GPSC - CIVIL

Fluid Mechanics and Hydraulic Machines

"Success Consists of going from Failure without Loss of Enthusiasm."

Winston Churchill

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

PREFACE

Fluid Mechanics and Hydraulic Machines, a comprehensive refresher for GPSC, is designed for aspirants who are targeting GPSC and definitely useful for other job oriented technical exams such as RPSC, MPSC, MPPSC, UPSC, RRB JE, SSC JE etc by Exam Acharya. This book provides knowledge of the field and also helpful hints to make the study and understanding easier to the aspirants. Each chapter in this book has been meticulously designed by the state PSC's toppers and experienced faculties with the idea of maximizing the potential of an individual in a limited time. Every chapter in the book is logically divided to various sections while ensuring that the content in the book is self-sufficient and requires no cross referencing. Extra efforts have been made to simplify and summarize the theoretical aspects of the subject. Over all the whole content of the book furnishes the students with the knowledge of the subject and paves a confident path for the aspirants to accomplish success in state PSC's.

Key Features:

- Conforms to the latest syllabus prescribed by GPSC.
- Presents each topic in a lucid manner for a quick recap.
- Facilitates quick revision of concepts.

Prepared by

Mukesh Rai

Guidelines for the Aspirants

How to use this book?

- While preparing a subject, first cover all the theoretical topics of each chapter so that you will get a basic idea about particular topic.
- After covering the theoretical portion, solve the questions under "CLEAR YOUR CONCEPT" title.
- After covering the questions under "CLEAR YOUR CONCEPT" move towards the next set of questions under "TEST YOUR SELF" title.
- After finishing the theory and numerical portion of this book for each chapter, solve previous year GPSC questions which is provided in GPSC – CIVIL ENGINEERING book.
- After solving the previous year GPSC questions, for getting best results give the weekly, mid subject and full-length test prepared by Exam Acharya.

FLUID MECHANICS AND HYDRAULIC MACHINES

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.

INDEX

CHAPTER – 1

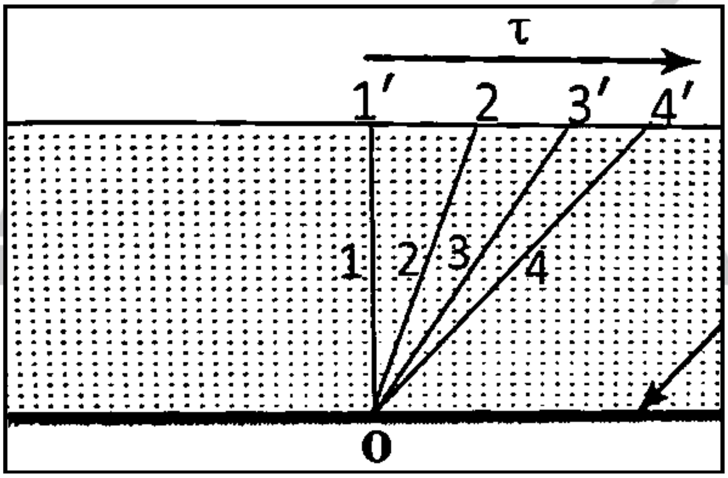
FLUID PROPERTIES

FLUID MECHANICS

Fluid mechanics is the branch of engineering science which involves the study of fluids and the forces on them.

Fluid

A fluid is a substance which deforms continuously when subjected to external shear stress however smaller the shear stress may be.



Shear stress on a fluid body

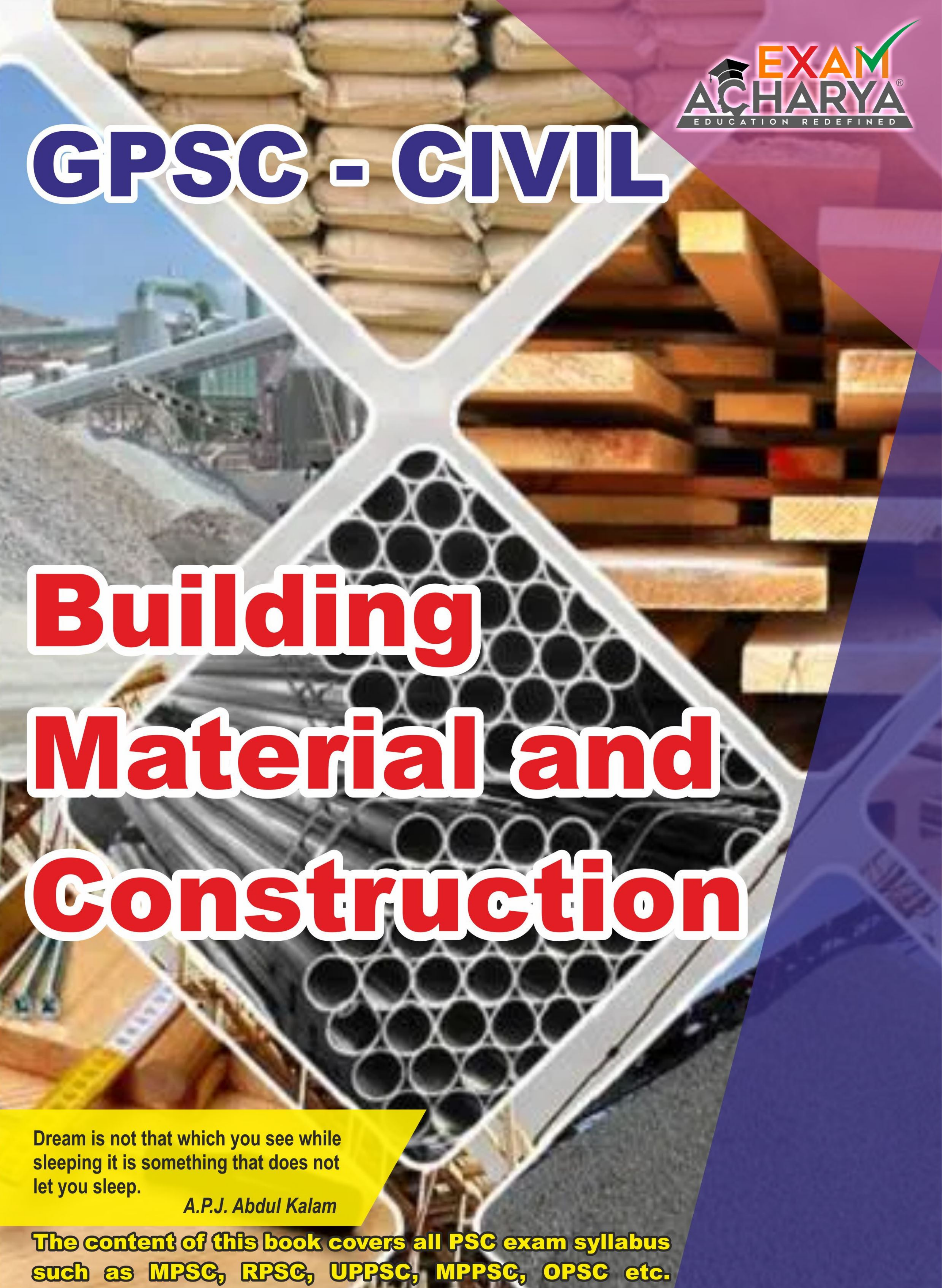
The continuous deformation of fluid under the action of shear stress causes a flow. Figure above shows a shear stress (τ) applied at certain location in a fluid, the element O11′ which is initially at rest, will move to O22′ then to O33′ and to O44′ and so on.

If a fluid is at rest, no shear stresses will act on it. The forces acting in the fluid will be normal to the planes on which they act.

Both liquids and gases come under the category of fluids.

EXAM ACHARYA
EDUCATION REDEFINED

GPSC - CIVIL



Building Material and Construction

Dream is not that which you see while sleeping it is something that does not let you sleep.

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Viscosity of liquids decreases with temperature whereas viscosity of gases increases with increase in temperature.

Fluids with increasing order of viscosity are air, gasoline, water, crude oil, castor oil.

Viscosity of water at 1°C is 1 Centipoise.

Viscosity of liquid is due to cohesion and molecular momentum transfer.

Factors affecting viscosity

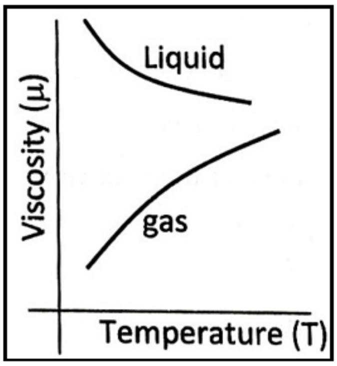
Effect of temperature

Liquids

In liquids viscosity is due to intermolecular cohesion. As temperature increases, cohesion reduces and hence viscosity decreases.

Gases

Transfer of molecular momentum (interchange between layers) is the reason for resistance against motion in gases. As temperature increases, the gases become more dynamic, more collisions leading to more transfer of molecular momentum between different layers. Hence, as temperature increases, viscosity of gases increases.



Graphical relation for viscosity vs temperature.

NEWTON'S LAW OF VISCOSITY

Shear stress between two adjacent fluid layers is directly proportional to rate of shear strain or rate of angular deformation or velocity gradient at that point.

$$\tau \propto \frac{d\phi}{dt} \text{ or } \frac{du}{dy}$$

$$\textbf{Shear stress, } \tau = \mu \left(\frac{du}{dy}\right)$$

μ = viscosity (property of the fluid)

$\frac{du}{dy}$ = rate of shear strain or velocity gradient or rate of angular deformation

SI Unit: $\frac{N.S}{m^2}$ **or Pa.s or Kg/ms**

CGS unit: **Poise**

$\therefore$ 1 poise = $\frac{1g}{cm.s}$

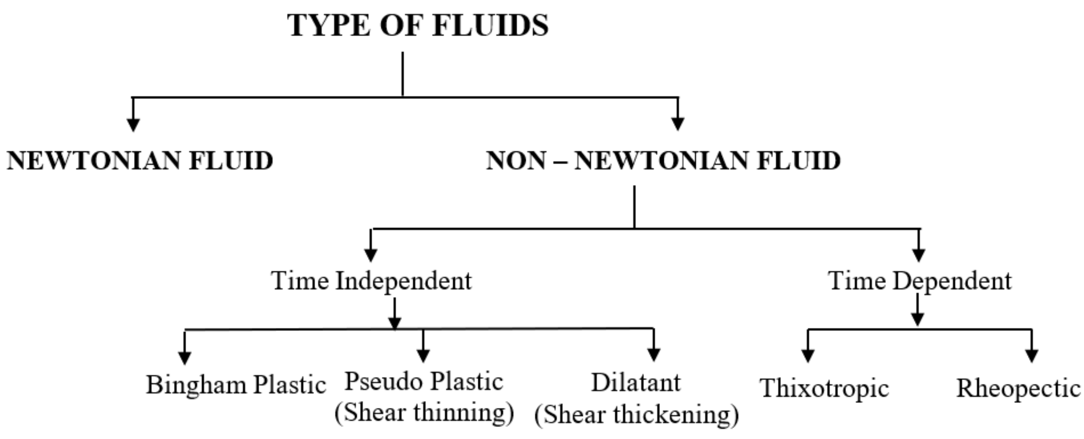
$\therefore \frac{1\ Kg}{m.s} = \frac{10^3 g}{10^2 cm.s}$

$\frac{1\ Kg}{m.s} = \frac{10\ g}{cms}$

1 Pa.s = 10 Poise

EXAM ACHARYA™ EDUCATION REDEFINED

Dimension: **[$ML^{-1}T^{-1}$]**



P = intensity of pressure

σ = Surface tension

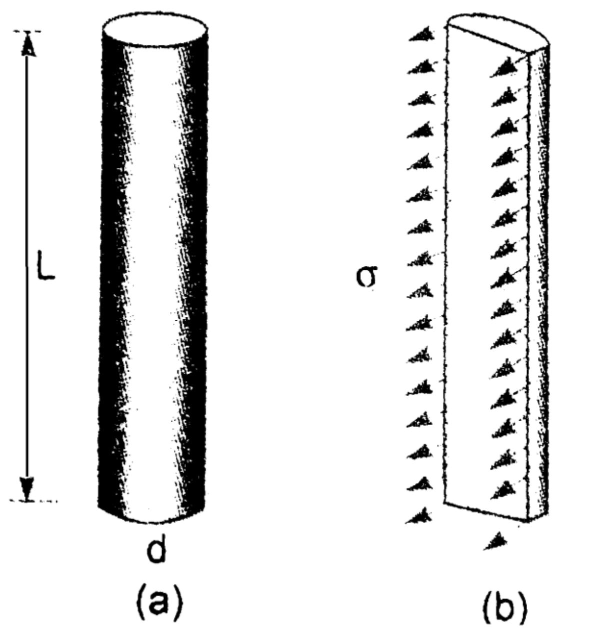
r = Radius of the droplet (sphere)

ii) Pressure intensity inside a soap bubble

$$P(\pi r^2) = 2\sigma(2\pi r)$$

$$\mathbf{P = \frac{4\sigma}{r} = \frac{8\sigma}{d}}$$

iii) Pressure intensity inside a liquid jet



Forces on liquid jet

$$P(2rL) = \sigma(2L)$$

$$\mathbf{P = \sigma/r = 2\sigma/d}$$

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

$$h = \frac{4\sigma\cos\theta}{\rho \times g \times D}$$

Value of θ between:

Water and Glass tube = 0°

Mercury and Glass tube = 128°

EXAM ACHARYA™ EDUCATION REDEFINED

CHAPTER – 2

FLUID KINEMATICS

FLUID KINEMATICS

- It is a branch of Fluid Mechanics which deals with motion of the fluids such as the displacement, velocity, acceleration, flow rate (mass flow rate or volumetric flow rate or discharge) and other related aspects of space time relations without considering the forces and energies causing that fluid motion.
- There are two methods by which the motion of a fluid is described. One is Lagrangian method and other one is Eulerian method.
- In the Lagrangian method, a single fluid particle is followed by an observer during its motion and its velocity, acceleration, density, etc are described.
- In Eulerian method, the velocity, acceleration, pressure, density etc, are described by an observer at a fixed point in the space of flow field.
- The Eulerian method is commonly used in fluid kinematics.

EXAM ACHARYA EDUCATION REDEFINED

TYPES OF FLUID FLOW

Fluids flows may be classified as

1. Steady flow and unsteady flow
2. Uniform flow and non-uniform flow
3. One, two and three-dimensional flow
4. Rotational flow and irrotational flow
5. Laminar flow and turbulent flow
6. Compressible flow and incompressible flow

GPSC - CIVIL

Construction, Planning and Management

"All Birds find shelter during a rain. But Eagle avoids rain by flying above the Clouds."

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

flow is determined by a non-dimensional number $Re = \frac{VD}{\nu}$, called the Reynolds number (Re)

Where D = Diameter of pipe

V = Mean velocity of flow in pipe

ν = kinematic viscosity of fluid.

If the Reynolds number is less than 2000, the flow is called laminar. If the Reynolds number is more than 4000, it is called turbulent flow. If the Reynolds number lies between 2000 and 4000, the flow may be transient.

Compressible & Incompressible Flows

Compressible Flow

Compressible flow is that type of flow in which the density of the fluid changes from point to point or in other words the density (ρ) is not constant for the fluid. Thus, mathematically, for compressible flow, **ρ ≠ constant**.

Ex. Flow of gases through a nozzle

Incompressible Flow

Incompressible flow is that type of flow in which the density is constant for the fluid flow. Liquids are generally incompressible while gases are compressible. Mathematically, for incompressible flow, **ρ = Constant**.

Ex. Flow of liquids like water and oil.

RATE OF FLOW OR DISCHARGE (Q)

It is defined as the quantity of a fluid flowing per second through a section of a pipe or channel. For an incompressible fluid (or liquid) the rate of flow or discharge is expressed as the volume of fluid flowing across the section per second. For compressible fluids, the rate of flow is usually expressed as the weight of fluid flowing across the section. Thus

Hence, acceleration in x, y and z direction becomes

$$\mathbf{a_x} = \frac{\partial u}{\partial t} = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}$$

$$\mathbf{a_y} = \frac{\partial v}{\partial t} = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}$$

$$\mathbf{a_z} = \frac{\partial w}{\partial t} = u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}$$

Acceleration vector $\mathbf{A} = a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k} = \sqrt{a_x^2 + a_y^2 + a_z^2}$

- In Equation (i), (ii) and (iii), the expression $\left(\frac{\partial u}{\partial t}\right), \left(\frac{\partial v}{\partial t}\right)$ and $\left(\frac{\partial w}{\partial t}\right)$ represents the rate of increase of velocity with respect to time at a particular point in the flow and hence it is known as local acceleration or temporal equation.

  The remaining terms in these expressions represents the rate of increase velocity due to particle's changed of position and hence known as convective acceleration.

  i.e.,

$$\left.\begin{matrix}\frac{\partial u}{\partial t}\\ \frac{\partial v}{\partial t}\\ \frac{\partial w}{\partial t}\end{matrix}\right\}\text{Local acceleration and } \left.\begin{matrix}u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\\ u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\\ u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\end{matrix}\right\}\text{ Convective acceleration}$$

FLOW PATTERN

To visualize the flow of fluids the following patterns generated by lines are used:

(A) Types of Lines

(i) Pathline

(ii) Streamline

(iii) Streakline

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test	: 35
Total mid subject test	: 16
Total full length test	: 13
Mock test	: 16
Total test	: 80

EXAM ACHARYA EDUCATION REDEFINED

- Converging of the streamlines indicates acceleration flow in that direction.
- Streamlines indicate tracing of motion of a group of particles.

Streakline

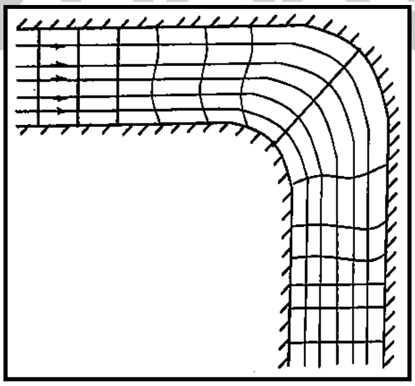
A streakline is a locus of particles which had earlier passed through a chosen point or a streakline traced by a single fluid particle passing through a fixed point in a flow field.

Ex: The trail of a colour dye injected at a point, Path taken by smoke coming out of exhaust {like a chimney).

Stream Tube

An imaginary tube formed by a group of streamlines passing through a small closed curve.

- There can be no flow across a stream tube.
- In a stream tube, fluid mass of the fluid is bounded by a group of stream lines.
- Only in a steady flow, a stream tube is fixed in space.
- In steady flow a streakline, streamline and a pathline are all identical.



Flow Net

It is a grid obtained by drawing a series of streamlines and equipotential lines.

It is a graphical technique for studying two- dimensional irrotational flows especially in the cases where mathematical relations for stream function and velocity function are either not available or are rather difficult.

SHEAR STRAIN (γ)

It is the average of velocity gradients in a 2-D coordinates.

$\gamma_{xy} = \frac{1}{2}\left[\left(\frac{\partial v}{\partial x}\right) + \left(\frac{\partial U}{\partial y}\right)\right]$

$\gamma_{yz} = \frac{1}{2}\left[\left(\frac{\partial v}{\partial z}\right) + \left(\frac{\partial w}{\partial y}\right)\right]$

$\gamma_{xz} = \frac{1}{2}\left[\left(\frac{\partial u}{\partial z}\right) + \left(\frac{\partial w}{\partial x}\right)\right]$

STREAM FUNCTION (ψ)

It is a scalar function of space and time such that its partial derivative with respect to any direction gives the velocity component at right angles (in counter clockwise direction) to this direction.

i.e. $\frac{\partial \psi}{\partial x} = v$ and $\frac{\partial \psi}{\partial y} = -U$

Slope of the streamline ($d\psi = 0$)

$d\psi = \frac{\partial \psi}{\partial x} dx + \frac{\partial \psi}{\partial y} dy = 0$

$vdx – udy = 0$

∴ Slope of the stream line $\frac{dy}{dx} = \frac{v}{u} = m_1$

Laplace Equation for 'ψ'

For an irrotational flow,

$$\left(\frac{\partial^2 \psi}{\partial x^2}\right) + \left(\frac{\partial^2 \psi}{\partial y^2}\right) = 0$$

Also (This will be true if ‘ψ’ is o continuous function and its second derivative exists)

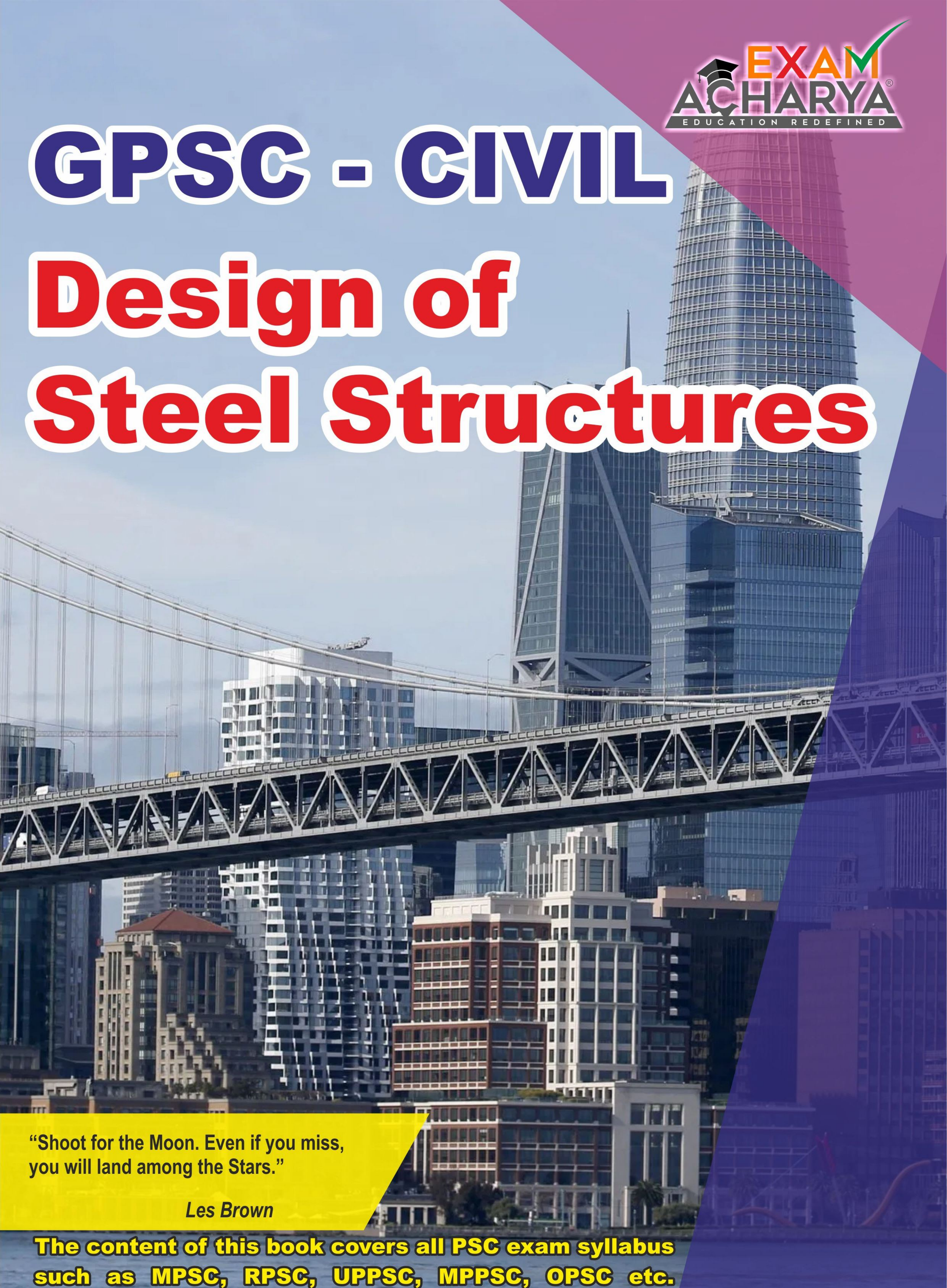
∴ Any function ‘ψ’ which is continuous is a possible case of fluid flow.

- It is constant along a streamline.
- The difference of stream functions for two streamlines is equal to the flow rate between them.

EXAM ACHARYA
EDUCATION REDEFINED

GPSC - CIVIL

Design of Steel Structures



"Shoot for the Moon. Even if you miss, you will land among the Stars."

Les Brown

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Q-5 What is the principal cause of action of buoyant force on a body submerged partially or fully in fluid?

a) Displacement of fluid due to submerged body

b) Development of force due to dynamic action

c) Internal shear forces mitigating external forces

d) None of the mentioned

Q-6 How can relatively denser object be made to float on the less dense fluid?

a) By altering the shape.

b) By altering the forces acting on the object

c) By altering the shear forces acting on the object

d) None of the mentioned

EXAM ACHARYA™ EDUCATION REDEFINED

TEST YOUR SELF

Q-7 A fluid flow field is given by

$V=y^2xi+z^2x-(2xyz+yz)k$

Calculate it's acceleration at the point (1,4,4)

a) 35i-28j+100k

b) 32i-28j-100k

c) 28i+27j+100k

d) None of the mentioned

BERNOULLI'S EQUATION

(a) Integration of Euler's equation for steady, incompressible and frictionless, non-viscous flow yields the Bernoulli's energy equation.

$$\frac{P}{\gamma} + \frac{V^2}{2g} + Z = \text{constant}$$

This is valid for ideal fluid flows.

i.e., total energy of the fluid remains constant.

Note

- It is applicable to all points in the flow field i.e., for all the stream lines, the value of the constant is same.

Assumption Made are

1. Flow is steady.
2. Flow is incompressible i.e., density does not change.
3. Flow is non-viscous (ideal).
4. Flow is continuous and homogeneous.
5. Velocity is uniform over a cross section.

EXAM ACHARYA™ EDUCATION REDEFINED

(b) For real fluids there will be some loss of energy between two points.

Energy Equation:

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

Here h_{Loss} = Energy head loss.

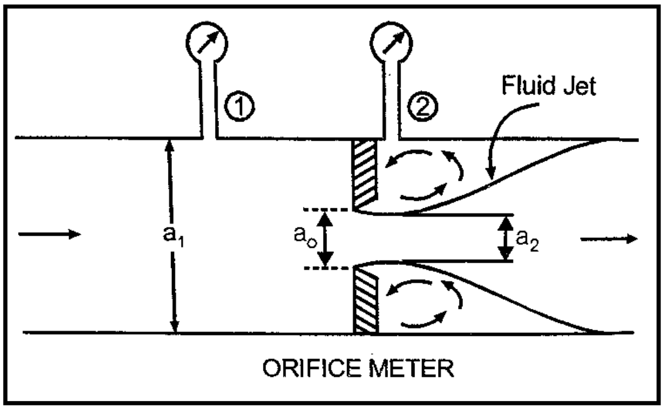
In the above equation each term represents "Energy per unit weight" (J/N = N.m/N).

(c) When the flow is steady but may not be irrotational i.e., rotational flow.

In this case Bernoulli's equation is applicable only to particular stream line that is the value of constant is different for different stream lines.

(D) Basis for Bernoulli's equation is 'Law of conservation of Energy'. Therefore, it is also called 'Energy equation'.

Orifice Meter



- This device is used for measuring discharge through pipes, which works on the same principle as venturimeter.
- However, orifice meter is a cheaper arrangement.
- As such, where the space is limited, the orifice meter may be used for measurement of discharge through pipes.
- An orifice meter consists of a flat circular plate with a circular hole called orifice, which is concentric with the pipe axis, an shown in figure.
- The diameter of orifice may vary from 0.2 to 0.85 times the pipe diameter but generally kept at 0.5 times the pipe diameter.
- Let p_1, p_2 and V_1,V_2 be the pressures and velocities respectively at sections (1) and (2). Then by applying Bernoulli's equation,

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 \quad \text{....(1)}$$

$$\left(\frac{P_1}{\gamma} + z_1\right) - \left(\frac{P_2}{\gamma} + z_2\right) = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} = h \quad \text{....(2)}$$

where, h = difference between piezometric heads.

From Equation (2) $V_2 = \sqrt{2gh + V_1^2}$

If C_v is the coefficient of velocity then

$$V_2 = C_v\sqrt{2gh + V_1^2} \quad \text{....(3)}$$

New Batches are going to start.....

Contact:

7622050066

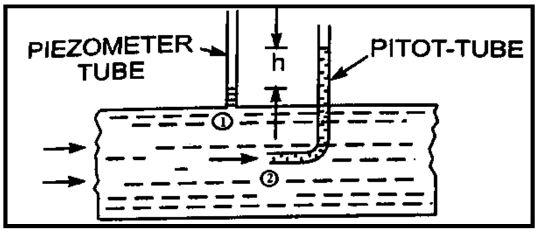
Test Series Available..

Total weekly test	: 35
Total mid subject test	: 16
Total full length test	: 13
Mock test	: 16
Total test	: 80

EXAM ACHARYA EDUCATION REDEFINED

Pitot Tube

- It is a device for measuring the velocity of flow.
- **Basic Principle:** The velocity of flow at a particular point is reduced to zero, which is known as stagnation point, the pressure there is increased due to the conversion of kinetic energy into pressure energy, and by measuring the increase in the pressure energy at this point, the velocity of flow may be determined.



Pitot tube with piezometer

Applying Bernoulli's equation between point 1 & 2.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

where $z_1 = z_2$

$$\frac{P_1}{\rho g} = H$$

$$\frac{P_2}{\rho g} = H + h$$

$$V_2 = d$$

∴ $$H + \frac{V_1^2}{2g} = H + h + 0$$

$$\frac{V_1^2}{2g} = h$$

$$V_1^2 = 2gh$$

or $$V_1 = \sqrt{2gh}$$

CLEAR YOUR CONCEPT

Q-1 Which of the following equations is a result of momentum conservation for inviscid steady flows?

a) Bernoulli's equation

b) Navier-Stokes equation

c) First law of thermodynamics

d) Euler's equation

Q-2 The Bernoulli's equation in fluid dynamics is valid for _________

a) Compressible flows

b) Transient flows

c) Continuous flows

d) Viscous flows

EXAM ACHARYA EDUCATION REDEFINED

Q-3 A water flows through a pipe at a velocity 4 m/s. The pressure gauge reading is 2 bar. The datum head is given to be 4 m. Find the piezometric head. (Assume all Bernoulli's assumptions, Density of water = 1000 kg/m^3, g = 9.8 m/s^2).

a) 24.4 m

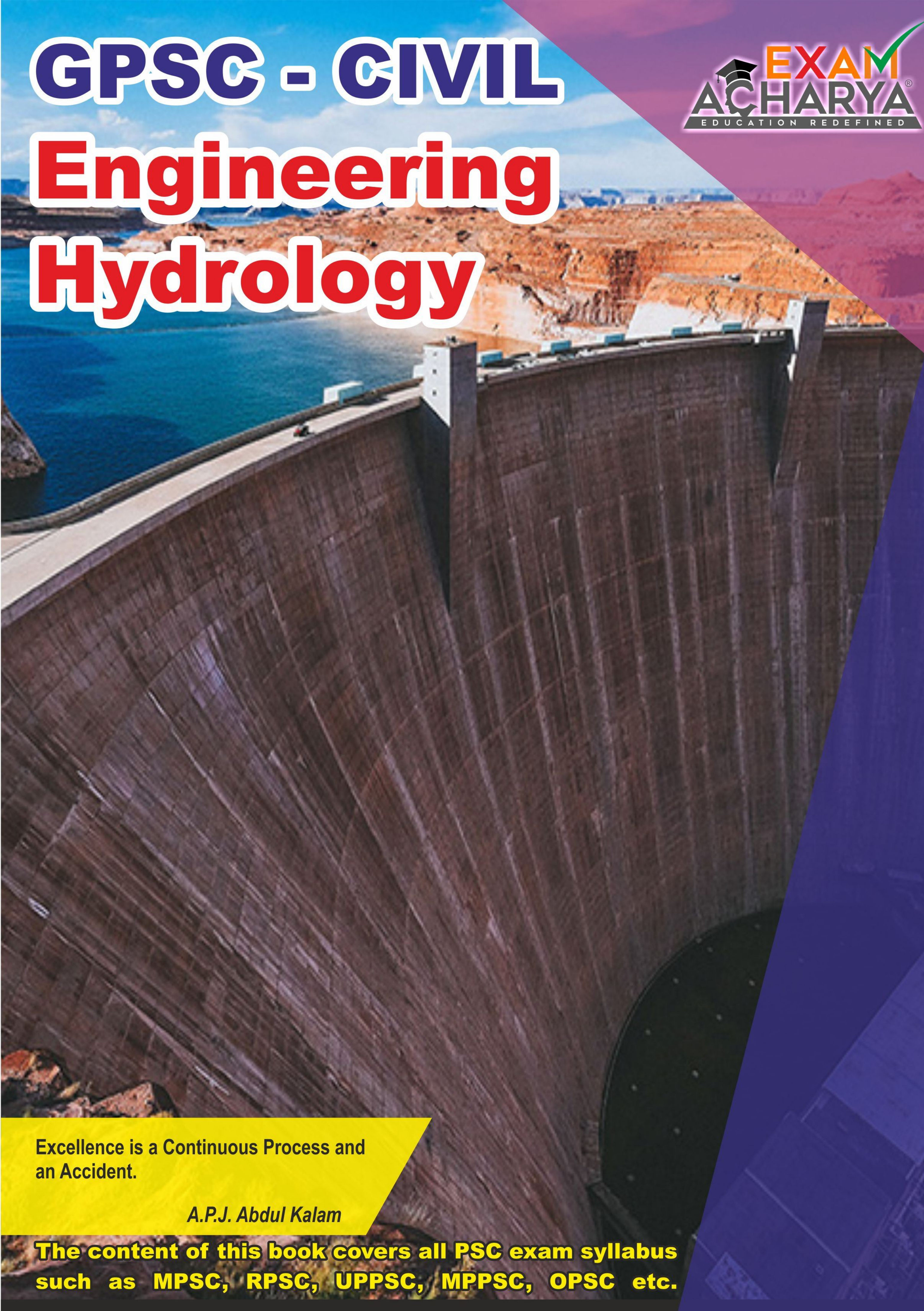
b) 22.6 m

c) 20.4 m

d) 20.6 m

GPSC - CIVIL

Engineering Hydrology



EXAM ACHARYA
EDUCATION REDEFINED

Excellence is a Continuous Process and an Accident.

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

HYDRAULIC DIAMETER

For non-circular pipes, $\mathbf{Re} = \frac{V D_h}{\nu}$

The hydraulic diameter, D_h is a commonly used term when handling flow in non-circular tubes and channels. Using this term one can calculate many things in the same way as for a round tube. It is defined as,

$$D_h = \frac{4A}{P}$$

A= cross sectional area,

P= wetted perimeter,

LAMINAR AND TURBULENT FLOWS

- Reynolds was first to show (Reynold's experiment) that Reynolds number is the criterion to identify the type of flow.
- A colour dye having same specific weight as that of water is used to study the flow pattern (generally 'Aniline').
- When velocity is small, the dye remains in the form of a straight and stable filament passing through the glass tube so steadily that it scarcely seems to be in motion i.e., laminar flow.
- With the increase in velocity, after a critical state, the filament of dye shows irregularities and begins to waver (i.e., turbulent).

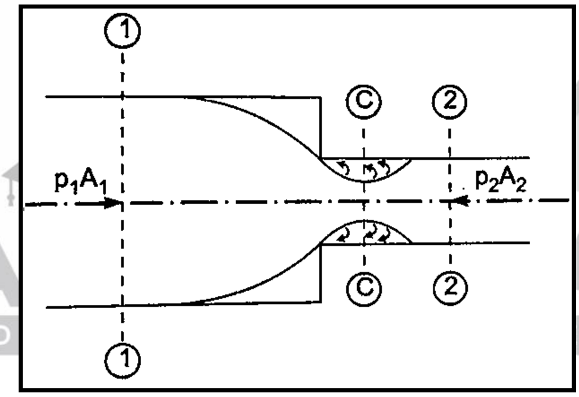
Flow condition	Reynolds Numbers (Re)	Type Of Flow
Flow in Pipes	<2000 2000-4000 >4000	Laminar Transition Turbulent
Flow Between Parallel Plates	<1000 1000-2000 >2000	Laminar Transition Turbulent
Flow in Wide open Channels	<500 500-1000 >1000	Laminar Transition Turbulent

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \text{loss of head due to sudden enlargement}$$

$$h_e = \frac{(V_1 - V_2)^2}{2g}$$

Loss of Head Due to Sudden Contraction

Consider a liquid flowing in a pipe which has a sudden contraction in area as shown in Fig. Consider two sections 1-1 and 2-2 before and after contraction. As the liquid flows from large pipe to smaller pipe, the area of flow goes on decreasing and becomes minimum at a section C-C as shown in Fig. This section C-C is called Vena-contracta. After section C-C, a sudden enlargement of the area takes place. The loss of head due to sudden contraction is actually due to sudden enlargement from Vena-contracta to smaller pipe.



Sudden Contraction

Let A_c = Area of flow at section C-C

V_c = Velocity of flow at section C-C

A_2 = Area of flow at section 2-2

V_2 = Velocity of flow at section 2-2

h_c = Loss of head due to sudden contraction.

Now h_c = actual loss of head due to enlargement from section C-C to section 2-2 and is given by equation as

$$h_c = \frac{(V_c - V_2)^2}{2g} = \frac{V_2^2}{2g}\left[\frac{V_c}{V_2} - 1\right]^2 \quad \text{......(i)}$$

Where

V = velocity of liquid in pipe.

This loss is denoted by h_i

$$\mathbf{h_i = 0.5\frac{V^2}{2g}}$$

Loss of Head Due to an Obstruction in a Pipe

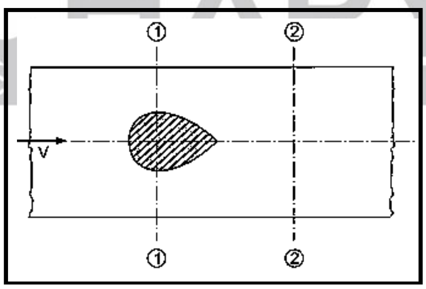
Whenever there is an obstruction in a pipe, the loss of energy takes place due to reduction of the area of the cross-section of the pipe at the place where obstruction is present. There is a sudden enlargement of the area of flow beyond the obstruction due to which loss of head takes place as shown in Fig.

Consider a pipe of area of cross-section A having an obstruction as shown in Fig.

Let a = Maximum area of obstruction

A = Area of pipe

V = Velocity of liquid in pipe



An obstruction in a pipe

Head loss due to obstruction $= \frac{(V_c - V)^2}{2g}$

$$= \frac{\left(\frac{A \times V}{C_c(A-a)} - V\right)^2}{2g}$$

$$= \mathbf{\frac{V^2}{2g}\left(\frac{A}{C_c(A-a)} - 1\right)^2}$$

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

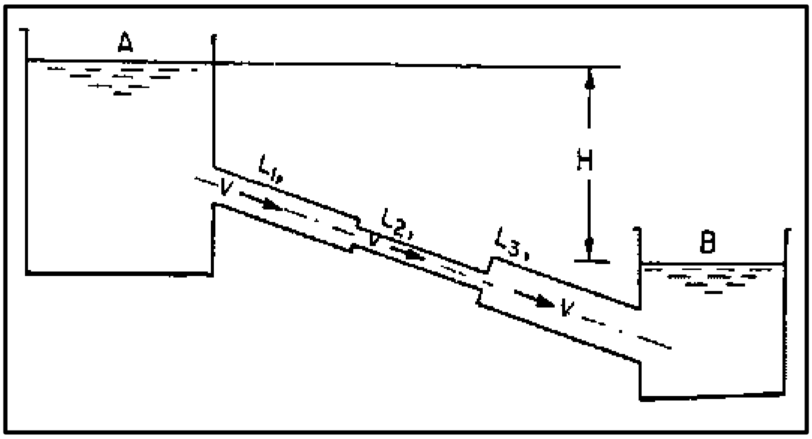
Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

(II) Discharge through each pipe will be same,

$$Q = \frac{\pi D_1^2 V_1}{4} = \frac{\pi D_2^2 V_2}{4} = \frac{\pi D_3^2 V_3}{4} \ldots$$



Equivalent Pipe

- When a compound pipeline consisting of several pipes of varying diameters and lengths, is replaced by a pipe of uniform diameter having same material, it is called equivalent pipeline.
- The uniform diameter of equivalent pipe is known as equivalent diameter of the compound pipe.
- If L_1, L_2, L_3 etc be the length and D_1, D_2, D_3 … etc be the diameter of the different pipes of a compound pipe line, and if D is the diameter and L_e is the length of the equivalent pipe, then

$$\frac{L_e}{D^5} = \frac{L_1}{D_1^5} + \frac{L_2}{D_2^5} + \frac{L_3}{D_3^5} + \cdots$$

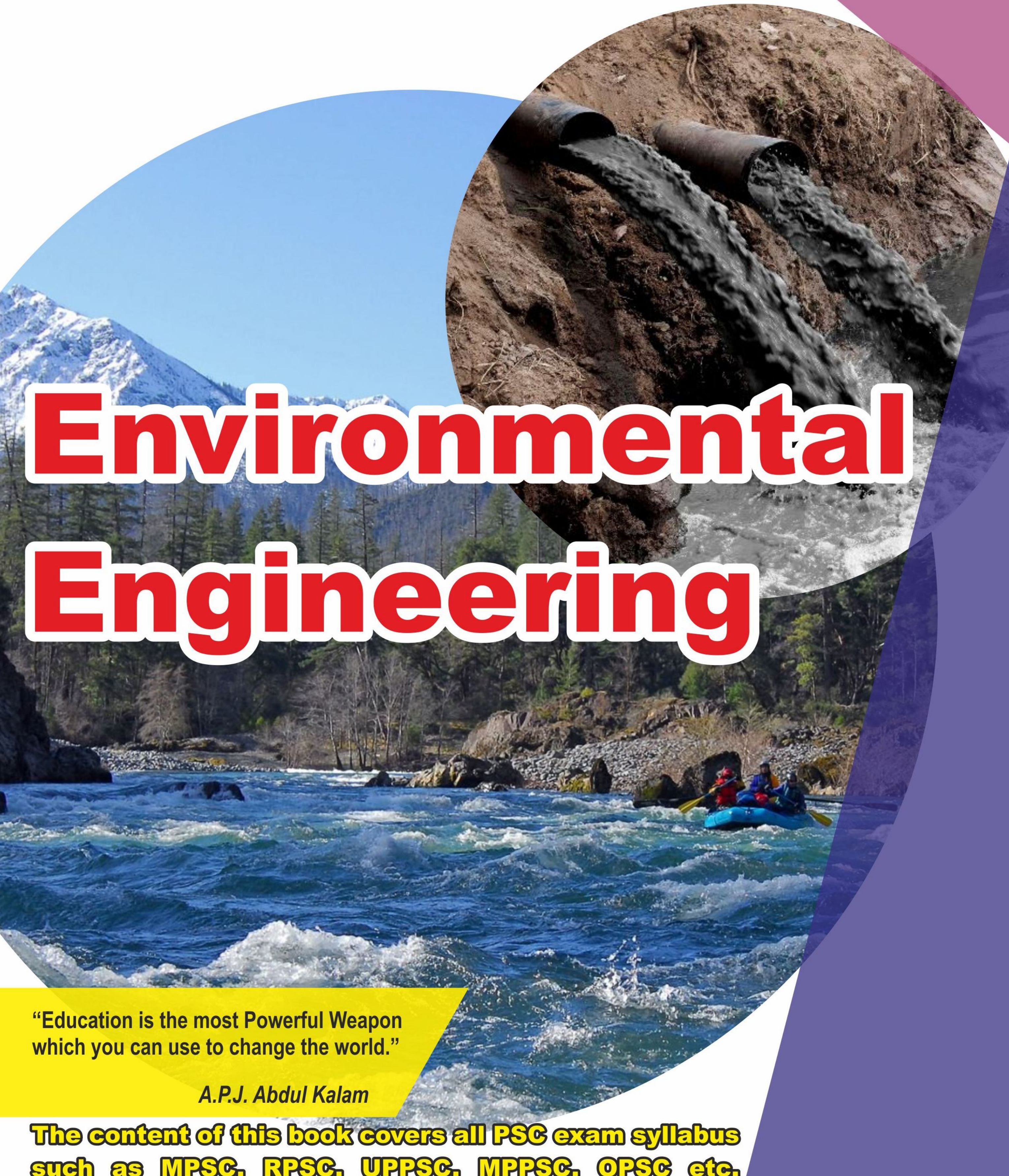
This equation is known as "Dupuit's equation".

PIPES IN PARALLEL

When a main pipe line divides into two or more parallel pipes which again join together downstream side and continue as a main line, the pipes are said to be in parallel.

EXAM ACHARYA
EDUCATION REDEFINED

GPSC - CIVIL



Environmental Engineering

"Education is the most Powerful Weapon which you can use to change the world."

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Q-4 A liquid flows through pipes 1 and 2 with the same flow velocity. If the ratio of their pipe diameters $d_1 : d_2$ be 5:2, what will be the ratio of the head loss in the two pipes?

a) 3:2

b) 9:4

c) 2:5

d) 4:9

Q-5 A liquid flowss through two similar pipes 1 and 2. If the ratio of their flow velocities $v_1 : v_2$ be 2:4, what will be the ratio of the head loss in the two pipes?

a) 3:2

b) 9:4

c) 2:3

d) 4:16

Q-6 The head loss at the entrance of the pipe is that at it's exit

a) Eequal to

b) Half

c) Twice

d) Four times

DIMENSIONAL HOMEGENEITY

- An equation is said to be dimensionally homogenous, if the dimensions of the terms on its left side are same as that of the terms on right side.
- A dimensionally homogeneous equation is independent of the fundamental units of measurement if the units there in are consistent.
- Let us consider the velocity equation,

$$V = \sqrt{2gh}$$

$$[LT^{-1}] = [2 \times LT^{-2} \times L]^{1/2} = [L^2T^{-2}]^{1/2} = [LT^{-1}]$$

Therefore, the above equation is dimensionally homogeneous.

- There are several equations in hydraulics which are dimensionally non-homogenous, but still well applicable to flow system within their limited ranges. Examples:

Manning's equation: $V = \frac{1}{n} R^{2/3} S^{1/2}$

Chezy's equation: $V = C\sqrt{RS}$

DIMENSIONALLY HOMOGENEOUS

(i) Continuity equation, Q = AV

(ii) Hydrostatic law of pressure, $P = \gamma h$

(iii) Newton's second law, F= ma

(iv) $\Delta P = 32\ \mu V. L/d^2$

(v) $\Delta P = f. l\rho V^2/2d,$

(vi) $T = 2\pi\sqrt{\frac{l}{g}}$

(vii) $v = u + at$

(viii) $Q = \frac{2}{3} C_d \sqrt{2g} L H^{3/2}$

Note

- Rational Formulas are dimensionally homogenous.

New Batches are going to start.....

EXAM ACHARYA™
EDUCATION REDEFINED

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA
EDUCATION REDEFINED

Where K is constant and a, b and c are arbitrary powers.

The values of a, b and c are obtained by comparing the powers of the fundamental dimension on both sides. Thus, the expression is obtained for dependent variable.

Buckingham's π-Theorem

The Rayleigh's method of dimensional analysis becomes more laborious if the variables are more than the number of fundamental dimensions (M, L, T). This difficulty is overcame by using Buckingham's π-theorem ,which states, "if there are n variables (independent and dependent variables) in a physical phenomenon and if these variables contain m fundamental dimensions (M, L, T), then the variables are arranged into (n-m) dimensionless terms. Each term is called π -term.

The repeated variables that will appear in every π-term can be selected by keeping the following rules.

(i) No. of repeated variables is equal to the number of fundamental quantities.
(ii) Repeated variables must be selected from independent variables.
(iii)Repeated variable must have dimensions.
(iv)The repeated variable group must contain all fundamental quantities.

EXAM ACHARYA TM EDUCATION REDEFINED

MODEL ANALYSIS

For predicting the performance of the hydraulic structures (such as dams, spillways etc.) or hydraulic machines (such as turbines, pumps etc.), before actually constructing or manufacturing, models of the structures or machines are made and tests are performed on them to obtain the desired information.

The model is the small-scale replica of the actual structure or machine. The actual structure or machine is called Prototype. It is not necessary that the models should be smaller than the prototypes (though in most of cases it is), they may be larger than the prototype. The study of models of actual machines is called Model analysis. Model analysis is actually an experimental method of finding solutions of complex flow problems. Exact analytical solutions are possible only for a limited number of flow problems. The followings are the advantages of the dimensional and model analysis:

DIMENSIONLESS NUMBERS

Dimensionless numbers are those numbers which are obtained by dividing the inertia force by viscous force or gravity force or pressure force or surface tension force or elastic force. As this is a ratio of one force to the other force, it will be a dimensionless number. These dimensionless numbers are also called non-dimensional parameters. The following are the important dimensionless numbers.

1. Reynold's number
2. Froude's number
3. Euler's number
4. Weber's number
5. Mach's number

Reynold's Number (R_e)

It is defined as the ratio of inertia force of a flowing fluid and the viscous force of the fluid. The expression for Reynold's number is obtained as

Inertia force (F_i) = Mass × Acceleration of flowing fluid

$$\rho \times \text{Volume} \times \frac{\text{Velocity}}{\text{Time}} = \rho \times \frac{\text{Volume}}{\text{Time}} \times \text{Velocity}$$

$$\rho \times AV \times V \qquad \{\because \text{Volume per sec} = \text{Area} \times \text{Velocity} = A \times V\}$$

$$F_i = \rho AV^2$$

Viscous force (F_v) = Shear stress × Area

$$\left\{\because \ \tau = \mu \frac{du}{dy} \therefore \text{Force} = \tau \times \text{Area}\right\}$$

$$\mathbf{F_v = \tau \times A}$$

$$= \left(\mu \frac{du}{dy}\right) \times A = \mu \frac{V}{L} \times A \qquad \left\{\because \frac{du}{dy} = \frac{V}{L}\right\}$$

By definition, Reynold's number,

$$R_e = \frac{F_i}{F_v} = \frac{\rho AV^2}{\mu \times \frac{V}{L} \times A} = \frac{\rho VL}{\mu}$$

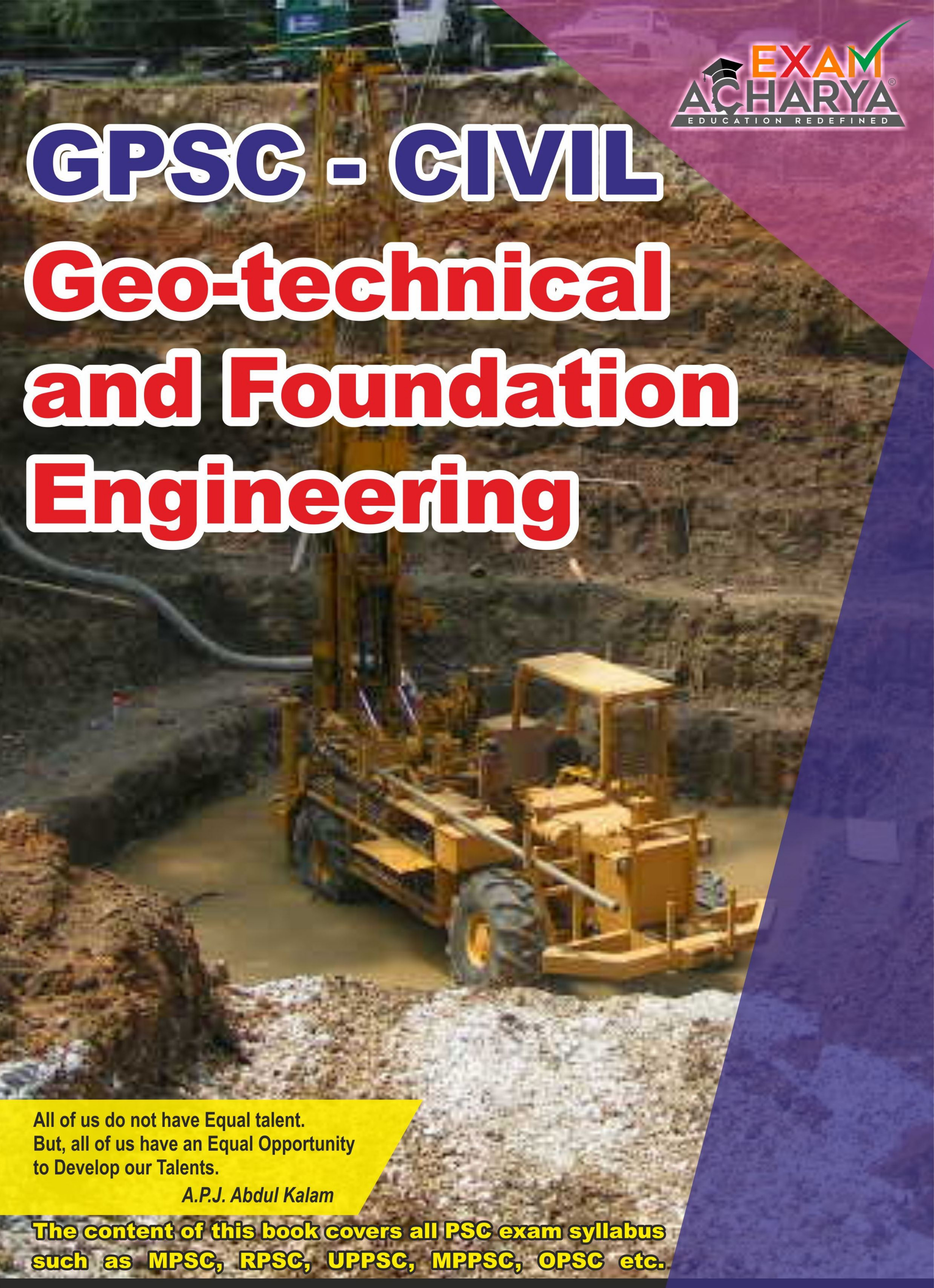
$$= \frac{V \times L}{\left(\frac{\mu}{\rho}\right)} = \frac{V \times L}{\nu} \qquad \left\{\because \frac{\mu}{\rho} = \nu = \text{Kinematic viscosity}\right\}$$

201, Siddhi Vinayak Complex, besides Bank of India, Near Panchratna furniture,
Ellorapark, Subhanpura, Vadodara – 390023
Contact: 7622050066 Website: www.acumenhr.in

EXAM ACHARYA
EDUCATION REDEFINED

GPSC - CIVIL

Geo-technical and Foundation Engineering



All of us do not have Equal talent.
But, all of us have an Equal Opportunity
to Develop our Talents.

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Froude Model Law

The gravity force is the only predominant force in addition to the inertia force, which controls the motion

$$(Fr)_{model} = (Fr)_{prototype}$$

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

$$\frac{V_r}{\sqrt{g_r L_r}} = 1;\ V_r = \sqrt{g_r L_r}$$

Since, in most of the cases $g_r = 1$, then

$$\mathbf{V_r = \sqrt{L_r}}$$

Froude model law is valid for:

(a) Free surface flows such as flow over spillways, sluices etc.

(b) Flow of jet from an orifice or nozzle.

(c) Flow over weir and notches

(d) Motion of ship

EXAM ACHARYA™ EDUCATION REDEFINED

Euler Model Law

This model is applicable where pressure force controls flow in addition to inertial force. Thus,

$$(Eu)_m = (Eu)_p$$

$$\frac{V_m}{\sqrt{\frac{P_m}{\rho_m}}} = \frac{V_p}{\sqrt{\frac{P_p}{\rho_p}}}$$

$$\frac{\mathbf{V_r}}{\sqrt{\frac{\mathbf{P_r}}{\boldsymbol{\rho_r}}}} = \mathbf{1}$$

From Froude law, $V_r = \sqrt{L_{rv}}$

Comparing these two equations

$$\mathbf{n_r} = \frac{(\mathbf{L_{rv}})^{2/3}}{(\mathbf{L_{rH}})^{1/2}}$$

n_r = scale ratio for rugosity coefficient.

EXAM ACHARYA™ EDUCATION REDEFINED

CHAPTER – 6

BOUNDARY LAYER FLOW

INTRODUCTION

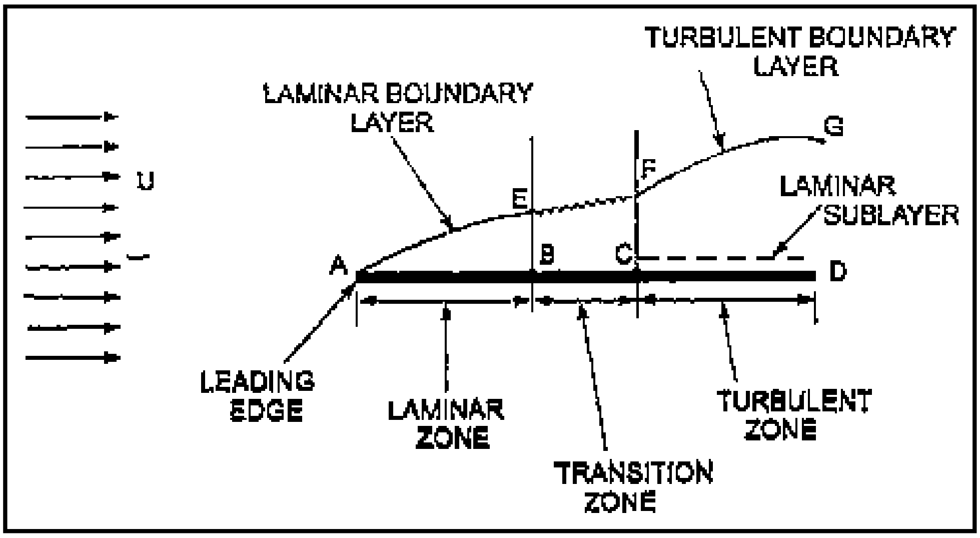
Concept of boundary layer (B.L) theory was introduced by L. Prandtl. It is an external flow over objects like airfoils, flow past a blunt body, & circular cylinder, which experiences boundary layer formation. Two regions exist in an external flow over a body:

(a) Flow outside the boundary layer, where viscosity influence is negligible and free stream velocity is uniform. Flow is irrotational. Hence, ideal flow theories may be used.

(b) Flow immediately adjacent to the object surface where viscous and inertia forces cause flow to be rotational. Velocity gradient (du/dy) exits normal to the boundary surface and corresponding shear stress is appreciable.

Figure below shows the boundary layer growth on a long thin plate held stationary in the direction parallel to the flow in a uniform stream of velocity U_∞.

EXAM ACHARYA EDUCATION REDEFINED



New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

Turbulent Boundary Layer

Reynolds number more than 5×10^5 for flat plates is considered for boundary analysis.

Boundary Layer Thickness (δ)

It is defined as the distance (vertically) from the boundary surface at which the velocity reaches 99% of the velocity of the main or free stream velocity. It is also called nominal thickness or disturbance thickness.

δ_{lam} = Thickness of laminar boundary layer

δ_{tur} = Thickness of turbulent boundary layer

Laminar Boundary Layer Thickness **(δ_{lam})**

The velocity distribution is parabolic.

As per Blasius, $= \frac{\delta}{x} = \frac{k}{\sqrt{Re_x}}$

$$\delta = K\sqrt{x\nu/U_\infty}$$

K is Blasius constant, varies from 4.64 to 5

x = distance from leading edge of plate

ν = Kinematic viscosity of fluid.

$$\delta_{lam} \propto x^{1/2}$$

<u>Factor Affecting Boundary Layer Thickness Along a Smooth Plate</u>

(a) It increases as the distance from leading edge increases.

(b) It decreases with the increase in the velocity of flow approaching stream of fluid.

(c) Greater is the kinematic viscosity of fluid greater is the Boundary Layer thickness.

Methods to Prevent Flow Separation

1. Use rough boundaries
2. Suction of the slow moving (decelerating) fluid by a suction slot
3. Suction of the retarded fluid within boundary layer.
4. Use smaller divergence angles in boundaries
5. Providing a bypass in the slotted wing.
6. Providing guide-blades in a bend.

EXAM ACHARYA™ EDUCATION REDEFINED

GPSC - CIVIL

Reinforced Cement Concrete

Education's purpose is to replace an empty mind with an open one.

Malcolm Forbes

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Q-5 The laminar boundary layer is a _________

a) Smooth flow

b) Rough flow

c) Uniform flow

d) Random flow

Q-6 The turbulent boundary layer is a _________

a) Non-uniform with swirls

b) Uniform

c) Less stable

d) Smooth

TEST YOUR SELF

Q-7 For laminar flow over a flat plate, the thickness of the boundary layer at a distance from the leading edge is found to be 5 mm. The thickness of the boundary layer at a downstream section, which is at twice the distance of the previous section from the leading edge will be

(a) 10 mm

(b) $5\sqrt{2}$ mm

(c) 5.2 mm

(d) 2.5 mm

1. Pressure force equal to $p \times dA$, acting perpendicular to the surface and
2. Shear force equal to $\tau_0 \times dA$, acting along the tangential direction to the surface.

Let θ = Angle made by pressure force with horizontal direction.

Drag Force (F_D)

The drag force on elemental area

= (Force due to pressure in the direction of fluid motion) +
(Force due to shear stress in the direction of fluid motion)

$= p\, dA \cos\theta + \tau_0 dA \cos(90° - \theta) = p\, dA \cos\theta + \tau_0 dA \sin\theta$

∴ Total drag,

F_D = Summation of $pdA \cos\theta$ + Summation of $\tau_0 dA \sin\theta$

$$\mathbf{F_D = \int P \cos\theta dA + \int \tau_0 \sin\theta dA}$$

The term $\int P \cos\theta dA$ is called the pressure drag or form drag while the term $\int \tau_0 \sin\theta dA$ is called the friction drag or skin drag or shear drag.

EXAM ACHARYA EDUCATION REDEFINED

Lift Force (F_L)

The lift force on elemental area =
(Force due to pressure in the direction perpendicular to the direction of motion) +
(Force due to shear stress in the direction perpendicular to the direction of motion)

$= -p\, dA \sin\theta + \tau_0\, dA \sin(90° - \theta) = -p\, dA \sin\theta + \tau_0 dA \cos\theta$

Negative sign is taken with pressure force as it acting in the downward direction while shear force is acting vertically up.

∴ Total lift, $F_L = \int \tau_0\ dA \cos\theta - \int p\, dA \sin\theta$

Total lift $= \mathbf{\int \tau_0 \cos\theta dA - \int p \sin\theta\, dA}$

If the Reynolds number of the flow is very small less than 0.2 $\left(\text{i.e., } R_e = \frac{UD\rho}{\mu} < 0.2\right)$, the viscous forces are much more important than the inertial forces as in this case viscous forces are much more predominate than the inertial forces, which may be assumed negligible. G.G. Stokes, developed a mathematical equation for the total drag on a sphere immersed in a flowing fluid for which Reynolds number is upto 0.2, so that inertia forces may be assumed negligible. According to his solution, total drag is

$$\mathbf{F_D = 3\pi\mu DU}$$

He further observed that out of the total drag given by equation, two – third is contributed by skin friction and the remaining one-third by pressure difference. Thus

Skin friction drag, $F_{D_f} = \frac{2}{3} F_D = \frac{2}{3} \times 3\pi\mu DU = 2\pi\mu DU$

and pressure drag, $F_{D_p} = \frac{1}{3} F_D = \frac{1}{3} \times 3\pi\mu DU\ C_D$

(i) Expression of C_D for sphere when Reynold's number is less than 0.2:

The total drag is given by,

$$F_D = C_D A \frac{\rho U^2}{2}$$

For sphere,

$$F_D = 3\pi\mu DU$$

A= Projected area of sphere $= \frac{\pi}{4} D^2$

$$\therefore 3\pi\mu DU = C_D \frac{\pi}{4} D^2 \frac{\rho U^2}{2}$$

$$\mathbf{C_D = \frac{24\mu}{\rho UD} = \frac{24}{R_e}} \qquad \left(\because \frac{\mu}{\rho UD} = R_e\right)$$

This equation is called 'stokes law'

(ii) Value of C_D for sphere when Reynold's number is in between 0.2 and 5:

With the increase of Reynold's number, the inertia forces increase and must be taken into account. When R_e lies between 0.2 and 5, then

$$\mathbf{C_D = \frac{24}{R_e}\left(1 + \frac{3}{16\,R_e}\right)}$$

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test	: 35
Total mid subject test	: 16
Total full length test	: 13
Mock test	: 16
Total test	: 80

EXAM ACHARYA EDUCATION REDEFINED

DRAG ON A CYLINDER

Consider a real fluid flowing over a circular cylinder of diameter D and length L, when the cylinder is placed in the fluid such that its length is perpendicular to the direction of flow. If the Reynolds number of the flow is less than 0.2 $\left(\text{i.e.}, \frac{U \times d}{\nu} < 0.2\right)$, the inertia force is negligibly small as compared to viscous force and hence the flow pattern about the cylinder will be symmetrical. As the Reynolds number is increased, inertia forces increase and hence they must be taken into consideration for analysis of flow over cylinder. With the increase of the Reynolds number, the flow pattern becomes unsymmetrical with respect to an axis perpendicular to the direction of flow. The drag force. i.e., the force exerted by the flowing fluid on the cylinder in the direction of flow depends upon the Reynolds number of the flow. From experiments, it has been observed that :

(i) When Reynolds number (R_e) < 1, the drag force is directly proportional to velocity and hence the drag co-efficient (C_D) is inversely proportional to Reynolds number.

(ii) With the increase of the Reynolds number from 1 to 2000, the drag co-efficient decreases and reaches a minimum value of 0.95 at R_e = 2000.

(iii) With the further increase of the Reynolds number from 2000 to 3 x 10^4, the co-efficient of drag increases and attains maximum value of 1.2 at $R_e = 3 \times 10^4$.

(iv) The value of co-efficient of drag decreases if the Reynolds number is increased from 3×10^4 to 3×10^5. At R_e =3 x 10^5 the value of C_D = 0.3.

(v) If the Reynolds number is increased beyond 3×10^6, the value of C_D increases and it becomes equal to 0.7 in the end.

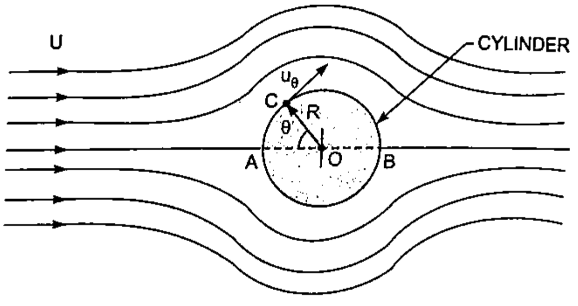
DEVELOPMENT OF LIFT ON A CIRCULAR CYLINDER

When a body is placed in a fluid in such a way that its axis is parallel to the direction of fluid flow and body is symmetrical, the resultant force acting on the body is in the direction of flow. There is no force component on the body perpendicular to the direction of flow. But the component to the force on the body perpendicular to the

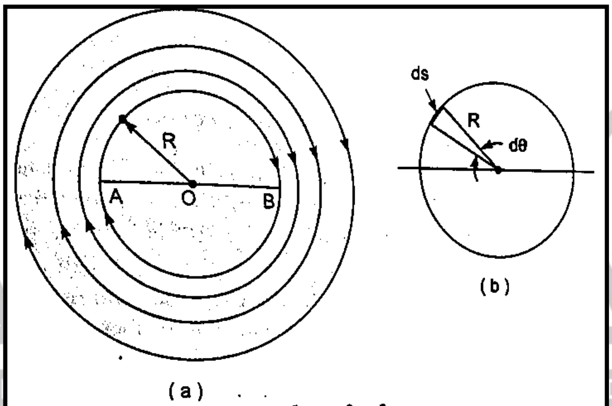
$$\therefore u_{\theta_1} = \frac{\Gamma}{2\pi R}$$

Flow Over Cylinder due to Constant Circulation

The flow pattern over a cylinder to which a constant circulation (**Γ**) is imparted is obtained by combining the flow pattern shown in fig.

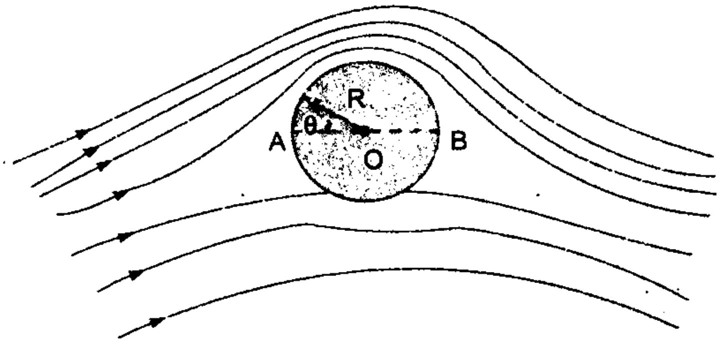


Flow of ideal fluid over stationary cylinder.



Stream-lines for free vortex.

The resultant flow pattern is shown in fig.



Flow Pattern over a rotating cylinder

EXAM ACHARYA

GPSC - CIVIL

Solid Mechanics

"Education is the most Powerful Weapon which you can use to change the world."

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

GPSC - CIVIL

Solid Mechanics

CHAPTER – 8

HYDRAULIC MACHINES

GENERAL LAYOUT OF A HYDROELECTRIC POWER PLANT

General layout of a hydroelectric power plant which consists of

(i) A dam constructed across a river to store water.

(ii) Pipes of large diameters called penstocks, which carry water under pressure from the storage reservoir to the turbines. These pipes are made of steel or reinforced concrete.

(iii) Turbines having different types of vanes fitted to the wheels.

(iv) Tail race, which is a channel which carries water away from the turbines after the water has worked on the turbines. The surface of water in the tail race channel is also known as tail race.

DEFINITIONS OF HEADS AND EFFICIENCIES OF A TURBINE

1. Gross Head

The difference between the head race level and tail race level when no water is following is known as Gross Head. It is denoted by 'H_g' in Fig.

2. Net Head

It is also called effective head and is defined as the head available at the inlet of the turbine. When water is flowing from head race to the turbine, a loss of head due to friction between the water and penstocks occurs. Though there are other losses also such as loss due to bend, pipe fittings, loss at the entrance of penstock etc., yet they are having small magnitude as compared to head loss due to power supplied by the water at the inlet of the turbine. The power at the inlet of the turbine is more and this power goes on decreasing as the water flows over the vanes of the turbine due to hydraulic losses as the vanes are not smooth. Hence, the power delivered to the runner of the turbine will be less than the power available at the inlet of the turbine.

Thus, mathematically, the hydraulic efficiency of a turbine is written as

$$\eta_h = \frac{\text{Power delivered to runner}}{\text{Power supplied at inlet}} = \frac{R.P}{W.P} \qquad \text{...... (1)}$$

where R.P = Power delivered to runner i.e., runner power

$$= \frac{W}{g}\frac{[V_{w1} \pm V_{w2}] \times u}{1000} \text{ kW} \qquad \text{.... for Pelton Turbine}$$

$$= \frac{W}{g}\frac{[V_{w1}u_1 \pm V_{w2}u_2]}{1000} \text{ kW} \qquad \text{.... for a radial flow turbine}$$

W.P = Power supplied at inlet of turbine and also called water power

$$= \frac{W \times H}{1000} \text{ kW}$$

Where

W = Weight of water striking the vanes of the turbine per second

= ρg × Q in which Q = Volume of water/s,

V_{w_1} = Velocity of whirl at inlet,

V_{w_2} = Velocity of whirl at outlet,

u = Tangential velocity of vane,

u_1 = Tangential velocity of vane at inlet for radial vane,

u_2 = Tangential velocity of vane at outlet for radial vane,

H = Net head on the turbine.

Power supplied at the inlet of turbine in S.I.units is known as water power. It is given by

1. **According to the Type of Energy at Inlet:**

   a) Impulse turbine, and (b) Reaction turbine.

2. **According to the Direction of Flow Through Runner:**

   (a) Tangential flow turbine, (b) Radial flow turbine

   (c) Axial flow turbine, and (d) Mixed flow turbine

3. **According to the Head at the Inlet of Turbine:**

   (a) High head turbine, (b) Medium head turbine and,

   (c) Low head turbine.

4. **According to the Specific Speed of the Turbine:**

   (a) Low specific speed turbine (b) Medium specific speed turbine, and

   (c) High specific speed turbine.

If at the inlet of the turbine, the energy available is only kinetic energy, the turbine is known as impulse turbine. As the water flows over the vanes, the pressure is atmospheric from inlet to outlet of the turbine. If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as reaction turbine. As the waters flows through the runner, the water is under pressure and the pressure energy goes on changing into kinetic energy. The runner is completely enclosed in an air-tight casing and the runner and casing is completely full of water. If the water flows along the tangent of the runner, the turbine is known as tangential flow turbine. If the water flows in the radial direction through the runner, the turbine is called radial flow turbine. If the water flows from outwards to inwards, radially, the turbine is known as inward radial flow turbine, on the other hand, if water flows radially from inwards to outwards, the turbine is known as outward radial flow turbine. If the water flows through the runner along the direction parallel to the axis of rotation of the runner, the turbine is called axial flow turbine. If the water flows through the runner in the radial direction but leaves in the direction parallel to axis of rotation of the runner, the turbine is called mixed flow turbine.

EXAM ACHARYA EDUCATION REDEFINED

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

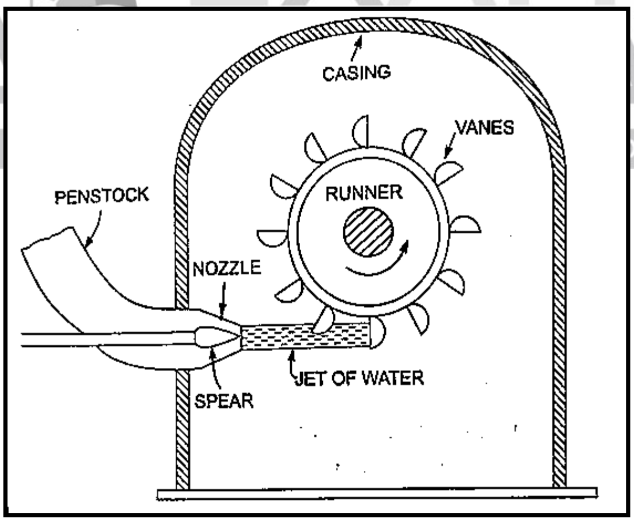
Runner with Buckets

Fig. shows the runner of a Pelton wheel. It consists of a circular disc on the periphery of which a number of buckets evenly spaced are fixed. The shape of the buckets is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter.

The jet of water strikes on the splitter. The splitter divides the jet into two equal parts and the jet comes out at the outer edge of the bucket. The buckets are shaped in such a way that the jet gets deflected through 160° or 170°. The buckets are made of cast iron, cast steel bronze or stainless steel depending upon the head at the inlet of the turbine.

Casing

Fig. shows a Pelton turbine with a casing. The function of the casing is to prevent the splashing of the water and to discharge water to tail race. It also acts as safeguard against accidents. It is made of cast iron or fabricated steel plates. The casing of the Pelton wheel does not perform any hydraulic function.



Pelton turbine

Breaking Jet

When the nozzle is completely closed by moving the spear in the forward direction, the amount of water striking the runner reduces to zero. But the runner due to inertia goes

Main Parts of a Radial Flow Reaction Turbine

The main parts of a radial flow reaction turbine are:

1. Casing, 2. Guide mechanism,

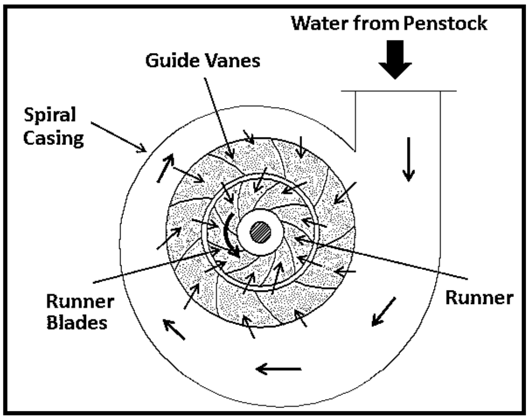
3. Runner, and 4. Draft-tube.

Casing

As mentioned above that in case of reaction turbine, casing and runner are always full of water. The water from the penstocks enters the casing which is of spiral shape in which area of cross-section of the casing goes on decreasing gradually. The casing completely surrounds the runner of the turbine. The casing as shown in Fig. is made of spiral shape, so that the water may enter the runner at constant velocity throughout the circumference of the runner. The casing is made of concrete, cast steel or plate steel.

Guide Mechanism.

It consists of a stationary circular wheel all round the runner of the turbine. The stationary guide vanes are fixed on the guide mechanism. The guide vanes allow the water to strike the vanes fixed on the runner without shock at inlet. Also by a suitable arrangement, the width between two adjacent vanes of guide mechanism can be altered so that the amount of water striking the runner can be varied.



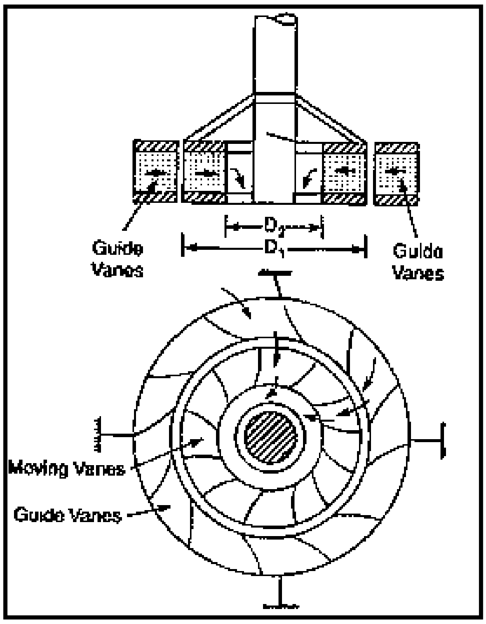
Main parts of radial reaction turbines

GPSC - CIVIL

Structural Analysis

"All of us do not have Equal Talent.
But, all of us have an Equal Opportunity
to Develop our Talents."
A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.



Inward radial flow turbine

The work done per second on the runner by water is given by equation as

$$= \rho a V_1 [V_{w_1} u_1 \pm V_{w_2} u_2]$$

$$= \rho Q [V_{w_1} u_1 \pm V_{w_2} u_2] \qquad (\because aV_1 = Q) \qquad \ldots(1)$$

The above equation also represents the energy transfer per second to the runner.

Where

V_{w_1} = Velocity of whirl at inlet,

V_{w_2} = Velocity of whirl at outlet

u_1 = Tangential velocity of wheel at inlet

$= \frac{\pi D_1 \times N}{60}$, where D_1 = Outer dia. Of runner

u_2 = Tangential velocity of wheel at outlet

$= \frac{\pi D_2 \times N}{60}$, where D_2 = Inner dia. of runner, N = Speed of the turbine in r.p.m.

Important Relations for Francis Turbines

The following are the important relations for Francis Turbines:

1. The ratio of width of the wheel to its diameter is given as n = $\frac{B_1}{D_1}$. The value of n varies from 0.10 to .40.
2. The flow ratio is given as,

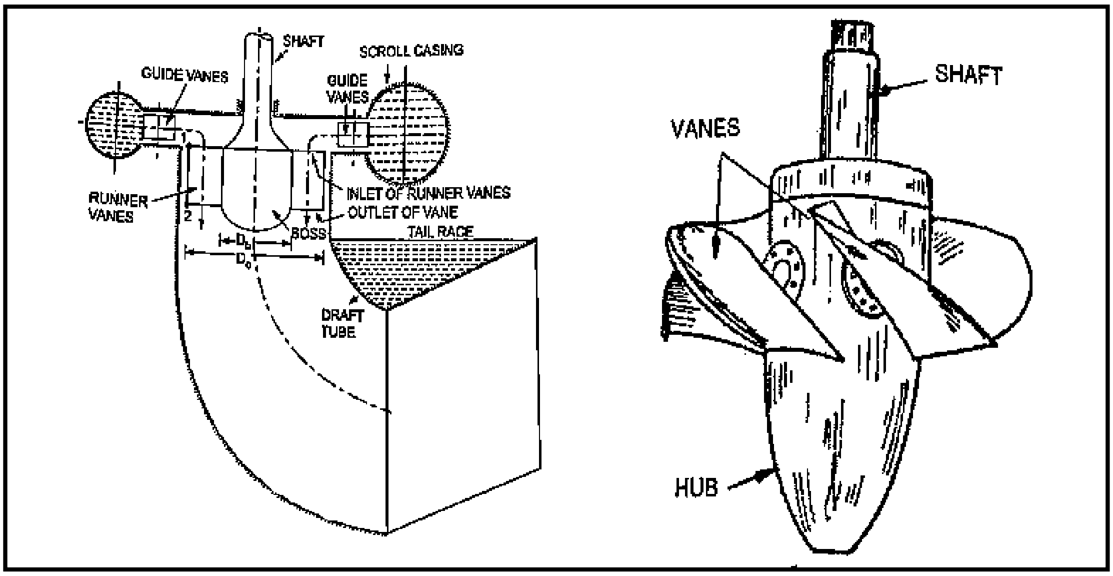
   Flow ratio = $\frac{V_{f_1}}{\sqrt{2gH}}$ and varies from 0.15 to 0.30.
3. The speed ratio = $\frac{u_1}{\sqrt{2gH}}$ varies from 0.6 to 0.9.

AXIAL FLOW REACTION TURBINE

If the water flows parallel to the axis of the rotation of the shaft, the turbine is known as axial flow turbine. And if the head at the inlet of the turbine is the sum of pressure energy and kinetic energy and during the flow of water through runner a part of pressure energy is converted into kinetic energy, the turbine is known as reaction turbine.

For the axial flow reaction turbine, the shaft of the turbine is vertical. The lower end of the is made larger which is known as 'hub' or 'boss'. The vanes are fixed on the hub and hence hub acts as runner for axial flow reaction turbine. The following are the important type of axial flow reaction turbines:

1. Propeller Turbine, and 2. Kaplan Turbine.



2. Velocity of flow at inlet and outlet arc equal

   ∴ $V_{f_1} = V_{f_2}$.

3. Area of flow at inlet = Area of flow at outlet

$$= \frac{\pi}{4}\left(D_o^2 - D_b^2\right).$$

EXAM ACHARYA™
EDUCATION REDEFINED

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test	: 35
Total mid subject test	: 16
Total full length test	: 13
Mock test	: 16
Total test	: 80

EXAM ACHARYA EDUCATION REDEFINED

4. Suction valve, and
5. Delivery valve.

WORKING OF A RECIPROCATING PUMP

Fig. shows a single acting Reciprocating pump, which consists of a piston which moves forwards & backwards in a close fitting cylinder. The movement of the piston is obtained by connecting the piston rod to crank by means of a connecting rod. The crank is rotated by means of an electric motor. Suction and delivery pipes with suction valve and delivery valve are connected to the cylinder. The suction and delivery valves are one way valves or non-return valves, which allow the water to flow in one direction only. Suction valve allows water from suction pipe to cylinder which delivery valve allows water from cylinder to delivery pipe only.

When crank starts rotating, the piston moves to and fro in the cylinder. When crank is at A, the piston is at the extreme left position in the cylinder. As the crank is rotating from A to C, (i.e., from $\theta = 0°$ to $\theta = 180°$), the piston is moving towards right in the cylinder. The movement of the Piston towards right creates a partial vacuum in the cylinder. But on the surface of the liquid in the sump the atmospheric pressure is acting, which is more than the pressure inside the cylinder. Thus, the liquid is forced in the suction pipe from the sump. This liquid opens the suction valve and enters the cylinder.

EXAM ACHARYA EDUCATION REDEFINED

When crank is rotating from C to A (i.e., from $\theta = 180°$ to $\theta = 360°$), the piston from its extreme right position starts moving towards left in the cylinder. The movement of the piston towards left increases the pressure of the liquid inside the cylinder more than atmospheric pressure. Hence suction valve closes and delivery valve opens. The liquid is forced into the delivery pipe and is raised to a required height.

Discharge Through a Reciprocating Pump

Consider a single acting reciprocating pump

Let D = Diameter of the cylinder

A = Cross-sectional area of the piston or cylinder

But slip is mostly expressed as percentage slip which is given by,

$$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100$$

$$= (1 - C_d) \times 100 \qquad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right)$$

Where C_d = Co-efficient of discharge.

Negative Slip of the Reciprocating Pump

Slip is equal to the difference of theoretical discharge and actual discharge. If actual discharge is more than the theoretical discharge, the slip of the pump will become -ve. In that case, the slip of the pump is known as negative slip.

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high Speed.

CLASSIFICATION OF RECIPROCATING PUMPS

EXAM ACHARYA™ EDUCATION REDEFINED

The reciprocating pumps may be classified as:

1. According to the water being in contact with one side or both sides of the piston, and
2. According to the number of cylinders provided.

If the water is in contact with one side of the piston, the pump is known as single-acting. On the other hand, if the water is in contact with both sides of the piston, the pump is called double-acting. Hence, following are the classification of pumps:

According to The Contact of Water

(i) Single-acting pump (ii) Double-acting pump

According to The Number of Cylinder Provided

(i) Single cylinder pump (ii) Double cylinder pump

(iii) Triple cylinder pump

GPSC - CIVIL

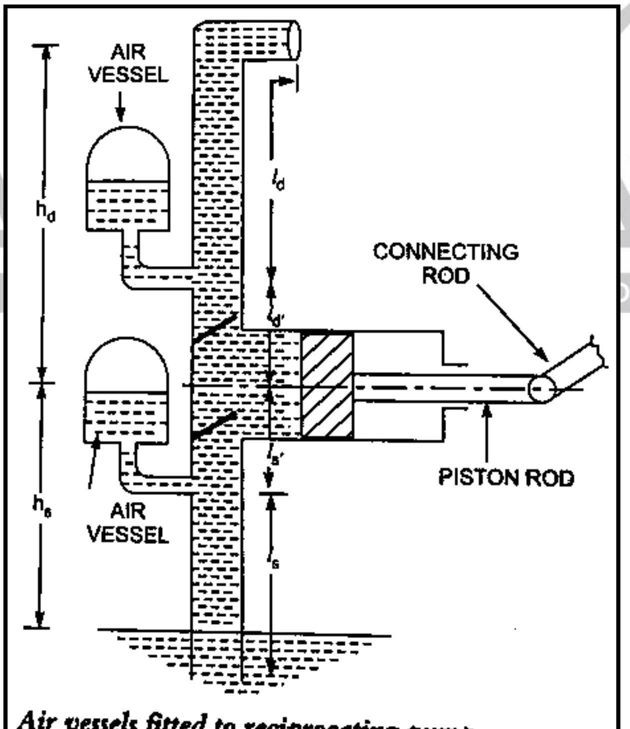
Surveying

The best Brains of the Nation may be found on the last Benches of the Classroom.

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

Fig. shows the single acting reciprocating pump to which air vessels are fitted to the suction and delivery pipes. The air vessels act like an intermediate reservoir. During the first half of the suction stroke, the piston moves with acceleration, which means the velocity of water in the suction pipe is more than the mean velocity and hence the discharge of water and entering the cylinder will be more than the mean discharge. The excess quantity of water will be supplied from the air vessel to the cylinder in such a way that the velocity in the suction pipe below the air vessel is equal to mean velocity of flow. During the second half of the suction stroke, the piston moves with retardation and hence velocity of flow in the suction pipe is less than the mean velocity of flow. Thus, the discharge entering the cylinder will be less than the mean discharge. The velocity of water in the suction pipe due to air vessel is equal to mean velocity of flow and discharge required in cylinder is less than mean the discharge. Thus, the excess water flowing in suction pipe will be stored into air vessel, which will be supplied during the first half of the next suction stroke.



Air vessels fitted to reciprocating pump.

When the air vessel is fitted to the delivery pipe, during the first half of delivery stroke, the piston moves with acceleration and forces the water into the delivery pipe with a velocity more than the mean velocity. The quantity of water in excess of the mean discharge will flow into the air vessel. This will compress the air inside the vessel. During

$$= \frac{AL}{60a} \times \frac{60\omega}{2\pi} \qquad \left(\because\ \omega = \frac{2\pi N}{60}\ 0r\ N = \frac{60\omega}{2\pi}\right)$$

$$= \frac{A}{a} \times L \times \frac{\omega}{2\pi} = \frac{A}{a} \times 2r \times \frac{\omega}{2\pi} \qquad (\because L = 2r)$$

$$= \frac{\mathbf{A}}{\mathbf{a}} \times \frac{\boldsymbol{\omega}}{\mathbf{2\pi}}$$

The velocity of water in the suction or delivery pipes for the length $l_s'$and l_d'due to acceleration and retardation of the piston is given by equation

$$v = \frac{A}{a}\ \omega r \sin \omega t = \frac{A}{a}\ \omega r \sin \theta \qquad (\because \theta = \omega t)$$

COMPARISON BETWEEN CENTRIFUGAL PUMPS AND RECIPROCATING PUMPS

Centrifugal Pumps	Reciprocating Pumps
1. The discharge is continuous and smooth.	1. The discharge is fluctuating and pulsating.
2. It can handle large quantity of liquid.	2. It handles small quantity of liquid only.
3. It can be used for lifting highly viscous liquids.	3. It is used only for lifting pure water or less viscous liquids.
4. It is used for large discharge through smaller heads.	4. It is meant for small discharge and high heads.
5. Cost of centrifugal pump is less as compared to reciprocating pump.	5. Cost of reciprocating pump is approximately four times the cost of centrifugal pump.
6. Centrifugal pump runs at high speed. They can be coupled to electric motor.	6. Reciprocating pump runs at low speed. Speed is limited due to consideration of separation and cavitation.
7. The operation of centrifugal pump is smooth and without much noise. The maintenance cost is low.	7. The operation of reciprocating pump is complicated and with much noise. The maintenance cost is high.
8. Centrifugal pump needs smaller floor area and installation cost is low.	8. Reciprocating pump requires large floor area and installation cost is high.
9. Efficiency is high.	9. Efficiency is low.

considerable extent. Thus the efficiency of the pump is more than the efficiency when only volute casing is provided.

Casing with Guide Blades

This casing is shown in Fig. (b) in which the impeller is surrounded by a series of guide blades mounted on a ring which is known as diffuser. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without stock. Also the area of the guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing, the pressure of water. The water from the guide vanes then passes through the surrounding casing which is in most of the cases concentric with the impeller as shown in Fig. (b)

Suction Pipe with a Foot Valve and a Strainer

A Pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe. A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe. The Foot valve opens only in the upward direction. A strainer is also fitted at the lower end of the suction pipe.

EXAM ACHARYA™ EDUCATION REDEFINED

Delivery Pipe

A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

(a) H_m = Head imparted by the impeller to the water – Loss of head in the pump

$$= \frac{V_{w2}u_2}{g} - \text{Loss of head in impeller and casing}$$

$$= \frac{V_{w2}u_2}{g} \text{ ...if loss of pump is zero}$$

(b) H_m = Total head at outlet of the pump – Total head at the inlet of the pump

$$= \left(\frac{P_0}{\rho g} + \frac{V_0^2}{2g} + Z_0\right) - \left(\frac{P_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right)$$

Where $\frac{P_0}{\rho g}$ = Pressure head at outlet of the pump = h_d

$\frac{V_0^2}{2g}$ = Velocity head at outlet of the pump

= Velocity head in delivery pipe = $\frac{V_d^2}{g}$

Z_0 = Vertical height of the outlet of the pump from datum line, and

$\frac{p_i}{\rho g}, \frac{V_i^2}{2g}, Z_i$ = Corresponding values of pressure head, velocity head and datum head at the inlet of the pump,

i. e., h_s, $\frac{V_s^2}{2g}$ and Z_s respectively.

(c) $H_m = h_s + h_d + h_{f_s} + h_{f_d} + \frac{V_d^2}{2g}$

Where h_s = Suction head, h_d = Delivery head,

h_{f_s} = Frictional head loss in suction pipe, h_{f_d} = Frictional head loss in delivery pipe, and

V_d = Velocity of water in delivery pipe.

(ii) Due to sudden collapse of vapour bubble, considerable noise and vibrations are produced.

(iii) The efficiency of a turbine decreases due to cavitation. Due to pitting action, the surface of the turbine blades becomes rough and the force exerted by water on the turbine blades decreases. Hence, the work done by water or output horse power becomes less and thus efficiency decreases.

Hydraulic Machines Subjected to Cavitation

The hydraulic machines subjected to cavitation are reaction turbines and centrifugal pumps.

Cavitation in Turbines

In turbines, only reaction turbines are subjected to cavitation. In reaction turbines the cavitation may occur at the outlet of the runner or at the inlet of the draft-tube where the pressure is considerably reduced (i.e., which may be below the vapour pressure of the liquid flowing through the turbine). Due to cavitation, the metal of the runner vanes and draft-tube is gradually eaten away, which results in lowering the efficiency of the turbine. Hence, the cavitation in a reaction turbine can be noted by a sudden drop in efficiency. In order to determine whether cavitation will occur in any portion of a reaction turbine, the critical value of Thoma's cavitation factor (σ sigma) is calculated.

Thoma's Cavitation Factor for Reaction Turbines

Prof. D. Thoma suggested a dimensionless number, called after his name Thoma's cavitation factor σ (sigma), which can be used for determining the region where cavitation takes place in reaction turbines. The mathematical expression for the Thoma's cavitation factor is given by

$$\sigma = \frac{H_b - H_s}{H} = \frac{(H_{atm} - H_v) - H_s}{H} \qquad \text{....(1)}$$

Where

H_b = Barometric pressure head in m of water,

H_{atm} = Atmospheric pressure head in m of water,

$$h_s = H_a - H_v - \frac{v_s^2}{2g} - h_{f_s}$$

Equation gives the value of maximum suction lift (or maximum suction height) for a centrifugal pump. Hence, the suction height of any pump should not be more than that given by equation. If the suction height of the pump is more, then vaporization of liquid at inlet of Pump will take place and there will be a possibility of cavitation.

NET POSITIVE SUCTION HEAD (NPSH)

The term NPSH (Net Positive Suction Head) is very commonly used in the pump industry. Actually, the minimum suction conditions are more frequently specified in terms of NPSH.

The net positive suction head (NPSH) is defined as the absolute pressure head at the inlet to the pump, minus the vapour pressure head (in absolute units) plus the velocity head.

∴ NPSH = Absolute pressure head at inlet of the pump - vapour pressure head (absolute units) + velocity head

$$= \frac{p_1}{\rho g} - \frac{p_v}{\rho g} + \frac{v_s^2}{2g} \quad (\because \text{Absolute pressure at inlet of pump} = p_1)$$

The absolute pressure head at inlet of the pump is given by as

$$\frac{p_1}{\rho g} = \frac{p_a}{\rho g} - \left(\frac{v_s^2}{2g} + h_s + h_{fs}\right)$$

Substituting this value in equation, we get

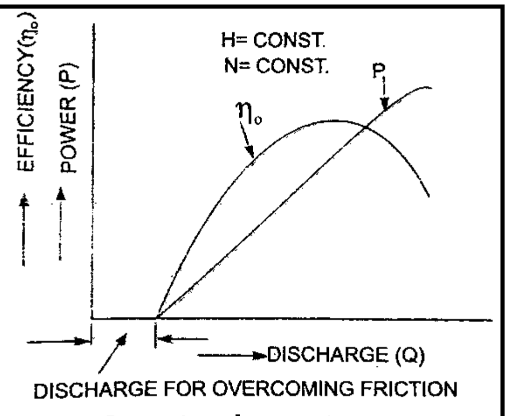
$$\text{NPSH} = \left[\frac{p_a}{\rho g} - \left(\frac{v_s^2}{2g} + h_s + h_{fs}\right)\right] - \frac{p_v}{\rho g} + \frac{v_s^2}{2g}$$

$$= \frac{p_a}{\rho g} - \frac{p_v}{\rho g} - h_s - h_{fs}$$

$$= H_a - H_v - h_s - h_{fs}$$

$$\left(\because \frac{p_a}{\rho g} = H_a = \text{Atmospheric pressure head}, \frac{p_v}{\rho g} = H_v = \text{Vapour pressure head}\right)$$

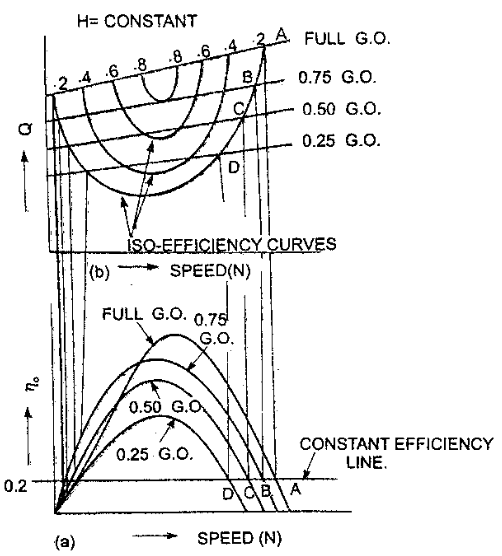
Hence the power and efficiency curves will be slightly away from the origin on the x-axis, as to overcome initial friction certain amount of discharge will be required. Fig. shows the variation of power and efficiency with respect to discharge.



Operating characteristic curves.

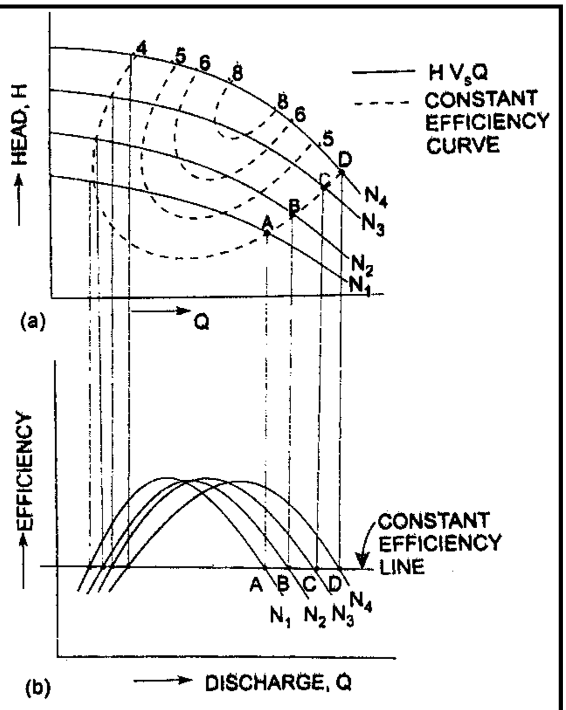
Constant Efficiency Curves or Muschel Curves or ISO-Efficiency Curves

These curves are obtained from the speed vs. efficiency and speed vs. discharge curves for different gate openings. For a given efficiency from the N_u vs. η_o curves, there are two speeds. From the N_u vs. Q_u curves, corresponding to two values of speeds there are two values of discharge. Hence for a given efficiency there are two values of discharge for a particular gate opening.



Constant efficiency curve.

CONSTANT EFFICIENCY CURVES



Constant efficiency curves of a pump.

For obtaining constant efficiency curves for a pump, the head versus discharge curves and efficiency versus discharge curves for different speed are used. Fig (a) shows the head versus discharge curves for different speeds. The efficiency versus discharge curve for the different speeds are as shown in Fig. (b). By combining these curves (H ~ Q curves and η ~ Q curves), constant efficiency curves are obtained as shown in Fig.

For plotting the constant efficiency curves (also known as iso-efficiency curves), horizontal lines representing constant efficiencies are drawn on the η ~ Q curves. The points, at Which these lines cut the efficiency curves at various speeds, are transferred to the corresponding H ~ Q curves. The points having the same efficiency are then joined by smooth curves. These smooth curves represents the iso-efficiency curves.

EXAM ACHARYA
EDUCATION REDEFINED

GPSC - CIVIL

Transportation Engineering

END is not the end if fact E.N.D. means
" Effort Never dies"

A.P.J. Abdul Kalam

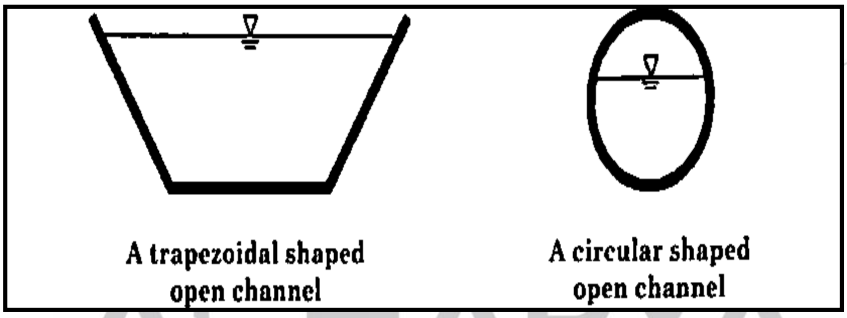
The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

CHAPTER 12

OPEN CHANNEL FLOW

INTRODUCTION

- An open channel is a natural or a man-made structure in which liquid flows with a free surface at atmospheric pressure.
- The prime motivating force in open channel flows is gravity flow.
- For example, flow in rivers, streams, flow in sanitary and storm sewers flowing partially full.



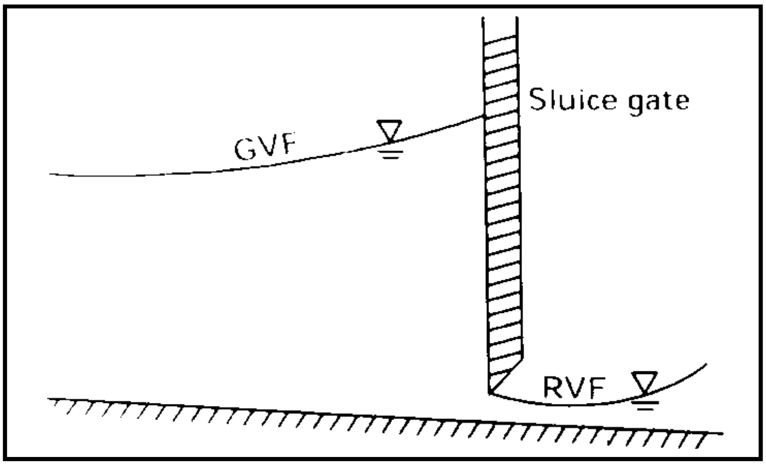
ACHARYA EDUCATION REDEFINED

TYPES OF CHANNELS

Prismatic and Non-Prismatic Channels

- A channel in which the cross-sectional shape, size and the bed slope are constant is termed as Prismatic channel.
- All-natural channels generally have varying cross section and consequently are known as non-prismatic channels.
- Most of the manmade channel are prismatic channels over long stretches. Rectangle, trapezoid, triangle and circle are commonly used shapes in man-made channels.

- If depth of flow changes gradually over a long distance along the length of channel such that curvature of free surface is mild, then flow is called as Gradually varied flow (GVF). For example flow at upstream side of sluice gate.



- In GVF, the loss of energy is mainly due to boundary friction.
- In GVF, the pressure distribution in vertical direction is taken as hydrostatic.
- If the curvature in a varied flow is large and the depth changes appreciably over short length, such flow is called Rapidly varied flow.
- For example, flow at downstream side of a sluice gate is a Rapidly varied flow.
- In RVF, frictional resistance are insignificant.
- GVF and RVF can further be classified as steady and unsteady flow.

  (a) **Gradually varied unsteady flow:** Passage of flood wave in a river.

  (b) **Gradually varied steady flow:** Backing up of water in a stream due to dam.

  (c) **Rapidly varied unsteady flow:** A surge moving upstream a canal and breaking of wave on the shore.

  (d) **Rapidly varied steady flow:** A hydraulic jump below a spillway or a sluice gate.

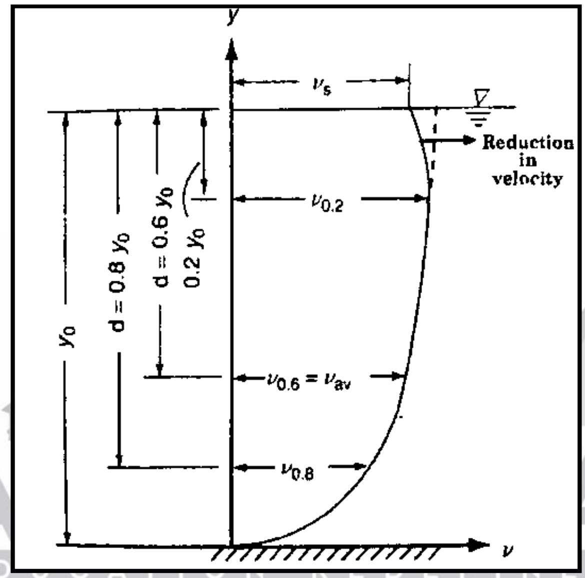
EXAM ACHARYA EDUCATION REDEFINED

section, flow conditions must be changed at an u/s location i.e., supercritical flow is said to have u/s control.

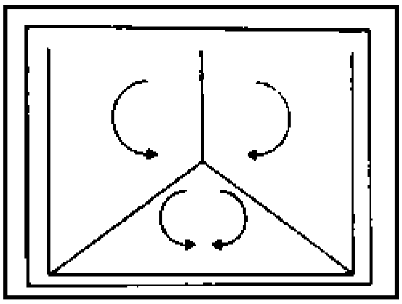
- Similarly subcritical flow is said to have d/s control.

VELOCITY DISTRIBUTION

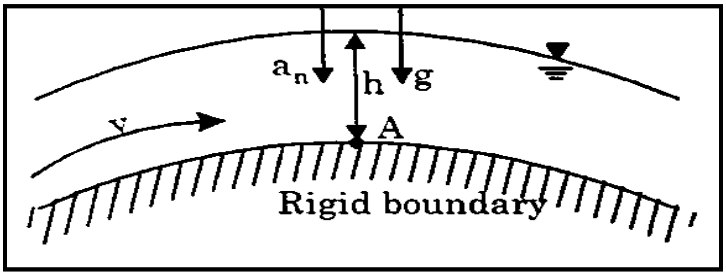
- A typical velocity profile at a section in a plane normal to the direction of flow is as shown below. This profile can be roughly described by a logarithmic distribution or a power law distribution.

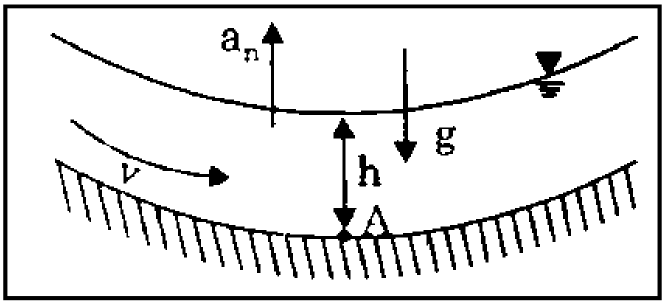


- Velocity is zero at the boundaries and gradually increases with the distance from the boundary.



- Maximum velocity of flow occurs at a certain distance below the free surface. This reduction is due to the production of secondary current which is a function of aspect ratio (ratio of depth to width.)





CONTINUITY EQUATION IN OPEN CHANNEL FLOW

Continuity equation is based on law of conservation of mass.

Steady State Flow

In a steady state flow of incompressible fluid, the continuity equation states that the volumetric rate of flow (discharge) across various section must be the same.

$$Q = VA = V_1A_1 = V_2A_2$$

Unsteady State Flow

In unsteady state flow of incompressible fluid, the continuity equation states that net discharge getting out of control volume should be equal to depletion of storage in control volume.

$$\frac{\partial Q}{\partial x} = -T\frac{\partial y}{\partial t}$$

MOMENTUM EQUATION IN OPEN CHANNEL FLOW

- Momentum is a vector quantity. The momentum equation commonly used in open channel flow problems is the linear-momentum equation.

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

We know that,

Total energy at any section = Pressure energy + Kinetic energy + Elevation energy

$$\frac{\text{Total energy}}{\text{weight}} = \text{Total energy head} = \frac{P}{\gamma} + \frac{v^2}{2g} + Z$$

Applying energy equation between section 1 & 2

$$\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + h_L$$

h_L = Energy loss between section 1 & 2

Note

- The term $\left(\frac{P}{\gamma} + Z\right)$ represents elevation of hydraulic gradient line (HGL) above datum, it is also called Piezometric head.

APPLICATION OF MOMENTUM AND ENERGY EQUATIONS

- The momentum and energy equations should give the same results if applied properly. However, which of these two to be applied for a particular situation depends in the problem under consideration. Following discussion will help us to choose the equations to be applied.

- Terms used in momentum equation are vectors and that in energy equation are scalars. Hence momentum equation can be applied only when magnitude and direction are known.

- The losses in the energy equation are internal losses that occur in the volume of liquid.

- The losses to be considered in the momentum equation are those due to external shear acting on the boundaries of the control volume.

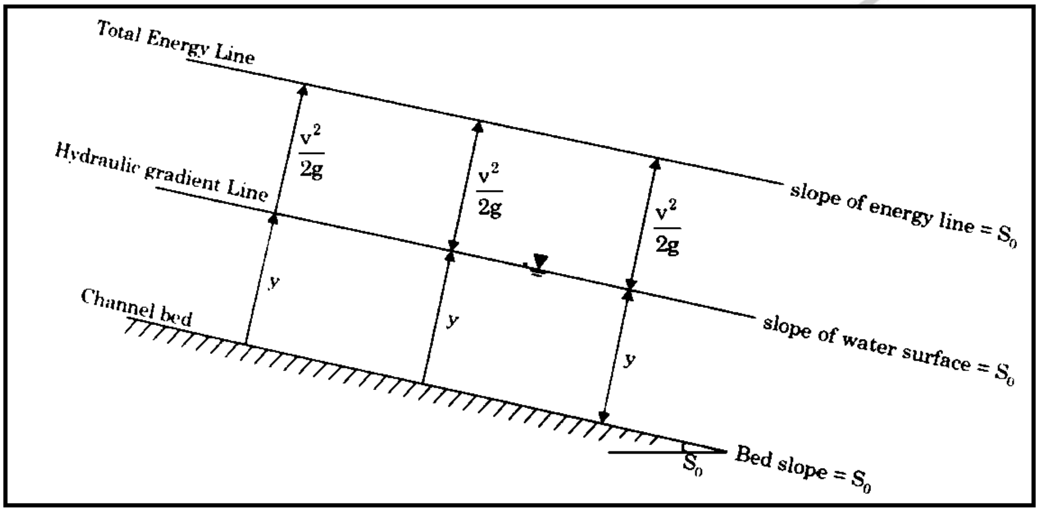
- The local losses such as those in a bend or in a hydraulic jump, occur in a short stretch. In such cases, loss due to shear at the boundary are small and may be

CHAPTER – 13

UNIFORM FLOW

INTRODUCTION

- A flow in open channel is said to be uniform flow if its properties remains constant with respect to distance. i.e depth of flow, area of cross section and velocity of flow remains constant along the channel.
- This constant depth of flow in uniform flow is called Normal depth.
- As the depth of flow and velocity at every section are constant therefore the channel bed slope, water surface slope and energy line slope will all be same.



- In uniform flow, the frictional resistance acting between the fluid and channel boundary are balanced by the gravity forces.

VELOCITY MEASUREMENT

- In uniform flow since the velocity of flow does not change along the length of the channel, acceleration is zero. Hence, the sum of the components of all the external forces in the direction of flow must be equal to zero.

RELATION BETWEEN CHEZY'S CONSTANT AND FRICTION FACTOR

We know that

$$v = C\sqrt{RS}$$

Hence S is the slope of energy line, for uniform flow in open channel

$$\text{Slope of Energy Line} = S = \frac{h_f}{L}$$

From the Darcy's weisbach equation

$$h_f = f\frac{L}{D}\frac{v^2}{2g}$$

Where,

h_f = head loss due to friction in a pipe of diameter D and length l.

f = Darcy's weisbach friction factor

EXAM ACHARYA™ EDUCATION REDEFINED

Note

- The above formula of head loss was mainly given for pipe flow, but an open channel flow can be related to the pipe flow at atmospheric pressure.

For a circular pipe of diameter D

$$R = \frac{A}{P} = \frac{\frac{\pi}{4}D^2}{\pi D}$$

$$R = \frac{D}{4}$$

$$\therefore \quad h_f = f\frac{L}{4R}\frac{v^2}{2g}$$

$$\therefore \quad \mathbf{v = \sqrt{\frac{8g}{f}}\sqrt{R}\sqrt{\frac{h_f}{L}}} \qquad \textbf{...(A)}$$

EXAM ACHARYA®
EDUCATION REDEFINED

GPSC - CIVIL

Water Resource Engineering

"Don't Fear for Facing Failure in the First Attempt, Because even the Successful Maths Start with 'Zero' only."

A.P.J. Abdul Kalam

The content of this book covers all PSC exam syllabus such as MPSC, RPSC, UPPSC, MPPSC, OPSC etc.

$$R = \frac{B \times y}{B+B}$$

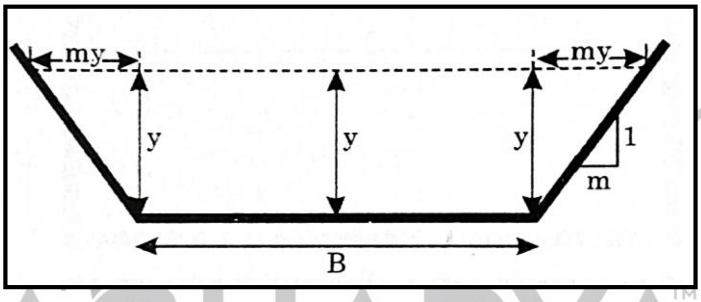
$$R = \frac{Y}{2}$$

For most efficient rectangular channel section depth of flow y = B/2 and Hydraulic radius $R = \frac{y}{2}$.

Most efficient trapezoidal section

Case I: When side slope is fixed

Consider a channel section of bottom width = B, Depth of flow = y, Side slope = 1 : m (V : H)



There are 3 variables y, B, m but as m is fixed, the number of variable left out are two, y and B.

$$\text{Area, } A = \frac{1}{2}(B + B + 2my)y$$

$$A = \frac{1}{2}(2B + 2my)\, y$$

$$\mathbf{A = (B + my)\, y}$$

$$\text{Top flow width, } \mathbf{T = B + 2ym}$$

$$\text{Perimeter, } P = B + 2y\sqrt{m^2 + 1}$$

$$\text{Substituting } B = \frac{A}{y} - my$$

$$\mathbf{P = \frac{A}{y} - my + 2y\sqrt{m^2 + 1}} \quad \ldots\text{(i) (A \& m are constant)}$$

$$3m^2 = 1$$

$$m^2 = \frac{1}{3}$$

$$m = \frac{1}{\sqrt{3}} \qquad \left[\tan\theta = \frac{1}{m}\right]$$

$\therefore$ $$\tan\theta = \sqrt{3}$$

$$\theta = \tan^{-1}(\sqrt{3})$$

$$\boxed{\theta = 60°} \quad 4^{th} \text{ condition}$$

For economical trapezoidal section with varying side slope, the value of side slope should be 1: $\sqrt{3}$ (1 : m).

Conclusion

For most economical trapezoidal section following conditions should be satisfied.

(1) $\frac{T}{2}$ = Length of side slope

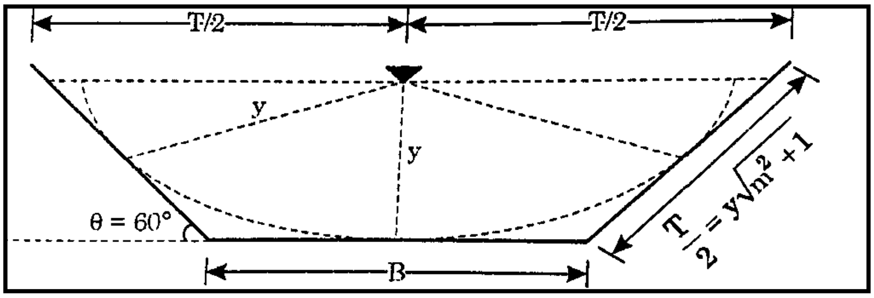
(2) $R = \frac{y}{2}$

(3) A circle of radius y (normal flow depth) should be inscribed in trapezoidal section.

(4) $\theta = 60°$

Note

- Above conditions implies that most economical trapezoidal section should be half of rectangular hexagon.



$$5A^4 P^{-2}\frac{dA}{d\theta} - 2A^5 P^{-3}\frac{dp}{d\theta} = 0$$

$$5P\frac{dA}{d\theta} - 2A\frac{dP}{d\theta} = 0$$

$\because$ $\frac{dA}{d\theta} = R^2 (1 - \cos 2\theta)$ $\quad [A = \frac{R^2}{2}(2\theta - \sin 2\theta)]$

$\because$ $\frac{dP}{d\theta} = 2R$ $\quad [P = 2R\theta]$

Substituting the values of $\frac{dA}{d\theta}$ and $\frac{dP}{d\theta}$

$$\therefore 5 \times (2R\theta) \times R^2 (1 - \cos 2\theta) - 2 \times \frac{R^2}{2}(2\theta - \sin 2\theta) \times 2R = 0$$

$$10R^3\theta (1- \cos 2\theta) = 2R^3 (2\theta - \sin 2\theta)$$

$$10\theta - 10\theta \cos 2\theta = 4\theta - 2\sin 2\theta$$

$$6\theta - 10\theta \cos 2\theta + 2\sin 2\theta = 0$$

Solving By Hit and trial

$$\theta = 2.636 \text{ rad or } 2\theta = 302° 22'$$

$$d = R - R\cos\theta$$

$$d = R(1 - \cos\theta)$$

$$\frac{d}{R} = (1 - \cos\theta)$$

$$\frac{d}{R} = 1.876$$

$$\frac{d}{D} = 0.938$$

Condition for maximum velocity:

$$A = \frac{R^2}{2}(2\theta - \sin 2\theta)$$

$$P = 2R\theta$$

We know that

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

$$v = \frac{1}{n}\frac{A^{2/3}}{P^{2/3}} S^{1/2}$$

New Batches are going to start.....

Contact:

7622050066

Test Series Available..

Total weekly test : 35

Total mid subject test : 16

Total full length test : 13

Mock test : 16

Total test : 80

EXAM ACHARYA EDUCATION REDEFINED

Note

From Chezy's Equation

For condition for maximum discharge

$$2\theta = 308° \text{ or } \frac{d}{D} = 0.95$$

For condition for maximum velocity

$$2\theta = 257° 27' \text{ or } \frac{d}{D} = 0.81$$

EXAM ACHARYA™ EDUCATION REDEFINED

CHAPTER – 14

ENERGY DEPTH RELATIONSHIP

SPECIFIC ENERGY

Specific energy is the total energy at a section w.r.t the channel bed as datum and is expressed as summation of flow depth and velocity head.

When the channel slope is small, specific energy is given by

$$\mathbf{E = y + \frac{v^2}{2g}}$$

Assuming K.E. correction factor as unity. Because channel flow will always be turbulent flow and for turbulent flow K.E. correction factor is approximately unity

When the channel slope is large and K.E correction factor is not unity specific energy is given by

EXAM ACHARYA™ EDUCATION REDEFINED

$$E = y\cos\theta + \frac{v^2}{2g}.\propto$$

Where,

θ = Bed slope of channel bottom.

∝ = K.E correction factor.

dA can be written as T dy. Therefore $\frac{dA}{dy} = T$,

∴ $$\frac{dE}{dy} = 1 - \frac{Q^2T}{gA^3}$$

$$1 - \frac{Q^2T}{gA^3} = 0$$

$$\mathbf{\frac{Q^2T}{gA^3} = 1}$$

$$\frac{\left(\frac{Q^2}{A^2}\right)\times T}{gA} = 1$$

$$\frac{v^2T}{gA} = 1$$

$$\frac{v}{\sqrt{g\frac{A}{T}}} = 1$$

For a rectangular channel, we know that $\frac{A}{T} = y$

$$\frac{v}{\sqrt{gy}} = 1 \qquad \left[F_r = \frac{v}{\sqrt{gy}} = 1\right]$$

Thus, when the specific energy is minimum for a given discharge, flow will be critical flow and death of flow will be called as critical depth y_c and velocity of flow is called as critical velocity v_c.

When the depth of flow is greater than the critical depth, the velocity of flow is less than the critical velocity for the given constant discharge and hence flow is subcritical.

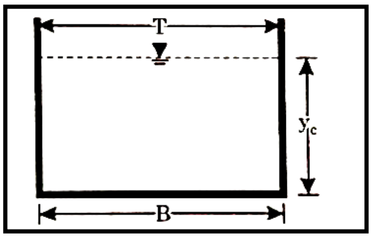
When the depth of flow is less than the critical depth, the flow is supercritical.

Type of flow	**Depth of flow condition**	**Froude Number** $F_r = \frac{v}{\sqrt{gy}}$
Subcritical	$y > y_c$	$F_r < 1$
Critical	$y = y_c$	$F_r = 1$
Super Critical	$y < y_c$	$F_r > 1$

CALCULATION OF CRITICAL DEPTH

Rectangular Channel Section

Consider a rectangular channel section of width B′ and having constant discharge Q under a critical depth of flow $y = y_c$.



Area of flow, $A = B\,y_c$

Top width, $T = B$

For critical flow condition

$$\frac{Q^2T}{gA^3} = 1$$

$$\frac{Q^2B}{gB^3y_c^3} = 1$$

$$y_c^3 = \frac{Q^2}{B^2g}$$

Let discharge per unit width (B), $q = \frac{Q}{B}$

$$y_c^3 = \frac{q^2}{g}$$

$$y_c = \left(\frac{q^2}{g}\right)^{1/3}$$

Specific energy at critical depth y_c, will be

$$E_c = y_c + \frac{V_c^2}{2g}$$

$$E_c = y_c + \frac{\left(\frac{q}{y_c}\right)^2}{2g}$$

$$E_c = y_c + \frac{q^2}{2gy_c^2} \qquad \left[\because \frac{q^2}{g} = y_c^3\right]$$

EXAM ACHARYA EDUCATION REDEFINED

- It is observed that there are two possible depth for a certain value of q, as long as q is less than a certain value.
- At maximum discharge the two depths become one, equal to the critical depth y_c.
- If $y < y_c$, supercritical flow.
- If $y > y_c$, subcritical flow.

SECTION FACTOR "Z"

Section factor, z is a function of depth y for a given channel geometry.

$$\mathbf{Z = A\sqrt{\frac{A}{T}}}$$

At Critical flow condition $y = y_c$

∴ $$Z_c = A_c\sqrt{\frac{A_c}{T_c}}$$

As $$\frac{Q^2T}{gA^3} = 1, \text{ for critical flow}$$

$$\frac{A^3}{T} = \frac{Q^2}{g}$$

$$z_c = \frac{Q_c}{\sqrt{g}}$$

$$Q_c = z_c\sqrt{g}$$

Q_c is the discharge that would make the depth flow y critical discharge, and is known as critical discharge.

GPSC - CIVIL

Previous Year Question

EXAM ACHARYA®
EDUCATION REDEFINED

Qu 4. If the Froude number of flows in an open channel is more than 1.0, then the flow is said to be

(a) Critical

(b) Shooting

(c) Streaming

(d) Transitional

TEST YOUR SELF

Qu 5. Which one of the following conditions is a typical characteristic of critical flow?

(a) $\frac{Q^2T}{gA^3} = 1$

(b) $\frac{QT^2}{gA^2} = 1$

(c) $\frac{Q^2}{gA^2} = 1$

(d) $\frac{Q^2T^2}{gA^2} = 1$

EXAM ACHARYA EDUCATION REDEFINED

$$y_n = \left(\frac{Q_n}{B\sqrt{S_0}}\right)^{3/5}$$

1. Hance for larger S_0, y_n will be smaller and also $y_c = \left(\frac{q^2}{g}\right)^{1/3}$
2. Critical depth is independent of bed slope and depends only on cross- section of channels. The two conclusion although derived for wide rectangular channel are valid for all types of channel.

- In a given channel y_n and y_c are two fixed depth if Q, n and S_0 are fixed.

  Where,

  y_n = normal depth of flow

  y_c = critical depth of flow

- There are 3 relations between y_n and y_c.

  (1) $y_n > y_c$ Mild slope

  (2) $y_n = y_c$ Critical slope

  (3) $y_n < y_c$ Steep slope

EXAM ACHARYA™ EDUCATION REDEFINED

- There are 2 relations when y_n does not exists.

  (1) $S_0 < 0$ Adverse slope

  (2) $S_0 = 0$ Horizontal slope.

  Based on above relations channel are classified into five categories.

Sl. No.	Channel category	Symbol	Characteristic Condition	Remark
1.	Mild slope	M	$y_0 > y_c$	Subcritical flow at normal depth
2.	Steep slope	S	$y_c > y_0$	Supercritical flow at normal depth
3.	Critical slope	C	$y_c = y_0$	Critical flow at normal depth
4.	Horizontal bed	H	$S_0 = 0$	Cannot sustain uniform flow
5.	Adverse slope	A	$S_0 < 0$	Cannot sustain uniform flow

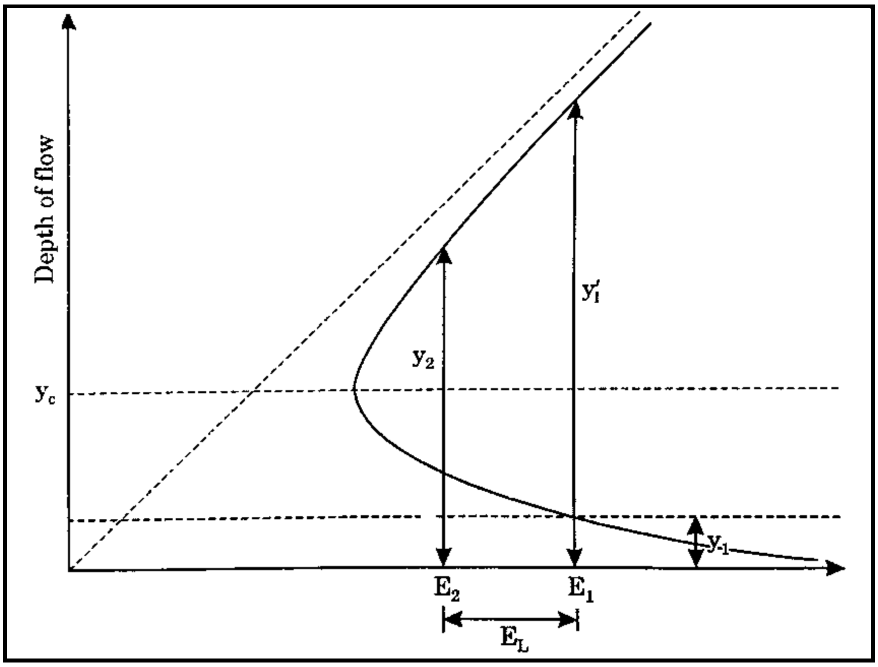
New Batches are going to start.....

Contact: 7622050066

Test Series Available..

Total weekly test	: 35
Total mid subject test	: 16
Total full length test	: 13
Mock test	: 16
Total test	: 80

EXAM ACHARYA EDUCATION REDEFINED



Thus, the resulting depths y_1 and y_2 are called as sequent depth or conjugate depth.

Note
- **Alternate depth:** Depth with same specific energy.
- **Sequent depth:** Two depth of hydraulic jump with same specific Force.

Toe of Jump

Section 1, where the incoming supercritical stream undergoes an abrupt rise in the depth forming the commencement of jump is called as Toe of jump.

End of Jump

It is the point at which the roller formation terminates and water surface is levelled. Section 2 in the figure represents the end of jump.

Length of Jump

Distance between Toe of jump (section 1) and end of jump (section 2) is called as length of jump.

- For critical flow condition following condition will hold true. For all type of channel.

$$\frac{Q^2}{g} = \frac{A^3}{T}$$

Energy Loss

The energy loss E_L in the jump is given by the energy equation application between section 1 and 2.

$$E_L = E_1 - E_2$$

$$E_L = \left(y_1 + \frac{q^2}{2gy_1^2}\right) - \left(y_2 + \frac{q^2}{2gy_2^2}\right)$$

$$E_L = (y_1 - y_2) + \frac{1}{2}\frac{q^2}{g}\left(\frac{y_2^2 - y_1^2}{y_1^2 y_2^2}\right)$$

We know that,

$$\frac{2q^2}{g} = y_1 y_2 (y_1 + y_2)$$

$$E_L = (y_1 - y_2) + \frac{y_1 y_2 (y_1 + y_2)}{4}\left(\frac{y_2^2 - y_1^2}{y_1^2 y_2^2}\right)$$

$$E_L = (y_1 - y_2) + \frac{(y_1 + y_2)(y_2^2 - y_1^2)}{4y_1 y_2}$$

$$E_L = \frac{4y_1^2 y_2 - 4y_1 y_2^2 + y_1 y_2^2 - y_1^3 + y_2^3 - y_2 y_1^2}{4y_1 y_2}$$

$$E_L = \frac{y_2^3 - y_1^3 + 3y_1^2 y_2 - 3y_1 y_2^2}{4y_1 y_2}$$

$$E_L = \frac{(y_2 - y_1)^3}{4y_1 y_2} \qquad [(a-b)^3 = a^3 - b^3 - 3ab^2 - 3ba^2]$$

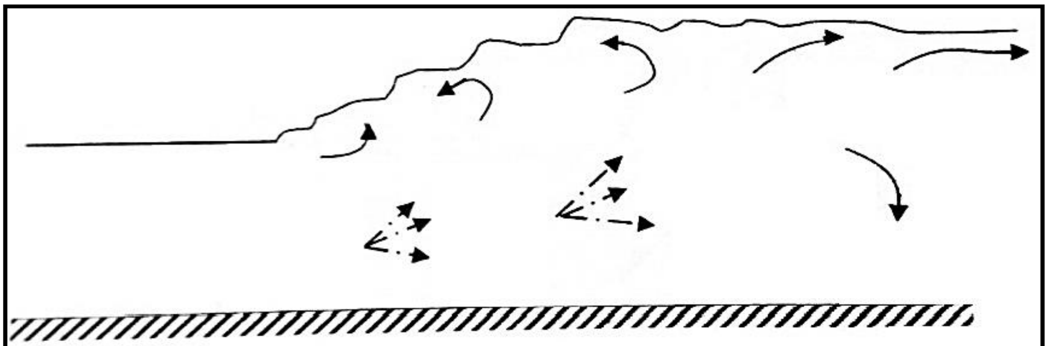
Relative Energy Loss

$$\text{Relative Energy Loss} = \frac{E_L}{E_1}$$

$$E_L = y_1 + \frac{v_1^2}{2g} = \left(y_1 + \frac{q^2}{2gy_1^2}\right)$$

3. **Oscillating Jump** $2.5 < F_1 \leq 4.5, \frac{E_L}{E_1} = 18 - 45\%$

The entering jet of water oscillates in a random manner between bed and surface. These oscillations are very common in canals and can travel considerable distances and damaging earthen banks.

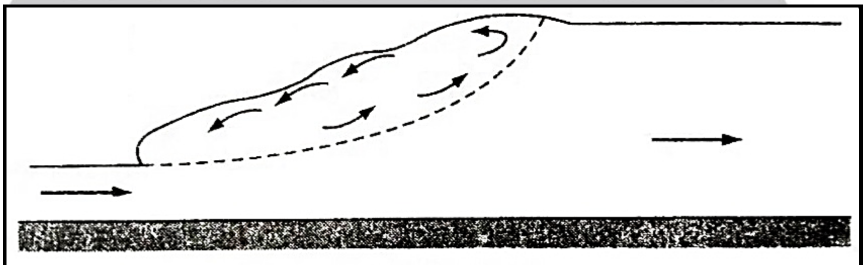


Oscillating jump

4. **Steady Jump** $4.5 < F_1 \leq 9.0, \frac{E_L}{E_1} = 45 - 70\%$

- The jump is well established, the roller and jump action is fully developed to cause appreciable energy loss (downstream surface smooth).
- It is always preferred to have steady jump

EXAM ACHARYA TM EDUCATION REDEFINED



'Steady' jump

5. **Strong or Choppy Jump** $F_1 > 9.0, \frac{E_L}{E_1} \geq 70\%$

- During this jump water surface is very rough and Choppy, which continues downstream for a long distance.
- Sequent depth ratio $\frac{y_2}{y_1}$ is quite large.

TEST YOUR SELF

Qu 8 If y_2 = sequent depth for rectangular channel obtained by assuming horizontal frictionless channel in the momentum equation and y_{2a} = corresponding actual sequent depth measured in a horizontal rectangular channel having high friction, one should expect

(a) $y_2 > y_{2a}$

(b) $y_2 = y_{2a}$

(c) $y_2 < y_{2a}$

(d) $y_2 \leq y_{2a}$

Qu 9 If the length of the jump in a sloping rectangular channel = L_{js} and the corresponding length of the jump in a horizontal rectangular channel having same y_1 and F_1 is L_j, then

(a) $L_j > L_{js}$

(b) $L_{js} > L_j$

(c) $L_j = L_{js}$

(d) $L_j / L = 0.80$

EXAM ACHARYA™ EDUCATION REDEFINED

Qu 10 A sluice gate discharges a flow with a depth of y_1 at the vena contracta. Y_2 is the sequent depth corresponding to y_1. If the tail water depth y_t is larger then y_2 then

(a) A repelled jump occurs

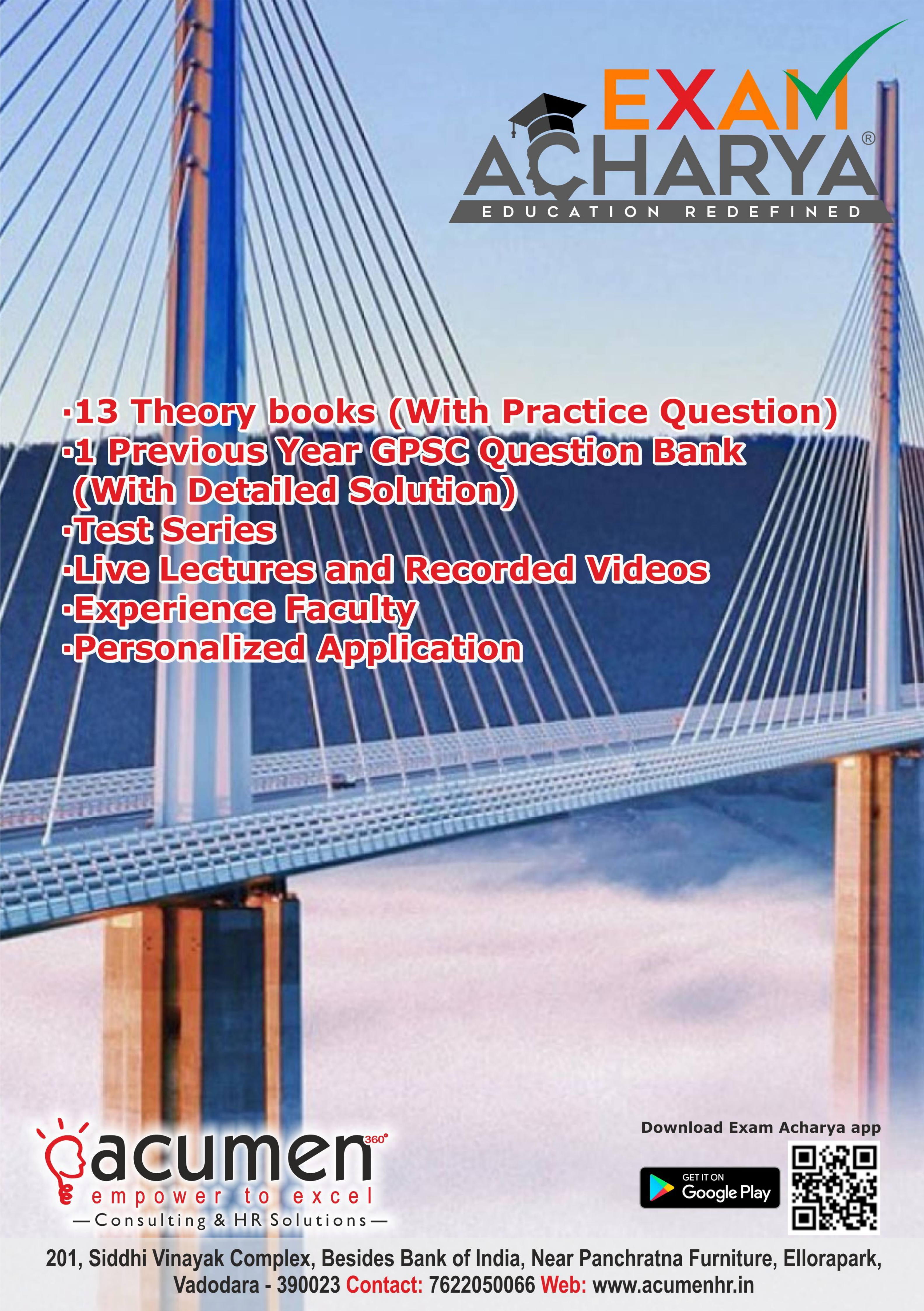
(b) A free jump occurs

(c) A submerged jump takes place

(d) No jump takes place

ANSWERS

1 (d), 2 (d), 3 (a), 4. (b), 5 (c), 6 (b), 7 (c), 8 (a), 9 (b), 10. (c)


EXAM ACHARYA®
EDUCATION REDEFINED
·13 Theory books (With Practice Question)
·1 Previous Year GPSC Question Bank (With Detailed Solution)
·Test Series
·Live Lectures and Recorded Videos
·Experience Faculty
·Personalized Application
acumen 360°
empower to excel
— Consulting & HR Solutions —
Download Exam Acharya app
GET IT ON Google Play
201, Siddhi Vinayak Complex, Besides Bank of India, Near Panchratna Furniture, Ellorapark,
Vadodara - 390023 Contact: 7622050066 Web: www.acumenhr.in