Introduction

The proper functioning of a sewer system is dependent to a large degree on the performance of its appurtenances, and especially its manholes. As with many buried structures, the proper design of manholes should take into account the effect of the water table and its specific effect on installation and operating conditions.

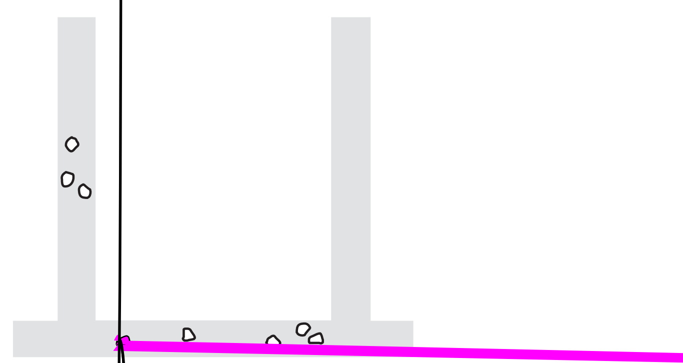
The Buoyancy Concept

From a fluid dynamics standpoint, the buoyant force acting on a submerged object is equal to the weight of fluid which that object displaces. In the case of a buried structure or manhole, this concept is applicable when a high ground water table or other subaqueous condition exists. As with the design of buried pipe, flotation should be checked when conditions such as the use of flooding to consolidate backfill, flood planes or future man-made drainage changes are anticipated.

Manhole Buoyancy Analysis

Vertical manhole structures of two types (Figure 1) are generally constructed, and each type should be considered when analyzing the flotation potential. The first case to be considered is a structure in which the base does not extend past the walls of the manhole. This structure will be called a smooth-wall manhole installation. Smooth-wall manholes utilize the weight of the structure itself and the downward frictional resistance of the soil surrounding the manhole to resist the upward buoyant force. Some manufacturers and designers use an extended base to provide additional resistance to buoyant forces. These structures are constructed with a lip extending beyond the outer edges of the manhole and are termed extended base manhole installations. An extended base manhole uses the additional weight of soil above the lip as well as its self-weight and frictional forces to resist flotation.

Design methods, using basic soil mechanics to determine if a manhole is susceptible to flotation, are presented here to aid the engineer in their design of the structure.



Shear Strength

For an installed and backfilled structure to actually "float", or exhibit upward movement, the buoyant forces must overcome both the weight of the structure and the shear between the walls and the soil. Shear strength is defined in soils engineering to be the resistance to sliding of one mass of soil against another. Shear strengths, as typically provided, are a measure of the resistance to sliding within a single uniform soil mass. The shear strength of a soil has traditionally been related by two strength parameters: internal friction and cohesion.

Shear strength ($_{f}$) as typically expressed by Coulomb's equation is:

$$_f = c + \quad (\tan \quad)$$

where: $\quad _f$ = shear strength, lbs/ft^2 (kPa)

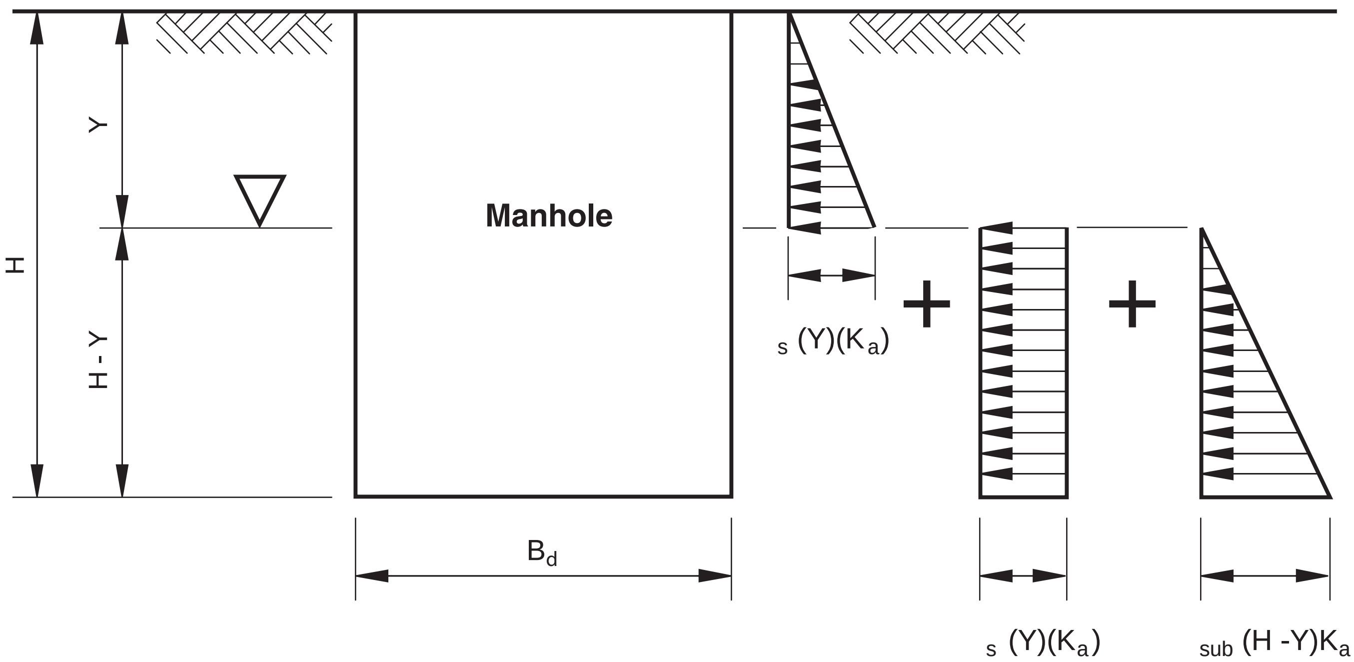
c = cohesion, lbs/ft^2 (kPa)

