PART 1

Introduction to Open Channel Flows

River bank erosion at Chenchung, PingTung county, Taiwan about 5 km upstream of the river mouth in December 1999. View from the right bank looking upstream.

1

Introduction

Summary

This introduction chapter briefly reviews the fluid properties and some result for static fluids. Then open channel flows are defined.

1.1 Presentation

The term 'Hydraulics' is related to the application of Fluid Mechanics' principles to water engineering structures, and civil and environmental engineering facilities. We consider open channels in which liquid (i.e. water) flows with a free surface. Examples of open channels are natural streams and rivers. Man-made channels include irrigation and navigation canals, drainage ditches, sewer and culvert pipes running partially full, and spillways.

In open channel flows, the free surface rises and falls in response to perturbations to the flow (e.g. changes in channel slope or width). The location of the free surface is unknown beforehand. The main parameters of a hydraulic study are the geometry of the channel, the properties of the flowing fluid and the flow parameters.

1.1.1 Discussion: hydraulic engineering through history

Hydraulic engineers were at the forefront of science for centuries (Fig. 1.1). For example, although the origins of seepage water was long the subject of speculation, the arts of tapping groundwater developed early in the antiquity. The construction of qanats, which were hand-dug underground water collection tunnels, in Armenia and Persia is considered as one great hydrologic achievement of the ancient world. Roman aqueducts were magnificient water-works and demonstrated the 'savoir-faire' of Roman engineers. The 132-km long Carthage aqueduct was considered one of the marvels of the world by the Muslim poet El Kairouani. Many aqueducts were used, repaired and maintained for centuries and some are still used in parts (e.g. Carthage). A major navigation canal system was the *Grand canal* fed by the Tianping diversion weir in China. Completed in BC 219, the 3.9 m high and 470 m long weir diverted the Xiang River into the South and North canals, allowing navigation between Guangzhou (formerly Canton), Shanghai and Beijing.

(a)

(b)

Fig. 1.1 Ancient hydraulic engineering. (a) Nabataean Dam on the Mamshit stream (also called Mampsis or Kunub) on 10 May 2001 (courtesy of Dennis Murphy). Dam wall built around the end of 1st Century BC, downstream slope of the dam wall. (b) Roman aqueduct in Fréjus, Arches de Sainte Croix, downstream of Chateau Aurélien on 14 September 2000. Looking upstream, note the slight bend in the aqueduct in the background.

The development of hydraulic engineering is closely linked to the beginnings of civil engineering as a separate discipline, and the foundation of the 'Corps des Ponts et Chaussées' (Bridge and Highway Corps) in France in 1716 with the establishment of the 'École Nationale des Ponts et Chaussées' (National School of Bridges and Highways) in 1747. Among the directors of the school were the famous hydraulicians A. Chézy (1717–1798) and G. de Prony (1755–1839). Other famous professors included B.F. de Bélidor (1693–1761), J.B.C. Bélanger (1789–1874), J.A.C. Bresse (1822–1883), G.G. Coriolis (1792–1843) and L.M.H. Navier (1785–1835).

(c)

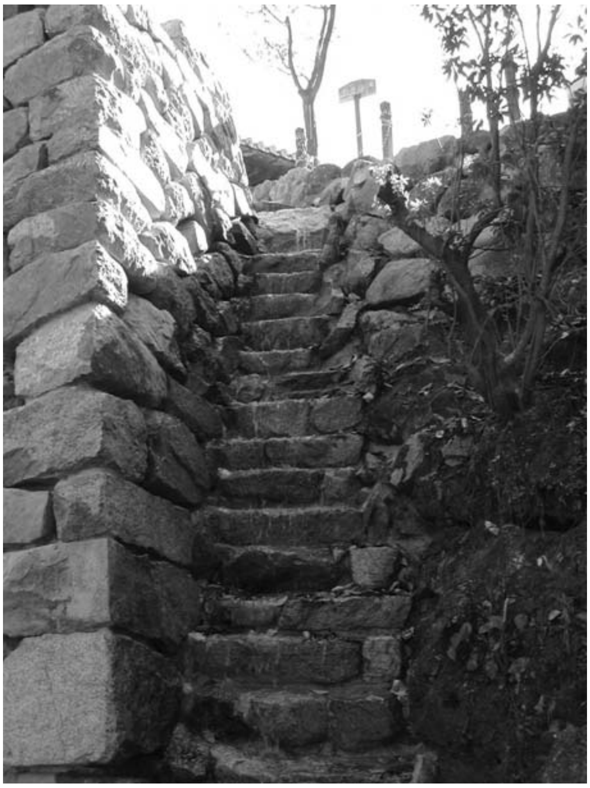


Fig. 1.1 (c) Storm waterway at Miya-jima (Japan) below Senjò-kaku wooden hall on 19 November 2001. The steep stepped chute ($\theta > 45°$, $h \sim 0.4\,\mathrm{m}$) was built during the 12th Century AD. The Senjò-kaku wooden hall was built by Kyomori (AD 1168) and left unfinished after his death.

