Shallow Foundations for Bridges

This module presents the design methods, examples (Appendices 1 and 2), and communication steps between Structure Design (SD) and Geotechnical Services (GS) for the load and resistance factor design (LRFD) of shallow footing foundations for bridges. It may aid in the design of shallow foundations for retaining walls, non-standard walls, and other structures, however many design aspects for those other structures are not adequately addressed.

Upon receipt of a foundation design request from SD, the Geoprofessional must review the request and verify that the information is sufficient to allow the design process to begin.

Design of a spread footing is an iterative process between the Structure Designer and the Geoprofessional. Some of the communication and data exchanges are specific to Caltrans and may not be applicable to consultant work. The process presented in this module begins after adequate subsurface site data has been obtained and a shallow foundation has been type selected.

The reference standards for shallow foundation investigations, design, and reporting are:

- Caltrans Seismic Design Criteria (SDC)
- AASHTO LRFD Bridge Design Specifications with CA Amendments (AASHTO)
- Bridge Memos to Designers (MTD) 4-1, *Spread Footings*
- Caltrans Geotechnical Manual
  - *Foundation Reports for Bridges*
  - *Geotechnical Investigations*

Geotechnical Services provides the Structure Designer with a foundation report addressing:

- Permissible Net Contact Stress (q_{pn}): The vertical footing stress, that produces a permissible settlement under the Service Limit State (resistance factor, φ=1).
- Gross Nominal Bearing Resistance (q_n): The soil's ability to resist a uniform bearing stress (or a maximum bearing stress for rock) that will cause a bearing capacity failure.
- Factored Gross Nominal Bearing Resistance (q_R): This is determined by multiplying the Gross Nominal Bearing Resistance by a resistance factor, $q_R = \varphi_b \cdot q_n$. The q_R uses a resistance factor, φ, which varies for the Strength and/or Construction Limit State, or uses resistance factor, φ=1, for the Extreme Event Limit State.
- The recommended internal friction angle (drained), or the undrained shear strength at the bottom of footing elevation for cohesionless or cohesive soil respectively. SD inputs these values into the CT Abut/WinFoot computer programs for sliding analysis.

- The bearing stress distribution between the footing and the soil/rock. In soil, the bearing stress is based on a uniform stress distribution applied to the effective footing area. In rock, the bearing stress is based on a triangular or trapezoidal stress distribution, as appropriate, on the footing area.
- Global stability analysis for Service-I Limit State and Extreme Event Limit State for a footing on or near sloping ground.
- The stiffness matrix for dynamic response analyses (per GEC Circular No. 3), if requested.
- That the footing size selected by the Structure Designer is adequate.

The Structure Designer will:

- Provide Foundation Footing Design and Load Information to GS (per MTD 4-1)
- Check Eccentricity
- Check Overturning Stability
- Check Sliding Stability

For further information on the Structure Designer's role, refer to Bridge Design Practice (BDP), Chapter 15.

Investigations

The geotechnical investigation for a shallow foundation should identify the properties and behaviors of soil and/or rock, the groundwater conditions, and other subsurface conditions that might affect the foundation design and performance.

The Geoprofessional must first review existing information related to site geology, strength of soil and rock, groundwater, and geologic hazards. Refer to *Geotechnical Investigations* for direction on performing a literature (data) search.

If the literature search does not provide all required information, the Geoprofessional must develop an exploration plan based on site constraints, geologic variability, and available resources. Locate borings as close as possible to the foundations.

The exploration plan should include:

- An appropriate number of exploratory borings and/or cone penetration tests (CPT) to develop the design soil profile (AASHTO Table 10.4.2-1).
- An appropriate depth for the borings or CPT. The depth of the explorations should generally extend below the foundation to:
    - 4 times the estimated footing width below the proposed bottom of footing
    - a depth where material strength and strain characteristics are acceptable (e.g. very dense or hard soil).
    - to the full depth of soft, loose, and/or weak soils upon which stability, bearing resistance, and settlement is dependent.

- Standard penetration tests (SPT) with sampling intervals no greater than 5 feet. Closer intervals of SPT testing should be considered within a depth of 2 times the footing width below the bottom of footing.
- Groundwater measurements.
- Soil and water samples for corrosion testing in accordance with *Caltrans Corrosion Guidelines*.
- Adequate samples for laboratory testing such as particle analysis tests, Atterberg limit tests, consolidation tests, direct shear tests, and/or triaxial tests, for soil below the bottom of footing within a depth of 4 times the estimated footing width.
    - For cohesionless materials, any remolded samples that will be tested in the laboratory should have characteristics similar to the field conditions.
    - For cohesive soils, consolidation testing may be necessary where settlement magnitude and rate are significant project considerations.

Design

The following design methodologies are used for calculating settlement (Service-I Limit State).

- Use a resistance factor (φ) of 1.0.
- Calculate the settlement of cohesionless soils using the Hough method and SPT data (AASHTO 10.6.2.4.2).
- Calculate the settlement of cohesive soils using AASHTO (10.6.2.4.3).
- Calculate settlement on rock using AASHTO (10.6.2.4.4).
- For foundations on sloping ground, make appropriate reductions in overburden stresses (see design example in the appendix).

In cases where unacceptable settlements are predicted, or low bearing resistance results from the presence of near-surface loose, soft, or non-uniform materials, consider removing the inadequate material and replacing it with structure backfill or lean concrete.

Differential settlement between supports must be evaluated and discussed with the SD. Typically, multi-span structures, and single span structures with end-diaphragm abutments can tolerate no more than ½ inch of differential settlement between adjacent supports. Typically, single span structures with seat abutments can tolerate no more than 2 inches of differential settlement. For multi-column bent supports differential settlement should be evaluated and discussed with the SD when subsurface conditions show variable soil/rock compressibility across a bent support. Differential settlement should be evaluated for soil foundations by calculating the settlement at each support location using the applied net uniform bearing stress.

The following design methodologies are used for calculating bearing resistance (Strength and Extreme Event Limit States) in accordance with AASHTO.

- For bearing resistance calculations use a resistance factor of 0.45 to 0.55 for the strength limit state, and 1.0 for the extreme event limit state.
- Calculate the bearing resistance of soil using the bearing capacity equation (AASHTO 10.6.3.1.2). Use the appropriate bearing capacity equation when there are sloping ground conditions (AASHTO 10.6.3.1.2c). These methods may also be used for design in weak rock that behaves like a very dense or hard soil.
- Calculate bearing resistance on rock using AASHTO 10.6.3.2.

The soil properties used in design should come from: (1) SPT correlations (see *Soil Correlations Module*), and/or (2) results from laboratory tests.

Shallow foundations founded on rock must be designed using procedures developed specifically for the characteristics of rock masses. Foundation engineering on rock differs from foundation engineering on soil in several respects:

- Applied stress distribution pattern is trapezoidal or triangular.
- Nominal bearing resistance and settlement are calculated using the physical footing width, B.
- Rock foundation conditions must be evaluated for both intact rock properties (unconfined compressive strength) and rock mass properties (discontinuity spacing(s), orientation(s), aperture(s), and condition(s)).
- Engineering calculation procedures for rock foundations are tailored to the rock foundation conditions.
- Acceptance of the foundation configuration is performed by comparing the gross maximum bearing stress to the gross nominal bearing resistance.

The design must also account for geologic hazards such as:

- Earthquakes: Guidance for use of shallow foundations at abutments related to structure type and Peak Ground Acceleration (PGA) is in MTD 5-1, Table 1.
- Liquefaction (see *Liquefaction Evaluation* module)
- Lateral spreading (see *Lateral Spreading* module)
- Scour: Shallow foundations are permissible in a watercourse if the top of footing is below the total scour elevation.

Bridge widenings pose a challenge because it is likely that the existing structure was designed using different methodologies. Caltrans designs the foundation for the widening as if it were a separate structure, regardless of the reality that the superstructure and substructure will be connected to the existing structure. Ask SD for the allowable differential settlement between the existing and new foundations.

