UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

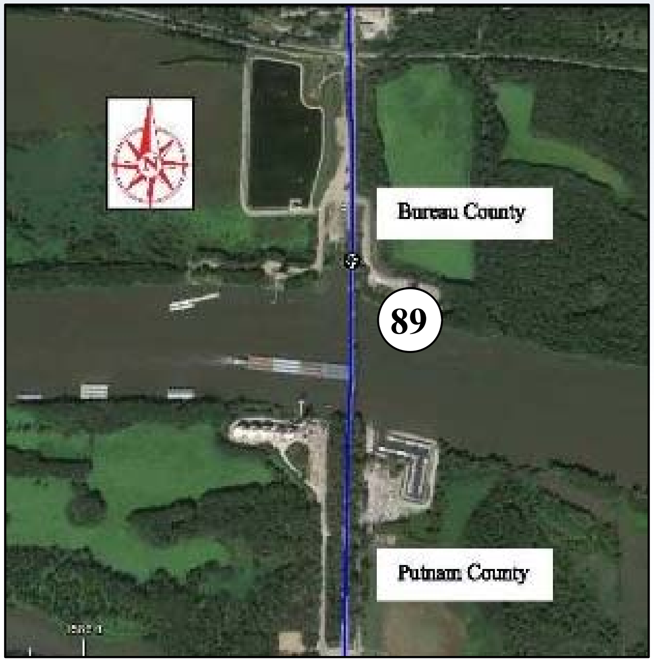
Drilled Shaft Design in Weak Illinois Rocks

Timothy D. Stark, James H. Long, & Ahmed Baghdady
University of Illinois at Urbana-Champaign
&
Abdolreza Osouli
Southern Illinois at Edwardsville

THE Conference 2018
Champaign, Illinois
February 28, 2018

illinois.edu

IL 89 Bridge – Spring Valley, IL



illinois.edu

Illinois Shales

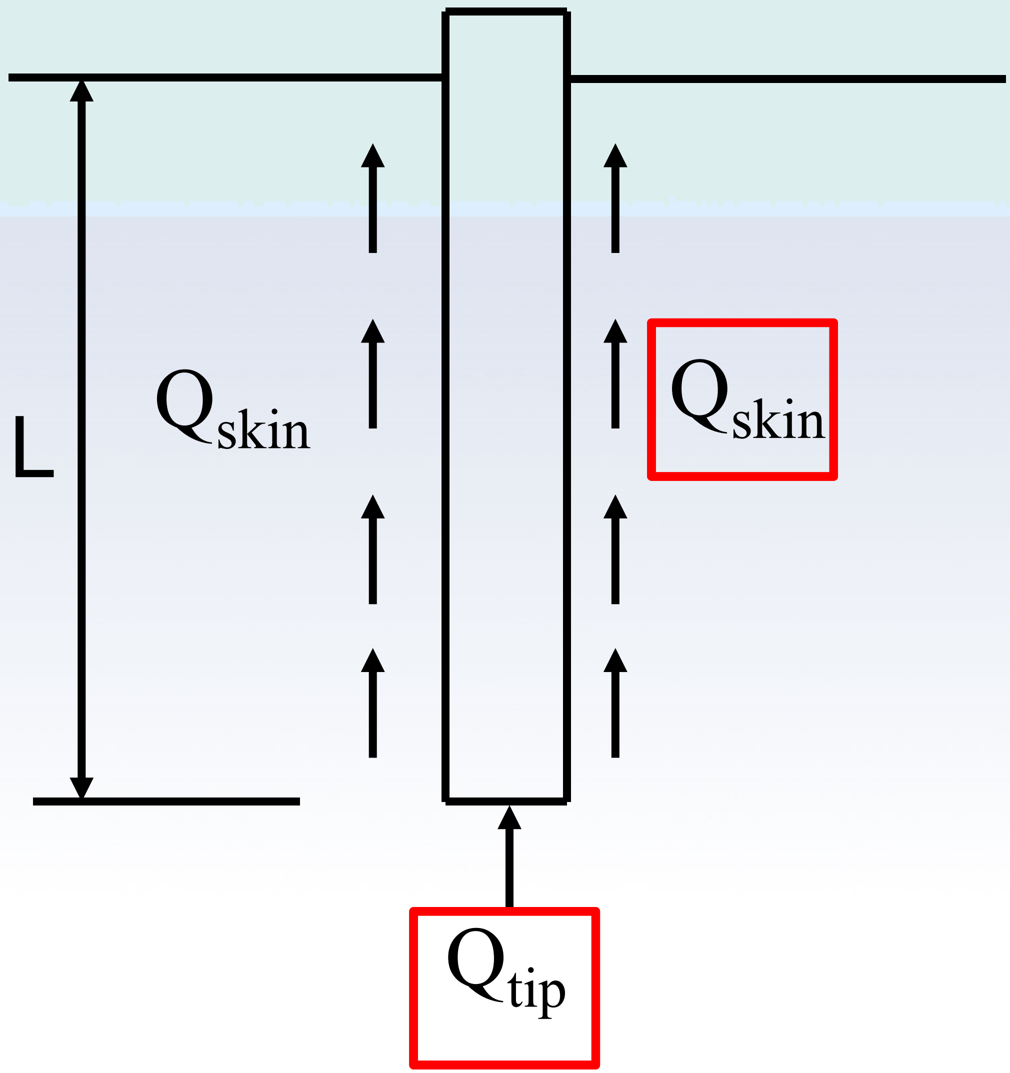
Weak Rock: 10 $\leq$ UCS $\leq$ 100 ksf

illinois.edu

Outline

- Drilled Shaft Design in Weak Rock
- Laboratory q_u Measurement
- Field q_u Measurement
- q_u Correlation
- Summary

