APPENDIX A: DESIGN OF MSE WALL

1. 5-ft high MSE wall with 8-ft long strips design

<table>
<thead>
<tr>
<th>Wall</th>
<th>Wall height, ( H ) = 6.190 ft</th>
<th>1/2 ( H ) = 3.095 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reinforcing fill length, ( L ) = 8.000 ft</td>
<td>Length of slab = 4.500 ft</td>
</tr>
<tr>
<td></td>
<td>( B ) = 8.458 ft</td>
<td>( D_{60} ) = 6.800 mm</td>
</tr>
<tr>
<td></td>
<td>Soil unit weight, ( \gamma_{soil} ) = 0.125 kcf</td>
<td>( D_{10} ) = 0.075 mm</td>
</tr>
<tr>
<td></td>
<td>Traffic surcharge, ( q ) = 0.25 ksf</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reinforcement fill, ( \phi ) = 34 degrees -&gt; 0.593 radians</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retained fill, ( \phi ) = 30 degrees -&gt; 0.524 radians</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Static load = 10 kips</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel</th>
<th>First strip location = 2.460 ft</th>
<th>Strip width = 1.969 in. = 0.164 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Location of slab bottom = 1.670 ft</td>
<td>Strip thickness = 4 mm = 0.013 ft</td>
</tr>
<tr>
<td></td>
<td>Vertical spacing of strips, ( S_v ) = 2.460 ft</td>
<td>Horizontal spacing of strip = 1.623 ft</td>
</tr>
<tr>
<td></td>
<td>Panel width = 4.870 ft</td>
<td>Steel Reinforcement Strength ( f_y ) = 60 ksi</td>
</tr>
<tr>
<td></td>
<td>Panel height = 4.854 ft</td>
<td>density of strip per panel = 6</td>
</tr>
<tr>
<td></td>
<td>Panel thickness = 0.458 ft</td>
<td></td>
</tr>
</tbody>
</table>

Load Factor, \( \gamma \) (LRFD 11.5.5)

1. Typical application
1.a. Bearing Resistance
\[ \gamma_{EV} = 1.35 \quad \gamma_{EH} = 1.5 \]
1.b. Sliding and Eccentricity
\[ \gamma_{EV} = 1 \quad \gamma_{EH} = 1.5 \]

2. Live Load Surcharge on MSE wall
2.a. Bearing and reinforcement tensile resistance
\[ \gamma_{LS} = 1.75 \]
2.b. Sliding, eccentricity and reinforcement pullout resistance
\[ \gamma_{LS} = 1.75 \]

(LRFD Figure C11.5.5-3(b))
Resistance Factor, $\phi$ (LRFD Table 11.5.6-1)

<table>
<thead>
<tr>
<th>Mechanically Stabilized Earth Walls</th>
<th>Pullout resistance of tensile reinforcement,</th>
<th>Static loading = 0.9</th>
<th>Combined static and impact loading = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Resistance of strip reinforcement,</td>
<td>Static loading = 0.75</td>
<td>Combined static and impact loading = 1</td>
<td></td>
</tr>
</tbody>
</table>

1. External Stability
1.1 Static Mass Stability

1.1.1 Vertical loads

1. Reinforced Soil

\[
V = \gamma_{soil} \times H \times L
\]

\[
V_1 = 0.125 \text{ (kcf)} \times 6.19 \text{ (ft)} \times 8 \text{ (ft)} = 6.190 \text{ kips/ft}
\]

\[
\gamma_{EV} \times V_1 = 1.35 \times V_1 = 8.357 \text{ kips/ft}
\]

Moment arm of $V_1 = 4 \text{ ft}$

\[
M_{v_1} = 6.19 \text{ (kips/ft)} \times 4 \text{ (ft)} = 24.760 \text{ ft-kips/ft}
\]

\[
\gamma_{EV} \times M_{v_1} = 1.35 \times M_{v_1} = 33.426 \text{ ft-kips/ft}
\]

2. Traffic surcharge

\[
V_2 = 0.25 \text{ (ksf)} \times 8 \text{ (ft)} = 2.000 \text{ kips/ft}
\]

\[
\gamma_{LS} \times V_2 = 1.75 \times V_2 = 3.500 \text{ kips/ft}
\]

Moment arm of $V_2 = 4 \text{ ft}$

\[
M_{v_2} = 2 \text{ (kips/ft)} \times 4 \text{ (ft)} = 8.000 \text{ ft-kips/ft}
\]

\[
\gamma_{LS} \times M_{v_2} = 1.750 \times M_{v_2} = 14.000 \text{ ft-kips/ft}
\]

\[
\sum V = 8.19 \text{ kips/ft}
\]

\[
\sum \gamma V = 11.86 \text{ kips/ft}
\]

\[
\sum M_v = 32.760 \text{ ft-kips/ft}
\]

\[
\sum \gamma M_v = 47.426 \text{ ft-kips/ft}
\]
1.1.2 Horizontal loads

1. Retained soil

\[ F_1 = \frac{1}{2} \times \gamma_{\text{soil}} \times H^2 \times K_{af} \]

\[ F_1 = \frac{1}{2} \times 0.125 \, (\text{kcf}) \times 38.316 \, (\text{ft}^2) \times 0.333 = 0.798 \, \text{kips/ft} \]

\[ \gamma_{EH} \times F_1 = 1.5 \times F_1 = 1.197 \, \text{kips/ft} \]

Moment arm of \( F_1 = \frac{6.19}{3} = 2.06 \, \text{ft} \)

\[ M_{F1} = 0.798 \, (\text{kips/ft}) \times 2.063 \, (\text{ft}) = 1.647 \, \text{ft-kips/ft} \]

\[ \gamma_{EH} \times M_{F1} = 1.5 \times M_{F1} = 2.471 \, \text{ft-kips/ft} \]

2. Traffic surcharge

\[ F_2 = q \times H \times K_{af} \]

\[ F_2 = 0.250 \, (\text{ksf}) \times 6.190 \, (\text{ft}) \times 0.333 = 0.516 \, \text{kips/ft} \]

\[ \gamma_{LS} \times F_2 = 1.5 \times F_2 = 0.774 \, \text{kips/ft} \]

Moment arm of \( V_2 = \frac{3.095}{3} = 1.032 \, \text{ft} \)

\[ M_{F2} = 0.51583 \, (\text{kips/ft}) \times 3.095 \, (\text{ft}) = 1.597 \, \text{ft-kips/ft} \]

\[ \gamma_{LS} \times M_{F2} = 1.5 \times M_{F2} = 2.395 \, \text{ft-kips/ft} \]

\[ \sum F = 1.31 \, \text{kips/ft} \]

\[ \sum \gamma F = 1.97 \, \text{kips/ft} \]

\[ \sum M_F = 3.244 \, \text{ft-kips/ft} \]

\[ \sum \gamma M_F = 4.865 \, \text{ft-kips/ft} \]

1.1.3 Sliding (LRFD 11.10.5.3)

Sliding without Load Factor:

\[ \sum V \times \tan \phi = 8.190 \times \tan 30 = 3.598 \]

\[ \sum F_H = 1.314 \]

Sliding with Load Factor:

\[ \sum \gamma_{EH} V \times \tan \phi = 11.857 \times \tan 30 = 3.473 \]

\[ \sum \gamma_{EH} F_H = 1.971 \]

1.1.4 Overturning (LRFD 11.10.5.3)

Overturning w/o Load Factor:

\[ \sum M_v = 32.760 = 10.100 \]

\[ \sum M_F = 3.244 \]

Overturning w/ Load Factor:

\[ \sum \gamma_{EH} M_v = 47.426 = 9.748 \]

\[ \sum \gamma_{EH} M_F = 4.865 \]

1.2 Bearing Capacity at Base

Eccentricity w/o Load Factor:

\[ L \times \left( \frac{1}{2} \right) \times \frac{-\sum M_v}{\sum V} - \frac{-\sum M_F}{2} \]

\[ = \frac{8}{2} \times \frac{-32.760}{8.190} - \frac{-3.244}{2} = 0.396 \]

Eccentricity w/ Load Factor:

\[ L \times \left( \frac{1}{2} \right) \times \frac{-\sum \gamma_{EH} M_v}{\sum \gamma_{EH} V} - \frac{-\sum \gamma_{EH} M_F}{2} \]

\[ = \frac{8}{2} \times \frac{-47.426}{11.857} - \frac{-4.865}{2} = 0.410 \]

\[ \leq \frac{B}{6} = 1.410 \, \text{ft} \]

OK
\[ \sigma_v \text{ w/o Load Factor } = \frac{\sum V}{(L-2e)(2e)} = \frac{8.19}{8 - 2 \times 0.39604} = 1.136 \text{ ksf} \]

\[ \sigma_v \text{ w/ Load Factor } = \frac{\sum \gamma_{EV} V}{(L-2e)(2e)} = \frac{11.86}{8 - 2 \times 0.41035} = 1.651 \text{ ksf} \]

2. Internal Stability
2.1 Static Load

2.1.1 Compute \( K_r \) (LRFD Figure 11.10.6.2.1-3)

\[ \gamma_{EH} K_r = 1.7 \times K_a = 1.7 \times 0.28 = 0.48 \text{ at 0 ft} \]

\[ \gamma_{EH} K_r = 1.2 \times K_a = 1.2 \times 0.28 = 0.34 \text{ under 20 ft} \]

Use interpolation at other depths.

2.1.2 First strip at \( h_1 = 2.46 \text{ ft} \)

\( h_1 = 2.46 \text{ ft} \)

\( k_r = 0.463 \)

1. Vertical stress

1) Reinforced Soil

\[ \sigma_{V1} = \gamma_{soil} \times H \]

\[ \sigma_{V1} = 0.125 \text{ (kcf)} \times 2.460 \text{ (ft)} = 0.308 \text{ kips/ft}^2 \]

\[ \gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.308 = 0.415 \text{ kips/ft}^2 \]

2) Traffic surcharge

\[ \sigma_{V2} = 0.25 \text{ ksf} \]

\[ \gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2 \]

a) ignoring traffic surcharge

b) including traffic surcharge

\[ \sum \sigma_v = 0.308 \text{ kips/ft}^2 \]

\[ \sum \gamma_{EV} \sigma_v = 0.415 \text{ kips/ft}^2 \]

2. Horizontal stress, \( \sigma_H = \gamma_p (\sigma_v k_r + \Delta \sigma_H) \) (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

\[ \sigma_h = \sigma_v k_r = 0.308 \text{ ksf} \times 0.463 = 0.142 \text{ ksf} \]

\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 0.415 \text{ ksf} \times 0.463 = 0.192 \text{ ksf} \]

\[ A_i \text{ per strip } = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 3 = 3.993 \text{ ft}^2 \]

\[ T_{max} = \sigma_H S_v = 0.142 \text{ ksf} \times 3.993 \text{ ft}^2 = 0.57 \text{ kips per strip} \]

\[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_H S_v = 0.192 \text{ ksf} \times 3.993 \text{ ft}^2 = 0.77 \text{ kips per strip} \]
b) including traffic surcharge

\[ \sigma_v = \sigma_k \times 0.558 \text{ ksf} \times 0.463 = 0.258 \text{ ksf} \]

\[ \gamma_E \sigma_v = \gamma_E \sigma_k \times 0.853 \text{ ksf} \times 0.463 = 0.395 \text{ ksf} \]

\[ \gamma_E \sigma_v = 0.558 \text{ ksf} \times 0.463 = 0.258 \text{ ksf} \]

\[ \gamma_E \sigma_v = 0.853 \text{ ksf} \times 0.463 = 0.395 \text{ ksf} \]

\[ \sigma_H = \sigma_v \times k_r = 0.258 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.03 \text{ kips per strip} \]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using \( L_e \) for static case

\[ P = F^* \alpha \sigma_v L_e C b = 1.138 \text{ kips} \]

\[ \phi P = 0.9 \times 1.138 = 1.025 \text{ kips} \]

