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Hydraulic engineering in the 21st century: Where to?

13th Arthur Ippen awardee, IAHR Member

Technologie hydraulique au 21ème siècle : Vers où ?

13ème Prix Arthur Ippen

HUBERT CHANSON, Professor in Civil Engineering, *Department of Civil Engineering, The University of Queensland, Brisbane QLD 4072, Australia. Fax: 61 7 33 65 45 99; e-mail: h.chanson@uq.edu.au; Url: http://www.uq.edu.au/∼e2hchans/*

ABSTRACT
For centuries, hydraulic engineers were at the forefront of science. The last forty years marked a change of perception in our society with a focus on environmental sustainability and management, particularly in developed countries. Herein, the writer illustrates his strong belief that the future of hydraulic engineering lies upon a combination of innovative engineering, research excellence and higher education of quality. This drive continues a long tradition established by eminent scholars like Arthur Thomas Ippen, John Fisher Kennedy and Hunter Rouse.

RÉSUMÉ
Pendant des siècles, les ingénieurs hydrauliciens étaient sur le front de la science. Les quarante dernières années ont marqué un changement de perception dans notre société avec une focalisation sur la gestion de l'environnement et le développement durable, en particulier dans les pays développés. Ici, l'auteur illustre sa foi profonde sur le fait que le futur de la technologie hydraulique se trouve dans une combinaison de la technologie innovatrice, de l'excellence de la recherche et d'une formation plus approfondie de qualité. Cette tendance poursuit une longue tradition établie par des disciples éminents comme Arthur Thomas Ippen, John Fisher Kennedy et Hunter Rouse.

Keywords: Hydraulic engineering, innovation, excellence, quality, teaching, engineering, research, culvert, stepped chute, air–water flow, student field work.

1 Introduction

Hydraulic engineering is the science of water in motion, and the interactions between the flowing fluid and the surrounding environment. Hydraulic engineers were at the forefront of science for centuries (Fig. 1). Although, the origins of seepage water were long the subject of speculations, the construction of *qanats* in Armenia and Persia is considered as one great hydrologic achievement of the ancient world. Roman aqueducts were magnificent waterworks and demonstrated the "savoir-faire" of Roman engineers (e.g. Chanson, 2002a). The 132 km long Carthage aqueduct was regarded as one of the marvels of the world by the Muslim poet El Kairouni. In China, a major hydraulic work was the Grand Canal fed by the Tianping diversion weir in China completed in BC 219. The 3.9 m high 470 m long weir diverted the Xiang river into the South and North canals, allowing navigation between Guangzhou, Shanghai and Beijing (Schnitter, 1994).

Hydraulic engineers have had an important role to contribute but the technical challenges are huge. The extreme levels of complexity are closely linked with the variety of water systems, the broad range of relevant time and length scales, the variability of river flows from droughts to gigantic floods, the complexity of basic fluid mechanics with non-linear governing equations, natural fluid instabilities, interactions between water, solid, air and biological life, and more importantly Man's total dependence on water. The last forty years marked a change of perception in our society especially in developed countries. Sustainability and environmental management have become "fashionable" topics. So is there a need for further hydraulic engineering? Herein the writer outlines his strong belief that the future of hydraulic engineering relies upon a combination of innovative engineering, research excellence and higher education of quality.

2 Innovative hydraulic engineering

After centuries of developments, advances in hydraulic engineering have sometimes lacked flair during the second half of the 20th century. Examples include the design of common civil engineering structures such as culverts and energy dissipators. In each case, modern designs differs barely from ancient

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(a)

(b)

Figure 1 Ancient hydraulic works. (a) Arcades de Chaponost, Roman aqueduct of Gier, Lyon France (flow from right to left) on 8 February 2004. (b) Stepped storm waterway at Miya-jima (Japan) below Senjò-kaku wooden hall on 19 November 2001—The steep stepped chute ($\theta > 45°$, $h \sim 0.4$ m) was built during the 12th century AD.

designs. A culvert is a covered channel of relatively short length designed to pass safely water through an embankment. Although the world's oldest culvert is unknown, the Minoans and the Etruscans built culverts in Crete and Northern Italy respectively nearly 3000 years ago (Evans, 1928; O'Connor, 1993). Later the Romans built numerous culverts beneath roads and aqueducts (Ballance, 1951). One advanced design along the Nîmes aqueduct could discharge rainfall runoff in excess of ten times the maximum aqueduct flow rate (Chanson, 2002b).