Design Information and Communication

Shallow foundation design requires an iterative process that begins when Structure Design sends a request to Geotechnical Services including:

- General Plan
- Foundation Plan
- Foundation Data Table (MTD 4-1, Attachment 1, Table 1)
- Scour Data Table (MTD 4-1, Attachment 1, Table 2)

Foundation Data
(MTD 4-1, Attachment 1, Table 1)

Support No.	Finished Grade Elevation (feet)	Bottom of Footing Elevation (feet)	Estimated Footing Dimensions (feet)		Permissible Settlement Under Service-I Load (inches)	Approximate Ratio of Permanent/Total Service-I Load*
			B	L		
Abut 1	214.0	206.0	16	72	1	0.87
Bent 2	199.0	192.0	18	18	1	0.85
Abut 3	214.0	206.0	16	72	1	0.87

*For calculating consolidation settlement of spread footing founded on cohesive soils.

Design Process

Step 1: Initial Evaluation of Shallow Foundation

- Verify that the proposed bottom of footing elevation is appropriate. If, for example, the requested bottom of footing elevation is in a layer of unsuitable material (e.g., loose sand), inform the Structure Designer and provide a revised bottom of footing elevation or discuss options for improving the bearing layer by removing unsuitable soils and replacing with engineered fill or lean concrete.
- Verify that the shallow foundation is acceptable considering known geological hazards (e.g., faulting, scour).

Step 2: Calculate the Permissible Net Contact Stress (Service Limit State)

Calculate the Permissible Net Contact Stress (q_{pn}) that produces the permissible settlement (usually 1" or 2") for the footing dimensions provided by the Structure Designer in the Foundation Data table, and footing dimensions with varying length to width (L/B) ratios as shown in MTD 4-1, Attachment 2. This is an indirect calculation that produces a permissible settlement for an initial guess at the net contact stress. Further guesses are used until the chosen net contact stress produces the required permissible settlement.

The footing dimensions provided in these tables are labeled as “Effective” with an assumed eccentricity of zero (i.e., L=L’ and B=B’) because the support loads are unknown at this stage of the design process. The Structure Designer will use the data as input for the software that calculates the structural loads and the effective footing sizes. The Permissible Net Contact Stress results are presented differently for abutment and bent supports:

- For abutment design determine the Permissible Net Contact Stress (q_{pn}) for one effective footing length (fixed by the bridge dimensions) and at least five effective footing widths. Determine the range of effective footing widths and physical constraints with the Structure Designer. Present the agreed upon footing size range results in the End Supports (Abutments) table (after MTD 4-1 Attachment 2, Table 1).
- For bent design determine the permissible net contact stress (q_{pn}) for at least five effective footing widths and five L’/B’ ratios. Determine the desired range of L’/B’ ratios and physical constraints (e.g. maximum widths) with the Structure Designer. Present the effective footing widths and L’/B’ ratio range results in the Intermediate Supports (Bents and Piers) table (after MTD 4-1 Attachment 2, Table 2).

Step 3: Calculate the Gross Nominal Bearing Resistance

Calculate the Gross Nominal Bearing Resistance (q_n) for the effective footing sizes in the End Supports (Abutments) table and the Intermediate Supports (Bents and Piers) table. As discussed in step 2, the effective footing widths have an assumed eccentricity of zero at this stage of the design process (i.e., L=L’ and B=B’). Enter the results in the appropriate columns of each table.

Step 4: Calculate the Factored Gross Nominal Bearing Resistance (Strength Limit State)

Calculate the Factored Gross Nominal Bearing Resistance (q_R) for the effective footing sizes in the End Supports (Abutments) table and the Intermediate Supports (Bents and Piers) table. Enter the results in the appropriate columns of each table.

Step 5: Send Preliminary Design Data to Structure Design

Email the completed tables to the Structure Designer:

- End Supports (Abutments) table (MTD 4-1 Attachment 2, Table 1)
- Intermediate Supports (Bents and Piers) table (MTD 4-1 Attachment 2, Table 2)

See Appendix 1 and 2 for examples of these tables.

Step 6: Request Design Data from Structure Design

Request that SD provide the following tables with the appropriate load information:

- Foundation Data (MTD 4-1 Attachment 4, Table 1)
- Scour Data (MTD 4-1 Attachment 4, Table 2), if applicable

- LRFD Service-I Limit State Loads for Controlling Load Combination (MTD 4-1 Attachment 4, Table 3)
- LRFD Strength/Construction and Extreme Event Loads for Controlling Load Combinations (MTD 4-1 Attachment 4, Table 4)

The Structure Designer will use the information from the End Supports (Abutments) and the Intermediate Supports (Bents and Piers) tables to design the footings using the CTAbut and WinFoot programs, and will return the design details (dimensions, elevations, loads, and moments). If the range of footing sizes and resistances supplied by GS in Step 5 are not acceptable, the Structure Designer will request the entire procedure begin again with a new preliminary footing size.

Step 7: Evaluate Inclination Factors (if omitted, then go to Step 8)

After receiving the tables from Step 6, calculate the settlement and bearing capacity to verify the footing design and calculate inclination factors to determine if the gross nominal bearing resistance is affected. In general, inclination factors should be omitted when calculating the gross nominal bearing resistance (AASHTO 10.6.3.1.2a-1), however there are some cases when it may be necessary to consider these factors.

Unusual column geometry or loading configurations may require consideration be given to evaluating load inclination factors. A column that is not aligned normal to the footing bearing surface would be one example where inclination factors would be given consideration.

In the rare case where inclination factors are to be evaluated, use the lower value of the bearing resistance using either inclination factors or shape factors. Applying both shape and inclination factors will result in overly conservative design. If the inclination factor produces a lower bearing resistance than the shape factor, the nominal bearing resistances determined in Steps 3 and 4 must be recalculated using the inclination factors in place of the shape factors and provided to the Structure Designer.

Step 8: Verify the Shallow Foundation Design

Use the updated information (MTD 4-1, Attachment 4) to calculate the eccentricities and determine the effective footing dimensions. Check the footing design for all limit states:

- For the Service Limit State, verify that the Permissible Net Contact Stress is greater than or equal to the Net Uniform Bearing Stress (soil) or Net Maximum Bearing Stress (rock).
- For soil foundations, verify if the differential settlement between adjacent supports, using the Net Uniform Bearing Stresses, is acceptable.
- For the Strength and Extreme Event Limit States, verify that the calculated Factored Gross Nominal Bearing Resistance is greater than or equal to the Gross Uniform Bearing Stress (soil) and Gross Maximum Bearing Stress (rock).

If any of the above criteria are not met, inform the Structure Designer.

Step 9: Global Stability Check

The calculated resistance factors for global stability must be less than or equal to the AASHTO LRFD criteria for both the Service-I (static) Limit State ($\varphi = 0.65$), as well as the Extreme Event (pseudo-static) Limit State ($\varphi = 0.9$). If the stability analysis resistance factors are greater than the resistance factors listed in AASHTO 10.5.2.3 and 11.6.2.3, inform the Structure Designer and discuss design alternatives or site improvements to address the issue.

Step 10: Reporting

Report foundation recommendations as required by the *Foundation Reports for Bridges* module.

Appendix 1: Shallow Foundation Design Example (Bridge Abutment)

A spread footing is to be designed for an abutment on a soil slope. The Geoprofessional has received the foundation report request memorandum, the Foundation Data Table, the General Plan, the Foundation Plan, and has completed the field investigation.

Foundation Data Table (MTD 4-1, Attachment 1)

Support No.	Finished Grade Elevation (feet)	Bottom of Footing Elevation (feet)	Estimated Footing Dimensions (ft)		Permissible Settlement under Service-I Load (inches)
			B	L	
Abut 1	5	0	10	64	1.0
Abut 2	5	0	10	64	1.0

Information from Site Investigation:

- Soil Identification: Silty Sand (SM) with Gravel; well-graded sand; some silt; little fine gravel.
- Apparent Density: Dense and very dense based on Standard Penetration Test (SPT).
- Groundwater Elevation = -100 ft.

Step 1: Initial Evaluation of Shallow Foundation

The site investigation shows the footing location is acceptable. There are no known geologic hazards that would preclude the use of shallow foundations.

Step 2: Calculate the Permissible Net Contact Stress (Service Limit State)

Calculate the Permissible Net Contact Stress (q_{pn}) that produces the permissible settlement of 1 inch for the footing dimensions provided by the Structure Designer in the Foundation Data table, as well as for a range of other footing widths.

The Hough formula (shown below) is used to calculate settlement as the cohesionless soil is loaded from the proposed footing. The apparent density of the soil varies with depth, therefore multiple layers are used to calculate the total settlement.

