## PROBLEMS

**2.1** Prove that the pressure is the same in all directions at a point in a static fluid for the three-dimensional case.

**2.2** The container of Fig. 2.37 holds water and air as shown. What is the pressure at *A*, *B*, *C*, and *D* in pascals?

**2.3** The tube in Fig. 2.38 is filled with oil. Determine the pressure at *A* and *B* in metres of water.

**2.4** Calculate the pressure at *A*, *B*, *C*, and *D* of Fig. 2.39 in pascals.

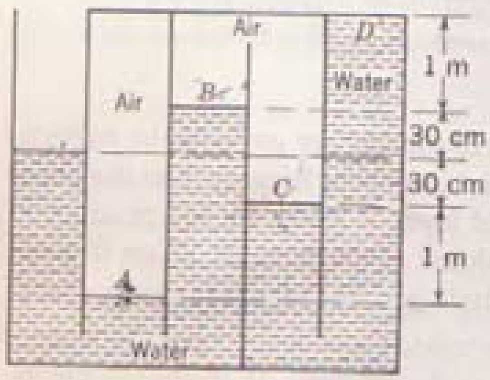


Figure 2.37 Problem 2.2.

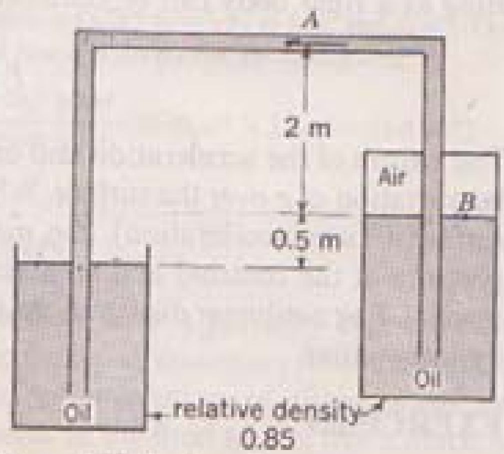


Figure 2.38 Problem 2.3.

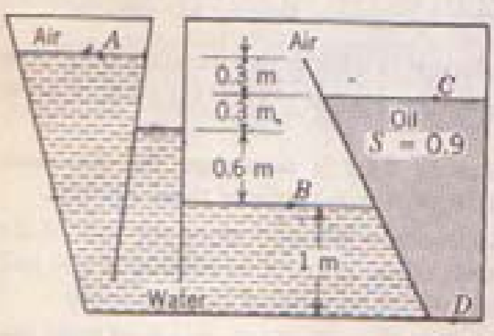


Figure 2.39 Problem 2.4.

**2.5** Derive the equations that give the pressure and density at any elevation in a static gas when conditions are known at one elevation and the temperature gradient $\beta$ is known.

**2.6** By a limiting process as $\beta \to 0$, derive the isothermal case from the results of Prob. 2.5.

**2.7** By use of the results of Prob. 2.5, determine the pressure and density at 3000 m elevation when $P = 100$ kPa, $t = 20°C$, at elevation 300 m for air and $\beta = -0.005°C/m$.

**2.8** For isothermal air at 0°C, determine the pressure and density at 3000 m when the pressure is 0.1 MPa abs at sea level.

**2.9** In isothermal air at 25°C what is the vertical distance for reduction of density by 10 percent?

**2.10** Express a pressure of 50 kPa in (*a*) millimetres of mercury, (*b*) metres of water, (*c*) metres of acetylene tetrabromide, S = 2.94.

**2.11** A bourdon gage reads 15 kPa suction, and the barometer is 750 mm Hg. Express the pressure in two other ways.

**2.12** Express 300 kPa abs in metres of water gage, barometer reading 750 mm.

**2.13** Bourdon gage *A* inside a pressure tank (Fig. 2.40) reads 80 kPa. Another bourdon gage *B* outside the pressure tank and connected with it reads 120 kPa, and an aneroid barometer reads 750 mm Hg. What is the absolute pressure measured by *A* in centimetres of mercury?

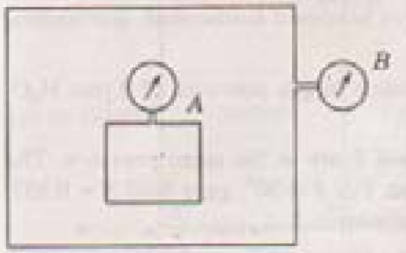


**Figure 2.40** Problem 2.13.

**2.14** Determine the heights of columns of water; kerosene, S = 0.83; and acetylene tetrabromide, S = 2.94, equivalent to 200 mm Hg.

**2.15** In Fig. 2.6*a*, for a reading *h* = 50 cm, determine the pressure at *A* in pascals. The liquid has a relative density of 1.90.

**2.16** Determine the reading *h* in Fig. 2.6*b* for $p_A$ = 30 kPa suction if the liquid is kerosene, S = 0.83.

**2.17** In Fig. 2.6*b*, for *h* = 15 cm and barometer reading 750 mm Hg, with water the liquid, find $P_A$ in metres of water absolute.

**2.18** In Fig. 2.6*c* $S_1$ = 0.86, $S_2$ = 1.0, $h_2$ = 90 mm, $h_1$ = 150 mm. Find $P_A$ in millimetres of mercury gage. If the barometer reading is 720 mm, what is $P_A$ in metres of water absolute?

**2.19** Gas is contained in vessel *A* of Fig. 2.6*c*. With water the manometer fluid and $h_1$ = 75 mm, determine the pressure at *A* in millimetres of mercury.

**2.20** In Fig. 2.7*a* $S_1$ = 1.0, $S_2$ = 0.95, $S_3$ = 1.0, $h_1$ = $h_2$ = 280 mm, and $h_3$ = 1 m. Compute $p_A - p_B$ in millimetres of water.

**2.21** In Prob. 2.20 find the gage difference $h_2$ for $p_A - p_B$ = −350 mm $H_2O$.

**2.22** In Fig. 2.7*b* $S_1$ = $S_3$ = 0.83, $S_2$ = 13.6, $h_1$ = 150 mm, $h_2$ = 70 mm, and $h_3$ = 120 mm. (*a*) Find $p_A$ if $p_B$ = 70 kPa gage. (*b*) For $p_A$ = 140 kPa gage abs and a barometer reading of 720 mm, find $p_B$ in metres of water gage.

