# Improved Design of Drilled Shafts in Rock

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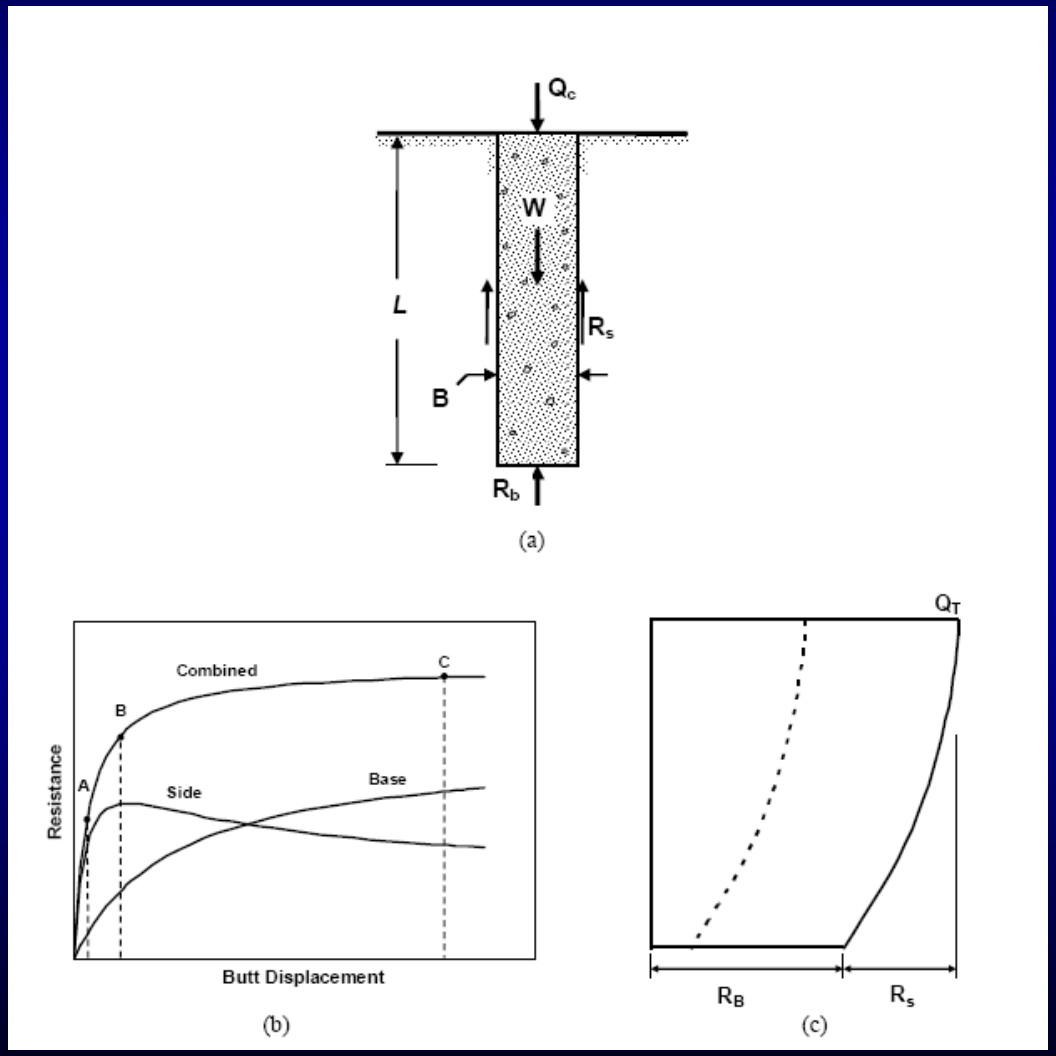
# Objectives

- Improve design methodology in rock
- Improve cost-effectiveness of drilled shafts in rock in key Southeastern markets
- Demonstrate reliability of drilled shafts founded on rock

# Design for Axial Loading

- Geotechnical Strength Limit State
  - Plunging failure
- Structural Strength Limit State
  - Structural failure
- Servicability Limit State
  - Settlements or Axial Displacement

# Generalized Behavior Under Axial Load



# Dilation at Rock/Shaft Interface

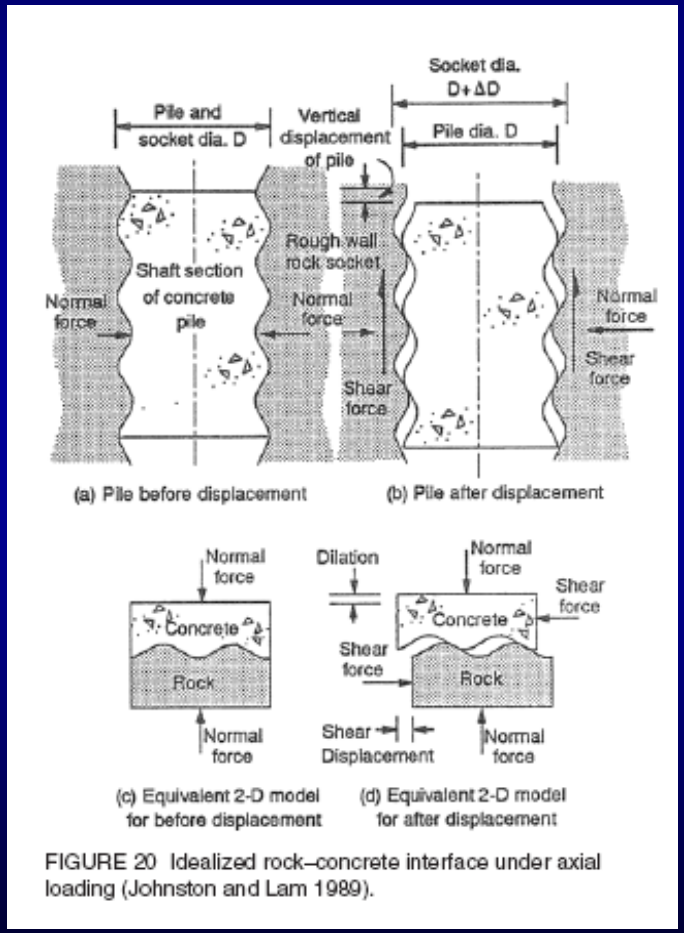



FIGURE 20 Idealized rock–concrete interface under axial loading (Johnston and Lam 1989).

