HYDRAULIC ENGINEERING: WHERE TO ?
(QUEL FUTUR POUR L'INGÉNIERIE HYDRAULIQUE ?)

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Abstract : Hydraulic engineering was at the forefront of science for centuries. The end of the 20th century marked a change of perception in our society, especially in developed countries, with a focus on environmental sustainability and management. In this paper, the writer illustrates his belief that the future of hydraulic engineering reposes in a combination of innovative engineering, research excellence and higher education of quality. Such a thrust pursues a long tradition established by eminent scholars like Arthur Thomas IPPEN, John Fisher KENNEDY and Hunter ROUSE.

Keywords : hydraulic engineering, innovation, excellence, quality, teaching, engineering, research, culvert, stepped chute, air-water flow, dam break, student field work.

1. INTRODUCTION

Hydraulic engineering relates predominantly to the science of water in motion, and the interactions between the flowing fluid (water) 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*, 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 magnificent waterworks and demonstrated the "savoir-faire" of Roman engineers (e.g. CHANSON 2002a). The 132 km long Carthage aqueduct (Fig. 1B) was regarded as one of the marvels of the world by the Muslim poet EL KAIROUANI. A major navigation system 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 although the technical challenges are gigantic. The extreme complexity of hydraulic engineering is closely linked with the geometric scale of water systems, the broad range of relevant time scales, the variability of river flows from zero during droughts to gigantic floods, the complexity of basic fluid mechanics with governing equations characterised by non-linearity, natural fluid instabilities, interactions between water, solid, air and biological life, and Man's total dependence on water. The end of the 20th century marked a change of perception in our society, especially in developed countries. Environmental issues, sustainability and environmental management have become "fashionable" topics. So is there a need for further hydraulic engineering ? In the following paragraphs, the writer outlines his belief that the future of hydraulic engineering rests on a combination of innovative engineering, research excellence and higher education of quality.

2. INNOVATIVE HYDRAULIC ENGINEERING

2.1 PRESENTATION

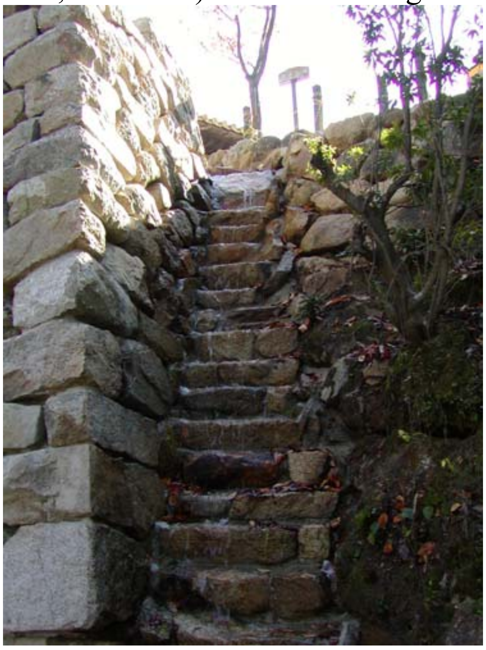
After centuries of developments, advances in hydraulic engineering have been sometimes described as "sluggish" and lacking flair during the second half of the 20th century. Some examples include the designs of culverts and energy dissipators which are among the most common civil engineering structures. Modern designs do not differ from ancient designs.

