Evaluating the Effect of Temporary Casing on Drilled Shaft Rock Socket Friction

GRIP 2017

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Civil & Environmental Engineering

Ultimate Side Resistance

- Usually designed as a function of the parent rock properties and characteristics:
  - UCS
  - Unconfined Compression Strength
  - Recovery
  - RQD
  - Split Tensile Strength

Ultimate Side Resistance

- O'Neill and Reese (1999) – AASHTO (2012)

$$fmax = 0.65p_a\sqrt{\frac{q_u}{p_a}} \quad and\ qu \ \le f'c$$

- Kulhawy et al. (2005) – Base of FHWA (2010)

$$fmax = C * p_a\sqrt{\frac{q_u}{p_a}} \quad and\ qu \ \le f'c$$ (C = 0.63 to 1.00)

- McVay et al. (1992) – Base of FDOT (2015)

$$fmax = \frac{1}{2}\sqrt{q_u}\sqrt{q_t} \quad and\ qu \ \le f'c$$

Construction Effects (GRIP 2016)

not addressed by design

- Excavation Equipment
- Reinforcement Bar Size and Cage Spacing
- Concrete properties
- Cased or Slurry Supported
- Vibrated or Oscillated Casing
- Slurry Type
- Slurry Exposure
- Temporary or Permanent Casing

Problem Statement

- Construction methods affect drilled shaft side shear resistance which is not fully addressed by design.
- The effects from full length or partial length temporary casing can present the same concern.
- The primary objective of this study is to **quantify the effects of temporary casing** installation and extraction on the resulting side shear in the portions of the rock sockets used to embed and seal the casing.

Study Motivation

455-15.7 Casings. Ensure casings are metal . . .

*. . . . **If temporary casing is advanced deeper than** the minimum top of rock socket elevation shown in the **Plans** or actual top of rock elevation is deeper, withdraw the casing from the rock socket and overream the shaft. If the temporary casing cannot be withdrawn from the rock socket before final cleaning, **extend the length of rock socket** below the authorized tip elevation one-half of the distance between the minimum top of rock socket elevation or actual elevation if deeper, and the temporary casing tip elevation.*

Field Scenarios

- Top of rock is not where the borings put it and so the rock socket has to start deeper,
- Operator inadvertently forces the casing deeper than planned although the "rock" is really pretty good
- Top of rock is technically where the borings put it, but the quality is so bad the casing must be advanced deeper to ensure a tight/adequate seal.

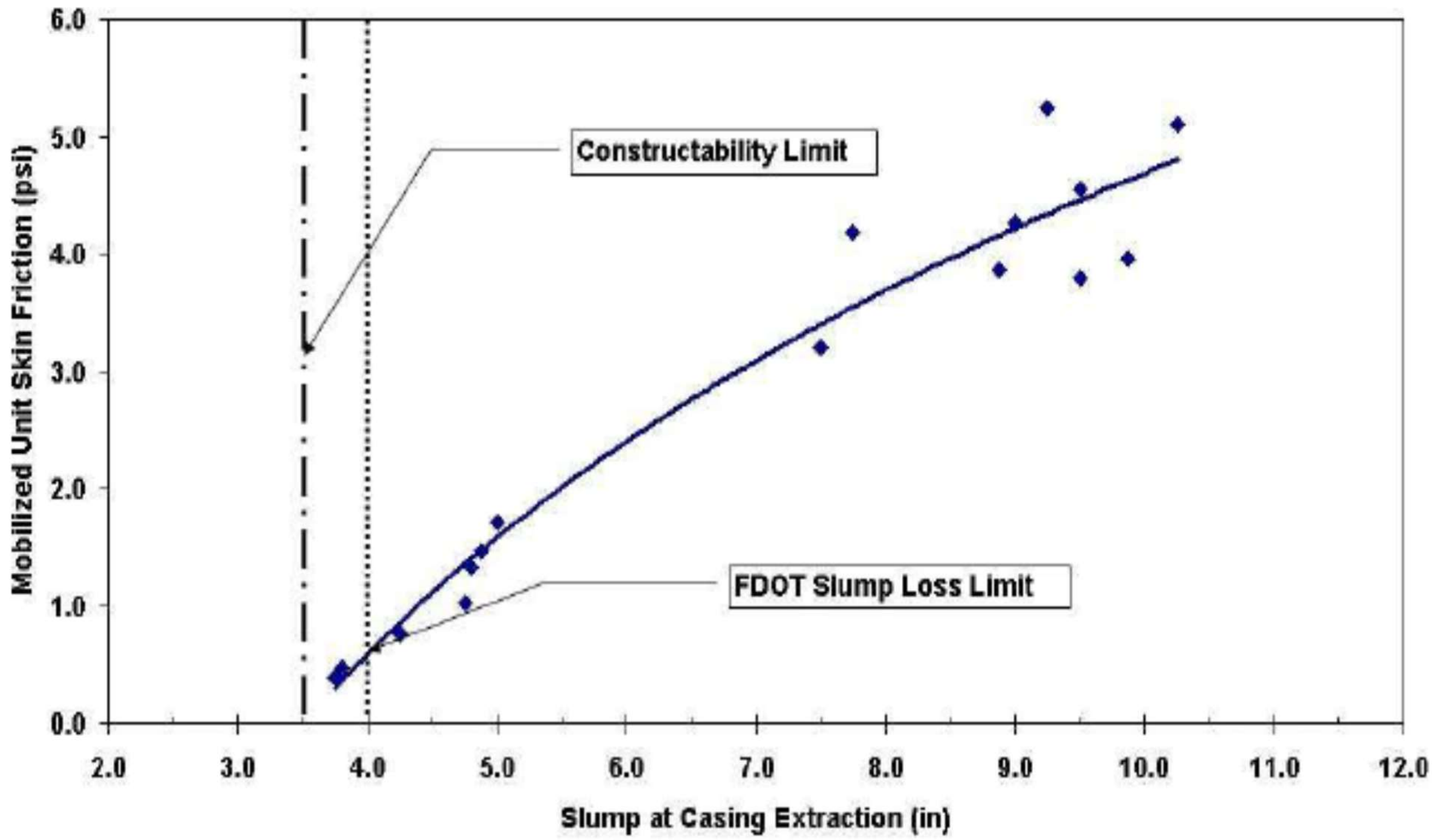
Casing Conditions

- Permanent
  - Full length
  - Partial length
- Temporary
  - Full length
  - Partial length
- Telescoping / Combination

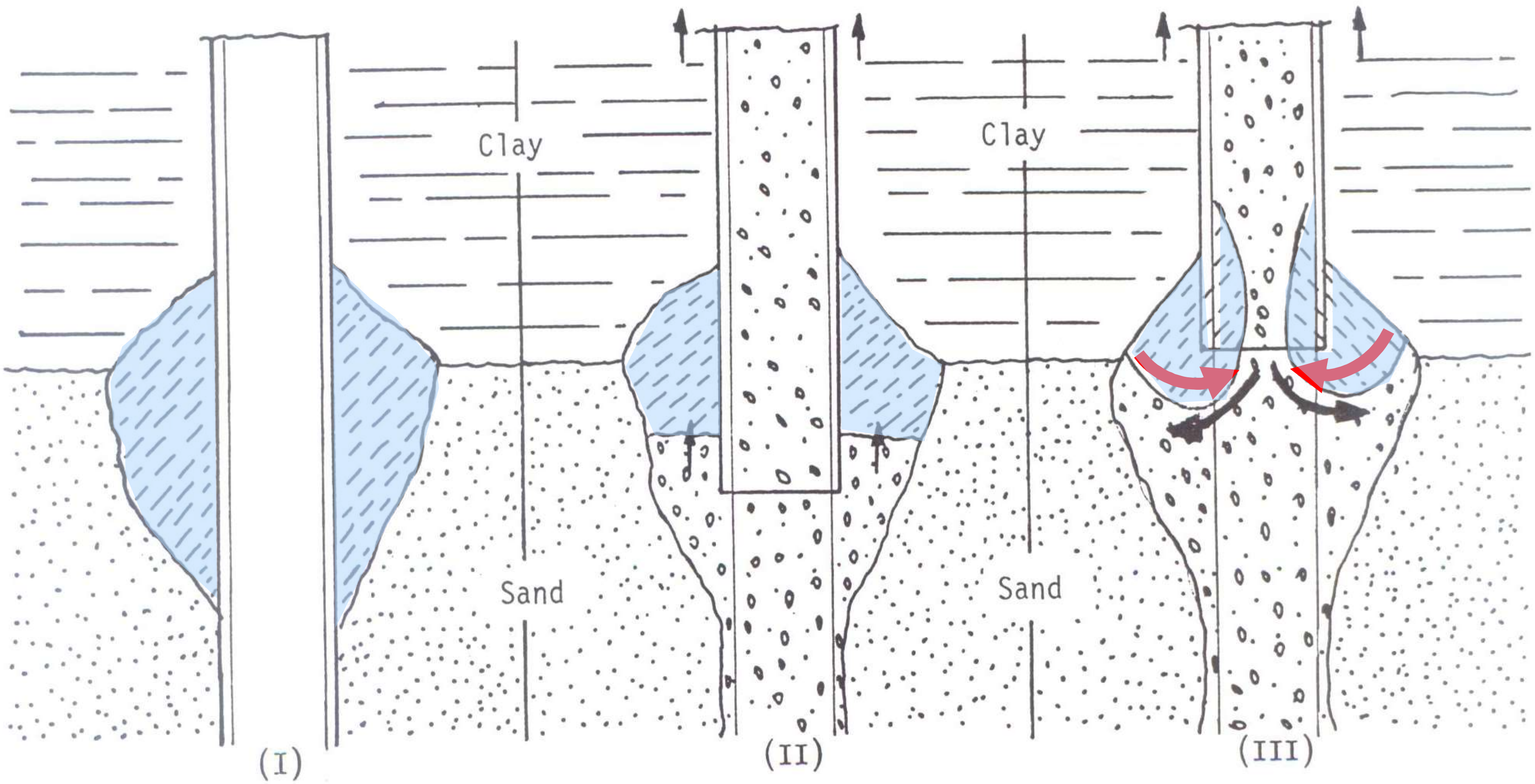
Misconceptions

- Use of casing makes more predicable shaft
- No anomalies occur within permanent cased regions
- Temporary cased sections have more reliable cross sections

Slump Loss in Temporary Casing



Temporary Casing Removal



SLURRY FILLED CAVITY FORMED OUTSIDE THE CASING

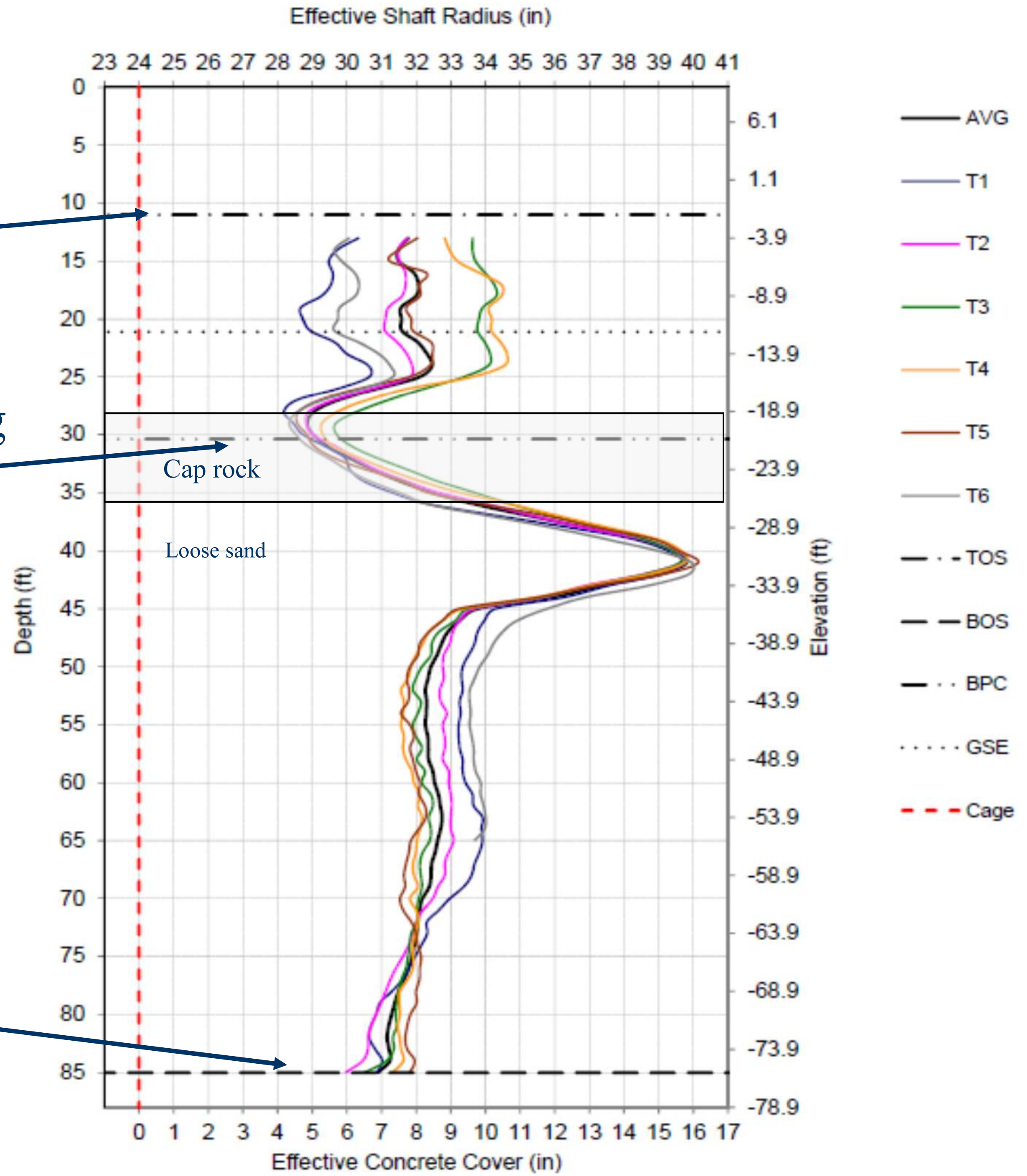
PILE CONCRETED, CASING LIFTED IN CAVITY UNDER PRESSURE

CASING IS LIFTED HIGHER
CONCRETE SLUMPS INTO THE VOID
CONTAMINATED SLURRY FLOWS INTO PILE

Permanent casing (top)

Permanent casing (bottom)

Temporary full length casing



Quantifying the Effects

- How does temporary casing affect the resulting side shear?
- Does concrete flow out and form intimate bond with surrounding rock?