**2.23** Find the gage difference $h_2$ in Prob. 2.22 for $p_A = p_B$.

**2.24** In Fig. 2.41, *A* contains water, and the manometer fluid has a relative density of 2.94. When the left meniscus is at zero on the scale, $p_A$ = 90 mm $H_2O$. Find the reading of the right meniscus for $p_A$ = 8 kPa with no adjustment of the U tube or scale.

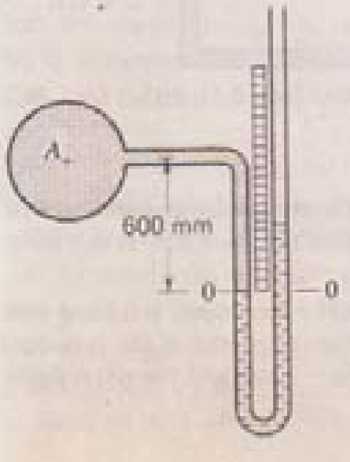


**Figure 2.41** Problem 2.24.

**2.25** The Empire State Building is 381 m high. What is the pressure difference in pascals of a water column of the same height?

**2.26** What is the pressure at a point 10 m below the free surface in a fluid that has a variable density in kilograms per cubic metre given by $\rho = 450 + ah$, in which $a = 12$ kg/m$^4$ and $h$ is the distance in metres measured from the free surface?

**2.27** A vertical gas pipe in a building contains gas, $\rho = 0.72$ kg/m$^3$ and $p = 8$ cm $H_2O$ gage in the basement. At the top of the building 250 m higher, determine the gas pressure in centimetres water gage for two cases: (*a*) gas assumed incompressible and (*b*) gas assumed isothermal. Barometric pressure 10.34 m $H_2O$; $t = 20$°C.

**2.28** In Fig. 2.8 determine $R$, the gage difference, for a difference in gas pressure of 9 mm $H_2O$. $\gamma_2 = 9.8$ kN/m$^3$; $\gamma_3 = 10.5$ kN/m$^3$; $a/A = 0.01$.

**2.29** The inclined manometer of Fig. 2.9 reads zero when $A$ and $B$ are at the same pressure. The diameter of reservoir is 5 cm, and that of the inclined tube 6 mm. For $\theta = 30°$, gage fluid S = 0.832, find $p_A - p_B$ in pascals as a function of gage reading $R$ in centimetres.

**2.30** Determine the gravity force $W$ that can be sustained by the force acting on the piston of Fig. 2.42.

**2.31** Neglecting the mass of the container (Fig. 2.43), find (*a*) the force tending to lift the circular top $CD$ and (*b*) the compressive load on the pipe wall at $A$-$A$.

**2.32** Find the force of oil on the top surface $CD$ of Fig. 2.43 if the liquid level in the open pipe is reduced by 1.3 m.

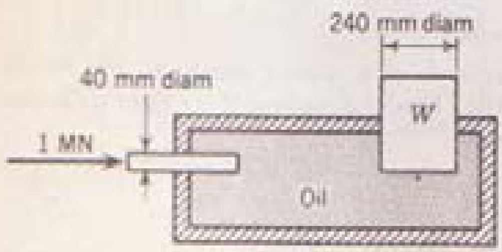


**Figure 2.42** Problem 2.30.

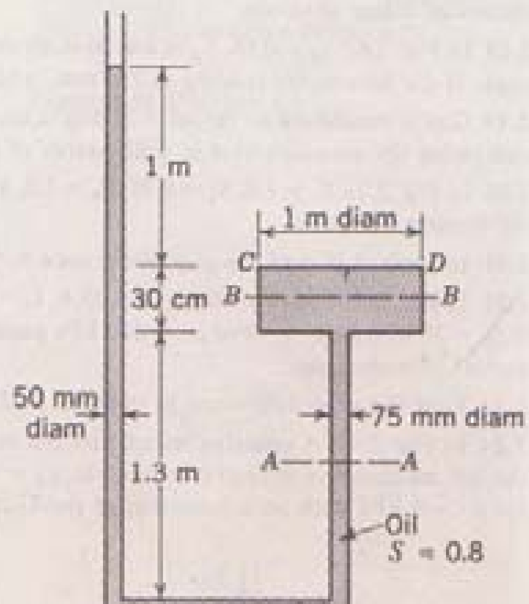


**Figure 2.43** Problems 2.31, 2.32.

**2.33** The container shown in Fig. 2.44 has a circular cross section. Determine the upward force on the surface of the cone frustum $ABCD$. What is the downward force on the plane $EF$? Is this force equal to the gravity force of the fluid? Explain.

**2.34** The cylindrical container of Fig. 2.45 has a gravity force of 400 N when empty. It is filled with water and supported on the piston. (*a*) What force is exerted on the upper end of the cylinder? (*b*) If an additional 600-N gravity force is placed on the cylinder, how much will the water force against the top of the cylinder be increased?

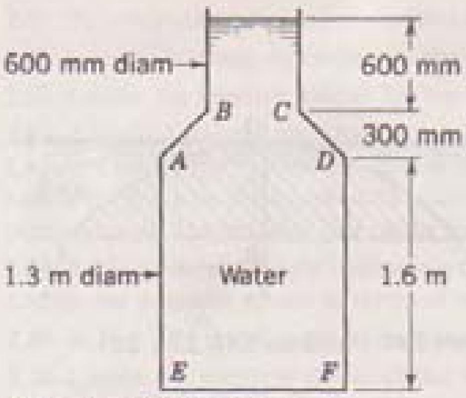


**Figure 2.44** Problem 2.33.

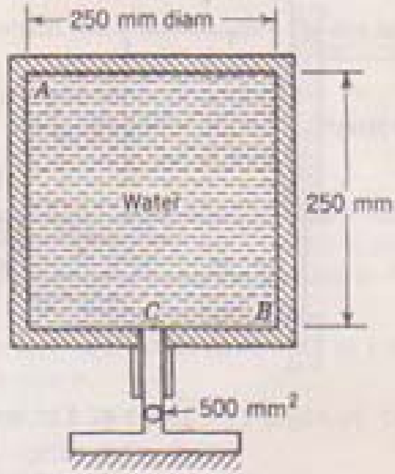


**Figure 2.45** Problem 2.34.

**2.35** A barrel 600 mm in diameter filled with water has a vertical pipe of 12 mm diameter attached to the top. Neglecting compressibility, how many kilograms of water must be added to the pipe to exert a force of 4 kN on the top of the barrel?

