Research Highlights

University of Western Australia – The Centre for Offshore Foundation Systems (COFS) (Continued)

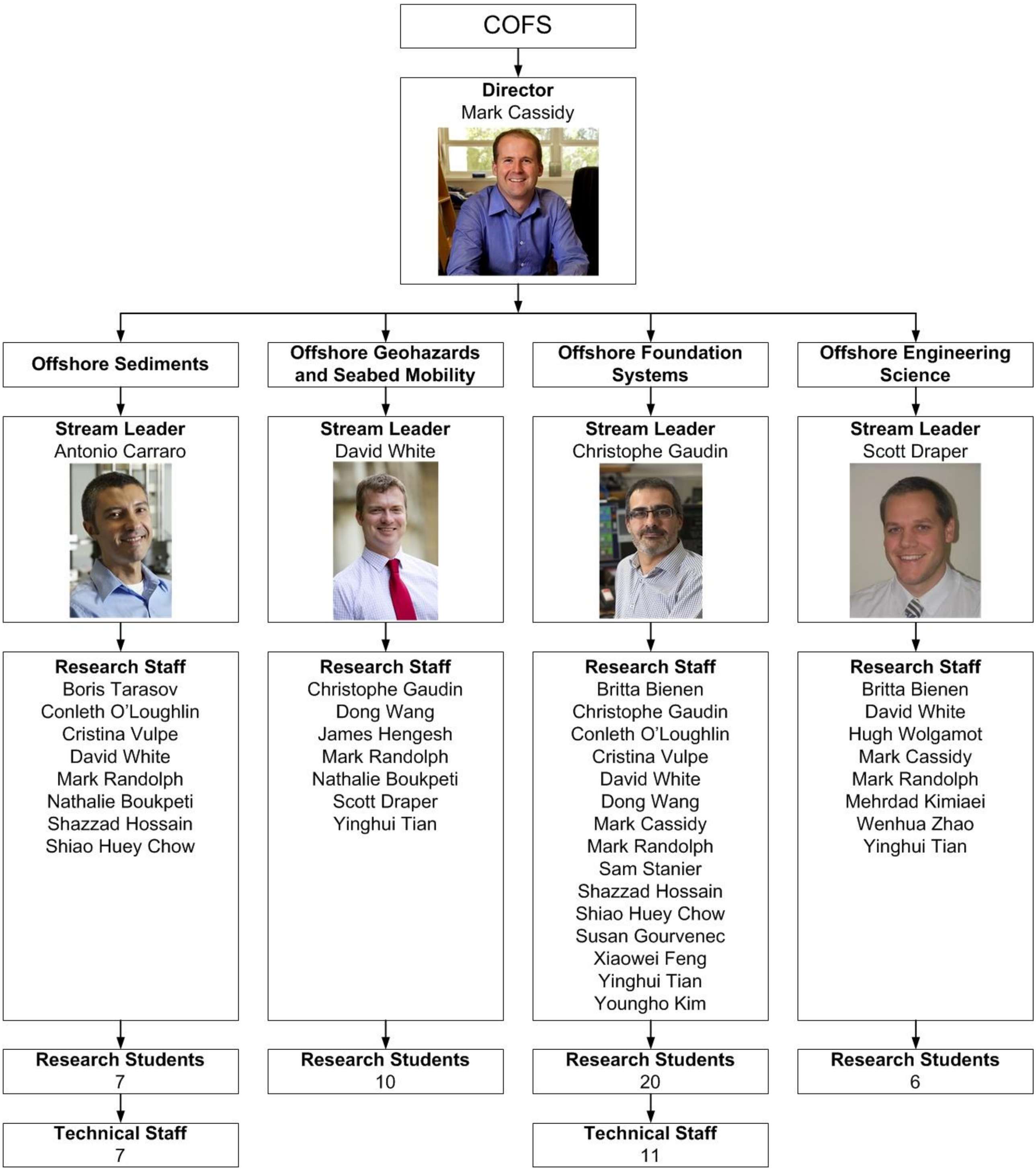

Figure 1. COFS organisation structure

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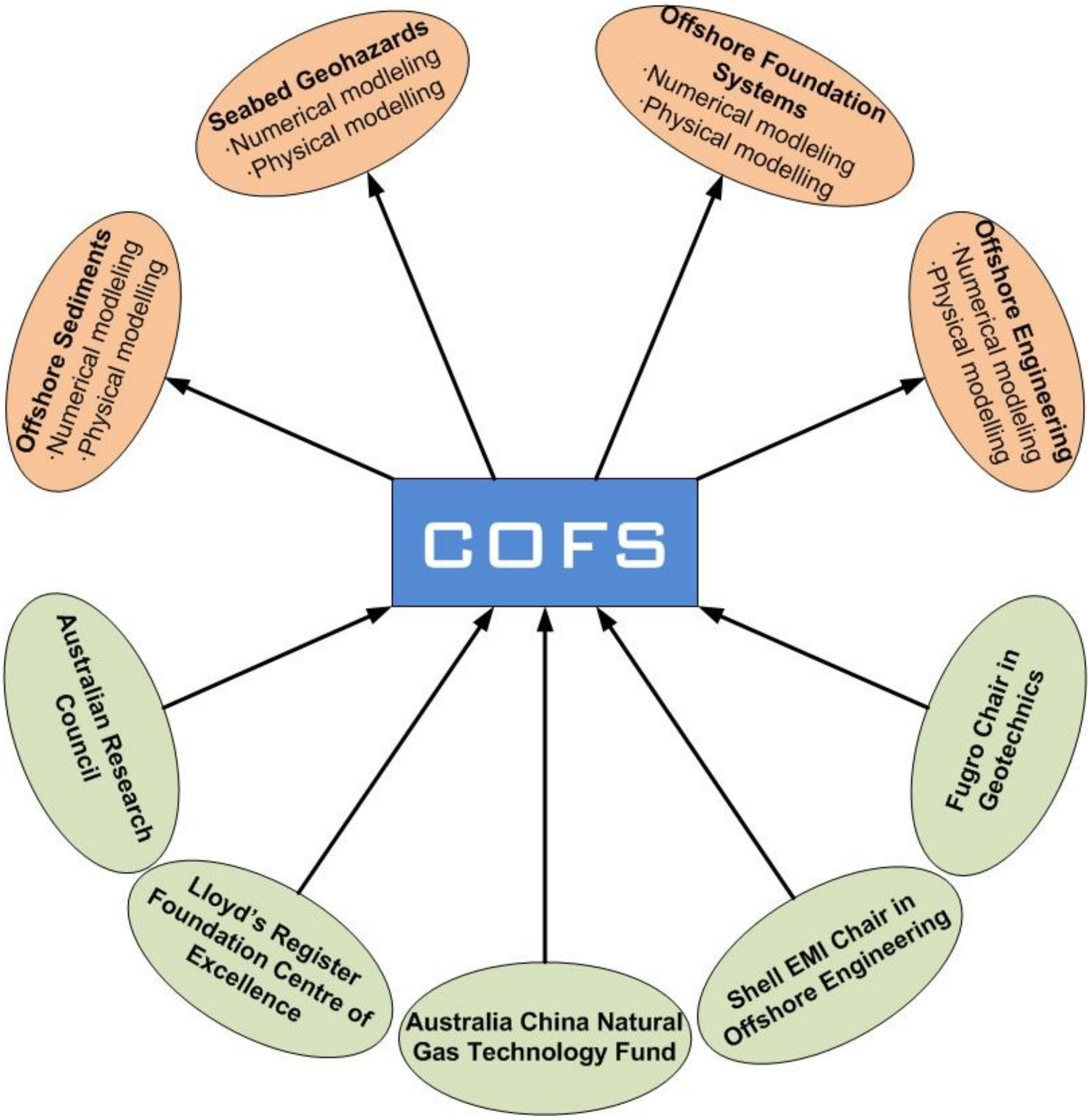

Figure 2. COFS main research, funding sources and industry engagements

Facilities

COFS currently operates the only geotechnical centrifuge facility in Australia, comprising a 1.8 m radius fixed beam centrifuge (Figure 3) and a 1.2 m diameter drum centrifuge (Figure 4). A third 10 m beam centrifuge is currently being built and will be installed in 2015. The centrifuge team works closely with our in-house workshop to design and test scale models of offshore infrastructure components. We are currently handling over 50 research and industry projects each year.