Fig. 1 - Ancient hydraulic works

(A) Nabataean dam (1st century BC) on the Mamshit stream (also called Mampsis or Kunub) on 10 May 2001 (Courtesy of Dennis MURPHY) - Downstream slope of the dam wall

(B) Arcades at Oued Milliane, Carthage aqueduct, Tunisia on 3 April 2003 (Courtesy of Jean-Claude LITAUDON)

(C) Storm waterway at Miya-jima (Japan) below Senjò-kaku wooden hall on 19 Nov. 2001 - The steep stepped chute ($\theta > 45°$, $h \sim 0.4$ m) was built during the 12th century AD



A culvert is a covered channel of relatively short length designed to pass safely water through an embankment. Culverts have been used for more than 3,000 years. Although the world's oldest culvert is unknown, the Minoans and the Etruscans built culverts in Crete and Northern Italy respectively (EVANS 1928, O'CONNOR 1993). Later the Romans built numerous culverts beneath roads and aqueducts (BALLANCE 1951). One advanced design along the Nîmes aqueduct was capable of discharging rainfall runoff in excess of 10 times the maximum aqueduct flow rate (CHANSON 2002b).

In hydraulic structures, energy dissipation is usually achieved by a high velocity water jet taking off from a ski jump and impinging into a downstream plunge pool, a hydraulic jump stilling basin, a dropshaft structure, or the construction of steps on the chute. Energy dissipator designs 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 3,500 years (CHANSON 2001). At the end of the 19th century, the stepped spillway design accounted for nearly one third of all spillway constructions in North-America.

For both types of 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 in the next paragraphs.

2.2 MINIMUM ENERGY LOSS (MEL) CULVERT DESIGNS

Standard culverts are characterised by significant afflux at design flow conditions. The afflux is the rise in upstream water level caused by the hydraulic structure. It is a 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: e.g., California Division of Highways (1956), NEILL (1962), Federal Highway Administration (1972,1985). These solutions are expensive and often marginal.

Fig. 2 - Photographs of a Minimum Energy Loss culvert in Brisbane ($Q_{des} = 220$ m^3/s, $B_{max} = 42$ m, $B_{min} = 21.3$ m, $D = 3.0$ m)

(A) Culvert outlet looking upstream on 13 May 2002 (Courtesy of Craig HINTON) - Note the low-flow channel and students surveying the waterway

(B) Culvert outlet in operation on 31 Dec. 2001 for about 80 m^3/s (flow from left to right)

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 ([1]). 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). 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

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[1] Minimum Energy Loss culverts are also called Energy, Constant Energy, Minimum Energy, Constant Specific Energy culverts ... (e.g. APELT 1983).

(APELT 1994). The writer highlighted the wide range of design options (CHANSON 2000).

Prototype experience

The first 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 to more than 800 m^3/s. 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. 2). 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 (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. 2). MEL culverts are usually designed for $Fr = 0.6$ 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 40 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 Figure 2 is equipped with a well-designed drainage system. 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).

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.

2.3 STEPPED CHUTES FOR EMBANKMENT

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 (e.g. 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.

Observations highlighted strong interactions between the free-surface and the flow turbulence (e.g. CHANSON and TOOMBES 2002a, YASUDA and CHANSON 2003). 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 a 16º stepped chute (1V:3.5H). The results illustrate longitudinal oscillations of flow properties. These were observed on steep and flat slopes (e.g. MATOS 2000, CHANSON and TOOMBES 2002b). It is believed that this seesaw pattern results 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:

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

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 (Fig. 4) affect in turn flow property estimates Flow resistance may be grossly underestimated or overestimated when calculated between two adjacent step edges. For example, in Figure 4, the friction slope between adjacent steps range between +0.1 to +0.9 for an average value of $S_f = 0.30$ corresponding to a 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).

3. HYDRAULIC RESEARCH EXCELLENCE : AIR-WATER FLOW EXPERTISE ?

3.1 PRESENTATION

In Nature, air-water flows are commonly encountered at waterfalls, in mountain torrents and at wave breaking. 'White waters' are also observed in aesthetical fountains and in hydraulic structures (e.g. PLUMPTRE 1993, CHANSON 1997). One of the first scientific accounts was made by LEONARDO DA VINCI (AD 1452-1519) (Fig. 5). He described air-water flow situations at waterfalls, hydraulic structures and breaking waves, highlighting air-water mixture foam (*schiuma*) and white waters (*bianchezza*). LEONARDO DA VINCI recognised with discernment that air entrainment is related to the flow velocity (CHANSON 1997 pp. 327-329).