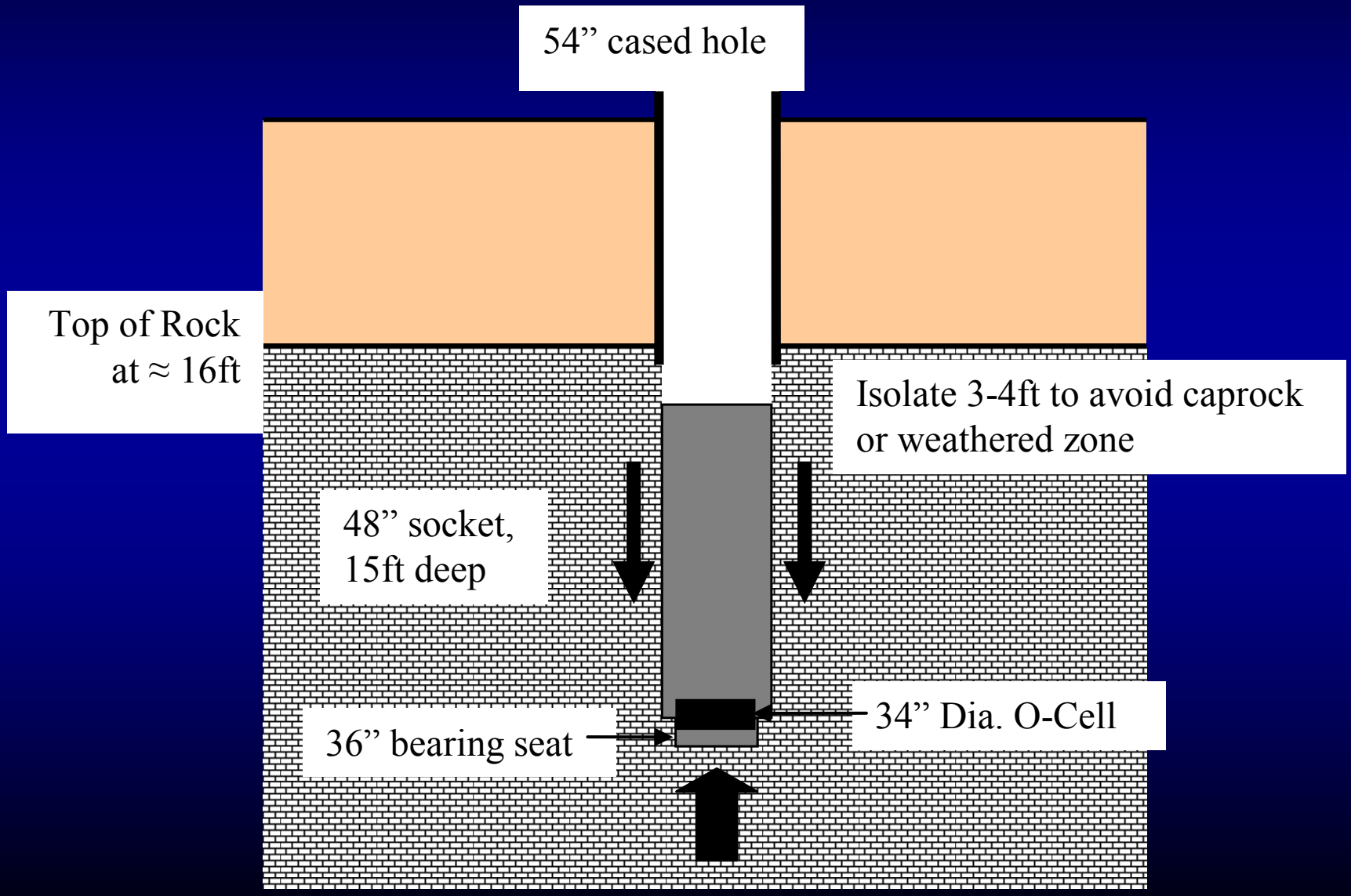
# Methodology and Scope

- Review & evaluate available load test data
- Perform select load tests under carefully controlled and well defined conditions, representative of local area
- Involve local practicing engineers to ensure that the tests are representative and meaningful for local practice
- Evaluate test data and develop recommendations
- Organize local seminars to transfer research into practice and share local experiences

# Test Plan for Nashville

- Select site with appropriate geologic characteristics
- Perform two O-cell tests, with machine-only bottom cleaning and less than ideal rock conditions
- Adjust dimensions of 2$^{nd}$ test based on results of 1$^{st}$ test

# 1st Test


54” cased hole
Top of Rock
at ≈ 16ft
Isolate 3-4ft to avoid caprock
or weathered zone
48” socket,
15ft deep
34” Dia. O-Cell
36” bearing seat

# Boring Logs (thanks PSI)

Project: **Long Project** | PSI No.: | Date: 5
Location: **Nashville, TN**

Boring No.: **B-1** | Total Depth: **36.0'** | Elev.: | Water at Completion of Drilling: **After Co**
Boring Method: **Hollow Stem Auger** | Drill Type: **CME-55** | Driller: **JH**

| Elevation (MSL) | Depth (feet) | Sample | DESCRIPTION OF MATERIALS | N | N VALUE (bpf) 10 20 30 40 50 60 70 80 90 | %M | LL | PI | Q |
|---|---|---|---|---|---|---|---|---|---|
| | 0.5 | | 6" CRUSHED LIMESTONE<br>Brown CLAY with chert and silt.<br>(DRILLER DESCRIPTION) | | | | | | |
| | 16.0 | | Auger Refusal 16.0 Feet; Begin Coring.<br><br>Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, slightly fractured.<br>REC=100%; RQD=64% | | | | | | |
| | 26.0 | | Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, slightly fractured.<br>REC=100%; RQD=65% | | | | | | |
| | 36.0 | | Coring Terminated 36.0 Feet<br><br>Water Level After Coring 3.0 Feet | | | | | | |

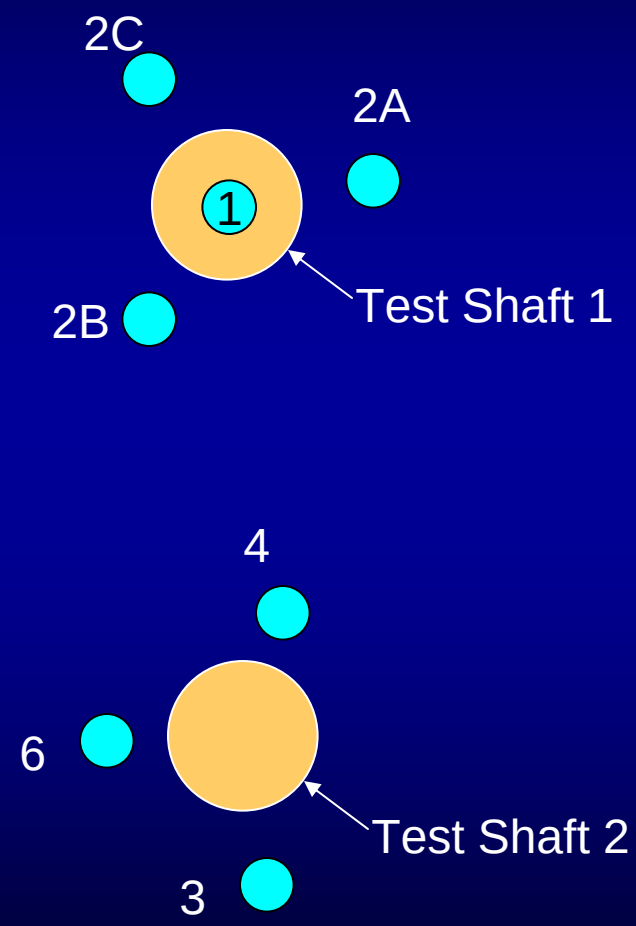
Project: **Long Project** | PSI
Location:

Boring No.: **B-2** | Total Depth: **36.5'** | Elev.: | Water at
Boring Method: **Hollow Stem Auger** | Drill Type: **CME-55**

| Elevation (MSL) | Depth (feet) | Sample | DESCRIPTION OF MATERIALS | N | N VALUE (bp 10 20 30 40 50 6 |
|---|---|---|---|---|---|
| | 0.7 | | 8" CRUSHED LIMESTONE<br>Brown CLAY with chert and silt.<br>(DRILLER DESCRIPTION) | | |
| | 16.5 | | Auger Refusal 16.5 Feet; Begin Coring.<br><br>Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, moderately fractured.<br>REC=93%; RQD=51% | | |
| | 26.5 | | Very Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, moderately fractured.<br>REC=97%; RQD=46% | | |
| | 36.5 | | Coring Terminated 36.5 Feet<br><br>Water Lost During Coring | | |