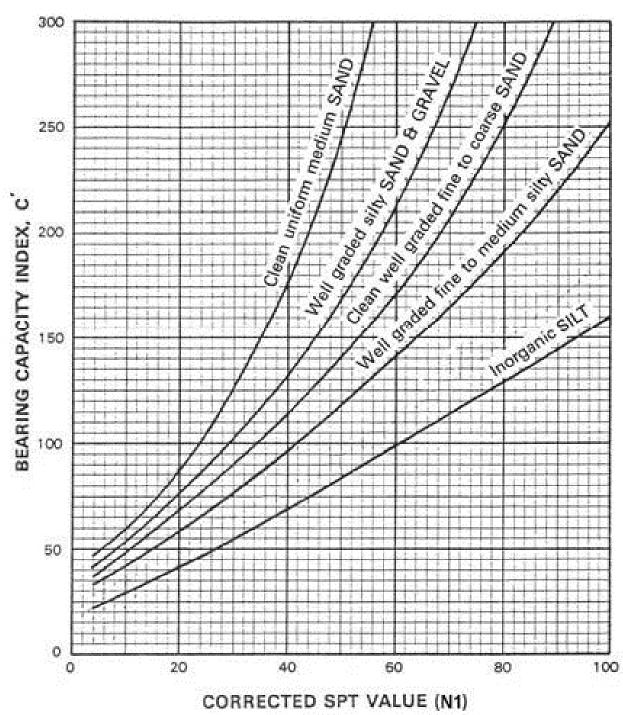
$$S_e = \sum_{i=1}^{n} \Delta H_i$$

$$\Delta H_i = \left(\frac{H_c}{C'}\right) \left[\log\left(\frac{\sigma'_o + \Delta\sigma'_v}{\sigma'_o}\right)\right]$$

where:

- S_e = total elastic settlement
- n = number of soil layers within zone of stress influence of the footing
- ΔH_i = elastic settlement of layer *i*
- H_c = initial thickness of layer *i* (maximum 10 ft per AASHTO C10.6.2.4.2)
- C' = bearing capacity index (from AASHTO Figure 10.6.2.4.2-1)
- σ'_o = initial vertical effective stress at midpoint of layer *i*
- $\Delta\sigma'_v$ = increase in effective vertical stress at midpoint of layer *i*

Bearing Capacity Index
(per AASHTO, Figure 10.6.2.4.2-1)



- *N1 shall be taken as $N1_{60}$ (SPT blow count corrected for both overburden and hammer efficiency).*

To calculate the permissible settlement of 1 inch, first pick a depth of influence based on the footing dimensions and soil types. Here, the depth of influence is assumed to be three times the footing width (3B = 30 feet). Situations in which the depth of influence should be greater are when the incremental rate of settlement has not tapered off or reduced in the soil layers near a depth of 3B (e.g., if the lowest layer contributed less than 5% of the total settlement, contributions for deeper layers can be considered insignificant assuming demonstrably more compressible soils do not exist below).

The increase in effective vertical stress ($\Delta\sigma'_v$) is determined by projecting an equivalent footing area at the midpoint of each layer assuming a 1:2 (H:V) pressure distribution that extends down from the bottom of the footing (Figure 1). At this stage, the footing dimension is assumed to have an eccentricity of zero (B=B' and L=L'). Eccentricity effects are considered in Step 8.

The pressure distribution used to determine the total settlement is shown below. To calculate the initial effective overburden pressure, use the finished grade above the toe of footing as the original ground elevation (elev. +5 ft in the example shown Figure 1). The applied load is the load at which the cumulative settlement = 1.0 inch. In this example, a 4032-kip load produced 1 inch of settlement for an effective footing width of 10 feet (Table 1).

Figure 1: Elevation View Showing Pressure Distribution Used for Estimating Settlement

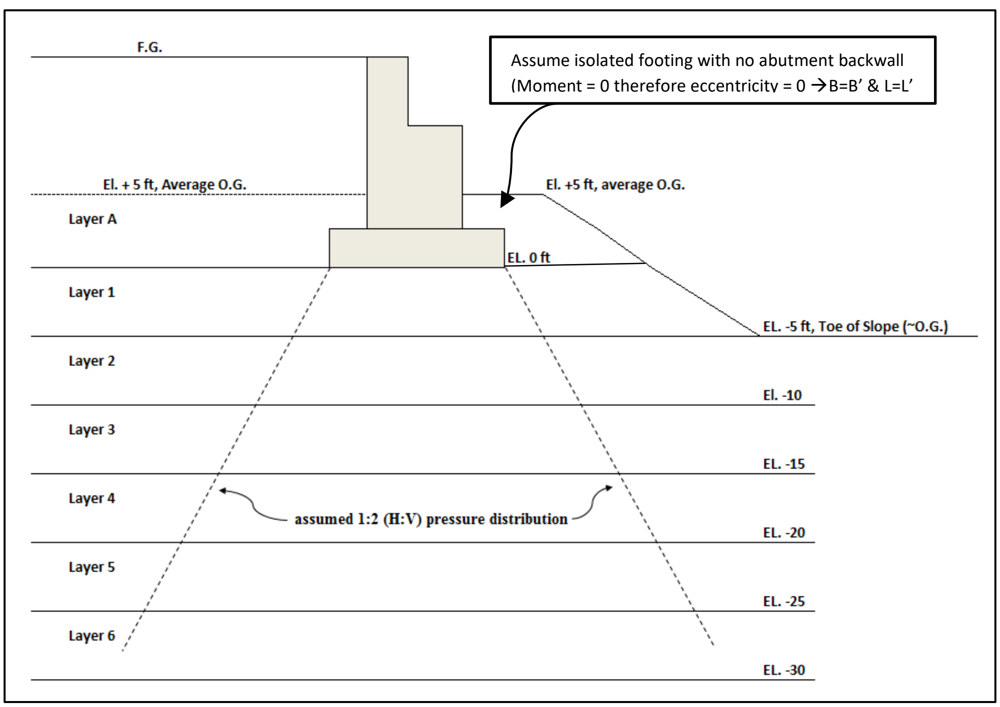


Table 1: Calculating Settlement using the Hough Method

(Footing Size, B x L = 10 feet x 64 feet)													
(Applied Load = 4032 kips)													
Layer No.	Bottom of Layer Elevation (ft)	Layer Thickness H_i (ft)	Depth Below Footing (ft)	Effective Unit Wt. γ' (pcf)	Effective Overburden Pressure at Mid-Layer σ'_o (ksf)	Depth to mid-layer (ft)	SPT Corrected Blow Count $N1_{60}$	Estimated Bearing Capacity Index C'	Projected Equivalent Footing Area at Mid-Layer (ft^2)	Increase in Effective Vertical Stress at Mid-Layer $\Delta\sigma'_v$ (ksf)	$\frac{\sigma'_o+\Delta\sigma'_v}{\sigma'_o}$	Layer Sett. (in)	Cumulative Settlement S_e (in)
A	0.0	5.0	0.0	125	-	-	-	-	-	-	-	-	-
1	-5.0	5.0	5.0	120	0.93	2.5	32	110	831	4.9	6.24	.43	.43
2	-10.0	5.0	10.0	120	1.53	7.5	34	115	1251	3.2	3.11	.27	.70
3	-15.0	5.0	15.0	120	2.13	12.5	38	125	1721	2.3	2.10	.15	.85
4	-20.0	5.0	20.0	120	2.73	17.5	42	140	2241	1.8	1.66	.09	.94
5	-25.0	5.0	25.0	125	3.34	22.5	68	250	2811	1.4	1.43	.04	.98
6	-30.0	5.0	30.0	125	3.96	27.5	68	250	3431	1.2	1.30	.03	1.00

The Permissible Net Contact Stress (q_{pn}) is:

q_{pn} = Load (to induce 1” settlement) / Effective Footing Area = 4032 k / (10 ft * 64 ft) = **<u>6.3 ksf</u>**

Step 3: Calculate Gross Nominal Bearing Resistance (qn)

Since the abutment footing is on a slope the “N_γ” term must be replaced with $N_{\gamma q}$, and N_q = 0, per AASHTO, Sec. 10.6.3.1.2c.

$$\text{For cohesionless soils: } q_n = 0.5 * \gamma * B' * N_{\gamma q} * s_\gamma * C_{w\gamma}$$

where:

γ = total unit weight of soil

B’= effective footing width

$N_{\gamma q}$ = modified bearing capacity factor for footing on/near a slope

s_γ = footing shape correction factor

$C_{w\gamma}$ = correction factor to account for the location of the groundwater table