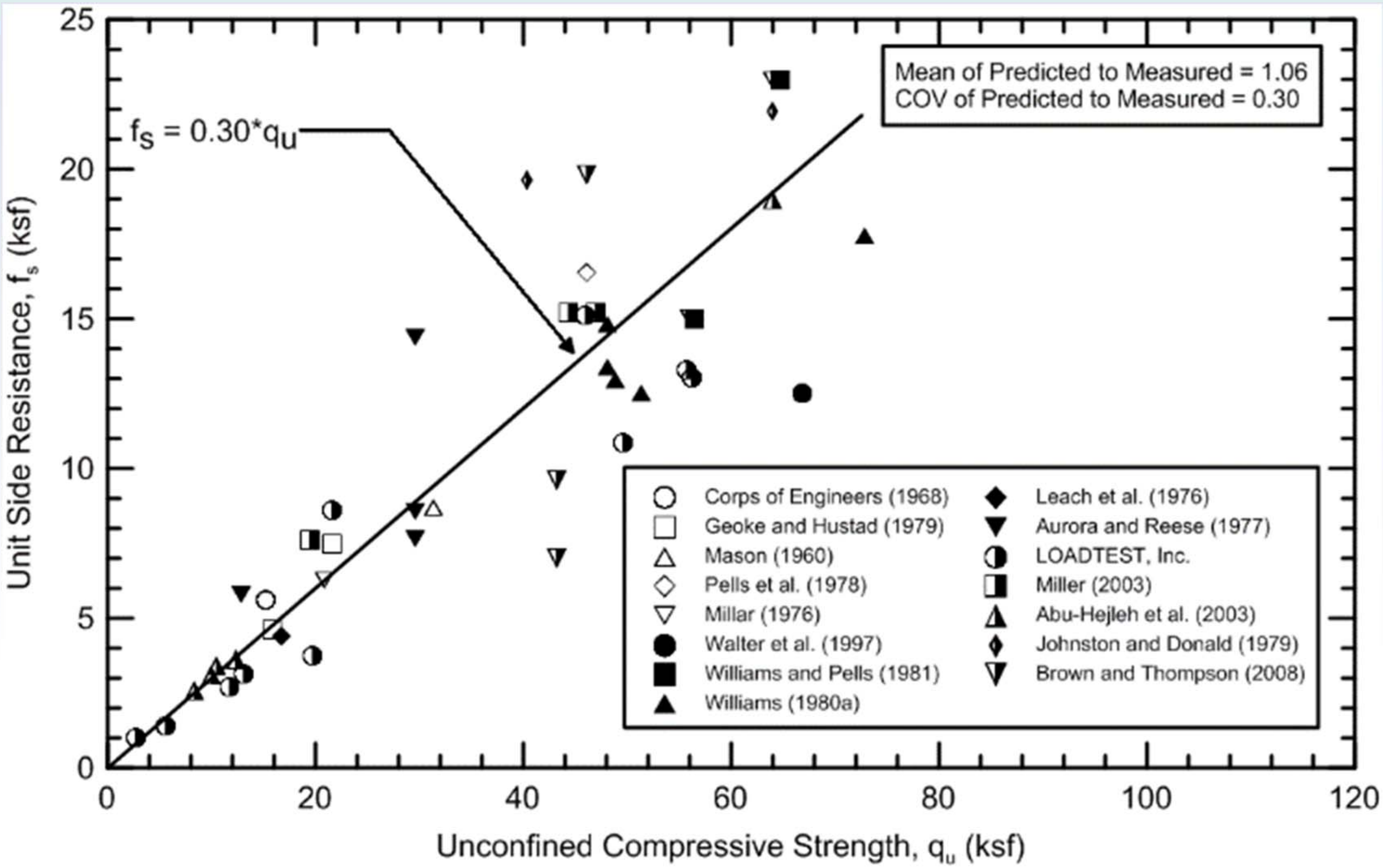
Axial Capacity



illinois.edu

Side Resistance

$$Q_{skin} = 0.3 * q_u \leq 30 \text{ ksf}$$



Tip Resistance

$$Q_{tip} = \frac{3.2 * \delta / D}{\delta / D + 1.3} * q_u * d_c$$

where

$q_t =$ tip resistance, ksf

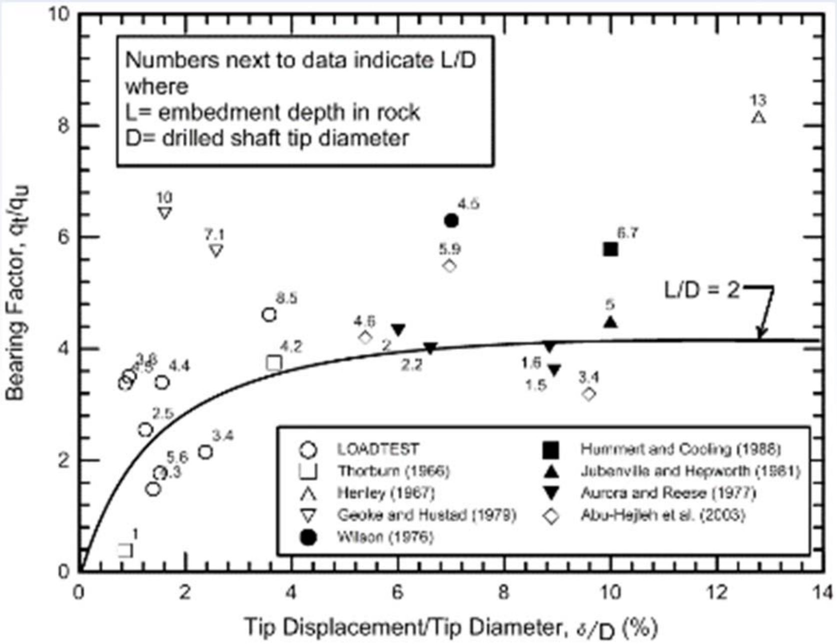
$q_u =$ unconfined compressive strength, ksf

$\frac{\delta}{D} =$ ratio of tip movement to tip diameter,in percent

$d_c =$ Vesic's depth correction factor $= 1.0 + 0.4 * k$, dimesionless

$$k = \begin{cases} k = L/D & L/D \le 1 \\ k = \tan^{-1}(L/D) & L/D > 1 \end{cases}$$

$L =$ embedment depth in weak rock, in.



illinois.edu

Outline

- Drilled Shaft Design in Weak Rock
- Laboratory q_u Measurement
- Field q_u Measurement
- q_u Correlation
- Summary

