Centre for Offshore Foundation Systems
Annual Report 2008

Established under the Australian Research Council’s Research Centres Program
Supported by the State Government of Western Australia
through the Centres for Excellence in Science and Innovation Program
<table>
<thead>
<tr>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Statement and Goals</td>
<td>3</td>
</tr>
<tr>
<td>Director's Report</td>
<td>5</td>
</tr>
<tr>
<td>Personnel and Organisation</td>
<td>7</td>
</tr>
<tr>
<td>Project teams</td>
<td>8</td>
</tr>
<tr>
<td>Visitors</td>
<td>9</td>
</tr>
<tr>
<td>International Collaboration</td>
<td>14</td>
</tr>
<tr>
<td>Industry Links</td>
<td>19</td>
</tr>
<tr>
<td>Conferences</td>
<td>25</td>
</tr>
<tr>
<td>Seminars</td>
<td>30</td>
</tr>
<tr>
<td>COFS and Pipeline Workshops</td>
<td>32</td>
</tr>
<tr>
<td>Research Reports</td>
<td>34</td>
</tr>
<tr>
<td>Characterisation of Soft Sediments</td>
<td>34</td>
</tr>
<tr>
<td>Foundation Piles</td>
<td>40</td>
</tr>
<tr>
<td>Shallow Foundations</td>
<td>43</td>
</tr>
<tr>
<td>Pipelines</td>
<td>53</td>
</tr>
<tr>
<td>Geohazards</td>
<td>71</td>
</tr>
<tr>
<td>Mobile Jack-up Drilling Rigs</td>
<td>80</td>
</tr>
<tr>
<td>Installation of Subsea Modules</td>
<td>88</td>
</tr>
<tr>
<td>Rock Mechanics</td>
<td>90</td>
</tr>
<tr>
<td>Social and Awards pages</td>
<td>91</td>
</tr>
<tr>
<td>Publications</td>
<td>93</td>
</tr>
<tr>
<td>Financial Report</td>
<td>100</td>
</tr>
</tbody>
</table>
Turmoil within world financial markets saw the clouds of “global economic crises” close in by year’s end. To date COFS has weathered the inevitable storm and we continued to prosper and grow in 2008. With the world’s appetite for energy still predicted to significantly expand in the coming decades, COFS is evolving to meet major research challenges in the offshore sector.

COFS continues to diversify its activities, with 2008 seeing our first appointment in the marine geology field. We also continue to pursue major projects in marine geohazards and their effect on offshore infrastructure (predominantly through our Western Australian State Government Centre of Excellence Grant and a MERWA facilitated JIP) and in the design of ultra-long tiebacks of on-bottom pipelines (CSIRO Flagship Cluster on Subsea pipelines and a new ARC Linkage grant with Woodside Energy). These projects are timely, with the Ichthys project recently announcing a 850 km long offshore pipeline to be built offshore Australia.

The COFS soil laboratory and centrifuge facilities continue to be heavily utilised by the local and international resource industry. As detailed later in this report, over $1.7 million of funding was derived from industry sources in 2008. COFS owes much of this success to the professional management of Binaya Bhattarai (soils laboratory), Martin Fahey (soils laboratory) and Dr Christophe Gaudin (centrifuge manager), as well as our dedicated team of technical staff John Breen, Claire Bearman, Shane de Catania, Alex Duff, Aaron Groves, Ying Guo, Phil Hortin, Kristin Hunt, Don Herley, Dave Jones, Kin Seint and Bart Thompson.

The seabed soil of the majority of Australia’s major offshore gas developments continues to be characterised at COFS. In 2008 this included Blacktip, Brecknock, Gorgon, Ichthys, Marlin-B, Pluto and Wheatstone. Our geotechnical centrifuges are also seeing an increased use in model tests commissioned to underpin prototype designs and methodologies. Dedicated tests performed in 2008 include:

(i) pipe-soil interaction for BP’s Block 31 in Angola West Africa and for the Janisz flow lines in Australia,
(ii) suction caisson tests for a gravity platform in the Caspian Sea and a meteorological mast in Hong Kong, and
(iii) modelling the impact of ship anchors on a rock berm protected pipelines in Hong Kong Harbour. Further detail is provided in this annual report.

COFS continues its involvement with major international research projects, including the NSF funded researcher exchange on “developing international protocols for offshore sediments and their role in Geohazards”, the SafeBuck JIP, and the recently launched InSafeJIP. In the latter nineteen international oil and gas companies, safety regulators and engineering service providers have joined to develop new guidelines for the safe installation of mobile drilling platforms.

After a successful ISFOG symposium in 2005, COFS has recovered its organisational spirit under the enthusiastic leadership of Susan Gourvenec. Abstracts for ISFOG-2010 are due in mid-2009. We hope that this will provide the opportunity for many of you who receive copies of this annual report to (again) visit our facilities in Perth.

Khader Rammah, Mark Richardson, Shazzad Hossain, Nobutaku Yamamoto, Kervin Yeow and Hongjie Zhou are all congratulated for successfully completing their PhD theses. Khader, Nobu and Mark all made a smooth transition into Perth’s consultancy industry, with Khader now working for Golder Associates and Nobu and Mark joining Advanced Geomechanics. Shazzad and Hongjie continued at COFS, though in their new roles of Research Associates.

2008 has seen a major boost in our academic ranks with seven new appointments.

After a stint with Perth consultants Golders Associates, Britta Bienen returned to COFS as a Research Fellow. Maintaining our (occasionally advertised) Irish pedigree, Noel Boylan joined us from University College Dublin and immediately found a home modelling submarine landslides and their impact on pipelines in the drum centrifuge. We also welcomed Long Yu from Dalian University of Technology and Hongxia Zhu from Tianjin University, both in China.

James Schneider and Andrew Deeks also made short cameos as COFS Research Associates in 2008 before returning to the USA (Assistant Professor, University of Wisconsin) and UK (Buro Happold Pty Ltd) respectively. Richard Merfield also returned ‘home’ to the University of Newcastle where he has rejoined the Centre for Geomechanical and Materials Modelling.

Continuing COFS engagement with the Western Australia Energy Research Alliance, James Hengesh has been appointed as a WA:ERA MRF funded Research Fellow. James brings to COFS many years of practical experience as a marine geologist. As geotechnical engineers we look forward to the many lessons we will learn from having a geologist in our midst.
Congratulations also to Mark Randolph who was elected an international honorary member of the Japan Geotechnical Society. Other COFS staff who received accolades included David White who was awarded the Canadian Geotechnical Journal’s R.M. Quigley Honorable Mention. This was awarded for his collaborative paper with Johnny Cheuk (University of Hong Kong) and Malcolm Bolton (University of Cambridge) entitled “Large-scale modelling of soil-pipe interaction during large amplitude cyclic movements of partially embedded pipelines”. Susan Gourvenec, Mark Randolph and COFS 4th year honours student Oliver Kingstown were awarded the 2008 ASCE International Journal of Geomechanics Excellent Paper Award for “Undrained bearing capacity of square and rectangular footings”.

On a personal note special thanks to Christophe Gaudin for adeptly acting as Director in the latter months of 2008, allowing me to marry and even go on a honeymoon.

This is our twelfth annual report and its highlights are presented here.

Mark Cassidy
Director
Management Committee: The Management Committee is chaired by the Director and membership consists of the Deputy Director, Business Manager, ARC Federation Fellow, Centrifuge Manager, senior academics in COFS, and a senior academic in the Geomechanics discipline within the School of Civil and Resource Engineering. The terms of reference of the Management Committee are:

1. to formulate long term strategies;
2. to review the progress of scientific objectives; and
3. to maintain budgetary targets.

Staff

Director
Professor Mark Cassidy
Deputy Director
Professor Martin Fahey
Federation Fellow
Professor Mark Randolph
Business Manager
Mrs Lisa Melvin
Administrative Officer
Mrs Monica Mackman
Accounts Officer
Mr Ivan Kenny
Purchasing Officer
Ms Michelle Harman
Administrative Assistant
Mrs Inga Carr
Research Associates
Dr Noel Boylan
Dr Andrew Deeks
Dr Shazzad Hossain
Mr Zhenhe Song
Dr Yinghui Tian
Dr Dong Wang
Dr Long Yu
Dr Zhigang Zhang
Dr Hongjie Zhou
Dr Hongxia Zhu
Research Fellows
Dr Britta Bienen
Dr Nathalie Boukpeti
Mr James Hengesh
Dr Mehrdad Khiali
Dr Ming Zhao
Dr Xingxin Zhu
Senior Lecturers
Dr Susan Gourvenec
Dr Christophe Gaudin
Dr Britta Bienen
Senior Research Fellow
Professor Boris Tarasov
Professor David White
Dr Martin Fahey
/Centrifuge Manager
Dr Wenge Liu
Professor Mark Randolph
Systems Administrator
Mr Keith Russell
Senior Engineer
Mr Binaya Shattarai
Senior Technicians (Soils)
Mrs Claire Bearman
Technicians (Soils)
Ms Kristin Hunt
Mr Aaron Groves
Ms Ying Guo
Mr Lewis Waters
Mr Alex Duff
Mr John Breen
Dr Mark Cassidy
Senior Technicians (Electronic)
Mr Shane De Catania
Mr Phil Hortin
Technician (Electronic)
Ms Khin Seint
Mr Don Herley
Chief Technician (Beam Centrifuge)
Mr Bart Thompson
Chief Technician (Drum Centrifuge)
Mr Dave Jones
Senior Technician (Workshop)
Administrative Assistant (Workshop)
Ms Shae Harris
Project Teams

SEABED CHARACTERISATION

Research staff
Mark Fahey
Mark Randolph
Nathalie Boukpeti
James Hengesh
Boris Tarasov

Research students
Han Eng Low
Chin Chai Ong
Khader Rammah
Mark Richardson

Final year students
Joshua Mikolajczyk

FLUID-STRUCTURE-SOIL INTERACTION

Research staff
Mark Cassidy
Liang Cheng
Mehrdad Kimiaei
Mark Randolph
David White
Britta Bienen
Yinghui Tian

Research students
Marc Senders
Matthew Hodder
Kok Kuen Lee
Hodjat Shiri
Bassem Youssef
Muhammad Shazzad Hossain

Final Year students
Sally Wong
Ryan Hannon
Xu Jianging
He Yu

FOUNDATION DESIGN

Research staff
Mark Randolph
Mark Fahey
Susan Gourvenec
Christophe Gaudin
Nathalie Boukpeti
James Hengesh
David White
Noel Boylan
Hongjie Zhou
Dong Wang
Hongxia Zhu
Britta Bienen

Research students
Hugo Acosta-Martinez
Santriam Chatterjee
Indranil Guha
Muhammad Shazzad Hossain
Shinji Taenaka
Anj-ju Li
Fauzan Sahdi

Final year students
Saskia Barnett
Katie Jenson
Charles Simmons
Nicholas Bennett
September – November 2008
Northeastern University, USA

Nicholas worked with Nathalie Boukpeti on experimental characterization of the strength of kaolin over a wide range of water contents. He also worked with Britta Bienen, experimentally investigating the combined load capacity in vertical-torsional space of a flat circular footing and a spudcan on clay.

Johnny Cheuk
August 2008
The University of Hong Kong, Hong Kong

Johnny worked with Dave White on the collaborative research into the behaviour of on-bottom pipelines. He spent his visit developing models for pipe-soil interaction related to their joint grant “Seabed-pipe interaction for deepwater applications”, funded by the Research Grants Council of the Hong Kong Special Administrative Region.

Davene Daley
June – July 2008
Vassar College, USA

Davene worked with Mark Cassidy and Shazzad Hossain investigating the benefits of Swiss Cheese Drilling on the installation of jack-up platforms. She also assisted Britta Bienen and Honours student Sally Wong in the experimental investigation of the push-over capacity of jack-ups on sand. Funded through the researcher exchange scheme of the United States National Science Foundation, Davene continues the excellent contribution US undergraduate students are making at COFS.

Eleonora Di Mario
January – June 2008
University of Rome, Italy

Eleonora worked with Christophe Gaudin on the use of suction caissons as foundations for wind turbines.

Sam Frydman
February 2008
Technion – Israel Institute of Technology, Israel

Sam visited COFS for one day to learn more about COFS research and presented a seminar on ‘Unsaturated soil mechanics – a critical review of physical foundations’.
Cheng Ti Gan
August – September 2008
National University of Singapore

Cheng Ti worked with Mark Cassidy and Christophe Gaudin on jack-up re-installation behaviour. She conducted a series of experiments in the UWA drum centrifuge to complement her NUS PhD study. Cheng Ti also attended and presented at the COFS workshop.

Jayantha Kodikara
February – March 2008
Monash University, Australia

Kodi spent two months of his sabbatical with us working with Mark Cassidy, Mark Randolph and Dave White on the Wealth from Oceans Flagship Collaboration Cluster on Subsea Pipelines project, of which he is a participant.

Karoline Krost
October 2007 – April 2008
Technischen Universität Darmstadt, Germany

Karoline worked with Susan Gourvenec on the research topic of consolidation around partially embedded pipelines. They used the finite element method to define the frictional resistance of the pipeline by deriving an appropriate enhancement factor and ascertained the optimal time lag required between pipeline laying and a pipeline becoming operational.

Melissa Landon
September 2007 – April 2008
University of Massachusetts Amherst, USA

Melissa’s visit was part of the International Partnership Commitment for NSF Grant Entitled: “Developing International Protocols for Offshore Sediments and their Role in Geohazards: Characterization, Assessment, and Mitigation”.

She worked on various centrifuge projects with Christophe Gaudin and performed an extensive experimental study on re-installation of jackup near pre-existing footprint in collaboration with Christophe Gaudin and Mark Cassidy. She also worked with Mark Randolph and Han Eng Low on centrifuge model tests on pipe-soil segment tests in various clays, ranging from kaolin, to local deepwater carbonate ‘silt’ (high sensitivity, fine-grained material) and an offshore high plasticity clay. Melissa focussed in particular on full-flow penetrometer tests and their interpretation, relative to laboratory tests.

Colin Leung
September 2008
National University of Singapore

Colin visited to participate in the COFS workshop. While in Perth he also continued his collaboration with Mark Cassidy and Christophe Gaudin on installation of spudcan foundations next to existing footprints, and held discussion on the joint InSafe JIP.
Harry Lynch
December 2008 – February 2009
James Cook University, Australia

Harry was awarded a COFS Vacation Scholarship and worked with Britta Bienen as his supervisor on the load-displacement behaviour of shallow foundations.

Brian McAdoo
June 2008
Vassar College, USA

Brian visited COFS to have a look at the centrifuge and to learn a bit more about our research. He presented a seminar on ‘From (geo)technical to tents: offshore geohazards and tsunami risk reduction’.

