4. Buoyancy of Pipelines.

a. General.

1) The possibility of pipe flotation exists when the pipeline is constructed in areas which will be inundated, such as stream crossings, flood plains and high ground water areas. When such conditions exist, evaluate the possibility of pipe flotation.

2) The buoyancy of a pipeline 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 analytical practice, consider the pipeline empty for two reasons; so the weight of the liquid will be considered as an additional safety factor and the possibility of the pipeline not being in use during a period of time.

b. Design Procedures.

1) The <u>first step.</u> Determine if the pipeline will float with no backfill material. The sum of the pipe weight and weight of displaced water will determine if the pipeline will float. This can be calculated by:

   a) <u>Pipe weight</u>. Weight of pipe to be determined by selecting the pipe material to be used and finding the weight per linear foot. (Include the weight of the bell joint and appurtenances). Obtain this information from the approved manufacturer's published product data giving the actual dimensions, weights per linear foot, etc. If the manufacturer's data is not available, the information provided in this section can be used.

      W_p =   weight of pipe per linear foot (downward force $\downarrow$, positive)

      (1) <u>ASTM C76, Reinforced Concrete Pipe (RCP)</u>. The Specifications do not give the requirements for wall thickness, but references ASTM C76 standards. ASTM C76 specifies three wall thickness (A, B and C), with the thinnest wall being Wall "A". Unless otherwise specified in the Specifications or on the drawings, calculate the pipe weight using the weight of RCP Wall "A" pipe. To obtain the pipe weight for RCP, contact the approved manufacturers for RCP. The approximate weight of RCP can be calculated, using the following equation. This calculation will provide the average density of concrete without reinforcing steel. If the pipe requires additional weight, specify wall thickness Wall "B" or "C".

      $$W_p = (\pi \div 4)\ (B_c^{\,2} - D^2)\ 150\ \text{lb/ft}^3$$
         Where:
            Unit weight of plain concrete = 150 lb/ft^3.
            W_p = weight of pipe per linear foot, (downward force $\downarrow$, positive)
            B_c = outside pipe diameter (feet)   D = inside pipe diameter (feet)

      (2) <u>Ductile Iron Pipe (DIP)</u>. Determine the thickness of DIP, see Part One, Section 4 (Selection of Pipe Material), and for weight of DIP, see AWWA C151. If the pipe requires additional weight, a higher class of DIP can be specified.

(3) <u>Polyvinyl Chloride Pipe (PVC)</u>. PVC is a light weight pipe material, for the weight of pipe, contact the approved manufacturers of PVC. If pipe flotation occurs using PVC, change the pipe material.

b) <u>Displaced water weight</u>. When water is displaced, a buoyant or upward force exists. If the buoyant force is greater than the weight of the object displacing the water (which is the pipe), flotation will occur. The density of fresh water is 62.4 pounds per cubic foot and the average density of seawater is 64.0 pounds per cubic foot. The density of brackish water will be between that of fresh and seawater depending upon the degree of salinity. Investigate local conditions for the specific project. For computations, using the density of fresh water (62.4 lb/ft^3), will provide sufficient accuracy. The weight of fresh water per linear foot of circular pipe can be calculated by using the following equation:

$$W_w = (\pi \div 4)(B_c^2)\,62.4 \qquad (W_w \text{ is always negative, upward force } \uparrow)$$

Where:
  Unit weight of fresh water =   62.4 lb/ft^3 B_c = outside pipe diameter (feet)
  W_w = weight of displaced water, pounds per linear foot (upward force $\uparrow$, negative)

c) <u>Summation of forces</u>. After determining the pipe weight and weight of displaced water, add the sum of W_p and W_w and the resultant of the forces will determine if the weight of pipe will be adequate to prevent flotation. If the resultant force is positive, the pipe will not float. If the resultant force is negative, the pipe by itself will float. Determine the weight of backfill directly over the pipe necessary to prevent flotation as outlined in Step 2 below. This can be calculated by:

$$W_t = W_p + W_w$$

Where:
  W_w = weight of displaced water, pounds per linear foot (upward force $\uparrow$, negative)
  W_p = weight of pipe, pounds per linear foot, (downward force $\downarrow$, positive)
  W_t = resultant buoyant force of the submerged pipe, pounds per linear foot

2) The <u>second step</u>. The weight of the backfill directly over the pipe assists in resisting buoyant forces. The unit weight of compacted backfill material varies with the material, grain size, degree of compaction, etc. For computations, the average values for specific gravity and unit weight of backfill material provide sufficient accuracy.

