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MODELING SOIL BEHAVIOR WITH SIMPLE SPRINGS, PART 2

Determining the Ultimate Lateral Capacity of a Post/Pier Foundation

This is the second of a two-part article covering the use of simple springs to model soil behavior. Covered in Part 1 were suggestions for spring placement and procedures for calculating spring stiffness and ultimate spring strength. Covered in Part 2 are the use of springs in a plane-frame structural analysis, ANSI/ASAE EP486.2 safety factors for allowable stress design, ANSI/ASAE EP486.2 resistance factors for load and resistance factor design and new procedures for determining the ultimate lateral capacity of a post/pier foundation. Both parts of the article include example calculations.

Part 1 of this article (Bohnhoff, 2014) introduced the use of a series of soil springs to model the behavior of soil surrounding a post/pier foundation. Each of these springs is assumed to be characterized by the general load-displacement curve shown in **Figure 1**, which consists of a linear-elastic region and a purely plastic region. In the linear-elastic region, the force applied to the post by each spring is equal to the product of that spring's stiffness K_H and lateral post movement Δ at the point where the spring is attached to the post. When the force in a spring reaches F_{ult}, it remains in a plastic state of strain, and any additional lateral movement of the post in the same direction will be resisted by a constant force F_{ult}. Equations for K_H and F_{ult} are given as

$$K_H = 2.0\, t\, E_S \quad (1)$$

$$F_{ult} = p_{U,z}\, t\, b \quad (2)$$

where

K_H = initial stiffness of an individual soil spring located at depth *z*, lbf/in

F_{ult} = ultimate load that an individual spring at depth z can sustain, lbf

E_S = Young's modulus for soil at depth *z*, lbf/in^2

$p_{U,z}$ = ultimate lateral soil resistance at depth *z*, lbf/in^2

b = width of the face of the post/pier, footing or collar that applies load to the soil when the foundation moves laterally, inches

t = thickness of a soil layer that is represented by the soil spring, inches

z = distance of spring below grade, inches

Readers are referred to Part 1 of this article for information on the placement of soil springs and information required to determine Young's modulus E_S and ultimate lateral soil resistance $p_{U,z}$.

Structural Analysis with Soil Springs

Modeling the complete elastic-to-plastic spring behavior in Figure 1 requires a nonlinear structural analysis program that allows for nonlinear material properties. In practice, this is avoided by assuming that (1) few if any soil springs will reach a plastic state of strain when structural loads are acting on a building frame, and (2) the impact on a structural analysis of some springs entering a plastic strain state is minimal if the foundation being modeled is indeed adequate under the applied structural loads. In other words, for routine structural analysis purposes, all soil springs are assumed to exhibit a linear-elastic load-displacement relationship (defined by stiffness K_H) regardless of how much they are compressed. This means that yielding is ignored, as shown in Figure 1, and thus the force in some soil springs may exceed F_{ult} during the analysis.

With respect to foundation design, structural analyses provide the groundline shear forces (V_G values) and groundline bending moments (M_G values) that are required to check the adequacy of post/pier foundations. For example, a structural analysis of the frame in **Figure 2** shows the left and

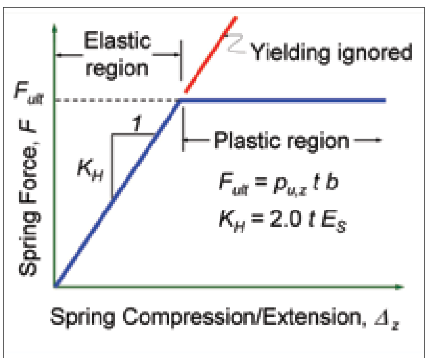

Figure 1. Load-displacement relationship for a soil spring

Table 1. Spring Properties and Induced Forces

Spring number	Face width of foundation at spring location, *b*, inches	Thickness of soil layer represented by spring, *t*, inches	Distance from surface, *z*, inches	Horizontal spring stiffness, K_H, lbf/in	Ultimate spring strength, F_{ult}, lbf	Nodal displacement due to applied loads[a], inches		Spring force due to applied loads[a], lbf	
						Left post	Right post	Left post	Right post
1	5.5	5.5	2.75	67800	794	-0.0041	0.0141	275	959
2	5.5	5.5	8.25	67800	1110	-0.0076	0.0041	513	281
3	5.5	5.5	13.75	67800	1430	-0.0074	-0.0012	500	79
4	5.5	5.5	19.25	67800	1750	-0.0056	-0.0032	381	217
5	5.5	8	26	98600	2770	-0.0031	-0.0032	310	315
6	5.5	6	33	87100	837	-0.0011	-0.002	100	178
7	5.5	6.5	39.25	112300	1080	-0.00007	-0.0008	8	93
8	12	5.5	45.25	109500	2300	0.001	0.0003	106	32

