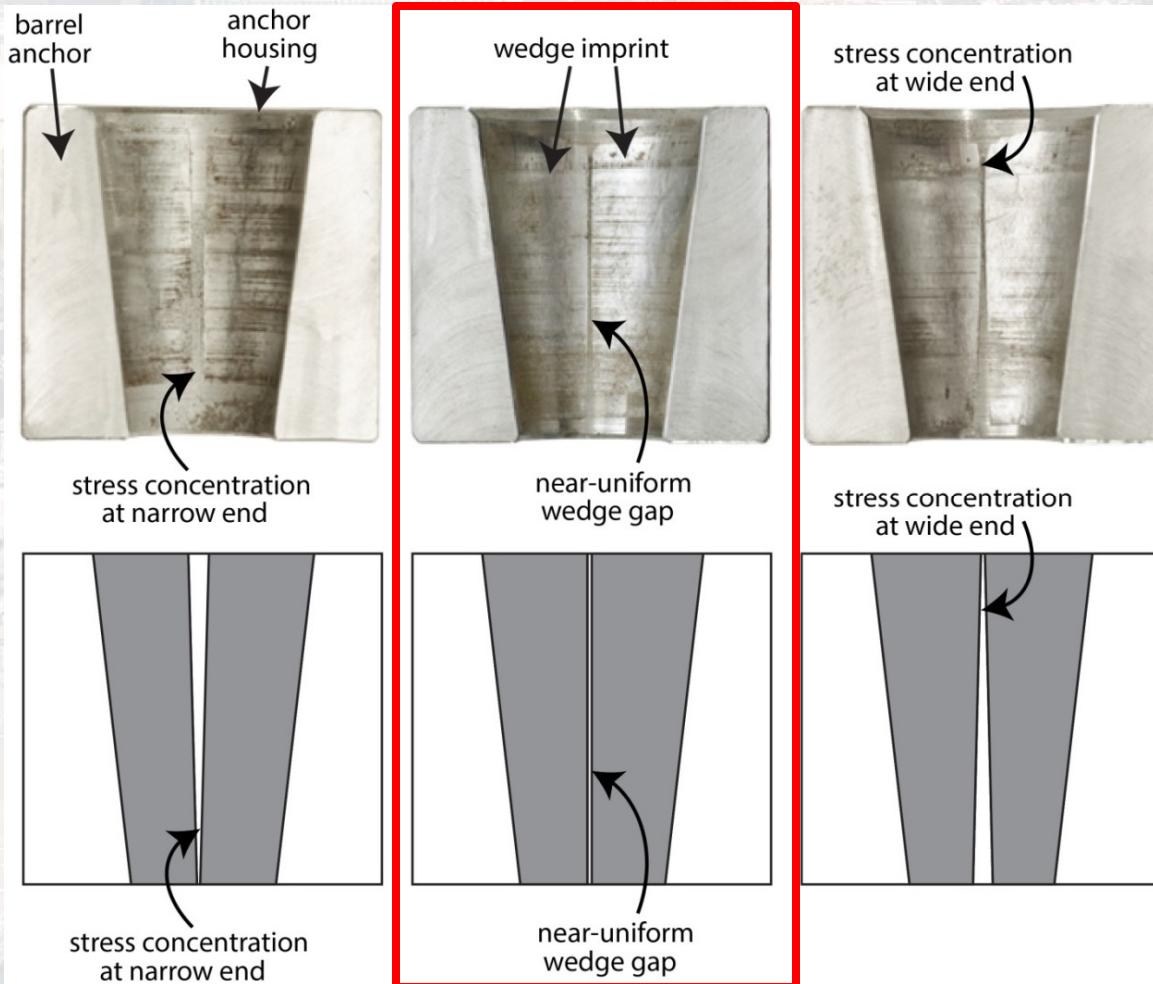
Wedge crown thickness



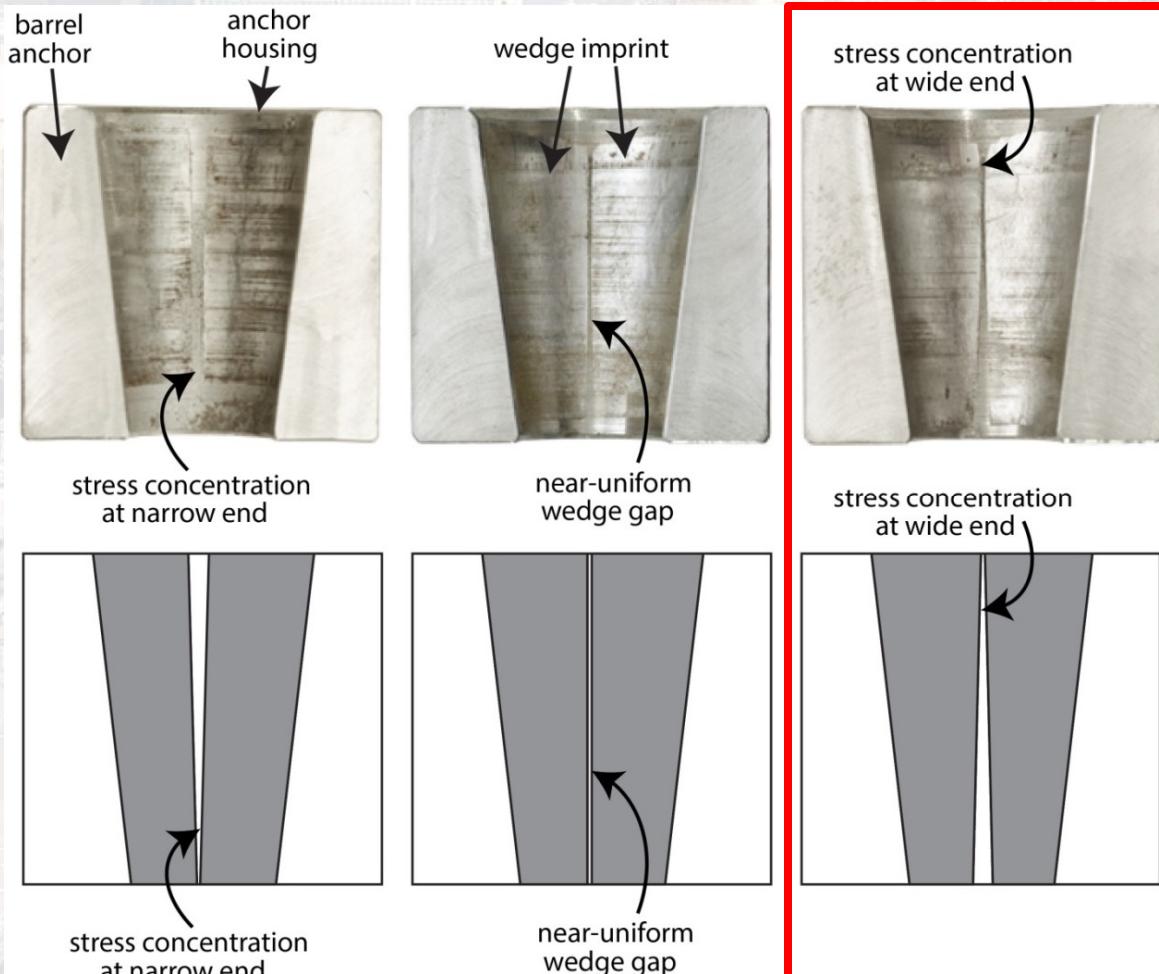
Wedge Taper Angle Differential



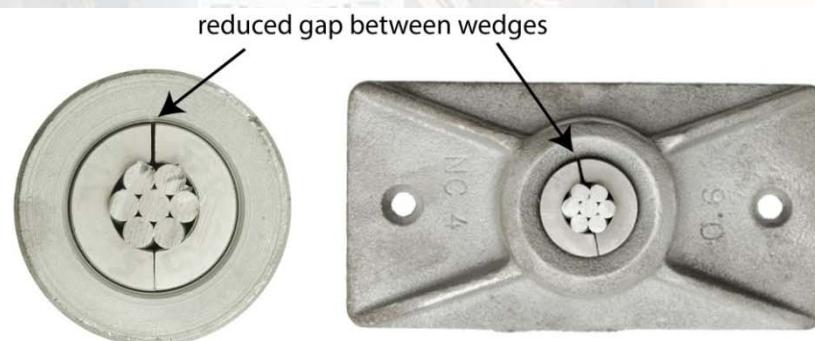
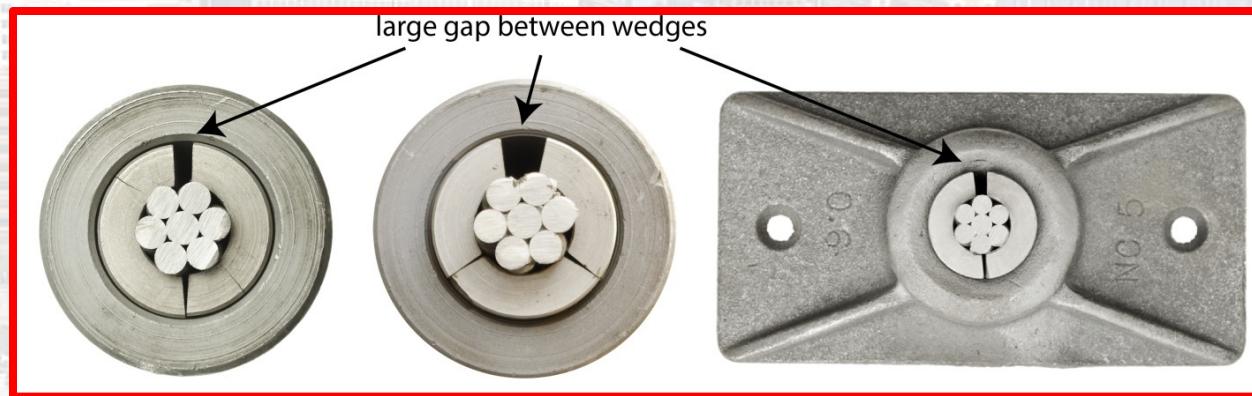
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