Fort Hood Review Sessions for Professional Engineering Exam

March 15&16 - Fluid Mechanics
March 22&23 - Hydraulic Engineering
March 29&30 - Hydrologic Design

Ralph A. Wurbs
Civil Engineering Department
Texas A&M University
(409)845-3079

Fluid Mechanics (March 15, 16)

- fluid properties
- fluid statics
- fluid dynamics

Hydraulic Engineering (March 22, 23)

- pressure conduit hydraulics
- open channel hydraulics
- hydraulic structures

Hydrologic Design (March 29, 30)

- ground water hydrology
- flood hydrology
- water supply hydrology

Fluid Properties

- density, specific weight, and related properties
- viscosity

Mass and Force Units

dimension: mass force

Systeme International (SI) units:

kilogram (kg) newton (N)

British Gravitational System units:

slug pound

English Engineering System units:

pound mass (lbm) pound force (lbf)

Newton's Second Law:

force = mass · acceleration

$$F = m \cdot a$$

weight = mass · acceleration of gravity

$$W = m \cdot g$$

standard acceleration of gravity

$$g = 9.807\ m/s^2 = 32.174\ ft/s^2$$

SI System

$$w = m\,g$$

$$1\text{N} = 1\text{Kg}\cdot\text{m/s}^2$$

British Gravitational System

$$m = w / g$$

$$1\ \text{slug} = \text{lb} / (\text{ft/s}^2) = \text{lb}\cdot\text{s}^2/\text{ft}$$

English Engineering System

$$F = m\,a / g_c$$

where: $g_c = 32.174\ \text{ft}\cdot\text{lbm/lbf}\cdot\text{s}^2$

$$1\ lbf = \frac{1\ lbm \times 32.174\ ft/s^2}{32.174\ ft \times lbm\ /\ lbf \times s^2}$$

Density (ρ) and Specific Weight (γ)

ρ = mass / unit volume

(kg/m^3, $slugs/ft^3$, lbm/ft^3)

γ = weight / unit volume

(N/m^3, lb/ft^3, lbf/ft^3)

SI and British Gravitational System:

$$\gamma = \rho g$$

English Engineering System:

$$\gamma = \rho \, (g / g_c)$$

For water at temperature

of 10°C or 50°F:

$$\rho = 1{,}000 \text{ kg/m}^3$$

$$= 1.94 \text{ slugs/ft}^3$$

$$= 62.4 \text{ lbm/ft}^3$$

$$\gamma = 9.80 \text{ kN/m}^3$$

$$= 62.4 \text{ lb/ft}^3$$

$$= 62.4 \text{ lbf/ft}^3$$

Specific Gravity (S.G.)

The specific gravity of a fluid is the ratio of the density of the fluid to the density of water at a specified temperature and pressure.

$$S.G. = \rho_{fluid} / \rho_{water}$$

Viscosity

The viscosity of a fluid is a measure of its resistance to flow.

Newton's law of viscosity: $\tau = \mu\ (dv/dy)$

absolute or dynamic viscosity (μ)

in $N \cdot s/m^2$ or $lb \cdot s/ft^2$

kinematic viscosity (ν) in m^2/s or ft^2/s

$$\nu = \mu / \rho$$

For water at temperature of

of 10°C or 50°F:

$\mu = 1.307 \times 10^{-3}\ \mathrm{N \cdot s/m^2}$

$= 2.735 \times 10^{-5}\ \mathrm{lb \cdot s/ft^2}$

$\nu = 1.306 \times 10^{-6}\ \mathrm{m^2/s}$

$= 1.410 \times 10^{-5}\ \mathrm{ft^2/s}$

Fluid Statics

$$P_1 - P_2 = \gamma (z_2 - z_1)$$

$$P = \gamma h$$

$$F = pA$$

where:

P_1 = pressure at elevation z_1

P_2 = pressure at elevation z_2

$h = z_2 - z_1$ = head

p = pressure for head h

γ = specific weight

F = force

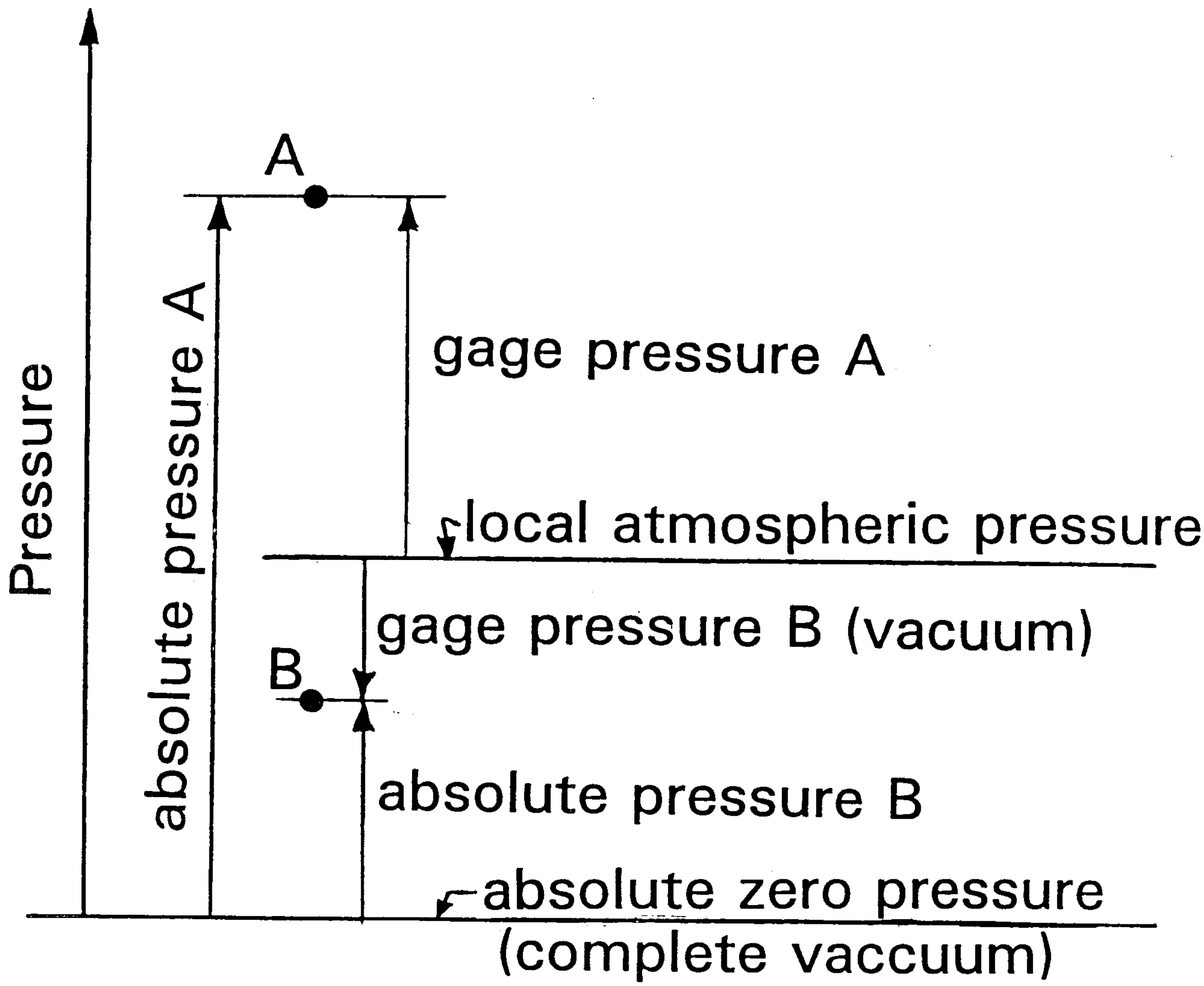
A = area

Absolute and Gage Pressure

absolute pressure =

gage pressure + atmospheric pressure

$$P_{abs} = P_{gage} + P_{atm}$$

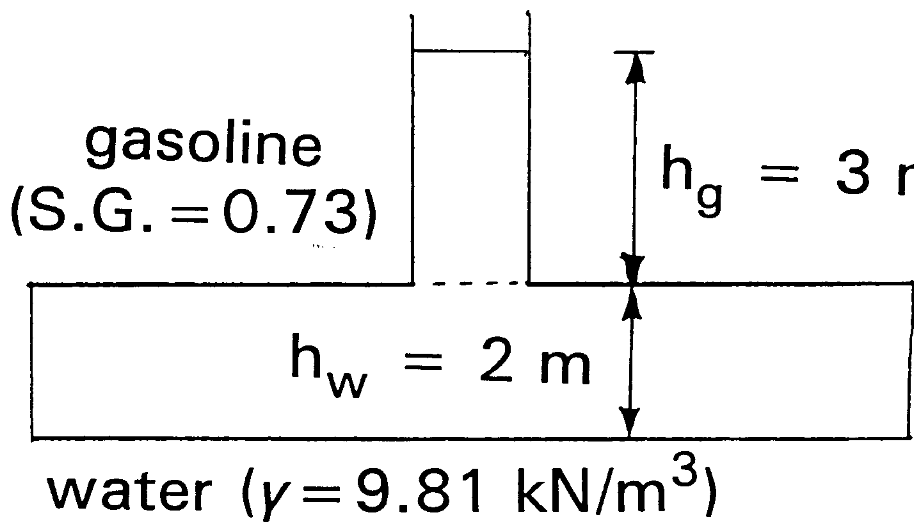

Pressure
A
absolute pressure A
gage pressure A
local atmospheric pressure
gage pressure B (vacuum)
B
absolute pressure B
absolute zero pressure
(complete vaccuum)

Example: What is the pressure 10 feet below the surface of a swimming pool?

$$p = \gamma h = (62.4\ \text{lb/ft}^3)\ (10\text{ft})$$

$$= 624\ \text{lb/ft}^2$$

Example: The tank of water has a 3-m column of gasoline (S.G. = 0.73) above it. Atmospheric pressure is 101 kPa. Compute the pressure on the bottom of the tank.



