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Post and Pier Foundation Design Aid

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ABSTRACT. *A Microsoft Excel workbook for calculating uplift, bearing, and lateral load capacities of shallow post and pier foundations in accordance with provisions of ANSI/ASAE EP486.3 was developed at the University of Wisconsin-Madison by Dr. David Bohnhoff. This paper serves as an instruction manual for the Excel workbook, which is available at no charge from the author or from the National Frame Building Association (www.nfba.com).*

Keywords. *ASAE EP486, foundation design, post foundation, post-frame building, soil strength*

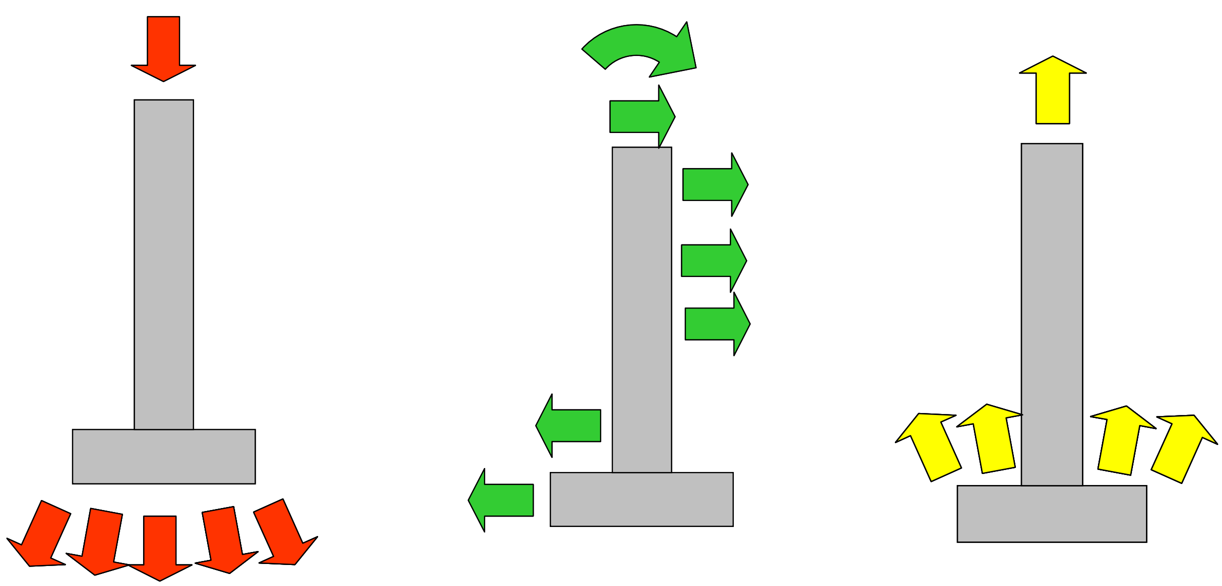
Introduction

In 2017, ASAE EP486.3 *Shallow Post and Pier Foundation Design* was released. This fourth version of the standard is a slightly modified edition of the third version (i.e., EP486.2). Both the third and fourth versions of EP486 are broken into the clauses given in Table 1.

Table 1. Outline of ASAE EP486.3 Shallow Post and Pier Foundation Design

Clause	Clause Title	Content Description
1	Purpose and scope	Use/limitations of EP486.3
2	Normative references	Referenced documents (e.g. ASTM Standards) needed for application of various portions of EP 486.3
3	Definitions	Definitions covering foundation types and components, foundation geometry and constraints, material properties and characteristics, and structural loads and analysis
4	Nomenclature (Symbols)	Abbreviations; symbols for variables and constants
5	Soil and backfill properties	Soils that should be avoided during post/pier construction; appropriate backfill materials; establishment of Young's modulus, undrained shear strength, and friction angle of soils from laboratory and in-situ tests; presumptive soil properties
6	Foundation material properties	Material requirements for post and pier foundation elements
7	Structural load combinations	ASCE 7 load combinations for allowable stress design (ASD) and load and resistance factor design (LRFD)
8	Structural analysis	Methods for modeling resistance of soil to lateral foundation movement
9	Resistance and safety factors	Resistance factors for LRFD design and corresponding safety factors for ASD design
10	Bearing strength assessment	Determination of the maximum downward force that can be applied to a foundation at grade without causing a soil failure
11	Lateral strength assessment	Determination of the maximum groundline bending moment and shear force combinations that can be applied to a foundation without causing a soil failure
12	Uplift strength assessment	Determination of the maximum upward force that can be applied to a foundation without causing a soil failure
13	Frost heave considerations	Factors that affect frost heave; options for reducing frost heave
14	Installation requirements	Soil compaction requirements; footing and foundation placement tolerances

Commencing with the third version of ASAE EP486 were entirely new methods for determining the bearing capacity (figure 1a), lateral capacity (figure 1b) and uplift capacity (figure 1c) of a post/pier foundation as limited by soil resistance. These calculations, which are provided in ASAE EP486.3 clauses 10, 11 and 12, respectively (Table 1), can be tedious and in some cases confusing to perform by hand. For this reason, users of ASAE EP486.3 requested that software be developed to facilitate its use.



(a) (b) (c)

Figure 1. (a) Bearing load, (b) lateral load, and (c) uplift load on a shallow pier/post foundation.

Spreadsheet Development

As a result of the ASAE EP86.3 software support request, a workbook (i.e., a collection of worksheets/spreadsheets) for Microsoft Excel that performs major EP486.3 calculations was developed by the author of this paper. The sections that follow will somewhat serve as an introduction and user manual for this Excel spreadsheet application.

The Excel workbook is available at no charge to users. That said, anyone who uses the Excel workbook for EP 486.3 should possess a copy of the standard itself, available for a nominal fee from ASABE, St Joseph, MI (http://www.asabe.org/). Realize that by purchasing the standard, you are supporting future revisions to EP486 as well as development of other standards of potential value to you.

Development of an Excel workbook for ASAE EP486.3 (instead of a specialized applications program) was done so individuals and companies could easily modify its contents to fit their needs. This includes dropping individual worksheets into other workbooks used in building design, formatting worksheet contents for enhanced display/printing, adding company logos, etc. Prior to modifying workbook contents, it is wise to save an original version that can be used to check if fundamental calculations were corrupted during content modification.

Another reason for going the workbook route is that workbooks for popular spreadsheet programs such as Excel have a longer average life than special applications programs. Previous software developed by this author includes numerous special applications programs. Those of note include: FEAST - a finite element analysis program written in FORTRAN for modeling vertically, mechanically laminated assemblies (Bohnhoff, 1987; Bohnhoff and others, 1989), MLBeam - a similar program written in FORTRAN for modeling horizontally, mechanically laminated assemblies (Bohnhoff, 1992), NBShear – a program written in Turbo BASIC for calculating allowable loads for wood fasteners, and DAFI – a program written first in FORTRAN and later in Visual Basic.NET for determining the interaction between building diagrams and supporting post-frames (Bohnhoff, 1992). All of these specialized application programs have not been updated or otherwise recompiled since their original release. As such, their use is generally limited to operating systems and hardware in use at the time they were created. Additionally, anyone desiring to alter FEAST, MLBeam, NBShear or DAFI would need to both possess and understand the source code for the program.

Workbook Overview

The workbook has seven worksheets. Titles and description for these seven worksheets are given in Table 2. The following five sections in this paper overview, respectively, the last five worksheets listed in Table 2. The first two worksheets are informational only (i.e., they do not contain calculations). Specifically, the **Introduction** worksheet contains Tables 1 and 2 as given here; a legend that explains use of color in the workbook; the purpose, scope and limitations of ASAE EP486.3 from Clause 1 of the standard; a link to the ASABE site that explains how to obtain a copy of the standard; and reference to this paper. The second worksheet – titled **Definitions and Nomenclature** – contains all definitions and variable descriptions from ASAE EP486.3 along with figure 1 through 5 from the standard (i.e., figures that help explain some of the terminology that is fundamental to the standard).

Table 2. Contents of ASAE EP486.3 Shallow Post and Pier Foundation Design Workbook

Worksheet Title	Worksheet Description
Introduction	Material from ASAE EP486.3 Clause 1 plus additional introductory material
Definitions and Nomenclature	All definitions from ASAE EP486.3 Clause 3, variable descriptions and symbols from ASAE EP486.3 Clause 4, and ASAE EP486.3 figures 1 through 5.
Soil Profile	Calculation of total vertical stress and ultimate lateral resistance for 1.0 inch thick soil layers. Requires input of soil properties for depths from the ground surface to a depth of 1.5 *B* below the footing where *B* is the footing width. Includes ASAE EP486.3 Table 1 (Presumptive soil properties for post and pier foundation design).
Bearing Strength Assessment	Calculation of bearing strength in accordance with ASAE EP486.3 Clause 10. Includes ASAE EP486.3 Table 2 (LRFD resistance factors and ASD safety factors for bearing strength assessment).
Lateral Strength Assessment - U	Calculation of lateral strength in accordance with the Universal Method outlined ASAE EP486.3 Clause 11. Includes ASAE EP486.3 Table 3 (LRFD resistance factors and ASD safety factors for lateral strength assessment using the Universal Method of analysis).
Lateral Strength Assessment - S	Calculation of lateral strength in accordance with the Simplified Method outlined ASAE EP486.3 Clause 11. Includes ASAE EP486.3 Table 4 (LRFD resistance factors and ASD safety factors for lateral strength assessment using the Simplified Method of analysis).
Uplift Strength Assessment	Calculation of uplift strength in accordance with ASAE EP486.3 Clause 12. Includes ASAE EP486.3 Table 5 (LRFD resistance factors and ASD safety factors for uplift strength assessment) and a foundation mass estimator.

The color of individual cells in the workbook identifies the type of content the cell contains. Cells that identify units are in green, column headings are in blue, cells containing calculated values are in orange, specials alerts are in red, fixed values and basic information are uncolored (white), and cells that require the user to input a value are in yellow. All cells except those in yellow are locked so that their content can not be altered by the user without first unprotecting the worksheet.

Soil Profile Worksheet

The **Soil Profile** worksheet is the first worksheet that must be completed by the user as it contains soil profile information that is used by the "strength assessment" worksheets.

Prior to using the **Soil Profile** worksheet, the user should have soil profile characteristics. There are a variety of ways to obtain this information. The method used largely depends on the importance (from a life safety perspective) of the post/pier foundation. For commercial and industrial building foundations, an engineer may require an extensive investigation involving standard in-situ and laboratory soil tests. For an agricultural building foundation, it is common for engineers to rely on information from the USDA NRCS Web Soil Survey (WSS) after verifying make-up of the soil profile with an on-site visual examination.

Because of the value of the WSS to the establishment of soil profile characteristics, an example of its use is explained and illustrated in figures 2a thru 2d. Resulting soil reports are shown in figures 3 and 4.

Step 1. Access the USDA NRCS Web Soil Survey at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. By default, the **Area of Interest (AOI)** tab should be selected displaying a menu and map of the contiguous United States.

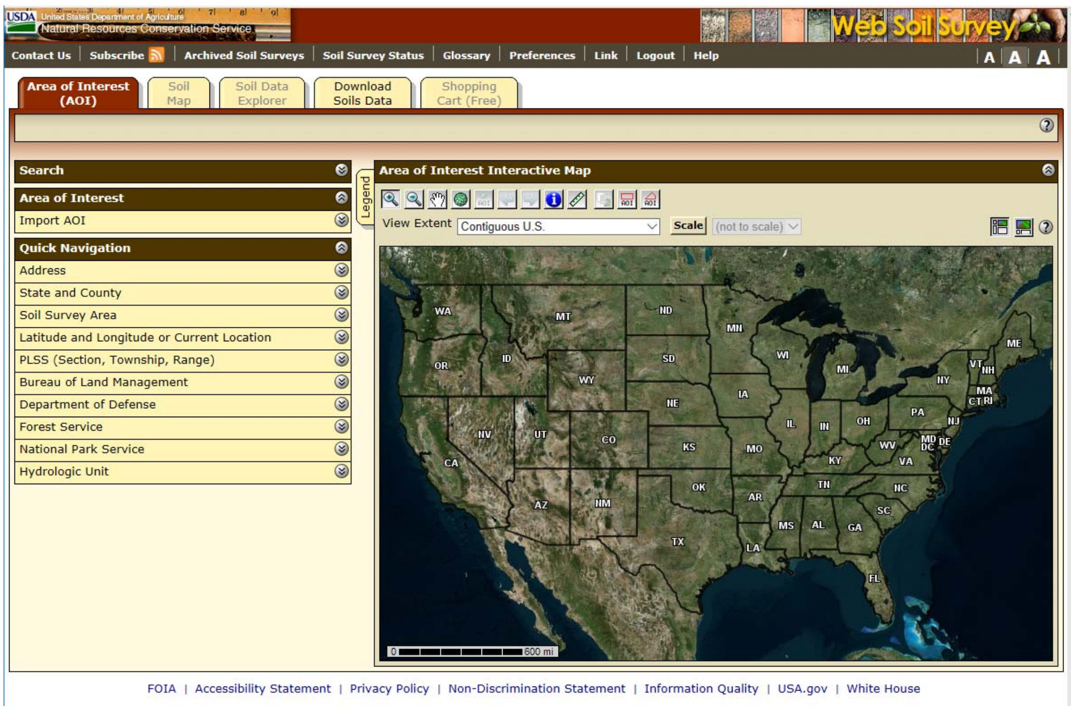


Figure 2a. Step 1 of WSS use example.

