3-61E

Solution The height of a water reservoir is controlled by a cylindrical gate hinged to the reservoir. The hydrostatic force on the cylinder and the weight of the cylinder per ft length are to be determined.

Assumptions **1** The hinge is frictionless. **2** Atmospheric pressure acts on both sides of the gate, and thus it can be ignored in calculations for convenience.

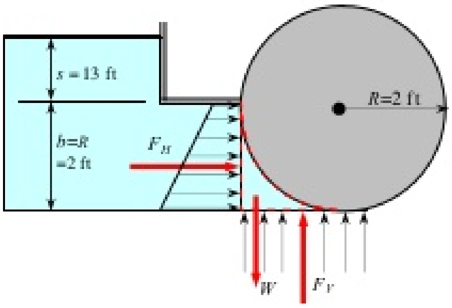
Properties We take the density of water to be 62.4 lbm/ft^3 throughout.

Analysis (*a*) We consider the free body diagram of the liquid block enclosed by the circular surface of the cylinder and its vertical and horizontal projections. The hydrostatic forces acting on the vertical and horizontal plane surfaces as well as the weight of the liquid block per ft length of the cylinder are:

Horizontal force on vertical surface:

$$F_H = F_x = P_{ave}A = \rho g h_C A = \rho g(s + R/2)A$$
$$= (62.4\ \text{lbm/ft}^3)(32.2\ \text{ft/s}^2)(13 + 2/2\ \text{ft})(2\ \text{ft} \times 1\ \text{ft})\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right)$$
$$= 1747\ \text{lbf}$$

Vertical force on horizontal surface (*upward*):



$$F_y = P_{avg}A = \rho g h_C A = \rho g h_{bottom} A$$
$$= \left(62.4\ \text{lbm/ft}^3\right)\left(32.2\ \text{ft/s}^2\right)\left(15\ \text{ft}\right)\left(2\ \text{ft} \times 1\ \text{ft}\right)\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right)$$
$$= 1872\ \text{lbf}$$

Weight of fluid block per ft length *(downward):*

$$W = mg = \rho g V = \rho g(R^2 - \pi R^2/4)(1\ \text{ft}) = \rho g R^2(1 - \pi/4)(1\ \text{ft})$$
$$= (62.4\ \text{lbm/ft}^3)(32.2\ \text{ft/s}^2)(2\ \text{ft})^2(1 - \pi/4)(1\ \text{ft})\left(\frac{1\ \text{lbf}}{32.2\ \text{lbm}\cdot\text{ft/s}^2}\right)$$
$$= 54\ \text{lbf}$$

Therefore, the net upward vertical force is

$$F_V = F_y - W = 1872 - 54 = 1818\ \text{lbf}$$

Then the magnitude and direction of the hydrostatic force acting on the cylindrical surface become

$$F_R = \sqrt{F_H^2 + F_V^2} = \sqrt{1747^2 + 1818^2} = 2521\ \text{lbf} \cong \mathbf{2520\ lbf}$$

$$\tan\theta = \frac{F_V}{F_H} = \frac{1818\ \text{lbf}}{1747\ \text{lbf}} = 1.041 \quad \rightarrow \quad \theta = 46.1°$$

Therefore, the magnitude of the hydrostatic force acting on the cylinder is 2521 lbf per ft length of the cylinder, and its line of action passes through the center of the cylinder making an angle 46.1° upwards from the horizontal.

(*b*) When the water level is 15-ft high, the gate opens and the reaction force at the bottom of the cylinder becomes zero. Then the forces other than those at the hinge acting on the cylinder are its weight, acting through the center, and the hydrostatic force exerted by water. Taking a moment about the point *A* where the hinge is and equating it to zero gives

$$F_R R\sin\theta - W_{cyl}R = 0 \quad \rightarrow \quad W_{cyl} = F_R \sin\theta = (2521\ \text{lbf})\sin 46.1° = 1817\ \text{lbf} \cong \mathbf{1820\ lbf} \quad \text{(per ft)}$$

Discussion The weight of the cylinder per ft length is determined to be 1820 lbf, which corresponds to a mass of 1820 lbm, and to a density of 145 lbm/ft^3 for the material of the cylinder.

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