USING SOIL PROPERTIES FROM USDA/NRCS FOR POST-FRAME DESIGN

Jonathan Fleischmann, Ph.D.
Engineer, Walters Buildings

Many current practitioners involved in embedded column foundation design for post-frame buildings follow International Building Code (IBC) Section 1806.2 for vertical strength design and soil load-bearing capacities, and Section 1807.3 for lateral strength design of embedded columns. IBC Sections 1806.2 and 1807.3 require knowledge of only two properties of the soil: the allowable vertical foundation soil load-bearing pressure capacity (in pounds per square foot, or psf) and lateral soil load-bearing pressure capacity (in pounds per square foot per foot of depth below natural grade, or psf/ft). These two values are listed in IBC Table 1806.2 for five broad classes of rock and/or soil, along with corresponding approximate designations of the Unified Soil Classification System (USCS). For example, for sandy gravel and/or gravel (GW and GP), a vertical foundation soil load-bearing capacity of 3,000 psf and a lateral soil load-bearing pressure capacity of 200 psf/ft are assumed, while for clay, sandy clay, silty clay, clayey silt, silt and sandy silt (CL, ML, MH and CH), a vertical foundation soil load-bearing capacity of 1,500 psf and a lateral soil load-bearing pressure capacity of 100 psf/ft are assumed.

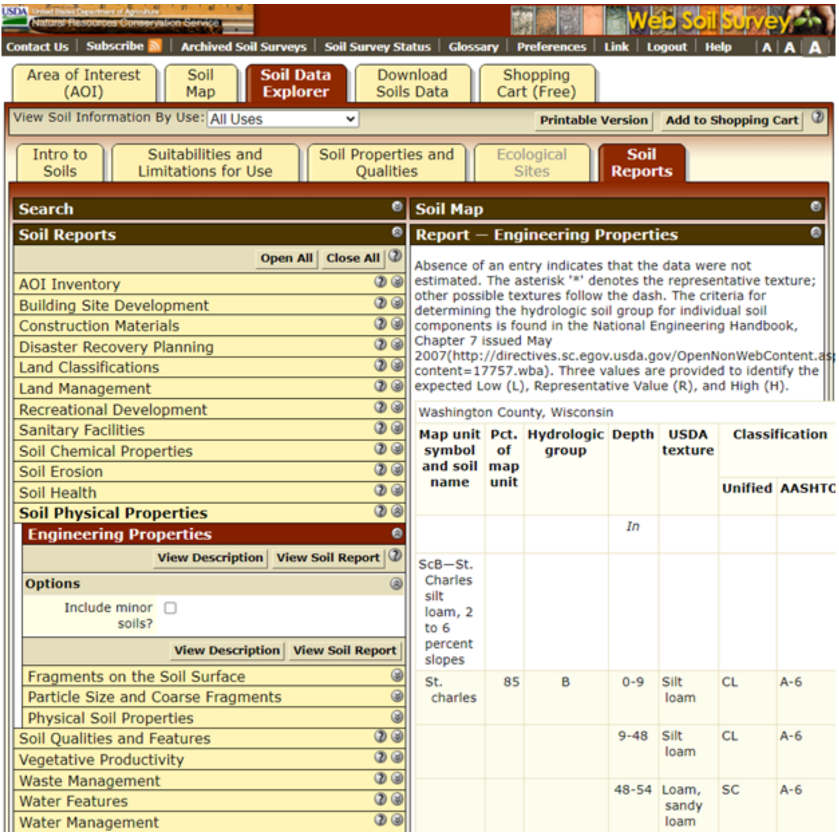
The simplicity of having just two relevant soil parameters, both contained in a single table, is certainly attractive. However, despite this simplicity, IBC Table 1806.2 and the corresponding methods of IBC Sections 1806.2 and 1807.3 oversimplify multiple factors in both vertical and lateral soil load-bearing strength design. To address these factors, ASAE EP486.2, and its subsequent revision ASAE EP486.3, *Shallow Post and Pier Foundation Design*, were developed. These engineering practices, which are referenced by the IBC as acceptable alternatives to its own foundation requirements for post-frame buildings, represents a great step forward, both in a correct understanding of geomechanics, as well as in conformity among building codes. For example, the soil bearing strength calculations of ASAE EP486.3 Section 10 are very close to the corresponding calculations of soil bearing strength in the AASHTO *LRFD Bridge Design Specifications*, and the soil spring model (Universal Method) of ASAE EP486.3 Section 8.3 is conceptually similar to the soil spring model used in the structural analysis of laterally loaded bridge piles.

