PROBLEM SOLVING EXERCISE

PROBLEM SOLVING EXERCISE
OVERVIEW

The efforts of five teams were adjudicated based on the following criteria. It should be noted, of course, that time prevented the design details of various proposals being checked by the referees.

1. Design Concept/Layout
   - Pile design and construction classification
   - Number of piles
   - Length, diameter, and bond zone
   - Design service load
   - Reinforcement details
   - Inclination/orientation
   - Construction details (drill/grout)
2. QA/QC
   - Processes
   - Materials
   - Overall Performance
3. Schedule
4. Cost

The different solutions offered for Problem 1 are summarized in Table 1. While four teams selected a "conventional" Type 1B pile approach, the fifth team proposed an extremely innovative solution featuring the creation of two "towers" of reticulated Type 2A piles, tied back by anchors. This concept, which owed much to the revolutionary personalities within the team, was in fact adjudged the winner, although, as noted by some of the contractors involved in the unsuccessful teams, the concept would not have been accepted if the project were located in the U.S. given its radical (but wholly appropriate and realistic) nature!

For the second problem (Table 2) four teams adopted a standard Case 1 structure, including the team which relied exclusively on a Japanese standard. The fifth team, driven by Teutonic forces, offered a radical solution which was labeled both "Case 1½" and "proprietary". For both reasons it was not successful, and the winner again proved to be the franks and masons, although again protests by defeated teams relating to the short schedule claimed were heard above the popping of champagne corks.

This whole exercise appeared to be an outstanding success, and proved to be a very direct way of transferring information between engineers of different cultures and experiences. Such peer competitions are not common in many of the countries represented, and it is to the credit of all participants that any awkwardness was quickly lost, and natural camaraderie soon took over.

INTERNATIONAL WORKSHOP ON MICROPILES
DOUBLETREE INN, SEATTLE, WASHINGTON
SEPTEMBER 26-28, 1997

PROBLEM 1
STATIC/SEISMIC DESIGN

The following sample problem illustrates the design of foundation support for a bridge abutment using micropiles. This sample problem is intended to illustrate the qualification and grouping of typical abutment loads and the design of a micropile foundation for the controlling load group/groups. Practitioners typically follow different procedures around the United States in the design of bridge abutments, and therefore this sample problem is not intended to depict a "standard abutment" or a "standard abutment design procedure".

A. PROBLEM STATEMENT

The structure is a simple span bridge, 30 meters long, supported on concrete retaining abutments. The superstructure consists of five AASHTO Type IV precast - prestressed concrete girders with a cast-in-place concrete deck.

The bridge abutment width is 10.5 meters. The abutment wall backfill material is medium dense sand with an angle of internal friction of 35 degrees and a unit weight of 17.5 kN/m^3. The unit weight of the concrete is 23.6 kN/m^3. The dimensions of the abutment are shown on Figure 1.

A summary of loading applied to the bridge abutment is shown on Figure 2. All load values are per 1-meter width of abutment. The seismic site design coefficient is 0.3g.

The foundation soil conditions are described in the boring log on Figure 3. These soils consist of 2.5 meters of loose sandy gravel underlain by a moderately compressible soft, brown, fine sandy silt, which is 1.5 meters thick. The silt is underlain by a dense to very dense gravel with cobbles and boulders, which extend to a maximum depth of 30 meters. Ground water is 4 meters below the top of footing.

Unit costs and times for different micropile types are shown in Table 1.

B. GOAL

1. Complete a design for a micropile system including:
    a. the structural capacity of the upper cased length (if used)
    b. the structural capacity of the lower uncased length
    c. determination of the geotechnical bond length.

2. Estimate anticipated displacements under service loading.

3. Estimate time and cost

C. SUGGESTIONS TO REACH GOAL

Step 1: Determine the magnitude and point of application of the design loading acting on the abutment.

Step 2: Determine the summary horizontal force, vertical force, and overturning moment acting on the abutment for each load combination group. Select a pile layout and determine the front and rear pile axial design loading required to support the summary forces and moment.