# Rock Conditions

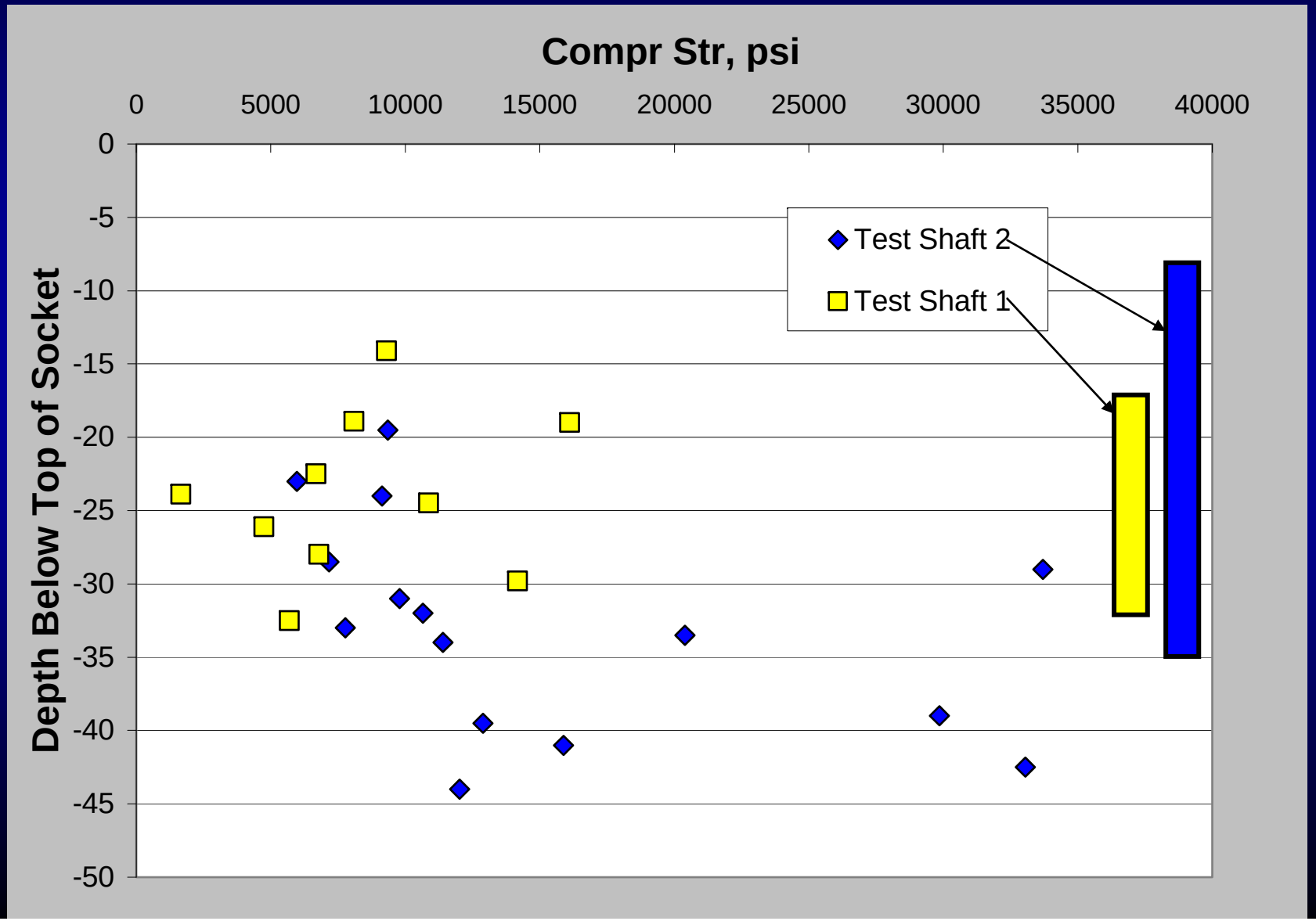
# Borings



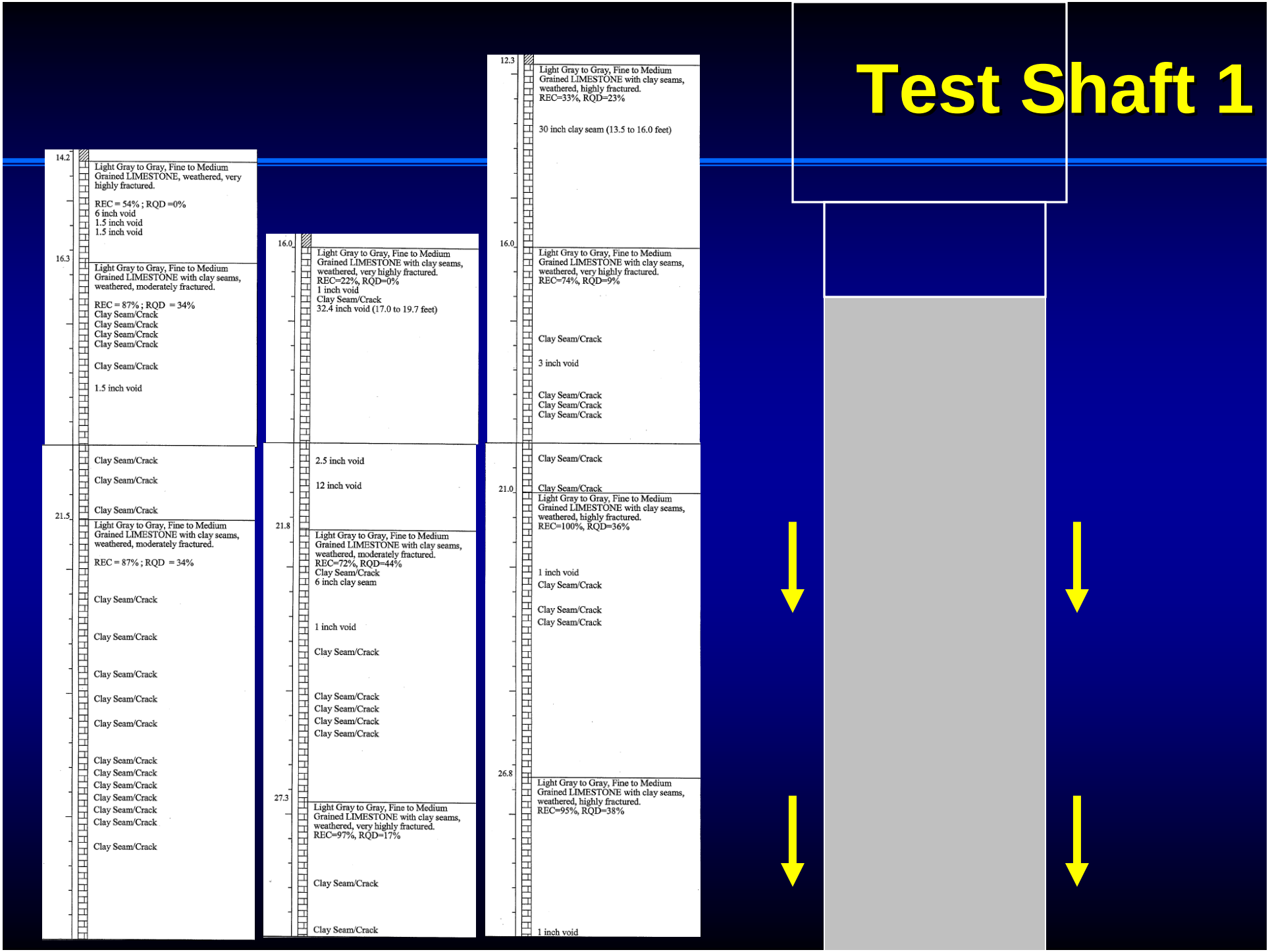
# Cores

# Cores

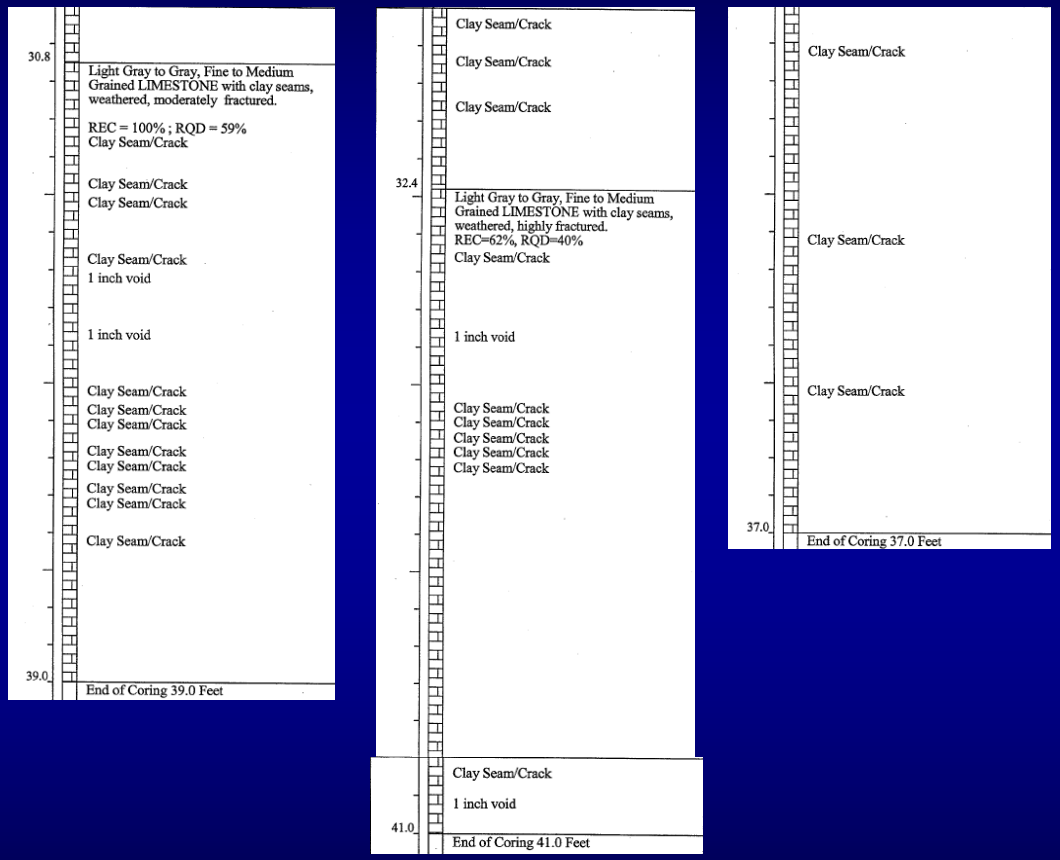
# Core Test Data

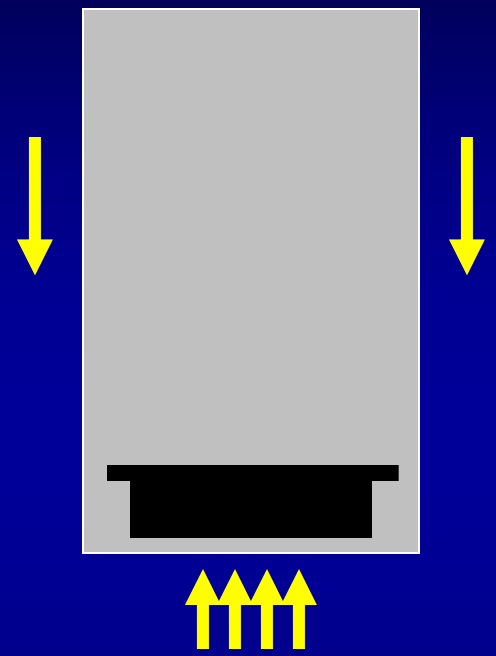


# Test Shaft 1


14.2
Light Gray to Gray, Fine to Medium Grained LIMESTONE, weathered, very highly fractured.
REC = 54% ; RQD =0%
6 inch void
1.5 inch void
1.5 inch void
16.3
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, moderately fractured.
REC = 87% ; RQD = 34%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
1.5 inch void
21.5
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, moderately fractured.
REC = 87% ; RQD = 34%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
16.0
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, very highly fractured.
REC=22%, RQD=0%
1 inch void
Clay Seam/Crack
32.4 inch void (17.0 to 19.7 feet)
2.5 inch void
12 inch void
21.8
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, moderately fractured.
REC=72%, RQD=44%
Clay Seam/Crack
6 inch clay seam
1 inch void
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
27.3
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, very highly fractured.
REC=97%, RQD=17%
Clay Seam/Crack
Clay Seam/Crack
12.3
