Offshore geohazards and seabed mobility

This research stream is focussed on offshore hazards, with particular attention to the mobility of the seabed – whether through large scale geological events, or local scale sediment transport processes. This report is divided into two broad areas. We have extensive activity to report on the subject of seabed mobility, through studies around the O-Tube program (see also the separate report on the O-Tube), and we have continuing studies by Jim Hengesh and Beau Whitney into the geological hazards arising from seismicity onshore and offshore Western Australia.

The seabed mobility program received wide acclaim during 2012, as our experiments impacted design practices offshore Australia. Woodside acknowledged that improved engineering solutions resulting from their initial ~$1M investment in the O-Tube program have given a return of more than 10:1 on their research investment. In return, the university has benefitted from the capital investment in our facilities by Woodside and Chevron, in addition to funding from the Australian Research Council. We now have several PhD students using the mini and large O-Tubes in their research and a complementary program of numerical activity and field data interpretation.

Meanwhile, Jim and Beau's work is receiving continued support from Chevron, where it forms an important contribution to the understanding of seismic hazards around the Gorgon project and other future developments offshore and onshore Western Australia. This project is of increasing importance in the light of carbon capture and storage schemes associated with oil and gas developments on the North West Shelf.

O-Tube testing of submarine pipelines on mobile seabeds

PhD student Chengcai Luo, supervised by Liang Cheng and David White, started his research entitled 'On-bottom stability of submarine pipelines on mobile seabeds' in 2009 and finished his PhD at the end of 2012.

This research has improved the understanding of how seabed mobility, specifically local scour around a pipe, influences pipeline stability under realistic storm conditions. A wide range of pipeline dynamic stability tests were conducted in the UWA's large O-Tube facility, which is capable of simulating cyclonic storm-induced hydrodynamic conditions at seabed level so that the responses of a model pipeline and a model seabed can be revealed at a relatively large scale. Figure 66 shows a test setup with a pipeline at large initial embedment, connected with an actuator system that can provide active control to the pipe. Various parameters affecting pipeline stability, including pipeline specific gravity, initial embedment and flow conditions, were investigated. Based on the experimental findings, a model capturing the pipe sinkage due to local scour was proposed. In addition, pipe-soil resistance on calcareous sand was investigated through a range of O-Tube pullout tests in still water conditions. A slope-adjusted friction approach provides a good basis for estimating the pipe-soil resistance for pipes in a scour hole. The O-Tube test findings provide new insights into pipeline stability assessment and have been highly valued by the industry partners, including Woodside Energy and Chevron Australia.

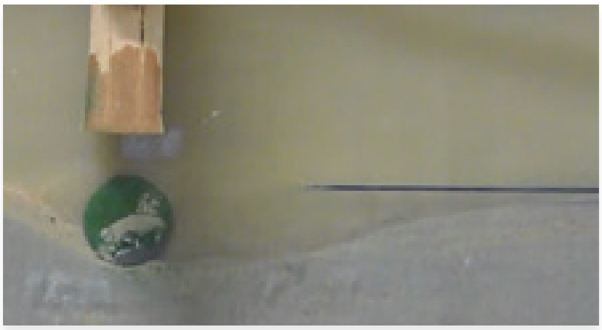
Figure 66: O-Tube test setup with large initial embedded pipe

Physical modelling of scour around pipelines in calcareous sediment

To complement the full-scale testing in the large O-Tube, systematical experimental studies of scour around pipelines have been performed in the mini O-Tube. Very little is presently known about scour around subsea pipelines placed on calcareous sediments, though many pipelines have been laid in calcareous conditions on the North West Shelf In 2012 research and physical model testing of pipeline scour in calcareous sediment was started by Scott Draper, in collaboration with PhD student Qin Zhang, and fellow academics Liang Cheng, Hongwei An, and Dave White. Initial experiments were performed with a 50 mm model pipe (Figure 67) in the mini O-Tube under steady currents, wave velocities, and combined steady current and wave velocities, using a calcareous sediment obtained from the North West Shelf of Australia and uniform silica sand. Through detailed comparison of the calcareous and siliceous sediment O-Tube experiments, and comparison with existing empirical formulae developed for scour around pipes in uniform non-cohesive sands, we observed differences in (i) velocities required to initiate piping and the onset of scouring, (ii) the rate of tunnel erosion following the onset of scour occurs, (iii) the final equilibrium scour hole depth, and (iv) subsequent pipeline backfill rate and mechanism. Some results from this work were presented at the 2013 Subsea Australia Conference in Perth, Western Australia.

