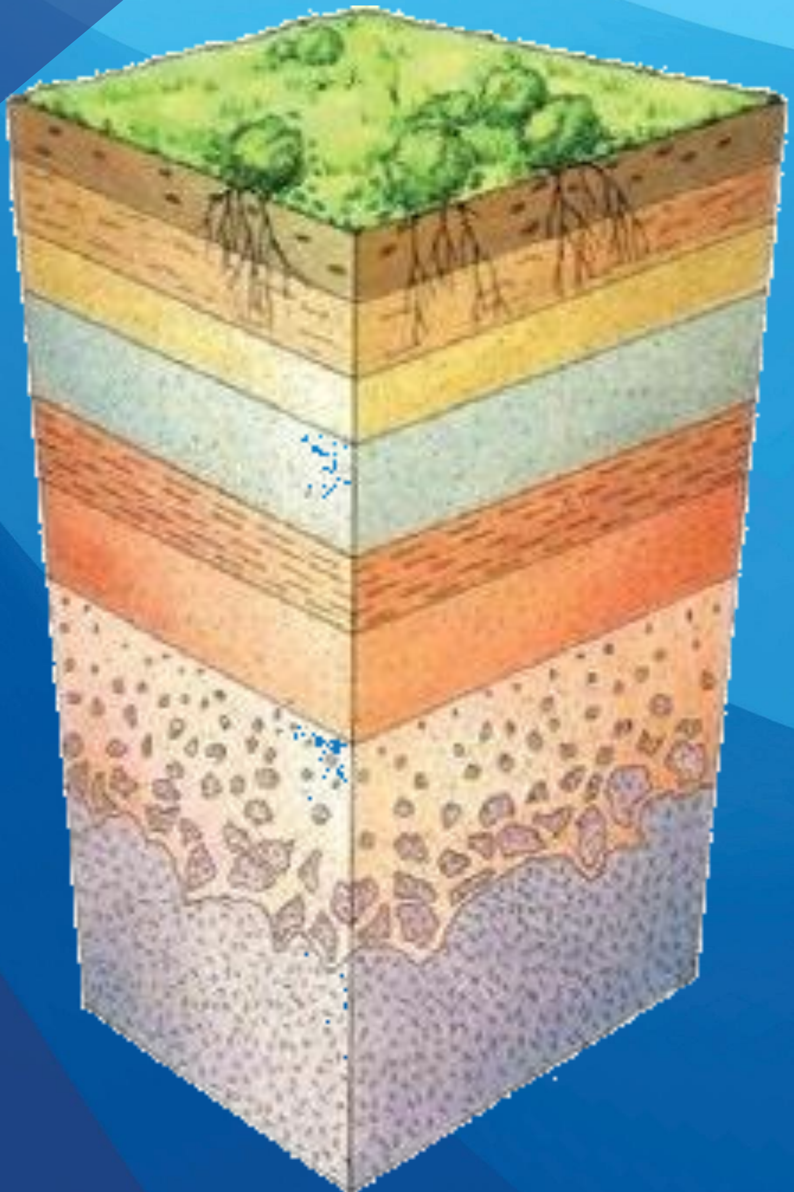
RMC Site Classification Toolbox

RMC Seismic Hazard Suite

RMC-CPD-2023-01

November 2023

US Army Corps of Engineers®
Dam and Levee Safety Programs



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Cover graphic excerpted from the Federal Emergency Management Agency (FEMA) (2021). *The role of the NEHRP recommended seismic provisions in the development of nationwide seismic building code regulations: A thirty-five-year retrospective* (FEMA P-2156), Figure 4.
https://www.fema.gov/sites/default/files/documents/fema_bssc-35-year-retrospective.pdf

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Prepared by the Risk Management Center

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14. ABSTRACT
The spreadsheet tools contained in this toolbox assess the site classification based on the upper 100 feet of the site profile using the procedures of ASCE/SEI 7-16 and ASCE/SEI 7-22.

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PREPARED

The results, findings, and recommendations provided in this document are technically sound and consistent with current Corps of Engineers practice.

Tim O'Leary, Risk Management Center

REVIEWED

This report has been checked and reviewed and is believed to be in accordance with the standards of the profession.

Carmen Williams, Risk Management Center

APPROVED

Nate Snorteland, Risk Management Center

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1. Introduction

The Risk Management Center (RMC) of the U.S. Army Corps of Engineers (USACE) has developed a suite of Microsoft Excel spreadsheets to support risk assessments for dam and levee safety. Each analysis suite is composed of multiple toolboxes (Microsoft Excel workbooks), and each toolbox contains multiple spreadsheet tools or calculation worksheets (Microsoft Excel worksheets). The RMC Site Classification Toolbox is part of the RMC Seismic Hazard Suite.