The purpose of this article is to explain how soil properties obtained from the USDA/NRCS Web Soil Survey can be used in conjunction with ASAE EP486.3 to obtain soil strengths for post-frame building design. It is also noted that the vertical and lateral soil strengths obtained from ASAE EP486.3 can differ significantly from the values obtained from IBC Table 1806.2.

Soil Properties

The drawback of having any higher-resolution model, such as the soil models presented in ASAE EP486.3, is the need for more detailed input data. Indeed, this is one reason why many engineers are probably still using Table 1806.2 of the IBC rather than ASAE EP486.3. In some cases, a full geotechnical report may be needed. However, in lieu of that, all of the soil data needed to supply the input parameters for ASAE EP486.3 design can be obtained from the USDA/NRCS Web Soil Survey online app (WSS Homepage). Note that ASAE EP486.3 Tables 2-5 specify adjusted factors of safety for every soil calculation depending on whether or not the soil input parameters have been obtained via on-site testing, or via a source such as the USDA/NRCS website, combined with ASAE EP486.3 Table 1.

The Web Soil Survey can be searched based on location, address, latitude and longitude, the Public Land Survey System (PLSS), or the included map. Once an area of interest has been specified on the map under the “Area of Interest (AOI)” tab, select the “Soil Data Explorer” tab, and under it select the “Soil Reports” tab. Once in the “Soil Reports” tab, select “Soil Physical Properties” in the list of options on the left side of the webpage, and under that select “Engineering Properties”. Clicking on the “View Soil Report” button brings up a list of engineering properties for the soils in the AOI, including the unified soil classification by depth of the soils at the site, as shown in Figure 1.



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.as content=17757.wba). Three values are provided to identify the expected Low (L), Representative Value (R), and High (H).

Washington County, Wisconsin

Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification	
					Unified	AASHTO
			In			
ScB—St. Charles silt loam, 2 to 6 percent slopes						
St. charles	85	B	0-9	Silt loam	CL	A-6
			9-48	Silt loam	CL	A-6
			48-54	Loam, sandy loam	SC	A-6

Figure 1: Partial soil report showing engineering properties obtained from the USDA/NRCS Web Soil Survey online app.

In the example shown in Figure 1, the soil type to a depth of 48 inches is “CL”, which according to the USCS is a homogeneous inorganic clay with low plasticity. Table 1 of ASAE EP486.3 lists different properties for a CL soil that depend on if the soil is a “soft”, “medium to stiff”, or “very stiff to hard” clay. These three CL categories are associated with moist unit weights of 125, 130, and 135 pcf, respectively. In the absence of in-situ moist unit weight data, a designer would select the most conservative option (which in this case is to assume a “soft” clay). For the example calculations that follow, a “medium to stiff” clay is assumed. In addition to the tabulated moist unit weight $\gamma = 130$ pcf, this clay has an undrained shear strength $S_U = 7$ psi, a Young’s modulus $E_S = 6{,}160$ psi, and a Poisson’s ratio $\nu = 0.5$. Note that none of these values are directly comparable to the values obtained from IBC Table 1806.2. To make such a comparison, the data obtained from ASAE