Brett McKiernan
September – November 2008
Northeastern University, USA

Brett worked with Nathalie Boukpeti on experimental characterization of the strength of kaolin over a wide range of water contents. He also worked with Britta Bienen, experimentally investigating the combined load capacity in vertical-torsional space of a flat circular footing and a spudcan on clay.

Stephen Michna
February – May 2008
Northeastern University, USA

Stephen worked with Mark Randolph and Han Eng Low on experimental characterization of the strength of Burswood clay over a wide range of water contents.

Ashraf Osman
July – September 2008
Durham University, UK

Ashraf worked with David White and Mark Randolph on analytical and numerical modeling of shallow foundations and piles. A new solution for consolidation around a laterally-loaded pile was derived, and a novel technique for assessing the settlement response of foundations under combined loading on non-linear soil was developed.
**Siew Renard**  
December 2008 – January 2009  
University of New South Wales, Australia

Renard was awarded a COFS Vacation Scholarship and worked with Nathalie Boukpeti as his supervisor on experimental study of the influence of water content on the shear strength of kaolin.

**Fauzan Sahdi**  
February – March 2008  
UNIMAS University, Malaysia

Fauzan was awarded a Malaysian scholarship to study his Masters at UWA. He spent a few weeks as a visitor to see the laboratory facilities and learn about the research techniques used at COFS. He enrolled as a Masters student in May 2008, and is working on the behaviour of submarine slides.

**Paul Schaminee**  
September 2008  
Deltares, Netherlands

Paul visited COFS in September 2008 to discuss potential collaborations and to work on data archiving with Dave White and Christophe Gaudin within the working group activities of TC2 committee. He presented a seminar on that particular topic entitled From STREAM to a flood of knowledge.

**Donghee Seo**  
October 2007 – January 2009  
Yonsei University, Korea

Donghee worked with Mark Randolph and Dave White on research into the behaviour of seabed pipelines subjected to submarine slides. During his time with COFS he was involved in the analysis of pipeline-slide interaction, developing simple models for the structural response, providing designers with a flexible tool for use in preliminary design studies.

**Motoyuki Suzuki**  
June 2008 – March 2009  
Yamaguchi University, Japan

Motoyuki was awarded a UWA Gledden Senior Visiting Fellowship and is working with Mark Randolph investigating the remoulding properties of clay.
Kar Lu Teh  
August – September 2008  
National University of Singapore  

Kar Lu (on her 4th visit to COFS) worked with Mark Cassidy, Mark Randolph, Britta Bienen and Shazzad Hossain on the InSafe JIP project. Kar Lu also attended and presented at the COFS workshop.

Kee Kiat Tho  
September 2008  
National University of Singapore  

KK participated in the COFS workshop in September and discussed his work on spudcan-pile interaction with COFS academics.

Yue Yan  
March – June 2008  
Tianjin University, China  

Yue is working with Mark Randolph and Dave White on the CSIRO Flagship Collaboration Cluster on Subsea Pipelines. She was awarded a PhD scholarship under this flagship cluster and has been enrolled as student since June 2008.

Chenrong Zhang  
September 2008 – September 2009  
Tongji University, China  

Chenrong is working with Mark Randolph and Dave White on a research project related to the cyclic lateral response of piles in soft clay.

Hongxia Zhu  
May 2007 – April 2008  
Tianjin University of China, China  

Hongxia is working with Mark Randolph on research into submarine slides and their impact on offshore pipelines. She became a Research Associate at COFS in April 2008.
University of Oxford, UK

Matt Hodder visited the University of Oxford to work with Byron Byrne on the topic of touchdown region behaviour of steel catenary risers (SCRs). During his visit, Matt developed an instrumented 7.65 m long model riser to be used in the flume in the Department of Engineering Science’s soil mechanics laboratory. The 110 mm diameter model pipe connects to an actuator at one end to impose vertical motion. The vertical load and displacement at the actuator, along with the bending moment, displacement and soil pore water pressure can be monitored at several positions along the pipe. A maximum uplift of three diameters above the soil surface can be imposed, resulting in a touchdown point approximately 4-5 m from the actuator, depending on the pipe weight. A pilot test was conducted in which the pipe was cycled on sand with plans to conduct tests on soft clay in the future.

Figure 1: Matt providing some cheap physical labour in the lab

Figure 2: Cyclic riser test in progress

Figure 3: Soil deformation after riser cycling
Durham University, UK

DAshraf Osman of Durham University spent a productive two months at COFS during August and September, collaborating with Dave White and Mark Randolph. During this time Ashraf extended his MSD method of foundation settlement analysis to combined loading and generating a new analytical solution for consolidation around a laterally-loaded pile.

Southampton University, UK

David Richards of Southampton University made his traditional annual visit to COFS during April 2008, and continued his collaboration with Barry Lehane and Dave White, related to the uplift capacity of foundations and the excavation of beaches.

Deltares (formerly GeoDelft), The Netherlands

Haike Van Lottum and Paul Schaminee from the research centre Deltares in Netherlands (which host one of the biggest centrifuge in Europe), visited COFS in June and September respectively. Haike performed some centrifuge tests with Christophe Gaudin and Dave White to study the potential of resistivity probes developed at Deltares to measure moisture content in centrifuge samples and to investigate the comparative compression, strength and remoulding behaviours of natural and artificial clay. Paul’s visit was the opportunity to discuss with Christophe and Dave activities on data archiving within the TC2 committee and potential collaborations between COFS and Deltares.
Giken Seisakusho Co. Ltd, Japan
and Cambridge University

Dave White and long-time COFS visitor Andrew Deeks, visited Giken Seisakusho in Kochi, Japan, during July 2008. Andrew’s Cambridge-badged PhD on pile jacking was completed whilst he was based at COFS during 2008. Andrew used the UWA beam centrifuge to undertake a series of tests simulating the behaviour of piles installed using Giken’s pile jacking technology. After he presented the outcomes of this work to colleagues at Giken, a barbeque was lit and fresh bonito was smoked.

Andrew remained at COFS for a further 3 months after completing his PhD, to undertake a study into foundation capacity under combined loading, supervised by Susan Gourvenec, to support a revision of the API design code.
Offshore Technology Research Centre (OTRC), USA

PhD student Hugo Acosta-Martinez visited the OTRC in Texas and the universities that jointly operate the centre, namely the University of Texas at Austin and Texas A&M University. These visits were kindly hosted by Robert Gilbert (UT-Austin) and Charles Aubeny (Texas A&M). During his time in Texas, Hugo presented seminars at both venues on the response of skirted shallow foundations under transient and sustained uplift loading. He also visited their specialized laboratories for physical modelling of offshore foundations, had individual meetings with leading academics and fellow graduate students and enjoyed a day trip to the headquarters of BP in Houston to attend a workshop on an industry project about the “Analysis of spatial variability in deep water geotechnical design data”.

Orcina Ltd, UK

Collaboration has continued between Mark Randolph and Orcina Ltd, in particular with Peter Quiggin, over the implementation of a non-linear seabed interaction model into their general purpose dynamic analysis software, OrcaFlex. The model was finally released in January 2009, and details will be presented later in 2009 at the OMAE conference to be held in Honolulu.

National Science Foundation Collaborative Exchange Scheme: University of Massachusetts, University of California, Davis, Northeastern University, Tufts University and Vassar College (USA) and the International Centre for Geohazards, Norwegian Geotechnical Institute (Norway)

COFS academics continued their collaboration with Don DeGroot, Jason DeJong, Tom Sheahan, Laurie Baise and Brain McAdoo on a 5-year NSF-funded collaboration ‘Developing International Protocols for Offshore Sediments and their Role in Geohazards: Characterization, Assessment, and Mitigation’. The collaboration has led to various visitors to COFS in 2008. Melissa Landon, a PhD graduate from the University of Massachusetts, Amherst, and a visiting researcher with COFS during 2007-08 led this involvement. We congratulate Melissa on her appointment as an Assistant Professor at the University of Maine and hope that she will continue as a regular visitor to COFS. Professor McAdoo presented his work on offshore geohazards at COFS in June, and other visitors include Vassar undergraduate student Davene Daley, and Northeastern University students Stephen Michna, Nicholas Bennett and Brett McKiernan. In reverse, Mark Cassidy spent a week at the International Centre for Geohazards, NGI in November.
National University of Singapore

COFS continued developing its links with the Centre for Offshore Research and Engineering (CORE) at the National University of Singapore, with Mark Randolph, Mark Cassidy and Britta Bienen all visiting CORE in 2008. Collaborative projects on sand-over-clay punch-through, reinstallation of spudcans next to existing footprints and the InSafeJIP continued in 2008. The COFS annual workshop also had a strong NUS feel with Colin Leung joining Kar Lu Teh, Cheng Ti Gan and Kee Kiat Tho in Perth (Figure 7). During that period NUS PhD student Cheng Ti conducted a set of drum centrifuge experiments at COFS (Figure 8).

Figure 7: NUS academics working hard after the COFS workshop

Figure 8: Cheng Ti Gan and Mark during testing

Figure 9: Kar Lu Teh in Perth
Centrifuge experiments

The centrifuge facility continued to be heavily utilised by industry in 2008. Five projects were completed, totalling 16 weeks of testing. The continuing collaboration with existing industry partners Advanced Geomechanics and Arup Energy and the establishment of new collaborations in 2008 with BP, CLP Power Ltd and Worley Parsons Singapore are testimony to the high quality work provided by the centrifuge team and its capability to answer new challenges.

Among these five projects, two related to on-bottom pipeline-soil interaction and lay effects on pipeline embedment, highlighting the expertise developed at COFS in pipeline modelling techniques. COFS has a history of pipe-soil modelling for industry, originating in studies for Woodside's second trunkline expansion project, several years ago. Since pipeline-soil interaction studies were recommenced in 2007 for Woodside's Pluto development, COFS has been involved in many of the major pipeline developments offshore Australia. We have also performed tests for a project in West Africa, which was being designed by consultants based in the UK – this was a truly global collaboration. Our capability to simulate dynamic lay processes, and detailed sequences of load and displacement controlled motion, allows sophisticated simulations of the various stages in the ‘life-cycle’ of a pipeline to be conducted. Many of Australia’s largest gas fields include dense networks of infield flowlines and long export trunklines to shore. The assessment of pipe-soil interaction forces is extremely challenging for designers. Our project-specific centrifuge modelling studies and our research within the SAFEBUCK JIP have made significant contributions to many projects.

During this year, on-going developments of the facilities have been undertaken by the technical team, with new features on both the motion control system and the data acquisition system implemented to answer the ever-increasing technical challenges associated with industry projects. Special credit has to be given to the centrifuge team, John Breen, Tuarn Brown, Shane De Catania, Don Herley, Phil Hortin, Dave Jones, Khin Seint and Bart Thompson for another successful year.

Centrifuge modelling of pipeline soil interaction – Block 31 PSVM – BP

A series of centrifuge tests were commissioned by BP Angola in relation to pipeline design for the PSVM Development located in Block 31NE, offshore Angola. The tests aimed to investigate (i) the influence of dynamic lay effects on pipe embedment and lateral breakout response and (ii) the lateral resistance during cycles of lateral movement. The tests aimed to simulate pipelines which are relatively heavy compared to the seabed soil, to represent the conditions relevant to the flowlines and planned for the PSVM field.

Two types of dynamic lay effect were simulated, involving cyclic horizontal movement of the pipe (within a prescribed triangular envelope) whilst under a controlled vertical load. The two types of lay effect aimed to simulate the behaviour experienced by an element of pipe (i) which touches down on the seabed and passes entirely through the touchdown zone during load-out of a length of pipeline and (ii) which remains in the centre of the touchdown zone during a welding period, when the vessel is stationary.

The response within a buckle during cycles of thermal loading was then simulated by imposing cycles of horizontal motion with varying amplitude, whilst maintaining the vertical pipe-soil contact force constant. Cycles of movement with and without pause periods for consolidation were simulated, and the operating pipe weight was varied between tests.

A total of 8 pipe tests were conducted, and the soil strength was characterised by T-bar penetrometer tests. Each pipe test comprised of a lay simulation stage (or monotonic embedment of the pipe under displacement control) followed by a thermal cycling stage.

Figure 1: Post-test view of soil berms prior to extraction of pipe
Suction caisson installation
– Turkmenistan Block 1 Gas development – Arup Energy

Arup commissioned a study examining soil flow around stiffened caissons during installation. The study was motivated in part through the challenges of designing the steel skirted foundation of the MCR-A gravity-based platform to be installed in stiff clay in the Caspian Sea. An issue was whether the adopted stiffener arrangement, which comprised both vertical and horizontal stiffeners, would jeopardize the installation of the foundation. A centrifuge testing programme was developed to investigate three types of stiffener arrangements: one caisson without stiffeners, one caisson with horizontal stiffeners only, and one with both vertical and horizontal stiffeners, the latter analogous to the actual MCR-A foundation design (Figure 2). The caissons were penetrated into heavily overconsolidated clay using suction-assisted and jacked methods. The results showed that minimal soil flow-round occurred, evident through both the penetration resistance profiles, the magnitude of seabed heave within the caisson, and observations of trapped soil between stiffeners following penetration. Back-analysis of the penetration resistance showed that current design methods to predict caisson installation are quite accurate (Figure 3), which was good news to the project team. A further study has since been commissioned by Arup examining similar stiffener-soil interaction in normally-consolidated clay, including rate effects.

![Figure 2: Model caissons with (a) only horizontal stiffeners and (b) vertical and horizontal stiffeners](image)

![Figure 3: Comparison of measured and predicted penetration resistance assuming zero flow-round conditions](image)
Rock berm model testing – Hong Kong LNG – Worley Parsons Singapore

A series of centrifuge tests has been performed at COFS for Worley Parsons Singapore in order to assist in the design of the rock berm cover of a pipeline commissioned by Castle Peak Power Company Limited for a LNG project in Hong Kong.

The testing programme included 10 tests featuring 3 different US Navy Stockless anchors of weights 3t, 5.1t and 20.4t respectively. The anchors were dragged by a specific actuation system after being pre-embedded manually to a depth of three times their fluke height against rock berms of varying thickness, covering a large-diameter gas pipeline. Variables in the tests included bigger size rock particles and additional rock material in the trench in comparison to the original design.

The tests were successful and provided interesting insight into the rock-chain-anchor interaction. It was notable that the total width of the rock cover and hence the amount of material in front of the pipeline had a more beneficial role than the thickness of the rock cover. The main explanation is that the chain rock interaction appeared to be limited (with evidence of deep penetration of the chain into the rock cover) in comparison to the anchor shank-rock interaction which governs the uplift of the anchor as the anchor travels through the rock cover.

Figure 4 shows the model anchor and pipeline after completion of the test.

