LRFD Soil Site Class Definition

This design guide illustrates the Department's procedure for determining the Site Class Definition for seismic design considering Article 3.10 of the 2008 Interim Revisions for the AASHTO LRFD Bridge Design Specifications. The Site Class Definition quantifies the soil's propensity to amplify, or in some cases decrease, surface ground motion propagating from underlying rock. The Site Class Definition is also used by designers to determine the Seismic Performance Zone for a structure (3.10.6). Presented in this design guide is an excerpt from a sample soil boring log illustrating how data from within the log should be averaged and applied using the methods mentioned herein to calculate the Site Class Definition. Also included with the design guide is an example structure illustrating how data from the soil boring logs is used to determine local Site Class Definitions at the individual substructure units and how the data should be combined and averaged for "short structures" to determine a global Site Class Definition applicable to the entire structure.

Applying and Averaging Soil Boring Data

The AASHTO LRFD Bridge Design Specifications Article C3.10.3.1 gives three methods for determining site class. The first, known as Method A, requires measurement of the soils shear wave velocities. While it is desirable to use shear wave velocities to determine site class, such information is not currently obtained using established IDOT geotechnical sampling practices. As such, Site Class Definitions shall be determined by Methods B and C, which evaluate Standard Penetration Test (SPT) blow counts (N) and undrained shear strengths (s_u) for the geotechnical material within the upper 100 ft. at a given location.

Method B ($\overline{N}$ method) simultaneously evaluates geotechnical parameters for cohesive and cohesionless soil using SPT blow counts (N) for each layer within the upper 100 ft. at a given location, as follows:

$$\overline{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{N_i}}$$

(Table C3.10.3.1-1)

Where:

d_i = soil layer thickness d_i (ft.), taken as the soil layer thickness as defined by the limits shown in the soil description column shown on the boring logs rather than considering each individual test sample as a 2.5 ft. layer. $\sum_{i=1}^{n} d_i$ shall equal 100 ft. An example determination of d_i is given later in this design guide.

N_i = average SPT N value within soil layer thickness d_i. The SPT N value from an individual soil sample shall not be taken as greater than 100 blows/ft.

Method C ($\bar{s}_u$ method) separately evaluates geotechnical parameters for cohesive soils using undrained shear strengths (s_u) and cohesionless soils using SPT blow counts (N) for each layer within the upper 100 ft. at a given location, as follows:

$$\bar{N}_{ch} = \frac{d_s}{\sum_{i=1}^{m} \frac{d_i}{N_{chi}}}$$

(Table C3.10.3.1-1)

$$\bar{s}_u = \frac{d_c}{\sum_{i=1}^{k} \frac{d_i}{s_{ui}}}$$

(Table C3.10.3.1-1)

Where:

d_s = total thickness of cohesionless soil layers in the top 100 ft. (ft.)

d_i = soil layer thickness d_i (ft.), as defined above

N_{chi} = average SPT N value within cohesionless soil layer thickness d_i, as defined above for N_i

d_c = total thickness of cohesive soil layers in the top 100 ft. (ft.)

s_{ui} = average s_u within cohesive soil layer d_i. The s_u from an individual soil sample shall not to be taken as larger than 5 ksf.

These methods will result in a corresponding value of $\overline{N}$ being calculated for all structures and values for $\overline{N}_{ch}$ for cohesionless soils and $\overline{s}_u$ for cohesive soils when such soils exist except as noted herein.