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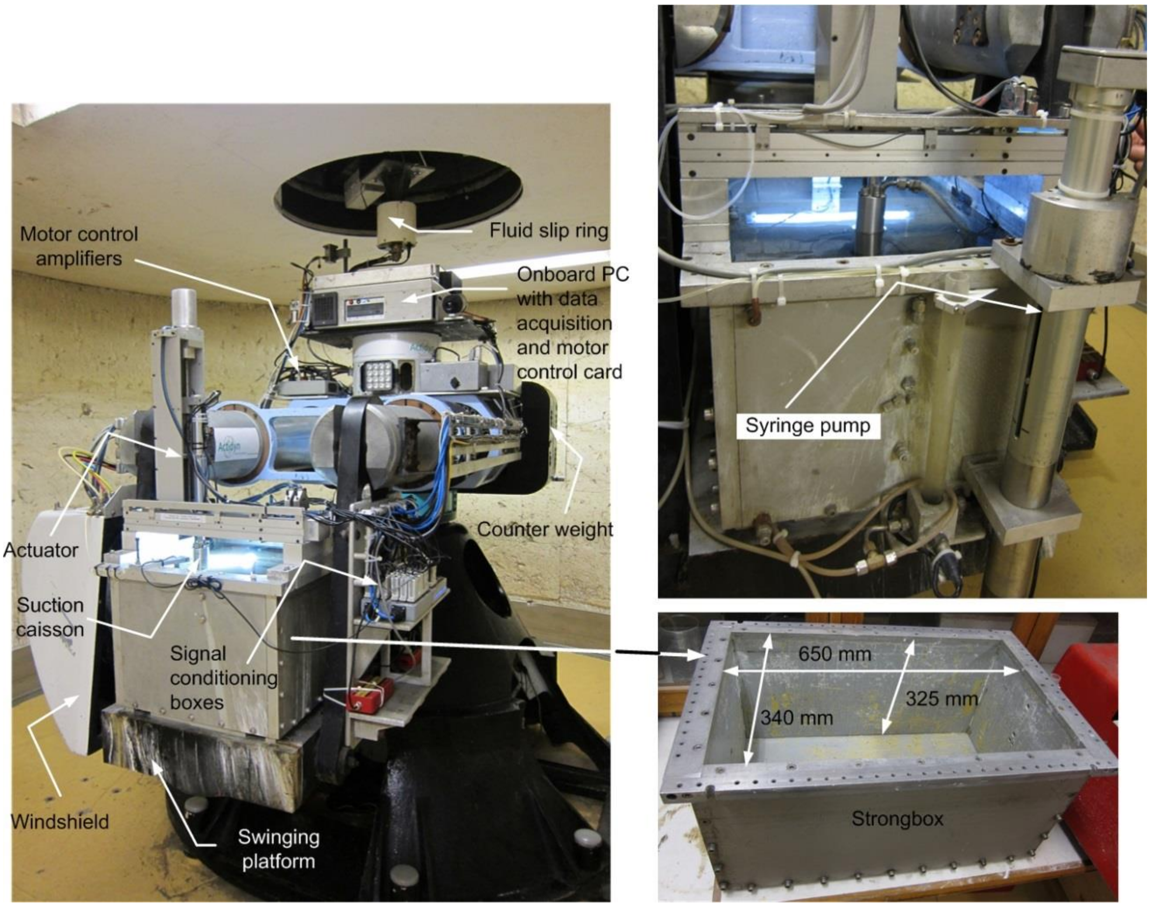

