



Fluid Mechanics & Hydraulics

Detailed notes + compact revision summary

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CHAPTER 01

Properties of Fluids

Mass properties, viscosity and rheology, surface tension and capillarity, compressibility, vapour pressure and cavitation.

1.1 Fluids, continuum and mass properties

A **fluid** is a substance that deforms continuously under the smallest shear stress, however small. A solid resists shear by a finite deformation; a fluid at rest cannot carry any shear at all. Liquids have a free surface and are nearly incompressible; gases fill the whole container and are highly compressible.

In engineering analysis a fluid is treated as a **continuum** — properties such as density and velocity are assumed to vary continuously from point to point, ignoring molecular gaps. This holds as long as the mean free path of molecules is very small compared with the body size (it fails only in rarefied gases).

Mass density

$$\rho = \frac{M}{V}$$

kg/m³; water = 1000 kg/m³ at 4 °C

Specific (unit) weight

$$\gamma = \rho g$$

N/m³; water = 9810 N/m³ = 9.81 kN/m³

Specific volume

$$v_s = \frac{1}{\rho}$$

m³/kg (volume per unit mass)

Specific gravity (relative density)

$$S = \frac{\rho}{\rho_w} = \frac{\gamma}{\gamma_w}$$

ρ_w, γ_w = values for water at 4 °C; for gases the reference is air or H₂

Equation of state (perfect gas)

$$p = \rho RT$$

p absolute (Pa); R = 287 J/kg·K for air; T in kelvin

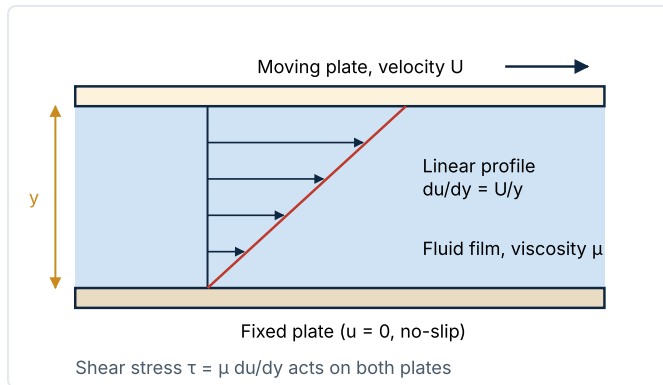
Typical properties at about 20 °C and 1 atm

Fluid	ρ (kg/m ³)	Sp. gr.	μ (Pa·s)	ν (m ² /s)
Water	998 (1000 used)	1.0	1.0×10^{-3}	1.0×10^{-6}
Sea water	≈ 1025	1.025	$\approx 1.07 \times 10^{-3}$	$\approx 1.05 \times 10^{-6}$
Mercury	13 600	13.6	1.55×10^{-3}	1.1×10^{-7}
Air	1.20	—	1.8×10^{-5}	1.5×10^{-5}

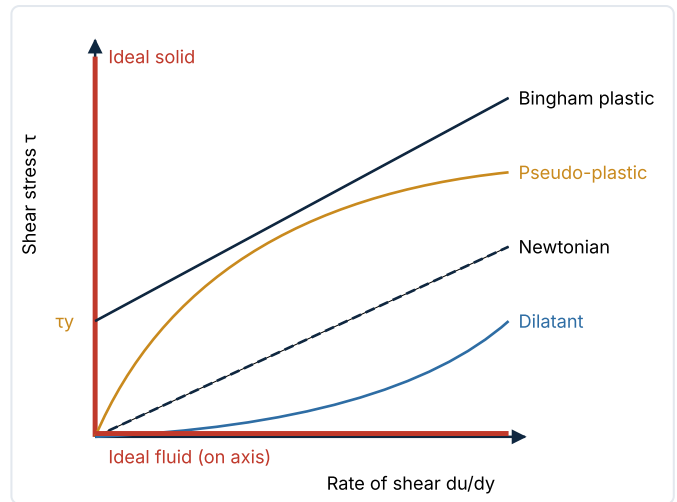
Exam trap: Air has a **smaller μ** than water but a **larger ν** (about 15 times) because its density is so low. Questions often ask which is larger — check whether dynamic or kinematic viscosity is meant.

