USING NOVEL PHOTOMETRIC TECHNIQUES FOR INVESTIGATION OF ECOHYDRAULIC SEDIMENTATION PROCESSES: TURBIDITY CURRENTS

RICHARD I. WILSON

Department of Civil & Environmental Engineering, University of Auckland, 20 Symonds St., Auckland, 1010, New Zealand

HEIDE FRIEDRICH

Department of Civil & Environmental Engineering, University of Auckland, 20 Symonds St., Auckland, 1010, New Zealand

CRAIG STEVENS

National Institute of Water and Atmospheric Research, 301 Evans Bay Parade, Wellington, 6021, New Zealand and Department of Physics, University of Auckland, 20 Symonds St., Auckland, 1010, New Zealand

The turbulent propagation and sediment deposition of turbidity currents is known to cause degradation to benthic flora and fauna with key physical aspects being the depth and resilience of the sediment deposited. Often induced by earthquakes causing submarine landslides – such as the November 2016 Kaikōura, New Zealand earthquake – they also pose a risk to submarine structures, including pipelines and submarine cables. In laboratory models, it has become popular to use quantitative photometric techniques to measure turbidity current flow characteristics. This is driven by the low cost and non-intrusive nature of the technique. However, existing quantitative techniques are not readily suitable for unconfined experimental turbidity currents that are visually obstructed by obstacles and conventional measurement techniques. In the present study, we develop a spatial calibration and thresholding technique to allow the spatial propagation of an obstructed, unconfined turbidity current to be quantified. Testing currents over a range of initial densities and substrate conditions, we then apply the technique to investigate the flow characteristics of the current, providing insights into how obstacles affect current entrainment mechanisms and lateral propagation.

1 INTRODUCTION

Various geophysical and anthropogenic initiation mechanisms of turbidity currents exist, which Meiburg and Kneller [1] provide a descriptive review of. In a marine setting, currents may be initiated by earthquakes which can cause sediment failure of slopes [2]. This causes a debris flow, of which turbidity currents can shear off. A recent example was the 13th November 2016 Kaikōura earthquake, where evidence of seafloor deformation, and a turbidity current extending over 300 km from Kaikōura was recorded [3, 4].

Better understanding of sedimentation processes, such as turbidity current initiation and propagation, is paramount for waterway and coastal management of ecosystems. For example, previous field studies have shown that macro-invertebrate species reduce nearly to zero in a short reach downstream of a dam due to hydropeaking [5]. There is only limited knowledge on the effect of turbidity currents, which can also be anthropogenically by hydropeaking, on ecosystems and sediment management.

Thomas, et al. [6] discuss how physical modelling of ecohydraulic processes often rely on surrogates such as plastics or wood, in order to study responses. In our laboratory experiments we use an obstacle representing a barrier to turbidity currents as a surrogate. There has been little focus so far on how the lateral movements and ambient entrainment mechanisms of a turbidity current may be affected by an obstacle. Given the need for a greater understanding of obstructed turbidity current flow characteristics in unconfined environments, and the potential for this to be realized through a combination of photometry and intrusive flow instruments, the ultimate objectives of our overall research project fall under two components. Firstly, to evaluate and develop photometric techniques suited for confined and unconfined currents interacting with obstacles, whilst synchronized with conventional flow and density measurement instruments. Secondly, to apply these techniques to both confined and unconfined turbidity currents interacting with an obstacle and substrates; allowing new insights into flow characteristics, and a basis for understanding the effects of confinement on obstacle interaction.

2 PHOTOMETRY

Photometry is becoming a popular measurement technique of turbidity currents (Figure 1). In laboratory environments, the majority of confined studies have applied photometric techniques to measure entrainment characteristics. This is driven by the approach of using cost-effective, consumer grade cameras to obtain high-level spatio-temporal detail of the current boundary, and its unobtrusive nature on flow. Therefore, it provides opportunity for the study of obstructed turbidity currents. Although quantitative photometry has been applied to confined obstacle studies [7, 8], it has not been applied in a strictly quantitative manner to unconfined studies, with the majority of assessment being done qualitatively [9, 10]. When combined with in-situ measurement techniques, detailed insights into the internal and external flow structure of turbidity currents can be met; particularly in the immediate regions of a basal obstacle.

