American Concrete Pipe Association

Live Load Design

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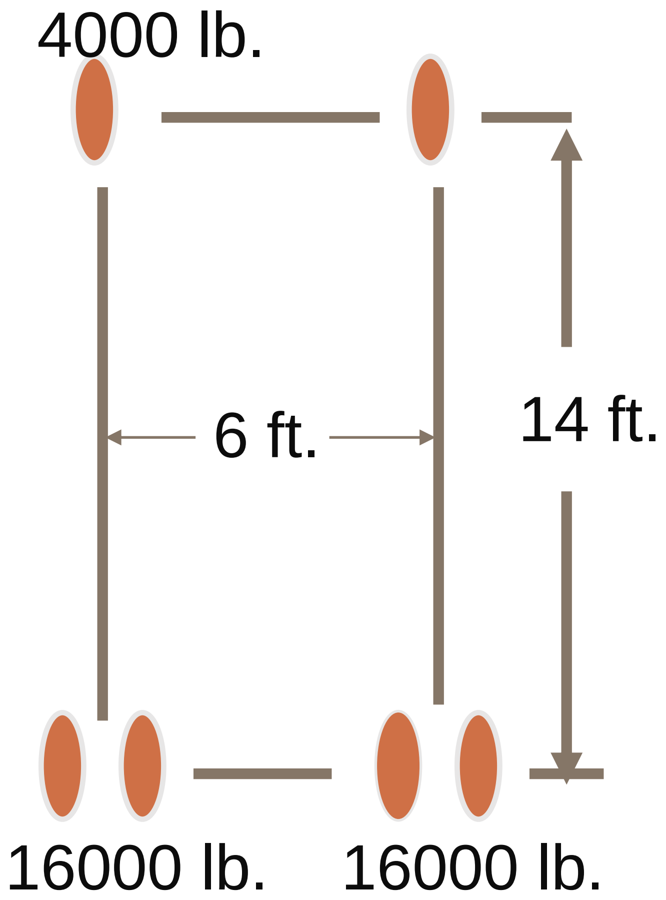
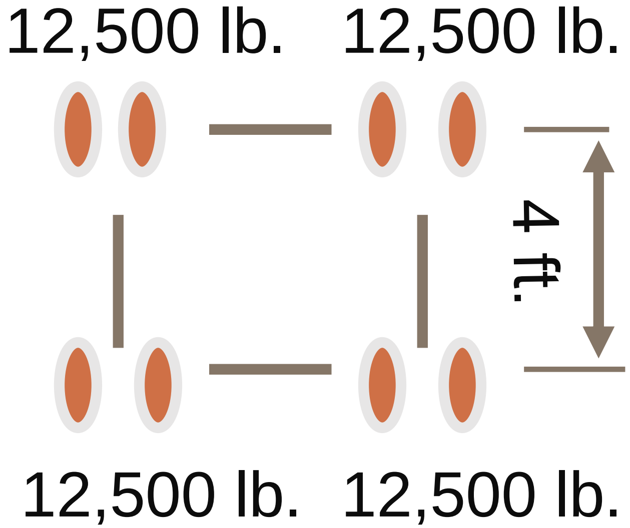
Outline

- AASHTO HL – 93 Live Load
- Application of the Load
  - < 2 feet
  - ≥ 2 feet
- Live Load Bedding Factors
- Examples

Live Load Spacing – HL-93



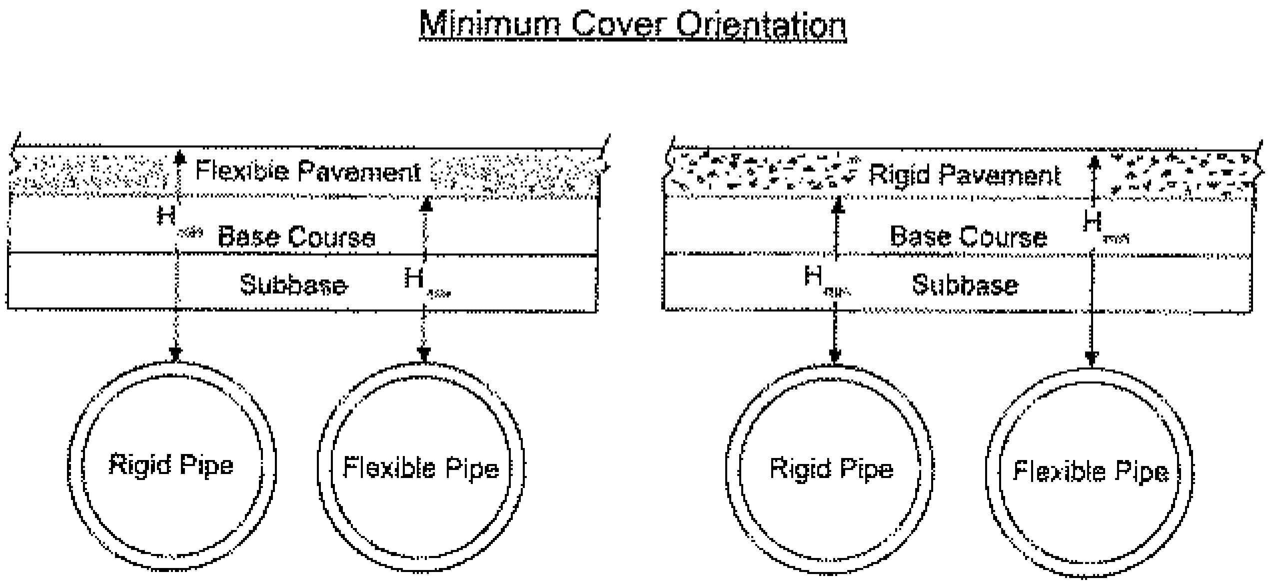
AASHTO HS 20 LOAD



(12,00 lb per STD)

AASHTO ALTERNATE LOAD

Where are We Measuring From?
(C12.6.6.3)



H_{min} = minimum allowable cover dimension

Note: The minimum cover dimension is not to be confused with the fill height used for calculation purposes, which shall be from the top of the pipe to the top of the surface, regardless of the pipe type or pavement type.

Less Than 2 Feet of Cover

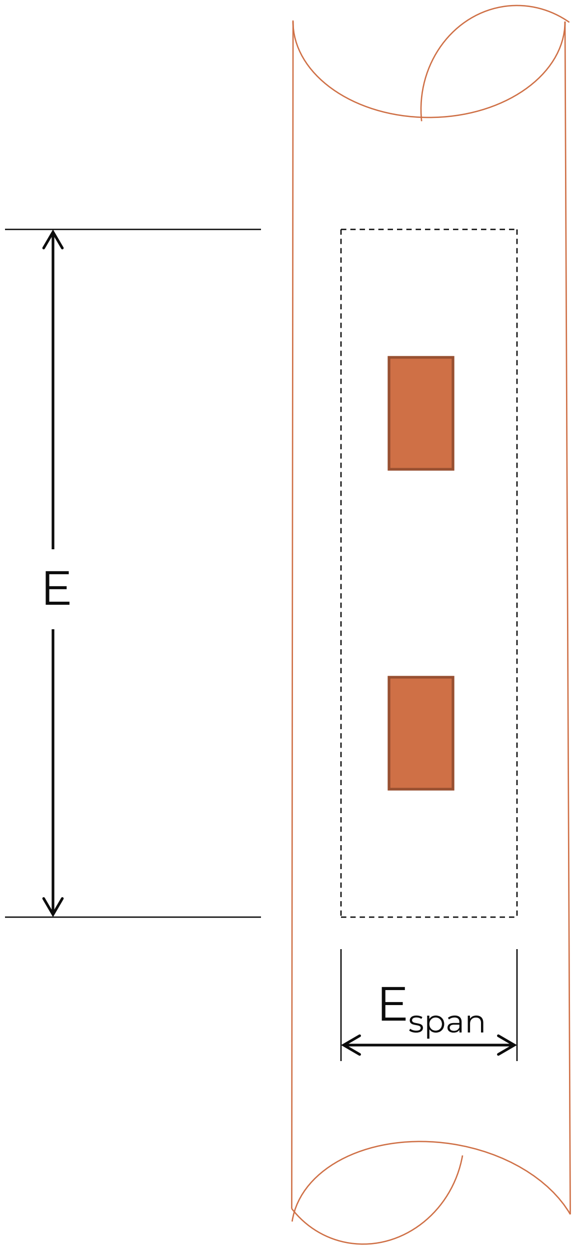
$E = 96 + 1.44S$ (4.6.2.10.2-1)

E = Distribution width perpendicular to span in inches
S = Clear Span in feet

E_{span} = Distribution width parallel to span in inches

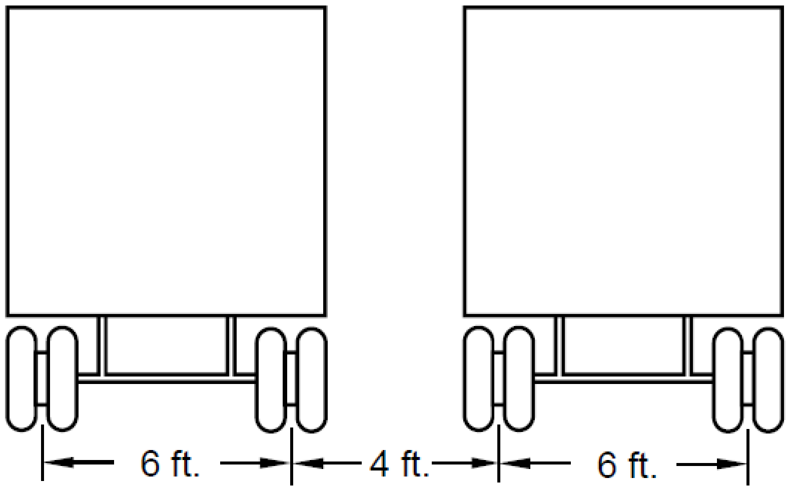
$E_{span} = L_T + LLDF(H)$

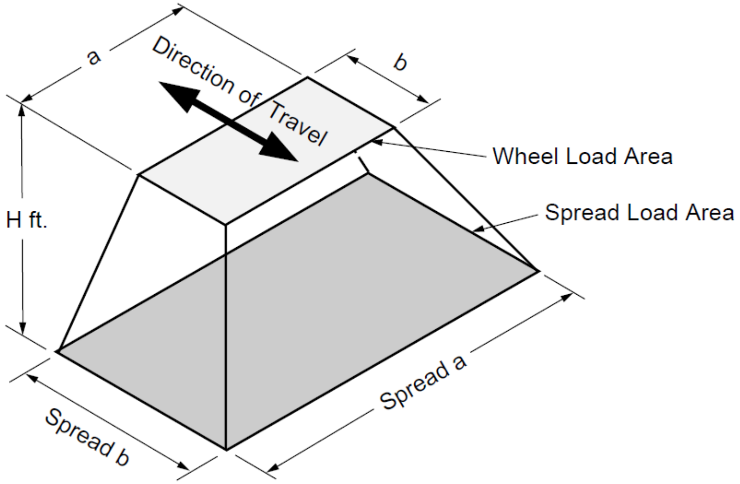
L_T = length of contact area parallel to span (in)
LLDF = live load distribution factor
H = depth of fill

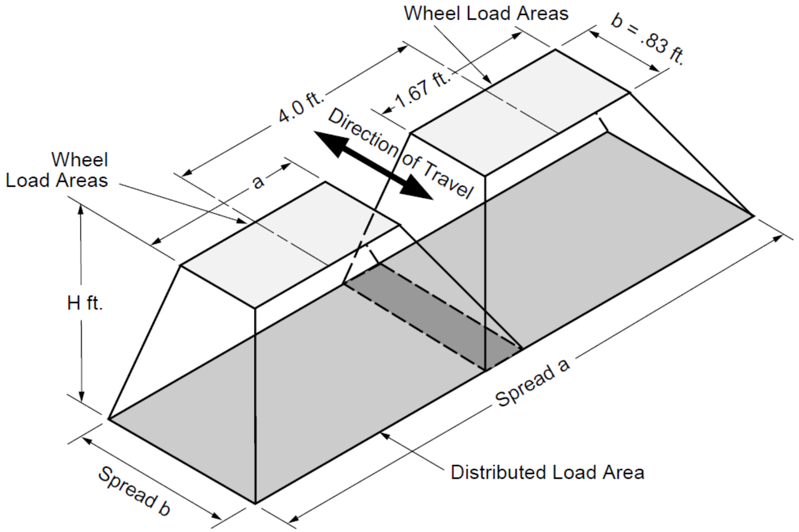


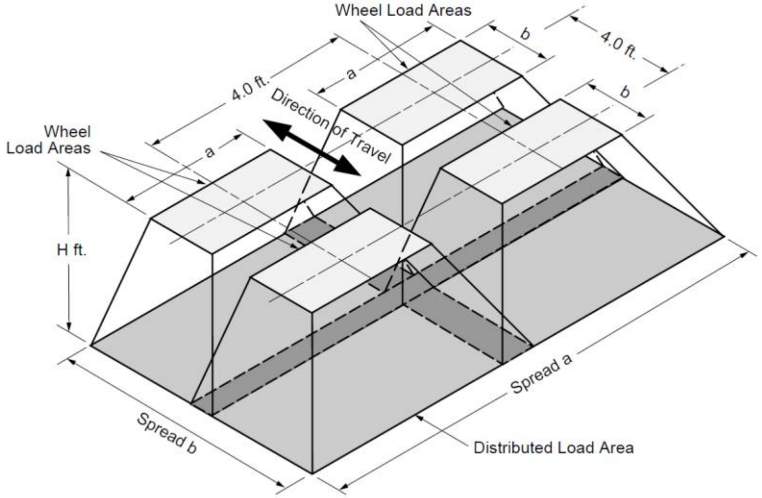
Live Load Spread for Less Than 2 feet of Cover (single axle)
(Parallel to Span)

Live Load ≥ 2 ft.







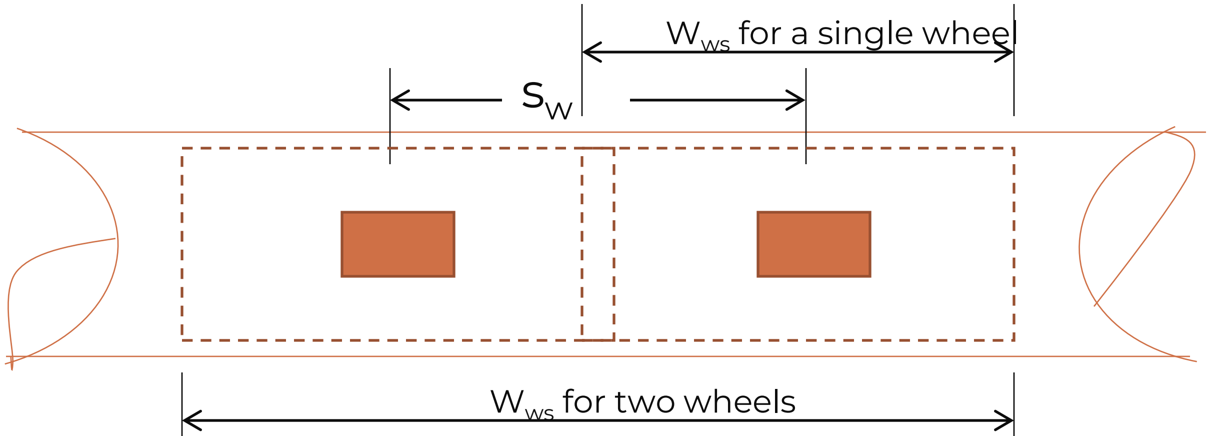


Live Load Distribution Through Soil

Table 3.6.1.2.6a-1—Live Load Distribution Factor (LLDF) for Buried Structures

Structure type	Transverse to span	Parallel to span
Concrete Pipe with depth 2 ft or greater	1.15 for diameter 2 ft. or less 1.75 for diameters 8 ft or greater Linearly interpolate for LLDF between these limits	Same as transverse
All other culverts and buried structures	1.15	1.15