**2.36** A vertical right-angled triangular surface has a vertex in the free surface of a liquid (Fig. 2.46). Find the force on one side (*a*) by integration and (*b*) by formula.

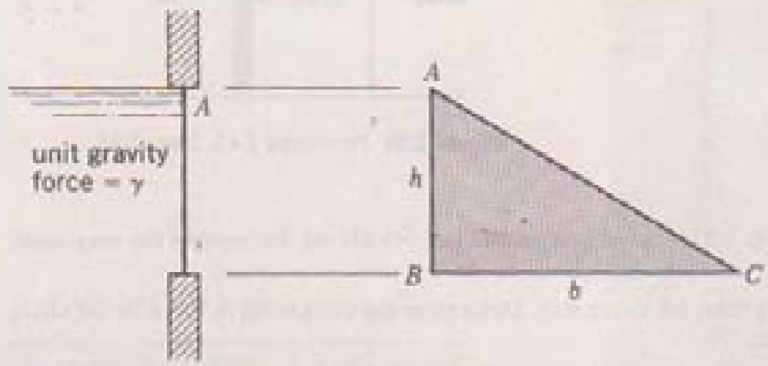


**Figure 2.46** Problems 2.36, 2.38, 2.49, 2.50.

**2.37** Determine the magnitude of the force acting on one side of the vertical triangle *ABC* of Fig. 2.47 (*a*) by integration and (*b*) by formula.

**2.38** Find the moment about *AB* of the force acting on one side of the vertical surface *ABC* of Fig. 2.46. $\gamma = 9000\ N/m^3$.

**2.39** Find the moment about *AB* of the force acting on one side of the vertical surface *ABC* of Fig. 2.47.

**2.40** Locate a horizontal line below *AB* of Fig. 2.47 such that the magnitude of pressure force on the vertical surface *ABC* is equal above and below the line.

**2.41** Determine the force acting on one side of the vertical surface *OABCO* of Fig. 2.48. $\gamma = 9\ kN/m^3$.

**2.42** Calculate the force exerted by water on one side of the vertical annular area shown in Fig. 2.49.

**2.43** Determine the moment at *A* required to hold the gate as shown in Fig. 2.50.

**2.44** If there is water on the other side of the gate (Fig. 2.50) up to *A*, determine the resultant force due to water on both sides of the gate, including its line of action.

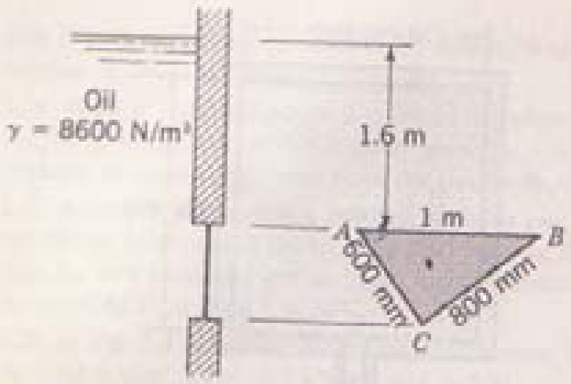


**Figure 2.47** Problems 2.37, 2.39, 2.40, 2.47, 2.48.

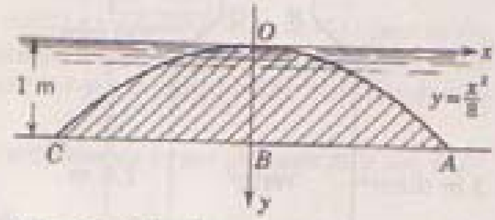


**Figure 2.48** Problems 2.41, 2.56, 2.83.

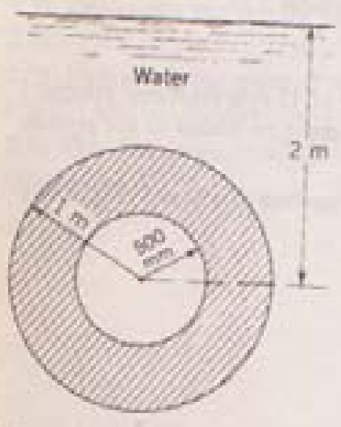


**Figure 2.49** Problems 2.42, 2.51.

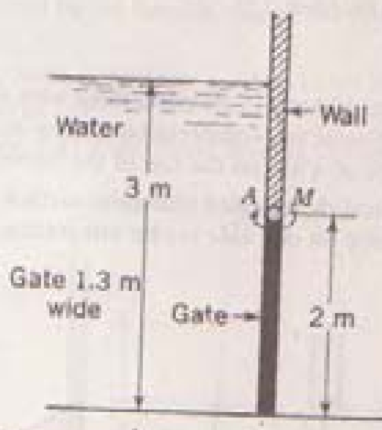


**Figure 2.50** Problems 2.43, 2.44, 2.52.

**2.45** The shaft of the gate in Fig. 2.51 will fail at a moment of 145 kN · m. Determine the maximum value of liquid depth $h$.

**2.46** The dam of Fig. 2.52 has a strut $AB$ every 6 m. Determine the compressive force in the strut, neglecting the mass of the dam.

**2.47** Locate the distance of the pressure center below the liquid surface in the triangular area $ABC$ of Fig. 2.47 by integration and by formula.

**2.48** By integration locate the pressure center horizontally in the triangular area $ABC$ of Fig. 2.47.

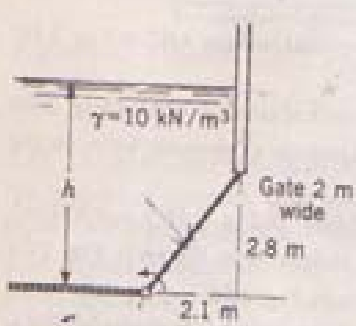


**Figure 2.51** Problems 2.45, 2.55.

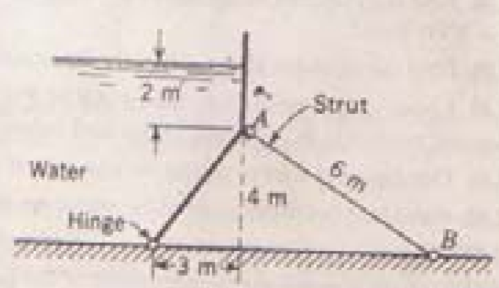


**Figure 2.52** Problem 2.46.

2.49 By using the pressure prism, determine the resultant force and location for the triangle of Fig. 2.46.

2.50 By integration, determine the pressure center for Fig. 2.46.

2.51 Locate the pressure center for the annular area of Fig. 2.49.

2.52 Locate the pressure center for the gate of Fig. 2.50.

2.53 A vertical square area 2 by 2 m is submerged in water with upper edge 1 m below the surface. Locate a horizontal line on the surface of the square such that (*a*) the force on the upper portion equals the force on the lower portion and (*b*) the moment of force about the line due to the upper portion equals the moment due to the lower portion.

