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DISCUSSION

A method for measuring low water velocities in large hydraulic models

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The Authors are to be complimented for having devised a simple piece of apparatus to measure depth-averaged velocities in model reservoirs. These velocities are usually very small and difficult to measure accurately. Although the apparatus is simple, the photogrammetric surveying method is more difficult and has required computer assistance.

28. The Authors have assumed that the calibration results obtained by testing 10% of the experimental buoys may be applied to all of them. Such a practice requires careful control of the diameter, length, straightness and rigidity of the polythene rods.

29. In attempting to follow the Authors' lead in these measurements, we have constructed and tested a float similar to theirs. We found difficulty in attaching the buoy to the model bed as the 2 mm long cotton ties easily became (accidentally) stiffened or effectively shortened by the adhesive used; any departure from a completely resistance-free hinge is undesirable.

30. The Authors calibrated their buoys in a flume so that the vertical distribution of horizontal velocities would follow either a parabola for laminar flow or a power law curve in turbulent or transitional conditions. Using a 1/7 power law to describe the velocity distribution acting on the buoy implies that turbulent flow is taking place over the range of velocities.

31. Working in a channel 0·3 m wide and 12 m long (water depth 8 cm), and using a laser to measure velocities, we found that in conditions the same as those of the Authors' the flow was transitional and that the power law required to describe the vertical distribution of horizontal velocities called for an exponent of 1/3·4. This brings the Authors' theoretical curve in Fig. 6 closer to their experimental curves.

32. On further consideration of velocity distributions, we have found that for jetted circulation in model reservoirs of the type that the Authors are studying, the vertical centre line velocity distributions are quite complicated (Fig. 7). Fig. 7 also shows the effect of the inlet position, relative to the bed, on the velocity distributions.

33. Small water velocities can be measured using time-lapse photography. Fig. 8 shows time exposures of illuminated surface floats. The tracks were broken by the covering of the camera lens at regular intervals, thus permitting the rapid calculation of surface velocities. Each run in Fig. 8 took about ten minutes. The main advantages of this technique are

(*a*) it illustrates the circulation patterns well
(*b*) it is not liable to systematic errors
(*c*) the mean velocity can be calculated from the surface velocities for an assumed velocity distribution.

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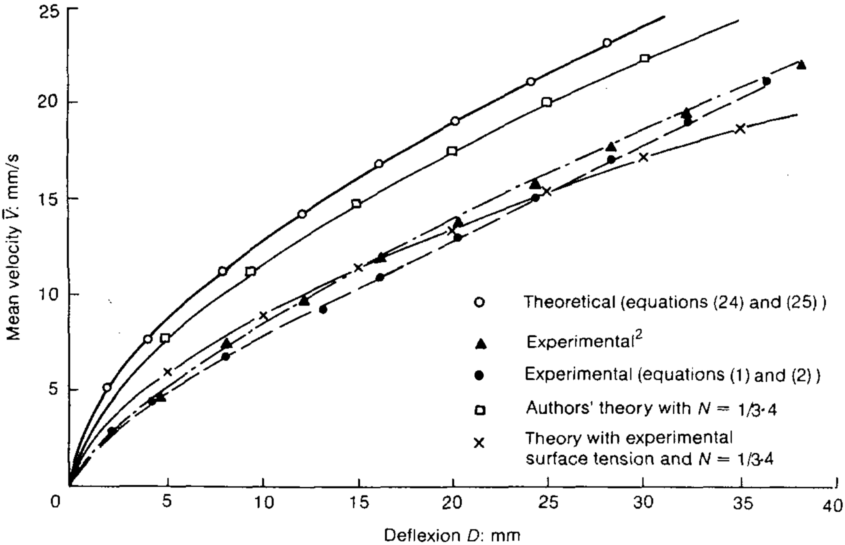

Fig. 6. Theoretical and experimental calibrations for the polyethylene buoy

34. The upper section of the buoy breaks through the free surface; meniscal forces are thus brought into play and are much influenced by any surface films lying on the solid or the liquid surface at the triple interface. A slight greasiness of the solid or dustiness of the liquid surface will modify the characteristics of the buoy; in industrial atmospheres an oily film often forms on the water surface after only a few hours' exposure.

