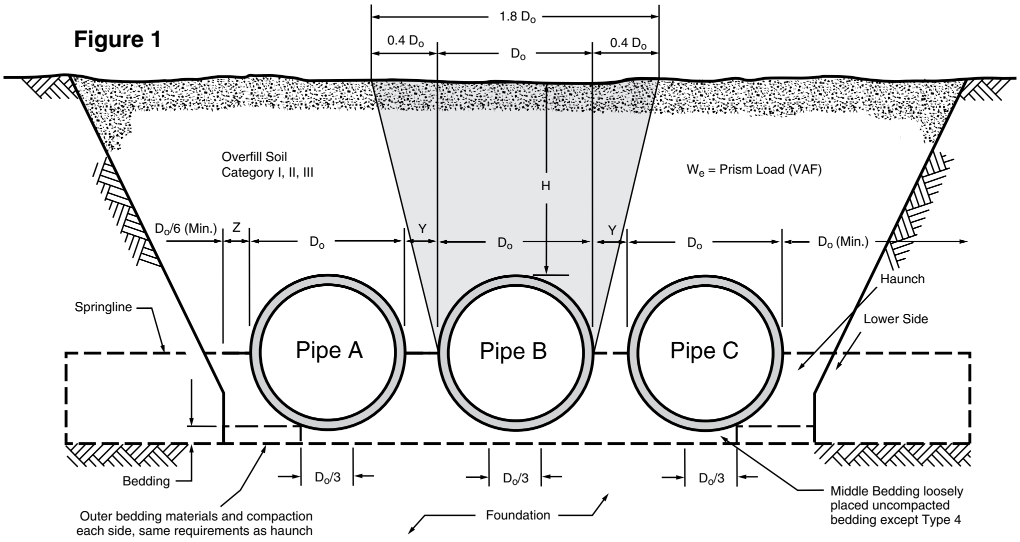
Design Data 5

Multiple Pipe Installations: Trench Condition

A multiple pipe installation is the placement of two or more pipelines in a single trench or embankment condition. This installation procedure is most commonly used where restrictive cover requirements preclude the use of a single pipe of larger diameter, where an assembly of pipes is used to create a buried storm water storage system, or where a storm and sanitary sewer are installed in the same trench at different elevations.

Although multiple pipe installations are common, the determination of the pipe loads may present unusual problems. This Design Data will use the Indirect Design Method to determine the required pipe strength using ACPA's Standard Installations Direct Design (SIDD) methods to determine the dead and live loads, and bedding factors. Standard Installations provide a range of installations from highly compacted select material installed with thorough inspection (Type 1), to native material minimally compacted around the pipeline (Type 4). See Chapter four of the Concrete Pipe Design Manual for more information regarding Standard Installations. Lesser installation types require greater pipe strength. This design method does not develop new theory, but by the application of engineering judgment, develops a design method for multiple pipe installations that produces a reasonable and conservative design solution.

Figure 1



FLAT TRENCH

For most cases, it is more practical to install multiple pipelines in a single, wide trench rather than using an individual trench for each line. Because multiple pipelines are generally used when there are restrictive (shallow) cover conditions and the trench is extraordinarily wide, the Standard Installations positive projecting embankment installation most closely represents the actual loading on the pipes and will be used for the analysis of this design condition.

Pipe Installation. Standard Installations have specific compaction requirements for the soil in the haunch and lower side zones in each installation. The designer must provide adequate space between the pipelines that is appropriate for the method of compaction of the soil in the haunch and lower side zones. Because compaction of the soil in the space between multiple pipelines will be difficult in most cases, special care should be exercised by the designer when selecting the type of installation and bedding material for flat multiple pipeline installations.

In Figure 1, three pipelines are placed in a wide trench. For Standard Installations, the spacing between pipelines, Y, and the distance from the pipe to the trench wall, Z, must be at least 1/6 of the outer diameter of the pipe ($D_o/6$). When precast end sections are used on multiple culvert lines, the spacing must accommodate the width of the end sections.

The middle-third of bedding area under each pipeline is loosely placed uncompacted bedding. The intent is to maintain a slightly yielding bedding so the pipe may settle into the bedding and achieve improved load distribution. The optimum construction sequence is to place the bedding to grade; install the pipe to grade; compact the bedding outside the middle-third of the pipe; and then place and compact the haunch zone up to the springline of the pipe. To effectively compact the soil in the haunch zone, it may be necessary to increase the dimensions of Y and Z beyond $D_o/6$.

