UNIT 1 COMPARISON OF OPEN CHANNEL FLOW WITH PIPE FLOW

Structure

1.1 INTRODUCTION

In an open channel flow, the free surface is essentially an interface between two fluids of different density – i.e., water and air in contact with each other. In the case of the atmosphere, the density of air is much lower than the density of a liquid such as water. In addition, the pressure on the exposed surface is constant.

Objectives

After a study of this unit, you should be able to :

- define the concept of an open channel flow,
- distinguish between pipe flow and open channel flow,
- describe the practical applications,
- distinguish the different types of flow,
- appreciate the use of Froude Number in describing a state of flow, and
- appreciate the use of modified Moody's chart.

1.2 DESCRIPTION AND CHARACTERISTICS

In the case of a liquid, flowing in an open channel, the motion is usually caused by gravitational effects. Also the pressure distribution within the fluid is generally hydrostatic. Open channel flows are almost always turbulent and unaffected by surface tension. Open channel flow occurs in channels such as : rivulets flowing across a field; gutters along residential streets and continental highways; partially filled sewers carrying waste water; irrigation channels carrying water halfway across a continent; and big rivers as well, like Mississippi, Nile, Rhine, Yellow River, Ganges, Amazon, Mekong and Cauvery.

Obviously open channel flows also help in the transmission of water from one place to the other to meet the domestic and industrial requirements including hydro power generation. It is clear, therefore, that the size, shape and roughness of open channels vary over a considerable range.

1.3 COMPARISON WITH PIPE FLOW

The channel flow is comparable with pipe flow in the light of the concepts regarding hydralic and energy gradients.

1.3.1 Hydraulic and Energy Gradients

The hydraulic and energy grade lines are shown for both pipe flow and channel flow in Figure 1.1. The hydraulic grade line is obviously the profile of free surface in open channel flow. In the case of pipe flow the hydraulic line is above the pipe wall as a result of the pressure exerted by the fluid flowing in the pipe.

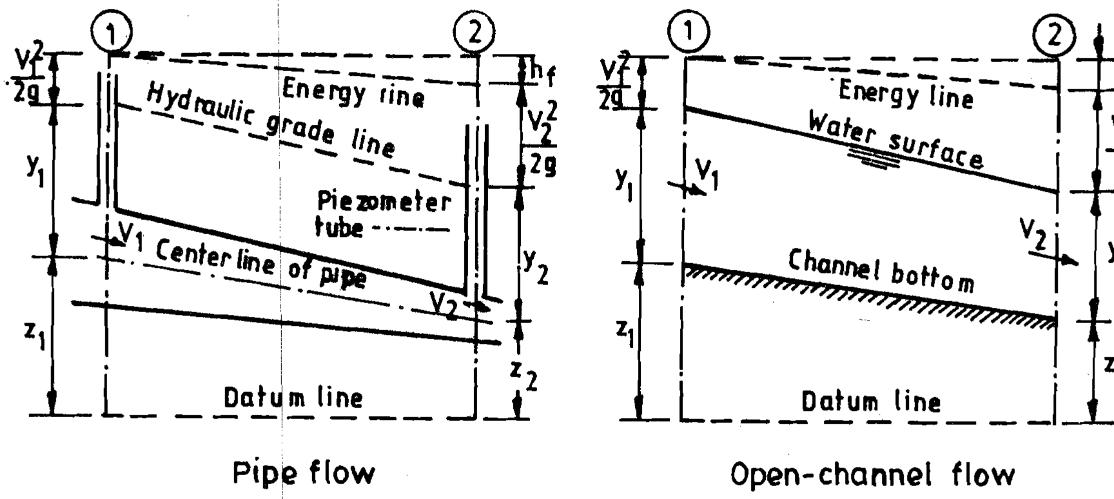

Figure 1.1 : Comparison Between Pipe Flow and Open Channel Flow

1.3.2 Steady and Unsteady Flows

Over a period of time while a flow is under observation, it can be classified as either being steady or unsteady. If the velocity of flow at any location does not change with respect to time, it is understood that the flow is steady; otherwise it is unsteady. This criterion applies in general to channel flow, as well as, to pressure flow (i.e. pipe flow). In open channel flow we can further simplify this statement, and say that if the depth (y) of flow does not change with time it is steady; constant depth of flow, as will be gradually understood, implies other parameters to be constant on the average. Therefore, if the depth of flow, at any location, does change with time it renders the flow unsteady.

We can write that, for a steady flow, $\frac{\partial y}{\partial t} = 0$, and also local acceleration is zero at any point of consideration.

Example 1.1

Distinguish between hydraulic grade line and energy grade line.

Solution

Hydraulic grade line is the line, joining the sum of depth of flow and datum head corresponding to various locations along the flow. Energy grade line is the join of the sum of datum head, depth of flow and velocity head corresponding to these locations.

1.3.3 Uniform and Varied Flows

In an open channel the depth of flow might vary longitudinally (x) along the channel, due to a change in the size or shape of the cross-section, or in the amount of bed slope, or due to an obstruction to flow. However, this varying depth along the flow profile can remain steady with time, over the length of the channel under consideration. This type of flow is termed a non-uniform (or varied flow,i.e. $dy/dx \neq 0$), but steady flow. As a corollary, it can be stated that a uniform, steady flow implies a constant depth of flow along the flow direction. Therefore, in a uniform flow the velocity of flow, at any instant, is invariant with distance; it can easily be seen that the same concept can be extended to pipe flows, while the pipe diameter and discharge remain constant.

Conceptually one can visualise an unsteady uniform flow (Figure 1.2, i.e. the depth of flow varies with time but remains constant with distance), but practically such a flow is nearly impossible, for it is difficult for a water surface profile to alter parallel to itself. Varied flow can be classified either as rapidly varied or gradually varied flow. In the case of a hydraulic jump, the depth of flow changes rapidly over a relatively short distance, while in the case of a reservoir behind a dam the depth of flow changes rather gradually over a long upstream reach. Such types of flow situations are illustrated in Figure 1.2.

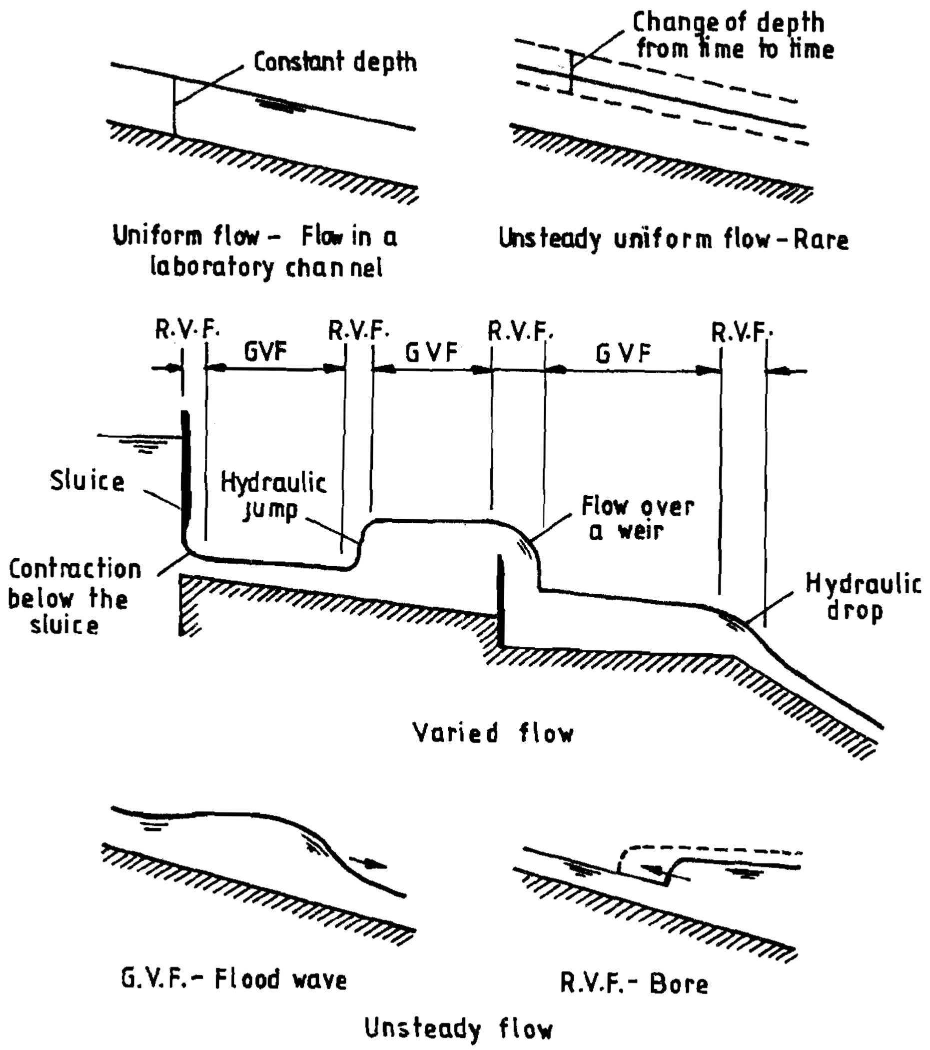

Figure 1.2 : Various Types of Open Channel Flow

Example 1.2

Distinguish between uniform and varied flow.

Solution

A uniform flow has same depth of flow at all cross sections at a given time. Varied flow is a nonuniform flow; it has different depths at different sections at any given instant.

1.3.4 Laminar and Turbulent Flows

Flows characterised by very small velocities are dominated by viscous forces in comparison to inertial forces. Such flows are called laminar flows in which the fluid particles move along definite, smooth paths in a coherent fashion. In turbulent flow, the inertial forces are large relative to the viscous forces; hence the inertial forces dominate the situation. In this type of flow the fluid particles move in an incoherent or apparently random fashion. A transitional flow is one which can be classified as neither laminar nor turbulent, viscous and inertial forces being of almost same importance.

Reynolds Number

Reynolds Number, Re, is defined as the ratio of intertial forces to viscous forces (per unit volume). It can be easily shown that this dimensionless ratio is equivalent to $\frac{V l}{\nu}$, where V is the characteristic velocity of flow, l the characteristic length and ν the kinematic viscosity of the fluid. In pipe flow the characteristic length commonly used is the diameter of the pipe and in open channel flow the hydraulic radius, R, which is the ratio of the flow area A (perpendicular to the flow) to the wetted perimeter, P. The magnitude of Reynolds Number, of a flow field, is a necessary (although not a sufficient) criterion to classify it either as a laminar or a turbulent flow. It is useful to note some approximate limits of Reynolds Number that distinguish a laminar flow from a turbulent flow :

	Laminar	Transition	Turbulent
Pipe Flow	2000	2000 to 40,000*	40,000 and above
Channel Flow	500	500 to 12,500	12,500 and above

* Flow with such a high value of Re is always turbulent except under controlled conditions.

Froude Number

Froude Number Fr is defined as the ratio of inertial forces to gravitational forces (per unit volume). It can be shown to be equivalent to $\frac{V}{\sqrt{gl}}$, where V is the average sectional velocity $\left(V = \frac{Q}{A}\right)$, and Q is the flow in volume passing per second at any given location. If the value of Froude Number is less than 1, the flow is subcritical, and, if it is more than 1 the flow is supercritical; and at its value being 1, critical flow conditions are said to exist.

The flow in an open channel can further be classified based on both Reynolds and Froude Numbers :

Subcritical laminar	Fr < 1 ,	Re < 500
Supercritical laminar	Fr > 1 ,	Re < 500
Subcritical transition	Fr < 1 ,	500 < Re < 12,500
Supercritical transition	Fr > 1 ,	500 < Re < 12,500
Subcritical turbulent	Fr < 1 ,	Re > 12,500
Supercritical turbulent	Fr > 1 ,	Re > 12,500

1.4 RESISTANCE DIAGRAM AND APPLICATIONS

The American Society of Civil Engineers Task Force on Friction Factors recommended that for an open channel roughness (similar to that encountered in pipes), a resistance diagram like that shown in Figure 1.3 was adequate for estimating friction factor f. This is a modified Moody Diagram, accounting for laminar, transition and turbulent regions of flow, and indicates that the friction factor, f, is a linear function of Reynolds Number only in the laminar region. In the transition region it is a function of both Reynolds Number and

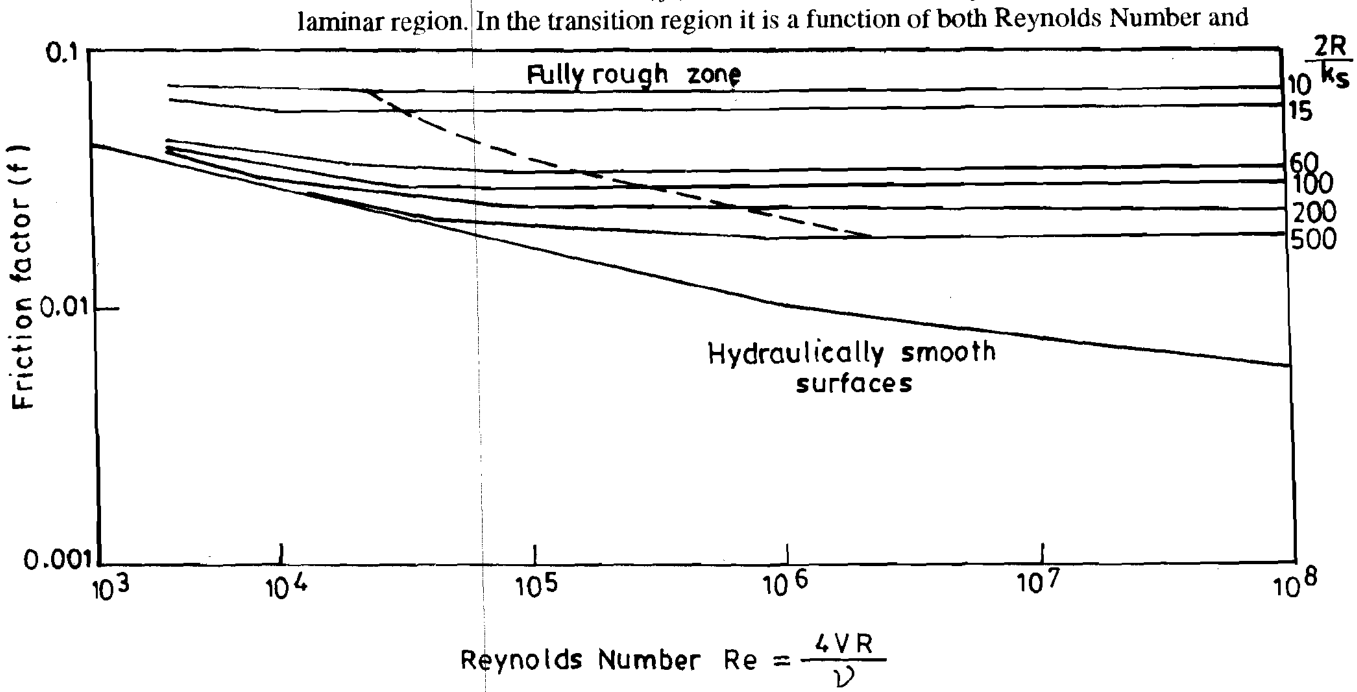

Figure 1.3 : Modified Moody Diagram Showing the Behaviour of the Friction Factor in Open Channel Flow

relative roughness. The relative roughness can be defined as the ratio of height of roughness k_s to the hydraulic radius R. It should be noted that the height of roughness is merely a measure of the linear dimension of the roughness elements but is not necessarily the actual or even an average height. The datum from which this height is to be measured is also subject to change (depending on various factors), and may not coincide with the bed of the channel. Depending on these factors, the position of this datum varies from the rigid bed to the top of the roughness element. The friction factor, f, is independent of Reynolds Number in the fully rough turbulent region and depends only on relative roughness.

The turbulent region consists of smooth, transition and fully rough zones. In the smooth zone the roughness protrusions are confined in the laminar sublayer; in the fully rough zone the roughness protrusions are well above the laminar sublayer; and, the roughness protrusions are distributed above and below the laminar sublayer in the transition zone. The laminar sublayer is a very thin stable film close to the bed of the channel in which the flow is always laminar irrespective of the main flow being in transition or turbulent state. A refined concept of laminar sublayer considers the existence of a small-size eddies vanishing very rapidly at the surface of the boundary. The average height of roughness, k_s, for several kinds of material as arrived at from many experimental data are given in Table 1.1.

Table 1.1 : Approximate Values of ks (Chow, 1959)

Material	k_s, mm
Cement	0.39 - 0.12
Brass, copper, lead, glass	0.03 - 0.90
Wood stave	0.18 - 0.90
Asphalted cast iron	0.12 - 2.10
Wrought iron, steel	0.06 - 2.40
Concrete	0.45 - 3.00
Drain tile	0.60 - 3.00
Galvanized iron	0.15 - 4.50
Cast iron	0.24 - 5.40
Riveted steel	0.90 - 9.00
Natural river bed	30.00 - 900.00

SAQ 1

A straight rectangular channel is having a slope of 1 in 1000. The width is 1 m, and the depth of flow is 0.5 m. Velocity of flow is 1 m/s. Construct the hydraulic grade line between two sections 1 km apart. Will it be parallel to energy grade line ?

SAQ 2

A straight wide river has a constant depth of flow of 1 m at all its sections. What type of flow does obtain in the channel ? A flood wave enters the river increasing the depth to [illegible] m at upstream, and to [illegible] m at downstream locations. Classify this type of flow.

1.5 SUMMARY

Let us summarise what you have learnt in this unit.

This module (Unit 1) of the course defined an open channel flow, and described its characteristics that differentiate it from pipe flow (i.e. pressure flow, which has no free surface). Concept of gradient lines was introduced, comparing the gravity flow (i.e, open channel flow) with the pipe flow.

Steady and unsteady flows, uniform and varied flows, laminar and turbulent flows were described; and, the importance of Reynolds and Froude Numbers was brought out.

Lastly, a preliminary concept of resistance to flow in open channels was introduced with the help of modified Moody Diagram which incorporates friction factor, a measure of roughness (i.e. resistance), as a function of Reynolds Number and relative roughness.

1.6 KEY WORDS

Open Channel Flow	:	Flow with its top surface open to atmospheric pressure.
Reynolds Number	:	Ratio of inertial forces to viscous forces (per unit volume).
Froude Number	:	Ratio of inertial forces to gravitational forces (per unit volume).
Hydraulic Gradient	:	Line joining the plot of the sum of depth of flow (potential head) and datum head.
Energy Head	:	Line joining plot of sum of datum head, potential head and kinetic energy (i.e., kinetic head).

1.7 ANSWERS/SOLUTIONS TO SAQs

SAQ 1

Hydraulic grade will be parallel to energy grade line.

SAQ 2

i) Uniform flow

ii) Varied flow