The information from these spreadsheet tools, along with other pertinent information, informs judgment when developing a list of more and less likely factors and estimating probabilities. USACE best practice for estimating probabilities is to use the best available and multiple methods, but all final probabilities are estimated using team elicitation based on the totality and strength of the evidence.

The RMC continuously works to improve the performance of RMC software; report possible bugs directly to the RMC at the address listed below. Ideally, report suspected errors in written form with a description of the problem and the steps that lead to its occurrence. Suggestions for improvement are also welcomed.

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3. General Overview

3.1. Getting Started

Copy or download the toolbox file to the computer. To open the toolbox file, either:

- Find the file on the computer and double-click it. This opens the file in Microsoft Excel.
- Open Microsoft Excel and use the application to open the file: Once Microsoft Excel is open, go to the File menu at the top of the window and select Open.

The toolbox is an Excel binary workbook (.xlsb) that uses macros. You may need to enable the macros, either before opening the file or by clicking “Enable Content” in the yellow Security Warning message bar with a shield icon that appears after the file is opened. The actual message in the message bar will vary depending on the computer’s settings and installed add-ins. Figure 1 displays examples of different wordings that may appear in the message bar.

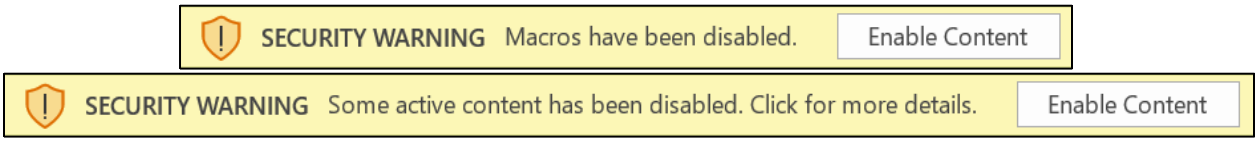


Figure 1. Security warning message bars with the “Enable Content” option to enable macros.

3.2. Organization

Although the toolbox does not provide a calculation cover sheet, adding one is strongly recommended. A calculation cover sheet captures project information, a description and purpose of the calculation, the assumptions for critical input parameters, a summary of the major conclusion and results, and a revision history.

Each toolbox has a similar appearance and organizational structure:

- The first worksheet, About, summarizes the purpose of the toolbox and gives contact information for the RMC software development team.
- The second worksheet, Terms and Conditions, contains the terms and conditions for use of the toolbox (IWR software).
- The third worksheet, Version History, contains the revision history. Semantic versioning is used in the format of MAJOR.MINOR.PATCH:
    - MAJOR – significant worksheet changes not compatible with previous versions.
    - MINOR – additional features or enhancements that do not fundamentally change the calculations.
    - PATCH – backward-compatible bug fixes.

- The fourth worksheet, References, lists the references cited for each calculation worksheet.

The workbook and worksheets are not protected to prevent unwanted changes. However, because the toolbox has user-defined functions (UDFs) and subroutines in Visual Basic, you cannot directly copy worksheets to another workbook without potentially losing functionality. A note in a bold red font at the upper right margin indicates if the selected worksheet includes such features.

At the top of each calculation worksheet, input information for the preparer and checker for quality control (QC) documentation and the calculation title in case multiple copies of the worksheet are created for different analysis scenarios (Figure 2). The footer of each calculation worksheet contains the version number, which can be cross-referenced with the revision history on the third worksheet.

Prepared by:		Office:		Date:	
Checked by:		Office:		Date:	
Calculation Title:					

Figure 2. Calculation worksheet heading.

User-specified input includes values and selections from drop-down lists. User input cells are light yellow, and these cells are unprotected. When cells use drop-down lists, a note in blue font in the right margin of the row alerts the user to use the drop-down list. Conditional formatting applies a gray background to cells that are not based on a user selection. When a user-specified value or calculated value is outside of acceptable ranges, the cell is orange to indicate caution to the user.

All units for user-specified input values are clearly labeled. Most user-specified input values use English units. However, values may be in metric where metric units are more common in practice (e.g., particle size in millimeters or permeability in centimeters per second). The toolbox may convert English units to metric units to perform some calculations or if required for a specific formula based on the reference material for the equation.