35. The Authors, comparing their experimental and theoretical calibration curves, absorb the discrepancy into unconsidered surface tension effects. They state that it is impossible to quantify the surface tension forces on the inclined glass rod when flow is occurring at the water surface. However, we consider that the effect of surface tension is so large that it can be usefully included in the analysis in spite of using crude assumptions.

36. Figure 9(a) shows a simple configuration of the meniscus on the glass rod penetrating the water surface. If the angles of contact of the meniscus on the rod are zero, then the only surface tension forces acting directly on the rod act parallel to its axis, thereby producing no moment. The weight of water in the meniscus develops a vertical force on the rod. The deflexion of the rod is reduced when the surface tension force is reduced by adding detergent to the water. The vertical force is, therefore, reduced but continues to produce a clockwise moment on the rod. It follows that the effective angles of contact cannot be zero.

37. In Fig. 9(b) it is assumed that the surface tension forces on the rod reduce to a single force F acting at α to the horizontal. Investigation of movement of the mass centre of the suspended water may give information about the value of α and whether any horizontal component of the surface tension resultant would increase or decrease the clockwise moment acting on the rod. For $\alpha = 90°$

$$W = F$$

$$M_T = WD \qquad (26)$$

where M_T is the moment produced by the surface tension force.

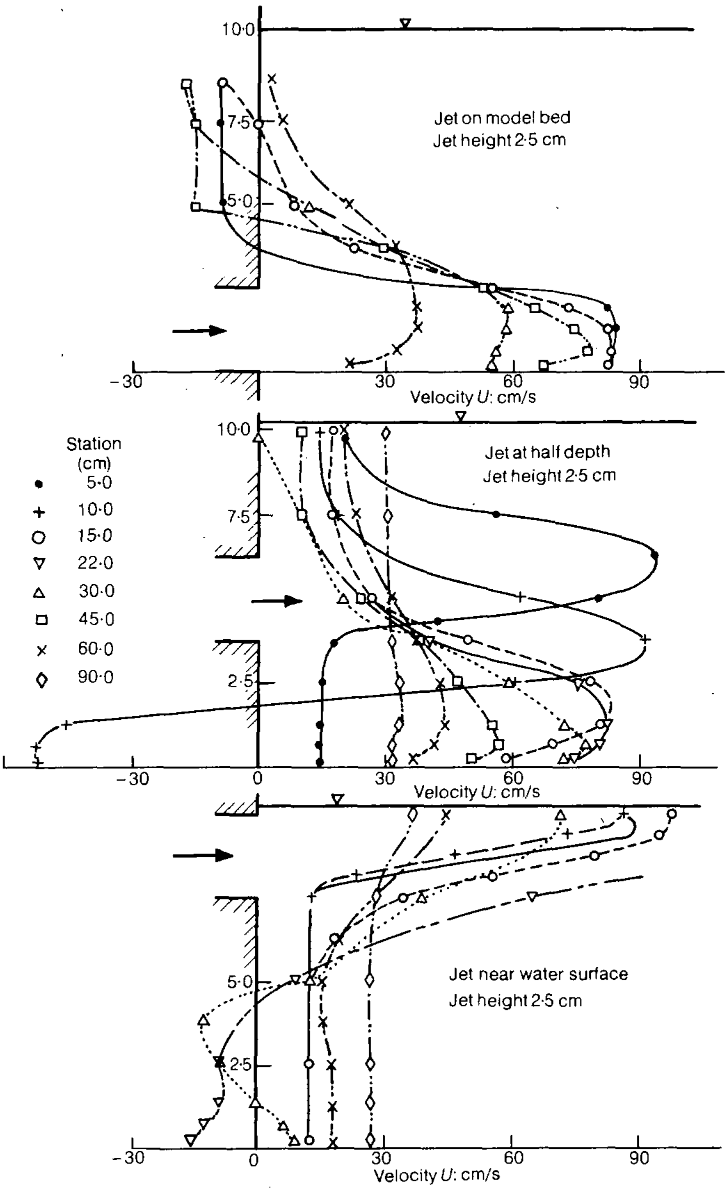

Fig. 7. Velocity distributions for various jet positions

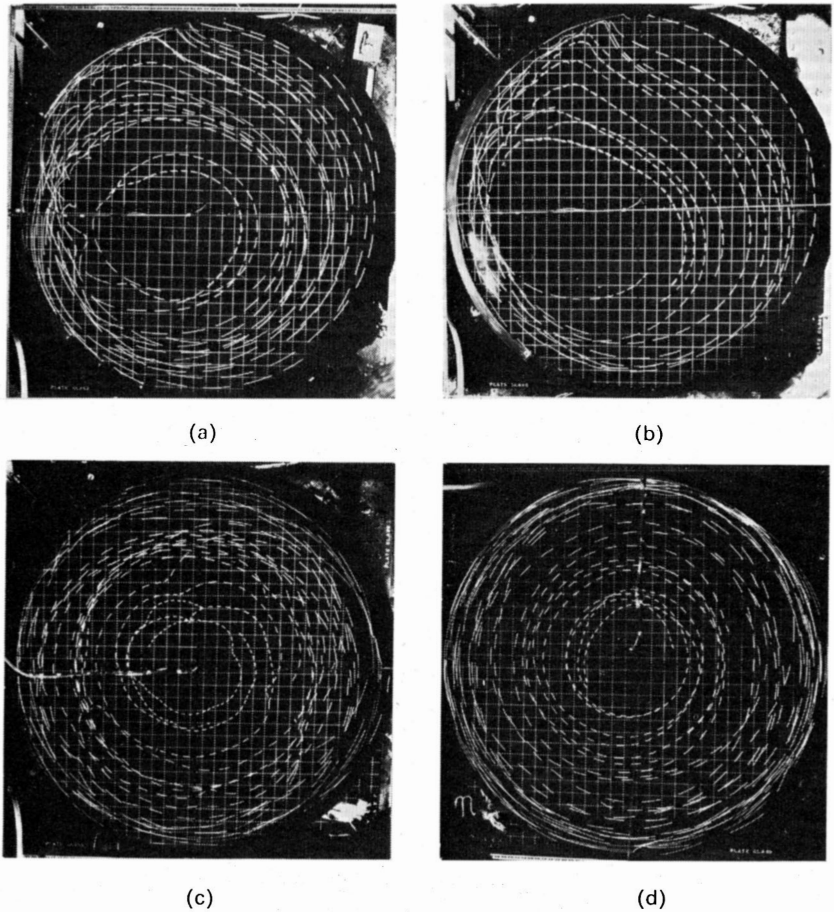

Fig. 8. Circulation patterns illustrated by illuminated floats; (a) $L = 3$ m, $Q_0 = 34{\cdot}6$ cm^3/s, $L/h = 150$, $h = 2$ cm, steps of 10 s, (b) $L = 3$ m, $Q_0 = 28{\cdot}4$ cm^3/s, $L/h = 150$, $h = 2$ cm, steps of 10 s, (c) $L = 3$ m, $Q_0 = 73{\cdot}5$ cm^3/s, $L/h = 30$, $h = 10$ cm, steps of 5 s, (d) $L = 3$ m, $Q_0 = 73{\cdot}5$ cm^3/s, $L/h = 15$, $h = 20$ cm, steps of 5 s

38. We conducted an experiment to investigate the change in the vertical component W with change in angle ϕ of the rod. A Mettler balance was used, reading to 0·1 mg, and a siphon arrangement was set up to make minute adjustments to the water surface elevation. Using equation (26) and various substitutions from geometry, gives

$$M_{\mathrm{T}} = \frac{s}{5}\sqrt{[1+(s/h)^2]}(41-2\,s/h) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

where s is as defined in Fig. 9(a). This can be incorporated into the equation where the moments due to buoyancy and dynamic forces are balanced. The resulting curve (Fig. 6) agrees well with the Authors' experimental curve.