Meteorological mast foundation – CLP Power Hong Kong Ltd

The Buildings Department of Hong Kong required laboratory centrifuge tests to be performed under compressive cyclic loading to validate the design of suction caissons to be used as tripod foundations for a meteorological mast offshore Hong Kong. The mast aims to support a feasibility study of a future wind farm development. COFS was commissioned by Advanced Geomechanics to perform a series of centrifuge tests on a model caisson to (i) satisfy the requirements from the Buildings Department of Hong Kong and (ii) provide relevant information about the behaviour and performance of the suction caisson in order to assist in the validation of the design.

One of the challenges associated with these tests was to reconstitute the complex in-situ stratigraphy which includes a lightly overconsolidated clay layer overlaying a loose carbonate sand. In order to ensure undrained behaviour in both layers during cyclic loading, it was necessary to saturate the materials with different pore fluids, using water and silicon oil, for the clay and sand respectively. This necessitated both materials to be reconstituted separately and assembled in a last stage, just before testing (Figure 5).
Lay effects on pipeline embedment – Jansz Infield flowlines – Gorgon Upstream Joint Venture

A centrifuge modelling programme has been performed at COFS for the Gorgon Upstream Joint Venture, concerning the Jansz infield flowlines. The objectives of this programme were to investigate the as-laid embedment and subsequent breakout response of the flowlines. A variety of different dynamic lay processes were simulated, based on previous numerical modelling of the pipe laying activity.

The tests were conducted in a sample of seabed sediment from the Jansz field which was reconstituted from a slurry in the centrifuge. The strength properties of the sample were assessed using miniature T-bar penetrometer test.

A total of 10 pipe tests were conducted, many of which included simulations of the lay process. Each dynamic simulation involved a series of motion sequences. Each series was designed to mimic a stage in the passage of an element of pipe through the touchdown and process zones as the pipe reaches the seabed, moves dynamically due to the vessel motion, and then reaches a stationary embedment. The sequences involved specified patterns of cyclic vertical movement (under load control) and cyclic horizontal movement (under displacement control). The pipe embedment accumulated throughout these sequences until the as-laid condition was reached (Figure 7).

After each lay process, the elevated pipe weight during hydrotesting was simulated. The pipe was then unloaded to the operating weight and pushed laterally. In one test, the breakout stage was followed by cycles of lateral movement, designed to simulate thermal operating cycles within a lateral buckle.

Figure 6: Simulation of lateral pipe sweeping in a centrifuge model test

Figure 7: Example of cumulative embedment during dynamic laying
InSafe JIP

Incidents of unpredicted, and often adverse, jack-up foundation performance continue to occur regularly, while the safety records of other jack-up activities, such as towing, drilling, structural fatigue, collision, fire and blow-outs have improved significantly. Even with comprehensive site assessment procedures in place, and at a time when the jack-up industry is increasingly focused on the control of risks, foundation incidents continue to occur. To address these issues a Joint Industry Funded Project ("InSafe JIP") has been launched with the intention of developing a document titled “Improved Guidelines for the Prediction of Geotechnical Performance of Spudcan Foundations during Installation and Removal of Jack-up Units”.

COFS, the University of Oxford, the National University of Singapore (NUS) and RPS Energy, UK, form the Project team to the InSafe JIP.

The InSafe JIP has received over 120 case records of jack-up installations provided by its industry sponsors. Mark Cassidy, Mark Randolph, Britta Bienen and Shazzad Hossain of COFS are providing advice on the optimisation of down-hole tool selection, laboratory testing and bearing capacity predictions. They are working with Julian Osborne (RPS Energy), Guy Houlsby (Oxford University), Colin Leung and Kar Lu Teh (National University of Singapore) as members of the project team.

The project has widespread industry support from nineteen international oil and gas companies, safety regulators and engineering service providers. Further details of the InSafe Project can be found at http://insafe.woking.rps plc.co.uk/ or in the publications:


An integrated soil testing device for jackup rigs – Keppel Offshore & Marine, Singapore

COFS continues its productive partnership with KeppelFELS, a Singapore-based company specialised in the design and construction of offshore drilling vessels, through their technology arm KOMtech. Mark Randolph and Mark Cassidy are collaborating with Matthew Quah and Okky Purwana (KOMtech) and Loek Keizer (A.P. van den Berg) on the design of a soil penetrometer device and interpretation system integrated with mobile jack-up rigs. The system is designed to enable characterizations of seabed underneath jack-up legs prior to its installation. The system is currently under development and the prototype design is expected to be introduced to the market by KeppelFELS and A.P van den Berg in the second half of 2009.

Figure 8: Concept of integrated penetrometer
Geomechanics Laboratory Activity 2008

The Geomechanics Laboratory, under manager Binaya Bhattarai, with laboratory staff Claire Bearman, Kristin Hunt, Aaron Groves and Ying Guo had another busy year, carrying out testing services for offshore oil and gas projects, and onshore (mainly mining) projects. Clients included Advanced Geomechanics, Arup, Benthic Geotech, Coffey Mining, Iluka Resources, JP Kenny, Knight Piesold, Pt Calmarine (Indonesia) and Worley Parsons, on behalf of end-clients Barrick, BP, Chevron, Esso/BHP, Hong Kong Government, Inpex, Shell and Woodside.

Offshore projects included Blacktip, Brecknock, F-Block, Gorgon, Icythys, Marlin-B, Pluto, Tangguh (Indonesia), Wheatstone, and onshore projects included CLP Power (Hong Kong), and mining projects Callie Deeps, Cloud Break, Gingin, Jacinth-Ambrosia, Murray Basin, Surprise Pit, Poltava (Ukraine), Reko Diq (Pakistan), Tutunup South, and Wagerup.

Services included X-ray photograph of core samples, monotonic and cyclic simple shear and triaxial tests, standard and ‘constant normal stiffness’ (CNS) direct shear tests, fall-cone sensitivity tests, Rowe cell and standard oedometer consolidation tests, and thermal and electrical conductivity tests.

Figure 9: General view of section of the Geomechanics Laboratory, showing 1 simple shear machine (right) and 3 triaxial machines in the background
**Conferences**

**GeoCongress, New Orleans, USA**

Mark Randolph and David White made the long journey to New Orleans for the ASCE's annual GeoCongress event in March. They both made presentations in a special session organised by Rodrigo Salgado – a former visitor to COFS – on “The confluence of visualisations from experimental and theoretical modelling”. They also presented an invited paper co-authored with Hongjie Zhou entitled “Physical and numerical simulation of shallow penetration of a cylindrical object into soft clay”.

**3rd International Conference on Site Characterization, Taipei, Taiwan**

COFS and UWA were well represented at the 3rd International Conference on Site Characterization, Taipei, Taiwan, in April. Martin Fahey attended as a member of TC16, the technical committee of the ISRMGE dealing with site characterisation, the sponsor of the conference, and chaired a couple of sessions. The Conference was also attended by Mark Randolph, Han Eng Low, and James Schneider, who presented a General Report.

Figure 1: Martin Fahey, leading the discussion at a session at the 3rd International Conference on Site Characterization. Session chaired by Pedro Sêco e Pinto (Portugal), with Roberto Quintal Coutinho (U. Pernambuco, Recife, Brazil) and António Viana de Fonseca (U. Porto, Portugal).

Figure 2: Mark Randolph explaining the finer points of a Taiwanese tea ceremony to An-Bin Huang, the organiser of the conference, at the 3rd International Conference on Site Characterization, Taipei, Taiwan, April. Among the interested spectators is Carlos Santamarina (Georgia Tech).

Figure 3: “But you’re not Fernando Schnaid?” (Martin Fahey impersonating Fernando Schnaid at the 3rd International Conference on Site Characterization, but James Schneider is not fooled!)
Offshore Technology Conference, Houston, USA

Mark Cassidy, Christophe Gaudin, Mark Randolph and David White all attended the Offshore Technology Conference in Houston at the start of May 2008. Four papers involving COFS authors (Mark Randolph, David White, Christophe Gaudin and Han Eng Low) and honorary COFS author, Chuck Aubeny (following a 2006 UWA Gledden Visiting Senior Fellowship at COFS) from Texas A & M University were presented in the technical sessions. Mark Randolph had the pleasure of receiving, on behalf of his former PhD supervisor, the late Professor Peter Wroth, an award marking Peter’s entry into the ASCE OTC Hall of Fame for his seminal paper with Robert Kirby (then with Woodward Clyde) on the application of critical state soil mechanics to the prediction of axial capacity for driven piles in clay.

The ASME 27th International Conference on Offshore Mechanics and Arctic Engineering, Estoril, Portugal

The ASME 27th International Conference on Offshore Mechanical and Arctic Engineering was held in Estoril, Portugal in June 2008. The total of five papers were presented by Mehrdad Kimiaei, Yinghui Tian, Dong Wang, Matt Hodder and Johnny Cheuk (co-authored with David White), covering the topics of seismic lateral response of piles, pipe-soil interaction macroelement, the keying of plate anchors and centrifuge modelling of pipe/riser laying.

Géotechnique’s 60th Birthday Commemoration, London, United Kingdom

Dave White, Susie Gourvenec and Matt Hodder represented COFS at the meeting and dinner held at London’s ICE to commemorate the 60th Birthday of Géotechnique. The June 2008 issue of the journal comprised of review papers documenting the past, present and future of Géotechnique. Dave authored a review focused on physical modelling, which provided a good excuse to showcase some of the achievements involving the UWA centrifuge facility that have been published in Géotechnique over the past 20 years.
2nd British Geotechnical Association International Conference in Foundations (ICOF), Dundee, United Kingdom

ICOF2008 was organised by the Geotechnical Engineering Research Group of the University of Dundee. Mark Randolph delivered a keynote lecture entitled “Offshore foundation design – A moving target”, co-authored with Dave White. Additional COFS staff who were authors or co-authors on papers included Britta Bienen, Mark Cassidy, Susan Gourvenec, Matt Hodder, Nina Levy and Shinji Taenaka. Interestingly, COFS contributed the most papers out of any organisation whilst also possibly having to travel the furthest to the conference location – approximately 14 700 km ‘as the crow flies’.

18th International Offshore and Polar Engineering Conference (ISOPE-2008), Vancouver, British Columbia, Canada

Figure 6: Fraser Bransby (University of Dundee, UK), Dave White, Ana Ivanovic (University of Aberdeen, UK) and Matt Hodder enjoying Lord Provost’s Reception and Poster Exhibition

Figure 7: Carlo Viggiani (Frederico II University, Naples, Italy) and Mark Randolph at question time after Prof Viggiani’s keynote lecture concerning horizontally loaded piles, where he urged the engineering craftsmen of the world to unite

Figure 8: Mark Cassidy at the ISOPE-08 conference presenting a paper co-authored with Yinhui Tan on a practical approach to numerical modelling of pipe-soil interaction

The annual conference of the International Society for Offshore and Polar Engineering was held in Vancouver, Canada. Ten papers were presented among Mark Cassidy, Christophe Gaudin and Hugo Acosta-Martinez from COFS, and Liang Cheng, Yuxia Hu, Ming Zhao and Hongwei An, from the School and Civil and Resource Engineering. The topics covered problems related with plate anchors, cyclic loading on shallow skirted foundations, and numerical simulation of pipe-soil interaction, load-displacement behaviour of spudcans, and a variety of hydrodynamics issues.

Figure 8: Mark Cassidy at the ISOPE-08 conference presenting a paper co-authored with Yinhui Tan on a practical approach to numerical modelling of pipe-soil interaction

The annual conference of the International Society for Offshore and Polar Engineering was held in Vancouver, Canada. Ten papers were presented among Mark Cassidy, Christophe Gaudin and Hugo Acosta-Martinez from COFS, and Liang Cheng, Yuxia Hu, Ming Zhao and Hongwei An, from the School and Civil and Resource Engineering. The topics covered problems related with plate anchors, cyclic loading on shallow skirted foundations, and numerical simulation of pipe-soil interaction, load-displacement behaviour of spudcans, and a variety of hydrodynamics issues.
5th International Geotechnical Seminar – Deep Foundations on Bored and Auger Piles (8–10 September), Ghent, Belgium, 4th International Symposium on Deformation Characteristics of Geomaterials (22–24 September), Atlanta, Georgia, USA

Barry Lehane had a busy September on the Conference Circuit, presenting keynote lectures at the 5th International Geotechnical Seminar – Deep Foundations on Bored and Auger Piles (8–10 September), Ghent, Belgium, and at the 4th International Symposium on Deformation Characteristics of Geomaterials (22–24 September), Atlanta, Georgia, USA.

12th International Conference of the International Association for Computer Methods and Advances in Geomechanics (IACMAG), Goa, India

The 12th IACMAG conference was held in Goa at the start of October 2008, bringing together several hundred researchers and practitioners involved in numerical simulation of geotechnical problems. The conference was attended by Mark Randolph, who presented a keynote lecture prepared jointly with Dong Wang, Hongjie Zhou and Shazzad Hossain from COFS and Yuxia Hu from the School of Civil and Resource Engineering at UWA. The lecture highlighted the diverse application of large deformation finite element analysis to a range of problems in offshore geotechnical engineering. Other COFS papers presented at the conference included one by Christian Le Blanc (a former visitor to COFS) and Mark Randolph on the interpretation of piezocone data in silts, and one by Richard Merifield (formerly at COFS), Dave White and Mark Randolph on the breakout resistance of partially embedded pipelines. In the awards ceremony at the conference, Susan Gourvenec and her co-authors Mark Randolph and Oliver Kingsnorth were awarded a ‘best paper’ award for a paper published in the International Journal of Geomechanics.
2nd Jack-Up Asia Conference and Exhibition 2008, Singapore

The 2nd Jack-Up Asia Conference was held in Singapore in November 2008, bringing together academia and industry in the field. Presentations made by Mark Cassidy, Shazzad Hossain and regular COFS visitor Kar Lu Teh included a recent experimental investigation of Swiss Cheese Drilling as a preventative mitigation method against punch-through in stiff over soft clay, an overview of spudcan performance on clays as well as a comparison of the penetration behaviour of spudcan and skirted footings in sand overlying clay. The fruitful collaboration with Keppel Offshore Technology Development resulted in the presentation of an integrated in-situ soil testing device for jack-up rigs. The conference was also used as a platform to introduce the Joint Industry Project (JIP) “InSafe” on the development of improved guidelines for the installation and extraction of jack-up platforms. With widespread industry support from 19 international oil and gas companies and safety regulators, the project brings together the expertise of three universities: COFS at UWA, Oxford University and the National University of Singapore (NUS). The conference was also attended by Mark Randolph and Britta Bienen.