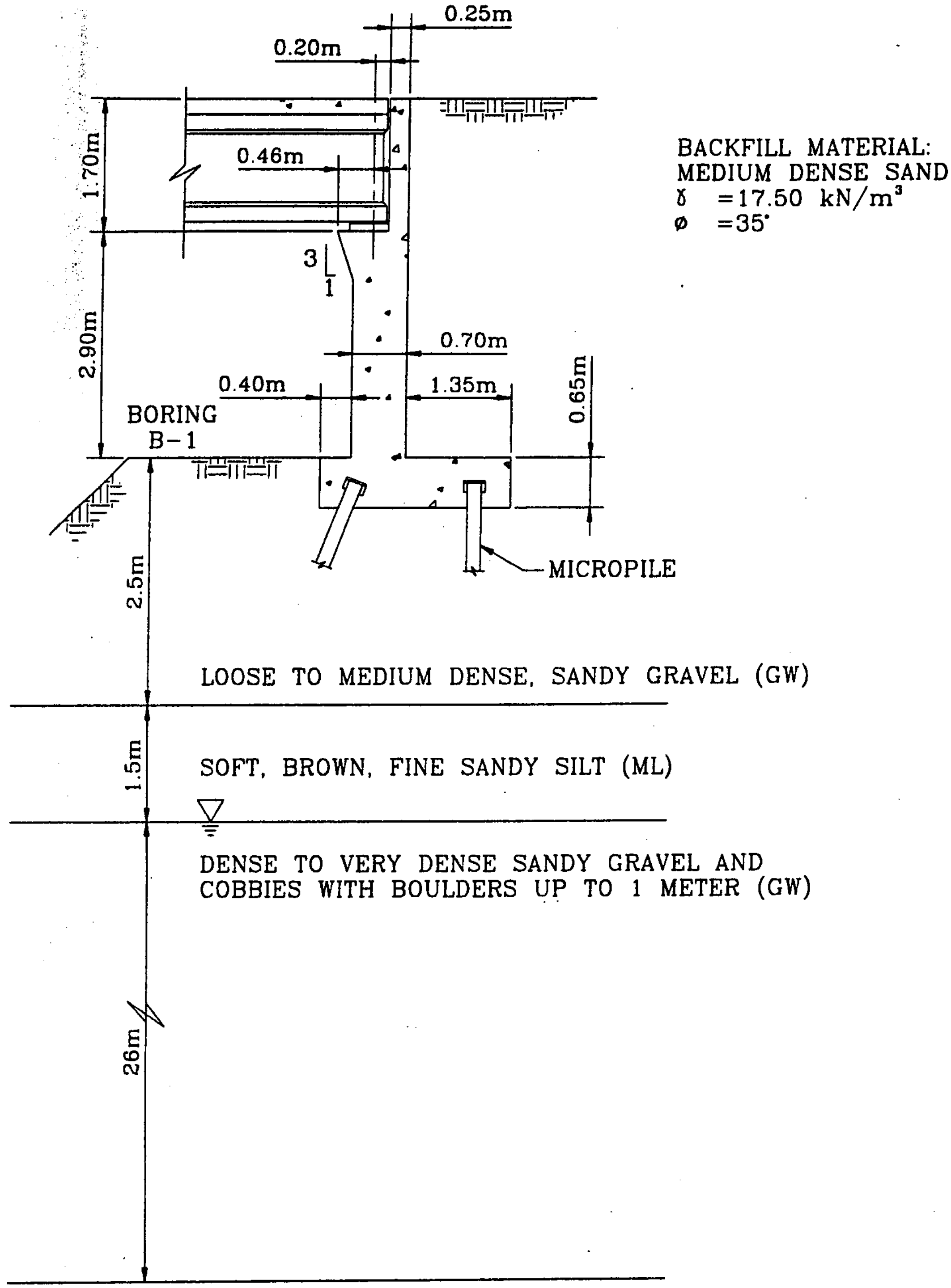
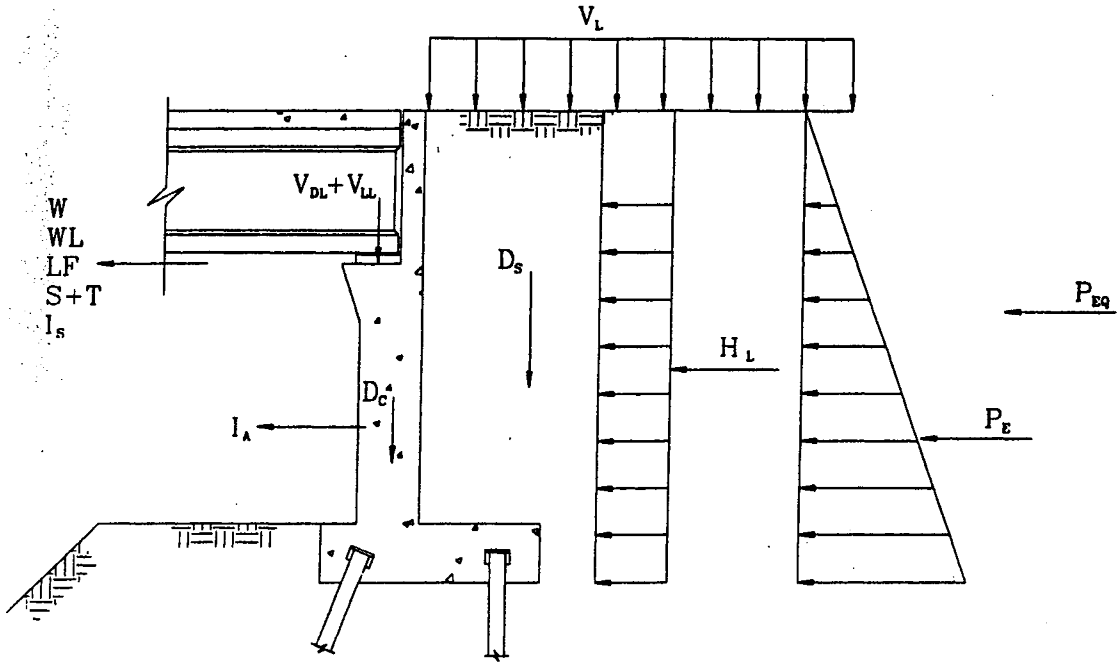


Figure 1. Abutment section detail.



D_C	=	Dead load of concrete abutment
D_S	=	Dead load of soil
V_{DL}	=	178.70 kN/m (dead load from bridge structure)
V_{LL}	=	73.00 kN/m (live load from bridge structure)
H_L	=	Earth pressure due to live load surcharge
W	=	3.00 kN/m (wind load on superstructure)
LF	=	3.65 kN/m (wind load on live load)
S+T	=	18.00 kN/m (longitudinal force)
P_E	=	Active earth pressure
P_E	=	Seismic earth pressure
I_A	=	63.73 kN/m (seismic inertia force of concrete abutment and soil weight)
I_S	=	53.6 kN/m (seismic inertia force of the superstructure)

Figure 2. Summary of abutment loading.

