

Highway Live Loads on Concrete Pipe

FOREWORD

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), "Concrete Pipe Design Manual" (4) and the Ontario Concrete Pipe Association, OCPA, "Concrete Pipe Design Manual" (5).

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. For these pavements, there is no generally accepted theory for estimating load distribution effects, and, therefore, these pavements should be considered as unsurfaced roadways.

This Design Data addresses the method of determining the live load pressure transmitted through unsurfaced roadways to circular and elliptical concrete pipe in accordance with the criteria of the Canadian Highway Bridge Design Code, CHBDC (6).

INTRODUCTION

To determine the required supporting strength of concrete pipe installed under intermediate and thin thickness of asphalt or flexible pavements, or relatively shallow earth cover, it is necessary to evaluate the effect of live loads, such as highway truck loads, in addition to dead loads imposed by the soil and surcharge loads.

LIVE LOADS

If a rigid pavement or a thick flexible pavement designed for heavy duty traffic is provided with a sufficient

buffer between the pipe and pavement, then the live load transmitted through the pavement to the buried concrete pipe is usually negligible at any depth. If any culvert or sewer pipe is within the heavy duty traffic highway right-of-way, but not under the pavement structure, then such pipe should be analyzed for the effect of live load transmission from an unsurfaced roadway, because of the possibility of trucks leaving the pavement.

DEAD LOADS

Various methods for analyzing soil dead loads, which have been developed over the years, are presented in the ACPA "Concrete Pipe Technology Handbook" (7) and the OCPA "Concrete Pipe Design Manual" (5).

SURCHARGE LOADS

A common type of surcharge load is additional soil fill placed after the pipe has been installed for a period of time. 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 pipe has been installed underground, the soil-structure system will continually show an increase in load capacity. Data on concrete pipe, which have been removed from service and tested, indicate 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.

LIVE LOADS

The CHBDC design loads are the CL-W Truck and CL-625 ONT Truck (Figure 2). The average pressure intensity caused by a wheel load is calculated by Equation 2.

The CL-W Truck and CL-625 ONT Truck design axles are carried on dual wheels (Figure 1). The contact area of the dual wheels with the ground is assumed to be a rectangle (Figure 1), with dimensions presented in Table 1.

Figure 1 CHBDC Wheel Load Surfaces Contact Area (Foot Print)

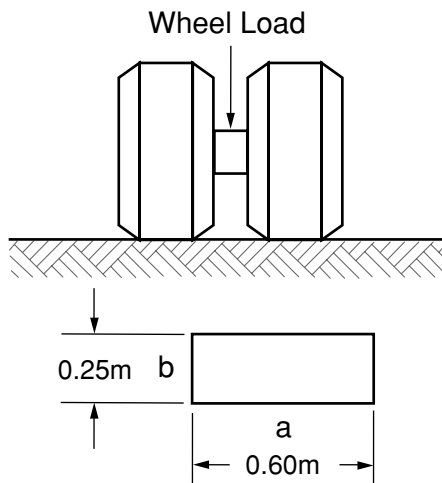


Table 1 Wheel Surface Contact Area

a(width), m	b(length), m
0.60	0.25

IMPACT FACTORS

The CHBDC applies a dynamic load allowance to account for the truck load being non-static. The dynamic load allowance, IM, is determined by Equation 1:

$$IM = 0.40 (1.0 - 0.5 D_E) \geq 0.10 \quad [1]$$

where: D_E = height of earth cover over the top of the pipe, m.

LOAD DISTRIBUTION

The 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 axles 2 and 3 in passing mode. On a horizontal soil plane, the dimensional increases to the wheel contact area are based on height of earth cover over the top of the pipe. The dimensional increase factor is $1.75H$ for depths of cover greater than 0.6 meters. CHBDC states that for depths of cover less than 0.6 meters, “no distribution beyond the footprints of the wheels shall be considered”.

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. At less than 0.6 meters of cover, the maximum pressure will be developed by the fourth axle dual wheel, since at 87.5kN

it applies a greater load than any other wheel (Figures 2 and 3), and no dimensional increase is allowed beyond the footprint of the wheel. At intermediate depths, the maximum pressure will be developed by the fourth axle wheels of two trucks in the passing mode, since at 87.5kN each, these two wheels apply a greater load, 175kN, than any other two wheels in passing mode (Figures 2 and 4). At greater depths, the maximum pressure will be developed by wheels of axles 2 and 3 in the passing mode, since at 62.5kN or 70kN each, the four wheels apply the greatest load (250kN or 280kN) (Figures 2 and 5). Intermediate depths occur when the spread area a of dual wheels of two trucks in the passing mode overlap. Greater depths occur when the spread area b of two single dual wheels of axles 2 and 3 in the passing mode overlap.