2.54 An equilateral triangle with one edge in a water surface extends downward at a 45° angle. Locate the pressure center in terms of the length of a side *b*.

2.55 In Fig. 2.51 develop the expression for $y_p$ in terms of *h*.

2.56 Locate the pressure center of the vertical area *OABCO* of Fig. 2.48.

2.57 Locate the pressure center for the vertical area of Fig. 2.53.

2.58 Demonstrate the fact that the magnitude of the resultant force on a totally submerged plane area is unchanged if the area is rotated about an axis through its centroid.

2.59 The gate of Fig. 2.54 weighs 450 kg/m normal to the paper. Its center of gravity is 45 cm from the left face and 60 cm above the lower face. It is hinged at *O*. Determine the water-surface position for the gate just to start to come up. (Water surface is below the hinge.)

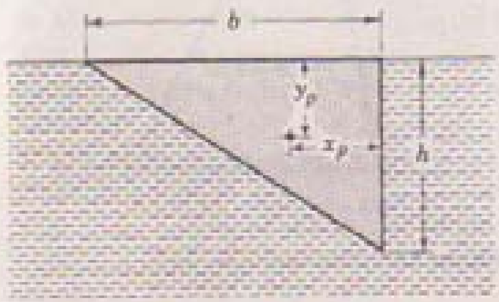


**Figure 2.53** Problem 2.57.

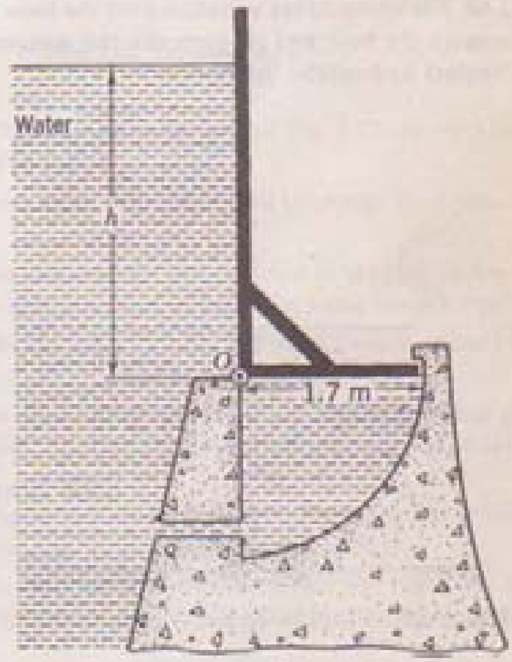


**Figure 2.54** Problems 2.59, 2.60, 2.61.

2.60 Find *h* of Prob. 2.59 for the gate just to come up to the vertical position shown.

2.61 Determine the value of *h* and the force against the stop when this force is a maximum for the gate of Prob. 2.59.

2.62 Determine *y* of Fig. 2.55 so that the flashboards will tumble when water reaches their top.

2.63 Determine the pivot location *y* of the rectangular gate of Fig. 2.56 so that it will open when the liquid surface is as shown.

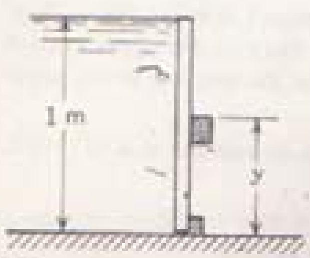


Figure 2.55 Problem 2.62.

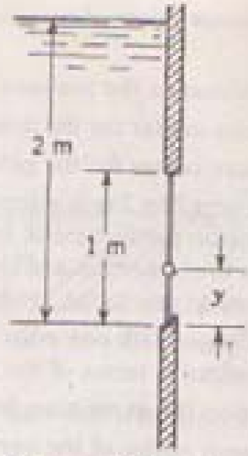


Figure 2.56 Problem 2.63.

**2.64** By use of the pressure prism, show that the pressure center approaches the centroid of an area as its depth of submergence is increased.

**2.65** (*a*) Find the magnitude and line of action of force on each side of the gate of Fig. 2.57. (*b*) Find the resultant force due to the liquid on both sides of the gate. (*c*) Determine $F$ to open the gate if it is uniform and has a mass of 2 Mg.

**2.66** For linear stress variation over the base of the dam of Fig. 2.58, (*a*) locate where the resultant crosses the base and (*b*) compute the maximum and minimum compressive stresses at the base. Neglect hydrostatic uplift.

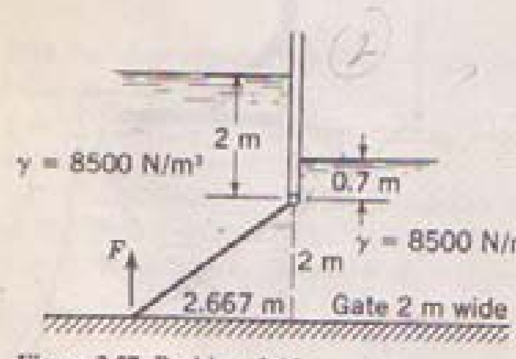


Figure 2.57 Problem 2.65.

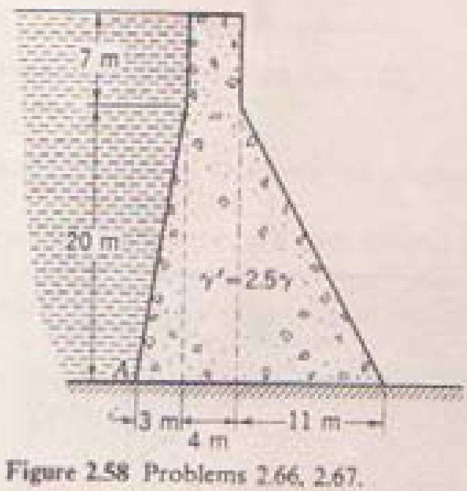


Figure 2.58 Problems 2.66, 2.67.

**2.67** Work Prob. 2.66 with the addition that the hydrostatic uplift varies linearly from 20 m at $A$ to zero at the toe of the dam.