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

$$w_I = w - [(w \div (SG \times 62.4)) \times 62.4]$$

Where:
  w_I = average unit weight of inundated backfill, pounds per cubic foot
  w = average unit weight of dry backfill, pounds per cubic foot
 SG = specific gravity of backfill material

For computations, assume sandy soil, $w = 110$ and $SG = 2.65$, this will provide sufficient accuracy. Certain conditions may require soil investigations to determine the actual soil conditions. Assuming sandy soil, the computations for the average unit weight of inundated backfill, computed as follows:

$$w_I \quad = \quad w - [(w \div (SG \times 62.4)) \times 62.4]$$
$$= \quad 110 - \quad [(110 \div (2.65 \times 62.4)) \times 62.4]$$
$$= \quad 110 - \quad [0.67 \times 62.4]$$
$$w_I \quad = \quad 68 \text{ pounds per cubic foot}$$

b) The different volumes of backfill over the pipe to be considered are illustrated in Figure "B".
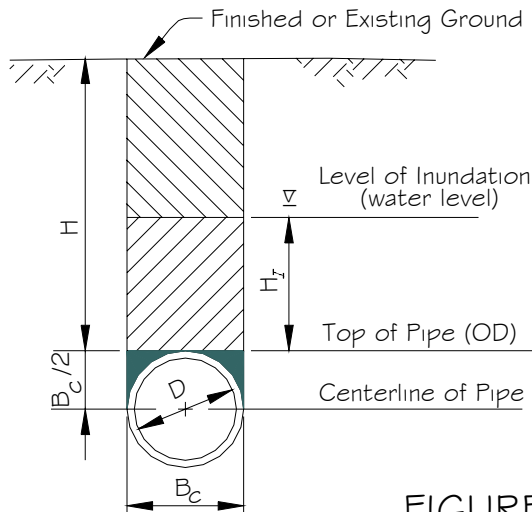
Where:

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

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

B_c = outside pipe diameter, feet

D = nominal pipe diameter, feet

$B_c/2$ = the radius of the outside diameter of the pipe, feet

FIGURE "B"

Backfill Volumes Over Pipe

c) Weight of inundated backfill, acting downward per linear foot of pipe can be calculated by:

$$W_I \quad = \quad w_I\,(0.1073\,B_c{}^2 + H_I B_c)$$
Where:
    W_I = weight of inundated backfill directly over the pipe, pounds per linear foot
    w_I = average unit weight of inundated backfill, pounds per cubic foot
    B_c = outside pipe diameter, feet
    H_I = depth of inundated backfill above top of pipe, feet

d) Weight of backfill above the water level, if any, acting downward per linear foot of pipe can be calculated by the equation:

$$W_D \quad = \quad w\,(H - H_I)\,B_c$$
Where:
    W_D = weight of the backfill above the water level, pounds per linear foot
    w = average unit weight of dry backfill, pounds per cubic foot
    H = depth from top of pipe to surface of backfill, feet
    H_I = depth of inundated backfill above top of pipe, feet
    B_c = outside pipe diameter, feet

(1) For pipelines crossing streams, assume $H = H_I$. This means that the ground water is at the bottom of the stream invert.

$$W_D = w (H - H_I) B_c$$
$$= w (0) B_c$$
$$W_D = 0$$

    (2) In all other cases, determine the ground water conditions.

e) Therefore, the total weight of backfill acting downward on the pipe is determined from the sums of W_D and W_I.

$$W_B = W_D + W_I$$

  Where:
       W_B = total weight of backfill directly over the pipe, pounds per linear foot
       W_D = weight of the backfill above the water level, pounds per linear foot
       W_I = weight of inundated backfill directly over the pipe, pounds per linear foot

    (1) For pipelines crossing streams, $W_B = W_I$. The weight of the material directly over the pipe is to be considered as inundated backfill.

    (2) In all other cases, determine the ground water conditions.

f) Apply the factor of safety based on the extent of knowledge of the backfill material and site conditions. This factor of safety is applied to decrease the calculated downward force of the backfill acting on the pipe. Factor of safety can be calculated by:

$$W_f = W_B \div FS$$

  Where:
       W_B = total weight of backfill directly over the pipe, pounds per linear foot of pipe. (downward force $\downarrow$, positive)
       W_f = total weight of backfill directly over the pipe with the factor of safety, pounds per linear foot of pipe. (downward force $\downarrow$, positive)
       FS = factor of safety, use 1.5

3) After determining both the upward force due to the displacement of water and the downward force from the backfill material directly over the pipe, determine the resultant upward force W_t (from $W_p + W_w$) and the downward force W_f (from $W_B \div FS$).

  a) If the resultant is positive (downward $\downarrow$), the pipe will not float.

  b) If the resultant force is negative (upward $\uparrow$), select and analyze the procedures required to prevent flotation.