(a) Displacements and associated forces due to the structural loads shown in Figure 2 right posts to be subjected to groundline shears of 1,966 lbf and 392 lbf, respectively, and to groundline bending moments of 25,447 in-lbf and 16,526 in-lbf, respectively. Soil spring properties and placements used to model the soil for this analysis are from example 1 of Part 1 of this article (Bohnhoff, 2014). They are listed in **Table 1**, along with nodal displacements and spring forces obtained from the analysis. A VisualAnalysis model of the structure is shown in **Figure 3**. **Figure 4** contains a plot of the displaced shape of each post foundation, along with its groundline shear and bending moment.

For this example analysis, the left foundation was not allowed to move horizontally at grade so as to simulate the lateral resistance provide by the concrete slab. This was accomplished by placing a vertical roller support at grade, which in this case was assumed to be the likely point of contact between the post and the slab. The groundline shear force of 1,966 lbf shown for this surface-constrained post is the shear force induced in the post at a point just below the vertical roller support.

It is clear from the plots in Figure 4 that the traditional assumption of a rigid post below grade would produce a much different displaced shape for both foundations. In this case, soil stiffness relative to the post's flexural stiffness is such that the very base of each post has a positive displacement. If indeed the posts were assumed to be completely rigid, the base of each post would actually be the location of greatest negative displacement.

Like many structural analysis programs, the VisualAnalysis program used for this example contained a special spring element for modeling. Application of this element required designation of an attaching node, an orientation (horizontal in this case), and a spring stiffness value. When a special spring element is unavailable, the resisting force applied to a post by soil can be modeled with a pinned-end element (also known as a truss element) by equating the axial stiffness of the element (AE/L) to spring stiffness K_H (see **Figure 5**). For K_H values in lbf/

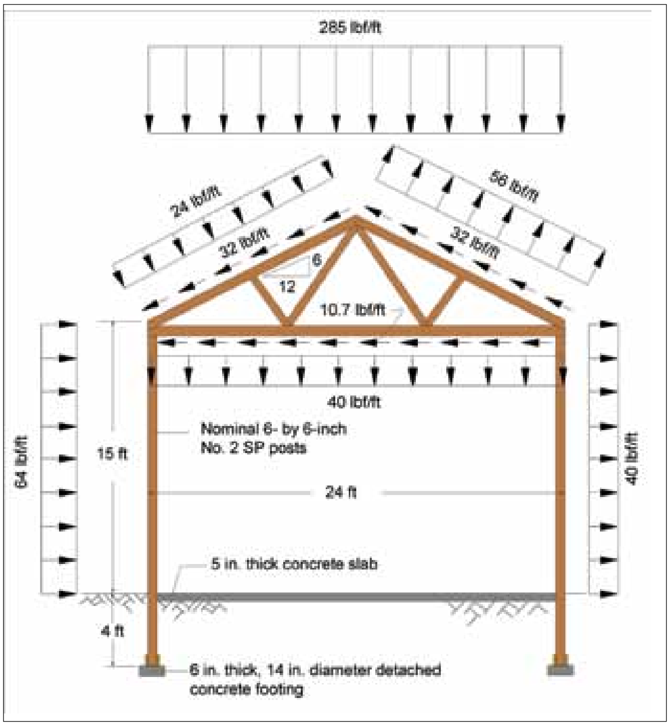

Figure 2. Geometry and an ASD load diagram for example analysis. In-plane forces applied to the top and bottom truss chords are sidesway-resisting forces applied by roof and ceiling diaphragms, respectively.