**2.68** Find the moment $M$ at $O$ (Fig. 2.59) to hold the gate closed.

**2.69** The gate shown in Fig. 2.60 is in equilibrium. Compute $W$, the gravity force of counterbalance per metre of width, neglecting the mass of the gate. Is the gate in stable equilibrium?

**2.70** How high ($h$) will the water on the right have to rise to open the gate shown in Fig. 2.61? The gate is 2 m wide, and it is constructed of material with relative density $S = 2.5$. Use the pressure prism method.

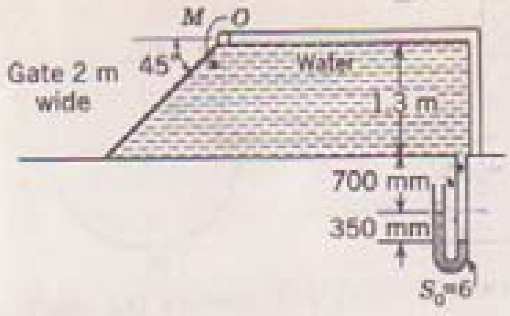


Figure 2.59 Problem 2.68.

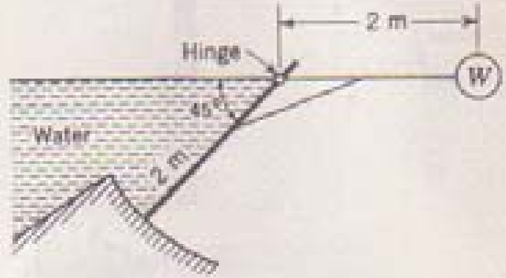


Figure 2.60 Problem 2.69.

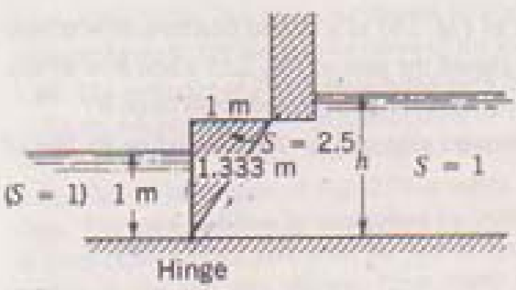


Figure 2.61 Problem 2.70.

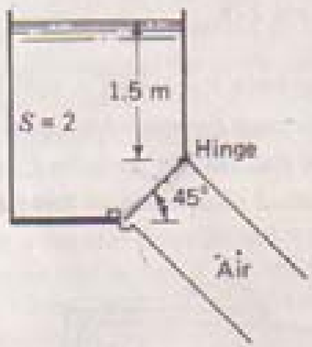


Figure 2.62 Problem 2.71.

**2.71** Compute the air pressure required to keep the 700-mm-diameter gate of Fig. 2.62 closed. The gate is a circular plate that has a gravity force of 1800 N.

**2.72** A 5 m-diameter pressure pipe carries liquid at 1.4 MPa. What pipe-wall thickness is required for maximum stress of 70 MPa.

**2.73** To obtain the same flow area, which pipe system requires the least steel, a single pipe or four pipes having half the diameter? The maximum allowable pipe-wall stress is the same in each case.

**2.74** A thin-walled hollow sphere 3 m in diameter holds gas at 1.5 MPa. For allowable stress of 60 MPa determine the minimum wall thickness.

**2.75** A cylindrical container 2.3 m high and 1.3 m in diameter provides for pipe tension with two hoops 30 cm from each end. When it is filled with water, what is the tension in each hoop due to the water?

**2.76** A 20-mm-diameter steel ball covers a 10-mm-diameter hole in a pressure chamber where the pressure is 30 MPa. What force is required to lift the ball from the opening?

**2.77** If the horizontal component of force on a curved surface did *not* equal the force on a projection of the surface onto a vertical plane, what conclusions could you draw regarding the propulsion of a boat (Fig. 2.63)?

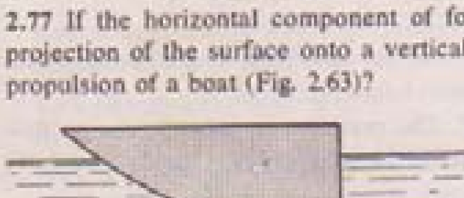

Figure 2.63 Problem 2.77.

X **2.78** (*a*) Determine the horizontal component of force acting on the radial gate (Fig. 2.64) and its line of action. (*b*) Determine the vertical component of force and its line of action. (*c*) What force *F* is required to open the gate, neglecting its mass? (*d*) What is the moment about an axis normal to the paper and through point *O*?

