Highway Live Load on Concrete Pipe

Forward

This Design Data addresses the method of determining the live load pressure transmitted through unsurfaced roadways to circular, elliptical, and arch concrete pipe in accordance with the criteria of the AASHTO LRFD Bridge Design Specifications.

Thick, high-strength pavements designed for heavy truck traffic substantially reduce the pressure transmitted through a wheel to the subgrade and, consequently, to the underlying concrete pipe. The pressure reduction is so great that generally the live load can be neglected. In 1926, Westergaard presented a paper summarizing the results of an extensive study of the effects of loading conditions, subgrade support, and boundary conditions on concrete pavements (1). These results formed the basis by which Westergaard developed a method to calculate the stresses in concrete slabs. Based upon the work of Westergaard and others, the Portland Cement Association (PCA) developed a method to determine the vertical pressure on buried pipe due to wheel loads applied to concrete pavements (2). The PCA method is presented in the American Concrete Pipe Association (ACPA) "Concrete Pipe Handbook" (3) and "Concrete Pipe Design Manual" (4).

Intermediate and thin thicknesses of asphalt or flexible pavements do not reduce the pressure transmitted from a wheel to the pavement subgrade to any significant degree. Therefore, the design is typically conducted the same as an unsurfaced roadway.

Design of Highway Loads in the US often follows the American Association of State Highway and Transportation Officials (AASHTO) criteria. The AASHTO LRFD Bridge Design Specifications (5) specifies the applicable highway loads and their distribution through the soil.

Introduction

To determine the required supporting strength of concrete pipe installed under intermediate and thin thicknesses of asphalt, flexible pavements, and relatively shallow earth cover, it is necessary to evaluate the effect of live loads, such as highway truck loads, in addition to other loads applied to the pipe.

Live Load

Under shallow and intermediate depths of cover a concrete pipe must support the forces created by live loads, which can be vehicles and other moving loads on the road. Things to consider during the design are the magnitude of the load, load distribution, and material properties. Proper design along with proper installation techniques help to ensure that the concrete pipe can safely accommodate the moving forces while providing efficient drainage solutions for the infrastructure.

Dead Load

Dead loads are constant forces that do not change over time. Dead loads on a concrete pipe are static and permanent loads such as, the weight of the pipe itself, the weight of the soil/backfill that surrounds the buried pipe, and any other permanent structure that will affect the pipe. Various methods for analyzing soil loads, which have been developed over the years, are presented in the ACPA's "Concrete Pipe Technology Handbook" (6). The most current method of calculating soil loads on circular concrete pipe per AASHTO are presented in Design Data #9 "Standard Installations and Bedding Factors for the Indirect Design Method" (7).

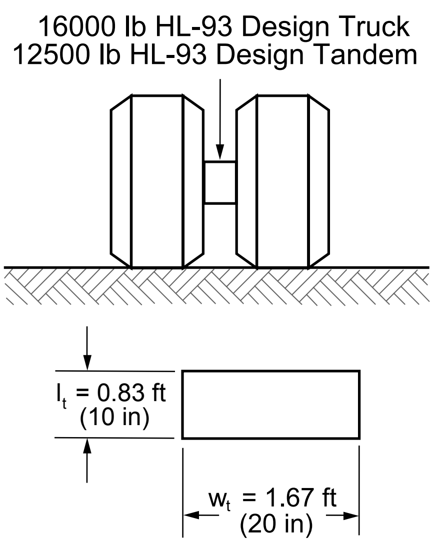
Surcharge Loads

A common type of surcharge load is an additional load placed directly on top or close to the top of the pipe following a period of time after its installation. If the surcharge load is a building or other surface load, the resultant uniformly distributed load can be converted to an equivalent height of fill, and then evaluated as an additional soil load. When concrete pipes have been installed underground, the soil-structure system will continually show an increase in load capacity. Data on concrete pipes, which have been removed from service and tested, indicates an increase in concrete strength and an increase in load carrying capacity of 10 to 40 percent. Settlement and consolidation will improve the soil structure surrounding the pipe, which also improves load carrying capacity. For more information on surcharge loads, refer to Design Data 22.

Live Load Design Method

The AASHTO LRFD Bridge Design Specifications require that roadways, bridges, or incidental structures be designed for a notional live load designated as HL-93. HL-93 consists of a design truck, and design tandem. The design truck has a 32,000-pound axle load with another axle of equal weight no closer than 14 ft, as shown in Figure 2a. The design tandem consists of two 25,000-pound axle loads spaced 4 ft apart, as shown in Figure 2b. Per the AASHTO LRFD Bridge Design Specifications, an additional lane load is incorporated for bridge design, but not required for culverts. The design truck and the tandem axles are carried on dual wheels as shown in Figure 1. The contact area of the dual wheels with the ground is assumed to be a rectangle with width w_t= 20 in and length l_t = 10 in as shown in Figure 1.

