

## Book 2: Chapter 8 - Groundwater Flotation

A buried pipe or manhole may be subject to flotation from high groundwater levels around the pipe. While lightweight polyethylene is easily handled and installed, its lesser weight compared to that of metal or concrete pipe, compels design evaluation of groundwater flotation effects.

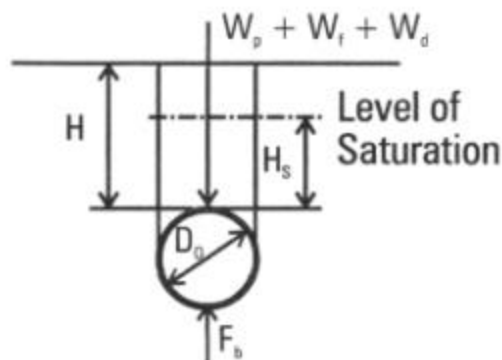
Flotation may occur when the groundwater around the pipe produces a buoyant force greater than the downward force of the soil prism above the pipe plus the weight of the pipe and its contents. When flooded some soils may lose cohesiveness, which may allow the pipe to float out of the ground. Groundwater saturation may also cause significant reduction of soil support around the pipe, and allow the pipe to buckle from the external hydrostatic pressure.

**Table 8-1 Typical soil Densities**

Soil Type	Density, lb/ft <sup>3</sup>	
	Saturated	Dry
Sands and Gravels	118-150	93-114
Silts and Clays	87-131	37-112
Glacial Till	131-150	106-144
Crushed rock	119-137	94-125
Organic Silts and Clays	81-112	31-94

Several design checks are available to see if groundwater flotation may be a concern. Obviously, if the pipeline typically runs full or nearly full of liquid, or if groundwater is always below the pipe, flotation may not be a significant concern. A quick rule of thumb is that when buried in common saturated soil (about 120 lb/ft<sup>3</sup>) with at least one and one half pipe diameters of cover, pipe is generally not subject to groundwater flotation. However, groundwater flotation should be checked if the pipe is buried in lighter soils, or with lesser cover, or the pipe frequently has little liquid flow during high groundwater conditions.

**Figure 8-1 Groundwater Flotation (Empty Pipe)**



## Groundwater Flotation of Pipe

For 1 foot of an empty pipe, flotation will occur if

$$F_b > W_p + W_f + W_d \quad (8-1)$$

Where

$F_b$  = buoyant force, lb/ft

$$F_b = \nu_G \frac{\rho}{4} D_o^2 \quad (8-2)$$

$\nu_G$  = specific weight of groundwater, lb/ft<sup>3</sup>  
(fresh water = 62.4 lb/ft<sup>3</sup>)  
(seawater = 64.0 lb/ft<sup>3</sup>)

$D_o$  = pipe outside diameter, ft

$W_p$  = empty pipe weight, lb/ft

$$W_f = (w_d - w_G) \left( \frac{D_o^2 (4 - p)}{8} + D_o H_s \right) \quad (8-3)$$

$W_f$  = weight of flooded soil, lb/ft

$w_d$  = specific weight of dry soil, lb/ft<sup>3</sup>

$H_s$  = level of groundwater saturation above pipe, ft

$W_d$  = weight of dry soil, lb/ft

$$W_d = w_d (H - H_s) D_o \quad (8-4)$$

$H$  = height of cover above pipe, ft

$H_s$  = level of groundwater saturation above pipe, ft

When an area is flooded, the soil particles are buoyed by their immersion in the liquid. The effective weight of flooded soil is the soil's dry density less the density of the flooding liquid. For example, a soil of 120 lb/ft<sup>3</sup> dry density has an effective density of 57.6 lb/ft<sup>3</sup> when completely immersed in fresh water (120 - 62.4 = 57.6 lb/ft<sup>3</sup>).