Deep Offshore Technology Conference, Perth, Australia

The Deep Offshore Technology Conference came to Perth in December 2008. COFS was represented by David White and Christophe Gaudin who presented a paper entitled “Simulation of seabed pipe-soil interaction using geotechnical centrifuge modelling”. The paper summarised the recent advances in modelling technology achieved for pipeline design studies in the beam centrifuge. These techniques have raised the profile of COFS amongst the local pipeline engineering community, and are now widely used on project-specific testing.

SHIRMS 2008 – 1st Southern Hemisphere International Rock Mechanic Symposium, Perth, Australia

The Australian Centre for Geomechanics, in collaboration with The University of Western Australia held the First Southern Hemisphere International Rock Mechanic Symposium. SHIRMS is a new initiative and its success is the result of an active involvement and outstanding contribution from a world-wide authorship. This event attracted publications from world leaders in fundamental, mining, civil and petroleum rock mechanics engineering. Boris Tarasov delivered a keynote lecture entitled “New insight into the nature of shear rupture propagation in pristine rocks and pre-existing faults”. He outlined a new rupture mechanism which can eliminate friction and create positive forces assisting the shear rupture displacement and propagation. This mechanism explains a number of paradoxes observed in rock behaviour during earthquakes and rockbursts. The lecture generated much informal discussion.

1st European Symposium on Geotechnical Centrifuge Modelling (Eurofuge08), City University, London, United Kingdom

Christophe Gaudin and David White took advantage of their dual citizenships to attend the first European Symposium on Geotechnical Centrifuge Modelling, Eurofuge, in May in City University, London. The Symposium was the opportunity to gather the community of centrifuge modellers and industry partners to discuss centrifuge developments and impact on industry practices. Christophe and Dave made three presentations showcasing new modelling techniques developed in the COFS centrifuges and successful industry research projects on pipeline-anchor interaction and pipeline buckling.
19 February 2008
Sam Frydma
Technion - Israel Institute of Technology, Israel
*Unsaturated soil mechanics – a critical review of physical foundations*

29 February 2008
Jayantha Kodikara
Monash University
*Modelling of Geo-structures subject to climate forcing*

7 March 2008
Martin Fahey
Civil & Resource Engineering, UWA
*Modelling creep with Plaxis*

14 March 2008
Melissa Landon
University of Massachusetts USA
*Development of a non-destructive sample quality assessment method for soft clays*

28 March 2008
Karoline Krost
Technischen Universitat Darmstadt, Germany
*Consolidation around partially embedded submarine pipelines*

4 April 2008
Tong Ming Zhou
Civil & Resource Engineering, UWA
*Dependence of the wake on cylinder inclination*

11 April 2008
Silvan Marchetti
Aquila University, Italy
*Recent developments in DMT testing*

18 April 2008
Jonathan Liang
PhD Student, UWA
*Seismic risk analysis for Perth*

2 May 2008
Edmond Tang
Masters Student, UWA
*Numerical analysis of cable stayed bridge subject to blast load*

9 May 2008
James Schneider
Research Associate, COFS
*Analysis of cyclic liquefaction triggering for compressible and aged sands using in situ tests*

23 May 2008
Norhisham Bakhary
PhD Student, UWA
*Damage detection using Artificial Neural Network*

30 May 2008
Hugo Acosta-Martinez
PhD Student, UWA
*Degradation of uplift capacity of skirted foundations with time*

6 June 2008
Shazzad Hossain
PhD Student, UWA
*Novel mechanism-based design approaches for spudcan foundations on clays*

1 August 2008
A. Sivakumar
Queens University Belfast, Ireland
*Assessment of earth pressure coefficient in overconsolidated clays and a new method of measuring plastic limit of fine materials*
8 August 2008

Lina Ding
PhD Student, UWA
Evaluation of bridge load carrying capacity using updated finite-element model and nonlinear analysis

15 August 2008

Nathan Scott
School of Mechanical Engineering, UWA
Monadelphous – Introducing the Monadelphous Integrated Learning Centre

22 August 2008

Ashraf Osman
Durham University, UK
The Mobilisable Strength Design Method

29 August 2008

Motoyuki Suzuki
Yamaguchi University, Japan
Residual state strength of cemented clays

1 September 2008

Tejas Murthy
Purdue University, USA
Deformation fields in indentation problems

5 September 2008

Boris Tarasov
COFS, UWA
New mechanisms of spontaneous rock failure at great depth (source of earthquakes)

10 September 2008

Paul Schamine
Deltares, France
From STREAM to a flood of knowledge

12 September 2008

Bernd Zastrau
On the prediction of the textile reinforced concrete behaviour

26 September 2008

Zhenhe Song
Civil and Resource Engineering, UWA
Pullout capacity and keying of plate anchors in clay

10 October 2008

Long Yu
COFS, WA
A 3-dimensional RITSS large deformation finite element method and its application on the foundation punch-through failure and plate anchor keying problems

17 October 2008

Noel Boylan
COFS, UWA
The development of a DSS apparatus for Peat soils

24 October 2008

Daniela Ciancio
Civil and Resource Engineering, UWA
Comparison between elasto-plastic and rigid-plastic interface elements in the FE simulation of crack nucleation and propagation

31 October 2008

Britta Bienen
COFS, UWA
Modelling of jack-ups and their shallow foundations in 3D

14 November 2008

James Hengesh
COFS and School of Environmental Systems Engineering, UWA
Seismic source characterisation and geohazard assessments for critical infrastructure engineering
After a break in 2007, COFS held two workshops in September 2008: The annual research workshop as well as a pipelines workshop. The COFS workshop is an informal in-house conference that allows every researcher in the group to present their recent activities and latest findings as well as participate in group discussions and social events. Five international visitors took part in the 2008 workshop: Colin Leung, Kee Kiat Tho, Kar Lu Teh and Cheng Ti Gan from NUS as well as Andrew Deeks, our long-term visitor from Cambridge University. The total number of participants was 40.

The presentations were grouped into five sessions, with time allowed at the end of each session for intensive discussion on the key research areas in COFS:

- Shallow foundations I and II,
- Anchors and piles, and
- Soil characterisation I and II.

The separate pipelines workshop, held in the same week, illustrates the recent focus on this area of research. The CSIRO Wealth from Ocean Flagship Cluster on Subsea Pipelines provided a focus of the workshop, with presenters including Edson Nakagawa (CSIRO Wealth from Ocean Flagship), Mehdi Golbahar and Jaya Kumar Seelam (University of Queensland), Donghee Seo (Yonsei University, Korea), Zhi Gang Xiao and Xiao Ling Zhao (Monash University) and Grant Pusey (Curtin University). CSIRO’s Cedric Griffith, Luiz Franca, Chris Dyt and Reem Freij-Ayoub also participated.

Over the two days workshop 21 presentations of 15 minutes length were made, allowing the majority of the researchers in the Pipeline cluster and COFS the opportunity to present their findings, as well as participate in group discussions. Five sessions were held, covering the topics of:

- Research aims and site characterisation,
- Site characterisation and seabed morphology,
- Soil-pipe modelling,
- Pipeline hazards, and
- Structural fatigue and monitoring.

In the opening session, Edson Nakagawa presented an overview of Blue GDP research at CSIRO.

A highlight of the workshop week was the invited keynote address by Nick Brown of JP Kenny, Perth. In his lecture, Nick outlined current trends within the Australian and international pipeline industry and emphasised areas where research could make an impact on future projects. The lecture was well attended by both academics and the local geomechanics and offshore industry.

The workshop week was concluded with a dinner, allowing all participants to relax, catch up and look forward to 2009!
Characterisation of Soft Sediments

For a large number of projects within COFS, developing improved methods of determining the strength and deformation characteristics of very soft seabed sediments is of primary interest. Such projects include behaviour of pipelines on the seabed, stability of seabed slopes and the run-out behaviour of shallow seabed slides. The emphasis is on to determine the strength in situ using the T-bar and ball penetrometers. Initially, such devices were used to obtain strength profiles in a single ‘push’ (as in the standard cone penetrometer test), but the current emphasis is on cyclic tests and tests with piezometers installed in the T-bar or cone, to enable consolidation characteristics, and inherent rate effects, to be investigated.

Determination of soft seabed shear strength at very shallow depth

Within the framework of the MERIWA (Mining and Energy Research Institute of WA) submarine landslide research programme and the associated need for quantifying accurately the seabed strength at very shallow depth, Dave White, Christophe Gaudin, Noel Boylan and Hongjie Zhou developed a new analysis for the interpretation of T-bar penetrometer tests at shallow embedment and in soft soils, which is an increasingly significant consideration in the design of seabed infrastructure, including pipelines. The analysis captures two mechanisms that are usually neglected: (i) soil buoyancy and (ii) the reduced bearing factor arising from the shallow failure mechanism mobilised prior to full flow of soil around the bar (Figure 1). The framework derives from theoretical considerations and is calibrated using large deformation finite element analyses. The depth at which the steady deep penetration condition is reached is shown to depend on the normalised soil strength, $s_u/\gamma D$, and may be up to several diameters. The effect of this new procedure on the inferred soil strength compared to the conventional approach is illustrated through T-bar tests in three different centrifuge samples, spanning a range of strength ratios (Figure 2).

Figure 1: Soil deformation patterns at onset of backflow

Figure 2: Penetration resistance and undrained shear strength profiles from centrifuge T-bar tests with and without corrections for soil buoyancy and shallow effects (grey and black lines respectively)
Piezoball Penetrometer

Research on the application of the piezoball penetrometer in soft soil characterisation is currently being undertaken by Han Eng Low as part of his PhD project. A miniature and a field scale piezoball has been designed by Han Eng and fabricated at COFS. The miniature piezoball has a diameter of 15 mm and is fitted with a pore pressure transducer at the mid-height of the ball, while the field piezoball has a diameter of 60 mm and is fitted with four pore pressure transducers at the mid-height of the ball and one pore pressure transducer at the tip of the ball. Figure 3 shows photographs of the miniature and field piezoballs.

Miniature piezoball and piezocone penetration tests were carried out in reconstituted Burswood clay in the UWA centrifuge. Figure 4 presents the comparison of pore pressure and the corresponding normalised pore water pressure ratio profiles measured by piezoball \[ u_{m-ball} = \frac{(u_{m-ball} - u_0)}{q_{ball}} \] and piezocone \[ u_p, B_q = \frac{(u_p - u_0)}{q_{net}} \]. Figure 4 clearly shows that the \( u_{m-ball} \) measured by the piezoball is consistently lower than the \( u_p \) measured by the piezocone. Correspondingly, \( B_{m-ball} \) values are generally lower than \( B_q \).

Figure 5 shows the comparison between the normalised dissipation curves measured by piezoball and piezocone. It is interesting to find that the normalised time factor \( T = \frac{c_v t}{d^2} \) for the piezocone is about 2.5 times higher than that for the piezoball to achieve the same degree of consolidation. This implies that, when the two penetrometers have the same diameter, the excess pore pressure around the piezoball dissipates faster than that around the piezocone. The findings from these tests suggest that the piezoball could prove a viable alternative tool, and possibly better than the piezocone, for estimating the in situ coefficient of consolidation.

![Piezoball Penetrometer](image)

Figure 3: (a) Miniature piezoball (b) Field piezoball

![Piezoball Penetrometer](image)
Figure 4: Profiles of (a) $u_2$ and $u_{mball}$ (b) $B_q$ and $B_{mball}$

Figure 5: Normalised piezocone and piezoball dissipation curves
Numerical simulation of piezoball dissipation test

Complementing the experimental research by Han Eng Low, large-deformation finite element analysis is being undertaken by Hongjie Zhou to provide the theoretical solution for the interpretation of piezoball dissipation tests. This approach combines small strain finite element computations interspersed by frequent regeneration of the finite element mesh and interpolation of field values from the old mesh to the new mesh (See COFS Annual Report 2005 – 2007). By this means, the notorious numerical difficulty in large displacement problems due to excessive mesh distortion can be completely overcome. To ensure an accurate distribution of penetration-induced excess pore pressure and decay after the arrest of the piezoball, the Modified Cam-Clay model representing the soil skeleton has been successfully incorporated into the LDFE method with the flow of pore fluid governed by a Biot-type consolidation formulation.

Figure 6 shows the distribution of excess pore pressure after a 3-diameter undrained penetration of smooth-shafted ball in kaolin clay, which is commonly used in physical modelling. Figure 7 plots the normalised dissipation curves at the four monitored locations indicated in Figure 6. It can be seen that there is slight oscillation in pore pressure for the position on the equator (point D). Accordingly it seems B or C is the preferable location for pore pressure transducers.

Figure 6: Distribution of excess pore pressure after a 3-diameter penetration

Figure 7: Normalised dissipation curves
Shaft effect on the behaviour of the ball penetrometer

In addition, the effect of the shaft on the behaviour of the ball penetrometer was evaluated in terms of the monotonic penetration resistance in Tresca soil and the resistance degradation during cyclic penetration and extraction in strain-rate-dependent and strain-softening clay. Meanwhile, the change in mean total stress during cycling was monitored at some locations around the ball. Figure 8 compares the variation in mean total stress at three positions (indicated in Figure 6) for (a) a ball without a shaft, (b) a ball with a shaft, with a shaft ratio of (1:3). Figure 9 plots the excess pore pressure measured on the equator of the centrifuge piezoball by PhD student Han Eng Low. It is interesting to note that the variation trend of pore pressure agrees well between the large deformation finite element modelling and centrifuge testing. Due to the cavity expansion mechanism resulting from the ball's shaft, the pore pressure gradually increases during penetration and decreases during extraction. For the no-shaft case, the pore pressure profile is nearly symmetrical about the vertical axis.

Figure 8: Variation of mean total stress during cyclic penetration and extraction in strain-rate-dependent and strain-softening clay

Figure 9: Variation of excess pore pressure on the equator of the piezoball
Strength of clays at high water contents

Nathalie Boukpeti has focused her work on characterising the strength of fine-grained soils over a wide range of water contents, spanning the domains of behaviour that are usually defined separately as soil and fluid. A testing campaign was conducted on remoulded samples prepared in the laboratory, which included T-bar and Ball penetrometer tests (see Figure 10), vane shear tests, fall cone tests and viscometer tests. These tests were performed with the help of Han Eng Low, Honours student Joshua Mikolajczyk, visiting students Nicholas Bennett and Brett McKiennan, and Vacation Scholar Siew Renand. Effects of rate and remoulding on the measured strength were investigated. Three materials were tested, namely kaolin clay, Burswood clay, and a carbonate soil. Analysis of the results shows that the variation in shear strength over the solid and liquid ranges can be described by a unique function of water content – suitable normalized for a given soil (see Figure 11). Furthermore, the effect of strain rate and degree of remoulding can be accounted for by multiplying the basic strength parameter by appropriate functions, which seem to be independent of the current water content.