Figure 3. The UWA beam centrifuge and associated equipment

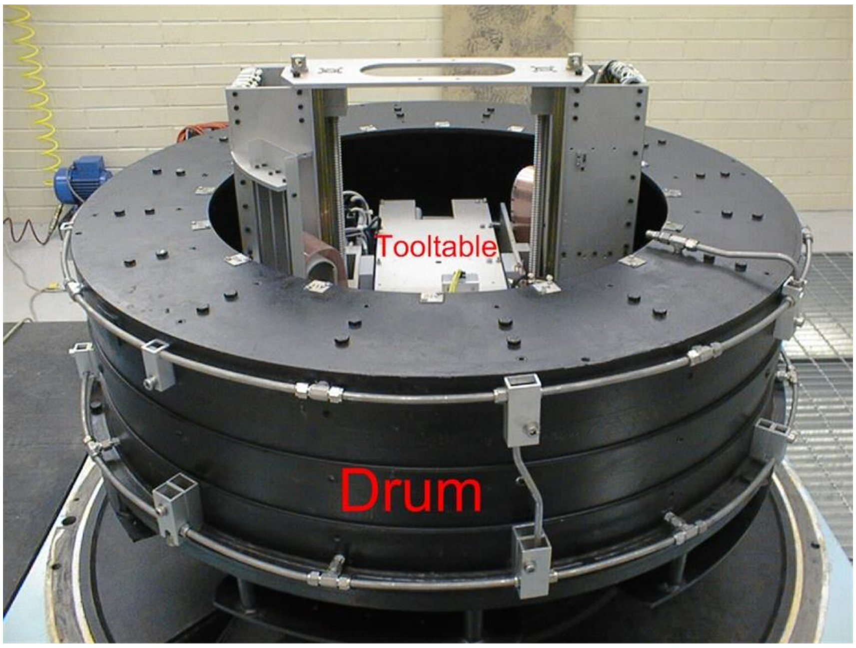

Figure 4. The UWA drum centrifuge

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In 2009, COFS, in conjunction with the UWA School of Civil Environmental and Mining Engineering, established an award-winning O-Tube program. The large (Figure 5) and mini O-Tubes are revolutionizing research on pipeline stability design and sediment transport. By forcing 60 tonnes of water through the 1.5 m^2 working section with a 16 meter long bed of natural seabed soil, researchers are able to use the large O-Tube to track the impact of wave and current loading on underwater infrastructure. The mini O-Tube, at a 1:5 scale of the larger O-Tube, allows for rapid turn-a-round on smaller scale experiments and has been instrumental in studying in-situ soil erosion.

Figure 5. The large O-Tube at UWA's Shenton Park campus

The COFS geotechnical testing laboratory provides access to one of the best geotechnical testing facilities (e.g. Figures 6 and 7) available in the world to both our industry clients and academic users. One of the main goals of the laboratory is to allow assessments of the mechanical behaviour of geomaterials under conditions that are representative of the soils state in situ. This ranges from being able to test undisturbed soil samples to allowing soil fabric and anisotropy analyses to be carried out, whenever reconstituted samples must be used.

Figure 6. New generation of UWA simple shear apparatus

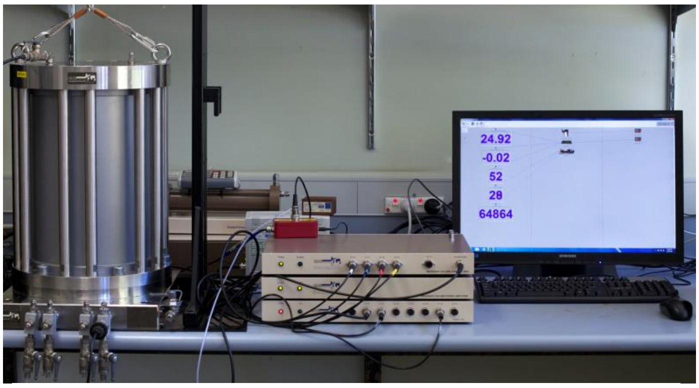

Figure 7. New resonant column apparatus at COFS

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Stream 1: Offshore Sediments

The main goal of the Offshore Sediments research stream is to identify the key mechanisms at a micro-structural level that dictate critical aspects of behaviour, and quantify that behaviour through scientifically sound models.

Fundamental studies focus on the rigorous characterisation, both in situ and in the laboratory, and analysis of various aspects of the mechanical behaviour of offshore sediments. A few innovative snapshots are given below.

Solutions for improved site investigation capabilities

A cone or ball penetrometer equipped with a pore pressure transducer can be used to obtain in situ consolidation characteristics of a seabed soil. Theoretical solutions exist to derive consolidation parameters from piezocone dissipation tests, but no such solution yet exists for the newer piezoball penetrometer. The large deformation effective stress finite element method, RITSS, has been used to benefit interpretation of the dissipation test, especially for piezoballs (Figure 8). An advanced, coupled pore-fluid stress, critical state soil model has been incorporated into our existing in-house developed large deformation capability to model piezocone and piezoball penetration and dissipation. Normalised times based on the operative coefficient of consolidation, for piezocone and piezoball respectively, have been proposed to unify dissipation curves following undrained penetration. This study provides insight for estimating the permeability of offshore sediments in an efficient and economical way. Ultimately, a piezoball test will be able to provide information on strength, remoulding and consolidation characteristics in a single test.