If the pipe contains a liquid, then the weight of the liquid will reduce the possibility of groundwater flotation. For 1 foot of pipe containing a liquid

$$F_b > W_p + W_f + W_d + W_L \quad (8-5)$$

Where

$W_L$  = weight of the liquid in the pipe, lb/ft

When a pipe is 100% full of liquid, the liquid weight is

$$W_{L,100\%} = w_L \frac{\rho D_l^2}{4} \quad (8-6)$$

And if 50% full, the liquid weight is

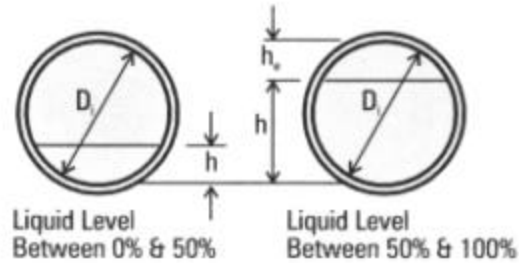
$$W_{L,50\%} = w_L \frac{\rho D_l^2}{8} \quad (8-7)$$

Where

$w_L$  = specific weight of the liquid in the pipe, lb/ft<sup>3</sup>  
 $D_I$  = pipe inside diameter, ft

For pipe liquid levels between empty and half-full (0% to 50%) or between half-full and full (50% to 100%) as illustrated in Figure 8-2, Formulas 8-8 and 8-9 provide an approximate liquid weight with an accuracy of about  $\pm 10\%$ .

**Figure 8-2 Pipe Liquid Level**



For a liquid level between empty and half-full, the weight of the liquid in the pipe is approximately

$$W_L = w_L \frac{4 h^3}{3} \sqrt{\frac{D_I - h}{h} + 0.392} \quad (8-8)$$

Where

$h$  = liquid level in the pipe, ft

For a liquid level between half-full and full, the weight of the liquid in the pipe is approximately

$$W_L = w_L \left( \frac{\pi D_I^2}{4} - 1.573 h_e \right) \quad (8-9)$$

Where

$h_e$  = height above liquid in pipe, ft

$$h_e = D_I - h \quad (8-10)$$

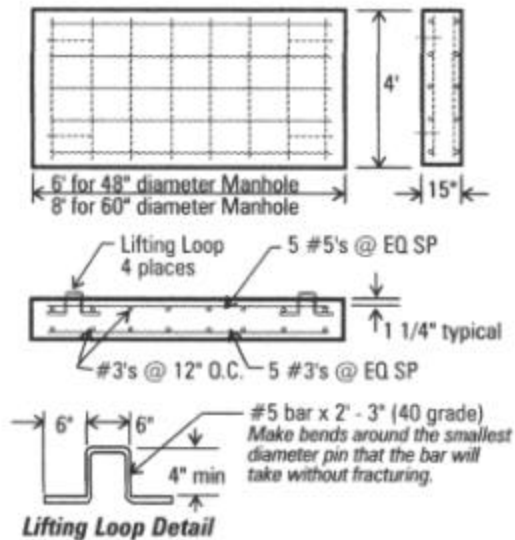
### **Groundwater Flotation of Manholes**

Compared to pipe, manholes are less resistant to groundwater flotation because the manhole riser eliminates the soil prism load that exists above buried pipe. Under some groundwater conditions, the frictional resistance of the soil surrounding the manhole riser, and the soil prism load over the manhole stub-outs may not be adequate to prevent flotation; so anti-flotation anchors may be required.

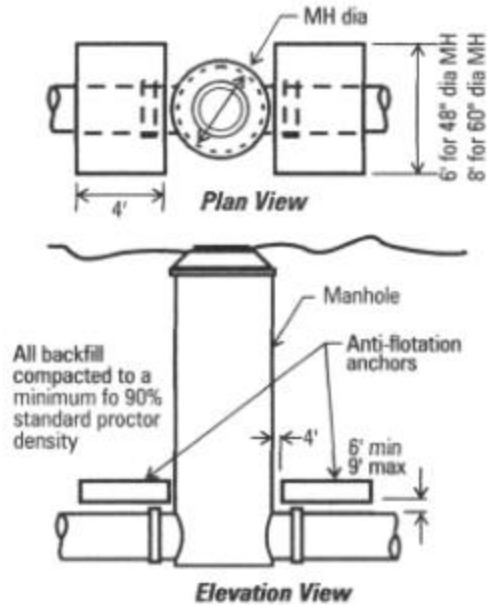
Anti-flotation anchors are reinforced concrete slabs that are placed above the manhole stub-outs. The anchors provide additional weight to counteract buoyant forces against the manhole base.