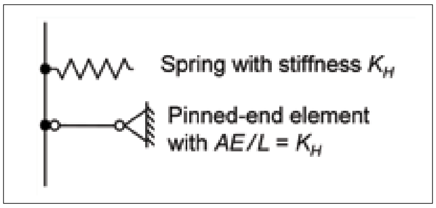

Figure 5. Two equivalent ways to model the lateral resisting force of soil

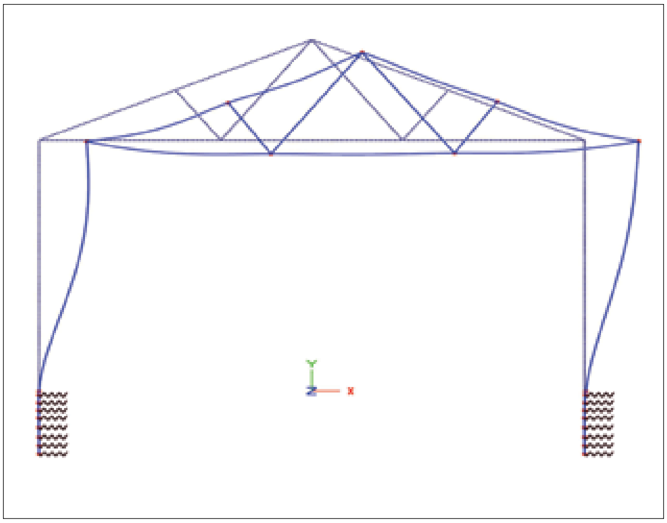

Figure 3. Exaggerated deformed shape of the post frame in Figure 2. To put displacements in perspective, eave displacements are 0.78 and 0.89 inches at the tops of the left and right posts, respectively.

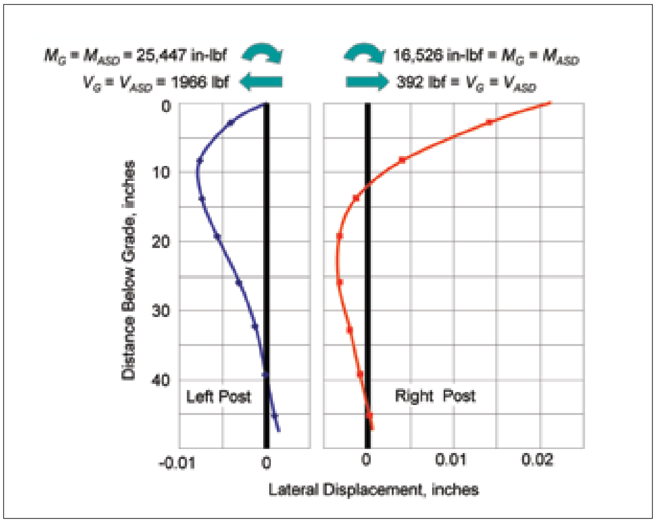

Figure 4. Groundline shear and bending moments and below-grade displacements of the left and right posts for the frame shown in Figure 2

Table 2. 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, $p_{U,z}$	LRFD resistance factor for lateral strength assessment, R_L	ASD safety factor for lateral strength assessment, f_L
Cohesive (CL,CH, ML, MH)	Undrained shear strength S_U determined from laboratory compression tests	0.68	2.1
	Undrained shear strength S_U determined from PBPMT data	0.68	2.1
	Undrained shear strength S_U determined from CPT data	0.68	2.1
	Undrained shear strength S_U determined from in-situ vane tests	0.68	2.1
	Undrained shear strength S_U from table of presumptive values	0.44	3.2
	Undrained shear strength S_U from table of presumptive values with soil type verified by construction testing	0.68	2.1
	PMT	0.68	2.1
Cohesionless (SP, SW, GP, GW, GW-GC, GC, SC, SM, SP-SM, SP-SC, SW-SM, SW-SC)	Soil friction angle ϕ determined from laboratory direct shear or axial compression tests	$0.86-0.01 \cdot \phi$	$1.4/(0.86-0.01 \cdot \phi)$
	Soil friction angle ϕ determined from SPT data	$0.66-0.01 \cdot \phi$	$1.4/(0.66-0.01 \cdot \phi)$
	Soil friction angle ϕ determined from CPT data	$0.76-0.01 \cdot \phi$	$1.4/(0.76-0.01 \cdot \phi)$
	Soil friction angle ϕ from table of presumptive values	$0.61-0.01 \cdot \phi$	$1.4/(0.61-0.01 \cdot \phi)$
	Soil friction angle ϕ from table of presumptive values, with soil type verified by construction testing	$0.82-0.01 \cdot \phi$	$1.4/(0.82-0.01 \cdot \phi)$
	Pressuremeter test (PMT)	0.56	2.5

Note. PBPMT = prebored pressuremeter test; CPT = cone penetration test; PMT = pressuremeter test; and SPT = standard penetration test.

inch, this can be achieved by (1) positioning element nodes so they are exactly an inch apart, (2) setting the element's cross-sectional area equal to exactly one square inch and (3) setting the element's *E* value in lbf/in^2 equal to the numeric value of spring stiffness K_H in lbf/in.