pressure at bottom of tank

$$P_{gage} = \gamma_w h_w + \gamma_g h_g$$

$$= (9.81\ kN/m^3)\ (2m)$$

$$+ (0.73)\ (9.81\ kN/m^3)\ (3m)$$

$$= 41.1\ kN/m^2$$

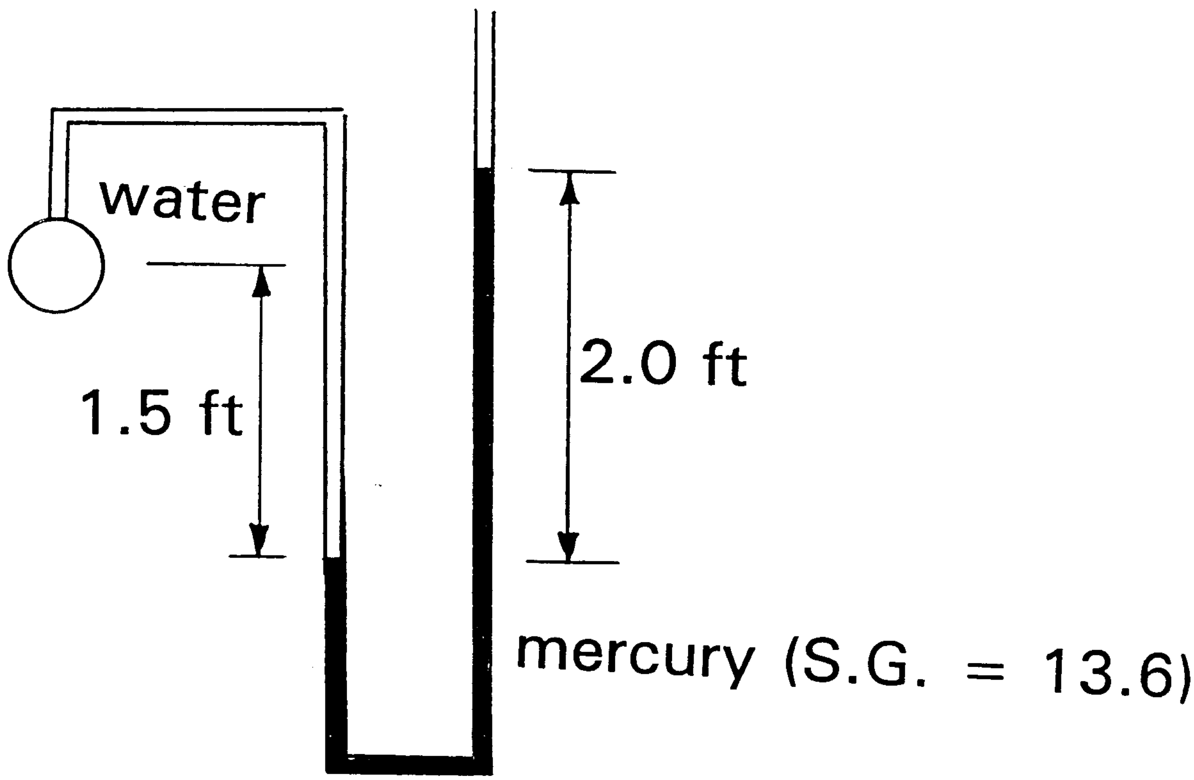
$$P_{abs} = P_{gage} + P_{atm}$$

$$= 41\ kN/m^2 + 101\ kN/m^2$$

$$= 142\ kN/m^2$$

$$= 142\ kPa$$

Example: Use the manometer measurements to compute the pressure in the pipe.



$$P_{pipe} + \gamma_w h_w - \gamma_m h_m = 0$$