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, highly fractured.
REC=33%, RQD=23%
30 inch clay seam (13.5 to 16.0 feet)
16.0
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, very highly fractured.
REC=74%, RQD=9%
Clay Seam/Crack
3 inch void
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
21.0
Clay Seam/Crack
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, highly fractured.
REC=100%, RQD=36%
1 inch void
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
26.8
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, highly fractured.
REC=95%, RQD=38%
1 inch void

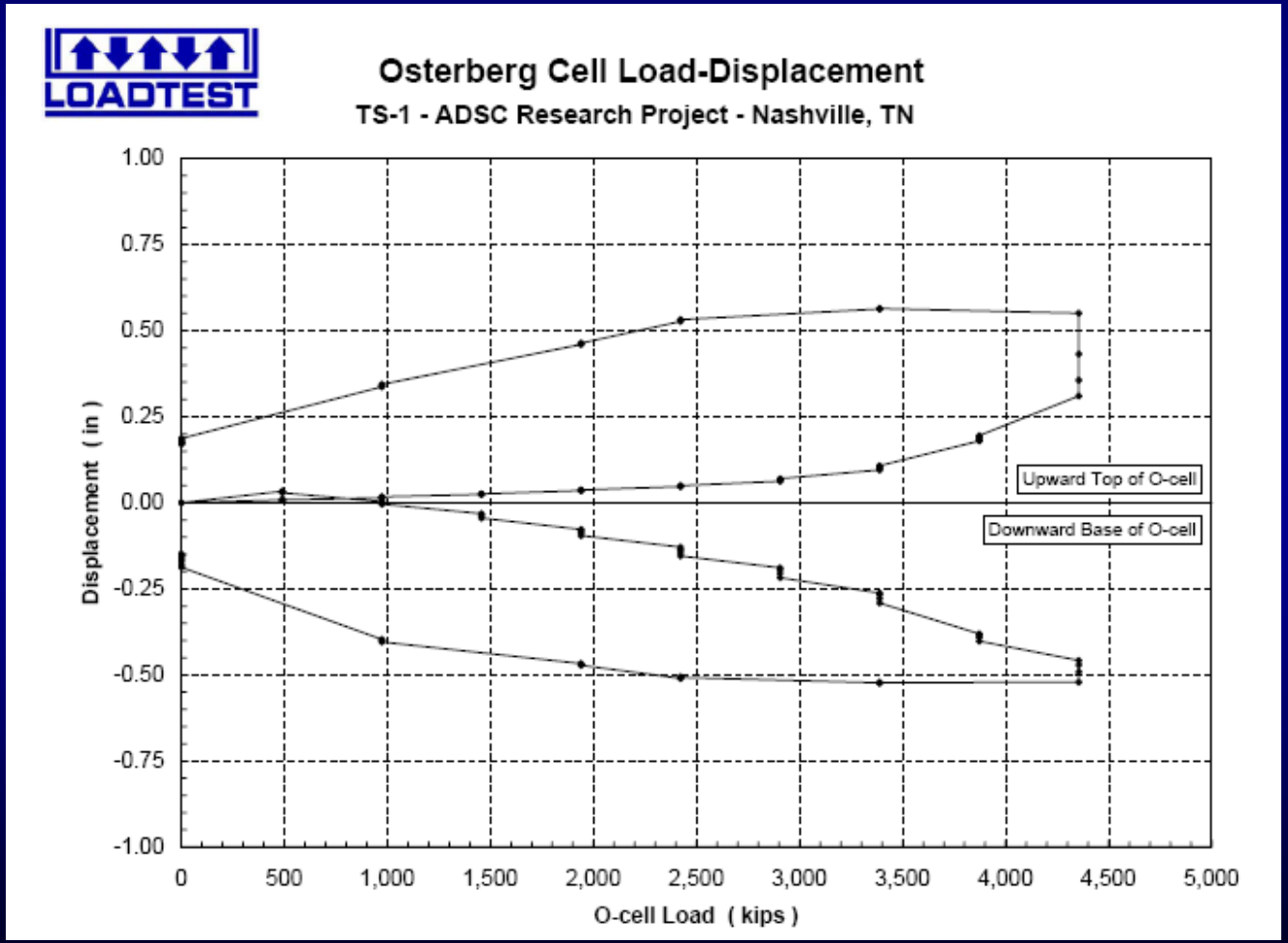
# Test Shaft 1


30.8
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, moderately fractured.
REC = 100% ; RQD = 59%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
1 inch void
1 inch void
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
39.0
End of Coring 39.0 Feet
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
32.4
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, weathered, highly fractured.
REC=62%, RQD=40%
Clay Seam/Crack
1 inch void
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
1 inch void
41.0
End of Coring 41.0 Feet
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
37.0
End of Coring 37.0 Feet

