Case History: Multiple Axial Statnamic Tests on a Drilled Shaft Embedded in Shale

Paul J. Axtell[1], P.E.

J. Erik Loehr[2], Ph.D., P.E.

Daniel L. Jones[1], P.E.

1. Geotechnical Engineer, U.S. Army Corps of Engineers, Kansas City District
2. Associate Professor, University of Missouri-Columbia

Project Overview

1. A flood control project on the Blue River in Kansas City, Missouri began in 1983.

2. Currently, the reconstruction of two railroad bridges that cross the Blue River are under construction.

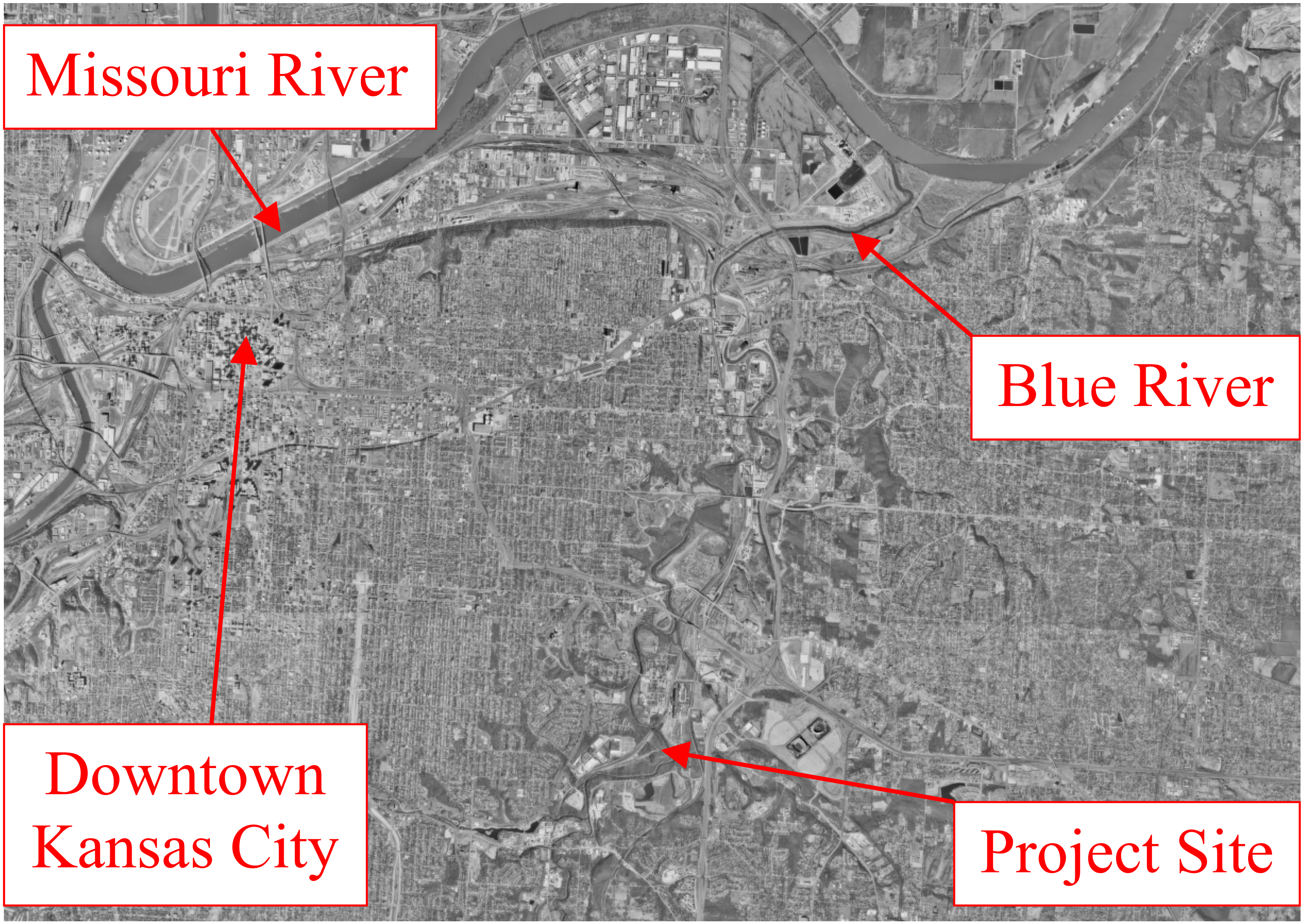
3. The bridge bents are founded on drilled shafts.

