American **Concrete Pipe** Association

ACPA » Design Data 22

Flotation of Circular Concrete Pipe

There are several installation conditions where there is the possibility that concrete pipe may float, even though the density of concrete is approximately 2.4 times that of water. Some of these conditions are: the use of flooding to consolidate backfill; pipelines in areas which will be inundated, such as a flood plain or under a future man-made lake; subaqueous pipelines; flowable fill installations; and pipelines in areas with a high groundwater table. When such conditions exist, flotation probability should be checked.

Flotation Factors

The buoyancy of concrete pipe depends upon the weight of the pipe, the weight of the volume of water displaced by the pipe, the weight of the liquid load carried by the pipe and the weight of the backfill. As a conservative practice in analysis, the line should be considered empty so the weight of any future liquid load is then an additional safety factor.

Design Procedure

A suggested seven step logical procedure is presented for determining the degree of buoyancy of an empty concrete pipeline and possible measures needed to prevent flotation. Downward forces are considered positive and upward forces are considered negative.

1. Determine the downward force of the pipe weight in pounds per linear foot of pipe.
2. Determine the bouyant upward force of the weight of the displaced water in pounds per linear foot of pipe.
3. Find the algebraic sum of the forces determined in Steps 1 and 2. If the resultant force is positive, the pipe will not float. If the resultant force is negative, proceed with Step 4.
4. Determine the downward force of the total weight of backfill in pounds per linear foot of pipe.
5. Apply a factor of safety to determine the decreased total weight of backfill.
6. Find the algebraic sum of the downward force determined in Step 5 and the excess upward force determined in Step 3. If the resultant force is positive, the pipe will not float. If the resultant force is negative, proceed with Step 7.
7. Select and analyze the procedures to be used to prevent flotation.

Preventive Procedures

If the total weight of the pipe and backfill is not adequate to prevent flotation of the pipe, preventative nonflotation procedures, such as additional backfill, mechanical anchorage, heavier pipes, or combinations of these would be required. Some of the commonly used methods are:

1. Increased wall thickness.
2. Precast or cast-in-place concrete collars.
3. Precast or cast-in-place concrete blocks, fastened by suitable means.
4. Pipe strapped to piles or concrete anchor slab.
5. Additional backfill.

When computing the volume of concrete required per linear foot for pipe anchorage, remember that concrete, which weighs 150 pounds per cubic foot in air, weighs only 87.6 pounds per cubic foot under water.

Factor of Safety

Construction soils are noted for lack of uniformity. Depending on the extent of information of the proposed backfill material and site condition, a factor of safety ranging between 1.0 and 1.5 should be applied. This factor of safety shall be applied to decrease the downward force of the backfill. Generally, if the weight of the structure is the primary force resisting flotation than a safety factor of 1.0 is adequate. However, if friction or cohesion are the primary forces resisting flotation, then a higher safety factor would be more appropriate to account for the variability of the soil properties.

Consideration must also be given to the interface between layers of differing soil types. If fine grained soils (such as clays or silts) are placed adjacent to coarse grained soils (such as crushed stone), upon wetting, these layers may combine at the interface thereby allowing the pipe to float a distance equal to the loss in volume. Increased factor of safety in combination with layer separation methods are recommended.

Pipe Weights

The average density of concrete is 150 pounds per cubic foot and the approximate weight per linear foot of circular concrete pipe may be calculated with the equation:

$$W_p = \frac{\pi}{4}(B_c^2 - D^2)\,150 \quad (1)$$

where:

W_p = weight of pipe in pounds per linear foot

B_c = outside pipe diameter in feet

D = inside pipe diameter in feet

Average weights in pounds per linear foot for ASTM C76 Reinforced Concrete Culvert, Storm Drain and Sewer Pipe are given in **Table 1**. Most pipe Manufacturers publish data that tabulates product dimensions and weights. The data from these publications should be used when available.

Water Density

The density of fresh water is 62.4 pounds per cubic foot for normal ranges of ambient temperature. The average density of seawater is 64.0 pounds per cubic foot. In this Design Data, only fresh water is considered, but local conditions should be investigated when seeking solutions for specific projects.