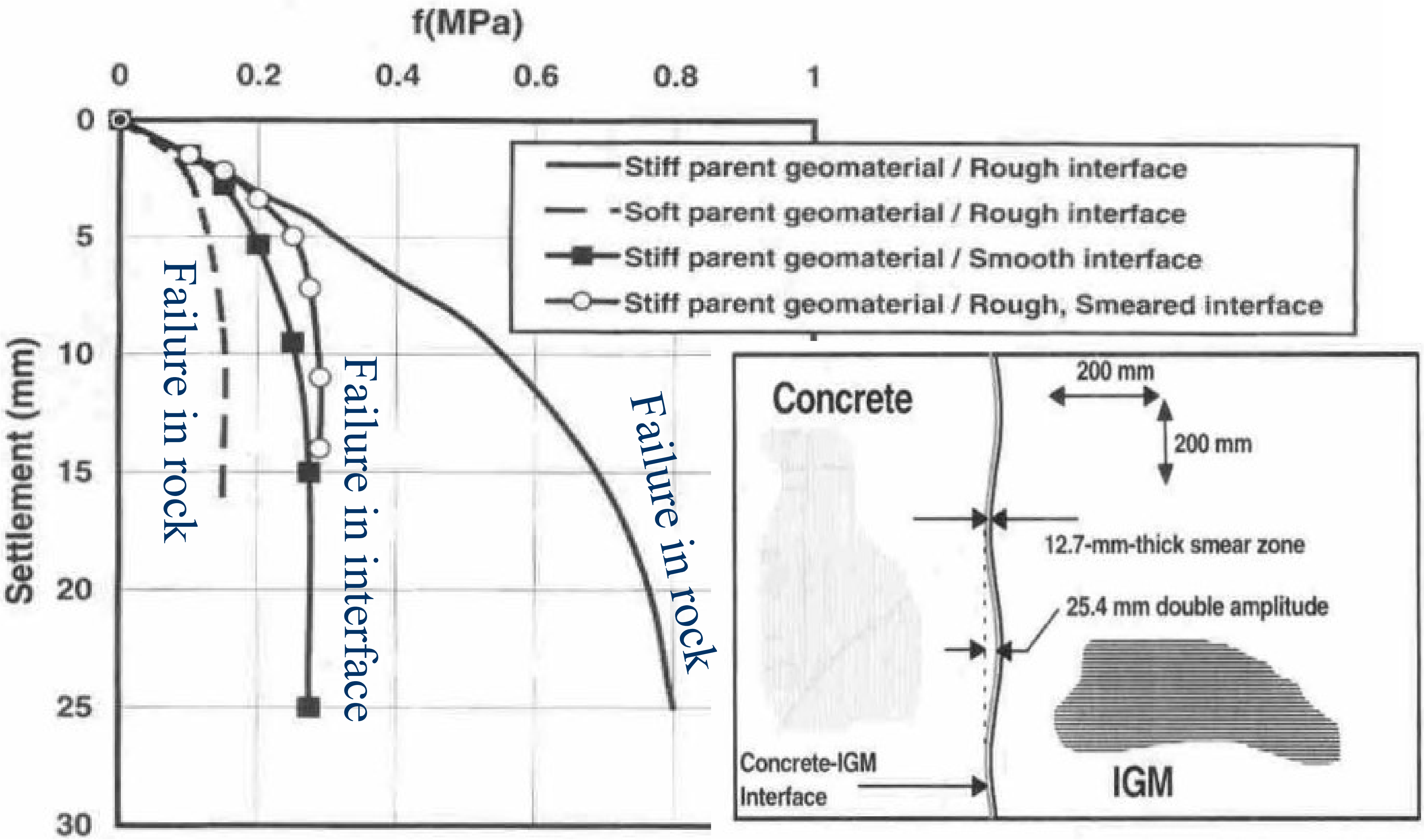
or

- Do residual fragments of crushed rock remain and get squeezed/trapped between outward flowing concrete?

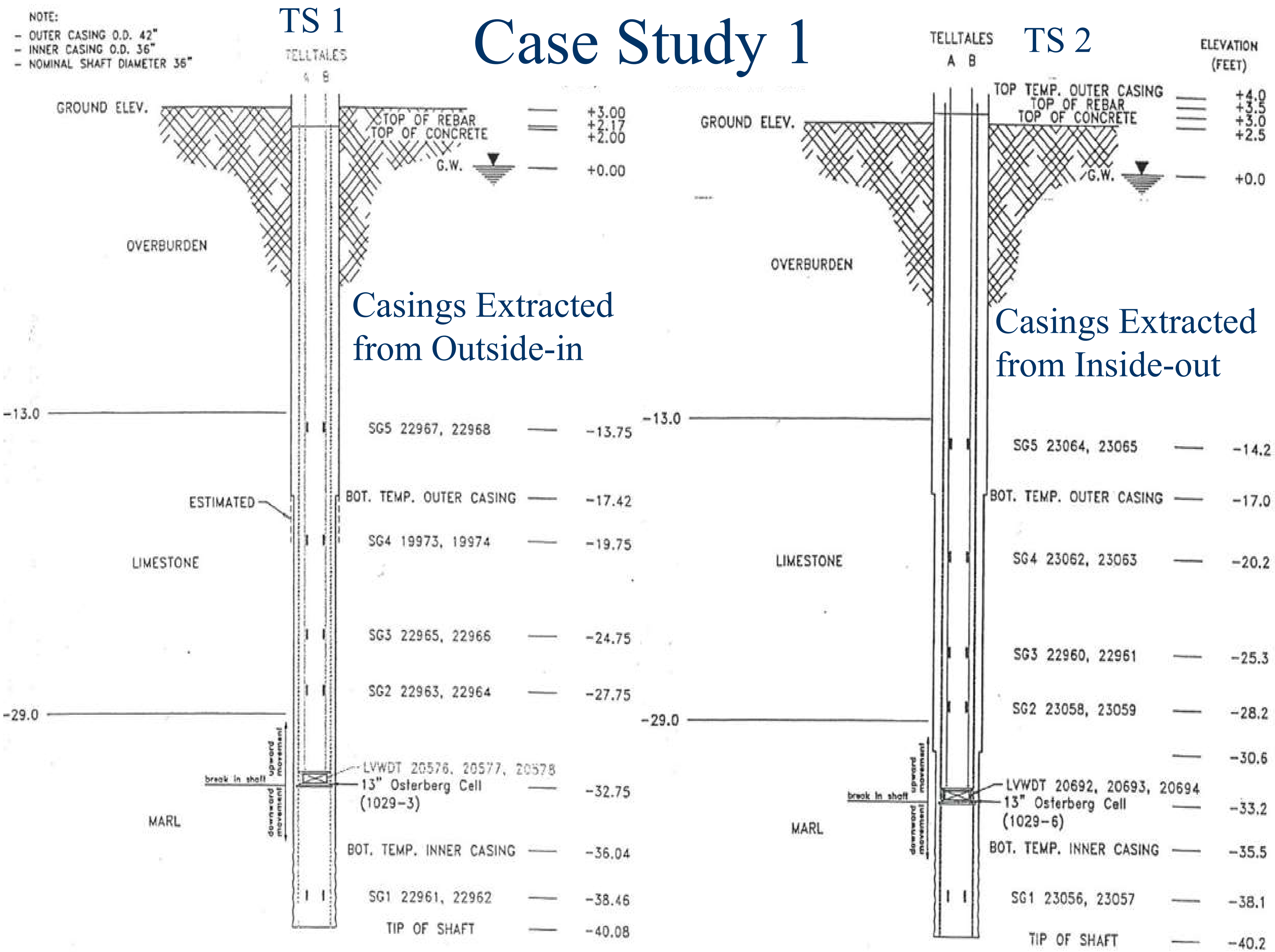
Construction with temporary casing
Effects of casing extraction

Construction of rock sockets

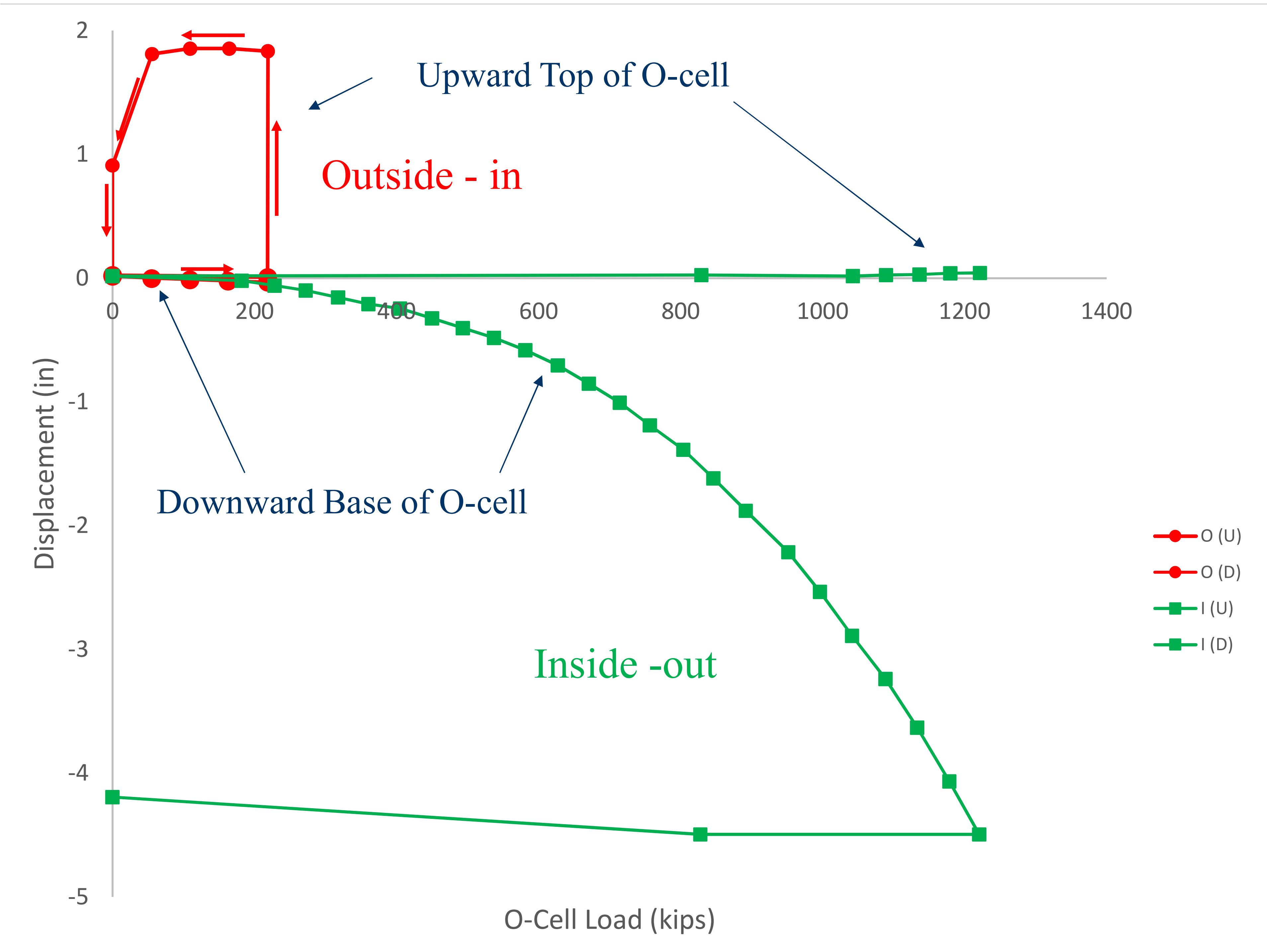
Effects on the side resistance (O'Neill and Hassan, 1994)



Case Study 1

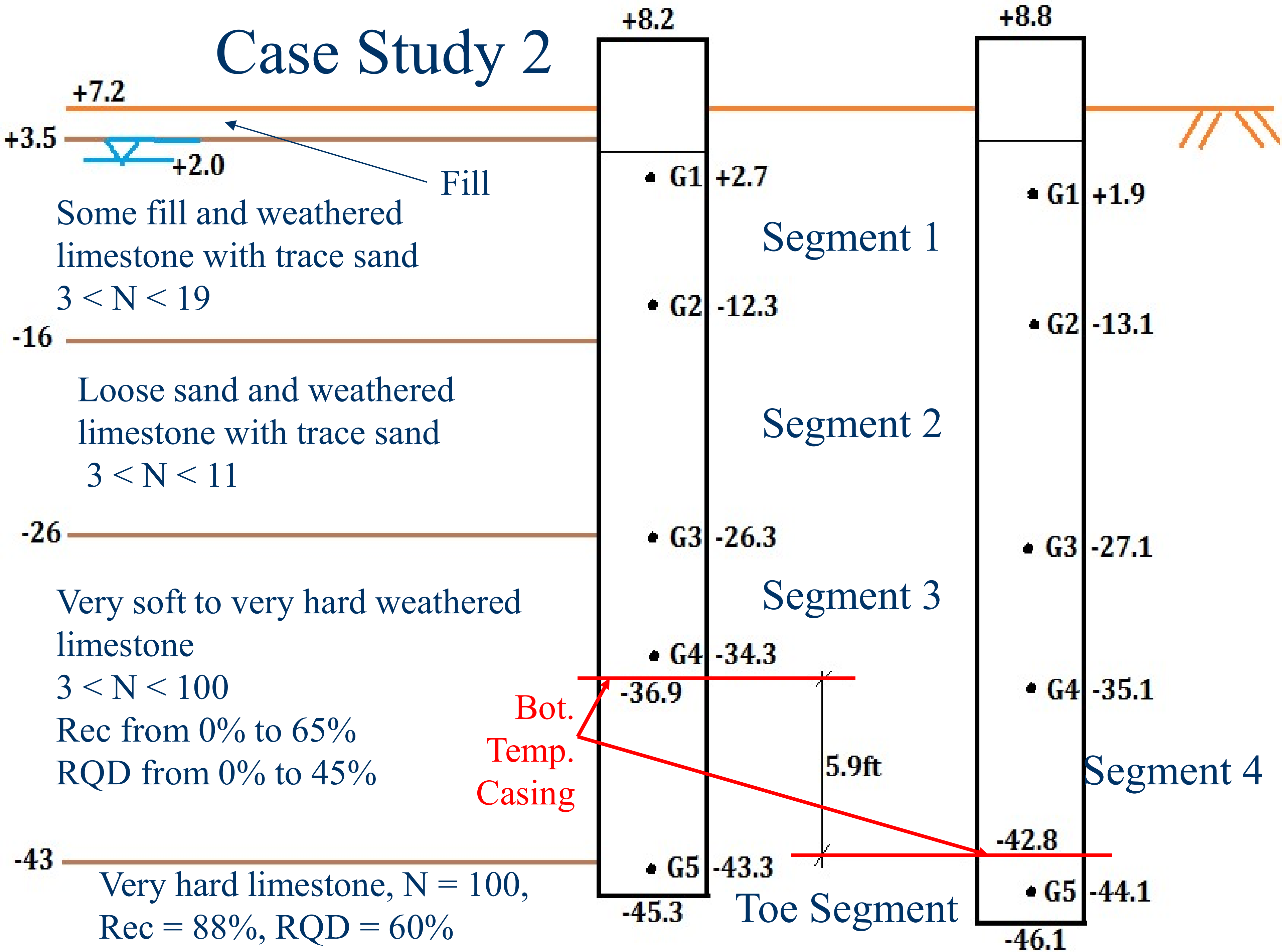


NOTE:
- OUTER CASING O.D. 42"
- INNER CASING O.D. 36"
- NOMINAL SHAFT DIAMETER 36"
TS 1
TELLTALES
A B
GROUND ELEV.
TOP OF REBAR
TOP OF CONCRETE
G.W.
+3.00
+2.17
+2.00
+0.00
OVERBURDEN
Casings Extracted from Outside-in
-13.0
SG5 22967, 22968
-13.75
ESTIMATED
BOT. TEMP. OUTER CASING
-17.42
SG4 19973, 19974
-19.75
LIMESTONE
SG3 22965, 22966
-24.75
SG2 22963, 22964
-27.75
-29.0
upward movement
break in shaft
downward movement
LVWDT 20576, 20577, 20578
13" Osterberg Cell
(1029-3)
-32.75
MARL
BOT. TEMP. INNER CASING
-36.04
SG1 22961, 22962
-38.46
TIP OF SHAFT
-40.08
TELLTALES
A B
TS 2
ELEVATION
(FEET)
TOP TEMP. OUTER CASING
TOP OF REBAR
TOP OF CONCRETE
+4.0
+3.5
+3.0
+2.5
GROUND ELEV.
G.W.
+0.0
OVERBURDEN
Casings Extracted from Inside-out
-13.0
SG5 23064, 23065
-14.2
BOT. TEMP. OUTER CASING
-17.0
LIMESTONE
SG4 23062, 23063
-20.2
SG3 22960, 22961
-25.3
SG2 23058, 23059
-28.2
-29.0
-30.6
upward movement
break in shaft
downward movement
LVWDT 20692, 20693, 20694
13" Osterberg Cell
(1029-6)
-33.2
MARL
BOT. TEMP. INNER CASING
-35.5
SG1 23056, 23057
-38.1
TIP OF SHAFT
-40.2