Test Objectives

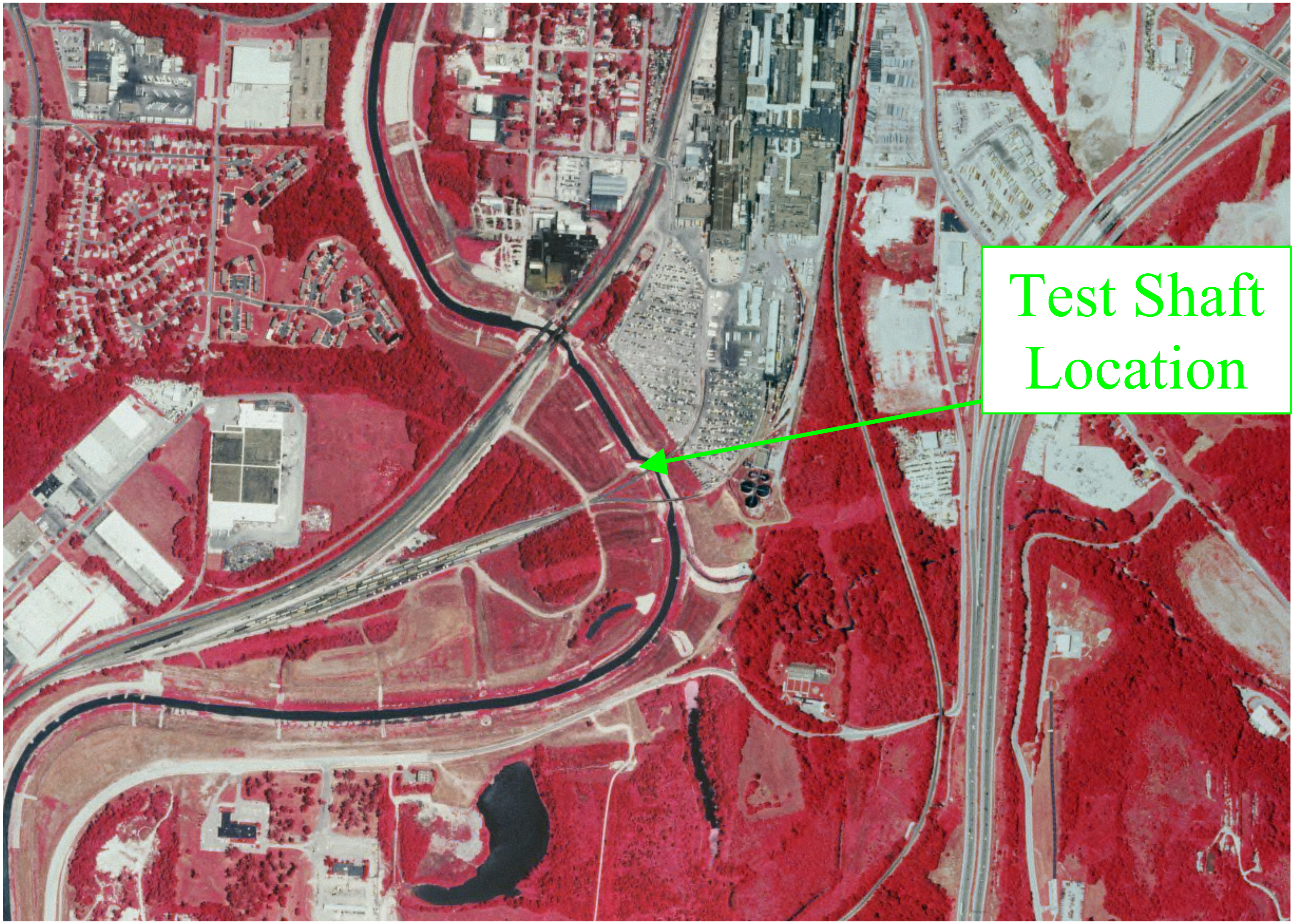
A Statnamic load test program was developed to:

1. ensure adequate capacity and acceptable deflections under anticipated loads.
2. potentially reduce the size (cost) of the foundations.
3. evaluate the drilled shaft design methodologies.
4. create a local load-test database, particularly with foundations embedded in shale.