Figure 1. Image of turbidity current in a confined environment, highlighting the wealth of information that can be captured.

We developed a synchronised photometric and ultrasonic Doppler velocimetry profiling (UVP) technique for the measurement of both confined and unconfined currents interacting with obstacles. The pairing of photometric and UVP measurement techniques holds promise for the study of turbidity currents and their interaction with obstacles, by providing greater insights into how turbidity currents interact, thus a better understanding on their effects on ecosystems. Hacker, et al. [11] introduced the method of obtaining turbidity current density from photometric techniques by image analysis of captured pixels. The majority of past studies developed photometric processes for saline density currents. This is of limited use to opaque, sediment-laden currents. Recently, we further developed previous methodologies for saline density currents to apply photometry to sediment-laden currents in confined environments [7, 8].

3 EXPERIMENTAL SETUP

To study the effect of turbidity currents on an obstacle in unconfined environments, we designed a 2445 mm long and 2415 mm wide unconfined basin with a maximum water depth of 900 mm in the Water Engineering Laboratory at the University of Auckland (Figure 2). The basin has a false floor with adjustable slope, a motorised lock-box gate, allowing for consistent release of currents and an overflow weir to ensure a constant head within the tank, particularly useful for quasi-steady currents. The basin incorporated a 595 mm long (x_0) and 400 mm wide lock-box and release gate at the upstream end. An acrylic, rectangular obstacle of length 140 mm and height 50 mm was fixed on the flume bed at a location of 1460 mm from the lock-box gate. This distance was chosen to allow the current enough time to develop from the slumping to viscous phase, where viscous forces are dominant. The obstacle, which spanned the width of the flume, was constructed of 10 mm Perspex on the sides and 6 mm Perspex on the top. This material was found to have the least ultrasonic noise reflectivity from UVP probes when compared with 4 mm thick aluminium plating during initial tests. The rectangular shape was chosen due to its simplicity for replication in numerical simulations of future tests. The height and width were both chosen to allow four UVP probes to be installed vertically on both the upstream and downstream side of the obstacle.

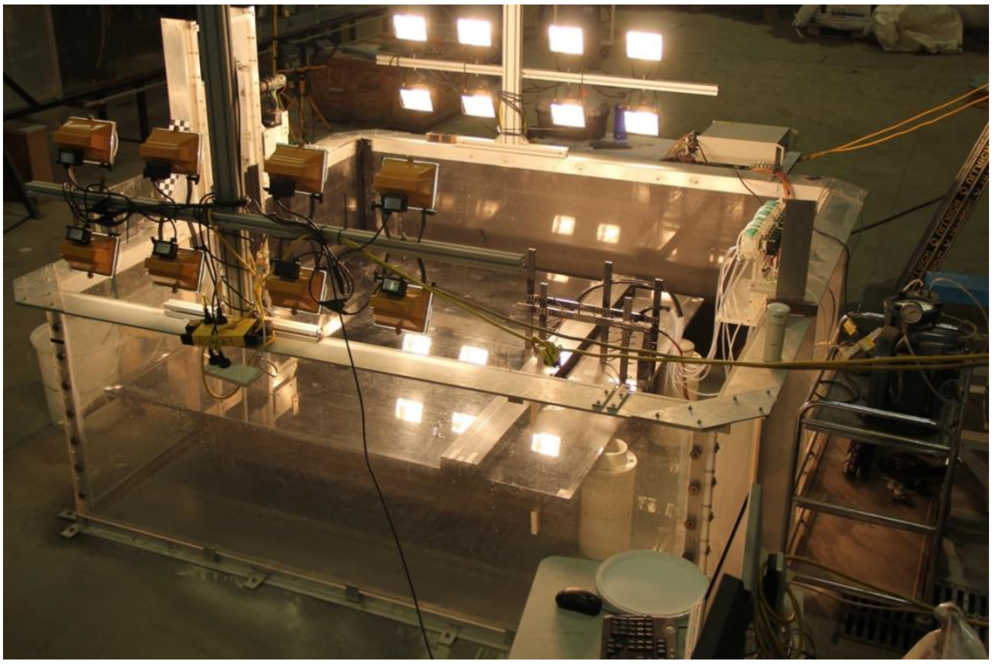

Figure 2. Experimental setup of the unconfined basin at the Water Engineering Laboratory at the University of Auckland.

