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Virginia Experience with Post-tensioned Tendon Grouts

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Prior to1995

- PT tendon grouts were a mixture of water & cement (w/c $\leq$ 0.42) and sometimes an expansive admixture.
- Most significant bridge was the Varina Enon (VE) Bridge completed in 1990 which has 480 grouted tendons in the superstructure.

1995-1996

- As a result of FHWA sponsored research to improve grouts,7 per cent silica fume was specified for grout used in tendons in the pier caps of Coleman bridge. Mockup showed voids in top of tendon. Addition of silica fume to mixer was not successful and prepackaged grout was needed.

2001

- Worked with industry to develop a prepackaged high performance grout (HPG).
- Smart Road bridge first to be grouted with a HPG.

2001

- 895 bridges grouted with a 2nd HPG.

- A 3rd HPG approved.

2001

- Voids found in many tendons in Varina Enon Bridge. Tendons not sealed. Strands not corroded.

2003 & 2004: Vacuum Grouting HPG to fill voids.

2007

- Tendon fails in Varina Enon Bridge after 17 years. Two tendons replaced. 20 tendon sites in VE bridge inspected by removing 2-ft of duct.

2007

- Eleven of 20 sites with different levels of corrosion selected for monitoring.

Incomplete vacuum grout, NP3T16

Broken Wires, NP13T10

2011

- Vendor announces grout contains chlorides.
- Chloride contaminated grout used in bridges:

1. 895 Interchange
2. US 33
3. US 123
4. Woodrow Wilson

Grout 1 Specification and Test Results, 2001

Test (independent lab1/lab2)	Requirement	Grout 1	Pass/Fail
Water to cementitious materials ratio	Max 0.45	0.43/0.41	Pass
Fluidity, initial (ASTM C939) seconds	11 to 30	12/22	Pass
Fluidity, after 30 minutes (ASTM C939) seconds	Max. 30	14/26	Pass
Cube strength at 28 days, wet (ASTM C109) psi	Min. 5000	9035/7800	Pass
Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs	Max. 2500	1975/2070	Pass
Total chloride ion content, % by weight of cementitious material	Max. 0.08	0.03/.003	Pass
Volume change at 28 days (ASTM C1090) %	0.0 to + 0.2	+ 0.0/+0.1	Pass
Expansion 0 to 3 hours (ASTM C940) %	≤ 2.0%	+ 0.0/+1.1	Pass
Bleeding @ 3 hours (ASTMC940)* %	Max. 0.0	0.0/0.0	Pass

Grout 2 Specification and Test Results, 2001

Test (VDOT/independent lab)	Requirement	Grout 2	Pass/Fail
Water to cementitious materials ratio	Max 0.45	0.33/0.33	Pass
Fluidity, initial (ASTM C939) seconds	11 to 30	18/15	Pass
Fluidity, after 30 minutes (ASTM C939) seconds	Max. 30	19/21	Pass
Cube strength at 28 days, wet (ASTM C109) psi	Min. 5000	7100/8039	Pass
Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs	Max. 2500	2011/1119	Pass
Total chloride ion content, % by weight of cementitious material	Max. 0.08	-/<0.01	Pass
Volume change at 28 days (ASTM C1090) %	0.0 to + 0.2	-/+0.023	Pass
Expansion 0 to 3 hours (ASTM C940) %	≤ 2.0%	-/1.25	Pass
Bleeding @ 3 hours (ASTMC940)* %	Max. 0.0	-/0.0	Pass