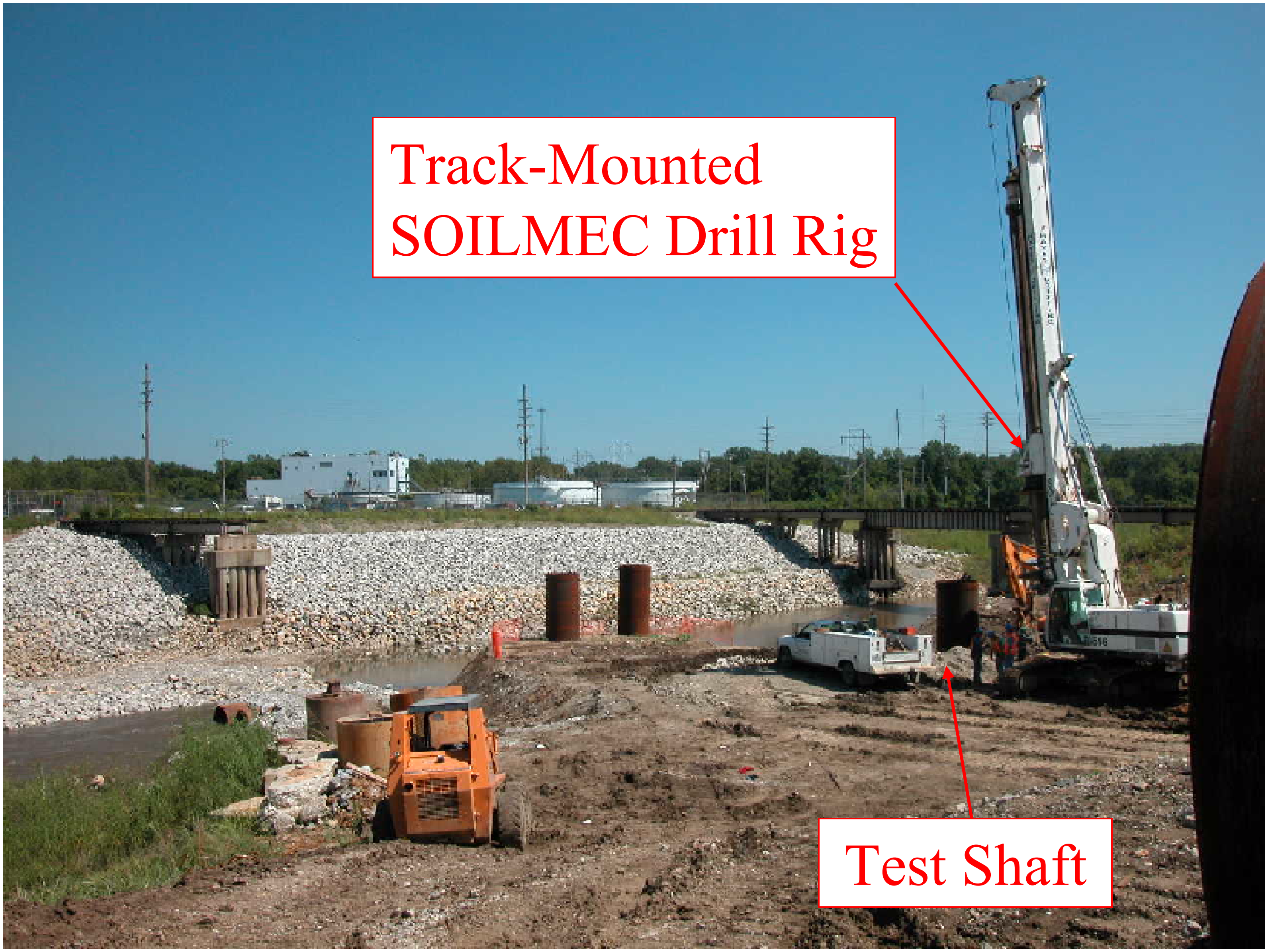
Project Vicinity



General Project Location

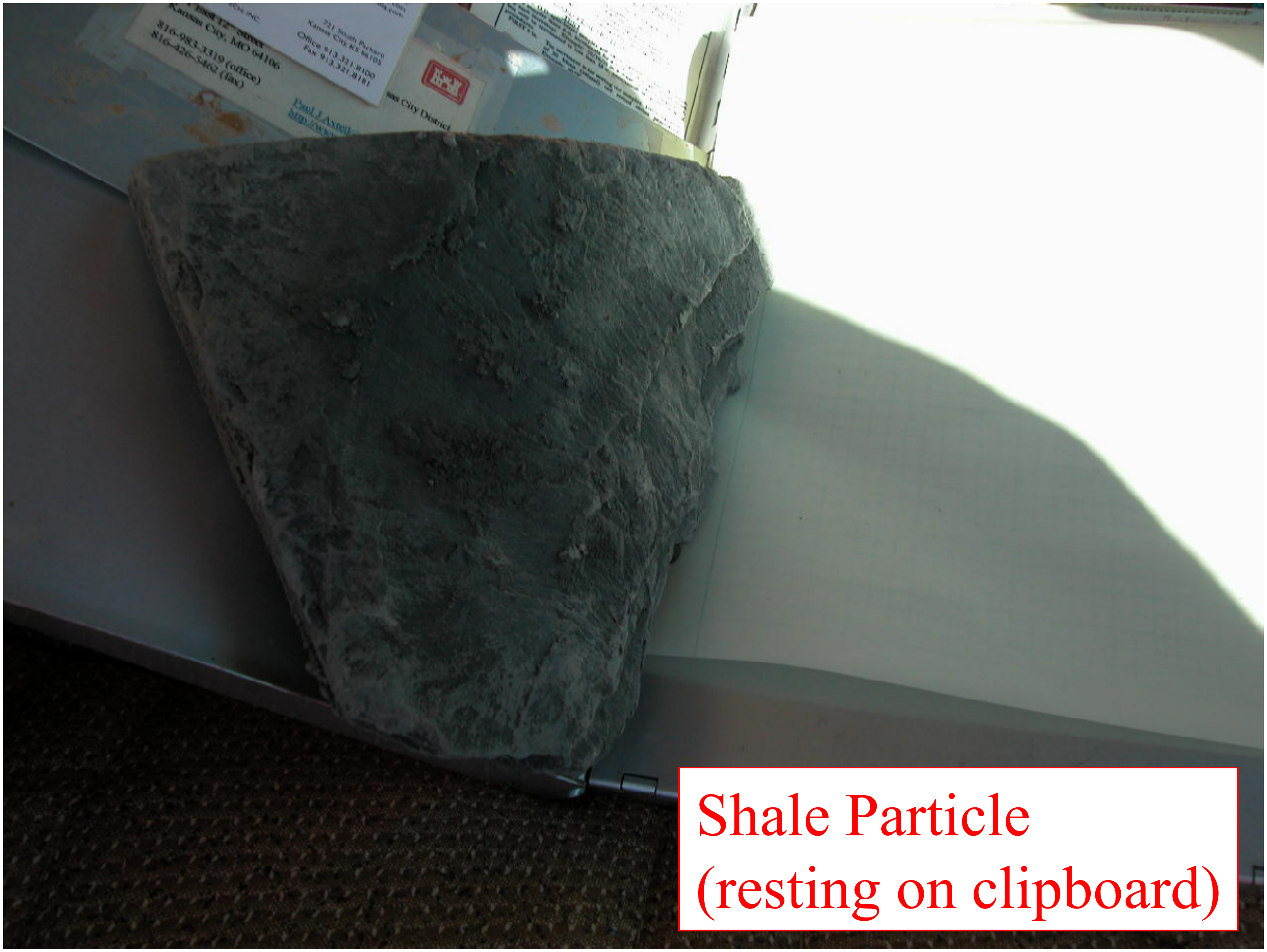


Test Shaft Location



Pleasanton Shale Drilling Spoils

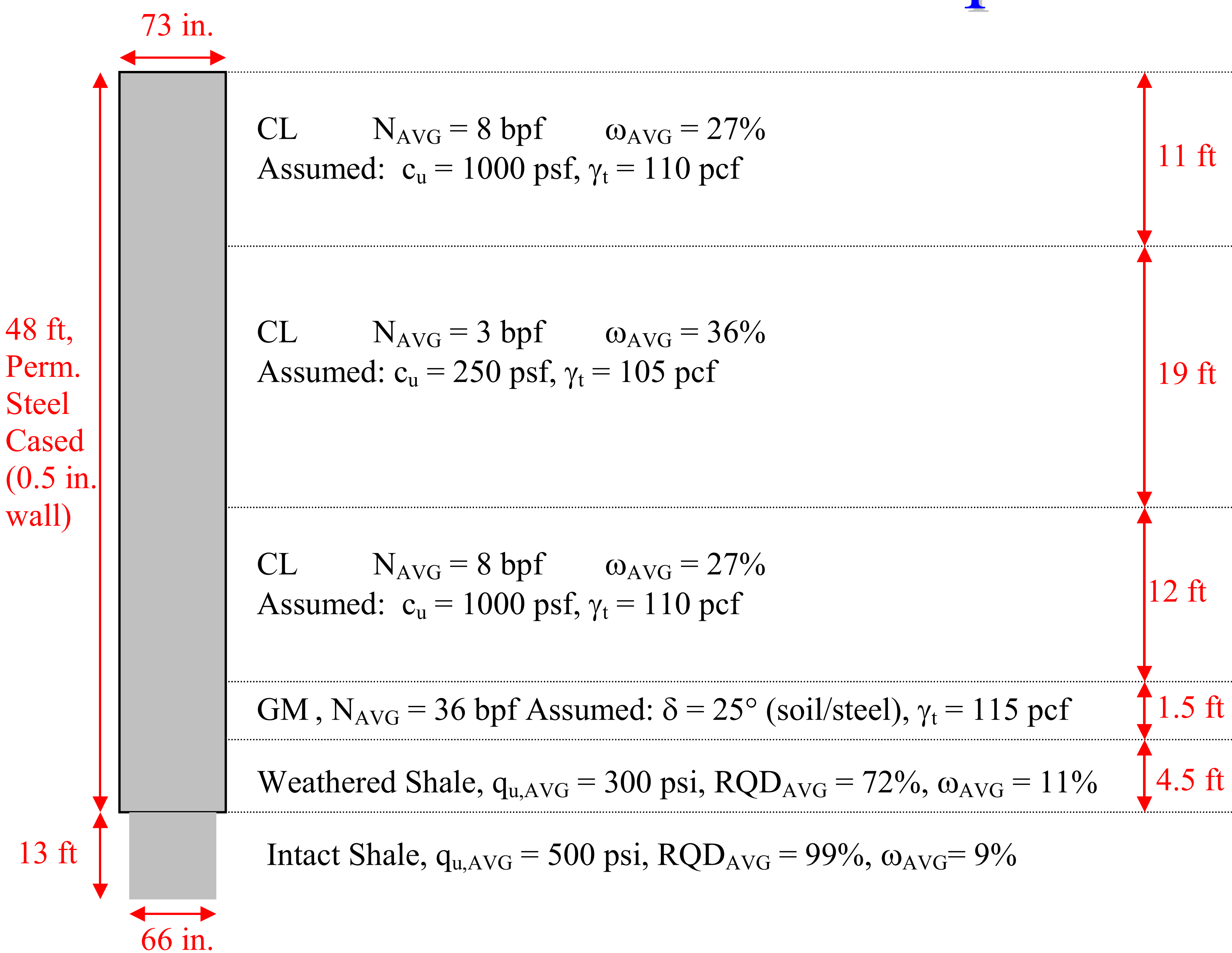
Pleasanton Shale



Reinforcing Cage

Concrete Placement

Shaft and Soil/Shale Properties



Design Side Resistance

1. CL: $\alpha = 0.55$ (O'Neill, 2001)

2. GM: $K = 0.8$ (Assumed)

3. Shale: $f_{max}/p_a = \Omega\,(q_u/2p_a)^{0.5}$

   (O'Neill, 2001 after Kulhawy and Phoon, 1993)

   where: f_{max} = max skin friction, psf

   $p_a = 2{,}116$ psf

   $\Omega = 1$ (smooth rock socket)

Design Side Resistance

Stratum I CL: side resistance = 116 kips

Stratum II CL: side resistance = 50 kips

Stratum III CL: side resistance = 126 kips

Stratum IV GM: side resistance = 27 kips

Stratum V-a Shale: side resistance = 581 kips

Stratum V-b Shale: side resistance = 1960 kips

Total Side Resistance = 2860 kips

Design Tip Resistance

$q_{max} = 4.83(q_u)^{0.51}$

(O'Neill and Reese, 1999, for intermediate geomaterials, cohesive rock with RQD between 70 and 100)

where: q_{max} = max tip resistance (MPa)

q_u = 3.45 MPa (72,000 psf)