Air-water flows have been studied recently compared to classical fluid mechanics. The first successful experimental investigations were conducted by hydraulic engineers during the mid-20th century. That is, EHRENBERGER (1926) in Austria, and STRAUB and ANDERSON (1958) in North-America. Since, however, the contribution of hydraulic engineers to gas-liquid flow research has been modest and fundamental research was dominated by chemical, mechanical and nuclear engineers. For example, the intrusive phase-detection needle probe design was developed by Professor S.G. BANKOFF (NEAL and BANKOFF 1963,1965); phase detection optical fibre probes were developed in the late 1960s (JONES and DELHAYE 1976). In 2003, the hydraulic community lacks advanced gas-liquid flow expertise, as illustrated by a thin contribution to specialised journals: e.g., less than 3% of publications in International Journal of Multiphase Flow for the period 1985-2003.

3.2 NEW ADVANCES IN AIR-WATER FLOW MEASUREMENTS

3.2.1 Basic measurements

In hydraulic engineering, classical measurement devices (e.g. Pitot tube, LDV) are affected by entrained bubbles which might lead to inaccurate readings. When the void fraction C exceeds 5 to 15%, and when the liquid fraction (1-C) is larger than 5 to 10%, the most robust instrumentation is the intrusive phase detection probes designed to pierce bubbles and droplets (JONES and DELHAYE 1976, BACHALO 1994, CHANSON 1997,2002d). A typical probe signal output is shown in Figure 6. 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.

Fig. 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, h = 0.6 m)

Fig. 4 - Longitudinal distributions of mean air contents C_{mean}, dimensionless air-water depth Y_{90}/d_c, clear-water depth d/d_c, air-water velocity V_{90}/V_c and mean flow velocity U_w/V_c - Stepped chute: 16º slope, h = 0.05 m, d_c/h -= 1.7 (YASUDA and CHANSON 2003)