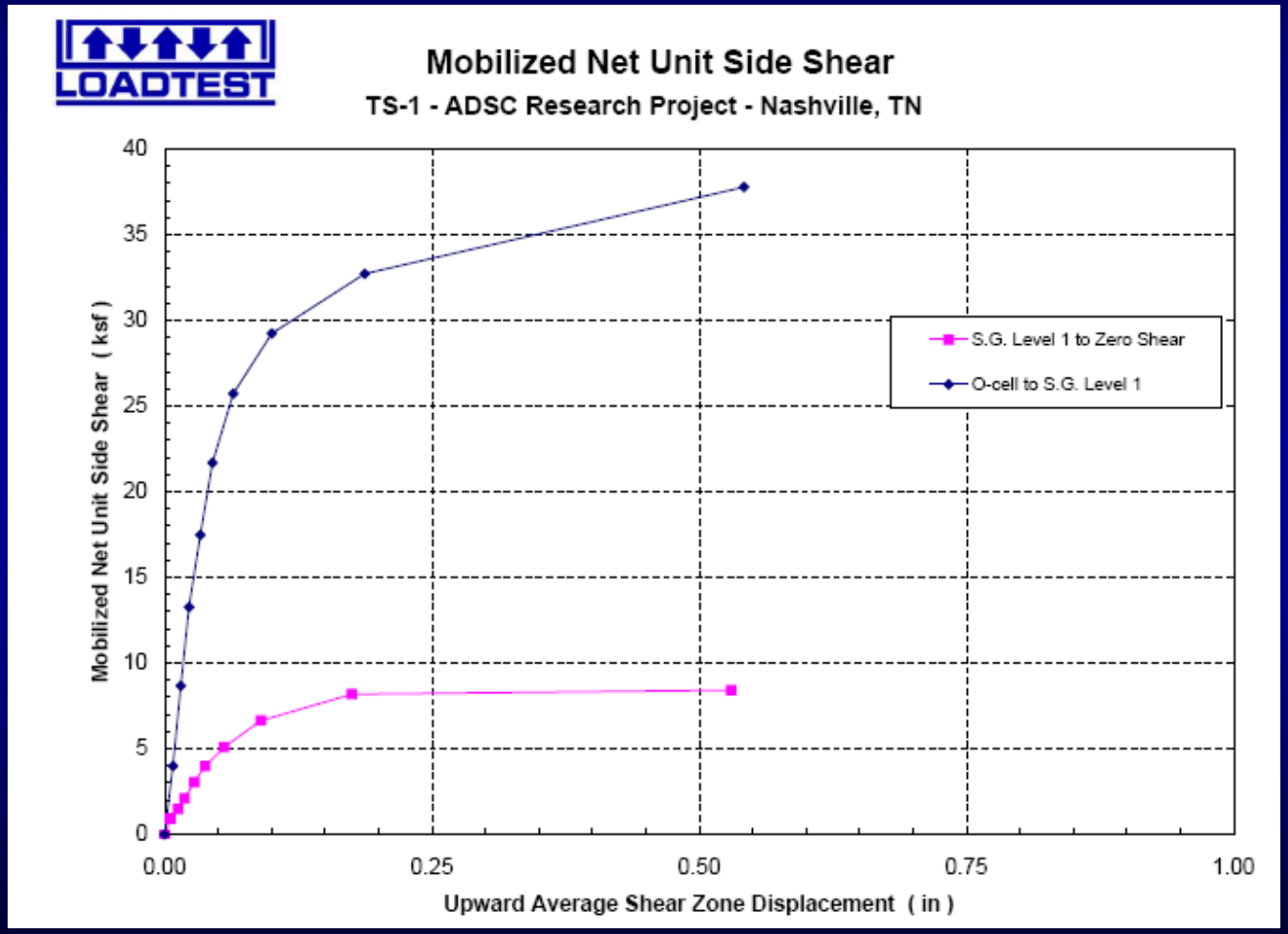


# Load Test

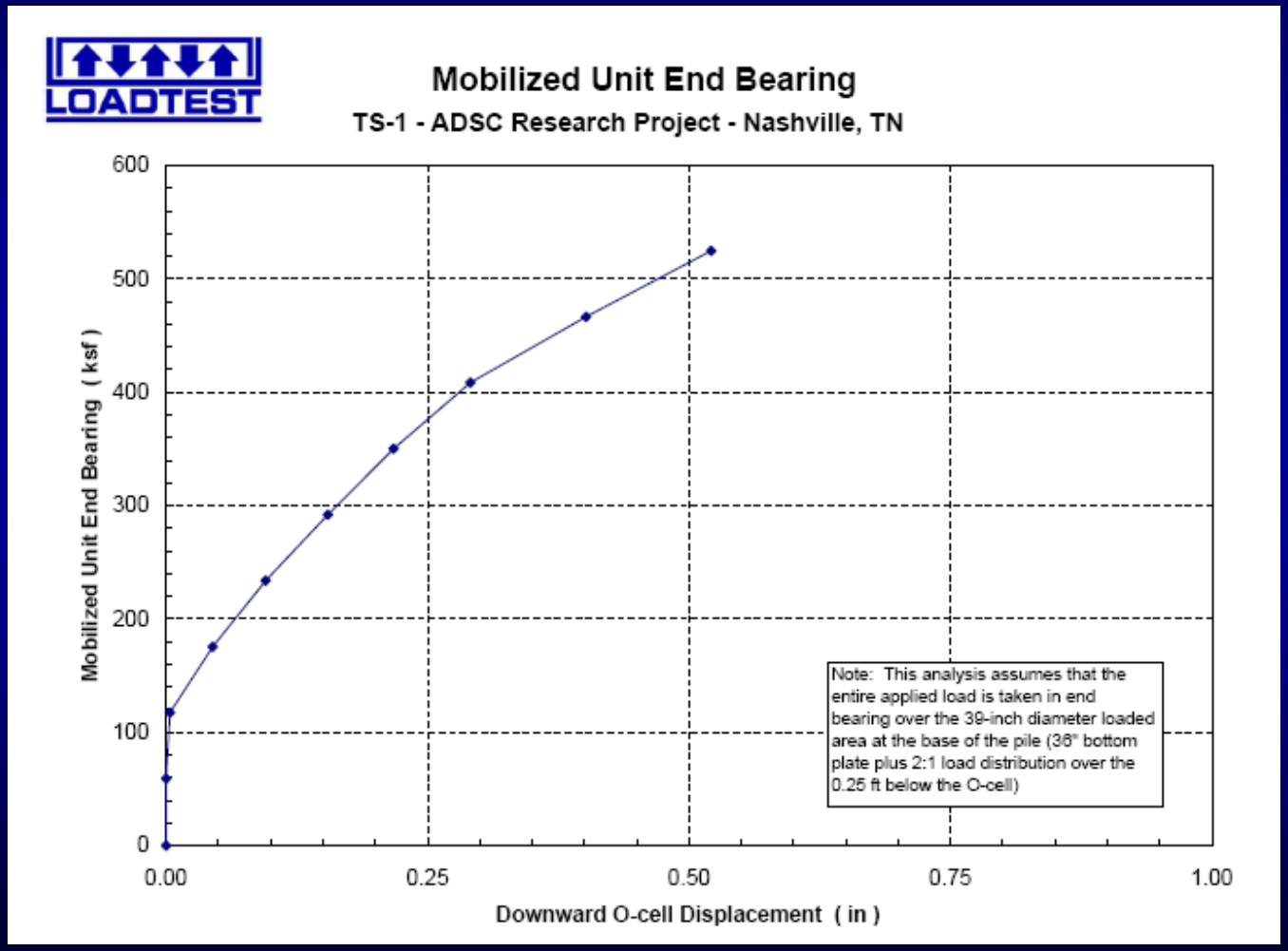
# Test Results – Shaft 1



# Test Results – Shaft 1



# Test Results – Shaft 1



# Predictions

**ADSC SE Chapter Research Project - Nashville Test Site Shaft #1**

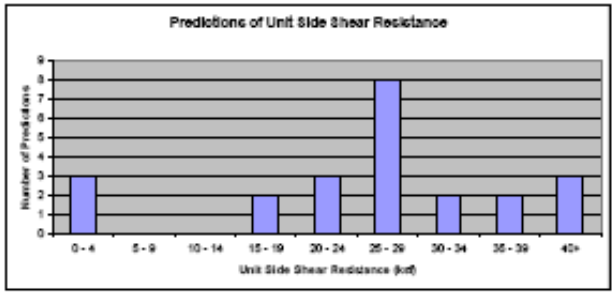
**Test Results Summary**

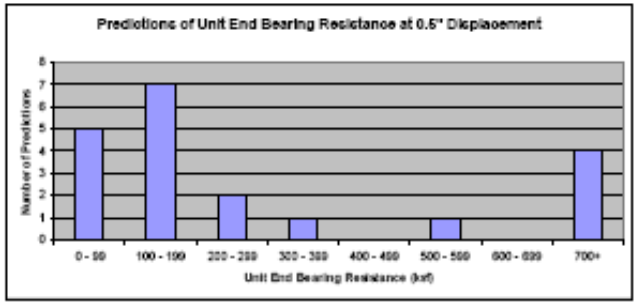
| | | |
|---|---|---|
| Maximum Displacement | 0.55 | Inch |
| Mobilized Unit End Bearing at 0.55" | 530 | ksf |