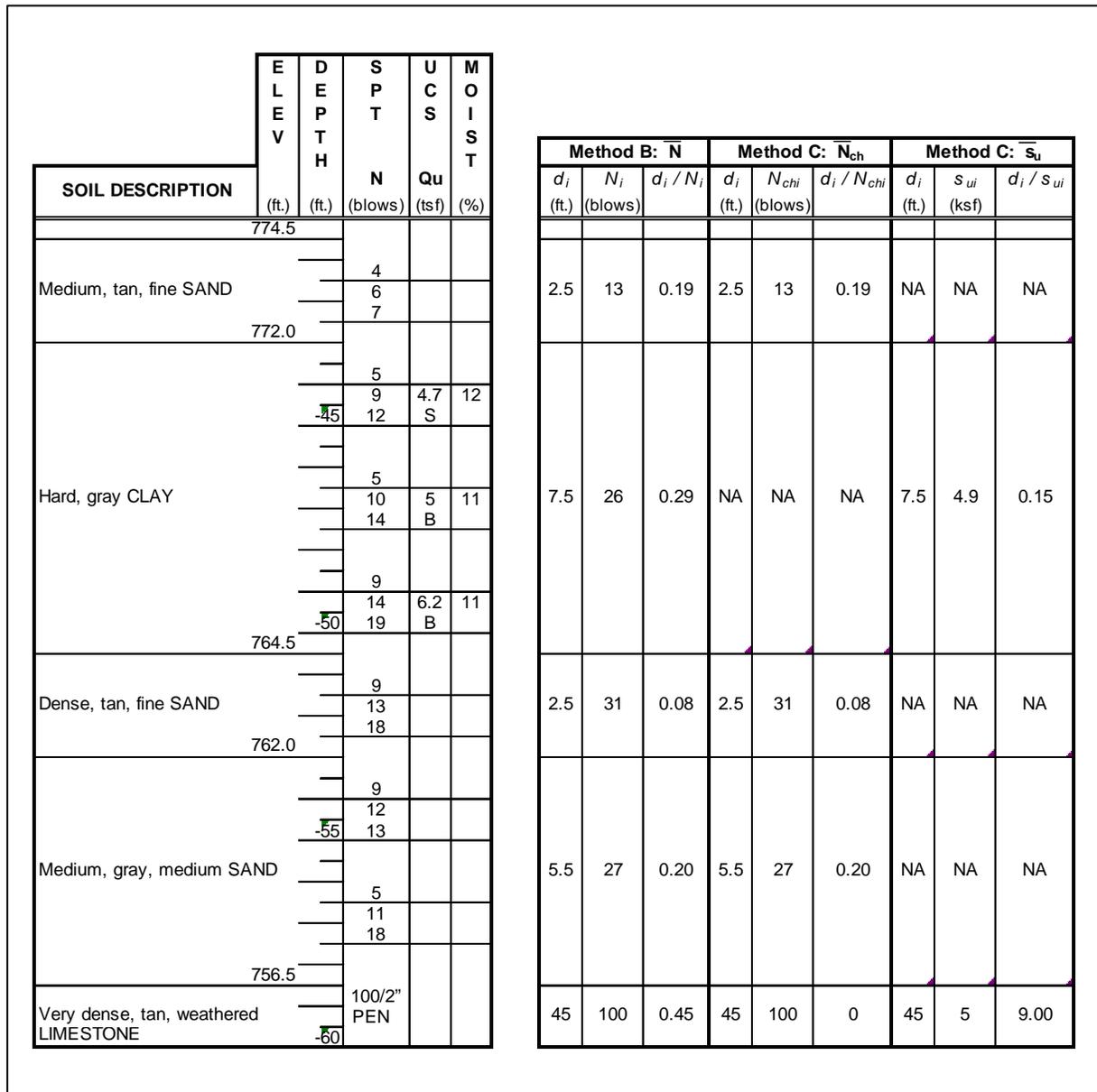| SOIL DESCRIPTION	ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Qu (tsf)	MOIST (%)	Method B: $\overline{N}$ d_i (ft.)	N_i (blows)	d_i / N_i	Method C: $\overline{N}_{ch}$ d_i (ft.)	N_{chi} (blows)	d_i / N_{chi}	Method C: $\overline{s}_u$ d_i (ft.)	s_{ui} (ksf)	d_i / s_{ui}
	774.5													
Medium, tan, fine SAND			4 6 7			2.5	13	0.19	2.5	13	0.19	NA	NA	NA
	772.0													
		-45	5 9 12	4.7 S	12									
Hard, gray CLAY			5 10 14	5 B	11	7.5	26	0.29	NA	NA	NA	7.5	4.9	0.15
		-50	9 14 19	6.2 B	11									
	764.5													
Dense, tan, fine SAND			9 13 18			2.5	31	0.08	2.5	31	0.08	NA	NA	NA
	762.0													
		-55	9 12 13											
Medium, gray, medium SAND			5 11 18			5.5	27	0.20	5.5	27	0.20	NA	NA	NA
	756.5													
Very dense, tan, weathered LIMESTONE		-60	100/2" PEN			45	100	0.45	45	100	0	45	5	9.00

Figure 1. Example Soil Boring Log & Resulting d_i, N_i, N_{chi} and s_{ui}.

Figure 1 contains an excerpt from a sample soil boring log and reflects how the soil descriptions are used to establish the soil layer thickness, d_i, as well as how the soil property data is averaged to define N_i, N_{chi}, and s_{ui}. The summation of the total thickness of all layers used to evaluate Method B and Method C shall equal 100 ft. In many instances the 100 ft. of cumulative layers will include bedrock as is the case presented in Figure 1. All classes of bedrock shall be assumed to have an N_i or N_{chi} value of 100 blows/ft. or s_{ui} value of 5 ksf over the full depth of bedrock. These values shall be applied to both N_{chi} and s_{ui} when using Method C. These parameters specified for bedrock are also the maximum values that shall be used for soils.

The clay layer indicated in Figure 1 contains a soil sample with an s_{ui} of 6.2 ksf which is greater than the maximum previously specified. As stated above, s_{ui} shall not be taken as larger than 5.0 ksf. Shown below is an example calculation for d_i and s_{ui} for the clay layer assuming a maximum s_{ui} of 5.0 ksf:

$$d_i = 772.0 - 764.5 = 7.5 \text{ ft.}$$

$$s_{ui} = \frac{(4.7 + 5.0 + 5.0)\,\text{ksf}}{3} = 4.9 \text{ ksf}$$

Determining Local and Global Site Class Definitions

The geotechnical material within the upper 100 ft. shall be evaluated at each substructure unit using Methods B and C. As previously mentioned, the summation of the total thickness of all layers used to compute $\overline{N}$, $\overline{N}_{ch}$, or $\overline{s}_u$, shall equal 100 ft. The 100 ft. of cumulative layers should start at the bottom elevation of spread footings, 6 times the pile or shaft diameter/width below the bottom of abutment or pier footing elevations for pile supported foundations (except bent type piers), or 6 times the pile or shaft diameter/width below the ground surface elevation for bent type piers. Soils above these points are not anticipated to have a significant influence on the dynamic response of the structure.

In cases where bedrock is not encountered and the boring data does not extend to the base of the 100 ft. of cumulative layers, the average of the last 3 sample values should be used to characterize the balance of the 100 ft. soil profile.

There may be instances where the boring data does not encounter bedrock, but a bedrock elevation is anticipated within the upper 100 ft. based on adjacent boring data. In these situations, bedrock parameters should be applied starting at the estimated bedrock elevation. For the soil between the bottom of the boring log and the estimated bedrock elevation, the average of the last three sample values in the boring should be used.

There are also occasional projects where borings are not obtained at or near a particular substructure unit. In such instances it is permissible to interpolate between adjacent boring logs in order to estimate data within the upper 100 ft. at the subject location. Establishing geotechnical profile by interpolating between adjacent borings or averaging the last 3 sample values (especially when the last 3 sample values are composed of different materials) requires considerable judgment being exercised. Structure Geotechnical Report (SGR) authors should adequately document the rationale used to estimate such geotechnical conditions.