Since the exact geometric relationship of individual or combinations of surface wheel loads cannot be anticipated, the most critical loading configurations along with axle loads and rectangular spread load area are presented in Tables 2 and 3 for the two CHBDC design trucks.

DESIGN METHOD

The design method encompasses 4 steps.

1. Obtain the following project data:
Pipe shape, size and wall thickness.
Height of cover over the concrete pipe.
Design load criteria.
2. Calculate the average pressure intensity of the wheel loads on the soil plane on the outside top of the pipe.
3. Calculate the total live load acting on the pipe.
4. Calculate the total live load acting on the pipe in kN/m.

Project Data

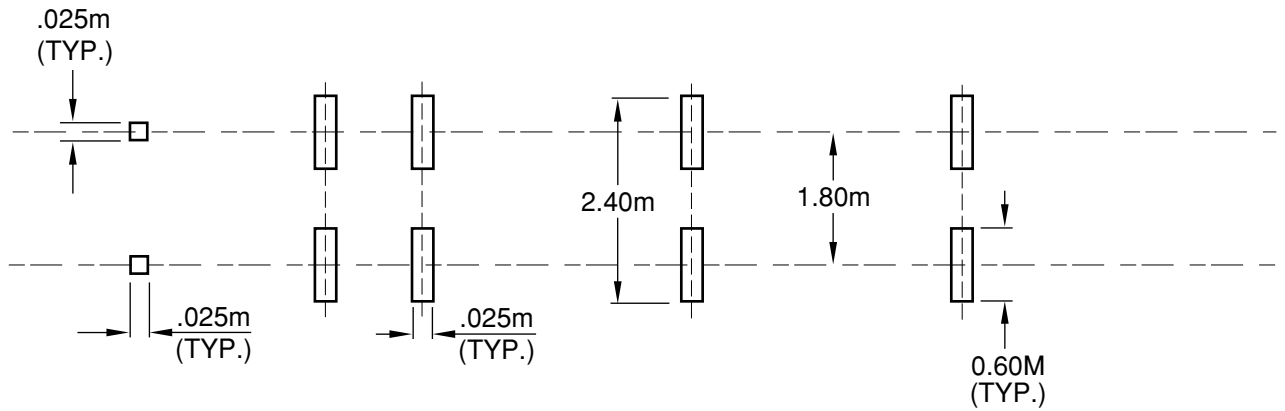
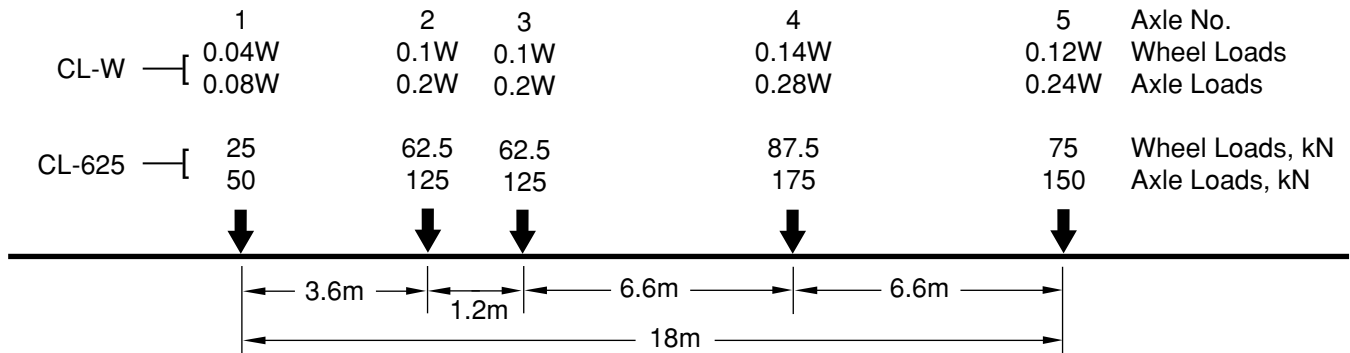
Pipe shape and internal dimensions are shown on the project plans. Complete information on dimensional details are included in CAN/CSA-A257.1 for nonreinforced circular concrete pipe, CSA-A257.2 for reinforced concrete circular pipe and ASTM C 507M for reinforced concrete elliptical pipe (8). Internal size, wall thickness and outside dimensions are presented in Tables 6 and 7 for circular and elliptical pipe.

The minimum earth cover over the concrete pipe can be obtained from the project plans.

A decision regarding whether the CHBDC or other criteria will be used should be obtained from the project authority.