Figure 1: AASHTO Wheel Load Surface Contact Area

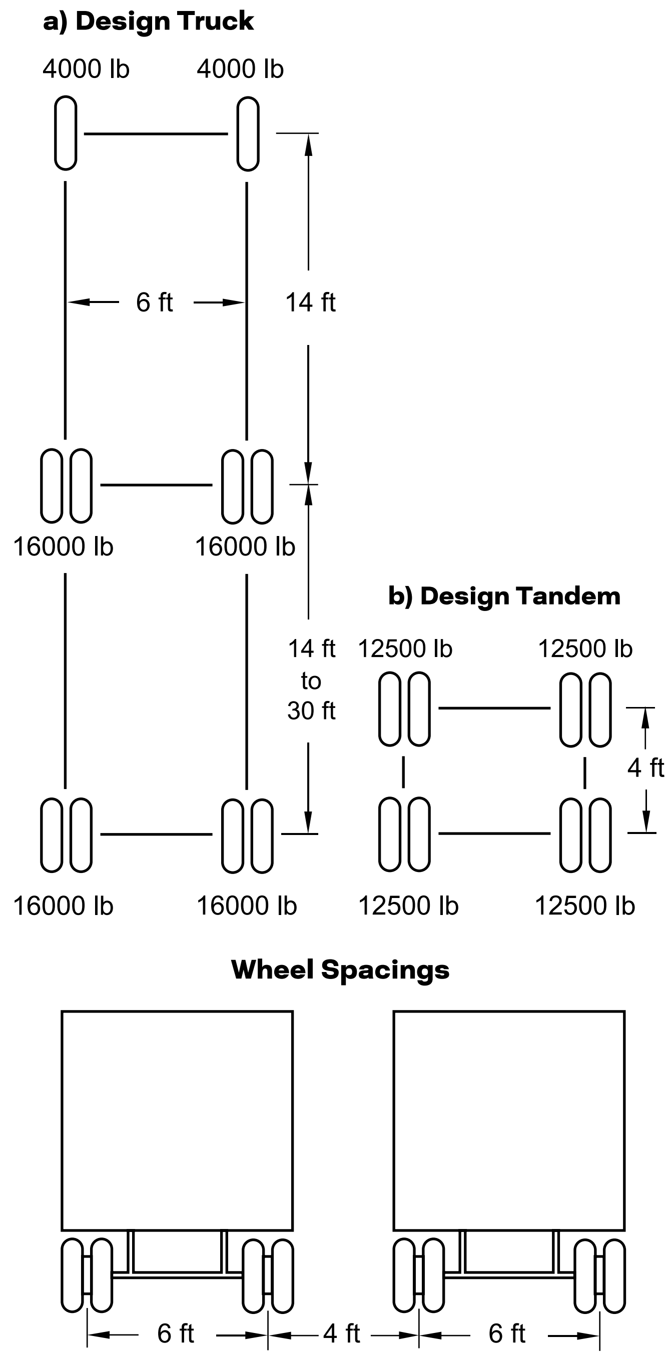


Load Distribution

The live load surface load is assumed to be uniformly spread on any horizontal subsoil plane. The spread load area is developed by increasing the length and width of the wheel contact area for a load configuration as illustrated in Figure 3 for a dual wheel; in Figure 4 for dual wheels of two trucks in passing mode; and in Figure 5 for two dual wheels of the design tandem in passing mode.

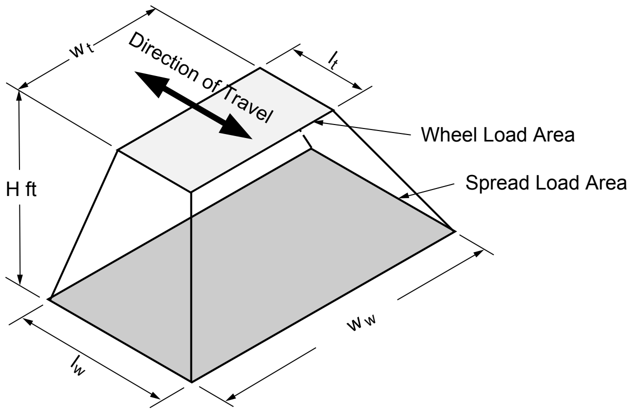
These dimensional increases to the wheel contact area are based on height of earth cover over the top of the pipe times a live load distribution factor.

Figure 2: AASHTO Wheel Loads and Wheel Spacings



As indicated by Figures 3, 4 and 5, the spread load areas from adjacent wheels will overlap as the height of earth cover over the top of the pipe increases. This height of interaction needs to be considered when designing for vehicular live loads.

Figure 3: Spread Load Area - Single Dual Wheel



Live Load Distribution Factor

The Live Load Distribution Factor (LLDF), shown on Table 2, is important for assessing how loads disperse within the soil, reaching the horizontal plane at the buried structure. The LLDF is used to reduce the load as it dissipates through the soil down to the buried structure.

Table 2: Live Load Distribution Factor (LLDF) for Buried Structures

Structure Type	LLDF Transverse or Parallel to Span
Concrete Pipe with fill depth 2.0 ft or greater	1.15 for diameter 2.0 or less 1.75 for diameters 8.0 or greater Linearly interpolate for LLDF between these limits
All other culverts and buried structures	1.15

Live Load Traveling Parallel to the Span of the Pipe

In most cases, the pipe will be running perpendicular to the road, or as is also said, traffic is traveling in a direction parallel to the span of the pipe. In these cases the pipe is acting as a culvert, storm drain etc.

Since this is the predominant application of vehicle live loads, this orientation will be addressed first, and in detail, and then guidance will be provided on when traffic is traveling perpendicular to the span.

As the vehicle load is applied at the surface above the pipe, the live load will be spread in a direction perpendicular to the span of the pipe (along the axis of the pipe) as well as parallel to the pipe span. The spread perpendicular to the pipe (along the length of the pipe) as the vehicle travels parallel to its span will be addressed.

