AASHTO Vehicle Loading
HL93 Truck 32 kips/axle
HL93 Tandem 25 kips/axle

Corrugation Section Properties
Thickness (in) 0.079
Area, A (in^2/ft) 0.968
Radius of Gyration, r (in) 0.1721
Moment of Inertia, I (in^4/in) 0.002392

Cover Height Investigated, H (ft) = 51.0

(1) Determine the factored vertical crown pressure for dead load, P_{FD}, and live load P_{FL} (ksf):

\[ P_{FD} = \eta_{EV}\gamma_{EV}DL \]
\[ P_{FL} = \eta_{LL}\gamma_{LL}P_L \]
\[ P_L = (m)(IM)(LL) \]

\[ \eta_{EV} \text{ (vertical earth pressure load modifier)} = 1.05 \]
\[ \gamma_{EV} \text{ (vertical earth pressure load factor)} = 1.95 \]

The dynamic load allowance (IM) is a percentage increase in the live load to account for the rolling motion of the vehicle.

Geostatic Earth Pressure (i.e. dead load), DL (ksf) = \gamma_s H

DL = 6.12 ksf

Live Load for H = 51.0 ft

Where the depth of fill is greater than 1.0-ft the live load (LL) shall be distributed to the structure as wheel loads, uniformly distributed over a rectangular area with sides equal to the dimension of the tire contact area increased by the live load distribution factor (LLDF = 1.15). Compute the depth at which wheels on adjacent axles interact (Figure A), and the depth at which wheels on the same axle interact (Figure B). Wheel loads shall be added as appropriate and applied over the total interaction dimension for cover depths that exceed the interaction depth. Evaluate both the design truck and the design tandem to determine which configuration produces the maximum load.

\[ H_{int-t} = \frac{s_w - w_c/12 - 0.06D/12}{LLDF} \]
wheel interaction depth transverse to culvert span (ft)

\[ H_{int-p} = \frac{s_a - \ell/12}{LLDF} \]
axle interaction depth parallel to culvert span (ft)

AASHTO LRFD Bridge Design Specifications
Cover Height Calculations by the National Corrugated Steel Pipe Association
Corrugated Steel Pipe

48 -in CSP
14 gage
2¼"x⅜"
For $H < H_{int-p}$

\[ w = \frac{w_t}{12} + LLDF(H) + 0.06D/12 \]

For $H \geq H_{int-p}$

\[ w = \frac{w_t}{12} + s_w + LLDF(H) + 0.06D/12 \]

For $H < H_{int-t}$

\[ \ell = \frac{\ell_t}{12} + LLDF(H) \]

For $H \geq H_{int-t}$

\[ \ell = \frac{\ell_t}{12} + s \ell + LLDF(H) \]

### Dynamic Load Allowance, IM = 33(1.0 - 0.125H) ≥ 0%

<table>
<thead>
<tr>
<th>IM factor</th>
<th>IM = 0.00 %</th>
</tr>
</thead>
</table>

**HL93 Truck**

- $H_{int-p} = 11.45$ ft
- $H_{int-t} = 3.56$ ft
- $\ell = 73.48$ ft
- $w = 66.56$ ft
- $A_{LL} = 4890.81$ ft²
- $P = 64$ k
- $LL = 0.01$ ksf

**HL93 Tandem**

- $H_{int-p} = 2.75$ ft
- $H_{int-t} = 3.56$ ft
- $\ell = 63.48$ ft
- $w = 66.56$ ft
- $A_{LL} = 4225.24$ ft²
- $P = 50$ k
- $LL = 0.01$ ksf