Analyze Loading Condition. The selection of pipe strength by the indirect design method requires six steps: determine the dead load, determine the live load, select bedding, determine bedding factors for dead and live loads, apply the factor of safety, and select the pipe strength.

Dead Load. For a Standard Installations positive projecting embankment installation, the dead load supported by the pipe is the weight of the prism of earth over the outside diameter of the pipe and increased by the Vertical Arching Factor, (VAF).

$$PL = w\left[H + D_o\left(\frac{4-\pi}{8}\right)\right]D_o \qquad (1)$$

and Dead Load; $W_e = (VAF)\ PL$ (2)

where;
PL = prism load (lb./ft.),
w = soil unit weight (lbs./ft.^{3}),
H = height of fill (ft.),
D_o = outside diameter (ft.).

The VAF accounts for the additional dead load transferred to the pipe by settlement of the earth adjacent to the prism. The representation of the dead load from the earth prism and the additional effect of the VAF is shown

Table 1

Pipe Size D in Inches	B_c (ft.)	Height of Fill H Above Top of Pipe in Feet												
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0
12	1.33	3780	2080	1470	1080	760	550	450	380	290	230	190	160	130
15	1.63	4240	2360	1740	1280	900	660	540	450	350	280	230	190	160
18	1.92	4110	2610	1970	1460	1030	750	620	520	400	320	260	220	190
21	2.21	3920	2820	2190	1620	1150	840	690	580	450	360	300	250	210
24	2.50	4100	3010	2400	1780	1270	930	760	640	500	400	330	380	240
27	2.79	3880	2940	2590	1930	1380	1010	830	700	560	440	360	300	260
30	3.08	3620	2930	2770	2070	1480	1080	890	750	590	480	390	330	280
33	3.38	3390	2930	2950	2200	1580	1160	960	810	630	510	420	360	300
36	3.67	3190	2810	2930	2330	1670	1230	1020	860	670	550	450	380	330
39	3.96	3010	2670	2850	2440	1760	1290	1070	910	710	580	480	410	350
42	4.25	2860	2550	2770	2560	1840	1360	1130	950	750	610	510	430	370
48	4.83	2590	2330	2620	2480	1990	1470	1230	1040	820	670	560	470	410
54	5.42	2360	2150	2490	2360	2050	1580	1320	1120	890	730	610	520	440
60	6.00	2170	1990	2450	2250	1960	1680	1400	1190	950	780	650	560	480
66	6.58	2010	1850	2520	2160	1880	1640	1480	1260	1010	830	700	590	510
72	7.17	1870	1730	2580	2190	1810	1570	1510	1330	1060	880	740	630	540
78	7.75	1750	1630	2630	2240	1770	1520	1460	1390	1110	920	780	660	570
84	8.33	1650	1540	2730	2290	1810	1460	1410	1360	1160	960	810	690	600
90	8.92	1550	1460	2530	2330	1850	1470	1360	1310	1210	1000	850	720	630
96	9.50	1470	1380	2410	2290	1880	1500	1330	1270	1250	1040	880	750	650
102	10.08	1390	1320	2300	2190	1910	1530	1350	1240	1290	1070	910	780	680
108	10.67	1320	1260	2200	2090	1830	1560	1380	1230	1330	1110	940	810	700
114	11.25	1260	1200	2110	2010	1760	1540	1410	1260	1362	1140	970	830	730
120	11.83	1210	1150	2020	1930	1700	1480	1420	1280	1400	1170	990	860	750
128	12.42	1160	1100	1940	1860	1640	1430	1380	1300	1430	1200	1020	880	770
132	13.00	1110	1060	1870	1800	1580	1380	1330	1290	1460	1220	1040	900	790
138	13.58	1070	1020	1800	1730	1530	1340	1290	1250	1490	1250	1070	920	810
144	14.17	1020	980	1740	1670	1480	1300	1250	1210	1470	1280	1090	940	830

Data:
1. Unsurfaced roadway.
2. Loads – AASHTO HS 20, two 16,00 lb. dual-tired wheels, 4 ft. oncenters, or alternate loading, four 12,000 lb. dual-tired wheels, 4 ft. on centers with impact included.