Upward Top of O-cell
Outside - in
Downward Base of O-cell
Inside -out
Displacement (in)
O-Cell Load (kips)
2
1
0
-1
-2
-3
-4
-5
0
200
400
600
800
1000
1200
1400
O (U)
O (D)
I (U)
I (D)

Case Study 2

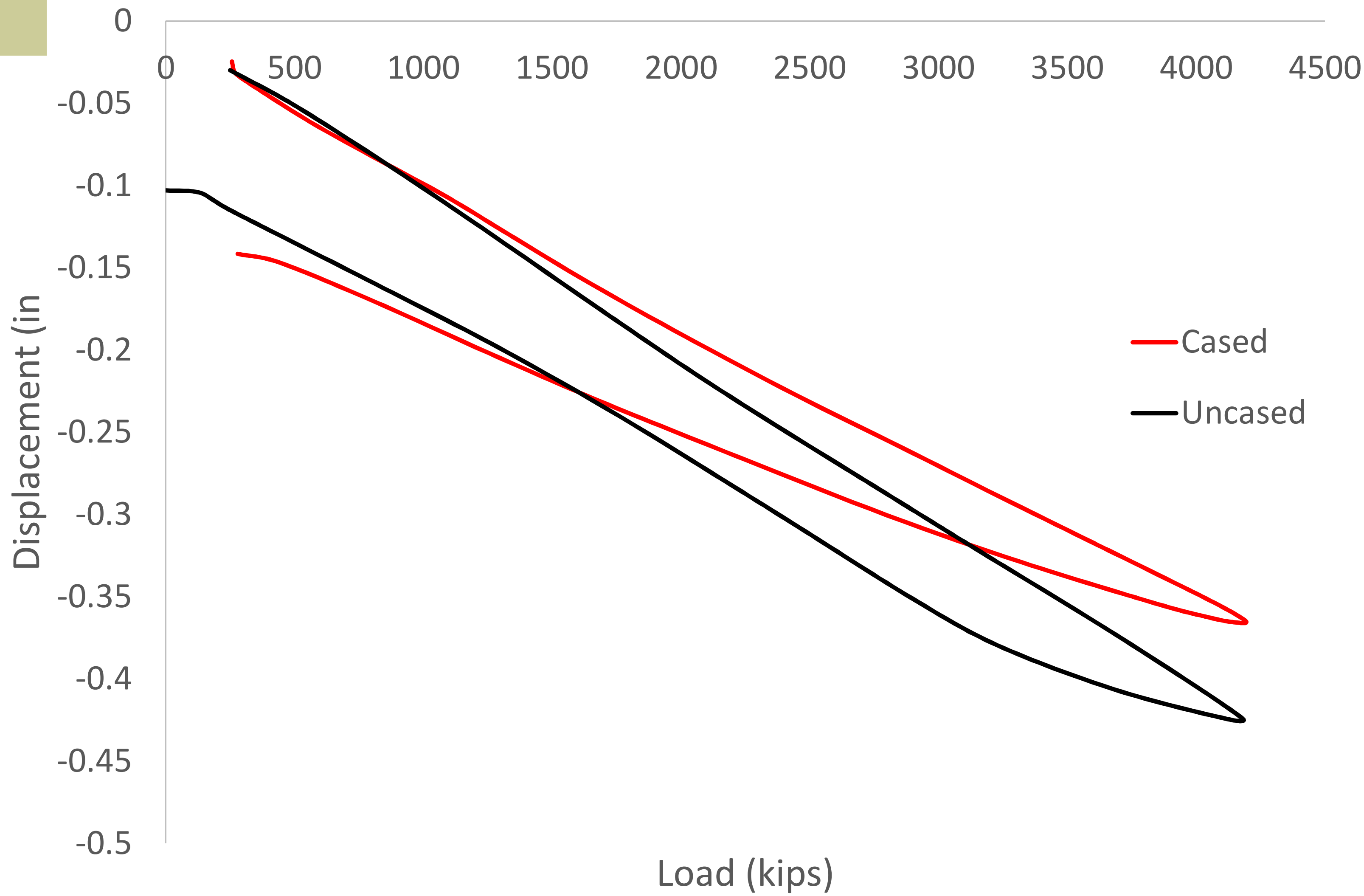


+8.2
+8.8
+7.2
+3.5
+2.0
Fill
Some fill and weathered limestone with trace sand
3 < N < 19
-16
Loose sand and weathered limestone with trace sand
3 < N < 11
-26
Very soft to very hard weathered limestone
3 < N < 100
Rec from 0% to 65%
RQD from 0% to 45%
-43
Very hard limestone, N = 100,
Rec = 88%, RQD = 60%
Bot. Temp. Casing
G1 +2.7
G2 -12.3
G3 -26.3
G4 -34.3
-36.9
G5 -43.3
-45.3
Segment 1
Segment 2
Segment 3
5.9ft
Segment 4
Toe Segment
G1 +1.9
G2 -13.1
G3 -27.1
G4 -35.1
-42.8
G5 -44.1
-46.1

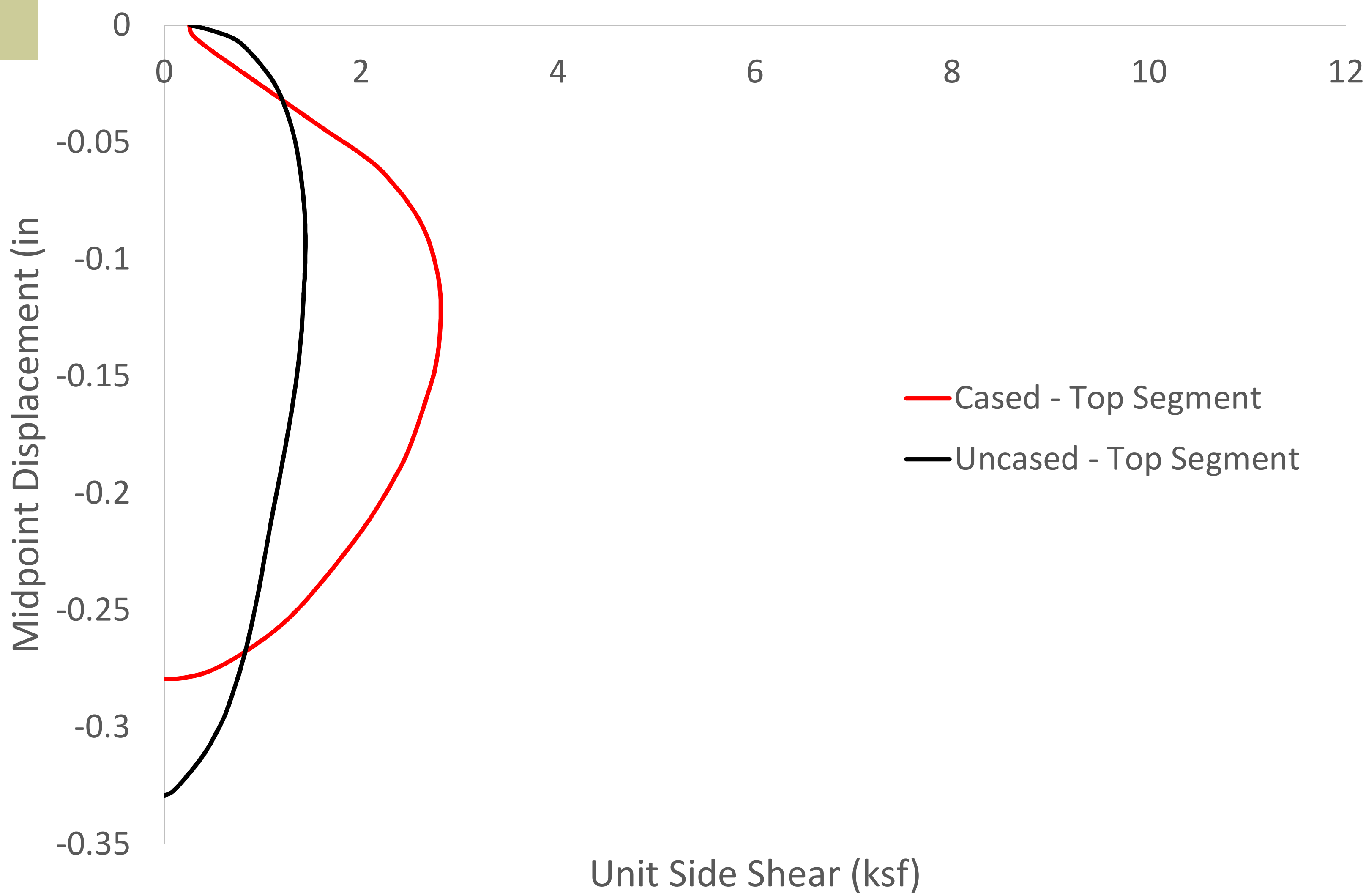
Case Study 2

	Uncased	Cased
Date constructed	7/15 and 7/16/09	7/20/09
Load test date	7/31/09	8/3/09
Reported Mobilized Capacity	4,183 kips	4,189 kips
Maximum displacement	0.43in	0.37in
Permanent displacement	0.10in	0.15in

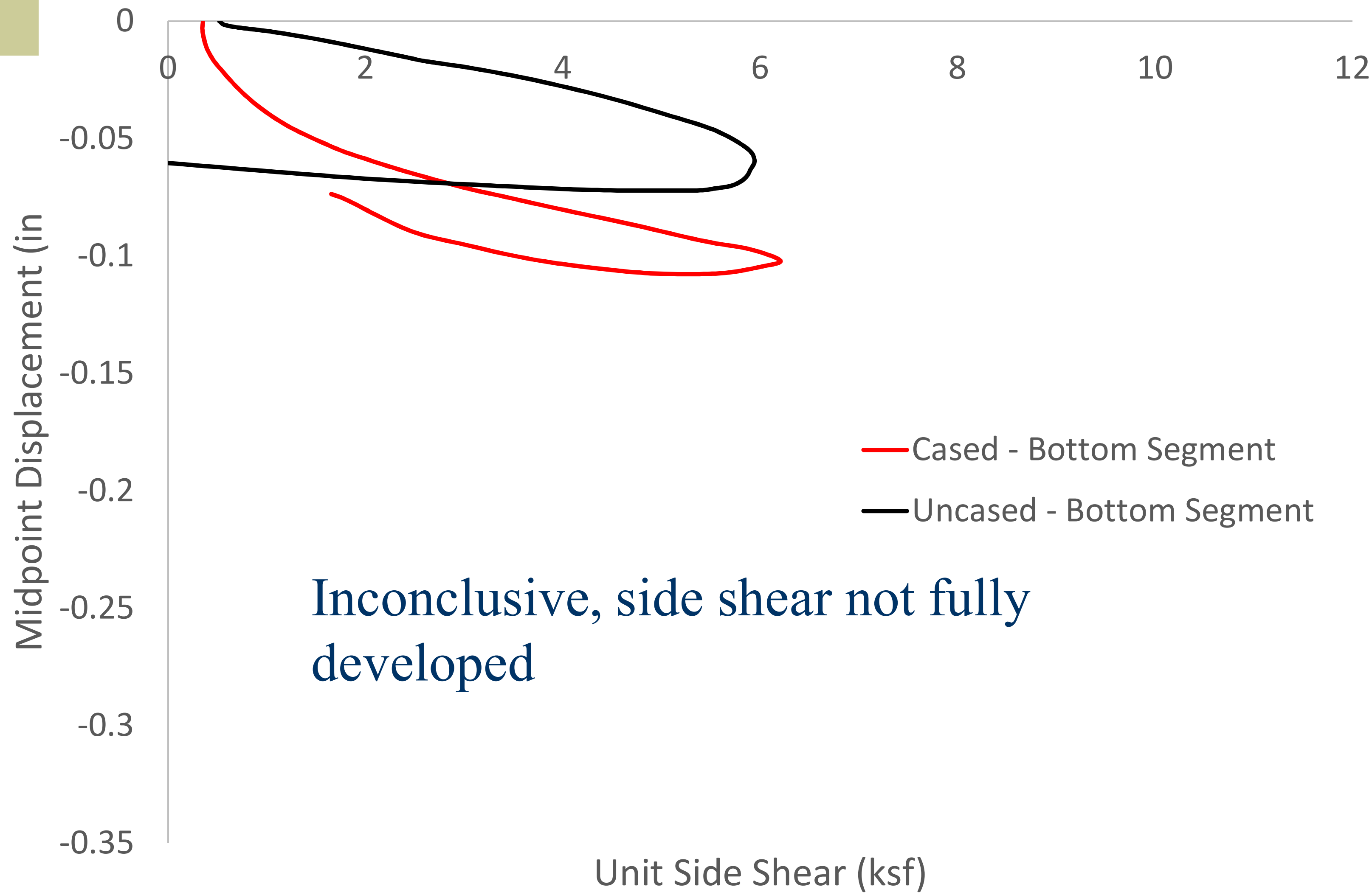
Top of Shaft Load – Displacement



Top Segment Unit Side Shear

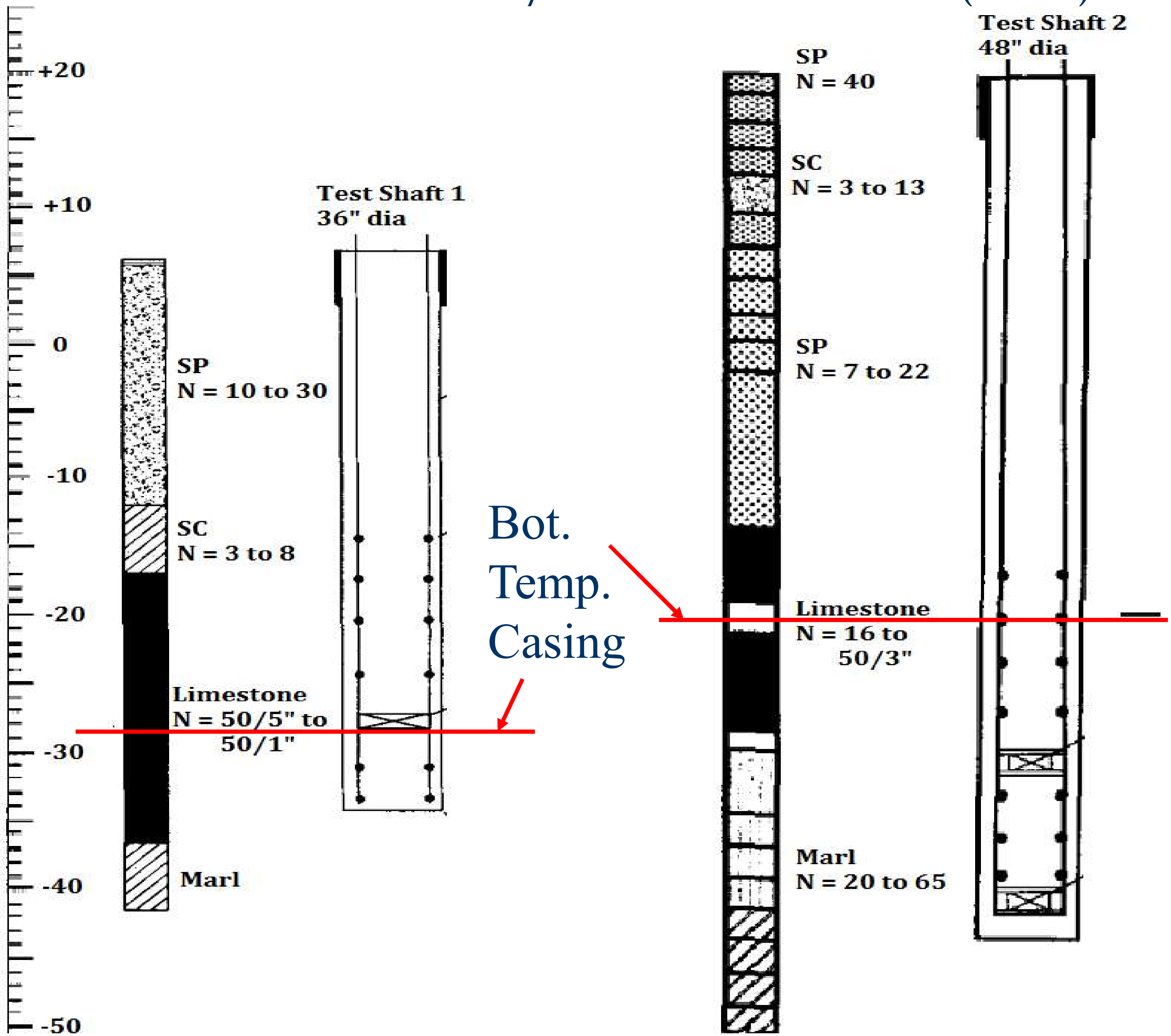


Comparison Segment Unit Side Shear



Inconclusive, side shear not fully developed

Case Study 3 Castelli and Fan (2002)