In hydraulic structures, the kinetic energy of the flow must be dissipated safely. Energy dissipator designs include ski jump and downstream plunge pool, a hydraulic jump stilling basin, a drop-shaft structure, and the construction of steps on the chute. All these are ancient, but for the hydraulic jump dissipator developed during the 1930s. Ancient dropshafts were built by the Romans. Some aqueducts were equipped with series or cascades of dropshafts in France, Spain and North Africa predominantly (Chanson, 2002c). Stepped chutes have been used for more than 3500 years (Chanson, 2001). At the end of the 19th century, this spillway design accounted for nearly one third of all spillway constructions in North-America.

For both culvert and energy dissipator structures, the primary design constraint is minimum construction costs, but additional constraints might include maximum acceptable upstream flood level and scour protection. Innovative developments are rare although two examples are outlined below.

2.1 Minimum Energy Loss (MEL) culvert designs

Standard culverts are characterised by significant afflux at design flow conditions, where the afflux is the rise in upstream water level caused by the hydraulic structure. The afflux is a quantitative measure of upstream flooding. Numerous solutions were devised to reduce the afflux for a given design flow rate by rounding the inlet edges, using throated entrances and warped wing walls. These solutions are expensive and often marginal.

(a)

(b)

Figure 2 Photographs of a Minimum Energy Loss waterway in Brisbane ($Q_{\mathrm{des}} = 220\,\mathrm{m}^3\,\mathrm{s}^{-1}$, zero afflux design). (a) Waterway inlet and barrel looking downstream on 18 September 2003 during a CIVL3140 Catchment hydraulics field work. (b) Standing waves in the waterway throat during a flood on 7 November 2004 looking downstream.

During the late 1950s and early 1960s, a new culvert design was developed in Queensland, Australia under the leadership of late Professor Gordon R. McKay (1913–1989): the Minimum Energy Loss (MEL) culvert. (Minimum Energy Loss culverts are also called Energy, Constant Energy, Minimum Energy, Constant Specific Energy culverts (Apelt, 1983).) A MEL culvert is a structure designed with the concept of minimum head loss and near-critical flow conditions along the entire waterway. The flow in the approach channel is contracted through a streamlined inlet into the barrel where the channel width is minimum, and then is expanded in a streamlined outlet before being finally released into the downstream natural channel (Fig. 2). Figure 2 shows a Minimum Energy Loss waterway with a design discharge of $220\,\mathrm{m}^3\,\mathrm{s}^{-1}$. The resulting MEL design is often capable to operate with zero afflux at design flow. Professor C.J. Apelt presented an authoritative review (Apelt, 1983) and a well-documented audio-visual documentary (Apelt, 1994). The writer highlighted a wide range of design options (Chanson, 2000, 2004a).

2.1.1 *Prototype experience*

The first MEL structure was the Redcliffe MEL culvert completed in 1960. Since about 150 structures were built in Eastern Australia with discharge capacities ranging from less than 2 $m^3 s^{-1}$ to more than 800 $m^3 s^{-1}$. Several structures were observed operating at design flows and for floods larger than design. Inspections during and after flood events demonstrated a sound operation associated with little maintenance (Fig. 2b). While McKay (1971) outlined general guidelines, Professor Colin APELT stressed that a successful MEL design must follow closely two basic design concepts: streamlining of the flow and near-critical flow conditions at design flow (Apelt, 1983). Both inlet and outlet must be streamlined to avoid significant form losses. In one structure, separation was observed in the inlet associated with flow recirculation in the barrel (Cornwall St, Brisbane). The barrel invert is often lowered to increase the discharge capacity (Fig. 2a). MEL culverts are usually designed to operate at design flow with Fr = 0.6 to 0.8 and supercritical flow conditions must be avoided. This is particularly important in the outlet where separation must be averted as well.

The successful operation of large MEL culverts for over 45 years has highlighted further practical considerations. An adequate drainage is essential to prevent water ponding in the barrel invert. Drainage channels must be preferred to drainage pipes. For example, the MEL waterway shown in Fig. 2 is equipped with a well-designed drainage system (Fig. 2a bottom left). One issue has been a loss of expertise in MEL culvert design. In Brisbane, two culvert structures were adversely affected by the construction of a new busway 25 years later. As a result, a major arterial will be overtopped during a design flood (Marshall Rd, Brisbane). For completeness, MEL culverts may be designed for non-zero afflux. The design process is similar (e.g. Chanson, 1999, 2004a).