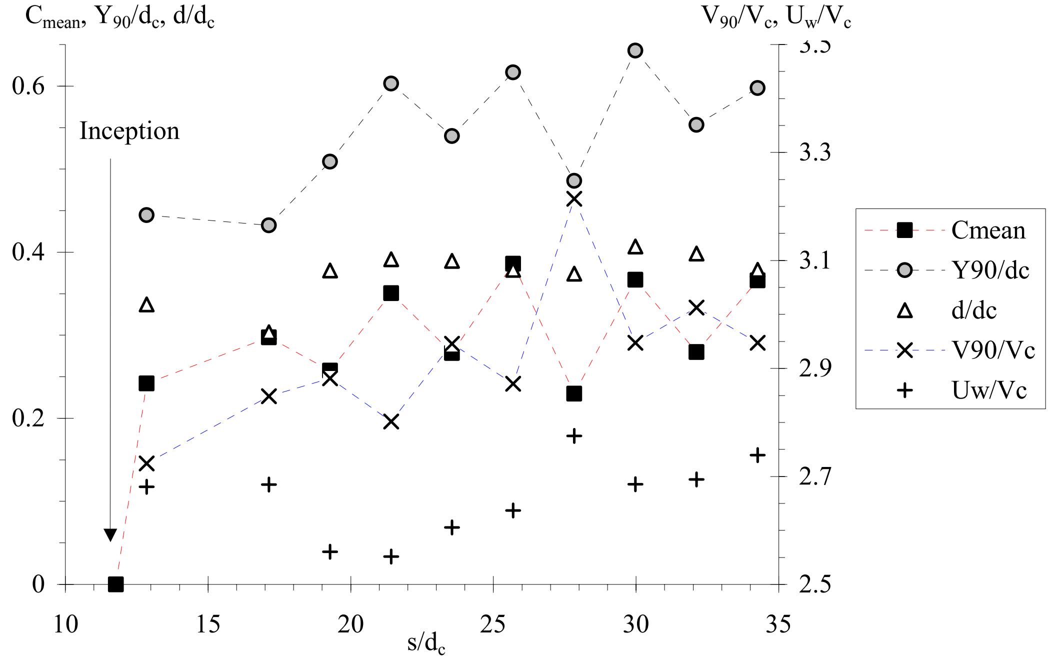


Fig. 5 - Sketch of plunging jet flow at a pipe outlet by LEONARDO DA VINCI - Original drawing from about A.D. 1509 called "sketch of waterfall" or "impact of water on water"

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 cross-correlation 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):

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

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

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

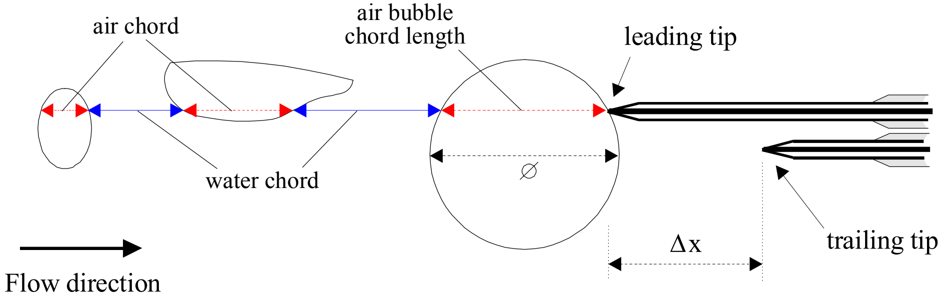
Chord sizes may be calculated from the raw probe signal outputs. The results provide a complete characterisation of the streamwise distribution of air and water chords, and of particle clustering (CHANSON and TOOMBES 2002a). The measurement of air-water interface area is a function of void fraction, velocity, and bubble sizes. For any bubble shape, bubble size distribution and chord length distribution, the specific air-water interface area a defined as the air-water interface area per unit volume of air and water may be derived from continuity : $a = 4*F/V$.

3.2.2 Unsteady flow measurements

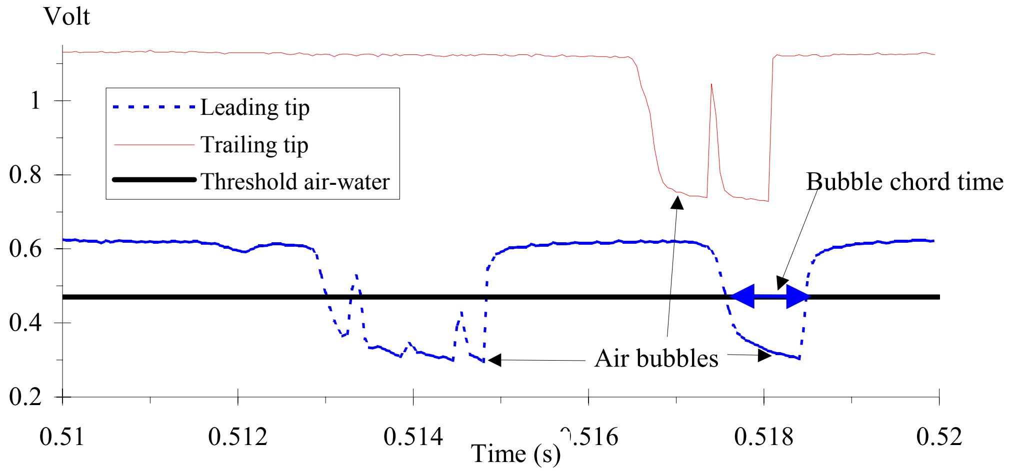
Air-water flow measurements in unsteady flows are difficult, although prototype observations of sudden spillway releases and flash floods highlighted strong aeration of the leading edge of the wave associated with chaotic flow motion and energy dissipation (Fig. 7). Figure 7A presents a flood wave advancing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

