TECHNICAL MEMORANDUM

Contract No.: T4541-AO
Test Report No.: 405160-22
Project Name: Signs and Light Standard Foundation Design When Installed on 2(H):1(V) or Flatter Slopes
Sponsor: Roadside Safety Research Program Pooled Fund Study

DATE: February 28, 2012

TO: David Olson
Chair, Pooled Fund

COPY TO: Rhonda Brooks, Washington State DOT
Epifania Davila, TTI RDO
D. L. Bullard, Jr., Head, TTI Roadside Safety & Physical Security Systems
Roger P. Bligh, TTI Roadway Safety Program
Rebecca Haug, TTI Roadside Safety & Physical Security Systems

FROM: William F. Williams, P.E., Associate Research Engineer, TTI Roadside Safety & Physical Security Systems
Wanda L. Menges, Research Specialist, TTI Proving Ground

FOR MORE INFORMATION:
Name: William F. Williams
Phone: 979-862-2297
Email: w-williams@ttimail.tamu.edu

SUMMARY REPORT:

INTRODUCTION

Many steel sign supports and light standards require a concrete foundation. This foundation is usually a 2 ft to 3 ft diameter shaft. When these foundations are located on a slope, the down slope edge of the foundations typically extends more than 4 inches above ground, creating a potential snagging point. These foundations are generally used to support a triangular slip base shown in Figure 1. One option is to install the foundation below grade such that the pipe support with slip base connection does not extend more than 4 inches above grade shown in Figure 2.
Figure 1 – Triangular Slip Base Details.
For this project, a foundation was designed for a single sign support that utilizes a multi-directional breakaway sign support. This foundation was designed for a sign area of approximately 30 ft$^2$ or less with 7 ft from grade to the bottom of the sign. A new foundation was designed and detailed for omni-directional large sign supports that incorporate a larger sign area of approximately 110 ft$^2$. This design incorporates the use of a proprietary omni-directional...
slip base system. For both designs, the structural supports with slip base attachments will extend approximately 4 inches maximum from the down slope grading edge.

BACKGROUND

Sign supports placed on roadside slopes must not allow impacting vehicles to snag on either the foundation or any components extending above the foundation. Surrounding terrain must be graded to permit vehicles to pass over any non-breakaway portion of the installation that remains in the ground or rigidly attached to the foundation. Figure 3 taken from the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (1), illustrates the method used to measure the required 100 mm (4 inches) maximum stub height.

![Figure 3 – Breakaway Support Stub Height Limits](image)

In February 2001, Bligh and Buth (2) reported on a study that evaluated various configurations of a bolt-down slip base for small sign supports. These different configurations were tested in an attempt to achieve an anchor system that would accommodate design wind loads, be crashworthy in vehicular collision, and have a high degree of reusability after impact. Information and the full-scale testing data from this study and other similar research projects involving sign slip base supports were considered for this project.

OBJECTIVE

The objective of this study was to design a concrete foundation for small sign supports using multi-directional slip base supports that can be constructed completely below grade on a 2(H):1(V) slope or flatter similar to that shown in Figure 2. This new foundation design will incorporate a new steel stub post that is bolted to the foundation with a multi-directional slip base connection at the ground line for the break-away features for the sign. Foundation details as well as slip base anchoring details to the top of the foundation were developed for this project. In addition, engineering calculations were performed for a foundation and sign support attachment to be used for larger signs incorporating multiple supports and using a proprietary omni-
directional slip base system. TTI received design information from Washington State Department of Transportation (WSDOT) for this project. The information provided on WSDOT Standard Plans J-28.30-01, G-24.30, G-25.10-01, G-24.60 were used for this project.

**DESIGN SUMMARY AND CONCLUSIONS**

**Foundation Design for Small Sign Supports on a 2(H):1(V) or Flatter Slopes**

Engineering analyses were performed on a typical single sign support installed on a 2(H):1(V) side slope. The sign foundation with breakaway device was oriented similar to the details shown in Figure 2, with 4 inches between the ground surface at the support and the top of stub for the breakaway device. Design information for the sign installation was obtained from Washington State Department of Transportation Standard Plan G-25.10-01 dated January 6, 2009. This drawing is shown as Figure 3. Analyses were performed on a 5.0 ft wide (X) by 6.0 ft high (Y) sign panel located 7 ft above the finished grade. The height to the sign centroid (Z) was calculated to be 10 ft. Based on this information, the XYZ calculation based on Standard Plan G-25.10-01 was 300.0 ft³. In addition, analyses were performed using a smaller sign area (XYZ = 266 ft³). The design wind speed used in the analyses was 90 mile per hour. Wind loading on the signs and single sign supports were calculated based on the “American Association of State Highways and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Sign, Luminaires and Traffic Signal, 5th Edition, 2009 (3). Calculations were performed using cohesionless (sand) and cohesive (clay) materials. For the cohesionless soil, a friction angle (φ) equal to 30 degrees was used in the analyses. For cohesive soil, a shear strength of 1000 psf was used in the analyses.