Shale Coring

Shale Core Recovery

illinois.edu

Shale Core Recovery

illinois.edu

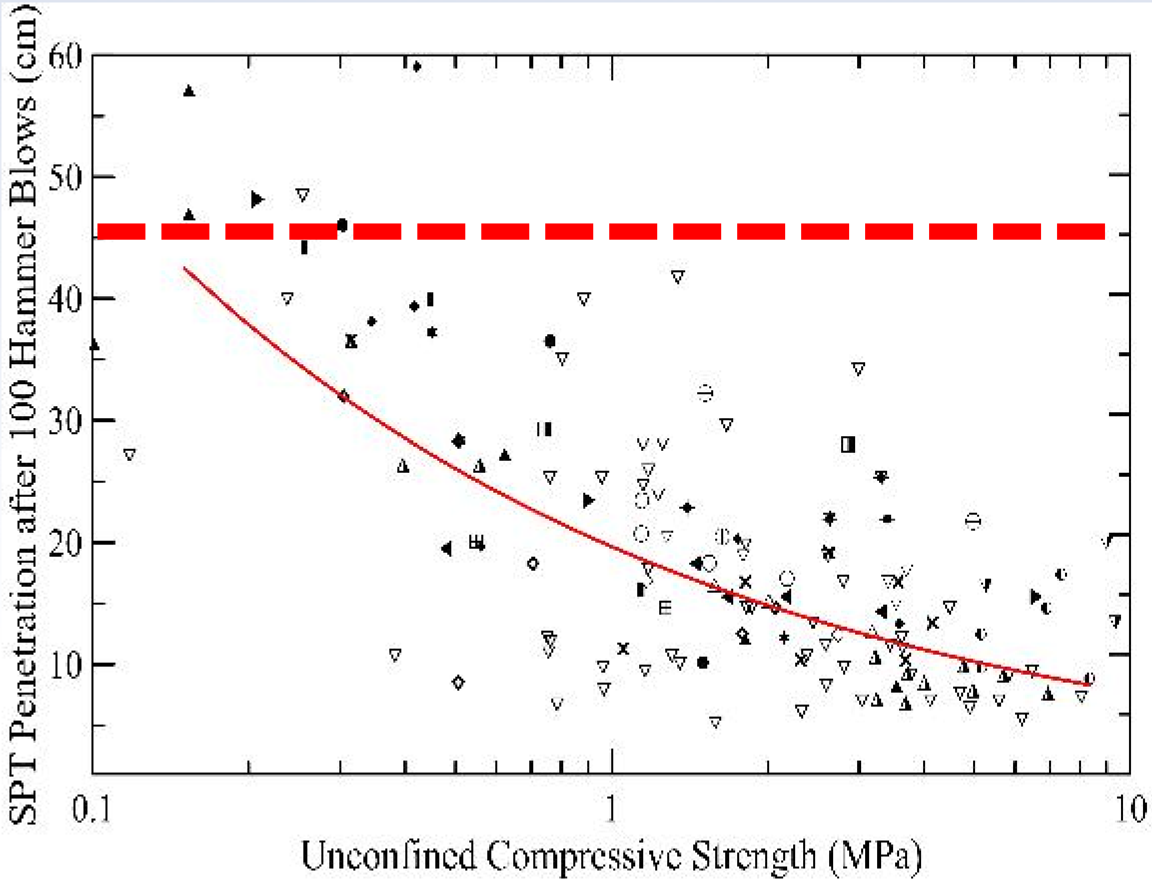
Outline

- Drilled Shaft Design in Weak Rock
- Laboratory q_u Measurement
- Field q_u Measurement
- q_u Correlation
- Summary

MODIFIED STANDARD PENETRATION TEST

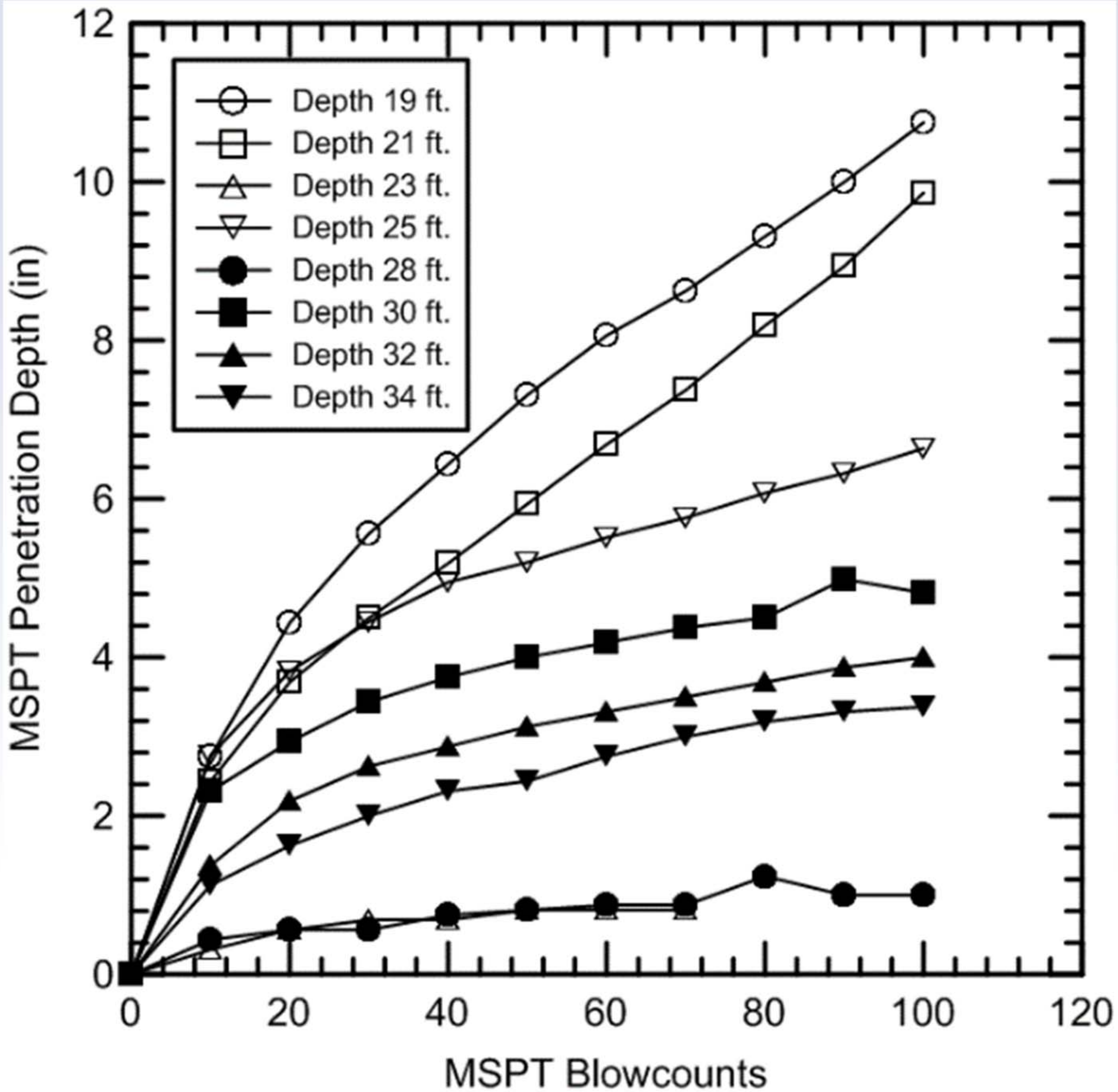
Standard Penetration Test (SPT)

- 140 lbs
- Hammer drop = 30 inches
- 18 inches (45 cm) of Penetration (Not Achieved in Soft Shales)