Governing Strength Equations

The shear force in a post at grade V_G is identified as V_{ASD} when induced by an allowable stress design (ASD) load combination, and as V_{LRFD} when induced by a load and resistance factor design (LRFD) load combination. Likewise, the bending moment in a post at grade M_G is identified as M_{ASD} and M_{LRFD} when induced by ASD and LRFD load combinations, respectively. Because the applied loads shown in Figure 2 are from an ASD load combination, the V_G and M_G values are simultaneously identified in Figure 4 as V_{ASD} and M_{ASD} values.

To ensure that ASD building loads do not induce forces in the soil that result in a foundation failure, V_{ASD} and M_{ASD} are limited as follows:

$$f_L \, V_{ASD} \leq V_U \quad (3)$$

$$f_L \, M_{ASD} \leq M_U \quad (4)$$

Likewise, to ensure that LRFD building loads do not induce forces in the soil that result in a foundation failure, V_{LRFD} and M_{LRFD} are limited as follows:

$$V_{LRFD} \leq V_U \, R_L \quad (5)$$

$$M_{LRFD} \leq M_U \, R_L \quad (6)$$

where

V_U = ultimate groundline shear capacity for the foundation

M_U = ultimate groundline moment capacity for the foundation

f_L = ASD factor of safety for lateral strength assessment from **Table 2**

R_L = LRFD resistance factor for lateral strength assessment from Table 2

It is important to note that the ASD factor of safety and the LRFD resistance factor are a function of the method used to arrive at values for ultimate lateral soil resistance, $p_{U,z}$. Simply put, the more accurate the method, the lower the factor of safety.

Lateral Strength Capacity of the Foundation

The lateral strength capacity of a foundation is reached when all soil resisting the foundation's movement reaches a plastic state of strain. For soil modeled with springs, this point is reached when *all* springs have reached their maximum ultimate strength capacity F_{ult}. In other words, a foundation has reached its lateral strength capacity when there is not a single remaining soil spring that can take additional load.

The groundline shear V_G and groundline bending moment M_G that will result in a plastic state of strain in all soil springs are defined respectively as the ultimate groundline shear capacity V_U and ultimate groundline moment capacity M_U for the foundation. It is important to note that V_U and M_U are not dependent on soil spring *stiffness*; nor are they dependent on the flexural stiffness of the post/pier or any other foundation element.

M_U and V_U for a Constrained Foundation

For a foundation restrained at or not too far above the soil surface, all soil springs will load the foundation in the same direction *when all soil springs have yielded*, as shown in **Figure 6**. Note that prior to the yielding of *all* soil springs, it is possible that some springs may be applying forces in opposite directions even when the foundation is constrained at grade. For example, at lower load levels, the bottom spring for the surface-constrained (left) post in the example problem (i.e., spring 8) applies a force in a direction opposite to that of the seven springs above it (see Table 1 and Figure 4).

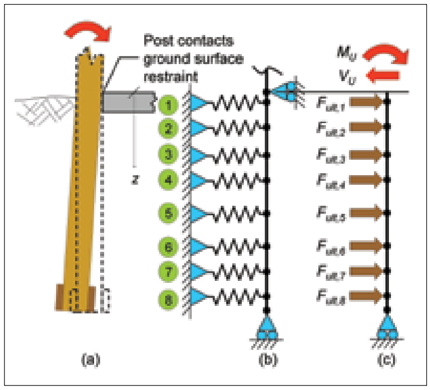

Figure 6. Schematics of a surface-constrained foundation show (a) point of rotation, (b) spring model and (c) free body diagram at failure with sectioning just below the vertical roller support.

When all soil springs apply a force to the foundation in the same direction, M_U and V_U are calculated as follows:

$$V_U = \sum_{i=1}^{n} F_{ult,i} \quad (7)$$

$$M_U = \sum_{i=1}^{n} z_i \, F_{ult,i} \quad (8)$$

where n is the number of springs used to model the soil surrounding the foundation; $F_{ult,i}$ is the ultimate strength of spring i; z_i is the distance from the groundline to spring i; M_U is the ultimate groundline moment capacity of the foundation; and V_U is the ultimate shear capacity of the foundation at groundline.

Equation 7 is obtained by summing forces in the horizontal direction on the below-grade portion of a foundation, and equation 8 is obtained by summing moment about the groundline on the below-grade portion of a foundation.