Figure 10: Ball penetrometer test on remoulded sample of Burswood clay

![Ball penetrometer test on remoulded sample of Burswood clay](image)

Figure 11: Variation of shear strength with water content

![Variation of shear strength with water content](image)
Foundation Piles

Research into the behaviour of foundation piles continues on two fronts, both related to optimisation of the shape and construction processes used for foundation piles. This represents a trend away from the refinement of design methods, which was a task that occupied a group led by Barry Lehane, over the period 2005-2007, leading to publications and PhD completions in 2008. The API recommended practice for offshore pile design now includes the design expressions derived by Barry’s group, which are referred to as the “UWA-05” method. Barry’s PhD student James Schneider was awarded his PhD in 2008. A series of publications authored by Barry, James, and former COFS PhD student Xiangtao Xu emerged in 2008, providing guidance on the improved accuracy provided by their new design methods (Figure 1). Their studies also provide cautionary advice in relation to the reliability of all pile design methods that are based on extrapolation of correlations that have been calibrated using a database of smaller, predominantly onshore, pile load tests.

Figure 1: Statistical performance (mean and standard deviation) of pile design methods compared to UWA database of 77 high quality pile load tests (Schneider et al. 2008)
Rotary-jacking of foundation piles

The method by which a pile is installed influences the strength and stiffness (the ‘performance’) of the resulting foundation. In collaboration with Japan’s Giken Seisakusho Ltd., University of Cambridge PhD student Andrew Deeks, conducted centrifuge tests to investigate the pile jacking process in sand under supervision of Dave White.

Tests were conducted using the UWA beam centrifuge to investigate ‘rotary-jacking’; in which simultaneous application of torque and axial force is used to install tubular displacement piles by rotating them into the ground (Figure 2). This rotary-jacking technique is used in practice by Giken’s giant ‘gyropiler’, which is a large machine capable of installing tubular piles in difficult ground conditions without the noise and vibration associated with conventional dynamic techniques.

Theoretical models were developed to aid interpretation of the rotary-jacking behaviour and to extend the models developed for the behaviour of closed-ended piles to that of open-ended piles.

The key outcomes of these tests were:

(a). The development of new methods to predict the axial and torsional installation loads required to install closed and open ended rotary-jacked piles in sand (Figure 3). These methods used failure envelopes in combined axial-torsional load space, and corresponding flow rules, to allow the resistance under a particular combination of axial and torsional movement to be assessed.

(b). The observation of behaviour that helps to explain the creep and ‘set-up’ of pile shaft capacity in sand. The unit shaft resistance was consistently observed to increase with increasing rotation of the pile during the centrifuge model tests. Mechanisms were proposed that link this increase in strength to the observation of increasing pile capacity with time, ‘set-up’, in the field.

Figure 2: Rotary-jacking experimental setup

Figure 3: Failure envelope of combined axial and torsional pile base loads (closed ended pile)
Shape effect of piles in sand

The behavior of different shaped piles such as sheet piles and H-piles has been investigated in collaboration with Nippon Steel Corporation. In this study, particular emphasis is given to the effect of the cross-sectional geometry of a pile on the performance in sand (i.e. shape effects). PhD student Shinji Taenaka performed comparative experimental studies using the drum centrifuge at UWA under supervision of Dave White and Mark Randolph.

The centrifuge test program compared horizontal stresses acting on the shaft of 7 different shaped piles during installation in medium dense sand, where the model pile had 6 pressure cells on centre shaft and double attachment plates to form different shapes (Figure 4). Measured profiles during installation demonstrated an extremely dramatic variation in the horizontal stresses acting on the pile shaft, arising from shape effect as shown in Figure 5. These observations show that the shear stresses on the shaft can be strongly influenced by the cross-sectional geometry. Small changes in the cross-sectional geometry have the potential to significantly enhance the shaft capacity of axially-loaded piles.

Figure 4: Drum centrifuge modeling (left: a model pile)

Figure 5: Horizontal stress changes with depth for different shaped piles
Shallow Foundations

Research on foundation and anchoring systems has ranged from extremely shallow interaction, aimed ultimately at pipeline response, to skirted foundations, spudcans and deeply embedded plate anchors. With the exception of punch-through of spudcans on sand overlying clay, the studies have focused mainly on foundation response on soft, lightly overconsolidated clay.

PhD Student Yue Yan is currently working on the theoretical understanding of the response of a new class of seabed penetrometer, designed specifically for assessing pipe-soil interaction parameters, under supervision of Dave White and Mark Randolph. With the aim to focus on the axial pipe-soil interaction, a toroidal pipe geometry has been explored. A series of numerical simulations of toroidal footings penetrating into soft clay have been performed using ABAQUS. The analyses focused on the shape effects of the penetrometer and key behaviour of the soft clay that influences the pipe-soil interaction. Figure 1 shows the three-dimensional model.

Figure 2a shows that the torsional capacity factor is related to the aspect ratio of the toroid, where L is the internal radius and D is the diameter of the pipe forming the toroid. The embedment ratio, w/D, also affects the normalised capacity. A maximum increase of 38% was found for a hemi-toroid with L/D = 0.6 relative to a hemi-toroid with L/D = 2. The torsional capacity factor is up to 20% greater for an embedment ratio of w/D = 0.5, compared with w/D = 0.1. The aspect ratio of the toroid (L/D) also has a significant effect on the normalised torsional stiffness, as shown in Figure 2b.

The findings have helped to establish an optimal geometry for a toroidal penetrometer to be used in experimental work, aiming to minimise the size of the instrument whilst avoiding unwanted interaction effects.

Ashraf Osman (visiting from Durham University) and Dave White devised a simple technique for assessing the response of a circular foundation to vertical (V) and horizontal (H) load in undrained conditions, taking into account the load path and the non-linearity of the soil stress-strain response.

Firstly, non-linear finite element analysis was used to illustrate that a unique elastic soil stiffness does not apply for combined V-H loading on non-linear soil. The equivalent secant elastic stiffness for a given load combination is different in each direction, and is affected both by the magnitude of the V and H loads, and by the order in which they are applied.

A simplified calculation method for estimating the foundation response in these conditions was devised. This method assumes that the element and the boundary value responses

Figure 1: Finite element model

Figure 2a: Normalised torsional capacity for fully rough toroidal penetrometer

Figure 2b: Normalised torsional stiffness, $K_T = T/GD^3\theta$
are similar – i.e. they have the same normalized shape. This assumption yields a simple calculation tool which provides a swift alternative to numerical analysis, in return for a modest loss of accuracy.

The accuracy of this simple approach was confirmed for different combinations of vertical and horizontal load, different load paths, and for different soil stress-strain responses. Close agreement between the finite element analysis and the simplified calculation method is evident from Figure 3, with a maximum error of ∼20%.

![Figure 3: Comparison of non-linear FE analysis and simplified calculation method](image)

A series of centrifuge model tests was conducted by COFS visitor David Richards, of Southampton University, working with Dave White and Barry Lehane. These tests examined the failure mechanisms during rapid horizontal pushover of an electricity transmission line support tower (Figure 4), simulating the response in the event of a broken transmission line or under wind gust loading. A model transmission tower supported on four pad foundations buried in clay and backfilled with sand was loaded horizontally at different rates. The resulting loads at each foundation were measured during fast and slow pushover events. In particular, the tests examined the influence of tensile resistance mobilised at the underside of the footings. Conventional design practice is to neglect this tensile resistance, which could be overly conservative. The measured performance of the tower footings is compared with the results of a series of tests in which a single footing is subjected to purely vertical loading in compression and tension. There was good agreement between the measured vertical response of the tower footings and the single footing tests. The tower response was back-analysed as a simple push-pull model (Figure 5a), since the moment capacity of the individual footings provides minimal resistance to horizontal loading. The calculated uplift capacity of the footing backfill provides a close match to the observed response of the tower footings when subjected to slow pushover (see Figure 5b). During a fast pushover event, additional capacity is mobilised, which arises from the tensile resistance created by the reverse bearing capacity beneath the base of the footings that are subjected to uplift.

![Figure 4: Model transmission tower](image)
Figure 5a: Transmission tower pushover failure mechanisms

Figure 5b: Transmission tower pushover failure mechanisms
Shazzad Hossain, who was recently appointed as a Research Associate, has explored during his PhD the effects of strain rate and strain softening on the penetration resistance of spudcan foundations. He carried out some analyses using a large deformation finite element (LDFE) approach, modifying the simple elastic-perfectly plastic Tresca soil model to incorporate strain-softening, and strain-rate dependency of shear strength. Parametric analyses were undertaken varying the strain-rate parameter $\mu$, the sensitivity $S_t$ and ductility $\xi_{95}$ of the soil, and the normalised penetration rate. For a single layer clay, adjustment factors were proposed to modify the bearing capacity factors, $N_c$ or $N_{cd}$, obtained on the basis of ideal elastic-perfectly plastic soil behaviour as (see Figure 6)

$$\frac{N_{c, \text{adjust}}}{N_c} \quad \text{or} \quad \frac{N_{cd, \text{adjust}}}{N_{cd}} = \frac{(1+R_b\mu)}{S_t} \left(1+\left(S_t - 1\right)e^{-7.2/\xi_{95}}\right)$$

$R_b$ ranges from 1.45 to 0.7

For stiff-over-soft clay, the analyses demonstrated that strain softening and rate dependency significantly influenced the likelihood of spudcan punch-through and its severity. While either no punch-through or very minor reduction in penetration resistance occurred for ideal (non-softening) soils, mild to more catastrophic punch-through was predicted in deposits of rate-dependent, softening clays. The degree of bearing capacity reduction with penetration, that is the severity of punch-through, increased with increasing rate dependency and brittleness (see Figure 7).
Long Yu, a Research Associate working with Yuxia Hu, has been working on developing a robust and accurate numerical method to simulate the penetration response of spudcan foundations on sand overlying clay. The AFENA FE code was used in conjunction with RITSS (Remeshing and interpolation Techniques with Small Strain) to simulate the large deformation behaviour of soil. A simple two-dimensional axisymmetric soil model with Mohr-Coulomb failure criteria was employed to simulate loose sand (with friction angle \( \phi' \leq 35^\circ \) and dilation angle \( \psi = 0 \)), in which the soil softening can be ignored. Figure 8 shows the penetration responses for the cases with sand thickness of \( H/D = 1.0 \). An obvious peak spudcan capacity is observed in each case. The critical penetration depth, where the peak capacity is reached, increases linearly from 0.18D to 0.33D with the \( s_u \) increases from 10 kPa to 100 kPa. The larger is \( s_u \), the more profound is the peak in the bearing capacity. The height and shape of the sand plug, which was formed underneath the spudcan during penetration, depend on the relative thickness of the sand layer (\( H/D \)) and the shear strength of clay (\( s_u \)), as illustrated in Figure 9.

For the cases of dense sand (\( \phi' > 35^\circ \)) over clay, the strain softening in sand is dominant during loading, which will affect the peak capacity of spudcan and the punch through failure mechanism. Currently, Long and Yuxia are trying to carry out some modifications to the Mohr-Coulomb model, such as reducing the friction and dilation angles with increasing soil strain or stress, to simulate the softening in dense sand. Their focus is to establish practical equations or charts for the punch through peak capacity and critical penetration depth of spudcans on any sand overlying clay.

![Figure 8: Penetration response of spudcan on sand over clay (\( H/D = 1.0, \phi' = 30^\circ \))](image)

![Figure 9: Sand plug underneath the spudcan (\( H/D = 1.0, \phi' = 30^\circ \))](image)

(a) \( s_u = 10 \) kPa
(b) \( s_u = 100 \) kPa
Susan Gourvenec and Honours students Saskia Barnett and Katie Jensen used finite element analysis to investigate the effect of embedment, soil strength heterogeneity and structural connectivity on the undrained bearing capacity of skirted foundations under general loading (Figure 10). Saskia Barnett was awarded the Australian Geomechanics Society GFWA prize for her work on the project.

Susan Gourvenec and Mark Randolph used finite element analysis to investigate the effect of different types of embedment and interface roughness on the consolidation response around shallow foundations. Comparison was made between a rough and smooth buried plate, solid embedded foundation and skirted foundation. The results indicated the potentially significant increase in consolidation settlement and rate of consolidation for skirted foundations due to additional one-dimensional compression within the soil plug (Figure 11).

Figure 10: Undrained failure envelopes for skirted foundations under general loading; \(d/D = 0.5\), \(V/V_{ul} = 0.5\) (a) effect of soil strength heterogeneity \(\kappa\), \(s/B = 0\) and (b) effect of footing spacing \(s/B\), \(\kappa = 0\)

Susan Gourvenec and COFS visitor Andrew Deeks carried out a comparison of the failure surface method and classical methods to predict undrained bearing capacity under general loading. The study will be presented to the Shallow Foundation Task Group of the ISO 19901-4 and API RP-2A for consideration to include the failure envelope method in the main text of the current industry recommended practices.

Susan Gourvenec continued investigation into the drained response of circular surface and buried foundations under general loading in collaboration with Laura Govoni and Guido Gottardi from the University of Bologna, Italy, based on centrifuge tests carried out while Laura was a student visitor at COFS.

The response of shallow skirted foundations under transient (undrained) and sustained uplift loading continued being investigated by Hugo Acosta-Martinez in collaboration with Susan Gourvenec and Mark Randolph. Detailed interpretation of beam centrifuge tests involving eccentric uplift and the effect of gapping along the skirt-soil interface was carried out during 2008. All tests were carried out with an instrumented foundation model with skirt depth to diameter ratio \(d/D = 0.3\), in lightly over consolidated clay.

Figure 11: Consolidation response around shallow foundations; (a) Magnitude and (b) Rate of consolidation settlements

Susan Gourvenec and COFS visitor Andrew Deeks carried out a comparison of the failure surface method and classical methods to predict undrained bearing capacity under general loading. The study will be presented to the Shallow Foundation Task Group of the ISO 19901-4 and API RP-2A for consideration to include the failure envelope method in the main text of the current industry recommended practices.
For the case of eccentric uplift, results showed that load eccentricity reduces undrained capacity – by up to 40% for a normalised eccentricity \( e/D = 0.25 \), and increased displacement rates under sustained uplift by an order of magnitude compared with concentric loading. A similar kinematic mechanism was observed under eccentric transient and sustained uplift, involving initial rotation followed by rotation and vertical displacement. Figure 12 illustrates the kinematic mechanism during transient uplift with \( e/D = 0.25 \).