Spread of the Load Perpendicular to the Pipe Span

The designer should be aware that a multiple presence factor, m accounting for the probability of simultaneous lane occupation by the full HL-93 live load needs to be applied to the calculated live load. The appropriate multiple presence factors, m can be found in Table 3, and are used when calculating the resulting pressure at the top of the pipe.

When the live load is traveling parallel to the span of the pipe, AASHTO only requires the designer to evaluate a single loaded lane with the single lane multiple presence factor m, shown in Table 3. Thus, in determining whether the effect of wheel loads overlap in the direction perpendicular to the pipe span, it is only necessary to evaluate whether the effects from the two-wheel footprints of an axle overlap each other.

Figure 4: Spread Load Area - Two Single Dual Wheels of Trucks in Passing Mode

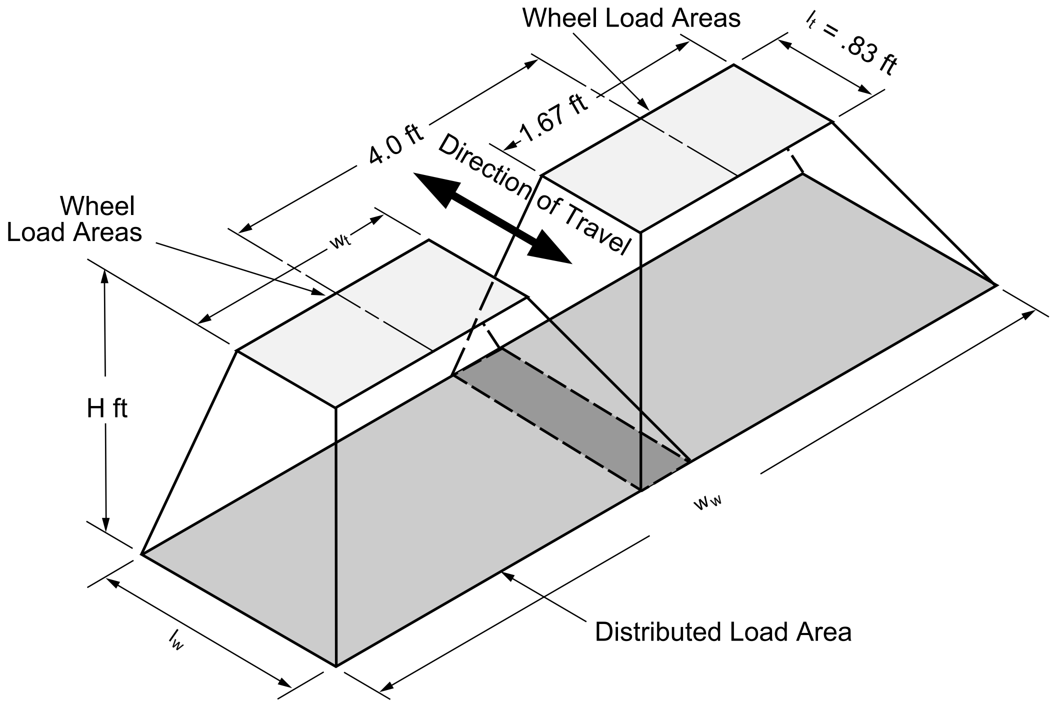


Figure 5: Spread Load Area - Two Single Dual Wheels of Design Tandem in Passing Mode