Stratum V-b Shale: tip resistance = <u>4505 kips</u>

Design Capacity

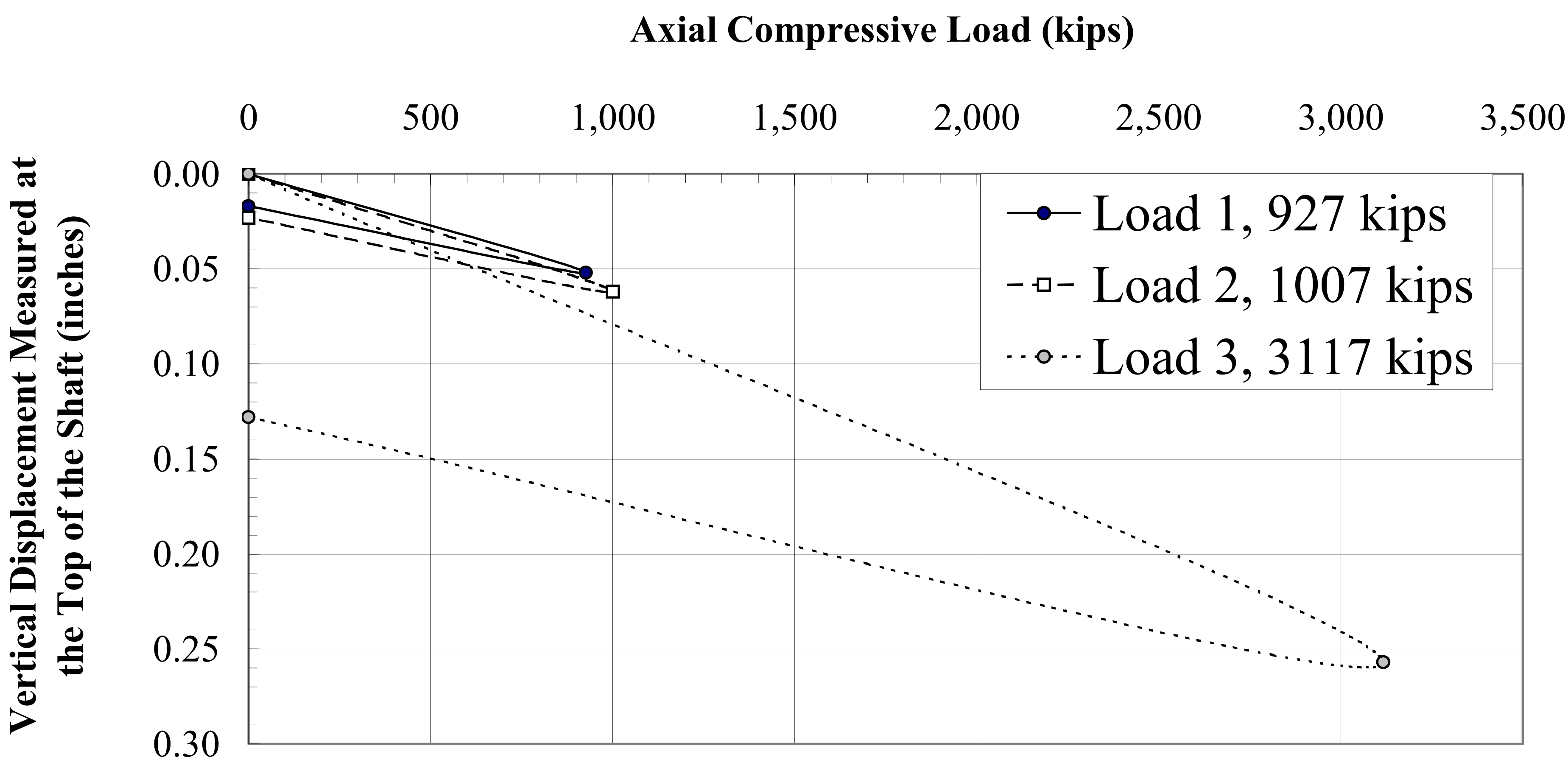
Side Resistance + Tip Resistance = Capacity

2860 + 4505 = **7365 kips**

General Statnamic Test Set-Up

Statnamic Test in Progress

Test Results



Proof-Test Problem

1. Statnamic loads were not sufficient to reach the capacity of shaft. Direct comparison of measured and calculated capacities is therefore not possible.

2. Evaluation of estimated design capacity can be accomplished based on Statnamic results by utilizing normalized load transfer relations presented by the Federal Highway Administration (O'Neill and Reese, 1999).

3. Such comparisons require *extrapolation* of the data measured in the Statnamic tests following typical load-displacement response.

Required Data to use Normalized Curves

Δ_L = elastic change in member length

k = 0.5 (all load transferred in side resistance), 0.67 (portion of the load transferred in base resistance)

$\delta_s = k\,\Delta_L$ (δ_s is the compression within the drilled shaft due to column action)