$\overline{N}$, $\overline{N}_{ch}$, and $\overline{s}_u$ shall be calculated at each substructure unit. For structures with individual spans less than or equal to 200 ft. or a total length less than or equal to 750 ft., the calculated results at each substructure unit shall be averaged to obtain a global Site Class Definition. For $\overline{N}$ (Method B), a simple or direct average of the results at each substructure unit shall be calculated. For $\overline{N}_{ch}$ and $\overline{s}_u$ (Method C), a weighted average shall be calculated. The global Site Class Definition for the structure shall be determined from AASHTO Table 3.10.3.1-1 and the following decision method. The softer (weaker) Site Class Definition corresponding to the global (averaged) $\overline{N}_{ch}$ and $\overline{s}_u$ (Method C) shall be compared to the results from Method B. When comparing the results from Methods B and C, the less soft (stronger) soil shall govern the determination of global Site Class Definition for the structure. The example at the end of this design guide provides complete calculations and detailed methods for determining local (substructure) and global (bridge) Site Class Definitions for a typical structure.

For structures with span lengths or a total structure length exceeding the values mentioned above, site class data from the individual substructure units shall not be averaged to obtain a global $\overline{N}$, $\overline{N}_{ch}$, or $\overline{s}_u$ for the structure. It is anticipated that the magnitude of influence due to local conditions (individual substructures) on the response of such structures will be greater than for smaller structures that are shorter in length. Therefore, the global Site Class Definition
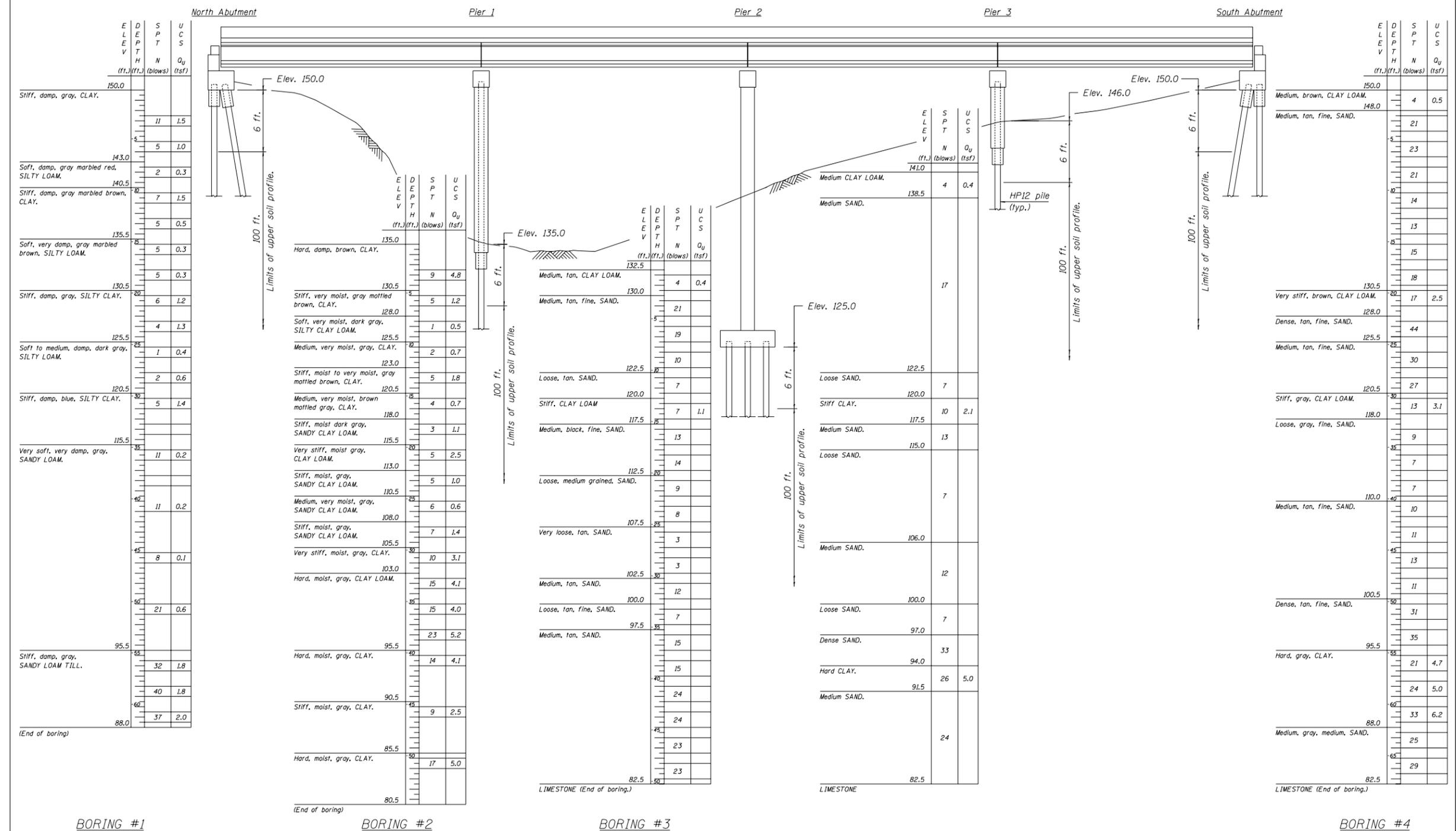
for such structures should typically reflect the softest (weakest) individual Site Class Definition determined. For larger, more complex projects, designers may elect to consider the individual response spectra at each substructure unit or develop a response spectra envelope for the structure that is reflective of the varying soil conditions. In such instances, the local Site Class Definition for each individual substructure unit should be specified. The seismic analysis for such projects should be simultaneously coordinated between the designer, SGR author, and Bureau of Bridges and Structures.