Displaced Water Weight

When water is displaced, a buoyant or upward force exists, and, if the buoyant force is greater than the weight of the object displacing the water, flotation will occur. The weight of fresh water displaced per linear foot of circular pipe can be calculated with the equation:

$$W_p = \frac{\pi}{4}(B_c^2)\ 62.4 \quad (2)$$

where:

W_w = weight of displaced water per linear foot in pounds

The average weights of the volume of fresh water displaced per linear foot of C76 pipe are presented in **Table 2**.

Backfill Weight

The weight of the backfill directly over the pipe assists in holding the pipe down. The unit weight of compacted backfill material varies with specific gravity, the grain size, and the degree of compaction. For preliminary computations, however, average values for dry density and specific gravity of backfill materials are of sufficient accuracy.

The unit weight of inundated backfill is equal to the dry density of the backfill minus the weight of water displaced by the solid particles, and can be calculated with the equation:

$$w_I = w - \left[\frac{w}{(SG * 62.4)} * 62.4\right] \quad (3)$$

which reduces to

$$w_I = w - \left[\frac{w}{SG}\right] \text{or } w\left[1 - \frac{1}{SG}\right] \quad (4)$$

where:

w_I = average unit weight of inundated backfill in pounds per cubic foot

w = average unit weight of dry backfill in pounds per cubic foot

SG = specific gravity of backfill

Figure 1 illustrates the backfill over the pipe and the different volumes to be considered. The volume of backfill over the haunches from the springline to the top of the pipe is equal to 0.1073 times B_c^2 cubic feet per linear foot of pipe. The volume of backfill from the top of the pipe to the level of inundation equals H_I times B_c cubic feet per linear foot of pipe.

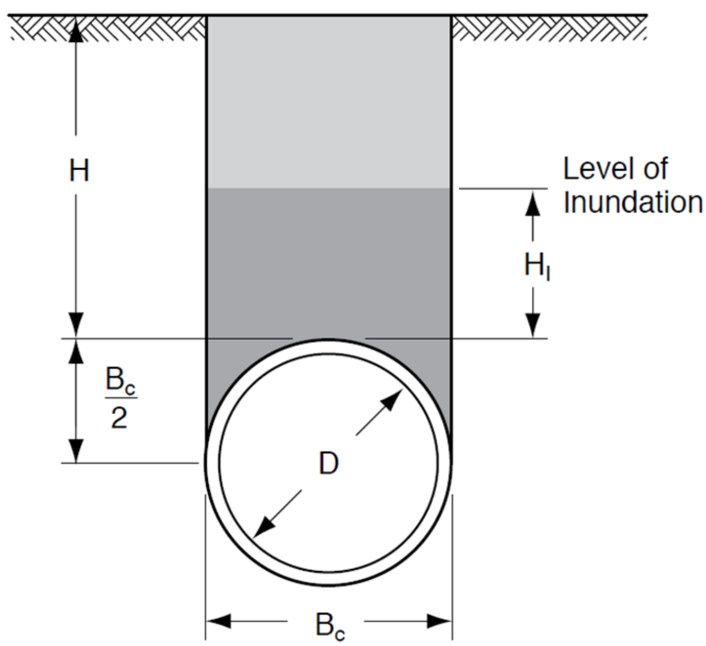

Figure 1: Backfill Volumes Over Pipe

Therefore, the weight of inundated backfill per linear foot of pipe acting downward on the pipe can be calculated with the equation:

$$W_I = w_I\,(0.1073 * B_C^2 + H_I B_C) \quad (5)$$

where:

W_I = weight of inundated backfill directly over the pipe in pounds per linear foot

H_I = depth of inundated backfill above top of pipe in feet

The weight of dry backfill above the water level, if any, per linear foot of pipe acting downward on the pipe can be calculated with the equation:

$$W_D = w\,(H - H_I)\,B_C \quad (6)$$

where:

W_D = weight of dry backfill directly over the pipe in pounds per linear foot

H = depth from top of pipe to surface of backfill in feet

Therefore, the total weight of backfill per linear foot of pipe acting downward on the pipe is the algebraic sum of¬ Equations 5 and 6 as follows:

$$W_B = W_I + W_D \quad (7)$$

where:

W_B = total weight of backfill directly over the pipe in pounds per cubic foot

Example 1

Given:

A 72-inch diameter, B wall, ASTM C76 reinforced concrete pipe is to be installed in a trench in a sandy coastal area with 8 feet of backfill over the top of the pipe. Since the groundwater table is near the ground surface in this area and the natural soil is basically sand, flooding of the backfill for consolidation is permitted. The sandy soil is assumed to have a dry density of 110 pounds per cubic foot and a specific gravity of 2.65.

Find:

If the pipe would float under conditions of complete backfill, determine the procedures necessary to prevent flotation and what height of backfill is necessary to prevent flotation.

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe						
	Wall A		Wall B		Wall C	
Internal Diameter, Inches	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot	Minimum Wall Thickness, Inches	Average Weight, Pounds Per Foot
12	1 ¾	79	2	92	2 ¾	133
15	1 ⅞	104	2 ¼	127	3	177
18	2	131	2 ½	168	3 ¼	226
21	2 ¼	171	3 ¾	214	3 ½	281
24	2 ½	217	3	265	3 ¾	341
27	2 ⅝	254	3 ¼	322	4	406
30	2 ¾	295	3 ½	384	4 ¼	476
33	2 ⅞	338	3 ¾	451	4 ½	552
36	3	383	4	524	4 ¾	633
42	3 ½	521	4 ½	685	5 ¼	812
48	4	681	5	867	5 ¾	1011
54	4 ½	861	5 ½	1071	6 ¼	1232
60	5	1064	6	1296	6 ¾	1474
66	5 ½	1287	6 ½	1542	7 ¼	1738
72	6	1532	7	1810	7 ¾	2023
78	6 ½	1797	7 ½	2098	8 ¼	2329
84	7	2085	8	2409	8 ¾	2656
90	7 ½	2393	8 ½	2740	9 ¼	3004
96	8	2723	9	3093	9 ¾	3374
102	8 ½	3074	9 ½	3466	10 ¼	3765
108	9	3446	10	3862	10 ¾	4178
114	9 ½	3839	10 ½	4278	11 ¼	4611
120	10	4254	11	4716	11 ¾	5066
126	10 ½	4690	11 ½	5175	12 ¼	5542
132	11	5148	12	5655	12 ¾	6040
138	11 ½	5626	12 ½	6156	13 ¼	6558
144	12	6126	13	6679	13 ¾	7098
150	12 ½	6647	13 ½	7223	14 ¼	7659
156	13	7190	14	7789	14 ¾	8242
162	13 ½	7753	14 ½	8375	15 ¼	8846
168	14	8338	15	8983	15 ¾	9471
174	14 ½	8945	15 ½	9612	16 ¼	10117
180	15	9572	16	10263	16 ¾	10785

Table 1: Dimensions and Approximate Weights of Reinforced Concrete Pipe

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter concrete.

Note: Pipe listed above the heavy black line will not float in sea water and need not be considered.

Solution:

1. Weight of pipe from **Table 1**:

   W_P = +1811 pounds per linear foot of pipe (downward force)

2. Weight of displaced water from **Table 2**:

   W_W = -2519 pounds per linear foot of pipe (upward force)

3. Algebraic sum of Steps 1 and 2:

   $W_P + W_W = +1181 + (-2519) = -708$ pounds per linear foot of pipe (upward force)

   The resultant force is upward, therefore proceed to Step 4.

4. Total weight of backfill:

   Weight of inundated backfill:

   Given the compacted dry density of sand is 110 pounds per cubic foot with a specific gravity of 2.65.

   From Equation 4, the unit weight of inundated backfill equals:

   $$w_I = 110\left(1 - \frac{1}{2.65}\right) = 68 \text{ pounds per cubic foot}$$

   From Equation 5, the weight of inundated backfill equals:

   $$W_I = 68\,[0.1073\,(7.17)^2 + (8 * 7.17)] = +4276 \text{ pounds per linear foot of pipe (downward force)}$$

   Weight of dry backfill:

   Since the groundwater table was assumed to be at the ground surface, there would be no additional downward force.