Based on the results of the analyses, and the information provided on WSDOT Standard Plan G-25.10-01, the required minimum depth for an 18-inch diameter foundation supporting signs with maximum XYZ of 265 ft³ and less, is 5 ft-5 inches. The required minimum depth for sign foundations supporting signs with a maximum XYZ between 265 to 300 ft³ is 5 ft-6 inches. Therefore, for signs with XYZ less than or equal to 300 ft³, the recommended foundation diameter and minimum foundation depth are 18 inches and 5 ft-6 inches, respectively. This design is valid for signs oriented in the down slope direction (wind loading on the sign perpendicular to the down slope direction). For additional information on the XYZ parameter, please refer to the details shown in Figure 4. These foundations should have a minimum diameter of 18 inches with eight #4 vertical bars equally spaced inside #3 spiral stirrups, as shown in Figure 5. Figure 5 provides details for foundations using a breakaway spiral stirrups embedded in the foundation. Figure 6 provides details for foundations constructed with a breakaway support welded to a base plate anchored to the foundation. Details of the base plated pipe support are provided in Figure 7. Engineering calculations are provided in Appendix A.
Figure 3 – Washington State Department of Transportation Standard Plan G-25.10-01
Figure 4 – Sign Details and Parameters from WSDOT Standard Plan G-25.10-01
D = 18 inches
L = 5 ft-6 inches for XYZ of 300 ft³ and Less

Figure 5 – Foundation Design Details for Small Sign Supports 300 ft³ and Less Using Embedded Pipe Stub
Figure 6 – Foundation Design Details for Small Sign Supports 300 ft³ and Less Using Base Plated Pipe Support

D = 18 inches
L = 5 ft-6 inches for XYZ 300 ft³ and Less
Foundation Design for Large Sign Supports on a 2(H):1(V) or Flatter Slopes

Engineering analyses were performed on a typical large multi-post sign support system installed on a 2(H):1(V) or flatter side slope. The sign foundation with breakaway device was oriented similar to the details shown in Figure 2 with 4 inches between the ground surface at the support and the top of stub for the breakaway device. Design information for the sign installation was obtained from Washington State Department of Transportation Standard Plan G-25.10-01 dated January 6, 2009. This drawing is shown as Figure 3. Analyses were performed on a single sign support supporting a sign area 20 ft wide (X) by 9 ft high (Y) with the bottom of the sign located 7 ft from the finished grade. The height to the sign centroid (Z) was calculated to be 11.5 ft. Based on this information, the XYZ calculation based on Standard Plan G-25.10-01 was 2070.0 ft³. In addition, analyses were performed using a smaller sign area (XYZ = 1170 ft³). The design wind speed used in the analyses was 90 mile per hour. Wind loading on the signs and sign supports were calculated based on the “American Association of
State Highways and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Sign, Luminaires and Traffic Signal, 5th Edition, 2009. Calculations were performed using cohesionless (sand) and cohesive (clay) materials. For the cohesionless soil, a friction angle ($\phi$) equal to 30 degrees was used in the analyses. For cohesive soil, a shear strength of 1000 psf was used in the analyses.

Analyses were performed using a foundation diameter of 30 inches. Based on the results of the analyses, and the information provided on WSDOT Standard Plan G-25.10-01, the required minimum depth for sign foundations with XYZ (sign width $\times$ sign height $\times$ sign centroid height) between 1170 ft$^3$ to 2070 ft$^3$ is 10 ft-6 inches. The recommended minimum depth for sign foundations with XYZ less than 1170 ft$^3$ is 9 ft-6 inches. This design is valid for signs oriented in the down slope direction (wind loading on the sign perpendicular to the down slope direction). For additional information on the XYZ parameter, please refer to the details shown in Figure 4. These foundations should have a minimum diameter of 30 inches with eight (8) #8 vertical bars equally spaced inside #4 spiral stirrups as shown in Figure 8. Figure 8 provides details for foundations using either a proprietary or nonproprietary breakaway sign support embedded in the foundation. Engineering calculations are provided in Appendix A.

SUMMARY & CONCLUSION

Based on the results of the analyses and the information provided on WSDOT Standard Plan G-25.10-01, the required minimum depth for an 18-inch diameter foundation supporting signs with maximum XYZ of 265 ft$^3$ and less is 5 ft-5 inches. The required minimum depth for sign foundations supporting signs with a maximum XYZ between 265 to 300 ft$^3$ is 5 ft-6 inches. Therefore, for signs with XYZ less than or equal to 300 ft$^3$, the recommended foundation diameter and minimum foundation depth are 18 inches and 5 ft-6 inches, respectively. This design is valid for signs oriented in the down slope direction (wind loading on the sign perpendicular to the down slope direction). These foundations should have a minimum diameter of 18 inches with eight #4 vertical bars equally spaced inside #3 spiral stirrups.

For larger signs, analyses were performed using a foundation diameter of 30 inches. Based on the results of the analyses and the information provided on WSDOT Standard Plan G-25.10-01, the required minimum depth for sign foundations with XYZ (sign width $\times$ sign height $\times$ sign centroid height) between 1170 ft$^3$ to 2070 ft$^3$ is 10 ft-6 inches. The recommended minimum depth for sign foundations with XYZ less than 1170 ft$^3$ is 9 ft-6 inches. This design is valid for signs oriented in the down slope direction (wind loading on the sign perpendicular to the down slope direction). These foundations should have a minimum diameter of 30 inches with eight #8 vertical bars equally spaced inside #4 spiral stirrups.
D = 30 inches
L = 9 ft-6 inches for XYZ 1170 ft\(^3\) and Less
L = 10 ft-6 inches for XYZ 1170 ft\(^3\) to 2070 ft\(^3\)

Figure 8 – Foundation Design Details for Single Large Sign Supports Supporting XYZ = 2070 ft\(^3\) and Less
REFERENCES