When using Method C, the Site Class Definition determined for $\overline{N}_{ch}$ or $\overline{s}_u$ shall be neglected when the total amount of cohesionless or cohesive soil present is less than 10% of the total soil amount under consideration (excluding any bedrock). This is applicable to the calculations for both individual and global Site Class Definition. If a site happens to reflect a soil profile conforming to the properties outlined in steps 1 and 2 of LRFD Table C3.10.3.1-1, the soils shall be classified or evaluated as indicated in the LRFD Code. The Bureau of Bridges and Structures should be contacted if soils characteristic of Site Class F are thought to be present. Also, projects that contain soils potentially susceptible to liquefaction shall have a single Site Class Definition determined assuming the soils at the site do not liquefy. The site factors that correspond to this Site Class Definition shall be applied by the designer to both the nonliquefied and liquefied analysis.

Site Class Definition Example

An elevation view of a 4-span bridge is indicated in Figure 2. Soil boring logs obtained near each abutment and Piers 1 and 2 are indicated in the figure. The geotechnical characteristics of the soil at Pier 3 have been estimated by interpolating between the soil boring logs at Pier 2 and the South Abutment.

North Abutment   Pier 1   Pier 2   Pier 3   South Abutment

BORING #1

ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Q_u (tsf)
150.0			
		11	1.5
		5	1.0
143.0			
140.5		2	0.3
		7	1.5
		5	0.5
135.5			
		5	0.3
		5	0.3
130.5			
		6	1.2
		4	1.3
125.5			
		1	0.4
		2	0.6
120.5			
		5	1.4
115.5			
		11	0.2
		11	0.2
		8	0.1
		21	0.6
95.5			
		32	1.8
		40	1.8
88.0		37	2.0

150.0 — Stiff, damp, gray, CLAY.
143.0 — Soft, damp, gray marbled red, SILTY LOAM.
140.5 — Stiff, damp, gray marbled brown, CLAY.
135.5 — Soft, very damp, gray marbled brown, SILTY LOAM.
130.5 — Stiff, damp, gray, SILTY CLAY.
125.5 — Soft to medium, damp, dark gray, SILTY LOAM.
120.5 — Stiff, damp, blue, SILTY CLAY.
115.5 — Very soft, very damp, gray, SANDY LOAM.
95.5 — Stiff, damp, gray, SANDY LOAM TILL.
(End of boring)

BORING #2

ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Q_u (tsf)
135.0			
130.5		9	4.8
128.0		5	1.2
125.5		1	0.5
123.0		2	0.7
120.5		5	1.8
118.0		4	0.7
115.5		3	1.1
113.0		5	2.5
110.5		5	1.0
108.0		6	0.6
105.5		7	1.4
103.0		10	3.1
		15	4.1
		15	4.0
95.5		23	5.2
		14	4.1
90.5		9	2.5
85.5		17	5.0
80.5			

Elev. 150.0
135.0 — Hard, damp, brown, CLAY.
130.5 — Stiff, very moist, gray mottled brown, CLAY.
128.0 — Soft, very moist, dark gray, SILTY CLAY LOAM.
125.5 — Medium, very moist, gray, CLAY.
123.0 — Stiff, moist to very moist, gray mottled brown, CLAY.
120.5 — Medium, very moist, brown mottled gray, CLAY.
118.0 — Stiff, moist dark gray, SANDY CLAY LOAM.
115.5 — Very stiff, moist gray, CLAY LOAM.
113.0 — Stiff, moist, gray, SANDY CLAY LOAM.
110.5 — Medium, very moist, gray, SANDY CLAY LOAM.
108.0 — Stiff, moist, gray, SANDY CLAY LOAM.
105.5 — Very stiff, moist, gray, CLAY.
103.0 — Hard, moist, gray, CLAY LOAM.
95.5 — Hard, moist, gray, CLAY.
90.5 — Stiff, moist, gray, CLAY.
85.5 — Hard, moist, gray, CLAY.
80.5 — (End of boring)

BORING #3

ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Q_u (tsf)
132.5			
130.0		4	0.4
		21	
		19	
122.5		10	
120.0		7	
117.5		7	1.1
		13	
		14	
112.5		5	
		9	
107.5		8	
		3	
102.5		3	
100.0		12	
97.5		7	
		15	
		15	
		24	
		24	
		23	
82.5		23	

Elev. 135.0
132.5 — Medium, tan, CLAY LOAM.
130.0 — Medium, tan, fine, SAND.
122.5 — Loose, tan, SAND.
120.0 — Stiff, CLAY LOAM
117.5 — Medium, black, fine, SAND.
112.5 — Loose, medium grained, SAND.
107.5 — Very loose, tan, SAND.
102.5 — Medium, tan, SAND.
100.0 — Loose, tan, fine, SAND.
97.5 — Medium, tan, SAND.
82.5 — LIMESTONE (End of boring.)

Pier 2 / Pier 3 log

ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Q_u (tsf)
141.0		4	0.4
138.5			
		17	
122.5		7	
120.0		10	2.1
117.5		13	
115.0			
		7	
106.0		12	
100.0		7	
97.0		33	
94.0		26	5.0
91.5			
		24	
82.5			

Elev. 125.0
141.0 — Medium CLAY LOAM.
138.5 — Medium SAND.
122.5 — Loose SAND.
120.0 — Stiff CLAY.
117.5 — Medium SAND.
115.0 — Loose SAND.
106.0 — Medium SAND.
100.0 — Loose SAND.
97.0 — Dense SAND.
94.0 — Hard CLAY.
91.5 — Medium SAND.
82.5 — LIMESTONE

Elev. 146.0   Elev. 150.0
HP12 pile (typ.)