Calculations:

$N_{\gamma q}$ = 32.5 (AASHTO figure 10.6.3.1.2c-2)

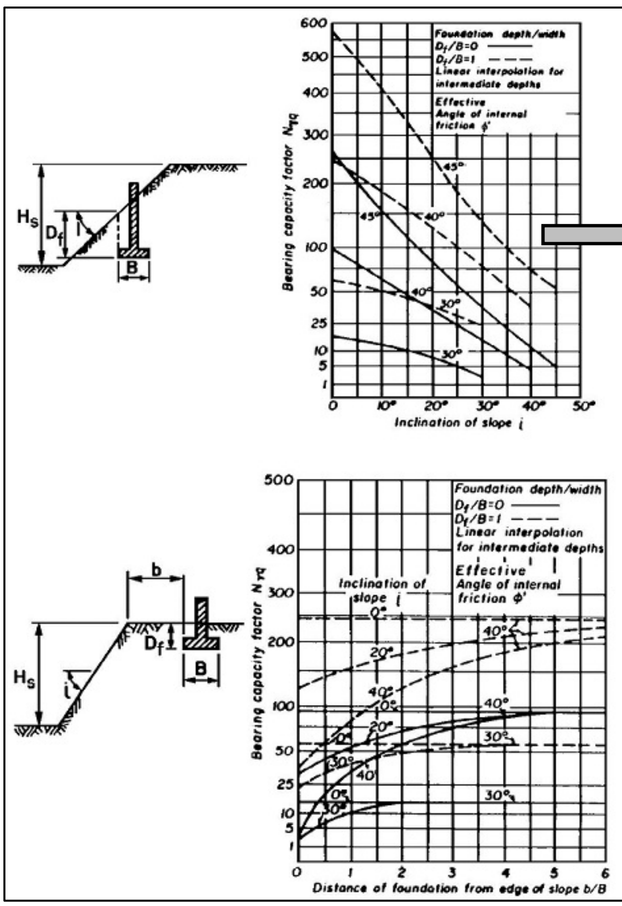
$s_\gamma = 1 - 0.4(B' / L') = 1 – 0.4(10/64) = 0.94$ (AASHTO table 10.6.3.1.2a-3)

$C_{w\gamma}$ =1.0 (depth to groundwater is 100 ft) (AASHTO table 10.6.3.1.2a-2)

q_n = 0.5 * 120 pcf * 10 ft * 32.5 * 0.94 * 1.0 = <u>18.3 ksf</u>

Modified Bearing Capacity Factor $N_{\gamma q}$ for Cohesionless Soil

AASHTO Figure 10.6.3.1.2c-2



D_f /B' = 5 ft /10 ft = 0.5 (D_f is the depth of footing from finish grade)
Use the top figure to interpolate for D_f /B' = 0.5 and ϕ_f =34°

D_f/B'	Inclination of Slope = 26.5°		
	$N_{\gamma q}$ -ϕ_{f-30}	$N_{\gamma q}$-ϕ_{f-34}	$N_{\gamma q}$ -ϕ_{f-40}
0	5.0	11.6	21.6
0.50		**32.5**	
1	27.9	53.4	92.0

Use the top figure to find $N_{\gamma q}$ -ϕ_{f-30} & $N_{\gamma q}$ -ϕ_{f-40} for D_f /B'=0 (5.0, 21.6)
Use the top figure to find $N_{\gamma q}$ -ϕ_{f-30} & $N_{\gamma q}$ -ϕ_{f-40} for D_f /B'=1 (27.9, 92.0)

$N_{\gamma q}$ Interpolation:

Step 1:
Interpolate for $N_{\gamma q}$ -ϕ_{f-34} for D_f /B'=0
Interpolate between 5.0 and 21.6 to get $N_{\gamma q}$ -ϕ_{f-34}=11.6

Step 2:
Interpolate for $N_{\gamma q}$ -ϕ_{f-34} for D_f /B'=1
Interpolate between 27.9 and 92.0 to get $N_{\gamma q}$ -ϕ_{f-34}=53.4

Step 3:
Interpolate for $N_{\gamma q}$ -ϕ_{f-34} for D_f /B'=0.5
Interpolate between 11.6 and 53.4 to get

$N_{\gamma q}$ -ϕ_{f-34} = 32.5 for D_f /B'=0.5

Shape Factors (after AASHTO LRFD 10.6.3.1.2a)

Factor	Friction Angle	Cohesion Term (s_c)	Unit Weight Term (s_γ)	Surcharge Term (s_q)
Shape Factors s_c , s_γ , s_q	$\phi_f = 0$	$1 + (\frac{B'}{5L'})$	1.00	1.00
	$\phi_f > 0$	$1 + (\frac{B'}{L'})(\frac{N_q}{N_c})$	$1 - 0.4\ (\frac{B'}{L'})$	$1 + (\frac{B'}{L'} \tan\phi_f)$

Correction Factor for Location of Water

Depth of Ground Water Table, D_w	$C_{w\gamma}$	C_{wq}
0	0.5	0.5
D_f	0.5	1.0
> (1.5B' + D_f)	1.0	1.0

Step 4: Calculate Factored Gross Nominal Bearing Resistance (q_R)

Determine the Factored Gross Nominal Bearing Resistance (q_R) for Strength and Extreme Event Limit States by multiplying the Gross Nominal Bearing Resistance (q_n) by the appropriate resistance factors for the Strength and Extreme Event Limit States (AASHTO CA Amendments Table 10.5.5.2.2-1). Here the resistance factor (φ_b) is 0.45 for the Strength Limit State because strength values were based on SPT values and 1.0 for the Extreme Event Limit State.

$$q_R = \varphi_b * q_n$$

$$q_R = 0.45 * 18.3 \text{ ksf} = 8.2 \text{ ksf (Strength Limit State)}$$

$$q_R = 1.0 * 18.3 \text{ ksf} = 18.3 \text{ ksf (Extreme Event Limit State)}$$

Repeat Step 2 through Step 4 for several footing dimensions. Present results in the *End Supports (Abutments)* table (see below).

At this stage, the actual footing dimension is assumed to have an eccentricity of zero, (B = B' and L = L'). Eccentricity effects are considered in Step 8.

Step 5: Send Preliminary Data to Structure Design

Email the *End Supports (Abutments)* table to the Structure Designer.

End Supports (Abutments)

Support Number: Abut 1
Foundation Material (Soil or Rock): Soil
Friction Angle or Undrained Shear Strength: 34°
Permissible Settlement (in): 1
Resistance Factor (Strength) – φ_b: 0.45
Resistance Factor (Seismic) – φ_b: 1.0

	Total Number of B' =	5		
No	Effective Footing Width	Gross Nominal Bearing Resistance	Permissible Net Contact Stress (Settlement)	Factored Gross Nominal Bearing Resistance (Strength)
	B' (feet)	q_n (ksf)	q_{pn} (ksf)	q_R (ksf)
1	8	17.2	6.9	7.8
2	10	18.3	6.3	8.2
3	12	19.4	5.8	8.7
4	14	20.4	5.5	9.2
5	16	21.4	5.2	9.6

- Select “Soil” or “Rock” depending on design methodology used.
- Based on L’ =____ ft.

Step 6: Request Design Data from Structure Design

Request that the Structure Designer return the following tables (MTD 4-1 Attachment 4) with the controlling load combination information:

- *Foundation Data*
- *LRFD Service-I Limit State Loads for Controlling Load Combination*
- *LRFD Strength, Construction, and Extreme Event Loads for Controlling Load Combinations*

Step 7: Evaluate Inclination Factors

Nothing to do here. Since axial and shear forces are checked against the available resistance using effective footing dimensions in the respective directions (i.e. bearing capacity and sliding), inclination factors were omitted.

Step 8: Verify the Shallow Foundation Design

Receive and review the design tables (requested in Step 6), the footing design information, and controlling load confirmation. The physical footing width is 16 feet.