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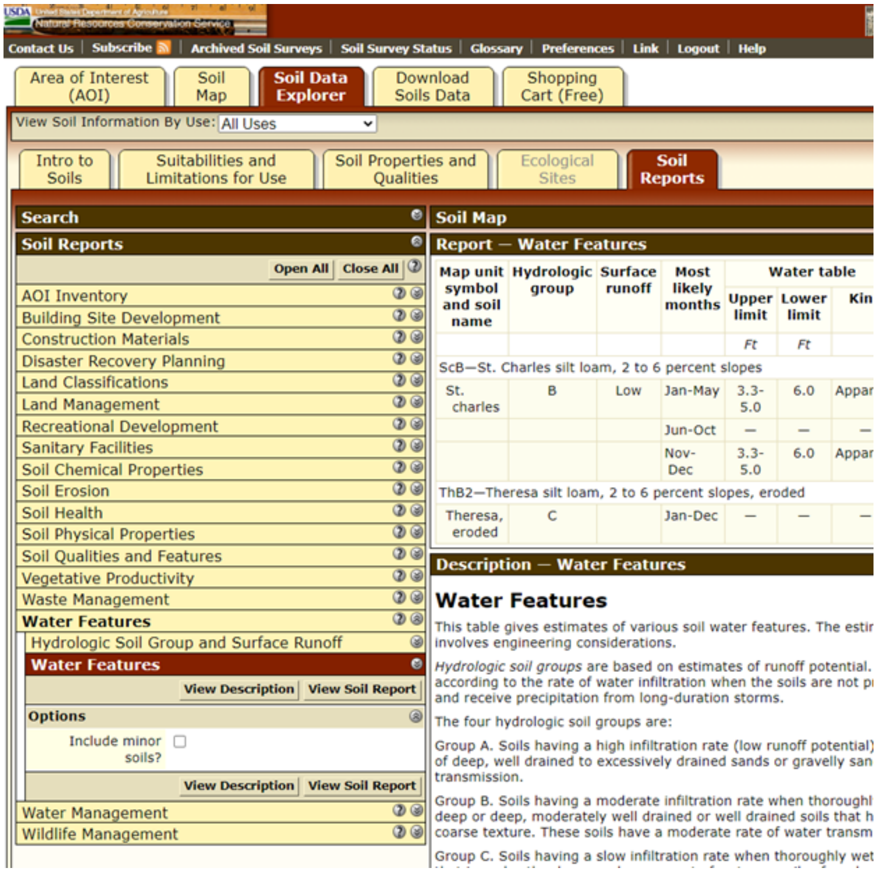
EP486.3 Table 1 must be combined with the equations of ASAE EP486.3 Section 10 for vertical load-bearing capacity, and Section 11 for lateral load-bearing capacity.

To take a second example, if the soil type had been "GW", which according to the USCS is a well-graded clean to sandy gravel, then, assuming a loose packing (which is most conservative), Table 1 of ASAE EP486.3 predicts a unit weight $\gamma = 135$ pcf, a drained internal friction angle $\phi = 35°$, an increase in Young's modulus per unit depth $A_E = 220$ psi/in, and a Poisson's ratio $\nu = 0.3$.



Report — Water Features

Map unit symbol and soil name	Hydrologic group	Surface runoff	Most likely months	Water table		
				Upper limit	Lower limit	Kin
				Ft	*Ft*	
ScB—St. Charles silt loam, 2 to 6 percent slopes						
St. charles	B	Low	Jan-May	3.3-5.0	6.0	Appar
			Jun-Oct	—	—	—
			Nov-Dec	3.3-5.0	6.0	Appar
ThB2—Theresa silt loam, 2 to 6 percent slopes, eroded						
Theresa, eroded	C		Jan-Dec	—	—	—

Description — Water Features

Water Features

This table gives estimates of various soil water features. The esti
involves engineering considerations.

Hydrologic soil groups are based on estimates of runoff potential.
according to the rate of water infiltration when the soils are not p
and receive precipitation from long-duration storms.

The four hydrologic soil groups are:

Group A. Soils having a high infiltration rate (low runoff potential)
of deep, well drained to excessively drained sands or gravelly san
transmission.

Group B. Soils having a moderate infiltration rate when thorough
deep or deep, moderately well drained or well drained soils that
coarse texture. These soils have a moderate rate of water transm

Group C. Soils having a slow infiltration rate when thoroughly wet

Figure 2: Partial soil report showing water features obtained from the USDA/NRCS Web Soil Survey online app.

Another important geotechnical parameter strongly influencing the strength of soils, both vertical and lateral, is water table depth. This parameter can also be obtained from the USDA/NRCS Web Soil Survey online app. Once in the "Soil Reports" tab, instead of selecting "Soil Physical Properties" as before, select "Water Features" in the list of options on the left side of the webpage, and under that select "Water Features". Clicking on the "View Soil Report" button reveals a list of water features for the soils in the AOI, including the upper and lower limits of the water table depth depending on season, as shown in Figure 2.