2) using \( L \) for static + dynamic case

\[ P = F^* \alpha \sigma_v L C b = 1.483 \text{ kips} \]

\[ \phi P = 0.9 \times 1.483 = 1.334 \text{ kips} \]

a) \( F^* \) = 1.837 (LRFD Figure 11.10.6.3.2-1)

b) \( \alpha = 1 \) (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v = 0.125 \text{ (kcf)} \times 2.46 \text{ (ft)} = 0.3075 \text{ ksf} \)

d) \( L_e = 8 - 0.3 \times 6.19 = 6.143 \text{ ft} \) (LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C = 2 \) for strip (LRFD 11.10.6.3.2)

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the \( H/2 \), the location of max. tensile force is located in \( 0.3H \).

\[ \begin{align*}
0.3H &= 1.857 \text{ ft} \\
H/2 &= 3.095 \text{ ft} \\
L_{\text{max}} &= 1.857 \text{ ft}
\end{align*} \]
2.1.3 Second strip at $h_2 = 4.92$ ft

$h_1 = 4.920$ ft

$K_r = 0.446$

1. Vertical stress

1) Reinforced Soil

$$\sigma_{V1} = \gamma_{soil} \times H$$

$$\sigma_{V1} = 0.125 \text{ (kcf)} \times 4.920 \text{ (ft)} = 0.615 \text{ kips/ft}^2$$

$$\gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.615 = 0.830 \text{ kips/ft}^2$$

2) Traffic surcharge

$$\sigma_{V2} = 0.25 \text{ ksf}$$

$$\gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2$$

\[\text{a) ignoring traffic surcharge} \quad \quad \text{b) including traffic surcharge}\]

$$\sum \sigma_v = 0.615 \text{ kips/ft}^2$$

$$\sum \sigma_v = 0.865 \text{ kips/ft}^2$$

$$\sum \gamma_{EV}\sigma_v = 0.830 \text{ kips/ft}^2$$

$$\sum \gamma_{EV}\sigma_v = 1.268 \text{ kips/ft}^2$$

2. Horizontal stress, $\sigma_H = \gamma_p (\sigma_v k_r + \Delta \sigma_H)$ (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

$$\sigma_h = \sigma_v k_r = 0.615 \text{ ksf} \times 0.446 = 0.274 \text{ ksf}$$

$$\gamma_{EV}\sigma_h = \gamma_{EV}\sigma_v k_r = 0.830 \text{ ksf} \times 0.446 = 0.370 \text{ ksf}$$

$$A_t \text{ per strip} = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 3 = 3.993 \text{ ft}^2$$

$$\text{depth for } A_t \text{ at the second layer} = S_v = 2.460 \text{ ft}$$

$$T_{max} = \sigma_H S_v = 0.274 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.095 \text{ kips per strip}$$

$$\gamma_{EV}T_{max} = \gamma_{EV}\sigma_H S_v = 0.370 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.478 \text{ kips per strip}$$

b) including traffic surcharge

$$\sigma_h = \sigma_v k_r = 0.865 \text{ ksf} \times 0.446 = 0.386 \text{ ksf}$$

$$\gamma_{EV}\sigma_h = \gamma_{EV}\sigma_v k_r = 1.268 \text{ ksf} \times 0.446 = 0.565 \text{ ksf}$$

$$T_{max} = \sigma_H S_v = 0.386 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.54 \text{ kips per strip}$$

$$\gamma_{EV}T_{max} = \gamma_{EV}\sigma_H S_v = 0.565 \text{ ksf} \times 3.993 \text{ ft}^2 = 2.26 \text{ kips per strip}$$

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using $L_e$ for static case

$$P = F^* \alpha \sigma_v L e C b = 2.445 \text{ kips}$$

$$\phi P = 0.9 \times 2.44 = 2.200 \text{ kips}$$
2) using $L$ for static + dynamic case

$$P = F^* \alpha \sigma_v L C b = 2.702 \text{ kips}$$

$$\phi P = 0.9 \times 2.702 = 2.432 \text{ kips}$$

a) $F^*$

$$K_r = 2.000 \text{ at } 0 \text{ ft}$$

$$K_r = \tan \phi_f = 0.675 \text{ under } 20 \text{ ft}$$

Use interpolation at other depth

$$F^* = 1.674 \text{ (LRFD Figure 11.10.6.3.2-1)}$$

b) $\alpha = 1 \text{ (LRFD Table 11.10.6.3.2-1)}$

c) $\sigma_v = 0.125 \text{ (kcf)} \times 4.920 \text{ (ft)} = 0.615 \text{ ksf}$

d) $L_e = 7.238 \text{ ft} \text{ (LRFD Figure 11.10.2-1 and 11.10.10.1-2)}$

e) $C = 2 \text{ for stip (LRFD 11.10.6.3.2)}$

f) $b = 0.164 \text{ ft}$

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the $H/2$, the location of max. tensile force is located in $0.3H$.

$$L_{max.} = 0.762 \text{ ft}$$

2.1.4 Reinforcement Tensile Strength

1) 75.00 years Design Life

$$R = f_y \times A_{steel} = f_y \times (\text{Strip width} \times E_c)$$

$$= 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.102 \text{ in.}) = 12.016 \text{ kips}$$

$$\phi R = 0.75 \times 12.016 = 9.012 \text{ kips}$$

2) 100.00 years Design Life

$$R = f_y \times A_{steel} = f_y \times (\text{Strip width} \times E_c)$$

$$= 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.078 \text{ in.}) = 9.226 \text{ kips}$$

$$\phi R = 0.75 \times 9.226 = 6.919 \text{ kips}$$

For corrosion Losses

$$E_c = E_n - E_s \text{ (LRFD Eq. 11.10.6.4.2a-1)}$$

Zinc Coating Lift = 16 years

Loss of carbon steel = 0.012 mm/yr. after zinc depletion

1) 75.00 years Design Life

$$E_c = 4.00 \text{ mm} - 1.416 \text{ mm} = 2.584 \text{ mm} = 0.102 \text{ in.}$$

2) 100.00 years Design Life

$$E_c = 4.00 \text{ mm} - 2.016 \text{ mm} = 1.984 \text{ mm} = 0.078 \text{ in.}$$

2.1.5 Summary

1) Pullout - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>Rein Layer NO.</th>
<th>$Z$</th>
<th>$T$</th>
<th>$\gamma T$</th>
<th>$P$</th>
<th>$\phi R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.569</td>
<td>0.768</td>
<td>1.138</td>
<td>1.025</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.095</td>
<td>1.478</td>
<td>2.445</td>
<td>2.200</td>
</tr>
</tbody>
</table>
2) Tensile - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>NO.</th>
<th>75 year Design Life</th>
<th>100 year Design Life</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z (ft)</td>
<td>T (kips)</td>
</tr>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.569</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.095</td>
</tr>
</tbody>
</table>

2.2 Including Impact Load

<table>
<thead>
<tr>
<th>Load</th>
<th>Z (kips)</th>
<th>Z (ft)</th>
<th>γT (degrees)</th>
<th>γT (degrees)</th>
<th>tan(γT (degrees))</th>
<th>C (radian)</th>
<th>I (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.50</td>
<td>34</td>
<td>62</td>
<td>1.082</td>
<td>1.881</td>
<td>0.000</td>
<td>8.463</td>
</tr>
</tbody>
</table>

2.2.1 Tensile stress

5 ft => \( \sum F = 2 \text{ kpf} \)

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>/1</th>
<th>Δσh max</th>
<th>A₀</th>
<th>Timpact</th>
<th>γTimpact</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom of sl</td>
<td>1.670</td>
<td>8.463</td>
<td>0.473</td>
<td>3.993</td>
<td>1.711</td>
<td>1.711</td>
</tr>
<tr>
<td>1</td>
<td>2.460</td>
<td>7.673</td>
<td>0.429</td>
<td>3.993</td>
<td>1.711</td>
<td>1.711</td>
</tr>
<tr>
<td>2</td>
<td>4.920</td>
<td>5.213</td>
<td>0.291</td>
<td>3.993</td>
<td>1.163</td>
<td>1.163</td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Z (ft)</th>
<th>γT (kips)</th>
<th>γTimpact (kips)</th>
<th>Total γT (kips)</th>
<th>φR (kips)</th>
<th>φR (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.569</td>
<td>1.711</td>
<td>2.280</td>
<td>12.016</td>
<td>9.226</td>
</tr>
</tbody>
</table>
2.2.2 Pullout stress

\[ \sum F = \begin{array}{c} 0.5 \text{ kpf} \end{array} \]

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>( l / )</th>
<th>( \Delta \sigma_{\text{max}} )</th>
<th>( A_t )</th>
<th>( T_{\text{impact}} )</th>
<th>( \gamma T_{\text{impact}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom of sl</td>
<td>1.670</td>
<td>8.463</td>
<td>0.118</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.460</td>
<td>7.673</td>
<td>0.107</td>
<td>3.993</td>
<td>0.428</td>
<td>0.428</td>
</tr>
<tr>
<td>2</td>
<td>4.920</td>
<td>5.213</td>
<td>0.073</td>
<td>3.993</td>
<td>0.291</td>
<td>0.291</td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>( Z )</th>
<th>( \gamma T )</th>
<th>( \gamma T_{\text{impact}} )</th>
<th>Total ( \gamma T )</th>
<th>( \phi P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.569</td>
<td>0.428</td>
<td>0.997</td>
<td>1.483</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.095</td>
<td>0.291</td>
<td>1.386</td>
<td>2.702</td>
</tr>
</tbody>
</table>
2. 5-ft high MSE wall with 16-ft long strips design