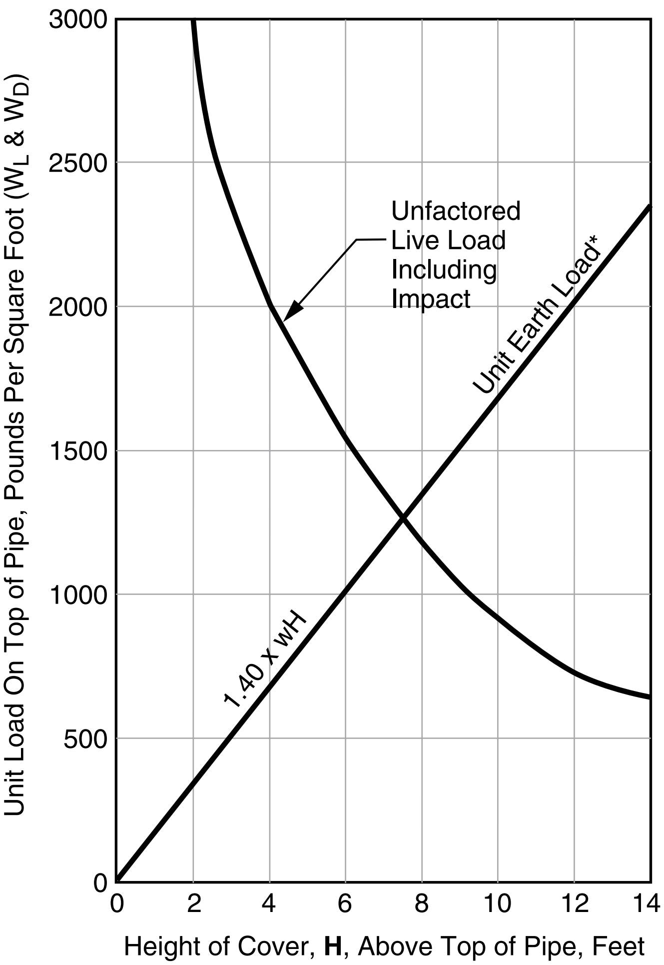
Notes:
1. Interpolate for intermediate pipe sizes and / or fill heights.
2. Critical loads:
   a. For H = 0.5 and 1.0 ft., a single 16,000 lb dual-tired wheel.
   b. For H = 1.5 through 4.0 ft., two 16,000 lb. dual-tired wheels, 4 ft. on center.
   c. For H > 4.0 ft. alternate loading
3. Truck live load for H = 10.0 ft or more are insignificant.

on Pipe B in Figure 1. The values for VAF for each type of bedding are:

- Type 1 VAF = 1.35
- Type 2 VAF = 1.40
- Type 3 VAF = 1.40
- Type 4 VAF = 1.45

Live Load. The live load effect may be a significant factor in the design of shallow multiple pipelines because intensity of a live load is highest at the surface. It is distributed over a larger area as the depth of cover over a pipeline increases. Loads on pipe from highway, and railway loading are found in Table 1 and Figure 2. The AASHTO LRFD Standard applies a dynamic load allowance to account for the truck load being non-static. The dynamic load allowance, IM is determined by Equation 3:

Figure 2 Loads on Concrete Pipe Installed Under Railways



$$IM = \frac{33(1.0 - 0.125H)}{100} \qquad (1)$$

Selection of Bedding and Determination of Bedding Factors. Bedding is provided to distribute the vertical reaction around the lower exterior surface of the pipe and to reduce stress concentrations within the pipe wall. Embankment bedding factors for five common diameters of pipe are found in Table 2. For sizes not tabulated, the bedding factor for the next larger size may be selected, or a more exact factor may be interpolated between the tabulated sizes that bracket the selected size. Live Load bedding factors are found in Table 3. The live load factors may be selected by a method similar to that used

Table 2 Bedding Factors, Embankment Conditions, B_{fe}

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

Notes: 1. For pipe diameters other than listed in Table 3, embankment condition factors, Bfe can be obtained by interpolation.
2. Bedding factors are based on the soils being placed with the minimum compaction specified in Illustrations 4.5 and 4.7 for each standard installation.

Table 3 Bedding Factors, B_{fLL}, for HS20 Live Loadings

Fill Height	Pipe Diameter, Inches										
Ft.	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	2.2	2.0	1.8	1.5	1.5	1.4	1.4	1.3	1.3
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

Notes: 1. For pipe diameters other than listed in Tabel 4, B_{fLL} values can be obtained by interpolation.

to find the embankment factors; choose the lower factor of the two tabulated bracketing sizes, or interpolate for a more exact value. The bedding factors appear in the denominator of the pipe strength equation, therefore, a smaller bedding factor means higher pipe strengths are required.