The value of water table depth is significant in many ASAE EP 486.3 calculations. For example, if the upper limit of the water table depth is lower than the embedment depth of the column during all seasons, then footnote (e) of ASAE EP 486.3 Table 1 stipulates that the value of A_E for a cohesionless soil can be doubled! Returning to the second example, this means that the increase in Young's modulus per unit depth for loosely packed gravel (GW) above the water table becomes $A_E = 440$ psi/in, rather than $A_E = 220$ psi/in.

Vertical Load-Bearing Capacity

To compute the ultimate vertical load-bearing capacity q_B of the example soils of the previous section, the general bearing capacity equation in Section 10.4 of ASAE EP486.3 is used. There are two versions of this equation, one for saturated clay soils (such as clay or silt, which are the soils in the upper half of ASAE EP486.3 Table 1: CL, CH, ML, MH), and one for cohesionless soils (such as sand or gravel, which are the soils in the lower half of ASAE EP486.3 Table 1: SM, SC, SP, SW, GC, GP, GW).

For saturated clay soils, the general bearing capacity equation is

$q_B = S_U N_C d_C s_C + \gamma d_F$, where:

$N_C = 5.14$ (for $\phi = 0$),

$s_C = 1.2$ for square or round footings,

$$d_C = \begin{cases} 1 + 0.2 d_F/B & \text{for } d_F/B < 2.5 \\ 1.5 & \text{for } d_F/B \ge 2.5 \end{cases}$$

d_F = post or column embedment depth,

B = breadth (e.g., diameter) of footing.

For the example CL soil of the previous section and $d_F = 48$ in and $B = 12$ in, the general bearing capacity equation yields $q_B = 68.4$ psi. Note that this value is still not directly comparable with the presumptive vertical load-bearing capacity in Table 1806.2 of the IBC, since Section 10.2 of ASAE EP486.3 requires that the vertical (compressive) load P_{ASD} applied to the column divided by the bearing area of the footing should be compared with $(q_B - q_0)/f_B$, where $q_0 = \gamma d_F$ is the soil overburden pressure, and f_B is a factor of safety obtained from Table 2 of ASAE EP486.3, which for soil of type CL is $f_B = 2.3$ or $f_B = 3.0$, depending on whether or not the soil type has been verified by construction testing. Even if $f_B = 3.0$, however, which assumes that the soil type has not been verified at the construction site, the value of $(q_B - q_0)/f_B = 21.6$ psi = 3,110 psf for CL obtained from ASAE EP486.3 is more than double the presumptive value of 1,500 psf for CL obtained from Table 1806.2 of the IBC.

For cohesionless soils, the general bearing capacity equation is:

$$q_B = \gamma\left(0.5 B C_{W1} N_\gamma s_\gamma + d_F C_{W2} N_q d_q s_q\right),$$

where:

$N_\gamma = 2\left(N_q + 1\right)\tan\phi$,

$N_q = \exp\left(\pi \tan\phi\right)\tan^2\left(45° + \phi/2\right)$,

$s_\gamma = 0.6$ for square or round footings,

$s_q = 1 + \tan\phi$,

$d_q = 1 + 2\tan\phi\left(1 - \sin\phi\right)^2 \tan^{-1}\left(d_F/B\right)$.

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Here the values of C_{W1} and C_{W2} depend strongly on the depth of the water table, d_W, and are computed as:

$$C_{W1} = \begin{cases} 0.5 & \text{for } d_W \le d_F \\ 0.5 + \left(d_W - d_F\right)/(3B) & \text{for } d_F < d_W < 1.5B + d_F \\ 1.0 & \text{for } d_W \ge 1.5B + d_F \end{cases}$$

$$C_{W2} = \begin{cases} 0.5 + 0.5 d_W / d_F & \text{for } d_W < d_F \\ 1.0 & \text{for } d_W \ge d_F \end{cases}$$