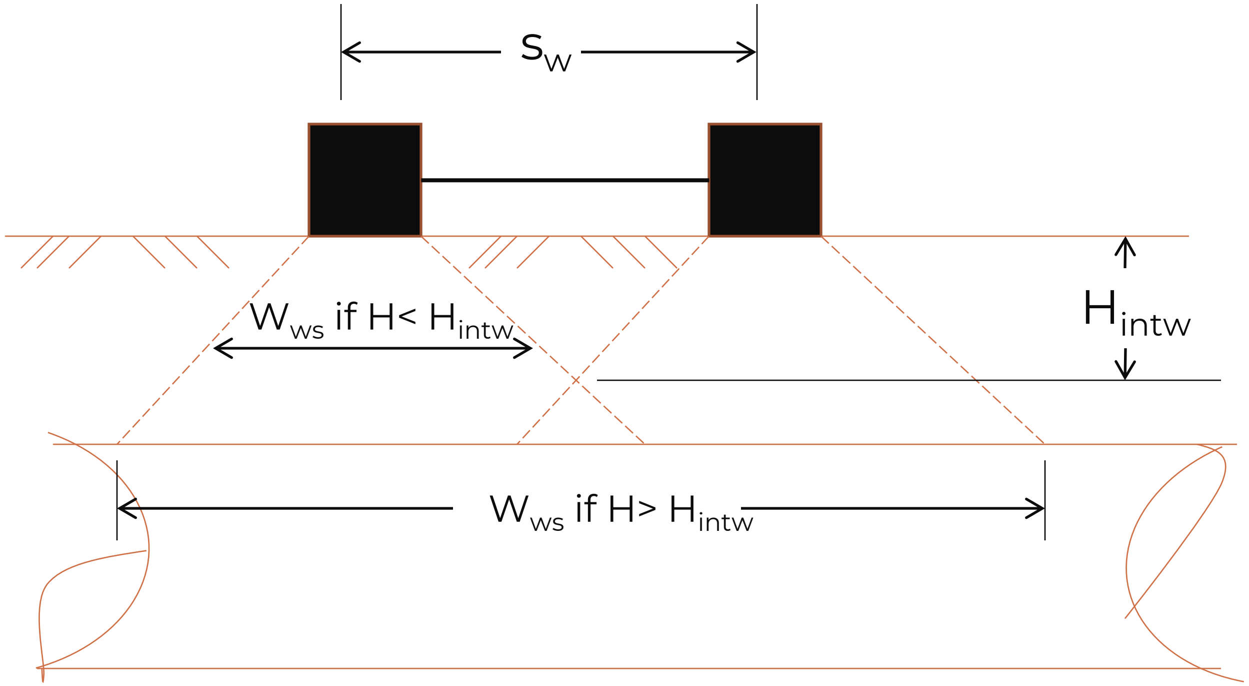
Interaction Depth for Wheels



Plan View

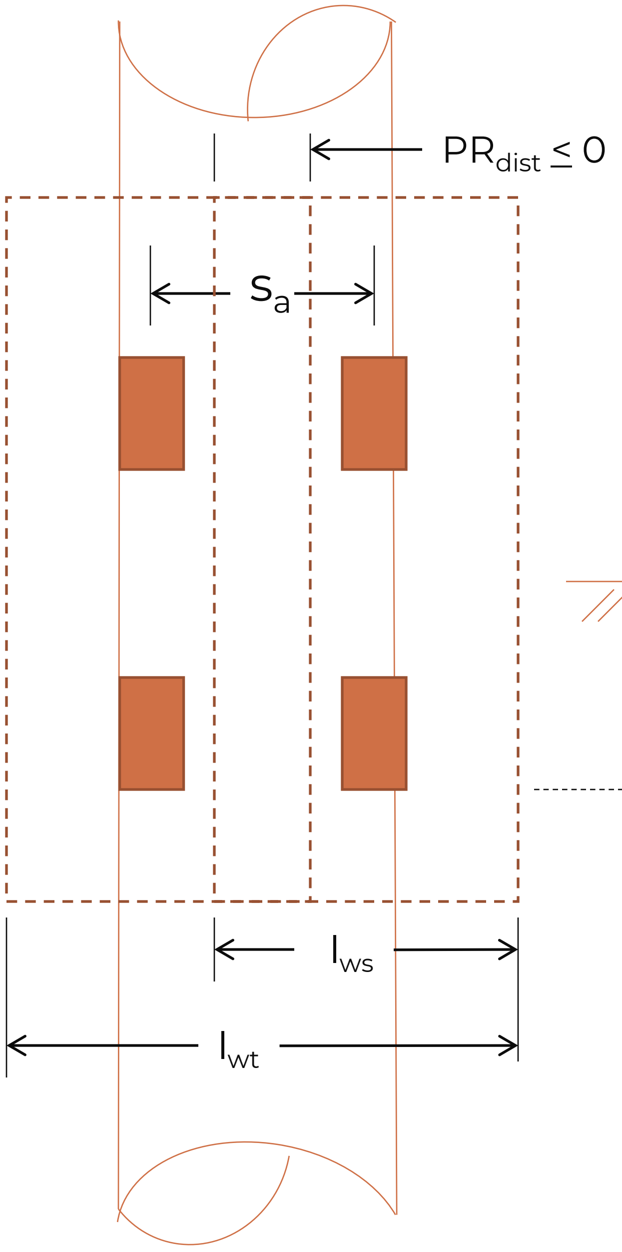
AASHTO Eq. 3.6.1.2.6b-1

$$H_{int} = \frac{s_w - \frac{w_t}{12} - \frac{0.06D_j}{12}}{LLDF}$$



Elevation View

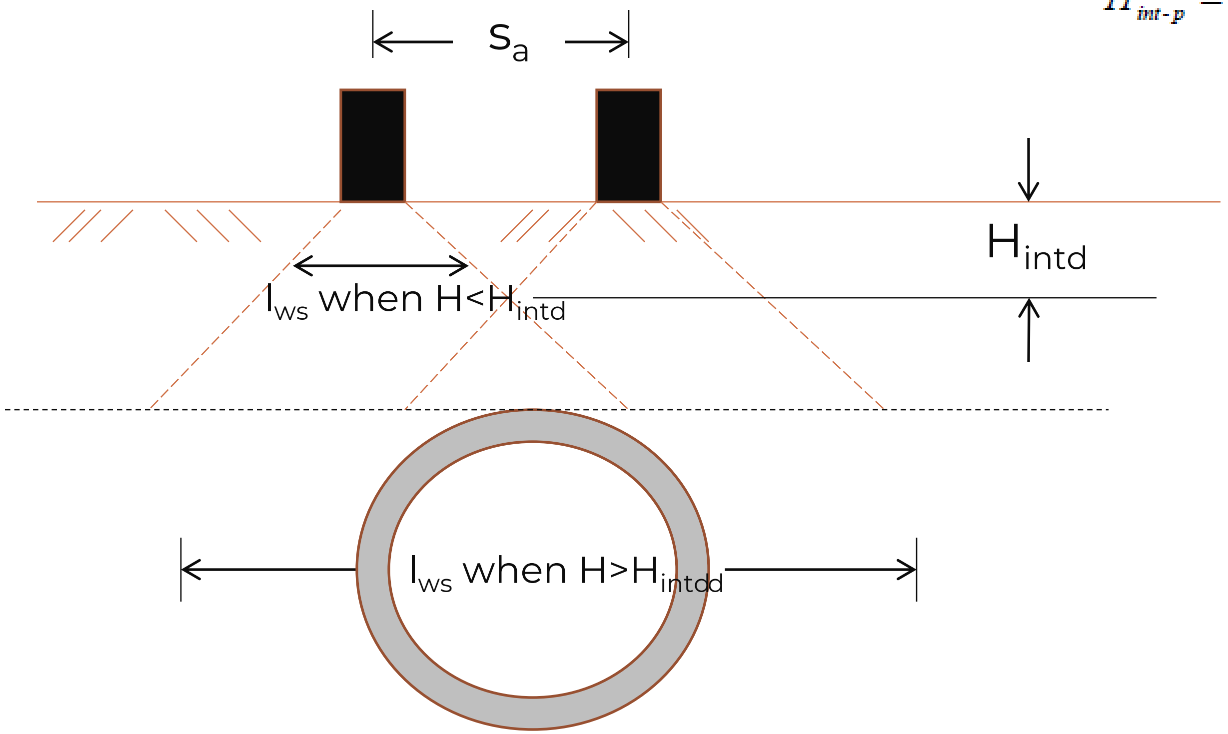
Interaction Depth for (Tandem) Axles



Plan View

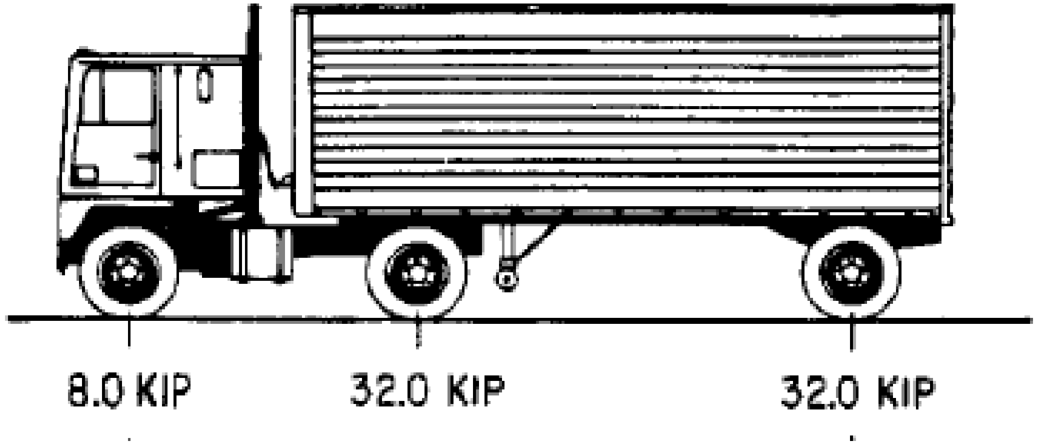
AASHTO Eq. 3.6.1.2.6b-4

$$H_{int-p} = \frac{S_a - \frac{l_t}{12}}{LLDF}$$

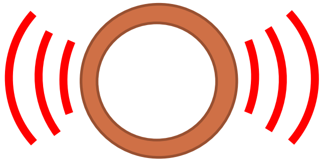


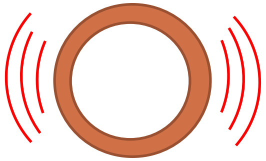
Elevation View

Impact Factor



$$IM = 33\ (1.0 - 0.125\ H) \geq 0\%$$





Multiple Presence Factor

Table 3.6.1.1.2-1—Multiple Presence Factors, *m*

Number of Loaded Lanes	Multiple Presence Factors, *m*
1	1.20
2	1.00
3	0.85
>3	0.65

AASHTO 3.6.1.2.6
“For traffic parallel to the span, culverts shall be analyzed for a single loaded with the single lane multiple presence factor.”

Live Load on the Pipe

$$LL_{press} = \frac{P\left(1 + \frac{IM}{100}\right)(mpf)}{A_{LL}}$$

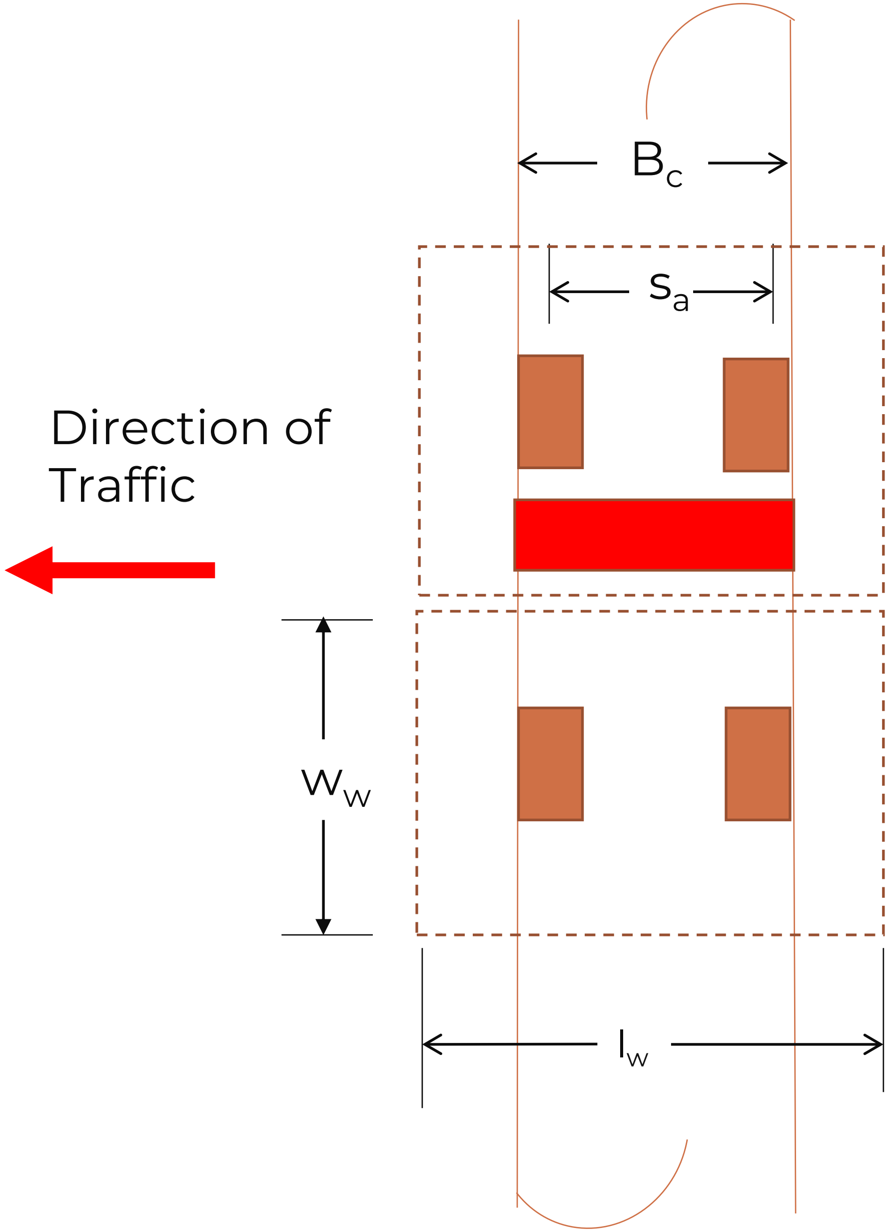
mpf = 1.2 for traffic parallel to span

$A_{LL} = w_w \times l_w$

Dim = smaller of B_c or l_w

W_{LL} = Dim x LL_{press}

W_{LL} = lbs/ft



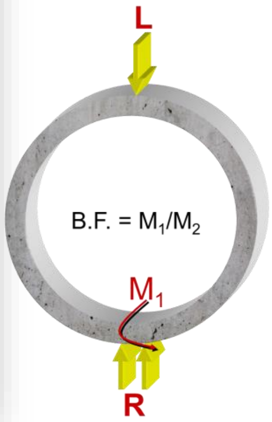
D-Load Equation

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \quad (12.10.4.3.1\text{-}1)$$