Factor of Safety. The Indirect Design method is based on service load conditions. The 0.01-inch crack width is used as the criterion of service strength of pipes tested in the three-edge-bearing test. The relationship of ultimate test strength and the 0.01-inch test strength criteria is 1.5 for D-loads of 2000 pounds/ft./ft. or less and 1.25 for D-load strengths greater than 3000 pounds/ft./ft. The ratio of factors is interpolated between 1.5 and 1.25 for D-loads between 2000 and 3000 pounds/ft./ft. A Factor of Safety of 1.0 shall be applied to the 0.01 inch cracking strength of the pipe.

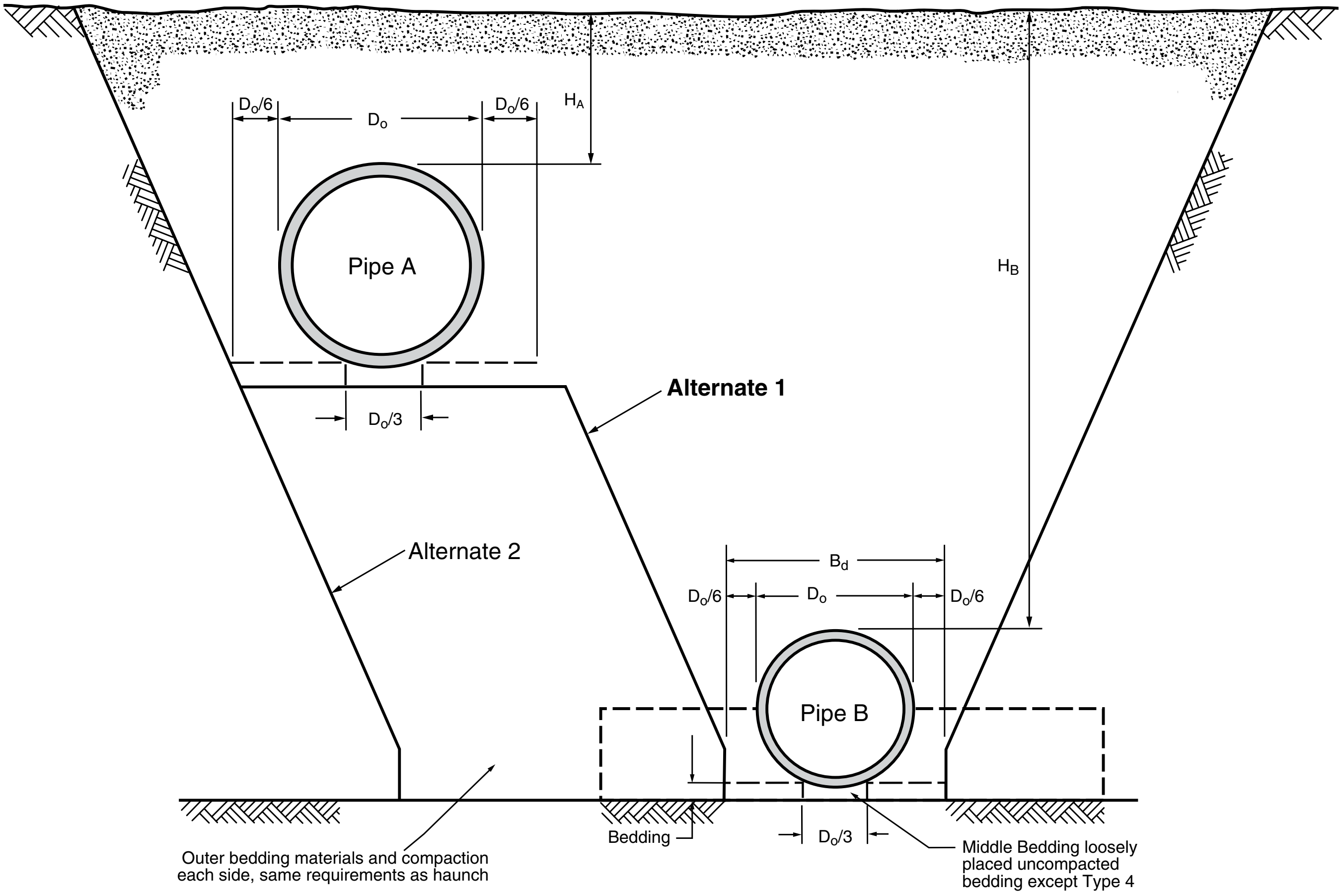
Selection of Pipe Strength. Since numerous reinforced concrete pipe sizes are available, three-edged-bearing (TEB) test strengths are classified by D-loads. The D-load concept provides strength classification independent of pipe diameter. For reinforced circular pipe, the TEB test load in pounds per linear foot equals D-load x inside diameter in feet. For arch, horizontal elliptical, and vertical elliptical pipe, the TEB test load in pounds per linear foot equals D-load x nominal inside diameter in feet. The required TEB test strength for non-reinforced concrete pipe is expressed in pounds per lineal feet of pipe. The required TEB strength of a circular reinforced concrete pipe is expressed as the D-load, and is computed by:

$$D - \text{load} = \left[\left(\frac{W_e}{B_{fe}} + \frac{W_L}{B_{fLL}}\right)\right]\frac{F.S.}{D} \qquad (4)$$

where; W_e = dead load (lb./ft.)
B_{fe} = embankment bedding factor,
W_L = live load (lb./ft.),
B_{fLL} = live load bedding factor,
F.S. = Factor of Safety,
D = inside diameter.

For arch and elliptical pipe, replace D, the inside diameter, with S, the inside span. When calculating HS20 highway live loading, if the value of the dead load bedding factor is smaller than the live load bedding factor,

Figure 3



substitute the lower value for the tabulated live load factor in the D-load equation.

BENCHED TRENCH

Another common type of multiple pipeline installations is illustrated in Figure 3, where the pipe is separated vertically as well as horizontally. Generally, the criteria established by the local jurisdiction will require minimum vertical and horizontal separations between the pipelines, and possibly the minimum dimension of Y in respect to X, especially if pipe A is a storm sewer and B is a sanitary sewer, or if there is concern for the stability of the bench under pipe A.

A benched trench installation includes more complex design variables to consider than does the flat trench. The economy of a common excavation, or restricted trench width, is the principle reason for using the benched trench installation. Dead Loads on the pipelines may resemble either a Standard Installations trench or positive projecting embankment installation. Construction of a benched installation trench is frequently made in one of two following sequences;

- For the first method, the lower pipeline is installed in a conventional trench and the trench is backfilled and compacted to the foundation elevation of the upper pipeline. In some cases. A partial bench may be excavated in the side slope. If any portion of the pipe installation cross-section of the upper pipeline is within the side slope of the trench, the backfill material in the trench must be uniformly compacted to specified SIDD installation requirements.
- In the second method, the lower pipeline is installed in a conventional trench and the trench is backfilled to the foundation elevation of the upper pipeline. When the horizontal alignment of the upper pipeline is entirely outside the side slope of the trench of the lower pipeline, a bench is excavated at the foundation elevation of the upper pipeline.

In moderate trench width conditions, as is typically found in the lower pipeline, the resulting earth load is equal to the weight of the soil within the trench minus the shearing or frictional forces on the sides of the trench. Since the newly installed backfill material will settle more than the existing soil on the side of the trench, the friction along the trench wall will relieve the pipe of some of the soil burden.

As the trench width increases, the reduction in the load from frictional forces is offset by the increase in the soil weight in the trench. As the trench width increases it starts to behave as an embankment, where the soil on the side of the pipe settles more than the soil above the pipe. Eventually, the embankment condition is reached when the trench walls are too far away from the pipe to help support the soil immediately adjacent to it. This is the transition width of the trench, where the trench load equals the embankment load. Any pipe designed in a trench width equal to or greater than the transition width should be designed as an embankment condition.

Analyze Loading Condition. The selection of pipe strength by the indirect design for a benched trench requires the same six steps as the flat trench: determine the dead load, determine the live load, select bedding, determine bedding factors for dead and live loads, apply factors of safety, and select pipe strength. For a benched trench installation, both trench and embankment dead loads must be compared because for the same depth of cover, trench dead loads are less, but the bedding factors are also smaller.

Dead Load. The dead load on the lower pipeline should be selected as the greater load from either the SIDD trench or positive projecting embankment condition, while the dead load on the upper pipeline may be calculated by SIDD positive projecting embankment methods as used for flat trenches. For the trench condition:

$$W_d = w\left[C_d B_d^2 + \left(\frac{4-\pi}{8}\right) D_o^2\right] \qquad (5)$$

$$\text{and, } C_d = \frac{1 - e^{-2K\mu'\left(\frac{H}{B_d}\right)}}{2K\mu'} \qquad (6)$$

where; W = soil with weight (lbs./ft^3.)
B_d = width of trench (ft.),
D_o = outside diameter (ft.),
K = ratio of active lateral unit pressure to vertical unit pressure,
μ' = Tan ø, coefficient of friction between fill material and side of trench.