APPENDIX A. ENGINEERING CALCULATIONS

A1. Maximum XYZ of 265 ft³ and Less at 5 ft-5 inches

Subject: 405160-22 - Foundations on Slopes

1.) Given the following Details and Design Information:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>5.6 ft</td>
</tr>
<tr>
<td>Y</td>
<td>5 ft</td>
</tr>
<tr>
<td>Z</td>
<td>9.5 ft</td>
</tr>
<tr>
<td>XYZ</td>
<td>266 ft³</td>
</tr>
<tr>
<td>X*Y</td>
<td>28 ft²</td>
</tr>
</tbody>
</table>

Post Properties

\[ OD_{\text{post}} = 2.875 \text{ in} \]

Find: The size of the foundation & Depth required on a 2(H):1(V) Slope considering Cohesionless Soil (Sand) and Cohesive Soil (Clay) using the design parameters for each Cohesionless Soil Friction Angle Used in Analysis

\[ \phi = 30 \text{ degrees} \]

Cohesive Soil Strength:

\[ C = 1000 \text{ psf} \]

Unit weight of soil = 110 pcf

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{wind}$</td>
<td>90 mph</td>
<td>See Table 3-5, Page 3-12 for Height 16.4 feet or less</td>
</tr>
<tr>
<td>$k_z$</td>
<td>0.87</td>
<td>See Table 3-2, page 3-10</td>
</tr>
<tr>
<td>$I_r$</td>
<td>0.71</td>
<td>See Section 3.8.5, page 3-12</td>
</tr>
<tr>
<td>$G_0$</td>
<td>1.14</td>
<td>Wind drag coefficient as per Table 3-6, page 3-16</td>
</tr>
<tr>
<td>$C_d_{sign}$</td>
<td>1.19</td>
<td>Wind drag coefficient on 2.5&quot; Sch. 80 Pipe</td>
</tr>
<tr>
<td>$C_d_{tube}$</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

3.) Calculate the design Wind Pressure on the sign & post

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{z_{sign}}$</td>
<td>17.3762 psf</td>
</tr>
<tr>
<td>$P_{z_{post}}$</td>
<td>16.0620 psf</td>
</tr>
</tbody>
</table>
4.) Calculate the Moment & Shear on the Sign due to Wind loading

| Sign Area = | 28 ft\(^2\) | Area\(_{post}\) = | 1.677083 |
| Z = | 9.5 ft | | |
| OD\(_{post}\) = | 2.875 in | | |
| M\(_{wind}\) = | 4.712978 kip*ft | Moment applied to the top of foundation | |
| V\(_{shear}\) = | 0.51347 kip | Shear applied to the top of the foundation | |

5.) Design Information for Footing Design:


<table>
<thead>
<tr>
<th>Degrees</th>
<th>Radians</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi) =</td>
<td>30</td>
</tr>
<tr>
<td>(\alpha) =</td>
<td>-14</td>
</tr>
<tr>
<td>(\theta) =</td>
<td>0</td>
</tr>
<tr>
<td>(\delta) =</td>
<td>0</td>
</tr>
<tr>
<td>FS =</td>
<td>3</td>
</tr>
<tr>
<td>(Y_{soil}) =</td>
<td>0.11 kip/ft(^3)</td>
</tr>
<tr>
<td>D =</td>
<td>18 in</td>
</tr>
</tbody>
</table>

\[ K_p = 1.931597 \]

Reference: Principles of Geotechnical Engineering, Braja Das, 2nd Edition, page 387, EQ 5.58. (This equation takes into account a reduced \(K_p\) for sloping ground).

6.) Calculate Factored Forces for Design based on FS (Factor of Safety):

| \(V_F\) = | 1.540411 kip | Factored forces used for design of footing |
| MF = | 14.13894 kip*ft |

\[ H = 9.178674 \] See Section 13
7.) Calculate the required length of footing in Cohesionless Soil (Sand)
as per AASHTO Signs & Luminaires Standards, Section 13, 2009 Edition

Use Trial & Error to determine the required depth needed as per Eq. C13-7, Section 13, page 13-5

<table>
<thead>
<tr>
<th>( L_{\text{sand}} )</th>
<th>5.177 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D )</td>
<td>1.5 ft</td>
</tr>
<tr>
<td>( V_s )</td>
<td>1.540411 kips</td>
</tr>
<tr>
<td>( M_r )</td>
<td>14.13894 kip*ft</td>
</tr>
<tr>
<td>( K_p )</td>
<td>1.931597</td>
</tr>
</tbody>
</table>

Required depth for **Cohesionless Soil (Sand)**

\[ \text{EQ-C13-7} = -0.01769 \]

Equation converges close to zero "0" for \( L_{\text{sand}} \) depth (trial & error)

\[ M_{\text{max,sand}} = 15.96766 \text{ kip*ft} \]

Maximum calculated bending moment as per Equation C13-9, Section 13 AASHTO 2009 Specifications in Cohesionless Soil (Sand)

8.) Calculate the required footing depth and bending moment for **Cohesive soil (Clay)**
as per the AASHTO Specifications

<table>
<thead>
<tr>
<th>( c_{\text{clay}} )</th>
<th>1000 lbf/ft^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H )</td>
<td>9.178674 ft</td>
</tr>
</tbody>
</table>

Assumed undrained shear strength of clay material

See equation C13-4, Section 13 AASHTO 2009 Specifications

\[ q = 0.114105 \text{ ft} \]