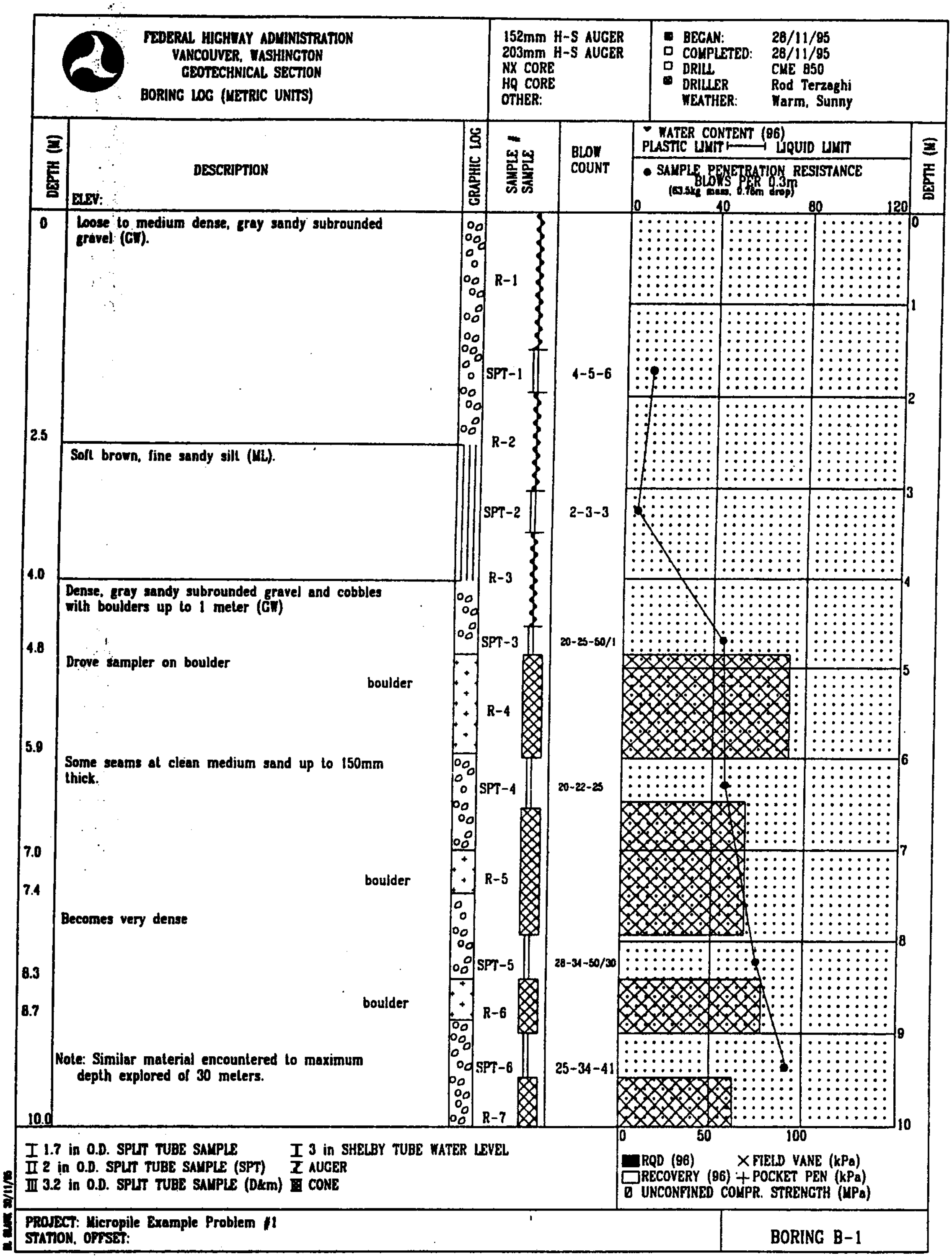


Figure 3. Soil boring log.

Grade	Grade 60						Grade 75		
Rebar No.	8	9	10	11	14	18	11	14	18
Length in	1.00	1.13	1.27	1.41	1.69	2.26	1.41	1.69	2.26
mm	25	29	32	35	43	57	35	43	57
Area in^2	0.79	1.00	1.27	1.56	2.25	4.00	1.56	2.25	4.00
mm^2	510	645	819	1006	1452	2580	1006	1452	2580
Yield Load kips	47	60	76	94	135	240	117	169	300
kN	211	267	339	416	600	1068	520	751	1334
Ult. Load kips	71	90	114	140	203	360	164	236	420
kN	316	400	508	624	901	1601	729	1051	1868

BAR NO.	APPROXIMATE DIAMETER (mm)	BAR PROPERTIES DIAMETER (inches)	AREA ($inches^2$)	CONVERTED AREA (mm^2)
2	6.4	0.250	0.05	32.255
3	9.5	0.375	0.11	70.961
4	12.8	0.500	0.2	129.02
5	16.0	0.625	0.31	199.981
6	19.0	0.750	0.44	283.844
7	22.2	0.875	0.6	387.06
8	25.5	1.000	0.79	509.629
9	28.7	1.128	1	645.1
10	32.3	1.270	1.27	819.277
11	35.8	1.410	1.56	1006.356
14	43.0	1.693	2.25	1451.475
18	57.3	2.257	4	2580.4

Notes:

(1) Certain dimensions are shown rounded off in the table. Specifically, bars #9, #14, and #18 have diameters of 1.128, 1.693, and 2.257 inches, respectively.

(2) Grade 60 reinforcing steel has a yield stress of f_y = 60 kips/in² (415 MPa) and a tensile strength of f_u = 90 kips/in² (620 MPa).

(3) Grade 75 reinforcing steel has a yield stress of f_y = 75 kips/in² (517 MPa) and a tensile strength of f_u = 105 kips/in² (723 MPa).

Table 1A. Axial tension and compression loads for ASTM A615 and ASTM A706 reinforcing bars.

Casing OD	in mm	5-1/2 139.7	7 177.8	9-5/8 244.5
Wall Thickness	in mm	0.361 9.17	0.498 12.65	0.472 11.99
Steel Area	in^2 mm^2	5.83 3760	10.17 6563	13.57 8756
Yield Load	kips kN	466 2075	814 3619	1086 4829

Notes:

(1) Casing outside diameter (OD) and wall thickness (t) are nominal dimensions.

(2) Steel area is calculated as $A_s = \pi\ t\ (OD - t)$.

(3) Nominal yield stress for API N-80 steel is F_y = 80 kips/in² (551 MPa).

(4) Conversion data are: 1 inch = 25.4 mm; 1 in² = 64.5 mm²; 1 kip/in² = 6.89 MPa; 1 kip = 4.448 kN.

Table 1B. Axial tension and compression loads for API N-80 steel casing.