If the calculation worksheet is a function of headwater level, up to seven headwater and tailwater levels may be specified at the top of the worksheet. Tailwater may be required to calculate the net hydraulic head and hydraulic gradient. Specify the elevation datum by selecting one of three options from the drop-down list: ft-NAVD88, ft-NGVD29, and Other. The two datum selections include English units of length (feet). If Other is selected, provide a user-specified datum along with feet (e.g., ft-MSL [Mean Sea Level]). Figure 3 through Figure 5 illustrate the three possible scenarios.

Elevation datum		ft-NAVD88		Specify datum				◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-NAVD88)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-NAVD88)

Figure 3. Headwater and tailwater input: NAVD88.

Elevation datum		ft-NGVD29		Specify datum				◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-NGVD29)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-NGVD29)

Figure 4. Headwater and tailwater input: NGVD29.

Elevation datum		Other		Specify datum		ft-MSL		◄ Use drop-down list.
HW (ft)	195.5	201.6	213.5	218.9	223.0	234.0	239.0	◄ Headwater level, HW (ft-MSL)
TW (ft)	184.0	184.0	184.0	184.0	184.0	184.0	184.0	◄ Tailwater level, TW (ft-MSL)

Figure 5. Headwater and tailwater input: user-specified datum.

Most calculation worksheets break down complex analysis into computational steps following a logical sequence (Figure 6). Some simpler worksheets do not have steps. Generally, different methodologies are unique worksheets. Some worksheets may include multiple methodologies, which are labeled as options (Figure 7).

Step 1: Select the method of analysis

Figure 6. Example of step banner.

Option 1: Riverside blanket (top stratum) for Cases 5, 7, and 8

Figure 7. Example of option banner.

Some calculation worksheets can perform either a deterministic or probabilistic analysis. Although not required to perform a probabilistic analysis, Palisade @RISK software (standalone version or as part of the Palisade DecisionTools Suite) can customize the probabilistic analysis. A note appears in a bold red font at the upper right-hand margin of a calculation worksheet indicating if this feature is included with the toolbox.

User notes generally appear in the right margin of each calculation worksheet. Some notes are in blue or red font for heightened awareness. These notes include references to source materials for equations, figures, tables, pages, etc. If the RMC modified the source material, the reference citation says “adapted from” instead of “from.”

Tabular and/or graphical summaries are generally the primary output of the toolbox. The UDFs in the PlotScale module change the minimum and maximum values of the x-axis and y-axis for charts. If the calculation worksheet is a function of headwater level, you can define up to five headwater levels of interest and plot them as vertical reference lines. By selecting the chart and then selecting the Filter icon to display the filter pane, you can choose which data series to display. This is useful when computing the results from multiple methodologies, but not all are applicable or desired to display.

4. Background

The effects of local soil conditions on ground motion characteristics must be considered when designing and evaluating structures. Ground motion amplification in soil relative to hard rock is illustrated in Figure 8. According to Federal Emergency Management Agency publication *Earthquake-Resistant Design Concepts: An Introduction , Seismic Provisions for New Buildings* (FEMA P-749) (2nd ed.), hard, competent rock efficiently transmits shaking with high-frequency (short-period) energy content but tends to attenuate shaking with low-frequency (long-period) energy content. Deep deposits of soft soil transmit high-frequency motion less efficiently but tend to amplify the low-frequency energy content.

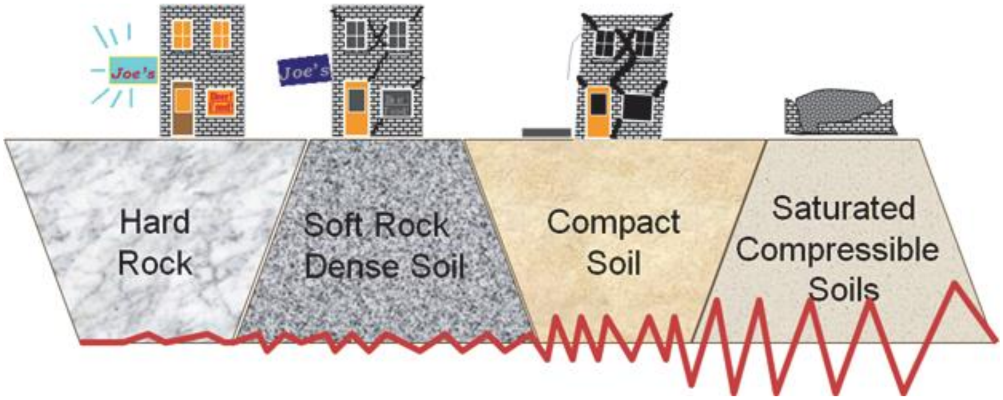


Figure 8. Ground motion amplification (FEMA 2022).