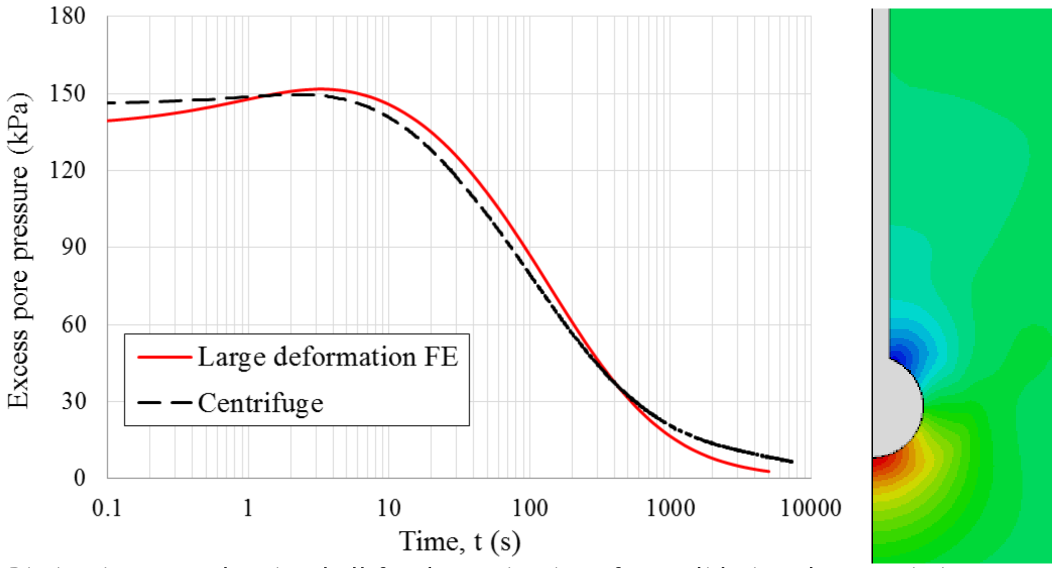

Figure 8. Dissipation around a piezoball for determination of consolidation characteristics – measured in the centrifuge and predicted with LDFE

For assessing consolidation characteristics at shallow depths, a new concept, operation and interpretation of a new simple tool has been introduced. The tool is a large diameter cylindrical penetrometer with a hemispherical tip, which is embedded statically under self-weight, for example from a winch (Figure 9). After embedment, the tool is parked – not requiring support from a drill-string – and the pore pressure dissipation is monitored. The operation of the tool has been simulated using large deformation finite element analysis with the Cam Clay plasticity soil model. Results in the form of the normalised undrained penetration response and pore water pressure dissipation-time history are presented (Figure 10).

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A novel penetrometer, toroid, based on the similar concept has also been introduced mainly to characterise the axial pipe-soil interaction forces.

