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:

\[ \text{force} = \text{mass} \cdot \text{acceleration} \]

\[ F = m \cdot a \]

weight = mass \cdot \text{acceleration of gravity}

\[ W = m \cdot g \]

standard acceleration of gravity

\[ g = 9.807 \text{ m/s}^2 = 32.174 \text{ ft/s}^2 \]
SI System

\[ w = m \cdot g \]

1 N = 1 Kg\cdot m/s^2

British Gravitational System

\[ m = \frac{w}{g} \]

1 slug = lb / (ft/s^2) = lb\cdot s^2/ft

English Engineering System

\[ F = \frac{m \cdot a}{g_c} \]

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

\[ 1 \text{ lbf} = \frac{1 \text{ lbm} \times 32.174 \text{ ft/s}^2}{32.174 \text{ ft} \times \text{lbm} / \text{ lbf} \times s^2} \]
Density ($\rho$) and Specific Weight ($\gamma$)

$\rho = \text{mass} / \text{unit volume}$

($\text{kg/m}^3$, slugs/ft$^3$, lbm/ft$^3$)

$\gamma = \text{weight} / \text{unit volume}$

($\text{N/m}^3$, lb/ft$^3$, lbf/ft$^3$)

SI and British Gravitational System:

$\gamma = \rho g$

English Engineering System:

$\gamma = \rho \left(\frac{g}{g_c}\right)$
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.

$$\text{S.G.} = \frac{\rho_{\text{fluid}}}{\rho_{\text{water}}}$$
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 ($\mu$)

in N.s/m² or lb.s/ft²

kinematic viscosity ($\nu$) in m²/s or ft²/s

$\nu = \mu / \rho$
For water at temperature of 10° C or 50° F:

\[ \mu = 1.307 \times 10^{-3} \text{ N} \cdot \text{s/m}^2 \]

\[ = 2.735 \times 10^{-5} \text{ lb} \cdot \text{s/ft}^2 \]

\[ \nu = 1.306 \times 10^{-6} \text{ m}^2/\text{s} \]

\[ = 1.410 \times 10^{-5} \text{ ft}^2/\text{s} \]
Fluid Statics

\[ P_1 - P_2 = \gamma (z_2 - z_1) \]

\[ P = \gamma h \]

\[ F = pA \]

where:

\[ P_1 = \text{pressure at elevation } z_1 \]

\[ P_2 = \text{pressure at elevation } z_2 \]

\[ h = z_2 - z_1 = \text{head} \]

\[ p = \text{pressure for head } h \]

\[ \gamma = \text{specific weight} \]

\[ F = \text{force} \]

\[ A = \text{area} \]
Absolute and Gage Pressure

absolute pressure =

gage pressure + atmospheric pressure

\[ P_{abs} = P_{gage} + P_{atm} \]
Pressure

absolute pressure A

gage pressure A

local atmospheric pressure

gage pressure B (vacuum)

absolute pressure B

absolute zero pressure (complete vacuum)
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.

\[ h_g = 3 \text{ m} \]

\[ h_w = 2 \text{ m} \]

water \( (\gamma = 9.81 \text{ kN/m}^3) \)
pressure at bottom of tank

\[ P_{gage} = \gamma_w h_w + \gamma_g h_g \]
\[ = (9.81 \text{ kN/m}^3) (2\text{ m}) \]
\[ + (0.73) (9.81 \text{ kN/m}^3) (3\text{ m}) \]
\[ = 41.1 \text{ kN/m}^2 \]

\[ P_{abs} = P_{gage} + P_{atm} \]
\[ = 41 \text{ kN/m}^2 + 101 \text{ kN/m}^2 \]
\[ = 142 \text{ kN/m}^2 \]
\[ = 142 \text{ kPa} \]
Example: Use the manometer measurements to compute the pressure in the pipe.

\[ P_{\text{pipe}} + \gamma_w h_w - \gamma_m h_m = 0 \]