The value of C_d may be read directly from Figure 4, Load Coefficient Diagram For Trench Installations. Typical values for $K\mu'$ are:

- $K\mu'$ = 0.1924 Max. for granular materials without cohesion
- $K\mu'$ = 0.165 Max. for sand and gravel
- $K\mu'$ = 0.150 Max. for saturated top soil
- $K\mu'$ = 0.130 Max. for ordinary soil
- $K\mu'$ = 0.110 Max. for saturated clay

Figure 4 = Figure 214, page 403 of the Design Manual.

For a Standard Installations positive projecting embankment condition, the dead load supported by the pipe is the weight of the prism of earth over the outside diameter of the pipe and increased by the Vertical Arching Factor, (VAF).

$$PL = w\left[H + D_o\left(\frac{4-\pi}{8}\right)\right]D_o \qquad (1)$$

and Dead Load; $W_e = (VAF)\ PL$ (2)

where; PL = prism load (lb./ft.),
w = soil unit weight (lbs./ft.^{3}),
H = height of fill (ft.),
D_o = outside diameter (ft.).

Live Load. Loads on pipe from highway and railway loading are found in Table 1 and Figure 2. Impact or dynamic loads need not be added to highway live loads for buried concrete pipelines constructed from circular, elliptical, and arch shaped pipe sections with cover less than eight feet.

Selection of Bedding and Determination of Bedding Factors. Most benched trench installations will have adequate space for compaction of haunch and sidefill materials, therefore, any of the four Standard Installations bedding installation types may be used. Embankment bedding factors for five common diameters of pipe are found in Table 3. For sizes not tabulated, the bedding factor for the next larger size may be selected, or a factor may be interpolated between the tabulated sizes if a more accurate value is required. Minimum trench bedding factors for each of the four types of Standard Installations beddings are found in Table 4. The variable trench bedding factor may be determined by a series of interpolations of positive projecting embankment and trench bedding factors. Live Load bedding factors are found in Table 3. The live load factors may be selected by a method similar to that used to find the embankment factors: choose the lower factor of the two tabulated sizes, or interpolate for a more exact value.

Table 4 Trench Minimum Bedding Factors, B_{fo}

Standard Installation	Minimum Bedding Factors, B_{fo}
Type 1	2.3
Type 2	1.9
Type 3	1.7
Type 4	1.5

Notes: 1. Bedding factors are based on the soils being placed with the minimum compaction specified in Illustrations 4.5 and 4.7 for each Standard Installation.

2. For pipe installed in trenches dug in previously constructed embankment, the load and the bedding factor should be determined as an embankment condition unless the backfill placed over the pipe is of lesser compaction than the embankment.

Factor of Safety. A Factor of Safety of 1.0 shall be applied to the 0.01 inch cracking strength of the pipe.

Selection of Pipe Strength. The required TEB strength of a circular reinforced concrete

pipe is expressed as the D-load, and is computed by Equation 4:

$$D - load = \left[\left(\frac{W_e}{B_{fe}} + \frac{W_L}{B_{fLL}}\right)\right]\frac{F.S.}{D} \qquad (4)$$

where; W_e = dead load (lb./ft.)
B_{fe} = embankment bedding factor,
W_L = live load (lb./ft.),
B_{fLL} = live load bedding factor,
$F.S.$ = Factor of Safety,
D = inside diameter.

For arch and elliptical pipe, replace D, the inside diameter, with S, the inside span. When applying HS20 highway live loading, if the value of the dead load bedding factor is smaller than the live load bedding factor, substitute the lower value for the tabulated live load factor in the D-load equation.

DESIGN EXAMPLES

Given: A builder is developing a business on an environmentally sensitive site near a lake. The designer is required to provide a storm water retention system that will store the additional runoff due to development, before it can reach the lake. Because the cost of land is expensive, and for aesthetic reasons, a buried system will be used. The natural ground elevation averages ten feet above ground water.

To avoid the cost of dewatering, the designer has selected an assembly of parallel rows of 60-inch diameter B-wall concrete pipe that have an outer diameter of 72 inches installed two feet above the ground water. The rows of pipe will be connected with special precast 60-inch diameter tees that have an eight-foot laying length. The native soil where the storm water detention structure will be constructed is poorly graded sand with a unit weight of 120 pounds per cubic foot.

Find: The required strength of the 60-inch pipe.

Solution: This is an example of a flat multiple trench installation.