<table>
<thead>
<tr>
<th>Wall</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall height, ( H ) =</td>
<td>6.190 ft</td>
<td>1/2 ( H ) =</td>
<td>3.095 ft</td>
</tr>
<tr>
<td>Reinforcing fill length, ( L ) =</td>
<td>16.000 ft</td>
<td>Length of slab =</td>
<td>4.500 ft</td>
</tr>
<tr>
<td>( B ) =</td>
<td>16.458 ft</td>
<td>( D_{60} ) =</td>
<td>6.800 mm</td>
</tr>
<tr>
<td>Soil unit weight, ( \gamma_{soil} ) =</td>
<td>0.125 kcf</td>
<td>( D_{10} ) =</td>
<td>0.075 mm</td>
</tr>
<tr>
<td>Traffic surcharge, ( q ) =</td>
<td>0.25 ksf</td>
<td>( \log C_u ) =</td>
<td>1.957</td>
</tr>
<tr>
<td>Reinforcement fill, ( \phi ) =</td>
<td>34 degrees ( \rightarrow ) 0.593 radians</td>
<td>(LRFD 11.10.6.2)</td>
<td>( \tan \phi ) =</td>
</tr>
<tr>
<td>Retained fill, ( \phi ) =</td>
<td>30 degrees ( \rightarrow ) 0.524 radians</td>
<td>( \tan \phi_f ) =</td>
<td>0.577 ( \rightarrow ) ( K_{af} ) =</td>
</tr>
<tr>
<td>Static load =</td>
<td>10 kips</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First strip location =</td>
<td>2.460 ft</td>
<td>Strip width =</td>
<td>1.969 in. = 0.164 ft</td>
</tr>
<tr>
<td>Location of slab bottom =</td>
<td>1.670 ft</td>
<td>Strip thickness =</td>
<td>4 mm = 0.013 ft</td>
</tr>
<tr>
<td>Vertical spacing of strips, ( S_v ) =</td>
<td>2.460 ft</td>
<td>Horizontal spacing of strip =</td>
<td>2.435 ft</td>
</tr>
<tr>
<td>Panel width =</td>
<td>4.870 ft</td>
<td>Steel Reinforcement Strength ( f_y ) =</td>
<td>60 ksi</td>
</tr>
<tr>
<td>Panel height =</td>
<td>4.854 ft</td>
<td>density of strip per panel =</td>
<td>4.000</td>
</tr>
<tr>
<td>Panel thickness =</td>
<td>0.458 ft</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Factor, ( \gamma ) (LRFD 11.5.5)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Typical application</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.a. Bearing Resistance</td>
<td>( \gamma_{EV} ) =</td>
<td>1.35</td>
<td>( \gamma_{EH} ) =</td>
</tr>
<tr>
<td>1.b. Sliding and Eccentricity</td>
<td>( \gamma_{EV} ) =</td>
<td>1</td>
<td>( \gamma_{EH} ) =</td>
</tr>
</tbody>
</table>

\[ \text{Figure C11.5.5-1 Typical Application of Load Factors for Bearing Resistance.} \]

\[ \text{Figure C11.5.5-2 Typical Application of Load Factors for Sliding and Eccentricity.} \]

2. Live Load Surcharge on MSE wall
2.a. Bearing and reinforcement tensile resistnace
\( \gamma_{LS} \) = 1.75
2.b. Sliding, eccentricity and reinforcement pullout resistance
\( \gamma_{LS} \) = 1.75

\[ \text{(LRFD Figure C11.5.5-3(b))} \]
Resistance Factor, $\phi$ (LRFD Table 11.5.6-1)

Mechanically Stabilized Earth Walls

Pullout resistance of tensile reinforcement, Static loading = 0.9
Combined static and impact loading = 1

Tensile Resistance of strip reinforcement, Static loading = 0.75
Combined static and impact loading = 1

1. External Stability
1.1 Static Mass Stability

1.1.1 Vertical loads
1. Reinforced Soil

\[ V = \gamma_{soil} \times H \times L \]

\[ V_1 = 0.125 \text{ (kcf)} \times 6.19 \text{ (ft)} \times 16 \text{ (ft)} = 12.380 \text{ kips/ft} \]

\[ \gamma_{EV} \times V_1 = 1.35 \times V_1 = 16.713 \text{ kips/ft} \]

Moment arm of $V_1 = 8 \text{ ft}$

\[ M_{v1} = 12.38 \text{ (kips/ft)} \times 8 \text{ (ft)} = 99.040 \text{ ft-kips/ft} \]

\[ \gamma_{EV} \times M_{v1} = 1.35 \times M_{v1} = 133.704 \text{ ft-kips/ft} \]

2. Traffic surcharge

\[ V_2 = 0.25 \text{ (ksf)} \times 16 \text{ (ft)} = 4.000 \text{ kips/ft} \]

\[ \gamma_{LS} \times V_2 = 1.75 \times V_2 = 7.000 \text{ kips/ft} \]

Moment arm of $V_2 = 8 \text{ ft}$

\[ M_{v2} = 4 \text{ (kips/ft)} \times 8 \text{ (ft)} = 32.000 \text{ ft-kips/ft} \]

\[ \gamma_{LS} \times M_{v2} = 1.750 \times M_{v2} = 56.000 \text{ ft-kips/ft} \]

\[ \sum V = 16.38 \text{ kips/ft} \]

\[ \sum \gamma V = 23.71 \text{ kips/ft} \]

\[ \sum M_v = 131.040 \text{ ft-kips/ft} \]

\[ \sum \gamma M_v = 189.704 \text{ ft-kips/ft} \]
1.1.2 Horizontal loads

1. Retained soil

\[ F_1 = \frac{1}{2} \times \gamma_{\text{soil}} \times H^2 \times K_{af} \]
\[ F_1 = \frac{1}{2} \times 0.125 \text{ (kcf)} \times 38.316 \text{ (ft}^2) \times 0.333 = 0.798 \text{ kips/ft} \]
\[ \gamma_{\text{EH}} \times F_1 = 1.5 \times F_1 = 1.197 \text{ kips/ft} \]

Moment arm of \( F_1 \) = \( \frac{6.19}{3} = 2.06 \text{ ft} \)

\[ M_{F1} = 0.798 \text{ (kips/ft)} \times 2.063 \text{ (ft)} = 1.647 \text{ ft-kips/ft} \]

2. Traffic surcharge

\[ F_2 = q \times H \times K_{af} \]
\[ F_2 = 0.250 \text{ (klsf)} \times 6.190 \text{ (ft)} \times 0.333 = 0.516 \text{ kips/ft} \]
\[ \gamma_{\text{LS}} \times F_2 = 1.5 \times F_2 = 0.774 \text{ kips/ft} \]

Moment arm of \( V_2 \) = \( 3.095 \text{ ft} \)

\[ M_{F2} = 0.51583 \text{ (kips/ft)} \times 3.095 \text{ (ft)} = 1.597 \text{ ft-kips/ft} \]

\[ \sum F = 1.31 \text{ kips/ft} \]
\[ \sum \gamma F = 1.97 \text{ kips/ft} \]

1.1.3 Sliding (LRFD 11.10.5.3)

Sliding without Load Factor = \[ \Sigma V \tan \phi = \frac{16.380 \times \tan 30}{1.314} = 7.197 \]

Sliding with Load Factor = \[ \sum \gamma_{\text{EH}} V \tan \theta = \frac{23.713 \times \tan 30}{1.971} = 6.946 \]

1.1.4 Overturning (LRFD 11.10.5.3)

Overturning w/o Load Factor = \[ \Sigma M_v = \frac{131.040}{3.244} = 40.400 \]

Overturning w/ Load Factor = \[ \sum \gamma_{\text{EH}} M_V = \frac{189.704}{4.865} = 38.991 \]

1.2 Bearing Capacity at Base

Eccentricity w/o Load Factor = \[ \frac{L}{2} - \frac{\sum M_v}{\Sigma V} - \frac{\sum M_f}{\Sigma V} \]
\[ \frac{16}{2} - \frac{131.040}{16.380} - \frac{3.244}{16.380} = 0.198 \]

Eccentricity w/ Load Factor = \[ \frac{L}{2} - \frac{\sum \gamma_{\text{EH}} M_v}{\Sigma \gamma_{\text{EH}} V} - \frac{\sum \gamma_{\text{EH}} M_f}{\Sigma \gamma_{\text{EH}} V} \]
\[ \frac{16}{2} - \frac{189.704}{23.713} - \frac{4.865}{23.713} = 0.205 \]

\[ \leq \frac{B}{6} = 2.743 \text{ ft} \quad \text{OK} \]
\[ \sigma_v \text{ w/o Load Factor } = \frac{\sum V}{(L-2e)} = \frac{16.38}{16 - 2 \times 0.19802} = 1.050 \text{ ksf} \]

\[ \sigma_v \text{ w/ Load Factor } = \frac{\sum \gamma_{EV} V}{(L-2e)} = \frac{23.71}{16 - 2 \times 0.20518} = 1.521 \text{ ksf} \]

### 2. Internal Stability
#### 2.1 Static Load

**2.1.1 Compute \( K_r \) (LRFD Figure 11.10.6.2.1-3)**

\[ \gamma_{EH} K_r = 1.7 \times K_a = 1.7 \times 0.28 = 0.48 \text{ at 0 ft} \]

\[ \gamma_{EH} K_r = 1.2 \times K_a = 1.2 \times 0.28 = 0.34 \text{ under 20 ft} \]

Use interpolation at other depth

**2.1.2 First strip at \( h_1 = 2.46 \text{ ft} \)**

\( h_1 = 2.46 \text{ ft} \)

\( k_r = 0.463 \)

1. Vertical stress
   
   *a) Reinforced Soil*
   
   \[ \sigma_{V1} = \gamma_{soil} \times H \]

   \[ \sigma_{V1} = 0.125 \text{ (kcf)} \times 2.460 \text{ (ft)} = 0.308 \text{ kips/ft}^2 \]

   \[ \gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.308 = 0.415 \text{ kips/ft}^2 \]

   *b) Traffic surcharge*

   \[ \sigma_{V2} = 0.25 \text{ ksf} \]

   \[ \gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2 \]

   a) ignoring traffic surcharge

   \[ \sum \sigma_v = 0.308 \text{ kips/ft}^2 \]

   b) including traffic surcharge

   \[ \sum \gamma_{EV} \sigma_v = 0.415 \text{ kips/ft}^2 \]

2. Horizontal stress, \( \sigma_H = \gamma_f (\sigma_v k_r + \Delta \sigma_H) \) (LRFD Eq. 11.10.6.2.1-1)

   a) ignoring traffic surcharge

   \[ \sigma_H = \sigma_v k_r = 0.308 \text{ ksf} \times 0.463 = 0.142 \text{ ksf} \]

   \[ \gamma_{EV} \sigma_H = 0.415 \text{ ksf} \times 0.463 = 0.192 \text{ ksf} \]

   \[ A_1 \text{ per strip } = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 2 = 5.990 \text{ ft}^2 \]

   \[ T_{max} = \sigma_H S_v = 0.142 \text{ ksf} \times 5.990 \text{ ft}^2 = 0.85 \text{ kips per strip} \]

   \[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_H S_v = 0.192 \text{ ksf} \times 5.990 \text{ ft}^2 = 1.15 \text{ kips per strip} \]
b) including traffic surcharge

\[ \sigma_h = \sigma_v k_r = 0.558 \text{ ksf} \times 0.463 = 0.258 \text{ ksf} \]

\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 0.853 \text{ ksf} \times 0.463 = 0.395 \text{ ksf} \]

\[ T_{max} = \sigma_h S_v = 0.258 \text{ ksf} \times 5.990 \text{ ft}^2 = 1.55 \text{ kips per strip} \]

\[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_h S_v = 0.395 \text{ ksf} \times 5.990 \text{ ft}^2 = 2.37 \text{ kips per strip} \]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using \( L_e \) for static case

\[ P = F^* \alpha \sigma_v L_e C b = 2.621 \text{ kips} \]

\[ \phi P = 0.9 \times 2.621 = 2.359 \text{ kips} \]