Over the summer period at the end of his 2012 internship, student Darren Kosh preformed experiments in a fish tank (Figure 68) to explore the potential or 'piping' (and the mode of erosion) beneath a pipeline on shallow seabed of silica sediment and calcareous silty sediment.

(a)



(b)

Figure 67: (a) Equilibrium scour hole formed beneath model pipe simulated in the Mini O-Tube. (b) Pipe moved to the bottom of the scour hole to investigate backfill around the pipe

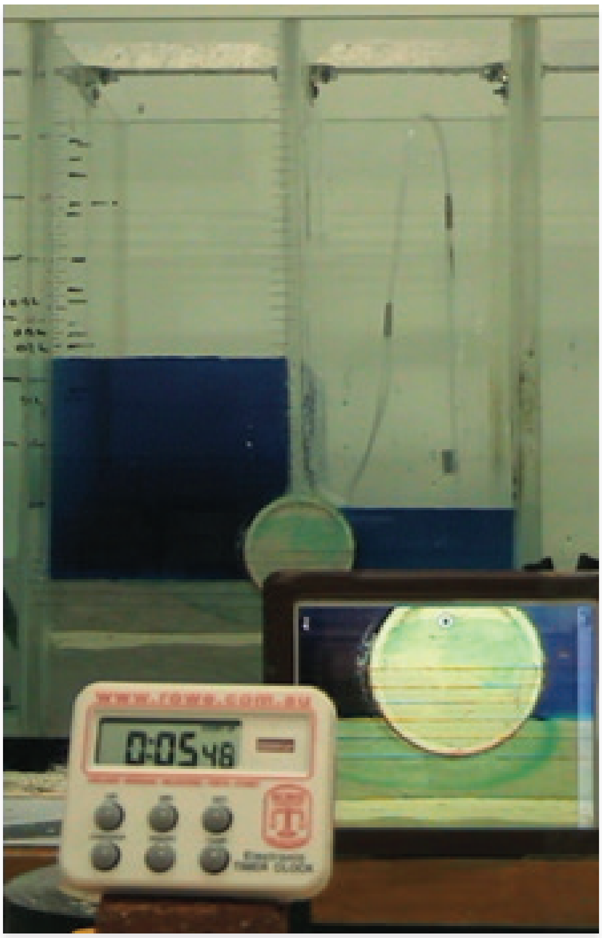


Figure 68: 'Fish tank' used to investigate piping beneath on-bottom pipelines. Fish tank background. In fore ground is a close up video of seepage flow (in blue) beneath the pipe

Mobility of calcareous sediments at the seabed

Under cyclonic conditions, sediment on the North West Shelf (NWS) of Australia may become mobile in shallow water due to classical sediment transport or local liquefaction. This can affect the on-bottom stability of subsea pipelines.

For his PhD study, Henning Mohr, working with Scott Draper and Dave White, are investigating seabed mobility of calcareous sediment originating from the NWS. By carrying out a set of experiments on erosion resistance and excess pore pressure dissipation, simple theoretical models can be applied to illustrate the potential risk of seabed instability under realistic metocean storm conditions. As shown in Figure 69, the developed model produces a seabed mobility matrix for the four soils assuming three storm conditions with approximate return periods of less than 10 years, 10 years and 100 years. This figure demonstrates that different soils may become mobile due to either sediment transport or liquefaction. The fact that both mobility types could theoretically coexist leads to the conclusion that the interaction of liquefaction and sediment transport should also be considered. Conventional methods for assessing pipeline stability do not yet cover this aspect suggesting that there is the potential for improved design reliability through better underlying science.