Grout 3 Specification and Test Results, 2001

Test (VDOT/independent lab)	Requirement	Grout 3	Pass/Fail
Water to cementitious materials ratio	Max 0.45	0.38/-	Pass
Fluidity, initial (ASTM C939) seconds	11 to 30	15/-	Pass
Fluidity, after 30 minutes (ASTM C939) seconds	Max. 30	17/-	Pass
Cube strength at 28 days, wet (ASTM C109) psi	Min. 5000	8240/-	Pass
Permeability at 28 days, wet (AASHTO T277 at 30 V) coulombs	Max. 2500	-/1076	Pass
Total chloride ion content, % by weight of cementitious material	Max. 0.08	-/0.02	Pass
Volume change at 28 days (ASTM C1090) %	0.0 to + 0.2	-/+0.045	Pass
Expansion 0 to 3 hours (ASTM C940) %	≤ 2.0%	-/0	Pass
Bleeding @ 3 hours (ASTMC940)* %	Max. 0.0	-/0	Pass

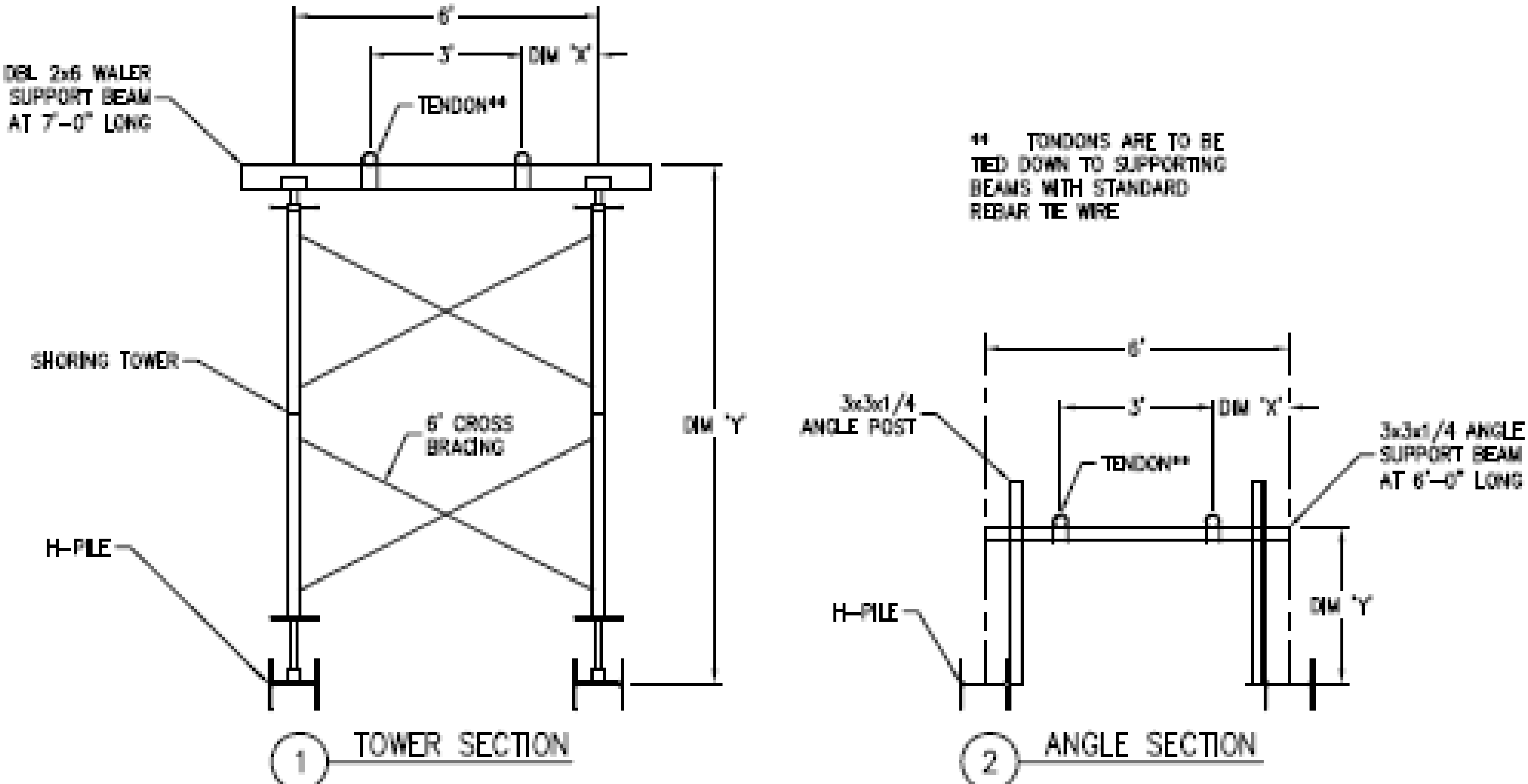
Performance vs specification

- First grout was developed to provide high performance as defined by a series of test measurements for: zero segregation, zero bleed, zero shrinkage, low permeability, adequate strength.
- Future grouts were developed to meet a specification.
- Performance requires robustness (some idiot proof-ness)
- Grout should have acceptable properties with the addition of 10 per cent or more extra water

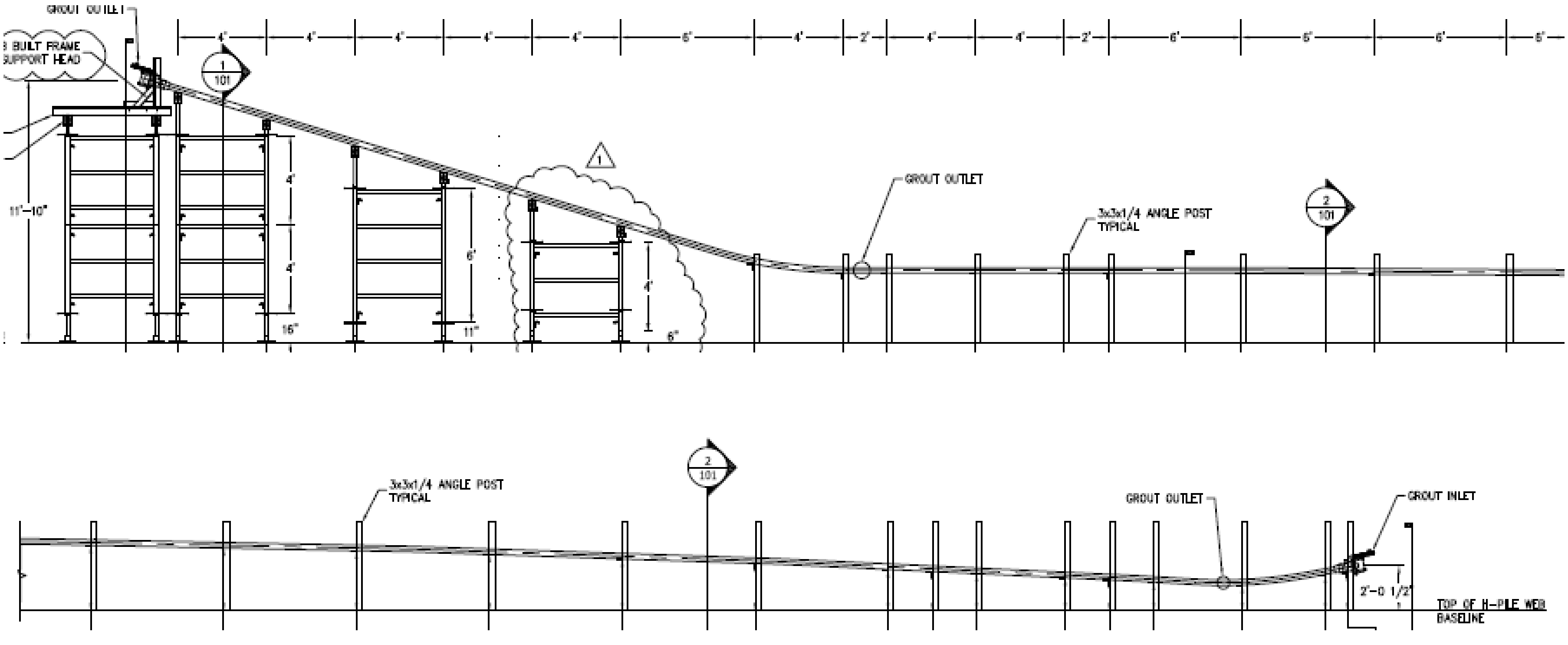
2012

- Mockup for US 460 segmental bridge identifies voids, segregation and soft grout in tendon grouted with an approved Grout 2.