For the example GW soil of the previous section and $d_F = 48$ in and $B = 12$ in, and a water table depth $d_W = 12$ in, the general bearing capacity equation yields $q_B = 184.2$ psi. For comparison, for a water table depth $d_W = 48$ in, this value becomes $q_B = 290.6$ psi. Note the strong influence of the water table depth d_W on q_B for a cohesionless soil. The factor of safety f_B for a cohesionless soil, which is still obtained from Table 2 of ASAE EP486.3, now depends on the internal friction angle ϕ. Assuming that the soil type has not been verified at the construction site, Table 2 of ASAE EP486.3 calls for $f_B = 6.1$, which results in $\left(q_B - q_0\right)/f_B = 29.6$ psi = 4,262 psf for GW obtained from ASAE EP486.3 for a water table depth $d_W = 12$ in. For comparison, for a water table depth $d_W = 48$ in, $\left(q_B - q_0\right)/f_B = 47.0$ psi = 6,768 psf. Note that both of these values are significantly higher than the presumptive value of 3,000 psf for GW obtained from Table 1806.2 of the IBC, with the value for the deeper water table being more than double.

Lateral Load-Bearing Capacity

When considering lateral soil response, there are two separate issues to address. First, there is lateral load-bearing capacity, which is addressed in Section 11 of ASAE EP486.3. This lateral load-bearing capacity is given in ASAE EP486.3 Section 11.2.1 as an ultimate lateral soil pressure $p_{U,z}$, which depends on depth z. Following the Universal Method of ASAE EP486.3 Section 8.3, the soil below grade is divided into layers, and the interaction of each soil layer with the embedded column is modeled as a lateral soil spring. An individual lateral soil spring yields (and provides a constant resisting force) when the force in the soil spring F_{ASD} reaches F_{ult}/f_L, where f_L is a factor of safety obtained from Table 3 of ASAE EP486.3, and $F_{ult} = p_{U,z} t b$, where t is the thickness of the soil layer represented by the soil spring, and b is the face width of the embedded column at depth z below grade. Note that, according to Section 11.3.3 of ASAE EP486.3, all soil springs (except at most one soil spring at the pivot point) must yield for the soil to be said to fail under lateral load. In the interest of space, the formulas for the calculation of $p_{U,z}$ are not included here.

The second issue to address in lateral soil response is lateral soil stiffness. The stiffness of an individual lateral soil spring is given in ASAE EP486.3 Section 8.3 as $K_H = 2tE_{SE}$, where t is the thickness of the soil layer represented by the soil spring, and E_{SE} is the effective Young's modulus for the soil at depth z. For cohesive soils (the upper half of ASAE EP486.3 Table 1), $E_{SE} = E_S$ is constant, while for cohesionless soils (the lower half of ASAE EP486.3 Table 1), $E_{SE} = A_E z$ increases linearly with depth z below grade. These stiffness values determine the distribution of lateral forces among the soil springs, and thus also determine the overall structural response of the embedded columns below grade when the entire post-frame building is analyzed for lateral displacement under wind load (being careful to include diaphragm and frame interaction, or DAFI).

Figures 3 and 4 show distributions of lateral soil pressure $p_z = F_{ASD}/\left(tb\right)$, derived from the force F_{ASD} in each lateral soil spring, as functions of depth below grade for two embedded columns in a single frame of an example post-frame building subjected to wind loads. These results were obtained via a structural analysis of the entire building (including DAFI effects) using in-house finite element software developed by the author for Walters Buildings. Figure 3 shows the lateral pressure distribution for the cohesive soil example (CL), and Figure 4 shows the lateral pressure distribution for the cohesionless soil example (GW). Note the pressure discontinuity due to the change in the face width b of the embedded column at the