Step 2. Use the tools above the map to zoom in on the site that contains your area of interest (AOI), and then click on one of the AOI icons to outline your "area of interest" within the site. If you so choose, you may enter a name for the AOI in the box provided in the pull down menu to the left of the map.

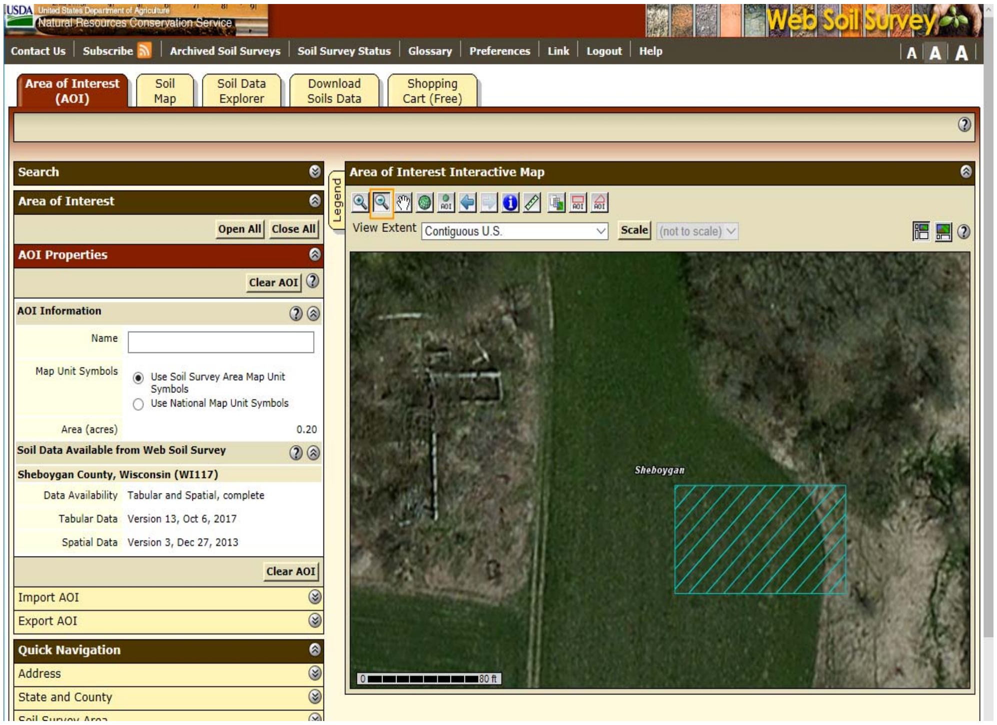


Figure 2b. Step 2 of WSS use example.

Step 3. Click on the **Soil Data Explorer** tab. This will bring up another set of tabs including a **Soil Reports** tab. Click on the **Soil Reports** tab.

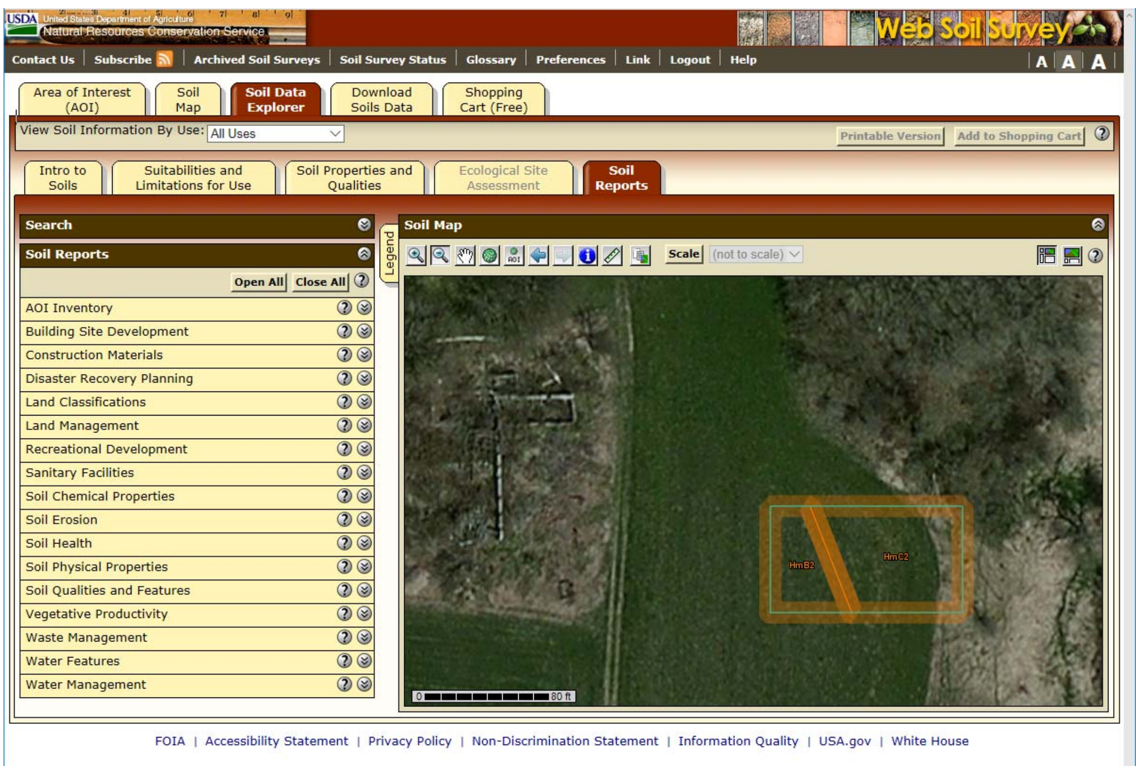


Figure 2c. Step 3 of WSS use example.

Step 4. In the drop down menu to the left, click on **Soil Physical Properties**, then **Engineering Properties**, and then **View Soil Report** to obtain the engineering properties report in figure 3. Likewise, click on **Soil Physical Properties**, then **Physical Properties**, and then **View Soil Report** to obtain the physical properties report in figure 4.

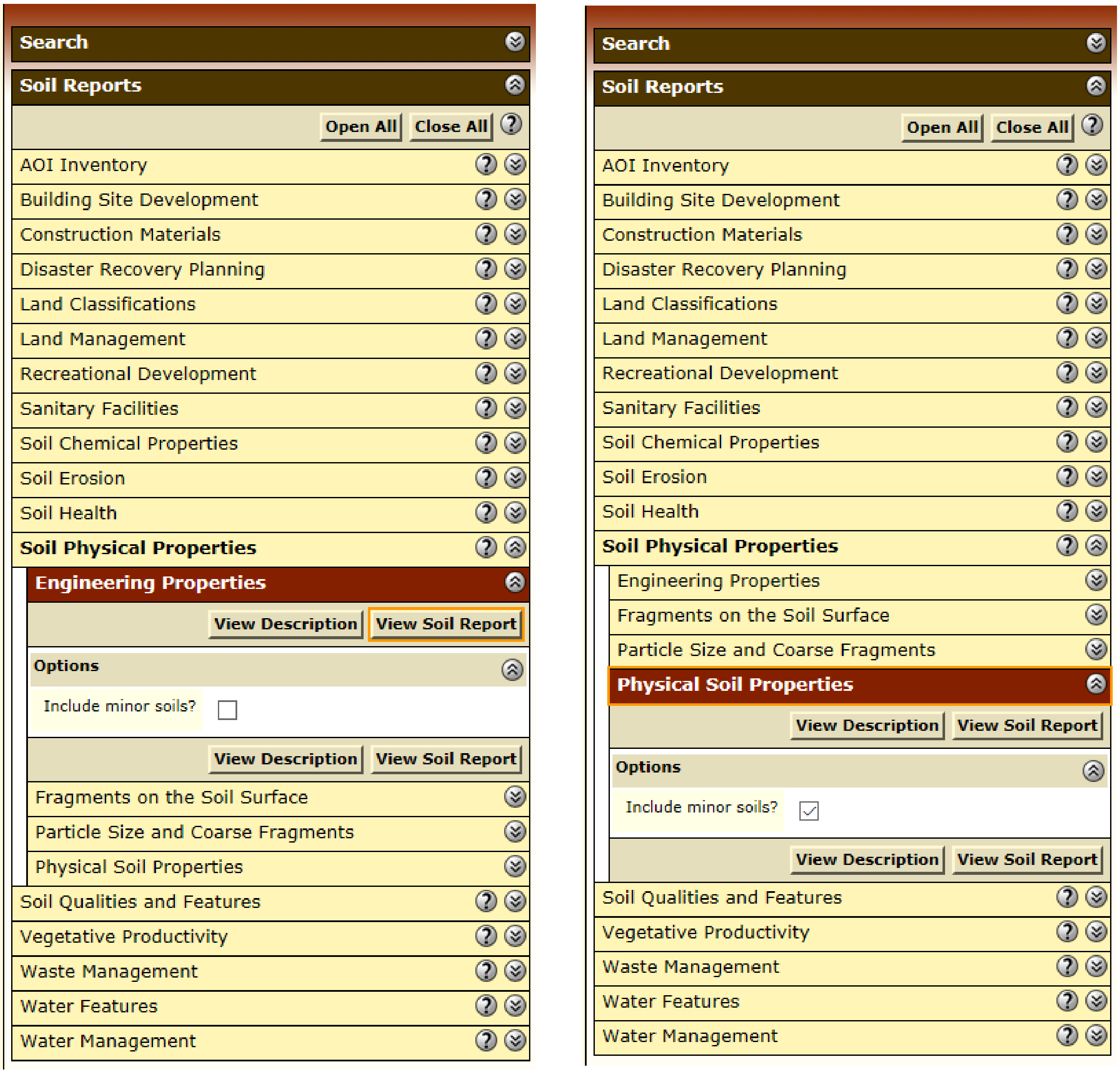


Figure 2d. Step 4 of WSS use example.

Report — Engineering Properties

Absence of an entry indicates that the data were not estimated. The asterisk '*' denotes the representative texture; other possible textures follow the dash. The criteria for determining the hydrologic soil group for individual soil components is found in the National Engineering Handbook, Chapter 7 issued May 2007(http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba). Three values are provided to identify the expected Low (L), Representative Value (R), and High (H).

Sheboygan County, Wisconsin

Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Pct Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				*L-R-H*	*L-R-H*	*L-R-H*	*L-R-H*	*L-R-H*	*L-R-H*	*L-R-H*	*L-R-H*
HmB2— Hochheim silt loam, 2 to 6 percent slopes, eroded														
Hochheim, eroded	90	C	0-8	Silt loam, loam	CL	A-4	0- 0- 0	0- 3- 6	95- 97- 100	89- 95- 100	79- 90- 100	65- 79- 90	22-32 -37	3-9 -12
			8-22	Clay loam, loam	CH, CL	A-7-6, A-6	0- 0- 0	0- 4- 4	92- 94- 100	84- 87- 100	70- 80- 100	51- 64- 86	28-45 -51	12-25-28
			22-79	Gravelly loam, sandy loam, loam	SM, SC-SM, CL, ML	A-2, A-4	0- 3- 6	2- 6- 10	65- 80- 93	63- 79- 93	50- 69- 93	33- 49- 72	18-22 -37	3-6 -19
HmC2— Hochheim silt loam, 6 to 12 percent slopes, eroded														
Hochheim, eroded	85	C	0-5	Silt loam	CL-ML	A-4	0- 0- 0	0- 3- 6	95- 97- 100	89- 95- 100	80- 90- 97	70- 79- 85	21-27 -31	2-6 -7
			5-22	Clay loam	CL	A-7-6	0- 0- 0	0- 4- 4	92- 93- 100	83- 86- 100	64- 80- 97	48- 63- 78	30-45 -51	13-25-28
			22-79	Loam, gravelly loam	SC-SM	A-4	0- 4- 6	2- 6- 11	63- 79- 93	61- 78- 93	51- 68- 93	35- 48- 72	18-22 -37	3-6 -19

Figure 3. Engineering properties report for the area of interest identified in figure 2.

Report — Physical Soil Properties

Three values are provided to identify the expected Low (L), Representative Value (R), and High (H).

Sheboygan County, Wisconsin

Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors			Wind erodibility group	Wind erodibility index
										Kw	Kf	T		
	In	*Pct*	*Pct*	*Pct*	*g/cc*	*micro m/sec*	*In/In*	*Pct*	*Pct*					
HmB2— Hochheim silt loam, 2 to 6 percent slopes, eroded														
Hochheim, eroded	0-8	20-20-50	43-65-73	7-15-18	1.45-1.50-1.55	4.23-9.17-14.11	0.20-0.22-0.24	0.4- 1.1- 1.5	2.0- 3.0- 4.0	.43	.43	3	5	56
	8-22	20-32-45	15-33-53	18-35-40	1.50-1.60-1.75	4.23-9.17-14.11	0.12-0.13-0.16	1.3- 4.0- 5.6	0.0- 0.8- 1.0	.28	.28			
	22-79	23-46-52	21-43-50	7-11-27	1.80-1.95-2.00	0.42-0.92-1.41	0.06-0.07-0.08	0.3- 0.6- 2.5	0.0- 0.3- 0.5	.28	.49			
HmC2— Hochheim silt loam, 6 to 12 percent slopes, eroded														
Hochheim, eroded	0-5	20-20-50	38-70-75	5-10-12	1.45-1.49-1.53	4.23-9.17-14.11	0.22-0.22-0.24	0.2- 0.7- 0.9	2.0- 3.0- 4.0	.43	.43	3	5	56
	5-22	20-32-45	15-33-53	27-35-40	1.41-1.49-1.57	4.23-9.17-14.11	0.15-0.17-0.19	2.0- 4.0- 5.6	0.0- 0.8- 1.0	.28	.28			
	22-79	23-46-52	28-43-50	7-11-27	1.75-1.80-1.85	0.42-0.92-1.41	0.06-0.07-0.08	0.3- 0.6- 2.5	0.0- 0.3- 0.5	.28	.49			

Figure 4. Physical soils properties report for the area of interest identified in figure 2.