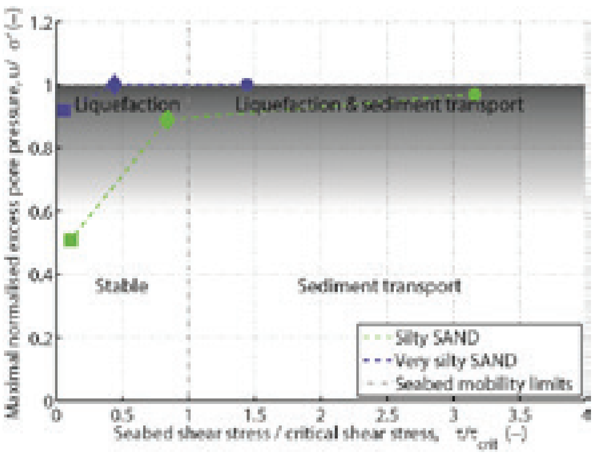


Figure 69. Seabed mobility matrix for typical NWS storms (square: <10 year storm, diamond: 10 year storm, circle: 100 year storm)

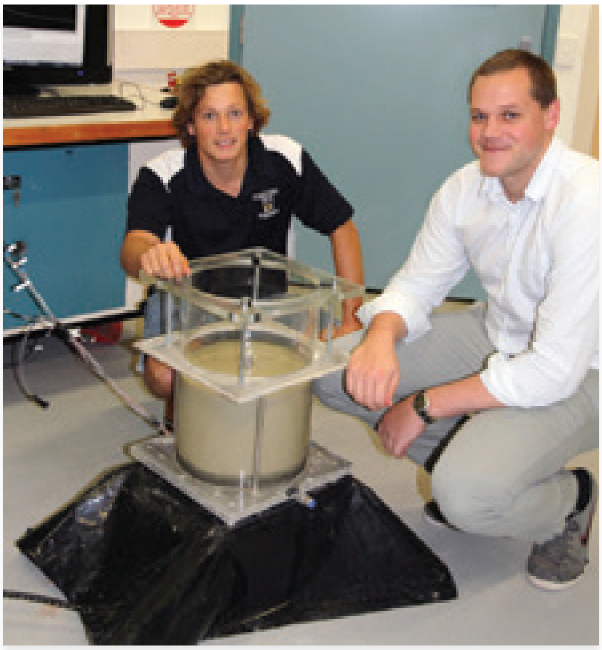


Figure 70: Henning Mohr and Scott Draper performing liquefaction experiments using a NWS soil

Field observations of offshore pipelines

PhD student Simon Leckie joined COFS in November 2012 to begin research into the self-burial and on-bottom stability of offshore pipelines with Nino Fogliani of Woodside Energy providing industry supervision. Figure 71 shows an example observation from a pipeline survey, where a pipeline has self-buried under the action of scour and backfilling.

Simon is working with pipeline survey data in an effort to determine the principal factors influencing the self-burial process. In addition to this wider study, locations within the pipeline network where a pipeline may have moved significantly due to wave and current loading will be examined. In particular the degree of self-burial prior to the movement will be explored.

Additionally, numerical modelling of the fluid-pipe-soil interaction will enable field data to be interpreted in such a way as to establish useful design tools for engineers to assess the development of pipeline embedment over time. This will assist in improved designs for both on-bottom stability and pipeline buckling.