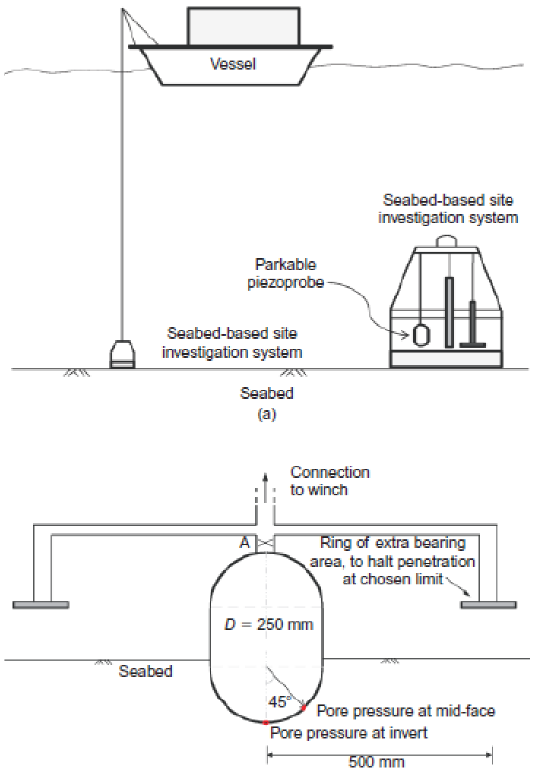

Figure 9. Seabed-based site investigation system and parkable piezoball

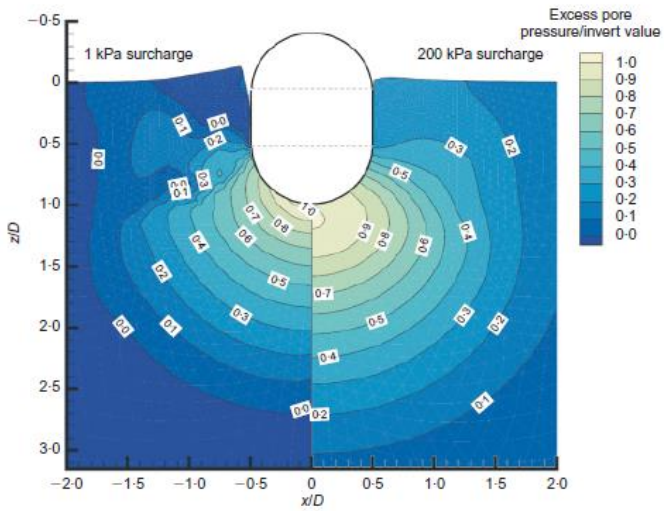

Figure 10. Fields of initial excess pore pressure at one diameter penetration

Characterising stratified seabed sediments is critical for the accurate prediction of foundation response and in determining the potential for geohazards. Extensive investigations on ball, T-bar and cone penetrometers in layered soils consisting of both clay and sand layers were carried out through large deformation finite element analyses (e.g. Figure 11). Sand layers have been modelled using the recently developed critical state Mohr-Coulomb (CSMC) model. The Mohr-Coulomb model has been extended utilising the critical state concept to define the variation in friction and dilation. Separately, a systematic statistical analysis of normalised CPTu data (tip resistance, sleeve friction and pore pressure) and soil classification charts were used. Frameworks were proposed for identification of layer boundaries and interpretation of soil type and design strength parameters for each identified layer from measured raw data from in-situ penetrometer tests. The resulting stratigraphies were compared with borehole logs for several case histories encompassing a range of soil types, and good agreement was obtained.

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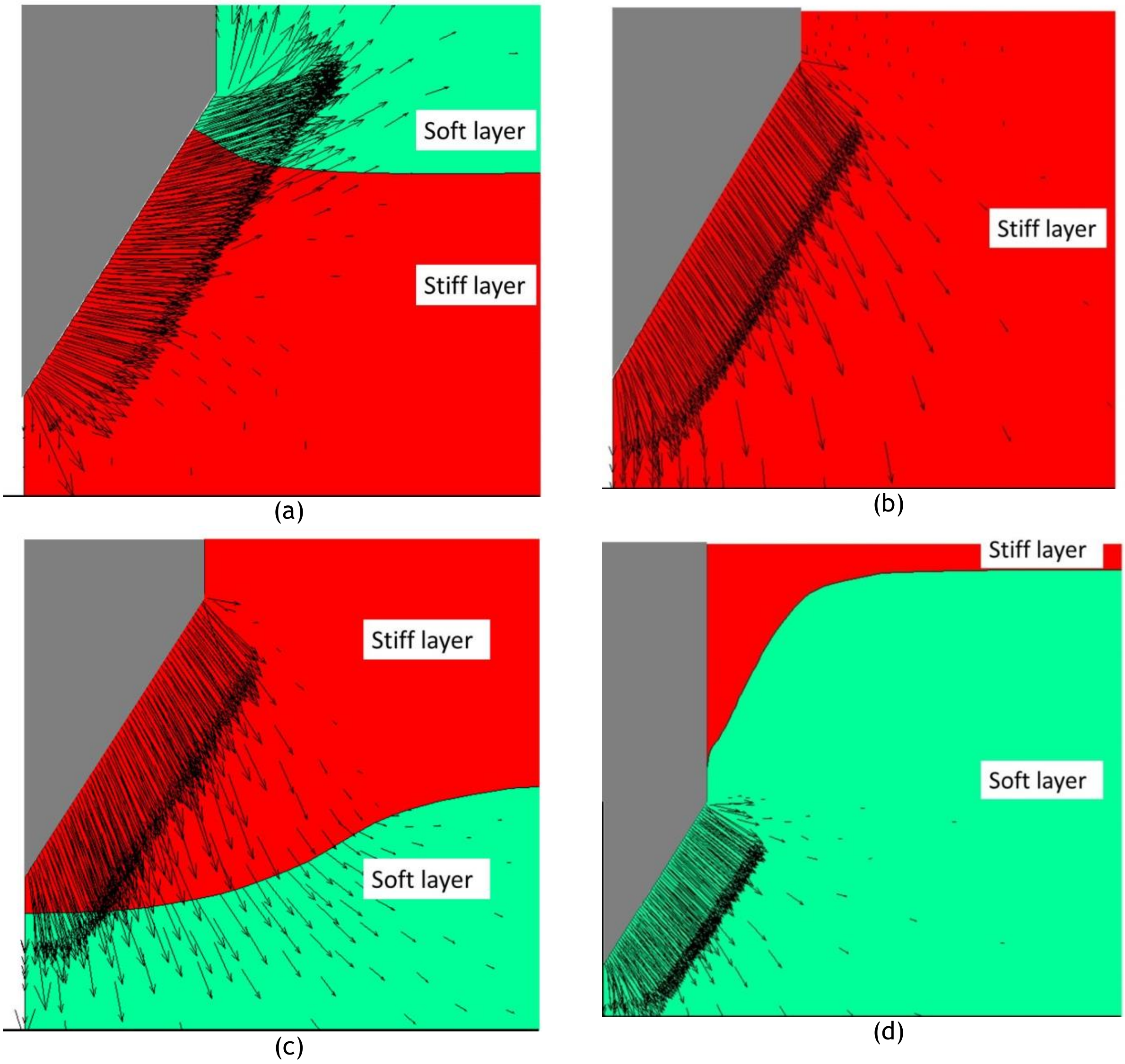