The effect of gapping was assessed in relation to tests that maintained nominal contact along the skirt-soil interface. It was found that consolidation following formation of a gap and prior to uplift had a significant detrimental effect, reducing undrained uplift capacity by up to 40% of that without a gap. In relation to sustained uplift, the rate of displacement was adversely affected by the presence of a gap along the skirt-soil interface, with or without consolidation following gap formation. The later is illustrated in Figure 13 showing the results from sustained uplift tests with and without gapping, in terms of degradation of uplift capacity with time for time-dependant displacements \( w/D = 0.5, 1 \) and 2%. It can be observed that the presence of a gap shifts the degradation curves to the left, indicating the increased rate of degradation of uplift capacity with time. The results show that the effect of gapping is potentially significant in accurately predicting the uplift resistance of shallowly skirted foundations.

The findings of these experimental results highlight the necessity to consider carefully the effect of eccentric loading and the likelihood of gapping along the skirt-soil interface occurring in the field in the design of shallow skirted foundation systems for offshore structures.
Christophe Gaudin, Mark Cassidy and Britta Bienen have been awarded a three year ARC Linkage Project to pursue the collaboration initiated with Keppel Offshore & Marine Pte Ltd to develop a new concept of hybrid foundation system to operate mobile jack-up unit to water depths up to 200 m. The concept relies on the development of suction to preload the foundation (and hence increase its overall capacity) and consequently reduce the dependency on self weight. Centrifuge tests were performed in 2007 on a simplified model of the hybrid foundation (Figure 14) and validated the concept of suction-induced preloading. The early stages of the new research programme focus on the quantification and the prediction of the effect of preloading on the V,H,M capacity of skirted foundations. A new series of centrifuge tests have been performed on skirted mats, indicating that a gain in vertical capacity of up to 35% could be reached, providing sufficient consolidation is achieved (Figure 15). Subsequent tests are in progress to quantify the associated gain in horizontal and moment capacity, before developing a more realistic model of the hybrid system.

Figure 14: Simplified model of hybrid foundation with skirted and caisson compartment

Figure 15: Example of vertical bearing capacity increase for a skirted mat resting on normally consolidated clay preloaded at 50% of its bearing capacity.
Plate anchors

Christophe Gaudin pursued his work on plate anchors and performed centrifuge tests along with PIV analysis to investigate the keying mechanism of plate anchors of various eccentricities subjected to pullout at various inclinations (Figure 16). Results have demonstrated that while the loss of embedment during keying is independent of the load inclination and remained limited to 0.1 times the anchor height for an eccentricity ratio of 1, it did increase with the loading inclination from 0.25 times the anchor height, for an loading inclination lower or equal to 45°, to 1.15 times the anchor height for a loading inclination equal to 90°. The PIV analysis also allowed identification of the plate anchor failure mechanisms generated during the different stages of the pullout. Different mechanisms were identified according to the eccentricity ratio, the load inclination and the loading stages. During keying, the mechanisms varied between pure rotational mechanisms for high eccentricity ratio, to plane shearing mechanisms along the anchor for low eccentricity ratio. During pullout, the mechanisms varied between a classical symmetrical flow around the edge of the anchor for a vertical pullout to a dissymmetrical ellipsoidal mechanism for inclined pullouts.

Subsequently, the model developed by Song et al., (2008) to predict the loss of embedment of plate anchors during keying, accounting for the load eccentricity, the plate thickness and the plate weight, has been updated to incorporate the load inclination. Results have been compared to the existing database and demonstrated the robustness of the model (Figure 17).
Continuous pullout processes of horizontal rectangular plate anchors were studied by Dong Wang in collaboration with Yuxia Hu and Mark Randolph using three-dimensional large deformation finite element method. Interface conditions of no-breakaway (bonded) and immediate breakaway (no tension) were considered at the anchor base. The effects of anchor roughness, aspect ratio, soil properties and soil overburden pressure were investigated. It was found that for rectangular deep anchors under immediate breakaway conditions, the maximum uplift capacity increased with soil elastic modulus, which suggests that lower bound limit analysis and small strain finite element analysis may overestimate the capacity. The soil beneath the anchor base separated from the anchor at a certain embedment depth near the mudline, once tensile stresses were generated (Figure 18). The ratio of separation depth to anchor width was found to increase linearly with the ratio of soil undrained shear strength to the product of soil effective unit weight and anchor width and was independent of the initial anchor embedment depth.

Suction embedded plate anchors used in practice are usually rectangular in plane shape, rather than strip, and the depth of embedment is restricted by the length-to-diameter ratio of the suction caissons used to install them. Dong Wang developed a 3D large deformation method based on ABAQUS to investigate the loss of embedment during the keying of plate anchors. The frictional ‘anchor chain – soil’ interaction was also integrated. It was found that the embedment loss decreases dramatically with increasing loading eccentricity ratio and decreasing chain angle at the mudline, and that it is independent of the soil rigidity. A fitted equation was proposed to predict the maximum embedment loss for a loading eccentricity ratio not less than 0.5 (Figure 19).
Pipelines

As offshore hydrocarbon developments extend into deeper waters located further from shore, the pipelines and risers that link the production facility to the wells, the offloading point, and in some cases provide an export route to shore, represent an increasingly important part of the development infrastructure. COFS has devoted increasing attention to the geotechnical behaviour of pipelines, partly through major research projects including the SAFEBUCK JIP, the CSIRO Wealth from Ocean Cluster on Subsea Pipelines and the MERIWA JIP on submarine slide – pipeline interaction (which is described in the geohazards section of this report). As well as the fundamental and applied research being conducted, COFS has significant engagement in testing for offshore pipelines currently being constructed in Australia and internationally. These are discussed in our industry collaboration section of this annual report.

Dave White, Christophe Gaudin and Helen Dingle published the outcomes of a centrifuge modelling study from the SAFEBUCK Joint Industry Project, which provided insight into the mechanisms during pipe laying and breakout (Dingle et al. 2008). The tests used PIV to observe the soil deformation mechanisms as the pipe penetrated into the seabed and then swept laterally (Figure 1).

These observations inspired theoretical and numerical modelling by Mark Randolph and David White (and Richard Merifield – formerly of COFS and now at the University of Newcastle). Plasticity limit analysis solutions (Figure 2) and finite element results were used to establish failure envelopes for shallowly embedded pipelines, which have now been published in Geotechnique. These analyses explored the influence of bonding at the pipe-soil interface and the effects of strength gradient, self-weight and heave around the pipe shoulders. These developments have already been used in practice, to interpret the results from a centrifuge modelling study undertaken at COFS for BP Angola, providing pipe-soil models for their design analysis.

Much of this recent research has been incorporated in the SAFEBUCK design guideline, and an updated report summarising the geotechnical research within the SAFEBUCK JIP was presented at the 2008 OTC in Houston by Dave White, with collaborators David Bruton and Malcolm Carr from AtkinsBoreas, and Dr Johnny Cheuk from Hong Kong University.

Collaboration with Johnny Cheuk has continued. During his second visit in August 2008 he worked with Dave White on a new model for the cycle-by-cycle embedment of a pipeline during dynamic embedment, based on centrifuge modeling observations. This study showed that very small dynamic movements of the pipe during laying can lead to significant remoulding of the surrounding soil, and a consequent increase in the pipe embedment. The model is based on theoretical plasticity failure envelopes, with additional laws to capture the remoulding of the surrounding soil and the consequent reduction in capacity.

In parallel, Hongjie Zhou and Dong Wang, working with Dave White and Mark Randolph, conducted numerical studies of static and dynamic pipe embedment in softening soil (Zhou et al. 2008, Wang et al 2009). These studies revealed the seabed deformation and the localized remoulding behaviour during pipe embedment, and achieved good agreement with Johnny’s centrifuge modeling study (Figures 3 and 4).
Figure 3: Dynamic embedment of pipelines. Left: centrifuge and analytical modeling, right: numerical modeling

Figure 4: Large-amplitude lateral sweeping of pipelines. Left: centrifuge modeling, right: numerical modeling

Figure 5: Pipeline lay simulations using the beam centrifuge
These developments related to pipeline embedment were summarized in a review paper presented by Mark Randolph and Dave White at the OTC and a keynote lecture given by the same authors at the ICOF conference in Dundee. Although the theoretical studies have contributed to a more robust understanding of pipe-soil interaction forces, the centrifuge modeling activity in this research stream has highlighted the complexity of the large-amplitude and cyclic pipe-soil interaction behaviour (Figure 5). Model testing is an increasing important aspect of the design process, where pipe-soil forces have a strong influence on the design. Based on studies conducted for industry at COFS, Dave White and Christophe Gaudin prepared a paper for the Deep Offshore Technology conference in Perth which highlighted the role that model testing can play in seabed pipeline design. This paper included simulations of dynamic pipeline embedment, achieved using the sophisticated new control system on the beam centrifuge. Images from a dramatic centrifuge test involving simulation of the laying and lateral buckling of a heavy pipe-in-pipe flowline are shown in Figure 6.

Figure 6: Simulation of the laying and buckling of a heavy pipe-in-pipe flowline on soft soil
The motion of a pipeline when interacting with the seabed during laying or lateral buckling leads to significant remoulding of the seabed soil. During reconsolidation, as excess pore pressures generated during remoulding dissipate, the strength can recover. **Dave White** and **Matt Hodder** have been studying these related processes. A new framework has been proposed, based on critical state soil mechanics, which allows episodes of remoulding and reconsolidation to be linked to the underlying effective stress behaviour (Figure 7). Data from cyclic T-bar tests with wait periods has been used to investigate the ultimate remoulded strength that is reached after many episodes of disturbance and reconsolidation.

![Figure 7: Time is the greatest healer: strength changes during remoulding and reconsolidation](image)

**Zack Westgate**, **Dave White** and **Mark Randolph** are studying dynamic lay effects on pipeline embedment using data from field surveys of as-laid pipelines, provided by Acergy. The surveys, from soft clay sites in the North Sea and offshore West Africa, provide details of the seabed profiles along the lay route which can be linked to the lay rate and pipelay vessel motions via the seastate (Figure 8). Numerical analyses, using offshore modelling software such as OrcaFlex, can then be used to quantify the transfer of vessel motions through the pipe catenary to pipeline motions in the touchdown zone.

![Figure 8: Observed dynamic embedment compared to predicted static embedment](image)
The surveys indicate that the duration of the lay process has a significant effect on the pipeline embedment and geometry of the adjacent seabed, with short duration lay effects resulting in heaved seabed profiles and moderate (<0.5D) embedment, and long duration lay effects resulting in trenched seabed profiles and deeper embedment, similar to the early stages in the life of a steel catenary riser (SCR). Theoretical models can then be used to back-calculate the dynamic embedment, shown to be several times greater than that predicted based on the catenary-induced pipeweight during normal lay conditions (Figure 9), and more than an order of magnitude greater during downtime events.

Susan Gourvenec and Dave White have been working with student visitor Karoline Krost, from Darmstadt University, Germany, on consolidation around partially embedded pipelines using finite element analyses. This work has provided a new basis for interpreting pore pressure dissipation around seabed pipelines, and for quantifying the “wedging” effect that raises the normal contact force above the pipe weight. These analyses have been used to assist interpretation of the results from Fugro’s SMARTPIPE seabed tool. The new solutions provide a basis for assessing the consolidation characteristics of surficial seabed soils in situ, and deriving the consequent axial pipe-soil interaction forces.

Figure 9: Effects of seastate on pipeline embedment during normal lay conditions

Figure 10: Fugro’s SMARTPIPE device for assessing pipe-soil forces in deep water. CCFE’s theoretical studies are providing the framework to interpret SMARTPIPE data (photo courtesy of David Bruton, AtkinsBoreas)
UWA’s new O-tube facility and the STABLEPIPE JIP

Pipeline on-bottom stability is a more significant design challenge in Australian waters compared to most other regions worldwide due to (i) large diameter lighter gas trunklines crossing the shallow continental shelf (Figure 11), (ii) the high level of cyclonic loading and (iii) the mobile and liquefiable seabed conditions, which comprise low density calcareous sediments. On-bottom stabilisation measures account for about 30% of the total pipeline construction cost, which for a large trunkline is in the order of a billion dollars.

It is increasingly recognised that conventional geotechnical analyses of on-bottom stability are flawed, because they neglect to consider the mobility of the seabed sediment. This mobility, which is manifested through the processes of scour and full or partial liquefaction, may enhance or reduce the horizontal pipe-soil forces available to equilibrate hydrodynamic loading on the pipe during cyclone events.

A major new research initiative at UWA is being led by Liang Cheng of the School of Civil and Resource Engineering, in collaboration with Dave White and Mark Randolph of COFS. A large new experimental facility – the O-tube – is currently under construction and a miniature pilot O-tube is in operation. The purpose of these facilities is to allow accurate simulation of the tripartite interaction between the fluid (via wave and current action), the seabed and the pipeline, as shown schematically in Figure 12. Current design approaches neglect this full interaction process.

Figure 11: Large-diameter gas trunklines. Top: with Susan Gourvenec, for scale. Bottom: partially buried at the seabed

Figure 12: Fluid-soil-pipe interaction on pipeline on-bottom stability behaviour
Initial support for this development has been provided by a linkage grant from the Australian Research Council and Woodside. This activity is also integrated into the STABLEPIPE JIP, initiated by JP Kenny, which involves other local Operators.

The O-tube is a unique design of flume, which is capable of producing both steady and oscillatory flow. It is a similar concept to the pendulous U-tube flume, but has a full circuit of fluid, driven by a turbine which can be controlled to produce any desired pattern of fluid flow. The miniature O-tube was commissioned in July 2008, and has already been used for several student projects and industry studies (Figure 13).

Figure 14 shows some pictures from a pilot study in the mini O-tube, conducted by Honours Student Suan Guo. During fast build-up of storm conditions, the pipe is pushed laterally under the hydrodynamic load. When the storm builds up more slowly, the scour and sediment transport processes lead to self-burial of the pipeline. This self-burial increases the geotechnical resistance and reduces the hydrodynamic loading, so the pipe remains stable.

The full size O-tube is currently being manufactured in China. The test section will be more than 1 m high, allowing near full-scale modelling of trunkline stability.
The mini O-tube has also been employed to carry out an industry project, investigating the stability of rock berms. The project was conducted by Liang Cheng and Zhipeng Zang. The stability of rock berm with different cross sections was examined under JONSWAP random waves. The measured velocity in the mini O-tube was compared with the scaled metocean conditions as shown in Figure 15. Figure 16 shows the photographs of a rock berm prior to and after being exposed to a design wave condition for 2000 waves.

![Figure 15: Time series of the velocity for 1000-year cyclonic conditions](image1)

(a) Model rock berm profile prior to testing  
(b) Model rock berm profile after testing

![Figure 16: Photographs of the rock berm with 1:3 slope prior to and after being exposed to 100-year cyclonic conditions for 2000 waves](image2)
Onset of scour below pipeline in waves

Local scour is a potential risk to the safe operation of offshore pipelines if free spans develop as the results of local scour. Local scour can also sometimes be beneficial to the stability of a pipeline if scour leads to natural burial of the pipeline. Therefore understanding of critical onset conditions of scour is important for pipeline design and operations.