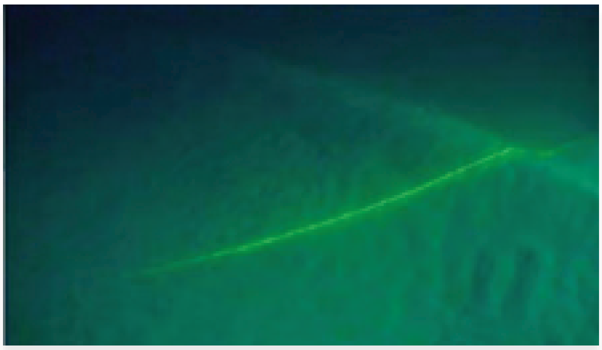


Figure 71: Example observation of self-burial from a pipeline survey

Morphodynamics of subsea trenches

Where weight coating alone is insufficient to stabilise a pipeline, a common engineering solution is to embed the pipeline in a trench. Narrow trenches, which have a depth to width ratio of ~1, are often used to stabilise subsea oil and gas pipelines in shallow water. It is therefore of practical importance to predict how fast these narrow trenches will migrate and backfill in ambient field conditions. At present, however, this prediction is difficult because most previous research has focused on wide trenches (i.e. width to depth > 10). In 2012 Scott Draper worked with final year undergraduate student Ryan Epstein to perform a series of experiments in the Mini O-Tube to investigate the backfill of narrow trenches. The experimental results were explored in terms of the morphological evolution of the trenches (i.e. their apparent 'migration/advection' and 'backfill/diffusion'; Figure 72) for different Shields number, Keulegan-Carpenter number and Current number. Detailed observations of the experiments show that the mechanisms of narrow trench advection and diffusion include sand sliding, flow separation and recirculation of sediment within the trench, all of which are fundamentally different mechanisms to that assumed in the depth-averaged models often used to assess the backfill of wider navigation channels. These results are of importance to numerical modellers looking to accurately simulate scour. In particular, advanced numerical models must be able to accurately model the phenomena of sand sliding (which is sometimes only treated approximately) and flow separation leading to recirculation, together with quantities such as sediment transport rate, to provide satisfactory predictions. The results from the first part of this study are being reported in a conference paper, which will be presented by Ryan at the upcoming International Society of Offshore and Polar Engineers (ISOPE) conference.

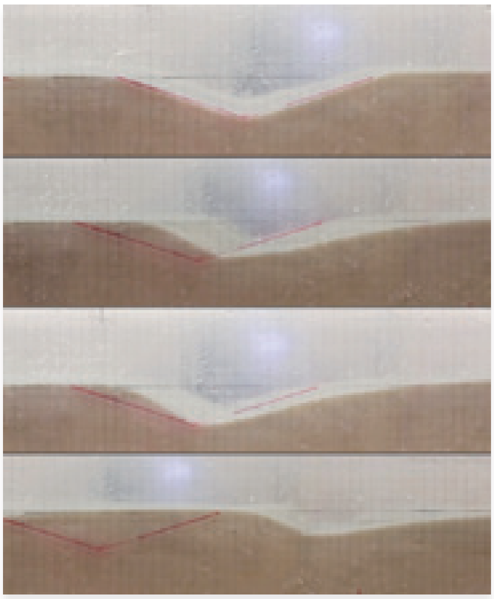


Figure 72: Model scale trench simulate din Mini O-Tube. The trench is migrating or 'running' to the left and become shallow and wide. Top to bottom, successive points in time

Geohazards and seafloor stability of Australia's North West Shelf

The North West Shelf of Australia is responding to stresses imposed by the collision along the northern plate margin. This collision is causing regional lithospheric scale warping, surface faulting, and reactivation of former rift-related structures along the continental margin. A combination of onshore and offshore geomorphologic and structural investigations are being carried out by Jim Hengesh, Beau Whitney and colleagues to document the locations, magnitudes and rates of this deformation.

Some structures along the continental margin of Western Australia (WA) are capable of producing large magnitude earthquakes. For example, the Mt. Narryer fault zone in west central Australia may have produced the 1885 M_L 6.6 Mt. Narryer and the 1941 M_L 7.1 to 7.3 Meeberrie earthquakes. The fault zone is a 120-km long north-trending structure that has captured and diverted active stream flow, formed sag ponds, and impounded Lake Wooleen. Field studies by Jim and Beau have surveyed scarp heights of 3 to 8 meters, which suggest either single large magnitude displacements, or repeated surface deformation events (i.e. repeated large magnitude earthquakes). Additional structures trend offshore and these have caused local inversion of older rift basins and in places have offset the seafloor indicating recent movement. Structures with evidence of Neogene to historical deformation are present over a length of more than 2,000 km along the continental margin of west-central and northwestern WA. Unlike most of the stable Australian plate, earthquake magnitude-frequency relationships suggest that rates of tectonic deformation along the western continental margin are inconsistent with the notion of a stable continental setting. The rates of occurrence of earthquakes (Figure 73) would require several millimeters per year of deformation along the plate margin.