BORING #4

ELEV (ft.)	DEPTH (ft.)	SPT N (blows)	UCS Q_u (tsf)
150.0			
148.0		4	0.5
		21	
		23	
		21	
		14	
		13	
		15	
		18	
130.5		17	2.5
128.0		44	
125.5		30	
		27	
120.5		13	3.1
118.0		9	
		7	
		7	
110.0		10	
		11	
		13	
		11	
100.5		31	
		35	
95.5		21	4.7
		24	5.0
88.0		33	6.2
		25	
		29	
82.5			

Elev. 150.0
150.0 — Medium, brown, CLAY LOAM.
148.0 — Medium, tan, fine, SAND.
130.5 — Very stiff, brown, CLAY LOAM.
128.0 — Dense, tan, fine, SAND.
125.5 — Medium, tan, fine, SAND.
120.5 — Stiff, gray, CLAY LOAM.
118.0 — Loose, gray, fine, SAND.
110.0 — Medium, tan, fine, SAND.
100.5 — Dense, tan, fine, SAND.
95.5 — Hard, gray, CLAY.
88.0 — Medium, gray, medium, SAND.
82.5 — LIMESTONE (End of boring.)

Limits of upper soil profile.   100 ft.   6 ft.

Figure 2. Bridge Elevation and Soil Boring Plot.

Determine Local Site Class Definitions

North Abutment Site Class Definition

Figure 3 provides a summary of the geotechnical characteristics for the upper 100 ft. of the soil profile at the North Abutment. HP12 piles are driven at each substructure unit and as such the upper 100 ft. of the soil profile is defined at the North Abutment as beginning 6 ft. (6 x 12 in. (pile width) = 6 ft.) below the bottom of the abutment cap elevation. Since the depth of the soil boring log does not extend the full depth of the soil profile being analyzed, data for the last 3 soil samples have been averaged to define the lower portion of the soil profile indicated below as Layer #10. The consistency in the bedrock elevation indicated in Borings #3 and #4 would typically suggest that bedrock could also be assumed at approximately the same elevation for Borings #1 and #2. Bedrock has been neglected in Borings #1 and #2 for the sake of the example to illustrate those instances when bedrock is not apparent and the soil borings do not extend the full depth of the soil profile being analyzed. The average N and s_u values indicated in Figure 3, and the subsequent figures for each substructure unit, have been calculated per the previous discussion *Applying and Averaging Soil Boring Data*.

Soil Layer Information				Total	Avg.	Avg.	Method B: $\overline{N}$			Method C: $\overline{N}_{ch}$			Method C: $\overline{s}_u$		
Layer #	Description		Thickness (ft.)	Thickness (ft)	N (blows)	s_u (ksf)	d_i (ft.)	N_i (blows)	d_i / N_i	d_i (ft.)	N_{chi} (blows)	$d_i * N_{chi}$	d_i (ft.)	s_{ui} (ksf)	d_i / s_{ui}
1	Stiff Clay		1.0	1.0	5	1.00	1.0	5	0.20				1.0	1.00	1.00
2	Soft Silty Loam		2.5	3.5	2	0.30	2.5	2	1.25				2.5	0.30	8.33
3	Stiff Clay		5.0	8.5	6	1.00	5.0	6	0.83				5.0	1.00	5.00
4	Soft Silty Loam		5.0	13.5	5	0.30	5.0	5	1.00				5.0	0.30	16.67
5	Stiff Silty Clay		5.0	18.5	5	1.25	5.0	5	1.00				5.0	1.25	4.00
6	Soft Silty Loam		5.0	23.5	2	0.50	5.0	2	2.50				5.0	0.50	10.00
7	Stiff Silty Clay		5.0	28.5	5	1.40	5.0	5	1.00				5.0	1.40	3.57
8	Very Soft Sandy Loam		20.0	48.5	13	0.28	20.0	13	1.54				20.0	0.28	71.43
9	Stiff Sandy Loam Till		7.5	56.0	36	1.87	7.5	36	0.21				7.5	1.87	4.01
10			44.0	100	36	1.87	44.0	36	1.22				44.0	1.87	23.53
							100		10.75	NA		NA	100		147.54
							=		=	=		=	=		=
							Σd_i		$\Sigma(d_i / N_i)$	d_s		$\Sigma(d_i / N_{chi})$	d_c		$\Sigma(d_i / s_{ui})$

Figure 3. North Abutment Soil Profile.

From LRFD Tables 3.10.3.1-1 and C3.10.3.1-1:

- Method B, $\overline{N} = \dfrac{\sum\limits_{i=1}^{n} d_i}{\sum\limits_{i=1}^{n} \dfrac{d_i}{N_i}} = \dfrac{100 \text{ ft.}}{10.75 \dfrac{\text{ft.}^2}{\text{blows}}} = 9 \dfrac{\text{blows}}{\text{ft.}} \leftarrow$ Site Class E

- Method C, $\overline{N}_{ch} = \dfrac{d_s}{\sum\limits_{i=1}^{m} \dfrac{d_i}{N_{chi}}} =$ NA, no cohesionless soil present.

- Method C, $\overline{s}_u = \dfrac{d_c}{\sum\limits_{i=1}^{k} \dfrac{d_i}{s_{ui}}} = \dfrac{100 \text{ ft.}}{147.54 \dfrac{\text{ft.}}{\text{ksf}}} = 0.68 \text{ ksf} \leftarrow$ Site Class E

$\rightarrow$ Both Methods B and C indicate a local Site Class E for the North Abutment. From here on in the example, the method that produces the highest normalized value is referred to as the controlling method whenever Methods B and C result in the same governing Site Class.