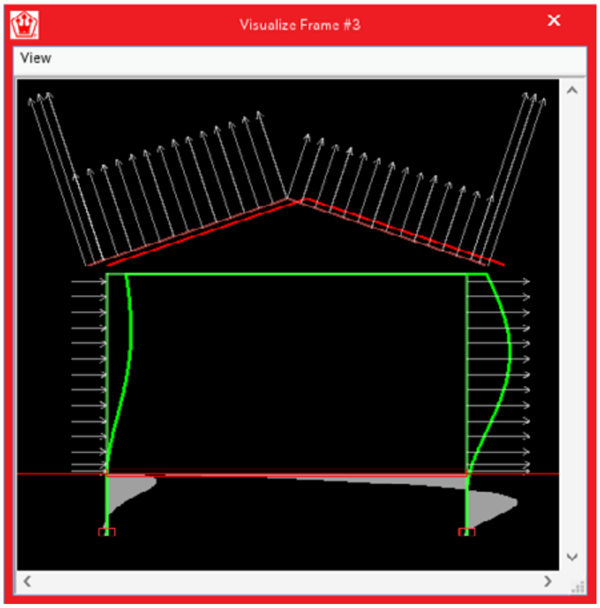

Figure 3: Cohesive soil example (CL) lateral pressure distributions as functions of depth below grade for two embedded columns in a single frame of an example post-frame building subjected to wind load.

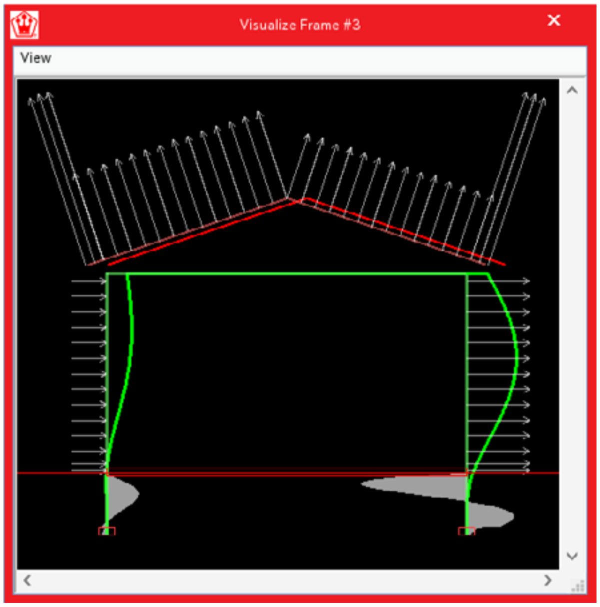

Figure 4: Cohesionless soil example (GW) lateral pressure distributions as functions of depth below grade for two embedded columns in a single frame of an example post-frame building subjected to wind load.

attached footing. Figures 3 and 4 also include exaggerated lateral displacement under the applied wind loads. Note the slight lateral displacements of the columns below grade. Also note the presence of a lateral constraint on one of the columns at grade due to the concrete floor.

All loads and displacements in Figures 3 and 4 are elastic (i.e., it is assumed that no soil springs are yielding). In order to accurately account for the plasticity of the soil springs, either an iterative finite element approach must be used, or the $V_U - M_U$ envelope method of EP486.3 Section 11.3.2 must be employed. Note that, according to EP486.3, lateral soil strength is not linear with depth, and so it is more difficult to make a meaningful comparison with the values obtained from IBC Table 1806.2 than it was for vertical soil strength.

Uplift Capacity

In the interest of space, calculation of soil uplift capacity, which is covered in ASAE EP486.3 Section 12, will not be summarized here. Soil uplift resistance is of utmost importance, since it is often the limiting design criterion, especially when embedment depth is relatively shallow. The calculations of soil uplift strength use the same soil data from the USDA/NRCS website, combined with ASAE EP486.3 Table 1, as in the examples of the previous sections.

Conclusion

In this article, soil data from the USDA/NRCS Web Soil Survey online app was used to compute vertical and lateral soil load-bearing capacities according to Sections 10 and 11 of ASAE EP486.3. The examples contained herein should make it clear that, while attractive for its simplicity, the approach of IBC Table 1806.2 for post-frame design oversimplifies multiple factors, which can lead to significantly lower (i.e., more conservative) soil strengths when compared to ASAE EP486.3. Since the only drawback of ASAE EP486.3 is the need for more detailed soil input data, the fact that this data is readily available from the USDA/NRCS Web Soil Survey online app will hopefully make the use of ASAE EP486.3 more prevalent in post-frame building design.

References

IBC 2018, International Building Code

ANSI/ASAE EP486.3 SEP2017, Shallow Post and Pier Foundation Design

WSS Homepage, https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm, accessed 1/6/2021