The research group led by Liang Cheng developed a numerical model to predict the onset of local scour below offshore pipelines in steady currents and waves (Zang et al. 2008). The scour is assumed to start when the pressure gradient underneath the pipeline exceeds the floatation gradient of the sediments.

In the numerical model, flow field around the pipeline above the bed is determined by solving the two-dimensional (2-D) Reynolds-averaged Navier-Stokes equations with a $k$-$\omega$ turbulence closure. The seepage flow below the seabed is calculated by solving the Darcy’s law (Laplace’s equation). The seepage pressure distributions along the seabed were determined from solving the flow field around the pipeline above the bed. The numerical method used for both the turbulent flow and Darcy’s flow is a fractional finite element method. The average pressure gradient along the buried pipe surface is employed in the evaluation of onset conditions with a calibration coefficient. A unified empirical formula for onset condition is proposed, which can be applied in both wave and current conditions and is of much significance to practical engineering. Figure 17 shows the mean pressure distributions around partially buried pipelines and Figure 18 shows the comparison of computed and experimental onset conditions.

![Figure 17: Pressure distributions in water and in the seabed](image_url)
Use of large concrete gravity anchors (GA) is one of the means for secondary stabilization of large diameter pipelines. Scour of seabed sediment around GA poses a threat to the stability of GA. Laboratory tests were conducted by Liang Cheng, Ming Zhao and Zhipeng Zang to investigate local scour around GAs. The tests were carried out in a wave/current flume of 50 m in length, 4 m in width and 2.5 m in height. The flume is equipped with an irregular wave maker that can generate both regular and irregular waves.
Tests were conducted under three flow conditions (steady currents, waves and combined waves and currents) and three oblique angles of flow to the pipeline (flow perpendicular to pipeline, flow parallel to pipeline and 45 degree angle between the flow and pipeline). Figure 20 shows a typical test setup where there was a 45 degree angle between the flow and the pipeline.

Ming Zhao and Liang Cheng have developed a three-dimensional scour model for simulating local scour around subsea structures. The model is comprised of a flow model and a scour model. Flow is simulated by a three-dimensional Reynolds Averaged Navier-Stokes (RANS) equations and k-ω turbulent model. Both bed load and suspended sediment transport are considered in scour model. The bed load is calculated by an empirical formula and the suspended sediment concentration is obtained by solving a convection-diffusion equation. Scour around a submerged vertical circular cylinder and scour around a pipeline were simulated by the numerical model. The numerical results are compared with the experimental data. Figure 21 shows the simulation results for scour below a pipeline.
The GUJV analysis of large storms revealed the need to extend the applicability of the pipe-soil interaction model in low vertical load (and uplift) regimes. In order to explore the UWAPIPE flow rule under small vertical forces, centrifuge tests were conducted in the UWA beam centrifuge. This has allowed modification of the hardening law and flow rule. Figure 23 shows the nonlinear fitting recession of the flow rule. Retrospective predictions using the new UWAPIPE model (Model B perhaps) show good agreement with the centrifuge test results for lateral horizontal displacements of up to two pipe diameters. Development of a model for larger displacements is on-going.

Yinghui Tian and Mark Cassidy continued the development and implementation of the pipe-soil interaction macroelement models. Now named the UWAPIPE model, the three pipe-soil interaction models developed by former COFS PhD student and now senior engineer at Advanced Geomechanics, Jianguo Zhang, were slightly modified and incorporated into ABAQUS as user element through the UEL user subroutine. The implementation of the macroelement is illustrated in Figure 22. Four explicit and implicit numerical integration schemes (Euler forward, Modified Euler forward, Runge-Kutta and Euler backward) were utilised in the incorporation with the aim to improve the robustness and efficiency of the UEL code. The integrated program was applied to analyse storm conditions relevant to the Gorgon Upstream Joint Venture (GUJV). This work was conducted with Jianguo Zhang and Jonathan Woodward. GUJV will incorporate the models into their PipeStab programme in 2009.
A three dimensional pipe-soil interaction model was also developed by adding the axial behaviour to the UWAPIPE model as a nonlinear elastic perfectly plastic spring related to the vertical force through a Coulomb friction coefficient. Although further experimental or numerical study is needed to investigate the three dimensional behaviour, it is considered to be the first step to develop a fully coupled 3D code.

After completing a Bachelor and Masters degree in Civil Engineering at Suez Canal University, Egypt, Bassem Youssef joined COFS in September 2008 to conduct his PhD degree under the supervision of Mark Cassidy and Yinghui Tian. The research of Bassem’s PhD will focus on the application of probabilistic models in the analysis of offshore pipelines. The research will investigate the long-term use of pipelines in harsh environments.

During 2008, Bassem developed a computer code to simulate the hydrodynamic forces acting on the on-bottom offshore pipelines. The code employs a variety of wave spectrums in simulating the ocean waves. In addition, Morison and Fourier methods are implemented to calculate the hydrodynamic forces on the pipeline. This code will be incorporated into ABAQUS as a user element through the UWAVE user subroutine, linking the loading to other in-house UELs for soil-pipe interaction. More specifically, the current code and its future extensions will take into account instantaneous updating of the hydrodynamic forces used in the analysis based on the displacements and the new position of the pipeline. Figure 24 shows an example of pipeline displacement calculated by ABAQUS during a three-hour storm.

Figure 24: Pipeline displacement after 3 hrs hydrodynamic loads
CFD modelling of hydrodynamic forces on oblique pipelines

Ming Zhao and Liang Cheng developed a finite element numerical model for simulating three-dimensional turbulent flow. Steady flow past an isolated stationary circular cylinder at yaw angles in the range of 0 – 60° was investigated numerically. The effects of the yaw angles on the wake flow, the hydrodynamic force and the vortex shedding frequency were examined. Parallel computations were carried out using the IVEC facility (Western Australia Computational Facility). Figure 25 shows spanwise vorticity contours for yawed cylinder at α = 60°.

(b) \( |\omega_z| = 0.25 \) and \( \alpha = 60^\circ \)

Figure 25: Spanwise vorticity contours for yawed cylinder at \( \alpha = 60^\circ \)

Liang Cheng and PhD student Hongwei AN carried out an industry sponsored research work on numerical modeling of piggyback pipeline in combined oscillatory flow and steady currents. The piggyback pipeline is comprised of a trunk-line and a MEG line as shown in Figure 26. A numerical model, namely SCOUR-2D, developed at UWA is employed in this study. SCOUR-2D is a CFD package that is capable of modeling the coupled processes of the turbulent flow around the pipeline, seepage flow in the seabed and associate local seabed scour around offshore pipelines. SCOUR-2D is a Finite Element Model, which solves the RANS equations with a k-ω turbulence closure to simulate the turbulent flow above seabed, and solves the Laplace equation for seepage flow in the seabed based on Darcy’s law to obtain the pore fluid pressure for the partially buried pipeline. The computational mesh around a partially buried pipeline is plotted in Figure 26. SCOUR-2D has been validated against independent experimental data and has been employed in a number of industrial projects. The details of SCOUR-2D can be found in a technical paper by Zhao et al. (2007) published in Journal of Waterway, Port, Coastal, and Ocean Engineering.

In this work, three configurations of the piggyback pipeline are investigated, which include i) trunk line is above impermeable seabed with a gap of 0.01D; ii) idealized touch to impermeable seabed; iii) partially buried in permeable seabed. The drag, inertia, and lift coefficient of the pipeline, pressure distribution around the pipeline and the onset of scour beneath the pipeline are analyzed. An improved understanding of the effect of seepage fluid pressure on the total hydrodynamic force exerted on a partially buried pipeline has been achieved. Some results are present in Figure 27.
Figure 26: The computational mesh around the pipeline with embedment depth of 0.25D.

Figure 27: Instantaneous pressure distribution along the surface pipes in combined flow of KC = 20, Re = 2 × 10^5. (a) corresponds to the instant of maximum velocity flowing to the right side of the pipeline, (b) corresponds to the instant of maximum velocity flowing to the left side of the pipeline. Um and Uc are the amplitude of oscillatory flow and steady current, respectively. e/D = -0.25, where e is the embedment depth.

\begin{align*}
(a) \quad u &= U_m + U_c \\
(b) \quad u &= U_m - U_c
\end{align*}
CSIRO Flagship Collaboration Cluster on Subsea Pipelines

COFS continues to lead and manage the CSIRO Flagship Cluster on subsea pipelines. The goal of the Flagship cluster on Subsea pipelines is to provide engineering solutions for the safe and economic design and operation of subsea pipelines in Australia’s offshore frontiers. The cluster brings together six Australian universities (UWA, Sydney, Curtin, Flinders, Monash and Queensland) and 16 academics across civil engineering geotechnical, structural and hydraulic disciplines, as well as naval architects and control theory specialists in electrical engineering. We are working in collaboration with Dr Edson Nakagawa and Dr Luiz Franca of the Blue GDP Theme of the Wealth from Ocean Flagship.

- Established in late 2007, already 20 Journal and 22 conference papers have been submitted by the cluster participants. Other research highlights (some are covered in other sections of this annual report) include:
  - Geotechnical centrifuge tests on miniature piezoball penetrations, along with elements of pipelines aimed at the development of pipe-soil interaction models.
  - Implementation of a coupled effective stress Modified Cam Clay model for large deformation finite element analysis, and the subsequent development of back-bone curves for pore-pressure dissipation during a piezoball test.
  - Establishment and successful operation of a mini O-tube facility for testing of soil erosion properties.
  - Establishment of a numerical model for three-dimensional flow and scour under pipelines, with results validated against experiments conducted at UWA.
  - Establishment of a framework for incorporating soil-pipe models into structural analysis programs, including uplift and reattachment.
  - Analysis of the influence of boundary conditions, hydrocarbon products and axial pipeline tension on the natural frequency of on-bottom pipelines (Monash University).
  - The development and commissioning of a facility for simulating submarine slides at small scale within a geotechnical drum centrifuge.
  - First series of tests from the new facility for simulating submarine slides at small scale within a geotechnical drum centrifuge, and complementary large-deformation finite element numerical modelling of the run-out of submarine slides.
  - Establishment of laboratory testing apparatus to measure bed shear stress under tsunami shaped waves (University of Queensland).

Further details of the Flagship Cluster on Subsea Pipelines can be found at http://www.csiro.au/partnerships/PipelineCluster.html

Risers

Matt Hodder has been investigating pipe-soil interaction issues in the region where steel catenary risers (SCRs) ‘touch down’ on the seabed (the touchdown region). Fatigue life predictions of risers are sensitive to the assumed stiffness between the riser pipe and the seabed. Typical practice involves modelling the seabed as a bed of linear springs, although some analyses include non-linearity. Uncertainty exists in the industry surrounding the choice of appropriate stiffness values for adoption within a linear idealisation of the pipe-soil unload-reload behaviour. A riser will be subjected to many cycles of loading during its life, which can cause changes in the strength of the seabed soil. Remoulding, which can be exacerbated by the entrainment of water, decreases the soil strength, while reconsolidation can induce an increase in strength in the normally consolidated soils typically found in the deep offshore environments where SCRs are used. These changes in soil strength have a direct influence on the pipe-soil spring stiffness.

Further analysis was performed on the data obtained from a series of tests Matt conducted in the beam centrifuge in 2007. The tests involved subjecting a short section of riser pipe to a range of displacement and load cycles in soft kaolin clay. The aim of the tests was to quantify the influence of remoulding and reconsolidation on the pipe-soil response when subjected to various loading regimes. The results were processed into values of a ‘secant stiffness ratio’ for use within a linear idealisation of the pipe-soil interaction.

Figure 28 shows a comparative summary of the calculated secant stiffness ratio, K_{sec}, observed across a range of tests. The values of K_{sec} calculated in the first unload of the large amplitude motion tests compare well with predictions found in the current literature when using an initial value of undrained shear strength. The stiffness dropped to 30% of the first unload value after reaching a steady, remoulded state within 10 cycles (Episode 1 in Figure 28). After two additional episodes of large amplitude cycling with intervening reconsolidation periods of 1 year between episodes, the remoulded stiffness increased by 50% relative to the remoulded stiffness observed in Episode 1. During the early phase of many small amplitude cycles, a stiffness 75% of the first unload value was observed, while after many cycles (approximately 1.5 years) this value approximately doubled. Overall, K_{sec} varied by a factor of over 4 across the tests. These results illustrate the importance of accounting for the variability in soil strength due to remoulding and reconsolidation when calculating an appropriate value of K_{sec} for use in fatigue analysis.
Mark Randolph has continued his collaboration with Peter Quiggin of Orcina, UK, in the development of a non-linear seabed interaction model, and implementation within the dynamic analysis software, OrcaFlex. The model is designed to simulate the effects of suction and hysteretic penetration of objects such as risers or pipelines into the seabed during dynamic motion. The main modes of behaviour that must be modelled are shown in Figure 29. The model has a hyperbolic formulation and has been validated by comparisons with laboratory test data and also simulation of the Watchet harbour riser tests. Results from the calibration against the large displacement cyclic model tests reported by Aubeny et al. (2008) are shown in Figure 30. Full details of the model are provided in a forthcoming OMAE conference paper.
Hodjat Shiri is carrying out numerical modelling of riser-seabed interaction in the touchdown zone for steel catenary risers. The influence of seabed interaction on trench formation and consequent fatigue performance of steel catenary risers have been investigated using an implementation of the non-linear seabed interaction model discussed above as a user-element in ABAQUS.

A typical configuration of SCR (12 ¾” diameter) in 1800 m water depth and a SPAR system with a generic RAO has been simulated, then the distribution of riser-seabed contact force, SCR cyclic bending stresses and distribution of fatigue damage along the riser through the touch down zone have been studied. A wide range of different sea states have been considered with various hierarchies, along with the effects of gradual trench formation and pre-trenching (Figure 31) to explore the impact of the trench on SCR fatigue performance (Figure 32). Pre-trenching has been modelled in a consistent method utilizing the capabilities of the non-linear riser-seabed interaction model. Artificially high values of the repenetration delay parameter (\(n_z\)) are adopted for a few cycles of riser motion for the pre-trenching phase, before reverting to more realistic values of this parameter. Various trials have shown increasing level of fatigue damage with increasing trench depth.
Geohazards

A critical challenge as Australian developments move into water depths in excess of 1 km, is the assessment and mitigation of geohazards and safe routing of the long distance pipelines required to tie new fields back to the onshore processing facilities. COFS is supported by the State Government of Western Australia as a designated State Centre of Excellence for the period 2005-10. This status is allowing us to expand our capabilities into deep-water geohazards and pipeline and riser mechanics, underpinning future deep-water developments. We have involvement in several developments in deep water offshore Australia that are at different stages of planning, and we have strong links with other groups worldwide who are conducting complementary research in this area.