Spread Footing Design Information (from Structure Designer)

Support No.	Finished Grade Elevation (feet)	Bottom of Footing Elevation (feet)	Footing Dimensions (feet)		Permissible Settlement under Service Load (inches)
			B	L	
Abutment 1	+5.0	0	16.0	64	1
Abutment 2	+5.0	0	16.0	64	1

LRFD Service-1 Limit State Loads for Controlling Load Combination (from Structure Designer)

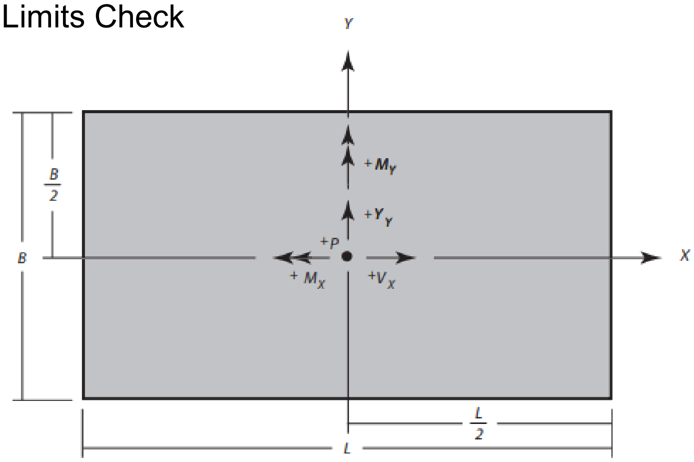
Support Location	Total Load					Permanent Load				
	P_{Total} Net (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)	P_{Perm} Net (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)
Abutment 1	2668	6058	N/A	N/A	888	2338	3558	N/A	N/A	686
Abutment 2	2668	6058	N/A	N/A	888	2338	3558	N/A	N/A	686

Note: P_{Total} Net is provided in the table above, however, for calculating eccentricity P_{Total} Gross is required. The Geoprofessional will need to ask for this information in addition to the MTD tables.

LRFD Strength and Extreme Event Loads for Controlling Load Combination Provided by Structure Designer

Support Location	Strength Limit State (Controlling Group)					Extreme Event Limit State (Controlling Group)				
	P_{Total} Gross (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)	P_{Total} Gross (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)
Abutment 1	3058	11158	N/A	N/A	1068	N/A	N/A	N/A	N/A	N/A
Abutment 2	3058	11158	N/A	N/A	1068	N/A	N/A	N/A	N/A	N/A

1. Eccentricity Limits Check



For Service Limit State:

- Maximum eccentricity is not to exceed B/6 for footings on soil where B is the actual footing width.
- Eccentricity, $e_y = M_x / P_{Total,\ Gross}$

  Where:

  e_y= eccentricity

  M_x = factored bending moment

  P_{Total}, Gross = total gross factored axial force

  (In the future, SD will provide $P_{Total,\ Gross}$ for the Service-I Limit State but until MTD 4-1 is updated, the Geoprofessional will need to request $P_{Total,\ Gross}$ from SD).

Calculations:

$e_y = M_x / P_{Total, Gross}$

e_y = 6058 kips-ft / 2888 kips = 2.1 ft

B / 6 = 16 ft / 6 = 2.7 ft (maximum allowed eccentricity for soil)

e_y < B/6 (2.1 ft < 2.7 ft) for footing on soil, O.K.

No need to check eccentricity limits under Extreme Event Limit State load combinations because loads were not provided by Structure Design. If loads were provided then we would repeat the above calculations to check eccentricity for the Extreme Event Limit State.

2. Calculate the Permissible Net Contact Stress after using loads and moments to determine the eccentricity and the effective footing dimensions. Verify that the calculated Permissible Net Contact Stress is greater than or equal to the Net Uniform Bearing Stress ($q_{pn} \geq q_{n,u}$).

   Calculate B’ for Service I Limit State:

   $B' = B - 2 * e_y$

   B’ = 16 ft – 2 * 2.1 ft = 11.8 ft

   $q_{nu} = P_{Total, Net} / (B' * L')$ = 2668 kips / (11.8 ft * 64 ft) = 3.5 ksf (Demand)

   q_{pn} = 5.9 ksf (repeat Step 2 to calculate q_{pn} with B’ = 11.8 ft) (Stress required to induce 1” settlement)

   $q_{pn} > q_{n,u}$ (5.9 ksf > 3.5 ksf) O.K.

3. Calculate the Factored Gross Nominal Bearing Resistance for Strength Limit State (and Extreme Event Limit State, if applicable) using loads, moments, and corresponding effective footing dimensions. Verify that the calculated Factored Gross Nominal Bearing Resistance is greater than or equal to the Gross Uniform Bearing Stress ($q_R \geq q_{g,u}$).

   Calculate B’ for Strength Limit State: $B' = B - 2 * e_y$

   Where:

   $e_y = M_x / P_{Total\ Gross}$

$B' = B - 2 * M_x / P_{Total\ Gross}$

$B' = 16\ ft - 2 * 11158\ kips\text{-}ft / 3058\ kips = 8.7\ ft$

Calculate $q_{g,u}$ and q_R:

$N_{\gamma q} = 35.6$ (repeat Step 3 to calculate $N_{\gamma q}$ with $D_f / B' = 5.0/8.7\ ft = 0.57$)

$q_{g,u} = P_{Total\ Gross} / (B' * L') = 3058\ kips / (8.7\ ft * 64\ ft) = 5.5\ ksf$ (Demand)

$q_R = \varphi_b * 0.5 * \gamma' * B' * N_{\gamma q} * s_\gamma * C_{w\gamma}$

$= 0.45 * 0.5 * .120\ kcf * 8.7\ ft * 35.6 * (1 - 0.4 * (8.7\ ft / 64\ ft)) * 1 = 7.9\ ksf$ (Resistance)

$q_R > q_{g,u}$ (7.9 ksf > 5.5 ksf) O.K.

If any of the above design criteria are not met, inform the Structure Designer.

Step 9: Global Stability Check

The global stability was determined using the Slide program. The calculated resistance factors for global stability met the current AASHTO LRFD criteria for both the Service-I (static) Limit State, φ = 0.65 (equivalent to a factor of safety ~ 1.5 for Slide), as well as the Extreme Event (pseudo-static) Limit State, φ = 0.9 (equivalent to a factor of safety ~ 1.1 for Slide).

Step 10: Design Approval and Reporting

Email the Structure Designer to communicate design approval. Prepare the Foundation Report as per *Foundation Reports for Bridges*. The required tables are presented below with values generated from this example (abutment 1 only).

Foundation Design Recommendations for Spread Footing
(after MTD 4-1, Attachment 5, Table 2)

Support Location	Footing Size (feet)		Bottom of Footing Elevation (feet)	Minimum Footing Embedment Depth (feet)	Total Permissible Support Settlement (inches)	Service Limit State	Strength or Construction Limit State (ϕb=0.45)	Extreme Event Limit State (ϕb=1.0)
	B	L				Permissible Net Contact Stress (ksf)	Factored Gross Nominal Bearing Resistance (ksf)	Factored Gross Nominal Bearing Resistance (ksf)
Abutment 1	16	64	0	5	1.0	5.9 (B' = 11.8 ft)	7.9 (B' = 8.7 ft)	N/A
Abutment 2						(B' =)	(B' =)	N/A

- Abutment 2 not completed in this example

Spread Footing Data Table
(after MTD 4-1, Attachment 5, Table 3)

Support Location	Service Permissible Net Contact Stress (Settlement) (ksf)	Strength/Construction Factored Gross Nominal Bearing Resistance (φ_b=0.45) (ksf)	Extreme Event Factored Gross Nominal Bearing Resistance (φ_b=1.0) (ksf)
Abutment 1	5.9	7.9	N/A
Abutment 2			N/A

- Abutment 2 not completed in this example

Appendix 2: Shallow Foundation Design Example for Intermediate Bridge Support

A spread footing is designed for a single column bent supported by soil below level ground. The Geoprofessional has received the foundation report request memorandum, the Foundation Data Table, the General Plan, the Foundation Plan, and has completed the field investigation.

Foundation Data Table (MTD 4-1, Attachment 1)

Support No.	Finished Grade Elevation (feet)	Bottom of Footing Elevation (feet)	Estimated Footing Dimensions (feet)		Permissible Settlement under Service-I Load (inches)	Approximate Ratio of Permanent/Total Service I Load
			B	L		
Bent 2	48.5	40.0	22	22	1.0	

Information from Site Investigation:

- Soil Identification: Silty Sand (SM) with Gravel; well-graded sand; some silt; little fine gravel.
- Apparent Density: Dense and very dense based on Standard Penetration Test (SPT).
- Groundwater Elevation = 10 ft.

