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Flotation of Circular Pipe

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Design engineers of buried structures appreciate the need for a comprehensive geotechnical investigation. In addition to determining the soil conditions below the surface, it is vital that the groundwater levels, including fluctuations throughout the year, be verified during the design stage.

While lightweight pipe materials such as corrugated steel or plastic are more prone to flotation, all buried pipe can experience flotation under a variety of installation conditions such as insufficient soil cover, a high groundwater table or in flood plains. Even concrete pipe, with a density of approximately 2.4 times that of water, could experience buoyant forces significant enough to heave the pipe and compromise the grade elevation or alignment.

Culverts under high embankments may also require suitable end treatments to resist buoyant forces if the culvert pipe projects significantly beyond the embankment limits and is subjected to high headwater or backwater elevations.

Flotation Principle

The physical law of buoyancy, also known as Archimedes' principle, states that the upward buoyant force that is exerted on an object completely or partially submerged in a fluid is equal to the weight of the fluid displaced by the object.

In the case of a buried pipe where the groundwater encroaches into the pipe zone, flotation is normally determined by:

- Volume of groundwater displaced by the pipe;
- Weight of the pipe; and
- Weight of the backfill material over the pipe.

High water table and low cover

When the upward buoyant force on the pipe exceeds the downward force of the pipe weight and backfill weight, the pipe will rise or heave. Where flotation is a possibility, proper installation of the pipe is critical, and a preventative measure such as anchoring the pipe may be necessary. Figure 1 illustrates the acting vertical forces when the groundwater level is above a buried pipe.

Upward Buoyant Force

To estimate the upward buoyant force, the volume of displaced groundwater by the outside diameter of the pipe is multiplied by the density of the groundwater – typically 1000 kg/m^3 for fresh water and 1025 kg/m^3 for seawater. It is important to note that the use of a

controlled low strength material (CLSM), commonly referred to as flowable fill, during construction will result in a greater buoyant force due to the higher unit weight of CLSM over water.

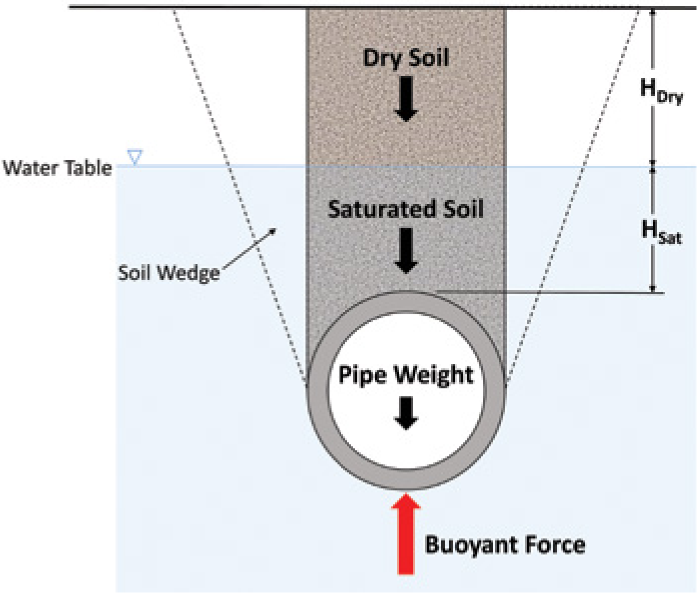

Figure 1 – Vertical forces considered for pipe flotation

$$F_b = \frac{\pi D^2}{4} \times 1000 \text{ kg/m}^3$$

Where:

F_b = weight of displaced water, kg/m of pipe
D = outside pipe diameter, m

Downward Pipe and Soil Weights

The weight of different pipe materials or wall profiles can vary greatly and can usually be found in design manuals or manufacturer's catalogues. The unit weight of compacted backfill material varies with specific gravity, the grain size, and the level of compaction. For the unit weight of dry backfill above the water table, average values for saturated surface dry (SSD) density and specific gravity of backfill materials are commonly used. The unit weight of the saturated backfill soil below the water table is equal to the SSD density of the backfill minus the weight of water displaced by the solid particles.

Factor of Safety

In any design, a factor of safety is required to account for variations in the installed condition such as poor installation practices, unexpected external loads or natural disasters. For pipe buoyancy calculations, designers may use one overall factor of safety for flotation resistance. That is, the downward forces (soil and pipe) should be greater than or equal to a factor of safety times the upward buoyant force. Alternatively, another approach may be to use a reduction factor to decrease the weight of the backfill soil by dividing this downward force by a factor of safety ranging between 1.0 and 1.5. This would avoid being excessively conservative since backfill density is the one parameter that could lack uniformity, or have varying degrees of compaction.

Columbus, Ohio Airport – polypropylene pipe floating out of ground

Other considerations that make the analysis of buoyancy inherently conservative with additional factors of safety are the neglecting of skin friction between the pipe and soil, assuming an empty pipe and ignoring the weight of any effluent inside it, and only considering the weight of the soil column directly over the pipe to hold the pipe down. The reality is that a floating pipe must lift a soil wedge, as depicted in Figure 1.