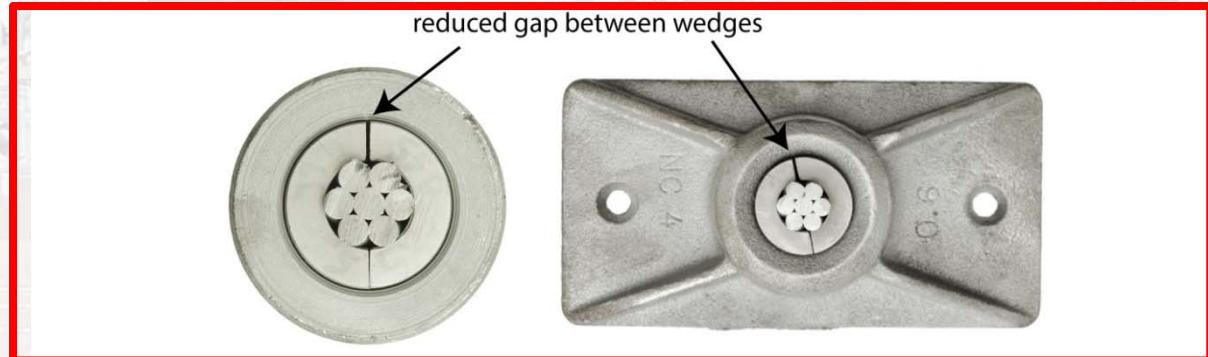
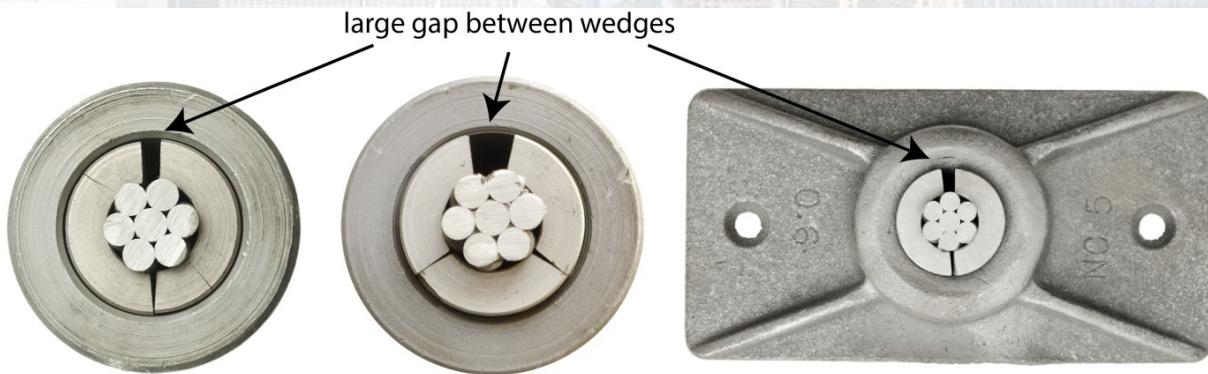
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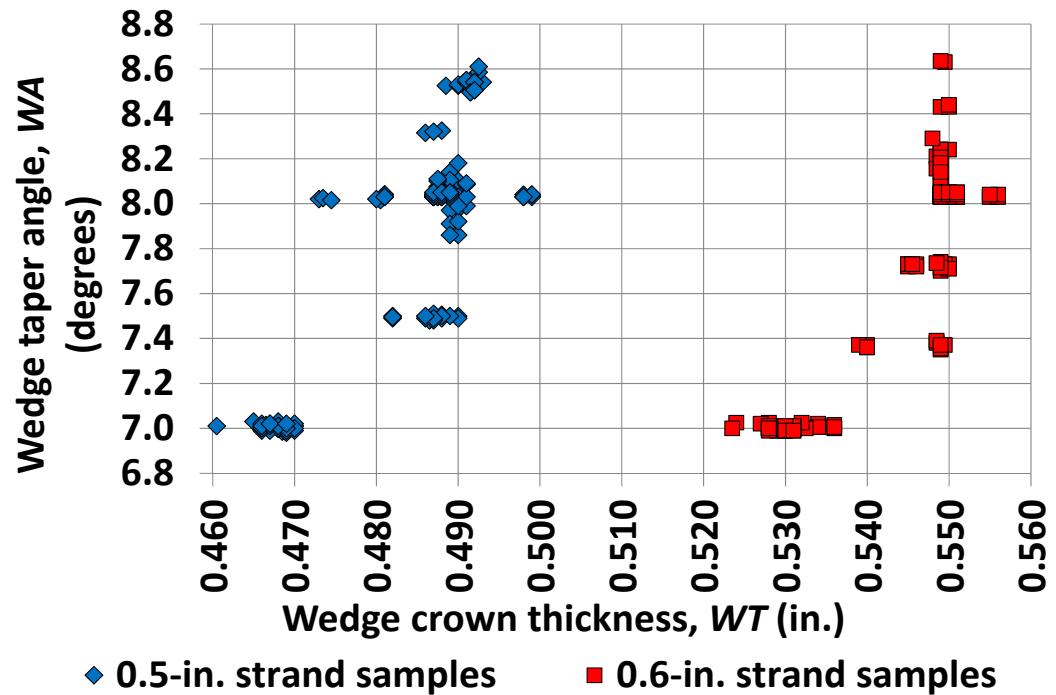
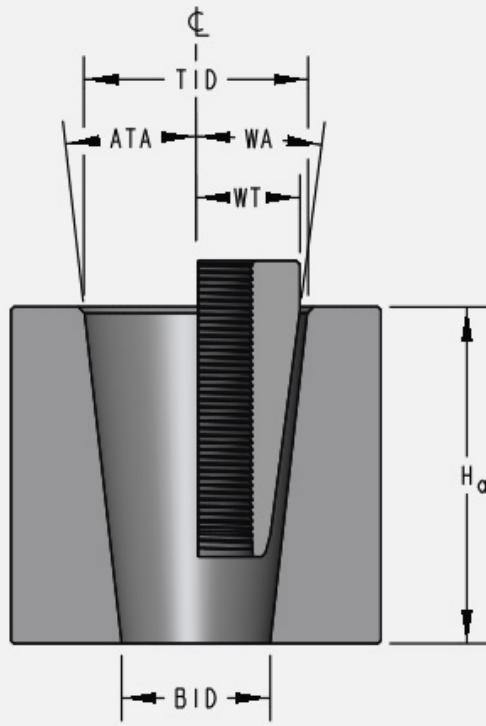
Wedge Thickness Measured at Crown