US 460 Tendon Mock up end sections



Tendon Mock up longitudinal sections



US 460 Tendon Mock up inlet end caps

grout 3 no void or soft grout, grout 2 void and soft grout

US 460 Tendon Mock up <u>outlet</u> end caps

Grout 3 no void or soft grout

Grout 2 void and soft grout

US 460 Tendon Mock up

grout 3 provides filled tendon
grout 2 leaves void on top

2012 Lab tests at VCTIR

- Tests were conducted to determine the effect of grout water content on the segregation, length change and compressive strength.
- The water to dry bag material ratio (w/b) recommended by the manufactures for grout 3 was 0.25 -0.28 and for grout 2 was 0.24 -0.27.
- Given that we estimated the w/c ratio for grout in two tendons of the Varina Enon bridge exceeded 0.6 and the PTI specification allows a maximum w/c of 0.45 we batched mixes with w/b ratios that ranged between those recommended by the manufacturers and 0.65.

Sieve Analysis, ASTM C 136

Sieve Number	Percent Retained, grout 3	Percent Retained, grout 2
16	0.1	0.2
30	0.5	0.1
40	0.0	0.0
50	51.1	0.3
100	38.0	3.0
200	8.0	11.2
Pan	1.7	85.2

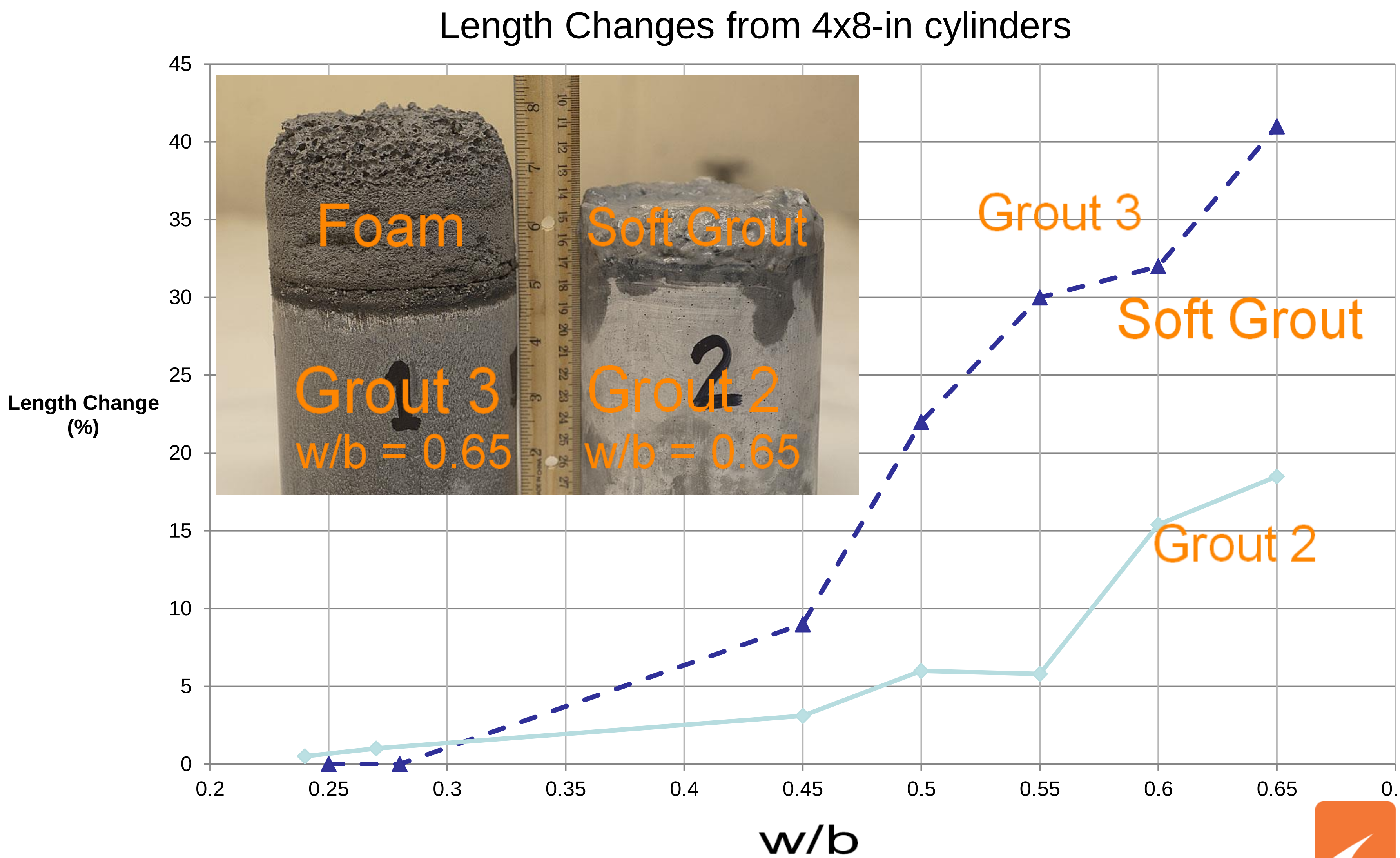
Schupack Pressure Bleed Test* Results, ml @ water to bag wt. ratios PTI M-55 Specification Sect. 4.4.6.2