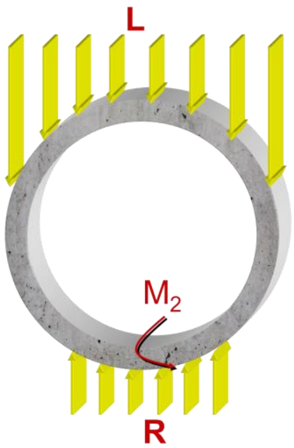
B_F = Bedding Factor

Bedding Factors

$$B_f = \frac{M_{TEST}}{M_{FIELD}}$$



3 - Edge Bearing



In Situ

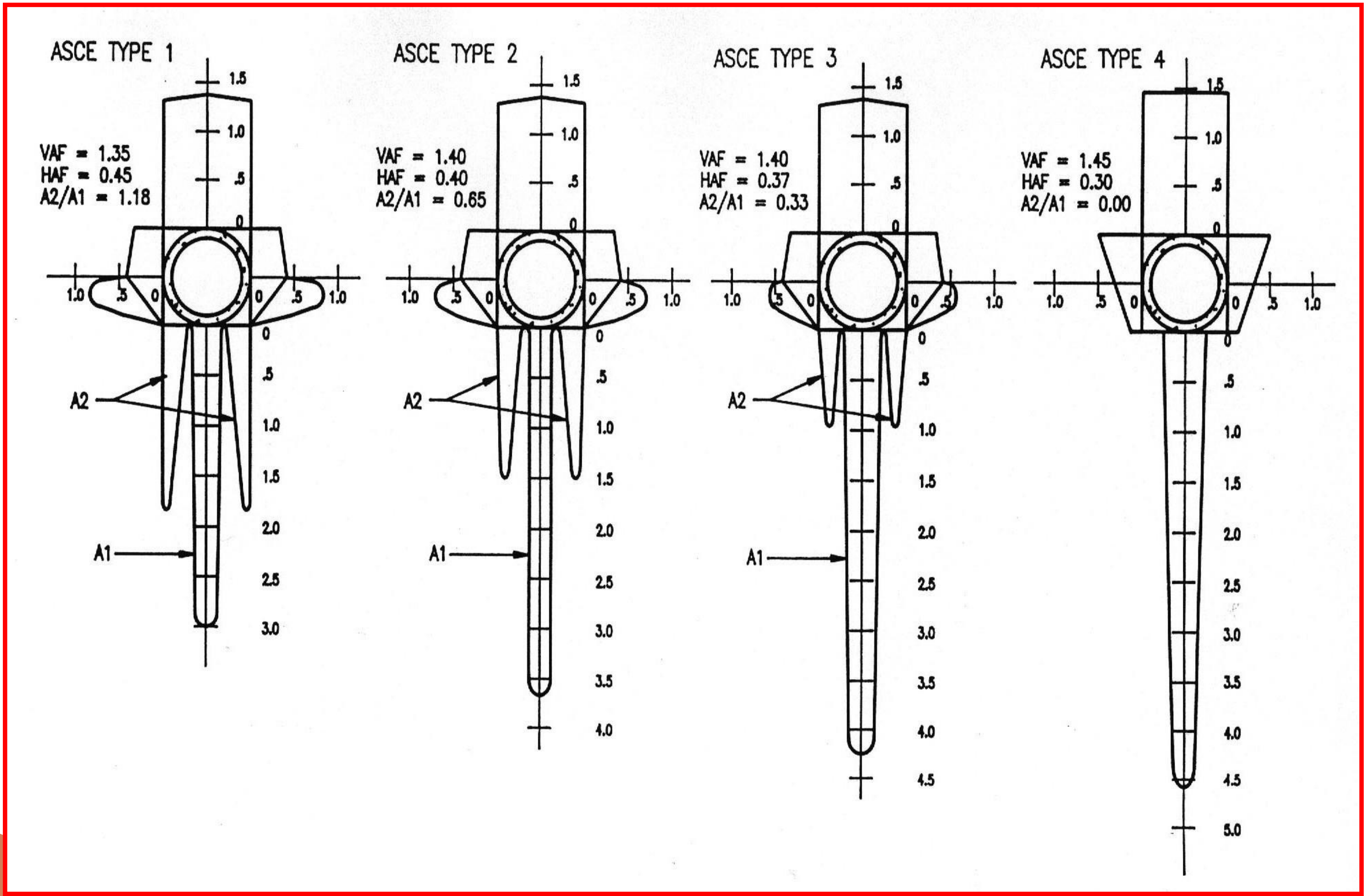
Where:

Bf = Bedding factors

M_{FIELD} = Maximum moment in pipe under field loads before failure, (inch-pounds)

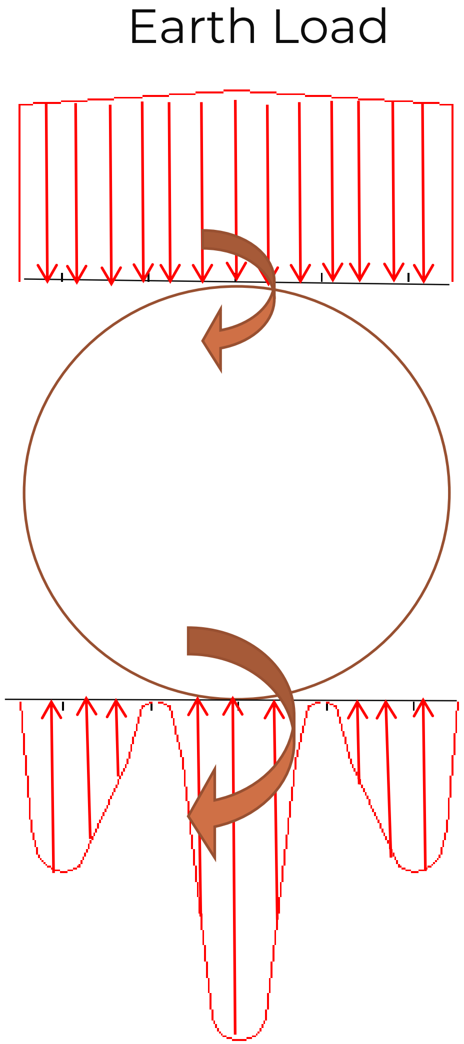
M_{TEST} = Maximum moment in pipe under three-edge bearing test before failure, (inch-pounds)

Heger Distribution Drawn to Scale

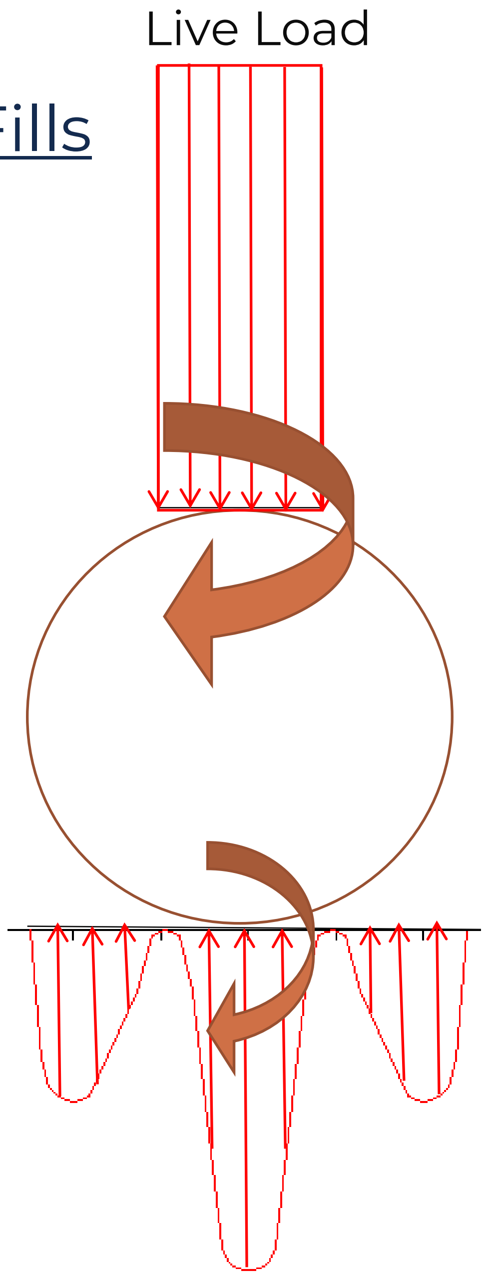


Under Shallow Fills

$Bf_{LL} < Bf_E$



Higher Moment at Invert
with Earth Load



Higher Moment at Crown
with Shallow Live Load

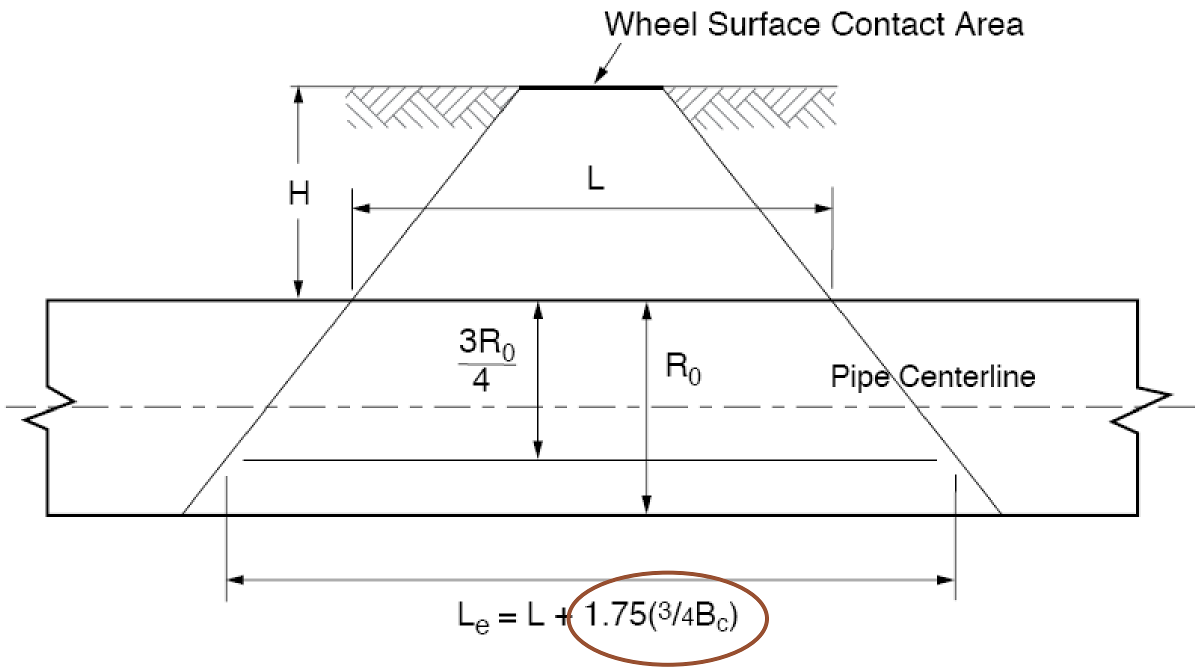
Moment from Live Load – Bedding Factor

OLD

Table 12.10.4.3.2c-1—Bedding Factors, B_{FLL}, for the Design Truck

Fill Height, ft	Pipe Diameter, in.										
	12	24	36	48	60	72	84	96	108	120	144
0.5	2.2	1.7	1.4	1.3	1.3	1.1	1.1	1.1	1.1	1.1	1.1
1.0	2.2	2.2	1.7	1.5	1.4	1.3	1.3	1.3	1.1	1.1	1.1
1.5	2.2	2.2	2.1	1.8	1.5	1.4	1.4	1.3	1.3	1.3	1.1
2.0	2.2	2.2	2.2	2.0	1.8	1.5	1.5	1.4	1.4	1.3	1.3
2.5	2.2	2.2	2.2	2.2	2.0	1.8	1.7	1.5	1.4	1.4	1.3
3.0	2.2	2.2	2.2	2.2	2.2	2.2	1.8	1.7	1.5	1.5	1.4
3.5	2.2	2.2	2.2	2.2	2.2	2.2	1.9	1.8	1.7	1.5	1.4
4.0	2.2	2.2	2.2	2.2	2.2	2.2	2.1	1.9	1.8	1.7	1.5
4.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8	1.7
5.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8
5.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9
6.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.1	2.0
6.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

Previous Distribution of Live Load Through the Pipe



Current Distribution of Live Load Through the Pipe

$$w_w = \frac{w_t}{12} + LLDF(H) + 0.06\frac{D_i}{12}$$

Moment from Live Load – Bedding Factor

CURRENT

Table 12.10.4.3.2c-1—Bedding Factors, B_{FLL}

Pipe diameter, in.	Fill Height, ft	
	< 2.0 ft	≥ 2.0 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

C12.10.4.3.2c

The relatively large bending stiffness in the longitudinal direction of concrete pipe results in the distribution of the live load force along the length of the pipe. This ratio of distribution length to pipe diameter is higher in small diameter pipes designed by the Indirect Design Method. The bedding factor has been adjusted in Table 12.10.4.3.2c-1 to account for this higher distribution length.

D-Load Equation

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

where:

B_{FE} = earth load bedding factor specified in Article 12.10.4.3.2a or Article 12.10.4.3.2b

B_{FLL} = live load bedding factor specified in Article 12.10.4.3.2c

S_i = internal diameter of pipe (in.)

W_E = total unfactored earth load specified in Article 12.10.2.1 (kip/ft)

W_F = total unfactored fluid load in the pipe as specified in Article 12.10.2.2 (kip/ft)

W_L = total unfactored live load on unit length pipe specified in Article 12.10.2.3 (kip/ft)

Indirect Design Process

1. Determine pipe installation method
2. Select bedding / standard installation
3. Calculate earth load
4. Calculate live load
5. Determine bedding factors
6. Factor of safety (Service Load)
7. Select pipe strength

Example
Circular RCP

Indirect Design Process

1. Determine pipe installation method
2. Select bedding / standard installation
3. Calculate earth load
4. Calculate live load
5. Determine bedding factors
6. Factor of safety (Service Load)
7. Select pipe strength

Example Problem

- Pipe = 48” Circular Pipe
- Fill Height = 3 ft.
- Bedding = 90% Compaction of Granular Material up to Springline
- Live Load = AASHTO HL-93
- Direction of Traffic = Parallel to Span

Pipe Information

- Circular Pipe
  - ID = 48 inches
  - t = 48/12 + 1.75 = 5.75 inches
    - A C-wall pipe is conservatively assumed
  - B_c = 48 + 2(5.75) = 4.96 feet

Installation Information

- Standard Installation = Type 2
  - 90% compaction of a granular material
- Soil Unit Weight - γ_s = 120 pcf
- Vertical Arching Factor – VAF = 1.40

AASHTO LRFD 12.10.2.1

Table 12.10.2.1-3 Coefficients for use with Figure 1.

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30
A1	0.62	0.85	1.05	1.45
A2	0.73	0.55	0.35	0.00
A3	1.35	1.40	1.40	1.45
A4	0.19	0.15	0.10	0.00
A5	0.08	0.08	0.10	0.11
A6	0.18	0.17	0.17	0.19
a	1.40	1.45	1.45	1.45
b	0.40	0.40	0.36	0.30
c	0.18	0.19	0.20	0.25
e	0.08	0.10	0.12	0.00
f	0.05	0.05	0.05	—
u	0.80	0.82	0.85	0.90
v	0.80	0.70	0.60	—

Earth Load on Pipe

$$PL = \gamma_s \times B_c \times H$$

$$W_e = VAF \times PL$$

Circular

$PL = 120 \text{ pcf} \times 4.96 \text{ ft} \times 3 \text{ ft}$
$PL = 1786 \text{ lbs/ft}$

$W_e = 1.40 \times 1786 \text{ lbs/ft}$
$W_e = 2500 \text{ lbs/ft}$

Fluid Load

Pipe Area = π x $(ID/24)^2$
Pipe Area = 12.57 ft^2

W_f = Pipe Area x γ_w
W_f = 784 lbs/ft

Pipe Area = π x $(48/24)^2$

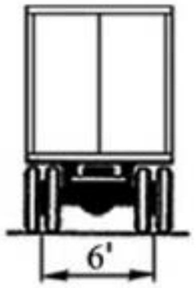
W_f = 12.57 ft^2 x 62.4 pcf

Live Load Dimensions

- Length of tire patch
  - l_t = 10 inches
- Width of tire patch
  - w_t = 20 inches
- Spacing of wheels on a single axle
  - s_w = 6 ft.
- Spacing of tandem axles
  - s_{ta} = 4 ft
- Spacing of single axles
  - s_{sa} = 14 ft

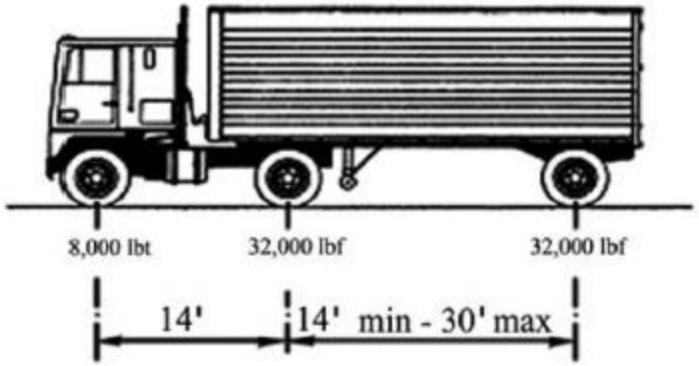
WHEEL SPACING

Design Truck
and
Design Tandem



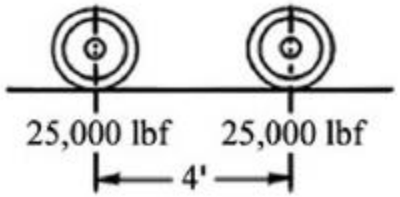
AXLE LOADS

Design Truck



AXLE LOADS

Design Tandem



Live Load

- Since traffic is running parallel to the span of the pipe (across the pipeline) we can analyze the pipe for a single lane using the appropriate multiple presence factor.
- mpf = 1.2

Impact Factor (Dynamic Load Allowance)

$$IM = 33\,(1 - 0.125\,H)$$

$$IM = 33\,[1 - 0.125(3)]$$

$$IM = 20.625$$

Determine the Live Load Distribution Factor (LLDF)