See Equation C13-5, Section 13 AASHTO 2009

<table>
<thead>
<tr>
<th>( L_{\text{clay,soil}} )</th>
<th>5.40371 ft</th>
</tr>
</thead>
</table>

Length required in Cohesive Soil (clay) as per Section 13, AASHTO 2009

<table>
<thead>
<tr>
<th>( M_{\text{max,clay}} )</th>
<th>18.84805 kip*ft</th>
</tr>
</thead>
</table>

Maximum calculated bending moment as per AASHTO Section 13 Specifications in Cohesive Soil (clay)

8.) Determine worst case length as per the different soil conditions:

<table>
<thead>
<tr>
<th>( L )</th>
<th>5.40371 ft</th>
</tr>
</thead>
</table>

Worst case (longest length) in clay
9.) Calculate vertical reinforcement as per ACI 318-83 Specifications for circular columns

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (units)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'_c$</td>
<td>4000 psi</td>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>$f_y$</td>
<td>60000 psi</td>
<td>Yield strength of rebar</td>
</tr>
<tr>
<td>$h$</td>
<td>1.5 ft</td>
<td>Diameter of pier (ft.)</td>
</tr>
<tr>
<td>$cover$</td>
<td>2.5 in</td>
<td>Concrete cover</td>
</tr>
<tr>
<td>$Tie_{dia}$</td>
<td>0.375 in</td>
<td>Diameter of stirrups</td>
</tr>
<tr>
<td>$Vertical_{dia}$</td>
<td>0.5 in</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>No. of bars</td>
<td>8</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>$A_{st}$</td>
<td>1.570796 in$^2$</td>
<td>Area of Steel provided (in$^2$)</td>
</tr>
<tr>
<td>$Ag$</td>
<td>254.469 in$^2$</td>
<td>Area of footing</td>
</tr>
<tr>
<td>$\rho_{act}$</td>
<td>0.006173</td>
<td>calculated reinforcement ratio</td>
</tr>
<tr>
<td>$\gamma_p$</td>
<td>11.75 in</td>
<td>Strength reduction factor</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.9</td>
<td>As per ACI 318-83 Bending diagram for circular columns</td>
</tr>
<tr>
<td>$\phi M_{act, hAg}$</td>
<td>0.1366</td>
<td>Nominal moment capacity of footing (kip*ft)</td>
</tr>
<tr>
<td>$M_n$</td>
<td>57.93411 kip*ft</td>
<td>Nominal moment capacity of footing (kip*ft)</td>
</tr>
</tbody>
</table>
10.) Final Design Details:

D = 18 inches
L = 5'-5" - XYZ 265ft³ and less

Embedded Pipe Stub Option
Subject: 405160-22 - Foundations on Slopes

D = 18 inches
L = 5'-5" - XYZ 265ft³ and less

Base Plated Slip Base Support Option
Subject: 405160-22 - Foundations on Slopes

5/8" DIA. HOLE FOR 1/2" DIA. A325 ANCHOR BOLT, 12 IN. LONG
EMBED, 10 IN. MIN. (TYP.)

9" x 9" x 5/8" PLATE
A572 GRADE 50

3" DIA. SCH 80 PIPE

ELEVATION
DETAIL 1 - SLIP BASE ANCHOR PLATE
A2. XYZ between 265 to 300 ft$^3$ at 5 ft-6 inches

WADOT Type PL, PL-T, & PL-U
Foundations (Small Sign Supports)
WSDOT Standard Plan G-25.10-01
XYZ = 300 ft$^3$

Subject: 405160-22 - Foundations on Slopes

1.) Given the following Details and Design Information:

**XYZ = 300 ft$^3$**

**Sign Properties & Geometry**

\[
\begin{align*}
X &= 5 \text{ ft} \\
Y &= 6 \text{ ft} \\
Z &= 10 \text{ ft} \\
XYZ &= 300 \text{ ft}^3 \\
X \times Y &= 30 \text{ ft}^2
\end{align*}
\]

**Post Properties**

\[
OD_{post} = 2.875 \text{ in}
\]

**Find:** The size of the foundation & Depth required on a 2(H):1(V) Slope considering Cohesionless Soil (Sand) and Cohesive Soil (Clay) using the design parameters for each Cohesionless Soil Friction Angle Used in Analysis

\[
\phi = 30 \text{ degrees}
\]

**Cohesive Soil Strength:**

\[
C = 1000 \text{ psf}
\]

Unit weight of soil = 110 pcfs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{wind}$</td>
<td>90 mph</td>
<td>See Table 3-5, Page 3-12 for Height 16.4 feet or less</td>
</tr>
<tr>
<td>$K_z$</td>
<td>0.87</td>
<td>See Table 3-2, page 3-10</td>
</tr>
<tr>
<td>$I_r$</td>
<td>0.71</td>
<td>See Section 3.8.5, page 3-12</td>
</tr>
<tr>
<td>$G$</td>
<td>1.14</td>
<td>Wind drag coefficient as per Table 3-6, page 3-16</td>
</tr>
<tr>
<td>$C_{d_{sign}}$</td>
<td>1.19</td>
<td>Wind drag coefficient on 2.5&quot; Sch. 80 Pipe</td>
</tr>
<tr>
<td>$C_{d_{tube}}$</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

3.) Calculate the design Wind Pressure on the sign & post

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{z_{sign}}$</td>
<td>17.3762 psf</td>
</tr>
<tr>
<td>$P_{z_{post}}$</td>
<td>16.0620 psf</td>
</tr>
</tbody>
</table>