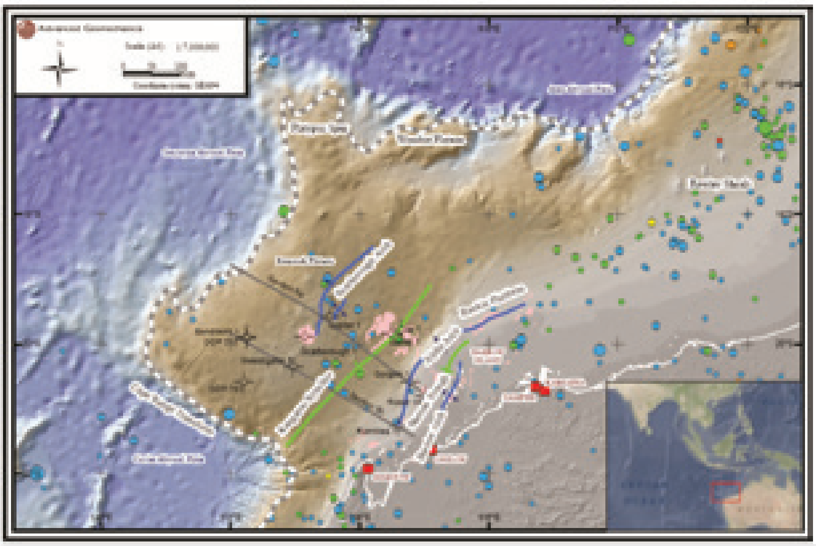


Figure 73: Distribution of earthquake on Exmouth Plateau

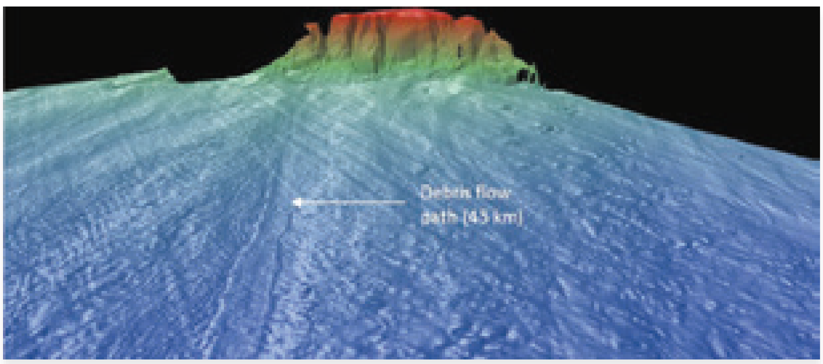


Figure 74: Seafloor rendering of Willem Survey showing large scale failure of the continental slope, small scale failures within the submarine canyons, and pock-marks indicating occurrence of fluid/gas expulsion in the mass transport deposit (inset). Sea-bed rendering developing using Seisnetics TM

Earthquakes may be a major trigger for instability of the seabed, especially along the continental slope. Large scale slope failures are present along the continental slope and relict landslide deposits are present along the continental rise (Figure 74). Some slides have widths of several 10's of kilometres with run out lengths of up to 100 km. Smaller slide deposits are concentrated at the base of the slope with run out lengths commonly of <10 km.

Some of these failures, however, may be related to fluid expulsion features. Expulsion features are common in the Gorgon, Salsa, Bonaventure, and Glencoe survey areas. Upward fluid migration from structurally controlled traps have likely destabilised weak slopes through reduction of effective soil stress (Figure 75).