Vertical Rise, ft	Press., psi	Max. % (ml) bleed	Grout 3 @ 0.25, 0.28, 0.45, 0.65	Grout 2 @ 0.24, 0.27, 0.45, 0.65
$0 \leq 2$	20	4 (8)	0,0, 1.2,3.3	0,0,0, 2.3
$2 \leq 6$	30	2 (4)	-,-,-,-	-,-,-,-
$6 \leq 20$**	50	0 (0)	-,1.2,-,-	-,-,-,-
> 20	100 ***	0 (0)	0,1.2,2.6,6.0	0,0,1.5,4.3

*ASTM C 1741, **US460,*** 90, fails

Wick Induced Bleed Test
cement and water, aluminum powder, high performance prepackaged grout (R. Gulyas)

Length Change Tests @ VCTIR



Prepackaged grouts with different W/B

Grout 1: diminished properties

Grout 2: bleed, segregation, soft grout

Grout 3: foam

W/B

Spec.

Spec.

0.45

0.50

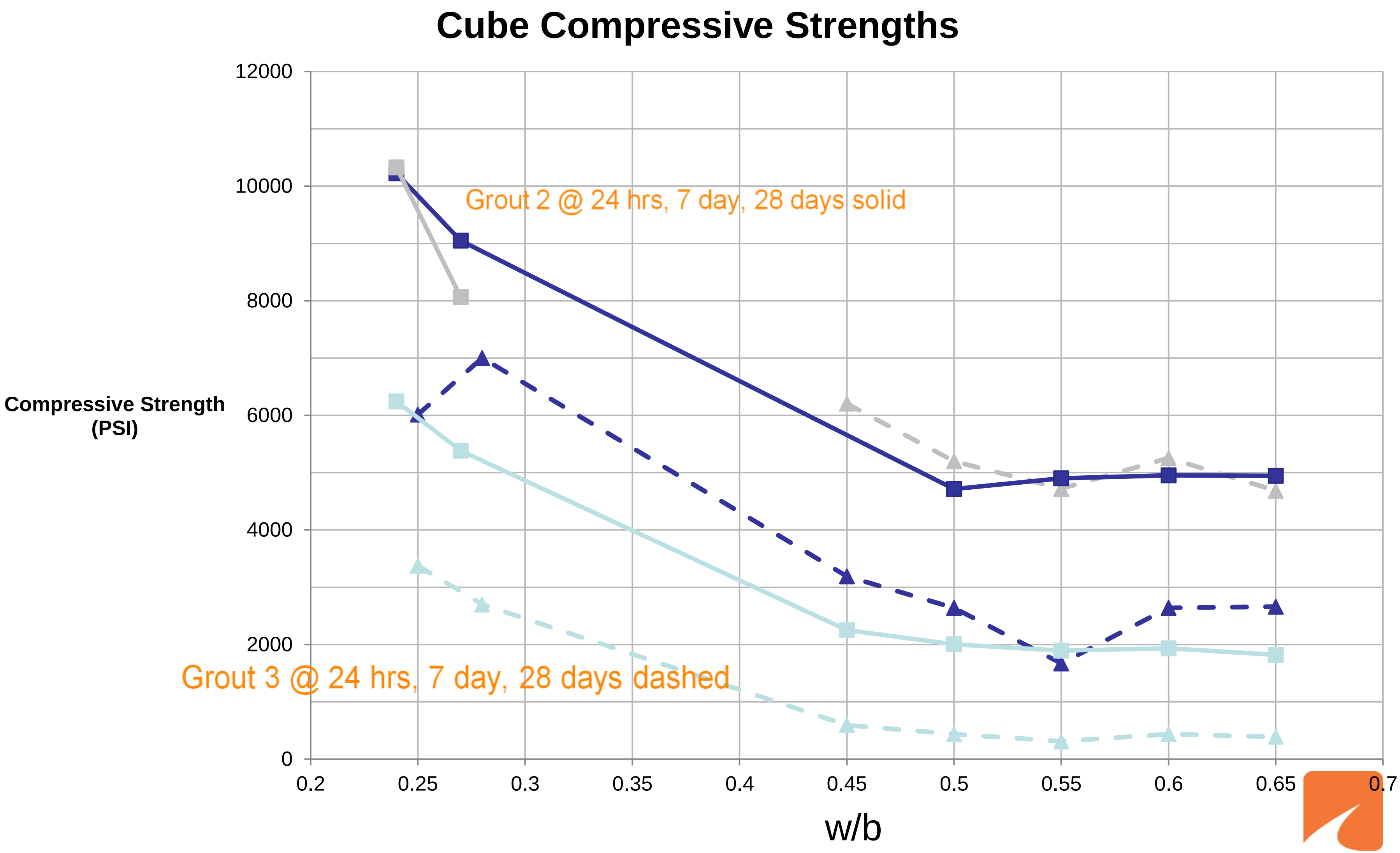
0.55

0.60

0.65

Grout 3 Grout 2 Grout 1

Grout Compressive Tests can be used to detect too much water (sample at outlet)



Excess Water Should not be a Problem

- PTI M55.1-12 requires that equipment consist of measuring devices (5.5.1) and that all materials shall be batched by weight except liquids may be batched by volume (5.6.1).
- Tendons should be capped and sealed to prevent water from entering prior to grouting.
- Sampling and testing the grout at the out let end of the tendons can indentify excess water in the grout regardless of the source.

Need for Mockups

- HPG has the potential to solve the material problem of bleeding, segregation and voids.
- Lab tests developed to approve HPG include:

1. Schupack pressure bleed test ASTM C1741, 0-4%
2. Volume change test ASTM C1090, 0%- + 0.2%
3. Wick-induced bleed test ASTM C940, 0%
4. Inclined tube test EN 445, $\leq$ 0.3% bleed

- Tendons with segregated grout, soft grout and voids have been identified that were grouted with HPG that pass lab tests.