w_T = maximum movement measured during each test

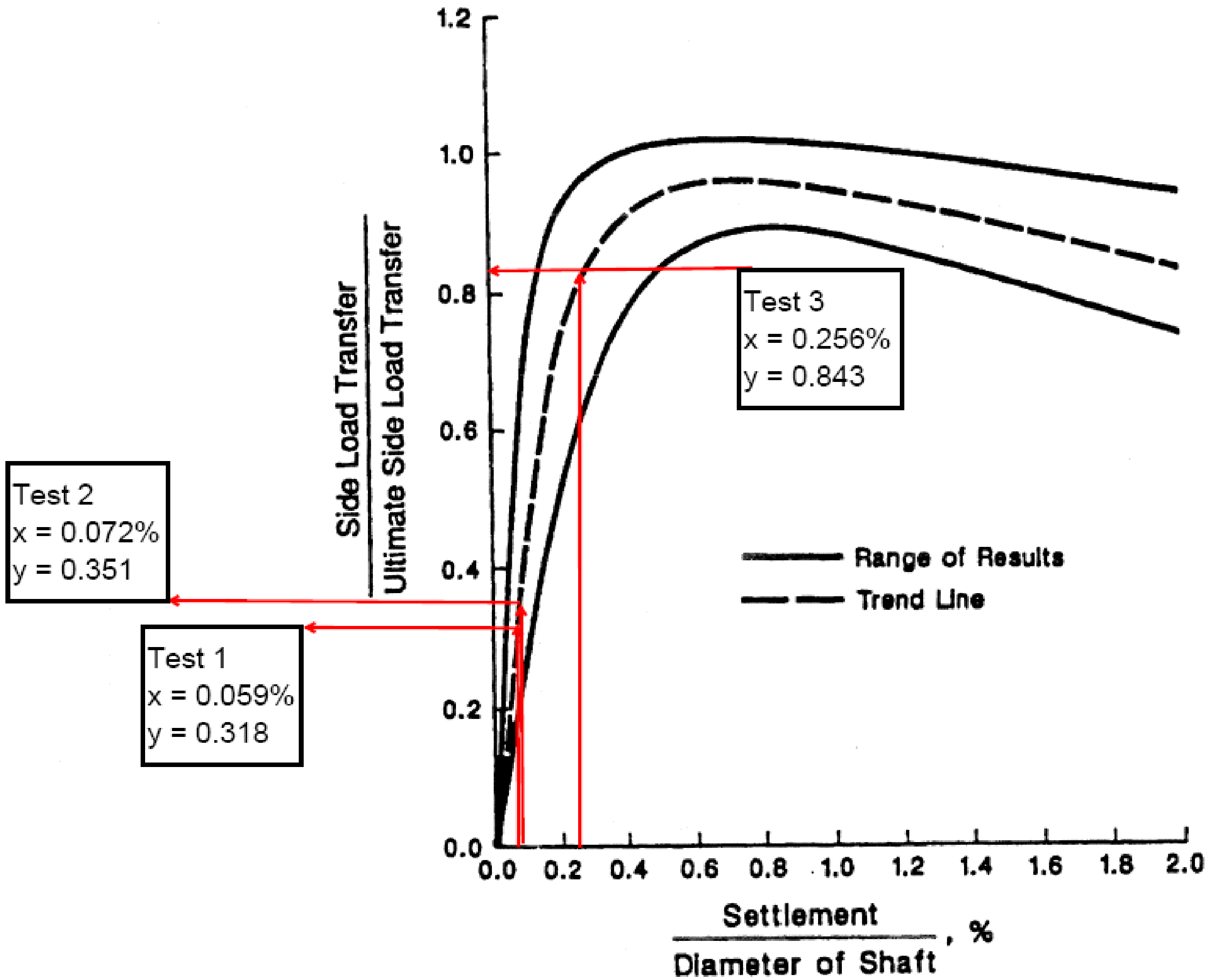
$w_s = w_T - 0.5\delta_s$ (w_s is the movement at the center of the shaft assuming uniform side load transfer rate)

$w_b = w_T - \delta_s$ (w_b is the settlement at the base)

Required Information for Use of FHWA Normalized Curves

Test	Δ_L (inches)	k	δ_s (inches)	w_T (inches)	w_s (inches)	w_b (inches)	w_s/71.5 in. (%)	w_b/66 in. (%)
1	0.039	0.5	0.020	0.052	0.043	0	0.059	0
2	0.042	0.5	0.021	0.062	0.052	0	0.072	0
3	0.131	0.67	0.088	0.257	0.213	0.169	0.298	0.256