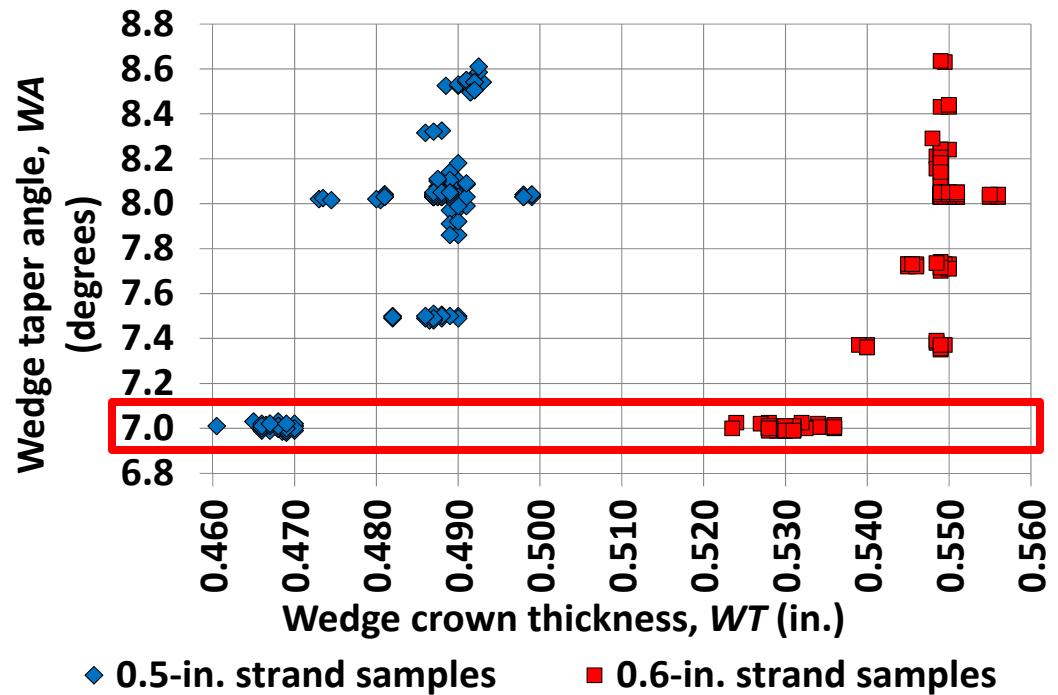
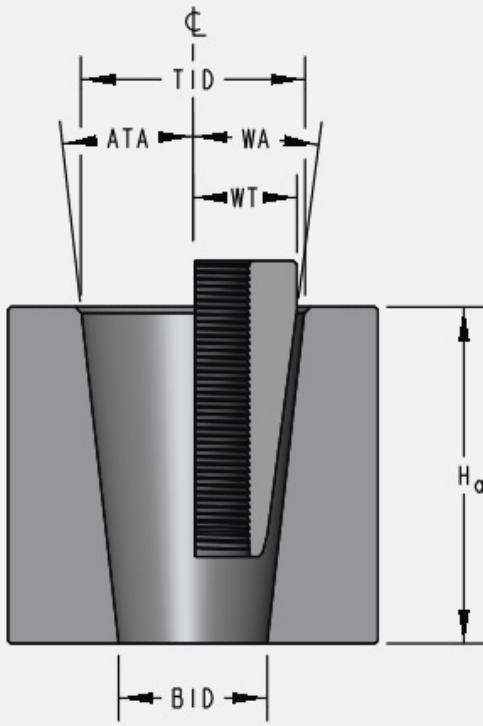
Wedge Thickness Measured at Crown



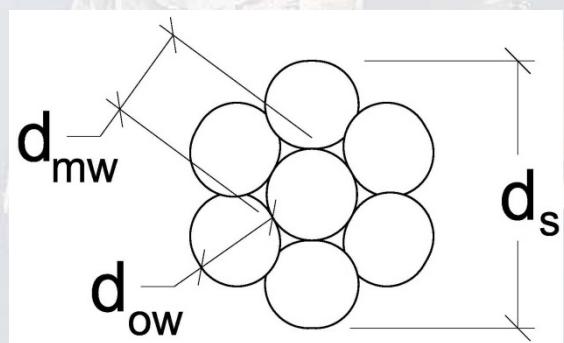
Wedges Tested



Wedges Tested



Strand Tested



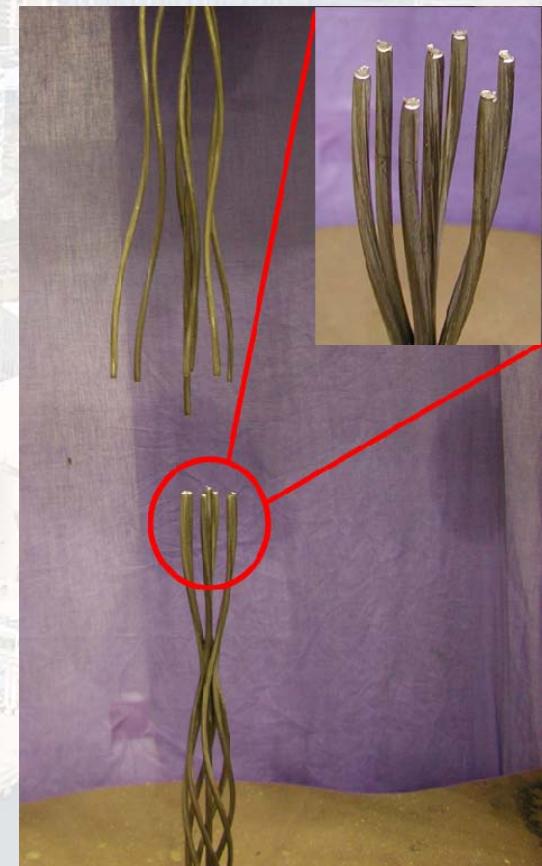
Component	Publication	Required Strength (ksi)	Required Strain at Ultimate Load
Strand	ASTM A416-06 Section 6	$1.00f_{nominal}$ $f_{actual} > f_{nominal}$	3.5%
Strand/Anchor System	ACI 318-08 Section 18.21.1	$0.95f_{nominal}$	2.0%
Strand/Anchor System	ACI 423.7-07 Section 2.6	$0.95f_{actual}$	2.0%
Strand/Anchor System	ACI 423.3R-05 Section 4.1	$0.95f_{actual}$	2.0%
Strand/Anchor System	PTI-2000 Section 2.2.1	$0.95f_{actual}$	2.0%

Strand Tested

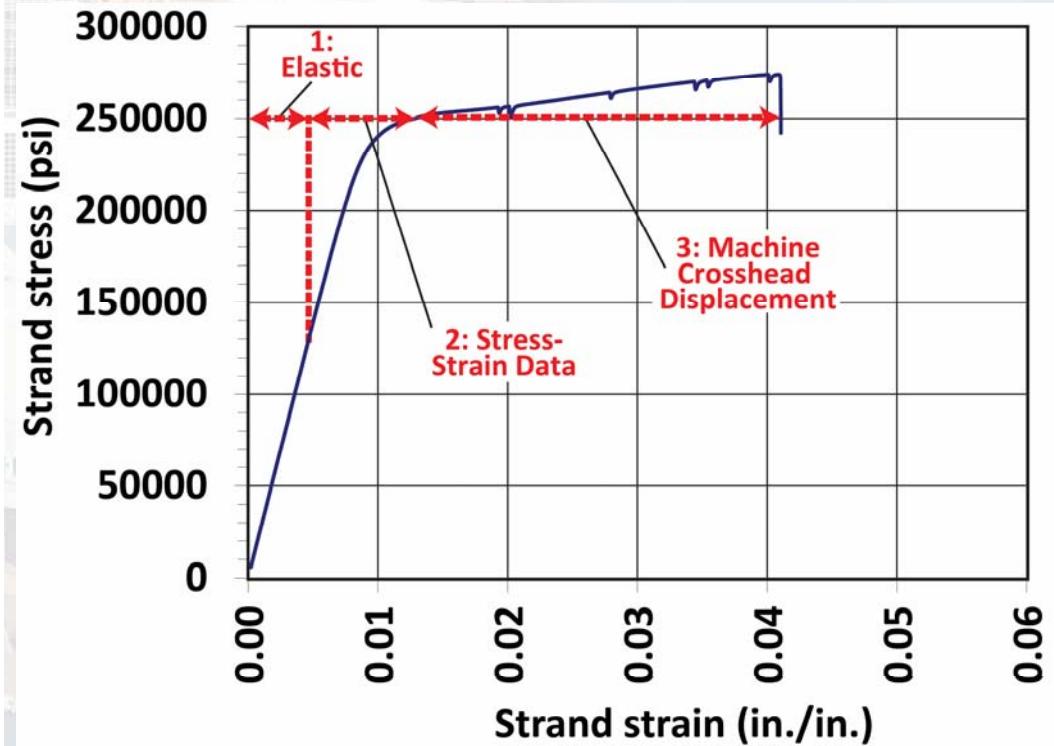
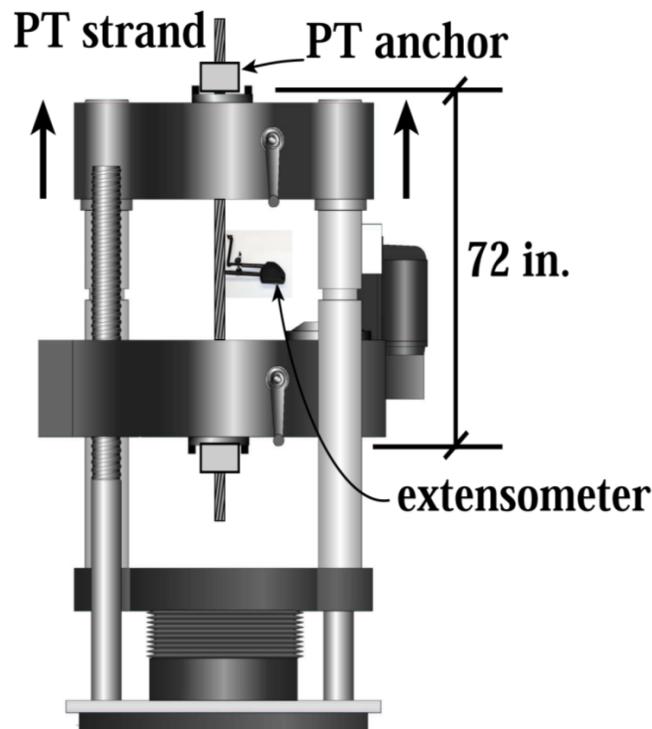
• VIDEO