Need for Mockups

- Incorrect batching and mixing, tendon geometry and length, and high pump pressures have been suggested as reasons for the problems.
- Until we have lab tests that can identify acceptable grouts, mockup tests should be done to identify problems prior to grouting the bridge.
- The mockup should include the most critical tendon situation (greatest height change and length) using grouts proposed for the project.
- The mockup done in 2012 for the US 460 bridge was successful.

US 460 Test Results

Batch	14 day comp., psi	28 day comp., psi	Perm. Top 2-in, coulombs	Perm. Bottom 2-in, coulombs
1	6135 [a]	8705 [a]	-	-
2	5420 [a]	7885	1964	1998
3	4665 [a]	7895	1839	1916
average	5407	8162	1902	1957

Test results for grout 3 samples taken on 11-22-13 outlet end (average of 2 samples) [a] one sample
Compressive strength based on ASTM C109 cubes
Permeability based on AASHTO T277 @ 30 volts

Performance of Tendons in VE Bridge
Voids in Tendons Exposed Strands to Moisture and Oxygen

- Bleeding was approximately 4 percent in a properly batched grout (w/c $\leq$ 0.42) prior to 1995.
- In a typical 150 ft long tendon 6 ft of void at the high points adjacent to the anchor plates in draped tendons is expected.

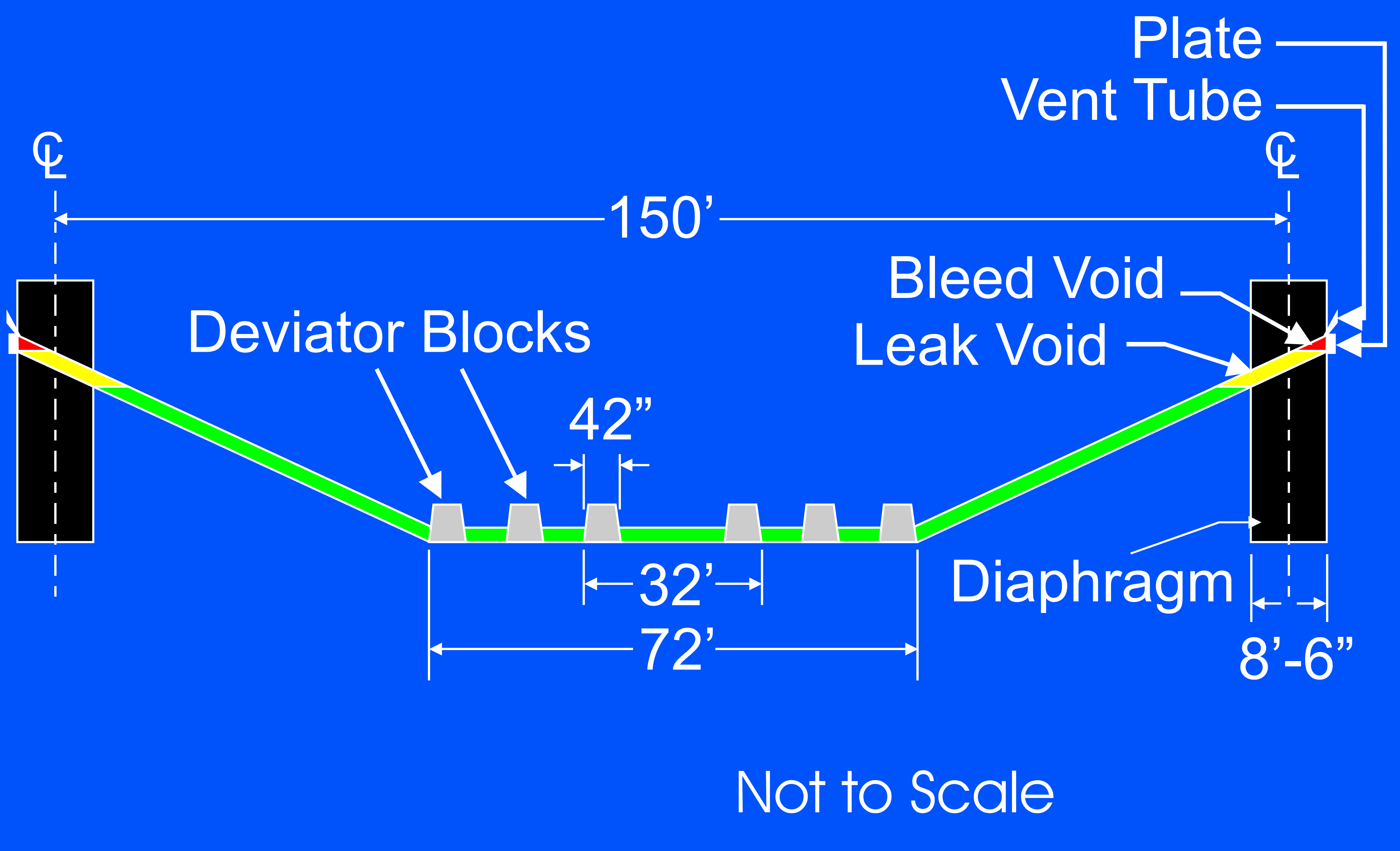
Design and Construction Practices Exposed Strands to Oxygen and Moisture