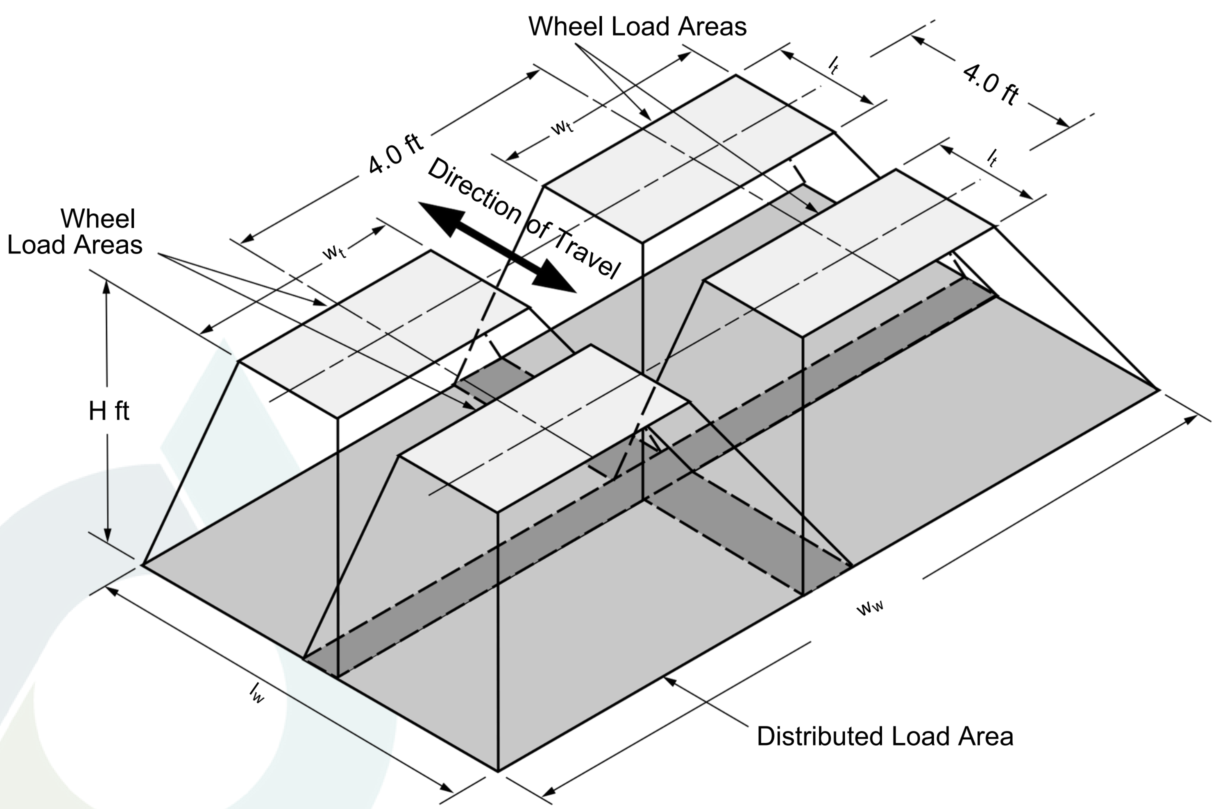


Table 3: Multiple Presence Factors, m

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

The first step will be to calculate the interaction depth where the effect from the wheel footprints on the same axle overlap. The equation to calculate the height of interaction is as follows:

$$H_{int-i} = \frac{s_w - \frac{w_t}{12} - 0.06 * \frac{D_i}{12}}{LLDF} \quad [1]$$

where:

s_w = wheel spacing, 6.0 ft

w_t = tire patch width, 20 in

D_i = inside diameter or clear span of the culvert, in

The next step is to calculate the width of the live load patch at the horizontal surface at the top of the pipe. If the soil cover, H, is less than the height of interaction, H_{int-i} , use:

$$w_w = \frac{w_t}{12} + H * LLDF + 0.06\frac{D_i}{12} \quad [2]$$

where:

H = depth of fill over culvert (ft)

w_w = live load patch width at depth H (ft)

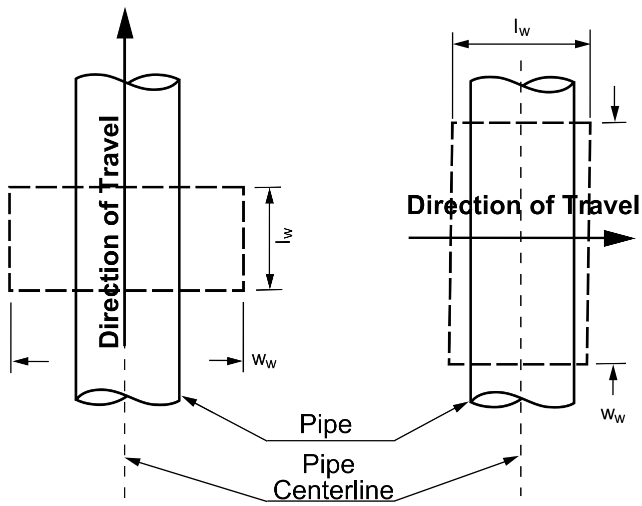
If the soil cover, H, is greater than the height of interaction, H_{int-i}, then include the width of the axle, and use:

$$w_w = s_w + \frac{w_t}{12} + H * LLDF + 0.06\frac{D_i}{12} \quad [3]$$

Spread of the Load Parallel to the Pipe Span

When determining whether the effects of loads from axles on the same truck interact, the engineer must consider the spacing of the axles. For the design truck, the minimum spacing of axles is 14 ft, and will not interact until the height of fill is sufficiently deep for interaction to occur. The spacing of the tandem axles is 4 ft, and interaction will occur at much shallower depths. Both axle spacings should be checked.

Figure 6: Spread Load Area Dimensions vs Direction of Truck



To calculate the distribution of the load parallel to the pipe, the first step will be to calculate the height of interaction for an axle:

$$H_{int-p} = \frac{s_a - \frac{l_t}{12}}{LLDF} \quad [4]$$

where:

s_a = axle spacing, 14 ft for single axles, and 4 ft between individual tandem axles

l_t = tire patch length, 10 in

If the soil cover, H, is less than the height of interaction, H_{int-p} , use:

$$l_w = \frac{l_t}{12} + H * LLDF \quad [5]$$

where:

l_w = live load patch length at depth H (ft)

If the soil cover is greater than the height of interaction, then include both axles, and use:

$$l_w = s_a + \frac{l_t}{12} + H * LLDF \quad [6]$$

Live Load Travelling Perpendicular to the Span of the Pipe

Although not common, there are occasions when the pipe will be running along the centerline of the road, or parallel to the road in close proximity, where the live load would thus be travelling perpendicular to the span of the pipe.

In these instances, the same basic concept will be used to determine the heights of interaction, but the orientation of the wheel footprints and axles will have to be rotated 90 degrees. Additionally, multiple axles may need to be checked if the wheel loads from passing vehicles interact.