A site response analysis can determine the importance of these effects. However, site class is a simplified method for characterizing the ground motion attenuation and amplifying effects during an earthquake. Site class is defined in terms of the average shear wave velocity in the upper 100 feet of the site profile. Shear waves generated by an earthquake create the strongest horizontal shaking, which is most damaging to structures. Soft soils with lower shear wave velocities generally produce greater amplification than stiff soils with higher shear wave velocities.

The National Earthquake Hazards Reduction Program (NEHRP) Recommended Seismic Provisions defines a suite of site classes to which typical ground motion attenuation and amplification effects are assigned. Site Class A represents a “hard rock” condition, typically found only in the eastern United States. Site Class B represents a “firm rock” condition in the upper 100 feet and indicates limited amplification at the ground surface of predicted bedrock motions. Site Classes C through E represent increasingly looser or softer soil conditions with progressively increasing amplification. Site Class F represents unstable soils requiring site-specific site response analyses.

The site classification procedure is incorporated into seismic design standards and building codes. The RMC Seismic Hazard Curves Toolbox uses the site coefficients in the general procedures in the American Society of Civil Engineers/Structural Engineering Institute’s *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (American Society of Civil Engineers [ASCE]/Structural Engineering Institute [SEI] 7-16) to adjust the Site Class B/C hazard curve from the United States Geological Survey (USGS) legacy datasets for the user-specified site class. Since these site coefficients may not be applicable to Site Class F, only Site Classes A through E are evaluated by the RMC Site Classification Toolbox.

5. ASCE/SEI 7-16

This worksheet determines the site classification using ASCE/SEI 7-16 when site-specific site response analyses are not required. The site class definitions are based on the average shear wave velocity of the upper 100 feet of the site profile. Measured shear wave velocities should be used for site classification if they are available; however, often they are not available. If measured shear wave velocity data are not available, ASCE/SEI 7-16 provides alternate definitions of site class using the more readily available geotechnical parameters of standard penetration test (SPT) resistance (N or blow count) for cohesionless soils and rock and SPT blow count and undrained shear strength for cohesive soils. Table 1 outlines the six site classes as defined by ASCE/SEI 7-16.

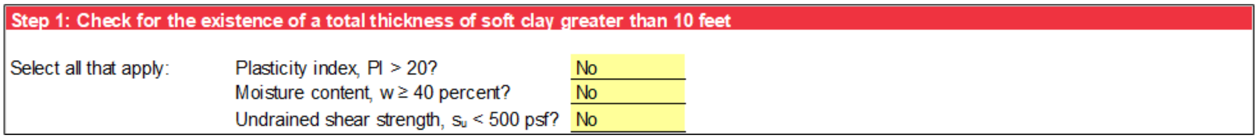
Table 1
Site classification (ASCE/SEI 7-16).

Site Class	$\overline{v_s}$ (ft/s)	$\overline{N}$ or $\overline{N_{ch}}$ (bpf)	$\overline{s_u}$ (psf)
A. Hard rock	$\overline{v_s} > 5{,}000$	N/A	N/A
B. Rock	$2{,}500 < \overline{v_s} \leq 5{,}000$	N/A	N/A
C. Very dense soil and soft rock	$1{,}200 < \overline{v_s} \leq 2{,}500$	$\overline{N}$ or $\overline{N_{ch}} > 50$	$\overline{s_u} > 2{,}000$
D. Stiff soil	$600 \leq \overline{v_s} \leq 1{,}200$	$15 \leq \overline{N}$ or $\overline{N_{ch}} \leq 50$	$1{,}000 \leq \overline{s_u} \leq 2{,}000$
E. Soft clay	$\overline{v_s} < 600$	$\overline{N}$ or $\overline{N_{ch}} < 15$	$\overline{s_u} < 1{,}000$
	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf
F. Unstable soils	N/A	N/A	N/A

5.1. Soft Clay Layer

In step 1, the characteristics for Site Class E are evaluated for a total thickness of soft clay greater than 10 feet. A soft clay layer is defined by the following criteria: undrained shear strength (s_u) less than 500 pounds per square foot (psf) as determined by the American Society for Testing and Materials (ASTM) D2166, *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil* or ASTM D2850, *Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils*, moisture content (*w*) greater than or equal to 40 percent as determined by ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, and a plasticity index (*PI*) greater than 20 as determined by ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*.

Each criterion is individually assessed (outside of this toolbox) based on the available site characterization data and judgment, and each criterion that is met is selected using a drop-down list as shown in Figure 9.