Strand Tested for Free-Length Failure

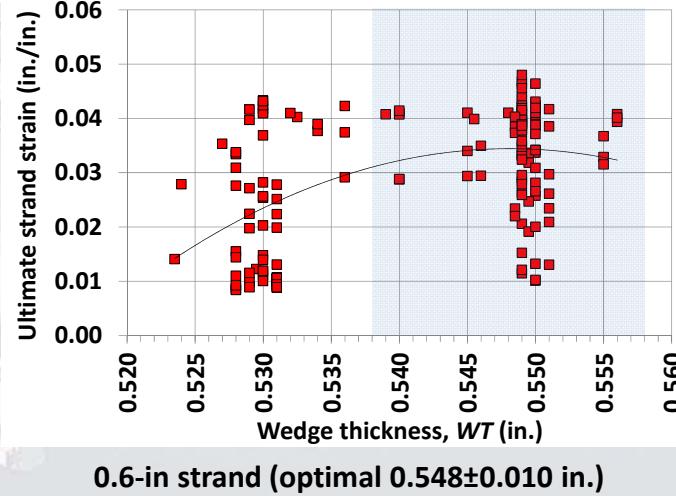
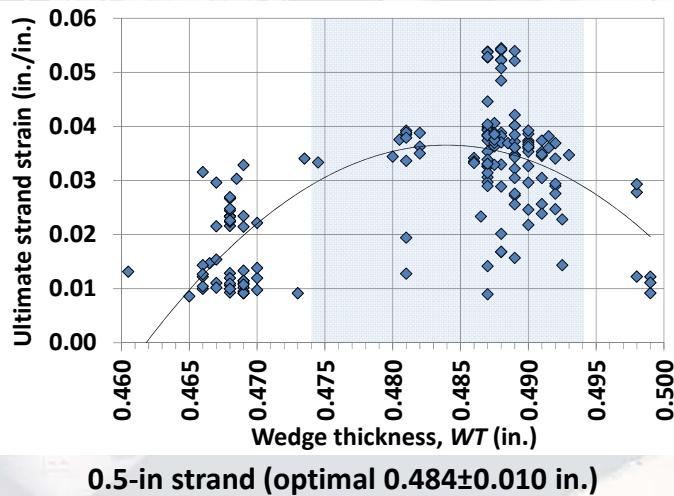
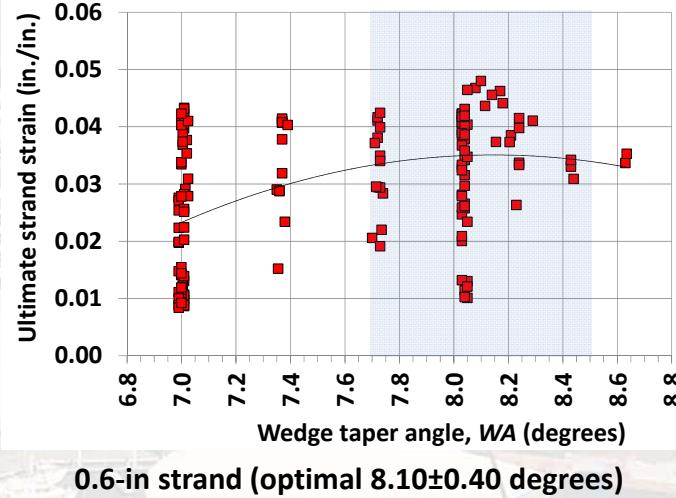
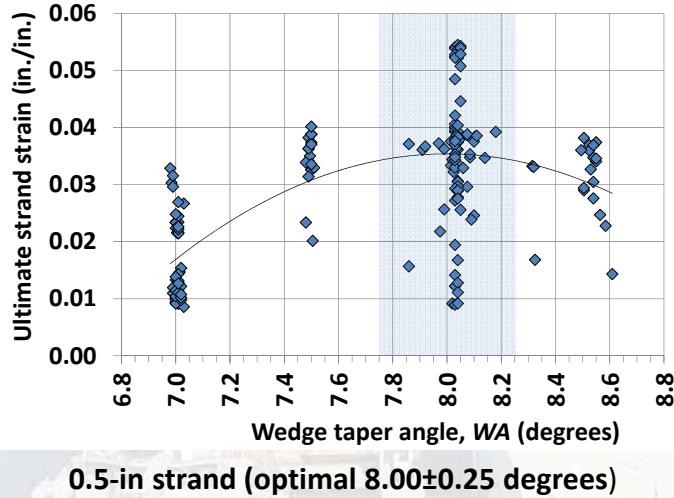
Strand spool	a_s (in ²)	$f_{pm,free-length}$ (ksi)	$\varepsilon_{pf,free-length}$	E (ksi)
0.5A	0.149	286.7	0.0736	28,028
0.5F	0.151	285.5	0.0726	28,767
0.5G	0.151	287.6	0.0680	29,874
0.6A	0.219	280.9	0.0752	27,872
0.6F	0.218	282.5	0.0677	28,811
0.6G	0.220	285.2	0.0675	28,985