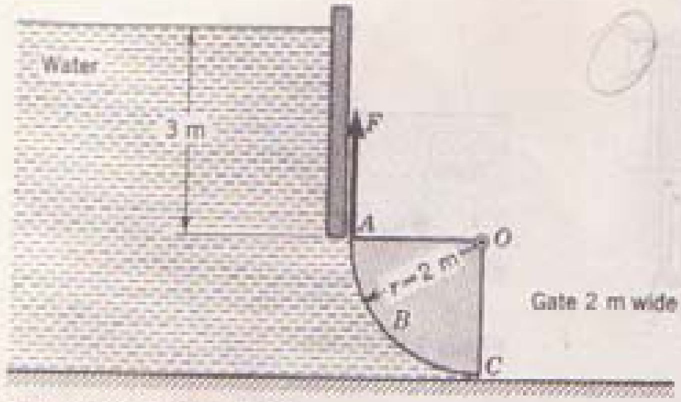


**Figure 2.64** Problem 2.78.

**2.79** Calculate the force $F$ required to hold the gate of Fig. 2.65 in a closed position, $R = 60$ cm.

**2.80** Calculate the force $F$ required to open or hold closed the gate of Fig. 2.65 when $R = 45$ cm.

**2.81** What is $R$ of Fig. 2.65 for no force $F$ required to hold the gate closed or to open it?

**2.82** Find the vertical component of force on the curved gate of Fig. 2.66, including its line of action.

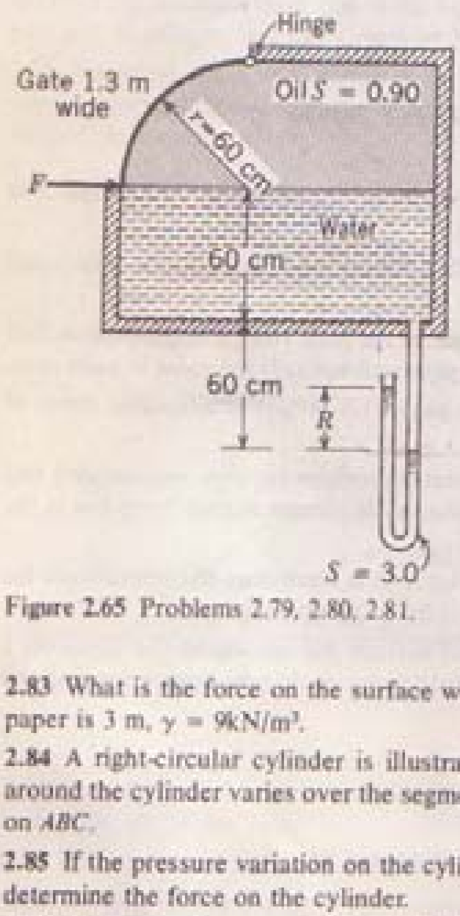


**Figure 2.65** Problems 2.79, 2.80, 2.81.

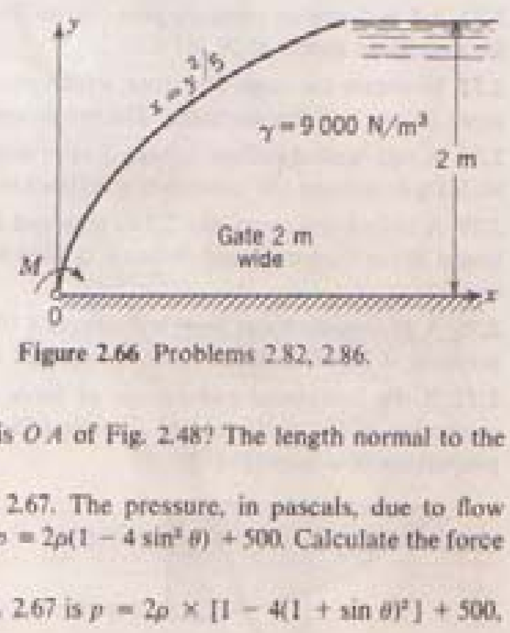


**Figure 2.66** Problems 2.82, 2.86.

**2.83** What is the force on the surface whose trace is $OA$ of Fig. 2.48? The length normal to the paper is 3 m, $\gamma = 9$kN/m$^3$.

**2.84** A right-circular cylinder is illustrated in Fig. 2.67. The pressure, in pascals, due to flow around the cylinder varies over the segment $ABC$ as $p = 2\rho(1 - 4\sin^2\theta) + 500$. Calculate the force on $ABC$.

**2.85** If the pressure variation on the cylinder in Fig. 2.67 is $p = 2\rho \times [1 - 4(1 + \sin\theta)^2] + 500$, determine the force on the cylinder.

**2.86** Determine the moment $M$ to hold the gate of Fig. 2.66, neglecting its mass.

**2.87** Find the resultant force, including its line of action, acting on the outer surface of the first quadrant of a spherical shell of radius 600 mm with center at the origin. Its center is 1.2 m below the water surface.

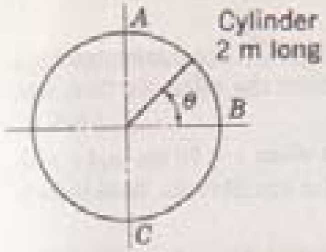


Figure 2.67 Problems 2.84, 2.85.

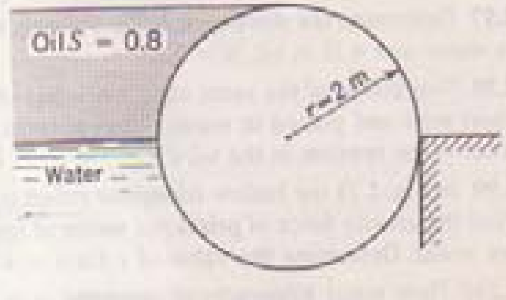


Figure 2.68 Problem 2.89.

2.88 The volume of the ellipsoid given by $x^2/a^2 + y^2/b^2 + z^2/c^2 = 1$ is $4\pi abc/3$, and the area of the ellipse $x^2/a^2 + z^2/c^2 = 1$ is $\pi ac$. Determine the vertical force on the surface given in Example 2.9.

2.89 A log holds the water as shown in Fig. 2.68. Determine (*a*) the force per metre pushing it against the dam, (*b*) the gravity force of the cylinder per metre of length, and (*c*) its relative density.

2.90 The cylinder of Fig. 2.69 is filled with liquid as shown. Find (*a*) the horizontal component of force on *AB* per unit of length, including its line of action, and (*b*) the vertical component of force on *AB* per unit of length, including its line of action.

2.91 The cylinder gate of Fig. 2.70 is made up from a circular cylinder and a plate hinged at the dam. The gate position is controlled by pumping water into or out of the cylinder. The center of gravity of the empty gate is on the line of symmetry 1.3 m from the hinge. It is in equilibrium when empty in the position shown. How many cubic metres of water must be added per metre of cylinder to hold the gate in its position when the water surface is raised 1 m?

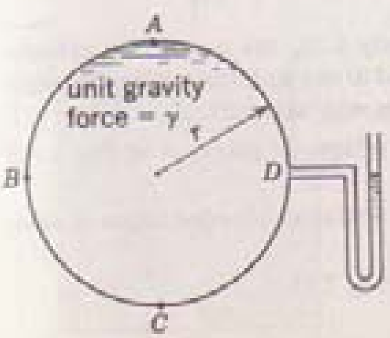


Figure 2.69 Problem 2.90.

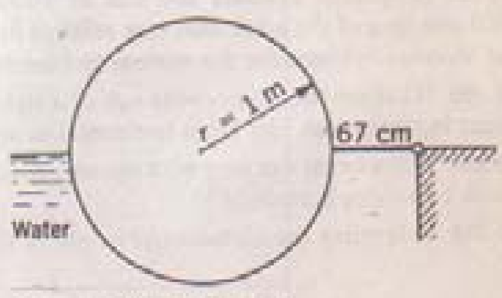


Figure 2.70 Problem 2.91.

2.92 A hydrometer with gravity force of 0.035 N and has a stem 5 mm in diameter. Compute the distance between relative density markings 1.0 and 1.1.