Table 3.6.1.2.6a-1—Live Load Distribution Factor (LLDF) for Buried Structures

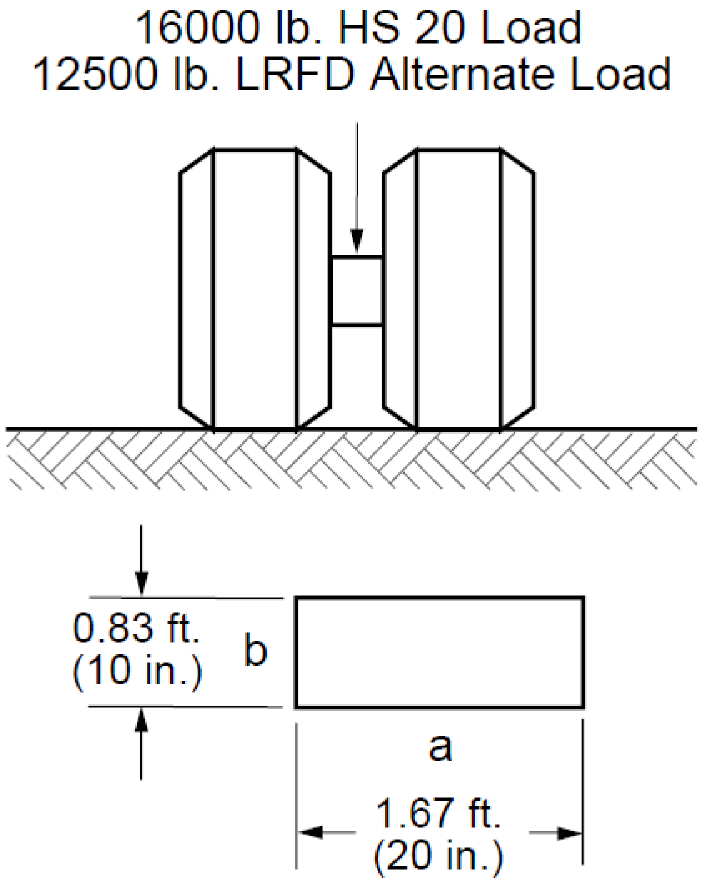
Structure Type	LLDF Transverse or Parallel to Span
Concrete Pipe with fill depth 2 ft or greater	1.15 for diameter 2 ft or less 1.75 for diameters 8 ft or greater Linearly interpolate for LLDF between these limits
All other culverts and buried structures	1.15

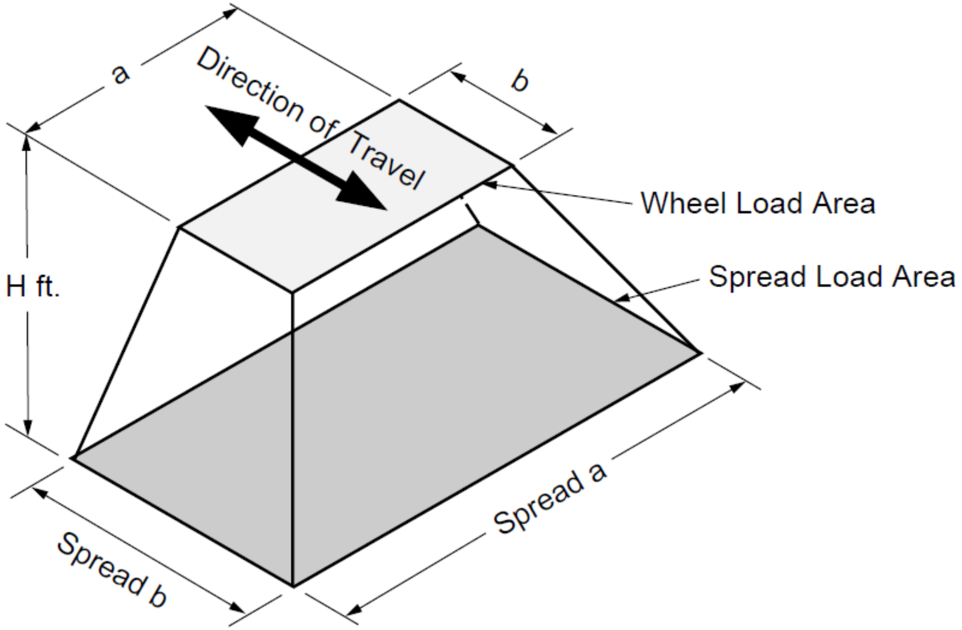
48” Circular RCP

$$LLDF = 1.15 + \frac{(48 - 24)}{(96 - 24)}(1.75 - 1.15)$$

$$LLDF = 1.35$$

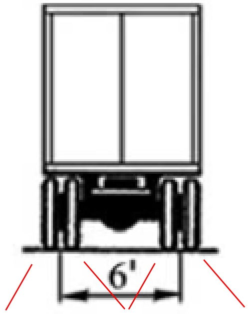
Live Load Spread





Spread a = $w_t/12$ + LLDF x H → 20/12 + 1.35 x 3 ft
Spread b = $l_t/12$ + LLDF x H → 10/12 + 1.35 x 3 ft

Do the wheels of an axle overlap?



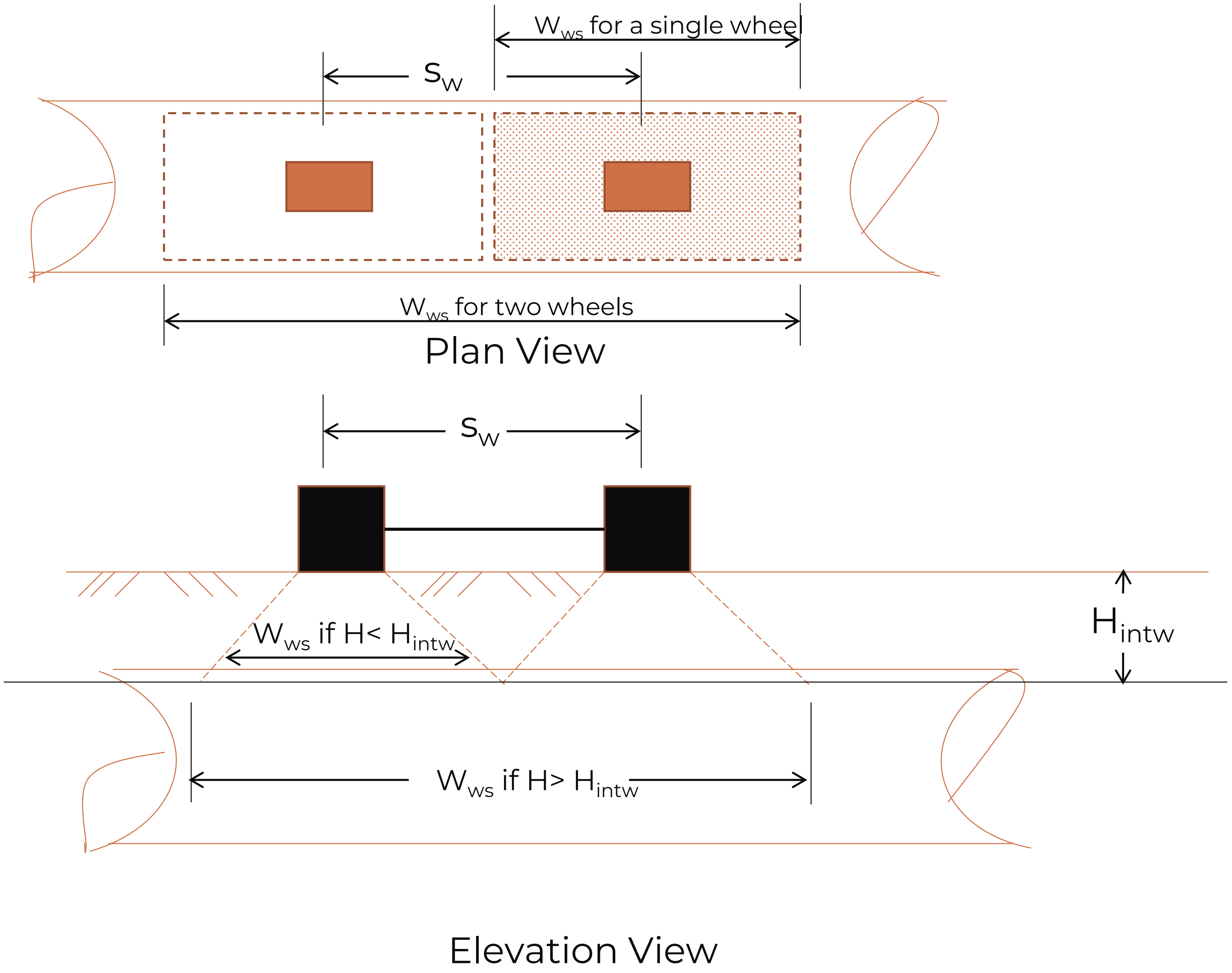
$$H_{int\text{-}t} = \frac{S_w - \frac{w_t}{12} - \frac{0.06\,ID}{12}}{LLDF}$$

$$H_{int\text{-}t} = \frac{6 - \frac{20}{12} - \frac{0.06(48)}{12}}{1.35}$$

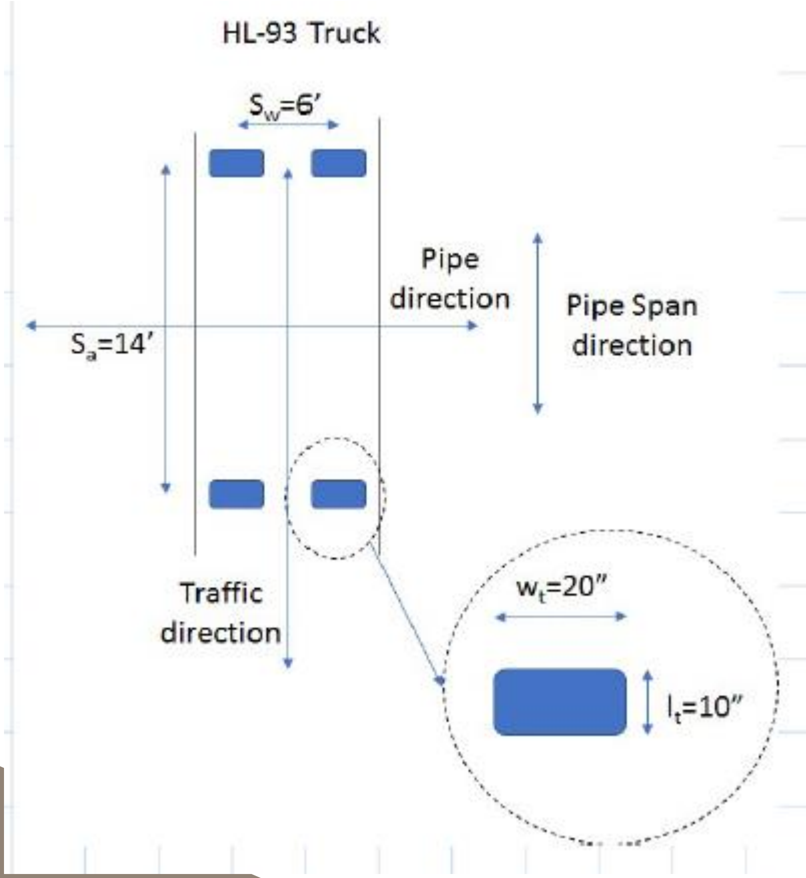
$H_{int\text{-}t} = 3.03$ ft

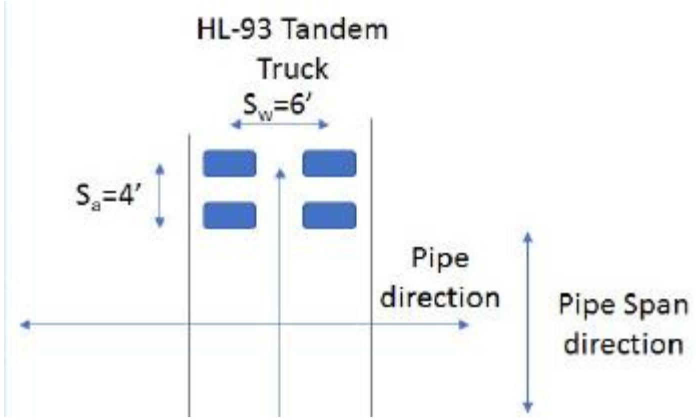
Pipe depth is less than the interaction depth, so use wheel load instead of axle load

Wheel Effects Do Not Overlap



Interaction Check for Single Axle and Tandem Axles

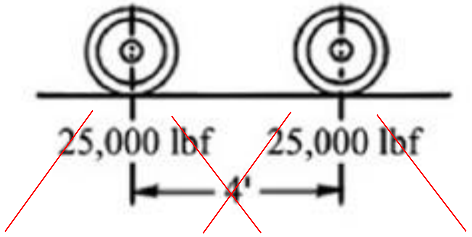




Do the tandem axle pressures overlap?

$$H_{int\text{-}p} = \frac{S_a - \frac{I_t}{12}}{LLDF}$$

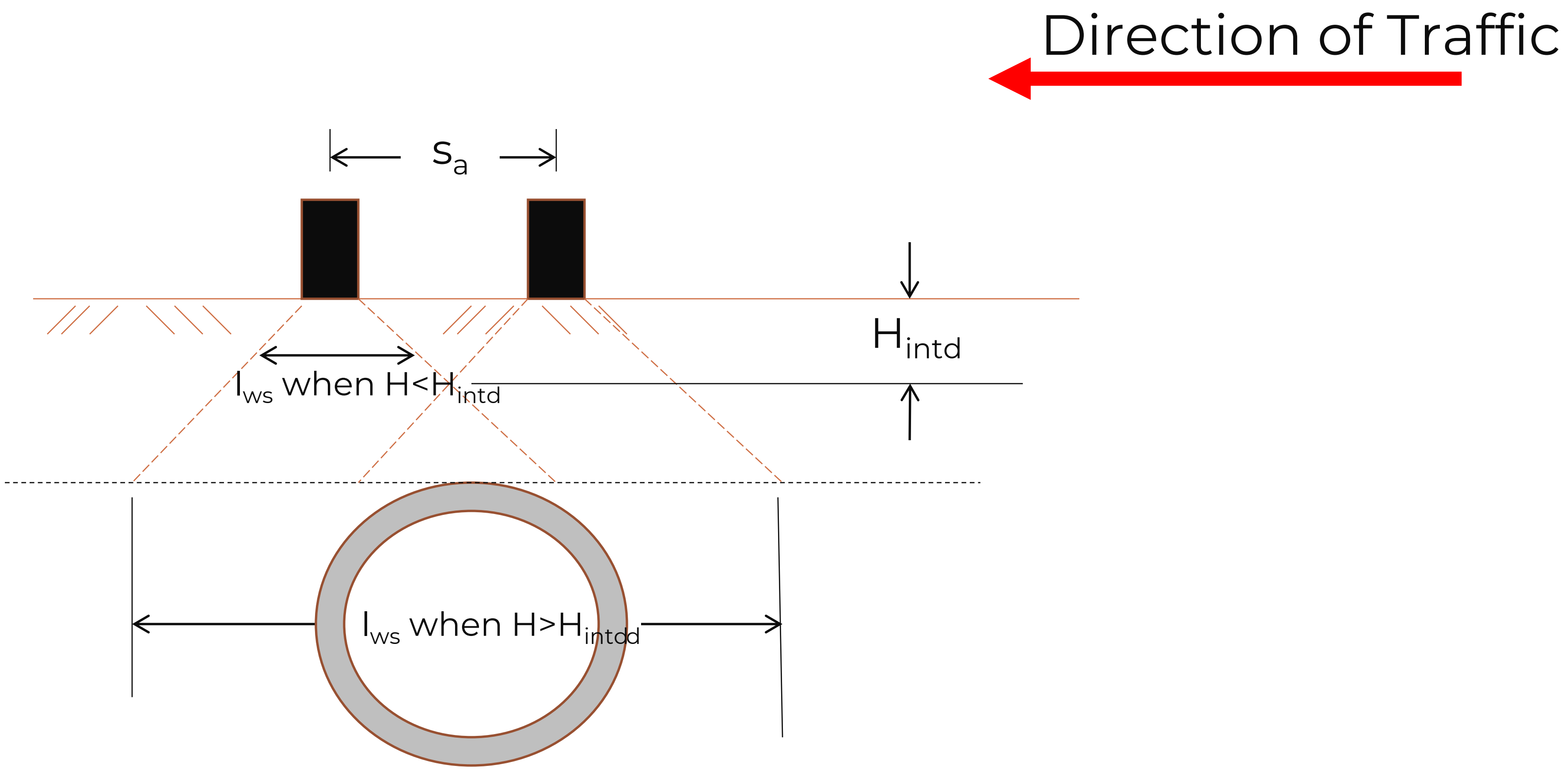
$$H_{int\text{-}t} = \frac{4 - \frac{10}{12}}{1.35}$$