Figure 6c contains a free body diagram (FBD) of the below-grade portion of the surface-constrained post of the example problem. Application of equations 7 and 8 to this FBD yields a V_U of 12.1 kips and an M_U of 311 inch-kips. The V_U value is obtained by simply summing all eight F_{ult} values in Table 1. The M_U value is obtained by multiplying each of the eight F_{ult} values in Table 1 by its corresponding *z* value and then summing the resulting eight products.

Because the example problem involves an ASD loading, equations 3 and 4 would be used to determine the adequacy of the example surface-constrained foundation. Required for this check is the ASD safety factor for lateral strength assessment f_L. In accordance with Table 2, the safety factor for cohesive soils is only dependent on the method used to determine the undrained shear strength S_U. For cohesionless soils, the safety factor depends on the method used to determine the soil friction angle ϕ as well as the magnitude of ϕ. The highest safety factor in Table 2 for a cohesive soil is 3.2. For a cohesionless soil with a soil friction angle of 35 degrees, the highest safety factor from Table 2 is 5.4. Even with the very high safety factor of 5.4, the example surface-constrained foundation is still found to be adequate because

$$f_L\,V_{ASD} = 5.4(1{,}966\text{ lbf}) = 10{,}616\text{ lbf} \le V_U = 12{,}066\text{ lbf} \qquad (9)$$

$$f_L\,M_{ASD} = 5.4(25{,}447\text{ in-lbf}) = 137{,}414\text{ in-lbf} \le M_U = 310{,}462\text{ in-lbf} \qquad (10)$$

M_U and V_U for a Nonconstrained Foundation

The key to determining M_U and V_U for any nonconstrained post or pier foundation is identifying the depth below grade at which the direction of soil forces acting on the foundation flips (switches direction 180 degrees). Prior to all springs' reaching their plastic state of strain, there can be more than one such point. This is evident when we view the displaced shape of the right post in Figure 4, which shows a change in direction of soil forces occurring at a depth between 12 and 13 inches and again at a depth near 44 inches.

The depth or depths at which soil forces switch in direction will change as (1) soil begins to yield under increased loading, and (2) the ratio of groundline bending moment to groundline shear changes. When applied loads are increased to a level that causes all soil in contact with the foundation to yield, there will be only a single point below grade at which the soil forces acting on the foundation change direction. This point is referred to as the *point of foundation rotation at ultimate load*. The distance between the groundline and this point of rotation is represented with the variable d_{RU} and is a function of the ratio of M_U to V_U.

Given that M_U and V_U are dependent on the ratio of M_U to V_U (i.e., the value of M_U/V_U), it is logical to ask how the ratio of M_U to V_U can be ascertained. The answer to this question begins with the realization that the most optimal foundation for a particular loading is the one that ensures both governing equations (equations 3 and 4 or equations 5 and 6) are *just* met (note the emphasis on "just"). A foundation that just meets both governing equations is a foundation whose M_U/V_U value equals the ratio of groundline bending moment M_G to groundline shear V_G induced in the foundation by the applied structural loads. For a given frame, the value of M_G/V_G will not change as long as (1) all loads acting on the structure are increased at the same rate, and (2) soil does not start to yield. Note that the latter will not happen to any significant degree under service loads if the foundation is indeed adequate.

For allowable stress design, the M_G/V_G value due to applied structural loads is defined as M_{ASD}/V_{ASD}. For load and resistance factor design, the M_G/V_G value due to applied structural loads is defined as M_{LRFD}/V_{LRFD}. It follows that the optimal M_U/V_U to be used in the determination of M_U and V_U is given as

$$M_U/V_U = M_{ASD}/V_{ASD} \quad \text{for ASD} \qquad (11)$$

and

$$M_U/V_U = M_{LRFD}/V_{LRFD} \quad \text{for LRFD} \qquad (12)$$

Figure 7a shows a nonconstrained post with M_G and V_G applied at the groundline. **Figure 7b** shows V_G located a distance M_G/V_G above the groundline. From a statics perspective, the diagrams in Figures 7a and 7b are equivalent. As force V_G in Figure 7b is increased, soil springs will begin to yield. As a