The MEL culvert design received strong interests in Canada, USA, and UK. For example, Lowe (1970), Loveless (1984), Federal Highway Administration (1985, p. 114), Cottman and McKay (1990). Two pertinent studies in Canada (Lowe, 1970) and UK (Loveless, 1984) demonstrated that MEL culverts can pass successfully ice and sediment load without clogging nor silting. These laboratory findings were confirmed by inspections of MEL culverts after major flood events demonstrating the absence of siltation.

2.2 *Stepped spillways for embankment dams*

In the last four decades, the regain of interest for stepped spillways has been associated with the development of new construction and design techniques. An innovative design is the embankment overtopping protection system (ASCE, 1994; Chanson, 2001). The downstream slope is typically reinforced with precast concrete blocks, conventional concrete or RCC placed in a stepped fashion (Fig. 3). At large flow rates, these structures operate in a skimming flow regime that is characterised by complicated hydrodynamic interactions between the main stream, the step cavity recirculation zones and the free-surface.

Experimental observations highlighted strong interactions between the free-surface and the flow turbulence (e.g. Chanson and Toombes, 2002a; Yasuda and Chanson, 2003; Gonzalez and Chanson, 2004). At the upstream end, the flow is non-aerated and the free-surface exhibits an undular profile in phase with the stepped invert profile. Free-surface instabilities are however observed and strong air–water mixing occurs downstream of the inception point of free-surface aeration. Detailed air–water flow measurements demonstrate large amounts of entrained air (Fig. 4). Figure 4 shows experimental data for one flow rate down

Figure 3 Melton dam stepped spillway on 30 January 2000—Completed in 1916, the Melton dam was equipped in 1994 with a secondary stepped spillway ($Q_{des} = 2,800\,m^3\,s^{-1}$, $h = 0.6\,m$).

a 16° stepped chute (1V:3.5H) illustrating longitudinal oscillations of air–water flow properties downstream of the inception point of free-surface aeration. Such oscillations were observed on both steep and flat slopes (e.g. Matos, 2000; Chanson and Toombes, 2002b) and it is believed that the seesaw patterns result from strong interference between vortex shedding behind each step edge and free-surface. Cavity recirculation and fluid exchange between cavities and main stream are very energetic and contribute to form drag. Energy considerations provide a relationship between cavity ejection frequency, form drag and energy dissipation. At uniform equilibrium, the head loss between adjacent step edges equals the step height, while the energy is dissipated in the recirculation cavity at a rate proportional to the ejection frequency F_{ej}, the volume of ejected fluid and the main flow velocity V. It yields:

$$\frac{F_{ej} \times (h \times \cos\theta)}{V} \approx \frac{f}{5} \qquad (1)$$

where f is the Darcy–Weisbach friction factor, h is the step height and θ is the chute slope (Chanson *et al.*, 2002b).

Observed longitudinal oscillations of depth-averaged flow properties as shown in Fig. 4 affect in turn physical modelling analyses and flow property estimates Flow resistance may be grossly underestimated or overestimated when calculated between two adjacent step edges. In Fig. 4, the friction slope between adjacent steps ranged between +0.1 to +0.9 for an average value of $S_f = 0.30$ corresponding to an average Darcy friction factor f = 0.12. The latter compares favourably with an analytical solution of the form drag generated by step cavity flows (Chanson *et al.*, 2002b; Gonzalez and Chanson, 2004).