4 RESULTS AND DISCUSSION

Figure 3 shows a spatial velocity contour plot, showing the combination of results from photometry and intrusive instrumentation. The head location, obtained from photometric analysis, is schematically plotted as a solid magenta line type. Figure 3a shows that as the current propagates over the obstacle, a basal region of reflected/recirculated flow is present immediately upstream of the obstacle. The subsequent UVP cycle (Figure 3b) shows that as the head propagates downstream of the obstacle, a secondary recirculation region is present immediately downstream of the obstacle. Both cycles show that a reverse ambient bore is present above the current.

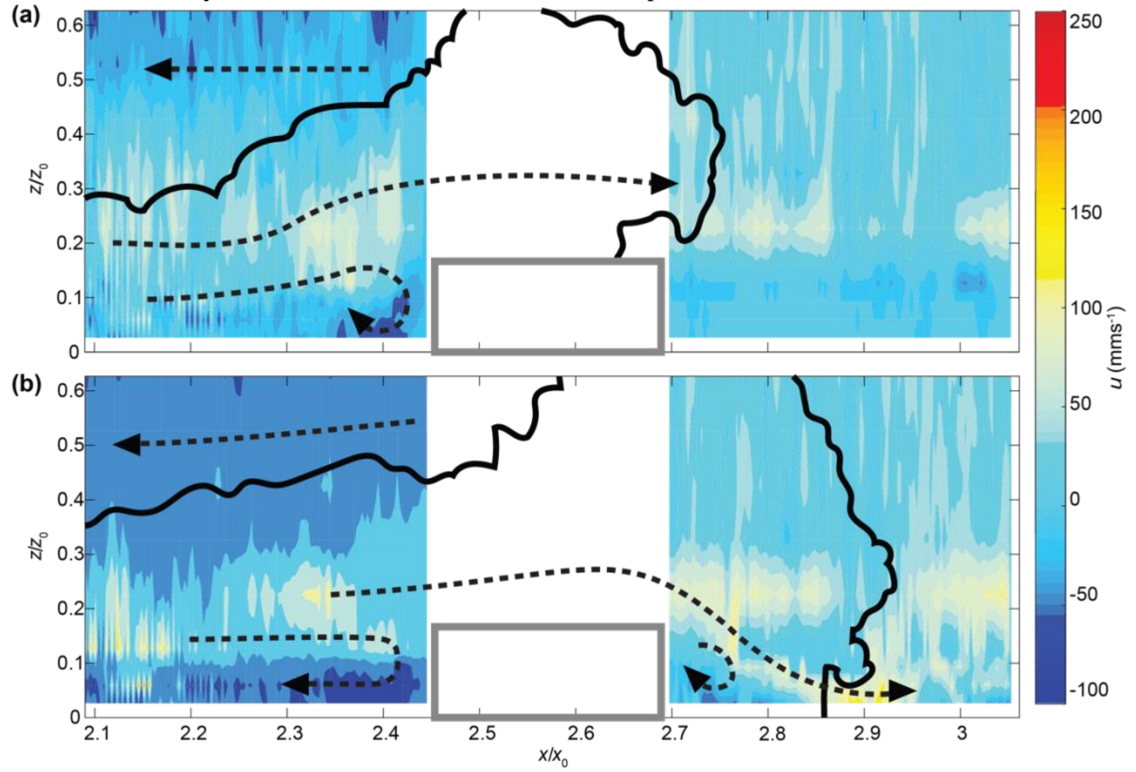

Figure 3. Combination of photometry and intrusive instrumentation.