- Normalized Method B, $\overline{N} = \dfrac{9 \dfrac{\text{blows}}{\text{ft.}}}{15 \dfrac{\text{blows}}{\text{ft.}}} = 0.60$

- Normalized Method C, $\overline{s}_u = \dfrac{0.68 \text{ ksf}}{1.0 \text{ ksf}} = 0.68 \leftarrow$ Controls

The 15 blows/ft. and 1.0 ksf shown above reflect the data defining the upper boundaries of Site Class E as indicated in LRFD Table 3.10.3.1-1.

Pier 1 Site Class Definition

Figure 4 provides a summary of the geotechnical characteristics for the upper 100 ft. of the soil profile at Pier 1. Since HP12 piles are driven for the bent type pier, the upper 100 ft. of the soil profile is defined as starting at 6 ft. below the ground line elevation at the pier. Similar to the North Abutment, data for the last 3 soil samples have been averaged to define the lower portion of the soil profile indicated below as Layer #16.

Layer #	Description	Thickness (ft.)	Total Thickness (ft)	Avg. N (blows)	Avg. s_u (ksf)	d_i (ft.)	N_i (blows)	d_i/N_i	d_i (ft.)	N_{chi} (blows)	$d_i * N_{chi}$	d_i (ft.)	s_{ui} (ksf)	d_i/s_{ui}
	Soil Layer Information					Method B: $\overline{N}$			Method C: $\overline{N}_{ch}$			Method C: $\overline{s}_u$		
1	Stiff Clay	1.0	1.0	5	1.20	1.0	5	0.20				1.0	1.20	0.83
2	Soft Silty Clay Loam	2.5	3.5	1	0.50	2.5	1	2.50				2.5	0.50	5.00
3	Medium Clay	2.5	6.0	2	0.70	2.5	2	1.25				2.5	0.70	3.57
4	Stiff Clay	2.5	8.5	5	1.80	2.5	5	0.50				2.5	1.80	1.39
5	Medium Clay	2.5	11.0	4	0.70	2.5	4	0.63				2.5	0.70	3.57
6	Stiff Sandy Clay Loam	2.5	13.5	3	1.10	2.5	3	0.83				2.5	1.10	2.27
7	Very Stiff Clay Loam	2.5	16.0	5	2.50	2.5	5	0.50				2.5	2.50	1.00
8	Stiff Sandy Clay Loam	2.5	18.5	5	1.00	2.5	5	0.50				2.5	1.00	2.50
9	Medium Sandy Clay Loam	2.5	21.0	6	0.60	2.5	6	0.42				2.5	0.60	4.17
10	Stiff Sandy Clay Loam	2.5	23.5	7	1.40	2.5	7	0.36				2.5	1.40	1.79
11	Very Stiff Clay	2.5	26.0	10	3.10	2.5	10	0.25				2.5	3.10	0.81
12	Hard Clay Loam	7.5	33.5	18	4.37	7.5	18	0.42				7.5	4.37	1.72
13	Hard Clay	5.0	38.5	14	4.10	5.0	14	0.36				5.0	4.10	1.22
14	Stiff Clay	5.0	43.5	9	2.50	5.0	9	0.56				5.0	2.50	2.00
15	Hard Clay	5.0	48.5	17	5.00	5.0	17	0.29				5.0	5.00	1.00
16		51.5	100	13	3.87	51.5	13	3.96				51.5	3.87	13.31
						100		13.52	NA		NA	100		46.14
						=		=	=		=	=		=
						Σd_i		$\Sigma (d_i/N_i)$	d_s		$\Sigma(d_i/N_{chi})$ d_c			$\Sigma(d_i/s_{ui})$

Figure 4. Pier 1 Soil Profile

- Method B, $\overline{N}$ $= \dfrac{100 \text{ ft.}}{13.52 \dfrac{\text{ft.}^2}{\text{blows}}} = 7 \dfrac{\text{blows}}{\text{ft.}}$ ← Site Class E

- Method C, $\overline{N}_{ch}$ = NA, no cohesionless soil present.

- Method C, $\overline{s}_u$ $= \dfrac{100 \text{ ft.}}{46.14 \dfrac{\text{ft.}}{\text{ksf}}} = 2.17 \text{ ksf}$ ← Site Class C

→ Method C governs with a local Site Class C for Pier 1.

Pier 2 Site Class Definition

Figure 5 provides a summary of the geotechnical characteristics for the upper 100 ft. of the soil profile at Pier 2. HP12 piles are provided at the pier and as such the upper 100 ft. of the soil profile is defined as starting 6 ft. below the bottom of pile cap elevation.

Soil Layer Information		Total Thickness	Avg. N	Avg. s_u	Method B: $\overline{N}$			Method C: $\overline{N}_{ch}$			Method C: $\overline{s}_u$		
Layer #	Description	Thickness (ft.)	(ft)	N (blows)	s_u (ksf)	d_i (ft.)	N_i (blows)	d_i / N_i	d_i (ft.)	N_{chi} (blows)	$d_i * N_{chi}$	d_i (ft.)	s_{ui} (ksf)	d_i / s_{ui}
1	Stiff Clay	1.5	1.5	7	1.10	1.5	7	0.21				1.5	1.10	1.36
2	Medium Sand	5.0	6.5	14		5.0	14	0.36	5.0	14	0.36			
3	Loose Sand	5.0	11.5	9		5.0	9	0.56	5.0	9	0.56			
4	Very Loose Sand	5.0	16.5	3		5.0	3	1.67	5.0	3	1.67			
5	Medium Sand	2.5	19.0	12		2.5	12	0.21	2.5	12	0.21			
6	Loose Sand	2.5	21.5	7		2.5	7	0.36	2.5	7	0.36			
7	Medium Sand	15.0	36.5	21		15.0	21	0.71	15.0	21	0.71			
8	Limestone	63.5	100	100	5.00	63.5	100	0.64	63.5	100	0.64	63.5	5.00	12.70
						100		4.71	98.5		4.49	65.0		14.06
						=		=	=		=	=		=
						Σd_i		$\Sigma(d_i / N_i)$	d_s		$\Sigma(d_i / N_{chi})$	d_c		$\Sigma(d_i / s_{ui})$

Figure 5. Pier 2 Soil Profile.