1.2 Fluid properties

The density ρ of a fluid is defined as its mass per unit volume.

All real fluids resist any force tending to cause one layer to move over another, but this resistance is offered only while the movement is taking place. The resistance to the movement of one layer of fluid over an adjoining one is referred to as the viscosity of the fluid. Newton's law of viscosity postulates that, for the straight parallel motion of a given fluid, the tangential stress between two adjacent layers is proportional to the velocity gradient in a direction perpendicular to the layers:

$$\tau = \mu \frac{\mathrm{dV}}{\mathrm{d}y} \tag{1.1}$$

where τ is the shear stress between adjacent fluid layers, μ is the dynamic viscosity of the fluid, V is the velocity and y is the direction perpendicular to the fluid motion.

At the interface between a liquid and a gas, a liquid and a solid or two immiscible liquids, a tensile force is exerted at the surface of the liquid and tends to reduce the area of this surface to the greatest possible extent. The surface tension is the stretching force required to form the film.

Notes

1. Isaac Newton (1642–1727) was an English mathematician.
2. The kinematic viscosity is the ratio of viscosity to mass density:

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

3. Basic fluid properties are summarized in Table 1.1. The standard atmosphere or normal pressure at sea level equals 360 mm of mercury (Hg) or 101 325 Pa.

Table 1.1 Fluid properties of air, freshwater and sea water at 20°C and standard atmosphere

Fluid properties (1)	Air (2)	Fresh water (3)	Sea water (4)	Remarks (at °C) (5)
Composition	Nitrogen (78%), oxygen (21%) and other gases (1%)	H_2O	H_2O, dissolved sodium and chloride ions (30 g/kg) and dissolved salts	
Density ρ (kg/m^3)	1.197	998.2	1024	20
Dynamic viscosity μ (Pa s)	18.1×10^{-6}	1.005×10^{-3}	1.22×10^{-3}	20
Surface tension between air and water σ (N/m)	N/A	0.0736	0.076	20
Conductivity (μS/cm)	–	87.7	48 800	25

References: Riley and Skirrow (1965), Open University Course Team (1995) and Chanson *et al.* (2002a).

1.3 Fluid statics

Considering a fluid at rest (Fig. 1.2), the pressure at any point within the fluid follows Pascal's law. For any small control volume, there is no shear stress acting on the control surface. The only forces acting on the control volume of fluid are the gravity and the pressure forces.

In a static fluid, the pressure at one point in the fluid has an unique value, independent of the direction. This is called Pascal's law. The pressure variation in a static fluid follows:

$$\frac{\mathrm{d}P}{\mathrm{d}z} = -\rho g \tag{1.2}$$

where P is the pressure, z is the vertical elevation positive upwards, ρ is the fluid density and g is the gravity constant.

For a body of fluid at rest with a free surface (e.g. a lake) and with a constant density, the pressure variation equals:

$$P(x, y, z) = P_{\text{atm}} - \rho g(z - d) \tag{1.3}$$

where P_{atm} is the atmospheric pressure (i.e. air pressure above the free surface) and d is the reservoir depth (Fig. 1.2).

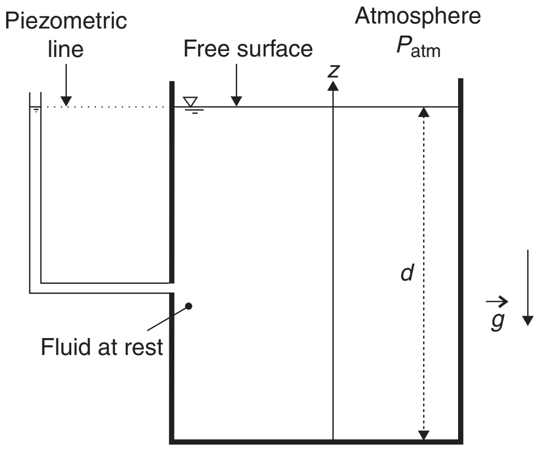


Fig. 1.2 Pressure variation in a static fluid.