MATERIALS COSTS

1 These costs apply for steel left in the hole only.
2 Assume grout is $100/m^3$.

Grade 60 Bar						
Diameter (mm)	25	29	32	35	43	57
Cost/meter	$10	$12	$13	$15	$18	$25

Grade 75 Bar			
Diameter (mm)	35	43	57
Cost/meter	$20	$23	$32

N-80 Casing					
Diameter (mm)	100	127	139.7	177.8	244.5
Cost/meter	$30	$40	$50	$80	$110

DRILLING COSTS (Drill and case temporarily)

Diameter (mm)	100	127	139.7	177.8	244.5
Cost/meter	$55	$70	$80	$100	$130

PRODUCTION RATES

Diameter (mm)	100	127	139.7	177.8	244.5
Meters of pile/day	100	90	80	70	50

Table 1C. Nominal costs and production rates for various drill diameters and types of reinforcement.

TABLE 1
SUMMARY OF PROBLEM 1 RESULTS

Design	Team				
	Green	**Blue**	**Red**	**Yellow**	**Black**
Classification	2A	1B	1B	1B	1B
No. of piles	2 networks of 18 piles, inclined at 10°, with 5 tiebacks	6 vertical and 4 inclined piles	20 piles total, vertical and inclined at 20°	5 vertical and 7 inclined piles	5 vertical and 5 inclined piles at 3:1
Length and diameter	7.6m long and 100mm diameter	10m (vertical), 14m (inclined) and 150mm diameter	8m (vertical) 11m (inclined), and 240mm diameter	12m long and 178mm diameter	12m long and 140mm diameter
Construction	Rotary, bentonite sand-cement grout	Rotary duplex, neat grout (w/c = 0.4)	Rotary percussion, neat grout (w/c = 0.5)	Rotary percussion duplex, neat grout (w/c = 0.4)	Rotary percussion ODS, neat grout (w/c = 0.4-0.5)
Service Load	100 kN	785 kN	720 kN compression and 400 kN (tension)	900 kN (compression) and 400 kN (tension)	450 kN
Reinforce-ment	200mm bar Grade 60	57mm bar Grade 75	Not specified	45mm bar Grade 75	57mm bar Grade 75
QA/QC	Integrity testing Load testing Flow testing	Static load testing Grout cubes Fluid tests Records	Static load testing (compression and testing) Fluid tests	Grout cubes Fluid tests Static load testing	Certificates Case histories Grout cubes Fluid tests
Time	5 days	5 days	5 days + 2 days for testing	5 days + 2 days for testing	1½ days +++
Cost	$25,000 + $20,000 for testing	$20,000	$40,000 + $20,000 for testing	$24,300	$17,180

INTERNATIONAL WORKSHOP ON MICROPILES
DOUBLETREE INN, SEATTLE, WASHINGTON
SEPTEMBER 26-28, 1997

PROBLEM 2
IN SITU SLOPE STABILIZATION

A. PROBLEM STATEMENT

Given: Roadway along a flank of a hill (valley floor downslope, sometimes a river or stream is present). The road is built across unstable ground (sometimes side cast fill, if of early origin then often uncompacted). Subsurface conditions and site topography for this example are shown on the attached sketches. The existing road is marginally stable, failing during winter due to high groundwater.

Project constraints include working in an environmentally sensitive area. No work is to be performed outside of the roadway prism. One-way traffic must be maintained, with temporary road closures for periods up to 30 minutes allowed. Micropiles are determined to be the best solution to meet the project constraints. The length of the roadway to be stabilized is 200m.

Geotechnical site characterization defining soil and rock units with material properties and groundwater level is provided in Figure 1 through 4. For an active slide, assume existing slope stability Factor of Safety (FS) = 1.0.

Unit costs and times for different micropile types are shown in Table 1.

B. GOALS

1. Design CASE 1 non-reticulated micropile structure in lower roadway shoulder to stabilize roadway to provide
   a. $FS_{static} \geq 1.5$
   b. $FS_{seismic} \geq 1.3$.

2. Provide internal and external stability design calculations for required micropile structure including final micropile spacing.