- Determine the % of soil composition for each soil type.

  - % d_s (cohesionless) = $\dfrac{d_s - d_s(\text{rock})}{100 - d_s(\text{rock})}$ = $\dfrac{(98.5 - 63.5)\text{ft.}}{(100 - 63.5)\text{ft.}}$ = 95.8%

  - % d_c (cohesive) = 100% - 95.8% = 4.2% < 10% ← Neglect $\overline{s}_u$ when analyzing the local Site Class Definition. However, calculate $\overline{s}_u$ for global Site Class Definition analysis.

- Method B, $\overline{N}$ = $\dfrac{100 \text{ ft.}}{4.71 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 21 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{N}_{ch}$ = $\dfrac{98.5 \text{ ft.}}{4.49 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 22 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{s}_u$ = $\dfrac{65 \text{ ft.}}{14.06 \dfrac{\text{ft.}}{\text{ksf}}}$ = 4.62 ksf ← NA for local Site Class Definition.

→ Method C, $\overline{N}_{ch}$, governs with a local Site Class D for Pier 2.

Pier 3 Site Class Definition

Figure 6 provides a summary of the geotechnical characteristics for the upper 100 ft. of the soil profile at Pier 3. The soil profile shown for Pier 3 is estimated by interpolation of the soil borings near the adjacent substructure units. Similar to Pier 1, the upper 100 ft. of the soil profile is defined as starting at 6 ft. below the ground line elevation at the pier.

	Soil Layer Information		Total	Avg.	Avg.		Method B: $\overline{N}$			Method C: $\overline{N}_{ch}$			Method C: $\overline{s}_u$		
Layer	Description	Thickness	Thickness	N	s_u		d_i	N_i	d_i/N_i	d_i	N_{chi}	$d_i * N_{chi}$	d_i	s_{ui}	d_i/s_{ui}
#		(ft.)	(ft)	(blows)	(ksf)		(ft.)	(blows)		(ft.)	(blows)		(ft.)	(ksf)	
1	Medium Clay Loam	1.5	1.5	4	0.40		1.5	4	0.38				1.5	0.40	3.75
2	Medium Sand	16.0	17.5	17			16.0	17	0.94	16.0	17	0.94			
3	Loose Sand	2.5	20.0	7			2.5	7	0.36	2.5	7	0.36			
4	Stiff Clay	2.5	22.5	10	2.10		2.5	10	0.25				2.5	2.10	1.19
5	Medium Sand	2.5	25.0	13			2.5	13	0.19	2.5	13	0.19			
6	Loose Sand	9.0	34.0	7			9.0	7	1.29	9.0	7	1.29			
7	Medium Sand	6.0	40.0	12			6.0	12	0.50	6.0	12	0.50			
8	Loose Sand	3.0	43.0	7			3.0	7	0.43	3.0	7	0.43			
9	Dense Sand	3.0	46.0	33			3.0	33	0.09	3.0	33	0.09			
10	Hard Clay	2.5	48.5	26	5.00		2.5	26	0.10				2.5	5.00	0.50
11	Medium Sand	9.0	57.5	24			9.0	24	0.38	9.0	24	0.38			
12	Limestone	42.5	100	100	5.00		42.5	100	0.43	42.5	100	0.43	42.5	5.00	8.50
							100		5.32	93.5		4.60	49.0		13.94
							‖		‖	‖		‖	‖		‖
							Σd_i		$\Sigma(d_i/N_i)$	d_s		$\Sigma(d_i/N_{chi})$	d_c		$\Sigma(d_i/s_{ui})$

Figure 6. Pier 3 Soil Profile.

- Determine the % of soil composition for each soil type.

  o % d_s (cohesionless) = $\dfrac{d_s - d_s(\text{rock})}{100 - d_s(\text{rock})}$ = $\dfrac{(93.5 - 42.5)\text{ft.}}{(100 - 42.5)\text{ft.}}$ = 88.7%

  o % d_c (cohesive) = 100% - 88.7% = 11.3% > 10% ← Consider $\overline{s}_u$ and $\overline{N}_{ch}$ when analyzing the local Site Class Definition.

- Method B, $\overline{N}$ = $\dfrac{100 \text{ ft.}}{5.32 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 19 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{N}_{ch}$ = $\dfrac{93.5 \text{ ft.}}{4.60 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 20 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{s}_u$ = $\dfrac{49 \text{ ft.}}{13.94 \dfrac{\text{ft.}}{\text{ksf}}}$ = 3.51 ksf ← Site Class C

→ Method C, $\overline{N}_{ch}$, governs with a local Site Class D for Pier 3.

South Abutment Site Class Definition

Figure 7 provides a summary of the geotechnical characteristics for the upper 100 ft. of the soil profile at the South Abutment and is reflective of the guidelines highlighted in the examples for the previous substructure units.