Spread of the Load Parallel to the Pipe Span

Because it's perpendicular the pressure will be applied from multiple lanes, check to see if the effect from passing vehicles overlaps.

$$H_{int-l} = \frac{s_p - \frac{w_t}{12}}{LLDF} \quad [7]$$

where:

s_p = Passing distance is assumed to be 4 ft

The following equation calculates the height of interaction from wheels on the same axle:

$$H_{int-i} = \frac{s_w - \frac{w_t}{12}}{LLDF} \quad [8]$$

where:

s_w = the wheel spacing is 6 ft for wheels on the same axle

w_t = the tire width is 20 in

If the height of cover is less than the H_{int-l} then only one side of an axle needs to be considered.

$$l_w = \frac{w_t}{12} + H * LLDF \quad [9]$$

If the height of cover is greater than the H_{int-l}, but less than H_{int-i} the passing wheels need to be considered, but additional lanes need not be considered.

$$l_w = \frac{w_t}{12} + s_p + H * LLDF \quad [10]$$

If the height of cover is greater than the H_{int-i} then the live load for one axle/lane is:

$$l_w = \frac{w_t}{12} + s_w + H * LLDF \quad [11]$$

Additionally, 2, 3, and 4 lanes need to be considered by adding the 10 ft lane width for each additional lane.

Spread of the Load Perpendicular to the Pipe Span

Determine the height where the effects of adjacent axles overlap each other.

$$H_{int-p} = \frac{s_a - \frac{l_t}{12} - 0.06 * \frac{D_i}{12}}{LLDF} \quad [12]$$

If the height of cover is less than the height of interaction between the axles, use:

$$w_w = \frac{l_t}{12} + H * LLDF + 0.06\frac{D_i}{12} \quad [13]$$

If the height of cover is greater than the height of interaction between the axles, use:

$$w_w = s_a + \frac{l_t}{12} + H * LLDF + 0.06\frac{D_i}{12} \quad [14]$$

Live Load for Less than 2 ft of Fill

AASHTO has special requirements for live loads on concrete pipe in shallow fill (less than 2 ft). Round culverts with 1.0 ft or more, but less than 2.0 ft of cover shall be designed for a depth of 1 ft. Round culverts with less than 1 ft of fill shall be analyzed with more comprehensive methods.

For concrete pipe with less than 2 ft of fill, but equal to or greater than 1 ft of fill, the distribution in the direction perpendicular to the span follows the equation below.

Distribution Perpendicular to Span

The distribution width (in) perpendicular to span for cover heights less than 2 ft is:

$$E = 28 + L_p + 0.72S \quad [15]$$

where:

L_p = the length of the tire contact area perpendicular to the span (in).

S = inside horizontal span of culvert (ft).

Distribution Parallel to Span

The distribution length parallel to the span is calculated similar to that of deeper fills, following the equation below:

$$E_{span} = L_T + LLDF(H) \quad [16]$$

where:

L_T = the length of the tire contact area parallel to the span (in).

H = depth of fill from top of culvert to top of pavement (in).

Applied Pressure

The live load pressure at the top of the pipe is a function of the live load force divided by the area over which it is distributed.

Calculate the distributed area as follows.

Live Load Area:

$$A_{LL} = l_w * w_w \quad [17]$$

For fill heights of less than 2 ft, l_w and w_w are replaced by E_{span} and E respectively.

Impact Factor

The AASHTO LRFD Standard applies a dynamic load allowance to the live load force to account for the truck load being nonstatic. The dynamic load allowance, IM, is determined by:

$$IM = 33 * (1.0 - 0.125 * D_E) \quad [18]$$

Where D_E is the depth (ft) of earth above the structure.

The resulting pressure (psf) at the top of the pipe is then:

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}} \quad [19]$$

Where P is the live load (lbs) applied at the surface of all interacting wheels and varies depending on the number of wheels/axles interacting at the depth of the pipe.

Precast concrete pipe is designed per ft of length. Thus, the final goal is to get the live load into units of lb/ft. To do this, we multiply the live load pressure by the length of the load over the pipe in the direction parallel to its span.

$$W_L = P_L * C_L \quad [20]$$

where:

C_L = the lesser of D_o or l_w , ft

D_o = outside diameter or outside span of culvert, ft

Example 1

Given: A 30-in diameter, B wall, concrete pipe is to be installed as a storm drain under flexible pavement and subjected to AASHTO highway loadings that run parallel to culvert span. The pipe will be installed with a minimum of 7 ft of cover over the top of the pipe.

Find: Find the maximum live load on the pipe in pounds (lbs) per linear foot (ft).

Solution: 1. Review project data.
A 30-in diameter, B wall, circular concrete pipe per ASTM C76 has a wall thickness of 3.5 in, therefore the outside diameter of the pipe, D_o, is [30+2(3.5)] / 12 = 3.08 ft. The height of earth cover is 7 ft.