1.0 Determine Dead Load. The 60-inch pipeline will be installed two feet above the water table. The fill height, $H = 10-(2+6) = 2$ ft. From Equations (1) and (2),

$$PL = 120\left[2 + 6\left(\frac{4 - \pi}{8}\right)\right]6 = 1904 \text{ lb./ft.}$$

For a Type 2 Installation the VAF = 1.40.

DeadLoad, W_e = 1.4 x 1904 = 2665.6 lb./ft.

2.0 Determine Live Load.
From Table 1, Highway loads on Circular Pipe, for 60-inch diameter pipe and H = 2 ft,

Live Load = 2250 lb./ft.

In this example, a portion of the ground surface over the pipelines will be a paved parking lot and the remainder green space. Highway live loads should be included in both cases, but since loads will never be severe, the impact factor may be deleted. Normally, a live load impact factor of 25% is applied to installations with two feet of cover over the pipeline as shown in Equation 3 of this document.

Live Load (Adjusted), W_L = 2250 ÷ 1.25 = 2813 lb./ft.

3.0 Selection of Bedding. Only Type 3 and Type 4 installations are recommended for multiple pipe installations in restricted areas, because it is difficult to adequately compact the haunch and side fill areas. Type 3 bedding instead of Type 4 has been selected for this installation, because native soils are suitable and a portion of the surface over the installation will be paved. A Type 4 installation would be adequate if the entire surface was green space.

4.0 Determine Bedding Factors.
The dead load bedding factors are found in Table 2, Bedding Factors, Embankment Condition. The 60-inch diameter pipe size is not included in the table. Select the bedding factor of 2.2 for 72-inch, the next larger size. In this case, because of the small difference between the factors for the next smaller size (36 inch) and 72 inch, it is not beneficial to interpolate for a more exact value.

The live load bedding factor is found in Table 3, Bedding Factors for HS20 Live Loadings. The factor for a 60-inch diameter pipe with 2 feet of fill is 1.8. That value is less than the dead load factor of 2.2 and may be used without adjustment.

5.0 Apply Factor of Safety.
The factor of safety is 1.0 based on a 0.01 crack width in a TEB Test.

6.0 Selection of Pipe Strength.
The required D-load strength of a pipe is found by Equation (3).

$$D - \text{Load} = \left[\frac{2665.6}{2.2} + \frac{2250}{1.8}\right]\frac{1.0}{5} = 492.3 \text{lb./ft./ft.}$$

For this installation, an ASTM C76 Class I pipe will be adequate. Many experienced designers will specify ASTM C76 Class II as a minimum strength if the pipe will be subjected to any highway live loading.

EXAMPLE 2

Given: The installation of two pipelines in a single trench beneath a city street is proposed. The lines are a 48-inch storm sewer line and a 30-inch sanitary sewer with a maximum of one foot between the outside of any pipe and the adjacent trench wall. The local code states, "The outside top of the sanitary sewer must be a minimum of three feet below the outside bottom of the storm sewer, and the horizontal spacing shall be equal to or greater than the vertical spacing." The height of fill over the 48-inch line is five feet, and 13 feet over the 30-inch line. The pipes will be installed with a Type 2 bedding and backfilled with ordinary clay weighing 130 PCF.

Find the required strength of the pipes in D-load:

Since the 48-inch storm sewer pipeline is installed in a wide and relatively shallow trench, it will be analyzed as a positive projecting embankment condition.

The 30-inch sanitary sewer pipeline is installed in a conventional trench, with the pipe centered with a distance of one foot between the pipe springline and trench walls. The transition width of the trench must be known to determine if the largest earth load on the pipe is due to either a positive projecting embankment, or a trench condition.

1.0 Determine Dead Loads.

1.1 48-inch storm sewer.
For a fill height, H = 5 ft., VAF=1.4 From Equations (1) and (2) for a SIDD positive projecting embankment,

$$PL = 130\left[5 + 4.83\left(\frac{4 - \pi}{8}\right)\right]4.83 = 3465 \text{ lb./ft.}$$

W_e = 1.4 (3465) = 4851 lb./ft.

1.2 30-inch sanitary sewer with a fill height, H = 13 ft.

1.2.1 Using the Transition Width tables, for a 30-inch B-wall pipe installed in ordinary clay, with 13 feet of fill, the transition trench width B_{dt}, is

5.8 feet. The trench width, B_d, for this example is found by adding two feet to the outside diameter of the pipe, or B_d, = ((30+(2)x3.5)/12)+2 = 5.1 feet. The trench width, B_d, is less than the transition width, B_{dt}, so using the trench condition is the appropriate method to determine the required pipe strength. Equation (5) will be used to determine the dead load on the pipe. The Load Coefficient Diagram, Figure 4, will be used to select C_d.