1.2 Viscosity and Newton's law

Viscosity is the property by which a fluid resists the relative motion (shear) between adjacent layers. If a plate moves over a thin fluid film, the layer touching each plate moves with that plate (**no-slip condition**) and a velocity gradient du/dy develops across the film.



Couette flow between plates: linear velocity profile and shear

Rheological diagram — τ versus du/dy for various fluids**Newton's law of viscosity**

$$\tau = \mu \frac{du}{dy}$$

 τ = shear stress (N/m^2); du/dy = rate of shear strain (s^{-1})
Kinematic viscosity

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

 m^2/s ; 1 stoke = $1 \text{ cm}^2/\text{s} = 10^{-4} \text{ m}^2/\text{s}$
Units of viscosity

Quantity	SI unit	CGS unit	Conversion
Dynamic μ	$\text{N}\cdot\text{s}/\text{m}^2 = \text{Pa}\cdot\text{s}$	poise = $\text{dyne}\cdot\text{s}/\text{cm}^2$	1 poise = $0.1 \text{ N}\cdot\text{s}/\text{m}^2$; 1 cP = $10^{-3} \text{ Pa}\cdot\text{s}$
Kinematic ν	m^2/s	stoke = cm^2/s	1 stoke = $10^{-4} \text{ m}^2/\text{s}$; 1 cSt = $10^{-6} \text{ m}^2/\text{s}$
Dimensions	$\mu: \text{ML}^{-1}\text{T}^{-1}$	$\nu: \text{L}^2\text{T}^{-1}$	ν has no mass term (kinematic)

- Effect of temperature** — in liquids viscosity is due mainly to *cohesion*, which weakens as temperature rises, so μ of liquids **decreases** with temperature (water: 1.79 cP at 0°C , 1.0 cP at 20°C , 0.28 cP at 100°C).
- In gases viscosity is due to *molecular momentum exchange*, which grows with molecular activity, so μ of gases **increases** with temperature.
- Effect of pressure on μ is negligible for ordinary engineering ranges.
- Water at 20°C has $\mu \approx 1$ centipoise and $\nu \approx 1$ centistoke — an easy value to remember.

Worked example — Viscosity from a sliding plate

A plate of area 0.25 m^2 moves at 0.5 m/s over a fixed plate, the 1 mm gap being filled with oil of specific gravity 0.9 . A force of 15 N keeps it moving. Find μ and ν .

- Shear stress $\tau = F/A = 15/0.25 = 60 \text{ N/m}^2$
- Velocity gradient $du/dy = 0.5/0.001 = 500 \text{ s}^{-1}$
- $\mu = \tau/(du/dy) = 60/500 = 0.12 \text{ N}\cdot\text{s}/\text{m}^2 = 1.2 \text{ poise}$
- $\nu = \mu/\rho = 0.12/900 = 1.333 \times 10^{-4} \text{ m}^2/\text{s}$

Answer: $\mu = 0.12 \text{ Pa}\cdot\text{s}$ (1.2 poise); $\nu = 1.33 \times 10^{-4} \text{ m}^2/\text{s}$ (1.33 stokes).

1.3 Newtonian and non-Newtonian fluids; ideal and real fluids

Fluids that obey Newton's law (τ proportional to du/dy , straight line through the origin) are **Newtonian** — water, air, petrol, thin oils. Others are **non-Newtonian**, generally represented by the power law below, where n is the flow-behaviour index.

Power-law (general rheological) model

$$\tau = A \left(\frac{du}{dy} \right)^n + B$$

$n = 1$, $B = 0$: Newtonian; $B = \text{yield stress } \tau_y$ for plastics

Classification of fluids by rheology

Type	Behaviour	n	Examples
Newtonian	$\tau \propto du/dy$, line through origin	1	Water, air, kerosene, glycerine
Pseudo-plastic (shear-thinning)	Apparent viscosity falls with shear rate	< 1	Blood, milk, paint, paper pulp, polymer solutions
Dilatant (shear-thickening)	Apparent viscosity rises with shear rate	> 1	Quicksand, starch/rice-starch suspensions, sugar in water
Bingham plastic (ideal plastic)	No flow until yield stress τ_y , then linear	1 (with τ_y)	Toothpaste, sewage sludge, drilling mud
Thixotropic	Viscosity falls with time of shearing	—	Printer's ink, some paints, lipstick
Rheopectic	Viscosity rises with time of shearing	—	Gypsum suspension, bentonite slurry

- **Ideal fluid** — incompressible and inviscid ($\mu = 0$, no shear stress, no surface tension); imaginary, used to simplify theory. Plots as the du/dy axis.
- **Real fluid** — possesses viscosity; all actual fluids. Real fluid may still be Newtonian or non-Newtonian.
- **Ideal plastic** — Bingham plastic. **Ideal solid** — plots on the τ -axis (no deformation).