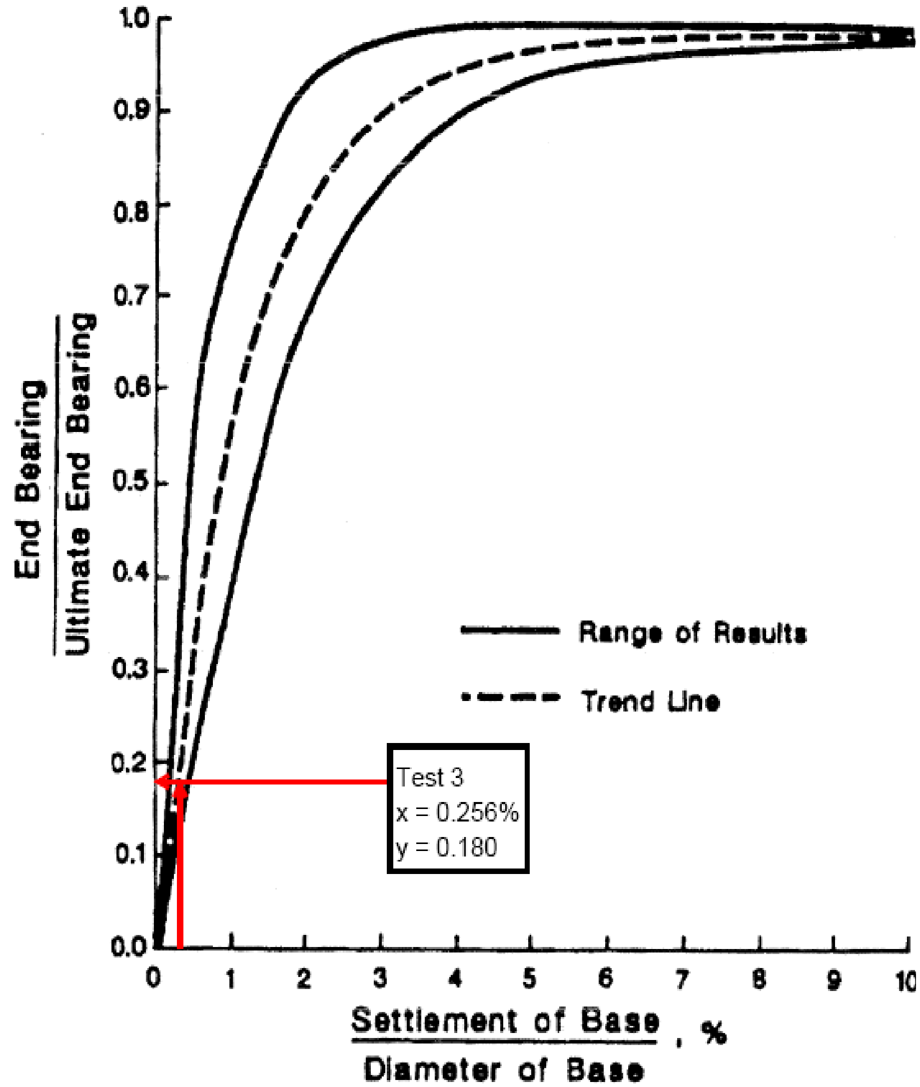
Normalized Curves for Side Resistance in Cohesive Soils



Evaluation of Side Resistance

1. Assume no load applied in Tests 1 and 2 reaches the tip
2. Ultimate side load transfer (USLT) estimated using normalized curves.
3. Entering the side resistance plot with the settlement-diameter ratio of 0.059 for Test 1, the USLT computed is 2915 kips (927/0.318).
4. Similarly, the USLT computed form Test 2 data is 2868 kips (1007/0.351).
5. The average USLT from Tests 1 and 2 is 2892 kips. This agrees very well with the design skin friction, which was 2860 kips (a difference of about 1 percent).

Normalized Curves for Base Resistance in Cohesive Soils



Evaluation of Base Resistance

1. Assuming the USLT determined in Tests 1 and 2 is accurate, the curves can be used to evaluate the base resistance using results from Test 3.
2. Based on Test 3 results, approximately 84% of the USLT is mobilized in side shear in Test 3, or 2438 kips (2892 x 0.843).
3. The remaining 679 kips (3117-2438) is therefore mobilized in end bearing.
4. Curves indicate approximately 18% of the ultimate end bearing (UEB) load is mobilized in Test 3.
5. If 679 kips are transferred in end bearing, the UEB based on the curves is 3772 kips (679/0.18).
6. Extrapolated UEB is 16% lower than the design tip resistance of 4505 kips, but within the range of variability expected of the extrapolation procedure.

Comparison

Sum of the extrapolated USLT and UEB is 6664 kips (2892+3772).

This underestimates the design capacity of 7365 kips by 10 percent.

Conclusions - 1

1. Kulhway and Phoon (1993) adequately estimates the side resistance of drilled shafts in Pleasanton shale rock sockets, assuming a smooth socket.
2. O'Neill and Reese (1999) adequately estimates the base resistance of drilled shafts in Pleasanton shale, assuming intermediate geomaterials and cohesive rock with RQD between 70 and 100.

Conclusions - 2

3. Based on Statnamic testing at varying loads and normalized curves, the contribution of side resistance to the capacity of a deep foundation can be determined assuming negligible load is transferred to the base during lower magnitude testing.
4. Normalized curves for cohesive soils appear to adequately model the load-settlement behavior of drilled shafts embedded in Pleasanton shale bedrock.

Conclusions - 3

5. No measurable rebound was observed at the conclusion of any of the three tests, perhaps suggesting plastic behavior of the shale, as opposed to elastic behavior. More data is required on this topic.

Completed Bridge

Contact Information

- Paul J. Axtell, P.E., 816-983-3319, U.S. Army Corps of Engineers, Kansas City District, paul.j.axtell@usace.army.mil

- J. Erik Loehr, Ph.D., P.E., 573-882-6380, University of Missouri-Columbia, eloehr@missouri.edu

- Daniel L. Jones, P.E., 816-983-3603, U.S. Army Corps of Engineers, Kansas City District, daniel.l.jones@usace.army.mil