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.

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 by the following equation:

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

where

W_P = weight of pipe in pounds per linear foot.
B_C = outside pipe diameter, feet.
D = inside pipe diameter, feet

Average weights in pounds per linear foot for ASTM C14 Nonreinforced Concrete Sewer, Storm Drain and Culvert Pipe and ASTM C76 Reinforced Concrete Culvert, Storm Drain and Sewer Pipe are given in Tables I and II. Most pipe manufacturers publish data that tabulates product dimensions and weight. 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 by the following equation:

$$W_w = \frac{}{4} (B_c^2)\, 62.4 \qquad (2)$$

where

W_W = weight of displaced water per linear foot, pounds,
B_C = outside pipe diameter, feet.

The average weights of the volume of fresh water displaced per linear foot of C14 and C76 pipe are presented in Tables 3 and 4.

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 surface dry density and specific gravity of backfill materials are of sufficient accuracy.

The unit weight of inundated backfill is equal to the surface dry density of the backfill minus the weight of water displaced by the solid particles and can be calculated as followed:

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

which reduces to:

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

where;

w_I = average unit weight of inundated backfill, pounds per cubic foot.
w = average unit weight of surface dry backfill, 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 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 $H_I B_C$ cubic feet per linear foot of pipe. Therefore, the weight of inundated backfill per linear foot of pipe acting downward on the pipe can be calculated as follows:

$$W_I = w_I\,(0.1073\,B_c^2 + H_I B_c) \qquad (5)$$

where;

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

H_I = depth of inundated backfill above top of pipe, 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 as follows:

$$W_D = w\,(H - H_I)\,B_c \qquad (6)$$

where;

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

H = depth from top of pipe to surface of backfill, 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:

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

where;

W_B = total weight of backfill directly over the pipe, pounds per cubic ft.

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.

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PREVENTIVE PROCEDURES

If the total weight of the pipe and backfill is not adequate to prevent flotation of the pipe, preventive 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.

DESIGN PROCEDURE

A suggested seven step logical procedure is presented for determining the degree of buoyancy of 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.
2. Determine the buoyant 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.

Figure 1 Backfill Volumes Over Pipe

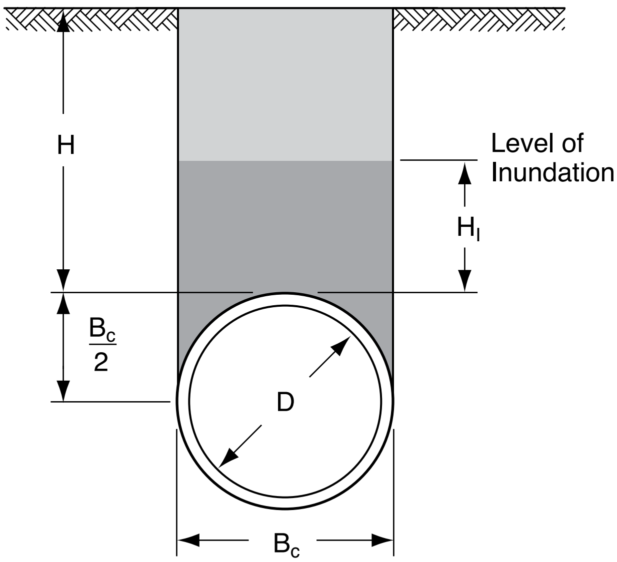

Table 1 Dimensions and Approximate Weights of Nonreinforced Concrete Pipe

ASTM C 14 - Nonreinforced Sewer, and Culvert Pipe, Bell and Spigot Joint

Internal Diameter, Inches	Class 1		Class 2		Class 3	
	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
4	5/8	9.5	3/4	13	3/4	13
6	5/8	17	3/4	20	7/8	21
8	3/4	27	7/8	31	1-1/8	36
10	7/8	37	1	42	1-1/4	50
12	1	50	1-3/8	68	1-3/4	90
15	1-1/4	78	1-5/8	100	1-7/8	120
18	1-1/2	105	2	155	2-1/4	165
21	1-3/4	159	2-1/4	205	2-3/4	260
24	2-1/8	200	3	315	3-3/4	350
27	3-1/4	390	4	450	3-7/8	450
30	3-1/2	450	4-1/4	54	4-1/4	540
33	3-3/4	520	4-1/2	620	4-1/2	620
36	4	580	4-3/4	700	4-3/4	700

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

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

Table 2 Dimensions and Approximate Weights of Circular Concrete Pipe

ASTM C 76 - Reinforced Concrete Culvert, Storm Drain and Sewer Pipe

Internal Diameter, Inches	Wall A		Wall B		Wall C	
	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	1-3/4	79	2	93	-	-
15	1-7/8	103	2-1/4	127	-	-
18	2	131	2-1/2	168	-	-
21	2-1/4	171	2-3/4	214	-	-
24	2-1/2	217	3	264	3-3/4	366
27	2-5/8	255	3-1/4	322	4	420
30	2-3/4	295	3-1/2	384	4-1/4	476
33	2-7/8	336	3-1/4	451	4-1/2	552
36	3	383	4	524	4-3/4	654
42	3-1/2	520	4-1/2	686	5-1/4	811
48	4	683	5	867	5-3/4	1011
54	4-1/2	864	5-1/2	1068	6-1/4	1208
60	5	1064	6	1295	6-3/4	1473
66	5-1/2	1287	6-1/2	1542	7-1/4	1735
72	6	1532	7	1811	7-3/4	2015
78	6-1/2	1797	7-1/2	2100	8-1/4	2410
84	7	2085	8	2409	8-3/4	2660
90	7-1/2	2395	8-1/2	2740	9-1/4	3020
96	8	2710	9	3090	9-3/4	3355
102	8-1/2	3078	9-1/2	3480	10-1/4	3760
108	9	3446	10	3865	10-3/4	4160
114	9-1/2	3840	10-1/2	4278	11-1/4	4611
120	10	4263	11	4716	11-3/4	5066
126	10-1/2	4690	11-1/2	5175	12-1/4	5542
132	11	5148	12	5655	12-3/4	6040
138	11-1/2	5627	12-1/2	6156	13-1/4	6558
144	12	6126	13	6679	13-3/4	7098
150	12-1/2	6647	13-1/2	7223	14-1/4	7659
156	13	7190	14	7789	14-3/4	8242
162	13-1/2	7754	14-1/2	8375	15-1/4	8846
168	14	8339	15	8983	15-3/4	9471
174	14-1/2	8945	15-1/2	9612	16-1/4	10,117
180	15	9572	16	10,263	16-3/4	10,785

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

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

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.

Example 1

Given:

A 72-inch diameter, wall B, 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

Table 3 Approximate Weight of Water Displaced by Circular Nonreinforced Concrete Pipe

ASTM C 14 - Nonreinforced Concrete Pipe, Bell and Spigot Joint			
Internal Diameter, Inches	Weight of Water Displaced, Pounds Per Linear Foot		
	Class 1	Class 2	Class 3
4	9.3	10.7	10.7
6	19.3	20.6	21.0
8	33	35	37
10	49	51	55
12	70	77	86
15	109	118	127
18	154	174	179
21	216	235	258
24	281	327	342
27	422	461	509
30	516	558	558
33	617	664	664
36	729	779	779

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

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 surface 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.

Solution:

1. Weight of pipe
   From Table 2, WP = + 1811 pounds per linear foot (downward force).

2. Weight of displaced water.
   From Table 4, WW = - 2519 pounds per linear foot of pipe (upward force).

3. Algebraic sum of Steps 1 and 2.
   WP + WW = + 1811 + (-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 surface 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, $wI = 110 \left(1- \frac{1}{2.65} \right) = 68$ pounds per cubic foot.

   From Equation 5, the weight of inundated backfill equals, WI = 68 [0.1073 (7.17)2 + (8 x 7.17)] = + 4276 pounds per linear foot of pipe (downward force).