$H/B_d = 13/5.1 = 2.55$, and $C_d = 1.85$

$$W_d = 130 \left[1.85(5.1)^2 + \left(\frac{4 - \pi}{8}\right) 3.1^2\right] = 6390 \text{ lb./ft.}$$

2.0 Determine Live Load.

2.1 48-inch storm sewer.

From Table 1, Highway loads on Circular Pipe, for 48-inch diameter pipe and H = 5 ft,

Live Load, $W_L = 820$ lb./ft

2.2 30-inch sanitary sewer.

The live load is negligible at a 13-foot depth and may be ignored for this installation.

Live Load, $W_L = 0$ lb./ft.

3.0 Selection of Bedding.

There is adequate space at the springline of the lower and upper pipelines for proper compaction of the haunch and sidefill material. A Type 2 installation with selected imported material was initially selected, because the native clay material may be difficult to compact.

If initial calculations indicate relatively low dead loads on the lower pipeline, a Type 3 installation should be investigated. An economic analysis will have to be made to see if the costs of importing select fill materials, and disposal of excavated soil, is offset by the increase in cost for a stronger pipe. The upper pipeline has only five feet of fill, and its required strength will be less sensitive to the type of bedding specified, than will the lower pipeline.

4.0 Determine Bedding Factors.

4.1 48-inch storm sewer.

The dead load bedding factors are found in Table 2, Bedding Factors, Embankment Condition. The 48-inch diameter pipe size is not included on the table. Select the bedding factor of 2.8 for 72-inch, the next larger size. In this case, because of the small difference between the factors for the next smaller size (36 inches) and 72 inches, it is not beneficial to interpolate for a more exact value.

The live load bedding factor is found in Table 3, Bedding Factors for HS20 Live Loadings. The factor for a 48-inch diameter pipe with 5 feet of fill is 2.2. That value is less than the dead load factor of 2.8 and may be used without adjustment.

4.2 30-inch sanitary sewer.

The bedding factors for the positive projecting embankment and trench installations must be determined to calculate the variable bedding factor used for this installation. In Table 2, the positive projecting embankment dead load factor is 2.9 for a 36-inch diameter pipe in a Type 2 installation. In this case, because of the small difference between the factors for the next smaller size, (24-inches) and 36-inches, it is not beneficial to interpolate for a more exact value. The minimum trench bedding factor of 1.9 is found in Table 4.

The Standard Installations variable trench bedding factor is calculated by adding an increment of the difference between the trench and positive projecting embankment load factors, to the minimum trench load factor.

$$B_{fv} = B_{fo} + \Delta_{Bf}\left(\frac{\Delta_{sw}}{\Delta_{tw}}\right) \qquad (7)$$

where; B_{fv} = variable trench bedding factor

B_{fo} = minimum trench bedding factor

Δ_{Bf} = (Bfe, bedding factor, embankment) – (Bfo, minimum trench bedding factor)

Δ_{sw} = (Bd, trench width at top of pipe)– (Do, outside horiz. span of pipe, feet)

Δ_{tw} = (Bdt, transit. width at top of pipe, ft.)– (Do, outside horiz. span of pipe, ft.)

The variable trench bedding factor from equation (7) is:

$$B_{fv} = 1.9 + 1.0\left(\frac{5.1 - 3.1}{5.9 - 3.1}\right) = 2.62 \qquad (7)$$

The live load is negligible at a 13-foot depth and may be ignored for this installation.

5.0 Apply Factor of Safety.

The factor of safety is 1.0 based on a 0.01 crack width in a TEB Test.

6.0 Selection of Pipe Strength.

6.1 48-eight inch storm sewer.

The required D-load strength of a pipe is found by Equation (4).

$$\text{D-Load} = \left[\frac{4851}{2.8} + \frac{820}{2.2}\right]\frac{1}{4} = 526.3 \text{ lb./ft./ft.} \qquad (1)$$

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6.2 30-inch sanitary sewer.

The required D-load strength of a pipe is found by Equation (4).

$$\text{D-Load} = \left[\frac{6390}{2.62} - 0\right]\frac{1}{2.5} = 975 \text{ lb./ft./ft.} \qquad (1)$$

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For this installation, ASTM C76 Class II pipes will provide adequate strength for both sizes. Since the cost increment between Class II and Class III strength tend to be small in these sizes, a Type 3 installation may be practical in spite of the extra effort required to compact clay material.