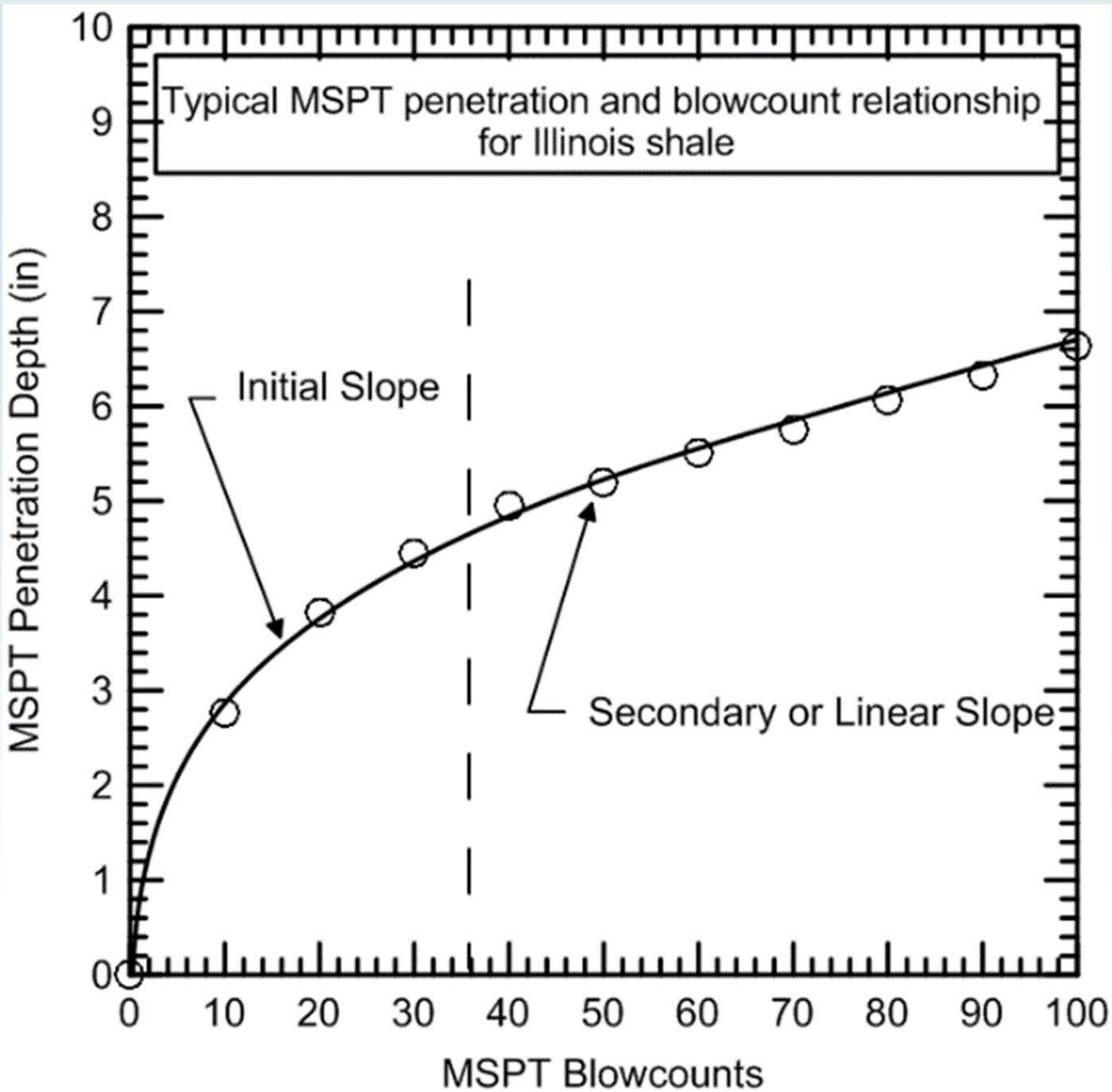
illinois.edu

SPT Penetration v. Blowcounts



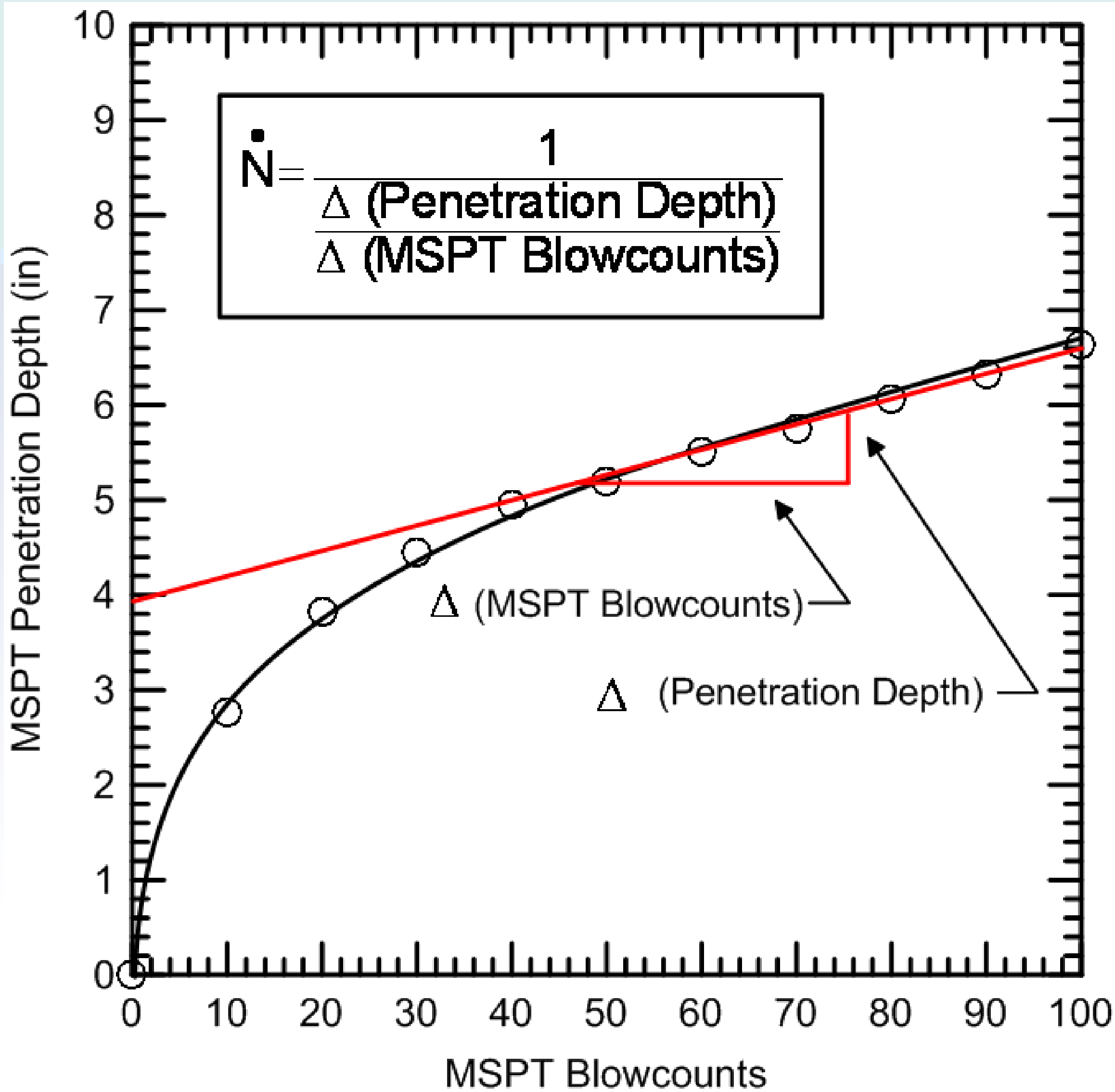
illinois.edu

Initial and Secondary Slopes

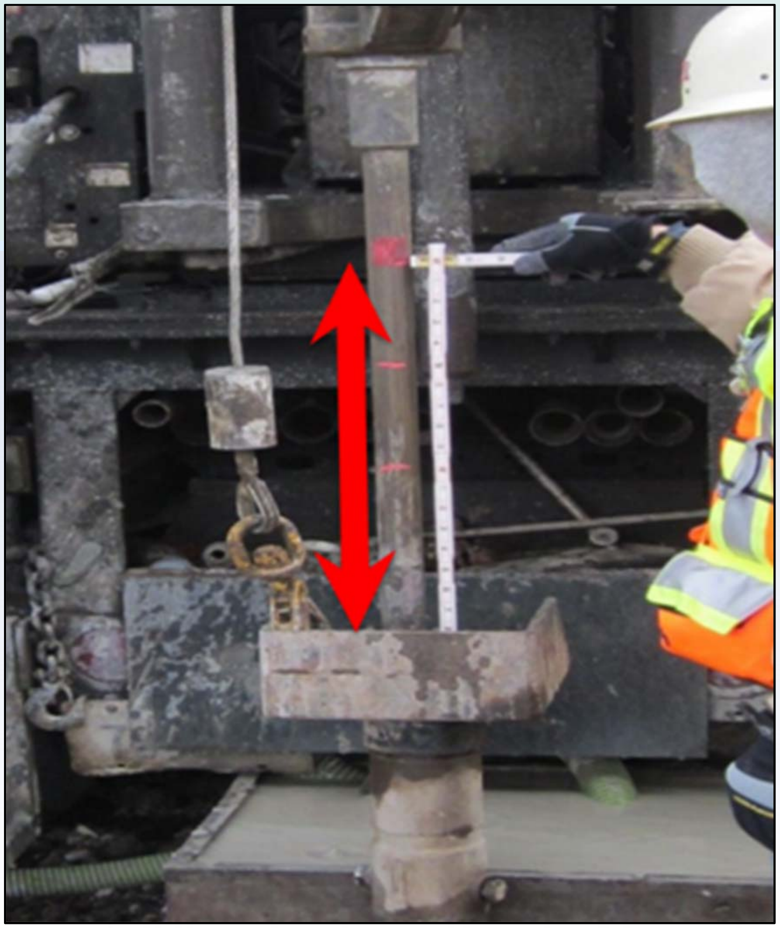


illinois.edu

Penetration Rate



MSPT Datasheet



Modified SPT Log

Illinois Department of Transportation

Clear Input | Print | Auto Calc Qu - All Layers

Route: IL 89 (FAP 698) Structure No.: 078-0006 (Exist.) 078-0047 (Prop.) Date: 5/22/14 Page: 1 of 1

Section: (1) BR Description: Illinois 89 over Illinois River at Spring Valley

County: Putnam / Bureau Logged by: TLM / MS Sampler Tube Length: 18 in.

Boring No.: 102 M (Pier #2) Station: 152+51 Offset: 10' LT Latitude: 41.3411987 Longitude: -89.211702

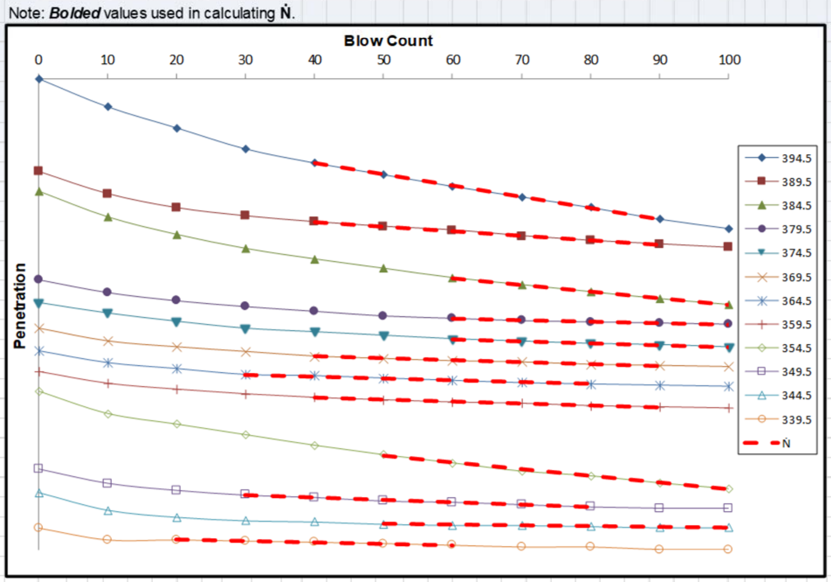
	Measured Rod Length (ft)	Blows where exposed rod length was measured											$\dot{N}$	q_u	Young's Modulus
		0	10	20	30	40	50	60	70	80	90	100	(bpf)	(ksf)	(ksi)
Test Elevation	394.50	3.24	3.00	2.82	2.64	**2.52**	**2.42**	2.32	**2.23**	**2.14**	**2.04**	1.96	104.9	6.6	1.57