   Total weight of backfill:

   From Equation 7, the total weight of backfill per linear foot of pipe equals:

   $$W_B = +4276 + 0 = +4276 \text{ pounds per linear foot of pipe (downward force)}$$

5. Application of Factor of Safety:

   Since no precise information is available on the density and the specific gravity of the sandy backfill, a Factor of Safety of 1.25 will be used to reduce the assumed total weight of the backfill.

   $$\frac{W_B}{F.S.} = \frac{+4276}{1.25} = +3421 \text{ pounds (downward force)}$$

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe			
	Weight of Water Displaced, Pounds Per Linear Foot		
Internal Diameter, Inches	Wall A	Wall B	Wall C
12	82	87	104
15	120	129	150
18	165	180	204
21	221	239	267
24	286	306	338
27	354	382	417
30	249	466	504
33	511	558	600
36	600	659	705
42	817	885	938
48	1067	1145	1205
54	1351	1438	1505
60	1668	1764	1839
66	2018	2124	2205
72	2401	2517	2606
78	2818	2944	3039
84	3269	3403	3506
90	3752	3897	4007
96	4269	4423	4540
102	4820	4983	5107
108	5403	5576	5708
114	6020	6203	6341
120	6671	6863	7008
126	7354	7556	7709
132	8071	8282	8443
138	8822	9042	9210
144	9606	9836	10010
150	10423	10662	10844
156	11273	11523	11711
162	12157	12416	12612
168	13074	13343	13546
174	14025	14303	14513
180	15009	15296	15513

Table 2: Approximate Weight of Water Displaced by Reinforced Concrete Pipe

Note: Pipe listed above the heavy black line will not float in sea water.

6. Algebraic sum of Steps 3 and 5:

   From Step 3, the resultant upward force is -708 and from Step 5, the downward force is +3421, which produces a resultant downward force of +2713 pounds per linear foot of pipe.

Answer:

Therefore, the pipe will not float when backfill is completed, and additional procedures described in Step 7 are not required. However, to find the required depth of inundated backfill necessary to prevent flotation during construction, use Equation 5. Solve for H_I by setting the algebraic sum of W_I, the weight of inundated backfill over the pipe, decreased by the factor of safety, and the resultant upward force determined in Step 2 equal to zero, as follows:

$$\frac{68\,[0.1073\,(7.17)^2 + (H_I * 7.17)]}{2.65} + (-708) = 0$$

H_I = 1.05 feet above the top of the pipe.

Therefore, a minimum depth of 1 foot 1 inch of inundated backfill above the top of the pipe is required to prevent flotation of the pipe.

Example 2

Given:

A 144-inch diameter, A wall, ASTM C76 reinforced concrete pipe is to be installed as an outfall line for a wastewater treatment plant. The line is to be installed underneath the flood plain of the stream and will have only one foot of cover over the top of the pipe for a portion of its length. It will have a flap gate at the discharge end to prevent flood water and debris from entering the pipe. Soil tests have determined that the average dry density of the in-place clay backfill is 123 pounds per cubic foot with specific gravity of 2.66.

Find:

If the pipe will float and if required, the volume of concrete per linear foot of pipe expressed as additional wall thickness necessary to prevent flotation.

Solution:

1. Weight of pipe from **Table 1**:

   W_P = +6126 pounds per linear foot of pipe (downward force)

2. Weight of displaced water from **Table 2**:

   W_W = -9606 pounds per linear foot of pipe (upward force)

3. Algebraic sum of Steps 1 and 2:

   $W_P + W_W$ = +6126 + (-9606) = -3480 pounds per linear foot of pipe (upward force)

   The resultant force is upward, therefore proceed to Step 4.

4. Total weight of backfill:

   Weight of inundated backfill:

   Given the average dry density of the clay backfill is 123 pounds per cubic foot with a specific gravity of 2.66. From equation 4, the unit weight of inundated backfill equals:

   $$w_I = 123\,(1 - \frac{1}{2.66}) = 77 \text{ pounds per cubic foot}$$

   From equation 5, the weight of inundated backfill equals:

   W_I = 77 [0.1073 $(14)^2$ + (1 * 14)] = +2697 pounds per linear foot of pipe (downward force)

   Weight of dry backfill:

   Since the site is a floodplain, the backfill is considered completely inundated, therefore there is no additional downward force.