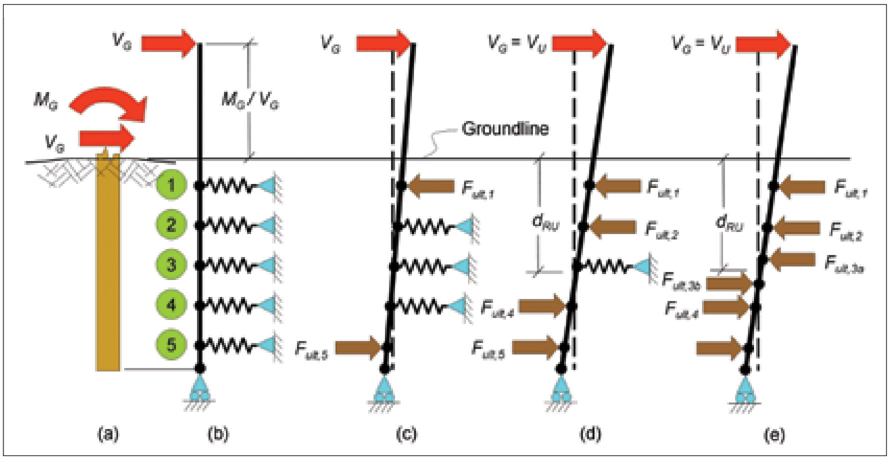

Figure 7. (a) Groundline shear V_G and groundline bending moment M_G, (b) equivalent load applied to spring model of foundation, (c) soil springs yield under increased load, (d) ultimate capacity of foundation is reached when all but one soil spring reaches its ultimate strength, (e) spring that doesn't reach its ultimate load is replaced by two opposing forces that represent force applied by soil yielding on both sides of the foundation.

spring yields, it is replaced with an equivalent force as shown in **Figure 7c**. Force V_G can be increased until all but one soil spring has reached its ultimate capacity F_{ult}. The value of V_G when this point is reached is defined as the ultimate groundline shear capacity of the foundation V_U (**Figure 7d**). The ultimate groundline bending moment capacity M_U is equal to the product of V_U and M_G/V_G.

The spring that has not reached its ultimate capacity when V_U is reached is the spring that represents the soil layer in which the *point of foundation rotation at ultimate load* is located. For discussion purposes, this spring will herein be referred to as the *pivot* spring because the foundation is essentially pivoting around a point close to the spring. It follows that the pivot spring is simultaneously representing soil forces applied to both sides of the foundation as shown in **Figure 7e**. Because these forces (1) counteract each other, and (2) individually cannot exceed F_{ult}, the pivot spring itself will always have a load less than F_{ult}. The only time this would not be the case is when the *point of foundation rotation at ultimate load* is exactly at the interface between soil layers represented by different springs.

Given that the forces in all soil springs that have yielded are known, the only unknowns in Figure 7d are V_U and the force in the pivot spring. Thus, V_U can be calculated by summing moments about the point at which the pivot spring attaches to the foundation, and the force in the pivot spring can be determined by summing moments about the point at which V_U is applied (i.e., at a distance M_G/V_G from the groundline). What is significant about these calculations is that they are dependent neither on the stiffness of the soil nor on the flexural stiffness of the foundation.

It is evident that the procedure for determining V_U (and thus M_U) is very straightforward if one knows which of the soil springs is the pivot spring. In practice, this can be determined by trial and error. If the wrong spring is selected, the absolute value of the force calculated for that spring will exceed the spring's F_{ult} value.

To demonstrate this procedure the right, nonconstrained post foundation for the frame in Figure 2 will be used. As previously noted, the ASD load combination in Figure 2 induces a groundline shear V_{ASD} of 392 lbf and a groundline bending moment M_{ASD} of 16,526 in-lbf in the right post foundation, thereby yielding a M_{ASD}/V_{ASD} ratio of 42.16 inches (**Figure 8a**).

For the trial-and-error analysis, spring 6 was first selected as the pivot spring. This resulted in a V_U value of 2,095 lbf and a pivot spring force of 2,379 lbf, as shown in **Figure 8b**. Because the force of 2,379 lbf exceeds the F_{ult} for spring 6 of 837 lbf, spring 6 is not the pivot spring. For the next analysis, spring 5 was selected as the pivot spring. This resulted in a V_U value of 1,936 lbf and a pivot spring force of -1,069 lbf, as shown in **Figure 8c**. Because the absolute value of -1,069 lbf does not exceed the F_{ult} for spring 5 of 2,770 lbf, spring 5 is indeed the pivot spring. For demonstration purposes springs 4, 7 and 8 were also selected as the pivot springs. The results of these analyses and those with springs 5 and 6 as the pivots are given in **Table 3**.