Once soil property information has been obtained, it is entered into the **Soil Profile** worksheet table shown in figure 5. This table was set up to enable users to enter information for up to seven different soil layers. The soil profile is established by first entering (into Column C) the distance from the surface to the bottom of each soil layer. When this is done, the distance to the top of the soil layer is automatically populated in Column B. It is important to note that the soil profile must be described to a depth below the footing of 1.5 *B* where *B* is the footing width/diameter. Insomuch as the user is unlikely to have defined neither the footing depth nor the footing width at this point, simply make sure to enter soil profile information to a depth that is sure to exceed a depth of 1.5 *B* below the bottom of the footing for your final design.

The average moist unit weight of soil in each layer is entered in Column D. This is followed by entry of properties that will be used to calculate lateral soil strength. Three options exist for entry of this information. If lateral soil resistance was determined directly from in-situ tests as outlined in EP486.3, then those values are input in Column H which is identified as Option 3. Alternatively, the user selects Option 1 for a drained soil or Option 2 for an undrained soil. In general, cohesionless soils (e.g., sands, gravels) are assumed to be drained, and cohesive soils (e.g., silts, clays) are assumed to be undrained when determining lateral soil resistance and other soil strength properties.

Soil Profile (From Ground Surface to 1.5 *B* Below the Footing)[a]

You must fill in all yellow colored cells in the table below (except values only need be entered for one of the three options)

				Option 1 [b]		Option 2 [b]	Option 3 [b]
Soil Layer (List Top to Bottom)	Distance to top of layer	Distance to bottom of layer	Moist unit weight, γ	Drained soil friction angle, ϕ'	Drained cohesion, *c*	Undrained soil shear strength, S_U	Ultimate lateral soil resistance from in-situ tests, p_U [c]
	whole inches	whole inches	lbf per cubic foot	degrees	lbf per square inch	lbf per square inch	lbf per square inch
1	0	24	135	40.0	0.00		
2	24	81	120	35.0	0.00		
3	81						
4	0						
5	0						
6	0						
7	0						

[a] *B* is footing width/diameter

[b] Values only need to be entered for the option identified in the table below

[c] Based on results from CPT or pressuremeter tests in accordance with ASAE EP486.3 Clauses 11.2.2.1 and 11.2.2.2, respectively

Variables Affecting Effective Vertical Soil Stress and Ultimate Lateral Soil Resistance Calculations

Variable	Description	Units	Value	Notes
d_W	Depth to water table	whole inches	40	Used to calculate effective vertical stress in table below
b	Width of foundation near grade	inches	4.5	Used to adjust *c* and S_U for depth in table below
-	Option (see above) for calculating ultimate lateral soil resistance	NA	1	Enter a "1" for Option 1, a "2" for Option 2, a "3" for Option 3

Figure 5. Tables within the Soil Profile Worksheet for entering soil profile data.

A given soil profile will frequently contain layers of both cohesive and cohesionless soils. Such is the case for the soil profile associated with the reports in figures 3 and 4. As indicated in figure 3, underneath the top soil (i.e., below the top 5 to 8 inches) is a clay layer that extends 22 inches below the surface. This cohesive soil is identified as a CL or CH soil with a plasticity index around 25. Below this clay layer is a cohesionless soil layer identified via an on-site inspection to be a silty sand (SM). For construction purposes, the top 22 inches of soil were removed and replaced by 24 inches of road gravel conforming to ASTM D1241 requirements for a Gradation C material. This road gravel can be classified as a GW soil. Note that the numbers appearing in figure 5 correspond to this modified soil profile – 24 inches of GW soil overlying a layer of SM soil.

Replacing cohesive soils with noncohesive soils should be done anytime the cohesive soil falls under the classification of an expansive soil. ASAE EP 486.3 Clause 5.2.1 states that a soil with an expansion index greater than 20, as determined in accordance with ASTM D482, is considered expansive and should be avoided. Clause 5.2.1 further states that a soil is also considered expansive if it has a plasticity index (PI) of 15 or greater as determined in accordance with ASTM D431, and 10% or more of its particles are less than 5 micrometers in size in accordance with ASTM D422.

Three other pieces of information that must be entered into the **Soil Profile** worksheet are (1) depth to the water table, (2) width of the foundation near grade, and (3) which of the three options (i.e., 1, 2 or 3) will be used to calculate ultimate lateral soil resistance. Depending on its value, water table depth can impact all three calculated strength assessments (bearing, lateral and uplift resistance) so entering a realistic value is important. The width of the foundation at grade influences lateral soil resistance near the surface for cohesive soils.

Once data input to the tables in figure 5 is complete, the table located below these two tables in the **Soil Profile** worksheet is automatically populated. This table is titled *Soil Properties for 1-Inch Thick Layers* and shown in figure 6. Moist unit weights appear in Column D and are used to calculate the total vertical stress values in Column E. Total vertical stress values are used along with the depth to the ground water table to calculate the effective vertical stress values in Column F. Columns G, H, I and J contain drained soil friction angle, drained cohesion, undrained soil shear strength, and ultimate lateral resistance from in-situ tests, respectively (note that two or three of these four columns will contain zero values, with the exact number of "zero populated" columns dependent on the option selected for calculating ultimate lateral soil resistance). Columns K and L are columns H and I, respectively, with a depth adjustment applied to all values within 4 times the foundation width of the soil surface. These adjustments account for the greater lack of soil confinement near the soil surface. Column M contains coefficients of passive earth pressure – values that are solely a function of drained soil friction angle. The last column in this table (column N) contains ultimate lateral soil resistance values. The values in this table are used in the **Lateral Strength Assessment – U** worksheet.

Soil Properties for 1-Inch Thick Layers

	A	B	C	D	E	F	G
	Layer Number	Distance to center of layer, z	Layer thickness, t	Moist unit weight, γ	Total vertical stress, σ_V	Effective vertical stress, σ'_V	Drained soil friction angle, ϕ'
		inches	inches	lbf per cubic foot	lbf per square inch	lbf per square inch	degrees
37	1	0.5	1	135	0.039	0.039	40
38	2	1.5	1	135	0.117	0.117	40
39	3	2.5	1	135	0.195	0.195	40
40	4	3.5	1	135	0.273	0.273	40

H	I	J	K	L	M	N
Drained cohesion, c	Undrained soil shear strength, S_U	p_U from in-situ tests	Drained cohesion (adjusted for depth), c	Undrained soil shear strength (adjusted for depth), S_U	Coefficient of passive earth pressure, K_P	Ultimate lateral resistance, $p_{U,z}$
lbf per square inch	lbf per square inch	lbf per square inch	lbf per square inch	lbf per square inch	dimensionless	lbf per square inch
0	0.00	0.00	0.00	0.00	4.60	0.54
0	0.00	0.00	0.00	0.00	4.60	1.62
0	0.00	0.00	0.00	0.00	4.60	2.69
0	0.00	0.00	0.00	0.00	4.60	3.77

Figure 6. Soil properties table for 1-inch thick soil layers.

ASAE EP 486.3 Table 1 *Presumptive Soil Properties for Post and Pier Foundation Design* is located in columns P through AD and rows 5 through 37 of the **Soil Profile** worksheet. Soil property values for a layer can be obtained from this table once the soil type associated with the layer has been identified.

Bearing Strength Assessment Worksheet

The **Bearing Strength Assessment** worksheet contains three tables: the *Bearing Strength Assessment* table shown in figure 7, *ASAE EP486.3 Table 2 - LRFD Resistance Factors and ASD Safety Factors for Bearing Strength Assessment* which is shown in figure 8, and the *Ultimate Bearing Capacity* table shown in figure 7.

The **Bearing Strength Assessment** worksheet is used to determine if the downward force acting on a round or square foundation footing/base exceeds allowable limits as dictated by soil strength. The first step in this analysis is to enter footing size (i.e., diameter for a round footing and side length of a square footing) in row 5, and the distance from the surface to the underside of the footing in row 6 of the *Bearing Strength Assessment* table (figure 7). Next, if you have an LRFD loading, enter it in row 7 and place a "0" (zero) in row 8 for the ASD loading. Alternatively, if you have an ASD loading, enter it in row 8 and place a "0" in row 7 of the table. Row 9 is used to identify the shape of the foundation footing/base; a "0" is entered to identify a round footing and a "1" is entered to indentify a square footing.

Bearing Strength Assessment

You must fill in all yellow colored cells in the table below

Variable	Description	Units	Value	Notes
B	Diameter of a round footing or side length of a square footing	inches	14	
d_F	Foundation or footing depth	inches	48	
P_{LRFD}	Axial load applied to foundation at grade by LRFD load combination	lbf	5000	Enter "0" (zero) for ASD loading
P_{ASD}	Axial load applied to foundation at grade by ASD load combination	lbf	0	Enter "0" (zero) for LRFD loading
	Shape of footing	NA	1	Enter "1" for square and "0" for round ftg.
q_B	Ultimate bearing capacity	lbf/in.^{2}	251.5	Use appropriate table below
R_B	LRFD resistance factor for bearing strength assessment	dimensionless	0.53	See table to the right
f_B	ASD factor of safety for bearing strength assessment	dimensionless	2.67	See table to the right
d_W	Distance between soil surface and top of the water table	whole inches	40	
q_0	Total overburden pressure at footing depth d_F	lbf/in^2	3.54	
γ	Average moist unit weight of soil above the footing	lbf/ft^3	127.5	
C_{w1}	Correction factor for effect of ground water location on the ultimate bearing strength of cohesionless soils	dimensionless	0.500	ASAE EP 486.3 Clause 10.4
C_{w2}	Correction factor for effect of ground water location on the ultimate bearing strength of cohesionless soils	dimensionless	0.917	
A	Footing bearing area	in^2	196.0	
Max P_{LRFD}	Maximum allowed LRFD axial load applied to foundation at grade	lbf	25758	ASAE EP 486.3 Clause 10.3
Max P_{ASD}	Maximum allowed ASD axial load applied to foundation at grade	lbf	18202	ASAE EP 486.3 Clause 10.2
		Are design requirements met?	Yes	

Figure 7. Bearing strength assessment table in the Bearing Strength worksheet. Note that worksheet column C (titled "equations") was collapsed during the screen capture of this image.

ASAE EP486.3 Table 2 - LRFD Resistance Factors and ASD Safety Factors for Bearing Strength Assessment

For ϕ = 35

Soil	Method used to determine ultimate bearing capacity q_B	LRFD resistance factor for bearing strength assessment, R_B [(b)]		ASD safety factor for bearing strength assessment, f_B [(b)]	
		Normal Risk	Low Risk [(c)]	Normal Risk	Low Risk [(c)]
Cohesionless (SP, SW, GP. GW, GW-GC, GC, SC, SM, SP-SM, SP-SC, SW-SM, SW-SC)	General bearing capacity equation with ϕ determined from laboratory direct shear or axial compression tests (see clause 5.8.1)	$0.80 - 0.01 \cdot \phi = 0.45$	0.56	$1.4/(0.80 - 0.01 \cdot \phi) = 3.11$	2.49
	General bearing capacity equation with ϕ determined from SPT data in accordance with clause 5.8.2	$0.62 - 0.01 \cdot \phi = 0.27$	0.34	$1.4/(0.62 - 0.01 \cdot \phi) = 5.19$	4.15
	General bearing capacity equation with ϕ determined from CPT data in accordance with clause 5.8.3	$0.71 - 0.01 \cdot \phi = 0.36$	0.45	$1.4/(0.71 - 0.01 \cdot \phi) = 3.89$	3.11
	General bearing capacity equation with presumptive soil properties from ASAE EP486.3 Table 1	$0.58 - 0.01 \cdot \phi = 0.23$	0.29	$1.4/(0.58 - 0.01 \cdot \phi) = 6.09$	4.87
	General bearing capacity equation with presumptive soil properties fromASAE EP486.3 Table 1 with soil type verified by construction testing	$0.77 - 0.01 \cdot \phi = 0.42$	0.53	$1.4/(0.77 - 0.01 \cdot \phi) = 3.33$	2.67
	Standard penetration test (SPT)	0.41	0.51	3.40	2.72
	Cone penetration test (CPT)	0.50	0.63	2.80	2.24
	Pressuremeter test (PMT)	0.50	0.63	2.80	2.24
Cohesive (CL,CH, ML, MH)	General bearing capacity equation with undrained shear strength determined from laboratory compression tests (see clause 5.7.1)	0.60	0.75	2.30	1.84
	General bearing capacity equation with undrained shear strength determined from PBPMT data in accordance with clause 5.7.2	0.60	0.75	2.30	1.84
	General bearing capacity equation with undrained shear strength determined from CPT data in accordance with clause 5.7.3	0.60	0.75	2.30	1.84
	General bearing capacity equation with undrained shear strength determined from in-situ vane tests in accordance with clause 5.7.4	0.60	0.75	2.30	1.84
	General bearing capacity equation with presumptive soil properties from ASAE EP486.3 Table 1	0.47	0.59	3.00	2.40
	General bearing capacity equation with presumptive soil properties from ASAE EP486.3 Table 1 with soil type verified by construction testing	0.60	0.75	2.30	1.84
	Cone penetration test (CPT)	0.60	0.75	2.30	1.84
	Pressuremeter test (PMT)	0.60	0.75	2.30	1.84

[(a)] Clause in ASAE EP 486.3 containing the q_B equation to which the resistance/safety factor applies.