2) using \( L \) for static + dynamic case

\[ P = F^* \alpha \sigma_v L C b = 2.965 \text{ kips} \]

\[ \phi P = 0.9 \times 2.965 = 2.669 \text{ kips} \]

a) \( F^* \) Kr = 2.000 at 0 ft

\[ Kr = \tan \phi_f = 0.675 \text{ under 20 ft} \]

Use interpolation at other depth

\[ F^* = 1.837 \text{ (LRFD Figure 11.10.6.3.2-1)} \]

b) \( \alpha = 1 \) (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v = 0.125 \text{ (kcf)} \times 2.46 \text{ (ft)} = 0.3075 \text{ ksf} \)

d) \( L_e = L-H/3 = 16 - 0.3 \times 6.19 = 14.143 \text{ ft} \)

(LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C = 2 \text{ for strip} \) (LRFD 11.10.6.3.2)

f) \( b = 0.164 \text{ ft} \)

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the H/2, the location of max. tensile force is located in 0.3H.

\[ \begin{align*}
0.3H &= 1.857 \text{ ft} \\
H/2 &= 3.095 \text{ ft} \\
L_{max.} &= 1.857 \text{ ft}
\end{align*} \]
2.1.3 Second strip at \( h_2 = 4.92 \) ft

\( h_1 = 4.92 \) ft

\( K_r = 0.446 \)

1. Vertical stress

1) Reinforced Soil

\[
\sigma_{V1} = \gamma_{soil} \times H
\]

\[
\sigma_{V1} = 0.125 \text{ (kcf)} \times 4.920 \text{ (ft)} = 0.615 \text{ kips/ft}^2
\]

\[
\gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.615 = 0.830 \text{ kips/ft}^2
\]

2) Traffic surcharge

\[
\sigma_{V2} = 0.25 \text{ ksf}
\]

\[
\gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2
\]

a) ignoring traffic surcharge

\[
\sum \sigma_v = 0.615 \text{ kips/ft}^2 \]

b) including traffic surcharge

\[
\sum \gamma_{EV} \sigma_v = 0.830 \text{ kips/ft}^2
\]

\[
\sum \gamma_{EV} \sigma_v = 1.268 \text{ kips/ft}^2
\]

2. Horizontal stress, \( \sigma_{H} = \gamma_p (\sigma_v + \Delta \sigma_H) \) (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

\[
\sigma_h = \sigma_v k_r = 0.615 \text{ ksf} \times 0.446 = 0.274 \text{ ksf}
\]

\[
\gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 0.830 \text{ ksf} \times 0.446 = 0.370 \text{ ksf}
\]

At per strip = \( 4.870 \) (ft) \times 2.460 (ft) / 2 = \( 5.990 \) ft

depth for At at the second layer = \( S_v = 2.460 \) ft

\[
T_{max} = \sigma_{H} S_v = 0.274 \text{ ksf} \times 5.990 \text{ ft}^2 = 1.642 \text{ kips per strip}
\]

\[
\gamma_{EV} T_{max} = \gamma_{EV} \sigma_{H} S_v = 0.370 \text{ ksf} \times 5.990 \text{ ft}^2 = 2.217 \text{ kips per strip}
\]

b) including traffic surcharge

\[
\sigma_h = \sigma_v k_r = 0.865 \text{ ksf} \times 0.446 = 0.386 \text{ ksf}
\]

\[
\gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 1.268 \text{ ksf} \times 0.446 = 0.565 \text{ ksf}
\]

\[
T_{max} = \sigma_{H} S_v = 0.386 \text{ ksf} \times 5.990 \text{ ft}^2 = 2.31 \text{ kips per strip}
\]

\[
\gamma_{EV} T_{max} = \gamma_{EV} \sigma_{H} S_v = 0.565 \text{ ksf} \times 5.990 \text{ ft}^2 = 3.39 \text{ kips per strip}
\]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using \( L_e \) for static case

\[
P = F^* \alpha \sigma_v L_e C b = 5.147 \text{ kips}
\]

\[
\phi P = 0.9 \times 5.15 = 4.632 \text{ kips}
\]
2) using \( L \) for static + dynamic case

\[
P = \frac{F^* \alpha \sigma_v L C b}{P} = 5.404 \text{ kips}
\]

\[
\phi P = 0.9 \times 5.404 = 4.864 \text{ kips}
\]

a) \( F^* \)

\[
K_r = \text{tan} \phi_r = 2.000 \text{ at 0 ft}
\]

Use interpolation at other depth

\[
F^* = 1.674 \text{ (LRFD Figure 11.10.6.3.2-1)}
\]

b) \( \alpha = 1 \) (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v = 0.125 \text{ (kcf)} \times 4.920 \text{ (ft)} = 0.615 \text{ ksf} \)

d) \( L_e = 15.238 \text{ ft} \) (LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C = 2 \) for stip (LRFD 11.10.6.3.2)

f) \( b = 0.164 \text{ ft} \)

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the \( H/2 \), the location of max. tensile force is located in \( 0.3H \).

\[
0.3H = 1.857 \text{ ft} \quad H/2 = 3.095 \text{ ft}
\]

\[
L_{max.} = 0.762 \text{ ft}
\]

2.1.4 Reinforcement Tensile Strength

1) 75.00 years Design Life

\[
R = f_y \times A_{steel} = f_y \times (\text{Strip width} \times E_c)
\]

\[
= 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.102 \text{ in.} = 12.016 \text{ kips}
\]

\[
\phi R = 0.75 \times 12.016 = 9.012 \text{ kips}
\]

2) 100.00 years Design Life

\[
R = f_y \times A_{steel} = f_y \times (\text{Strip width} \times E_c)
\]

\[
= 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.078 \text{ in.} = 9.226 \text{ kips}
\]

\[
\phi R = 0.75 \times 9.226 = 6.919 \text{ kips}
\]

For corrosion losses

\[
E_c = E_o - E_x \text{ (LRFD Eq. 11.10.6.4.2a-1)}
\]

Zinc coating lift = 16 years

Loss of carbon steel = 0.012 mm/yr. after zinc depletion

1) 75.00 years Design Life

\[
E_c = 4.00 \text{ mm} - 1.416 \text{ mm} = 2.584 \text{ mm} = 0.102 \text{ in.}
\]

2) 100.00 years Design Life

\[
E_c = 4.00 \text{ mm} - 2.016 \text{ mm} = 1.984 \text{ mm} = 0.078 \text{ in.}
\]

2.1.5 Summary

1. Pullout - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>( Z )</th>
<th>( T )</th>
<th>( \gamma T )</th>
<th>( P )</th>
<th>( \phi P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.853</td>
<td>1.152</td>
<td>2.621</td>
<td>2.359</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.642</td>
<td>2.217</td>
<td>5.147</td>
<td>4.632</td>
</tr>
</tbody>
</table>
2. Tensile - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Z (ft)</th>
<th>T (kips)</th>
<th>γT (kips)</th>
<th>R (kips)</th>
<th>φR (kips)</th>
<th>R (kips)</th>
<th>φR (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.853</td>
<td>1.152</td>
<td>12.016</td>
<td>9.012</td>
<td>9.226</td>
<td>6.919</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.642</td>
<td>2.217</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Including Impact Load

<table>
<thead>
<tr>
<th>Load</th>
<th>B_r (length of)</th>
<th>f</th>
<th>45+(ϕ/2)</th>
<th>45+(ϕ/2)</th>
<th>tan(45+(ϕ/2))</th>
<th>C_r</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kips)</td>
<td>(ft)</td>
<td>(degrees)</td>
<td>(degrees)</td>
<td>radian</td>
<td>(ft)</td>
<td>(ft)</td>
</tr>
<tr>
<td>10</td>
<td>4.50</td>
<td>34</td>
<td>62</td>
<td>1.082</td>
<td>1.881</td>
<td>0.000</td>
<td>8.463</td>
</tr>
</tbody>
</table>

![](image.png)

*Layout of load on footing:

a. Distribution of stress for internal stability calculations.

2.2.1 Tensile stress

\[ \sum F = 2 \text{kpf} \]

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>h/1</th>
<th>Δσ_h max</th>
<th>A_t</th>
<th>T_impact</th>
<th>γT_impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bottom of s/c</td>
<td>1.670</td>
<td>8.463</td>
<td>0.473</td>
<td>5.990</td>
<td>2.567</td>
<td>2.567</td>
</tr>
<tr>
<td>1</td>
<td>2.460</td>
<td>7.673</td>
<td>0.429</td>
<td>5.990</td>
<td>1.744</td>
<td>1.744</td>
</tr>
<tr>
<td>2</td>
<td>4.920</td>
<td>5.213</td>
<td>0.291</td>
<td>5.990</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Z (ft)</th>
<th>γT (kips)</th>
<th>γT_impact (kips)</th>
<th>Total γT (kips)</th>
<th>φR (kips)</th>
<th>φR (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.853</td>
<td>2.567</td>
<td>3.420</td>
<td>12.016</td>
<td>9.226</td>
</tr>
</tbody>
</table>
### 2.2.2 Pullout stress

\[ \sum F = 0.5 \text{kpf} \]

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>( h )</th>
<th>( \Delta \sigma_{h, \text{max}} )</th>
<th>( A_t )</th>
<th>( T_{\text{impact}} )</th>
<th>( \gamma T_{\text{impact}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottom of sk</td>
<td>1.670</td>
<td>8.463</td>
<td>0.118</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.460</td>
<td>7.673</td>
<td>0.107</td>
<td>5.990</td>
<td>0.642</td>
<td>0.642</td>
</tr>
<tr>
<td>2</td>
<td>4.920</td>
<td>5.213</td>
<td>0.073</td>
<td>5.990</td>
<td>0.436</td>
<td>0.436</td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>( Z )</th>
<th>( \gamma T )</th>
<th>( \gamma T_{\text{impact}} )</th>
<th>( \phi P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.46</td>
<td>0.853</td>
<td>0.642</td>
<td>1.495</td>
</tr>
<tr>
<td>2</td>
<td>4.92</td>
<td>1.642</td>
<td>0.436</td>
<td>2.078</td>
</tr>
</tbody>
</table>
### 3. 10-ft high MSE wall with 10-ft long strips design

**Wall**

- **Wall height**, $H = 9.15$ ft
- **1/2 H** = 4.575 ft
- **Reinforcing fill length**, $L = 10$ ft
- **Length of slab** = 4.500 ft
- **B** = 10.458 ft
- **D** = 0.250 mm
- **C** = 0.643
- **Soil unit weight**, $\gamma_{soil} = 0.125$ kfc
- **Traffic surcharge**, $q = 0.25$ ksf
- **Reinforcement fill, $\phi = 34$ degrees**
- **Retained fill, $\phi = 30$ degrees**
- **Static load** = 10 kips

**Panel**

- **First strip location** = 3.000 ft
- **Strip width** = 1.969 in. = 0.164 ft
- **Location of slab bottom** = 2.000 ft
- **Strip thickness** = 4 mm = 0.013 ft
- **Vertical spacing of strips, $S_v$** = 2.460 ft
- **Horizontal spacing of strip** = 1.623 ft
- **Panel width** = 4.870 ft
- **Panel height** = 4.854 ft
- **Panel thickness** = 0.458 ft
- **Steel Reinforcement Strength $f_y = 60$ ksi
- **Density of strip per panel** = 6

---

**Diagram:**

- **TL 3**
- **Accelerometer:** 2 (3: on the Panel, 10: on the Strips)
- **Strain Gages:** 13
- **Tape Switch:** 1
- **Displacement Bars:** 5

**Level-Up Concrete**

- **2 5/8"**
- **5"**

**Tape Switch**

**Displacement Bar**

**3/4" BEARING PAD**

**3/16" RUBBER SHIM** (2 PER PANEL)

**6"x12" UNREINFORCED CONCRETE LEVELING PAD**

---

*Note: Diagram not fully transcribed; key elements are highlighted.*
Load Factor, $\gamma$ (LRFD 11.5.5)

1. Typical application
   1.a. Bearing Resistance
   \[ \gamma_{EV} = 1.35 \quad \gamma_{EH} = 1.5 \]

1.b. Sliding and Eccentricity
   \[ \gamma_{EV} = 1 \quad \gamma_{EH} = 1.5 \]

2. Live Load Surcharge on MSE wall
   2.a. Bearing and reinforcement tensile resistance
   \[ \gamma_{LS} = 1.75 \]

2.b. Sliding, eccentricity and reinforcement pullout resistance
   \[ \gamma_{LS} = 1.75 \]

   (LRFD Figure C11.5.5-3(b))

Resistance Factor, $\phi$ (LRFD Table 11.5.6-1)

<table>
<thead>
<tr>
<th>Mechanically Stabilized Earth Walls</th>
<th>Static loading</th>
<th>Combined static and impact loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pullout resistance of tensile reinforcement,</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>Tensile Resistance of strip reinforcement,</td>
<td>0.75</td>
<td>1</td>
</tr>
</tbody>
</table>
1. External Stability

1.1 Static Mass Stability

1.1.1 Vertical loads

1. Reinforced Soil

\[ V = \gamma_{soil} \times H \times L \]

\[ V_1 = 0.125 \text{(kcf)} \times 9.15 \text{(ft)} \times 10 \text{(ft)} = 11.438 \text{kips/ft} \]

\[ \gamma_{EV} \times V_1 = 1.35 \times V_1 = 15.441 \text{kips/ft} \]

Moment arm of \( V_1 \) = 5 ft

\[ M_{V1} = 11.44 \text{(kips/ft)} \times 5 \text{(ft)} = 57.188 \text{ft-kips/ft} \]

\[ \gamma_{EV} \times M_{V1} = 1.35 \times M_{V1} = 77.203 \text{ft-kips/ft} \]

2. Traffic surcharge

\[ V_2 = 0.25 \text{(ksf)} \times 10 \text{(ft)} = 2.500 \text{kips/ft} \]

\[ \gamma_{LS} \times V_2 = 1.75 \times V_2 = 4.375 \text{kips/ft} \]

Moment arm of \( V_2 \) = 5 ft

\[ M_{V2} = 2.5 \text{(kips/ft)} \times 5 \text{(ft)} = 12.500 \text{ft-kips/ft} \]

\[ \gamma_{LS} \times M_{V2} = 1.750 \times M_{V2} = 21.875 \text{ft-kips/ft} \]

\[ \Sigma V = 13.94 \text{kips/ft} \]

\[ \Sigma \gamma V = 19.82 \text{kips/ft} \]

\[ \Sigma M_v = 69.688 \text{ft-kips/ft} \]

\[ \Sigma \gamma M_v = 99.078 \text{ft-kips/ft} \]

1.1.2 Horizontal loads

1. Retained soil

\[ F_1 = \frac{1}{2} \times \gamma_{soil} \times H^2 \times Kaf \]

\[ F_1 = \frac{1}{2} \times 0.125 \text{(kcf)} \times 83.723 \text{(ft)}^2 \times 0.333 = 1.744 \text{kips/ft} \]

\[ \gamma_{EH} \times F_1 = 1.5 \times F_1 = 2.616 \text{kips/ft} \]

Moment arm of \( F_1 \) = \( 9.15 / 3 = 3.05 \) ft

\[ M_{F1} = 1.744 \text{(kips/ft)} \times 3.050 \text{(ft)} = 5.320 \text{ft-kips/ft} \]

\[ \gamma_{EH} \times M_{F1} = 1.5 \times M_{F1} = 7.980 \text{ft-kips/ft} \]
2. Traffic surcharge

\[ F_2 = q \times H \times Kf \]

\[ F_2 = 0.250 \text{ (ksf)} \times 9.150 \text{ (ft)} \times 0.333 = 0.763 \text{ kips/ft} \]

\[ \gamma_{LS} \times F_2 = 1.5 \times F_2 = 1.144 \text{ kips/ft} \]

Moment arm of V2 = 4.575 ft

\[ M_{F2} = 0.7625 \text{ (kips/ft)} \times 4.575 \text{ (ft)} = 3.488 \text{ ft-kips/ft} \]

\[ \gamma_{LS} \times M_{F2} = 1.5 \times M_{F2} = 5.233 \text{ ft-kips/ft} \]

\[ \sum F = 2.51 \text{ kips/ft} \]

\[ \sum \gamma F = 3.76 \text{ kips/ft} \]

\[ \sum M_F = 8.808 \text{ ft-kips/ft} \]

\[ \sum \gamma M_F = 13.212 \text{ ft-kips/ft} \]

1.1.3 Sliding (LRFD 11.10.5.3)

Sliding without Load Factor:

\[ \sum V \times \tan \phi = \frac{13.938 \times \tan 30}{2.507} = 3.210 \]

Sliding with Load Factor:

\[ \sum \gamma EV \times \tan \phi = \frac{19.816 \times \tan 30}{3.760} = 3.043 \]

1.1.4 Overturning (LRFD 11.10.5.3)

Overturning w/o Load Factor:

\[ \sum M_v = \frac{69.688}{8.808} = 7.912 \]

Overturning w/ Load Factor:

\[ \sum \gamma EV M_v = \frac{99.078}{13.212} = 7.499 \]

1.2 Bearing Capacity at Base

Eccentricity w/o Load Factor:

\[ \frac{L}{2} - \frac{\sum M_v}{\sum V} - \frac{\sum M_F}{2} \]

\[ = \frac{10}{2} - \frac{69.688}{13.938} - \frac{8.808}{2} = 0.632 \]

Eccentricity w/ Load Factor:

\[ \frac{L}{2} - \frac{\sum \gamma EV M_v}{\sum \gamma EV V} - \frac{\sum \gamma EH M_F}{2} \]

\[ = \frac{10}{2} - \frac{99.078}{19.816} - \frac{13.212}{2} = 0.667 \]

\[ \leq \frac{B}{6} = 1.743 \text{ ft} \quad \text{OK} \]

\[ \sigma_v \text{ w/o Load Factor} = \frac{\sum V}{(L-2e) \times 10 - 2 \times 0.63199} = 1.595 \text{ ksf} \]

\[ \sigma_v \text{ w/ Load Factor} = \frac{\sum \gamma EV V}{(L-2e) \times 10 - 2 \times 0.6667} = 2.286 \text{ ksf} \]
2. Internal Stability
2.1 Static Load

2.1.1 Compute $K_r$ (LRFD Figure 11.10.6.2.1-3)

$\gamma_{EH} K_r = 1.7 \times K_a = 1.7 \times 0.28 = 0.48$ at 0 ft

$\gamma_{EH} K_r = 1.2 \times K_a = 1.2 \times 0.28 = 0.34$ under 20 ft

Use interpolation at other depth

2.1.2 First strip at $h_1 = 3.00$ ft

$h_1 = 3.00$ ft

$K_r = 0.459$

1. Vertical stress

1) Reinforced Soil

$\sigma_{V1} = \gamma_{soil} = 0.125 \text{ (kcf)} \times 3.000 \text{ (ft)} = 0.375 \text{ kips/ft}^2$

$\gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.375 = 0.506 \text{ kips/ft}^2$

2) Traffic surcharge

$\sigma_{V2} = 0.25 \text{ ksf}$

$\gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2$

2. Horizontal stress, $\sigma_H = \gamma_H (\sigma_V K_r + \Delta \sigma_H)$ (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

$\sigma_h = \sigma_v K_r = 0.375 \text{ ksf} \times 0.459 = 0.172 \text{ ksf}$

$\gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v K_r = 0.506 \text{ ksf} \times 0.459 = 0.233 \text{ ksf}$

$A_h \text{ per strip} = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 3 = 3.993 \text{ ft}^2$

$T_{max} = \sigma_h S_v = 0.172 \text{ ksf} \times 3.993 \text{ ft}^2 = 0.69 \text{ kips per strip}$

$\gamma_{EV} T_{max} = \gamma_{EV} \sigma_h S_v = 0.233 \text{ ksf} \times 3.993 \text{ ft}^2 = 0.93 \text{ kips per strip}$

---

A-23
b) Including traffic surcharge

\[ \sigma_h = \sigma_v k_r = 0.625 \text{ ksf} \times 0.459 = 0.287 \text{ ksf} \]

\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 0.944 \text{ ksf} \times 0.459 = 0.434 \text{ ksf} \]

\[ T_{max} = \sigma_H S_v = 0.287 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.15 \text{ kips per strip} \]

\[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_H S_v = 0.434 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.73 \text{ kips per strip} \]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

![Image](image.png)

**1) Using \( L_e \) for static case**

\[ P = F^* \alpha \sigma_v L_e C b = 1.489 \text{ kips} \]

\[ \phi P = 0.9 \times 1.489 = 1.340 \text{ kips} \]

**2) Using \( L \) for static + dynamic case**

\[ P = F^* \alpha \sigma_v L C b = 2.052 \text{ kips} \]

\[ \phi P = 0.9 \times 2.052 = 1.847 \text{ kips} \]

a) \( F^* \)

\[ K_r = 1.843 \text{ at } 0 \text{ ft} \]

\[ K_r = \tan \phi_f = 0.675 \text{ under } 20 \text{ ft} \]

Use interpolation at other depth

\[ F^* = 1.668 \text{ (LRFD Figure 11.10.6.3.2-1)} \]

b) \( \alpha = 1 \) (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v = 0.125 \text{ (kcf)} \times 3.00 \text{ (ft)} = 0.375 \text{ ksf} \)

d) \( L_e = L - H/3 = 10 - 0.3 \times 9.15 = 7.255 \text{ ft} \)

(LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C = 2 \) for strip (LRFD 11.10.6.3.2)

f) \( b = 0.164 \text{ ft} \)

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the \( H/2 \), the location of max. tensile force is located in 0.3H.

\[ 0.3H = 2.745 \text{ ft} \quad H/2 = 4.575 \text{ ft} \]

\[ L_{max} = 2.745 \text{ ft} \]
2.1.3 Second strip at \( h_2 = 5.46 \) ft

\( h_1 = 5.46 \) ft
\( K_r = 0.442 \)

1. Vertical stress

1) Reinforced Soil

\[ \sigma_{V1} = \gamma_{soil} \times H \]
\[ \sigma_{V1} = 0.125 \text{ (kcf)} \times 5.460 \text{ (ft)} = 0.683 \text{ kips/ft}^2 \]
\[ \gamma_{EV} \times \sigma_{V1} = 1.35 \times 0.683 = 0.921 \text{ kips/ft}^2 \]