Exam tip: Shear-thinning = pseudo-plastic ($n < 1$); shear-thickening = dilatant ($n > 1$). Toothpaste is the standard Bingham example; quicksand the standard dilatant one.

1.4 Surface tension and capillarity

Surface tension σ is the tensile force per unit length acting along a liquid surface, caused by unbalanced cohesive forces on molecules at the interface. Units N/m (dimensions MT^{-2}). For water against air $\sigma \approx 0.073$ N/m at 20 °C; for mercury $\sigma \approx 0.48$ N/m. Surface tension decreases as temperature rises.

Excess pressure inside a droplet

$$p = \frac{4\sigma}{d}$$

one surface

Excess pressure inside a soap bubble

$$p = \frac{8\sigma}{d}$$

two surfaces (inner and outer film)

Excess pressure inside a liquid jet

$$p = \frac{2\sigma}{d}$$

cylindrical surface, d = jet diameter

Capillary rise or fall in a tube

$$h = \frac{4\sigma \cos \theta}{\gamma d}$$

θ = contact angle; d = tube bore; γ = ρg of liquid

Capillary rise between two parallel plates

$$h = \frac{2\sigma \cos \theta}{\gamma t}$$

t = gap between plates

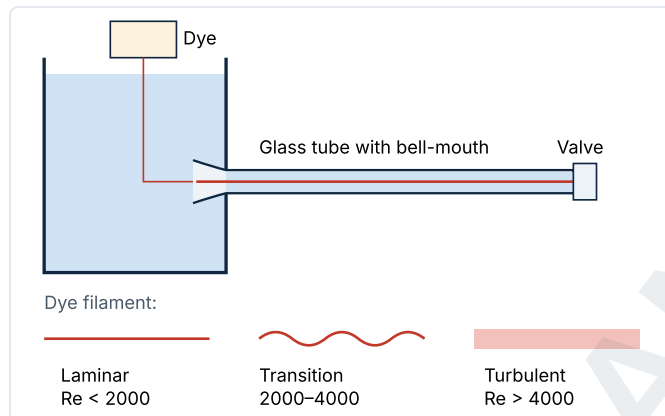
CHAPTER 06

Laminar Flow, Turbulent Flow, Boundary Layer and Drag

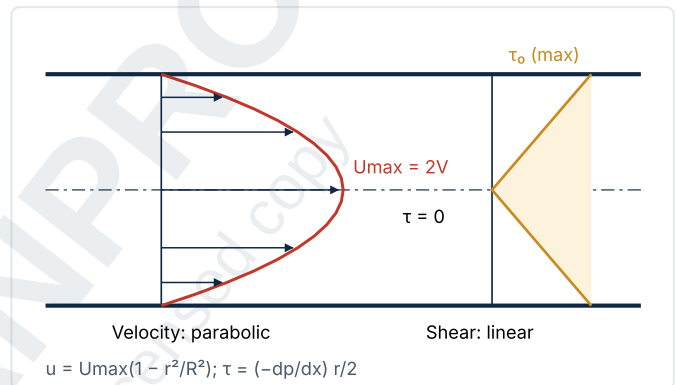
Reynolds' experiment, exact laminar solutions in pipes and between plates, viscometers, turbulence and friction factor, boundary-layer theory, separation, and drag and lift on immersed bodies.

6.1 Reynolds' experiment and laminar flow in pipes

Osborne Reynolds (1883) injected a dye filament into water flowing through a glass tube. At low velocity the filament remained a straight line (**laminar flow**); as velocity increased it became wavy (**transition**) and then mixed across the whole tube (**turbulent flow**). The governing parameter is the **Reynolds number**, the ratio of inertia to viscous forces.



Reynolds' apparatus and dye-filament behaviour



Laminar (Hagen–Poiseuille) flow: velocity and shear distribution

Reynolds number (pipe)

$$Re = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$$

pipe: laminar < 2000 , transition 2000–4000, turbulent > 4000

Velocity distribution

$$u = -\frac{1}{4\mu} \frac{dp}{dx} (R^2 - r^2)$$

parabolic; $U_{\max}$ at centre $= 2V$

Hagen–Poiseuille head loss

$$h_f = \frac{32\mu V L}{\rho g D^2}$$

$h_f \propto V$ (not V^2) in laminar flow

Discharge

$$Q = \frac{\pi D^4 \Delta p}{128\mu L}$$

Δp = pressure drop over length L

Friction factor (laminar)

$$f = \frac{64}{Re}$$

Darcy f ; (Fanning/'coefficient of friction' $f' = 16/Re$)

Shear stress

$$\tau = -\frac{dp}{dx} \frac{r}{2}, \tau_0 = \frac{\Delta p D}{4L}$$

zero at centre, maximum at wall (valid for turbulent too)

Laminar versus turbulent flow

Feature	Laminar	Turbulent
Particle motion	Smooth layers, no mixing	Random eddies, intense mixing
Velocity profile (pipe)	Parabolic; $U_{\max} = 2V$	Flat (log/1/7 power); $U_{\max} \approx 1.2V$
Head loss	$h_f \propto V$	$h_f \propto V^{1.75}$ to V^2
Friction factor	$64/Re$, independent of roughness	Depends on Re and ϵ/D
α, β	2, 4/3	$\approx 1.05, \approx 1.02$
Shear stress	Viscous only, $\tau = \mu du/dy$	Mainly turbulent (Reynolds) stress

Worked example — Laminar oil flow

Oil ($S = 0.9$, $\mu = 0.1 \text{ Pa}\cdot\text{s}$) flows at 5 L/s through a 100 mm pipe. Check the regime and find the head loss in 100 m , the centre-line velocity and the wall shear stress.

- $V = 0.005/0.007854 = 0.637 \text{ m/s}$; $Re = 900 \times 0.637 \times 0.1/0.1 = 573 \rightarrow \text{laminar}$
- $h_f = 32\mu VL/(\rho g D^2) = 32(0.1)(0.637)(100)/(900 \times 9.81 \times 0.01) = 2.31 \text{ m of oil}$
- Check: $f = 64/573 = 0.1117$; $fLV^2/(2gD) = 2.31 \text{ m} \checkmark$; $U_{max} = 2V = 1.27 \text{ m/s}$
- $\Delta p = \rho gh_f = 20.37 \text{ kPa}$; $\tau_0 = \Delta p D/(4L) = 20370 \times 0.1/400 = 5.09 \text{ N/m}^2$

Answer: Laminar ($Re = 573$); $h_f = 2.31 \text{ m of oil}$; $U_{max} = 1.27 \text{ m/s}$; $\tau_0 = 5.1 \text{ N/m}^2$.

6.2 Flow between parallel plates; viscometers**Fixed parallel plates (gap B)**

$$u = \frac{1}{2\mu} \left(-\frac{dp}{dx} \right) (By - y^2)$$

$U_{max} = 1.5 V$ at mid-gap

Head loss between plates

$$h_f = \frac{12\mu VL}{\rho g B^2}$$

$B = \text{gap}$; shear $\tau_0 = (-dp/dx)B/2$ at plates

Stokes' drag on a small sphere

$$F_D = 3\pi\mu Vd$$

$Re = \rho Vd/\mu < \text{about } 0.2 \text{ to } 1$ (creeping flow)

Falling-sphere viscometer

$$\mu = \frac{gd^2(\rho_s - \rho)}{18V}$$

$V = \text{terminal velocity of sphere}$

- Capillary-tube viscometer** — measures Q and Δp in laminar flow and uses Hagen–Poiseuille: $\mu = \pi D^4 \Delta p / (128QL)$.
- Rotating-cylinder viscometer** — torque on the stationary inner cylinder when the outer one rotates (Couette flow).
- Orifice-type (Saybolt, Redwood)** — time for a fixed volume to drain through a short tube; gives kinematic viscosity empirically.
- Plate moving over a fixed plate with no pressure gradient (simple Couette flow): linear velocity profile, $\tau = \mu U/B$.

Worked example — Falling-sphere viscometer

A steel ball 2 mm in diameter ($\rho_s = 7800 \text{ kg/m}^3$) falls through oil ($\rho = 900 \text{ kg/m}^3$) at a steady 0.05 m/s . Find μ and check Stokes' law validity.

- $\mu = gd^2(\rho_s - \rho)/(18V) = 9.81 \times (0.002)^2 \times 6900/(18 \times 0.05)$
- $\mu = 0.2708/0.9 = 0.301 \text{ Pa}\cdot\text{s}$
- $Re = 900 \times 0.05 \times 0.002/0.301 = 0.30$ — small, so Stokes' law is acceptable

Answer: $\mu \approx 0.30 \text{ Pa}\cdot\text{s}$ (3 poise).

6.3 Turbulent flow in pipes

In turbulent flow, momentum is transferred mainly by eddies, producing an apparent (Reynolds) shear stress much larger than the viscous one. Near the wall, where eddies are damped, a very thin **laminar sub-layer** remains. Whether the wall roughness k projects through this sub-layer decides whether the pipe behaves as **hydraulically smooth** or **rough**.

PART B

Compact Summary Notes

Fluid Mechanics & Hydraulics

Illustrated one-page-per-topic revision sheets — read these in the last days before the exam, after studying the detailed notes in Part A.

Part 1

page 58

Part 2

page 78

30 pages of summary notes



FLUID MECHANICS

— Complete Handwritten Notes —

GATE / IES / PSU — Civil & Mechanical Engineering



TOPICS COVERED

1. Properties of Fluids
2. Fluid Pressure & its Measurement
3. Hydrostatic Forces on Surfaces
4. Buoyancy & Flotation
5. Liquid in Relative Equilibrium
6. Fluid Kinematics
7. Fluid Dynamics (Euler & Bernoulli)
8. Momentum Equation & Applications
9. Orifices, Mouthpieces & Flow Measurement
10. Weirs & Notches
11. Laminar Flow
12. Turbulent Flow in Pipes
13. Boundary Layer Theory
14. Drag & Lift
15. Dimensional Analysis & Model Studies
16. Flow Through Pipes, Water Hammer

HOW TO USE THIS NOTE

- Every chapter starts with definitions, then key formulas (boxed), then diagrams, then exam tips.
- Formula boxes = must remember for numericals.
- **Orange notes** = common mistakes / exam traps.
- Tables = quick revision before exam.
- Tip: Read once for concept, then revise only the boxed formulas + tables before your exam.

FORMULA

$$P = \rho gh \quad (\text{Pa})$$

BASIC SYMBOLS USED

SYMBOL	DESCRIPTION	SYMBOL	DESCRIPTION
ρ	Density (kg/m^3)	τ	Shear stress (Pa)
μ	Dynamic viscosity ($\text{Pa}\cdot\text{s}$)	σ	Surface tension (N/m)
γ	Specific weight (N/m^3)	$g = 9.81 \text{ m/s}^2$	—
ν	Kinematic viscosity (m^2/s)	K	Bulk modulus (Pa)

Fluid Mechanics Handwritten Notes — compiled for exam revision

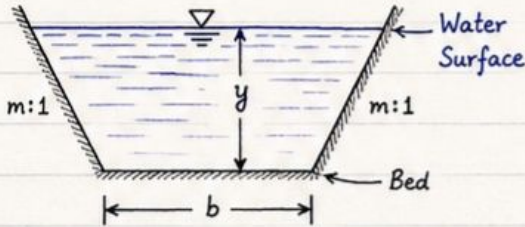
OPEN CHANNEL FLOW

Civil Engg.
Hydraulics
Quick Revision

Compact Handwritten Notes

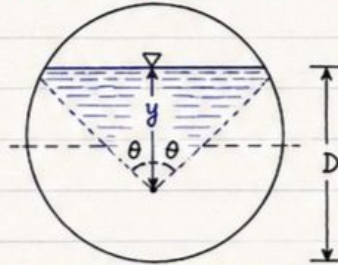
All major concepts retained • compacted for revision

① Trapezoidal Open Channel



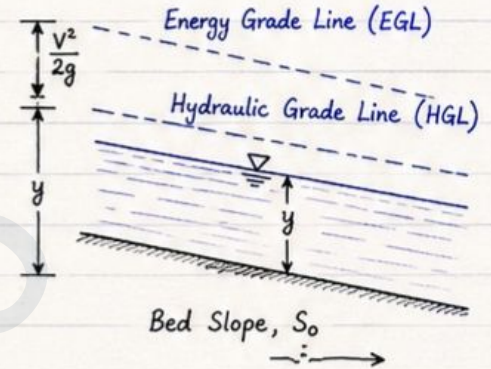
$$\begin{aligned}\text{Area, } A &= by + my^2 \\ \text{Wetted Perimeter, } P &= b + 2y\sqrt{1+m^2} \\ \text{Top Width, } T &= b + 2my\end{aligned}$$

② Part-Full Circular Channel

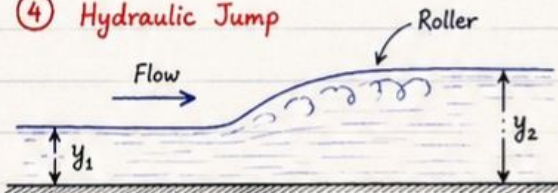


$$\begin{aligned}\theta &= 2 \cos^{-1} \left(1 - \frac{2y}{D} \right) \\ A &= \frac{D^2}{8} (\theta - \sin \theta) \\ T &= D \sin \left(\frac{\theta}{2} \right)\end{aligned}$$

③ Energy / Grade Lines

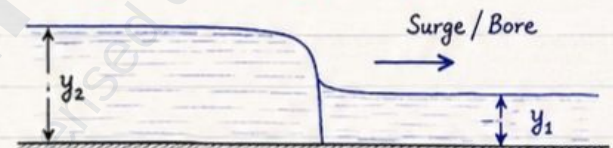


④ Hydraulic Jump



$$\begin{aligned}\frac{y_2}{y_1} &= \frac{1}{2} \left(\sqrt{1 + 8 Fr_1^2} - 1 \right) \\ Fr_1 &= \frac{V_1}{\sqrt{g y_1}} \quad y_2 > y_1\end{aligned}$$

⑤ Positive Surge (Bore)



$$y_2 > y_1$$

Bore moves in direction of flow

⇒ **ROADMAP** ⇐

OPEN CHANNEL FLOW

Start

STEADY FLOW

UNIFORM FLOW

- Normal depth (y_n)
- Manning / Chezy
- Channel design
- Slope & roughness

NON-UNIFORM FLOW

GVF

Gradually
Varied
Flow

RVF

Rapidly
Varied
Flow

SVF

Spatially
Varied
Flow

UNSTEADY FLOW

- Surges / Flood Waves
- Inflow / Outflow
- Transient conditions

CORE IDEAS (Remember!)

- Open-channel flow is governed by gravity, free surface, geometry, and resistance.
- Froude number ($Fr = \frac{V_1}{\sqrt{g y_1}}$) controls wave behavior → subcritical ($Fr < 1$), critical ($Fr = 1$), supercritical ($Fr > 1$).
- Manning / Chezy control UNIFORM FLOW (discharge for a given section & slope).
- Specific energy ($E = y + \frac{V^2}{2g}$) controls CRITICAL FLOW (minimum specific energy).
- GVF covers SLOW depth variation due to balance of gravity & resistance.
- Momentum principle controls HYDRAULIC JUMPS (rapid change in depth).
- Surge relations cover UNSTEADY FLOW (flood waves / bores / transients).

EXAM TIPS

- ✓ Draw neat sketches
- ✓ Write assumptions
- ✓ Use correct formulas
- ✓ Check units
- ✓ State conclusions

Coverage: Introduction • Uniform Flow • Energy-Depth Relationship • GVF • Hydraulic Jump • Unsteady Flow / Surges

1/10



End of the free preview

Fluid Mechanics & Hydraulics

The full PDF has 87 pages:

Part A — detailed typed notes: 10 chapters, 53 pages

Part B — handwritten compact summary: 30 pages

Chapters in the full notes

- 01 Properties of Fluids
- 02 Hydrostatics, Buoyancy and Relative Equilibrium
- 03 Fluid Kinematics
- 04 Fluid Dynamics and Flow Measurement
- 05 Orifices, Mouthpieces, Notches and Weirs
- 06 Laminar Flow, Turbulent Flow, Boundary Layer and Drag
- 07 Flow through Pipes
- 08 Dimensional Analysis and Model Studies
- 09 Open Channel Flow
- 10 Hydraulic Machines — Turbines and Pumps

Formula boxes with every symbol explained · IS / IRC code values in tables · labelled sketches
Worked examples step by step · exam tips & traps · quick revision points after every chapter

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