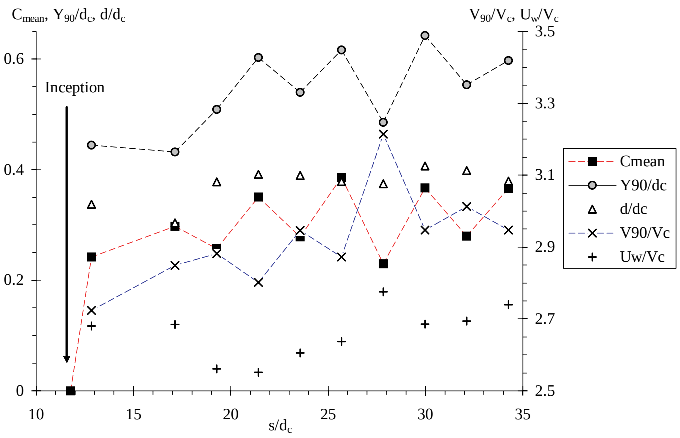
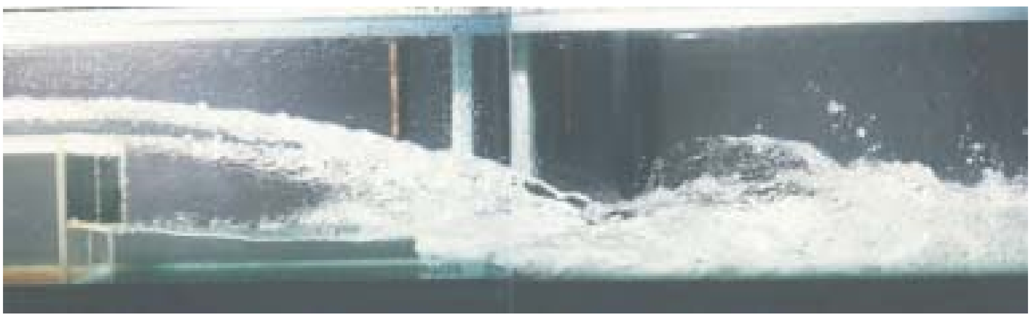


Figure 4 Longitudinal distributions of mean air contents C_{mean}, dimensionless air–water depth Y_{90}/d_c, clearwater depth d/d_c, air–water velocity V_{90}/V_c and mean flow velocity U_w/V_c—Stepped chute: 16° slope, $h = 0.05$ m, $d_c/h = 1.7$ (Yasuda and Chanson, 2003).

(a)



(b)

Figure 5 Air entrainment in water jets discharging into air. (a) Photographs of air–water flow at bottom outlets at Three Gorges Project on 20 October 2004, $V_o = 35\,\mathrm{ms^{-1}}$, $Q = 1700\,\mathrm{m^3\,s^{-1}}$ per outlet, Re $\sim$ 8E + 8, $W_o = 9$ m (per outlet). (b) Laboratory water jet, $V_o = 3.7\,\mathrm{ms^{-1}}$, $Q = 0.028\,\mathrm{m^3\,s^{-1}}$, inflow depth: 0.03 m, $h = 0.1433$ m, Re–4E + 5, $W_o = 0.23$ m—High-shutter speed photograph (1/125th s) (Toombes, 2002).

3 New advances in air–water flow measurements

Air entrainment or free-surface aeration is defined as the entrainment/entrapment of un-dissolved air bubbles and air pockets that are advected away within the flowing fluid (Fig. 5). The resulting air–water mixture consists of both air packets within water and water droplets surrounded by air. It includes also spray, foam and complex air–water structures. In hydraulic engineering, most prototype flow conditions are highly turbulent and large amounts of air are entrained within the flow. Void fractions are commonly larger than five to 10%, and the high-velocity flows have ratios of flow velocity to bubble rise velocity greater than 10 or even 20.

3.1 Basic metrology

Classical measurement devices (e.g. Pitot tube, ADV, PIV, LDV) are affected by entrained bubbles and may lead to inaccurate readings. When the void fraction C exceeds 5% and is less than 95%, the most robust instrumentation is the intrusive phase detection probes: optical fibre probe and conductivity/resistivity probe (Jones and Delhaye, 1976; Bachalo, 1994; Chanson, 1997, 2002d). Although the first designs were resistivity probes, both optical fibre and resistivity probe systems are commonly used today. The intrusive probe is designed to pierce bubbles and droplets (Fig. 6). For example, the probe design shown in Fig. 6(a) has a small frontal area of the first tip to facilitate interface piercing. A typical probe signal output is shown in Fig. 6(b). Although the signal is theoretically rectangular, the probe response is not square because of the tip finite size, the wetting/drying time of the interface covering the tip and the response time of probe and electronics.