[(b)] In all cases, R_B is limited to a maximum value of 0.93 and f_B is limited to a minimum value of 1.50.

[(c)] For buildings and other structures that represent a low risk to humans in the event of a failure. R_B values increased by 25% and f_B values reduced by 20%.

Figure 8. LRFD resistance factors and ASD safety factors table as presented in the Bearing Strength Assessment worksheet. Note that worksheet column I (titled "Associated clause [a]") was collapsed during the screen capture of this image.

Ultimate Bearing Capacity, q_B

Fill in the yellow cell(s) in the table below that corresponds to the methodology you are applying. Transfer resulting q_B value to table above.

q_B for Saturated Clay from the General Bearing Capacity Equation (Clause 10.4.1)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$S_U N_C d_C s_C + q_0$	lbf/in.^{2}	3.54
S_U	Undrained shear strength for soil located between d_F and (d_F+B). Numerically equal to cohesion, c, for a saturated clay soil		lbf/in.^{2}	0
d_c	depth factor for ultimate bearing strength of a cohesive soil based on the general bearing capacity equation	$1 + 0.2\, d_F/B$ for $d_F/B < 2.5$ else equal to 1.5	dimensionless	1.5
N_C	Bearing capacity factor that accounts for cohesion in the general bearing capacity equation	5.14 for $\phi = 0$	dimensionless	5.14
s_c	Shape factor for ultimate bearing strength of a cohesive soil based on the general bearing capacity equation	1.2 for square and round footings	dimensionless	1.2

q_B for Cohesionless Soils from the General Bearing Capacity Equation (Clause 10.4.1)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$0.5\gamma B C_{W1} N_\gamma s_\gamma + q_0 C_{W2} N_q d_q s_q$	lbf/in.^{2}	251.47
ϕ	Soil friction angle for soil located between d_F and (d_F+B)		degrees	35
N_q	Bearing capacity factor that accounts for surcharge pressures in the general bearing capacity equation	$\exp(\pi \tan\phi) \tan^2(45+\phi/2)$	dimensionless	33.30
N_γ	Bearing capacity factor that accounts for soil unit weight in the general bearing capacity equation	$2\,(N_q + 1) \tan\phi$	dimensionless	48.03
s_γ	Shape factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation	0.6 for square and round footings	dimensionless	0.60
s_q	Shape factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation	$1 + \tan\phi$ for square and round footings	dimensionless	1.70
d_q	Depth factor for ultimate bearing strength of a cohesionless soil based on the general bearing capacity equation	$1 + 2\tan\phi\,(1-\sin\phi)^2 \tan^{-1}(d_F/B)$	dimensionless	1.33

q_B for Sands from Standard Penetration Test (SPT) Results (Clause 10.4.2)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$(N_1)_{60} C_{SPT} B (C_{W1} + C_{W2} d_F/B)$	lbf/in.^{2}	0.00
N_{SPT}	SPT blow count as recorded during test. Should be taken between d_F and (d_F+B)		Blows per 12 in.	0
d_S	Depth at which SPT count started (should be near d_F)		whole inches	0
N_{60}	N_{SPT} blow count corrected for field procedures and equipment		Blows per 12 in.	0
$(N_1)_{60}$	N_{60} blow count normalized with respect to vertical effective stress	$N_{60}\,(p_A/\sigma'_v)^{0.5}$	Blows per 12 in.	0.00
p_A	Atmospheric pressure		lbf/in.^{2}	14.7
σ'_v	Effective vertical stress at depth where sample was recovered	Taken from Soil Profile worksheet	lbf/in.^{2}	0.70
C_{SPT}	Constant relating SPT blow counts to bearing resistance		lbf/in.^{3}	0.1157

The SPT blow count, N_{SPT} is determined for clayey soils in accordance with ASTM D1586 and for sandy soils in accordance with ASTM D6066. The SPT blow count value designated as N_{60} is obtained by multiplying N_{SPT} (i.e., the raw SPT blow count recorded in the field) by factors that adjust for hammer efficiency, sample barrel size, borehole diameter and rod length. The symbol $(N_1)_{60}$ is used to identify an N_{60} value that has been further adjusted to account for overburden pressure. The overburden correction factor is from Liao and Whitman (1986). A detailed discussion of how to calculate $(N_1)_{60}$, including correction factor values was published by the NCEER (1997).

q_B for Saturated Clay Soils from Cone Penetration Test (CPT) Results (Clause 10.4.3)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$C_{CPT1} + q_{cr}/3$	lbf/in.^{2}	79.20
q_{cr}	Average cone penetration resistance within a depth B below the bottom of the footing. Cone penetration resistance is equal to the vertical force applied to the cone divided by its horizontally projected area		lbf/in.^{2}	0
C_{CPT1}	Constant relating CPT blow counts to bearing resistance		lbf/in^2	79.2

q_B for Cohesionless Soils from Cone Penetration Test (CPT) Results (Clause 10.4.3)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$q_{cr} B (C_{W1} + C_{W2} d_F/B)/C_{CPT2}$	lbf/in.^{2}	0.00
q_{cr}	Average cone penetration resistance within a depth B below the bottom of the footing. Cone penetration resistance is equal to the vertical force applied to the cone divided by its horizontally projected area		lbf/in.^{2}	0
C_{CPT2}	Equation constant		inches	480

q_B for Sands from Pressuremeter Test (PMT) Results (Clause 10.4.4)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$q_0 + C_{PB}\,(p_L - \sigma_{0h})$	lbf/in.^{2}	3.54
p_L	Average value of limiting pressures obtained from pressurementer tests within a zone of +/- 1.5 B above and bellow footing depth d_F		lbf/in.^{2}	0
σ_{0h}	Horizontal total stress at rest for the depth where the pressuremeter test is performed		lbf/in.^{2}	0
C_{PB}	Empirical bearing capacity coefficient for adjustment of pressuremeter readings	$0.80 + 0.642(d_F/B) - 0.0839(d_F/B)^2$ for sands	dimensionless	2.015

q_B for Silts from Pressuremeter Test (PMT) Results (Clause 10.4.4)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$q_0 + C_{PB}\,(p_L - \sigma_{0h})$	lbf/in.^{2}	3.54
p_L	Average value of limiting pressures obtained from pressurementer tests within a zone of +/- 1.5 B above and bellow footing depth d_F		lbf/in.^{2}	0
σ_{0h}	Horizontal total stress at rest for the depth where the pressuremeter test is performed		lbf/in.^{2}	0
C_{PB}	Empirical bearing capacity coefficient for adjustment of pressuremeter readings	$0.80 + 0.384(d_F/B) - 0.0572(d_F/B)^2$ for silts	dimensionless	1.444

q_B for Clays from Pressuremeter Test (PMT) Results (Clause 10.4.4)

Variable	Description	Equation	Units	Value
q_B	Ultimate bearing capacity	$q_0 + C_{PB}\,(p_L - \sigma_{0h})$	lbf/in.^{2}	3.54
p_L	Average value of limiting pressures obtained from pressurementer tests within a zone of +/- 1.5 B above and bellow footing depth d_F		lbf/in.^{2}	0
σ_{0h}	Horizontal total stress at rest for the depth where the pressuremeter test is performed		lbf/in.^{2}	0
C_{PB}	Empirical bearing capacity coefficient for adjustment of pressuremeter readings	$0.80 + 0.223(d_F/B) - 0.0395(d_F/B)^2$ for clays	dimensionless	1.100

Figure 9. Ultimate bearing capacity calculation table as presented in the Bearing Strength Assessment worksheet.

Row 10 of the *Bearing Strength Assessment* table (figure 7) requires input of an ultimate bearing capacity (q_b) value. This is obtained from the *Ultimate Bearing Capacity* table (figure 9) which is located below the *Bearing Strength Assessment* table in the worksheet. The *Ultimate Bearing Capacity* table is itself comprised of eight tables. Each of these eight tables is for a specific combination of (1) soil type, and (2) ultimate bearing capacity calculation method. The first two tables utilize the general bearing capacity equation, the next table requires data from a standard penetration test (STP), the next two tables require data from a cone penetration test (CPT), and the last three tables require data obtained during a pressuremeter test (PMT). For the soil profile appearing in figure 5, the *Ultimate Bearing Capacity* table associated with the general bearing capacity equation for a cohesionless soil is used. The only input value required in this case is the drained soil friction angle for the soil located between a depth of d_f and $d_f + B$, which (from figure 5) is equal to 35 degrees, and produces a ultimate bearing capacity q_b of 251.5 lbf/in^2 (figure 9).

Row 11 and 12 of the *Bearing Strength Assessment* table (figure 7) require input of the LRFD resistance factor for bearing strength assessment and the ASD safety factor for bearing strength assessment, respectively. These two values can be obtained from *ASAE EP486.3 Table 2 - LRFD Resistance Factors and ASD Safety Factors for Bearing Strength Assessment* table (figure 8) which is directly to the right of the *Bearing Strength Assessment* table in the worksheet.

There are two sets of LRFD resistance factors and ASD safety factors: normal and low risk. Use of "low risk" factors is associated with buildings and other structures that represent a low risk to human life in the event of a failure. Low risk LRFD resistance factors are 25% greater than "normal risk" LRFD resistance factors. Low risk ASD safety factors are 20% less than "normal risk" ASD safety factors.

As is evident from figure 8, resistance and safety factors for cohesionless soils are a function of drained soil friction angle ϕ. By entering the appropriate soil friction angle in the table's only yellow box (i.e., column N, row 3), soil friction angle related adjustments are automatically performed.

As is clear from figure 8, resistance and safety factors are also dependent on the method used to calculate ultimate bearing capacity. For the example soil profile (figure 5), the general bearing capacity equation for a cohesionless soil with a soil friction angle of 35 degrees was used to determine ultimate bearing capacity q_b. The 35 degree angle was in turn obtained from presumptive values in ASAE EP486.3 Table 1 (found in the **Soil Profile** worksheet) after first using the USDA NRCS Web Soil Survey along with an on-site visual inspection of the soil profile to establish soil type. When ASAE EP486.3 Table 1 values are used without verification of soil type by on-site testing, the low risk LRFD resistance factor and low risk ASD safety factor for a soil friction angle of 35 degrees are 0.29 and 4.87, respectively. When soil type is verified by on-site testing, these two values are 0.53 and 2.67, respectively. Given that soil type was based on a combination of the USDA NRCS WSS reports (which involved in-situ testing) and an on-site visual inspection, it was felt that an ASD safety factor of 2.67 would be appropriate. For this reason, an ASD safety factor of 2.67 was entered in row 12 of the *Bearing Strength Assessment* table (figure 8), and an LRFD resistance factor of 0.53 was entered in row 11 of the table. Note that the LRFD resistance factor is equal to 1.4 divided by the ASD safety factor.

Data entered into the yellow boxes in the *Bearing Strength Assessment* table, along with information pulled from the **Soil Profile** worksheet are used to calculate the maximum allowable downward-acting LRFD and ASD axial loads that appear in rows 21 and 22 of the table, respectively. If the LRFD allowable load is exceeded by the axial load induced by the LRFD structural load entered in row 7 (or alternatively, the ASD allowable load is exceeded by the actual ASD loading entered in row 8), a "No" will appear in the red box located in column E and row 23, indicating the foundation design is insufficient. If a "No" appears and the difference between the actual and allowable loads is significant, the best option is to increase the size of the foundation base/footing. If a "No" appears and the difference between the actual and allowable downward axial loads is only a few percent, then a slight reduction in the ASD factor of safety (or a slight increase in the LRFD resistance factor) should be considered in place of an increase in foundation base/footing size. This is because anytime material can be saved, the environmental footprint of the foundation is reduced.

Lateral Strength Assessment – U Worksheet

The "- U" in "**Lateral Strength Assessment – U"** stands for "universal method" and refers to the method in ASAE EP486.3 that utilizes a series of soil springs to model the lateral stiffness and resisting strength of the soil surrounding the foundation. The *Universal* method is a powerful method of analysis since the soil surrounding the foundation does not need to be uniform (i.e., it does not need to be of one soil type with fixed properties) for the entire depth of the foundation, and the method is applicable to foundations with or without attached footings and/or collars, as well as those backfilled with concrete or a controlled low-strength material (CLSM). As defined in ASAE EP486.3 Clause 3.3.2, a CLSM is a self-leveling and self-compacting, cementitious material with an unconfined compressive strength of 8 MPa (1200 psi) or less. Other terms used to describe controlled low-strength material (CLSM) include flowable fill, unshrinkable fill, controlled density fill, flowable mortar, flowable fly ash, fly ash slurry, plastic soil-cement and soil-cement slurry.

