24 Years
Previous Solved Papers

ESE 2019

UPSC ENGINEERING SERVICES EXAMINATION

Preliminary Examination

Civil Engineering

Topicwise **Objective** Solved Questions

Volume-II

Topicwise Presentation | ***Thoroughly Revised and Updated***

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ESE-2019 : Preliminary Examination
Civil Engineering : Volume-II
Topicwise Objective Solved Questions : (1995-2018)

1st Edition : 2006
2nd Edition : 2007
3rd Edition : 2008
4th Edition : 2009
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12th Edition : 2017

13th Edition : 2018

Director's Message

Engineering is one of the most chosen graduating field. Taking engineering is usually a matter of interest but this eventually develops into "purpose of being an engineer" when you choose engineering services as a carrier option.

B. Singh (Ex. IES)

Train goes in tunnel we don't panic but sit still and trust the engineer, even we don't doubt on signalling system, we don't think twice crossing over a bridge reducing our travel time; every engineer has a purpose in his department which when coupled with his unique talent provides service to mankind.

I believe *"the educator must realize in the potential power of his pupil and he must employ all his art, in seeking to bring his pupil to experience this power"*. To support dreams of every engineer and to make efficient use of capabilities of aspirant, MADE EASY team has put sincere efforts in compiling all the previous years' ESE-Pre questions with accurate and detailed explanation. The objective of this book is to facilitate every aspirant in ESE preparation and so, questions are segregated chapterwise and topicwise to enable the student to do topicwise preparation and strengthen the concept as and when they are read.

I would like to acknowledge efforts of entire MADE EASY team who worked hard to solve previous years' papers with accuracy and I hope this book will stand up to the expectations of aspirants and my desire to serve student fraternity by providing best study material and quality guidance will get accomplished.

B. Singh (Ex. IES)
CMD, MADE EASY Group

Contents

Civil Engineering Volume-II

Objective Solved Questions

of UPSC Engineering Services Examination

UNIT

I

Fluid Mechanics & Hydraulic Machines

Syllabus

Fluid Mechanics, Open Channel Flow, Pipe Flow: Fluid properties; Dimensional Analysis and Modeling; Fluid dynamics including flow kinematics and measurements; Flow net; Viscosity, Boundary layer and control, Drag, Lift, Principles in open channel flow, Flow controls. Hydraulic jump; Surges; Pipe networks.

Hydraulic Machines and Hydro power: Various pumps, Air vessels, Hydraulic turbines – types, classifications & performance parameters; Power house – classification and layout, storage, pondage, control of supply.

Contents

1 Fluid Properties

1.1 Which one of the following pressure units represents the LEAST pressure?

(a) millibar (b) mm of Hg
(c) N/mm^2 (d) kgf/cm^2

[ESE : 1997]

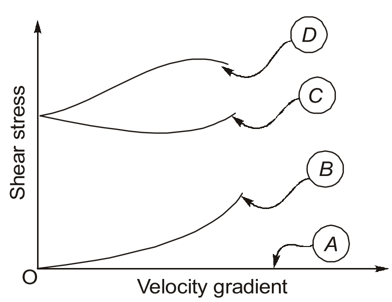
1.2 The surface tension of water at 20°C is 75×10^{-3} N/m. The difference in the water surfaces within and outside an open-ended capillary tube of 1 mm internal bore, inserted at the water surface would nearly be

(a) 5 mm (b) 10 mm
(c) 15 mm (d) 20 mm

[ESE : 1998]

1.3 Match **List-I** (Curves labelled *A*, *B*, *C* and *D* in figure) with **List-II** (Type of fluid) and select the correct answer using the codes given below the lists:

List-I



List-II

1. Ideal plastic
2. Ideal
3. Non-Newtonian
4. Thixotropic
5. Rheopectic

Codes:

	A	B	C	D
(a)	2	3	1	5
(b)	3	2	1	5
(c)	4	2	5	1
(d)	2	3	5	1

[ESE : 1999]

1.4 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

List-I

A. Concentrated sugar solution
B. Sewage sludge
C. Blood
D. Air

List-II

1. Dilatant fluid
2. Bingham plastic fluid
3. Pseudo-plastic fluid
4. Newtonian fluid

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	1	2	4	3
(c)	2	1	3	4
(d)	2	1	4	3

[ESE : 2001]

1.5 Match **List-I** (Definitions) with **List-II** (Properties) and select the correct answer using the codes given below the lists:

List-I

A. Newtonian fluid
B. Ideal fluid
C. Thixotropic fluid
D. Rheological fluid

List-II

1. Frictionless and incompressible
2. Viscosity is invariant with shear stress
3. Viscosity increases at higher shear stress
4. Viscosity decreases at higher shear stress

Codes:

	A	B	C	D
(a)	2	4	1	3
(b)	3	1	4	2
(c)	2	1	3	4
(d)	3	4	1	2

[ESE : 2002]

1.6 Which one of the following statements is correct?
(a) Dynamic viscosity of water is nearly 50 times that of air.
(b) Kinematic viscosity of water is 30 times that of air.
(c) Water in soil is able to rise a considerable distance above the groundwater table due to viscosity.
(d) Vapour pressure of a liquid is inversely proportional to the temperature.

[ESE : 2003]

1.7 Which of the following fluids can be classified as non-Newtonian?
1. Kerosene oil 2. Diesel oil
3. Human blood 4. Toothpaste
5. Water

Select the correct answer using the codes given below:
(a) 1 and 2 (b) 3 and 4
(c) 2 and 5 (d) 1 and 5

[ESE : 2003]

1.8 **Assertion (A):** At the standard temperature, the kinematic viscosity of air is greater than that of water at the same temperature.
Reason (R): The dynamic viscosity of air at standard temperature is lower than that of water at the same temperature.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2004]

1.9 The velocity distribution for flow over a plate is given by $u = 0.5y - y^2$ where 'u' is the velocity in m/s at a distance 'y' meter above the plate. If the dynamic viscosity of the fluid is 0.9 N-s/m^2, then what is the shear stress at 0.20 m from the boundary?
(a) 0.9 N/m^2 (b) 1.8 N/m^2
(c) 2.25 N/m^2 (d) 0.09 N/m^2

[ESE : 2005]

1.10 A flat plate of 0.15 m^2 is pulled at 20 cm/s relative to another plate, fixed at a distance of 0.02 cm from it with a fluid having μ = 0.0014 N-s/m^2 separating them. What is the power required to maintain the motion?
(a) 0.014 W (b) 0.021 W
(c) 0.035 W (d) 0.042 W

[ESE : 2006]

1.11 Which one of the following expresses the height of rise or fall of a liquid in a capillary tube?

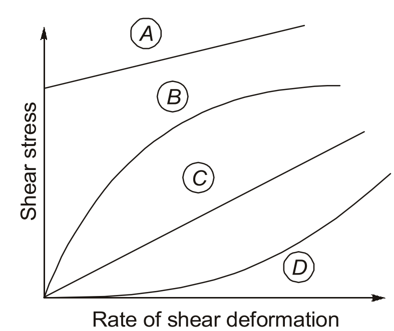
(a) $\dfrac{4wd}{\sigma \cos\alpha}$ (b) $\dfrac{\sigma \cos\alpha}{4w\alpha}$

(c) $\dfrac{4\sigma \cos\alpha}{wd}$ (d) $\dfrac{wd}{4\sigma \cos\alpha}$

where,
w = Specific weight of the liquid
α = Angle of contact of the liquid surface
σ = Surface tension

[ESE : 2007]

1.12 Match **List-I** (Curve identification in figure) with **List-II** (Nature of fluid) and select the correct answer using the codes given below the lists:



List-I	**List-II**
A. Curve *A*	**1.** Newtonian
B. Curve *B*	**2.** Dilatant
C. Curve *C*	**3.** Ideal bingham plastic
D. Curve *D*	**4.** Pseudo-plastic

Codes:

	A	B	C	D
(a)	3	4	1	2
(b)	2	4	1	3
(c)	3	1	4	2
(d)	2	1	4	3

[ESE : 2010]

1.13 **Assertion (A):** The movement of two blocks of wood welted with hot glue requires greater and greater effort as the glue is drying up.

Reason (R): Viscosity of liquids varies inversely with temperature.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

[ESE : 2010]

1.14 Match **List-I** with **List-II** and select the correct answer using the code given below the lists:

List-I
A. Specific Gravity
B. Coefficient of viscosity
C. Kinematic viscosity
D. Stress

List-II
1. $M^{\circ}L^{2}T^{-1}$
2. $M^{\circ}L^{\circ}T^{\circ}$
3. $ML^{-1}T^{-1}$
4. $ML^{-1}T^{-2}$

Code:

	A	B	C	D
(a)	2	3	1	4
(b)	4	3	1	2
(c)	2	1	3	4
(d)	4	1	3	2

[ESE : 2011]

1.15 Poise has the unit of
(a) Dyne-cm/s^2 (b) Dyne-cm/s
(c) Dyne-s/cm (d) Dyne-s/cm^2

[ESE : 2011]

1.16 Which one of the following statements is correct?
(a) For water at 100° Celsius at sea level, the vapour pressure is equal to atmospheric pressure.
(b) Surface energy (or tension) is caused by the force of adhesion between liquid molecules.
(c) Viscosity of a fluid is the property exhibited by it both in static and in dynamic conditions.
(d) Air is 50, 000 times more compressible than water.

[ESE : 2011]

1.17 Which one of the following statements is correct?
(a) Dynamic viscosity is the property of a fluid which is not in motion
(b) Surface energy is fluid property giving rise to the phenomenon of capillarity in water
(c) Cavitation results from the action of very high pressure
(d) Real fluids have lower viscosity than ideal fluids

[ESE : 2011]

Directions: Each of the next items consists of two statements, one labeled as the 'Statements (I)' and the other as 'Statement (II)'. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is NOT the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

1.18 **Statement (I):** As temperature increases, viscosity of air decreases.
Statement (II): As temperature increases, activity of the air molecules increases.

[ESE : 2013]

1.19 **Statement (I):** Fluid pressure is a scalar quantity.
Statement (II): Fluid thrust always acts downwards.

[ESE : 2013]

1.20 The surface tension in a soap bubble of 50 mm diameter with its inside pressure being 2.5 N/m^2 above the atmospheric pressure is
(a) 0.0125 N/m (b) 0.0156 N/m
(c) 0.2 N/m (d) 0.0312 N/m

[ESE : 2015]

1.21 The surface tension of water at 20°C is 75×10^{-3} N/m. The difference in water surfaces within and outside an open-ended capillary tube of 1 mm internal bore, inserted at the water surface, would nearly be
(a) 7 mm (b) 11 mm
(c) 15 mm (d) 19 mm

[ESE : 2016]

1.22 Statement (I): The shear strain graph for a Newtonian fluid is linear.

Statement (II): The coefficient of viscocity μ of the fluid is not constant.

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is ***not*** the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

[ESE : 2016]

1.23 The surface tension in a soap bubble of 20 mm diameter, when the inside pressure is 2.0 N/m^2 above atmospheric pressure, is

(a) 0.025 N/m (b) 0.0125 N/m

(c) 5×10^{-3} N/m (d) 4.25×10^{-3} N/m

[ESE : 2018]

1.24 A jet of water has a diameter of 0.3 cm. The absolute surface tension of water is 0.072 N/m and atmospheric pressure is 101.2 kN/m^2. The absolute pressure within the jet of water will be

(a) 101.104 kN/m^2 (b) 101.152 kN/m^2

(c) 101.248 kN/m^2 (d) 101.296 kN/m^2

[ESE : 2018]

1.25 A glass tube of 2.5 mm internal diameter is immersed in oil of mass density 940 kg/m^3 to a depth of 9 mm. If a pressure of 148 N/m^2 is needed to form a bubble which is just released, what is the surface tension of the oil ?

(a) 0.041 N/m (b) 0.043 N/m

(c) 0.046 N/m (d) 0.050 N/m

[ESE : 2018]

■■■■

Answers Fluid Properties

1.1 (a)	1.2 (c)	1.3 (a)	1.4 (a)	1.5 (c)	1.6 (a)	1.7 (b)	1.8 (b)	1.9 (d)
1.10 (d)	1.11 (c)	1.12 (a)	1.13 (a)	1.14 (a)	1.15 (d)	1.16 (a)	1.17 (b)	1.18 (d)
1.19 (c)	1.20 (b)	1.21 (c)	1.22 (c)	1.23 (c)	1.24 (c)	1.25 (a)		

Explanations Fluid Properties

1.1 (a)

1 atm = 10.1 m of water
= 760 mm of Hg
= 1013 millibar
= 101.3 kPa
= 1.013 kgf/cm^2
= 0.1013 N/mm^2 (MPa)

$$1 \text{ millibar} = \frac{1}{1013}\text{atm}$$

$$1 \text{ mm Hg} = \frac{1}{760}\text{atm}$$

$$1 \text{ N/mm}^2 = \frac{1}{0.1013}\text{atm}$$

$$1 \text{ kgf/cm}^2 = \frac{1}{1.013}\text{atm}$$

From the above relation, it is clear that

1 millibar < 1 mm Hg < 1 kgf/cm^2 < 1 N/mm^2

1.2 (c)

$d = 1 \times 2 = 2$ mm

$$\Delta h = \frac{4\sigma}{d\gamma_w} = \frac{4 \times 75 \times 10^{-3}}{2 \times 10^{-3} \times 9.81 \times 1000}$$

= 0.015 m = 15 mm

1.3 (a)

Horizontal line representing zero shear stress for any velocity gradient is the condition for ideal fluid. The curve B represents dilatant fluid.

$$\tau = \mu\left(\frac{du}{dy}\right)^n \qquad n > 1$$

For pseudoplastic fluid,

$$\tau = \mu\left(\frac{du}{dy}\right)^n \qquad n < 1$$

For thixotropic fluid,

$$\tau = \tau_0 = \mu\left(\frac{du}{dy}\right)^n \qquad n < 1$$

For rheopectic fluid,

$$\tau = \tau_0 = \mu\left(\frac{du}{dy}\right)^n \qquad n > 1$$

For plastic fluid,

$$\tau = \tau_0 + \mu\left(\frac{du}{dy}\right) \text{i.e.} \qquad n = 1$$

1.4 (a)

Newtonian Fluids: Air, water, mercury, glycerine, kerosene and other engineering fluids under normal circumstances.

Pseudoplastic: Fine particle suspension, gelatine, blood, milk, paper pulp, polymeric solutions such as rubbers, paints.

Dilatant fluids: Ultra fine irregular particle suspension, sugar in water, aqueous suspension of rice starch, quicksand, butter, printing ink.

Ideal plastics or Bingham fluids: Sewage sludge, drilling muds.

Visco-elastic fluids: Liquid solid combination in pipe flow, bitumen, tar, asphalt, polymerized fluids with drag reduction features.

Thixotropic: Printer's ink, crude oil, lipstick, certain paints and enamels.

Rheopectic fluids: Very rare liquid-solid suspensions, gypsum suspension in water and bentonite solutions.

1.5 (c)

For thixotropic fluid $\tau = \tau_0 + \mu\left(\frac{du}{dy}\right)^n \; n < 1$

As shear stress τ increases viscosity increases with higher rates of shear strain.

1.6 (a)

(i) Water is about 50 times more viscous than air.

(ii) Castor oil is about 1000 times more viscous than water.

(iii) Crude oil about 10 times more viscous than water.

(iv) Gasoline is about 1/3 times viscous than water.

Kinematic viscosity of air is more than that of water

1.7 (b)

Example of Newtonian fluids: Air, Water, Kerosene oil, Diesel oil

Example of non-Newtonian fluids: Toothpaste, Human blood, Paint, Shampoo.

1.8 (b)

Kinematic viscosity of air is greater because the density of air is very small compared to that of water.

1.9 (d)

Shear stress, $\tau = \mu\frac{du}{dy} = \mu(0.5 - 2y)$

at $y = 0.2$ m

$\tau = 0.9 \times (0.5 - 2 \times 0.2) = 0.09$ N/m^2

1.10 (d)

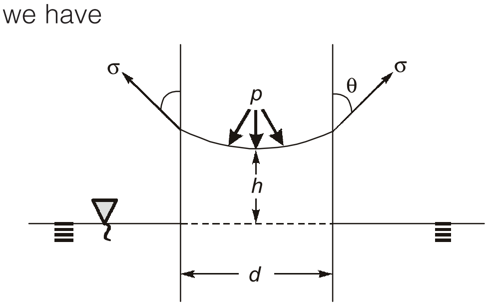
$$\text{Force, } F = \mu\frac{du}{dy} \times A$$

$$= 0.0014 \times \frac{0.2}{0.02 \times 10^{-2}} \times 0.15 = 0.21 \text{ N}$$

Power required = $F \times v = 0.21 \times 0.2 = 0.042$ W

1.11 (c)

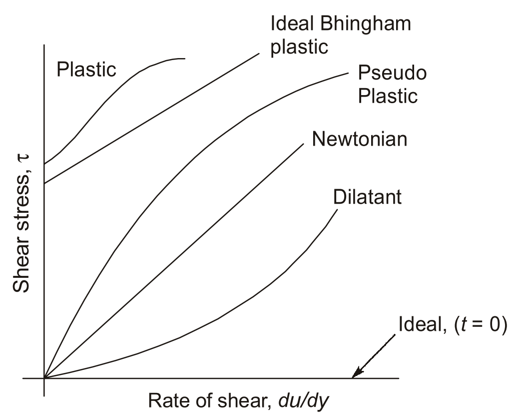
Let us suppose that the level of liquid has risen (or fallen) by 'h' above (or below) the general liquid surface when a tube of diameter 'd' is inserted in the liquid. For equilibrium of vertical forces acting on the mass of liquid lying above (or below) the general liquid level, the weight of liquid column 'h' (or the total internal pressure in the case of capillary depression) must be balanced by the force, at surface of the liquid, due to surface tension σ. Thus, equating these two forces we have



$$\frac{w\pi d^2}{4} \times h = \pi d\,\sigma\cos\theta$$

$$\Rightarrow \qquad h = \frac{4\sigma\cos\theta}{wd}$$

1.12 (a)



1.13 (a)

Viscosity of liquids varies inversely with temperature so as the glue is dries up and cools down, its viscosity increases. Thus movement of two blocks of wood welted with hot glue would require greater effort.

1.14 (a)

Specific gravity is the ratio of specific weight of a fluid to the specific weight of a standard fluid. Being a ratio of two quantities with same units, specific gravity has no unit.

$\therefore M^oL^oT^o$

Coefficient of viscocity $= \mu$

$$\text{unit of } \mu = Ns/m^2 = (MLT^{-2})T/L^2 = ML^{-1}T^{-1}$$

Kinematic viscocity :

$$\nu = \frac{\mu}{\rho}$$

$$\text{unit of } \nu = m^2/s = L^2T^{-1} = M^oL^2T^{-1}$$

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{MLT^{-2}}{L^2} = ML^{-1}T^{-2}$$

1.15 (d)

Poise is unit of dynamic viscocity.

$$\text{Poise} = \frac{\text{Dyne} - \text{s}}{\text{cm}^2}$$

$$1 \text{ Poise} = 0.1 \text{ Ns/m}^2$$

1.16 (a)

At boiling point the vapour pressure of a fluid becomes equal to the atmospheric pressure. Water boils at 100°C therefore at 100°C at sea level the vapour pressure, is equal to the atmospheric pressure.

Surface tension is caused by the force of cohesion between liquid molecules. Viscocity is exhibited by only fluid under dynamic conditions. Air is about 20000 times more compressible than water.

1.17 (b)

Dynamic viscosity is the property of fluid in motion in which one layer of fluid exerts viscous force on the other layer. Cavitation occurs due to negative pressure.

Ideal fluids have no viscosity and surface tension and they are incompressible.

1.18 (d)

As the temperature increases, molecules move faster and there is an increase in molecular interaction. Molecules start colliding with each other, retarding the motion of gases, resulting in increase in viscosity of gases.

1.19 (c)

Fluid pressure is a scalar quantity. Its magnitude is defined but its direction is not. Fluid thrust can act in any direction.

1.20 (b)

$$p \times \frac{\pi d^2}{4} = \sigma \times 2(2\pi r) = \sigma \times 2\pi d$$

$$\sigma = \frac{pd}{8} = \frac{2.5 \times 0.05}{8} = 0.0156 \text{ N/m}$$

1.21 (c)

In this problem, the bore is not defined properly. Here bore is used for radius.

$$h = \frac{2\sigma\cos\theta}{\rho \cdot g \cdot R}$$

$$= \frac{2\left(75\times10^{-3}\right)}{10^{3}\times9.81\times\left(1\times10^{-3}\right)}$$

$$= 15.29 \text{ mm}$$

1.23 (c)

For soap bubble

$$\Delta P = \frac{4\sigma}{R}$$

$$2 = \frac{4\sigma}{0.01}$$

$$\sigma = 5\times10^{-3} \text{ N/m}$$

1.24 (c)

For jet of water

$$\Delta P = \frac{\sigma}{R}$$

$$\Delta P = \frac{0.072}{0.15\times10^{-2}}$$

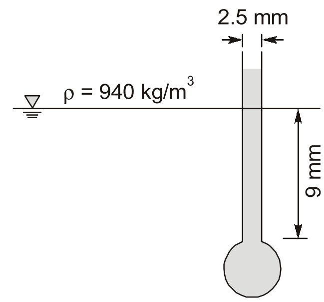
$$\Delta P = 0.048 \text{ kPa}$$

Absolute pressure within the jet

$$= 101.2 + 0.048$$

$$= 101.248 \text{ kPa}$$

1.25 (a)



$$\Delta P = \frac{2\sigma}{R}$$

$$\Delta P = 148 - (940\times9.81\times0.009)$$

$$= 148 - 82.99 = 65.01$$

Now, $65.01 = \dfrac{2\sigma}{1.25\times10^{-3}}$

$$\sigma = 0.04063 \text{ N/m}$$

■■■■

2 Manometry

2.1 A 10 m high rocket containing liquid fuel of specific gravity 1.2 lifts off at an acceleration of 5 g. The pressure on the bottom plate of the rocket during lift-off is

(a) 6.7 kg/cm^2 (b) 7.2 kg/cm^2
(c) 8.4 kg/cm^2 (d) 8.9 kg/cm^2

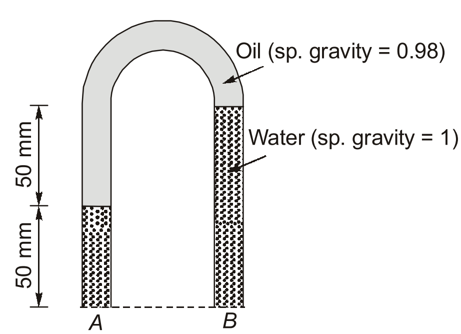
[ESE : 1995]

2.2 If a hole is made in the Torricelli's vacuum portion of a barometer, then the mercury

(a) level will fall in the stem and the mercury will collect in the reservoir
(b) level will oscillate between reservoir level and original level of the mercury in the stem
(c) will spill through the hole made
(d) level in the stem will remain at the same level indicating atmospheric pressure

[ESE : 1995]

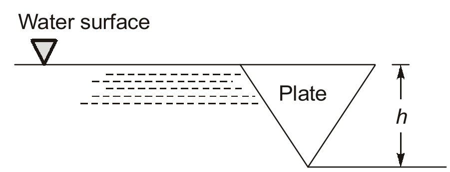
2.3 In the set-up shown in the given figure, assuming the specific weight of water as 10,000 N/m^3, the pressure difference between the points *A* and *B* will be



(a) 10 N/m^2 (b) –10 N/m^2
(c) 20 N/m^2 (d) –20 N/m^2

[ESE : 1999]

2.4 An equilateral triangular plate is immersed in water as shown in the figure below. The centre of pressure below the water surface is at a depth of



(a) $\frac{3h}{4}$ (b) $\frac{h}{3}$
(c) $\frac{2h}{3}$ (d) $\frac{h}{2}$

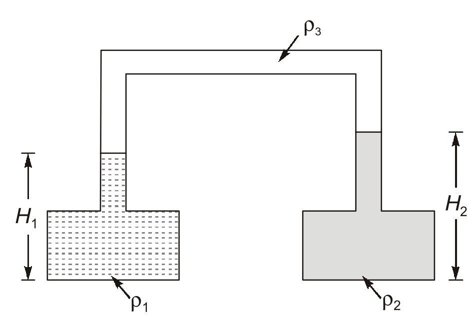
[ESE : 1999]

2.5 An isosceles triangular plate of base 3 m and altitude 3 m is immersed vertically in an oil of specific gravity 0.8. The base of the plate coincides with the free surface of oil. The centre of pressure will lie at a distance of (from free surface)

(a) 2.5 m (b) 2 m
(c) 1.5 m (d) 1 m

[ESE : 2002]

2.6 Which one of the following expresses the difference in the pressure at the floors of the tank shown above in the figure?



(a) $(\rho_2 - \rho_1)gH_2$
(b) $(\rho_2 - \rho_1)gH_1$
(c) $\rho_1 gH_1 + \rho_3 gH_2 - \rho_2 gH_2$
(d) $\rho_1 gH_1 + \rho_3 g(H_2 - H_1) - \rho_2 gH_2]$

where ρ_1, ρ_2 and ρ_3 are the densities of the different fluids.

[ESE : 2006]

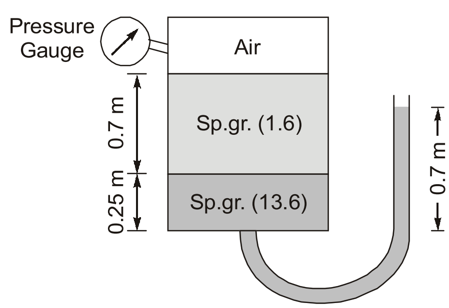
2.7 Multi U-tube manometers with different fluids are used to measure
(a) low pressures
(b) medium pressures
(c) high pressures
(d) very low pressures

[ESE : 2006]

2.8 A pressure gauge reads 57.4 kPa and 80 kPa, respectively at heights of 8 m and 5 m fitted on the side of a tank filled with liquid. What is the approximate density of the liquid in kg/m^3?
(a) 393 (b) 768
(c) 1179 (d) 7530

[ESE : 2008]

2.9 In the below figure the pressure gauge will record a gauge pressure equivalent to



(a) 6.12 m of water
(b) 1.21 m of mercury
(c) 0.5 bar
(d) 34,000 Pa

[ESE : 2011]

2.10 The absolute pressure at a point 2.5 m below the clear water surface is measured as 125.703 kN/m^2. If the atmospheric pressure is taken as 101.325 kN/m^2, the gauge pressure in kN/m^2 at this point would be
(a) 113.514 (b) 24.378
(c) 45.401 (d) 56.757

[ESE : 2013]

2.11 A centrifugal pump delivers a manometric head of 12 m when pumping a liquid of relative density 0.8. If all other factors remain the same but the liquid has a relative density of 1.2, the new manometric head would be:
(a) 8 m (b) 10 m
(c) 12 m (d) 18 m

[ESE : 2013]

2.12 The standard atmospheric pressure is 101.32 kPa. The local atmospheric pressure is 91.52 kPa. If a pressure at a flow path is recorded at 22.48 kPa (gauge), it is equivalent to
(a) 69.04 kPa (abs) (b) 88.4 kPa (abs)
(c) 114.0 kPa (abs) (d) 123.0 kPa (abs)

[ESE : 2014]

2.13 In a siphon, the summit is 5 m above the water level in the tank from which the flow is being discharged. If the head loss from the inlet to the summit is 2.5 m and the velocity head at the summit is 0.5 m, (taking γ = 10 appropriate units) the pressure head at the summit is
(a) –80 kPa
(b) –3 m of water (abs)
(c) 5 m of water (abs)
(d) 18 m of water (abs)

[ESE : 2018]

■■■■

Answers Manometry

2.1 (b) 2.2 (a) 2.3 (b) 2.4 (d) 2.5 (c) 2.6 (d) 2.7 (c) 2.8 (b) 2.9 (c)
2.10 (b) 2.11 (a) 2.12 (c) 2.13 (a)

Explanations Manometry

2.1 (b)

The height of fuel column, $h = 10$ m

Pressure at bottom, $p = \rho_{fuel}(a + g)h$

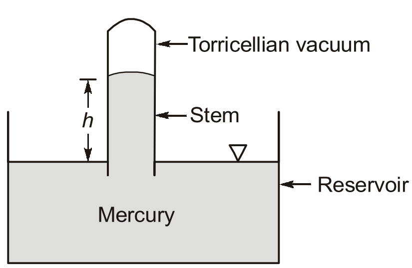
where a is the upward acceleration

$$\rho_{fuel} = \text{Specific gravity} \times \rho_w$$
$$= 1.2 \times 1000$$
$$= 1200 \text{ kg/m}^3$$
$$\therefore \quad p = 1200 \times (5g + g) \times 10$$
$$= 1200 \times 6 \times 10 \times 100$$
$$= 7.2 \times 10^5 \text{ N/m}^2$$
$$= 7.2 \text{ kg/cm}^2$$

2.2 (a)

Barometer measures the atmospheric pressure.

$$p_{atm} = \rho_{Hg}\, gh$$



If there is a hole in the vacuum portion, then there will be zero pressure difference at top and bottom of the stem. The mercury in the stem will show zero reading i.e. it will fall and get collected in the reservoir.

2.3 (b)

The equation for pressure at B is

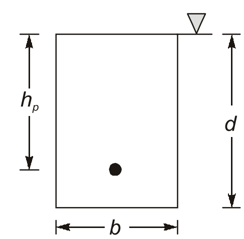
$$p_A - \rho_w gh - \rho_{oil} gh + 2\rho_w gh = p_B$$
$$\therefore \quad p_A - p_B = \rho_{oil} gh - \rho_w gh$$
$$= (0.98 - 1) \times 10000 \times 0.05$$
$$= -10 \text{ N/m}^2$$

2.4 (d)

The centre of pressure for certain bodies are:

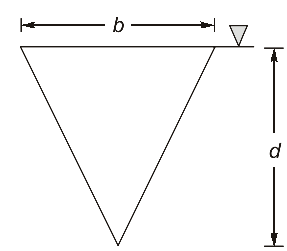
(a) Rectangular with face coinciding with free surface

$$h_p = \frac{2d}{3}$$



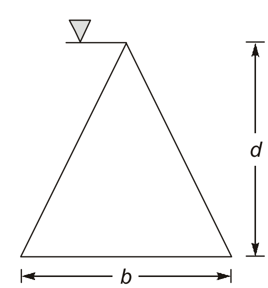
(b) Triangle with base at the free surface

$$h_p = \frac{d}{2}$$



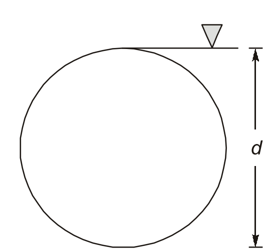
(c) Triangle with apex at free surface

$$h_p = \frac{3d}{4}$$

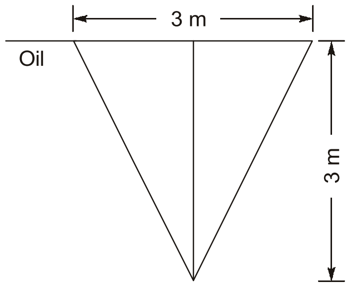


(d) Circle touching free surface

$$h_p = \frac{5d}{8}$$



2.5 (c)



Centre of Pressure depth

$$\bar{h} = \left(\bar{x} + \frac{I_G}{A\bar{x}}\right)$$

$$= \frac{3}{3} + \left(\frac{3 \times 3^3}{36 \times \frac{1}{2} \times 3 \times 3 \times \frac{3}{3}}\right)$$

$= 1 + 0.5 = 1.5$ m

2.6 (d)

$$p_1 - \rho_1 g H_1 - \rho_3 g(H_2 - H_1) + \rho_2 g H_2 = p_2$$

$$\therefore\ p_1 - p_2 = \rho_1 g H_1 + \rho_3 g(H_2 - H_1) - \rho_2 g H_2$$

2.7 (c)

When the pressure is high U-tube manometer with different fluid of specific gravity more than that of the liquid for which pressure is to be measured.

2.8 (b)

The pressure difference may be given as

$$p_1 - p_2 = \rho g\ (h_2 - h_1)$$

$$\Rightarrow\ 80 \times 10^3 - 57.4 \times 10^3 = \rho \times 9.81 \times (8 - 5)$$

$$\Rightarrow\ 22600 = \rho \times 29.43$$

$$\Rightarrow\ \rho = 768\ \text{kg/m}^3$$

2.9 (c)

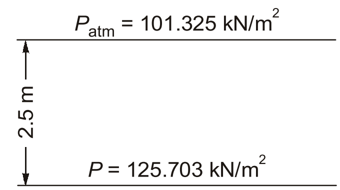
Let gauge pressure be = P

$P + (1.6 \times \rho_w) \times g \times 0.7 + (13.6 \times \rho_w) \times g \times 0.25 - (13.6 \times \rho_w) \times g \times 0.7 = 0$

$P = 5 \times g \times \rho_w$

$$= 50000 \frac{\text{N}}{\text{m}^2} = \frac{50000}{10^5} \text{bar} = 0.5\ \text{bar}$$

2.10 (b)



For gauge pressure,

$$P_{atm} = 0$$

$$\therefore\ P = 125.703 - 101.325$$

$$= 24.378\ \text{kN/m}^2$$

2.11 (a)

$$P = \rho Q g h$$

$$\therefore\ 800\ Qg(12) = 1200\ Qg(h)$$

$$\Rightarrow\ h = 8\text{m}$$

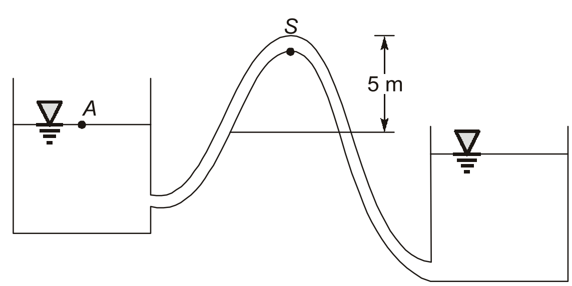
2.12 (c)

The absolute pressure = local atmospheric pressure + gauge pressure

$= 91.52 + 22.48$

$= 114$ kPa

2.13 (a)



Apply energy equation between (A) & (S)

$$\frac{P_A}{\rho g} + \frac{V_A^2}{2g} + z_A = \frac{p_s}{\rho g} + \frac{v_s^2}{2g} + z_s + h_{fs}$$

$$0 + 0 + 0 = \frac{p_s}{\rho g} + 0.5 + 5 + 2.5$$

$$\frac{p_s}{\rho g} = -8\ \text{m of}\ H_2O$$

$$p_s = -(10^3) \times (10) \times 8$$

$$= -80\ \text{kPa}$$

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3 Hydrostatic Forces

3.1 A vertical gate 6 m × 6 m holds water on one side with the free surface at its top. The moment about the bottom edge of the gate of the water force will be (γ_w is the specific weight of water)
(a) 18 γ_w (b) 36 γ_w
(c) 72 γ_w (d) 216 γ_w
[ESE : 1997]

3.2 When the water surface coincides with the top edge of a rectangular vertical gate 40 m (wide) × 3 m (deep), then the depth of centre of pressure is
(a) 1 m (b) 1.5 m
(c) 2 m (d) 2.5 m
[ESE : 2000]

3.3 If a water tank, partially filled with water is being carried on a truck, moving with a constant horizontal acceleration, the level of liquid will
(a) rise and fall alternately on the front side of the tank
(b) fall on the rear side of the tank
(c) remain the same on both sides of the tank
(d) rise on the rear side and fall on the front side of the tank
[ESE : 2000]

3.4 As the depth of immersion of a vertical plane surface increases, the location of centre of pressure
(a) falls closer to the centre of gravity of the area
(b) moves away from the centre of gravity of the area
(c) ultimately coincides with the centre of gravity of the area
(d) falls much below the centre of gravity of the area
[ESE : 2003]

3.5 A rectangular tank 10 m × 5 m in plan and 3 m deep is divided by a partition wall parallel to the shorter wall of the tank. One of the compartments contains water to a depth of 3 m, and the other a lighter liquid of specific gravity 0.75 to a depth of 2 m. The resultant pressure thrust on the partition wall is
(a) 1000 kg (b) 1500 kg
(c) 2000 kg (d) 2500 kg
[ESE : 2012]

3.6 A square gate, 1.5 m × 1.5 m, one of the vertical sides of a fully filled water tank, has one side on the free water surface. It is hinged on the lower horizontal side and is held in position by a force applied on the vertical central line at a depth of 0.75 m below the free surface. The right magnitude of this force is
(a) 500 × 9.81 N (b) 600 × 9.81 N
(c) 750 × 9.81 N (d) 1000 × 9.81 N
[ESE : 2015]

3.7 A tank is 1.8 m deep and square length of 4.5 m at the top and square length of 3 m at the bottom. The four sides are plane and each has the same trapezoidal shape. The tank is completely full of oil weighing 936 kg/m^3. What is the resultant pressure on each side?
(a) 5750 kgf (b) 5500 kgf
(c) 5250 kgf (d) 5140 kgf
[ESE : 2016]

■■■■

Answers **Hydrostatic Forces**

3.1	(d)	**3.2**	(c)	**3.3**	(d)	**3.4**	(a)	**3.5**	(*)	**3.6**	(*)	**3.7**	(a)

Explanations Hydrostatic Forces

3.1 (d)

The force on the gate = $\rho g h_c A$

$$= \gamma \times 3 \times 36 = 108\,\gamma$$

The depth of centroid from free surface,

$$h_p = \frac{2h}{3} = \frac{2\times 6}{3} = 4\text{ m}$$

From bottom edge the centroid will be at a distance of 6 – 4 = 2 m

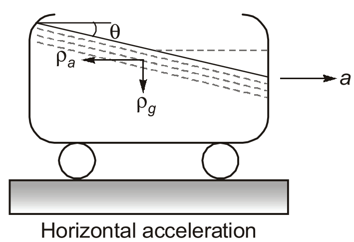
Therefore moment about the bottom edge of the gate of the water force = 108 × 2γ = 216 γ

3.2 (c)

Depth of centre of pressure,

$$h_p = \frac{2d}{3} = \frac{2\times 3}{3} = 2\text{m}$$

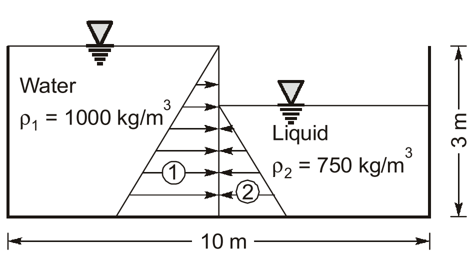
3.3 (d)



$$\theta = \tan^{-1}\left(\frac{a}{g}\right)$$

Water rises by θ angle on rear side and falls on the front end.

3.5 (*)



$$P_1 = \rho_1 \times \frac{3}{2}\times(3\times 5)$$

$$= 1000\times\frac{3}{2}\times 3\times 5 = 22500\text{ kg}$$

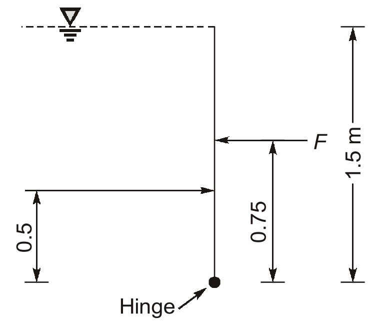
$$P_2 = \rho_2 \times \frac{2}{2}\times(2\times 5)$$

$$= 750 \times 1 \times 2 \times 5 = 7500\text{ kg}$$

Resultant pressure thrust,

$$P_R = P_1 - P_2 = 15000\text{ kg}$$

3.6 (*)

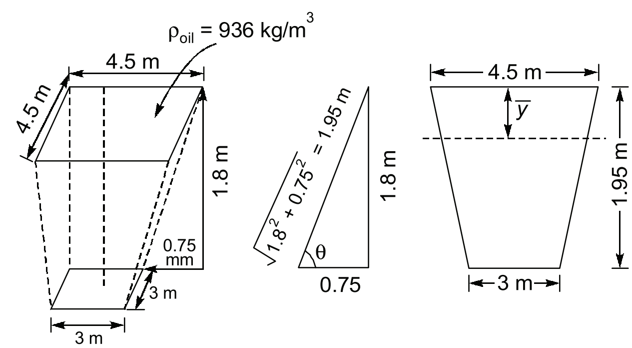


$$(\rho g A\bar{h})0.5 = F \times 0.75$$

$$1000 \times 9.81 \times (1.5 \times 1.5) \times 0.75 \times 0.5 = F \times 0.75$$

$$F = 1125 \times 9.81\text{ N}$$

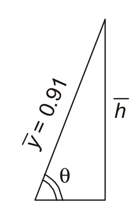
3.7 (a)



$$\sin\theta = \frac{1.8}{1.95}$$

$$\bar{y} = \left[\frac{2(3)+4.5}{3+4.5}\right]\times\frac{1.95}{3} = 0.91$$

Now, $\sin\theta = \dfrac{\bar{h}}{0.91}$



$$\frac{1.8}{1.9} = \frac{\bar{h}}{0.91}$$

$$\bar{h} = 0.84$$

$$F = \rho\cdot g\cdot\bar{h}\cdot A$$

$$= (936)(9.81)(0.84)$$

$$\times\left[\frac{1}{2}\times(3+4.5)\times 1.95\right]\text{N}$$

$$= 5749.38\text{ kgf}$$

■■■■

4 Buoyancy & Floatation

4.1 As depth of immersion of a vertical plane surface increases, the location of centre of pressure
(a) comes closer to the centre of gravity of the area
(b) moves apart from the centre of gravity of the area
(c) ultimately coincides with the centre of gravity of the area
(d) remains unaffected

[ESE : 1995]

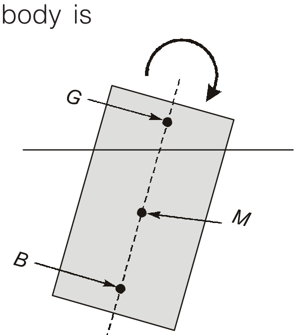
4.2 A symmetrical right-circular cone of wood floats in fresh water with axis vertical and the apex down. The axial height of the cone is 1 unit. The submerged portion has a height h, measured upwards from the apex. What would be the height of the centre of buoyancy from the apex?
(a) $\frac{h}{2}$ (b) $\frac{5}{8}h$
(c) $\frac{2}{3}h$ (d) $\frac{3}{4}h$

[ESE : 1998]

4.3 A homogeneous circular cylinder of length h, radius r and specific gravity S, floats in water. It is noted that $r = 2/3h$ Under which one of the following conditions will the flotation be unstable?
(a) $0.11 \le S < 0.22$ (b) $0.22 \le S < 0.33$
(c) $0.33 \le S < 0.66$ (d) $0.66 \le S \le 0.99$

[ESE : 1998]

4.4 A body is floating as shown in the given figure. The centre of buoyancy, centre of gravity and metacentre are labelled respectively as B, G and M. The body is



(a) vertically stable
(b) vertically unstable
(c) rotationally stable
(d) rotationally unstable

[ESE : 2000]

4.5 A metal cube of size 15 cm × 15 cm × 15 cm and specific gravity 8.6 is submerged in a two-layered liquid, the bottom layer being mercury and the top layer being water. The percentage of the volume of the cube remaining above the interface will be, approximately
(a) 68 (b) 63
(c) 40 (d) 25

[ESE : 2001]

4.6 Consider the following statements related to buoyancy in fluid statics:
1. Principle of buoyancy is applicable both to floating bodies and to submerged bodies.
2. Archimedes formulated the first theory of buoyancy.
3. In analyzing buoyancy of a floating body it is assumed that the resultant vertical force passes through centre of pressure.
4. In a free-body diagram of a floating body summation of all horizontal forces is taken as zero.

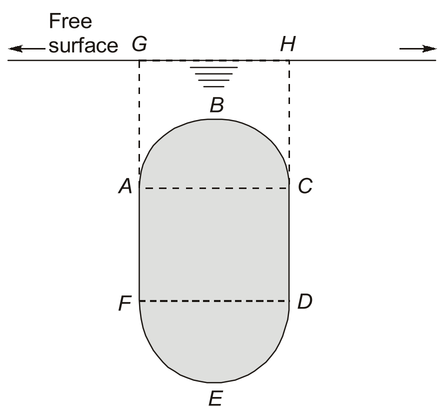
Which of these statements are correct?
(a) 1, 3 and 4 (b) 1, 2 and 4
(c) 1, 2 and 3 (d) 2, 3 and 4

[ESE : 2003]

4.7 A solid cylinder of length L, diameter D and specific gravity 0.6 floats in neutral equilibrium in water with its axis vertical. What is the ratio of L to D?
(a) $\frac{\sqrt{3}}{2}$ (b) $\frac{2\sqrt{3}}{5}$
(c) $\frac{4}{5\sqrt{3}}$ (d) $\frac{5}{4\sqrt{3}}$

[ESE : 2004]

4.8 Consider the figure below relating to buoyancy in water.



What will be the downward force upon the top of the body *ABCDEF*?

(a) The weight of the liquid column *ABCHG*
(b) The weight of the liquid column *DEFGH*
(c) The weight of the liquid column *ABCHG* – the weight of the liquid column *DEFGH*
(d) The weight of the liquid column *ABCHG* + the weight of the liquid column *DEFGH*

[ESE : 2009]

4.9 A rectangular pontoon has a width of 6 m, a length of 12 m, and a draught of 1.5 m in fresh water (density = 1000 kg/m^3). Its draught in sea water having density of 1025 kg/m^3 is

(a) 1.04 m (b) 1.24 m
(c) 1.46 m (d) 1.50 m

[ESE : 2014]

4.10 A ship has a metacentric height of 0.90 m and its period of rolling is 20 seconds. The relevant radius of gyration is nearly

(a) 5.5 m (b) 7.5 m
(c) 9.5 m (d) 11.5 m

[ESE : 2015]

4.11 A solid cylinder of length *H*, diameter *D* and of relative density *S* floats in neutral equilibrium in water with its axis vertical. What is the ratio of *H* to *D* if *S* = 0.6?

(a) 0.86 (b) 0.72
(c) 0.52 (d) 0.46

[ESE : 2016]

4.12 A solid cylinder of circular section of diameter *d* is of material with specific gravity S_s. This floats in a liquid of specific gravity S_l. What is the maximum length of the cylinder if equilibrium is to be stable with the cylinder axis vertical?

(a) $\dfrac{dS_s}{2\sqrt{S_s(S_l - S_s)}}$ (b) $\dfrac{dS_l}{\sqrt{8S_s(S_l - S_s)}}$

(c) $\dfrac{dS_l}{\sqrt{2S_s(S_l - S_s)}}$ (d) $\dfrac{d}{\sqrt{8(S_l - S_s)}}$

[ESE : 2016]

4.13 An ocean liner, 240 m long and 24 m wide, displaces 654 MN of sea-water (ρ = 1025 kgf/m^3). The second moment of inertia of the water plane about its fore-aft axis is 2/3 of that of the circumscribing rectangle. The position of the centre of buoyance is 2.30 m below the centre of gravity. How high is metacentre above the centre of buoyancy (to the nearest cm)?

(a) 49 cm (b) 53 cm
(c) 58 cm (d) 65 cm

[ESE : 2017]

■■■■

Answers Buoyancy & Floatation

4.1 (a)	4.2 (d)	4.3 (c)	4.4 (d)	4.5 (c)	4.6 (b)	4.7 (d)	4.8 (a)	4.9 (c)
4.10 (c)	4.11 (b)	4.12 (b)	4.13 (b)					

Explanations Buoyancy & Floatation

4.1 (a)

The centre of pressure from free surface is

$$h_p = h_c + \frac{I_G}{Ah_c}$$

where

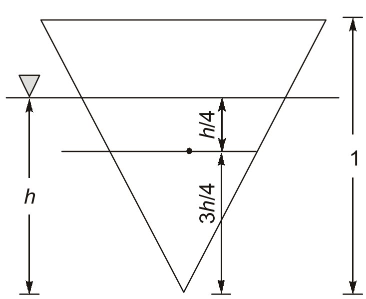
h_c is depth of centroid from free surface

I_G is moment of inertia of vertical plane about horizontal centroidal axis

A is area of the plane

As depth of immersion increases, h_c increases and therefore $\frac{I_G}{Ah_c}$ decreases. It means that centre of pressure comes closer to centroid.

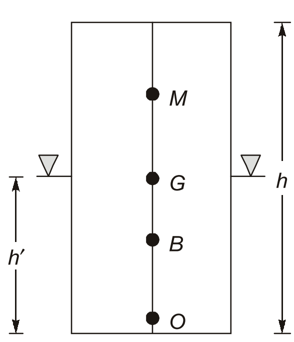
4.2 (d)



The centre of buoyancy from the water surface is $h/4$. So centre of buoyancy from apex is $3h/4$.

4.3 (c)

For unstable floatation GM < 0 i.e., metacentric height will be less than zero.



$$h'\pi r^2 = Sh\pi r^2$$

$$h = h'/S$$

$$OB = h'/2$$

$$OG = h/2$$

$$BM = I_G/V$$

$$r = \frac{2}{3}h = \frac{\pi r^4/4}{\pi r^2 h'} = \frac{r^2}{4h'}$$

$$= \frac{r^2}{4Sh} = \frac{\left(\frac{2}{3}h\right)^2}{4Sh} = \frac{h}{9S}$$

$$BG = \frac{h}{2}(1-S)$$

$$GM = BM - BG$$

$$= \frac{h}{9S} - \frac{h}{2}(1-S) < 0$$

$$= 2 - 9S + 9S^2 < 0$$

$$= 2 - 6S - 3S + 9S^2 < 0$$

$$= 2(1-3S) - 3S(1-3S) < 0$$

$$= (1-3S)(2-3S) < 0$$

$$S > \frac{1}{3} \text{ and } S < \frac{2}{3}$$

So $\frac{1}{3} < S < \frac{2}{3}$

4.4 (d)

Since metacentre is below centre of gravity the body is in unstable equilibrium in rotation.

4.5 (c)

Let the percentage of cube remain above interface is p. The buoyancy force is $\rho_w(0.01p) \times 15^3 g + 13.6\rho_w(1-0.01p) \times 15^3 g$

This will be equal to the weight of the cube $= 8.6\rho_w 15^3 g$

$\therefore\ 0.01p + 13.6\,(1-0.01p) = 8.6$

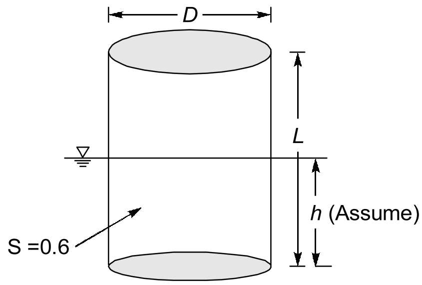
$12.6 \times 0.01p = 13.6 - 8.6 = 5$

$\therefore\ p = 39.7\%$

4.6 (b)

The resultant vertical force passes through centre of buoyancy.

4.7 (d)



$$GM = 0$$

$$\frac{I}{V_{Dis}} - BG = 0$$

$$\frac{\frac{\pi D^4}{64}}{\frac{\pi D^2}{4} \times h} = \frac{L}{2} - \frac{h}{2}$$

$$\frac{D^2}{8h} = L - h \quad \text{...(i)}$$

Force balancing

Weight of body = F_B

$$(600)\frac{\pi D^2}{4} \times L \times g = 10^3 \times \frac{\pi D^2}{4} \times h \times g$$

$$h = 0.6\,L \quad \text{...(ii)}$$

From (i) and (ii)

$$\frac{D^2}{8(0.6L)} = L - 0.6\,L$$

$$\frac{D^2}{L^2} = 8(0.6)\,(0.4)$$

$$\frac{D}{L} = \frac{4\sqrt{3}}{5}$$

or $$\frac{L}{D} = \frac{5}{4\sqrt{3}}$$

4.8 (a)

The downward force upon the top of the body *ABCDEF* will be equal to the weight of the liquid contained in the portion *ABC* extending vertically above the curved surface upto the free surface of the liquid.

4.9 (c)

In both the liquids water and sea water, the weight of the body is balanced by buoyant force so

$$F_{B_1} = F_{B_2}$$

$$1000 \times (6 \times 12 \times 1.5) \times g = 1025 \times (6 \times 12 \times h) \times g$$

$$h = 1.463\text{ m}$$

4.10 (c)

Time period,

$$T = 2\pi\sqrt{\frac{k^2}{gGM}} \text{ seconds}$$

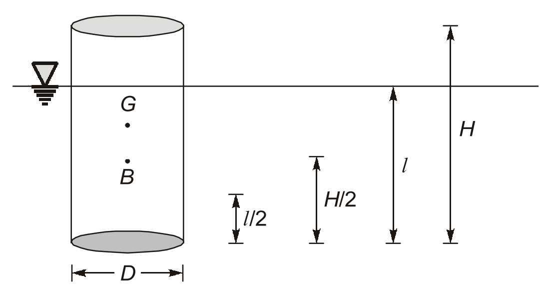
k = radius of gyration

GM = metacentric height = 0.90 m

$$20 = 2\pi\sqrt{\frac{k^2}{9.81 \times 0.9}}$$

$$k = 9.5\text{ m}$$

4.11 (b)



$$F_B = M_b \cdot g$$

$$(10^3)\left(\frac{\pi D^2}{4}\right) \cdot l \cdot g = (600) \cdot g \cdot H\left(\frac{\pi D^2}{4}\right)$$

$$l = 0.6\,H \quad \text{...(i)}$$

For Neutral equilibrium,

$$GM = 0$$

$$\frac{I}{\forall} - BG = 0$$

$$\frac{\frac{\pi D^4}{64}}{\frac{\pi D^2 \cdot l}{4}} - \frac{1}{2}[H - l] = 0$$

$$\frac{D^2}{16} - \frac{1}{2}[H - l] = 0$$

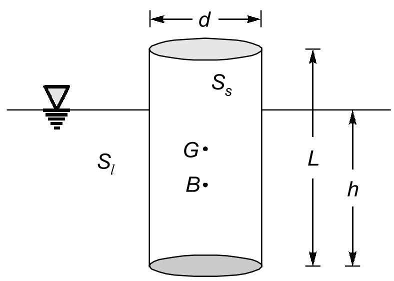
$$\frac{D^2}{8} = H - l$$

$$\frac{D^2}{8l} = H[1-0.6]$$

$$\frac{H^2}{D^2} = \frac{1}{8\times0.6\times0.4}$$

$$\frac{H}{D} = 0.721$$

4.12 (b)



$$M_b g = F_B$$

$$\rho_s\left[\frac{\pi d^2}{4}\right]Lg = \rho_l\left[\frac{\pi d^2}{4}\right]hg$$

$$\rho_s L = \rho_l h$$

$$h = \frac{\rho_s}{\rho_l}\times L$$

or $$h = \frac{S_s}{S_l}\times L \qquad \text{...(i)}$$

Take GM = 0

$$\frac{I}{\forall} - BG = 0$$

$$\frac{\frac{\pi d^4}{64}}{\frac{\pi d^2}{4}\times h} - \frac{1}{2}(L-h) = 0$$

$$\frac{d^2}{16h} - \frac{1}{2}[L-h] = 0$$

$$\frac{d^2}{8h} = L - h$$

$$d = \sqrt{8h(L-h)}$$

$$= \sqrt{8\frac{S_l}{S_l}L\left(L-\frac{S_s L}{S_l}\right)}$$

$$= L\sqrt{8\frac{S_s}{S_l}\left[1-\frac{S_s}{S_l}\right]}$$

$$= \frac{L}{S_l}\sqrt{8S_s[S_l-S_s]}$$

$$L = \frac{d\times S_l}{\sqrt{8S_s(S_l-S_s)}}$$

4.13 (b)

$$\rho_{\text{sea water}}\times\forall_{\text{dis}}\times g = \text{weight of displaced water}$$

$$1025\times\forall_{\text{dis}}\times9.81 = 654\times10^6$$

$$\forall_{\text{dis}} = 65040.65\ \text{m}^3$$

$$\frac{I}{\forall_{\text{dis}}} - \text{BG} = \text{GM}$$

$$\frac{\frac{2}{3}\times240\times\frac{24^3}{12}}{65040.65} - 2.3 = \text{GM}$$

$$2.833 - 2.3 = \text{GM}$$

So, GM = 0.533 m

= 53.3 cm

≃ 53 cm

■■■■