3. Estimate time and cost.

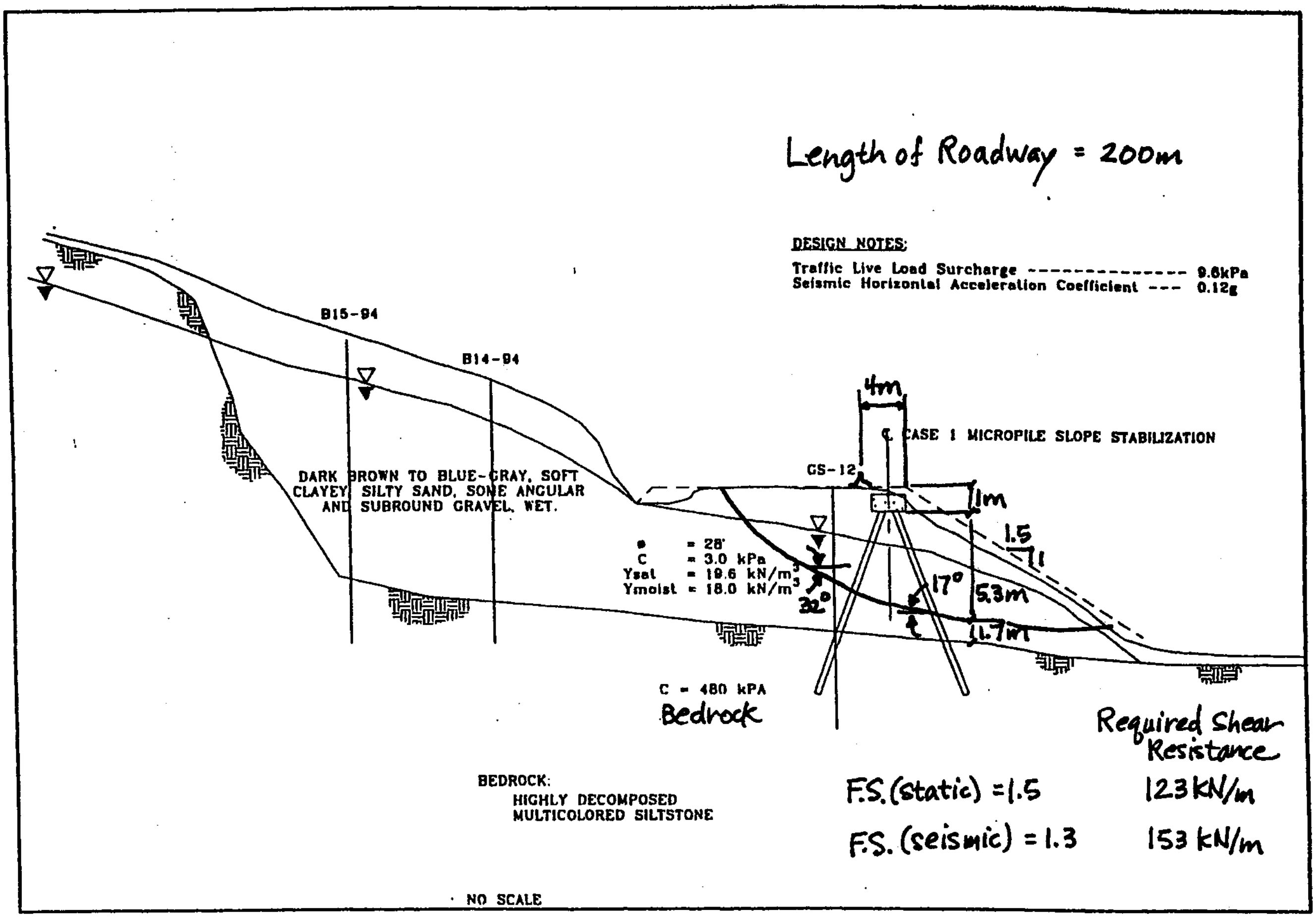


Figure 1. Micropile slope stabilization.

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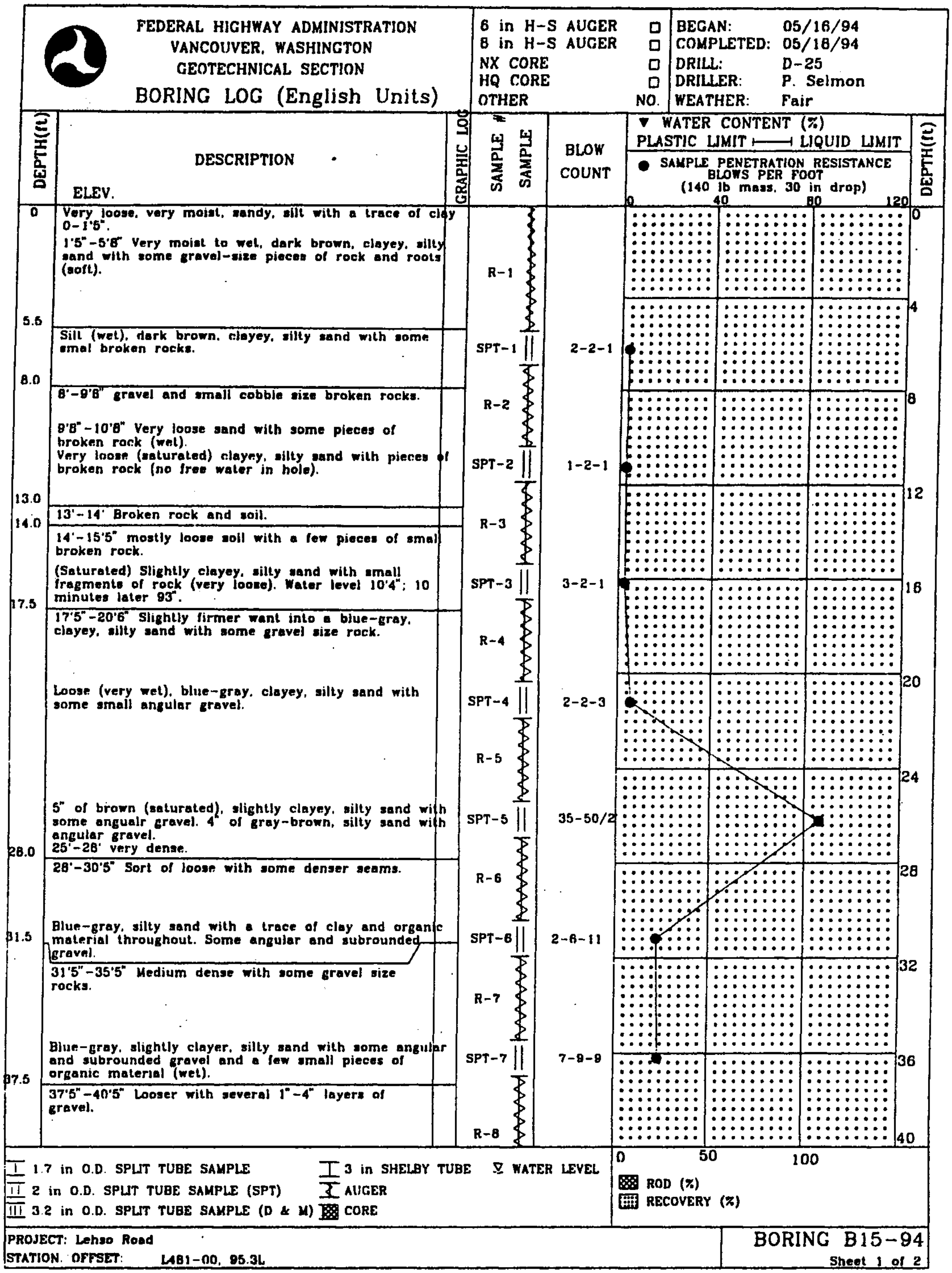
FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION
BORING LOG (English Units)

6 in H-S AUGER
8 in H-S AUGER
NX CORE
HQ CORE
OTHER
NO.