2. Calculate the live load per ft of the pipe.

LLDF is the live load distribution factor. The LLDF for a 30-in diameter RCP per the linear interpolation of the values shown in Table 2 is:

$$LLDF = 1.15 + \left(\frac{30-24}{96-24}\right) * (1.75 - 1.15) = 1.2$$

Design Truck

Wheel Load Overlap:

Check for overlapping of the effects from the wheels on a single axle. H_{int-i} is the axle interaction depth transverse to culvert span. Determine if the depth of the overlap would be greater, equal to, or less than the minimum of 7 ft of cover per Equation 1.

$$H_{int-i} = \frac{s_w - \frac{w_t}{12} - 0.06 * \frac{D_i}{12}}{LLDF}$$

$$H_{int-i} = \frac{6 - \frac{20}{12} - 0.06 * \frac{30}{12}}{1.2} = 3.49ft$$

H = 7ft > H_{int} = 3.49ft

The H_{int-i} is less than the minimum ft of fill over the culvert, thus the effects from the wheels are overlapping. The load of the entire axle is applied. Therefore, the width at 7 ft of cover per Equation 3 is:

$$w_w = s_w + \frac{w_t}{12} + H * LLDF + 0.06\frac{D_i}{12}$$

$$w_w = 6 + \frac{20}{12} + 7 * 1.2 + 0.06\frac{30}{12} = 16.22ft$$

Axle Load Overlap:

Check for overlapping of the effects from separate axles. H_{int-p} is the axle interaction depth parallel to culvert span. Determine if the depth of the overlap would be greater, equal to, or less than the minimum of 7 ft of cover per Equation 4.

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

$$H_{int-p} = \frac{14 - \frac{10}{12}}{1.2} = 10.97ft$$

7ft >10.97ft

The H_{int-p} is more than the height of fill over the culvert. Thus, the effects from individual axles of the design truck do not overlap. Therefore, the spread length at 7 ft of cover per Equation 5 is:

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

$$l_w = \frac{10}{12} + 7 * 1.2 = 9.23ft$$

The spread length of 9.23 ft is less than the width between the axles of 14 ft. This confirms there is no overlapping of the effects from the two axles.

Applied Pressure:

Area of the applied load can be calculated per Equation 17 as:

$$A_{LL} = l_w * w_w$$

$$A_{LL} = 9.23 * 16.22 = 149.71ft^2$$

The impact factor is the dynamic load allowance for culverts and other buried structures in percentage. Per Equation 18 the value is:

$$IM = 33 * (1.0 - 0.125 * D_E)$$

$$IM = 33 * (1.0 - 0.125 * 7) = 4.125$$

Since the effects of one single axle are governing, the force at the surface is P=32,000 lbs. Calculate the vertical live load applied on the top of the pipe using the impact factor and the area of applied load per Equation 19:

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}}$$

$$P_L = \frac{32,000 * \left(1 + \frac{4.12}{100}\right) * 1.2}{149.71} = 267.06lb/ft^2$$

Live Load on Pipe:

C_L = lesser of D_o or l_w

D_o = 3.08 ft < l_w = 9.23 ft C_L = 3.08

$W_L = P_L * C_L$

W_{LTruck} = 267.06 * 3.08 = 823 lbs/ft

Tandem Axles

Wheel Load Overlap:

From the calculations for the single axle, the distribution of the live load width down to the top of the pipe is:

w_w = 16.22 ft

Axle Load Overlap:

The spacing of tandems axles (4 ft) is smaller than the spacing of the two axles on the design truck (14 ft). Thus, check if the effects from the axles are interacting using Equation 4.

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

$$H_{int-p} = \frac{4 - \frac{10}{12}}{1.2} = 2.64ft$$

7 ft > 2.64 ft

Since H_{int-p} is less than the minimum height of cover, the axle spacing needs to be accounted for using Equation 6.

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

$$l_w = \frac{10}{12} + 4 + 7 * 1.2 = 13.23ft$$

Applied Pressure:

$$A_{LL} = l_w * w_w$$

$$A_{LL} = 13.23 * 16.22 = 214.59 ft^2$$

$$IM = 33 * (1.0 - 0.125 * D_E)$$

$$IM = 33 * (1.0 - 0.125 * 7) = 4.125$$

Each tandem axle carries a load of 25,000 lbs, and since the effects of the axles are overlapping, both axles must be accounted for in Equation 19:

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}}$$

$$P_L = \frac{50,000 * \left(1 + \frac{4.12}{100}\right) * 1.2}{214.59} = 291.12 lb/ft^2$$

Live Load on Pipe:

C_L = lesser of D_o or l_w

D_o = 3.08 ft < l_w = 13.23 ft C_L = 3.08

$W_L = P_L * C_L$

$W_{LTandem}$ = 291.12 * 3.08 = 898 lbs/ft

HL-93 Live Load

Take the maximum live load from either the design truck or the design tandem as the HL-93 live load.

W_{LTruck} = 823 lbs/ft < $W_{LTandem}$ = 898 lbs/ft

W_L = 898 lbs/ft

Example 2

Given: Same as Example 1, except the live load runs perpendicular to culvert span.

Find: The maximum live load on the pipe in pounds (lbs) per linear foot (ft).

Solution: 1. Review project data.

A 30-in diameter, B wall, circular concrete pipe has a wall thickness of 3.5 in, therefore D_o is 3.08 ft. The height of the earth cover is 7 ft.

2. Calculate the live load per ft of the pipe.

LLDF is the live load distribution factor. The LLDF for a 30-in diameter RCP per the linear interpolation of the values shown in Table 2 is:

$$LLDF = 1.15 + \left(\frac{30 - 24}{96 - 24}\right) * (1.75 - 1.15) = 1.2$$

Design Truck

Wheel Load Overlap:

Since we are going perpendicular to span, we check to see if we must address more than one lane. Check to see if the effect from passing vehicles overlaps.