$H_{int\text{-}p} = 2.35$ ft

Check Tandem Axles as well as Single Axle

Effect of Tandem Axles Overlap



Elevation View

Evaluate the Single Axle/Wheel

Calculate the Geometry of the Load at the top of the pipe for the wheel footprint

$$w_w = \frac{w_t}{12} + LLDF \times H + \frac{0.06\ ID}{12}$$

$$w_w = \frac{20}{12} + 1.35 \times 3 + \frac{0.06(48)}{12}$$

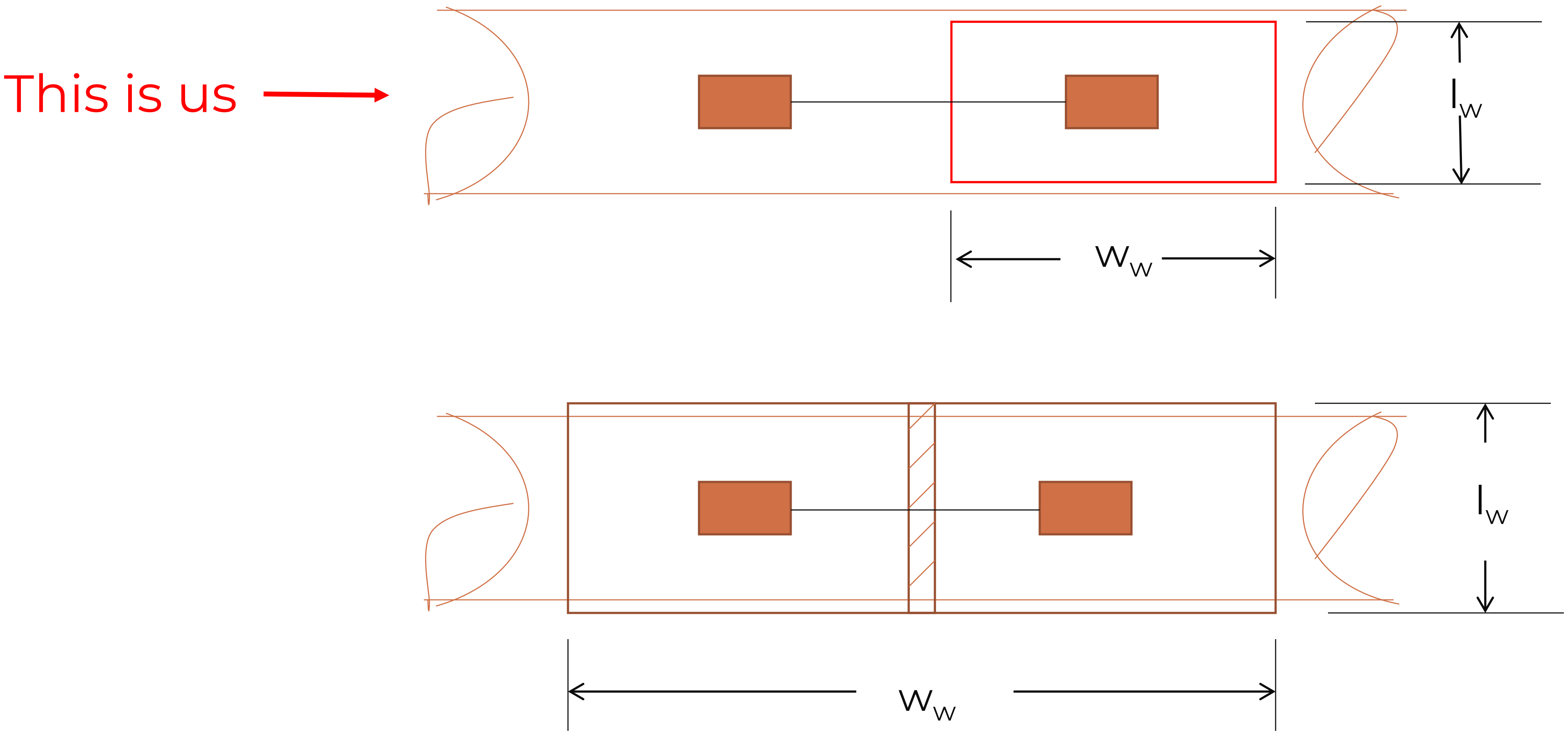
$$w_w = 5.96\ ft$$

$$l_w = \frac{l_t}{12} + LLDF \times H$$

$$l_w = \frac{10}{12} + 1.35 \times 3$$

$$l_w = 4.88\ ft$$

Pressure Area at the Top of the Pipe



Plan View

$A_{LL} = l_w w_w$ $A_{LL} = 4.88 \times 5.96$ $A_{LL} = 29\ ft^2$

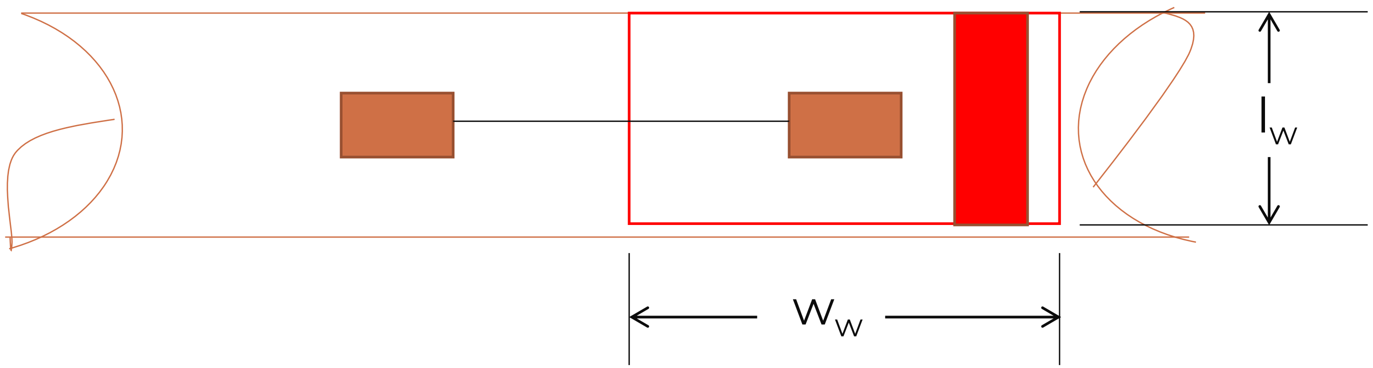
Determine the Live Load Pressure on the Pipe from a Single Wheel Footprint

$$S_{press} = \frac{P\left(1 + \frac{IM}{100}\right)(mpf)}{A_{LL}}$$

$$S_{press} = \frac{16{,}000\ \text{lbs}\left(1 + \frac{20.625}{100}\right)(1.2)}{29\ \text{ft}^2}$$

$S_{press} = 800$ psf

Determine the load on the pipe from the single axle/wheel



Dim = smaller of B_c or l_w 4.96 > 4.88   use Dim = 4.88 ft.

W_{SL} = Dim x S_{press} W_{SL} = 4.88 ft x 800 psf W_{SL} = 3,904 lbs/ft

Evaluate the Tandem Axles

Calculate the Geometry of the Load at the top of the pipe for the tandem axles

$$w_w = \frac{w_t}{12} + LLDF \times H + \frac{0.06\ ID}{12}$$

$$w_w = \frac{20}{12} + 1.35 \times 3 + \frac{0.06(48)}{12}$$

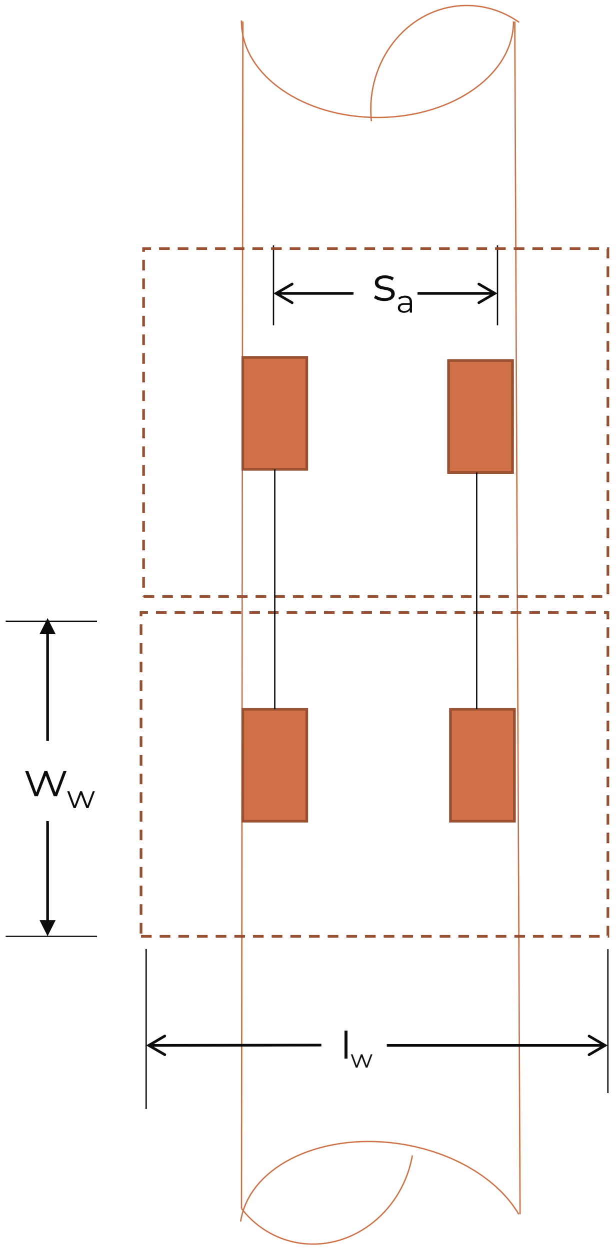
$$w_w = 5.96\ ft$$

$$l_w = \frac{l_t}{12} + LLDF \times H + 4\ ft$$

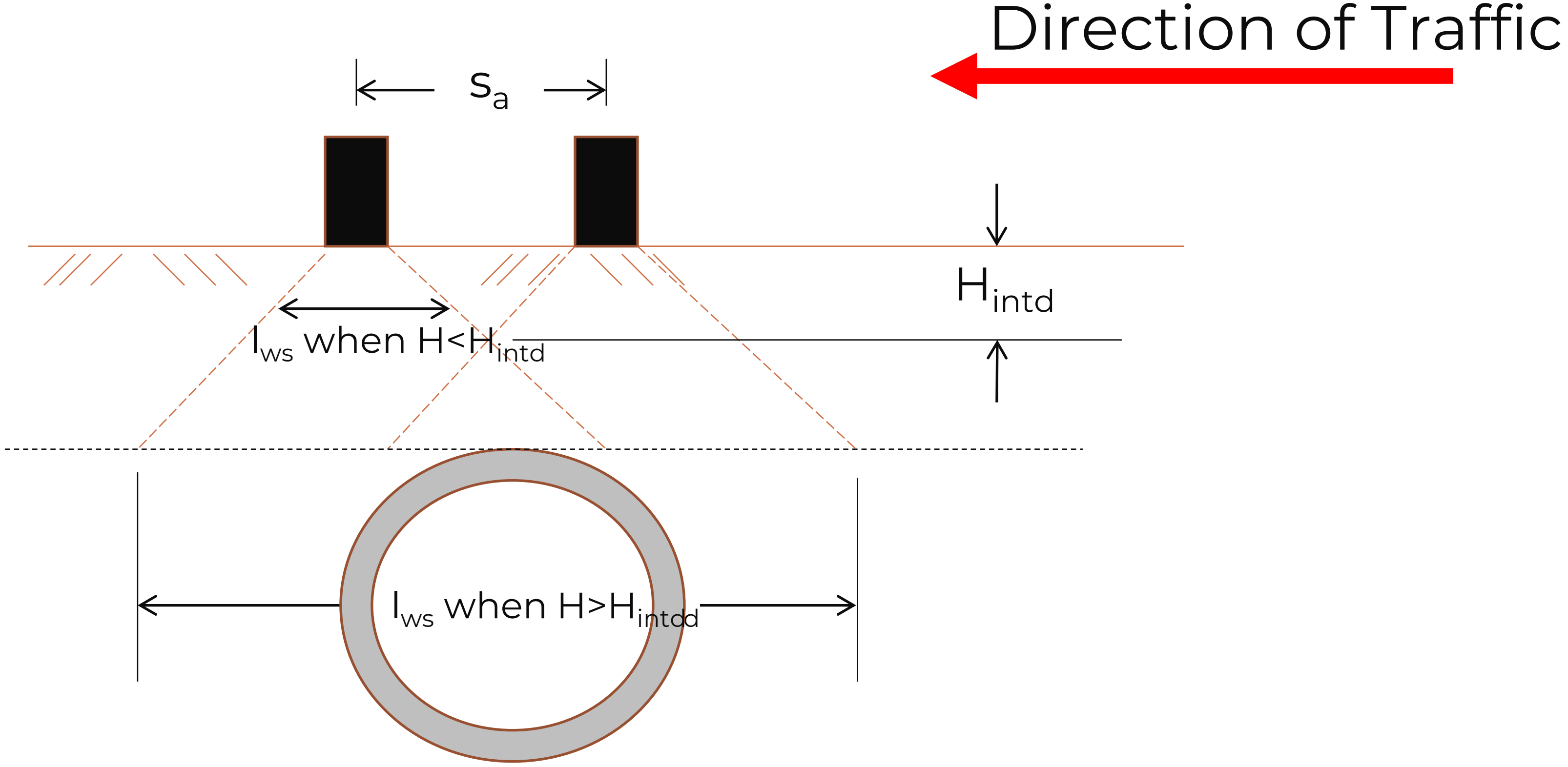
$$l_w = \frac{10}{12} + 1.35 \times 3 + 4\ ft$$

$$l_w = 8.88\ ft$$

Interaction Depth for Tandem Axles



Plan View



Elevation View

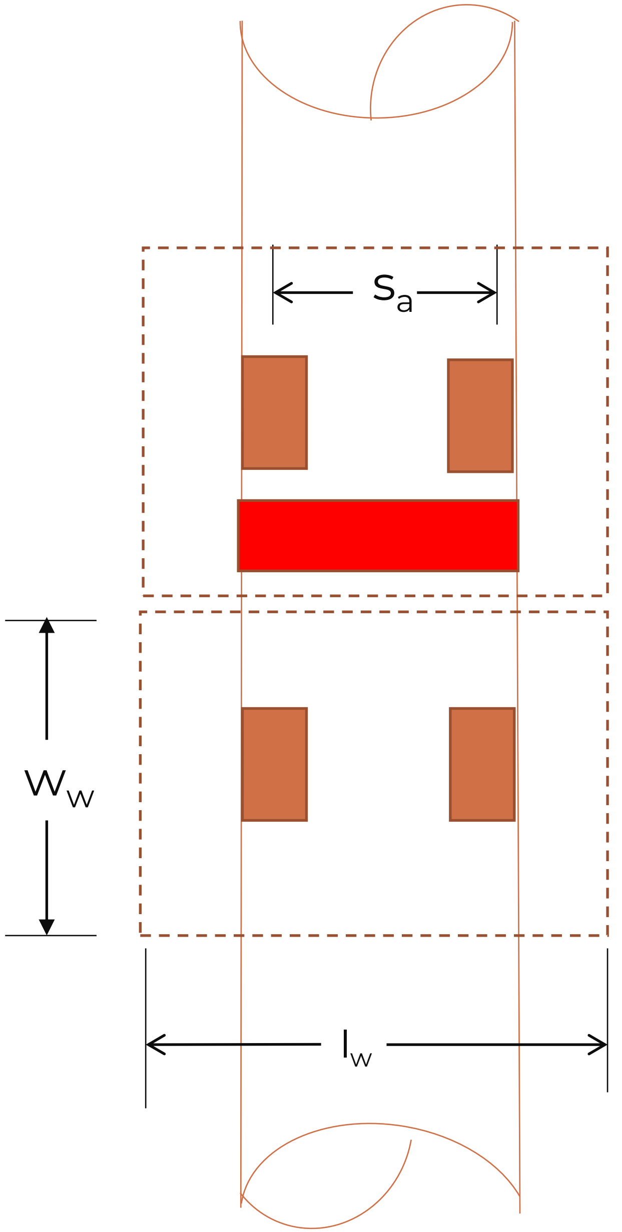
$A_{LL} = l_w \, w_w$ $\quad A_{LL} = 8.88 \times 5.96$ $\quad A_{LL} = 52.92 \text{ ft}^2$

Determine the Live Load Pressure on the Pipe from Tandem Axle Wheels

$$T_{press} = \frac{P\left(1 + \frac{IM}{100}\right)(mpf)}{A_{LL}}$$

$$T_{press} = \frac{25{,}000\ \text{lbs}\left(1 + \frac{20.625}{100}\right)(1.2)}{52.92\ \text{ft}^2}$$

$T_{press} = 684$ psf



Dim = smaller of B_c or l_w

4.96 < 8.88

use Dim = 4.96 ft.