Subject: 405160-22 - Foundations on Slopes
4.) Calculate the Moment & Shear on the Sign due to Wind loading

| Sign Area = 30 ft² | Area_post = 1.677083 |
| Z = 10 ft | |
| OD_post = 2.875 in | |
| M_w = 5.303769 kip*ft | Moment applied to the top of foundation |
| V_shear = 0.548223 kip | Shear applied to the top of the foundation |

5.) Design Information for Footing Design:


<table>
<thead>
<tr>
<th>Degrees</th>
<th>Radians</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ = 30</td>
<td>0.5236</td>
</tr>
<tr>
<td>α = -14</td>
<td>-0.2443</td>
</tr>
<tr>
<td>θ = 0</td>
<td>0</td>
</tr>
<tr>
<td>δ = 0</td>
<td>0</td>
</tr>
<tr>
<td>FS = 3</td>
<td></td>
</tr>
<tr>
<td>γ_soil = 0.11 kip/ft³</td>
<td>Unit weight of cohesionless soil used in the analysis (pcf)</td>
</tr>
<tr>
<td>D = 18 in</td>
<td>Diameter of Drilled footing (in.)</td>
</tr>
</tbody>
</table>

K_p = 1.931597


6.) Calculate Factored Forces for Design based on FS (Factor of Safety):

| V_f = 1.644669 kip | Factored forces used for design of footing |
| MF = 15.91131 kip*ft |

H = 9.674476 See Section 13
7.) Calculate the required length of footing in Cohesionless Soil (Sand) as per AASHTO Signs & Luminaires Standards, Section 13, 2009 Edition

Use Trial & Error to determine the required depth needed as per Eq. C13-7, Section 13, page 13-5

\[
\begin{array}{|c|c|}
\hline
L_{\text{Sand}} & 5.375 \text{ ft} \\
D & 1.5 \text{ ft} \\
V_F & 1.644669 \text{ kips} \\
M_F & 15.91131 \text{ kip*ft} \\
K_p & 1.931597 \\
\hline
\end{array}
\]

Required depth for **Cohesionless Soil (Sand)**

EQ-C13-7= -0.03357 \hspace{2cm} \text{Equation converges close to zero "0" for } L_{\text{Sand}} \text{ depth (trial & error)}

\[
M_{F_{\text{maxSand}}} = 17.92879 \text{ kip*ft}
\]

Maximum calculated bending moment as per Equation C13-9, Section 13 AASHTO 2009 Specifications in Cohesionless Soil (Sand)

8.) Calculate the required footing depth and bending moment for **Cohesive soil (Clay)** as per the AASHTO Specifications

\[
c_{\text{Clay}} = 1000 \text{ lbf/ft}^2 \hspace{2cm} \text{Assumed undrained shear strength of clay material}
\]

\[
H = 9.674476 \text{ ft} \hspace{2cm} \text{See equation C13-4, Section 13 AASHTO 2009 Specifications}
\]

\[
q = 0.121827 \text{ ft} \hspace{2cm} \text{See Equation C13-5, Section 13 AASHTO 2009}
\]

\[
L_{\text{Clay}} = 5.538559 \text{ ft} \hspace{2cm} \text{Length required in Cohesive Soil (clay) as per Section 13, AASHTO 2009}
\]

\[
M_{F_{\text{maxClay}}} = 20.94549 \text{ kip*ft} \hspace{2cm} \text{Maximum calculated bending moment as per aaSHTO Section 13 Specifications in Cohesive Soil (clay)}
\]

8.) Determine worst case length as per the different soil conditions:

\[
L = 5.538559 \text{ ft} \hspace{2cm} \text{Worst case (longest length) in clay}
\]
9.) Calculate vertical reinforcement as per ACI318-83 Specifications for circular columns

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f'_c )</td>
<td>4000 psi</td>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>( f_y )</td>
<td>6000 psi</td>
<td>Yield strength of rebar</td>
</tr>
<tr>
<td>( h )</td>
<td>1.5 ft</td>
<td>Diameter of pier (ft.)</td>
</tr>
<tr>
<td>( \text{cover} )</td>
<td>2.5 in</td>
<td>Concrete cover</td>
</tr>
<tr>
<td>( \text{Tie}_{\text{dia}} )</td>
<td>0.375 in</td>
<td>Diameter of stirrups</td>
</tr>
<tr>
<td>( \text{Vertical}_{\text{dia}} )</td>
<td>0.5 in</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>( \text{No}_{\text{verts}} )</td>
<td>8</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>( A_{\text{st}} )</td>
<td>1.570796 in^2</td>
<td>Area of Steel provided (in^2)</td>
</tr>
<tr>
<td>( A_g )</td>
<td>254.469 in^2</td>
<td>Area of footing</td>
</tr>
<tr>
<td>( \rho_{\text{act}} )</td>
<td>0.006173</td>
<td>Calculated reinforcement ratio</td>
</tr>
<tr>
<td>( \gamma_h )</td>
<td>11.75 in</td>
<td></td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.652778</td>
<td></td>
</tr>
<tr>
<td>( \phi )</td>
<td>0.9</td>
<td>Strength reduction factor</td>
</tr>
<tr>
<td>( \phi M_{\text{fact, hAg}} )</td>
<td>0.1366</td>
<td>As per ACI318-83 Bending diagram for circular columns</td>
</tr>
<tr>
<td>( M_n )</td>
<td>57.93411 kip*ft</td>
<td>Nominal moment capacity of footing (kip*ft)</td>
</tr>
</tbody>
</table>
10.) Final Design Details:

D = 18 inches
L = 5'-6" - XYZ 265ft³ to 300 ft³

Embedded Pipe Stub Option
D = 18 inches
L = 5’-6” - XYZ 265 - 300ft^3

Base Plated Slip Base Support Option
Subject: 405160-22 - Foundations on Slopes

PLAN

5/8" DIA. HOLE FOR 1/2" DIA. A325 ANCHOR BOLT, 12 IN. LONG EMBED. 10 IN. MIN. (TYP.)