$$P_{pipe} + (62.4\ \text{lb/ft}^3)\ (1.5\text{ft})$$

$$-\ (13.6)\ (62.4\ \text{lb/ft}^3)\ (2.0\ \text{ft}) = 0$$

$$P_{pipe} = 1{,}604\ \text{lb/ft}^2$$

Forces on Submerged Surfaces

Plane Surface

$F = \gamma h_c A$ magnitude

$l_p - l_c = I_c / (l_c A)$ location

Curved or Plane Surface

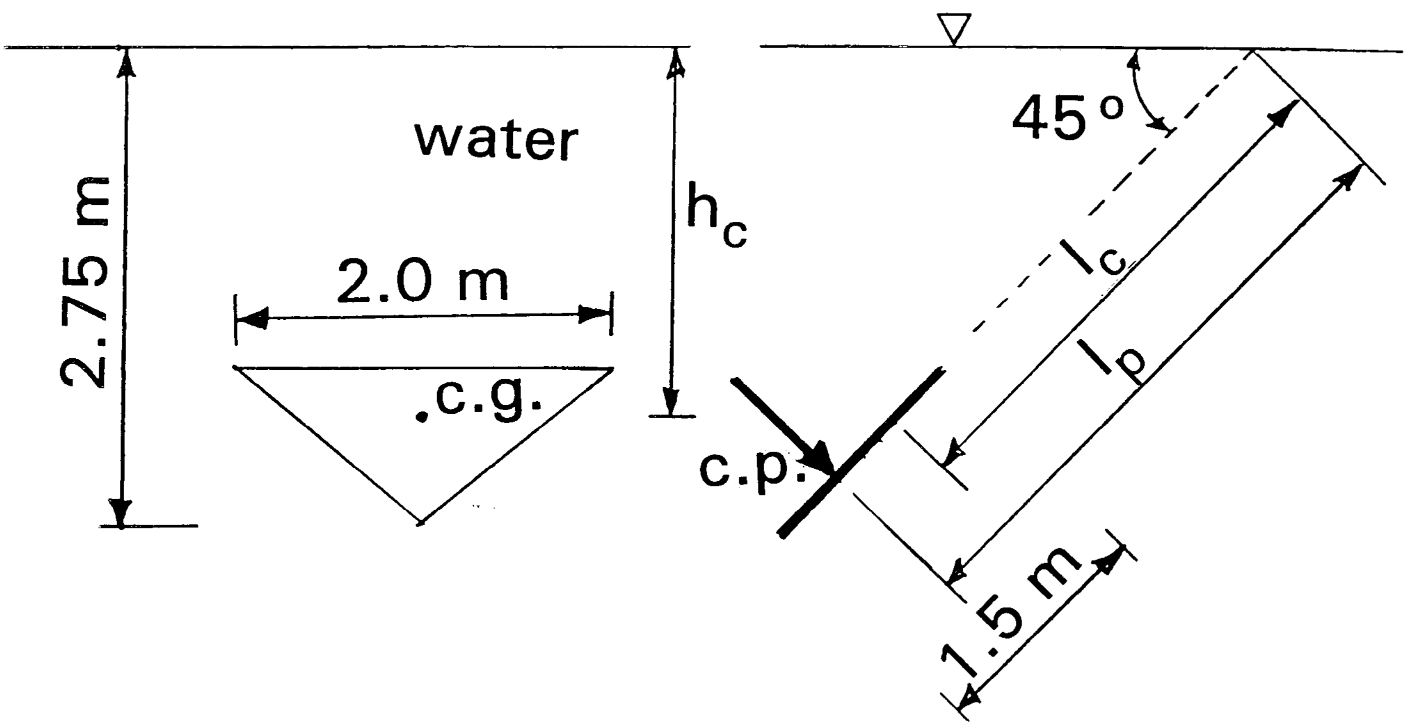
$F_h = \gamma h_c A$ (vertical projection)