4) To determine the minimum height of inundated backfill necessary to prevent flotation during construction, the force exerted by the inundated backfill must equal the buoyant force of the pipe and can be calculated by:

$$W_t = [w_I (0.1073 B_c^2 + H_I B_c)] \div FS$$

$$H_{Im} = (FS W_t \div w_I B_c) - 0.1073 B_c$$

Where:

W_t	=	resultant buoyant force of the submerged pipe, pounds per linear foot
w_I	=	average unit weight of inundated backfill, pounds per cubic foot
B_c	=	outside pipe diameter, feet
H_I	=	depth of inundated backfill above top of pipe, feet
H_{Im}	=	minimum depth of inundated backfill required above top of pipe, feet
FS	=	factor of safety

c. Preventive Procedures.

1) Procedures to prevent flotation when the weight of the pipe and backfill is not adequate include the following:

    a) Increase wall thickness of pipe or change the pipe to a heavier pipe material.

    b) Design concrete collars on the pipe. When computing the volume of concrete per linear foot pipe anchorage, use the submerged weight of concrete. Concrete weighs 150 pounds per cubic foot in the air and 87.6 pounds per cubic foot submerged.

d. Example.

48" diameter sewer crosses a stream with only two (2) feet of cover.

Determine: Will the empty pipe float in the fully backfilled condition ?

1) Select pipe material and determine W_p, weight of pipe.

    48" RCP, Wall B weight per linear foot $= +963 \downarrow$

2) Determine W_w, displaced water weight.

$$\begin{aligned} W_w &= (\pi \div 4)\,(B_c^2)\ 62.4 \qquad\quad B_c = 58" \text{ or } 4.833' \\ &= 0.7844\ (4.833^2)\ 62.4 \\ W_w &= -1144.93 \text{ pounds per linear foot of pipe, say } -1145 \uparrow \end{aligned}$$

3) Summation of forces.

$$\begin{aligned} W_t &= W_p + W_w \\ &= +963 \downarrow\ +\ (-1145)\ \uparrow \\ W_t &= -182 \text{ lb/lf, upward force, pipe will float with no backfill directly over the pipe} \end{aligned}$$

4) Determine weight of inundated backfill.

$$\begin{aligned} W_I &= w_I\,(0.1073\ B_c^2\ +\ H_I B_c) \qquad\quad w_I = 68,\ B_c = 4.833,\ H_I = 2 \\ &= 68\,(0.1073 \times 4.833^2\ +\ 2 \times 4.833) \\ &= 68\,(2.506 + 9.666) \\ &= 68 \times 12.172 \\ W_I &= 827.70 \text{ pounds per linear foot of pipe } \downarrow, \text{ say } 828 \downarrow \end{aligned}$$

5) Determine weight of backfill above water level. In this case we assume the water level equals the total depth of cover, for a stream crossing.

$$W_D = w\,(H - H_I)\,B_c \qquad\qquad w = 110,\ H = 2,\ B_c = 4.833$$
$$= 110\,(2 - 2)\,4.833$$
$$= 110\,(0)\,4.833$$
$$W_D = 0$$

6) Determine the total weight of the backfill.

$$W_B = W_D + W_I \qquad\qquad W_D = 0,\ W_I = 828$$
$$= 0 + 828$$
$$W_B = +828 \text{ pounds per linear foot of pipe } \downarrow$$

7) Factor of safety.

$$W_f = W_B \div FS$$
$$= 828 \div 1.5$$
$$W_f = +552 \text{ pounds per linear foot of pipe } \downarrow$$

8) Summation of forces.

$$W_t\,(\text{from } W_p + W_w) \quad = \quad -182$$
$$W_f\,(\text{from } W_B \div FS) \quad = \quad +552$$

W_f is greater, therefore the pipe will not float.

9) Determine the minimum height of inundated backfill necessary to prevent flotation during construction.

$$H_{im} = [(FS \times Wt) \div (w_I \times B_c)] - 0.1073 B_c$$

$FS = 1.5$, $W_t = 182$ (change W_t to positive in this equation), $B_c = 4.833$, $w_I = 68$

$$= (1.5 \times 182) \div (68 \times 4.833) - (0.1073 \times 4.833)$$
$$= (273 \div 328.644) - 0.1967$$
$$H_{Im} = 0.63 \text{ feet}$$

Therefore a minimum depth of slightly more than 8-inches of inundated backfill above the pipe is required to prevent flotation.

e. Reference.

1) Concrete Pipe Handbook, 1988, by the American Concrete Pipe Association.