2) Traffic surcharge

\[ \sigma_{V2} = 0.25 \text{ ksf} \]
\[ \gamma_{EV} \times \sigma_{V2} = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2 \]

a) ignoring traffic surcharge

\[ \sum \sigma_v = 0.683 \text{ kips/ft}^2 \]
\[ \sum \gamma_{EV} \sigma_v = 0.921 \text{ kips/ft}^2 \]

b) including traffic surcharge

\[ \sum \sigma_v = 0.933 \text{ kips/ft}^2 \]
\[ \sum \gamma_{EV} \sigma_v = 1.359 \text{ kips/ft}^2 \]

2. Horizontal stress, \( \sigma_H = \gamma_p (\sigma_v K_r + \Delta \sigma_H) \) (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

\[ \sigma_h = \sigma_v K_r = 0.683 \text{ ksf} \times 0.442 = 0.302 \text{ ksf} \]
\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v K_r = 0.921 \text{ ksf} \times 0.442 = 0.407 \text{ ksf} \]

\[ A_t \text{ per strip} = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 3 = 3.993 \text{ ft}^2 \]

\[ S_v = 2.460 \text{ ft} \]

\[ T_{max} = \sigma_H S_v = 0.302 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.205 \text{ kips per strip} \]
\[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_H S_v = 0.407 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.626 \text{ kips per strip} \]

b) including traffic surcharge

\[ \sigma_h = \sigma_v K_r = 0.933 \text{ ksf} \times 0.442 = 0.412 \text{ ksf} \]
\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v K_r = 1.359 \text{ ksf} \times 0.442 = 0.601 \text{ ksf} \]

\[ T_{max} = \sigma_H S_v = 0.412 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.65 \text{ kips per strip} \]
\[ \gamma_{EV} T_{max} = \gamma_{EV} \sigma_H S_v = 0.601 \text{ ksf} \times 3.993 \text{ ft}^2 = 2.40 \text{ kips per strip} \]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using \( L_e \) for static case

\[ P = F^* \alpha \sigma_v L_e C b = 2.658 \text{ kips} \]
\[ \phi P = 0.9 \times 2.66 = 2.392 \text{ kips} \]
2) using L for static + dynamic case

\[ P = F^* \alpha \sigma_v L C b = 3.413 \text{ kips} \]

\[ \phi P = 0.9 \times 3.413 = 3.072 \text{ kips} \]

a) \( F^* \)

\[ K_r = 1.843 \text{ at } 0 \text{ ft} \]

\[ K_r = \tan \phi_f = 0.675 \text{ under } 20 \text{ ft} \]

Use interpolation at other depth

\[ F^* = 1.524 \text{ (LRFD Figure 11.10.6.3.2-1)} \]

b) \( \alpha = 1 \) (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v = 0.125 \text{ (kcf)} \times 5.460 \text{ (ft)} = 0.683 \text{ ksf} \)

d) \( L_e = 7.786 \text{ ft} \) (LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C = 2 \) for stip (LRFD 11.10.6.3.2)

f) \( b = 0.164 \text{ ft} \)

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the \( H/2 \), the location of max. tensile force is located in \( 0.3H \).

\[ 0.3H = 2.745 \text{ ft} \quad H/2 = 4.575 \text{ ft} \]

\( L_{\text{max.}} = 2.214 \text{ ft} \)

2.1.4 Third strip at \( h_3 = 7.920 \text{ ft} \)

\( h_1 = 7.920\text{ ft} \)

\( K_r = 0.425 \)

1. Vertical stress

1) Reinforced Soil

\[ \sigma_v = \gamma_{\text{soil}} \times H \]

\[ \sigma_v = 0.125 \text{ (kcf)} \times 7.920 \text{ (ft)} = 0.990 \text{ kips/ft}^2 \]

\[ \gamma_{\text{EV}} \times \sigma_v = 1.35 \times 0.990 = 1.337 \text{ kips/ft}^2 \]

2) Traffic surcharge

\[ \sigma_v = 0.25 \text{ ksf} \]

\[ \gamma_{\text{EV}} \times \sigma_v = 1.75 \times 0.25 = 0.438 \text{ kips/ft}^2 \]

\[ \Sigma \sigma_v = 0.990 \text{ kips/ft}^2 \quad \Sigma \sigma_v = 1.240 \text{ kips/ft}^2 \]

\[ \Sigma \gamma_{\text{EV}} \sigma_v = 1.337 \text{ kips/ft}^2 \quad \Sigma \gamma_{\text{EV}} \sigma_v = 1.774 \text{ kips/ft}^2 \]

2. Horizontal stress, \( \sigma_h = \gamma_{\text{EV}} (\sigma_v k_r + \Delta \sigma_{\text{H}}) \) (LRFD Eq. 11.10.6.2.1-1)

a) ignoring traffic surcharge

\[ \sigma_h = \sigma_v k_r = 0.990 \text{ ksf} \times 0.425 = 0.420 \text{ ksf} \]

\[ \gamma_{\text{EV}} \sigma_h = \gamma_{\text{EV}} \sigma_v k_r = 1.337 \text{ ksf} \times 0.425 = 0.568 \text{ ksf} \]

\[ A_t \text{ per strip} = 4.870 \text{ (ft)} \times 2.460 \text{ (ft)} / 3 = 3.993 \text{ ft}^2 \]

\[ \text{depth for } A_t \text{ at the second layer} = S_v / 2 + 1.23 = 1.230 + 1.230 = 2.460 \text{ ft} \]
\[ T_{\text{max}} = \sigma_H S_v = 0.420 \text{ ksf} \times 3.993 \text{ ft}^2 = 1.679 \text{ kips per strip} \]
\[ \gamma_{EV} T_{\text{max}} = \gamma_{EV} \sigma_H S_v = 0.568 \text{ ksf} \times 3.993 \text{ ft}^2 = 2.266 \text{ kips per strip} \]

b) including traffic surcharge

\[ \sigma_h = \sigma_v k_r = 1.240 \text{ ksf} \times 0.425 = 0.527 \text{ ksf} \]
\[ \gamma_{EV} \sigma_h = \gamma_{EV} \sigma_v k_r = 1.774 \text{ ksf} \times 0.425 = 0.753 \text{ ksf} \]

\[ T_{\text{max}} = \sigma_H S_v = 0.527 \text{ ksf} \times 3.993 \text{ ft}^2 = 2.10 \text{ kips per strip} \]
\[ \gamma_{EV} T_{\text{max}} = \gamma_{EV} \sigma_H S_v = 0.753 \text{ ksf} \times 3.993 \text{ ft}^2 = 3.01 \text{ kips per strip} \]

3. Resistance in friction of one strip against soil (LRFD Equation 11.10.6.3.2-1)

1) using \( L_e \) for static case

\[ P = F^* \alpha \sigma_v L_e C b = 4.153 \text{ kips} \]
\[ \phi P = 0.9 \times 4.15 = 3.738 \text{ kips} \]

2) using \( L \) for static + dynamic case

\[ P = F^* \alpha \sigma_v L C b = 4.484 \text{ kips} \]
\[ \phi P = 0.9 \times 4.484 = 4.036 \text{ kips} \]

a) \( F^* \)

\[ K_r = 1.843 \text{ at } 0 \text{ ft} \]
\[ K_r = \tan \phi_f = 0.675 \text{ under } 20 \text{ ft} \]
Use interpolation at other depth
\[ F^* = 1.381 \] (LRFD Figure 11.10.6.3.2-1)

b) \( \alpha \)

\[ 1 \] (LRFD Table 11.10.6.3.2-1)

c) \( \sigma_v \)

\[ 0.125 \text{ (kcf)} \times 7.920 \text{ (ft)} = 0.990 \text{ ksf} \]

d) \( L_e \)

\[ 9.262 \text{ ft} \] (LRFD Figure 11.10.2-1 and 11.10.10.1-2)

e) \( C \)

\[ 2 \text{ for stip} \] (LRFD 11.10.6.3.2)

f) \( b \)

\[ 0.164 \text{ ft} \]

4. Location of Maximum Tensile Force (LRFD Figure 11.10.10.1-2)

If the height of reinforcement layer is above the \( H/2 \), the location of max. tensile force is located in 0.3H.

\[ 0.3H = 2.75 \text{ ft} \]
\[ H/2 = 4.58 \text{ ft} \]
\[ L_{\text{max.}} = 0.74 \text{ ft} \]

2.1.5 Reinforcement Tensile Strength

1) 75.00 years Design Life

\[ R = f_y \times A_{\text{steel}} = f_y \times (\text{Strip width} \times E_c) \]
\[ = 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.102 \text{ in.}) = 12.016 \text{ kips} \]
\[ \phi R = 0.75 \times 12.016 = 9.012 \text{ kips} \]
2) 100.00 years Design Life
\[ R = f_y \times A_{steel} = f_y \times (\text{Strip width} \times E_c) \]
\[ = 60.00 \text{ ksi} \times (1.969 \text{ in.} \times 0.078) \text{ in.} = 9.226 \text{ kips} \]
\[ \phi R = 0.75 \times 9.226 = 6.919 \text{ kips} \]

For corrosion losses
\[ E_c = E_n - E_d \text{ (LRFD Eq. 11.10.6.4.2a-1)} \]
Zinc Coating Lift = 16 years
Loss of carbon steel = 0.012 mm/yr. after zinc depletion
1) 75.00 years Design Life
\[ E_c = 4.00 \text{ mm} - 1.416 \text{ mm} = 2.584 \text{ mm} = 0.102 \text{ in.} \]
2) 100.00 years Design Life
\[ E_c = 4.00 \text{ mm} - 2.016 \text{ mm} = 1.984 \text{ mm} = 0.078 \text{ in.} \]

2.1.6 Summary

1) Pullout - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Z</th>
<th>T</th>
<th>( \gamma T )</th>
<th>P</th>
<th>( \phi P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO. (ft)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.00</td>
<td>0.688</td>
<td>0.929</td>
<td>1.489</td>
<td>1.340</td>
</tr>
<tr>
<td>2</td>
<td>5.46</td>
<td>1.205</td>
<td>1.626</td>
<td>2.658</td>
<td>2.392</td>
</tr>
<tr>
<td>3</td>
<td>7.92</td>
<td>1.679</td>
<td>2.266</td>
<td>4.153</td>
<td>3.738</td>
</tr>
</tbody>
</table>

2) Tensile - ignoring traffic surcharge

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Z</th>
<th>T</th>
<th>( \gamma T )</th>
<th>R</th>
<th>( \phi R )</th>
<th>R</th>
<th>( \phi R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO. (ft)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.00</td>
<td>0.688</td>
<td>0.929</td>
<td>12.016</td>
<td>9.012</td>
<td>9.226</td>
<td>6.919</td>
</tr>
<tr>
<td>2</td>
<td>5.46</td>
<td>1.205</td>
<td>1.626</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7.92</td>
<td>1.679</td>
<td>2.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Including Impact Load

<table>
<thead>
<tr>
<th>(kips)</th>
<th>(ft)</th>
<th>(degrees)</th>
<th>(degrees)</th>
<th>radian</th>
<th>(ft)</th>
<th>(ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.50</td>
<td>34</td>
<td>62</td>
<td>1.082</td>
<td>1.881</td>
<td>0.000</td>
</tr>
</tbody>
</table>

\[ \Delta \theta_{max} = 2 \frac{\Sigma F}{l} \]
\[ \Sigma F = q + F_1 + F_2 \]
\[ \Sigma F_1 = \text{lateral force due to earth pressure} \]
\[ F_z + \text{lateral force due to traffic surcharge} \]
\[ q_{\text{load}} + \text{lateral force due to} \]
\[ \text{superstructure or other} \]
\[ \text{concentrated lateral loads} \]