Castelli and Fan (2002)

Test Shaft No	Shaft Diameter (inches)	Maximum O-cell load (tons)	Strain Gage Elevation (ft)	Limestone Classification and SPT N-Value	Mobilized Side Shear (tsf)	Upward Disp. (inches)
1	36	970	-18 to -21	Decomposed Limestone, N ≈ 7	0.5	0.94
			-21 to -25	Cemented Limestone, N ≈ 50/1in to 50/5in	8.2	
			-25 to -28		19.0	
			-29 to -34.3		5.6*	
2	48	1465	-17.7 to -21.7	Decomposed Limestone, N ≈ 16	2.1*	0.50
			-21.7 to -25.6	Cemented Limestone, N ≈ 50/3in	6.2*	
			-25.6 to -29.5	Cemented Limestone, N ≈ 50/3in	14.1*	
			-29.5 to -32.3	Weakly Cemented Limestone, N ≈ 20 to 50/4in	4.1*	

* Failure was not observed on these segments.

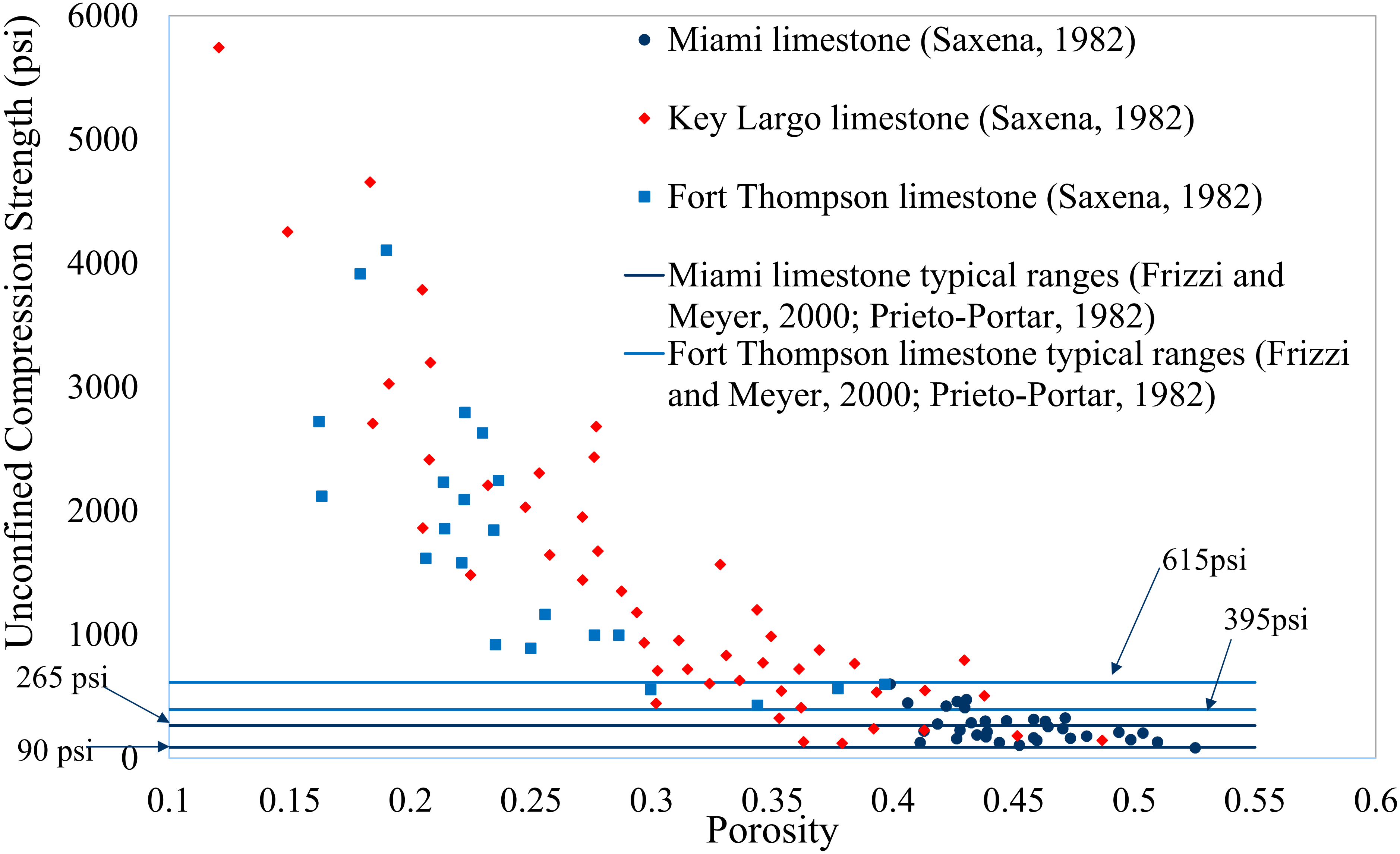
Inconclusive, side shear not fully developed

Research Approach

- Find / create suitable simulated limestone
- Cast simulated limestone beds
- Construct $1/10^{th}$ rock socketed shafts in beds
- Perform pull out tests
- Evaluate results

Initial Target Simulated Limestone

100psi – 600psi

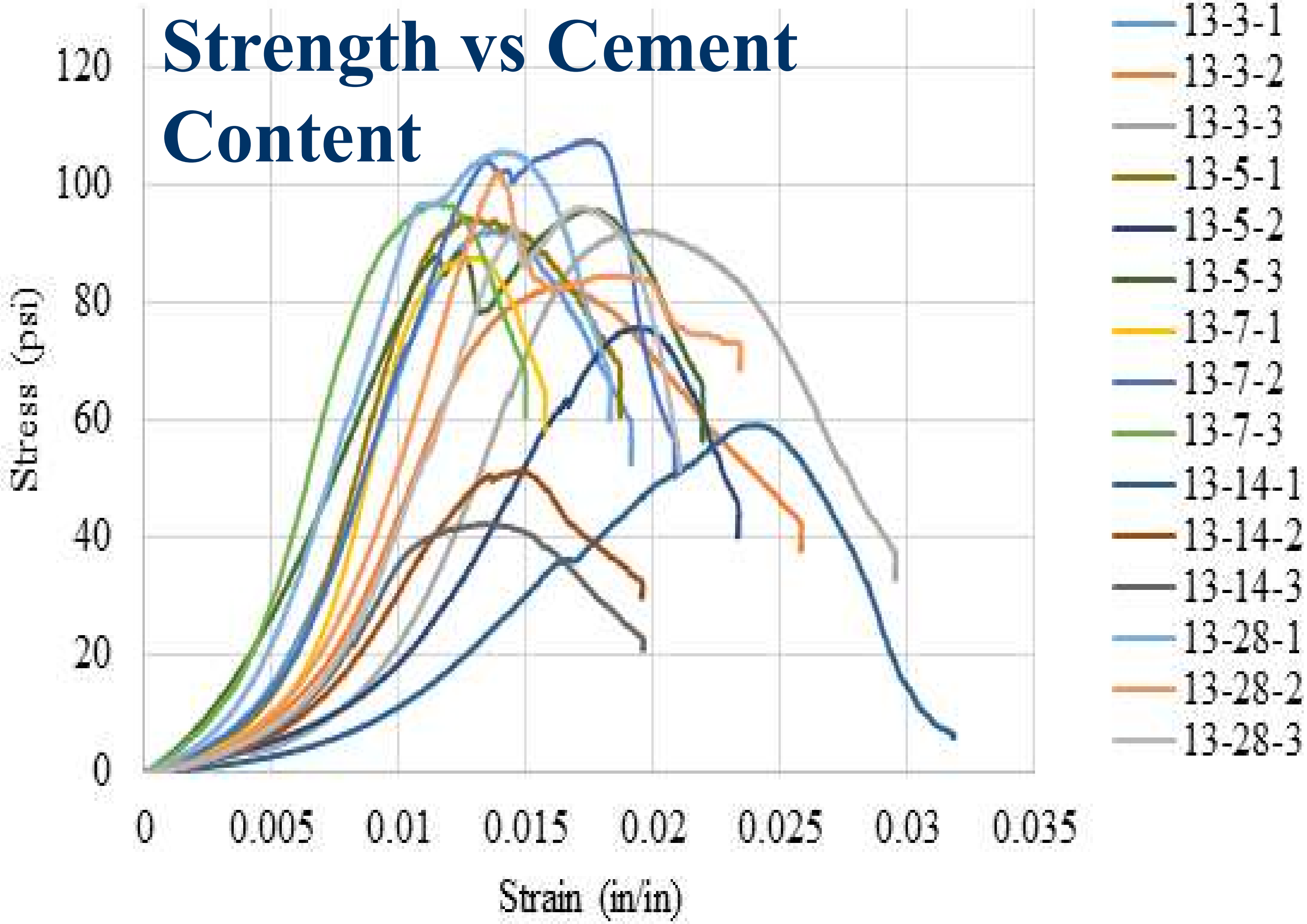


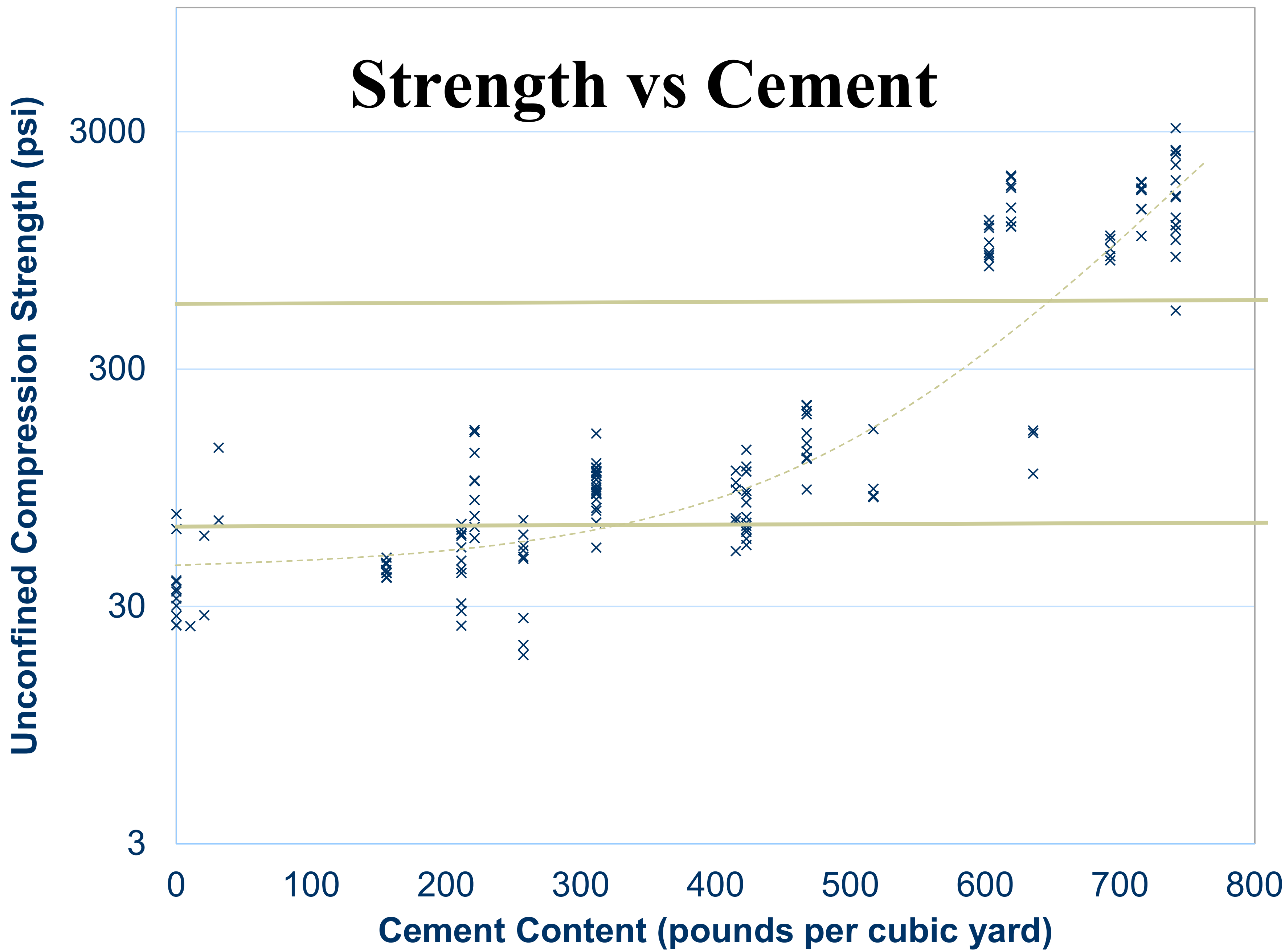
Simulated Limestone Lab-Scale

- Target UCS 60 psi – 800 psi,
- Texture with porous texture.
- Mixing materials
  - Cement (0-800pcy)
  - Lime (100-500pcy)
  - C/L ratio 0.5 - 2
  - w/c ratio 1-3
  - Sand
  - Conquina and Oyster shells (increased porosity)
- Over 200 UCS tests

Simulated Limestone Mixing

Strength vs Cement Content





Strength vs Cement
Unconfined Compression Strength (psi)
3000
300
30
3
0
100
200
300
400
500
600
700
800
Cement Content (pounds per cubic yard)

Simulated Limestone

Field limestone cores

Lab limestone cores

Test Bed Preparation

- Bulk supply of lime, cement, sand and coquina shells
- Drilling equipment for 3 methods of casing installation: driven, fine-tooth rotated and coarse-tooth rotated
- High strength anchor bars
- Large volume mixer (each bed ≈ 1cu yd)
- High strength shaft mix (1cu ft per shaft)

Test Beds

- 6 simulated limestone beds cast
- 42 in. diameter, 23 in. tall.
- UCS 60-850psi
- Cement Content 170 – 680 pcy (1 – 4bags)
- Cement / Lime =1
- w/c 1.6 - 3