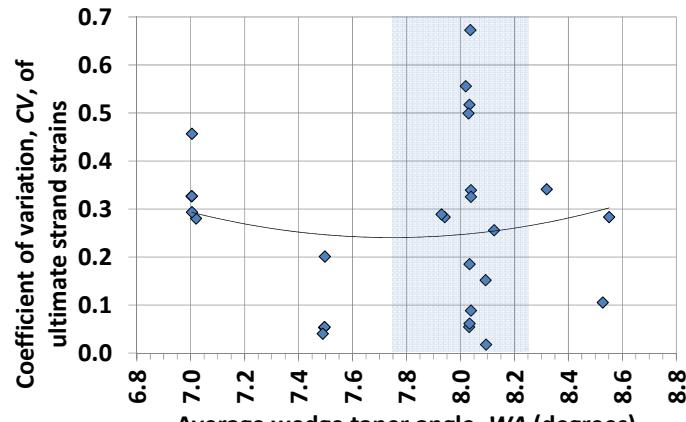
Test Program



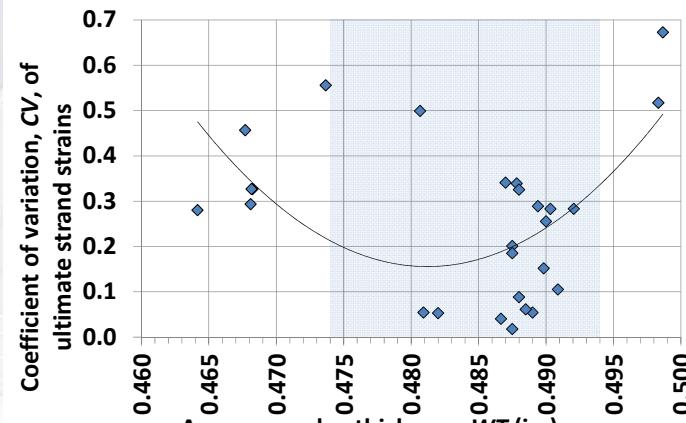
Dimensional Parameters versus Performance



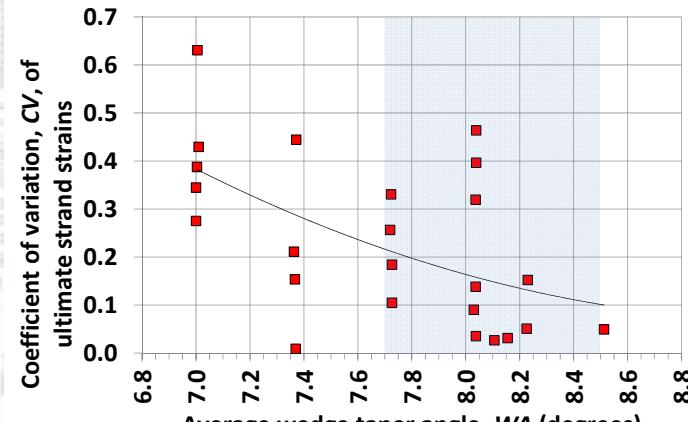
Dimensional Parameters versus Variation in Performance



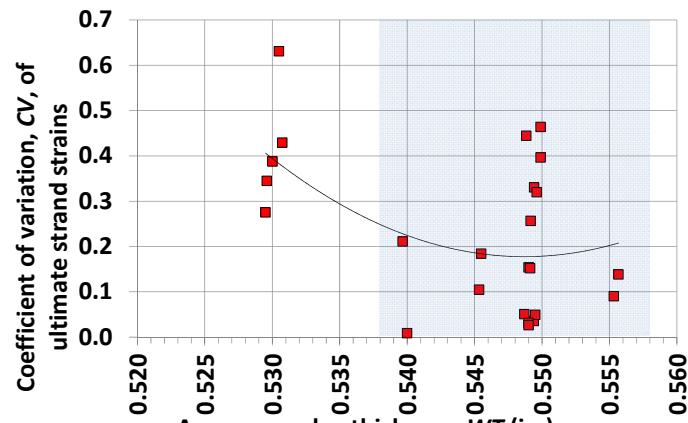
0.5-in strand (optimal 8.00 ± 0.25 degrees)



0.5-in strand (optimal 0.484 ± 0.010 in.)



0.6-in strand (optimal 8.10 ± 0.40 degrees)



0.6-in strand (optimal 0.548 ± 0.010 in.)

Statistical Validation of Results

Strand spool	Anchor	Wedge	# of tests	Wedge taper angle WA (degrees)	Wedge thickness WT (in.)	Average ultimate strain (in./in.)	p-value	$p\text{-value} < 0.05$
0.5A	Barrel	Std.	15	6.98 - 7.03	0.468 - 0.469	0.0218	3.17E-06	Yes
		Opt.	15	8.03 - 8.04	0.487 - 0.489	0.0357		
0.5A	Cast	Std.	9	7.00 - 7.02	0.467 - 0.469	0.0122	3.26E-04	Yes
		Opt.	9	8.03 - 8.06	0.487 - 0.489	0.0291		
0.5G	Barrel	Std.	10	6.99 - 7.02	0.466 - 0.470	0.0182	1.60E-08	Yes
		Opt.	10	8.03 - 8.05	0.487 - 0.489	0.0511		
0.5G	Cast	Std.	10	6.99 - 7.02	0.466 - 0.470	0.0126	3.20E-05	Yes
		Opt.	10	8.03 - 8.05	0.487 - 0.489	0.0399		
0.6A	Barrel	Std.	20*	6.99 - 7.03	0.528 - 0.531	0.0292	6.14E-04	Yes
		Opt.	20	8.03 - 8.05	0.549 - 0.551	0.0400		
0.6A	Cast	Std.	9	7.00 - 7.01	0.529 - 0.531	0.0138	9.62E-04	Yes
		Opt.	9	8.03 - 8.04	0.549 - 0.550	0.0298		
0.6G	Barrel	Std.	10	6.99 - 7.01	0.528 - 0.531	0.0217	3.94E-02	Yes
		Opt.	10	8.03 - 8.05	0.549 - 0.551	0.0297		
0.6G	Cast	Std.	10	6.99 - 7.01	0.528 - 0.531	0.0104	1.66E-03	Yes
		Opt.	10	8.03 - 8.05	0.549 - 0.551	0.0246		