Figure 2 CHBDC Wheel Loads and Wheel Spacings

CL-W TRUCK



CL-625-ONT TRUCK

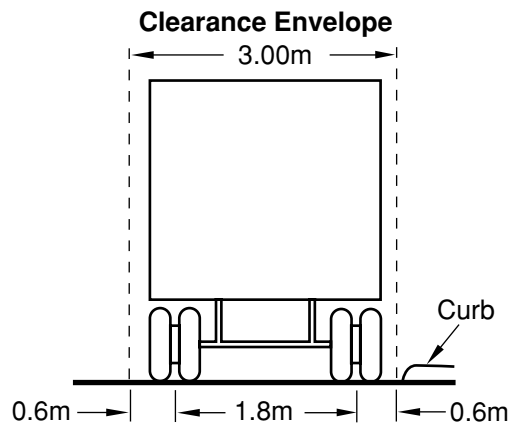
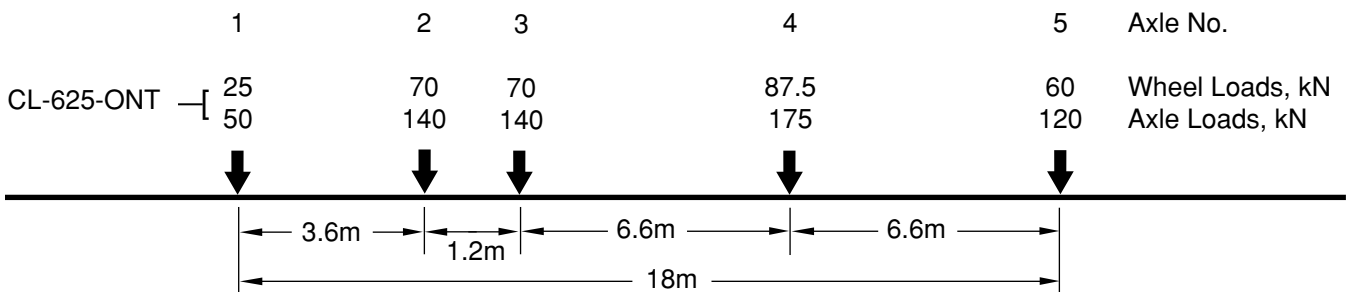