= angle of internal friction, degrees

= normal stress on the sliding surface or shear plane, lbs/ft^2 (kPa)

Groundwater Level Effect

Figure 4



Cohesive Soils

In clays and silty soils the cohesion coefficient (c) depends on the nature and consistency of the material. The angle of internal friction for clays ( ) can vary from 0° to 30°. Many soils are either dominantly cohesive or noncohesive and, for simplification in engineering computations, are considered to be either one or the other. Applying this assumption, the ( ) value for completely saturated clays is zero, and the sliding resistance equation reduces to:

$r_{sliding} = c$

The value of c can be derived as a fraction of the unconfined compressive strength (q_u) and is generally represented as follows:

$$c = \frac{q_u}{2}$$

Typical values for the unconfined compressive strength of clays are shown in Table 2:

Table 2

Consistency	Field Identification	Unconfined Compressive Strength q_u, psf (kPa)
Very Soft	Easily penetrated several inches by fist	Less than 500 (24)
Soft	Easily penetrated several inches by thumb	500-1,000 (24 - 48)
Medium	Can be penetrated several inches by thumb with moderate effort	1,000-2,000 (48 - 96)
Stiff	Readily indented by thumb but penetrated only with great effort	2,000-4,000 (96 - 192)
Very Stiff	Readily indented by thumbnail	4,000-8,000 (192 - 384)
|Hard	Indented with difficulty by thumbnail	Over 8,000 (384)

The designer is cautioned to use site specific values or, moreover, those determined to be valid by a professional skilled in the determination of geotechnical parameters. The values shown in Table 2 may not apply to individual project conditions.

With the value of (q_u) defined, $R_{sliding}$ is defined as:

$$R_{sliding} = (B_d)\left(\frac{q_u}{2}\right)(H)$$

or

$$R_{sliding} = (B_d)(c)(H)$$

Buoyancy Analysis

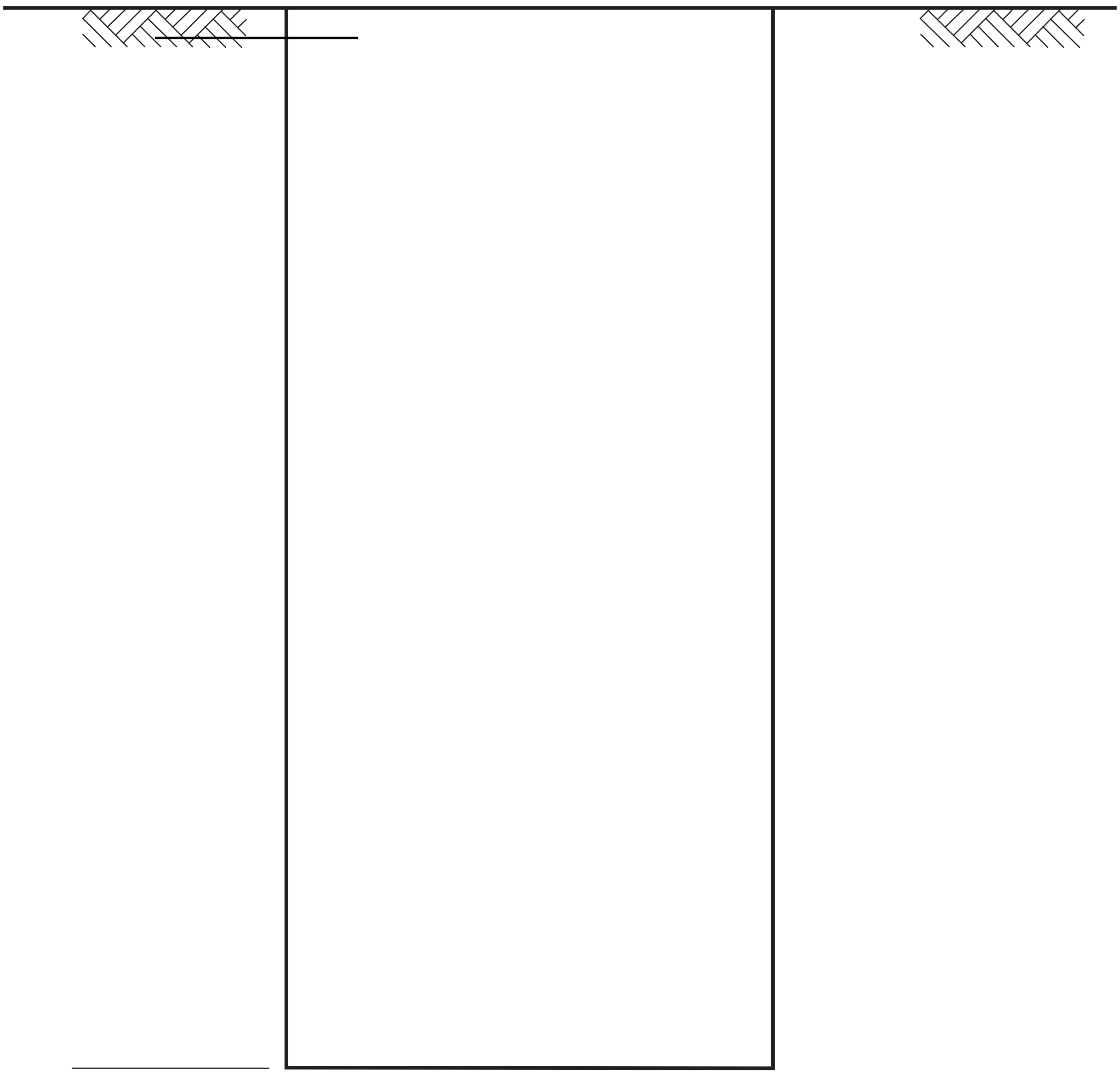
As previously stated, the buoyant force (B) is equal to the weight of water displaced by the manhole structure. This force is defined as the density of water multiplied by the volume of water displaced by the structure, and is expressed as:

$$B = {}_w\left(\frac{B_d{}^2}{4}\right) H$$

where: $_w$ = density of water = 62.4 lbs/ft^3 (9.8 kN/m^3)

Design Safety Factor

This buoyant force (B) is resisted by the weight of the



Solution: (U.S. Units)

1. Weight of the Structure

$$W_{total} = W_{walls} + W_{base} + W_{top} + W_{cover}$$

Assume the unit weight of concrete, $_c$ = 150 lbs/ft^3

$$_{tota} = \left[\left(\left(\frac{B_d}{\ } \right) - \left(\frac{D_i}{\ } \right) \right) (H - t_b - t_s)\ _c \right] + \left[\text{—} (B_d)\ (t_b)\ _c \right] + \left[\left(\left(\frac{B_d}{\ } \right) - \left(\frac{D_c}{\ } \right) \right) (t_s)\ (\ _c) \right] + W_{cover}$$

$$_{total} = \left[\left(\left(\frac{6}{\ } \right) - \left(\frac{5}{\ } \right) \right) (\ 3 - \ - .6\ )(\ 5\ ) \right] + \left[\text{—}\ (6)\ (\ )(\ 5\ ) \right] + \left[\left(\left(\frac{6}{\ } \right) - \left(\frac{3}{\ } \right) \right) (.6\ )\ (\ 5\ ) \right] + 5$$

$$_{total} = \ ,6\ +\ ,\ +5$$

$$_{total} = 3\ ,5\ lbs$$

2. Sliding Resistance

From Table 1 the friction coefficient (f) = .30

Assume K_a = 0.33

$$_{sub}\quad s \left[\ \right] \quad \left[\ \right] \quad lbs/ft^3$$

$$P \left[K_a\ \ _{sub} \right] \ \frac{H}{\ }$$

(=)T j 8 0 0 8 10852c760.78 10852c760859 /- 0 308 02 T j 10 0 0 10 180.8017 397.859 Tm (=)T j 8 0 0 8

The factor of safety is not great enough. Therefore, try an extended base with a 1 ft. extension around the entire diameter.