Step 1: Initial Evaluation of Shallow Foundation

The site investigation shows the footing location is acceptable. There are no known geologic hazards that would preclude the use of shallow foundations.

Step 2: Calculate the Permissible Net Contact Stress (Service Limit State)

Calculate the Permissible Net Contact Stress (q_{pn}) that produces the permissible settlement of 1 inch for the footing dimensions provided by the Structure Designer in the Foundation Data Table, as well as for a range of other footing widths and lengths.

The Hough formula (shown below) is used to calculate settlement as the cohesionless soil is loaded from the proposed footing. The apparent density of the soil varies with depth, therefore multiple layers are used to calculate the total settlement.

$$S_e = \sum_{i=1}^{n} \Delta H_i$$

$$\Delta H_i = \left(\frac{H_c}{C'}\right)\left[\log\left(\frac{\sigma'_0 + \Delta\sigma'_v}{\sigma'_0}\right)\right]$$

where:

S_e = total elastic settlement

n = number of soil layers within zone of stress influence of the footing

ΔH_i = elastic settlement of layer *i*

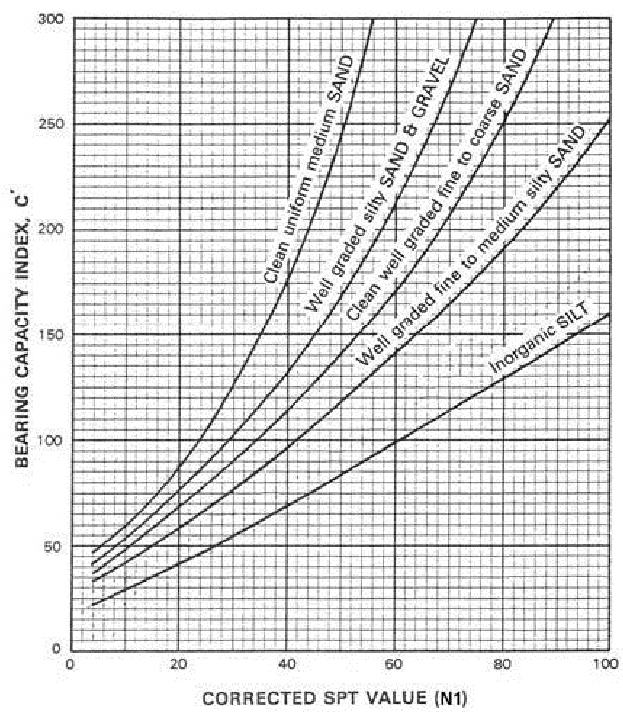
H_c = initial thickness of layer *i* (maximum 10 ft per AASHTO C10.6.2.4.2)

C' = bearing capacity index (from AASHTO Figure 10.6.2.4.2-1)

σ'_o = initial vertical effective stress at midpoint of layer *i*

$\Delta\sigma'_v$ = increase in effective vertical stress at midpoint of layer *i*

Bearing Capacity Index
(per AASHTO, Figure 10.6.2.4.2-1)



- *N1 shall be taken as $N1_{60}$ (SPT blow count corrected for both overburden and hammer efficiency).*

To calculate the permissible settlement of 1 inch first pick a depth of influence based on the footing dimensions and soil types. For this example, the depth of influence is assumed to be three times the footing width (3B = 66 feet). The depth of influence should be increased when significant settlement occurs in the lower layers.

The increase in effective vertical stress ($\Delta\sigma'_v$) is calculated by projecting an equivalent footing area at the midpoint of each layer assuming a 1:2 (H:V) pressure distribution (Figure 1).

The distributed stress used to determine the total settlement is shown in the figure below. In this example, a 2710-kip load produced 1 inch of settlement (Table 1).

Figure 1: Elevation View Showing Pressure Distribution Used for Estimating Settlement

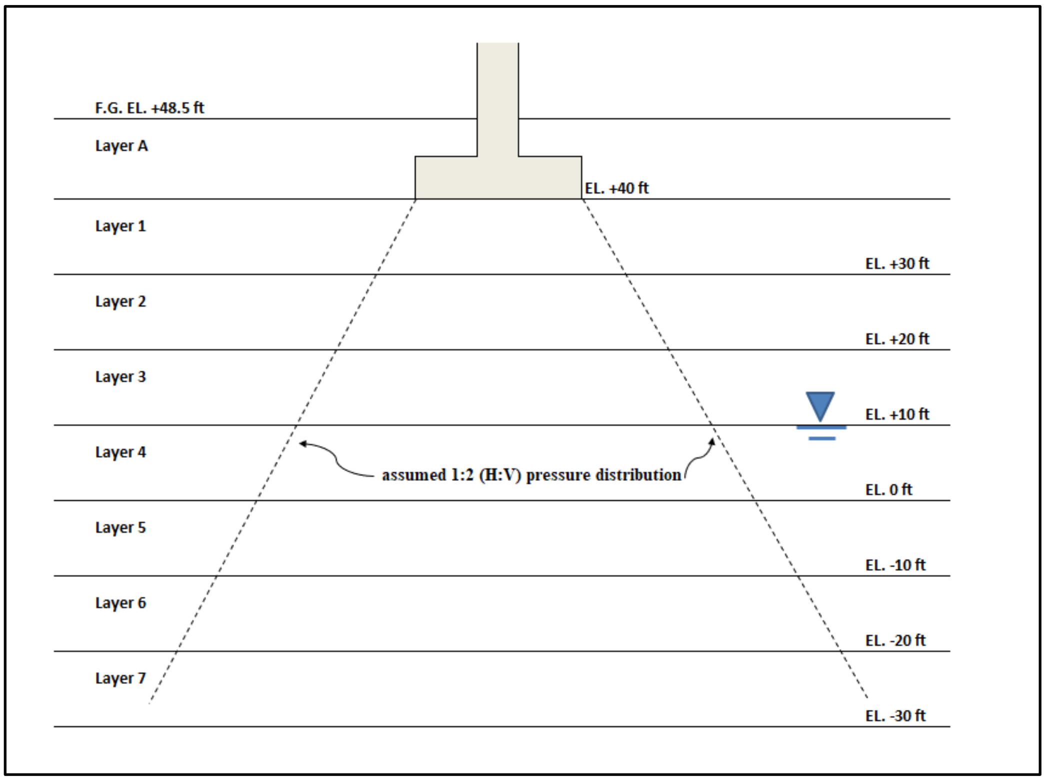


Table 1: Determining Settlement using Hough Method

(Footing Size, B x L = 22 feet x 22 feet)													
(Applied Load = 2710 kips)													
Layer No.	Bottom of Layer Elevation (feet)	Layer Thickness H_i (feet)	Depth Below Footing (feet)	Effective Unit Wt. γ' (pcf)	Effective Overburden Pressure at Mid-Layer σ'_o (ksf)	Depth to mid-layer (feet)	SPT Corrected Blow Count $N1_{60}$	Estimated Bearing Capacity Index C'	Projected Equivalent Footing Area at Mid-Layer (feet^2)	Increase in Effective Vertical Stress at Mid-Layer $\Delta\sigma'_v$ (ksf)	$\frac{\sigma'_o+\Delta\sigma'_v}{\sigma'_o}$	Layer Sett. (inches)	Cumulative Settlement S_e (inches)
A	40.0	8.5	0.0	125	0.53	4.25	36	-	-	-	-	-	-
1	30.0	10.0	10.0	125	1.69	5.0	38	119	729	3.7	3.2	.51	.51
2	20.0	10.0	20.0	125	2.94	15.0	32	102	1369	2.0	1.7	.26	.77
3	10.0	10.0	30.0	125	4.19	25.0	40	125	2209	1.2	1.3	.11	.88
4	0.0	10.0	40.0	63	5.13	35.0	43	134	3249	0.8	1.2	.06	.94
5	-10.0	10.0	50.0	63	5.76	45.0	37	116	4489	0.6	1.1	.04	.98
6	-20.0	10.0	60.0	63	6.39	55.0	50	156	5929	0.5	1.1	.02	1.00
7	-30.0	10.0	70.0	63	7.02	65.0	60	210	7569	0.4	1.1	.01	1.01

The *Permissible Net Contact Stress* (q_{pn}) is:

q_{pn} = Load (to induce 1” settlement) / Effective Footing Area = 2710 k / (22 ft * 22 ft) = **5.6 ksf**