| Mobilized Unit End Bearing at 0.5" | 520 | ksf |
| Average Mobilized Unit Side Shear | 24.2 | ksf |

**Prediction Analysis**

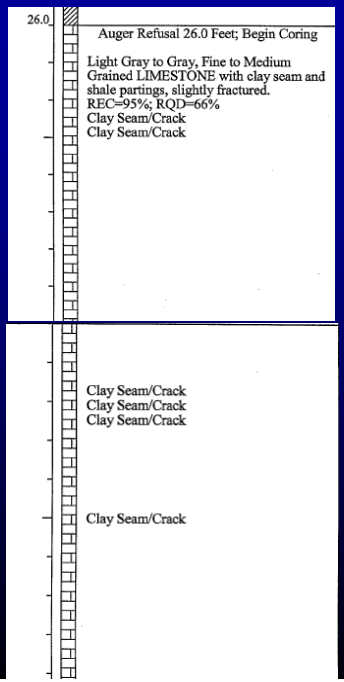
| | Max. Unit Base Resistance (ksf) | Max. Unit Side Shear (ksf) | Unit Base Resistance at 0.5" displ. (ksf) |
|---|---|---|---|
| Number of Predictions | 20 | 21 | 18 |
| Maximum | 1039 | 86.4 | 987 |
| Minimum | 23.5 | 0.5 | 2 |
| Mean | 332 | 28 | 305 |
| Median | 170 | 26 | 141 |
| Test Results | ?? | 24.2 | 520 |