Step 1: Check for the existence of a total thickness of soft clay greater than 10 feet

Select all that apply:	Plasticity index, PI > 20?	No
	Moisture content, w ≥ 40 percent?	No
	Undrained shear strength, s_u < 500 psf?	No

Figure 9. Step 1 of ASCE 7-16 worksheet.

5.2. Site Profile Characterization

If all three characteristics of a soft soil layer greater than 10 feet exist in step 1, step 2 is not evaluated, and conditional formatting applies a gray background to step 2. These cells are not used in subsequent calculations even if data is present. If all three characteristics of a soft soil layer greater than 10 feet do not exist in step 1, select the method of analysis to characterize the upper 100 feet of the site profile from the drop-down list.

- Average shear wave velocity (method 1)
- Average SPT blow count for cohesionless soils, cohesive soils, and rock (method 2)
- Average SPT blow count for cohesionless soils and rock and undrained shear strength for cohesive soils (method 3)

The 100-foot site profile is subdivided into a maximum of 14 distinct soil or rock layers based on the site characterization data. Each distinct layer is designated by a number from 1 to *n* (at the bottom of the site profile). The input includes depth (or elevation) below the ground surface or structure, a description of the layer, and geotechnical parameters based on the selected method of analysis. If site-specific data are not available to a depth of 100 feet, the soil and rock parameters must be estimated based on known geologic conditions and experience to extrapolate the site profile to a depth of 100 feet. The distinct layer thicknesses are computed by subtracting the top and bottom depth (or elevation).

For method 1, the average shear wave velocity in the upper 100 feet of the site profile $(\overline{v_s})$ is calculated using Equation 1.

$$\overline{v_s} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \tag{1}$$

where:

n = number of layers
d_i = thickness (feet) of any layer
v_{si} = small-strain shear wave velocity (ft/s) of any layer

The total thickness is calculated using Equation 2.

$$\sum_{i=1}^{n} d_i = 100 \text{ feet} \tag{2}$$

The sum of the distinct layer thicknesses must be 100 feet, no more and no less. If the sum is not exactly 100 feet, conditional formatting applies an orange background to the cell containing the total thickness of the profile. Figure 10 illustrates Step 2 for method 1.

Step 2: Characterize the upper 100 feet of the site profile

Method of analysis? Average shear wave velocity

$z_{top,i}$ (feet)	$z_{bot,i}$ (feet)	Soil or Rock Layer Description	v_{si} (ft/s) / N_i (bpf) / N_i (bpf)	d_i (feet) / d_i (feet) / d_{si} (feet)	d_i/v_{si} / d_i/N_i / d_{si}/N_i	s_{ui} (ft/s)	d_{ci} (feet)	d_i/s_{ui}
188.0	178.0	Lean Clay	550	10.0	0.018		-	-
178.0	168.0	Lean Clay	650	10.0	0.015		-	-
168.0	158.0	Fine to medium sand	800	10.0	0.013		-	-
158.0	148.0	Fine to medium sand	1,000	10.0	0.010		-	-
148.0	88.0	Fine to medium sand	1,300	60.0	0.046		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
			Total	100.0	0.102	Total	-	-

Average shear wave velocity, $\overline{v}_s = \Sigma(d_i) / \Sigma(d_i/v_{si})$ 978 ft/s
Average SPT blow count, $\overline{N} = \Sigma(d_i) / \Sigma(d_i/N_i)$ or $\overline{N}_{ch} = \Sigma(d_{si}) / \Sigma(d_{si}/N_i)$ - bpf
Average undrained shear strength, $\overline{s}_{ui} = \Sigma(d_{ci}) / \Sigma(d_{ci}/s_{ui})$ - psf

Figure 10. Step 2 of ASCE 7-16 worksheet using average shear wave velocity.

For method 2, the average field SPT resistance ($\overline{N}$) for cohesionless soil, cohesive soil, and rock layers is calculated using Equation 3.

$$\overline{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{m} \frac{d_i}{N_i}} \tag{3}$$

where:

> d_i = thickness (feet) of any cohesionless soil, cohesive soil, and rock layer
> N_i = SPT blow count not to exceed 100 blows per foot (bpf) as directly measured in the field without corrections in accordance with ASTM D1586, *Standard Test Method for Standard Penetration Test and Split-Barrel Sampling of Soils*

If refusal is met for a rock layer, N_i of 100 bpf can be used. Conditional formatting applies an orange background to N_i values not between 0 and 100 bpf. Figure 11 illustrates Step 2 for method 2.