9"x9"x5/8" PLATE A572 GRADE 50

ELEVATION

DETAIL 1 - SLIP BASE ANCHOR PLATE

3" DIA. SCH 80 PIPE

VARIES
A3. XYZ between 1170 ft$^3$ to 2070 ft$^3$ at 10 ft-6 inches

Subject: **405160-22 - Foundations on Slopes**

1.) Given the following Details and Design Information:

\[ \begin{align*}
X &= 15.2 \text{ ft} \\
Y &= 7.25 \text{ ft} \\
Z &= 10.625 \text{ ft} \\
XYZ &= 1170.875 \text{ ft}^3 \\
X*Y &= 110.2 \text{ ft}^2 \\
\end{align*} \]

Post Properties: Use W6x16

\[ b_1 = 4.03 \text{ in} \]

Find: The size of the foundation & Depth required on a 2(H):1(V) Slope considering Cohesionless Soil (Sand) and Cohesive Soil (Clay) using the design parameters for each Cohesionless Soil Friction Angle Used in Analysis

\[ \phi = 30 \text{ degrees} \]

Cohesive Soil Strength:

\[ C = 1000 \text{ psf} \]

Unit weight of soil = 110pcf
2.) Given the following Design Information for Wind Loading on Sign:


<table>
<thead>
<tr>
<th>$V_{wind}$</th>
<th>90 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_z$</td>
<td>0.87</td>
</tr>
<tr>
<td>$I_r$</td>
<td>0.71</td>
</tr>
<tr>
<td>$G$</td>
<td>1.14</td>
</tr>
<tr>
<td>$C_{d_{sign}}$</td>
<td>1.19</td>
</tr>
<tr>
<td>$C_{d_{tube}}$</td>
<td>1.7</td>
</tr>
</tbody>
</table>

See Table 3-5, Page 3-12 for Height 16.4 feet or less

See Table 3-2, page 3-10

See Section 3.8.5, page 3-12

Wind drag coefficient as per Table 3-6, page 3-16

Wind drag coefficient, See Table 3-6, page 3-12

3.) Calculate the design Wind Pressure on the sign & post

| $P_{z_{sign}}$ | 17.3762 psf |
| $P_{z_{post}}$ | 24.8231 psf |

Calculated Wind Pressures on Sign Area & Post
4.) Calculate the Moment & Shear on the Sign due to Wind loading

<table>
<thead>
<tr>
<th>Sign Area =</th>
<th>110.2 ft²</th>
<th>Area post =</th>
<th>2.350833</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z = 10.625 ft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b = 4.03 in</td>
<td>Flange width of post (in.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mwind = 20.54229 kip*ft</td>
<td>Moment applied to the top of foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vshear = 1.97321 kip</td>
<td>Shear applied to the top of the foundation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.) Design Information for Footing Design:

Reference: AASHTO Standard Specifications for Structural Supports for Highway Sign, Luminaires 

<table>
<thead>
<tr>
<th>Degrees</th>
<th>Radians</th>
<th>Cohesionless Soil Friction Angle Used in Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ = 30</td>
<td>0.5236</td>
<td>Slope Angle for 2(H):1(V) slope, assume sign loaded 4(H):1(V)</td>
</tr>
<tr>
<td>α = -14</td>
<td>-0.2443</td>
<td>considering burial as shown in the detail (wind loading perpendicular to slope)</td>
</tr>
</tbody>
</table>

| θ = 0 | Soil face used for Kp calculation (this value is zero for drilled footing application) |
| δ = 0 | This value is zero for drilled footing application |
| FS = 3 | Factor of Safety Recommended in Section 13. |
| Ysoil = 0.11 kip/ft³ | Unit weight of cohesionless soil used in the analysis (pcf) |
| D = 30 in | Diameter of Drilled footing (in.) |

Kp = 1.931597

Reference: Principles of Geotechnical Engineering, 
(This equation takes into account a reduced Kp for sloping ground).

6.) Calculate Factored Forces for Design based on FS (Factor of Safety):

| Vf = 5.919631 kip | Factored forces used for design of footing |
| MF = 61.62686 kip*ft | |
| H = 10.41059 | See Section 13 |
7.) Calculate the required length of footing in Cohesionless Soil (Sand) as per AASHTO Signs & Luminares Standards, Section 13, 2009 Edition

Use Trial & Error to determine the required depth needed as per Eq. C13-7, Section 13, page 13-5

\[
\begin{array}{|c|c|}
\hline
L_{\text{sand}} & 7.342 \text{ ft} \\
D & 2.5 \text{ ft} \\
V_f & 5.919631 \text{ kips} \\
M_f & 61.62686 \text{ kip*ft} \\
K_p & 1.931597 \\
\hline
\end{array}
\]

Required depth for Cohesionless Soil (Sand)

EQ-C13-7 = 0.096535 Equation converges for \( L_{\text{sand}} \)

\[
M_{f_{\text{maxsand}}} = 72.29801 \text{ kip*ft}
\]

Maximum calculated bending moment as per Equation C13-9, Section 13 AASHTO 2009 Specifications in Cohesionless Soil (Sand)

8.) Calculate the required footing depth and bending moment for Cohesive soil (Clay) as per the AASHTO Specifications

\[
c_{\text{clay}} = 1000 \text{ lbf/ft}^2 \quad \text{Assumed undrained shear strength of clay material}
\]

H = 10.41059 ft See equation C13-4, Section 13 AASHTO 2009 Specifications

q = 0.263095 ft See Equation C13-5, Section 13 AASHTO 2009

\[
L_{\text{clay}} = 9.141335 \text{ ft}
\]

Length required in Cohesive Soil (clay) as per Section 13, AASHTO 2009

\[
M_{f_{\text{maxclay}}} = 92.00373 \text{ kip*ft}
\]

Maximum calculated bending moment as per aASHTO Section 13 Specifications in Cohesive Soil (clay)

8.) Determine worst case length as per the different soil conditions:

\[
L = 9.141335 \text{ ft}
\]

Worst case (longest length) in clay
9.) Calculate vertical reinforcement as per ACI318-83 Specifications for circular columns

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'_c$</td>
<td>4000 psi</td>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>$f_y$</td>
<td>60000 psi</td>
<td>Yield strength of rebar</td>
</tr>
<tr>
<td>$h$</td>
<td>2.5 ft</td>
<td>Diameter of pier (ft.)</td>
</tr>
<tr>
<td>$h_{con}$</td>
<td>2.5 in</td>
<td>Concrete cover</td>
</tr>
<tr>
<td>$T_{dia}$</td>
<td>0.5 in</td>
<td>Diameter of stirrups</td>
</tr>
<tr>
<td>$V_{dia}$</td>
<td>1 in</td>
<td></td>
</tr>
<tr>
<td>$N_{verts}$</td>
<td>8</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>$A_s$</td>
<td>6.283185 in$^2$</td>
<td>Area of Steel provided (in$^2$)</td>
</tr>
<tr>
<td>$A_g$</td>
<td>706.8583 in$^2$</td>
<td>Area of footing</td>
</tr>
<tr>
<td>$\rho_{act}$</td>
<td>0.008889</td>
<td>calculated reinforcement ratio</td>
</tr>
<tr>
<td>$Y_h$</td>
<td>23 in</td>
<td></td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.766667</td>
<td></td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.9</td>
<td>Strength reduction factor</td>
</tr>
<tr>
<td>$\phi M_{act, hAg}$</td>
<td>0.189</td>
<td>As per ACI318-83 Bending diagram for circular columns</td>
</tr>
<tr>
<td>$M_n$</td>
<td>371.1006 kip*ft</td>
<td>Nominal moment capacity of footing (kip*ft)... o.k.!</td>
</tr>
</tbody>
</table>
10.) Final Design Details:

D = 30 inches
L = 9'-6" for XYZ = 1170 ft$^3$ and Less
A4. XYZ less than 1170 ft$^3$ is 9 ft-6 inches

Subject: 405160-22 - Foundations on Slopes

1.) Given the following Details and Design Information:

\[
\begin{align*}
X &= 20 \text{ ft} \\
Y &= 9 \text{ ft} \\
Z &= 11.5 \text{ ft} \\
XYZ &= 2070 \text{ ft}^3 \\
X \times Y &= 180 \text{ ft}^2 \\
\text{Post Properties: Use W8x21} \\
b_1 &= 5.27 \text{ in}
\end{align*}
\]

Find: The size of the foundation & Depth required on a 2(H):1(V) Slope considering Cohesionless Soil (Sand) and Cohesive Soil (Clay) using the design parameters for each Cohesionless Soil Friction Angle Used in Analysis \(\phi = 30 \text{ degrees}\)

Cohesive Soil Strength:
\(C = 1000 \text{ psf}\)

Unit weight of soil = 110 pcf
2.) Given the following Design Information for Wind Loading on Sign:


<table>
<thead>
<tr>
<th>$V_{wind}$</th>
<th>90 mph</th>
<th>See Table 3-5, Page 3-12 for Height 16.4 feet or less</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_z$</td>
<td>0.87</td>
<td>See Table 3-2, page 3-10</td>
</tr>
<tr>
<td>$I_r$</td>
<td>0.71</td>
<td>See Section 3.8.5, page 3-12</td>
</tr>
<tr>
<td>$G$</td>
<td>1.14</td>
<td>Wind drag coefficient as per Table 3-6, page 3-16</td>
</tr>
<tr>
<td>$C_{d_{sign}}$</td>
<td>1.19</td>
<td>Wind drag coefficient, See Table 3-6, page 3-12</td>
</tr>
<tr>
<td>$C_{d_{tube}}$</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

3.) Calculate the design Wind Pressure on the sign & post

Calculated Wind Pressures on Sign Area & Post

$P_{z_{sign}} = 17.3762 \text{ psf}$

$P_{z_{post}} = 24.8231 \text{ psf}$
Subject: **405160-22 - Foundations on Slopes**

4.) Calculate the Moment & Shear on the Sign due to Wind loading

<table>
<thead>
<tr>
<th>Sign Area =</th>
<th>180 ft^2</th>
<th>Area_post =</th>
<th>3.074167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z =</td>
<td>11.5 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_f =</td>
<td>5.27 in</td>
<td>Flange width of post (in.)</td>
<td></td>
</tr>
<tr>
<td>M_w =</td>
<td>36.22625 kip*ft</td>
<td>Moment applied to the top of foundation</td>
<td></td>
</tr>
<tr>
<td>V_s =</td>
<td>3.204023 kip</td>
<td>Shear applied to the top of the foundation</td>
<td></td>
</tr>
</tbody>
</table>

5.) Design Information for Footing Design:


<table>
<thead>
<tr>
<th>Degrees</th>
<th>Radians</th>
<th>Cohesionless Soil Friction Angle Used in Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ =</td>
<td>30</td>
<td>0.5236</td>
</tr>
<tr>
<td>α =</td>
<td>-14</td>
<td>-0.2443</td>
</tr>
<tr>
<td>θ =</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>δ =</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FS =</td>
<td>3</td>
<td>Factor of Safety Recommended in Section 13.</td>
</tr>
<tr>
<td>γ_s =</td>
<td>0.11 kip/ft^3</td>
<td>Unit weight of cohesionless soil used in the analysis (pcf)</td>
</tr>
<tr>
<td>D =</td>
<td>30 in</td>
<td>Diameter of Drilled footing (in.)</td>
</tr>
</tbody>
</table>

| Kp = 1.931597 |


6.) Calculate Factored Forces for Design based on FS (Factor of Safety):

| V_f = 9.61207 kip | Factored forces used for design of footing |
| MF = 108.6787 kip*ft |

| H = 11.30649 | See Section 13 |
7.) Calculate the required length of footing in Cohesionless Soil (Sand) as per AASHTO Signs & Luminaires Standards, Section 13, 2009 Edition

Use Trial & Error to determine the required depth needed as per Eq. C13-7, Section 13, page 13-5

\begin{align*}
L_{\text{sand}} & = 9.028 \text{ ft} \\
D & = 2.5 \text{ ft} \\
V_f & = 9.61207 \text{ kips} \\
M_f & = 108.6787 \text{ kip*ft} \\
P & = 1.931597
\end{align*}

\text{Required depth for Cohesionless Soil (Sand)}

\text{Equation converges for } L_{\text{sand}}

\text{Maximum calculated bending moment as per Equation C13-9, Section 13 AASHTO 2009 Specifications in Cohesionless Soil (Sand)}

8.) Calculate the required footing depth and bending moment for Cohesive soil (Clay) as per the AASHTO Specifications

\begin{align*}
c_{\text{clay}} & = 1000 \text{ lbf/ft}^2 \text{ Assumed undrained shear strength of clay material} \\
H & = 11.30649 \text{ ft} \text{ See equation C13-4, Section 13 AASHTO 2009 Specifications} \\
q & = 0.427203 \text{ ft} \text{ See Equation C13-5, Section 13 AASHTO 2009}
\end{align*}

\begin{align*}
L_{\text{claysoil}} & = 10.5354 \text{ ft} \\
M_{\text{Fmaxclay}} & = 158.7922 \text{ kip*ft}
\end{align*}

\text{Length required in Cohesive Soil (clay) as per Section 13, AASHTO 2009}

\text{Maximum calculated bending moment as per aASHTO Section 13 Specifications in Cohesive Soil (clay)}

8.) Determine worst case length as per the different soil conditions:

\begin{align*}
L & = 10.5354 \text{ ft} \\
\text{Worst case (longest length) in clay}
\end{align*}
9.) Calculate vertical reinforcement as per ACI318-83 Specifications for circular columns

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f'c</td>
<td>4000 psi</td>
<td>Compressive strength of concrete</td>
</tr>
<tr>
<td>fy</td>
<td>60000 psi</td>
<td>Yield strength of rebar</td>
</tr>
<tr>
<td>h</td>
<td>2.5 ft</td>
<td>Diameter of pier (ft.)</td>
</tr>
<tr>
<td>cover</td>
<td>2.5 in</td>
<td>Concrete cover</td>
</tr>
<tr>
<td>Tie_dia</td>
<td>0.5 in</td>
<td>Diameter of stirrups</td>
</tr>
<tr>
<td>Vertical_dia</td>
<td>1 in</td>
<td></td>
</tr>
<tr>
<td>No_vers=</td>
<td>8</td>
<td>Number of vertical bars</td>
</tr>
<tr>
<td>A_st=</td>
<td>6.283185 in^2</td>
<td>Area of Steel provided (in^2)</td>
</tr>
<tr>
<td>Ag</td>
<td>706.8583 in^2</td>
<td>Area of footing</td>
</tr>
<tr>
<td>ρ_rect=</td>
<td>0.008889</td>
<td>calculated reinforcement ratio</td>
</tr>
<tr>
<td>Y_h</td>
<td>23 in</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>0.766667</td>
<td></td>
</tr>
<tr>
<td>ϕ</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>ϕM_rect_A_g=</td>
<td>0.189</td>
<td>As per ACI318-83 Bending diagram for circular columns</td>
</tr>
<tr>
<td>Mn</td>
<td>371.1006 kip*ft</td>
<td>Nominal moment capacity of footing (kip*ft)... o.k.!</td>
</tr>
</tbody>
</table>
10.) Final Design Details:

D = 30 inches  
L = 10'-6" XYZ 1170 ft$^3$ to 2070 ft$^3$