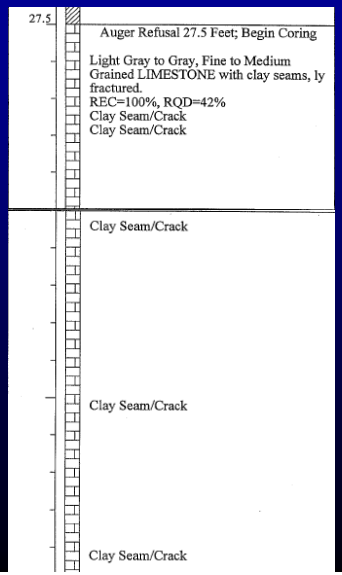
**Distributions of Predictions**

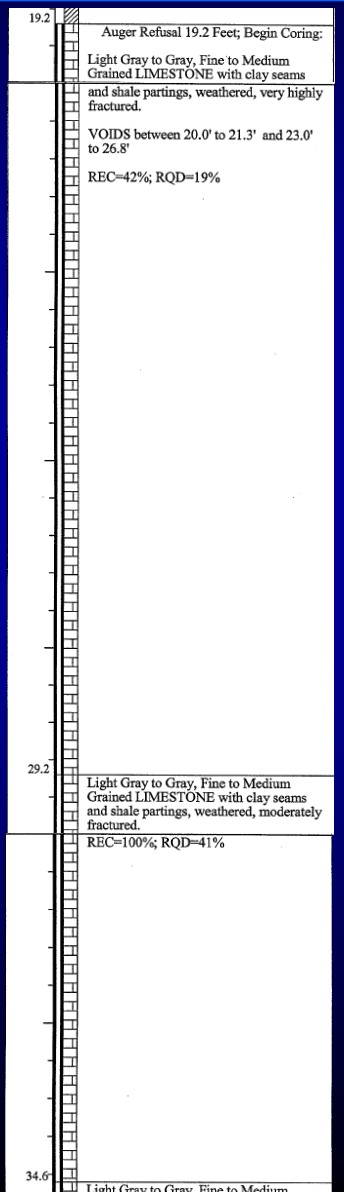


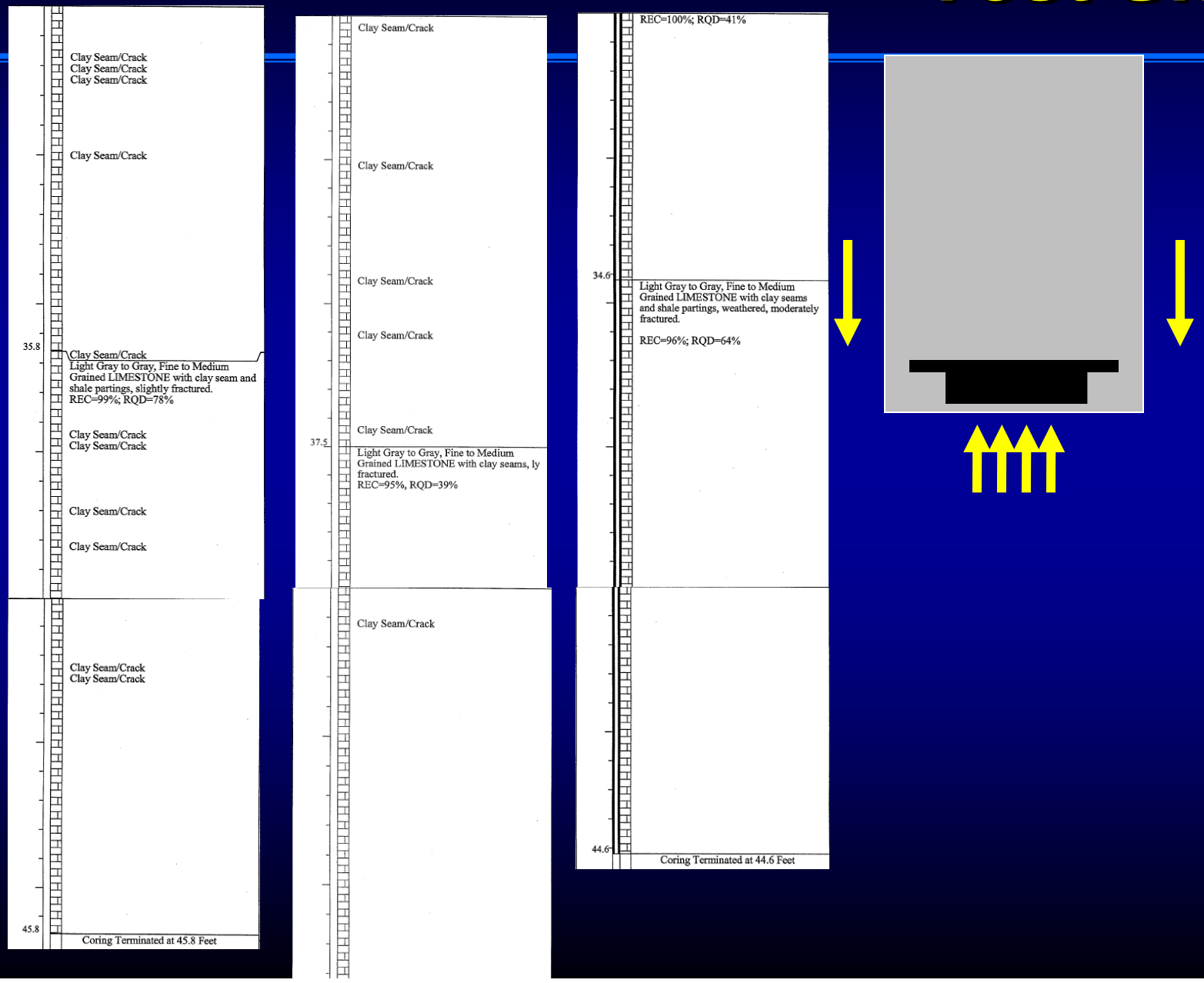
# Test Shaft 2


26.0
Auger Refusal 26.0 Feet; Begin Coring
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seam and shale partings, slightly fractured.
REC=95%; RQD=66%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack

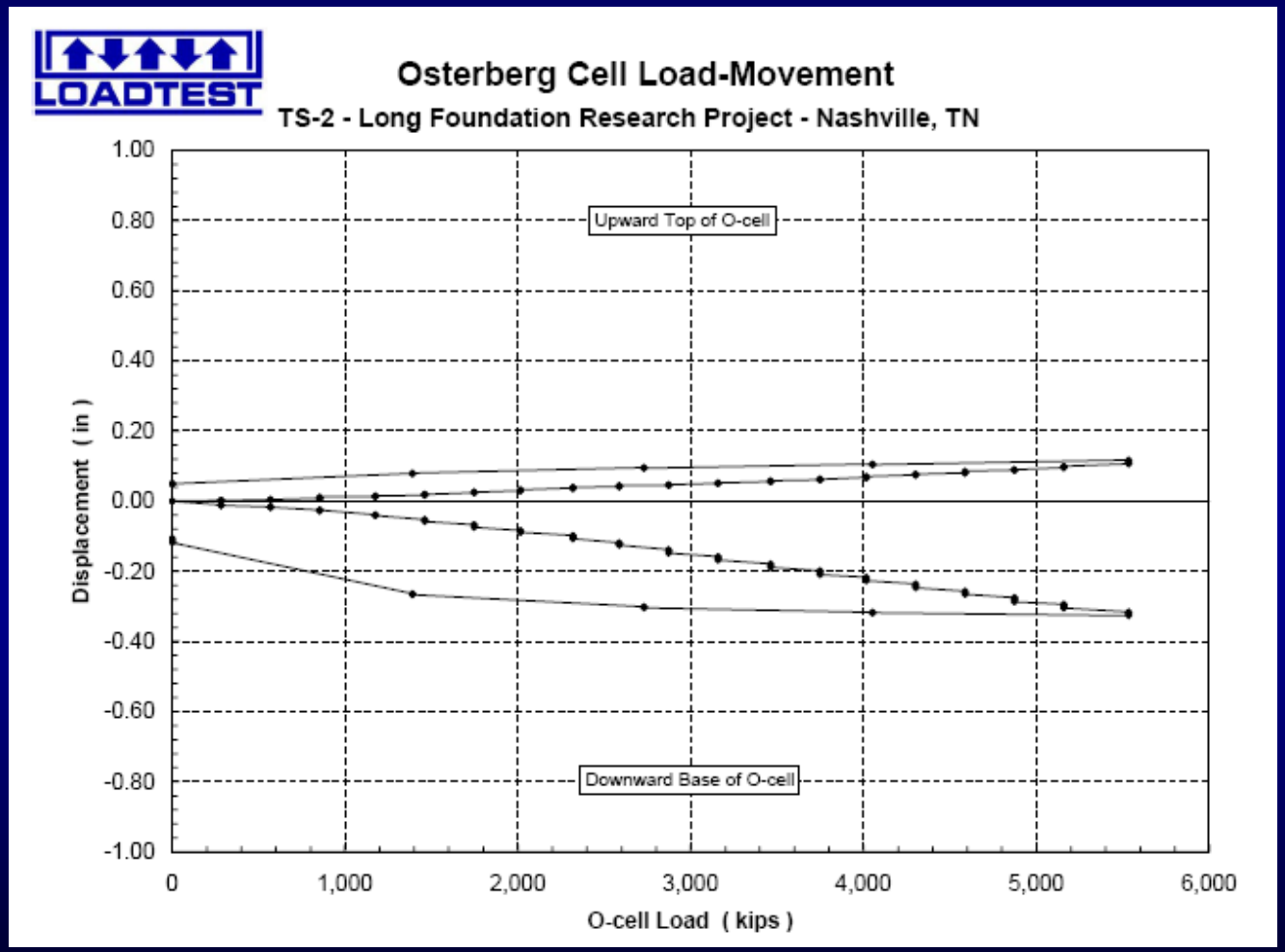

27.5
Auger Refusal 27.5 Feet; Begin Coring
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, ly fractured.
REC=100%, RQD=42%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack


19.2
Auger Refusal 19.2 Feet; Begin Coring:
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, weathered, very highly fractured.
VOIDS between 20.0' to 21.3' and 23.0' to 26.8'
REC=42%; RQD=19%
29.2
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, weathered, moderately fractured.
REC=100%; RQD=41%
34.6
Light Gray to Gray, Fine to Medium