Fig. 6 - Air-water flow measurements in skimming flow down stepped chute (θ = 16°, h = 0.05 m, d_c/h = 1.7) with double-tip conductivity probe (scan: 20 kHz per tip, ∅ = 0.025 mm, Δx = 7.8 mm) - C = 0.08, V = 2.3 m/s, F = 118 Hz, y = 7 mm, step 17

(A) Sketch of bubble impact on phase-detection probe tips (dual-tip probe design)



(B) Voltage outputs from a double-tip conductivity probe



(C) Normalised auto-correlation and cross-correlation functions

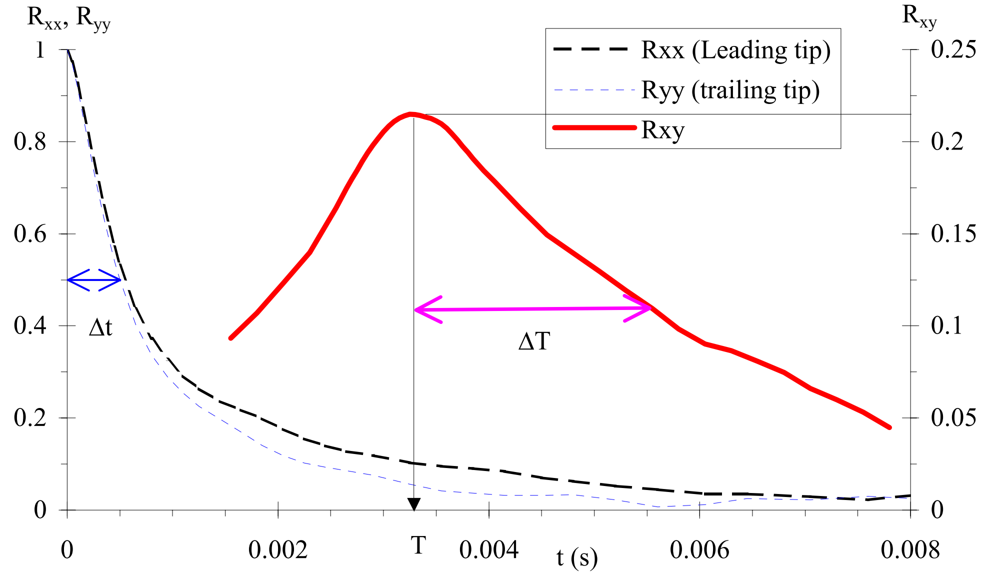


Fig. 7 - Advancing flood waves down stepped chutes (leading edge of dam break waves)

(A) Flood wave propagating down Brushes Clough dam spillway during field tests in 1994 (Courtesy of Dr R. BAKER) - $Q(t=0+) \sim 0.5$ m^3/s, 18.4° slope, h = 0.19 m
(B) Looking upstream at an advancing wave on step 16 with an array of conductivity probes in foreground - $Q(t=0+) = 0.055$ m^3/s, 3.4° slope, h = 0.07 m (W = 0.5 m)

In unsteady air-water flows, the measurement processing technique must be adapted, In recent experiments (CHANSON 2003a), 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 the control volume streamwise length. Measurements were conducted in a stepped chute at several locations X' measured from the vertical step edge. Figure 8 shows dimensionless distributions of void fractions at X' = 1.0 m for several times $(t-t_s)$, where t_s is the time of passage of wave front. The legend indicates the control volume streamwise length ΔX and the dimensionless time $(t - t_s)*\sqrt{g/d_o}$, where d_o is a measure of the initial flow rate $Q(t=0+)$:

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

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 data are compared with corresponding steady flow data. The distributions of void fractions demonstrated a very strong aeration of the leading edge for $(t - t_s)*\sqrt{g/d_o} < 1.1$ to 1.3. In Figure 8**,** the data for $(t - t_s)*\sqrt{g/d_o} = 0.25$, 0.455, 0.66 and 2.11 yielded depth-averaged void fractions, defined between 0 and 90%, of $C_{mean} = 0.47$, 0.54, 0.40 and 0.25 respectively. In steady flow, the mean air content was $C_{mean} = 0.20$.
At the front of the wave, the void fraction distributions had roughly a linear shape :

$$C = 0.90 * \frac{y}{Y_{90}} \qquad (t - t_s)*\sqrt{g/d_o} < 1.2 \quad (5)$$

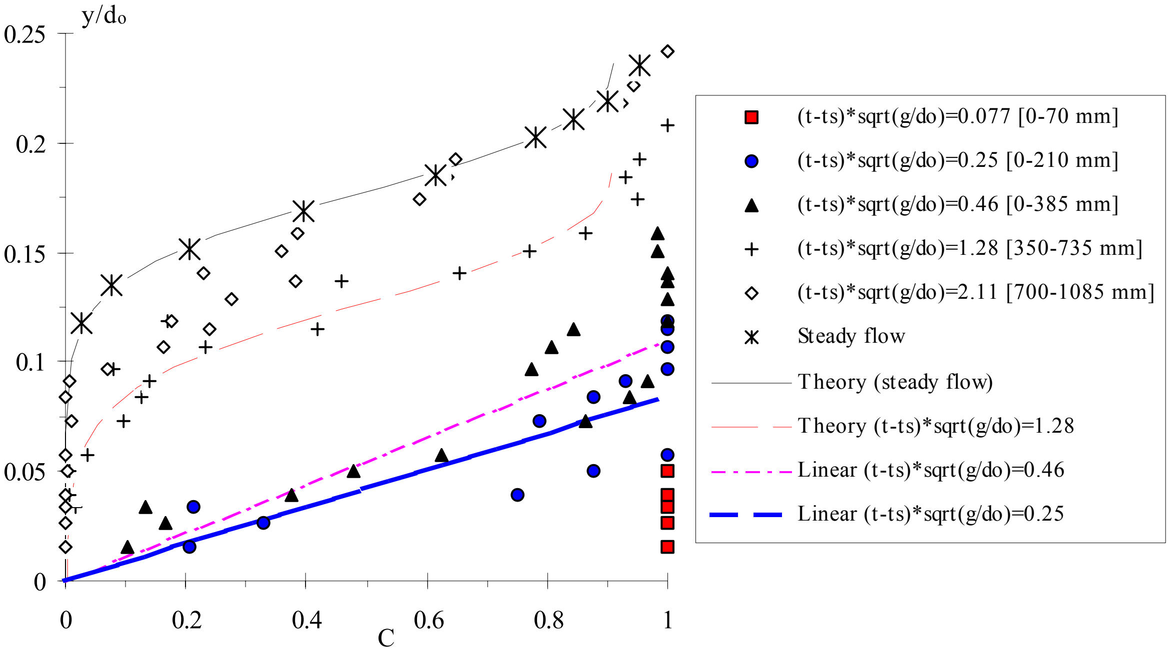
where Y_{90} is the location where C = 90%. Equation (5) is a limiting case of the analytical solution of air bubble diffusion equation for steady transition flows down stepped chute (CHANSON and TOOMBES 2002a). For larger times $(t - t_s)$, the distribution of air concentration may be described by an advective diffusion model:

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

where K' and D_o are functions of the mean air content only (CHANSON and TOOMBES

2002a). Equations (5) and (6) are plotted for steady and unsteady flow conditions in Figure 8. For all experiments, a major change in void fraction distribution shape took place for $(t - t_s)*\sqrt{g/d_o} \sim 1.1$ to 1.5. Possible explanations may include non hydrostatic pressure distributions at the leading wave front, some change in air-water flow structure associated with a change in rheological fluid properties, a change in gas-liquid flow regime, with a plug/slug flow regime in front a homogenous bubbly flow region behind, and some alteration in shear stress distributions and boundary friction.