Step 2: Characterize the upper 100 feet of the site profile

Method of analysis? Average SPT blow count for cohesionless soils, cohesive soils, and rock

$z_{top,i}$ (feet)	$z_{bot,i}$ (feet)	Soil or Rock Layer Description	v_{si} (ft/s) / N_i (bpf) / N_i (bpf)	d_i (feet) / d_i (feet) / d_{si} (feet)	d_i/v_{si} / d_i/N_i / d_{si}/N_i	s_{ui} (ft/s)	d_{ci} (feet)	d_i/s_{ui}
188.0	178.0	Lean Clay	7	10.0	1.429		-	-
178.0	168.0	Lean Clay	12	10.0	0.833		-	-
168.0	158.0	Fine to medium sand	15	10.0	0.667		-	-
158.0	148.0	Fine to medium sand	22	10.0	0.455		-	-
148.0	88.0	Fine to medium sand	31	60.0	1.935		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
			Total	100.0	5.319	Total	-	-

Average shear wave velocity, $\overline{v}_s = \Sigma(d_i) / \Sigma(d_i/v_{si})$	- ft/s
Average SPT blow count, $\overline{N} = \Sigma(d_i) / \Sigma(d_i/N_i)$ or $\overline{N}_{ch} = \Sigma(d_{si}) / \Sigma(d_{si}/N_i)$	19 bpf
Average undrained shear strength, $\overline{s}_{ui} = \Sigma(d_{ci}) / \Sigma(d_{ci}/s_{ui})$	- psf

Figure 11. Step 2 of ASCE 7-16 worksheet using average standard penetration test blow count.

For method 3, the average field SPT blow count for cohesionless soil layers in the upper 100 feet of the site profile ($\overline{N_{ch}}$) is calculated using Equation 4.

$$\overline{N_{ch}} = \frac{d_s}{\sum_{i=1}^{m} \frac{d_{si}}{N_i}} \tag{4}$$

where:

> m = number of cohesionless soil layers
> d_s = total thickness (feet) of cohesionless soil layers
> d_{si} = thickness (feet) of any cohesionless soil layer

The values of N_i and d_{si} are only for cohesionless soil layers in the upper 100 feet of the site profile, which are defined in ASCE/SEI 7-16 as having a *PI* less than 20. The total thickness of cohesionless soil layers (d_s) is calculated using Equation 5.

$$d_s = \sum_{i=1}^{m} d_{si} \tag{5}$$

For method 3, the average undrained shear strength for cohesive soils in the upper 100 feet of the site profile ($\bar{s_u}$) is calculated using Equation 6.

$$\bar{s_u} = \frac{d_c}{\sum_{i=1}^{k} \frac{d_{ci}}{s_{ui}}} \tag{6}$$

where:

> k = number of cohesive soil layers
> d_c = total thickness (feet) of cohesive soil layers
> d_{ci} = thickness (feet) of any cohesive layer
> s_{ui} = undrained shear strength (psf) not to exceed 5,000 psf

The values of s_{ui} and d_{ci} are only for cohesive soil layers in the upper 100 feet of the site profile, which are defined in ASCE/SEI 7-16 as having a *PI* greater than 20. Conditional formatting applies an orange background to s_{ui} values not between 0 and 5,000 psf. The total thickness of cohesive soil layers (d_c) is calculated using Equation 7.

$$d_c = \sum_{i=1}^{k} d_{ci} \tag{7}$$

For each distinct layer using method 3, either N_i or s_{ui} must be input. If a value of N_i only is input, conditional formatting applies a gray background to the corresponding cells for s_{ui} that do not require user-specified input and vice versa. If values of both N_i and s_{ui} are input for a distinct layer, conditional formatting applies an orange background to both values to indicate one must be deleted. The sum of d_s and d_c must be 100 feet, no more and no less. If the sum is not exactly 100 feet, conditional formatting applies an orange background to the cells containing the total thickness of cohesionless and cohesive layers. Figure 12 illustrates step 2 for method 3.