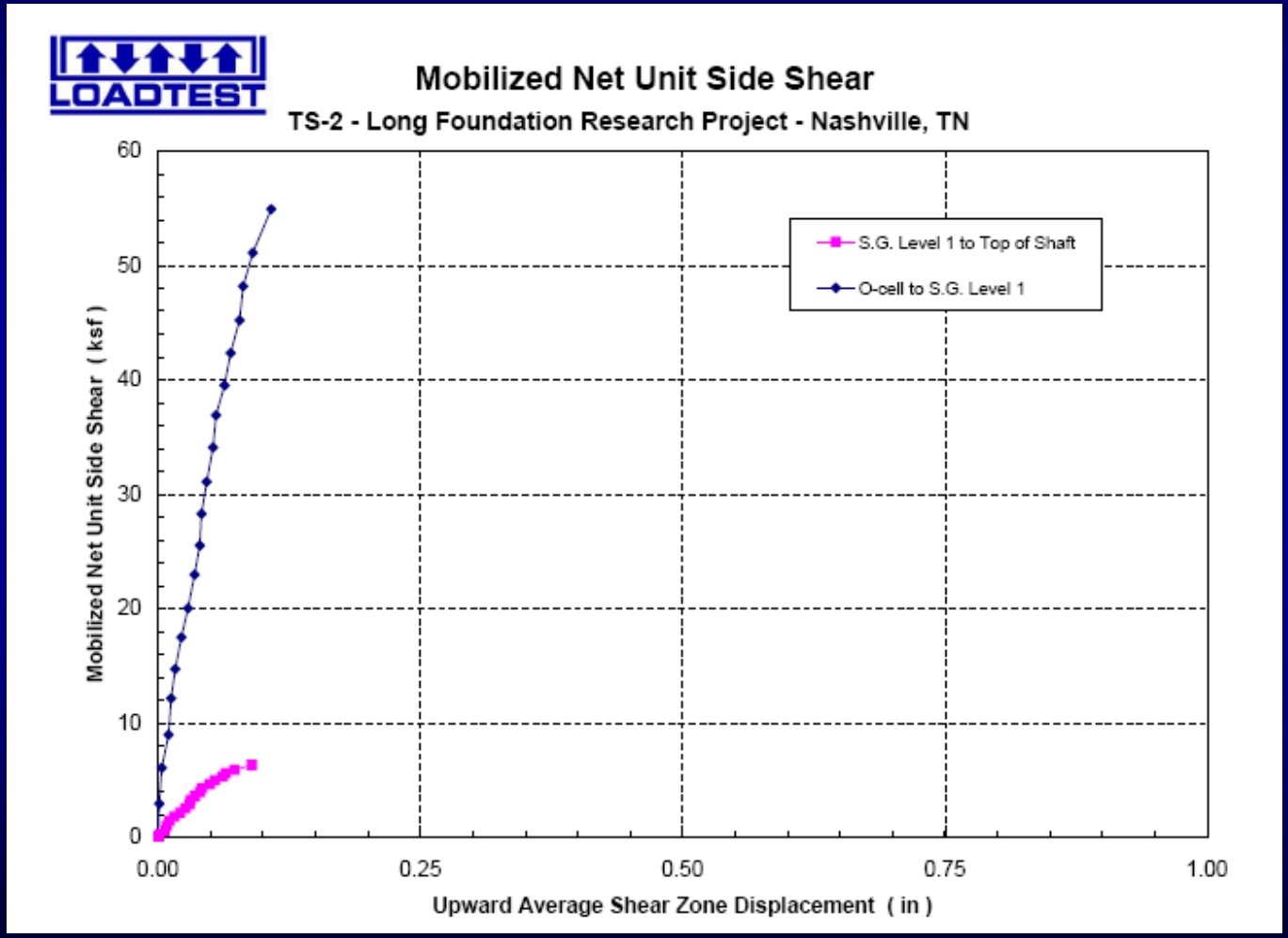
# Test Shaft 2


Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
35.8
Clay Seam/Crack
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seam and shale partings, slightly fractured.
REC=99%; RQD=78%
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
Clay Seam/Crack
37.5
Clay Seam/Crack
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams, ly fractured.
REC=95%, RQD=39%
Clay Seam/Crack
REC=100%; RQD=41%
34.6
Light Gray to Gray, Fine to Medium Grained LIMESTONE with clay seams and shale partings, weathered, moderately fractured.
REC=96%; RQD=64%
44.6
Coring Terminated at 44.6 Feet
Clay Seam/Crack
Clay Seam/Crack
45.8
Coring Terminated at 45.8 Feet

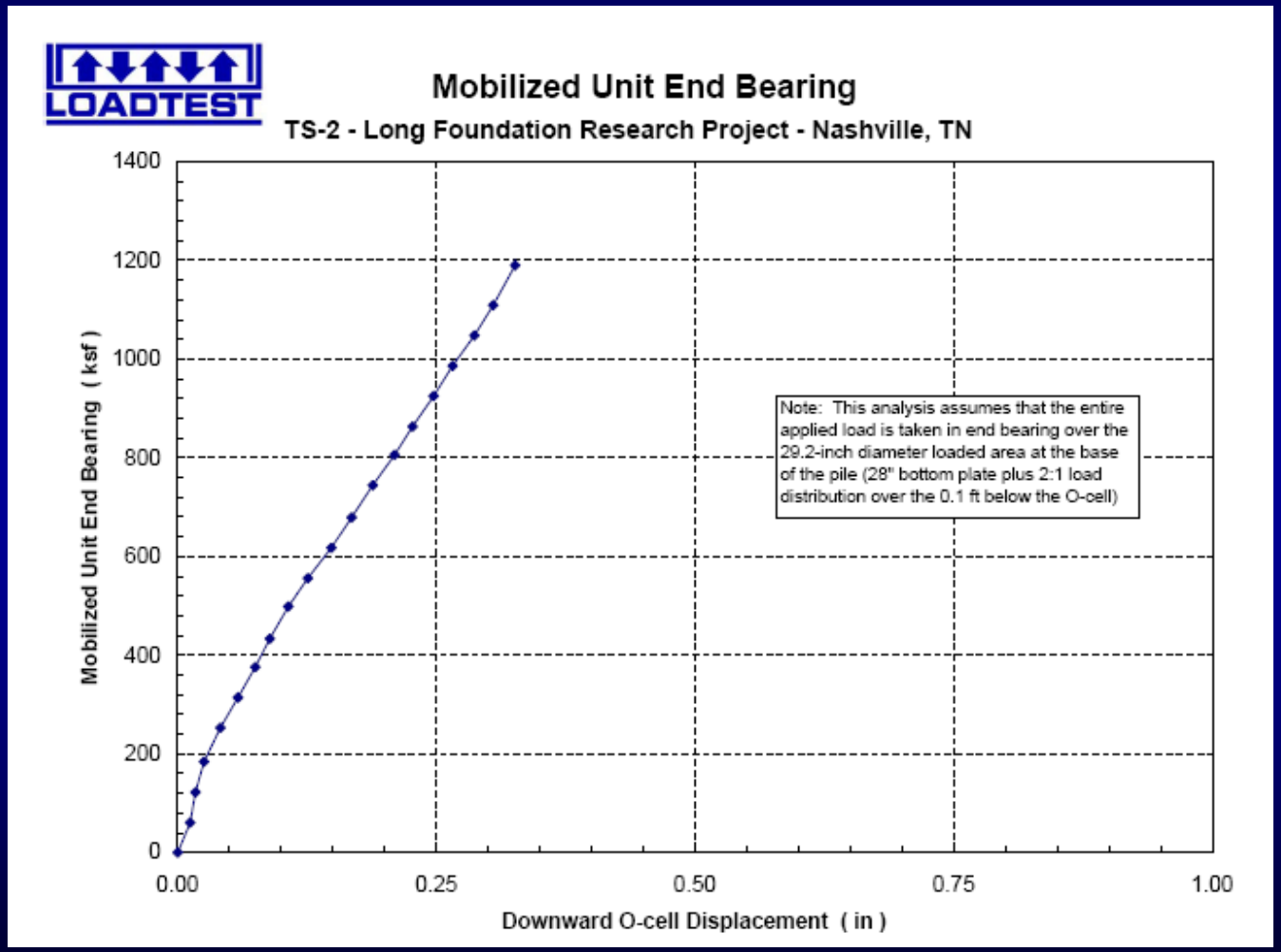
# Test Results – Shaft 2



# Test Results – Shaft 2



# Test Results – Shaft 2



# Conclusions

- Extremely high end bearing available in “imperfect” rock bearing stratum
- Unit side shear resistance >25ksf in limestone with low RQD
- Machine base cleaning was sufficient

**“A Well-performed Test Is Worth a Thousand Expert Opinions.”**