	389.50	3.28	3.09	2.97	2.90	**2.85**	**2.81**	2.78	**2.73**	**2.69**	**2.66**	2.63	259.0	18.2	4.07
	384.50	3.28	3.06	2.91	2.79	2.70	2.62	**2.54**	**2.48**	**2.42**	**2.36**	**2.31**	172.4	11.5	2.63
	379.50	3.27	3.16	3.09	3.04	3.00	2.96	**2.94**	**2.92**	**2.91**	**2.90**	**2.89**	833.3	67.2	18.60
	374.50	3.29	3.20	3.13	3.07	3.04	3.01	**2.98**	**2.96**	**2.94**	**2.93**	**2.91**	588.2	45.5	11.13
	369.50	2.90	2.79	2.74	2.70	**2.66**	**2.64**	2.62	**2.61**	**2.59**	**2.58**	2.57	618.7	48.2	11.97
	364.50	2.92	2.82	2.77	**2.72**	2.71	**2.69**	**2.67**	**2.65**	**2.64**	2.63	2.62	601.6	46.7	11.50
	359.50	2.95	2.85	2.80	2.76	**2.73**	**2.71**	2.69	**2.68**	**2.66**	**2.65**	2.64	618.7	48.2	11.97
	354.50	2.99	2.80	2.71	2.62	2.53	**2.45**	**2.38**	2.31	**2.27**	**2.21**	**2.16**	173.4	11.6	2.66
	349.50	3.00	2.88	2.82	**2.78**	**2.76**	2.73	**2.72**	**2.70**	**2.68**	2.67	2.67	500.0	37.9	8.89
	344.50	3.00	2.85	2.79	2.76	2.75	**2.73**	**2.72**	**2.72**	**2.71**	2.70	**2.70**	1721	151.5	102.38
	339.50	3.06	2.96	**2.96**	**2.95**		**2.93**		2.90	2.90	2.88	2.88	909.1	74.1	21.27

Note: ***Bolded*** values used in calculating $\dot{N}$.

MSPT Analysis Review Data

Elevation:	394.50		
Blow Counts		M.R.L. (in.)	Pen. (in.)
0		38.88	0
10		36	2.88
20		33.84	5.04
30		31.68	7.2
40	X	30.24	8.64
50	X	29.04	9.84
60		27.84	11.04
70	X	26.76	12.12
80	X	25.68	13.2
90	X	24.48	14.4
100		23.52	15.36
q_u (ksf):	6.6		

Auto Calc Qu - Shown Layer Only | Copy to MSPT Table



MSPT Datasheet

DRILLED SHAFT AXIAL CAPACITY---- SHALE

I.D.O.T. BBS FOUNDATIONS AND GEOTECHNICAL UNIT

Modified on 9/25/2014

STRUCTURE ========================== SN 100-1111
SUBSTRUCTURE & REFERENCE BORING ==== W. Abutment - Boring #2

ESTIMATED TOP OF SHALE ELEVATION ==== 600.50 FT
DRILLED SHAFT DIAMETER IN SHALE ====== 36 IN.
FACTORED AXIAL LOAD ================== 1000 KIPS

Clear Input | Print Design Table | Print Input | Print Unit Resistance Table

Drilled Shaft Dia.'s for Design Table

36 IN.
42 IN.
48 IN.
54 IN.
IN.
IN.

SOCKET DEPTH (FT)	TIP ELEV. (FT)	LAYER THICK. (FT)	UNCONFINED COMPRESSIVE STRENGTH (q_u) (KSF)	AVG. q_u W/IN 2 - SHAFT DIA. (KSF)	NOMINAL SIDE RESIST. (KIPS)	CUMULATIVE SIDE RESIST. (KIPS)	DEPTH CORR. FACTORS k	DEPTH CORR. FACTORS d_c	NOMINAL TIP RESIST. (KIPS)	NOMINAL SHAFT RESIST. (KIPS)	FACTORED SHAFT RESIST. (KIPS)	RANGE OF SERVICE LOADING AND CORRESPONDING SETTLEMENT: LOAD (KIPS)	SETTLEMENT (IN.)	LOAD (KIPS)	SETTLEMENT (IN.)
1.25	599.25	1.25	10.0	19.6	35	35	0.417	1.17	404	439	220	100	0.10	180	0.20
2.50	598.00	1.25	12.0	25.0	42	78	0.833	1.33	589	667	333	160	0.10	275	0.19
3.75	596.75	1.25	14.0	33.8	49	127	0.896	1.36	810	937	469	230	0.10	375	0.18
5.00	595.50	1.25	20.0	47.1	71	198	1.030	1.41	1175	1373	686	325	0.10	550	0.18
6.25	594.25	1.25	24.0	57.8	85	283	1.123	1.45	1481	1764	882	425	0.10	750	0.20
7.50	593.00	1.25	30.0	61.6	106	389	1.190	1.48	1606	1995	998	475	0.10	800	0.18
8.75	591.75	1.25	40.0	56.0	141	530	1.240	1.50	1481	2011	1005	500	0.10	850	0.18
10.00	590.50	1.25	60.0	47.1	212	742	1.279	1.51	1258	2000	1000	500	0.10	850	0.17
11.25	589.25	1.25	90.0	34.2	318	1060	1.310	1.52	920	1980	990	475	0.08	800	0.15
12.50	588.00	1.25	72.0	26.4	254	1315	1.335	1.53	716	2031	1015	500	0.08	850	0.14
13.75	586.75	1.25	42.0	25.8	148	1463	1.356	1.54	704	2167	1084	500	0.08	900	0.14
15.00	585.50	1.25	6.0	38.3	21	1484	1.373	1.55	1047	2532	1266	600	0.09	1100	0.16
16.25	584.25	1.25	20.0	48.4	71	1555	1.388	1.56	1331	2886	1443	700	0.10	1200	0.17
17.50	583.00	1.25	30.0		106	1661									
18.75	581.75	1.25	36.0		127	1788									
20.00	580.50	1.25	40.0		141	1930									
21.25	579.25	1.25	72.0		254	2184									
22.50	578.00	1.25	68.0		240	2425									

MSPT Procedure

MSPT Test Procedure

University of Illinois at Urbana–Champaign

ILLINOIS CENTER FOR TRANSPORTATION

Illinois Modified Standard Penetration Test Procedure

Prepared for
Illinois Department of Transportation

By:
Timothy D. Stark, James H. Long, Ahmed Baghdady, and Abdolreza Osouli
Department of Civil Engineering
University of Illinois at Urbana–Champaign
205 North Mathews
Urbana, Illinois 61801

Project Contacts:
Timothy D. Stark at (217) 333-7394
tstark@illinois.edu

Jim Long at (217) 333-2543
jhlong@illinois.edu

Abdolreza Osouli at (618) 650-2555
aosouli@siue.edu

Ahmed Baghdady at (319) 512-0170
Baghdad2@illinois.edu

April 4, 2017

Outline

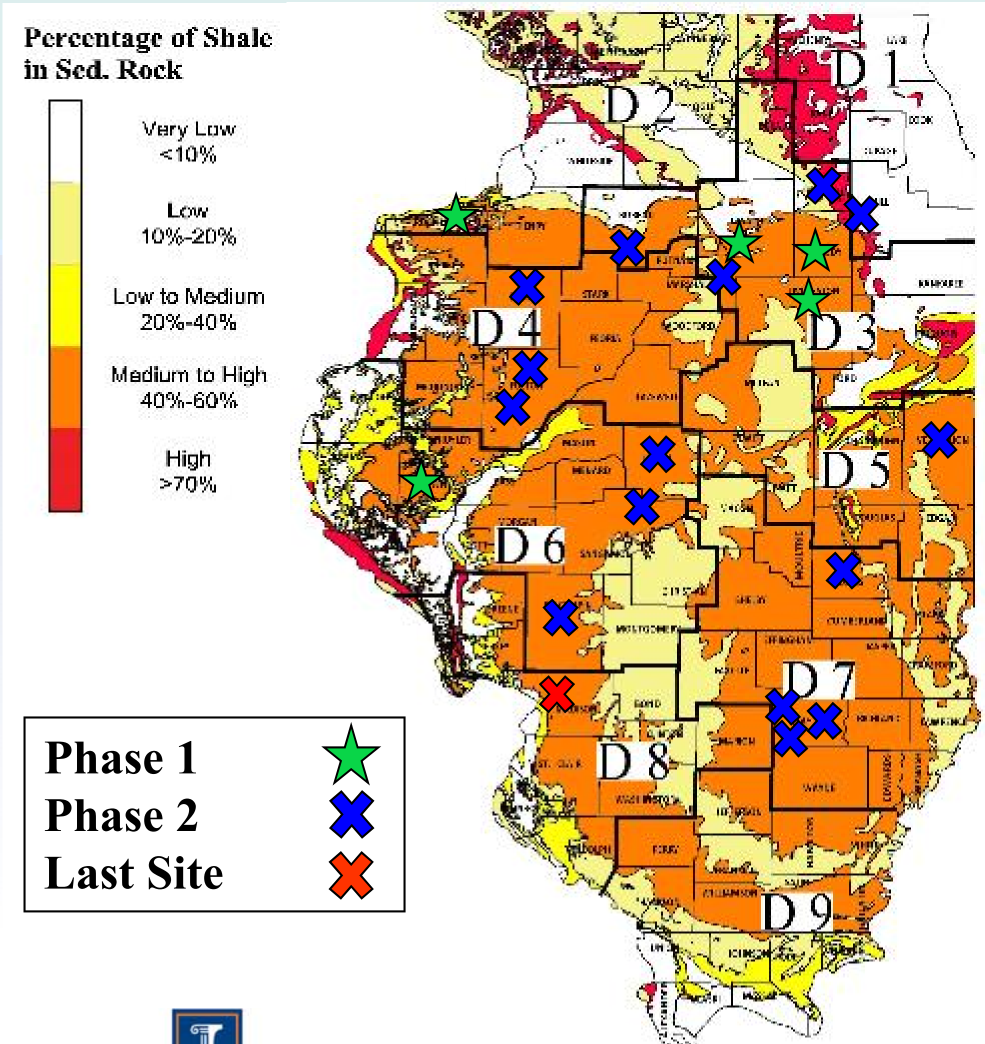
- Drilled Shaft Design in Weak Rock
- Laboratory q_u Measurement
- Field q_u Measurement
- q_u Correlation
- Summary

IDOT Bridge Sites

US 24 over Lamoine River, Brown County

IL 23 over Short Point Creek, Livingston County

Shale Subsurface Investigation



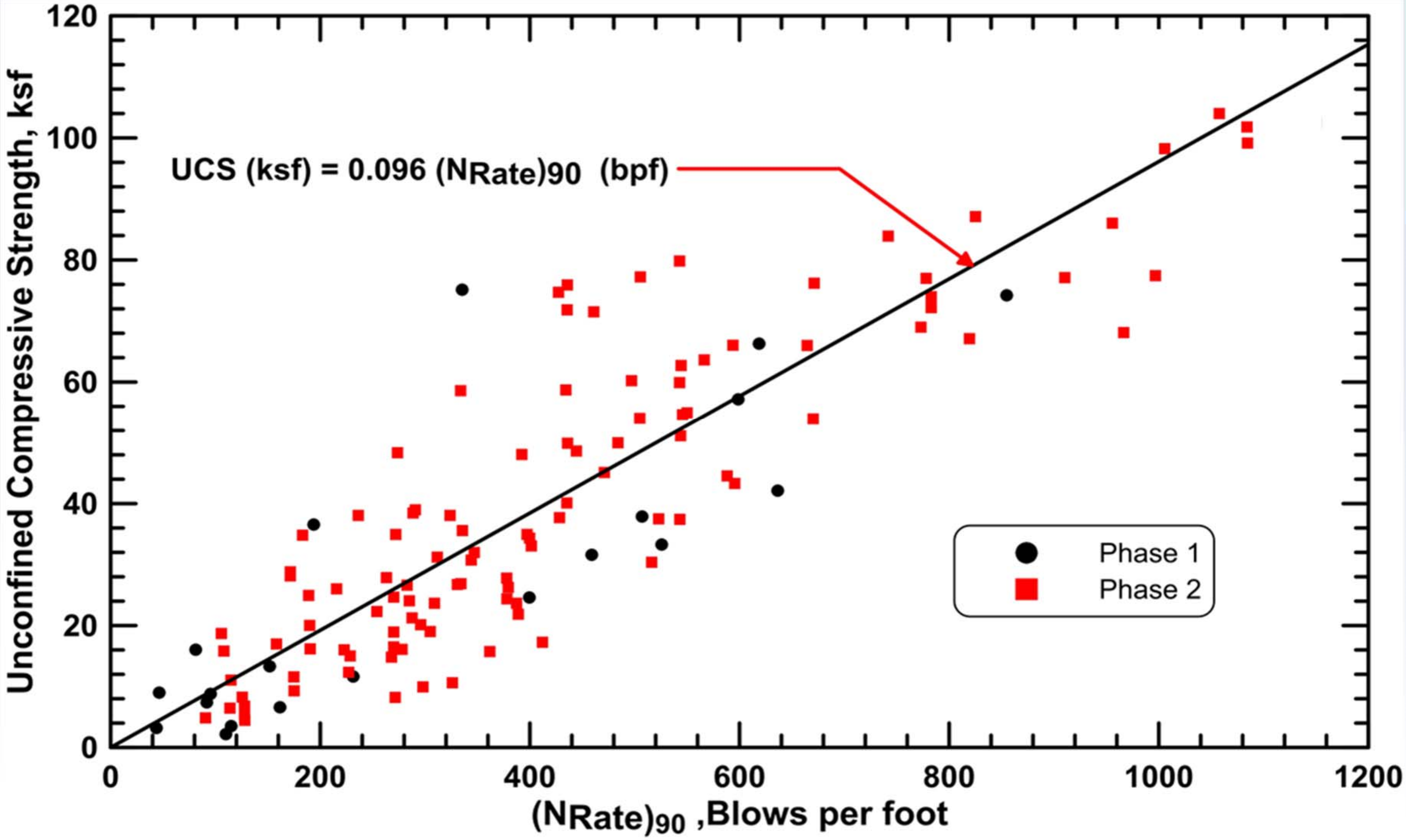
Site	County	District
PHASE 1		
John Deere Road (IL 5) over IL 84	Rock Island	2
IL 23 over Short Point Creek	Livingston	3
FAI 80 over Aux Sable Creek	Grundy	3
FAU 6265	LaSalle	3
US 24 over Lamoine River	Brown	6
PHASE 2		
I-55 over Des Plaines River	Will	1
IL 89 over the Illinois River	Bureau	3
IL 23 over Otter Creek	LaSalle	3
Eldamain Road over Fox River	Kendall	3
CH-9 over I-74	Knox	4
US 24 over Big Sister Creek	Fulton	4
US 24 over Little sister Creek	Fulton	4
US150/IL Rt.1 over Little Vermilion River	Vermilion	5
IL108 over Macoupin Creek	Macoupin	6
South of Pawnee Bridge	Sangamon	6
BL55 over Salt Creek	Logan	6
TR 325 over Elm Creek	Clay	7
TR 355 over Seminary Creek	Clay	7
IL 133 over Embarrass River	Coles	7
CH-10 over Buck Creek	Clay	7
IL 160 over Silver Creek site	Madison	8

21 Shale Sites Drilled

Ref.: Willman, H.B., and others, (compilers), 1967, Geologic Map of Illinois: Illinois State Geological Survey, scale= 1:500,000, paper

illinois.edu

UCS Correlation



illinois.edu

Energy Corrected for 90% of theoretical energy

O-Cell Loadtest

illinois.edu

Outline

- Drilled Shaft Design in Weak Rock
- Laboratory q_u Measurement
- Field q_u Measurement
- q_u Correlation
- Summary

Summary

- Improved Drilled Shaft Design in Weak Rocks
- **Cost Savings**
  - Less conservative q_u
  - Less conservative design
  - Less shale coring & laboratory testing
  - Shorter design time
- **Implementation**
  - IDOT MSPT Test Method & Spreadsheet

illinois.edu

Acknowledgements

- William Kramer - TRP Chair, Bridges
- Bradly Hessing - Bridges
- Heather Shoup – Materials
- Michael Short – District 3
- Brian Laningham - District 6
- Dan Tobias – Materials
- Greg Heckel – District 6
- Rob Graeff - District 9
- Luke Murphy - Bridges
- Megan Swanson - Materials
- Naser Abu-Hejleh - FHWA
- Michah Loesch - FHWA
- Chad Hodel – WHKS & Co.
- Terry McCleary - McCleary Engineering
- Tom Casey - SCI

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Drilled Shaft Design in Weak Illinois Rocks

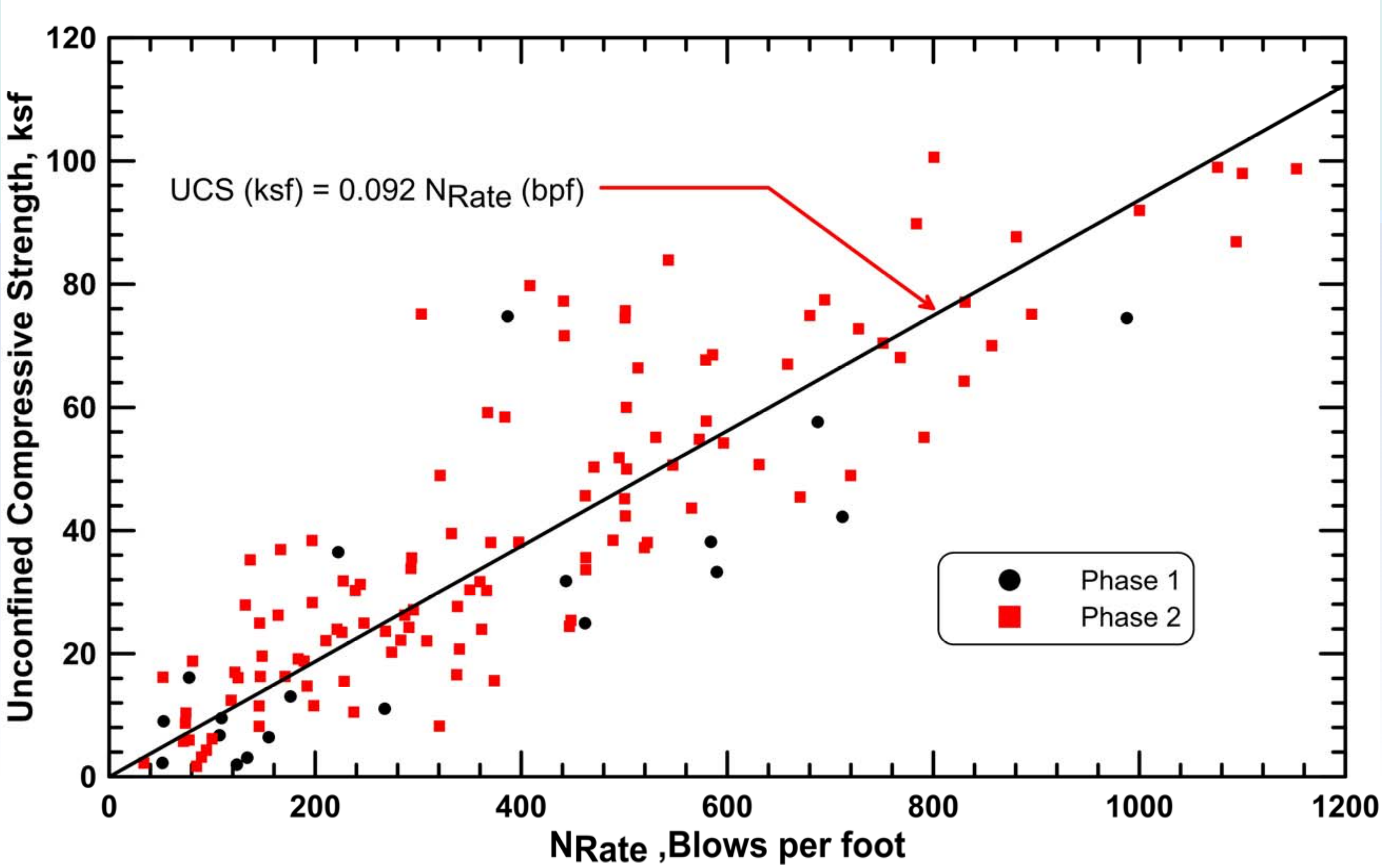
Timothy D. Stark, James H. Long, & Ahmed Baghdady
University of Illinois at Urbana-Champaign

Abdolreza Osouli
Southern Illinois at Edwardsville

THE Conference 2018
Champaign, Illinois
February 28, 2018

illinois.edu

UPDATED MSPT VS. UCS CORRELATION



illinois.edu

T.D.Stark-Drilled Shaft in Weak Rocks ©

When to Use MSPT

Case (A): Previously Investigated Sites (i.e., UCS and RQD Available)

Determine the Range of UCS for the shales from the Boring logs and Reported Testing,

- For UCS between 10 and 100 ksf, use MSPT for these materials and rock coring is not required,
- For UCS >100 ksf, rock coring is required,
- For UCS < 10 ksf, traditional SPTs and soil testing of the founding materials is needed to measure the UCS.

When to Use MSPT

Case (B): New Sites

- Start with Traditional SPT at reasonable intervals (e.g. 2.5 ft):
  - UCS of split-spoon sample measured using field Rimac
  - Switch to MSPT if split-spoon sampler is unable to penetrate 18 inches and/or field 10 $\leq$ UCS $\leq$ 100 ksf

- Switch to Rock Coring if field UCS > 100 ksf or penetration < 0.4 inch/last 40 blows

illinois.edu