Figure 11. Soil flow mechanisms at different stages of cone penetration in soft-stiff-soft clay deposit

Solutions for improved site investigation capabilities

Free-fall piezocone and peizoball have been tested in centrifuge, and the results have been interpreted to estimate the undrained shear strength and coefficient of consolidation of normally consolidated kaolin clay. The model penetrometers were highly instrumented. For instance, the model piezocone instrumentation included tip and sleeve load cells, a pore pressure transduce located just behind the cone shoulder (u_2 position), and a micro-electromechanical system (MEMS) accelerometer. The data from dynamic embedment tests were compared with equivalent data from quasi-static piezocone and peizoball penetration tests. Back-analysed undrained shear strengths from the measured acceleration trace of the free-fall penetrometers were found to be in good agreement with that derived from (static) piezocone and peizoball penetration tests (Figure 12). Free-fall penetrometers were also found to produce identical pore pressure dissipation behaviour as for statically penetrated penetrometers, despite of the negative excess pore pressures generated during dynamic penetration, and a significant rise in the pore pressure at the start of the dissipation phase (Figure 13).

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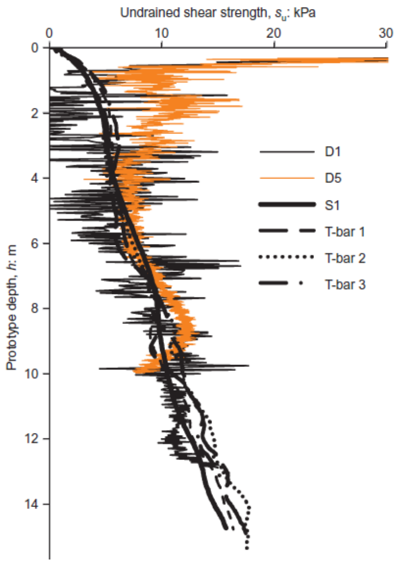

Figure 12. Comparison between undrained shear strength profiles estimated from free-fall piezocone and static piezocone and T-bar tests

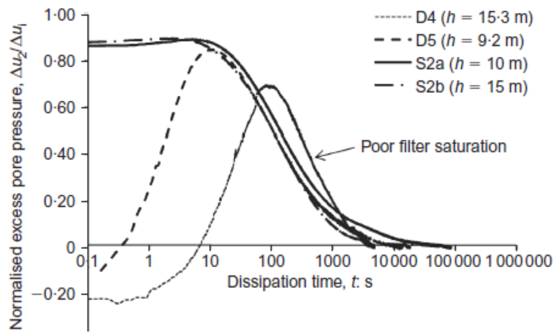

Figure 13. Static and free-fall piezocone dissipation test results

Stiffness degradation and damping of carbonate and silica sands

The large quantity of tests conducted in the COFS Geotechnical Testing Laboratory on carbonate soil samples over the past few years has triggered interest in investigating the behavioural difference between carbonate and silica sands. For example, a state-of-the-art resonant column apparatus has been used to assess the stiffness degradation and damping of a carbonate sand from the North West Shelf of Australia. A silica sand with particle size distribution identical to that of the carbonate sand was also tested to evaluate the effect of soil fabric and mineralogy on the test results. While the carbonate sand was typically stiffer than the silica sand at similar states, stiffness degradation in the carbonate sand was more pronounced and generally took place at smaller strains than in the case of silica sand tested (Figure 14).

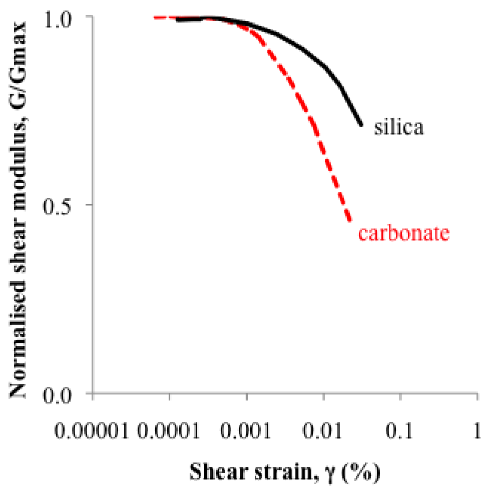

Figure 14. Stiffness degradation of silica and carbonate sands (with similar particle size distribution) tested at similar states in a resonant column apparatus

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Key recent publications

Carraro, J.A.H. and Bortolotto, M.S. (2015). Stiffness degradation and damping of carbonate and silica sands. *Proc. 3rd Int. Symp. on Frontiers in Offshore Geotechnics (ISFOG)*, Oslo.