- Tendons not sealed because metal straps used to connect duct at diaphragms and bulk heads.
- Vent tubes were not sealed.
- Holes were often drilled in the plastic ducts to check for voids and grout.

Inside vent tube

Hole in duct

Typical VE span with draped tendon and bleed, leak and excess water voids



Monitoring VE Tendons with Broken Wires

Tendon	Broken wires 2007	Broken wires 2013	*Avg. broken wires /yr	Section loss 2007	Section loss 2013	*Avg. section loss/yr
NP13 T10	2	4	0.33	7 wires 5.3 %	10 wires 2.9%	0.5 wires 0%
SP12 T9	1	1	0	4.8 wires 3.6 %	15 wires 4.4%	1.7 wires 0.13%
Avg.	1.5	2.5	0.17	5.9 wires 4.4%	12.5 wires 3.7%	1.1 wires 0.065%

* Change per year for 6 year period

Inadequate Corrosion Protection is a Local Rather Than a Widespread Issue

- Grout provides corrosion protection.
- Strands are often <u>not</u> protected because of voids or poor quality grout.
- Despite the perceived inadequate corrosion protection in the VE bridge, few tendons or wires have failed and corrosion is slow. Two of 480 tendons replaced after 24 years. Two wires of 133 wires in 1 tendon have failed over past 6 years (0.33 wires per years x 33 wires = 99 years until a tendon failure)(Section loss of 1.1 wire per year for 33 wires = 30 years until failure) (Section loss of 0.065% per year = 300 years).

Conclusions

- 99 per cent of the tendons in the V E Bridge appear to be performing well. Strand corrosion is slow.
- HPG 3 passed the mock up and is being successfully used to grout the US 460 bridge.
- Poor performing HPG 2 failed the mock up.
- Tests for identifying acceptable grouts need to be improved (bleeding and segregation are issues).
- Grouts need to be robust so that extra water that gets into the tendon or grout is not an issue.
- Mock ups must be used to identify acceptable grouts.
- Bag and water weights need to be correct during batching.

Recommendations

- Until we have lab tests that can identify acceptable grouts, perform a mockup test of the most critical tendon situation (greatest height change and length) using grouts proposed for the project.
- The mockup can be waived if the tendon design is similar and the proposed grout and grouting contractor are the same as approved for another project.
- While grouting, the water in each batch must to be carefully measured and the bags of grout weighed to provide the required w/b.

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QUESTIONS

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