Notes

1. Blaise Pascal (1623–1662) was a French mathematician, physicist and philosopher. He developed the modern theory of probability. He also formulated the concept of pressure (between 1646 and 1648) and showed that the pressure in a fluid is transmitted through the fluid in all directions (i.e. Pascal's law).
2. By definition, the pressure always acts normal to a surface. The pressure force has no component tangential to the surface.
3. The pressure force acting on a surface of finite area which is in contact with the fluid is distributed over the surface. The resultant force is obtained by integration:

$$F_p = \int P \, dA$$

where A is the surface area.

In Fig. 1.2, the pressure force (per unit width) applied on the sidewalls of the tank is:

$$F_p = \frac{1}{2}\rho g d^2 \qquad \text{Pressure force acting on the right wall per unit width}$$

1.4 Open channel flows

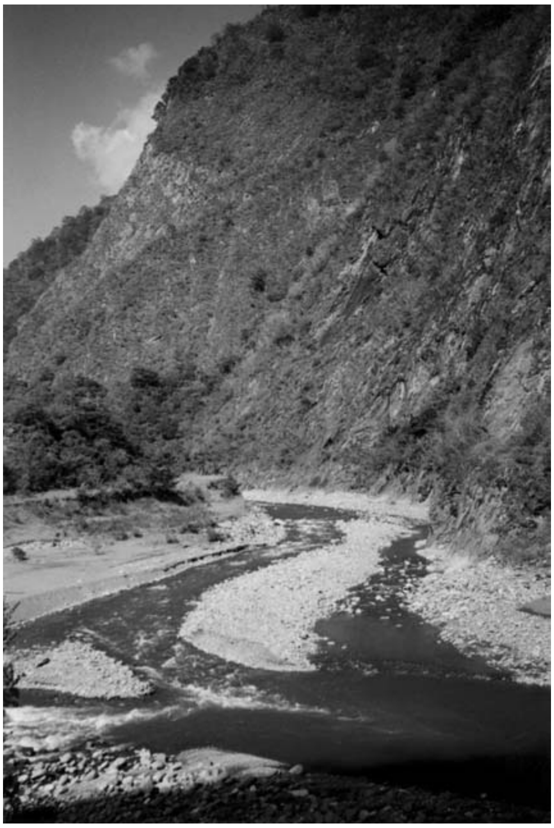
An open channel is a waterway, canal or conduit in which a liquid flows with a free surface. An open channel flow describes the fluid motion in open channel (Fig. 1.3). In most applications, the liquid is water and the air above the flow is usually at rest and at standard atmospheric pressure.

Open channel flows are found in Nature as well as in man-made structures. In Nature, rushing waters are encountered in mountain rivers, river rapids and torrents (Fig. 1.3(a)). Tranquil flows are observed in large rivers near their estuaries (Fig. 1.3(b)). Natural rivers

(a)

(b)

Fig. 1.3 Examples of open channel flow. (a) Russel Falls in Tasmania (Australia) (courtesy of Dr R. Manasseh). (b) Eprapah Creek, Queensland (Australia) on 24 November 2003 at sunrise.



(c)

(d)

Fig. 1.3 (c) Hsinwulu River, Taiwan East coast in December 1998. Looking upstream and confluence with tributary on left-foreground. (d) Pont d'Arc, Vallée de l'Ardèche (France) in July 1977. Looking upstream near Vallon-Pont-d'Arc.

have the ability to scour channel beds, to carry sediment materials, and to deposit sediment loads (Fig. 1.3(c) and (d)).

River flow rates may range from extreme values: the hydraulics of droughts and floods are both important.

1.5 Exercises

Give the values (*and* units) of the specified fluid and physical properties:

(a) Density of water at atmospheric pressure and 20°C.
(b) Density of air at atmospheric pressure and 20°C.
(c) Dynamic viscosity of water at atmospheric pressure and 20°C.
(d) Kinematic viscosity of water at atmospheric pressure and 20°C.
(e) Kinematic viscosity of air at atmospheric pressure and 20°C.
(f) Surface tension of air and water at atmospheric pressure and 20°C.
(g) Acceleration of gravity in Brisbane.

In a static fluid, express the pressure variation with depth.