Chatterjee, S., Randolph, M.F. and White, D.J. (2014). A parkable piezoprobe for measuring c_v at shallow depths for offshore design. *Géotechnique*, 64(1), 83-88.

Chow, S.H., O'Loughlin, C.D. and Randolph, M.F. (2014). A centrifuge investigation of free-fall piezocone in clay. *Géotechnique*, 64(10), 817-827.

Ma, H., Zhou, M., Hu, Y. and Hossain, M.S. (2014). Large deformation FE analyses of cone penetration in single layer non-homogeneous and three-layer soft-stiff-soft clays. Proc. 33rd Int. Conf. on Ocean, Offshore and Arctic Engineering, OMAE2014-23709.

Mahmoodzadeh, H. and Randolph, M.F. (2014). Penetrometer testing - the effect of partial consolidation on subsequent dissipation response. *J. of Geotechnical and Geoenvironmental Engineering*, ASCE, 140(6): DOI: 10.1061/(ASCE)GT.1943-5606.0001114.

Mahmoodzadeh, H., Wang, D. and Randolph, M.F. (2014). Numerical simulation of piezocone dissipation test in clays. *Géotechnique*, 64(8), 657–666; 64(10), 848-850 [DOI: 10.1680/geot.14.P.011].

Yan, Y., White, D.J. and Randolph, M.F. (2014). Cyclic consolidation and axial friction on seabed pipelines. *Géotechnique Letters*, 4, 165-169.

Zhou, M., Hossain, M.S., Hu and Liu, H. (2014). Behaviour of ball penetrometer in uniform single- and double-layer clays. *Géotechnique*, 64(1), 83-88.

Stream 2: Offshore Geohazards and Seabed Mobility

The Offshore Geohazards and Seabed Mobility research stream represents an important interface between geotechnical engineering, which has been the traditional core of COFS' activity, and the neighbouring disciplines of hydraulics, sediment transport, geomorphology and geology.

The most active trans-disciplinary interface in this stream is ocean-seabed interaction, particularly through research using UWA's unique O-tube facilities. The O-Tube flume concept is a UWA innovation. An O-Tube is a recirculating water tunnel, driven by an inline propeller, which can be used to create flow kinematics that mimic seabed conditions during storms, tides, solitons or simply ambient conditions.

Since 2008 UWA has been developing the O-Tube concept, to support research into new techniques for the stability design of subsea pipelines as well as research on other fluid-soil-structure interaction topics. The O-Tube program was initiated by UWA in partnership with Woodside, Chevron and the Australian Research Council. This industry involvement has underpinned the applied research focus of the O-tube facilities.

Numerical modelling highlights

A meshless method, material point method (MPM), has been used to tackle extremely large deformation problems in offshore geomechanics. Although the large deformation finite element analysis approach RITSS, developed in COFS, is versatile to cover many practical large deformation boundary value problems, the MPM takes advantage in reproducing high-velocity scenarios such as submarine sliding and subsequent slide impact on the pipeline (Figure 15). A modified total stress analysis model considering softening and rate-dependency of soil strength has been incorporated into the MPM codes. The run-out of sliding predicted by the MPM agrees well with centrifuge test results. The MPM codes with GPU parallelisation can achieve 20-fold speed-up of calculation times on an ordinary laptop.

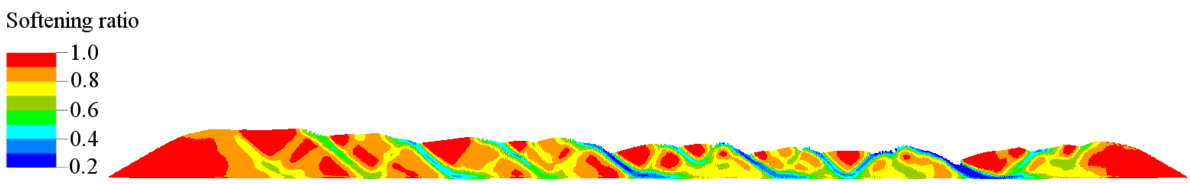

Figure 15. Modelling a submarine slide through the meshless MPM - soil softening in mass sliding along a gentle slope