Multiplication of the V_U value of 1,936 lbf by the M_{ASD}/V_{ASD} ratio of 42.16 inches yields an M_U of 81,620 in-lbf.

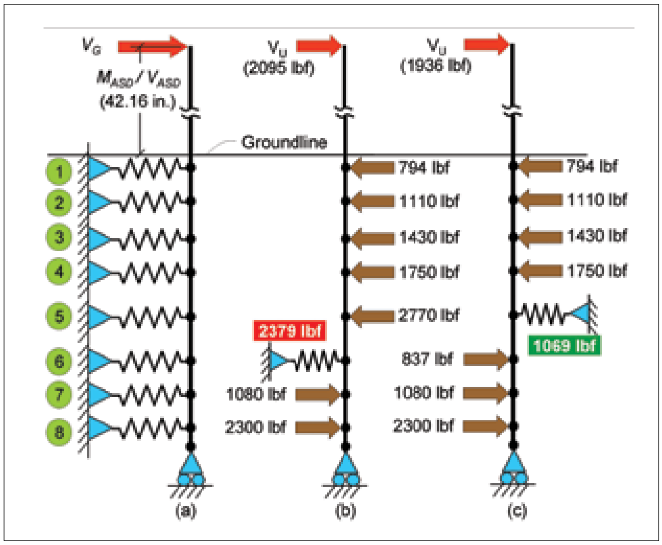

Figure 8. Shown are (a) spring model of nonconstrained post foundation, (b) free body diagram with an overloaded spring 6 as pivot spring and (c) free body diagram with spring 5 as the pivot spring.

Table 3. Spring Forces in a Nonconstrained Post Foundation[a]

Load element	Ultimate spring strength, F_{ult}, lbf	Pivot Spring 4	Pivot Spring 5	Pivot Spring 6	Pivot Spring 7	Pivot Spring 8
		Force in load element, lbf				
Spring 1	794	-794	-794	-794	-794	-794
Spring 2	1,110	-1,110	-1,110	-1,110	-1,110	-1,110
Spring 3	1,430	-1,430	-1,430	-1,430	-1,430	-1,430
Spring 4	1,750	-6,010[b]	-1,750	-1,750	-1,750	-1,750
Spring 5	2,770	2,770	-1,069	-2,770	-2,770	-2,770
Spring 6	837	837	837	2,379[b]	-837	-837
Spring 7	1,080	1,080	1,080	1,080	4,050[b]	-1,080
Spring 8	2,300	2,300	2,300	2,300	2,300	7,078[b]
V_U	NA	2,357	1,936	2,095	2,341	2,693

[a]For a M_G/V_G ratio of 42.16 inches with spring locations and ultimate strength from Table 1.
[b]Force exceeds maximum allowable value.

As before, equations 3 and 4 are used to determine the adequacy of the example foundation because of the ASD loading. By rearranging these equations, the effective factor of safety for lateral strength assessment can be ascertained as follows:

$$f_L = V_U/V_{ASD} = (1{,}936\text{ lbf})/(392\text{ lbf}) = 4.94 \qquad (13)$$

$$f_L = M_U/M_{ASD} = (81{,}620\text{ in-lbf})/(16{,}524\text{ in-lbf}) = 4.94 \qquad (14)$$

An f_L of 4.94 is a relatively high factor of safety. As previously noted, the highest factor of safety in Table 2 for a cohesive soil is 3.2, and the highest factor of safety for a cohesionless soil with a soil friction angle of 35 degrees is 5.4.

Equations 13 and 14 will always yield the same f_L value for a nonconstrained foundation when the M_G/V_G ratio used in an analysis is equated to M_{ASD}/V_{ASD} (or M_{LRFD}/V_{LRFD}). This specifically is what makes the values established for V_U and M_U the optimal combination (of the numerous viable combinations) for checking the adequacy of the foundation.