The basic probe outputs are the void fraction, bubble count rate and bubble chord time distributions with both single-tip and double-tip probe designs. The void fraction C is the proportion of time that the probe tip is in the air. The bubble count rate F is the number of bubbles impacting the probe tip. The bubble chord times provide information on the air–water flow structure. With a dual-tip probe design (Fig. 6a), the velocity measurement is based upon the successive detection of air–water interfaces by two tips. In turbulent air–water flows, the detection of all bubbles by each tip is highly improbable and it is common to use a crosscorrelation technique (e.g. Crowe *et al.*, 1998). The time-averaged air–water velocity equals: $V = \Delta x/T$ where Δx is the distance between tips and T is the time for which the cross-correlation function is maximum (Fig. 6c). The turbulent intensity may be derived from the broadening of the cross-correlation function compared to the auto-correlation function (Chanson and Toombes, 2002a):

$$T_u = \frac{u'}{V} = 0.851 \times \frac{\sqrt{\Delta T^2 - \Delta t^2}}{T} \tag{2}$$

where ΔT as a time scale satisfying: $R_{xy}(T + \Delta T) = 0.5 \times R_{xy}(T)$, R_{xy} is the normalised cross-correlation function, and Δt is the characteristic time for which the normalised autocorrelation function $R_{xx} = 0.5$. The autocorrelation function itself provides some information on the air–water flow structure. A dimensionless integral length scale is:

$$I_L = 0.851 \times \frac{\Delta t}{T} \tag{3}$$

A time series analysis gives information on the frequency distribution of the signal which is related to the air-and-water (or water-and-air) length scale distribution of the flow (Chanson and Gonzalez, 2004). Chord sizes may be calculated from the raw probe signal outputs. The results provide a complete characterisation of the streamwise distribution of air and water chords, including the existence of bubble/droplet clusters (Chanson and Toombes, 2002a). The measurement of air–water interface area is a function of void fraction, velocity, and bubble sizes. The

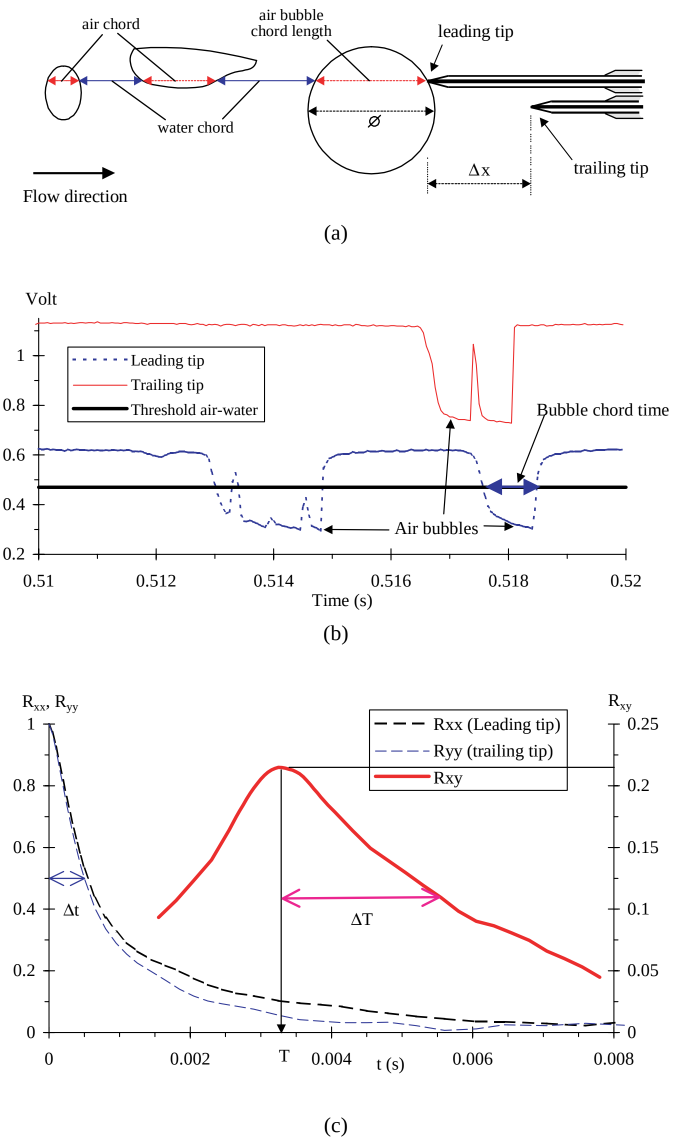


Figure 6 Intrusive phase detection probe measurements. (a) Sketch of bubble impact on phase-detection probe tips (dual-tip probe design). (b) Voltage outputs from a double-tip conductivity probe in skimming flow down stepped chute with double-tip conductivity probe (scan: 20 kHz per tip, Ø = 0.025 mm, $\Delta x = 7.8$ mm)—$\theta = 16°$, $h = 0.05$ m, $d_c/h = 1.7$, $C = 0.08$, $V = 2.3\,\mathrm{m\,s^{-1}}$, $F = 118$ Hz, $y = 7$ mm, step 17. (c) Normalised auto-correlation and cross-correlation functions (same flow conditions as Fig. 6b).