Fig. 8 - Dimensionless void fraction distributions behind the wave front leading edge ($Q(t=0+) = 0.075$ m^3/s, $h = 0.07$ m, Step 10, $C_s = 2.61$ m/s, $X' = 1.0$ m) - Comparison with steady flow data, and Equations (5) and (6)



3.2.3 Discussion

Most studies of air 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. Typical bubble sizes were millimetric in seawater, 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 less air and smaller bubbles entrained 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.

4. QUALITY IN HYDRAULIC ENGINEERING EDUCATION

4.1 PRESENTATION

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 hydraulic engineering involves the interactions between water, soil, air and aquatic life. 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 include field works and laboratory classes associated with tutorials and projects. 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. There is nothing "virtual" about hydraulic engineering.

4.2 THE ROLE OF PRACTICAL WORKS

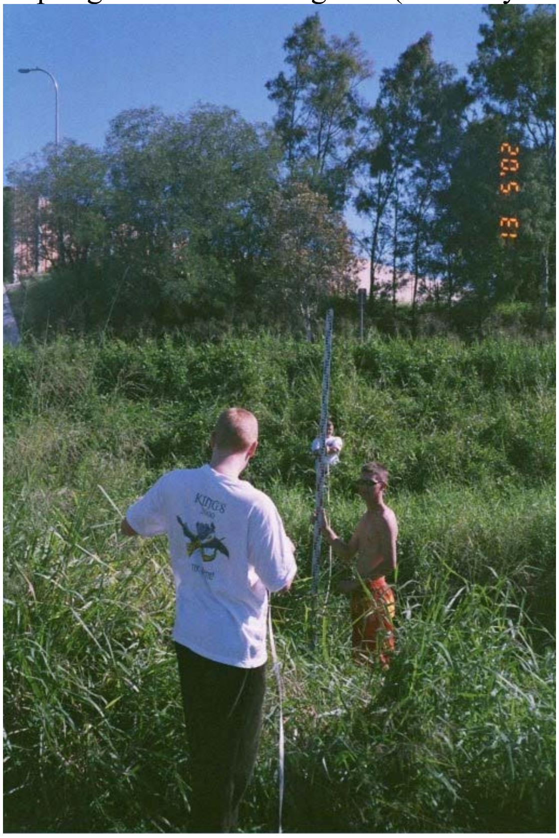
For the last 10 years, field studies have been incorporated into the undergraduate teaching of hydraulic engineering at the University of Queensland. Field studies complement traditional lectures and laboratory work (Fig. 9). For example, Figure 9B illustrates 4th Year students conducting a hydraulic and ecological assessment of the estuarine zone of a small subtropical creek. For 12 hours, students surveyed hydrodynamics, water quality parameters, fish populations, bird behaviours and wildlife sightings at four sites (CHANSON 2003b). They concluded their works with a group report and an oral presentation in front of student peers, lecturers, professionals and local community groups.

The writer has brought more than 1,000 undergraduate students in field studies. Anonymous student feedback demonstrated a strong student interest for field works. 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 requirement in all civil/environmental engineering curricula.

A key outcome of field works is the personal experience gained by students. While this aspect is hardly quantifiable and often ignored by university management, there is no doubt that field studies can 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.

Fig. 9 - Photographs of undergraduate student field trips

(A) Students surveying a flood plain (Courtesy of L. CHEUNG)
(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.)



SUMMARY AND CONCLUSIONS

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. 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 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. The technical challenges are formidable and sustained research efforts are essential. The writer believes that the future of hydraulic engineering is very 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 and carries through a long tradition established by eminent scholars like Arthur Thomas IPPEN (1907-1974), John Fisher KENNEDY (1933-1991) and Hunter ROUSE (1906-1996). 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.

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.

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