The one variation on the above procedure occurs when M_G and V_G independently rotate the foundation in opposite direc-

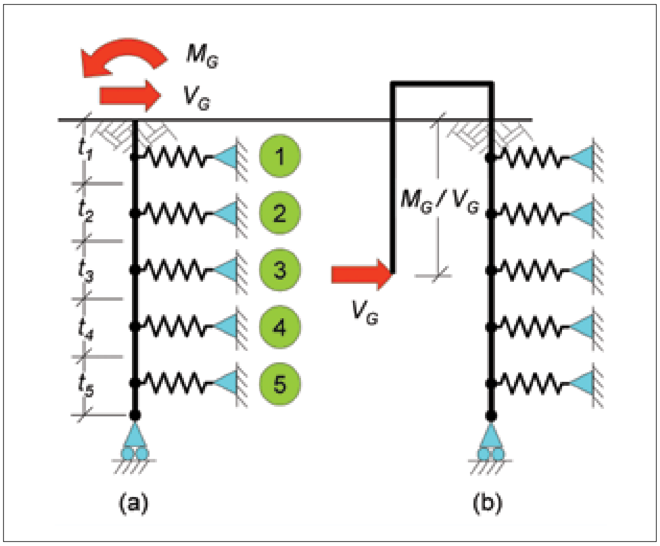

Figure 9. (a) Forces V_G and M_G independently rotate the top of the foundation in opposite directions, and (b) a statically equivalent spring model is used for determination of V_U and M_U.

tions, as shown in **Figure 9a**. This produces a negative M_G/V_G ratio. A negative value means that V_G is placed a distance M_G/V_G below the groundline as shown in **Figure 9b**. The rest of the analysis is conducted in the same manner, as if V_G was located a distance M_G/V_G above the groundline.

An Accompaniment to EP486.2

The procedures outlined in the previous sections for determining the lateral capacity (V_U and M_U) of constrained and nonconstrained foundations were developed by the author as an accompaniment to the ANSI/ASAE EP486.2 Universal Method for lateral strength assessment. In short, ANSI/ASAE EP486.2 does not actually contain equations or a procedure for determining V_U and M_U when soil springs are used to model soil behavior (note that it does contain such equations for the Simplified Method).

To make sure a foundation has adequate lateral strength, ANSI/ASAE EP486.2 requires that the force in every soil spring not exceed F_{max}, where F_{max} is equal to F_{ult}/f_L when ASD load combinations are acting on a frame, and F_{max} is equal to $F_{ult}\,R_L$ when LRFD load combinations are acting on a frame. When the force in a spring exceeds its F_{max} value, that spring must be replaced in the analysis by a force equal to F_{max}. It is important to note that whenever a soil spring is replaced by a fixed force, the structural frame analysis must be rerun.

Both the procedure outlined in this article and the method presented in ANSI/ASAE EP486.2 were developed by the author of this article. Both procedures will lead to the same conclusion regarding the adequacy of a particular foundation for a particular set of applied loads. Nevertheless, the method presented here has the advantage that it can be used to establish (and therefore compare) ultimate lateral strength capacities (V_U and M_U values) for various foundations without knowledge of what the foundations support. In the case of nonconstrained foundations, the method herein described does require an M_G/V_G ratio. In practice, values of V_U and M_U for a particular nonconstrained foundation can be established for various M_G/V_G ratios, and the resulting V_U and M_U values can be plotted against each other to obtain an envelope of ultimate lateral strength capacities for the foundation.

Process Automation

The procedures for establishing V_U and M_U values for a foundation do not require the use of any special software and thus can be completed with a basic calculator. Nevertheless, like any process that requires several hand calculations, development of a computer program to determine a foundation's lateral strength capacity would reduce the likelihood of errors and solution time, especially where a trial-and-error solution is required.

It is envisioned that such software would enable the user to specify soil properties and foundation dimensions by depth. In the case of soil properties, a dropdown menu could be provided. When groundline shear and groundline bending moment values due to applied structural loads (obtained from a separate plane-frame analysis) have been input, the program would output V_U and M_U values along with suggested and calculated factors of safety (or resistance factors in the case of LRFD). Actual selection, placement anduse of soil springs would be internal to the program.

Summary

The latest version of ANSI/ASAE EP486 incorporates the ability to use soil springs to model the behavior of shallow post/pier foundations for conditions not previously possible. This includes situations where soil properties vary with depth and the thickness of the foundation is not constant.

Covered in the Part 1 of this article were methods and corresponding equations for calculating the stiffness and strength of soil springs, along with recommendations for soil spring location.

Presented in this article were governing equations and associated safety and resistance factors for design, as well as procedures developed by the author for determining the lateral strength capacity (V_U and M_U values) of constrained and nonconstrained foundations. When the groundline shear and groundline bending moment due to applied structural loads have been determined, only a basic calculator is needed to determine the foundation's ultimate groundline shear capacity V_U and ultimate groundline bending moment capacity M_U. That said, it is recommended that a computer program be developed to automate the process.

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