There are five tables and a one plot in the **Lateral Strength Assessment-U** worksheet. Only two of the five tables are of importance to the user. These are the *Lateral Strength Assessment – Universal Method* table shown in figure 10 and the table in figure 12 that contains *ASAE EP486.3 Table 3 - LRFD Resistance Factors and ASD Safety Factors for Lateral*

Strength Assessment using the Universal Method of Analysis. The other three tables in the worksheet are titled: *Spring Properties*; *V_U Calculation for Specified M_U:V_U Ratio*; and *V_U -M_U Failure Envelope Data*. Within the worksheet, these three tables are located to the right of the table shown in figure 12. These three tables will neither be presented nor discussed here other than to note that: (1) each row in the first two tables is associated with a single soil spring, (2) each spring is used to model the behavior of a 1.0 inch thick layer of soil, and (3) the third table contains points for the $V_U – M_U$ failure envelope plot that appears in the worksheet and is shown in figure 13.

Inputting data to the *Lateral Strength Assessment – Universal Method* table in figure 10 is very straight forward. It begins with input of foundation dimensions. This includes: depth and width of the pier/post without any attached footing or collar; thickness and width of the attached footing if one is present; width, depth to the top, and depth to the bottom of an attached collar if one is present; and width, depth to the top, and depth to the bottom of any concrete or CLSM backfill. Three items of note. First, when a particular component is not present, a "0" (zero) is entered into the worksheet for each of the component's dimensions. Second, there is no place to enter dimensions for a detached footing since a footing that is detached from the pier/post its supports does not increase the lateral strength capacity of the foundation. Third, for all components, "width" refers to the horizontal dimension of the component face that is pushing on the soil. Consequently, component width can change if there is a change in the direction in which the foundation is loaded.

	A	B	C	D	E
1					
2	**Lateral Strength Assessment - Universal Method**				
3	**You must fill in all yellow colored cells in the tables below**				
4	**Foundation Dimensions**				
5	**Foundation Component**	**Dimension**	**Units**	**Value**	**Notes**
6	Post/Pier (less footing)	Embedment depth	whole inches	44	
7		Width [(a)]	inches	4.5	
8	Attached Footing	Thickness (depth)	whole inches	4	Enter "0" (zero) if no attached footing
9		Width [(a)]	inches	14	
10–11		Foundation depth, d_f	inches	48	For lateral load checks, d_f is equal to post/pier embedment depth plus thickness of attached footing
12	Attached Collar	Depth to top	whole inches	30	Enter "0" (zero) if no attached collar
13		Depth to bottom	whole inches	48	
14		Width [(a)]	inches	24	
15	Concrete or CLSM Backfill	Depth to top	whole inches	0	Enter "0" (zero) if no concrete/CLSM backfill
16		Depth to bottom	whole inches	0	
17		Width [(a)]	inches	0	
18	[(a)] Horizontal dimension of the face of the component that is pushing on the soil. Equal to diameter for round components.				
19					
20	**Groundline Forces Applied to Foundation and Associated Safety Factors**				
21	**Design Methodology**	**Design Variable**	**Units**	**Value**	**Notes**
22	Allowable Stress Design (ASD)	Goundline Bending Moment, M_{ASD}	in-lbf	10000	Enter "0" (zero) values if using LRFD.
23		Groundline Shear, V_{ASD}	lbf	500	
24		Factor of Safety, f_L	dimensionless	2.38	Obtain from table to the right
25		Max allowed M_{ASD} for surface constrained post	in-lbf	242964	Absolute value of M_{ASD} can't exceed this value
26	Load and Resistance Factor Design (LRFD)	Goundline Bending Moment, M_{LRFD}	in-lbf	0	Enter "0" (zero) values if using ASD
27		Groundline Shear, V_{LRFD}	lbf	0	
28		Resistance Factor, R_L	dimensionless	0	Obtain from table to the right
29		Max allowed M_{LRFD} for surface constrained post	in-lbf	0	Absolute value of M_{LRFD} can't exceed this value
30					
31	**Required and Allowed Ultimate Forces**				
32	**Variable**	**Equation**	**Units**	**Value**	**Notes**
33	Required M_U	f_L M_{ASD} or M_{LRFD}/R_L	in-lbf	23800	
34	Required V_U	f_L V_{ASD} or V_{LRFD}/R_L	lbf	1190	
35	Required M_U:V_U Ratio	(Required M_U)/(Required V_U)	inches	20.00	
36	Foundation Rotation Direction		NA	CW	
37	V_U		lbf	1694	
38	M_U		in-lbf	33882	
39		**Are design requirements met?**		**Yes**	

Figure 10. Lateral strength assessment – universal method table as presented in the Lateral Strength Assessment – U worksheet.

After foundation dimensions, the next items to be entered in the *Lateral Strength Assessment – Universal Method* table are the groundline bending moment and groundline shear force induced in the post/pier foundation by applied structural loads. These forces are identified, respectively, as M_{ASD} and V_{ASD} for allowable stress design loadings, and M_{LRFD} and V_{LRFD} for load and resistance factor design loadings. When non-zero values are input for M_{ASD} and V_{ASD}, enter "0" (zero) values for M_{LRFD} and V_{LRFD}. Conversely, when non-zero values are input for M_{LRFD} and V_{LRFD}, enter "0" (zero) values for M_{ASD} and V_{ASD}. When entering shear and bending moment values, the sign convention in figure 11 must be used. As a rule of thumb, the force is positive if, when acting independently, it rotates the foundation in a clockwise direction. If a post/pier is restrained at grade, the groundline bending moment and groundline shear force input to the worksheet are the bending moment and shear force in the post just below the ground surface restraint. Just below a ground surface restraint, the bending moment and shear will have opposite signs in accordance with the sign conventions in figure 11.

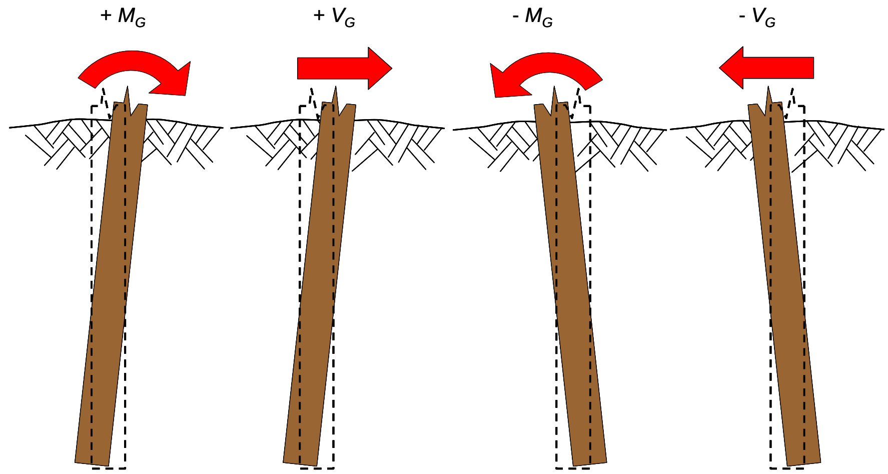


Figure 11. Sign convention for groundline bending moment M_G and shear force V_G. When M_G and V_G are induced by an ASD load combination they are written as M_{ASD} and V_{ASD}, respectively. When M_G and V_G are induced by an LRFD load combination they are written as M_{LRFD} and V_{LRFD}, respectively.

The last item to be entered in the *Lateral Strength Assessment – Universal Method* table is the ASD factor of safety, or alternatively, the LRFD resistance factor. For lateral strength assessment using the universal method of analyses, these values are obtained from ASAE EP486.3 Table 3 which is reproduced in the worksheet just to the right of the *Lateral Strength Assessment – Universal Method* table, and appears in the worksheet as shown in figure 12. The use of this table is identical to that previously described for the resistance and safety factors for bearing strength assessment table (figure 8). For the example soil profile (figure 5) a low risk ASD safety factor of 2.38 was entered into row 24 of the table in figure 10.

ASAE EP486.3 Table 3 - LRFD Resistance Factors and ASD Safety Factors for Lateral Strength Assessment using the Universal Method of Analysis

Soil	Method used to determine ultimate lateral soil resistance, $p_{u,z}$ [(a)]	LRFD resistance factor for lateral strength assessment, R_L [(b)] (For ϕ = 35): Normal Risk	LRFD: Low Risk [(c)]	ASD safety factor for lateral strength assessment, f_L [(b)]: Normal Risk	ASD: Low Risk [(c)]
Cohesionless (SP, SW, GP, GW, GW-GC, GC, SC, SM, SP-SM, SP-SC, SW-SM, SW-SC)	Equation from clause 11.2.1 with soil friction angle ϕ determined from laboratory direct shear or axial compression tests (see clause 5.8.1)	0.86 - 0.01 ϕ = 0.51	0.64	1.4/(0.86 - 0.01 ϕ) = 2.75	2.20
	Equation from clause 11.2.1 with soil friction angle ϕ determined from SPT data in accordance with clause 5.8.2	0.66 - 0.01 ϕ = 0.31	0.39	1.4/(0.66 - 0.01 ϕ) = 4.52	3.61
	Equation from clause 11.2.1 with soil friction angle ϕ determined from CPT data in accordance with clause 5.8.3	0.76 - 0.01 ϕ = 0.41	0.51	1.4/(0.76 - 0.01 ϕ) = 3.41	2.73
	Equation from clause 11.2.1 with soil friction angle ϕ from ASAE EP486.3 Table 1	0.61 - 0.01 ϕ = 0.26	0.33	1.4/(0.61 - 0.01 ϕ) = 5.38	4.31
	Equation from clause 11.2.1 with soil friction angle ϕ from ASAE EP486.3 Table 1, with soil type verified by construction testing	0.82 - 0.01 ϕ = 0.47	0.59	1.4/(0.82 - 0.01 ϕ) = 2.98	2.38
	Pressuremeter test (PMT) in accordance with clause 11.2.2	0.56	0.70	2.5	2.00
Cohesive (CL,CH, ML, MH)	Equation from clause 11.2.1 with undrained shear strength S_U determined from laboratory compression tests (see clause 5.7.1)	0.68	0.85	2.1	1.68
	Equation from clause 11.2.1 with undrained shear strength S_U determined from PBPMT data in accordance with clause 5.7.2	0.68	0.85	2.1	1.68
	Equation from clause 11.2.1 with undrained shear strength S_U determined from CPT data in accordance with clause 5.7.3	0.68	0.85	2.1	1.68
	Equation from clause 11.2.1 with undrained shear strength S_U determined from in-situ vane tests in accordance with clause 5.7.4	0.68	0.85	2.1	1.68
	Equation from clause 11.2.1 with undrained shear strength S_U from ASAE EP486.3 Table 1	0.44	0.55	3.2	2.56
	Equation from clause 11.2.1 with undrained shear strength S_U from ASAE EP486.3 Table 1 with soil type verified by construction testing	0.68	0.85	2.1	1.68
	Pressuremeter test (PMT) in accordance with clause 11.2.2	0.68	0.85	2.1	1.68

[(a)] Clause numbers refer to section numbers in ASAE EP 486.3

[(b)] In all cases, R_L is limited to a maximum value of 0.93 and f_L is limited to a minimum value of 1.50.

[(c)] For buildings and other structures that represent a low risk to humans in the event of a failure. R_L values increased by 25% and f_L values reduced by 20%

Figure 12. LRFD resistance factors and ASD safety factors table as presented in the Lateral Strength Assessment – U worksheet.

The red box in column D, row 39 of the *Lateral Strength Assessment – Universal Method* table (figure 10) and the M_G versus V_G plot below the table (figure 13) both indicate whether or not soil surrounding the foundation is adequate to resist the groundline bending moment and shear force applied to the foundation. The M_G versus V_G plot contains the $M_U – V_U$ failure envelope along with a blue diamond and a red diamond. If the red diamond is within the $M_U – V_U$ failure envelope, then the soil can handle the forces applied to the foundation by the structural loads. The blue diamond lies right on the $M_U – V_U$ failure envelope and on a line that runs through both the origin and the red diamond. Coordinates for the blue diamond on the M_G versus V_G plot are the values listed on rows 38 and 37 in figure 10. Within the worksheet, the distance between the origin and the red diamond is compared to the distance between the origin and the blue diamond to determine if the foundation is adequately sized.