W_{TL} = Dim x Spress

W_{TL} = 4.96 ft x 684 psf

W_{TL} = 3,393 lbs/ft

Determine the Governing Live Load

- Use the greater of W_{SL} or W_{TL}
  - W_{SL} = 3,904 lbs/ft
  - W_{TL} = 3,393 lbs/ft
  - W_{L} = 3,904 lbs/ft

Determine the Earth Load Bedding Factor

Table 12.10.4.3.2a-1 Bedding Factors for Circular Pipe.

Pipe Diameter, in.	Standard Installations			
	Type 1	Type 2	Type 3	Type 4
12	4.4	3.2	2.5	1.7
24	4.2	3.0	2.4	1.7
36	4.0	2.9	2.3	1.7
72	3.8	2.8	2.2	1.7
144	3.6	2.8	2.2	1.7

$$B_{f36} = 2.9$$

$$B_{f72} = 2.8$$

$$B_{FE} = B_{f36} - \left(\frac{ID - 36}{72 - 36}\right)(B_{f36} - B_{f72})$$

$$B_{FE} = 2.9 - \left(\frac{48 - 36}{72 - 36}\right)(2.9 - 2.8)$$

$$B_{FE} = 2.87$$

Determine the Live Load Bedding Factor

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

$B_{FLL} = 2.2$

Determine the D-Load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \quad (12.10.4.3.1\text{-}1)$$

$$D = \left(\frac{12}{48}\right)\left(\frac{2500 \text{ lbs/ft} + 784 \text{ lbs/ft}}{2.87} + \frac{3904 \text{ lbs/ft}}{2.2}\right)$$

$D_{0.01}$ = 730 lbs/ft/ft

ASTM C 76/AASHTO M 170 Pipe Classes

- Class I - $D_{0.01}$ = 800 lbs/ft/ft
- Class II - $D_{0.01}$ = 1000 lbs/ft/ft
- Class III - $D_{0.01}$ = 1350 lbs/ft/ft
- Class IV - $D_{0.01}$ = 2000 lbs/ft/ft
- Class V - $D_{0.01}$ = 3000 lbs/ft/ft

Fill Height Tables are based on:
1. γs = 120 pcf
2. AASHTO HL-93 live load
3. Positive Projecting Embankment Condition - this gives conservative results in comparison to trench conditions

D-Load (lb/ft/ft) for Type 2 Bedding

Class I | Class II | Class III | Class IV | Class V | Special Design

Pipe Size (in)	Fill Height in Feet													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
12	1492	1322	880	727	694	705	741	788	704	781	858	934	1011	1087
15	1434	1272	851	707	676	688	724	771	691	766	841	915	990	1065
18	1358	1240	834	697	668	680	717	763	688	761	835	909	983	1056
21	1220	1218	824	692	665	678	715	762	689	763	836	909	983	1056
24	1202	1203	818	690	665	680	717	764	694	768	841	915	988	1062
27	1344	1205	819	694	668	684	721	768	696	769	842	915	989	1062
30	1471	1213	823	701	674	690	727	773	699	772	845	919	992	1065
33	1347	1168	805	693	669	688	727	773	704	777	850	923	996	1069
36	1244	1137	789	687	665	687	728	775	710	783	856	929	1003	1076
42	1084	1059	759	673	659	685	726	773	715	788	861	933	1006	1079
48	966	935	732	663	655	684	726	774	722	795	867	940	1013	1085
54	923	899	712	655	654	685	728	777	731	803	876	948	1021	1094
60	948	875	696	650	654	688	731	781	740	813	885	958	1031	1103
66	906	855	687	646	655	691	736	787	750	823	896	969	1041	1114
72	850	837	679	643	658	696	741	793	761	834	907	980	1053	1126
78	802	820	672	642	660	697	744	796	768	841	913	986	1059	1131
84	763	805	665	641	661	700	747	799	775	848	920	993	1065	1138
90	730	791	660	641	664	703	750	803	863	855	927	999	1072	1144
96	703	756	655	642	666	706	754	807	867	862	934	1006	1078	1151
102	679	734	662	649	674	714	761	814	875	937	941	1013	1086	1158
108	660	723	668	657	681	721	769	822	882	945	949	1021	1093	1165
114	643	729	675	665	689	729	776	830	890	952	1016	1028	1100	1172
120	629	734	682	670	697	737	784	837	898	960	1024	1036	1108	1180
126	617	740	689	678	705	744	792	845	905	968	1032	1097	1115	1187
132	607	745	691	686	712	752	800	853	913	976	1039	1105	1171	1195
138	599	751	686	694	720	760	808	861	921	983	1047	1112	1178	1203
144	592	757	692	701	728	768	816	869	929	991	1055	1120	1186	1253

Example
Elliptical RCP

Indirect Design Process

1. Determine pipe installation method
2. Select bedding / standard installation
3. Calculate earth load
4. Calculate live load
5. Determine bedding factors
6. Factor of safety (Service Load)
7. Select pipe strength

Example Problem

- Pipe = 38” x 60” (48” Equiv.) Elliptical Pipe
- Fill Height = 3 ft.
- Bedding = 90% Compaction of Granular Material up to Springline
- Live Load = AASHTO HL-93
- Direction of Traffic = Parallel to Span

Pipe Information

Elliptical Pipe

- Span = 60 inches
- t = 5.5 inches (ASTM C507)
- B_c = 60 + 2(5.5) = 5.92 feet

Installation Information

- Standard Installation = Type 2
  - 90% compaction of a granular material
- Soil Unit Weight - γ_s = 120 pcf
- Vertical Arching Factor – VAF = 1.40

AASHTO LRFD 12.10.2.1

Table 12.10.2.1-3 Coefficients for use with Figure 1.

	Installation Type			
	1	2	3	4
VAF	1.35	1.40	1.40	1.45
HAF	0.45	0.40	0.37	0.30
A1	0.62	0.85	1.05	1.45
A2	0.73	0.55	0.35	0.00
A3	1.35	1.40	1.40	1.45
A4	0.19	0.15	0.10	0.00
A5	0.08	0.08	0.10	0.11
A6	0.18	0.17	0.17	0.19
a	1.40	1.45	1.45	1.45
b	0.40	0.40	0.36	0.30
c	0.18	0.19	0.20	0.25
e	0.08	0.10	0.12	0.00
f	0.05	0.05	0.05	—
u	0.80	0.82	0.85	0.90
v	0.80	0.70	0.60	—

Earth Load on Pipe

$$PL = \gamma_s \times B_c \times H$$

$$W_e = VAF \times PL$$

Elliptical

PL = 120 pcf x 5.92 ft x 3 ft
PL = 2131 lbs/ft

W_e = 1.40 x 2131 lbs/ft
W_e = 2984 lbs/ft

Fluid Load

- 38” x 60” Elliptical is a 48” Circular Equivalent

Pipe Area = π x $(ID/24)^2$
Pipe Area = 12.57 ft^2

Pipe Area = π x $(48/24)^2$

W_f = Pipe Area x γ_w
W_f = 784 lbs/ft

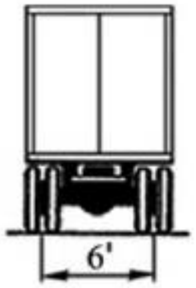
W_f = 12.57 ft^2 x 62.4 pcf

Live Load Dimensic

- Length of tire patch
  - l_t = 10 inches
- Width of tire patch
  - w_t = 20 inches
- Spacing of wheels on a single axle
  - s_w = 6 ft.
- Spacing of tandem axles
  - s_{ta} = 4 ft
- Spacing of single axles
  - s_{sa} = 14 ft

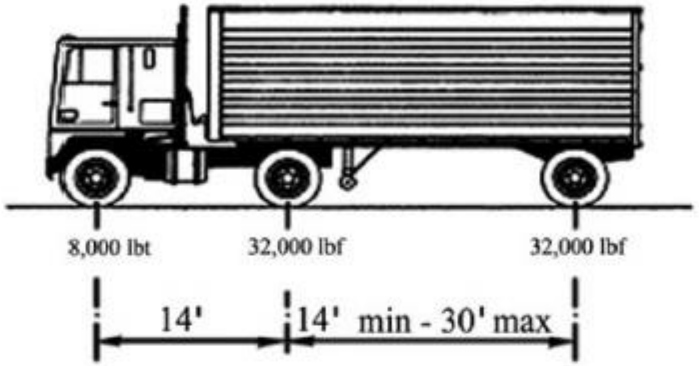
WHEEL SPACING

Design Truck
and
Design Tandem



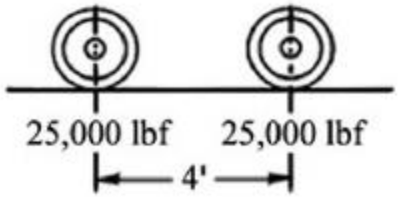
AXLE LOADS

Design Truck



AXLE LOADS

Design Tandem



Live Load

- Since traffic is running parallel to the span of the pipe (across the pipeline) we can analyze the pipe for a single lane using the appropriate multiple presence factor.
- mpf = 1.2

Impact Factor (Dynamic Load Allowance)

$$IM = 33\,(1 - 0.125\,H)$$

$$IM = 33\,[1 - 0.125(3)]$$

$$IM = 20.625$$

Determine the Live Load Distribution Factor (LLDF)

Table 3.6.1.2.6a-1—Live Load Distribution Factor (LLDF) for Buried Structures

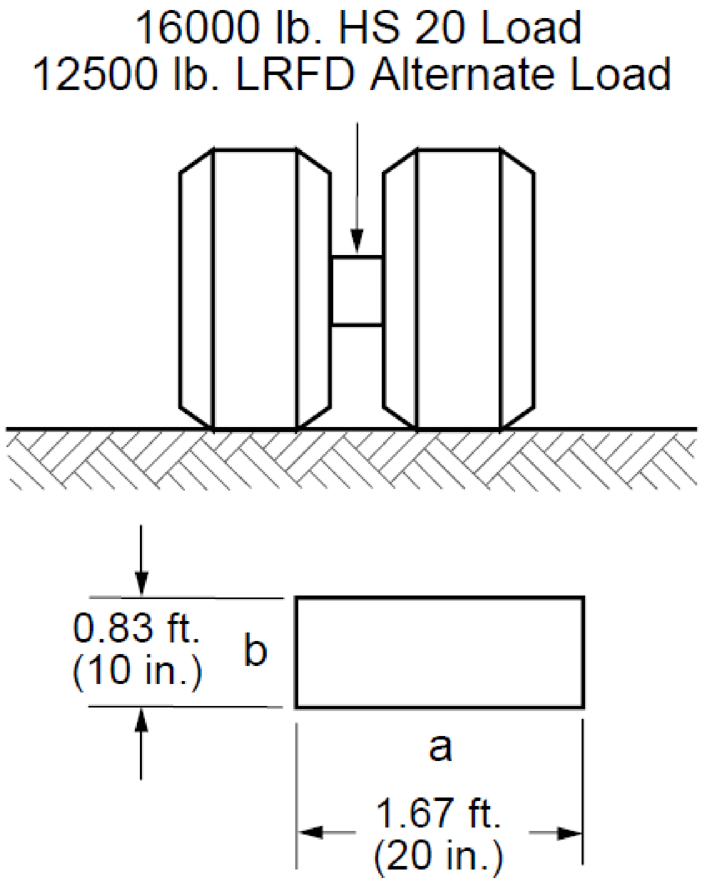
Structure Type	LLDF Transverse or Parallel to Span
Concrete Pipe with fill depth 2 ft or greater	1.15 for diameter 2 ft or less 1.75 for diameters 8 ft or greater Linearly interpolate for LLDF between these limits
All other culverts and buried structures	1.15

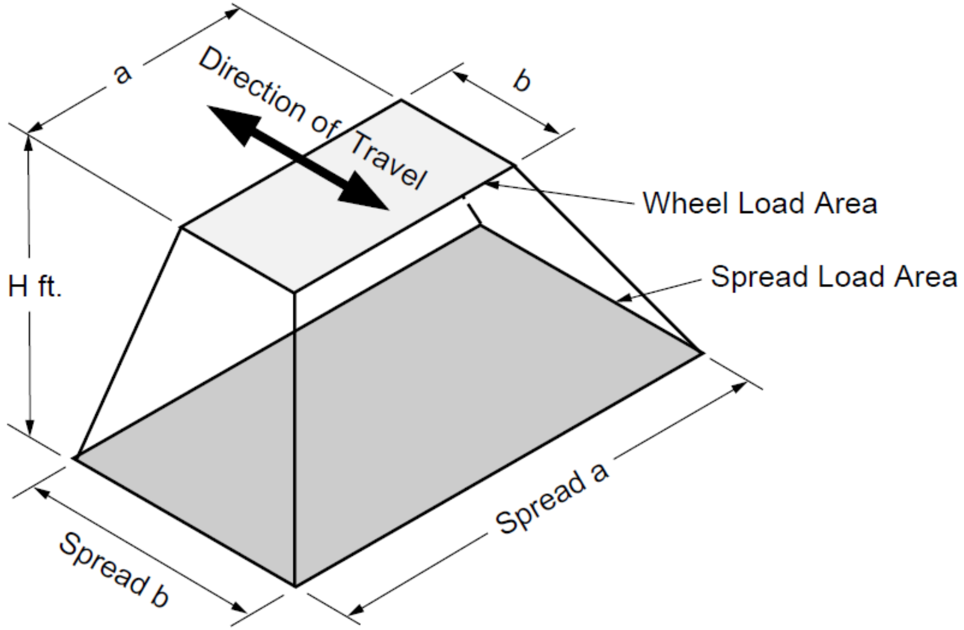
60" Span Elliptical RCP

$$\text{LLDF} = 1.15 + \frac{(60 - 24)}{(96 - 24)}(1.75 - 1.15)$$

$$\text{LLDF} = 1.45$$

Live Load Spread

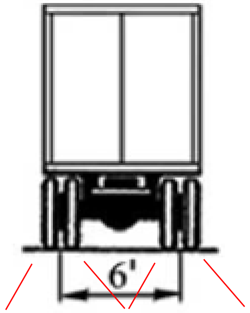




Spread a = $w_t/12$ + LLDF x H → 20/12 + 1.45 x 3 ft

Spread b = $l_t/12$ + LLDF x H → 10/12 + 1.45 x 3 ft

Do the wheels of an axle overlap?



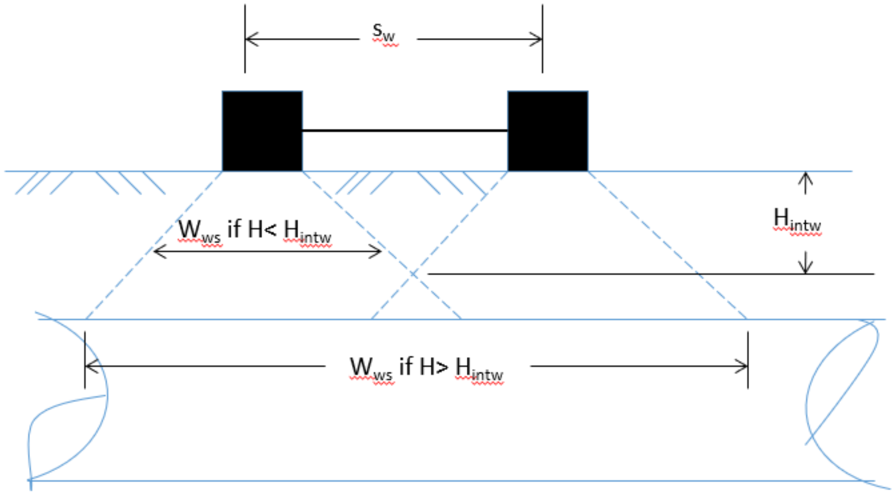
$$H_{int\text{-}t} = \frac{S_w - \frac{w_t}{12} - \frac{0.06\,ID}{12}}{LLDF}$$

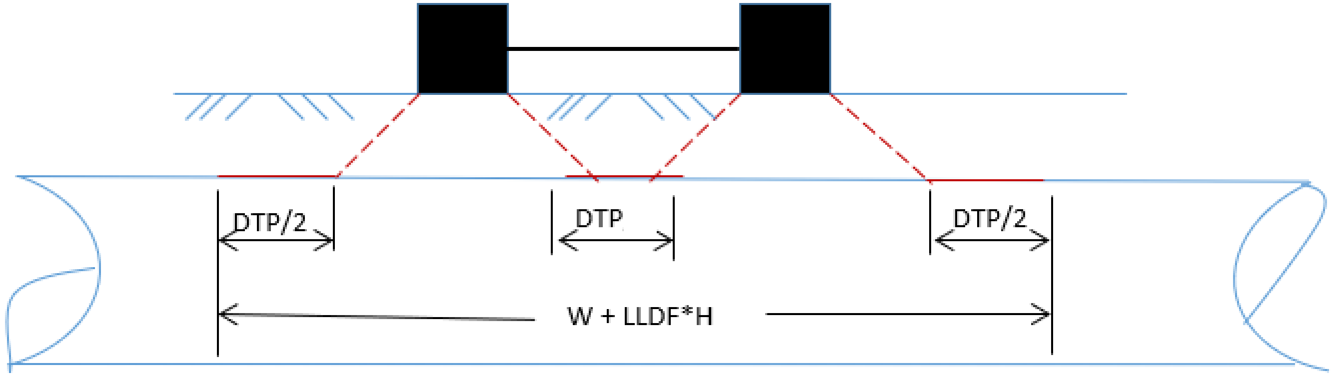
$$H_{int\text{-}t} = \frac{6 - \frac{20}{12} - \frac{0.06(60)}{12}}{1.45}$$

$H_{int\text{-}t} = 2.78$ ft

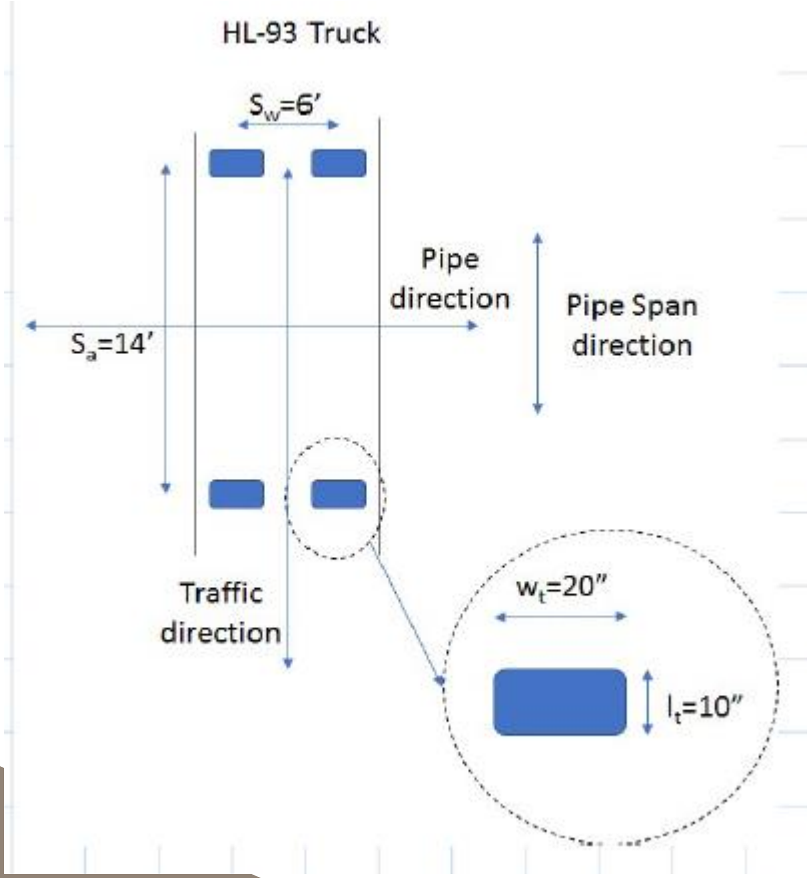
Pipe depth is greater than the interaction depth, so use axle load instead o

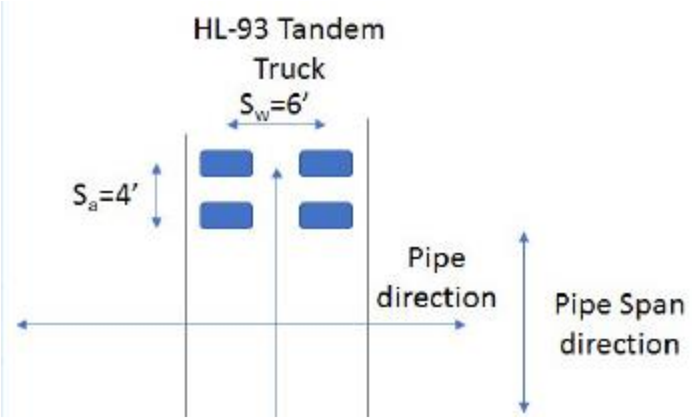
Wheel Effects Overlap, So Use Axle Load





Interaction Check for Single Axle and Tandem Axles

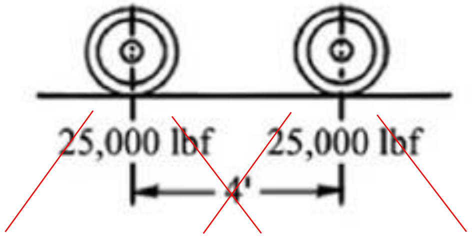




Do the tandem axle pressures overlap?

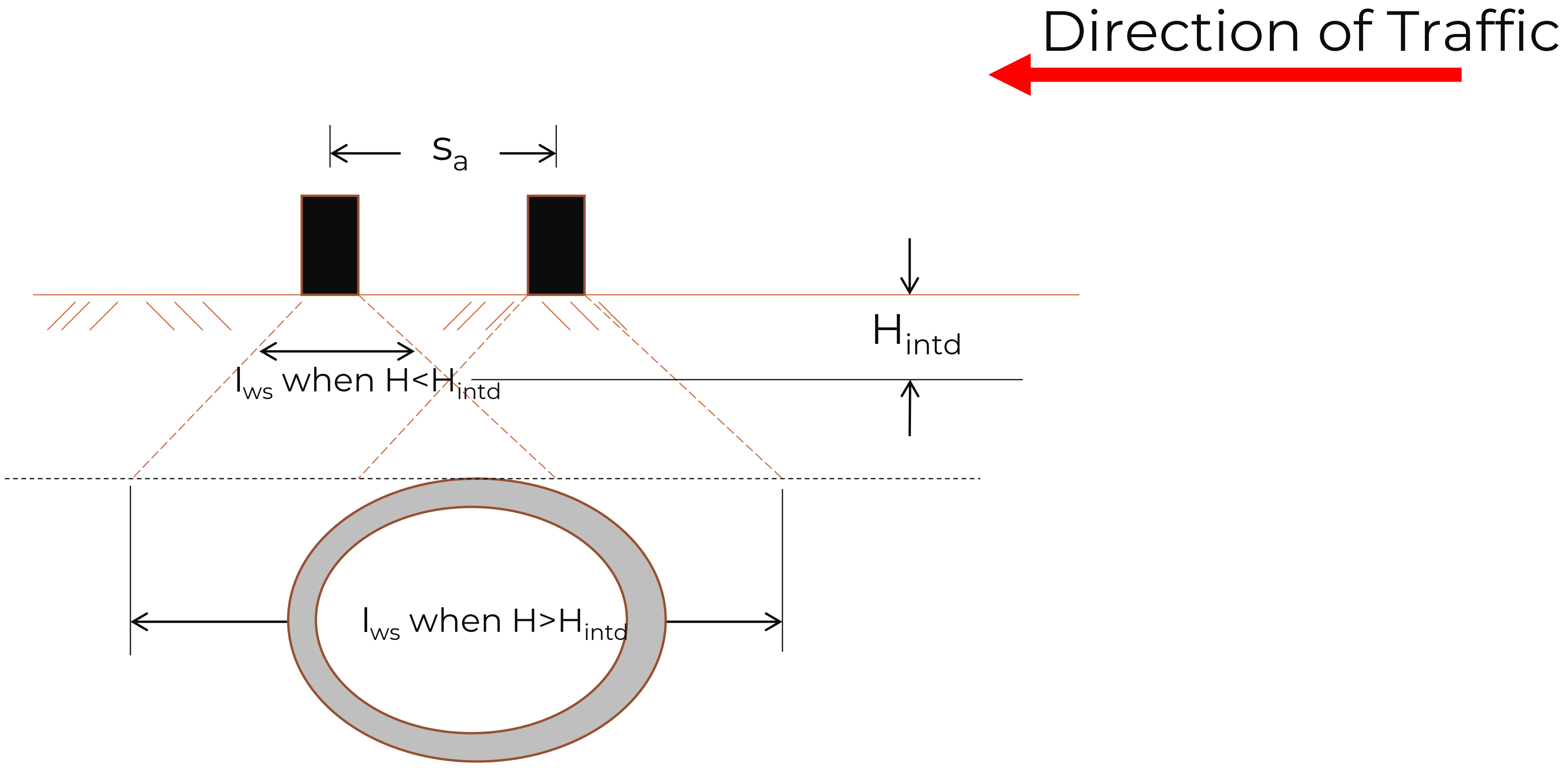
$$H_{int\text{-}p} = \frac{S_{ta} - \frac{l_t}{12}}{LLDF}$$

$$H_{int\text{-}t} = \frac{4 - \frac{10}{12}}{1.45}$$



$H_{int\text{-}p} = 2.18$ ft

Check Tandem Axles as well as Single Axle



Elevation View

Evaluate the Single Axle

Calculate the Geometry of the Load at the top of the pipe for the axle footprint

$$w_w = 6 + \frac{w_t}{12} + LLDF \times H + \frac{0.06\ Span}{12}$$

$$w_w = 6 + \frac{20}{12} + 1.45 \times 3 + \frac{0.06(60)}{12}$$

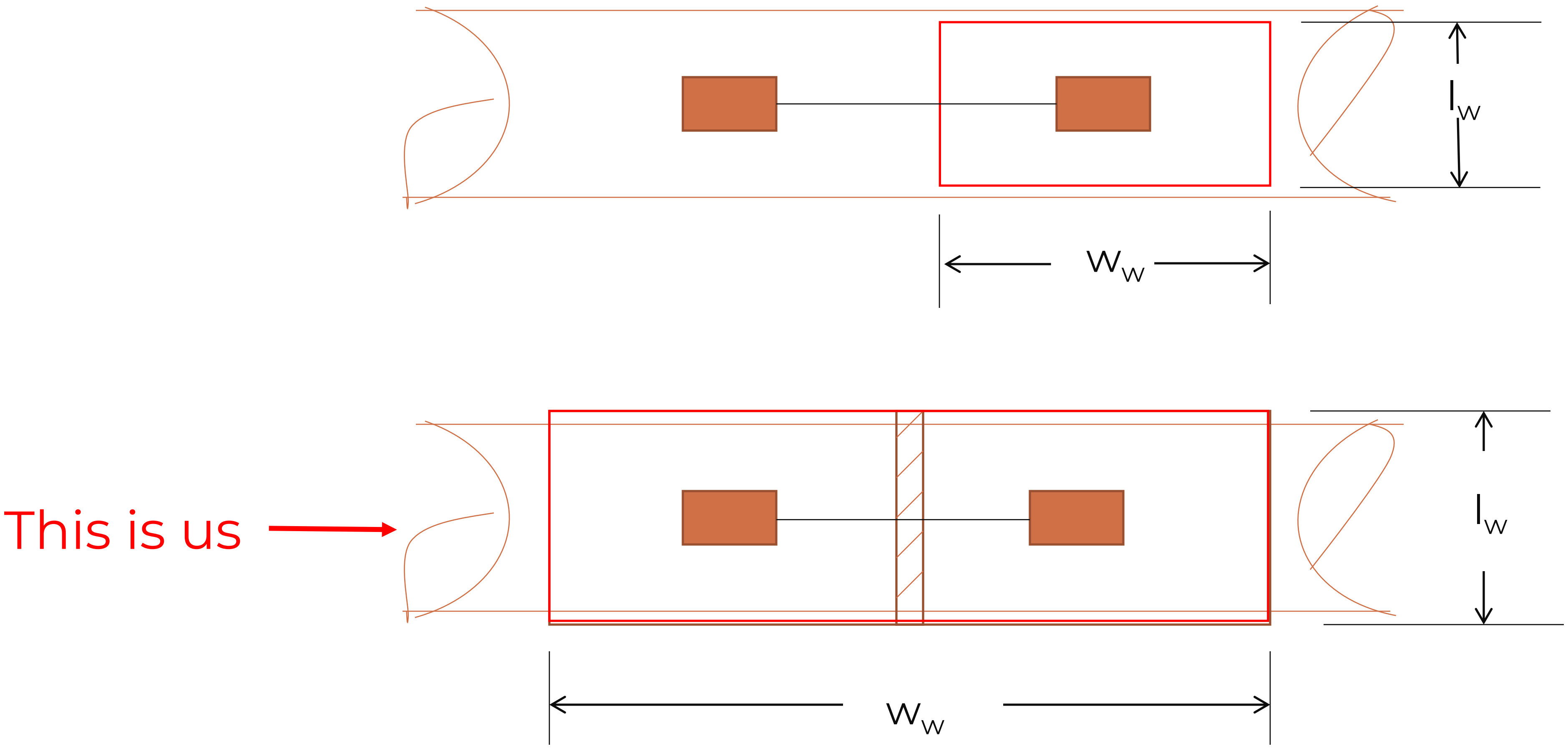
w_w = 12.32 ft

$$l_w = \frac{l_t}{12} + LLDF \times H$$

$$l_w = \frac{10}{12} + 1.45 \times 3$$

l_w = 5.18 ft

Pressure Area at the Top of the Pipe



Plan View

$A_{LL} = l_w w_w$ $A_{LL} = 5.18 \times 12.32$ $A_{LL} = 63.82\ ft^2$

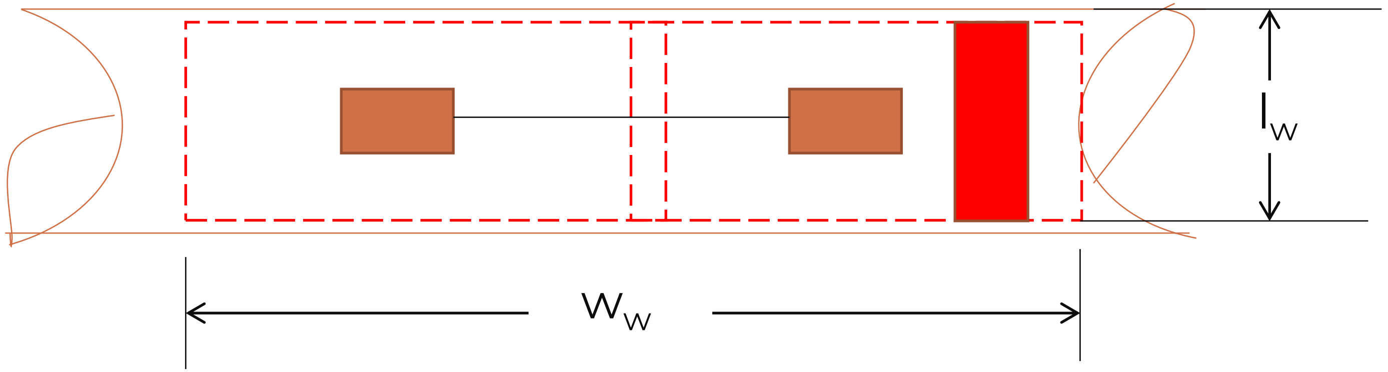
Determine the Live Load Pressure on the Pipe from a Single Wheel Footprint

$$S_{press} = \frac{P\left(1 + \frac{IM}{100}\right)(mpf)}{A_{LL}}$$

$$S_{press} = \frac{2 \times 16{,}000 \text{ lbs} \left(1 + \frac{20.625}{100}\right)(1.2)}{63.82 \text{ ft}^2}$$

$$S_{press} = 726 \text{ psf}$$

Determine the load on the pipe from the single axle/wheel



Dim = smaller of B_c or l_w 5.92 > 5.18 use Dim = 5.18 ft.

W_{SL} = Dim x S_{press} W_{SL} = 5.18 ft x 726 psf W_{SL} = 3,761 lbs/ft

Evaluate the Tandem Axles

Calculate the Geometry of the Load at the top of the pipe for the tandem axles

$$w_w = 6 + \frac{w_t}{12} + LLDF \times H + \frac{0.06\ Span}{12}$$

$$w_w = 6 + \frac{20}{12} + 1.45 \times 3 + \frac{0.06(60)}{12}$$

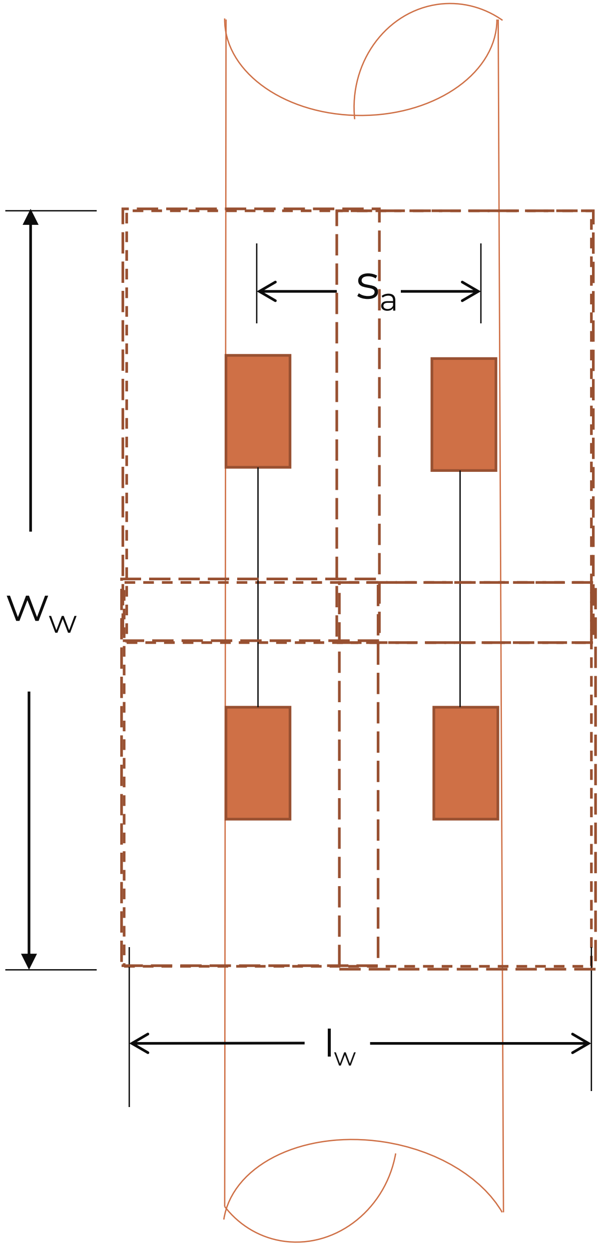
$$w_w = 12.32\ ft$$

$$l_w = \frac{l_t}{12} + LLDF \times H + 4\ ft$$

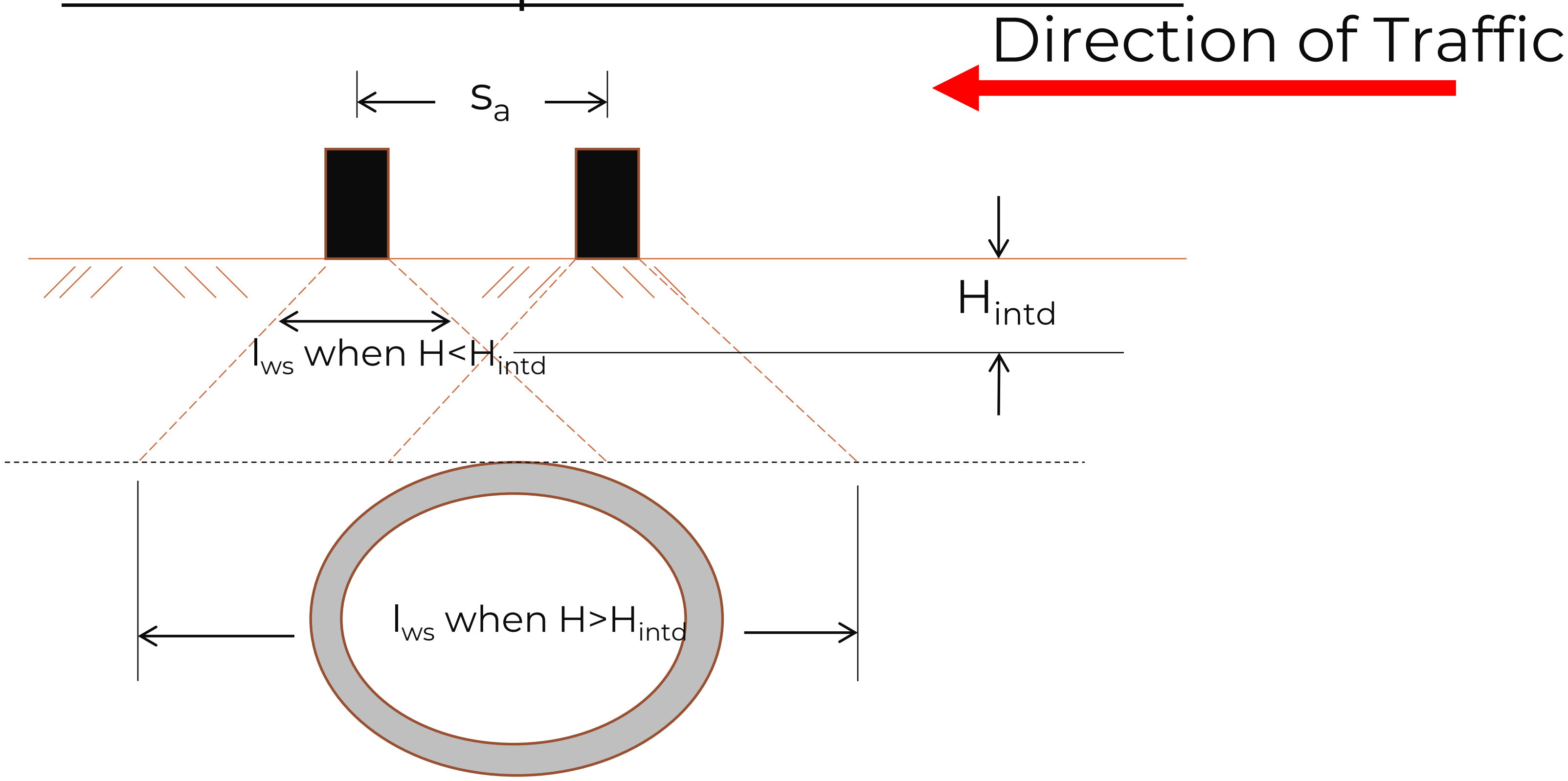
$$l_w = \frac{10}{12} + 1.45 \times 3 + 4\ ft$$

$$l_w = 9.18\ ft$$

Interaction Depth for Tandem Axles



Plan View



Elevation View

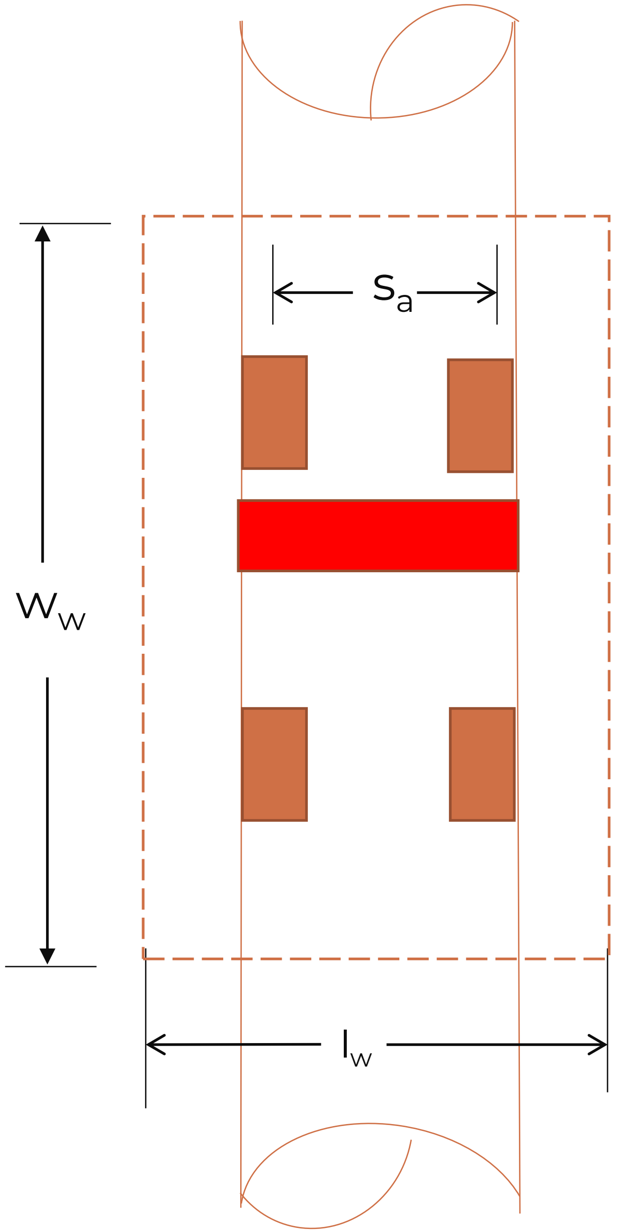
$A_{LL} = l_w\ w_w$ $\quad A_{LL} = 9.18 \times 12.32$ $\quad A_{LL} = 113.10\ ft^2$

Determine the Live Load Pressure on the Pipe from Tandem Axle Wheels

$$T_{press} = \frac{P\left(1 + \frac{IM}{100}\right)(mpf)}{A_{LL}}$$

$$T_{press} = \frac{2 \times 25{,}000 \text{ lbs} \left(1 + \frac{20.625}{100}\right)(1.2)}{113.10 \text{ ft}^2}$$

$$T_{press} = 640 \text{ psf}$$



Dim = smaller of B_c or l_w

5.92 < 9.18

use Dim = 5.92 ft.

W_{TL} = Dim x Spress

W_{TL} = 5.92 ft x 640 psf

W_{TL} = 3,789 lbs/ft

Determine the Governing Live Load

- Use the greater of W_{SL} or W_{TL}
  - W_{SL} = 3,761 lbs/ft
  - W_{TL} = 3,789 lbs/ft
  - W_L = 3,789 lbs/ft

Determine the Earth Load Bedding Factor

Table 12.10.4.3.2b-1—Design Values of Parameters in Bedding Factor Equation

Pipe Shape	C_A	Installation Type	C_N	Projection Ratio, p	x
Horizontal Elliptical and Arch	1.337	2	0.630	0.9	0.421
				0.7	0.369
		3	0.763	0.5	0.268
				0.3	0.148
Vertical Elliptical	1.021	2	0.516	0.9	0.718
				0.7	0.639
		3	0.615	0.5	0.457
				0.3	0.238

The value of the parameter q is taken as:

- For arch and horizontal elliptical pipe:

$$q = 0.23\frac{p}{F_e}\left(1 + 0.35p\frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}2)$$

- For vertical elliptical pipe:

$$q = 0.48\frac{p}{F_e}\left(1 + 0.73p\frac{B_c}{H}\right) \qquad (12.10.4.3.2b\text{-}3)$$

Use:

$p = 0.9$

Remember:

$F_e = 1.40$

$B_c = 5.92$ ft

$H = 3$ ft

$$q = 0.23\frac{0.9}{1.40}\left(1 + 0.35(0.9)\frac{5.92}{3}\right)$$

$q = 0.240$

Determine the Earth Load Bedding Factor

12.10.4.3.2b—Earth Load Bedding Factor for Arch and Elliptical Pipe

The bedding factor for installation of arch and elliptical pipe shall be taken as:

$$B_{FE} = \frac{C_A}{C_N - xq} \quad (12.10.4.3.2b\text{-}1)$$

Table 12.10.4.3.2b-1—Design Values of Parameters in Bedding Factor Equation

Pipe Shape	C_A	Installation Type	C_N	Projection Ratio, p	x
Horizontal Elliptical and Arch	1.337	2	0.630	0.9	0.421
				0.7	0.369
		3	0.763	0.5	0.268
				0.3	0.148
Vertical Elliptical	1.021	2	0.516	0.9	0.718
				0.7	0.639
		3	0.615	0.5	0.457
				0.3	0.238

Use:

$C_A = 1.337$

$C_N = 0.630$

$x = 0.421$

Remember:

$q = 0.240$

$$B_{FE} = \frac{1.337}{0.630 - (0.421)(0.240)}$$

$B_{FE} = 2.53$

Determine the Live Load Bedding Factor

Table 12.10.4.3.2c-1

Pipe Diameter, in	Fill Height, ft	
	< 2 ft	≥ 2 ft
12	3.2	2.4
18	3.2	2.4
24	3.2	2.4
30 and larger	2.2	2.2

$B_{FLL} = 2.2$

Determine the D-Load

$$D = \left(\frac{12}{S_i}\right)\left(\frac{W_E + W_F}{B_{FE}} + \frac{W_L}{B_{FLL}}\right) \qquad (12.10.4.3.1\text{-}1)$$

$$D = \left(\frac{12}{60}\right)\left(\frac{2984 \text{ lbs/ft} + 784 \text{ lbs/ft}}{2.53} + \frac{3789 \text{ lbs/ft}}{2.2}\right)$$

$D_{0.01}$ = 642 lbs/ft/ft

ASTM C 507/AASHTO M 207 Pipe Classes

- Class HE-A - $D_{0.01}$ = 600 lbs/ft/ft
- Class HE-I - $D_{0.01}$ = 800 lbs/ft/ft
- Class HE-II - $D_{0.01}$ = 1000 lbs/ft/ft
- Class HE-III - $D_{0.01}$ = 1350 lbs/ft/ft
- Class HE-IV - $D_{0.01}$ = 2000 lbs/ft/ft

Horizontal Elliptical Pipe

The following Fill Height Tables have been developed by the American Concrete Pipe Association (ACPA) using the indirect design method in accordance with Section 12.10.4.3 of the AASHTO LRFD Bridge Design Specification, 7th Edition, 2014.

Fill Height Tables are based on:

1. γ_s = 120 pcf
2. AASHTO HL-93 live load
3. Positive Projecting Embankment Condition - this gives conservative results in comparison to trench conditions
4. A projection ratio of 0.9.

D-Load (lb/ft/ft) for Type 2 Bedding

Pink	Class HE-A
Lavender	Class HE-I
Orange	Class HE-II
Green	Class HE-III
Blue	Class HE-IV
Yellow	Special Design

Inside Rise x Inside Span (inches)	Fill Height (feet)														
	0.5	1	1.5	2	2.5	3	4	5	6	7	8	9	10	11	12
14 x 23	1308	1140	1044	1160	942	815	714	709	742	797	860	813	901	989	1078
19 x 30	1445	1464	1323	1168	945	817	719	710	743	796	857	805	892	979	1065
22 x 34	1278	1298	1291	1112	910	789	703	698	733	788	849	801	887	973	1059
24 x 38	1148	1168	1196	1071	879	765	690	688	726	781	842	798	884	969	1054
27 x 42	1042	1063	1091	1023	838	737	671	674	714	768	828	789	873	957	1041
29 x 45	979	1002	1030	987	838	739	679	684	726	782	844	806	892	978	1063
32 x 49	904	928	956	908	813	720	668	678	721	777	839	805	890	976	1061
34 x 53	948	865	893	864	780	699	659	672	717	773	835	804	889	974	1059
38 x 60	925	882	826	833	733	676	647	666	713	770	833	808	892	977	1061
43 x 68	827	851	826	798	705	655	633	658	707	765	828	809	893	977	1061
48 x 76	751	777	803	767	681	637	621	652	703	761	825	810	894	978	1062
53 x 83	699	726	753	746	665	626	617	651	702	761	825	815	899	983	1066
58 x 91	650	678	705	724	645	612	610	647	699	759	824	818	901	985	1068
63 x 98	616	644	672	697	637	606	610	648	701	761	826	898	907	990	1073
68 x 106	582	611	639	665	638	607	612	651	704	764	829	901	975	993	1076
72 x 113	559	588	617	656	643	610	617	656	709	769	835	907	981	999	1082
77 x 121	534	564	594	659	647	611	619	659	712	773	838	910	984	1060	1085
82 x 128	518	548	578	661	643	615	620	662	715	776	841	913	987	1062	1139
87 x 136	501	531	561	662	626	616	621	663	717	777	843	914	988	1063	1139
92 x 143	489	520	550	667	627	609	626	668	722	783	848	920	994	1069	1145
97 x 151	477	507	538	670	631	612	628	671	726	787	852	924	998	1073	1149
106 x 166	460	491	522	679	641	623	634	679	734	796	862	934	1008	1083	1159
116 x 180	451	483	514	689	653	636	648	689	745	807	873	945	1020	1095	1172

Note: The ACPA Fill Height Tables include the larger of the two live load cases. In this instance, the live load case where the truck travels perpendicular to the span gives a slightly higher result than the case we analyzed, where the truck is traveling parallel to the span.
(676 lbs/ft/ft vs. 642 lbs/ft/ft)

The End

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