39. The vertical component of surface tension W was measured at various inclinations ϕ of the rod. It was assumed that the interfacial line was the elliptical trace of

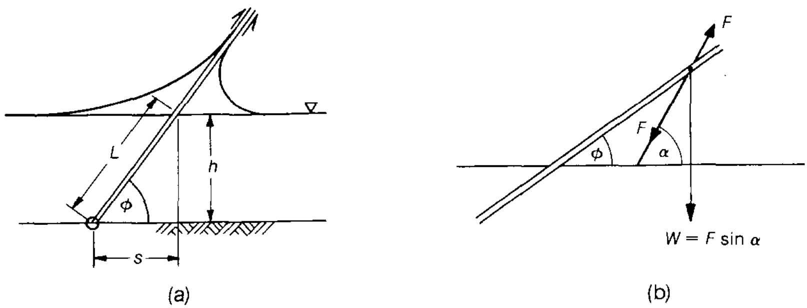

Fig. 9. Surface tension on the buoy ; (a) general configuration, (b) resultant surface tension force

the undisturbed surface on the rod and that this perimeter could be approximated by a circle. It follows that the unit surface tension σ would be $W \sin \phi / \pi d$ mg/mm, where d is the diameter of the glass rod.

40. For values of ϕ of 90°, 80°, 70° and 60° the corresponding values of σ mg/mm were 4·99, 5·23, 4·99 and 4·87, respectively. These values are for the triple interface (water–air–glass). For air–water bubbles at the same temperature, σ would be 7·4 mg/mm. The results show that the weight of the suspended liquid is approximately independent of ϕ.

41. This simple analysis for estimating the moment on the buoy due to surface tension did not take account of any moment due to a possible horizontal component of the tension.

Dr J. M. Townson, University of Strathclyde

The Authors have confined their work to the case of steady flow in which the depth is constant. Do they consider that there is any potential application to the unsteady case? Some time ago I tried to calibrate an inverted form of the present arrangement.[5] A surface penetrating cylinder was suspended from a three-point strain gauge mounting. By appropriate combinations of the three signals, buoyancy and drag forces were resolved into time-dependent surface displacements and current vectors. In that case, the ranges envisaged of from 0 to 250 mm/s velocity and up to 75 mm displacement were restricted by the response of the 16 mm cylinder and its elastic mounting to vortex shedding.

Mr Robinson and Mr Minton

We would agree that if batch calibration is used then the buoys must be manufactured to close tolerances, but we found little difficulty in practice. The problem of the attachment of the cotton to the model pointed out by Dr Ali and Mr Pateman was overcome by the use of sticky tape rather than an adhesive.

44. It was encouraging to see that a precise measurement of the velocity profile gave a better correlation between the predicted and measured buoy deflexions, but we agree that buoys should not be positioned in regions where jets cause non-uniform velocity profiles.

45. Dr Ali and Mr Pateman are correct to emphasize the sensitivity of the buoy deflexion to water surface contamination. Their measurements of the surface tension force on the glass rods would be of assistance in developing buoys of different size for other uses. However, as the effect of the water flow on the meniscus shape is still unknown we think experimental calibration will still be necessary.

46. One possible development which is being considered is to remove the glass rod and target and terminate the buoy below the water surface. This may cause optical difficulties but would eliminate the effects and uncertainties of surface tension.

47. The suggestion of Dr Townson that the buoy be used to measure unsteady flows had not been considered. The natural period of the buoy has been calculated as being about 3 seconds and hence it should not be used to measure other than slowly varying unsteady flows with periods of the order of a minute or greater.

Reference

5. TOWNSON J. M. A transducer for open channel flow. *J. Hydraul. Res.*, 1968, **6,** No. 1.