(Note: At this initial stage, the actual footing dimension is assumed to have an eccentricity of zero, (B = B’ and L = L’)

Step 3: Calculate Gross Nominal Bearing Resistance (q_n)

For cohesionless soils: $q_n = (\gamma * D_f * N_q * s_q * C_{wq}) + (0.5 * \gamma * B' * N_\gamma * s_\gamma * C_{w\gamma})$

where:

γ = total unit weight of soil

D_f = footing embedment depth

B’= effective footing width

N_q and N_γ = bearing capacity factors for footing on level ground

s_q and s_γ = footing shape correction factors

C_{wq} and $C_{w\gamma}$ = correction factors to account for the location of the groundwater table

Calculations:

For ϕ=35°, N_q = 33.3 and N_γ = 48.0 (AASHTO figure 10.6.3.1.2a-1)

s_q = 1 + (B'/L' * tan ϕ) = 1 + (22/22 * tan 35) = 1.7 (AASHTO table 10.6.3.1.2a-3)

s_γ = 1 - 0.4 * (B'/ L') = 1 – 0.4 * (22/22) = 0.6 (AASHTO table 10.6.3.1.2a-3)

C_{wq} = 1.0 and $C_{w\gamma}$ = 0.96 for depth to groundwater of 30 ft (AASHTO table 10.6.3.1.2a-2

q_n = (0.125 kcf * 8.5 * 33.3 * 1.7 * 1.0) + (0.5 * 0.125 kcf * 22 ft * 48.0 * 0.6 * 0.96) = <u>98.2 ksf</u>

Shape Factors (after AASHTO LRFD 10.6.3.1.2a-3)

Factor	Friction Angle	Cohesion Term (s_c)	Unit Weight Term (s_γ)	Surcharge Term (s_q)
Shape Factors s_c , s_γ , s_q	$\phi_f = 0$	$1 + (\frac{B'}{5L'})$	1.00	1.00
	$\phi_f > 0$	$1 + (\frac{B'}{L'})(\frac{N_q}{N_c})$	$1 - 0.4\,(\frac{B'}{L'})$	$1 + (\frac{B'}{L'}\tan\phi_f)$

Correction Factor for Location of Water (after AASHTO LRFD 10.6.3.1.2a-2)

Depth of Ground Water Table, D_w	$C_{w\gamma}$	C_{wq}
0	0.5	0.5
D_f	0.5	1.0
>(1.5B' + D_f)	1.0	1.0

Step 4: Calculate Factored Gross Nominal Bearing Resistance (q_R)

Determine the Factored Gross Nominal Bearing Resistances (q_R) for Strength and Extreme Event Limit States by multiplying the Gross Nominal Bearing Resistance (q_n) by the appropriate resistance factors for the Strength and Extreme Event Limit States (AASHTO CA Amendments Table 10.5.5.2.2-1). Here the resistance factor (φ_b) is 0.45

for the Strength Limit State because strength values were based on SPT values and 1.0 for the Extreme Limit State.

$$q_R = \varphi_b * q_n$$

$$q_R = 0.45 * 98.2 \text{ ksf} = 44.2 \text{ ksf (Strength Limit State)}$$

$$q_R = 1.0 * 98.2 \text{ ksf} = 98.2 \text{ ksf (Extreme Event Limit State)}$$

Repeat Steps 2 through 4 for the other footing widths and L/B ratios. Present results in the *Intermediate Supports (Bents)* table (see example below).

Notice that the column heading “Effective Footing Width” is a misnomer because the actual footing width was used in the calculation. Eccentricity effects are considered in Step 8.

Step 5: Send Preliminary Data to Structure Design

Email the *Intermediate Supports (Bents)* table to the Structure Designer.

Intermediate Supports (Bents)

Support Number: Bent 2
Foundation Material (Soil or Rock): Soil
Friction Angle or Undrained Shear Strength: 35°
Permissible Settlement (in): 1.0
Resistance Factor (Strength) – φ_b: 0.45
Resistance Factor (Seismic) – φ_b: 1.0

Total Number of unique *L′/B′*	5
Total Number of *B′*s per *L′/B′*	5

No	Effective Footing Width	Effective Footing Size Ratio	Gross Nominal Bearing Resistance	Permissible Net Contact Stress (Settlement)	Factored Gross Nominal Bearing Resistance (Strength)
	B' (ft)	L'/B'	q_n (ksf)	q_{pn} (ksf)	q_R (ksf)
1	14	1.00			
2	18	1.00			
3	22	1.00	98.2	5.6	44.2
4	26	1.00			
5	30	1.00			
1	14	1.25			
2	18	1.25			
3	22	1.25			
4	26	1.25			
5	30	1.25			
1	14	1.50			
2	18	1.50			
3	22	1.50			
4	26	1.50			
5	30	1.50			
1	14	1.75			
2	18	1.75			
3	22	1.75			
4	26	1.75			
5	30	1.75			
1	14	2.00			
2	18	2.00			
3	22	2.00			
4	26	2.00			
5	30	2.00			

Step 6: Request Design Data from Structure Design

Request that the Structure Designer send the following tables (MTD 4-1 Attachment 4) with the appropriate load information.

- *Foundation Data*
- *LRFD Service-I Limit State Loads for Controlling Load Combination*
- *LRFD Strength, Construction, and Extreme Event Loads for Controlling Load Combinations*

Step 7: Evaluate Inclination Factors

Nothing to do here. Since axial and shear forces are checked against the available resistance using effective footing dimensions in the respective directions (i.e. bearing capacity and sliding), inclination factors were omitted.

Step 8: Verify the Shallow Foundation Design

The Structure Designer sends the following new tables as requested in Step 6. The physical footing width is 22 feet.

Spread Footing Design Information Provided by the Structure Designer

Support No.	Finished Grade Elevation (feet)	Bottom of Footing Elevation (feet)	Footing Dimensions (feet)		Permissible Settlement under Service Load (inches)
			B	L	
Bent 2	48.5	40.0	22	22	1

LRFD Service-1 Limit State Loads for Controlling Load Combination
Provided by Structure Designer

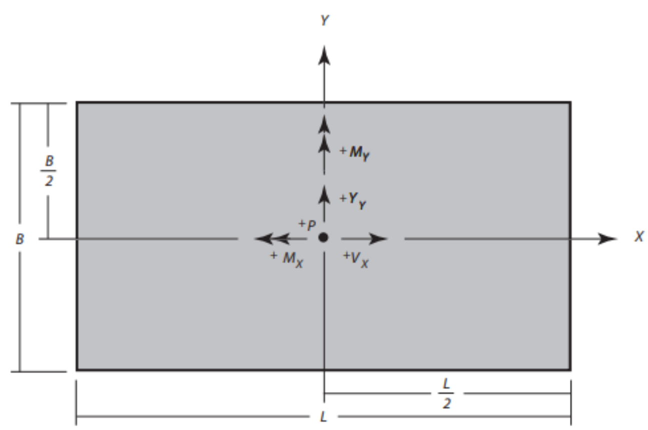
Support Location	Total Load					Permanent Load				
	P_{Total} (kips) Net	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)	P_{Perm} (kips) Net	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)
Bent 2	1287	3697	583	N/A	N/A	927	2062	108	N/A	N/A

Note: P_{Total}, Net is provided in the table, however, for calculating eccentricity P_{Total}, Gross is required. The Geoprofessional will need to ask for this information in addition to the MTD tables.

LRFD Strength and Extreme Event Loads for Controlling Load Combination
Provided by Structure Designer

Support Location	Strength Limit State (Controlling Group)					Extreme Event Limit State (Controlling Group)				
	P_{Total} Gross (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)	P_{Total} Gross (kips)	M_X (kip-ft)	M_Y (kip-ft)	V_X (kips)	V_Y (kips)
Bent 2	2287	2260	3140	N/A	N/A	1400	10588	10588	398	398

1. Eccentricity Limits Check



For Service Limit State:

- Maximum eccentricity is limited to B/6 for footings on soil. B is the footing width.
- Eccentricity, $e_y = M_x / P_{Total,\ Gross}$, $e_x = M_y / P_{Total,\ Gross}$

  (ask Structure Designer for the $P_{Total,\ Gross}$ for the Service-I Limit State)

  Where:

  $e_{x,y}$ = eccentricity

  $M_{x,y}$ = factored bending moment

  $P_{Total,\ Gross}$ = total gross factored axial force

Service Limit State Calculations:

$e_y = M_x / P_{Total, Gross}$

e_y = 3697 kips-ft / 1570 kips = 2.4 feet

B / 6 = 22 ft / 6 = 3.7 ft (maximum allowed eccentricity for soil)

e < B/6 (2.4 ft < 3.7 ft) for footing on soil, O.K.