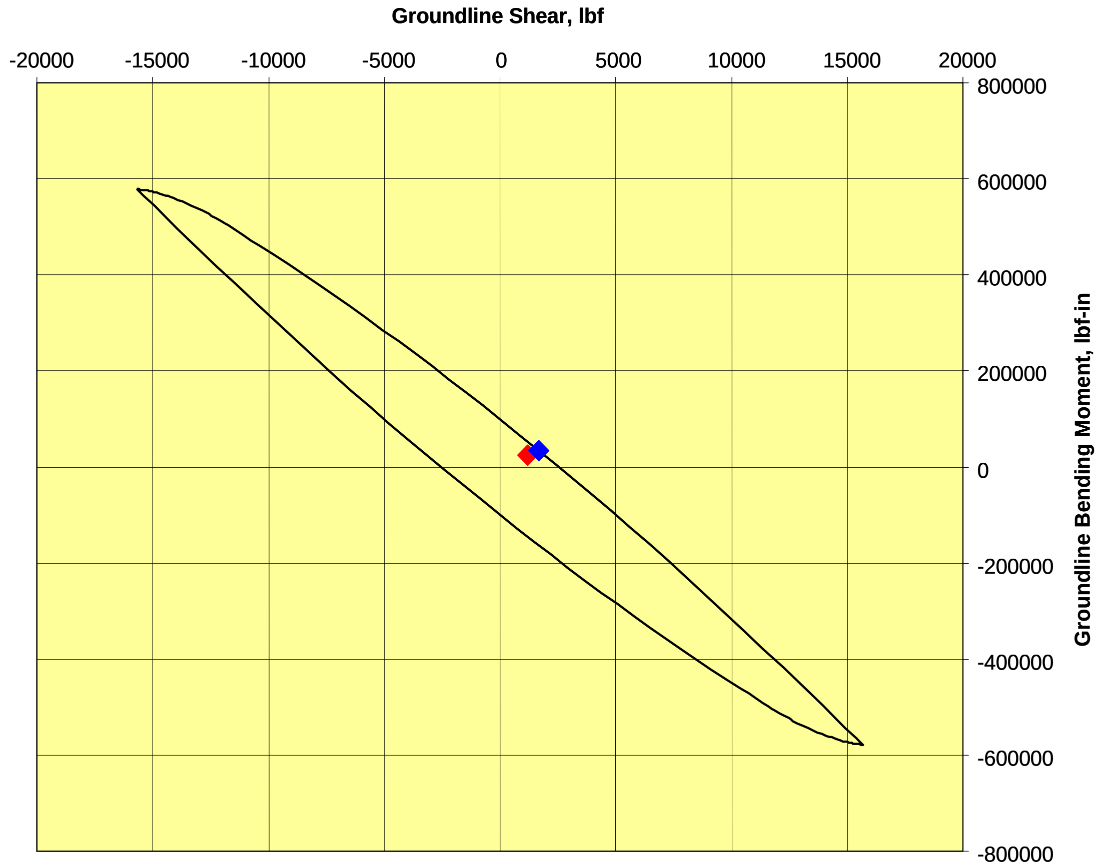


Figure 13. M_G versus V_G plot. The black line is the M_U - V_U failure envelope and a sole function of foundation dimensions and soil properties. The red diamond identifies the minimum required ultimate groundline bending moment and shear force necessary to resist the applied structural loads. As long as the red diamond is within the M_U - V_U failure envelope, the foundation design is adequate. The blue diamond is a point on the $M_U – V_U$ failure envelope that is collinear with the origin and red diamond.

The $M_U – V_U$ failure envelope is solely a function of the foundation dimensions entered into the *Lateral Strength Assessment – Universal Method* table (figure 10) and the soil information entered into the **Soil Profile** worksheet (figure 5). Given that the soil profile for a particular site is generally fixed, the only way to expand the $M_U – V_U$ failure envelope is to increase the width and/or depth of one or more foundation components. Again, it is important to keep in mind that footings (and the soil that surrounds them) are only effective in resisting applied loads when the footing is attached to the pier/post it supports.

As shown in figure 14, every point on a $M_U – V_U$ failure envelope is associated with a unique location of the *ultimate pivot point* which is the location below grade at which the foundation does not move laterally when the ultimate resisting capacity of the soil has been reached. The distance from the ground surface to the ultimate pivot point is identified as d_{RU} and is shown as a function of the total foundation depth d_F in figure 14. A ground surface restraint of a foundation will force the ultimate pivot point to be located at the surface (i.e., d_{RU} = 0). Thus, the two extreme points on the $M_U – V_U$ failure envelope identify combinations of ultimate groundline bending moment and ultimate groundline shear force for a foundation restrained from moving horizontally at the ground surface. The upper left point is for clockwise foundation rotation, and the lower right for counterclockwise foundation rotation.

The red diamond appearing in figure 13 is the location of the *required* M_U and *required* V_U as listed on rows 33 and 34, respectively, of the *Lateral Strength Assessment – Universal Method* table (figure 10). The *required* M_U is equal to $f_L\, M_{ASD}$

for an ASD analysis and M_{LRFD}/R_L for a LRFD analysis. Likewise the *required* V_U is equal to $f_L\ V_{ASD}$ for an ASD analysis and V_{LRFD}/R_L for a LRFD analysis. In any case, the only way to move the location of the red diamond on the M_G versus V_G plot (figure 13) is to alter the groundline forces applied to the foundation and/or adjust the associated resistance/safety factor. By far, the most effective way to alter the groundline shear force for a non-constrained foundation is to restrain the foundation at grade (keep in mind that the groundline shear force is the force in the foundation *just below* any ground surface restraint).

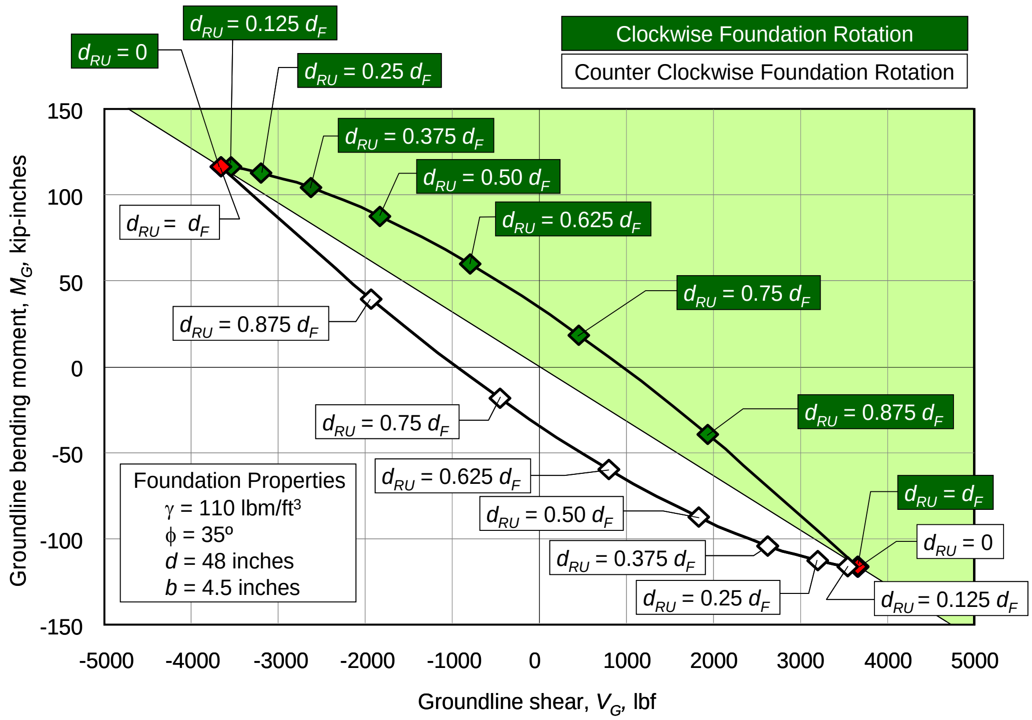


Figure 14. $V_U - M_U$ envelope from ASAE EP486.3 showing relationship between M_U, V_U and the location of the ultimate pivot point d_{RU}.

For a detailed explanation of lateral strength assessment using the universal method, see Bohnhoff (2015).

Lateral Strength Assessment – S Worksheet

The "- S" in "**Lateral Strength Assessment – S"** stands for "simplified method" and refers to the method in ASAE EP486.3 that uses simple algebraic equations to determine the maximum ultimate groundline bending moment that can be applied to a foundation before the lateral resisting capacity of the soil is exceeded. Two major restrictions for use of the simplified method are: (1) the soil is assumed to be homogenous for the entire embedment depth, and (2) width b of the below grade portion of the foundation must be constant. The latter generally means that there are no attached collars or footings that are effective in resisting lateral soil forces. Two additional requirements for use of the simplified method apply only to non-constrained foundations. These requirements are (1) groundline shear force and groundline bending moment must have the same sign as defined in figure 11, and (2) in soils with cohesion, depth to the ultimate pivot point below grade, d_{RU}, must be greater than four times the post/pier face width, b.

There are only two tables in the **Lateral Strength Assessment – S** worksheet: the *Lateral Strength Assessment – Simplified Method* table shown in figures 15 and 16, and *ASAE EP486.3 Table 4 - LRFD Resistance Factors and ASD Safety Factors for Lateral Strength Assessment using the Simplified Method of Analysis* shown in figure 17.

Use of the simplified method begins with input of foundation width and depth. This is followed by input of soil properties. Note here that unlike the **Lateral Strength Assessment – U** worksheet, the **Lateral Strength Assessment – S** worksheet does not utilize information from the **Soil Profile** worksheet. This is because the **Soil Profile** worksheet may contain information on more than one soil type (i.e., soil surrounding the foundation may be layered) and use of the simplified method is limited to a single soil type. Realize the simplified method can still be used where multiple soil layers surround a foundation. This is accomplished by running multiple analyses, with each analysis using properties associated with a different soil layer. The analysis that provides the most conservative design (i.e., the largest foundation) would then be selected for use.

	A	B	C	D	E
1					
2	**Lateral Strength Assessment - Simplified Method**				
3	**Requirements for use of this method:**				
4	**- Soil is homogeneous for entire embedment depth**				
5	**- Width of below-grade portion of the foundation is constant. This generally means there are no attached collars or footings effectively in resisting lateral soil forces**				
6	**- For non-constrained posts, the shear foce, V_G, and bending moment M_G must not independently cause post rotation in opposite directions (they must have the same signs in the following tables)**				
7	**- For non-constrained posts/piers in soils with cohesion, depth to ultimate pivot point below grade, d_{RU}, must be greater than four times the post/pier face width, b**				
8	**Symbol**	**Variable Description**	**Input Note or Equation/Source**	**Units**	**Value**
9	b	Width post/pier face pushing on the soil		inch	4.5
10	d	Depth of embedment		inch	48
11	ϕ	Soil friction angle	Enter "0" if a purely cohesive soil	degrees	35
12	γ	Moist unit weight of the soil	No input required for a purely cohesive soil	lbf/ft^3	135
13	c	Cohesion of soil with friction angle ϕ	Enter "0" if a purely cohesive soil	lbf/in.^{2}	0.00
14	S_U	Undrained soil shear strength	Enter "0" if cohesionless or mixed soil	lbf/in.^{2}	0.00
15		Is pier/post horizontally constrained at grade (i.e., ground surface)?	"0" = no, "1" =yes	NA	0
16	V_{ASD}	Shear force applied to foundation at grade by ASD load combination	Enter "0" for LRFD load combination	lbf	500
17	M_{ASD}	Bending moment applied to foundation at grade by ASD load combination	Enter "0" for LRFD load combination	in-lbf	10000
18	f_L	ASD safety factor for lateral strength assessment	See table to the right. Enter "0" for LRFD load combination	dimensionless	2.38
19	V_{LRFD}	Shear force applied to foundation at grade by LRFD load combination	Enter "0" for ASD load combination	lbf	0
20	M_{LRFD}	Bending moment applied to foundation at grade by LRFD load combination	Enter "0" for ASD load combination	in-lbf	0
21	R_L	LRFD resistance factor for lateral strength assessment	See table to the right. Enter "0" for ASD load combination	dimensionless	0
22	V_U	Required ultimate groundline shear for nonconstrained foundation	V_{LRFD}/R_L for LRFD; $f_L V_{ASD}$ for ASD	lbf	1190
23	K_P	Coefficent of passive earth pressure	$(1 + \sin\phi)/(1 - \sin\phi)$	dimensionless	3.69
24	S_{LU}	Increase in ultimate lateral force per unit depth due to soil friction	$3\, b\, K_P\, \gamma$	lbf/in^2	3.89
25	X	Intermediate calcuation for ultimate pivot point depth	$2c/(K_P^{0.5}\gamma)$	inches	0.00
26	d_{RU}	Depth to ultimate pivot point for all but purely cohesive soils	$(X^2 + V_U/S_{LU} + dX + d^2/2 + Xb/2)^{0.5} - X$	inches	38.18
27		Depth to ultimate pivot point for purely cohesive soils with $d_{RU} < 4b$	$[64b^2 + 4V_U/(3S_U) + 12\, bd]^{0.5} - 8b$	inches	NA
28		Depth to ultimate pivot point for purely cohesive soils with $d_{RU} > 4b$	$V_U/(18bS_U) + d/2 + 2b/3$	inches	NA
29		Depth to ultimate pivot point for purely cohesive soils	Depends on value of d_{RU} and 4 b	inches	NA
30	d_{RU} / d	Ratio of ultimate pivot point depth to foundation depth	d_{RU} / d	dimensionless	0.795
31	M_U	Maximum ultimate groundline moment		in-lbf	-939
32		Non-constrained post/pier in cohesionless or mixed soils	$S_{LU}(d^3 - 2\, d_{RU}^3)/3 + 6\, b\, c\, K_P^{0.5}(d^2/2 - d_{RU}^2 + b^2/4)$	in-lbf	-939
33		Non-contrained post in purely cohesive soils with $d_{RU} > 4b$	$9\, b\, S_U(d^2/2 - d_{RU}^2 + 16b^2/9)$	in-lbf	NA
34		Non-contrained post in purely cohesive soils with $d_{RU} < 4b$	$b\, S_U[4.5d^2 - 6d_{RU}^2 - d_{RU}^3/(2b)]$	in-lbf	NA
35		Constrained post in cohesionless or mixed soils with $d > 4b$	$d^3\, b\, K_P\, \gamma + b\, c\, K_P^{0.5}[3d^2 - 32b^2/3)$	in-lbf	NA
36		Constrained post in cohesionless or mixed soils with $d < 4b$	$d^3\, b\, K_P\, \gamma + b\, d^2\, c\, K_P^{0.5}[1 + d/(3b)]$	in-lbf	NA
37		Constrained post in cohesive soils with $d > 4b$	$b\, S_U(4.5d^2 - 16b^2)$	in-lbf	NA
38		Constrained post in cohesive soils with $d < 4b$	$b\, d^2 S_U[3/2 + d/(2b)]$	in-lbf	NA
39	Max M_{ASD}	Maximum ASD Groundline Moment	M_U/f_L	in-lbf	-395
40	Max M_{LRFD}	Maximum LRFD Groundline Moment	$M_U R_L$	in-lbf	NA
41				**Are design requirements met?**	**NO**

Figure 15. Lateral strength assessment – simplified method table as presented in the Lateral Strength Assessment – S worksheet. Example analysis for a non-constrained post.

