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Cheng, L.; Draper, S.; An, H.; White, D. J.

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Hydrolink

OCEAN-STRUCTURE-SEABED MODELLING IN UWA'S RECIRCULATING 'O-TUBE' FLUMES

BY L. CHENG, S. DRAPER, H. AN & D.J. WHITE

Figure 1 - Examining scour around the model pipe in the test section of the Large O-tube

The University of Western Australia (UWA) is home to a set of recirculating water tunnels, referred to as the 'O-tubes'. These flumes have been developed at UWA to allow simulation of ocean-structure-seabed interactions using realistic metocean and geo-technical conditions. The large, small and mini O-tube flumes allow seabed flows to be simulated at a range of scales, including full scale modelling of small subsea pipelines and scour and sediment transport around infrastructure.

O-Tube concept

Many physical modelling facilities have been developed to study offshore structures, including open channel flumes, U-tube flumes, and oscillating water tunnels. However, each of these facilities have limitations for studying ocean-structure-seabed interaction problems in storm conditions, such as that experienced on Australia's North West Shelf (NWS). Open channel flumes, for example, are limited to wave velocities below which wave breaking occurs, whilst the use of a driven trolley in an open channel allows higher velocities to be achieved but is impractical for large regions of mobile bed. U-tubes allow higher velocities to be achieved, but with limited flexibility (due to the requirement to operate at or near resonance). Piston driven water tunnels offer more flexible control but are limited by the stroke of the piston.

Because of these limitations an alternative flume configuration, known as an O-tube, has been developed at the University of Western Australia. This flume comprises a horizontal fully enclosed circulating water channel, with a rectangular test section and an impeller-type pump driven by a motor. With this arrangement currents can be introduced easily and wave velocities are limited only by the pump charac-teristics and not by wave breaking, resonance of the water mass or the stroke of a piston.

Three O-tubes have been constructed at the University of Western Australia (see Table and Figures 1-3). The mini O-tube (MOT) was constructed first to prove the concept, followed quickly by the large O-tube (LOT). The different scales of O-tube are suited to different purposes. The LOT is capable of modelling small pipelines at full scale, with 1:1 scale flow conditions. The MOT and Small O-tube (SOT) require less sediment to fill and nourish the working section compared with the LOT. This allows small scale tests and sediment-specific erosion testing to be undertaken using prototype sediments gathered from the field.

O-Tube measurement and control hardware

The LOT, SOT and MOT all use similar drive and control systems, varying only in scale and power. Flow is forced around the LOT with an impeller driven by a brushless 580 kW AC motor. The rotational speed of the motor is controlled by a Variable Frequency Drive (VFD) and can be controlled from a desktop computer via a signal that is transmitted digitally over a local wireless network. The internal control software on the VFD includes safety interlocks that limit motor acceleration and rotation speed. The SOT and MOT use smaller drives operating on the same principles.

Flow conditions including steady current, sinusoidal oscillatory flow, random oscillatory flow and any combination of the above conditions can be generated. These flows are achieved by controlling the propeller to run at a steady, oscillating or irregular rotational speed. Detailed studies of motor speed-flow speed relationships, flow asymmetry, turbulence intensity and secondary flows have been undertaken in all of the O-tubes (Luo et al. 2011, An et al. 2013, Cheng et al. 2014 and Mohr et al. 2016a).

An important component of the LOT facility is a 200 mm instrumented model pipe mounted on an actuator system to record the applied horizontal and vertical forces. The pipe is also equipped with a network of surface pressure cells to record the hydrodynamic load around the pipe circumference. The actuator system prevents model pipe movements in unrealistic degrees of freedom such as roll and yaw. The feedback system can provide neutral horizontal and vertical control, allowing the pipe free lateral movement in response to the natural balance between hydrodynamic loading and soil resistance, and free vertical movement as if acting under self-weight.

Table 1 - Key characteristics of UWA's O-tube flumes

		Large O-tube (LOT)	Small O-tube (SOT)	Mini O-tube (MOT)
Year commissioned		2010	2014	2008
Working section dimensions	Length, L (m)	17	3.0	2.0
	Width, W (m)	1.0	0.3	0.2
	Height, H (m)	1.4	0.45	0.3
Maximum steady current (m/s)		3	4.5	1.5
Typical oscillatory flow	maximum velocity, U_m (m/s)	1 – 2.5	1 – 3	0.5
	Period, T (s)	5 – 13 s	4 – 10 s	6 s

Figure 2 - General arrangement of the large O-tube (LOT) at UWA's Shenton Park campus

In addition to the actuator controlled model pipe, the O-tube laboratory is equipped with various measurement devices. Flow measurements within the O-tubes are made using Acoustic Doppler Velocimeters (ADVs) and an electrical-magnetic sensor. A two-dimensional Particle Image Velocimetry (PIV) system can be used for flow visualization, whilst an acoustic echo sounder and contact image sensors are used in various configurations for continuously detecting scour around subsea structures. A laser scanner and infra-red profiler have been adapted to scan three-dimensional scour profiles. Each of these devices can be used