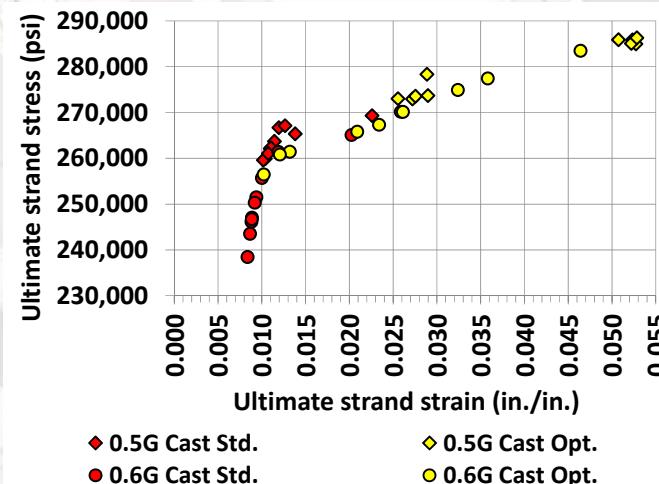
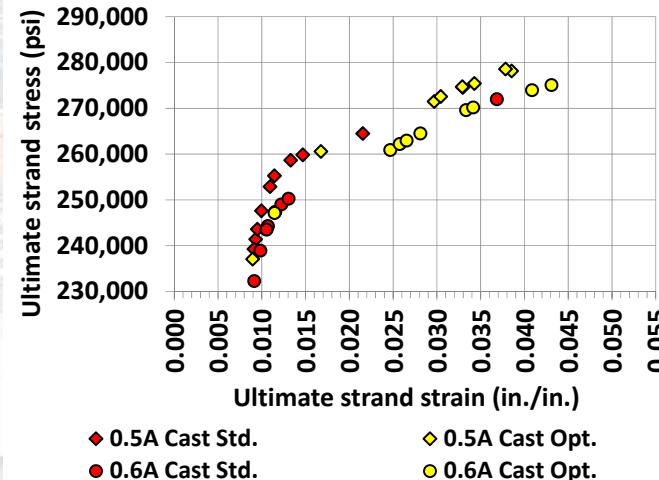
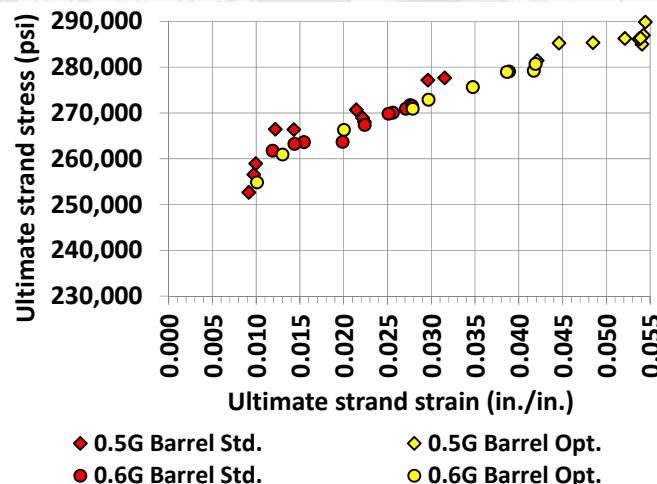
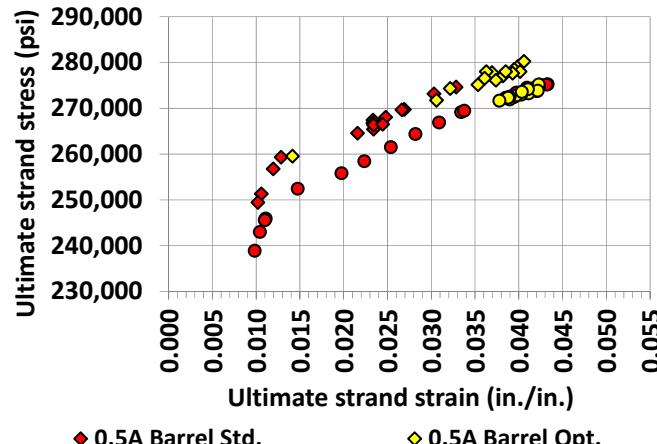
Statistical Validation of Results

Strand spool	Anchor	Wedge	# of tests	Wedge taper angle WA (degrees)	Wedge thickness WT (in.)	Average ultimate strain (in./in.)	p-value	$p\text{-value} < 0.05$
0.5A	Barrel	Std.	15	6.98 - 7.03	0.468 - 0.469	0.0218	3.17E-06	Yes
		Opt.	15	8.03 - 8.04	0.487 - 0.489	0.0357		
0.5A	Cast	Std.	9	7.00 - 7.02	0.467 - 0.469	0.0122	3.26E-04	Yes
		Opt.	9	8.03 - 8.06	0.487 - 0.489	0.0291		
0.5G	Barrel	Std.	10	6.99 - 7.02	0.466 - 0.470	0.0182	1.60E-08	Yes
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Statistical Validation of Results



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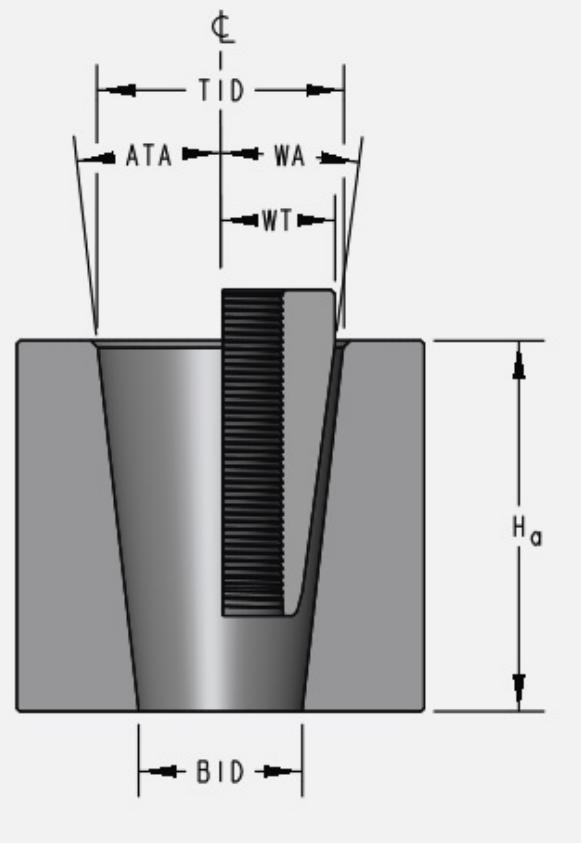
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		Opt.	10	8.03 - 8.05	0.549 - 0.551	0.0246		

Conclusions and Recommendations

- Increasing the **wedge taper angle** and **crown thickness** can improve the ultimate strand strain and potentially reduce the variance
 - Wedge taper angles with about a **+1 deg angle differential**, **7 deg + 1 deg = 8 deg** (placed within an anchor housing of about 7 degrees)
 - Wedge crown thickness of about **0.488 in.** for the 0.5-in. strand configurations and **0.549 in.** for the 0.6-in. strand configurations
 - For specimens tested in this program



Conclusions and Recommendations

- Visual evidence shows that there is an improved (i.e., more uniform) **distribution of stress transfer** within the anchor
- **Two different failure modes** limit the strain capacity of the PT strands – **outer wire slippage** through the anchor and **wire fracture** within the anchor
- Increasing the wedge taper angle or crown thickness too far outside the effective ranges results in exterior wire slips and reduced performance