The ASAE EP486.3 simplified method was developed for three different soil types: cohesionless, cohesive, and mixed. For a cohesionless soil, non-zero values are entered into the worksheet for drained soil friction angle ϕ and moist unit weight γ of the soil, and "0" (zero) values are input for soil cohesion c and undrained soil shear strength S_U. For a cohesive soil, a non-zero value is entered into the worksheet for undrained soil shear strength S_U, and "0" values are input for soil friction angle, moist unit weight of the soil, and soil cohesion. A mixed soil is considered to be a drained sand and/or gravel with a measurable amount of soil cohesion. Required input properties for a mixed soil include drained soil friction angle ϕ, moist unit weight γ, and soil cohesion c, with a "0" value entered into the worksheet for undrained soil shear strength S_U.

Enter a "0" (zero) on row 15 of the *Lateral Strength Assessment – Simplified Method* table if the foundation is not restrained from horizontal movement at grade, or enter a "1" for the special condition where the foundation is restrained at grade.

Applied load and resistance/safety factors are entered on rows 16 through 20 of the *Lateral Strength Assessment – Simplified Method* table. If nonzero values are entered for V_{ASD}, M_{ASD} and f_L, then "0" (zero) values are entered for V_{LRFD}, M_{LRFD} and R_L. Likewise, if nonzero values are entered for V_{LRFD}, M_{LRFD} and R_L, then "0" (zero) values are entered for V_{ASD}, M_{ASD} and f_L. Resistance factors and safety factors for lateral strength assessment (R_L and f_L values) using the simplified method are given in *ASAE EP486.3 Table 4 - LRFD Resistance Factors and ASD Safety Factors for Lateral Strength Assessment using the Simplified Method of Analysis* (figure 17). Note that the magnitude of these values is the same as those for the universal method of analysis given in figure 12.

	A	B	C	D	E
1					
2	**Lateral Strength Assessment - Simplified Method**				
3	**Requirements for use of this method:**				
4	**- Soil is homogeneous for entire embedment depth**				
5	**- Width of below-grade portion of the foundation is constant. This generally means there are no attached collars or footings effectively in resisting lateral soil forces**				
6	**- For non-constrained posts, the shear foce, V_G, and bending moment M_G must not independently cause post rotation in opposite directions (they must have the same signs in the following tables)**				
7	**- For non-constrained posts/piers in soils with cohesion, depth to ultimate pivot point below grade, d_{RU}, must be greater than four times the post/pier face width, b**				
8	**Symbol**	**Variable Description**	**Input Note or Equation/Source**	**Units**	**Value**
9	b	Width post/pier face pushing on the soil		inch	4.5
10	d	Depth of embedment		inch	28
11	ϕ	Soil friction angle	Enter "0" if a purely cohesive soil	degrees	35
12	γ	Moist unit weight of the soil	No input required for a purely cohesive soil	lbf/ft^3	135
13	c	Cohesion of soil with friction angle ϕ	Enter "0" if a purely cohesive soil	lbf/in.^{2}	0.00
14	S_U	Undrained soil shear strength	Enter "0" if cohesionless or mixed soil	lbf/in.^{2}	0.00
15		Is pier/post horizontally constrained at grade (i.e., ground surface)?	"0" = no, "1" =yes	NA	1
16	V_{ASD}	Shear force applied to foundation at grade by ASD load combination	Enter "0" for LRFD load combination	lbf	500
17	M_{ASD}	Bending moment applied to foundation at grade by ASD load combination	Enter "0" for LRFD load combination	in-lbf	10000
18	f_L	ASD safety factor for lateral strength assessment	See table to the right. Enter "0" for LRFD load combination	dimensionless	2.38
19	V_{LRFD}	Shear force applied to foundation at grade by LRFD load combination	Enter "0" for ASD load combination	lbf	0
20	M_{LRFD}	Bending moment applied to foundation at grade by LRFD load combination	Enter "0" for ASD load combination	in-lbf	0
21	R_L	LRFD resistance factor for lateral strength assessment	See table to the right. Enter "0" for ASD load combination	dimensionless	0
22	V_U	Required ultimate groundline shear for nonconstrained foundation	V_{LRFD}/R_L for LRFD; $f_L V_{ASD}$ for ASD	lbf	1190
23	K_P	Coefficent of passive earth pressure	$(1 + \sin\phi)/(1 - \sin\phi)$	dimensionless	3.69
24	S_{LU}	Increase in ultimate lateral force per unit depth due to soil friction	$3\,b\,K_P\,\gamma$	lbf/in.^{2}	3.89
25	X	Intermediate calcuation for ultimate pivot point depth	$2c/(K_P^{0.5}\gamma)$	inches	0.00
26	d_{RU}	Depth to ultimate pivot point for all but purely cohesive soils	$(X^2 + V_U/S_{LU} + dX + d^2/2 + Xb/2)^{0.5} - X$	inches	0.00
27		Depth to ultimate pivot point for purely cohesive soils with $d_{RU} < 4b$	$[64b^2 + 4V_U/(3S_U) + 12\,bd]^{0.5} - 8b$	inches	0.00
28		Depth to ultimate pivot point for purely cohesive soils with $d_{RU} > 4b$	$V_U/(18bS_U) + d/2 + 2b/3$	inches	0.00
29		Depth to ultimate pivot point for purely cohesive soils	Depends on value of d_{RU} and $4\,b$	inches	0.00
30	$d_{RU}\,/\,d$	Ratio of ultimate pivot point depth to foundation depth	$d_{RU}\,/\,d$	dimensionless	0.000
31	M_U	Maximum ultimate groundline moment		in-lbf	28479
32		Non-constrained post/pier in cohesionless or mixed soils	$S_{LU}(d^3 - 2\,d_{RU}^3)/3 + 6\,b\,c\,K_P^{0.5}(d^2/2 - d_{RU}^2 + b^2/4)$	in-lbf	NA
33		Non-contrained post in purely cohesive soils with $d_{RU} > 4b$	$9\,b\,S_U(d^2/2 - d_{RU}^2 + 16b^2/9)$	in-lbf	NA
34		Non-contrained post in purely cohesive soils with $d_{RU} < 4b$	$b\,S_U[4.5d^2 - 6d_{RU}^2 - d_{RU}^3/(2b)]$	in-lbf	NA
35		Constrained post in cohesionless or mixed soils with $d > 4b$	$d^3\,b\,K_P\,\gamma + b\,c\,K_P^{0.5}[3d^2 - 32b^2/3)$	in-lbf	28479
36		Constrained post in cohesionless or mixed soils with $d < 4b$	$d^3\,b\,K_P\,\gamma + b\,d^2\,c\,K_P^{0.5}[1 + d/(3b)]$	in-lbf	NA
37		Constrained post in cohesive soils with $d > 4b$	$b\,S_U(4.5d^2 - 16b^2)$	in-lbf	NA
38		Constrained post in cohesive soils with $d < 4b$	$b\,d^2S_U[3/2 + d/(2b)]$	in-lbf	NA
39	Max M_{ASD}	Maximum ASD Groundline Moment	M_U/f_L	in-lbf	11966
40	Max M_{LRFD}	Maximum LRFD Groundline Moment	$M_U R_L$	in-lbf	NA
41				**Are design requirements met?**	**Yes**

Figure 16. ***Lateral Strength Assessment – Simplified Method*** **table as presented in the Lateral Strength Assessment – S worksheet. Example analysis for a foundation constrained at grade.**

If a foundation is of sufficient size such that surrounding soil is not overloaded by the groundline shear force and bending moment acting on the foundation, a "yes" will appear in the red box (column E, row 41) of the *Lateral Strength Assessment – Simplified Method* table (figures 15 and 16). Conversely, if the foundation is not adequately sized, a "no" will appear in the box.

A comparison of the analyses in figures 15 and 16 demonstrates the significant impact of fixing a foundation from moving laterally at grade. Figure 15 contains the analysis for a 4.5 inch wide and 48 inch deep non-constrained foundation surrounded by soil with a drained soil friction angle of 35 degrees and moisture unit weight of 135 lbf/ft^3. This foundation is not large enough to resist the ASD groundline shear force and bending moment of 500 lbf and 10000 in-lbf, respectively, with a safety factor of 2.38. However, the same foundation is adequate under the same loads when it is constrained at grade and shortened to a 28 inch depth (figure 16).

For the simplified method, distance below grade d_{RU} of the ultimate pivot point is an intermediate calculation required in the determination of M_U for non-constrained foundations. These intermediate calculations appear in rows 26 through 29 of the *Lateral Strength Assessment – Simplified Method* table. In this case, d_{RU} is the depth to the ultimate pivot point when groundline bending moment is increased to the point that all soil surrounding the foundation has reached its maximum capacity while the groundline shear force remains at $f_L\,V_{ASD}$ for an ASD analysis or at V_{LRFD}/R_L for an LRFD analysis. Realize that at lower loads (i.e., combinations of groundline shear force and groundline bending moment located inside the M_U – V_U failure envelope) there could be more than one location below grade at which a foundation exhibits zero lateral displacement relative to its original unloaded position.

A detailed explanation of lateral strength assessment using the simplified method is provided by Bohnhoff (2015).

ASAE EP486.3 Table 4 - LRFD Resistance Factors and ASD Safety Factors for Lateral Strength Assessment using the Simplified Method

Soil	Required property [a]	Method used to determine required soil property [a]	For ϕ = 35: LRFD resistance factor for lateral strength assessment, R_L [b] – Normal Risk	LRFD – Low Risk [c]	ASD safety factor for lateral strength assessment, f_L [b] – Normal Risk	ASD – Low Risk [c]
Cohesionless (SP, SW, GP, GW, GW-GC, GC, SC, SM, SP-SM, SP-SC, SW-SM, SW-SC)	Soil friction angle ϕ for equations in clauses 11.4.1, 11.4.3, 11.4.4 and 11.4.6	Laboratory direct shear or axial compression tests (see clause 5.8.1)	0.86 - 0.01 ϕ = 0.51	0.64	1.4/(0.86 - 0.01 ϕ) = 2.75	2.20
		SPT data in accordance with clause 5.8.2	0.66 - 0.01 ϕ = 0.31	0.39	1.4/(0.66 - 0.01 ϕ) = 4.52	3.61
		CPT data in accordance with clause 5.8.3	0.76 - 0.01 ϕ = 0.41	0.51	1.4/(0.76 - 0.01 ϕ) = 3.41	2.73
	Soil friction angle ϕ for equations in clauses 11.4.1 and 11.4.4	ASAE EP486.3 Table 1	0.61 - 0.01 ϕ = 0.26	0.33	1.4/(0.61 - 0.01 ϕ) = 5.38	4.31
		ASAE EP486.3 Table 1 with soil type verified by construction testing	0.82 - 0.01 ϕ = 0.47	0.59	1.4/(0.82 - 0.01 ϕ) = 2.98	2.38
Cohesive (CL,CH, ML, MH)	Undrained shear strength S_U for equations in clauses 11.4.2, 11.4.3, 11.4.5 and 11.4.6	Laboratory compression tests (see clause 5.7.1)	0.68	0.85	2.1	1.68
		PBPMT data in accordance with clause 5.7.2	0.68	0.85	2.1	1.68
		CPT data in accordance with clause 5.7.3	0.68	0.85	2.1	1.68
		In-situ vane tests in accordance with clause 5.7.4	0.68	0.85	2.1	1.68
	Undrained shear strength S_U for equations in clauses 11.4.2 and 11.4.5	ASAE EP486.3 Table 1	0.44	0.55	3.2	2.56
		ASAE EP486.3 Table 1 with soil type verified by construction testing	0.68	0.85	2.1	1.68

[a] Clause numbers refer to section numbers in ASAE EP 486.3

[b] In all cases, R_L is limited to a maximum value of 0.93 and f_L is limited to a minimum value of 1.50.

[c] For buildings and other structures that represent a low risk to humans in the event of a failure. R_L values increased by 25% and f_L values reduced by 20%

Figure 17. LRFD resistance factors and ASD safety factors table as presented in the Lateral Strength Assessment – S worksheet. The cell containing the soil friction angle (35 degrees in the above example) is automatically populated when a value is entered in row 11 of the *Lateral Strength Assessment – Simplified Method* table (figures 15 and 16).

Uplift Strength Assessment Worksheet

The **Uplift Strength Assessment** worksheet is the last of the seven worksheets and is used to determine the extent that soil surrounding a foundation can resist uplift forces applied to the foundation.