Our confined studies showed that characteristic flow characteristics can be grouped into four stages: (i) lateral entrainment stage; (ii) jet stage; (iii) collapsing stage; and (iv) re-establishment stage [8]. These stages were identified and categorized based on the visual characteristics, and confirmed through quantification of the temporal entrainment parameter as obtained with our photometric analysis. Our unconfined tests showed similar characteristic stages. In general, the stream-wise flow characteristics were found to be comparable to confined tests, however, the importance of lateral movement was highlighted. Deflected lateral propagation along the obstacle face was found to entrap ambient fluid and encourage mixing, providing a starting point for understanding the implications of lateral propagation along submerged barriers. The current propagated within the so-called slumping phase. However, there was no presence of a reverse ambient bore, which initiates the transition to the self-similar phase. Similarly, Froude scaling was dependent on initial lock conditions. Although the absence of a bore for unconfined currents has been previously found, more research is needed to confirm their explanation of the absence, given the present study differs in velocity characteristics. On collision with the obstacle, the turbidity currents were found to deflect laterally and vertically as a jet, whilst also being reflected upstream as a blunt hydraulic jump.

5 CONCLUSIONS

We provide an overview of the current state of knowledge how photometry is needed to shed light on complex ecohydraulic sedimentation processes, in this specific case turbidity currents. With the technique we obtain new insights into the flow characteristics of unconfined turbidity currents interacting with basal obstacles and substrates – with emphasis on the ambient fluid entrainment mechanisms of the current, and understanding how they are influenced by the obstacle and lateral unconfinement. These new insights were met through the design and application of a novel photometric technique, which allowed the simultaneous integration of conventional UVP and density siphoning instruments. Our photometric advances can be summarised as a two-step process, comprising of preliminary and post-processing of images. The preliminary processing included Bayer filtering, lens distortion correction, image rotation and cropping. The post-processing techniques were specifically developed to address data noise, induced by the obstructing nature of the obstacle and instrument racks.

REFERENCES

[1] E. Meiburg and B. Kneller, "Turbidity Currents and Their Deposits," *Annual Review of Fluid Mechanics*, vol. 42, pp. 135-156, 2010.

[2] B. C. Heezen and M. Ewing, "Turbidity currents and submarine slumps, and 1929 grand banks earthquake," *American Journal of Science,* vol. 250, pp. 849-873, 1952.

[3] P. O. Barnes, A. Howarth, J. Patton, J. Lamarche, G. Woelz, S. Hopkins, J. Gerring, P. Mitchell, J. Quinn, W. McKeown, M. Ganguly, A. Banks, S. and Davidson, S., "New sedimentary-core records and a recent co-seismic turbidite help to unravel the paleoseismicity of the Hikurangi Subduction Zone, New Zealand," *19th European Geosciences Union General Assembly, Vienna, Austria,* 2017.

[4] Y. Bai, T. Lay, K. F. Cheung, and L. Ye, "Two regions of seafloor deformation generated the tsunami for the 13 November 2016, Kaikoura, New Zealand earthquake," *Geophysical Research Letters,* vol. 44, pp. 6597-6606, 2017.

[5] Z. Wang, J. H. W. Lee, and M. Xu, "Eco-hydraulics and eco-sedimentation studies in China," *Journal of Hydraulic Research,* vol. 51, pp. 19-32, 2013.

[6] R. E. Thomas, M. F. Johnson, L. E. Frostick, D. R. Parsons, T. J. Bouma, J. T. Dijkstra*, et al.*, "Physical modelling of water, fauna and flora: Knowledge gaps, avenues for future research and infrastructural needs," *Journal of Hydraulic Research,* vol. 52, pp. 311-325, 2014.

[7] R. I. Wilson, H. Friedrich, and C. Stevens, "Image thresholding process for combining photometry with intrusive flow instruments," *Journal of Hydraulic Research,* vol. 56, pp. 282-290, 2018.

[8] R. I. Wilson, H. Friedrich, and C. Stevens, "Turbulent entrainment in sediment-laden flows interacting with an obstacle," *Physics of Fluids,* vol. 29, 2017.

[9] J. Alexander and S. Morris, "Observations on experimental, nonchannelized, high-concentration turbidity currents and variations in deposits around obstacles," *Journal of Sedimentary Research A: Sedimentary Petrology & Processes,* pp. 899-909, 1994.

[10] S. A. Morris and J. Alexander, "Changes in flow direction at a point caused by obstacles during passage of a density current," *Journal of Sedimentary Research,* vol. 73, pp. 621-629, 2003.

[11] J. Hacker, P. F. Linden, and S. B. Dalziel, "Mixing in lock-release gravity currents," *Dyn. Atmos. Oceans,* vol. 24, p. 183, 1996.