Figure 7 Advancing dam break wave down an initially dry stepped cascade ($Q(t = 0+) = 0.065\,\mathrm{m}^3\,\mathrm{s}$, step 16, $h = 0.0715\,\mathrm{m}$, $l = 1.2\,\mathrm{m}$, $W = 0.5\,\mathrm{m}$), looking upstream at the advancing flood wave (left) and details of air–water flow structures (right) (Courtesy of Chye-guan Sim and Chee-chong Tan).

specific air–water interface area a is defined as the air–water interface area per unit volume of air and water. For any bubble shape, bubble size distribution and chord length distribution, it may be derived from continuity: $a = 4 \times F/V$. The equation is valid in bubbly flows ($C < 0.3$). In high air content regions, the flow structure is more complex and the specific interface area a becomes simply proportional to the number of air–water interfaces per unit length of flow ($a \propto 2 \times F/V$). With relative ease, intrusive phase-detection probes may provide detailed informations on bubble count rate, specific interface area and bubble chord sizes. Such information is essential to gain a better understanding of air–water mass transfer in hydraulic engineering applications (e.g. Toombes and Chanson, 2005). It further assists comprehension of the interactions between turbulence and entrained air.

3.2 Unsteady flow measurements

Air–water flow measurements in unsteady flows are difficult, although prototype observations of sudden spillway releases and flash floods highlighted strong aeration of the leading edge of the wave associated with chaotic flow motion and energy dissipation (Fig. 7). Figure 7 presents a large-size laboratory experiment of dam break wave propagation down a stepped waterway.

In unsteady air–water flows, the measurement processing technique must be adapted, In recent experiments (Chanson, 2003a, 2004b), local void fractions were calculated over a short time interval $\tau = \Delta X/C_s$ where C_s is the measured surge front celerity and ΔX is a control volume streamwise length. Measurements were conducted in a stepped chute (Fig. 7) at several locations X' measured from the vertical step edge. Figure 8 shows dimensionless distributions of void fractions at $X' = 0.3\,\mathrm{m}$ for

	0–70 mm	0–210 mm	350–770 mm	4200–4620 mm
$\Delta X(m) =$	0.07	0.21	0.42	0.42
$t(s) =$	0.012	0.037	0.196	1.54
$t \times g/d_o =$	0.072	0.215	1.15	9.0

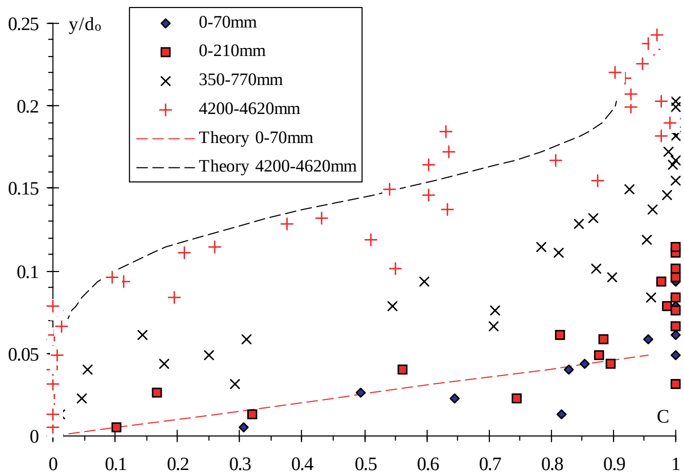


Figure 8 Dimensionless void fraction distributions behind the wave front leading edge ($Q(t = 0+) = 0.070\,\mathrm{m}^3\,\mathrm{s}$, $h = 0.07\,\mathrm{m}$, $W = 0.5\,\mathrm{m}$, Step 16, $C_s = 2.86\,\mathrm{ms}^{-1}$, $X' = 0.3\,\mathrm{m}$)—Comparison with Eqs (5) and (6).