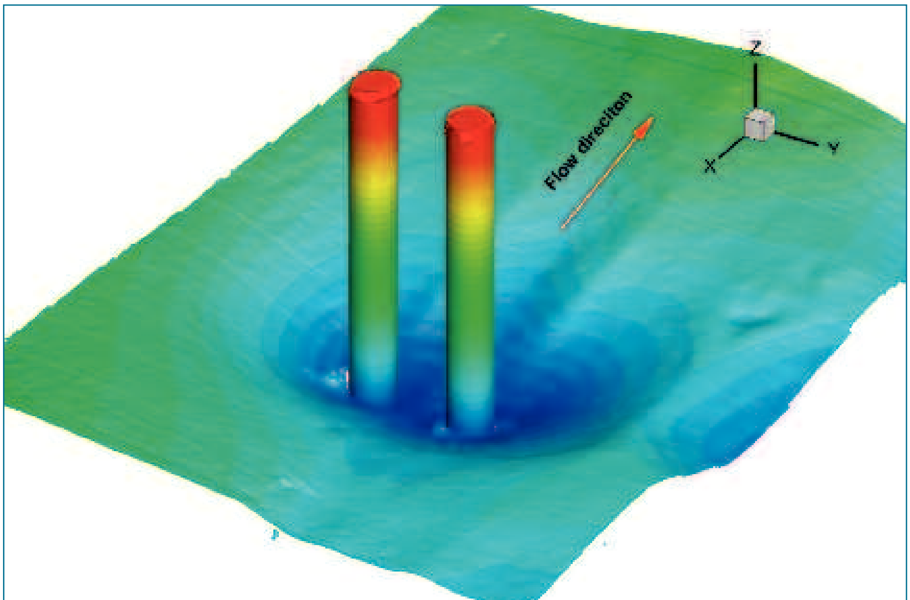

Figure 3 - A scour profile around two vertical piles recorded using the infra-red 3D camera.

synchronously to extract more comprehensive data, which enables an improved understanding of fundamental ocean-structure-seabed interactions.

Research activities and research outcomes

Significant research efforts have been devoted to pipeline on-bottom stability and seabed mobility at UWA over the past five years, supported by the Australian Research Council (ARC) and industry partners Woodside and Chevron through the STABLEpipe Joint Industry Project (JIP). Model tests in the LOT have highlighted the strong influence of seabed mobility on pipeline stability. The processes of scour and self-burial have been observed and quantified in controlled conditions, leading to new calculation methods for design purposes. Based on the STABLEpipe JIP, a new design guideline for the stability design for subsea pipelines has been prepared (DNV 2015). This work is a team effort involving det Norske Veritas (DNV) and provides methods for assessing pipeline stability that account for scour and sedimentation over the duration of the pipeline operating life.

Besides the stability of subsea pipelines, a wide range of research topics related to various subsea structures have been investigated using the O-tube facilities. These include local scour around pile foundations and caissons, both with and without protection; local scour around wave energy devices; onset of tunnel scour under subsea pipelines; stability of rock berms on solid and erodible seabed; stability of concrete/steel mattress on the seabed; erosion properties of various sediments, and estimation of hydrodynamic force on offshore structures. This work has been captured in over 20 academic publications, including multiple high impact journal publications in Coastal Engineering and the Proceedings of the Royal Society (An et al. 2013; Draper et al. 2015; Mohr et al. 2016b). Full details of the publications can be found on the UWA website (such as http://www.web.uwa.edu.au/people/liang.cheng).

Research outcomes from the O-tube have contributed directly to the oil and gas industry, through industrial and contract research projects. Experimental work in the O-tubes has already supported engineering design of more than 10 developments in locations including offshore Western Australia, the North Sea and Indonesia. This work has resulted in significant cost savings to the operators. The O-tube facilities also enable new fundamental research. In the last five years the team have received four Australian Research Council Grants from their Discovery and Linkage schemes. The O-tube facilities have also been used to support student research, including 5 PhD projects and more than 40 final year undergraduate and master degree projects at UWA.

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Liang Cheng **is a Winthrop Professor at The University of Western Australia and a "1000-Talents" Professor at Dalian University of Technology in China. Liang got his BE from Tsinghua University in Hydropower Engineering (1983) and PhD from Dalian University of Technology in Hydraulics (1990). Liang has more than 20 years' experience in research areas covering vortex-induced vibrations, local scour, flow/structure/seabed interactions and computational fluid dynamics (CFD) modelling. Liang has published widely in these areas and has been working closely with industry on consulting and contract research projects.**

Scott Draper **is a senior lecturer at The University of Western Australia (UWA). He completed a DPhil at the University of Oxford, UK, in 2011 working on tidal stream energy. At UWA Scott now works more generally in offshore fluid mechanics, applied to both the oil and gas and marine renewable energy industries. His research work focuses on: scour of subsea infrastructure at the seabed; the optimization of arrays marine renewable energy devices; and wave kinematics and statistics. Scott has written over 50 peer reviewed papers and presents public lectures to industry and the wider community.**

Hongwei An **is a lecturer and DECRA Research Fellow at the University of Western Australia. He finished his PhD degree in 2010 from UWA and since then he has been working at UWA in the offshore hydrodynamics area. His research interests include flow-structure interaction, subsea structure stability, scour and sediment transport through both physical model tests and numerical simulations.**

David White **holds the Shell EMI Chair of Offshore Engineering at the University of Western Australia. He completed MEng and PhD degrees at Cambridge University before holding a University Lectureship in Cambridge until 2006 when he moved to UWA. His specialism is offshore geotechnics and his research has led to >250 publications that feature in many industry guidelines, shaping engineering practice. He is a Fellow of the Royal Academy of Engineering, the Australian Academy of Technological Sciences and Engineering and the Institution of Engineers Australia.**