Anti-flotation anchors are installed beside the manhole shaft above the manhole stub-outs.

**Figure 8-3 Anti-Flotation Anchor**



**Figure 8-4 Anti-Flotation Anchor Installation**



**Table 8-2 Anti-Flotation Anchor Weights**

Effective Weight (based on 140 lb/ft <sup>3</sup> concrete)	Size	
	4' x 6'	4' x 8'
Dry	4200 lb	5600 lb
Submerged in seawater	2280 lb	3040 lb
Submerged in freshwater	2328 lb	3104 lb

To determine if anti-flotation anchors are required, the following condition must be checked:

$$UT_B + UT_R \leq DF_S + FR_R \quad (8-11)$$

Where

- UT<sub>B</sub> = upward thrust of base, lb
- UT<sub>R</sub> = upward thrust of riser, lb
- DF<sub>S</sub> = downward force of soil over stub-outs, lb
- FR<sub>R</sub> = frictional resistance of soil surrounding riser, lb

When the downward force over the stub-outs, and the frictional resistance against the riser are equal to or greater than the upward thrusts, anti-flotation anchors are not required.

Standard Manholes and Manhole Tees are constructed with two stub-outs of the same diameter on opposite sides of the riser as shown in the tables. If the manhole is a custom design with different stub-out sizes, or more than two stub-outs, contact Performance Pipe Technical Services for assistance.

If the check using Formula 8-11 indicates that anti-flotation anchors are needed, the following check completes the manhole flotation evaluation:

$$UT_{BA} + UT_R \leq DF_A \quad (8-12)$$

Where

- $UT_{BA}$  = upward thrust of anchored base, lb  
 $DF_A$  = downward force of anti-flotation anchors, lb

Tables 8-3 through 8-9 have been developed for use with Formulas 8-11 and 8-12. Safety factors are included in table values and the default soil weight is 120 lb/ft<sup>3</sup>. Soil weight multipliers in Table 8-5 may be used to convert table values for lighter or heavier soils.

**Table 8-3 Upward Thrust of Base,  $UT_B$**

<i>Stub-out Nominal Inside Diameter, in</i>	<i>Standard Manhole, 48" Diameter Riser, lb</i>	<i>Manhole Tee, 48" Diameter Riser, lb</i>	<i>Standard Manhole, 60" Diameter Riser, lb</i>	<i>Manhole Tee, 60" Diameter Riser, lb</i>
18	1,475	–	1,793	–
21	1,839	–	2,194	–
24	2,240	–	2,630	–
27	2,678	–	3,099	–
30	3,153	–	3,601	–
33	3,668	–	4,142	–
36	4,279	–	4,777	–
42	5,494	–	6,026	–
48	–	7,303	7,441	–
54	–	8,986	8,997	–
60	–	10,910	–	11,505
66	–	13,053	–	13,539
72	–	15,406	–	15,829
78	–	17,951	–	18,329
84	–	20,739	–	21,082

**Table 8-4 Riser Upward Thrust per Vertical Foot of Cover, UT<sub>B</sub>**

% of Water to Surface	48" Diameter Riser, lb	60" Diameter Riser, lb
10	85	132
20	170	264
30	256	396
40	341	528
50	426	660
60	511	793
70	597	925
80	682	1057
90	767	1189
100	852	1321

**Table 8-5 Soil Weight Multipliers**

Soil Weight, lb/ft <sup>3</sup>	Multiplier
140	1.17
130	1.08
110	0.92
100	0.83
90	0.75

**Table 8-6 Soil Downward Force over Two Anti-Flotation Anchors, DF<sub>A</sub>**

Cover Height Over Stub-out, ft	4' x 6' Anchor		4' x 8' Anchor	
	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb
2	2,304	4,800	3,072	6,400
3	4,608	9,600	6,144	12,800
4	6,912	14,400	9,216	19,200
5	9,216	19,200	12,288	25,600
6	11,520	24,000	15,360	32,000
7	13,824	28,800	18,432	38,400
8	16,128	33,600	21,504	44,800
9	18,432	38,400	24,576	51,200
10	20,736	43,700	27,648	57,600
12	25,344	52,800	33,792	70,400
14	29,952	62,400	39,936	83,200
16	34,560	72,000	46,080	96,000
18	39,168	81,600	52,224	108,800
20	43,776	91,200	58,368	121,600
22	48,384	100,800	64,512	134,400
24	52,992	110,400	70,656	147,200
26	67,600	120,000	76,800	160,000
Safety factor - 1.2; soil weight – 120 lb/ft <sup>3</sup>				