   Total weight of backfill:

   From equation 7, the total weight of backfill per linear foot of pipe equals:

   W_B = +2697 + 0 = +2697 pounds per linear foot of pipe (downward force)

5. Application of Factor of Safety:

   Since the soil information is based on tests, a Factor of Safety of 1.15 will be used to decrease the downward force of the inundated backfill.

   $$\frac{W_B}{F.S.} = \frac{+2687}{1.15} = +2345 \text{ pounds (downward force)}$$

6. Algebraic sum of Steps 3 and 5:

   From step 3, the resultant upward force is -3480 and from Step 5, the downward force is +2345, which produces a resultant upward force of -1135 pounds per linear foot of pipe. The pipe will float, therefore proceed to Step 7.

7. Analysis of method to prevent flotation:

   As given, the method will be to increase the wall thickness of the pipe. The algebraic sum of the unbalanced upward force of -1135 pounds per linear foot of pipe as determined in Step 6 must equal the weight of the additional wall thickness (t_x) required, and may be expressed in the following quadratic equation:

$$t_x = \frac{-B_C \pm \sqrt{B_C{}^2 - \frac{4 * F_B}{\gamma_C * \pi}}}{2}$$

   where:

   t_x = additional wall thickness in feet

   γ_C = density of submerged concrete, 87.6 pounds per cubic foot

   F_B = upward force in pounds per linear foot of pipe

   Substituting appropriate values in the above equation:

$$t_x = \frac{-14 \pm \sqrt{14^2 - \frac{4\,(-1135)}{87.6\,(3.14)}}}{2}$$

   t_x = +0.29 feet and -14.3 feet

   Since negative values have no significance, use t_x = 0.29 feet or 3.5 inches.

Answer:

Therefore, 3.5 inches of additional wall thickness are required to prevent flotation of the pipe in this installation.

Example 3

Given:

The 144-inch diameter pipe in Example 2 is submerged in a fresh water lake with no backfill placed over it.

Find:

The dimensions per linear foot of a concrete anchor slab required to prevent flotation.

Solution:

1. Steps 1, 2, and 3 are the same as Example 2, leaving -3480 pounds per linear foot of pipe upward force.

   The resultant force is upward, therefore, proceed to Step 4.

2. Total weight of backfill:

   Since the pipe is submerged with no backfill placed over it, there is no additional downward force.

3. Application of Factor of Safety:

   Since the pipe is submerged in water only, a Factor of Safety of 1.0 is used.

4. Algebraic sum of Steps 3 and 5:

   From Step 3, the resultant upward force is -3480 pounds per linear foot of pipe. The pipe will float, therefore, proceed to Step 7.

5. Analysis of method to prevent flotation:

   As stated, determine the required dimensions of a concrete anchor slab per linear foot of pipe.

   To prevent flotation, the algebraic sum of the submerged weight of the anchor slab per linear foot and the resultant upward force per linear foot must equal zero, and may be expressed in the equation form as follows:

$$F_B = \gamma_c\,(b * d * 1)$$

where:

   F_B = total negative buoyant force in pounds

   b = width of concrete slab in feet

   d = depth of concrete slab in feet

   γ_C = submerged weight of concrete per cubic foot

   1 = one linear foot

   Substituting appropriate values in the above equation:

$$87.6\,(b * d * 1) = 3480$$

   Therefore, b * d * 1 = 39.37 cubic feet

   Since the outside diameter of the pipe, B_C, is approximately 14 feet, select this dimension for the width of the concrete slab (b).

   Depth of the slab (d) will then be:

$$d = \frac{39.37}{14} = 2.84 \text{ feet}$$

Answer:

Therefore, a concrete anchor slab 14 feet wide and 2.84 feet deep will prevent flotation of the pipe, assuming proper anchorage of the pipe to the slab.