**Fig A. Total Interaction Length (H ≥ H_{int-p})**

- $\ell = 10$ in
- $\ell = 10$ in
- $s_i = 14$ ft

**Fig B. Total Interaction Width (H ≥ H_{int-t})**

- $\omega = 20$ in
- $\omega = 20$ in
- $s_w = 6$ ft

**Fig A. Total Interaction Length (H ≥ H_{int-p})**

- $\ell = 10$ in
- $\ell = 10$ in
- $s_i = 4$ ft

**Fig B. Total Interaction Width (H ≥ H_{int-t})**

- $\omega = 20$ in
- $\omega = 20$ in
- $s_w = 6$ ft

**Dynamic Load Allowance, IM = 33(1.0 - 0.125H) ≥ 0%**

- $P_L = (m)(IM)(LL_{max}) = 0.02$
- $P_{FD} = \eta_{EV}\gamma_{EV}DL = 12.53$
- $P_{FL} = \eta_{LL}\gamma_{LL}P_L = 0.03$
(2) Determine factored thrust per unit length of wall, \( T_L \) (kpf) = \( P_{FD}S/2 + P_{FL}C_LF_1/2 \)

\[
T_L = 25.12 \text{ kpf}
\]

\[
\begin{align*}
F_1 &= 0.75S/\ell_w \geq F_{\text{min}} \\
F_{\text{min}} &= 15/12S \geq 1 \\
C_L &= \ell_w \leq S
\end{align*}
\]

\( C_L \), width of culvert on which live load is applied parallel to the span (ft)

\( \ell_w \), live load patch length at depth \( H \)

\( F_{\text{min}} \) = \( 15/12S \geq 1 \) \( \ell_w \) = ### ft

\( C_L \) = \( 4.00 \) \( \ell_w \) = ### ft

(3) Determine Critical Buckling Stress, \( f_{cr} \) (ksi)

\[
\begin{align*}
(a) & \text{ If } S < (r/k)(24E_m/F_u)^{1/2}, \text{ then } f_{cr} = F_u - (F_u kS/r)^2/48E_m \\
& \quad E_m (\text{ksi}) = 29,000 \quad r, \text{ radius of gyration (in)} = 0.1721 \\
(b) & \text{ If } S > (r/k)(24E_m/F_u)^{1/2}, \text{ then } f_{cr} = 12E_m/(kS/r)^2 \\
& \quad F_u (\text{ksi}) = 33 \quad k (\text{soil stiffness factor}) = 0.22 \\
& \quad F_y (\text{ksi}) = 45 \quad S, \text{ pipe arch span (in)} = 48
\end{align*}
\]

\( E_m (\text{ksi}) = 29,000 \) \( r, \text{ radius of gyration (in)} = 0.1721 \)

\( F_u (\text{ksi}) = 33 \) \( k (\text{soil stiffness factor}) = 0.22 \)

\( F_y (\text{ksi}) = 45 \) \( S, \text{ pipe arch span (in)} = 48 \)

\[
S < (r/k)(24E_m/F_u)^{1/2} = 97.2874
\]

Therefore use equation (a) above

\( f_{cr} = 39.52 \text{ ksi} \)

(4) Determine the Factored Axial Resistance to Buckling \( R_n \) (kpf)

\[
R_n = \phi_n F_y A
\]

If the critical buckling stress is less than the actual yield stress then the resistance to buckling must be calculated using \( f_{cr} \) in place of \( F_y \).

\[
\begin{align*}
F_y (\text{ksi}) &= 33 \\
A &= \text{wall area (in}^2/\text{ft}) = 0.968 \\
\phi_n &= 1.0
\end{align*}
\]

The actual yield strength is less than the critical buckling stress therefore use \( F_y (\text{ksi}) = 33.00 \)

\[
R_n = 31.94 \text{ kpf}
\]

greater than \( T_L \), therefore OK

(5) Check Flexibility Factor, FF (in/kip)

\[
\begin{align*}
\text{Embarkment/Trench} & \quad \phi_{\text{crit}} = 0.1721 \\
\text{Em} (\text{ksi}) &= 29,000 \quad S, \text{ pipe arch span (in)} = 48 \\
I (\text{in}^4/\text{in}) &= 0.002392 \quad \text{FF max allowed (in/kip)} = 43.00
\end{align*}
\]

\[
\text{FF actual (in/kip)} = 33.21
\]

The actual FF is less than the maximum allowed, therefore OK