Soil Layer Information		Total Thickness (ft)	Avg. N (blows)	Avg. s_u (ksf)	Method B: $\overline{N}$			Method C: $\overline{N}_{ch}$			Method C: $\overline{s}_u$		
Layer #	Description (ft.)				d_i (ft.)	N_i (blows)	d_i / N_i	d_i (ft.)	N_{chi} (blows)	$d_i * N_{chi}$	d_i (ft.)	s_{ui} (ksf)	d_i / s_{ui}
1	Medium Sand 13.5	13.5	17		13.5	17	0.79	13.5	17	0.79			
2	Very Stiff Clay Loam 2.5	16.0	17	2.50	2.5	17	0.15				2.5	2.50	1.00
3	Dense Sand 2.5	18.5	44		2.5	44	0.06	2.5	44	0.06			
4	Medium Sand 5.0	23.5	29		5.0	29	0.17	5.0	29	0.17			
5	Stiff Clay Loam 2.5	26.0	13	3.10	2.5	13	0.19				2.5	3.10	0.81
6	Loose Sand 8.0	34.0	8		8.0	8	1.00	8.0	8	1.00			
7	Medium Sand 9.5	43.5	11		9.5	11	0.86	9.5	11	0.86			
8	Dense Sand 5.0	48.5	33		5.0	33	0.15	5.0	33	0.15			
9	Hard Clay 7.5	56.0	26	4.90	7.5	26	0.29				7.5	4.90	1.53
10	Medium Sand 5.5	61.5	27		5.5	27	0.20	5.5	27	0.20			
11	Limestone 38.5	100	100	5.00	38.5	100	0.39	38.5	100	0.39	38.5	5.00	7.70
					100		4.26	87.5		3.63	51.0		11.04
					=		=	=		=	=		=
					Σd_i		$\Sigma (d_i / N_i)$	d_s		$\Sigma (d_i / N_{chi})$	d_c		$\Sigma (d_i / s_{ui})$

Figure 7. South Abutment Soil Profile.

Determine the % of soil composition for each soil type.

- o   % d_s (cohesionless) = $\dfrac{d_s - d_s(\text{rock})}{100 - d_s(\text{rock})}$ = $\dfrac{(87.5 - 38.5)\text{ft.}}{(100 - 38.5)\text{ft.}}$ = 79.7%

- o   % d_c (cohesive) = 100% - 79.7% = 20.3% > 10% ← Consider $\overline{s}_u$ and $\overline{N}_{ch}$ when analyzing the local Site Class Definition.

- Method B, $\overline{N}$ = $\dfrac{100 \text{ ft.}}{4.26 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 23 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{N}_{ch}$ = $\dfrac{87.5 \text{ ft.}}{3.63 \dfrac{\text{ft.}^2}{\text{blows}}}$ = 24 $\dfrac{\text{blows}}{\text{ft.}}$ ← Site Class D

- Method C, $\overline{s}_u$ = $\dfrac{51 \text{ ft.}}{11.04 \dfrac{\text{ft.}}{\text{ksf}}}$ = 4.62 ksf ← Site Class C

→ Method C, $\overline{N}_{ch}$, governs with a local Site Class D for the South Abutment.

Global Site Class Definition

- The table shown below provides a summary of the cohesionless and cohesive soil present at the substructure units. Determine the % of soil composition for each material type for the structure location.

Soil Composition Summary		
Location	d_s (cohesionless)	d_c (cohesive)
	(ft.)	(ft.)
North Abutment	0	100
Pier 1	0	100
Pier 2	35	1.5
Pier 3	51	6.5
South Abutment	49	12.5
	135	220.5
	‖	‖
	$\Sigma\, d_s$ (cohesionless)	$\Sigma\, d_c$ (cohesive)

Figure 8. Soil Composition Summary.

o % d_s (cohesionless) = $\dfrac{\sum d_s(\text{cohesionless})}{\sum d_s(\text{cohesionless}) + \sum d_c(\text{cohesive})}$

$= \dfrac{(135)\text{ft.}}{(135 + 220.5)\text{ft.}} = 38.0\%$

o % d_c (cohesive) = 100% - 38% = 62.0% > 10% $\leftarrow$ Consider $\bar{s}_u$ and $\overline{N}_{ch}$ when calculating the global Site Class Definition.

$\rightarrow$ Determine the global Site Class Definition using a direct average of the data used to determine the local Site Class Definitions for Method B and using a weighted average for Method C.

- Method B, $\overline{N}_{Global}$ $= \dfrac{\sum \overline{N}}{(\text{\# Substructure Units})} = \dfrac{(9 + 7 + 21 + 19 + 23)\dfrac{\text{blows}}{\text{ft.}}}{(5\text{ Substructure Units})}$

$= 16\ \dfrac{\text{blows}}{\text{ft.}}$ $\leftarrow$ Site Class D

- Method C, $\overline{N}_{ch\,Global}$ $= \dfrac{\sum(\overline{N}_{ch} \times d_s)}{\sum d_s} = \dfrac{[(22)(98.5\text{ ft.}) + (20)(93.5\text{ ft.}) + (24)(87.5\text{ ft.})]\dfrac{\text{blows}}{\text{ft.}}}{(98.5 + 93.5 + 87.5)\text{ ft.}}$

$= 22\ \dfrac{\text{blows}}{\text{ft.}}$ $\leftarrow$ Site Class D

- Method C, $\bar{s}_{u\,Global}$ $= \dfrac{\sum(\bar{s}_u \times d_c)}{\sum d_c}$

$$= \frac{(0.68\,\text{ksf})(100\,\text{ft.}) + (2.17\,\text{ksf})(100\,\text{ft.}) + (4.62\,\text{ksf})(65\,\text{ft.}) + (3.51\,\text{ksf})(49\,\text{ft.}) + (4.62\,\text{ksf})(51\,\text{ft.})}{(100 + 100 + 65 + 49 + 51)\,\text{ft.}}$$

$$= 2.72\,\text{ksf} \leftarrow \text{Site Class C}$$

$\rightarrow$ Method C, $\overline{N}_{ch\,Global}$ governs for this structure with a Site Class D applicable to the entire bridge. This is the site class that will be reflected with the Seismic Data information shown on the bridge plans for this structure.