A distance of 4 ft center-to-center is assumed between passing vehicles. s_p = 4 ft

$$H_{int-l} = \frac{s_p - \frac{w_t}{12}}{LLDF}$$

$$H_{int-l} = \frac{4 - \frac{20}{12}}{1.2} = 1.94 ft$$

Note: Since the H_{int-l} is less than 7 ft, the effects from passing vehicles overlap. Therefore, we must consider trucks passing each other.

Check to see if the effects from wheels on the same axle overlap, using Equation 8:

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

$$H_{int-i} = \frac{6 - \frac{20}{12}}{1.2} = 3.61 ft$$

7 ft > 3.61 ft

We must consider multiple lanes with the full axle width from each lane. Evaluate the conditions for 1, 2, 3, and 4 lanes.

The spacing center to center of wheels on an axle is 6 ft. The spacing between axles per AASHTO is 4 ft, giving us a conservative lane width value of 10 ft. Thus, our wheel spacings for the multiple lane conditions will be:

$s1_w$ = 6 ft

$s2_w$ = 6 + 10 = 16 ft

$s3_w$ = 16 + 10 ft = 26 ft

$s4_w$ = 26 + 10 = 36 ft

Per Equation 11, for a single lane, the spread in the direction of the span is:

$$l1_w = \frac{w_t}{12} + s1_w + H * LLDF$$

$$l1_w = \frac{20}{12} + 6 + 7 * 1.2 = 16.07ft$$

For multiple lanes it is:

$l2_w = l1_w + 10 = 26.07$
$l3_w = l2_w + 10 = 36.07$
$l4_w = l3_w + 10 = 46.07$

Axle Load Overlap:

$$H_{int-p} = \frac{s_a - \frac{l_t}{12} - 0.06 * \frac{D_i}{12}}{LLDF}$$

$$H_{int-p} = \frac{14 - \frac{10}{12} - 0.06 * \frac{30}{12}}{1.2} = 10.84ft$$

7 ft < 10.84 ft

The H_{int-p} is more than the fill over the culvert. Thus, the effects from individual axles of the design truck do not overlap. Therefore, the width at a minimum of 7 ft of cover is:

$$w_w = \frac{l_t}{12} + H * LLDF + 0.06\frac{D_i}{12}$$

$$w_w = \frac{10}{12} + 7 * 1.2 + 0.06\frac{30}{12} = 9.38ft$$

Applied Pressure:

$$A_{LL} = l_w * w_w$$

$$A_{LL1} = 16.07 * 9.38 = 150.74ft^2$$

$$A_{LL2} = 26.07 * 9.38 = 244.54ft^2$$

$$A_{LL3} = 36.07 * 9.38 = 338.34ft^2$$

$$A_{LL4} = 46.07 * 9.38 = 432.14ft^2$$

$$IM = 33 * (1.0 - 0.125 * D_E)$$

$$IM = 33 * (1.0 - 0.125 * 7) = 4.125$$

Since we are evaluating the effects of a single axle, the force at the surface for each lane is P=32,000 lbs. Calculate the vertical live load applied on the top of the pipe using the impact factor and the area of applied load:

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}}$$

$$P_{L1} = \frac{32,000 * \left(1 + \frac{4.125}{100}\right) * 1.2}{150.74} = 265.25lb/ft^2$$

$$P_{L2} = \frac{64,000 * \left(1 + \frac{4.125}{100}\right) * 1.00}{244.54} = 272.51lb/ft^2$$

$$P_{L3} = \frac{96,000 * \left(1 + \frac{4.125}{100}\right) * .85}{338.34} = 251.13lb/ft^2$$

$$P_{L4} = \frac{128,000 * \left(1 + \frac{4.125}{100}\right) * .65}{432.14} = 200.47lb/ft^2$$

From the calculations above, the condition of two lanes is the governing pressure for the Single Axle Case

Live Load on Pipe:

C_L = lesser of D_o or $l2_w$
D_o = 3.08 ft < l_w = 26.07 ft C_L = 3.08

$W_L = P_L * C_L$
W_{LTruck} = 272.51 * 3.08 = 839.33 lbs/ft

Tandem Axles

Wheel Load Overlap

Because the H_{int-i} for the single axle is less than the bury depth, and the tandem axle has the same dimension in this direction, it's safe to state that the tire overlap will be the same for the tandem axles.

$l1_w$ = 16.07 ft
$l2_w$ = 26.07 ft
$l3_w$ = 36.07 ft
$l4_w$ = 46.07 ft

Axle Load Overlap:

$$H_{int-p} = \frac{s_a - \frac{l_t}{12} - 0.06 * \frac{D_i}{12}}{LLDF}$$

$$H_{int-p} = \frac{4 - \frac{10}{12} - 0.06 * \frac{30}{12}}{1.2} = 2.52ft$$

Since the H_{int-p} is less than the height of cover for the design, the effects from the tandem axles overlap each other.