From Jim's work, a pattern of association is emerging between tectonic deformation, formation of structurally controlled traps, upward fluid migration and escape, reduction in geotechnical soil strength, and slope instability. The occurrence of slides on slopes less that 1 degree strongly suggests the need for an outside triggering mechanism and we will continue investigating whether this is from fluid escape, seismic loading, or perhaps both. This association is likely the foundation of a process model for major instabilities on the Exmouth Plateau.

Beau Whitney worked with Jim Hengesh on neotectonic deformation of Western Australia. The goal of this research is to identify active tectonic features in the Stable Continental Region of Western Australia for use in seismic hazard analysis for critical infrastructure both onshore and offshore. Beau and Jim's research has identified a system of neotectonic features that extends approximately 2000 km from central Western Australia across the northwest shelf.

This past year, this project received an injection of funding from Chevron ABU via WAERA to facilitate project field work and data acquisition. Beau completed a paleoseismological investigation on a number of faults within this fault system in order to gather paleo-earthquake parameters. These parameters will be used to estimate earthquake magnitudes and seismogenic potential of faults within this fault system. Additionally, Beau surveyed a few hundred kilometres of coastline in northwest WA which documents late Quaternary (<125ka) tectonic deformation of coastal stratigraphy. Currently, Beau and Jim are working with Chevron ABU in order to utilise their in-house 3D seismic datasets to identify and map capable seismic sources and offshore fault architecture. All this data is being compiled, processed, and analysed and will be disseminated through publication and presentation.

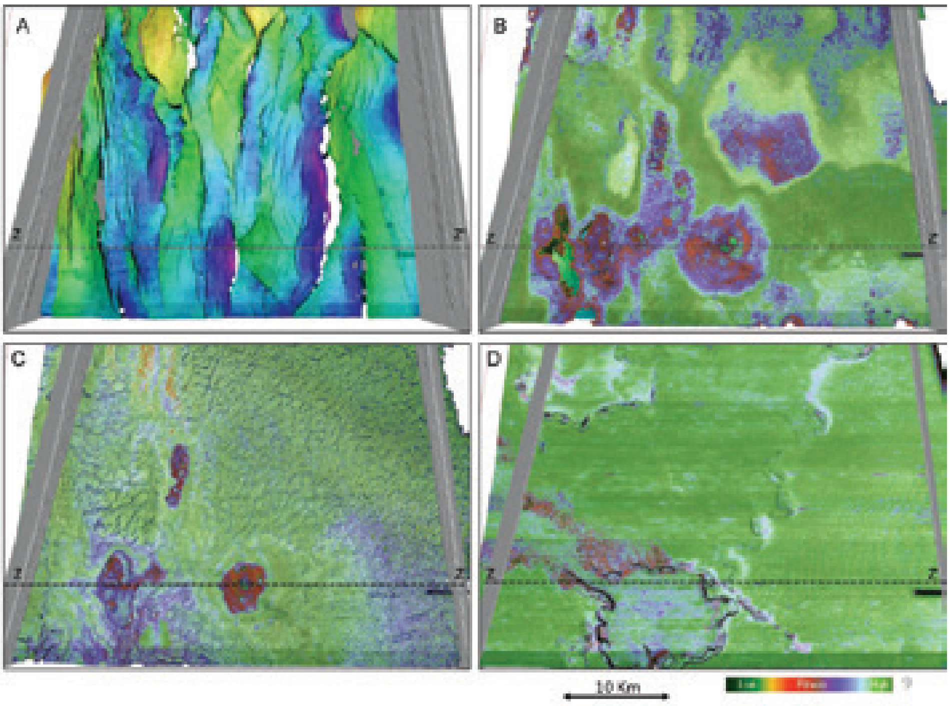


Figure 75: Several surfaces from the Bonaventure 3D survey are shown. The automatically extracted Top Triassic TWT surface (Part A) highlights the structural fault blocks and the presence of pockmarks of various sizes (100's to over 1,000 meters in diameter). Fitness maps of three other surfaces highlight the waveform variability up to and including the seafloor. Note the coincidence of the areas of Triassic structure, low Fitness circular fluid expulsion features, and seafloor instability. Horizon images developed using Seisnetics TM