Figure 3 Spread Load Area - Single Dual Wheel

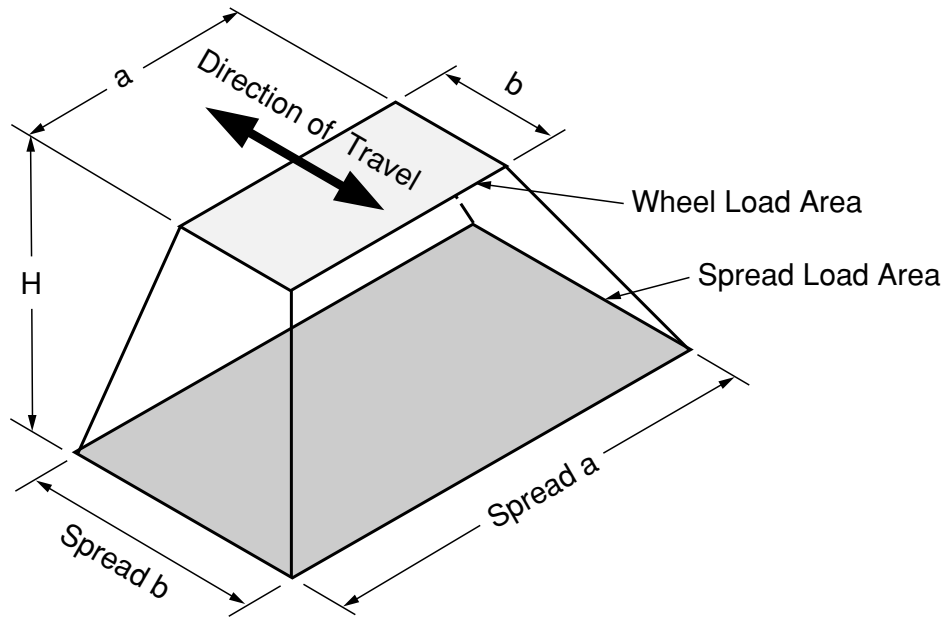


Figure 4 Spread Load Area - Two Single Dual Wheels of Trucks in Passing Mode

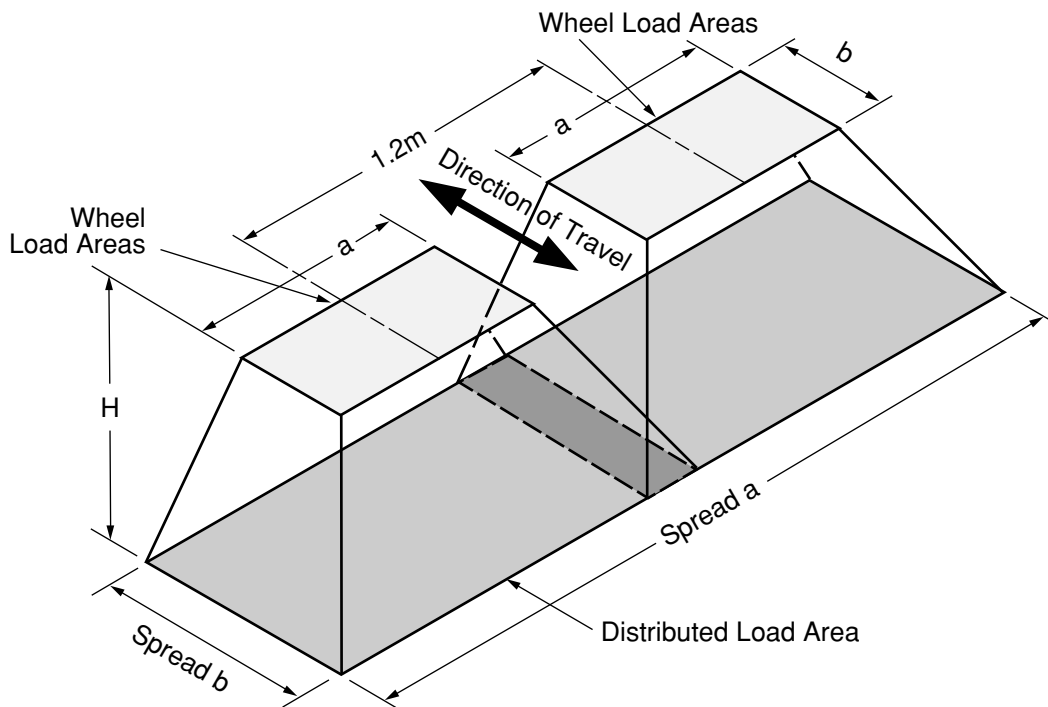


Figure 5 Spread Load Area - Two Single Dual Wheels of Axles 2 & 3 in Passing Mode

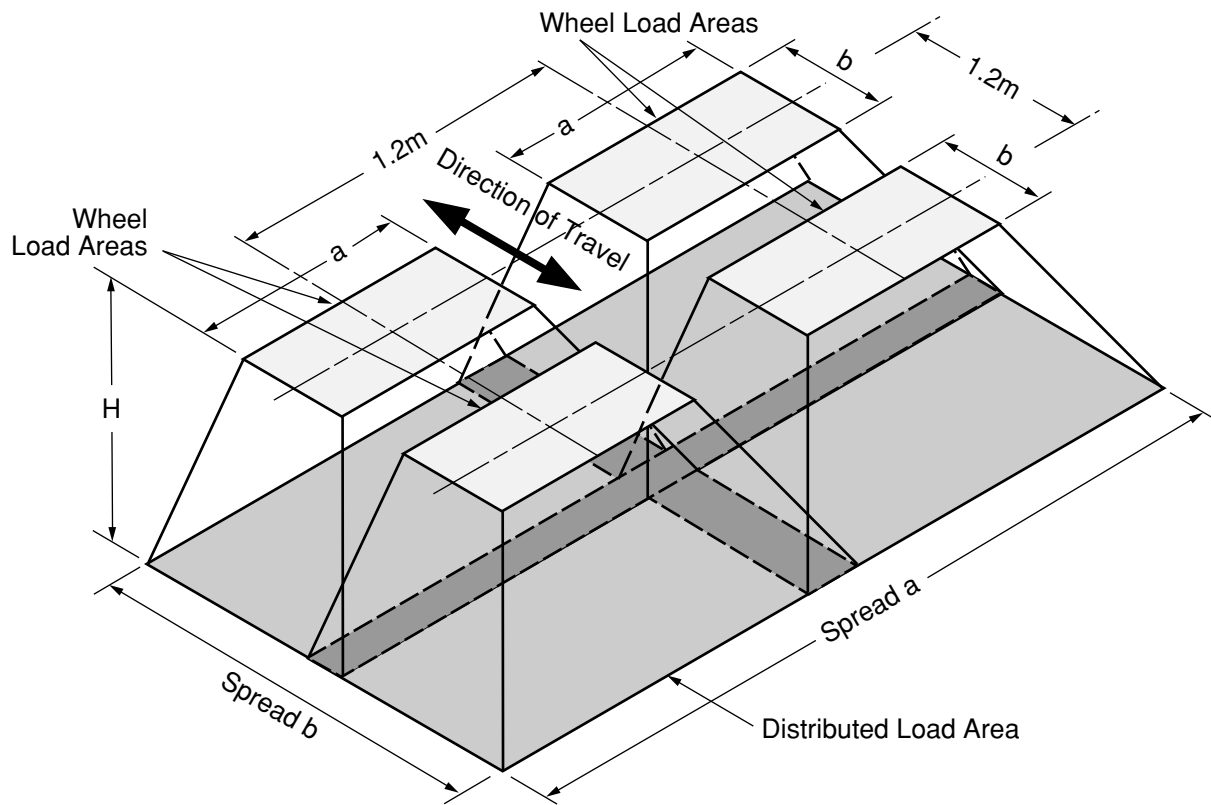


Table 2 CL-W Critical Values

H, meters	P, kN	Spread a, meters	Spread b, meters	Figure
$H < 0.60$	87.5	a	b	3
$0.60 \leq H < 1.46$	175	$a + 1.20 + 1.75H$	$b + 1.75H$	4
$1.46 \leq H$	250	$a + 1.20 + 1.75H$	$b + 1.20 + 1.75H$	5