Diameter of Base = D_b = 8ft.

5. Weight of Extended Base Structure

$$W_{base} = \left[\frac{\ }{4}\,(D_b)^2\,(t_b)\ \ _c\right]$$

$$W_{base} = \left[\frac{\ }{4}\,(8)^2\,(1)\,(150)\right] = 7{,}540\ \ lbs$$

$$W_{soil} = \left[\left(\frac{D_b}{2}\right)^2 - \left(\frac{B_d}{2}\right)^2\right](H\text{-}t_b)\ \ _{sub}$$

$$W_{soil} = \left[\left(\frac{8}{2}\right)^2 - \left(\frac{6}{2}\right)^2\right](23\text{-}1)\ (76.4) = 36{,}963\ lbs$$

From Step 1:

W_{walls} = 27,640 lbs
W_{top} = 2,131 lbs
W_{cover} = 500 lbs

W_{total} = 7,540 + 36,963 + 27,640 + 2,131 + 500
= 74,774 lbs

6. Sliding Resistance

From Step 2: P = 6,665 lbs

From Table 3 for sand: f = .5

$R_{sliding}$ = 6,665 (.5) ( ) (8) = 83,760 lbs (downward)

7. Buoyant Force

$$B = \ _w\left[\left(\frac{(B_d)^2}{4}\right)H_1 + \left(\frac{(D_b)^2}{4}\right)H_2\right]$$

$$B = 62.4\left[\left(\frac{(6)^2}{4}\right)22 + \left(\frac{(8)^2}{4}\right)1\right]$$

B = 41,952 lbs *(upward)*

8. Factor of Safety

$$FS = \frac{74{,}774 + 83{,}760}{41{,}952} = 3.8 > 2.0\ \textit{satisfactory condition}$$

Note: This example was completed to show the differences in design between a smooth-wall and extended base manhole. Most concrete manhole producers only make either a smooth-wall or extended base manhole. Therefore, the specifier may not have the option of adding an extended base.

Solution: (Metric Units)

1. Weight of the Structure

$W_{total} = W_{walls} + W_{base} + W_{top} + W_{cover}$

Assume the unit weight of concrete, $_{c}$ = 23.5 kN/m^3

$$W_{total} - \left[\left(\left(\frac{B_d}{\ } \right) - \left(\frac{D_i}{\ } \right) \right) (H - t_b - t_s) \ _c \right] + \left[\frac{\ }{4} (B_d) \ (t_b) \ _c \right] + \left[\left(\left(\frac{B_d}{\ } \right) - \left(\frac{D_c}{\ } \right) \right) (t_s) \ (\ _c) \right] + W_{cover}$$

$$W_{total} - \quad - \quad (\ -. \ -. \ )(\ . \ ) + \quad (1. \ ) \ (. \ )(\ . \ ) + \quad - \quad (. \ ) \ (\ . \ ) + \ . \ \Big]$$

$$W_{total} - 11 \ . \ + 1 \ . \ + \ .0 + \ .$$

$$W_{total} - 14 \ . \ kN$$

5. Weight of Extended Base Structure

$$W_{base} = \left[\frac{\quad}{4} \; (D_b) \; (t_b) \quad {}_c \right]$$

$$W_{base} = \qquad (2.4) \; (.3) \; (23.5) \; = 31.9 \; kN$$

Example 2:

Given: The 60-inch (1500mm) diameter manhole in Example 1 (without an extended base) is to be installed in a soft clay soil with native material used to backfill the structure. No geotechnical analysis is available for the site.

Find: If the manhole installation is stable with respect to buoyancy and has a minimum factor of safety of 2.0, as required by the project engineer.

Solution: (U.S. Units)

1. **Weight of the Structure**

   From Example 1, W_{total} = 34,510 lbs.

2. **Sliding Resistance**

$$For\ cohesive\ soils,\ R_{siding} = c = \frac{q_u}{2}$$

From Table 2, q_u for soft clay is 500 psf.

$$R_{sliding} = (B_d)(H)\left(\frac{q_u}{2}\right)$$

$$R_{sliding} = (6)(23)\left(\frac{500}{2}\right) = 108{,}385\ lbs$$

3. **Buoyant Force**

   From Example 1, the buoyant force, B = 40,580 lbs

4. **Factor of Safety**

$$FS = \frac{W + R_{sliding}}{B}$$

$$FS = \frac{34{,}510 + 108{,}385}{40{,}580} = 3.5$$

$$FS_{required} = 2.0 < 3.5\ satisfactory\ condition$$

Solution: (Metric Units)

1. Weight of the Structure

   From Example 1, W_{total} = 147.9 kN

References: