EXAMPLE 8: CANTILEVER WINGWALL DESIGN LOADS

Problem Statement

Example 8 covers the design of a wingwall cantilevered off a standard CDOT integral abutment. The example illustrates the following items:

- The 20 ft. length (measured as shown in Figures 1 & 2) used in Example 8 is the maximum length permitted for cantilevered wingwalls per BDM Section 11.3.6.1.
- The example wingwall is skewed 30°, which is the maximum allowed for an integral abutment per BDM Section 11.3.1.
- At-rest earth pressure is required for skewed wingwalls per BDM Section 11.3.6.2.
- Per BDM Section 11.3.6.2, a portion of the earth pressure acting on the buried part of the wingwall may be neglected, as shown in Figure 1 below. Equations are provided to assist in calculating the resultant wingwall force effects from the trapezoidal shape of earth pressure.
- Force effects are summarized at the two design sections shown in Figure 2. Design Section A is the critical design section for the wingwall. Design Section B summarizes the force-effects transferred to the abutment .

<u>Assumptions</u>

- The backfill is assumed to be sufficiently drained so that hydrostatic pressure does not develop.
- Example 8 assumes that no settlement of the backfill is anticipated. See BDM Section 11.3.6.1 for guidance when significant settlement is expected.

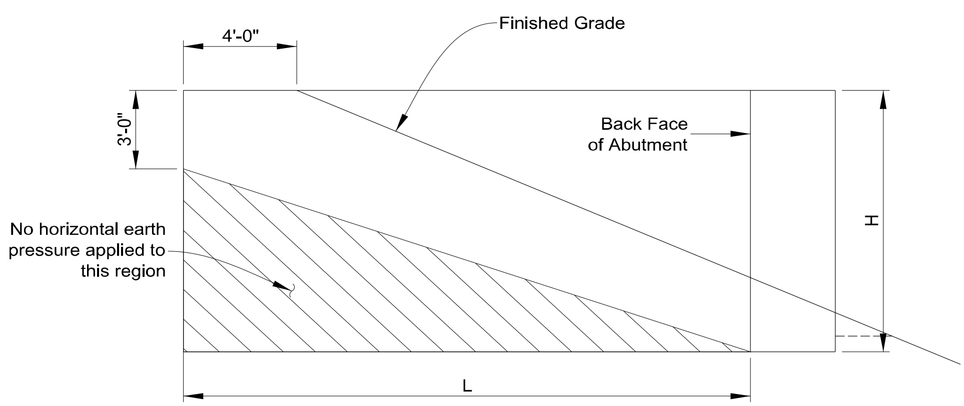


Figure 1 - Wingwall Elevation

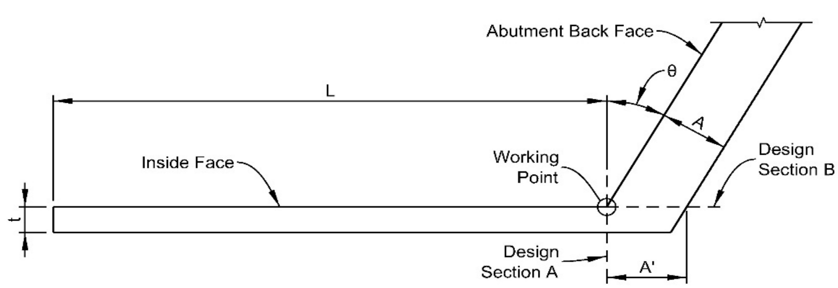
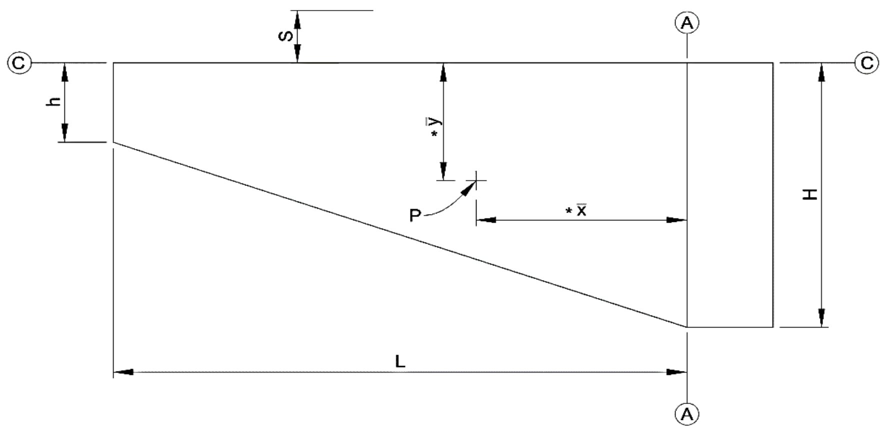


Figure 2 - Partial Plan

Givens

Wingwall Height, H =	10.00	ft.	
Wall Thickness, t =	1.00	ft.	
Live Load Surcharge Height, S =	2.00	ft.	BDM 11.3.6.2
End Height, h =	3.00	ft.	
Wingwall Length, L =	20.00	ft.	
Abutment Width, A =	3.00	ft.	
Skew Angle, θ =	30.00	degrees	
Backfill Unit Weight, γ^1 =	0.130	kcf (CDOT Class 1)	
Angle of Internal Friction of Backfill, Φ^1 =	34.0	degrees	
Dead Load Factor, γ_{DC} =	1.25		AASHTO 3.4.1
Horizontal Earth Pressure Factor, γ_{EH} =	1.35	*for at-rest pressure*	AASHTO 3.4.1
Live Load Surcharge Factor, γ_{LS} =	1.75		AASHTO 3.4.1
Unit Weight of Concrete, γ_c =	0.15	kcf	

[1]*Provided by Geotechnical Engineer.*



* $\bar{x}$ = distance from back face of abutment to location of Service thrust ($\bar{x}_S$) or Ultimate thrust ($\bar{x}_U$)
$\bar{y}$ = distance from top of wall to location of Service thrust ($\bar{y}_S$) or Ultimate thrust ($\bar{y}_U$)

Figure 3 - Horizontal Load Geometry

Calculations

Earth Pressure

Earth pressure moments are calculated about the A and C axes shown in Figure 3. The total thrust, P, due to horizontal earth pressure and live load surcharge, is also calculated and located. The following equations are adopted from a Caltrans design aid; the derivations are not provided.

At-rest Lateral Earth Pressure Coefficient, k_0 $= 1 - \sin \Phi$ — AASHTO Eq. 3.11.5.2-1

= 0.441

Effective Fluid Weight, W $= max[k_0 * \gamma, 0.057\ kcf]$ — BDM 11.3.6.2

= 0.057 kcf

Service Limit State:

Service Moment, M_{S_AA} $= \frac{WL^2}{24}\left(3h^2 + (H + 4S)(H + 2h)\right)$

= 301 kft

Service Moment, M_{S_CC} $= \frac{WL}{12}\left(2ShH + (H + h + 2S)(H^2 + h^2)\right)$

= 188 kft

Service Thrust, P_S $= \frac{WL}{6}\left(H^2 + (h + H)(h + 3S)\right)$

= 41.5 kip

$\bar{x}_S = \frac{M_{S\_AA}}{P_S}$

= 7.26 ft., from back face of abutment

$\bar{y}_S = \frac{M_{S\_CC}}{P_S}$

= 4.55 ft., from top of wall

Strength Limit State:

Effective Surcharge height, S' $= S\frac{\gamma_{LS}}{\gamma_{EH}}$ — *Nominal depth of live load surcharge is increased to account for the difference in load factors*

= 2.59 ft.

Ultimate Moment, M_{U_AA} $= \gamma_{EH}\frac{WL^2}{24}\left(3h^2 + (H + 4S')(H + 2h)\right)$

= 455 kft

Ultimate Moment, M_{U_CC} $= \gamma_{EH} \frac{WL}{12} \left(2S'hH + (H + h + 2S')(H^2 + h^2) \right)$

= 276 kft

Ultimate Thrust, P_U $= \gamma_{EH} \frac{WL}{6} \left(H^2 + \ (h + H)(h + 3S') \right)$

= 61.9 kip

$\bar{x}_U$ $= \frac{M_{U\_AA}}{P_U}$

= 7.35 ft., from back face of abutment

$\bar{y}_U$ $= \frac{M_{U\_CC}}{P_U}$

= 4.45 ft., from top of wall

<u>Self Weight:</u>

Service Wall Weight, V_S $= HLt * \gamma_c$

= 30.0 kip

Ultimate Wall Weight, V_U $= \gamma_{DC} V_S$

= 37.5 kip

Service Moment at Design Section A, M_{S_wall} $= V_S * \frac{L}{2}$

= 300 kft

Ultimate Moment at Design Section A, M_{U_wall} $= V_U * \frac{L}{2}$

= 375 kft

Design Section A Summary

Primary Horizontal Reinforcement

M_{S_AA} = 301 kft

M_{S_AA}, per ft. $= M_{S\_AA}/H$

= 30.1 kft/ft

M_{U_AA} = 455 kft

M_{U_AA}, per ft. $= M_{U\_AA}/H$

= 45.5 kft/ft.

These moments are used to design the primary horizontal reinforcement along the inside face of the wingwall for a 1 ft. wide section with a depth of t. For example calculations of reinforced concrete design, see BDM Design Examples 6 and 11. Per calculations not shown, #8 bars at 6 in. spacing are selected as primary reinforcing. All wingwall reinforcement is required to be corrosion resistant, in accordance with BDM Section 5.4.5.