Table 4 Dimensions and Approximate Weight of Reinforced Circular Concrete Pipe

ASTM C 76 - Reinforced Concrete Pipe, Tongue and Groove Joint			
Internal Diameter, Inches	Weight of Water Displaced, Pounds Per Linear Foot		
	Wall A	Wall B	Wall C
12	82	87	-
15	119	130	-
18	164	181	-
21	222	239	-
24	287	306	339
27	355	381	418
30	429	465	505
33	511	560	600
36	600	660	704
42	816	885	940
48	1069	1143	1206
54	1351	1440	1504
60	1666	1764	1842
66	2020	2122	2207
72	2401	2519	2605
78	2786	2944	3043
84	3271	3401	3508
90	3752	3899	4005
96	4266	4423	4545
102	4823	4980	5109
108	5403	5580	5706
114	6017	6203	6341
120	6674	6863	7008
126	7354	7556	7709
132	8067	8282	8443
138	8826	9042	9210
144	9906	9836	10,010
150	10,418	10,662	10,844
156	11,278	11,523	11,711
162	12,157	12,416	12,612
168	13,069	13,343	13,546
174	14,031	14,303	14,513
180	15,009	15,296	15,513

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

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, WB = +4267 + 0 = + 4276 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.

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

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, 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 HI by setting the algebraic sum of WI, 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:

$$\frac{+68\,[0.1073\,(7.17)^2 + (H_I \times 7.17)]}{1.25} + (-708) = 0$$

HI = 1.05 ft. 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 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 surface 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 2, WP = + 6126 pounds per linear foot (downward force).

2. Weight of displaced water.
From Table 4, WW = -9606 pounds per linear foot of pipe (upward force).

3. Algebraic sum of Steps 1 and 2.
WP + WW = +6126 + (-9606) = - 3480 pounds per linear foot of pipe (negative, upward force)

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

4. Total weight of backfill.
Weight of inundated backfill:
Given, the average surface 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, $WI = 123\left(1 - \frac{1}{2.66}\right) + 77$ pounds per cubic foot

From Equation 5, the weight of inundated backfill equals, WI = 77 [0.1073 (14)2 + (1 x 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, WB = +2697 + 0 = +2697 pounds per linear foot of pipe (downward force).

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

$$\frac{W_B}{F.S.} = \frac{+2697}{1.15} = +2345 \text{ pounds (downward force)}$$

6. Algebraic sum of Steps 3 and 5
From Step 3, the resultant upward force is –3480 pounds and from Step 5, the downward force is +2345 pounds, 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 pipe as determined in Step 6 must equal the weight of the additional wall thickness (tx) required, and may be expressed in the following quadratic equation:

$$(B_c + t_x)\, t_x\, \gamma + F_B = 0, \text{ or solving for } t_x$$

$$t_x = \frac{-B_c \sqrt{B_c^2 - \frac{4F_B}{\gamma_c}}}{2}$$

where;
t_x = additional wall thickness in feet.
γc = density of submerged concrete, +87.6 pounds per cubic foot.
F_B = upward force in pounds per linear foot of pipe.

Substitution appropriate values in the above equation:

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

$$t_x = +0.29 \text{ feet}$$

Since negative values have no significance, use tx = 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 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.
Since the resultant force is upward, proceed to Step

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

5. Application of Factor of Safety.
Since this pipe is submerged in water only, a Factor of Safety of 1.0 is used.

6. 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.

7. Analysis of method to prevent flotation.
As stated, determine the required dimensions of a concrete anchor slab 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 equation form as follows:

$$F_B = \gamma_c\, (bd\, x 1)$$

where;
F_B = The total negative (buoyant) force in pounds.
b = Width of concrete slab, feet.
d = Depth of concrete slab, feet.
1 = One linear foot.
γ_C = Submerged weight of concrete per cubic foot.

Substituting appropriate values in the above equation:

87.6 (bd x 1) = 3480
and b x d x 1 ft. = 39.37 ft.3

Since the outside diameter of the pipe, BC, is approximately 14 ft. selecting this dimension for b, d will then be:

$$d = \frac{39.37}{14} = 2.84 \text{ ft.}$$

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.