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

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

\[ P_{\text{pipe}} = 1,604 \text{ lb/ft}^2 \]
Forces on Submerged Surfaces

**Plane Surface**

\[ F = \gamma h_c A \quad \text{magnitude} \]

\[ l_p - l_c = I_c / (l_c A) \quad \text{location} \]

**Curved or Plane Surface**

\[ F_h = \gamma h_c A \quad \text{(vertical projection)} \]

\[ F_v = \gamma V \quad \text{(weight of fluid)} \]

**Buoyant Force**

\[ F = \gamma \quad \text{(volume displaced)} \]
Example: Compute the magnitude and location of the resultant force.

\[ I_c = bh^3/36 \]
\[ F = \gamma h_c A \]

\[ l_p - l_c = \frac{I_c}{(l_c A)} \]

\[ A = 0.5 \: (2\text{m})(1.5\text{m}) = 1.5 \: \text{m}^2 \]

\[ h_c = 2.75 \: \text{m} - [(2/3) \: (1.5\text{m})] \sin 45^\circ \]

\[ = 2.043 \: \text{m} \]

\[ I_c = \frac{h_c}{\sin 45^\circ} = 2.043 \: \text{m} / 0.7071 \]

\[ = 2.889 \: \text{m} \]
moment of inertia $I_c = bh^3/36$

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

$F = \gamma h_c A$

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

$$= 30.0 \text{ kN/m}^3$$

$I_p - I_c = I_c / (I_c A)$

$$= 0.1875 \text{ m}^4/(2.889 \text{ m}) \cdot (1.5 \text{ m}^2)$$

$$= 0.0433 \text{ m}$$

$I_p = 0.0433 \text{ m} + 2.889 \text{ m} = 2.932 \text{ m}$
Example: Compute the force on the curved corner for a unit width.
\[ F_H = \gamma h_c A \]
\[ = (9.80 \text{ kN/m}^3) \times (11.5 \text{ m}) \times (3 \text{ m}^2) \]
\[ = 338 \text{ kN} \]

\[ F_V = \gamma V \]

volume \((V) = \)

\( = (10 \text{ m}) \times (3 \text{ m}) \times (1 \text{ m}) + (1/4)\pi (3 \text{ m})^2 \times (1 \text{ m}) \)
\[ = 37.07 \text{ m}^3 \]

\[ F_V = (9.80 \text{ kN/m}^3)(37.07 \text{ m}^3) = 363 \text{ kN} \]

\[ F = \sqrt{F_H + F_V} = \sqrt{338^2 + 363^2} \]
\[ = 496 \text{ kN} \]
Laws of Buoyancy and Flotation

1. 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.

\[
\text{wood} \quad (\gamma = 40 \text{ lb/ft}^3)
\]

\[
\begin{array}{c}
\text{3 ft} \\
\downarrow \\
1 \text{ ft} \\
\downarrow \\
1 \text{ ft into paper} \\
\downarrow \\
2 \text{ ft} \\
\downarrow \\
\text{rope}
\end{array}
\]
buoyant force \( (F_B) = \) 

\[ \gamma \text{ (volume displaced)} \]

\[
F_B = (62.4 \text{ lbs/ft}^3) (2 \text{ ft}^3) \\
= 124.8 \text{ lbs}
\]

weight of wood \( (W) \)

\[
W = (40 \text{ lbs/ft}^3) (2 \text{ ft}^3) = 80 \text{ lbs}
\]

\[
F_B - W - F_{rope} = 0 \\
124.8 \text{ lbs} - 80 \text{ lbs} - F_{rope} = 0 \\
F_{rope} = 44.8 \text{ lbs}
\]
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.

\[ F = \gamma h_c A \quad \text{or} \quad F = \gamma V \]

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

\[ - (62.4 \, \text{lb/ft}^3)(3 \, \text{ft})(1 \, \text{ft}^2) \]

\[ = 44.8 \, \text{lb} \]
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)

\[ \text{total head} = z + \frac{P}{\gamma} + \frac{V^2}{2g} \]

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

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

Conservation of Momentum

(Impulse-Momentum Equation)

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