Simulated Limestone Beds

Simulated Limestone Beds

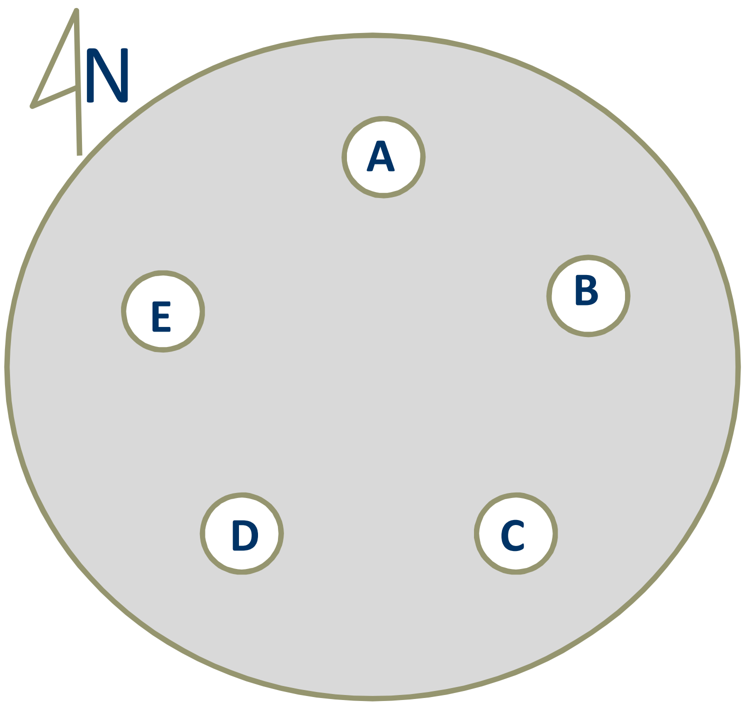
Simulated Limestone Beds

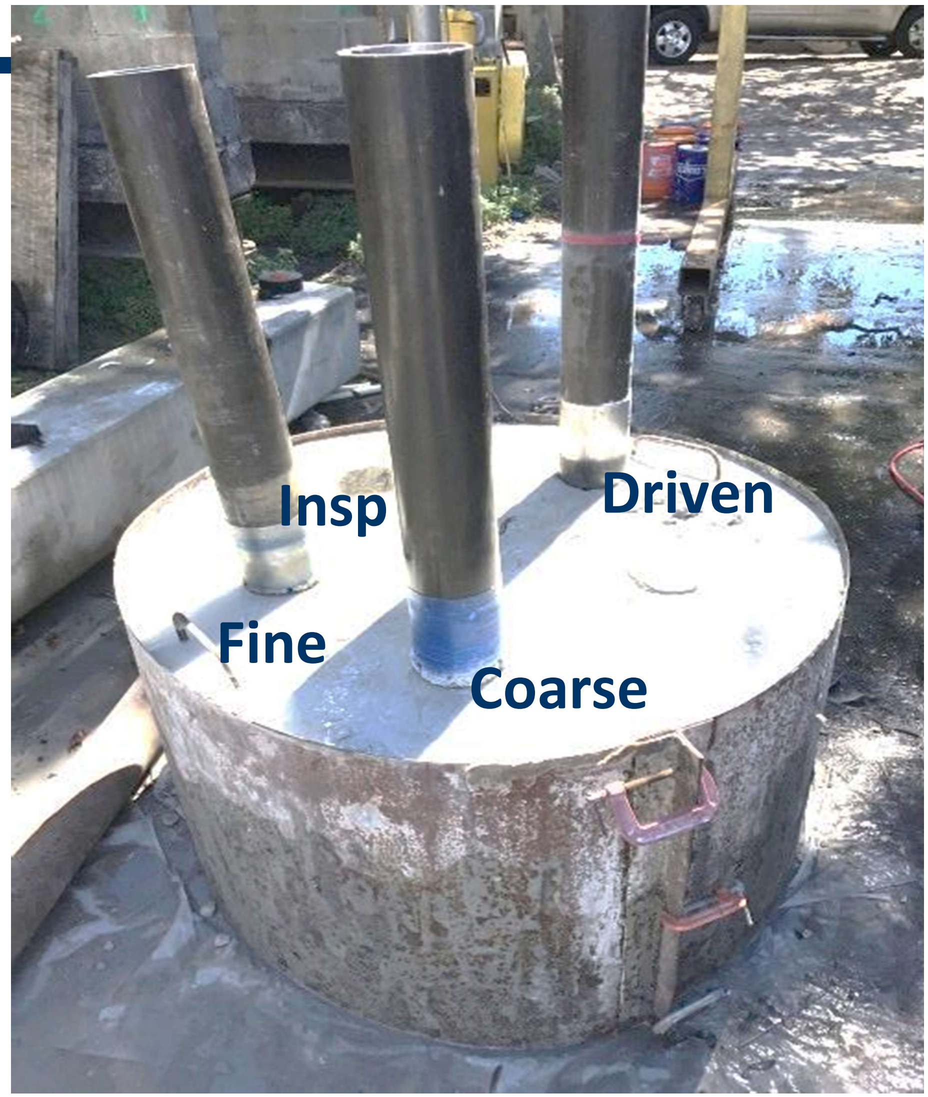





Centering Rods


Small Scale Tests Setup






RIDGID

Casing Types

Coarse-tooth

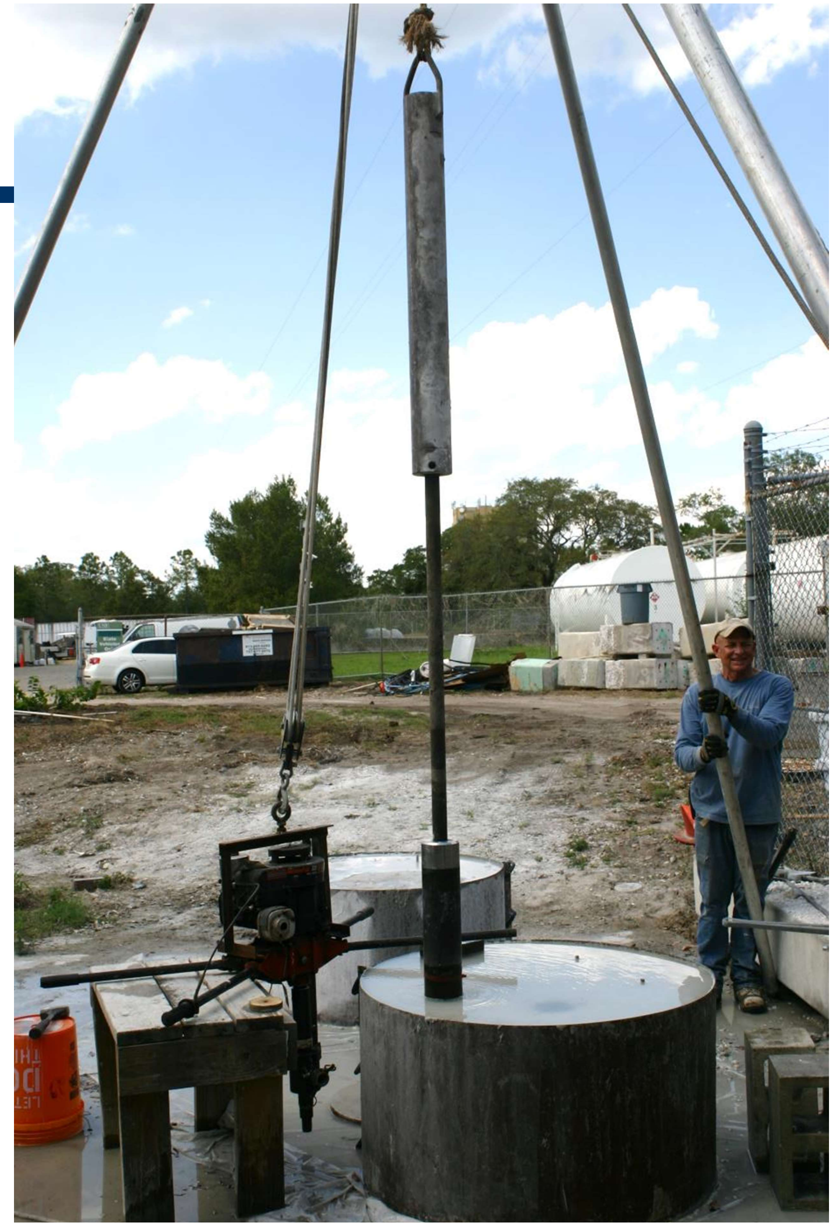
Fine-tooth

Driving Shoe

Small Scale Tests Setup

Bed I.D.	Specimen Position I.D.				
	A	B	C	D	E
1 (502.78 psi)	Coarse	Fine	Fine (insp)	Driven	Driven (insp)
2 (885.02 psi)	Coarse	Fine	Driven	Driven (insp)	Coarse (insp)
3 (487.42 psi)	Coarse	Fine	Abandoned	Driven	Driven (insp)
4 (64.78 psi)	Coarse	Fine	Fine (insp)	Driven	Driven (insp)
5 (163.40 psi)	Coarse	Fine	Driven	Driven (insp)	Coarse (insp)
6 (685.6 psi)	Coarse	Fine	Fine (insp)	Driven	Driven (insp)

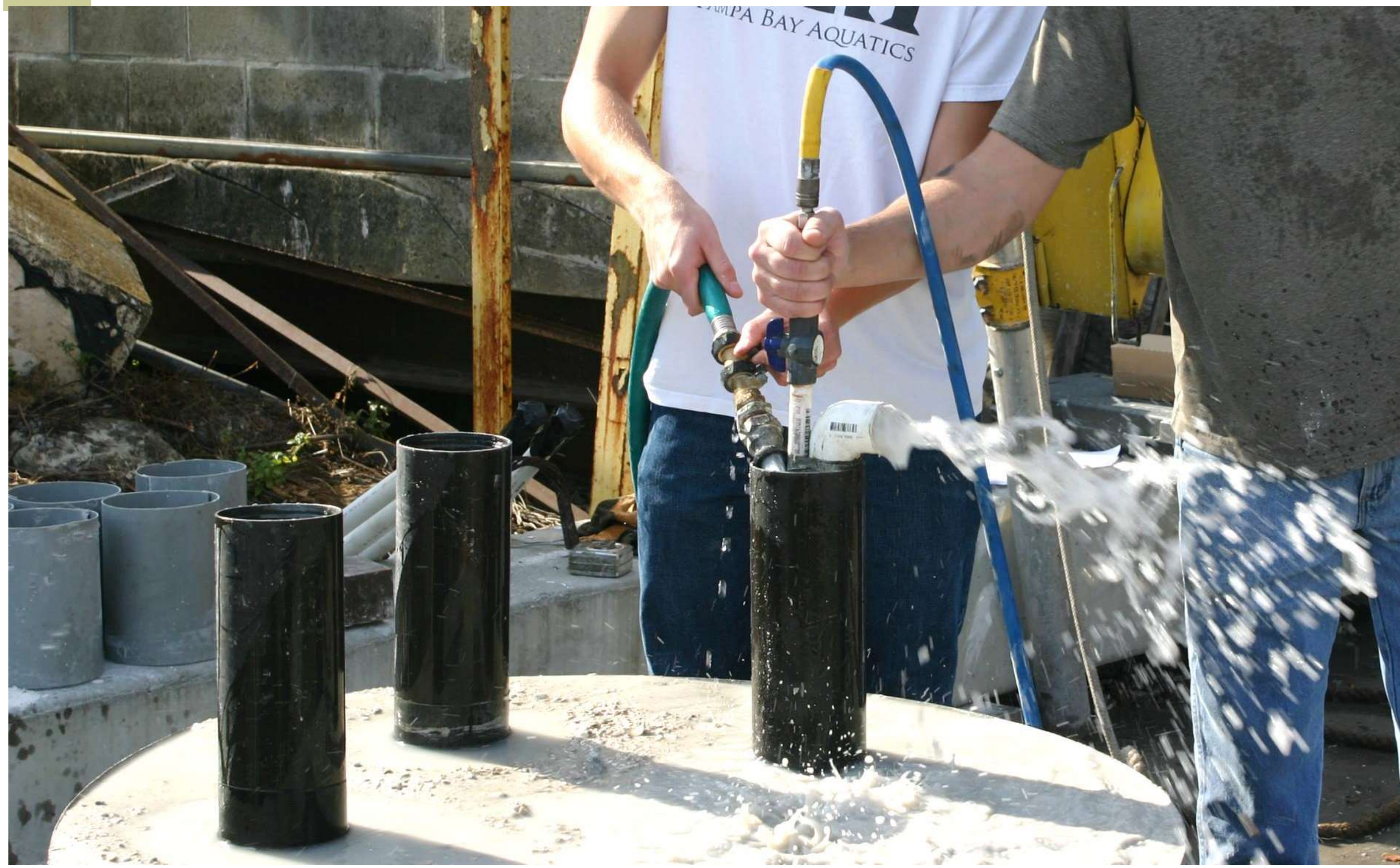
Preforming and Driving Casing




Rotated Casing
Installation
753H


Drill out
remaining core
753H

Airlift Bottom Cleanout



Cuttings Replacement

Casting Order

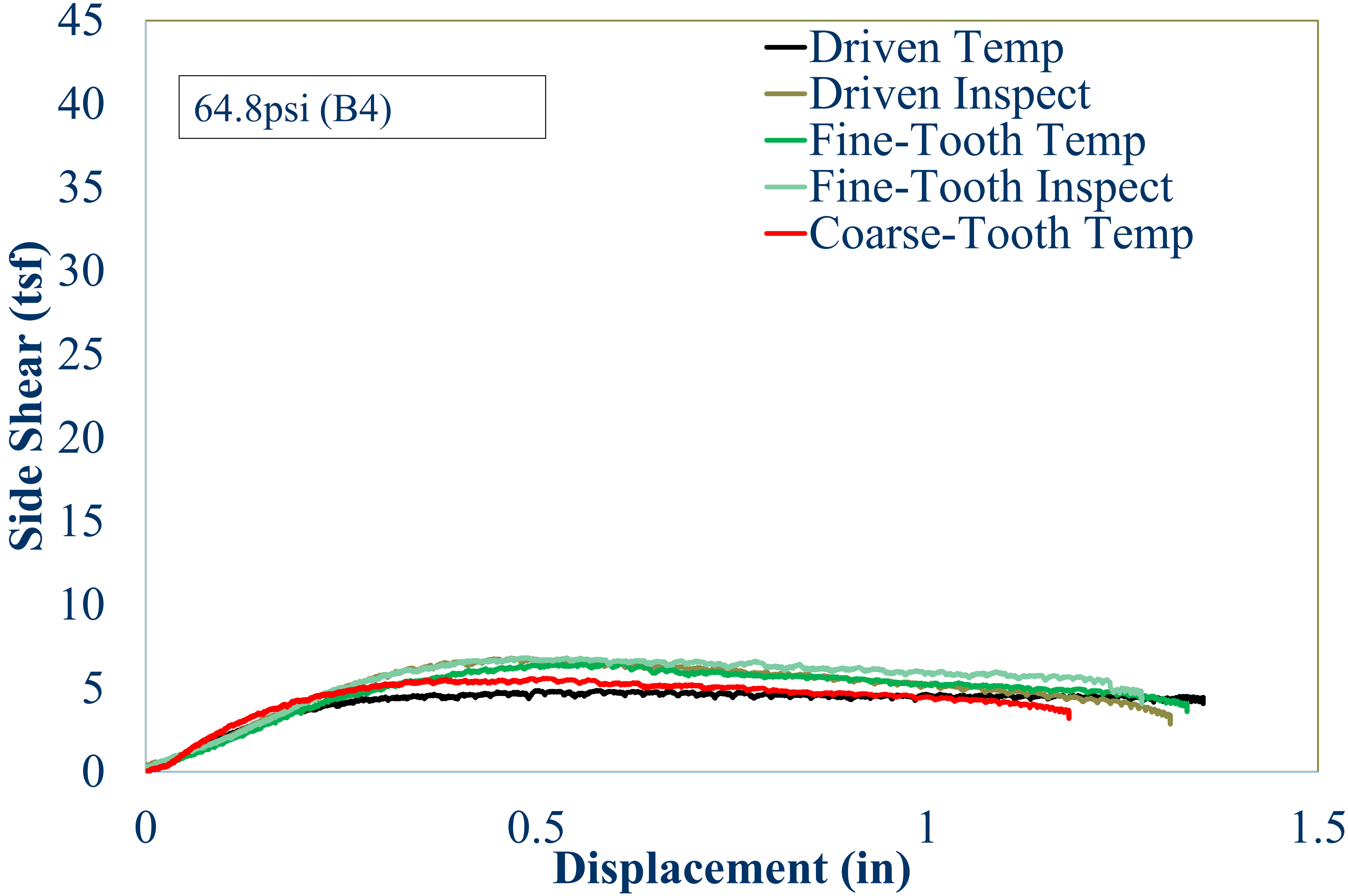
- Driven casing cast and removed first to prevent consolidation / vibration of other samples
- Rotated casings cast and removed second
- Controls last