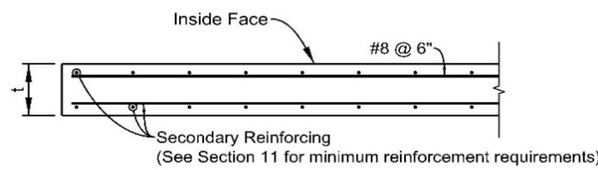


Figure 4 - Primary Horizontal Reinforcement

Top Horizontal Reinforcement

M_{S_wall} = 300 kft

M_{U_wall} = 375 kft

These moments are used to design the required top reinforcing bars in the wingwall for a section of width t and depth of H. Per calculations not shown, the primary horizontal reinforcing provided above is sufficient to resist the imposed moment; no additional bars are needed.

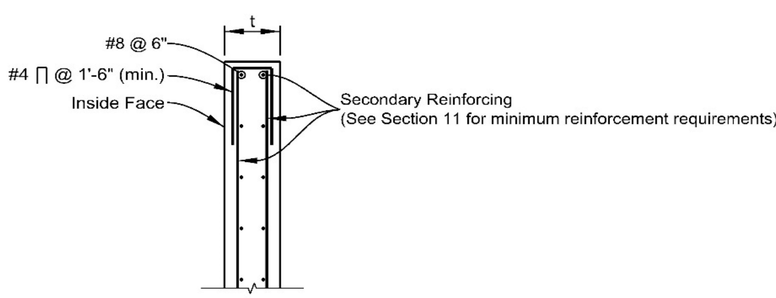


Figure 5 - Top Horizontal Reinforcement

Wingwall Reinforcement Details

See Figures 11.6-1, 11.6-2, and 11.7-1 of the Bridge Detail Manual for additional wingwall reinforcement details, including development of top and primary horizontal bars into the abutment.

Design Section B Summary

Earth pressure and dead loads are ultimately transferred to, and must be resisted by, the abutment and its supporting foundation elements. This section resolves earth pressure and self-weight forces into design forces and moments about centroidal axes of the abutment, and at Design Section B (see Figure 2).

The abutment width along the skew, A' $= A/\cos(\theta)$

= 3.46 ft.

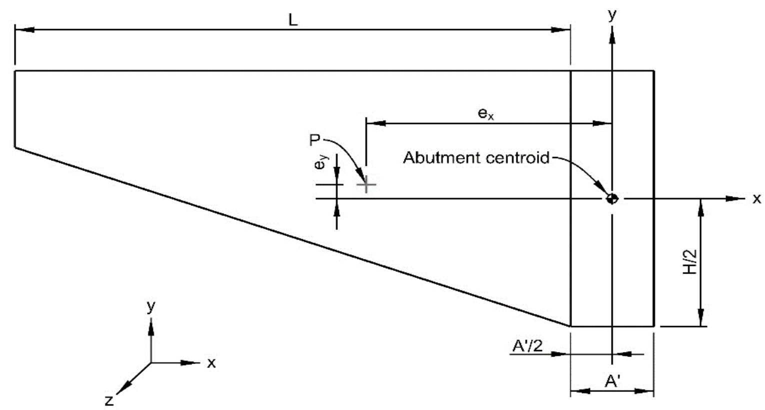


Figure 6 - Abutment Eccentricities

Service Limit State:

Tension, P_s = 41.5 kip

Shear, V_s = 30.0 kip

$$e_{x\_S} = \bar{x}_S + \frac{A'}{2}$$

= 8.99 ft.

$$e_{y\_S} = \frac{H}{2} - \bar{y}_S$$

= 0.454 ft.

My, Service $= P_S * e_{x\_S}$

= 373 kft

Mx, Service $= P_S * e_{y\_S}$

= 18.8 kft

Tz, Service $= V_S\left(\frac{L + A'}{2}\right)$

= 352 kft

Strength Limit State:

Tension, P_u = 61.9 kip

Shear, V_u = 37.5 kip

$$e_{x\_U} = \bar{x}_U + \frac{A'}{2}$$

= 9.08 ft.

$$e_{y\_U} = \frac{H}{2} - \bar{y}_U$$

= 0.548 ft.

My, Ultimate $= P_U * e_{x\_U}$

= 562 kft

Mx, Ultimate $= P_U * e_{y\_U}$

= 34.0 kft

Tz, Ultimate $= V_U \left(\frac{L + A'}{2} \right)$

= 440 kft

The shear, tension, torsion, and bi-axial moments summarized above are concurrent and must be resisted by the abutment. Careful detailing is required to provide adequate capacity and sufficient reinforcement development at Design Section B. See Figure 11-13 of the BDM for reinforcement details at the wingwall/abutment interface.

Conclusion

This design example shows the primary calculations needed to develop design forces for a cantilever wingwall supported by an integral abutment. While all force effects were calculated for completeness, it is noted that for this example the following force effects are negligible: self-weight shear at sections A & B, self-weight moment M_wall at Section A, and earth pressure moment Mx at Section B.

Other configurations, such as a cantilever wingwall attached to a semi-integral abutment cap, need to resist the same loading as illustrated in this design example. However, in this case, the structural section available to resist the wingwall forces is reduced because the wingwall is supported only by the abutment cap. It is noted that the aforementioned force effects that are typically inconsequential for an integral abutment are more critical for this configuration.