$$w_w = s_a + \frac{l_t}{12} + H * LLDF + 0.06\frac{D_i}{12}$$

$$w_w = 4 + \frac{10}{12} + 7 * 1.2 + 0.06\frac{30}{12} = 13.38ft$$

Applied Pressure:

$$A_{LL} = l_w * w_w$$

$$A_{LL1} = 16.07 * 13.38 = 215.02ft^2$$
$$A_{LL2} = 26.07 * 13.38 = 348.82ft^2$$
$$A_{LL3} = 36.07 * 13.38 = 482.62ft^2$$
$$A_{LL4} = 46.07 * 13.38 = 616.42ft^2$$

$$IM = 33 * (1.0 - 0.125 * D_E)$$
$$IM = 33 * (1.0 - 0.125 * 7) = 4.125$$

Since we are evaluating the effects of both tandem axles, the force at the surface for each lane is P=50,000 lbs. Calculate the vertical live load applied on the top of the pipe using the impact factor and the area of applied load:

$$P_L = \frac{P * (1 + \frac{IM}{100}) * m}{A_{LL}}$$

$$P_{L1} = \frac{50,000 * (1 + \frac{4.125}{100}) * 1.2}{215.02} = 290.5lb/ft^2$$

$$P_{L2} = \frac{100,000 * (1 + \frac{4.125}{100}) * 1.0}{348.82} = 298.5lb/ft^2$$

$$P_{L3} = \frac{150,000 * (1 + \frac{4.125}{100}) * .85}{482.62} = 275.0lb/ft^2$$

$$P_{L4} = \frac{200,000 * (1 + \frac{4.125}{100}) * .65}{616.42} = 219.6lb/ft^2$$

From the calculations above, the condition of two lanes is the governing pressure for the Tandem Axles

Live Load on Pipe:

C_L = lesser of D_o or $l2_w$

D_o = 3.08 ft < l_w = 26.07 ft C_L = 3.08

$W_L = P_L \cdot C_L$

$W_{LTandem}$ = 298.51 $\cdot$ 3.08 = 920 lbs/ft

HL-93 Live Load:

Take the maximum live load from either the design truck or the design tandem as the HL-93 live load.

$$W_{LTruck} = 898lbs/ft < W_{LTandem} = 920lbs/ft$$

W_L = 920lbs/ft

Example 3

Given: Same as Example 1, except the height of earth cover is 1 ft.

Find: The maximum live load on the pipe in pounds (lbs) per linear ft (ft).

Solution: 1. Review project data.

A 30-in diameter, B-wall Concrete Pipe. The circular concrete pipe has a wall thickness of 3.5 in, therefore D_o is 3.08 ft. The height of the earth cover is 1 ft.

2. Calculate the live load per ft of pipe.

Determine the spread width perpendicular to the span of the pipe.

The length of the wheel footprint in the direction perpendicular to the pipe span is 20 in.

$$L_p = w_t = 20in.$$

$$E = 28 + L_p + 0.72S$$

$$E = 28 + 20 + 0.72(30/12) = 49.8in = 4.15ft$$

Spacing between wheels on an axle is 72 in. center to center.

72 > 49.8

Since the distance between wheels on an axle is more than the spread dimension, only one wheel (one side of the axle) will be considered.

Determine the Spread Length Parallel to Span

LLDF is the live load distribution factor. The LLDF for a 30-in diameter pipe is:

$$LLDF = 1.15 + \left(\frac{30-24}{96-24}\right) * (1.75 - 1.15) = 1.2$$

The length of the wheel footprint in the direction parallel to the pipe span is 10 in.

$$L_T = l_t = 10in$$

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

$$E_{span} = \frac{10}{12} + 1.2\,(1) = 2.03ft$$

Design Truck

Area of the applied load can be calculated as:

$$A_{LL} = l_w * w_w$$

$$A_{LL} = 2.03 * 4.15 = 8.44ft^2$$

The impact factor is the dynamic load allowance for culverts and other buried structures in percentage:

$$IM = 33 * (1.0 - 0.125 * D_E)$$

$$IM = 33 * (1.0 - 0.125 * 1) = 28.875$$

Because the load is from one set of wheels, and not the entire axle, the force at the surface will be P=16,000 lbs. The live load pressure at the top of the pipe is:

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}}$$

$$P_L = \frac{16,000 * \left(1 + \frac{28.875}{100}\right) * 1.2}{8.44} = 2,932lb/ft^2$$

Live Load on Pipe:

C_L = lesser of D_o or l_w

D_o = 3.08 ft < l_w = 2.03 ft C_L= 2.03

$W_L = P_L * C_L$

W_{LTruck} = 2,932 * 2.03 = 5,962 lbs/ft

Tandem Axles

The center-to-center distance between tandem axles is:

$$48 > E_{span} = 2.03ft = 24.4in$$

Since the distance between the tandem axles is greater than the spread distance parallel to the span of the pipe, we need only worry about one axle.

Furthermore, we previously determined that only one wheel of an axle needs to be considered. Thus, the load at the surface will be P = 12,500 lbs.

Therefore, the spread area and the impact factor will be the same as what was used for the single axle.

$$P_L = \frac{P * \left(1 + \frac{IM}{100}\right) * m}{A_{LL}}$$

$$P_L = \frac{12,500 * \left(1 + \frac{28.875}{100}\right) * 1.2}{8.44} = 2,291lb/ft^2$$

Live Load on Pipe:

C_L = lesser of D_o or l_w

D_o = 3.08 ft < l_w = 2.03 ft C_L= 2.03

$W_L = P_L * C_L$

$W_{LTandem}$ = 2,291 * 2.03 = 4,658 lbs/ft

HL-93 Live Load

Take the maximum live load from either the design truck or the design tandem as the HL-93 live load.

W_{LTruck} = 5,962 lbs/ft < $W_{LTandem}$ = 4,658 lbs/ft

W_L = 5,962 lbs/ft

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