Pullout Load Tests



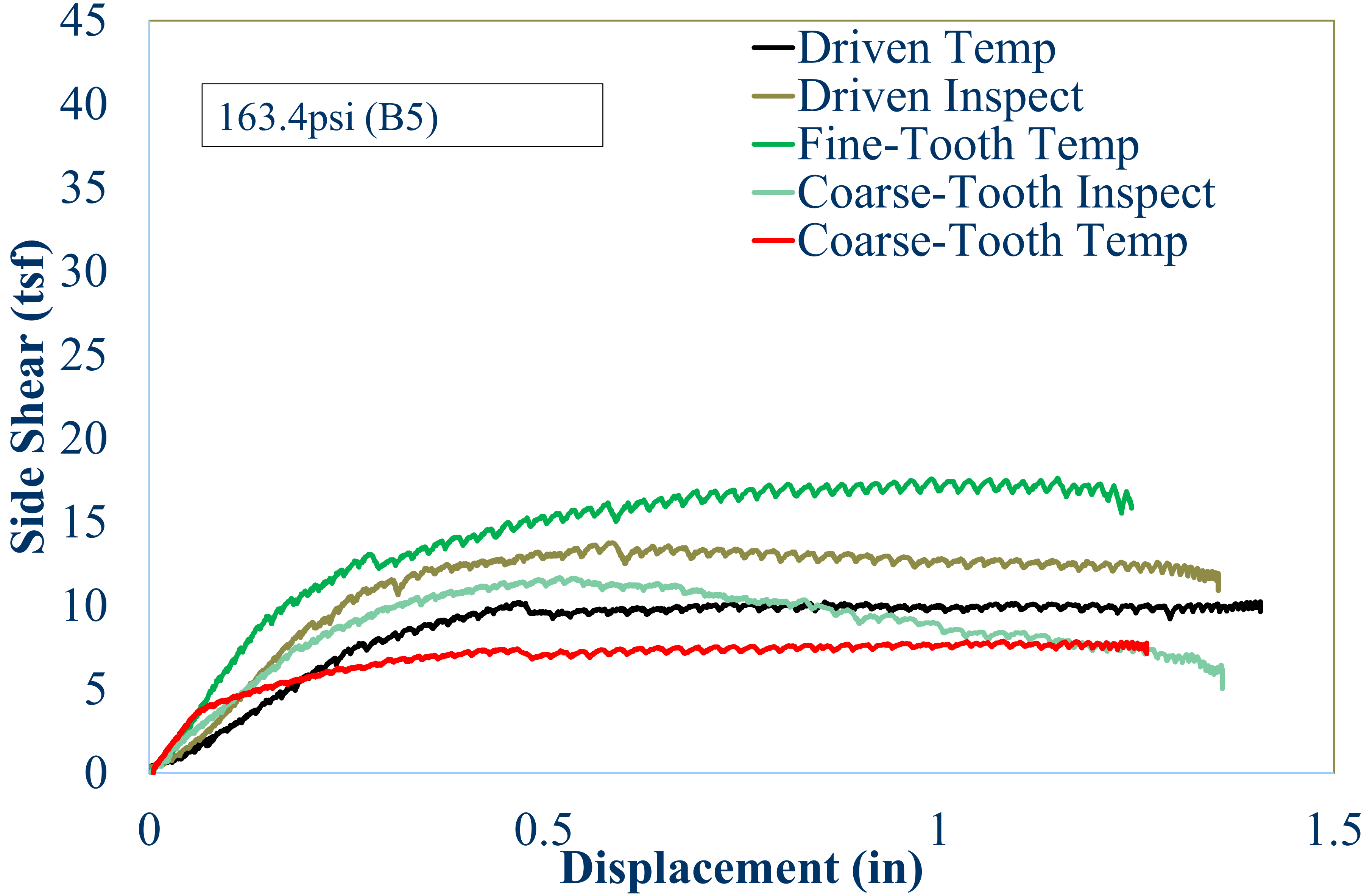



Results



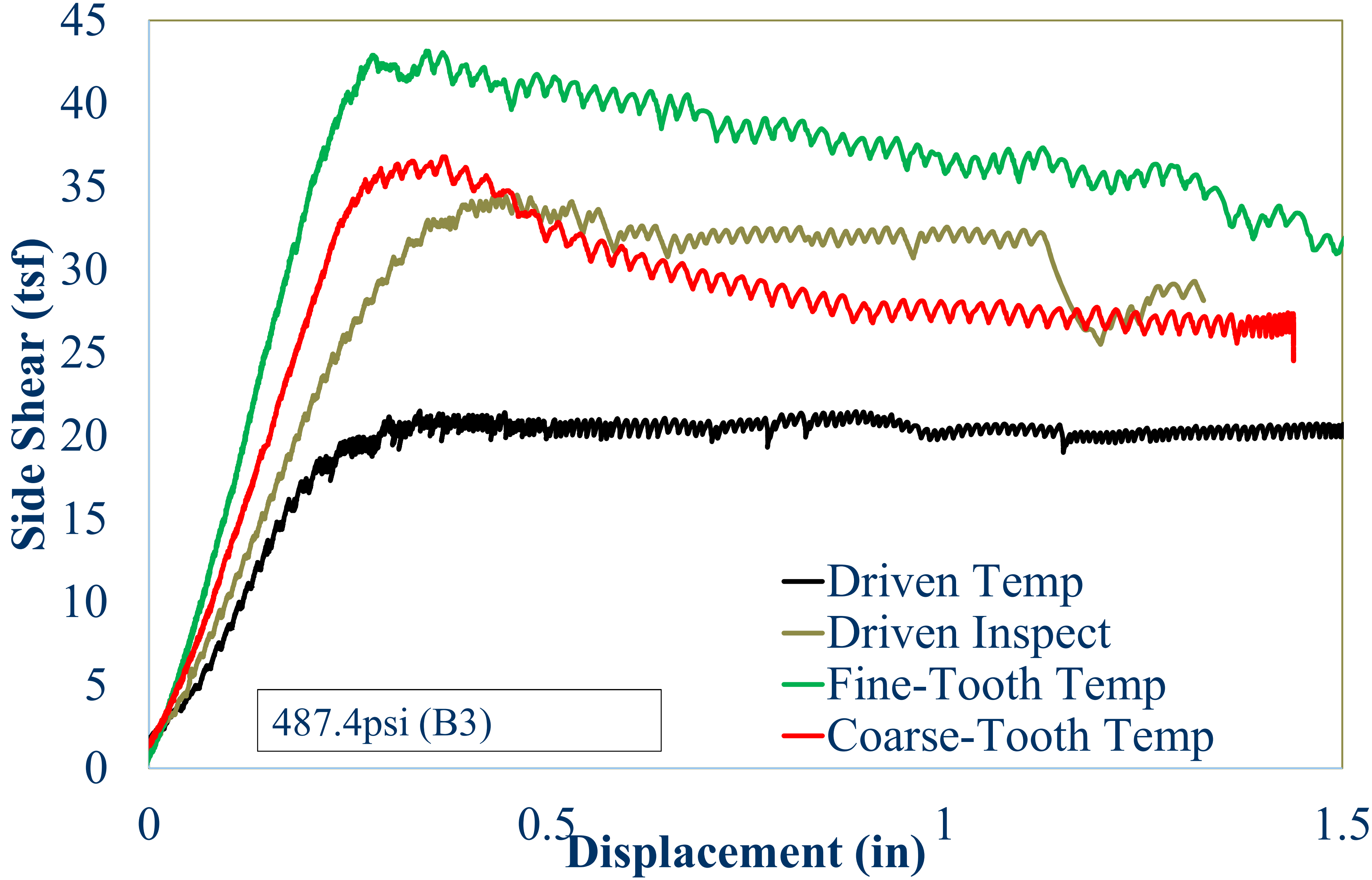
64.8psi (B4)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Fine-Tooth Inspect
Coarse-Tooth Temp
Side Shear (tsf)
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
Displacement (in)

Results



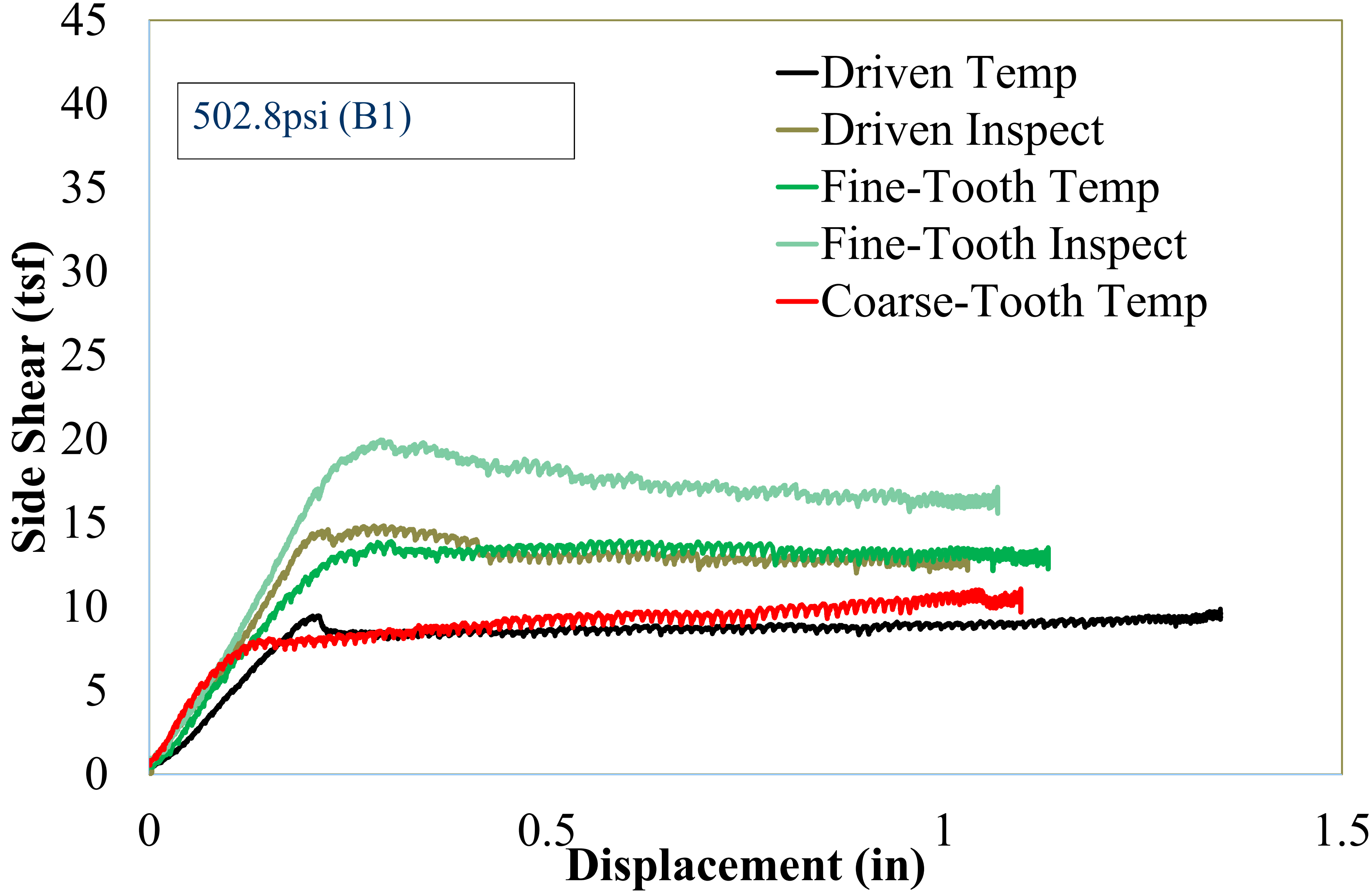
163.4psi (B5)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Coarse-Tooth Inspect
Coarse-Tooth Temp
Side Shear (tsf)
Displacement (in)
0
5
10
15
20
25
30
35
40
45
0.5
1
1.5

Results



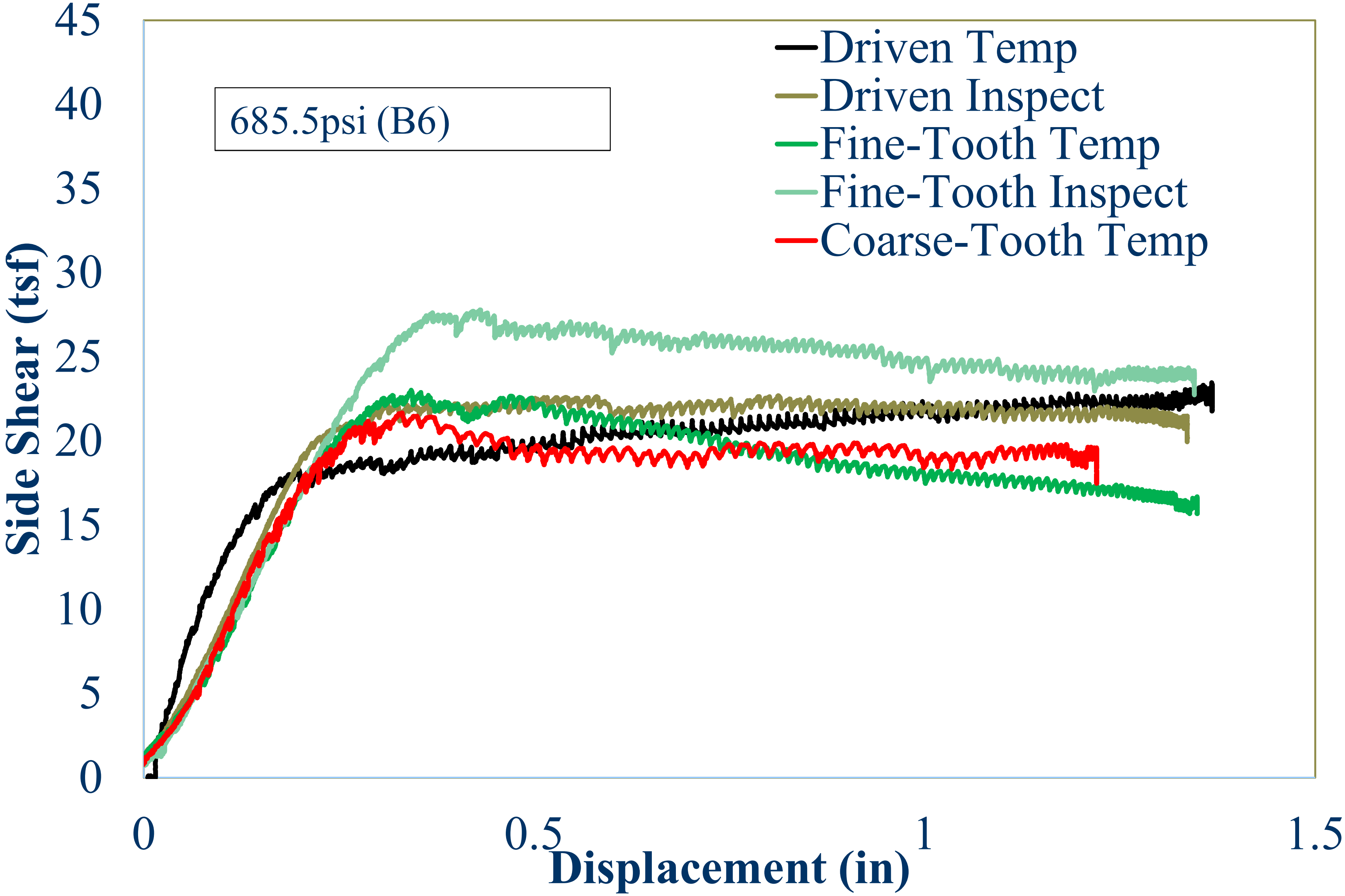
Side Shear (tsf)
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
Displacement (in)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Coarse-Tooth Temp
487.4psi (B3)

Results



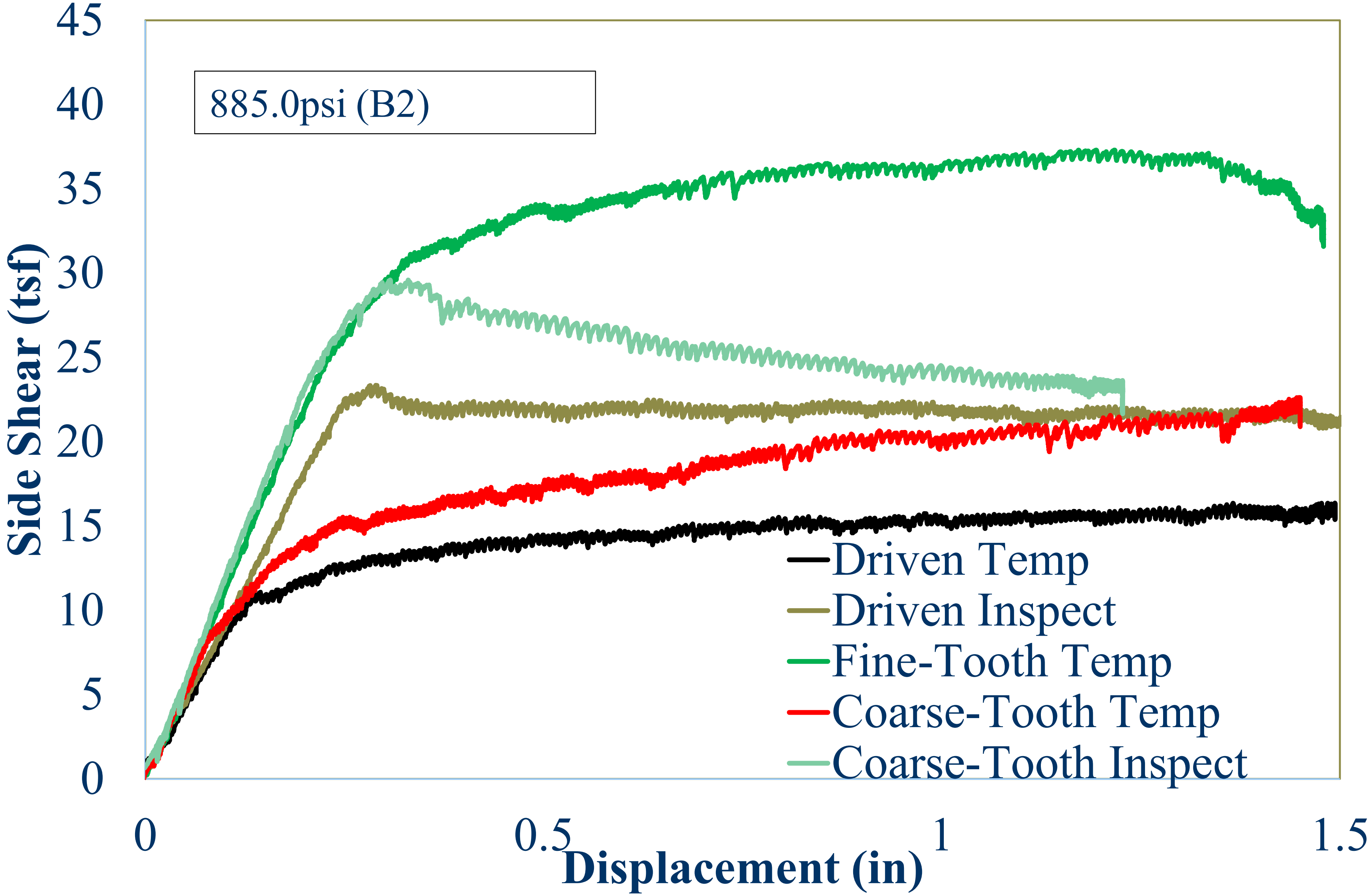
502.8psi (B1)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Fine-Tooth Inspect
Coarse-Tooth Temp
Side Shear (tsf)
Displacement (in)
0
5
10
15
20
25
30
35
40
45
0
0.5
1
1.5

Results



685.5psi (B6)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Fine-Tooth Inspect
Coarse-Tooth Temp
Side Shear (tsf)
Displacement (in)
0
5
10
15
20
25
30
35
40
45
0
0.5
1
1.5

Results

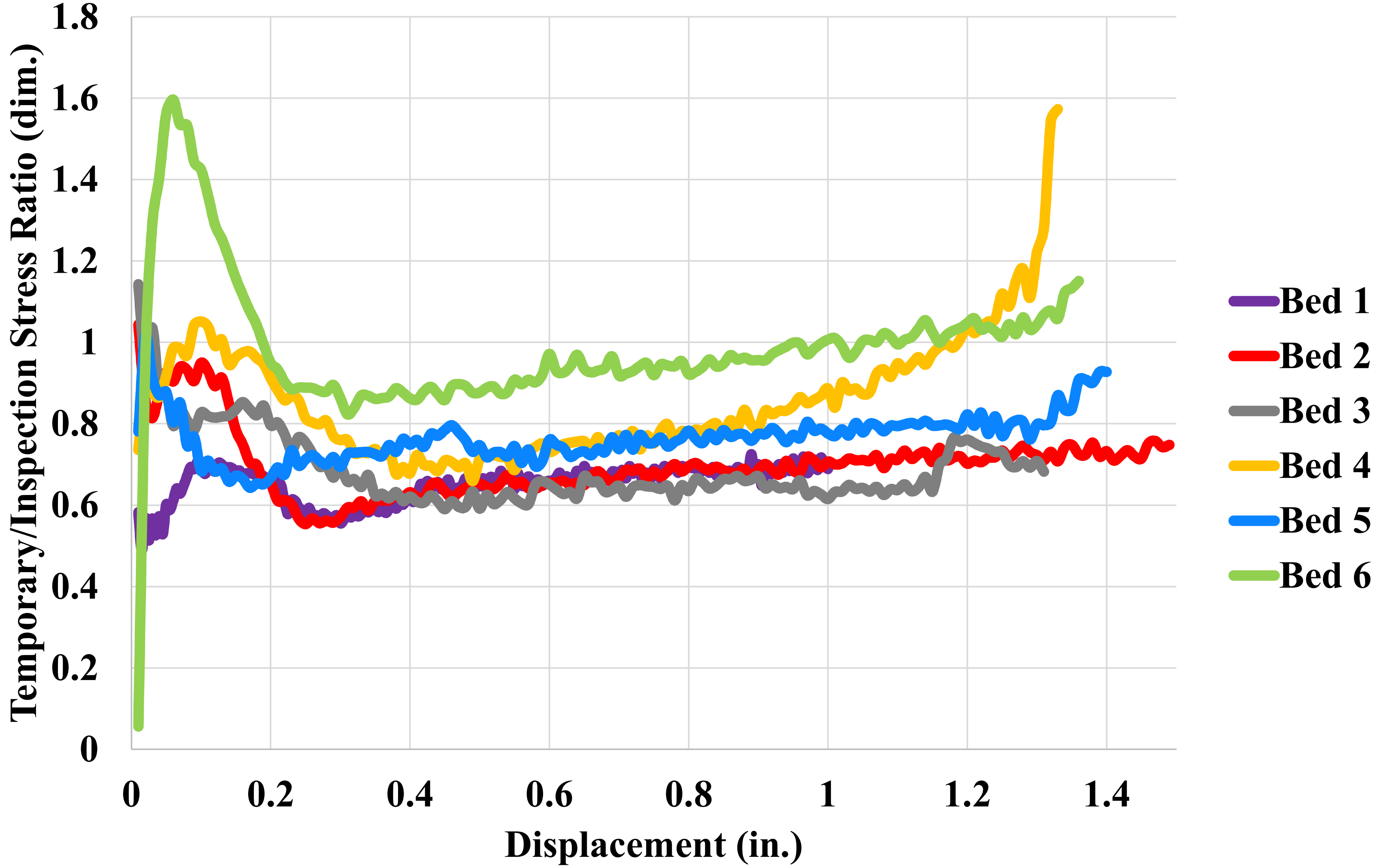


885.0psi (B2)
Side Shear (tsf)
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
Displacement (in)
Driven Temp
Driven Inspect
Fine-Tooth Temp
Coarse-Tooth Temp
Coarse-Tooth Inspect

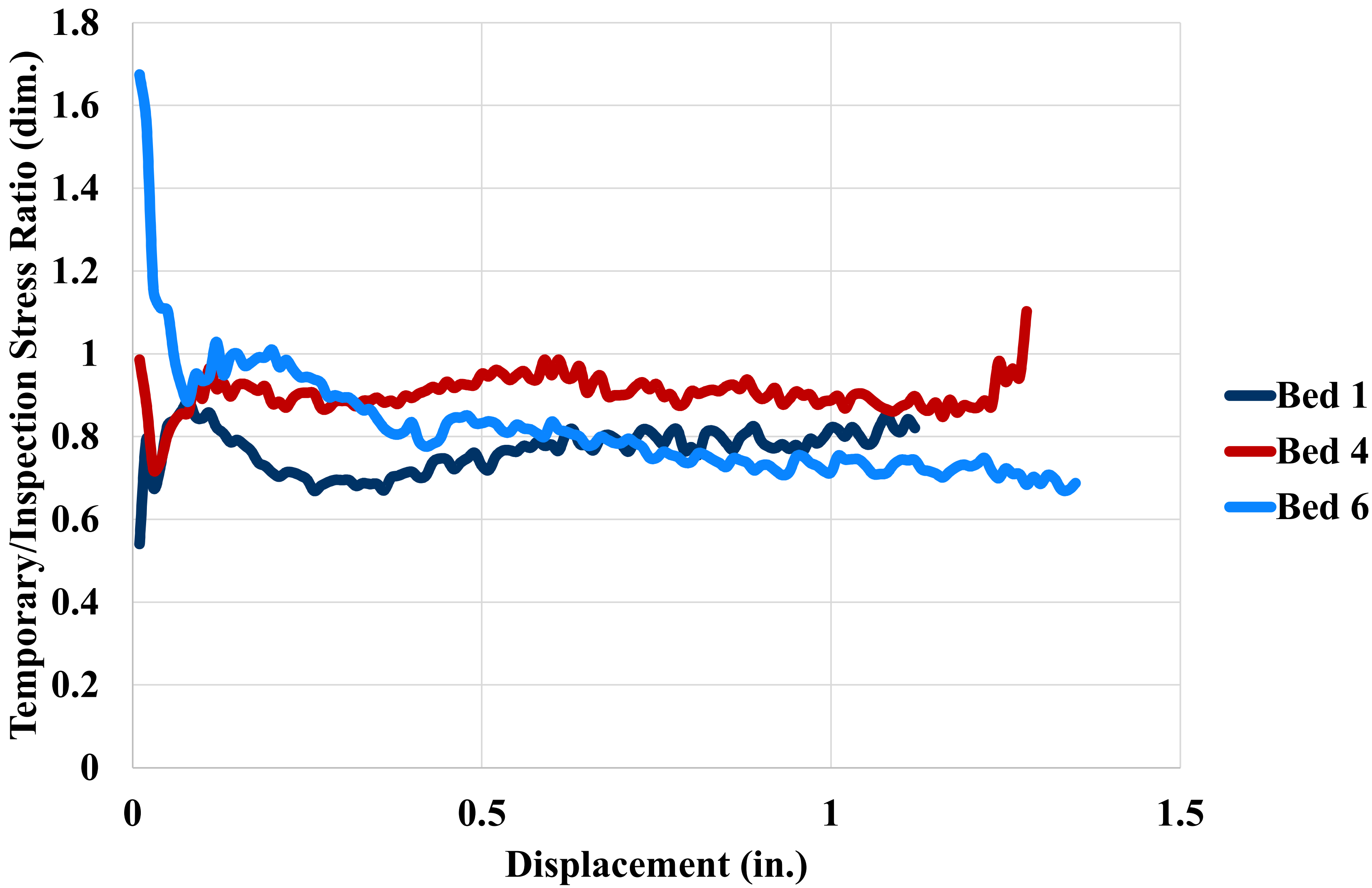
Ultimate Temp / Ultimate Control

Bed ID	Casing Type	Peak Displacement (in.)	Ultimate Stress Ratio	Minimum Residual Stress Ratio
Bed 1	Driven Casing	0.20	0.67	0.49
	Fine-Tooth Casing	0.30	0.69	0.54
Bed 2	Driven Casing	0.20	0.65	0.55
	Coarse-Tooth Casing	0.27	0.56	0.53
Bed 3	Driven Casing	0.30	0.70	0.59
Bed 4	Driven Casing	0.47	0.69	0.66
	Fine-Tooth Casing	0.60	0.95	0.72
Bed 5	Driven Casing	0.40	0.75	0.64
	Coarse-Tooth Casing	0.20	0.75	0.61
Bed 6	Driven Casing	0.30	0.86	0.82
	Fine-Tooth Casing	0.37	0.81	0.37

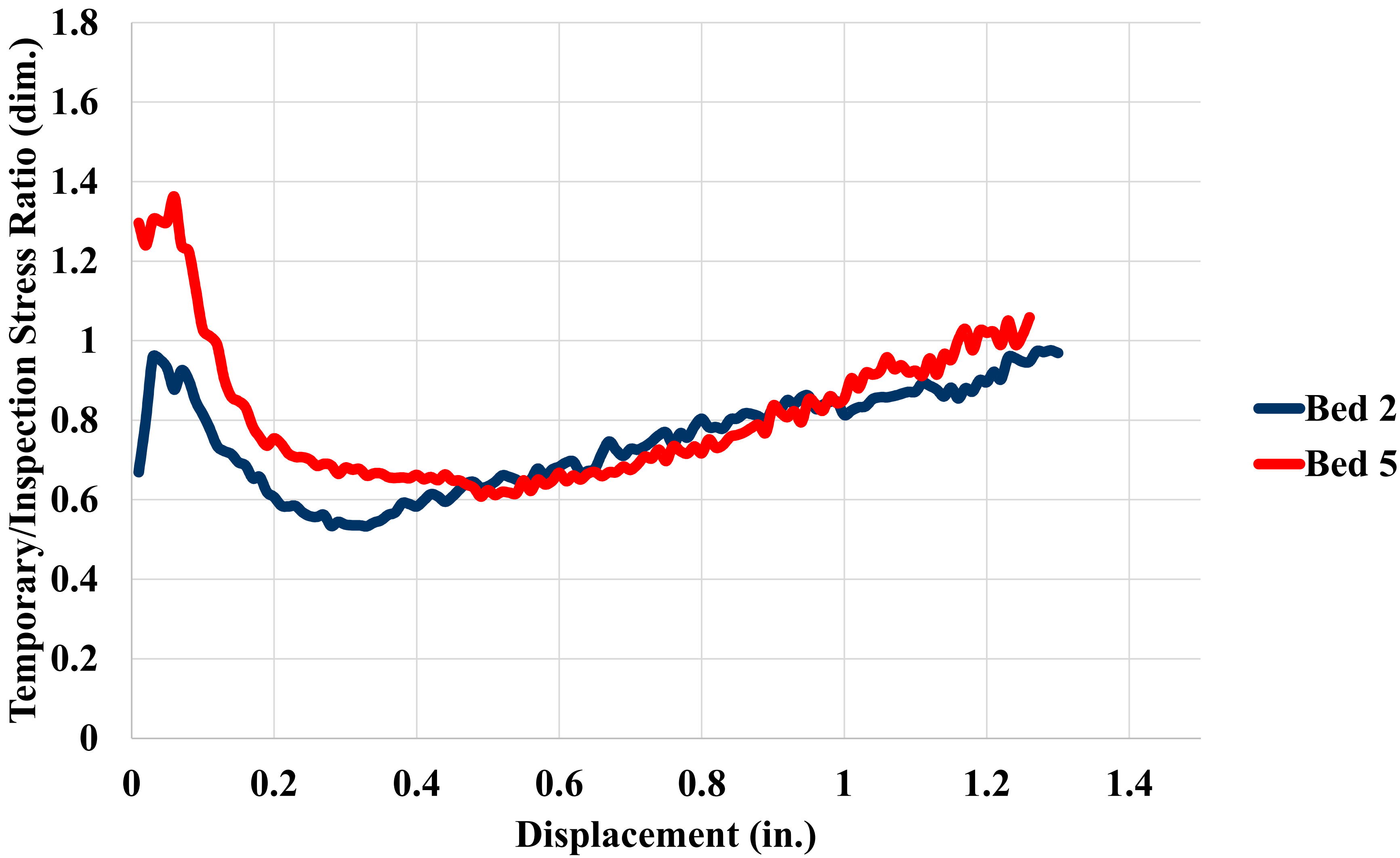
Stress Ratio (driven)



Stress Ratio (rotated fine)



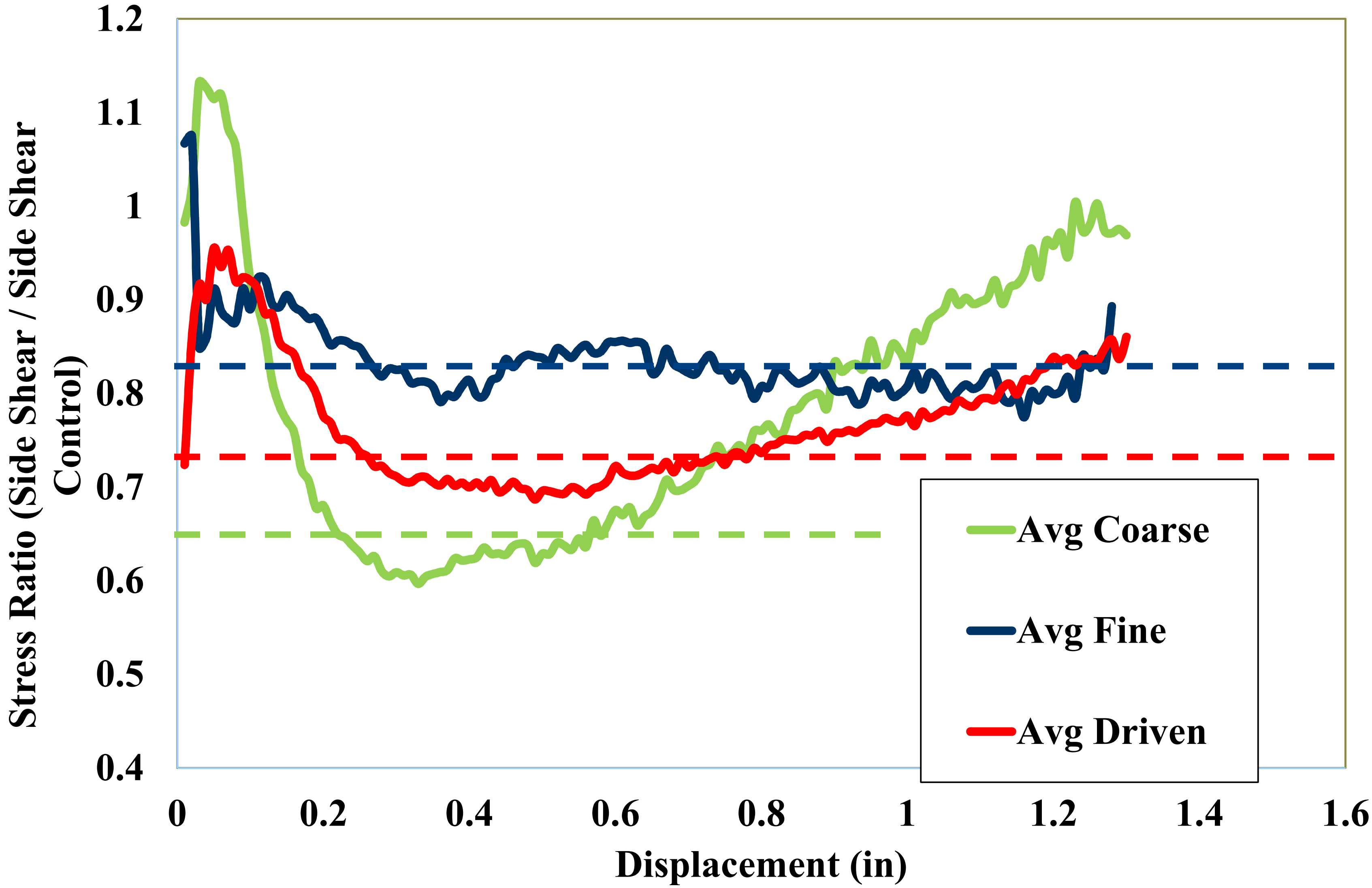
Stress Ratio (rotated coarse)



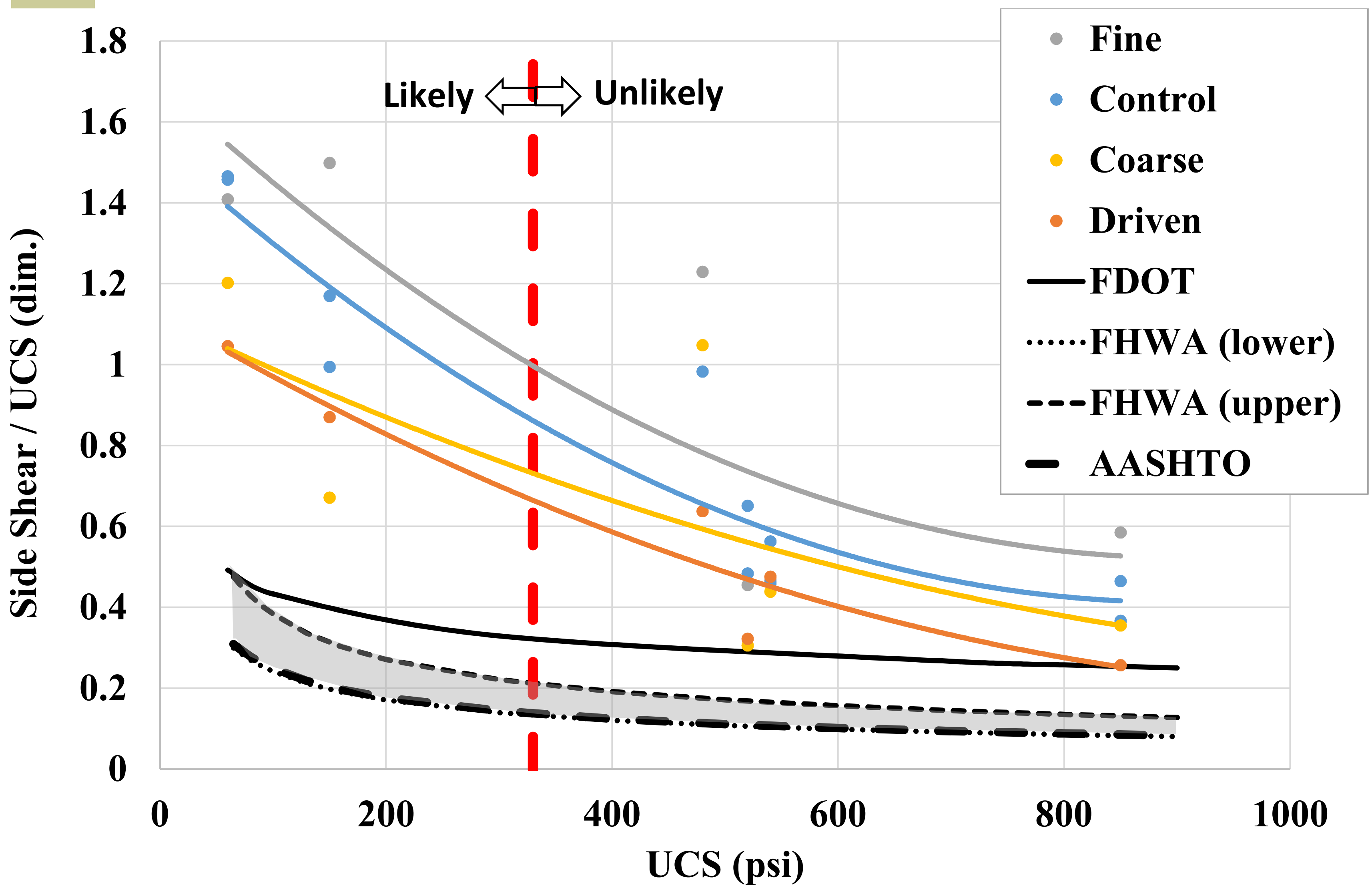
Average Stress Ratios

Casing Type	Peak Displacement (in.)	Ultimate Stress Ratio	Minimum Residual Stress Ratio	Avg Stress Ratio
Driven	0.20	0.67	0.49	0.72
	0.30	0.70	0.59	
	0.20	0.65	0.55	
	0.47	0.69	0.66	
	0.40	0.75	0.64	
	0.30	0.86	0.82	
Fine	0.30	0.69	0.54	0.82
	0.60	0.95	0.72	
	0.37	0.81	0.37	
Coarse	0.20	0.75	0.61	0.65
	0.27	0.56	0.53	

Average Stress Ratios



Measured vs Design

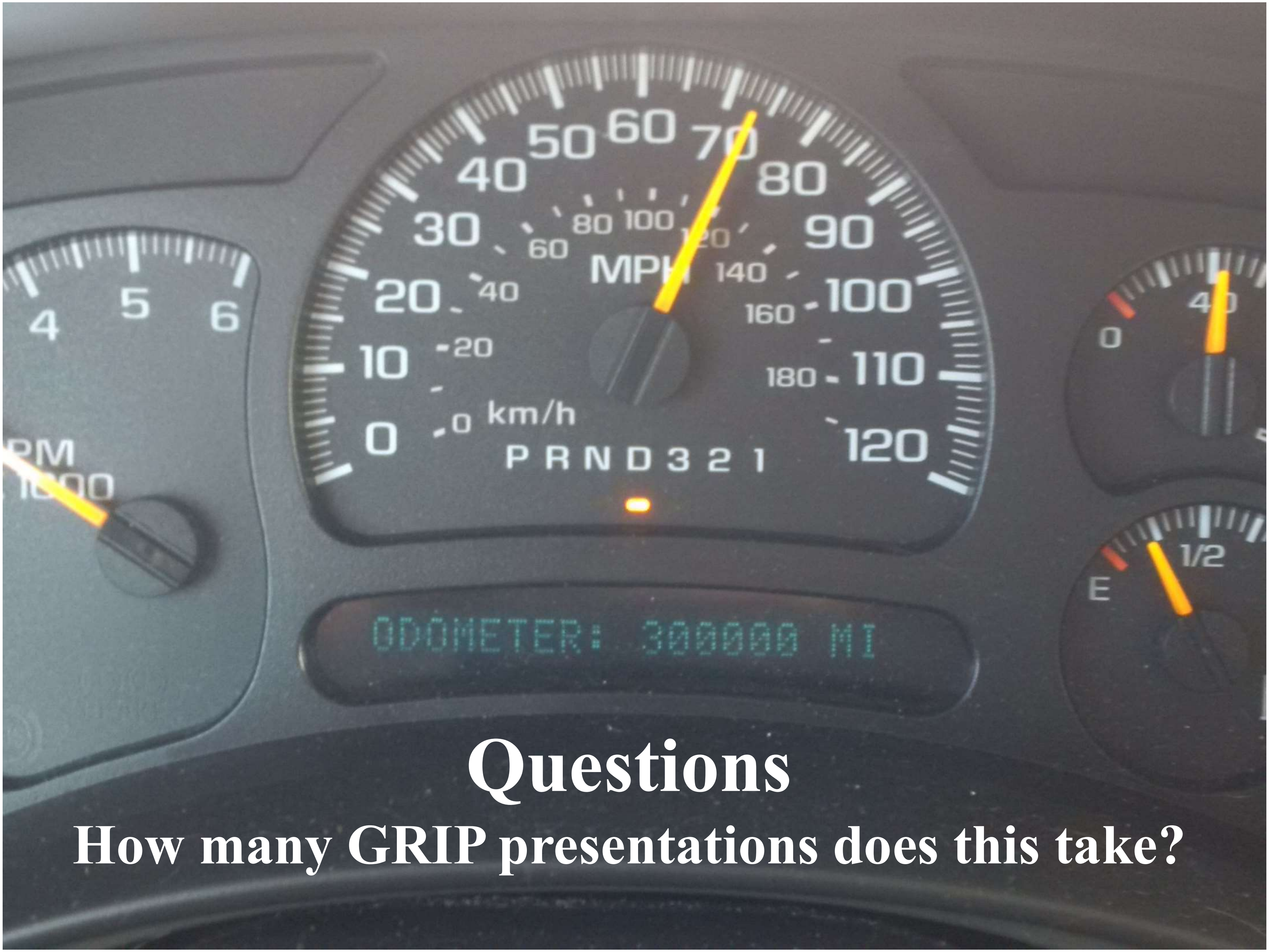


Conclusions

- Temporary casing does affect side shear in rock sockets
- Small annulus fine rotated casing had least effect
- Driven with no annulus caused damage making it more affected
- Large annulus coarse casing was most affected.
- Measured exceeded design capacity for all samples
- Present specification reducing side shear to 50% is reasonable, no specimen fell below that level.

Full Scale Tests

- RW Harris' Miami Office has limestone near surface
- Pull out frame or Simply supported beam D1143 or D3689
- Rapid Load Test ASTM D7383


MPH
km/h
P R N D 3 2 1
ODOMETER: 300000 MI
Questions
How many GRIP presentations does this take?