**Table 8-7 Soil Downward Force Per Vertical Foot of Cover over Two stub-outs, DF<sub>S</sub>**

Stub-out ID, in	48" Riser, lb/ft		60" Riser, lb/ft	
	Below Water	Above Water	Below water	Above Water
18	313	652	235	489
21	361	752	271	564
24	409	852	307	639
27	457	952	343	714
30	505	1052	379	798
33	553	1153	415	865
36	607	1264	455	948
42	703	1464	527	1098
48	946	1970	600	1251
54	1142	2379	674	1404
60	1338	2788	977	2036
66	1534	3196	1174	2445
72	1730	3604	1369	2853
78	1925	4010	1564	3258
84	2122	4420	1761	3669
Safety factor – 1.2; soil weight – 120 lb/ft <sup>3</sup>				

**Table 8-8 Upward Thrust of Anchored Base, UT<sub>BA</sub>**

Stub-out Inside Diameter, in	48" Diameter Riser, lb	60" Diameter Riser, lb
18	1,996	2,314
21	2,532	2,887
24	3,130	3,519
27	3,789	4,209
30	4,509	4,957
33	5,296	5,769
36	6,235	6,733
42	8,119	8,651
48	10,712	10,850
54	13,281	13,293
60	16,194	16,788
66	19,428	19,914
72	22,972	23,395
78	26,801	27,180
84	30,993	31,336

**Table 8-9 Frictional Resistance of soil Surrounding Riser for selected Cover Depths, FR<sub>s</sub>**

<b>Manhole with 48" Diameter Riser (for Manhole Tee, FR<sub>s</sub> = 0 lb)</b>										
Stub-out ID, in	5' Cover		10' Cover		15' Cover		20' Cover		25' Cover	
	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb
18	421	878	1,685	3,510	3,791	7,898	6,740	14,042	10,531	21,940
21	397	828	1,590	3,312	3,577	7,452	6,359	13,248	9,936	20,700
24	373	777	1,491	3,107	3,355	6,990	5,965	12,426	9,320	19,416
27	347	723	1,388	2,892	3,124	6,508	5,554	11,570	8,677	18,078
30	320	667	1,280	2,667	2,881	6,001	5,121	10,669	8,002	16,670
33	291	606	1,164	2,456	2,620	5,457	4,657	9,702	7,277	15,159
36	256	534	1,025	2,135	2,306	4,804	4,100	8,541	6,406	13,345
42	180	375	721	1,502	1,622	3,379	2,883	6,007	4,505	9,386
<b>Manhole with 60" Diameter Riser (for Manhole Tee, FR<sub>s</sub> = 0 lb)</b>										
Stub-out ID, in	5' Cover		10' Cover		15' Cover		20' Cover		25' Cover	
	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb	Below Water, lb	Above Water, lb
18	561	1,169	2,245	4,678	5,052	10,525	8,981	18,711	14,034	29,237
21	538	1,122	2,154	4,487	4,845	10,095	8,614	17,946	13,460	28,041
24	515	1,073	2,060	4,291	4,635	9,656	8,239	17,166	12,874	26,821
27	491	1,023	1,964	4,092	4,419	9,206	7,865	16,366	12,275	25,572
30	466	971	1,865	3,886	4,197	8,743	7,461	15,544	11,658	24,287
33	441	918	1,763	3,672	3,966	8,262	7,050	14,688	11,016	22,951
36	411	857	1,645	3,426	3,700	7,709	6,579	13,705	10,279	21,414
42	354	737	1,415	2,948	3,184	6,633	5,660	11,792	8,844	18,424
48	286	596	1,145	2,385	2,576	5,367	4,580	9,541	7,156	14,908
54	201	418	803	1,672	1,806	3,762	3,210	6,688	5,016	10,451
safety factor – 2.0; soil weight – 120 lb/ft <sup>3</sup>										