$F_v = \gamma V$ (weight of fluid)

Buoyant Force

$F = \gamma$ (volume displaced)

Example: Compute the magnitude and location of the resultant force.



moment of inertia $I_c = bh^3/36$

$$F = \gamma h_c A$$

$$l_p - l_c = I_c / (l_c A)$$

$$A = 0.5\ (2m)(1.5m) = 1.5\ m^2$$

$$h_c = 2.75\ m - [\ (2/3)\ (1.5m)\ ]\ \sin 45^\circ$$

$$= 2.043\ m$$

$$l_c = h_c / \sin 45^\circ = 2.043\ m / 0.7071$$

$$= 2.889\ m$$

moment of inertia $I_c = bh^3/36$

$I_c = (2m)(1.5m)^3/36 = 0.1875\ m^4$

$F = \gamma h_c A$

$= (9.80\ kN/m^3)(2.043\ m)(1.5\ m^2)$

$= 30.0\ kN/m^3$

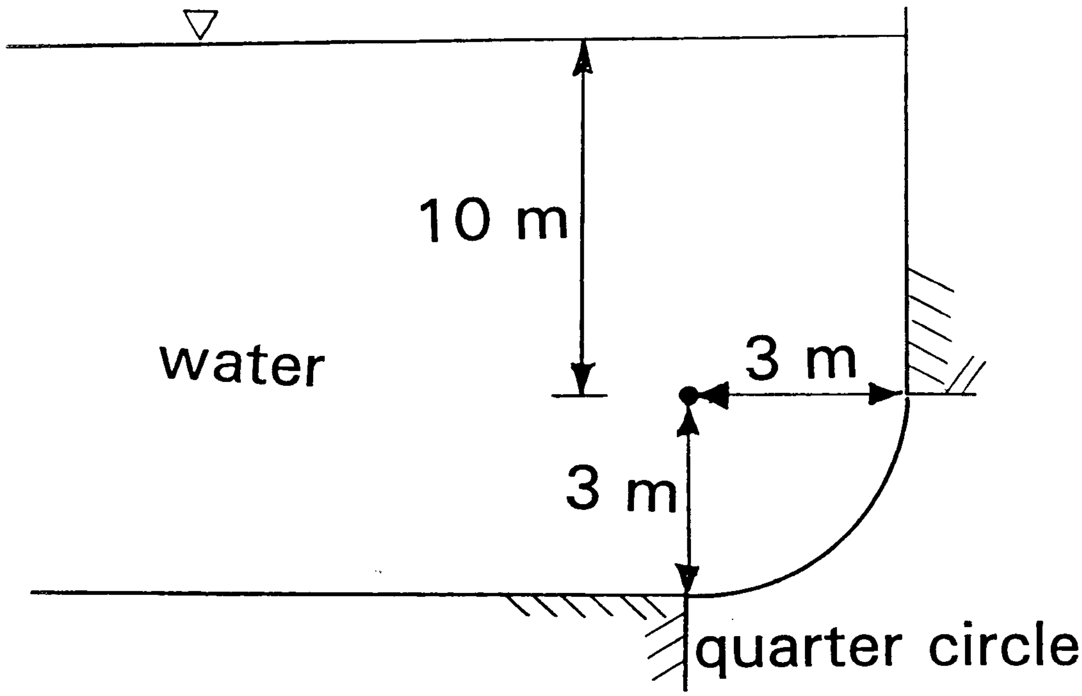
$l_p - l_c = I_c / (l_c A)$

$= 0.1875\ m^4/(2.889m)\ (1.5m^2)$

$= 0.0433\ m$

$l_p = 0.0433\ m + 2.889\ m = 2.932\ m$

<u>Example</u>: Compute the force on the curved corner for a unit width.