BEGAN: 05/16/94
COMPLETED: 05/18/94
DRILL: D-25
DRILLER: P. Selmon
WEATHER: Fair

DEPTH(ft)	DESCRIPTION / ELEV.	SAMPLE #	BLOW COUNT
0	Very loose, very moist, sandy, silt with a trace of clay 0-1'5". 1'5"-5'8" Very moist to wet, dark brown, clayey, silty sand with some gravel-size pieces of rock and roots (soft).	R-1	
5.6	Silt (wet), dark brown, clayey, silty sand with some smal broken rocks.	SPT-1	2-2-1
8.0	8'-9'8" gravel and small cobble size broken rocks. 9'8"-10'8" Very loose sand with some pieces of broken rock (wet). Very loose (saturated) clayey, silty sand with pieces of broken rock (no free water in hole).	R-2 SPT-2	 1-2-1
13.0	13'-14' Broken rock and soil.	R-3	
14.0	14'-15'5" mostly loose soil with a few pieces of small broken rock. (Saturated) Slightly clayey, silty sand with small fragments of rock (very loose). Water level 10'4"; 10 minutes later 93".	SPT-3	3-2-1
17.5	17'5"-20'6" Slightly firmer went into a blue-gray, clayey, silty sand with some gravel size rock. Loose (very wet), blue-gray, clayey, silty sand with some small angular gravel. 5" of brown (saturated), slightly clayey, silty sand with some angualr gravel. 4" of gray-brown, silty sand with angular gravel. 25'-28' very dense.	R-4 SPT-4 R-5 SPT-5	 2-2-3 35-50/2
28.0	28'-30'5" Sort of loose with some denser seams. Blue-gray, silty sand with a trace of clay and organic material throughout. Some angular and subrounded gravel.	R-6 SPT-6	 2-6-11
31.5	31'5"-35'5" Medium dense with some gravel size rocks. Blue-gray, slightly clayer, silty sand with some angular and subrounded gravel and a few small pieces of organic material (wet).	R-7 SPT-7	 7-9-9
37.5	37'5"-40'5" Looser with several 1"-4" layers of gravel.	R-8	

1.7 in O.D. SPLIT TUBE SAMPLE
2 in O.D. SPLIT TUBE SAMPLE (SPT)
3.2 in O.D. SPLIT TUBE SAMPLE (D & M)
3 in SHELBY TUBE
AUGER
CORE
WATER LEVEL

PROJECT: Lehso Road
STATION. OFFSET: L481-00, 95.3L
BORING B15-94
Sheet 1 of 2

Figure 2. Boring log B15-94 information (Station L481+00).

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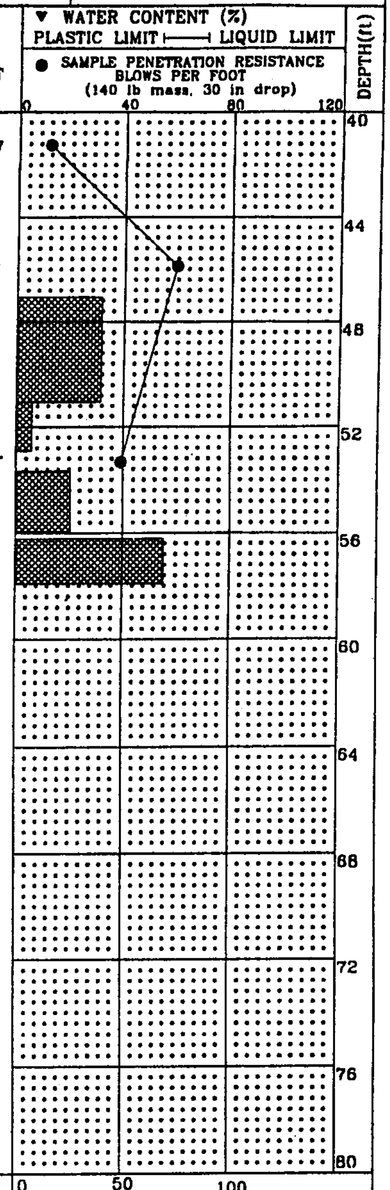
FEDERAL HIGHWAY ADMINISTRATION VANCOUVER, WASHINGTON GEOTECHNICAL SECTION BORING LOG (English Units)	6 in H-S AUGER ☐ 8 in H-S AUGER ☐ NX CORE ☐ HQ CORE ☐ OTHER NO.	BEGAN: 05/16/94 COMPLETED: 05/18/94 DRILL: D-25 DRILLER: P. Selmon WEATHER: Fair

DEPTH(ft) / ELEV.	DESCRIPTION	SAMPLE #	BLOW COUNT
	Blue-gray, silty sand or sandy silt with a trace of clay with some organic material throughout and a few small angular gravel and subrounded gravel. 40'6"-44'10" mediium dense with some small gravel. 44'10"-45'8" Slightly denser.	SPT-8 R-9	4-5-7
46.3	5" of blue-gray, sandy silt with some gray rock fragments. 4" of rust tan-brown, very highly decomposed rock with some harder pieces of rock (decomposed to sandy silt with a trace of clay) (wet). After 10 minutes water level at 41'	SPT-N9 II R-10	9-50/3"
47.1	46'3"-47' very dense gravel and silty sands. Refusal with auger Started coring	R-11	
47.9	6" of blue-gray and multicolored sand with a few subrounded gravel and a 5" weathered cobble.		
50.1	47'11"-48'5" soft zone. There is water coming out of hole - 10 min.	R-12	
	Three pieces of gravel 51'-53' highly decomposed siltstone. 5" of highly decomposed siltstone rusty-tan and light gray. 3" of dry siltstone. Decomposed, gray siltstone, ground most of the core up. Decomposing gray siltstone.	SPT-10 II R-13 R-14	14-25/3"
58.0	BORING TERMINATED AT A DEPTH OF 58'.		