In accordance with ASAE EP486.3, adhesion (and hence friction) between a foundation and soil is ignored in uplift calculations. While foundation-to-soil adhesion can significantly increase uplift resistance, it is highly dependent on soil type and moisture content, and thus is not a reliable component of uplift resistance. When foundation-to-soil adhesion is ignored, the only resistance to uplift forces provided by a straight pier/post foundation with a uniform cross-section is the dead weight of the foundation itself. It follows that to have any measureable resistance to uplift forces, a foundation must have an enlarged base and/or attachments near the base that bear against the soil as the foundation is pulled upward. Collectively, an enlarged foundation base and/or attachments near the base are referred as the uplift resisting system.

The **Uplift Strength Assessment** worksheet contains four tables: the *Uplift Strength Assessment* table (figure 18), *ASAE EP 486.3 Table 5 - LRFD Resistance Factors and ASD Safety Factors for Uplift Strength Assessment* (figure 19) located to the right of the *Uplift Strength Assessment* table, and the *Foundation Mass Estimator* table (figure 20) and *Foundation Mass Estimator - Example* table (figure 21) which are both located in the worksheet to the right of *ASAE EP 486.3 Table 5*.

The first two entries in the *Uplift Strength Assessment* table define the horizontal dimensions of the uplift resisting system. For a round uplift resting system, enter the diameter as B_U on row 5 and enter a “0” (zero) for L_U on row 6. For a rectangular uplift resisting system, enter the length of the shorter side as B_U on row 5, and the length of the longer side as L_U on row 6. For a square uplift resisting system, row 5 and 6 will have identical entries. Do not neglect to enter a “0” on row 6 for a round uplift resisting system as this triggers the worksheet to treat the uplift resisting system as a round system.

The distance between the soil surface and top of the foundation uplift resisting system is identified as d_U and entered on row 7 of the *Uplift Strength Assessment* table. Entered on row 8 is the cross-sectional area A_P of that portion of the foundation located above the uplift resisting system. For a post manufactured from three nominal 2- by 6-inch members, A_P would equal 24.8 square inches (4.5 in. x 5.5 in.).

The fifth entry in the *Uplift Strength Assessment* table (row 9) is the total mass M_F of all foundation components that would be pulled out of the ground should the soil surrounding the foundation fail. This would not include the mass of a detached footing. The *Foundation Mass Estimator* table (figure 20) was included in the worksheet to enable quick calculation of this mass. The *Foundation Mass Estimator* - ***Example*** table (figure 21) -- located in the worksheet just below the *Foundation Mass Estimator* table – explains how to use the estimator.

	A	B	D	E	F
1					
2	**Uplift Strength Assessment**				
3	**You must fill in all yellow colored cells in the table below**				
4	**Variable**	**Description**	**Units**	**Value**	**Notes**
5	B_U	Diameter of a round uplift resisting system or smaller of the two dimensions characterizing a rectangular uplift resisting system	inches	14	
6	L_U	Length of rectangular uplift resisting system with width B_U	inches	0	Enter "0" (zero) for round uplift resisting system
7	d_U	Distance from soil surface to top of foundation uplift resisting system	whole inches	40	
8	A_P	Cross-sectional area of foundation above uplift resisting system	in^2	24.8	
9	M_F	Mass of foundation components located below grade that provide anchorage	lbm	100	Estimate using table to the far right
10	ϕ	Soil friction angle for soil located above the uplift resisting system	degrees	35	Enter "0" (zero) for cohesive soils
11	S_U	Undrained soil shear strength for soil located above the uplift resisting system	lbf/in.^{2}	0	Enter "0" (zero) for cohesionless soils
12	P_{LRFD}	Axial uplift force applied to foundation at grade by LRFD load combination	lbf	0	Enter "0" (zero) for ASD loading
13	P_{ASD}	Axial uplift force applied to foundation at grade by ASD load combination	lbf	2000	Enter "0" (zero) for LRFD loading
14	R_U	LRFD resistance factor for uplift strength assessment	dimensionless	0.79	See table to the right
15	f_U	ASD factor of safety for uplift strength assessment	dimensionless	1.76	See table to the right
16	q_o	Total overburden pressure at footing depth d_U	lbf/in^2	2.99	
17	γ	Average moist unit weight of soil above the uplift resisting system	lbf/in.^{3}	0.0747	
18	h	Vertical extent of the uplift soil failure for cohesionless soil (Clause 12.5.1)	inches	71.8	Shallow foundation under uplift
19	g	Graviational acceleration	lbf/lbm	1.00	
20	K_U	Nominal uplift coefficient of earth pressure on a vertical plane for cohesionless soils	dimensionless	0.95	
21–22	s_F	Shape factor for uplift resistance in cohesionless soils	dimensionless	1.701	
23	F_c	Breakout factor for uplift in cohesive soils	dimensionless	3.429	
24	U	Ultimate uplift resistance due to soil mass	lbf	3358	U value for conditions given
25		Shallow foundation in cohesionless soils with circular uplift resisting system	lbf	3358	ASAE EP 486.3 Clause 12.5.1.1
26		Shallow foundation in cohesionless soils with rectangular uplift resisting system	lbf	0	ASAE EP 486.3 Clause 12.5.1.1
27		Deep foundation in cohesionless soils with circular uplift resisting system	lbf	0	ASAE EP 486.3 Clause 12.5.1.2
28		Deep foundation in cohesionless soils with rectangular uplift resisting system	lbf	0	ASAE EP 486.3 Clause 12.5.1.2
29		Foundation in cohesive soils with circular uplift system	lbf	0	ASAE EP 486.3 Clause 12.5.2
30		Foundation in cohesive soils with rectangular uplift system	lbf	0	ASAE EP 486.3 Clause 12.5.2
31	Max P_{LRFD}	Maximum allowed LRFD axial uplift force applied to foundation at grade	lbf	2008	ASAE EP 486.3 Clause 12.4
32	Max P_{ASD}	Maximum allowed ASD axial uplift force applied to foundation at grade	lbf	2753	ASAE EP 486.3 Clause 12.3
33			**Are design requirements met?**	**Yes**	

Figure 18. Uplift Strength Assessment table. Note that worksheet column C (titled "Equation") was collapsed during the screen capture of this image.

	H	I	J	K	L	M	N	O	P
2	**ASAE EP 486.3 Table 5 - LRFD Resistance Factors and ASD Safety Factors for Uplift Strength Assessment**								
3									
4				**For ϕ = 35**					
5	**Soil**	**Required property [(a)]**	**Method used to determine required soil property [(a)]**	**LRFD resistance factor for uplift strength assessment, R_U [(b)]**			**ASD safety factor for uplift strength assessment, f_U [(b)]**		
6				**Normal Risk**		**Low Risk [(c)]**	**Normal Risk**		**Low Risk [(c)]**
7	Cohesionless (SP, SW, GP. GW, GW-GC, GC, SC, SM, SP-SM, SP-SC, SW-SM, SW-SC)	Soil friction angle ϕ for use in the equations of clauses 12.5.1.1 and 12.5.1.2	Laboratory direct shear or axial compression tests (see clause 5.8.1)	1.20 - 0.015 ϕ =	0.68	0.84	1.4/(1.20 - 0.015 ϕ) =	2.07	1.66
8			SPT data in accordance with clause 5.8.2	0.93 - 0.015 ϕ =	0.41	0.51	1.4/(0.93 - 0.015 ϕ) =	3.46	2.77
9			CPT data in accordance with clause 5.8.3	1.07 - 0.015 ϕ =	0.55	0.68	1.4/(1.07 - 0.015 ϕ) =	2.57	2.06
10			ASAE EP486.3 Table 1	0.87 - 0.015 ϕ =	0.35	0.43	1.4/(0.87 - 0.015 ϕ) =	4.06	3.25
11			ASAE EP486.3 Table 1 with soil type verified by construction testing	1.16 - 0.015 ϕ =	0.64	0.79	1.4/(1.16 - 0.015 ϕ) =	2.20	1.76
12	Cohesive (CL,CH, ML, MH)	Undrained shear strength S_U for use in the equation of clause 12.5.2	Laboratory compression tests (see clause 5.7.1)	0.70		0.88	2.0		1.60
13			PBPMT data in accordance with clause 5.7.2	0.70		0.88	2.0		1.60
14			CPT data in accordance with clause 5.7.3	0.70		0.88	2.0		1.60
15			In-situ vane tests in accordance with clause 5.7.4	0.70		0.88	2.0		1.60
16			ASAE EP486.3 Table 1	0.56		0.70	2.5		2.00
17			ASAE EP486.3 Table 1 with soil type verified by construction testing	0.70		0.88	2.0		1.60
18	[(a)] Clause numbers refer to section numbers in ASAE EP 486.3								
19	[(b)] In all cases, R_U is limited to a maximum value of 0.93 and f_U is limited to a minimum value of 1.50.								
20	[(c)] For buildings and other structures that represent a low risk to humans in the event of a failure. R_U values increased by 25% and f_U values reduced by 20%								

Figure 19. LRFD resistance factors and ASD safety factors table. The cell containing the soil friction angle (35 degrees in the above example) is automatically populated when a value is entered in row 10 of the *Uplift Strength Assessment* table (figure 18).

	S	T	U	V	W	X	Y	Z	AA
1									
2	**Foundation Mass Estimator**								
3									
4	Component ID	Component Description	Component mass density [(a)(b)]	Round component dimensions		Rectangular component dimensions			Component Mass
5				Length or thickness	Diameter	Length	Width	Depth	
6			lbm/ft^3	inches	inches	inches	inches	inches	lbm
7	1								0.0
8	2								0.0
9	3								0.0
10	4								0.0
11	5								0.0
12	6								0.0
13	7	Hardware							
14	8	Miscellaneous							
15								**Sum**	**0.0**
16	[(a)] Common mass densities: Concrete = 150 lbm/ft^3; Steel = 490 lbm/ft^3; HDPE Plastic = 60 lbm/ft^3; 0.55 SG Wood = 34 lbm/ft^3								
17	[(b)] Enter a negative value for density to subtract a quantity from the total								

Figure 20. Foundation Mass Estimator table.

	S	T	U	V	W	X	Y	Z	AA
19	**Foundation Mass Estimator - Example**								
20–25	Below grade portion of the foundation consists of 48 inches of a three-ply post fabricated from nominal 2- by 6-inch lumber that rests on (but is not attached to) a precast concrete footing that is 6 inches thick with a diameter of 18 inches. For uplift resistance (and additional lateral resistance), a concrete collar is cast around the post. Two 16 inch long, U.S. No. 4 rebars are used to afix the collar to the post. Since the footing is not attached to the rest of the foundation, it does not provide uplift anchorage and therefore is assigned a zero mass density. The concrete collar mass of 265.1 includes concrete that is displaced by the wood post. This quantity (25.8 lbm) is subtracted from the total by assigning a negative density to the "center of concrete collar".								
26–29	Component ID	Component Description	Component mass density [(a)(b)]	Round component dimensions		Rectangular component dimensions			Component Mass
				Length or thickness	Diameter	Length	Width	Depth	
30			lbm/ft^3	inches	inches	inches	inches	inches	lbm
31	1	Wood Post	34			48	4.5	5.5	23.4
32	2	Concrete Collar	150	12	18				265.1
33	3	Center of Concrete Collar	-150			12	4.5	5.5	-25.8
34	4	Rebar	490	32	0.5				1.8
35	5	Non-attached Concrete Footing	0	6	18				0.0
36	6								0.0
37	7	Hardware							
38	8	Miscellaneous							
39								**Sum**	**264.4**
40	[(a)] Common mass densities: Concrete = 150 lbm/ft^3; Steel = 490 lbm/ft^3; HDPE Plastic = 60 lbm/ft^3; 0.55 SG Wood = 34 lbm/ft^3								
41	[(b)] Enter a negative value for density to subtract a quantity from the total								

Figure 21. Example use of the Foundation Mass Estimator table. Note the input of a negative component mass density to subtract the mass of that portion of the concrete collar that is displaced by the wood post.

Soil located above the uplift resisting system must be assumed to be either cohesionless (i.e., predominately sand and/or gravel) or cohesive. For a cohesionless soil, enter the drained soil friction angle ϕ on row 10 and enter a "0" (zero) on row 11 of the *Uplift Strength Assessment* table. For a cohesive soil, enter the undrained soil shear strength S_U on row 11 and enter a "0" (zero) on row 10 of the table. Where multiple soil types are located above the uplift resisting system, select the soil type/property that produces the lowest ultimate uplift resistance U as displayed on row 24 of the table.

The axial uplift force applied to the foundation at grade is entered on row 12 for LRFD loadings and on row 13 for ASD loadings. Make sure to enter a "0" (zero) on row 12 for an ASD loading or on row 13 for an LRFD loading.

After entering an appropriate resistance/safety factor from ASAE EP486.3 Table 5 (figure 19), the adequacy of the foundation in resisting the uplift force will be indicated in the red cell (column E, row 33) of the *Uplift Strength Assessment* table.

Summary

A Microsoft Excel workbook was developed to assist designers in determination of bearing, lateral, and uplift capacities of shallow pier and post foundations in accordance with ASAE EP486.3. Although ASAE EP486.3 also contains procedures for predicting the displacement of a shallow foundation due to lateral loads, the Excel workbook does not include any of these lateral displacement calculations.

A copy of the Microsoft Excel workbook is available at no charge from the author or from the National Frame Building Association (www.nfba.com).

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