Figure 5 Spread Load Area - Two Single Dual Wheels of Axles 2 & 3 in Passing Mode

H, meters	P, kN	Spread a, meters	Spread b, meters	Figure
$H < 0.60$	87.5	a	b	3
$0.60 \leq H < 1.00$	175	$a + 1.20 + 1.75H$	$b + 1.75H$	4
$1.00 \leq H$	280	$a + 1.20 + 1.75H$	$b + 1.20 + 1.75H$	5

Average Pressure Intensity

The wheel load average pressure intensity on the subsoil plane at the outside top of the concrete pipe is:

$$w = P(1 + IM) / A \quad [2]$$

where: w = wheel load average pressure intensity, kN/m²

P = total live wheel load applied at the surface, kN

A = spread wheel load area at the outside top of the pipe, m²

IM = dynamic load allowance

From the appropriate Table 2 or 3, select the critical wheel load and spread dimensions for the height of earth cover over the outside top of the pipe, H. The spread live

load area is equal to Spread a times Spread b. Select the appropriate dynamic load allowance, using Equation 1.

Total Live Load

A designer is concerned with the maximum possible loads, which occur when the distributed load area is centered over the buried pipe. Depending on the pipe size and height of cover, the most critical loading orientation can occur either when the truck travels transverse or parallel to the centerline of the pipe.

Figure 6 illustrates the dimensions of the spread load area, A, as related to whether the truck travel is transverse or parallel to the centerline of the pipe.

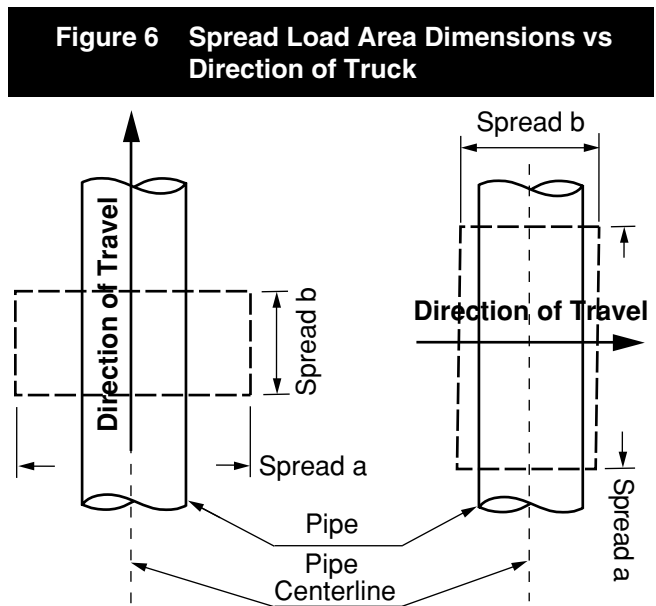


Figure 6 Spread Load Area Dimensions vs Direction of Truck

total live load in pounds, W_T , must be calculated for each travel orientation, and the maximum calculated value must be used in Equation 4 to calculate the live load on the pipe in kN per meter.

The total live load acting on the pipe is:

$$W_T = w L S_L \tag{3}$$

where: W_T =total live load, kN

w =wheel load average pressure intensity, kN/m² (at the top of the pipe)

L =dimension of A parallel to the longitudinal axis of pipe, meters

S_L =outside horizontal span of pipe, B_c , or dimension of A transverse to the longitudinal axis of pipe, whichever is less, meters

Total Live Load in kN per Linear Meter

The total live load in kN per linear meter, W_L , is calculated by dividing the Total Live Load, W_T , by the Effective Supporting Length, L_e (See Figure 7), of the pipe:

$$W_L = W_T / L_e \tag{4}$$

where: W_L =live load on top of pipe, kN per linear meter

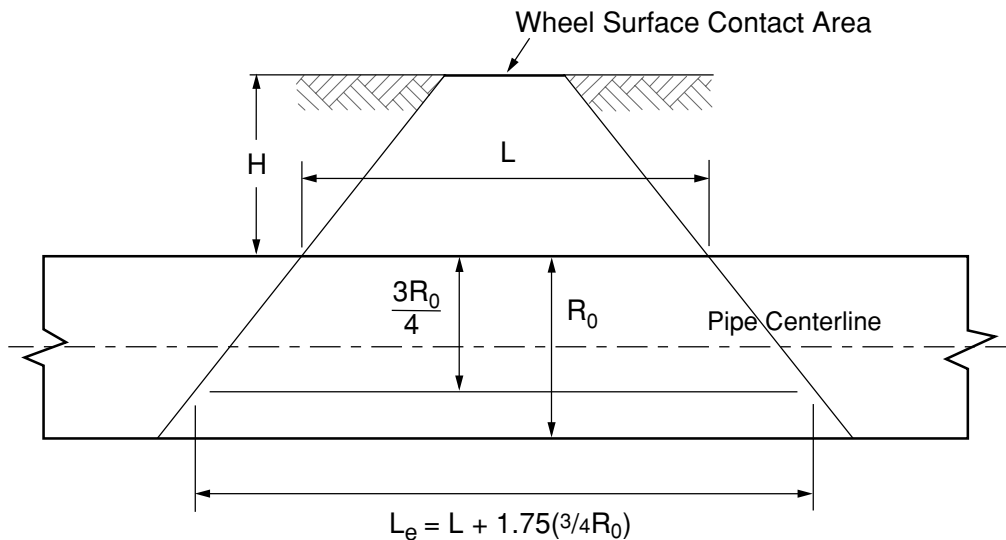
L_e =effective supporting length of pipe (see Figure 7), meters

The effective supporting length of pipe is:

$$L_e = L + 1.75(3/4R_0) \tag{5}$$

where: R_0 =outside vertical Rise of pipe, meters

Figure 7 Effective Supporting Length of Pipe



EXAMPLES

Four Example calculations are presented on the following pages to illustrate the four steps of the Design Method, and the effect of varying the depth of fill and design truck. The live loads per linear meter calculated in the four Examples are summarized in Table 4.

Table 4 Summary of Examples

Truck	D,mm	H, m	P, kN	Live Load, kN/m
CL-W	750	0.45	87.5	74.85
CL-W	750	0.605	175	40.3
CL-W	750	1.5	250	11.6
CL-625-ONT	750	1.5	280	12.93

EXAMPLE 1

Given: A 750mm diameter, C wall, concrete pipe is to be installed as a storm drain under a flexible pavement and subjected to CHBDC highway loading. The pipe will be installed in a trench with a minimum of 0.45m of cover over the top of the pipe.

Find: The maximum live load on the pipe in kN/m

Solution:

1. Review project data.

A 750mm diameter, C wall, circular concrete pipe has an I.D. of 762mm and a wall thickness of 107mm, therefore B_c is 0.976m and R_o is 0.976m. Height of earth cover is 0.45m. Use CHBDC CL-W loading.

2. Calculate average pressure intensity of the live load on the plane at the outside top of the pipe.

From Table 3, the critical load, P, is 87.5 kN and the Spread Area is:

$$A = (\text{Spread } a)(\text{Spread } b)$$

$$A = (.25)(0.6)$$

$$A = 0.15 \text{ m}^2$$

$$I.M. = 0.40(1.0 - 0.5H)$$

$$I.M. = 0.31$$

$$w = P(1 + IM)/A$$

$$w = 87.5(1 + 0.31)/0.15$$

$$w = 764 \text{ kN/m}^2$$

3. Calculate total live load acting on the pipe.

$$W_T = w L S_L$$

Assuming truck travel transverse to pipe centerline.

$$L = \text{Spread } a = 0.6 \text{ meters}$$

$$\text{Spread } b = 0.25 \text{ meters}$$

$$B_c = 0.976\text{m, which is greater than Spread } b, \text{ therefore}$$

$$S_L = 0.25 \text{ meters}$$

$$W_T = 764 \times 0.60 \times 0.25 = 114.6 \text{ kN}$$

Assuming truck travel parallel to pipe centerline.

$$\text{Spread } a = 0.6 \text{ meters}$$

$$L = \text{Spread } b = 0.25 \text{ meters}$$

$$B_c = 0.976\text{m, which is greater than Spread } a, \text{ therefore}$$

$$S_L = 0.6 \text{ meters}$$

$$W_T = 764 \times 0.25 \times 0.60 = 114.6 \text{ kN}$$

W_T Maximum = 114.6 kN; and the truck is travelling parallel to the pipe centerline, as this gives the shortest length for the supporting length calculation.

4. Calculate live load on pipe in kN per linear meter.

$$R_o = 0.976\text{m}$$

$$L_e = L + 1.75(3/4R_o)$$

$$L_e = 0.25 + 1.75(0.75 \times 0.976) = 1.531 \text{ m}$$

$$W_L = W_T / L_e$$

$$W_L = 114.6 / 1.531 = 74.85 \text{ kN per linear meter}$$

EXAMPLE 2

Given: Same as Example 1, except minimum depth of cover is 0.605m.

Find: The maximum live load on the pipe in kN/m.