Step 2: Characterize the upper 100 feet of the site profile

Method of analysis? Average SPT blow count for cohesionless soils and rock and undrained shear strength for cohesive soils

$z_{top,i}$ (feet)	$z_{bot,i}$ (feet)	Soil or Rock Layer Description	v_{si} (ft/s) N_i (bpf) N_i (bpf)	d_i (feet) d_i (feet) d_{si} (feet)	d_i/v_{si} d_i/N_i d_{si}/N_i	s_{ui} (ft/s)	d_{ci} (feet)	d_i/s_{ui}
188.0	178.0	Lean Clay		-	-	750	10.0	0.013
178.0	168.0	Lean Clay		-	-	1,200	10.0	0.008
168.0	158.0	Fine to medium sand	15	10.0	0.667		-	-
158.0	148.0	Fine to medium sand	22	10.0	0.455		-	-
148.0	88.0	Fine to medium sand	31	60.0	1.935		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
-				-	-		-	-
			Total	80.0	3.057	Total	20.0	0.022

Average shear wave velocity, $\overline{v}_s = \Sigma(d_i) / \Sigma(d_i/v_{si})$	-	ft/s
Average SPT blow count, $\overline{N} = \Sigma(d_i) / \Sigma(d_i/N_i)$ or $\overline{N}_{ch} = \Sigma(d_{si}) / \Sigma(d_{si}/N_i)$	26	bpf
Average undrained shear strength, $\overline{s}_{ui} = \Sigma(d_{ci}) / \Sigma(d_{ci}/s_{ui})$	923	psf

Figure 12. Step 2 of ASCE 7-16 worksheet using average standard penetration test blow count and undrained shear strength.

5.3. Site Classification

In step 3, the site class is assessed for the selected method of analysis in step 2 as shown in Figure 13. According to ASCE/SEI 7-16, Site Classes A and B must not be assigned to a site if there are more than 10 feet of soil between the rock surface and the bottom of the structure (or foundation).

Step 3: Assess the NEHRP site class

NEHRP Site Class	$\bar{v}_s$ (ft/s)	$\bar{N}$ (bpf)	$\bar{s}_u$ (psf)	
A. Hard rock	$\bar{v}_s > 5{,}000$	N/A	N/A	
B. Rock	$2{,}500 < \bar{v}_s \le 5{,}000$	N/A	N/A	
C. Very dense soil and soft rock	$1{,}200 < \bar{v}_s \le 2{,}500$	$\bar{N} > 50$	$\bar{s}_u > 2{,}000$	
D. Stiff soil	$600 \le \bar{v}_s \le 1{,}200$	$15 \le \bar{N} \le 50$	$1{,}000 \le \bar{s}_u \le 2{,}000$	
E. Soft clay soil	$\bar{v}_s < 600$	$\bar{N} < 15$	$\bar{s}_u < 1{,}000$	◄
	Soft clay thickness greater than 10 feet with the characteristics in Step 1			

Note: Do not use site classes A and B if more than 10 feet of soil overlies rock.

NEHRP Site Class E

Figure 13. Step 3 of ASCE 7-16 worksheet.

For method 3, the site class is determined using both the average SPT blow count for cohesionless soils and the average undrained shear strength for cohesive soils. If the site classes differ from these two methods, the site class with the softer site class is assigned. For the example data in Figure 12, the average SPT blow count for cohesionless soils of 26 bpf corresponds to Site Class D, and the average undrained shear strength for cohesive soils of 923 psf corresponds to Site Class E. The site classification is the softer Site Class E.

6. ASCE/SEI 7-22

This worksheet determines the site classification using ASCE/SEI 7-22 when site-specific site response analyses are not required. The site class definitions are based on the average shear wave velocity of the upper 100 feet of the site profile. Measured shear wave velocities should be used for site classification if they are available; however, often they are not available. If measured shear wave velocity data are not available, empirical correlations with SPT resistances, cone penetration test (CPT) tip resistance, undrained shear strength, or other geotechnical parameters can be used to obtain an estimated shear wave velocity profile. Table 2 outlines the nine site classes as defined by ASCE/SEI 7-22.

Table 2
Site classification (ASCE/SEI 7-22).

Site Class	Average Shear Wave Velocity, $\overline{v_s}$ (ft/s)
A. Hard rock	$\overline{v_s}$ > 5,000
B. Medium hard rock	3,000 < $\overline{v_s}$ ≤ 5,000
BC. Soft rock	2,100 < $\overline{v_s}$ ≤ 3,000
C. Very dense sand and hard clay	1,450 < $\overline{v_s}$ ≤ 2,100
CD. Dense sand or very stiff clay	1,000 < $\overline{v_s}$ ≤ 1,450
D. Stiff medium dense sand or stiff clay	700 < $\overline{v_s}$ ≤ 1,000
DE. Loose sand or medium stiff clay	500 < $\overline{v_s}$ ≤ 700
E. Very loose sand or soft clay	$\overline{v_s}$ ≤ 500
	Any site profile with more than 10 feet of soil with: • Plasticity index, *PI* > 20 • Moisture content, *w* ≥ 40 percent • Undrained shear strength, s_u < 500 psf
F. Unstable soils	N/A

6.1. Soft Clay Layer

This step is the same as described in section 5.1 for the ASCE 7-16 worksheet.