2.93 Design a hydrometer to read relative densities in the range from 0.80 to 1.10 when the scale is to be 75 mm long.

2.94 A sphere 250 mm in diameter, relative density 1.4, is submerged in a liquid having a density varying with the depth $y$ below the surface given by $\rho = 1000 + 0.03y$ kg/m³. Determine the equilibrium position of the sphere in the liquid.

2.95 Repeat the calculations for Prob. 2.94 for a horizontal circular cylinder with a relative density of 1.4 and a diameter of 250 mm.

2.96 A cube 60 cm on an edge, has its lower half of S = 1.4 and upper half of S = 0.6. It is submerged into a two-layered fluid, the lower S = 1.2 and the upper S = 0.9. Determine the height of the top of the cube above the interface.

**2.97** Determine the density, specific volume, and volume of an object that has a gravity force 3 N in water and 4 N in oil, S = 0.83.

**2.98** Two cubes of the same size, 1 $m^3$, one of S = 0.80, the other of S = 1.1, are connected by a short wire and placed in water. What portion of the lighter cube is above the water surface, and what is the tension in the wire?

**2.99** In Fig. 2.71 the hollow triangular prism is in equilibrium as shown when $z$ = 30 cm and $y$ = 0. Find the gravity force of prism per metre of length and $z$ in terms of $y$ for equilibrium. Both liquids are water. Determine the value of $y$ for $z$ = 45 cm.

**2.100** How many kilograms of concrete, $\rho$ = 2.55 Mg/$m^3$, must be attached to a beam having a volume of 0.1 $m^3$ and S = 0.65 to cause both to sink in water?

**2.101** The gate of Fig. 2.72 has a mass of 225 kg/m normal to the page. It is in equilibrium as shown. Neglecting the mass of the arm and brace supporting the counterbalance, (*a*) find $W$ and (*b*) determine whether the gate is in stable equilibrium. The mass $W$ is made of concrete, S = 2.50.

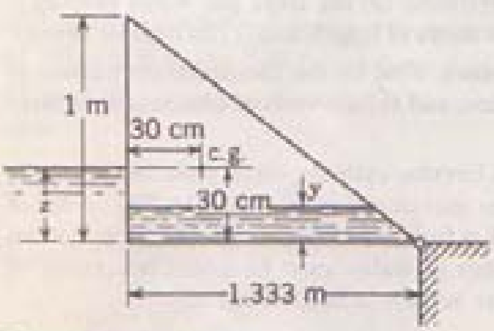


**Figure 2.71** Problem 2.99.

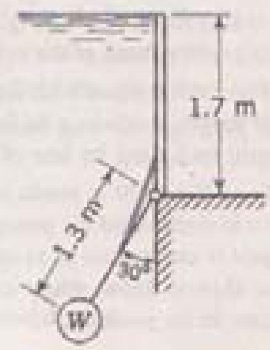


**Figure 2.72** Problem 2.101.

**2.102** A wooden cylinder 600 mm in diameter, relative density 0.50, has a concrete cylinder 600 mm long of the same diameter, relative density 2.50, attached to one end. Determine the length of wooden cylinder for the system to float in stable equilibrium with axis vertical.

**2.103** What are the proportions $r_0/h$ of a right-circular cylinder of specific gravity $S$ so that it will float in water with end faces horizontal in stable equilibrium?

**2.104** Will a beam 4 m long with square cross section, S = 0.75, float in stable equilibrium in water with two sides horizontal?

**2.105** Determine the metacentric height of the torus shown in Fig. 2.73.


**Figure 2.73** Problem 2.105.

**2.106** The plane gate (Fig. 2.74) weighs 2000 N/m normal to the paper, and its center of gravity is 2 m from the hinge at $O$. (*a*) Find $h$ as a function of $\theta$ for equilibrium of the gate. (*b*) Is the gate in stable equilibrium for any values of $\theta$?

**2.107** A spherical balloon 15 m in diameter is open at the bottom and filled with hydrogen. For barometer reading of 710 mm Hg and 20°C, what is the total gravity force of the balloon and the load to hold it stationary?

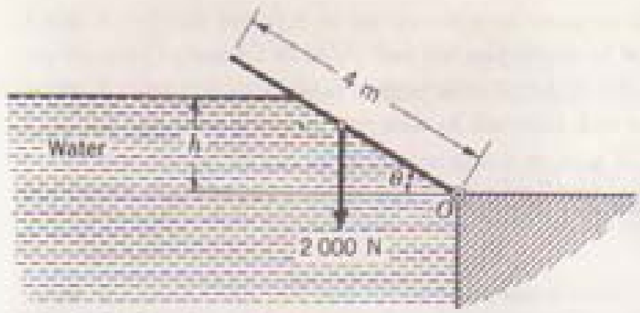


**Figure 2.74** Problem 2.106.

**2.108** A tank of liquid $S = 0.86$ is accelerated uniformly in a horizontal direction so that the pressure decreases within the liquid 20 kPa/m in the direction of motion. Determine the acceleration.

**2.109** The free surface of a liquid makes an angle of 20° with the horizontal when accelerated uniformly in a horizontal direction. What is the acceleration?

**2.110** In Fig. 2.75, $a_x = 3.9$ m/s², $a_y = 0$. Find the imaginary free liquid surface and the pressure at $B$, $C$, $D$, and $E$.

**2.111** In Fig. 2.75, $a_x = 0$, $a_y = 2.45$ m/s². Find the pressure at $B$, $C$, $D$, and $E$.

**2.112** In Fig. 2.75, $a_x = 2.45$ m/s², $a_y = 4.902$ m/s². Find the imaginary free surface and the pressure at $B$, $C$, $D$, and $E$.