Solution:

1. Review project data.

A 750mm diameter, C wall, circular concrete pipe has an I.D. of 762mm and a wall thickness of 107mm, therefore B_c is 0.976m and R_o is 0.976m. Height of earth cover is 0.605m. Use CHBDC CL-W loading.

2. Calculate average pressure intensity on the plane at the top of the pipe.

From Table 4, the critical load, P, is 175kN from axle 4 single dual wheels in passing mode, and the Spread Area is:

$$\begin{aligned}
 A &= (\text{Spread } a)(\text{Spread } b) \\
 A &= (0.60 + 1.2 + 1.75 \times 0.605)(0.25 + \\
 &\quad 1.75 \times 0.605) \\
 A &= (2.859)(1.309) \\
 A &= 3.74 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{I.M.} &= 0.40(1.0 - 0.5H) \\
 \text{I.M.} &= 0.279 \\
 w &= P(1 + \text{IM})/A \\
 w &= 175(1 + 0.279)/3.74 \\
 w &= 59.8 \text{ kN/m}^2
 \end{aligned}$$

3. Calculate total live load acting on the pipe.

$$W_T = w L S_L$$

Assuming truck travel transverse to pipe centerline.

$$\begin{aligned}
 L &= \text{Spread } a = 2.859 \text{ meters} \\
 \text{Spread } b &= 1.309 \text{ meters} \\
 B_c &= 0.976 \text{ meters, which is less than} \\
 &\quad \text{Spread } b, \text{ therefore} \\
 S_L &= 0.976 \text{ meters} \\
 W_T &= 59.8 \times 2.859 \times 0.976 = 166.9 \text{ kN}
 \end{aligned}$$

Assuming truck travel parallel to pipe centerline.

$$\begin{aligned}
 \text{Spread } a &= 2.859 \text{ meters} \\
 L &= \text{Spread } b = 1.309 \text{ meters} \\
 B_c &= 0.976 \text{ meters, which is less than} \\
 &\quad \text{Spread } a, \text{ therefore} \\
 S_L &= 0.976 \text{ meters}
 \end{aligned}$$

$$W_T = 59.8 \times 0.976 \times 1.309 = 76.4 \text{ kN}$$

W_T Maximum = 166.9kN; and truck travel is transverse to pipe centerline

4. Calculate live load on pipe in kN per linear meter.

$$R_o = 0.976 \text{ meters}$$

$$\begin{aligned}
 L_e &= L + 1.75(3/4R_o) \\
 L_e &= 2.859 + 1.75(.75 \times 0.976) = 4.14 \text{ meters}
 \end{aligned}$$

$$\begin{aligned}
 W_L &= W_T / L_e \\
 W_L &= 166.9 / 4.14 = 40.3 \text{ kN per linear meter}
 \end{aligned}$$

EXAMPLE 3

Given: Same as Example 1, except minimum depth of fill is 1.5 meters.

Find: The maximum live load on the pipe in kN per

linear meter.

Solution:

1. Review project data.

A 750mm diameter, C wall, circular concrete pipe has an I.D. of 762mm and a wall thickness of 107mm, therefore B_c is 0.976m and R_o is 0.976m. Height of earth cover is 1.5m. Use CHBDC CL-W loading.

2. Calculate average pressure intensity at the outside top of the pipe.

From Table 3, the critical load, P, is 250 kN two single dual wheels of axles 2 & 3 in the passing mode, and the Spread Area is:

$$\begin{aligned}
 A &= (\text{Spread } a)(\text{Spread } b) \\
 A &= (0.6 + 1.2 + 1.75 \times 1.5)(0.25 + 1.2 + \\
 &\quad 1.75 \times 1.5) \\
 A &= (4.425)(4.075) \\
 A &= 18.0 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{I.M.} &= 0.40(1.0 - 0.5H) \\
 \text{I.M.} &= 0.10 \\
 w &= P(1 + \text{IM})/A \\
 w &= 250(1 + 0.10)/18 \\
 w &= 15.3 \text{ kN/m}^2
 \end{aligned}$$

3. Calculate total live load acting on the pipe.

$$W_T = w L S_L$$

Assuming truck travel transverse to pipe centerline.

$$\begin{aligned}
 L &= \text{Spread } a = 4.425 \text{ meters} \\
 \text{Spread } b &= 4.075 \text{ meters} \\
 B_c &= 0.976 \text{ meters, which is less than Spread } b, \\
 &\quad \text{therefore} \\
 S_L &= 0.976 \text{ meters}
 \end{aligned}$$

$$W_T = 15.3 \times 4.425 \times 0.976 = 66.1 \text{ kN}$$

Assuming truck travel parallel to pipe centerline.