several times t, where t is the time from the first water detection by a reference probe. The legend indicates the control volume streamwise length ΔX and the dimensionless time $t \times \sqrt{g/d_o}$, where d_o is a measure of the initial flow rate $Q(t = 0+)$:

$$d_o = \frac{9}{4} \times \sqrt[3]{\frac{Q(t = 0+)^2}{g \times W^2}} \qquad (4)$$

and W is the channel width. For an ideal dam break, d_o would be equivalent to the initial water depth behind the dam. The distributions of void fractions demonstrated a very strong aeration of the leading edge for $t \times \sqrt{g/d_o} < 1.1$ to 1.3. In Fig. 8, the data for $t \times \sqrt{g/d_o} = 0.07$, 0.21, 1.1, and 9.0 yielded depth-averaged void fractions, defined between 0 and 90%, of $C_{\text{mean}} = 0.65$, 0.55, 0.31, and 0.29 respectively. For larger times, the results tended to the corresponding steady flow data.

At the front of the wave, the void fraction distributions had roughly a linear shape:

$$C = 0.9 \times \frac{y}{Y_{90}} \qquad t \times \sqrt{g/d_o} < 1.2 \tag{5}$$

where Y_{90} is the location where $C = 90\%$. Equation (5) is a limiting case of the analytical solution of air bubble diffusion equation for steady transition flows down stepped chute. For larger times t, the distribution of air concentration may be described by an advective diffusion model:

$$C = 1 - \tanh^2\left(K' - \frac{\frac{y}{Y_{90}}}{2 \times D_o} + \frac{\left(\frac{y}{Y_{90}} - \frac{1}{3}\right)^3}{3 \times D_o}\right) \qquad t \times \sqrt{g/d_o} > 1.3 \tag{6}$$

where K' and D_o are functions of the mean air content only (Chanson and Toombes, 2002a). Equations (5) and (6) are plotted in Fig. 8. For all experiments (Chanson, 2003a, 2004b), a major change in void fraction distribution shape took place for $t \times \sqrt{g/d_o} \sim 1.1$ to 1.5. Possible explanations may include a nonhydrostatic pressure field in the leading front of the wave, and some change in air–water flow structure between the leading edge and the main flow associated with a change in rheological fluid properties. Further visual observations seem to suggest some change in gas–liquid flow regime, with some plug/slug flow at the leading edge and a homogenous bubbly flow region behind. There might be also a change in boundary friction regime between the leading edge and the main flow behind. All these mechanisms would be consistent with high-shutter speed movies of leading edge highlighting very dynamic spray and splashing processes.

3.3 Discussion

Most studies of air bubble entrainment were conducted with freshwater. There were however a small number of basic studies suggesting that air entrainment may be an entirely different process in seawater. Scott (1975) studied the size of bubbles produced by a frit, and he showed that bubble coalescence was drastically reduced in saltwater compared to freshwater experiments. Slauenwhite and Johnson (1999) obtained a similar result with fragmented bubbles injected in seawater with a syringe. Walkden (1999) observed the same trend in an aerated column filled with filtered seawater, for aeration levels up to 18%.

A systematic study of the developing flow region of plunging jets was recently conducted with freshwater, seawater and salty freshwater (Chanson *et al.*, 2002a). The results indicated that significantly less air was entrained in seawater than in freshwater, all inflow parameters being equal. It was hypothesised that surfactants, biological and chemical elements harden the induction trumpet and diminish air entrapment at impingement in seawater. For all seawater experiments, typical bubble sizes were millimetric with mean chord sizes of about 3–6 mm. Seawater bubbly flows contained comparatively a greater number of fine bubbles than freshwater plunging jets for identical inflow conditions. Air entrainment at plunging jets differed between saltwater and seawater with lesser entrained bubbles in seawater. The overall results implied that air entrainment at plunging jets is affected by physical, chemical and biological properties other than simply density, viscosity and surface tension (Chanson *et al.*, 2002).