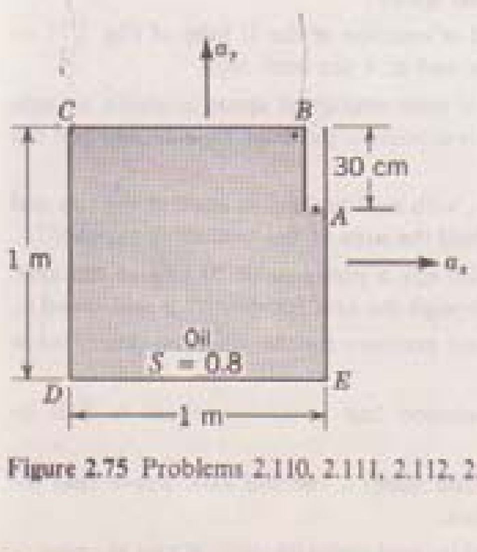


**Figure 2.75** Problems 2.110, 2.111, 2.112, 2.116.

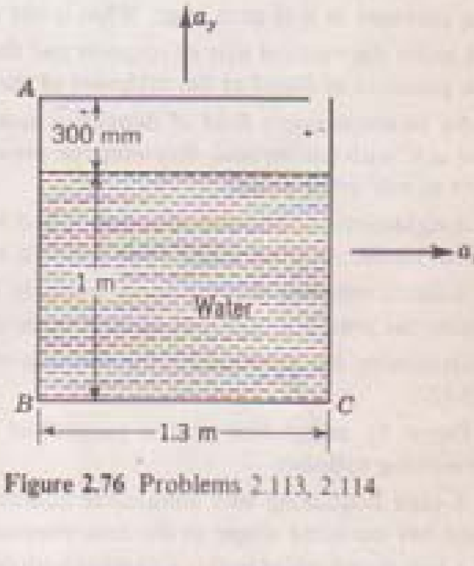


**Figure 2.76** Problems 2.113, 2.114.

**2.113** In Fig. 2.76, $a_x = 9.806$ m/s², $a_y = 0$. Find the pressure at $A$, $B$, and $C$.

**2.114** In Fig. 2.76, $a_x = 4.903$ m/s², $a_y = 9.806$ m/s². Find the pressure at $A$, $B$, and $C$.

**2.115** A circular cross-sectional tank of 2 m depth and 1.3 m diameter is filled with liquid and accelerated uniformly in a horizontal direction. If one-third of the liquid spills out, determine the acceleration.

**2.116** Determine $a_x$ and $a_y$ in Fig. 2.75 for pressure at $A$, $B$, and $C$ to be the same.

**2.117** The tube of Fig. 2.77 is filled with liquid, S = 2.40. When it is accelerated to the right 2.45 m/s², draw the imaginary free surface and determine the pressure at $A$. For $p_A = 56$ kPa vacuum determine $a_x$.

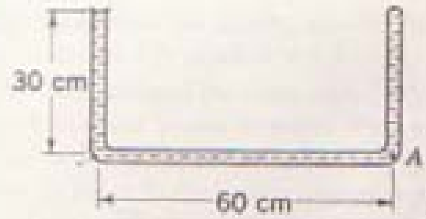


**Figure 2.77** Problems 2.117, 2.123, 2.124, 2.134.

**2.118** A cubical box 1 m on an edge, open at the top and half filled with water, is placed on an inclined plane making a 30° angle with the horizontal. The box alone has a gravity force of 500 N and has a coefficient of friction with the plane of 0.30. Determine the acceleration of the box and the angle the free-water surface makes with the horizontal.

**2.119** Show that the pressure is the same in all directions at a point in a liquid moving as a solid.

**2.120** A closed box contains two immiscible liquids. Prove that, when it is accelerated uniformly in the $x$ direction, the interface and zero-pressure surface are parallel.

**2.121** Verify the statement made in Sec. 2.9 on uniform rotation about a vertical axis that, when a fluix rotates in the manner of a solid body, no shear stresses exist in the fluid.

**2.122** A vessel containing liquid, $S = 1.2$, is rotated about a vertical axis. The pressure at one point 0.6 m radially from the axis is the same as at another point 1.2 m from the axis and with elevation 0.6 m higher. Calculate the rotational speed.

**2.123** The U tube of Fig. 2.77 is rotated about a vertical axis 15 cm to the right of $A$ at such a speed that the pressure at $A$ is zero gage. What is the rotational speed?

**2.124** Locate the vertical axis of rotation and the speed of rotation of the U tube of Fig. 2.77 so that the pressure of liquid at the midpoint of the U tube and at $A$ are both zero.

**2.125** An incompressible fluid of density $\rho$ moving as a solid rotates at speed $\omega$ about an axis inclined at $\theta$° with the vertical. Knowing the pressure at one point in the fluid, how do you find the pressure at any other point?

**2.126** A right-circular cylinder of radius $r_0$ and height $h_0$ with axis vertical is open at the top and filled with liquid. At what speed must it rotate so that half the area of the bottom is exposed?

**2.127** A liquid rotating about a *horizontal* axis as a solid has a pressure of 70 kPa at the axis. Determine the pressure variation along a vertical line through the axis for density $\rho$ and speed $\omega$.

**2.128** Determine the equation for the surfaces of constant pressure for the situation described in Prob. 2.127.

**2.129** Prove by integration that a paraboloid of revolution has a volume equal to half its circumscribing cylinder.

**2.130** A tank containing two immiscible liquids is rotated about a vertical axis. Prove that the interface has the same shape as the zero-pressure surface.

**2.131** A hollow sphere of radius $r_0$ is filled with liquid and rotated about its vertical axis at speed $\omega$. Locate the circular line of maximum pressure.

**2.132** A gas following the law $P\rho^{-n}$ = const is rotated about a vertical axis as a solid. Derive an expression for pressure in a radial direction for speed $\omega$, pressure $P_0$, and density $\rho_0$ at a point on the axis.

**2.133** A vessel containing water is rotated about a vertical axis with an angular velocity of 50 rad/s. At the same time the container has a downward acceleration of 4.903 m/s². What is the equation for a surface of constant pressure?

**2.134** The U tube of Fig. 2.77 is rotated about a vertical axis through $A$ at such a speed that the water in the tube begins to vaporize at the closed end above $A$, which is at 20°C. hat is the angular velocity? What would happen if the angular velocity were increased?

**2.135** A cubical box 1.3 m on an edge is open at the top and filled with water. When it is accelerated upward 2.45 $m/s^2$, find the magnitude of water force on one side of the box.

**2.136** A cube 1 m on an edge is filled with liquid, $S = 0.65$, and is accelerated downward 2.45 $m/s^2$. Find the resultant force on one side of the cube due to liquid pressure.

**2.137** A cylinder 60 cm in diameter and 2 m long is accelerated uniformly along its axis in a horizontal direction 4.903 $m/s^2$. It is filled with liquid, $\gamma = 7850\ N/m^3$, and it has a pressure along its axis of 70 kPa before acceleration starts. Find the horizontal net force exerted against the liquid in the cylinder.

**2.138** A closed cube, 300 mm on an edge, has a small opening at the center of its top. When it is filled with water and rotated uniformly about a vertical axis through its center at $\omega$ rad/s, find the force on a side due to the water in terms of $\omega$.