$$\begin{aligned}
 \text{Spread } a &= 4.425 \text{ meters} \\
 L &= \text{Spread } b = 4.075 \text{ meters} \\
 B_c &= 0.976 \text{ meters, which is less than Spread } a, \\
 &\quad \text{therefore} \\
 S_L &= 0.976 \text{ meters}
 \end{aligned}$$

$$W_T = 15.3 \times 0.976 \times 4.075 = 60.85 \text{ kN}$$

W_T Maximum=66.1 kN; and truck travel is transverse to pipe centerline

4. Calculate live load on pipe in kN per linear meter.

$$R_o = 0.976 \text{ meters}$$

$$L_e = L + 1.75(3/4R_o)$$

$$L_e = 4.425 + 1.75(0.75 \times 0.976) = 5.71 \text{ meters}$$

$$W_L = W_T / L_e$$

$$W_L = 66.1 / 5.71 = 11.6 \text{ kN per linear meter}$$

EXAMPLE 4

Given: Same as Example 3, except design load is CHBDC CL-625-ONT Truck.

Find: The maximum live load on the pipe in kN per linear meter.

Solution:

1. Review project data.

A 750mm diameter, C wall, circular concrete pipe has an I.D. of 762mm and a wall thickness of 107mm, therefore B_c is 0.976m and R_o is 0.976m. Height of earth cover is 1.5m. Use CHBDC CL-625-ONT loading.

2. Calculate average pressure intensity at the outside top of the pipe.

From Table 3, the critical load, P, is 280 kN two single dual wheels of axles 2 & 3 in the passing mode, and the Spread Area is:

$$A = (\text{Spread } a)(\text{Spread } b)$$

$$A = (0.6 + 1.2 + 1.75 \times 1.5)(0.25 + 1.2 + 1.75 \times 1.5)$$

$$A = (4.425)(4.075)$$

$$A = 18.0 \text{ m}^2$$

$$I.M. = 0.40(1.0 - 0.5H)$$

$$I.M. = 0.10$$

$$w = P(1 + I.M.) / A$$

$$w = 280(1 + 0.10) / 18$$

$$w = 17.1 \text{ kN/m}^2$$

3. Calculate total live load acting on the pipe.

$$W_T = w L S_L$$

Assuming truck travel transverse to pipe centerline.

$$L = \text{Spread } a = 4.425 \text{ meters}$$

$$\text{Spread } b = 4.075 \text{ meters}$$

$B_c = 0.976$ meters, which is less than Spread b, therefore

$$S_L = 0.976 \text{ meters}$$

$$W_T = 17.1 \times 4.425 \times 0.976 = 73.85 \text{ kN}$$

Assuming truck travel parallel to pipe centerline.

$$\text{Spread } a = 4.425 \text{ meters}$$

$$L = \text{Spread } b = 4.075 \text{ meters}$$

$B_c = 0.976$ meters, which is less than Spread a, therefore

$$S_L = 0.976 \text{ meters}$$

$$W_T = 17.1 \times 0.976 \times 4.075 = 68 \text{ kN}$$

W_T Maximum = 73.85 kN; and truck travel is transverse to pipe centerline

4. Calculate live load on pipe in kN per linear meters.

$$R_o = 0.976 \text{ meters}$$

$$L_e = L + 1.75(3/4R_o)$$

$$L_e = 4.425 + 1.75(0.75 \times 0.976) = 5.71 \text{ meter}$$

$$W_L = W_T / L_e$$

$$W_L = 73.85 / 5.71 = 12.93 \text{ kN per linear meter}$$

Designated Internal Diameter, mm	Actual Internal Diameter, mm	Wall A	Wall B	Wall C
		Minimum Wall Thickness, mm	Minimum Wall Thickness, mm	Minimum Wall Thickness, mm
300	305	44	50	69
375	381	47	57	75
450	457	50	63	82
525	533	57	69	88
600	610	63	75	94
675	686	66	82	100
750	762	69	88	107
825	838	72	94	113
900	914	75	100	119
1050	1067	88	117	132
1200	1219	100	125	144
1350	1372	113	138	157
1500	1524	125	150	169
1650	1676	138	163	182
1800	1829	150	175	194
1950	1981	163	188	207
2100	2134	175	200	219
2250	2286	188	213	232
2400	2438	200	225	244
2550	2591	213	238	257
2700	2743	225	250	269
3000	3048	-	279	298
3600	3658	-	330	349

Equivalent Round Size, mm	Minor Axis, mm	Major Axis, mm	Minimum Wall Thickness, mm
450	365	575	69
600	490	770	82
675	550	865	88
750	610	960	94
825	670	1067	94
900	730	1150	113
975	795	1250	119
1050	855	1345	125
1200	975	1535	138
1350	1095	1730	150
1500	1220	1920	163
1650	1340	2210	175
1800	1465	2305	188
1950	1585	2495	200
2100	1705	2690	213
2250	1830	2880	225
2400	1950	3070	238
2550	2075	3265	244
2700	2195	3455	250
2850	2315	3648	263
3000	2440	3840	275
3300	2680	4225	300
3600	2925	4610	325

References

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