6.2. Site Profile Characterization

If all three characteristics of a soft soil layer greater than 10 feet exist in step 1, step 2 is not evaluated, and conditional formatting applies a gray background to step 2. These cells are not used in subsequent calculations even if data is present. If all three characteristics of a soft soil layer greater than 10 feet do not exist in step 1, the upper 100 feet of the site profile is characterized using the average shear wave velocity.

The 100-foot site profile is divided into a maximum of 14 distinct soil or rock layers based on the site characterization data. Each distinct layer is designated by a number from 1 to *n* (at the bottom of the site profile). The input includes depth (or elevation) below the ground surface or structure, a description of the layer, and measured small-strain shear wave velocity. If site-specific data are not available to a depth of 100 feet, the soil and rock parameters must be estimated based on known geologic conditions and experience to extrapolate the site profile to a depth of 100 feet. The distinct layer thicknesses are computed by subtracting the top and bottom depth (or elevation).

The average shear wave velocity in the upper 100 feet of the soil profile is calculated using Equation 8.

$$\bar{v}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \tag{8}$$

where:

n = number of layers
d_i = thickness (feet) of any layer
v_{si} = small-strain shear wave velocity (ft/s) of any layer

The total thickness is calculated using Equation 9.

$$\sum_{i=1}^{n} d_i = 100 \text{ feet} \tag{9}$$

The sum of the distinct layer thicknesses must be 100 feet, no more and no less. If the sum is not exactly 100 feet, conditional formatting applies an orange background to the cell containing the total thickness of the profile. Figure 14 illustrates step 2.

Step 2: Characterize the average shear wave velocity in the upper 100 feet of the site profile

$z_{top,i}$ (feet)	$z_{bot,i}$ (feet)	Soil or Rock Layer Description	v_{si} (ft/s)	d_i (ft)	d_i/v_si (s^{-1})
188.0	178.0	Lean clay	550	10.0	0.018
178.0	168.0	Lean clay	650	10.0	0.015
168.0	158.0	Fine to medium sand	800	10.0	0.013
158.0	148.0	Fine to medium sand	1,000	10.0	0.010
148.0	88.0	Fine to medium sand	1,300	60.0	0.046
-				-	-
-				-	-
-				-	-
-				-	-
-				-	-
-				-	-
-				-	-
-				-	-
-				-	-
			Total	100.0	0.102

Average shear wave velocity, $\bar{v}_S = \Sigma(d_i) / \Sigma(d_i/v_{si})$ 978 ft/s

Figure 14. Step 2 of ASCE 7-22 worksheet.

6.3. Site Classification

In step 3, the site class is assessed for the average shear wave velocity calculated in step 2 as shown in Figure 15.

Step 3: Assess the NEHRP site class

NEHRP Site Class	$\bar{v}_s$ (ft/s)	
A. Hard rock	$\bar{v}_s$ > 5,000	
B. Medium hard rock	3,000 < $\bar{v}_s$ ≤ 5,000	
BC. Soft rock	2,100 < $\bar{v}_s$ ≤ 3,000	
C. Very dense sand and hard clay	1,450 < $\bar{v}_s$ ≤ 2,100	
CD. Dense sand or very stiff clay	1,000 < $\bar{v}_s$ ≤ 1,450	
D. Medium dense sand or stiff clay	700 < $\bar{v}_s$ ≤ 1,000	◄
DE. Loose sand or medium stiff clay	500 < $\bar{v}_s$ ≤ 700	
E. Very loose sand or soft clay	$\bar{v}_s$ ≤ 500	
	Soft clay thickness greater than 10 feet with the characteristics in Step 1	

Note: Do not use site classes A and B if more than 10 feet of soil overlies rock.

NEHRP Site Class D

Figure 15. Step 3 of ASCE 7-22 worksheet.

7. References

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Appendix A. Acronym List

ASCE	American Society of Civil Engineers
CONUS	Continental United States
CPD	Computer Program Document
CPT	Cone Penetration Test
FEMA	Federal Emergency Management Agency
HEC	Hydrologic Engineering Center
IWR	Institute for Water Resources
NEHRP	National Earthquake Hazards Reduction Program
OCONUS	Outside the Continental United States
PI	Plasticity Index
QC	Quality Control
RMC	Risk Management Center
SEI	Structural Engineering Institute
SPT	Standard Penetration Test
UDF	User-Defined Function
U.S.	United States
USACE	United States Army Corps of Engineers
USGS	United States Geologic Survey