\( a \) Distribution of stress for internal stability calculations.
### 2.2.1 Tensile stress

\[ \sum F = 2 \text{kpf} \]

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>(l_1)</th>
<th>(\Delta \sigma_{h\ max})</th>
<th>(A_t)</th>
<th>(T_{\text{impact}})</th>
<th>(\gamma T_{\text{impact}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>(ft)</td>
<td>(ft)</td>
<td>(ksf)</td>
<td>(ft(^2))</td>
<td>(kips)</td>
<td>(kips)</td>
</tr>
<tr>
<td>bottom of sl</td>
<td>2.000</td>
<td>8.463</td>
<td>0.473</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.000</td>
<td>7.463</td>
<td>0.417</td>
<td>3.993</td>
<td>1.664</td>
<td>1.664</td>
</tr>
<tr>
<td>2</td>
<td>5.460</td>
<td>5.003</td>
<td>0.279</td>
<td>3.993</td>
<td>1.116</td>
<td>1.116</td>
</tr>
<tr>
<td>3</td>
<td>7.920</td>
<td>2.543</td>
<td>0.142</td>
<td>3.993</td>
<td>0.567</td>
<td>0.567</td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>(Z)</th>
<th>(\gamma T)</th>
<th>(\gamma T_{\text{impact}})</th>
<th>(\text{Total} \gamma T)</th>
<th>(\phi R)</th>
<th>(\phi R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>(ft)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.688</td>
<td>1.664</td>
<td>2.352</td>
<td>12.016</td>
<td>9.226</td>
</tr>
<tr>
<td>2</td>
<td>5.46</td>
<td>1.205</td>
<td>1.116</td>
<td>2.320</td>
<td>12.016</td>
<td>9.226</td>
</tr>
<tr>
<td>3</td>
<td>7.92</td>
<td>1.679</td>
<td>0.567</td>
<td>2.246</td>
<td>12.016</td>
<td>9.226</td>
</tr>
</tbody>
</table>

### 2.2.2 Pullout stress

\[ \sum F = 0.5 \text{kpf} \]

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>Layer</th>
<th>(l_1)</th>
<th>(\Delta \sigma_{h\ max})</th>
<th>(A_t)</th>
<th>(T_{\text{impact}})</th>
<th>(\gamma T_{\text{impact}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>(ft)</td>
<td>(ft)</td>
<td>(ksf)</td>
<td>(ft(^2))</td>
<td>(kips)</td>
<td>(kips)</td>
</tr>
<tr>
<td>bottom of sl</td>
<td>2.000</td>
<td>8.463</td>
<td>0.118</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3.000</td>
<td>7.463</td>
<td>0.104</td>
<td>3.993</td>
<td>0.416</td>
<td>0.416</td>
</tr>
<tr>
<td>2</td>
<td>5.460</td>
<td>5.003</td>
<td>0.070</td>
<td>3.993</td>
<td>0.279</td>
<td>0.279</td>
</tr>
<tr>
<td>3</td>
<td>7.920</td>
<td>2.543</td>
<td>0.036</td>
<td>3.993</td>
<td>0.142</td>
<td>0.142</td>
</tr>
</tbody>
</table>

* Summary of Total

<table>
<thead>
<tr>
<th>Rein. Layer</th>
<th>(Z)</th>
<th>(\gamma T)</th>
<th>(\gamma T_{\text{impact}})</th>
<th>(\text{Total} \gamma T)</th>
<th>(\phi P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.</td>
<td>(ft)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
<td>(kips)</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.688</td>
<td>0.416</td>
<td>1.104</td>
<td>2.052</td>
</tr>
<tr>
<td>2</td>
<td>5.46</td>
<td>1.205</td>
<td>0.279</td>
<td>1.484</td>
<td>3.413</td>
</tr>
<tr>
<td>3</td>
<td>7.92</td>
<td>1.679</td>
<td>0.142</td>
<td>1.821</td>
<td>4.484</td>
</tr>
</tbody>
</table>
APPENDIX B: STATE-OF-PRACTICE SURVEY

Name: _____ Title: _____

Agency Name & Address: _____

Instructions (for electronic completion of survey):

For fill-in responses: You may enter your response by either tabbing through the form or by clicking on the shaded area. Please use as much space as needed to explain a selection of “Other.”

For check boxes: To check or uncheck a box, either type an “X” in the box or click on the box with your mouse. Unless noted otherwise, you can check more than one box for each item.

MSE Walls

1) Estimate percentage of each type of reinforcement used in MSE walls in your state:
   Steel strips _____% Wire mesh/bar mats _____%
   Geosynthetic grids _____% Other (explain) _____%

2) Estimate percentage of each type of facing panel used in your state:
   Concrete panel _____% Modular block _____%
   Other (explain) _____%

3) Estimate percentage of each type of facing panel connection used in your state:
   Dowels _____% Tongue & Groove _____%
   Ship Lap _____% Other (explain) _____%

Please provide standards and specifications for MSE walls used in your state (including soil backfill, panels, and reinforcement)
Barriers

4) Estimate percentage of each category of barrier used atop MSE walls in your state:
   Guardrail (post mounted) _____%  Bridge Rail (slab/pavement attached) _____%

5) Estimate percentage of each type of guardrail used atop MSE walls in your state:
   Strong post W-beam _____%  Weak post W-beam _____%
   Thrie beam _____%  Box beam _____%
   Cable _____%  Other (explain) _____%  _____

6) Estimate percentage of each type of bridge rail used atop MSE walls in your state:
   Concrete safety shape (N.J., F-shape, single slope) _____%
   Vertical concrete wall _____%  Concrete beam & post _____%
   Concrete parapet w/ steel rail _____%  Steel _____%
   Other (explain) _____%  _____

7) Estimate percentage of precast barrier versus cast-in-place barrier used atop MSE walls in your state:
   Precast coping & barrier unit _____%  Precast coping with cast-in-place barrier _____%
   Cast-in-place coping & barrier _____%  Other (explain) _____%  _____

   8) If precast barrier used, please specify minimum segment length allowed _____

Please provide standard detail sheets for each type of barrier used atop MSE walls in your state.

Barrier Connection to Wall/Pavement

9) Estimate percentage of each type of pavement used in your state in conjunction with MSE wall applications:
   RCP _____%  ACP _____%

Please answer the following in regard to post-mounted guardrail placed atop MSE walls:

   10) Lateral offset of guardrail from edge of wall _____

Please answer the following in regard to slab-attached bridge rails placed atop MSE walls:

For ACP pavement applications:

   11) Thickness of barrier/slab footing ______  12) Width of slab/footing ______
   13) Is barrier/slab footing continuous ☐ or jointed ☐?
   14) If jointed, what is joint spacing? _____
   15) Is barrier flush with wall ☐ Offset from face of wall ☐
   16) If offset, by what distance? _____
17) Is wall panel coped/recessed into bottom of coping? No ☐ Yes ☐

18) If yes, by how much? ______

19) Is lateral and vertical barrier movement connected ☐ or disconnected/isolated ☐ from wall panel?

**For RCP pavement applications:**

20) Thickness of barrier/slab footing ______ 21) Width of slab/footing ______

22) Is barrier/slab footing continuous ☐ or jointed ☐?

23) If jointed, what is joint spacing? ______

24) Is barrier flush with wall ☐ Offset from face of wall ☐

25) If offset, by what distance? ______

26) Is wall panel coped/recessed into bottom of coping? No ☐ Yes ☐

27) If yes, by how much? ______

28) Is lateral and vertical barrier movement connected ☐ or disconnected/isolated ☐ from wall panel?

29) How is barrier slab connected to pavement? Integrally poured ☐ Doweled ☐

Please provide standard connection/construction details used in your state.

**Design**

**MSE Walls**

30) How much horizontal load do you consider to be transferred to the top of the MSE wall due to barrier impact? ______

**Barrier**

31) NCHRP Report 350 Test Level TL-3 ☐ TL-4 ☐ TL-5 ☐

32) Do you follow AASHTO LRFD Bridge Specification, Chapter 13 “Railings,” for bridge railing design: No ☐ Yes ☐

If answer to previous question is “No”:

33) What is magnitude of barrier design load? ______

34) What is the height of the applied design load? ______

Please cite source ______

**Connections**

**Barrier to Wall**

35) How is maximum bending moment in the barrier and barrier slab/footing determined? ______
36) How is maximum shear in the barrier and barrier slab/footing determined? ____

For ACP pavement applications:

37) How do you calculate the required width and thickness of the barrier slab/footing? ____

For RCP pavement applications:

38) Do you calculate the bending moment in the pavement slab due to impact load on barrier? No ☐ Yes ☐

If yes, explain how _____

Please provide procedures for design of barriers on MSE walls (cite applicable manuals/references/guidelines (e.g., AASHTO LRFD or ASD Bridge Specification)).

Performance

39) Are you aware of any failures of MSE walls or barriers atop MSE walls due to vehicular impact? No ☐ Yes ☐

If yes, which components failed (check all that apply):
Barrier ☐ Coping ☐ Slab/Pavement ☐ Wall Panel ☐

Please provide any documentation (e.g., photographs, accident report, site details) that may exist for any known failures.

40) Are you aware of any other performance issues associated with MSE walls or barriers atop MSE walls? No ☐ Yes ☐

If yes, please describe _____
**APPENDIX C: DETAILED DRAWING OF MSE WALL FOR BOGIE TEST**

<table>
<thead>
<tr>
<th>Test Order</th>
<th>REFERENCE NUMBER</th>
<th>LENGTH OF BARRIERS</th>
<th>LENGTH OF WALL PANELS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>6 SPACES @ 10'</td>
<td>8.0' or 16.0'</td>
</tr>
<tr>
<td>(1) No test plan</td>
<td>(2) NJ Vertical</td>
<td>(3) Vertical 8-ft Strip</td>
<td>(4) Vertical 16-ft Strip</td>
</tr>
<tr>
<td>(2) Half connector</td>
<td>NJ Vertical 8-ft Strip</td>
<td>Vertical 8-ft Bar mats</td>
<td>Vertical 16-ft Strip</td>
</tr>
</tbody>
</table>

**Figure C 1 Updated Overall Elevation of Installation for Bogie Reference Tests**
Figure C 2 First Reinforcement Layer
Figure C 3 Second Reinforcement Layer
Figure C 4 Concrete Pad of Toe-System for Bogie Vehicle
Figure C 5 Detailed Connection of Two 30-ft Moment Slab
APPENDIX D: BOGIE TEST MSE WALL CONSTRUCTION PROCEDURE

Figure D.1 Delivery of Backfill Material

Figure D.2 Excavation for MSE Wall
Figure D.3 Completed Excavation and Temporary Shoring

Figure D.4 Form and Pour Concrete Pedestal
Figure D.5 Place Initial Course of Wall Panels
Figure D.6 Spread and Compact Backfill to Bottom Layer of Reinforcement
Figure D.7 Install Bottom Layer of Reinforcement
Figure D.8 Install Bar Mat Reinforcement
Figure D.9 Place Second Course of Panels and Backfill to Top Layer of Reinforcement
Figure D.10 Completed MSE Wall Construction
Figure D.11 Form and Pour Concrete Leveling Pad atop Wall Panels

Figure D.12 Install Concrete Strain Gages on Exterior Face of Wall Panels
Figure D.13 Install Tape Switches on Inside Face of Wall Panels/Level Up Concrete

Figure D.14 Place Barriers atop Wall Panels
Figure D.15 Form Moment Slab and Install Reinforcing Bars
Figure D.16 Pour Concrete for Moment Slab
Figure D.17 Completed Moment Slab
Figure D.18 Installation of Accelerometers on the Moment Slabs
Figure D.19 Form of Pad for Tow-System for Bogie Vehicle

Figure D.19 Pour Concrete for Tow-System Pad
Figure D.20 Completed Concrete Pad for Tow-System

Figure D.21 Fill the Soil above the Moment Slab and Backfill
Figure D.22 Installation of Accelerometers on top of the Barrier and Connection Bolts for Displacement Bars
Figure D.23 Installation of String Line
(a) Measure the Distance before Test

(b) Installation of Tow-System for Bogie Vehicle
(c) Installation of Displacement Bars with Target for High-Speed Film

Figure D.24 Preparation on Test Day
Figure E 1 Overall Layout for TL-3 Crash Test
1) Moment Slab

The precate parapet rail shall be braced until the moment slab can structurally support the rail. Workers shall not stand or work down in front of the wall until the rail has been structurally supported by the moment slab.