$$F_H = \gamma h_c A$$

$$= (9.80\ \text{kN/m}^3)\ (11.5\text{m})\ (3\text{m}^2)$$

$$= 338\ \text{kN}$$

$$F_v = \gamma V$$

volume (V) =

$$(10\text{m})\ (3\text{m})\ (1\text{m}) + (1/4)\pi\ (3\text{m})^2\ (1\text{m})$$

$$= 37.07\ \text{m}^3$$

$$F_v = (9.80\ \text{kN/m}^3)(37.07\ \text{m}^3) = 363\ \text{kN}$$

$$F = \sqrt{F_H + F_V} = \sqrt{338^2 + 363^2}$$

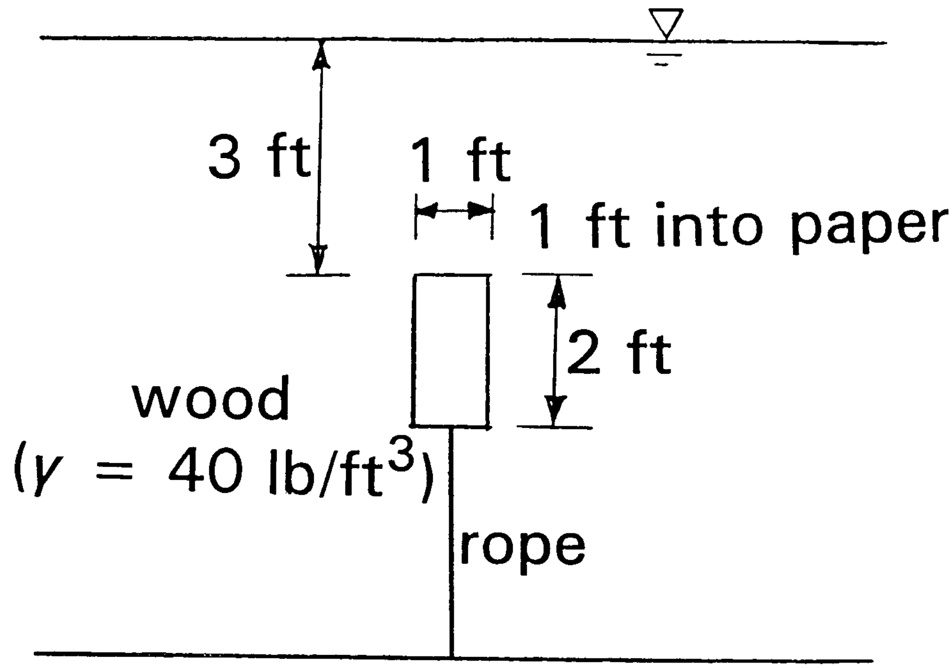
$$= 496\ \text{kN}$$

Laws of Buoyancy and Flotation

I. A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

2. A floating body displaces its own weight of the liquid in which it floats.

Example: Compute the force in the rope.



buoyant force (F_B) =

γ (volume displaced)

F_B = (62.4 lbs/ft^3) (2 ft^3)

= 124.8 lbs

weight of wood (W)

W = (40 lbs/ft^3) (2 ft^3) = 80 lbs

F_B - W - F_{rope} = 0

124.8 lbs - 80lbs - F_{rope} = 0

F_{rope} = 44.8 lbs

Alternative Solution

The buoyant force (F_B) on a submerged body is the difference between the vertical component of pressure force on its underside and upper side.

$$F = \gamma h_c A \qquad \text{or} \qquad F = \gamma V$$

$$F_B = (62.4\ \text{lb/ft}^3)(5\ \text{ft})(1\,\text{ft}^2)$$

$$- (62.4\ \text{lb/ft}^3)(3\ \text{ft})(1\ \text{ft}^2)$$

$$= 44.8\ \text{lb}$$

Conservation of Mass

(Continuity Equation)

$$\dot{m}_1 = \dot{m}_2$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

For incompressible fluids ($\rho_1 = \rho_2$)

$$A_1 V_1 = A_2 V_2$$

$$Q_1 = Q_2$$

Conservation of Energy

(Bernoulli and Energy Equations)

$$total\ head = z + \frac{P}{\gamma} + \frac{V^2}{2g}$$

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + h_p = Z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_L$$

Conservation of Momentum

(Impulse-Momentum Equation)

$$\sum F = \rho\ Q\ (\vec{V}_{out} - \vec{V}_{in})$$