4 Quality in hydraulic engineering education

The education of scientists and engineers is a major challenge. Basic fluid mechanics is introduced in engineering and applied mathematics degrees. Some hydraulics subjects might be offered in postgraduate courses, but "real-world" hydraulic engineering involves the interactions between water, soil, air, and aquatic life (Chanson, 2004d; Mossa *et al.*, 2004). Such topics are not taught in undergraduate nor postgraduate curricula in most universities. The writer believes that many researchers, professionals and government administrators do not fully appreciate the complexity of hydraulic engineering nor the needs for further education of quality.

During the last three decades, universities in developed countries have rationalised their engineering curricula without much pedagogical justification. This has been associated with the development of computer-based courses and "virtual teaching", project-based subjects and management courses, flexible delivery material. Such developments have been nearly always at the expenses of lecture quality, staff/student ratio, practical studies and field works. At undergraduate level, design applications are restricted to simple flow situations and boundary conditions for which the basic equations can be integrated. A sound teaching pedagogy should encompass practical works including field works and laboratory classes associated with tutorials and projects (Fig. 9). Laboratory classes are important tools to visualise the theory. Field studies are essential to illustrate real professional situations, and the complex interactions between all engineering and non-engineering constraints (Chanson, 2004c). There is nothing "virtual" about hydraulic engineering!

4.1 The role of practical works

For the last ten years, field studies have been incorporated into the undergraduate teaching of hydraulic engineering at the University of Queensland. Field works complement traditional lectures and laboratory works (Figs 2(a) and 9). For example, Fig. 9(b) illustrates fourth year students conducting some hydraulic and ecological assessment studies of the estuarine zone of a small subtropical creek. For 12 h, students surveyed hydrodynamics, water quality parameters, fish populations, bird behaviours and wildlife sightings at four sites (Chanson, 2003b; Ferris *et al.*, 2004). They concluded their works with a group report and an

(a)

(b)

Figure 9 Photographs of undergraduate student field works. (a) CIVL4511 Civil design students with the writer surveying a river bed in April 2005 (Courtesy of The University of Queensland). (b) Mixing in a sub-tropical estuary at Eprapah Creek on 4 April 2003—Students conducting sampling tests in the mangrove (Courtesy of Ms Joyce H.).

oral presentation in front of student peers, lecturers, professionals and local community groups.

The writer has brought more than 1200 undergraduate students in field studies. Anonymous student feedback demonstrated a strong student interest for field works (Chanson, 2004c). This was associated with greater motivation for the course, leading in turn to lower failure rates. Feedback from former students indicated that field work experience was an important component of their studies and helped their professional development. Employers testified that field works are an essential component of a hydraulic engineering course and that it should be a key requirement in all civil/environmental engineering curricula.

Figure 10 Arthur Thomas IPPEN at the age of 60 (Courtesy of his son Erich Ippen).

A key outcome of field works is the personal experience gained by students. This aspect is not quantifiable and too often ignored by university management, but there is no doubt that field studies enhance individual experience and personal development. Lecturers and professionals should not be complaisant with university hierarchy and administration clerks to cut costs by eliminating field studies. Professional institutions including the IAHR have a duty to emphasise the requirement for field studies in university curricula.

5 Summary and conclusion

Hydraulic engineers were at the forefront of science for centuries. Famous applications include the qanats, the Roman aqueducts, the Grand Canal in China, and the first air–water flow experiments by Ehrenberger (1926). The end of the 20th century marked a change perception of hydraulic engineering, especially in developed countries, with a shift in focus toward environmental issues, sustainability and management. These trends led by government institutions, industries and university administrations have placed more focus on political issues, cost-recovery and short-term "vision" (?) at the expenses of quality expertise and engineering innovation.

Water plays a major role in human perception of the environment because it is an indispensable element. More importantly Human Life is totally dependent upon water. The technical challenges facing hydraulic engineers are formidable and sustained research efforts are essential. The writer believes strongly that the future of hydraulic engineering is closely linked to engineering innovation, excellence in hydraulic research and quality teaching. This must be complemented by the indispensable interactions between professionals, researchers and educators. High-quality research does improve teaching by providing University's graduates with state-of-the-art expertise as well as enhancing the professional knowledge to the benefits of the society. This stance carries through a long tradition established by eminent scholars like A. T. Ippen (1907–1974), J. F. Kennedy (1933–1991) and H. Rouse (1906–1996). Professional institutions like the IAHR have a duty to emphasise the needs for strong interactions between research, teaching, professional development and service to the community. Figure 10 shows a photograph of Arthur IPPEN who was IAHR President between 1960 and 1963.

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