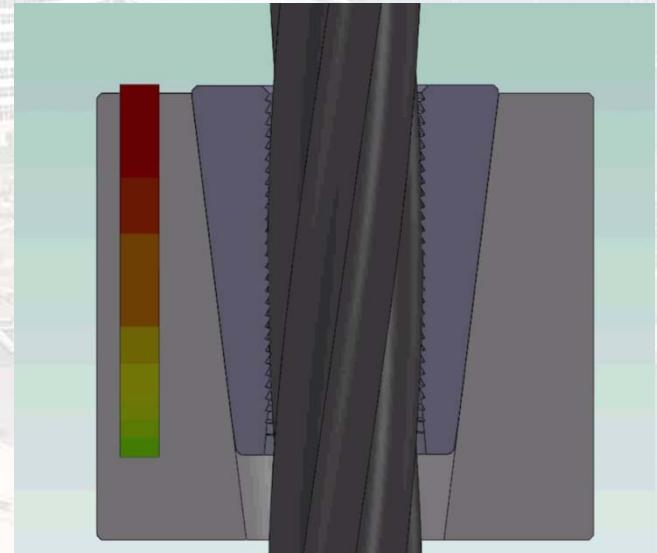
Conclusions and Recommendations

- No three-piece wedges were tested in the current study
- Two-piece wedges may be more desirable than three-piece wedges



Future and Ongoing Work

- Slightly longer wedges with increased crown thickness and taper angle may be investigated
- FEM analysis of stress distribution within anchor may be investigated
- Wedge seating depth and its relationship to strand/anchor performance is currently being investigated at ND

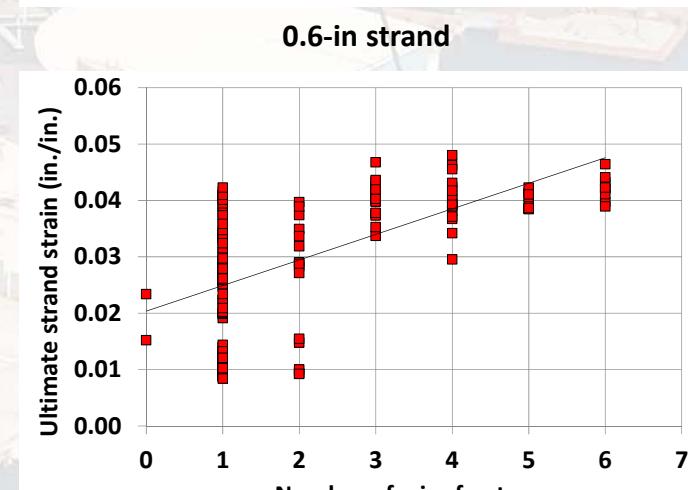
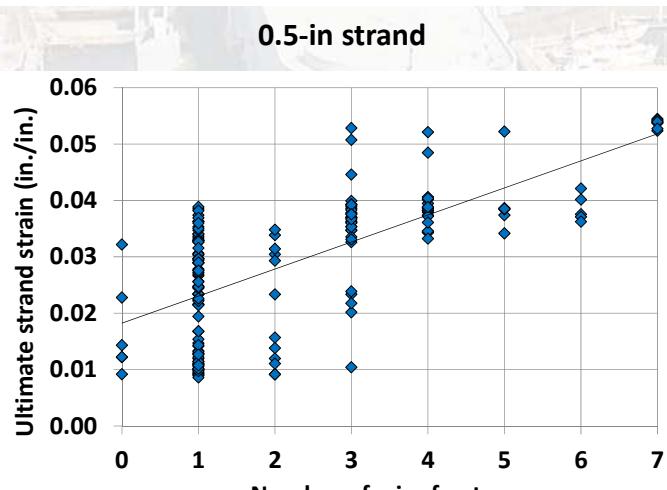
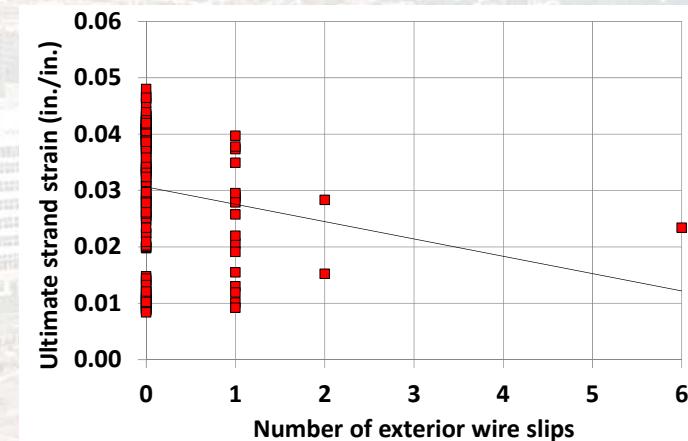
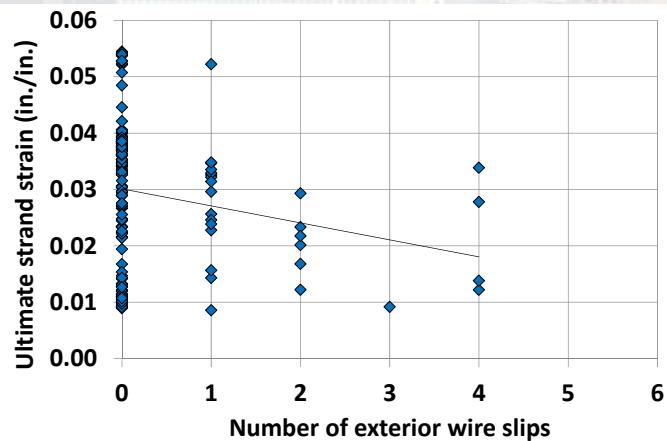


Acknowledgements

- Norris Hayes and co-author Randy Dragnis of Hayes Industries Ltd. in Sugar Land, Texas
- Steven Walsh, Eric Herbert, and co-author Richard Estes at University of Notre Dame
- Wiss, Janney, Elstner Associates Inc. in Northbrook, Illinois & Dr. Neil Hawkins, Professor Emeritus at University of Illinois at Urbana-Champaign
- Kevin's employers: Auckland Council and Professor Jason Ingham at the University of Auckland, New Zealand
- The opinions, findings, and conclusions expressed in the presentation are those of the authors and do not necessarily reflect the views of those acknowledged.

Additional slides

Failure Mode versus Performance



Dimensional Parameters versus Failure Mode