For Extreme Event Limit State:

- Maximum eccentricity is limited to B/2.5 for footings on soil. B is the footing width.
- Eccentricity, $e_y = M_x / P_{Total, Gross}$

Extreme Event Limit State Calculations:

$e_y = M_x / P_{Total, Gross}$

e_y = 10588 kips-ft / 1400 kips = 7.6 feet

B / 2.5 = 22 ft / 2.5 = 8.8 ft (maximum allowed eccentricity for soil)

e < B/2.5 (7.6 ft < 8.8 ft) for footing on soil, O.K.

2. Calculate the Permissible Net Contact stress after using loads and moments to determine the eccentricity and the effective footing dimensions. Verify that the calculated Permissible Net Contact Stress is greater than or equal to the Net Uniform Bearing Stress ($q_{pn} \geq q_{n,u}$).

Calculate B' for Service I Limit State:

$B' = B - 2 * e_y$

B' = 22 ft – 2 * 2.4 ft = 17.2 ft

Calculate L' for Service I Limit State:

$L' = L - 2 * e_x$

$e_x = M_y / P_{Total, Gross}$

e = 583 kips-ft / 1570 kips = 0.37 feet

L' = 22 ft – 2 * 0.37 ft = 21.3 ft

$q_{n,u} = P_{Total,\ Net}$ / (B' * L') = 1287 kips / (17.2 ft * 21.3 ft) = <u>3.5 ksf</u>   (Demand)

q_{pn} = <u>6.2 ksf</u> (repeat Step 2 to calculate q_{pn} with B' = 17.2 ft and L' = 21.3 ft) (Stress required to induce 1" settlement)

$q_{pn} > q_{n,u}$ (6.2 ksf > 3.5 ksf) O.K.

3. Calculate the Factored Gross Nominal Bearing Resistance for Strength Limit State (and Extreme Event Limit State, if applicable) using loads, moments, and corresponding effective footing dimensions. Verify that the calculated Factored Gross Nominal Bearing Resistance is greater than or equal to the Gross Uniform Bearing Stress ($q_R \geq q_{g,u}$).

Calculate B' and L' for Strength Limit State:

- B' = B – 2 * e_y

  Where:

  $e_y = M_x / P_{Total\ Gross}$

  B' = B – 2 * $M_x / P_{Total\ Gross}$

  B' = 22 ft – 2 * 2260 kips-ft / 2287 kips = 20.0 ft (this will become the L')

- L' = L – 2 * e_x

  Where:

  $e_x = M_y / P_{Total\ Gross}$

  L' = L – 2 * $M_y / P_{Total\ Gross}$

  L' = 22 ft – 2 * 3140 kips-ft / 2287 kips = 19.2 ft (this will become the B')

Switch the B' and L'

B' is the smaller of (B – 2 * e_y) and (L – 2 * e_x). In this example for the Strength Limit State design, B' changed from the longitudinal to the transverse direction. B' is 19.2 ft in transverse direction and L' is 20.0 ft is longitudinal direction.

Calculate q_R and $q_{g,u}$ for Strength Limit State:

- $q_{g,u} = P_{Total\ Gross}$ / (B' * L') = 2287 kips / (19.2 ft * 20.0 ft) = <u>6.0 ksf</u>   (Demand)

- $q_n = (\gamma * D_f * N_q * s_q * C_{wq}) + (0.5 * \gamma * B' * N_\gamma * s_\gamma * C_{w\gamma})$

Calculations:

$N_q = 33.3$ and $N_\gamma = 48.0$ (AASHTO figure 10.6.3.1.2a-1)

$s_q = 1 + (B'/L' * \tan \phi) = 1 + (19.2/20.0 * \tan 35) = 1.7$ (AASHTO table 10.6.3.1.2a-3)

$s_\gamma = 1 - 0.4 * (B'/ L') = 1 – 0.4 * (19.2/20.0) = 0.6$ (AASHTO table 10.6.3.1.2a-3)

$C_{wq} = 1.0$ and $C_{w\gamma} = 1.0$ for depth to groundwater of 30 ft (AASHTO table 10.6.3.1.2a-2)

q_n = (0.125 kcf * 8.5 * 33.3 * 1.7 * 1.0) + (0.5 * 0.125 kcf * 19.2 ft * 48.0 * 0.6 * 1.0)

= 94.7 ksf

$q_R = \varphi_b * q_n$ = 0.45 * 94.7 ksf = <u>42.6 ksf</u> (Resistance)

$q_R > q_{g,u}$ (42.6 ksf > 6.0 ksf) O.K.

Calculate B’ and L’ for Extreme Event Limit State:

- $B' = B – 2 * e_y$

  Where:

  $e_y = M_x / P_{Total\ Gross}$

  $B' = B – 2 * M_x / P_{Total\ Gross}$

  B’ = 22 ft – 2 * 10588 kips-ft / 1400 kips = 6.9 ft

- $L' = L – 2 * e_x$

  Where:

  $e_x = M_y / P_{Total\ Gross}$

  $L' = L – 2 * M_y / P_{Total\ Gross}$

  L’ = 22 ft – 2 * 10588 kips-ft / 1400 kips = 6.9 ft

Calculate q_R and $q_{g,u}$ for Extreme Event Limit State:

- $q_{g,u} = P_{Total\ Gross} / (B' * L')$ = 1400 kips / (6.9 ft * 6.9 ft) = <u>29.4 ksf</u> (Demand)
- $q_n = (\gamma * D_f * N_q * s_q * C_{wq}) + (0.5 * \gamma * B' * N_\gamma * s_\gamma * C_{w\gamma})$

Calculations:

N_q = 33.3 and N_γ = 48.0 (AASHTO figure 10.6.3.1.2a-1)

$s_q = 1 + (B'/L' * \tan \phi) = 1 + (6.9/6.9 * \tan 35) = 1.7$ (AASHTO table 10.6.3.1.2a-3)

$s_\gamma = 1 - 0.4 * (B'/L') = 1 – 0.4 * (6.9/6.9) = 0.6$ (AASHTO table 10.6.3.1.2a-3)

C_{wq} = 1.0 and $C_{w\gamma}$ = 1.0 for depth to groundwater of 30 ft (AASHTO table 10.6.3.1.2a-2)

q_n = (0.125 kcf * 8.5 * 33.3 * 1.7 * 1.0) + (0.5 * 0.125 kcf * 6.9 ft * 48.0 * 0.6 * 1.0)

= 72.6 ksf

$q_R = \varphi_b * q_n$ = 1.0 * 72.6 ksf = 72.6 ksf (Resistance)

$q_R > q_{g,u}$ (72.6 ksf > 29.4 ksf) O.K.

Step 9: Global Stability Check

Global stability calculations need not be performed in this example because the footing is on level ground.

Step 10: Design Approval and Reporting

Email the Structure Designer to communicate design approval. Write the Foundation Report as per *Foundation Reports for Bridges*.

Foundation Design Recommendations for Spread Footing
(after MTD 4-1, Attachment 5, Table 2)

Support Location	Footing Size (feet)		Bottom of Footing Elevation (feet)	Minimum Footing Embedment Depth (feet)	Total Permissible Support Settlement (inches)	Service Limit State	Strength Limit State (φ_b=0.45)	Extreme Event Limit State (φ_b=1.0)
	B	L				Permissible Net Contact Stress (ksf)	Factored Gross Nominal Bearing Resistance (ksf)	Factored Gross Nominal Bearing Resistance (ksf)
Bent 2	22	22	40	8.5	1.0	6.2 (B' = 17.2 feet)	42.6 (B' = 19.2 feet)	72.6 (B' = 6.9 feet)

Spread Footing Data Table
(after MTD 4-1, Attachment 5, Table 3)

Support Location	Service Permissible Net Contact Stress (Settlement) (ksf)	Strength/Construction Factored Gross Nominal Bearing Resistance (φ_b=0.45) (ksf)	Extreme Event Factored Gross Nominal Bearing Resistance (φ_b=1.0) (ksf)
Bent 2	6.2	42.6	72.6