Figure E 2 C.I.P Moment Slab Detail
Figure E 3 Dowels in Moment Slab
Figure E 4 Side View of TL-3 Crash Test with 32-in. Tall Vertical Wall Barrier Parapet
1) Steel Strain Gages on Reinforcement Strips

Figure E 5 Details of Strain Gages on Reinforcement Strips
Figure E 6 Details of Strain Gages on Reinforcement Strips
Strain Gauge Instrumentation of Steel Reinforcement Strips (7 strips × 2 gages = 10 gages total)

Note: The strain gages installed on top and bottom of each strip.

Figure E 7 Location of Steel Strain Gages on Steel Reinforcement Strips
2) Concrete Strain Gages on Wall Panel

Figure E8 Location of Concrete Strain Gages on Wall Panel
1: Concrete strain gages

Figure E 9 Location of Concrete Strain Gages on Wall Panel
Figure E 10 Location of Hole for Stain Gage Wire
3) Tape Switch

A tape switch is installed on the top edge at the centerline of the full panel (H6) shown in Error! Reference source not found..
4) Displacement Bar

Figure E 12 Location of Displacement Bars on Wall Panels
Figure E 13 Location of Displacement Bars on Wall Panels (Cont.)
5) Accelerometers on the Barrier and Moment slab

Figure E 14 Location of Accelerometers.
APPENDIX F: TL-3 TEST MSE WALL CONSTRUCTION PROCEDURE

Figure F.25 Delivery of Backfill Material

Figure F.26 Delivery of 10-ft Long Steel Strip
Figure F.27 Installation Strain Gages on the Strips

Figure F.28 Delivery of Wall Panels
Figure F.29 Excavation for MSE Wall

Figure F.30 Form and Pour Concrete Pedestal
Figure F.31 Place Initial Course of Wall Panels
Figure F.32 Spread and Compact Backfill to Bottom Layer of Reinforcement
Figure F.33 Install Bottom Layer of Reinforcement

Figure F.34 Fill Backfill Above the Strips
Figure F.35 Place Second Course of Panels

Figure F.36 Backfill to Top Layer of Reinforcement
Figure F.37 Fill Install Strips at Second Layer
Figure F.38 Place Half Panel at Second Layer
Figure F.39 Spread and Compact Backfill up to First Layer of Strip
Figure F.40 Install the Strips at Top Layer
Figure F.41 Read the Strain Gage on Strip at Top Layer to obtain Zeroed strain

Figure F.42 Spread and Compact Backfill up to Top of the Panel
Figure F.43 Form for the Leveling Pad
Figure F.44 Pour the Concrete for the Leveling Pad
Figure F.45 Completed MSE Wall Construction
Figure F.46 Test to Verify Full Bridge Strain Gages on the Strip
Figure F.47 Install Tape Switches on Inside Face of Wall Panels/Level Up Concrete

Figure F.48 Place Barriers atop Wall Panels
Figure F.49 Place Barriers atop Wall Panels
Figure F.50 Form Moment Slab and Install Reinforcing Bars
Figure F.51 Pour Concrete for Moment Slab
Figure F.52 Installation of Accelerometers on the Moment Slabs
Figure F.53 Installation of Accelerometers on top of the Barrier and Connection Bolts for Displacement Bars
Figure F.54 Fill the Soil above the Moment Slab and Backfill
APPENDIX G: TL-3 TEST VEHICLE PROPERTIES AND INFORMATION

Date: 2008-09-25  Test No.: 475350-1  VIN No.: 1D7HA18N74S569024
Year: 2004  Make: Dodge  Model: Ram 1500 Quad-Cab
Tire Size: 245/70R17  Tire Inflation Pressure: 35 psi
Tread Type: Highway  Odometer: 162279

Note any damage to the vehicle prior to test:

- Denotes accelerometer location.

NOTES:

Engine Type: V-8
Engine CID: 4.7 liter
Transmission Type: _x_ Auto or _ or Manual
___ FWD  _x_ RWD  ___ 4WD
Optional Equipment:

Dummy Data:
Type: No dummy
Mass:
Seat Position:

Geometry: inches

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>77.0</td>
<td>F</td>
<td>37.0</td>
<td>K</td>
<td>18.0</td>
<td>P</td>
</tr>
<tr>
<td>B</td>
<td>74.0</td>
<td>G</td>
<td>28.2</td>
<td>L</td>
<td>27.5</td>
<td>Q</td>
</tr>
<tr>
<td>C</td>
<td>224.5</td>
<td>H</td>
<td>62.4</td>
<td>M</td>
<td>68.2</td>
<td>R</td>
</tr>
<tr>
<td>D</td>
<td>47.0</td>
<td>I</td>
<td>13.8</td>
<td>N</td>
<td>67.2</td>
<td>S</td>
</tr>
<tr>
<td>E</td>
<td>140.5</td>
<td>J</td>
<td>26.0</td>
<td>O</td>
<td>44.5</td>
<td>T</td>
</tr>
</tbody>
</table>

Wheel Center Ht Front  Wheel Well Clearance (FR)  Frame Ht (FR)
Wheel Center Ht Rear  Wheel Well Clearance (RR)  Frame Ht (RR)

GVWR Ratings:

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass:</td>
<td>lb</td>
<td>Curb</td>
<td>Test Inertial</td>
<td>Gross Static</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>3650</td>
<td>M_{front}</td>
<td>2730</td>
<td>2751</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back</td>
<td>3900</td>
<td>M_{rear}</td>
<td>2064</td>
<td>2200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6650</td>
<td>M_{total}</td>
<td>4794</td>
<td>4951</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mass Distribution:

|   |   |   |   |   |
|---|---|---|---|
| lb | LF: 1357 | RF: 1394 | LR: 1096 | RR: 1104 |

Figure G1. Vehicle properties for test 475350-1.
Table G1. Exterior crush measurements for test 475350-1.

Date: 2008-09-25  Test No.: 475350-1  VIN No.: 1D7HA18N74S569024
Year: 2004  Make: Dodge  Model: Ram 1500 Quad-Cab

<table>
<thead>
<tr>
<th>VEHICLE CRUSH MEASUREMENT SHEET¹</th>
<th>Complete When Applicable</th>
<th>Side Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>End Damage</td>
<td></td>
<td>Bowing: B1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X2</td>
</tr>
<tr>
<td>Undeformed end width _________</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corner shift: A1 _________</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2 _______</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End shift at frame (CDC)</td>
<td></td>
<td>Bowing constant</td>
</tr>
<tr>
<td>(check one)</td>
<td></td>
<td>[\frac{X1 + X2}{2}] = ______</td>
</tr>
<tr>
<td>&lt; 4 inches _________</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 4 inches _________</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Measure C₁ to C₆ from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

<table>
<thead>
<tr>
<th>Specific Impact Number</th>
<th>Plane* of C-Measurements</th>
<th>Direct Damage</th>
<th>Field L**</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
<th>C₄</th>
<th>C₅</th>
<th>C₆</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front plane at bumper ht</td>
<td>19.7</td>
<td>13.8</td>
<td>23.6</td>
<td>13.8</td>
<td>9.1</td>
<td>6.3</td>
<td>3.1</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Side plane at bumper ht</td>
<td>19.7</td>
<td>15.8</td>
<td>63.0</td>
<td>2.8</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>14.6</td>
<td>15.8</td>
</tr>
</tbody>
</table>

¹Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.
Table G2. Occupant compartment measurements for test 475350-1.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Before (mm)</th>
<th>After (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>64.6</td>
<td>64.6</td>
</tr>
<tr>
<td>A2</td>
<td>64.9</td>
<td>64.9</td>
</tr>
<tr>
<td>A3</td>
<td>65.4</td>
<td>65.4</td>
</tr>
<tr>
<td>B1</td>
<td>44.7</td>
<td>44.7</td>
</tr>
<tr>
<td>B2</td>
<td>39.2</td>
<td>39.2</td>
</tr>
<tr>
<td>B3</td>
<td>45.3</td>
<td>45.3</td>
</tr>
<tr>
<td>B4</td>
<td>48.8</td>
<td>48.8</td>
</tr>
<tr>
<td>B5</td>
<td>45.2</td>
<td>45.2</td>
</tr>
<tr>
<td>B6</td>
<td>48.8</td>
<td>48.8</td>
</tr>
<tr>
<td>C1</td>
<td>29.5</td>
<td>29.5</td>
</tr>
<tr>
<td>C2</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>C3</td>
<td>27.4</td>
<td>27.4</td>
</tr>
<tr>
<td>D1</td>
<td>12.6</td>
<td>12.6</td>
</tr>
<tr>
<td>D2</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>D3</td>
<td>11.6</td>
<td>11.6</td>
</tr>
<tr>
<td>E1</td>
<td>63.3</td>
<td>61.2</td>
</tr>
<tr>
<td>E2</td>
<td>64.3</td>
<td>63.8</td>
</tr>
<tr>
<td>E3</td>
<td>64.2</td>
<td>63.5</td>
</tr>
<tr>
<td>E4</td>
<td>64.2</td>
<td>63.0</td>
</tr>
<tr>
<td>F</td>
<td>59.6</td>
<td>-----</td>
</tr>
<tr>
<td>G</td>
<td>59.6</td>
<td>-----</td>
</tr>
<tr>
<td>H</td>
<td>39.6</td>
<td>-----</td>
</tr>
<tr>
<td>I</td>
<td>39.6</td>
<td>-----</td>
</tr>
<tr>
<td>J*</td>
<td>22.9</td>
<td>21.6</td>
</tr>
</tbody>
</table>

*Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.*
Figure H1. Sequential photographs for test 475350-1 (overhead and frontal views).
Figure H1. Sequential photographs for test 475350-1 (overhead and frontal views) (continued).