I 1.7 in O.D. SPLIT TUBE SAMPLE
II 2 in O.D. SPLIT TUBE SAMPLE (SPT)
III 3.2 in O.D. SPLIT TUBE SAMPLE (O & M)
3 in SHELBY TUBE
AUGER
CORE
WATER LEVEL
ROD (%)
RECOVERY (%)

PROJECT: Lehso Road
STATION OFFSET: L481-00, 95.3'L

BORING B15-94
Sheet 2 of 2

Figure 2 (continued). Boring log B15-94 information (Station L481+00).

FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION

BORING LOG (English Units)

6 in H-S AUGER	☐	BEGAN:	05/09/94
8 in H-S AUGER	☐	COMPLETED:	05/10/94
NX CORE	☐	DRILL:	D-25
HQ CORE	☐	DRILLER:	P. Selmon
OTHER	NO.	WEATHER:	Hot

DEPTH(ft) — ELEV. — DESCRIPTION — GRAPHIC LOG

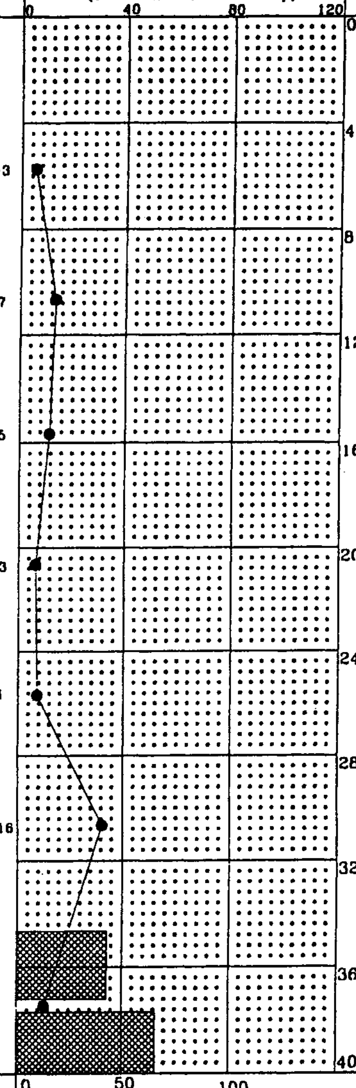
0 — 0-1'7" Loose, brown, clayey silt with organic material and a few gravel sixe broken rock.
1'7"-3'8" Brown clayey silty sand and a couple cobbles.
3'8"-5' Brown clayey silty sand with gravel size broken rock (very moist).
Brown, clayey, silty, sand with some angular and subrounded gravel and wet seams throughout.
Loose (wet) clayey, silty sand with four 4" seams of gravel size rock. End of auger bit (wet).

10.0 — (Wet) Brown, clayey silty sand with seams of gravel size broken rock. (Free water in hole) Water level 5'9"; 10 minutes later 5'3"
10'-13'7" Medium dense sand with a few cobbles and gravel size broken rock.
13'7"-15' softer sand with a few gravel size rocks.
5" of (wet) brown and gray, slightly clayey, silty sand with small subrounded and angular gravel. 5' (wet) blue-gray, slightly clayey, silty sand with some small fragments of harder rock.
19'5"-20' softer.
10' of (wet) blue-gray, clayey, silty sand with some harder fragments and pieces of wood or bark. 8" of rust gray and tan (saturated), slayey, silty sand with angular and subrounded gravel. Water level at bottom of hole; 1 hour later 16'3".
22'11"-25' firmer with gravel size rocks.
(Wet) blue-gray, clayey, silty sand with small hard fragments throughout and pieces of wood and bark throughout.
29'4"-30' firmer with more angular gravel.
Blue-gray, slightly clayey, silty sand with angular gravel and organic material throughout (wet).
33'7"-34'8" very dense. Refusal with auger. Started coring.

34.7 — Tight cobbles, gravel and blue-gray silty sand with a trace of clay to 36'11".
36'11"-37'2" softer. Refusal with SPT sampler.
Blue-gray highly decomposed siltstone, almost soil.
17" of gray mudstone or siltstone, highly fractured.
9" of highly weathered siltstone (or decomposing).
Had problems with the the water swivel, pullout of hole.

SAMPLE #	BLOW COUNT
R-1	
SPT-1	3-2-3
R-2	
SPT-2	5-6-7
R-3	
SPT-3	5-5-5
R-4	
SPT-4	2-3-3
R-5	
SPT-5	2-3-4
R-6	
SPT-6	10-16-16
R-7	
R-8	
SPT-7	10/8"
R-9	

▼ WATER CONTENT (%)
PLASTIC LIMIT ├──┤ LIQUID LIMIT
● SAMPLE PENETRATION RESISTANCE BLOWS PER FOOT (140 lb mass, 30 in drop)



▨ ROD (%)
▤ RECOVERY (%)

Ⅰ 1.7 in O.D. SPLIT TUBE SAMPLE — Ⅰ 3 in SHELBY TUBE — ▽ WATER LEVEL
Ⅱ 2 in O.D. SPLIT TUBE SAMPLE (SPT) — AUGER
Ⅲ 3.2 in O.D. SPLIT TUBE SAMPLE (O & M) — ▨ CORE

PROJECT: Lehso Road
STATION. OFFSET. L481-24. 49.7L

BORING B14-94
Sheet 1 of 2

Figure 3. Boring log B14-94 information (Station L481+24).

FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION

BORING LOG (English Units)

6 in H-S AUGER ☐	BEGAN:	05/09/94
8 in H-S AUGER ☐	COMPLETED:	05/10/94
NX CORE ☐	DRILL:	D-25
HQ CORE ☐	DRILLER:	P. Selmon
OTHER NO.	WEATHER:	Hot

DEPTH(ft)	DESCRIPTION	GRAPHIC LOG	SAMPLE #	SAMPLE	BLOW COUNT	▼ WATER CONTENT (%) PLASTIC LIMIT ⊢—⊣ LIQUID LIMIT ● SAMPLE PENETRATION RESISTANCE BLOWS PER FOOT (140 lb mass, 30 in drop) 0 40 80 120	DEPTH(ft)
40.4	Water level was at 3' 8:00 am 5-11-94 the water was running out top of the hole when we pulled core barrel at 37'2"; we had water run out of drill still.						40
	BORING TERMINATED AT A DEPTH OF 40'5"						
							44
							48
							52
							56
							60
							64
							68
							72
							76
							80

I 1.7 in O.D. SPLIT TUBE SAMPLE	3 in SHELBY TUBE	WATER LEVEL	0 50 100
II 2 in O.D. SPLIT TUBE SAMPLE (SPT)	AUGER		ROD (%)
III 3.2 in O.D. SPLIT TUBE SAMPLE (O & M)	CORE		RECOVERY (%)

PROJECT: Lehso Road
STATION. OFFSET: L481-24. 49.7L

BORING B14-94
Sheet 2 of 2

Figure 3 (continued). Boring log B14-94 information (Station L481+24).

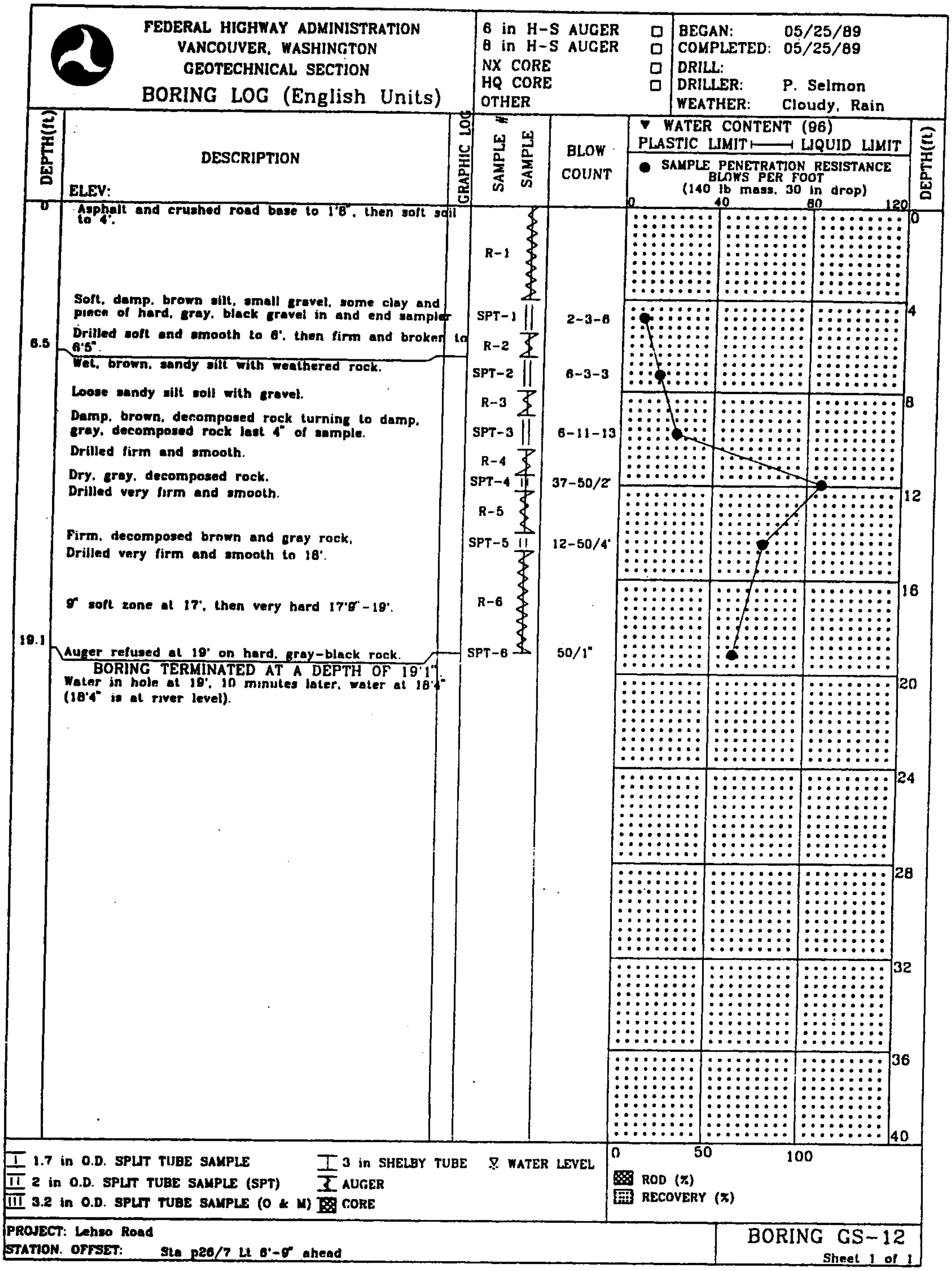


Figure 4. Boring log GS-12 information (Station P26/7)

TABLE 2
SUMMARY OF PROBLEM 2 RESULTS

Design	Team				
	Green	Blue	Red	Yellow	Black
Classification	1A	2½A	1B	1A-B	1A
No. of piles	334 piles, 2 rows	66 triangular structures of 3 piles each, total 198 piles	290 piles, 2 rows	400 piles, 2 rows	400 piles, 2 rows
Length and diameter	8.3m long inclined, and 139mm diameter	10m long, 106 and 117mm diameter	9m long inclined 20°, 177mm diameter	10.5m long inclined 30°, 127 and 200mm diameter	13m long inclined 20°, 140mm diameter
QA/QC	Certificates Fluid tests	Certificates Grout cubes Instrumentation Maintenance	Grout cubes Fluid tests Pullout test Environmental	Grout cubes Fluid tests 1 Pullout test	Certificates Load tests Instrumentation Fluid tests Grout cubes Case histories
Time	35 rig shifts	60 rig shifts	36 rig shifts	60 rig shifts	76 rig shifts
Cost	$390,000 including cap	$450,000, including $75,000 maintenance costs	$250,000	$620,000	$760,000 including cap