Drum Centrifuge Modelling Of Submarine Slides

As part of the COFS/MERIWA JIP on the impact of submarine slides on pipelines, Noel Boylan, Christophe Gaudin, Dave White, Mark Randolph and James Schneider have been developing a facility to model submarine slides in the geotechnical drum centrifuge. The objective of this facility is to study the breakdown of the slide from its initial intact condition to a debris flow and assess the interaction forces with a model pipeline in the route of the slide. Figure 1 shows the slide box device which has been developed for the channel of the drum to trigger submarine slides on a model seabed. An intact block of clay is initially consolidated and retained within the box by a sliding door in front of the block. Remote triggering of a slide causes the sliding door to rise while the swinging paddle behind the block is simultaneous released imparting an initial velocity to the block of clay.

Figure 1: Slide triggering device developed for the drum centrifuge

Figure 2 shows the run-out of a typical slide on a model seabed. To differentiate the slide material and the seabed, the latter has been dyed a dark grey colour. Miniature site investigations carried out with the T-bar penetrometer before and after a slide event are augmented with monitoring carried out by pore pressure transducers and Cantilever Loading Devices (CLD) during the slide run-out. The CLD monitors the dynamic load from a passing slide, from which the operative shear strength can be inferred. PhD student Fauzan Sahdi has carried out validation experiments with the CLD in normally and over consolidated clay to assess the appropriate distribution of bearing factors with embedment and the influence of strain rate effects. He has also been studying the influence of different dyes on the undrained shear strength (s_u) of kaolin clay.

Figure 2: Typical run-out of slide debris in drum centrifuge channel
Coloured Clay

To differentiate between the slide material and model seabed, the seabed has to be coloured with dye. This is a crucial measure to determine the degree of erosion due to the slide runout. Tests were done in the drum centrifuge to determine the changes (if any) in undrained shear strengths ($S_u$) for both samples coloured with a variety of different dyes. The undrained shear strengths were determined using the T-bar penetrometer. The samples used were standard UWA kaolin and kaolin coloured with different dyes at certain concentrations. Table 1 shows the types of dye used and their concentrations. Figure 3 shows the intact undrained shear strength profiles for the different samples. Sample B1-6 (dyed with green) showed the closest resemblance to the standard kaolin (B1-1 and B1-2). Future tests will involve quantification of any microscopic fabric changes in the dyed samples using the X-Ray Diffractometer (XRD) and Scanning Electron Microscope (SEM). Basic index tests will also be conducted.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type of Dye</th>
<th>Colour</th>
<th>Concentration per unit weight of dry kaolin (ml/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1-1</td>
<td>Standard Kaolin</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B1-2</td>
<td>Standard Kaolin</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B1-3</td>
<td>Black Ink</td>
<td>Black</td>
<td>0.031</td>
</tr>
<tr>
<td>B1-4</td>
<td>AS-Red</td>
<td>Red</td>
<td>0.031</td>
</tr>
<tr>
<td>B1-5</td>
<td>AS-Red</td>
<td>Red</td>
<td>0.063</td>
</tr>
<tr>
<td>B1-6</td>
<td>Various Ink</td>
<td>Green</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Table 1: Types of Dye used

Figure 3: Effect of coloured dye on undrained shear strength of normally consolidated kaolin clay
Submarine slide – pipeline interaction, MERIWA-supported JIP

Submarine slides represent a major geohazard which is relevant to major developments currently planned offshore WA, and other projects elsewhere. Our Joint Industry Project focussing on the interaction between submarine slides and seabed pipelines continued through 2008, led by Dave White, Mark Randolph and Christophe Gaudin. This project is administered by the Minerals and Energy Research Institute of Western Australia (MERIWA) and is supported by six major oil and gas operators.

This project addresses the technical challenges of assessing the effect of submarine slides on pipelines and subsea infrastructure, through new analytical and numerical “run-out” computations and novel centrifuge modelling. A critical scientific goal is to link the parameters required for the design tools used to simulate and analyse seabed slides to the geotechnical parameters obtained through conventional site investigation methods. The absence of this link prevents a consistent basis being applied through the engineering design associated with submarine slide hazards.

This research is integrated with the geohazards stream of the CSIRO Cluster on Subsea Pipelines, which is discussed in more detail in the pipelines and risers section of this report.

Cantilever Load Device (CLD)

Transformation of an intact slide to a debris flow involves degradation of the undrained shear strength ($s_u$) of the slide material. A CLD is a device used to quantify this phenomenon, which comprises of an instrumented cylindrical probe embedded in the path of the slide. Using the principles of laterally loaded piles, the $s_u$ profile of a slide can be determined from the bending moment measured at different levels of the probe, above the loaded zone. Validation tests were done in the beam centrifuge, where the moments measured on the CLD pushed at different velocities were compared to the predicted moments derived from the $s_u$ profile as measured from a T-bar. As submarine slides usually happen at high velocities, rate effects are also currently being investigated. From validation tests, the appropriate N-factors for the CLD can be determined. The N-factors varies from ~ 2.5 (due to heave at surface) to ~ 10.5 (full plastic flow mechanism). With the appropriate N-factors, the undrained shear strength of a slide can then be determined. Figure 4 shows the validation test set up within a strong box, which is in turn mounted on the beam centrifuge.

In order to establish the initial conditions of a pipeline prior to being in contact with a submarine slide, Dong Wang, Dave White and Mark Randolph investigated the pipe laying process and associated pipe penetration using a large deformation finite element approach based on ABAQUS. A strain-softening rate-dependent soil model was incorporated to replicate the instantaneous shear band shedding and to
capture the detailed flow patterns observed in experiments. The numerical approach has been verified by comparison with upper bound plasticity analysis and centrifuge tests in clays.

Prediction of the as-laid embedment of a pipeline, which affects many aspects of pipeline design, is complicated by the wave-induced motion of the lay vessel and the resulting pipeline movements within the touchdown zone. These motions cause pipelines to embed deeper than predicted based on static penetration models, as the seabed soil are both softened and physically displaced by the pipe motion. It was found that the sensitivity factor of the soil may be underestimated by cyclic T-bar tests in deep soil, since additional water becomes entrained in the soil with oscillations of the pipe. The soil is then softened due to both the remoulding effect of accumulated shear strain and also increasing water content. For pipes in kaolin clay and the offshore high plasticity clay, the numerical evolution of the pipe embedment agrees well with previous centrifuge data (Figure 5). An approximate steady embedment was reached at 30 cycles, and the softened zone around the pipe remains largely unchanged with subsequent cycles.

The zone of a pipeline lying outside of a submarine slide provides restraint against the movement imposed on the loaded section. This zone of pipe undergoes large-amplitude lateral movement relative to a seabed which is unaffected by the slide. Numerical simulations of this behaviour showed that for pipes undergoing large-amplitude lateral displacements, the apparent friction factors for both light and heavy pipes converge, in spite of different mechanisms, with a sliding berm for “light” pipes and deep ploughing for “heavy” pipes (Figure 6). The concept of an effective embedment has been proposed to account for the height of the berm or wall of soil ahead of the pipe. For an over-penetration ratio in the range of 1.25–10, the normalised lateral resistance is a power law function of the effective embedment, and is unaffected by the trajectory of the pipe.

Figure 5: Cyclic evolution of pipe embedment
Previous large deformation analyses at COFS were focused on static applications neglecting the inertial effect. Inertia may be a vital factor in assessing the long-distance submarine sliding. Dong Wang, Mark Randolph and Dave White developed the dynamic large deformation method, in which the accelerations and velocities are mapped from the old mesh to the new mesh as well as the stresses and material parameters. The element addition technique was also proposed to reduce the boundary effect while preserving the computation efficiency. This technique is illustrated in Figure 7 for the case of a rigid block sliding on a deformable seabed.

Figure 6: Instantaneous velocity fields during lateral breakout (light pipe)
Figure 7: Velocity fields during the sliding (using element addition technique)

- t = 0.1 s
- t = 5.9 s
- t = 14.8 s
Parametric study on the effect of submarine landslides on pipelines

Hongxia Zhu and Mark Randolph have been investigating the interaction forces as a slide passes over a pipeline, which might be shallowly buried. A numerical model was established in this study, to simulate the large flow deformation of debris slope and to quantify the loads imposed on the pipeline. AFENA-based large deformation finite element (LDFE) analyses were undertaken, using RITSS approach, with frequent re-meshing and interpolation of all field values. A simple two-dimensional elastic perfectly plastic soil model with plane strain condition was employed in this analysis. The pipeline was restrained by a set of springs so that the load on the pipeline built up to a stable value, representing the limit load imposed by the debris on the pipeline.

A parametric study was undertaken by varying the pipeline embedment and the relative strengths of the debris and seabed. The analysis result shows that the various combinations of soil strength and embedment depth lead to different debris-pipeline movement patterns and consequently lead to rather different magnitudes of the load imposed on the pipeline. Figure 8 shows one of the patterns for the cases where relatively strong material is sliding on a weak seabed surface. The initially partially embedded pipeline became entirely enclosed by the debris as the sliding progressed. For the cases where relatively low strength debris is flowing on a strong seabed, the pipeline may remain partially embedded in the seabed with the debris flowing over it. The variations of net pressures on the pipeline are plotted in Figure 9. It can be seen that the pipeline undertakes the largest load (11.5 times debris strength) imposed by the sliding when it is sitting on the weakest surface. The pressure is in direct proportion to the debris material strength and inversely proportional to the seabed strength for the partially embedded pipeline, while it is not affected significantly by the soil strength for the deep buried pipeline. In addition, for the cases where relatively strong material is sliding on a weak seabed surface, pressures on the pipeline fluctuate only within a quite small range with an increase in embedment depth; by contrast, for the cases where relatively low strength debris is flowing on a strong seabed, the pressure imposed on the pipeline decreases gradually with an increase in embedment depth.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Soil Strength/kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Debris</td>
</tr>
<tr>
<td>C1</td>
<td>1.0</td>
</tr>
<tr>
<td>C2</td>
<td>1.0</td>
</tr>
<tr>
<td>C3</td>
<td>3.0</td>
</tr>
<tr>
<td>C4</td>
<td>5.0</td>
</tr>
<tr>
<td>C5</td>
<td>5.0</td>
</tr>
<tr>
<td>C6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure 8: Debris flow around the pipeline

Figure 9: Variations of net pressures on the pipeline
Donghee Seo has been working with Mark Randolph and Dave White modelling the structural response of a pipeline to loading from a debris slide. Dr Seo has focused on numerical modelling, using ABAQUS, of ‘inclined’ slides that generate combined normal and axial loading of the pipeline. Analytical solutions for the simpler case of purely perpendicular loading have led to design charts expressing the resulting strain in the pipeline due to (a) bending and (b) membrane tension, in terms of the slide loading, q, and width, B, for a pipeline of diameter D. Results have been non-dimensionalised in terms of the pipe cross-sectional stiffness, EA, and the soil lateral resistance, p, and axial resistance, f, provided by the adjacent sections of pipeline. This work has highlighted the different characteristic modes of pipeline loading that result from different widths of slide. Narrow slides create predominantly bending strain, whereas wider slides lead to predominantly tensile strain (Figure 10). An example chart that can be used in an assessment of slide impact is shown in Figure 11.

Numerical analysis of inclined slide loading has shown that, for small angles of inclination from the normal, a superposition approach appears to work well in terms of estimating the maximum strains in the pipeline. These occur at the edge of the slide region, at the upstream edge (relative to the direction of the axial loading), where strains induced by the loading perpendicular to the pipeline are still large, and the additional tensile strains due to the axial component are a maximum.

![Figure 10: Contributions of bending and tensile strain to overall structural load during slide impact](image1)

![Figure 11: Example results from parametric study of pipeline structural response to slide impact](image2)
PhD student Anjui Li is undertaking a study under the supervision of Richard Merifield that has used the finite element upper and lower bound limit analysis methods to produce stability charts for soil slopes. The problem analysed is shown in Figure 12 and is for normally consolidated clays.

Two dimensionless parameters, \( N_r \) and \( \lambda_{cr} \), are introduced with \( N_r \) representing the stability number for inhomogeneous undrained slopes.

\[
N_r = \frac{\gamma HF}{c_{u0}}
\]

\[
\lambda_{cr} = \frac{\rho HF}{c_{u0}}
\]

The chart solutions for inhomogeneous undrained slopes from the upper and lower bound analyses are displayed in Figure 13 for \( \beta = 45^\circ \), \( d/H = 1.5 \) and various \( L/H \). It can be observed that the difference between the 2D and 3D stability numbers \( (N_r) \) decreases with increasing \( L/H \) ratio, as the 3D end boundary effect decreases. In addition, the difference in \( N_r \) between the 2D and 3D solutions increases slightly with increasing \( \lambda_{cr} \) for both the upper and lower bound results. This implies that, for inhomogeneous undrained slopes, the increasing strength with depth has a more significant effect on the stability numbers for slopes with a lower \( L/H \) ratio.

These chart solutions can be seen as convenient tools to be used by practising engineers to estimate the initial stability for excavated or man-made slopes.

To provide more sets of stability charts for preliminary design, more investigations will be undertaken by Anjui in the future for different soil properties and strength profiles.

![Figure 12: Slope stability of soil masses – problem definition](image_url1)

![Figure 13: Comparisons of stability numbers for different magnitudes of L/H (\( \beta = 45^\circ \) and \( d/H = 1.5 \))](image_url2)
Mobile Jack-up Drilling Rigs

In 2008, the research activity on mobile jack-up drilling rigs included all phases: installation, the capacity during operation as well as spudcan extraction. The installation phase received particular attention, with research projects into the punch-through potential in layered soil, the preventative mitigation measure “Swiss Cheese Drilling” and re-installation near existing footprints.

Punch-through in sand over clay strata

‘Punch-through’ failure occurs when spudcan foundations are unexpectedly and uncontrollably pushed through a relatively thin sand layer into the underlying soft clay. Such failure can lead to buckling of the legs and even toppling of the unit, and there is an enormous risk to safety and possible financial loss. To investigate the punch-through phenomenon, an extensive series of centrifuge tests and finite element (FE) analyses for spudcans penetrating through a sand layer into soft clay have been carried out. Observations from the FE results (see Figure 1) and visualisation experiments have shown that at peak bearing resistance a frustum of sand is forced into the underlying clay, with the outer angle reflecting the dilation in the sand.

Based on this finding, a new simplified conceptual model for evaluating the peak penetration resistance of spudcan foundations on sand overlying soft clay has been developed by Kok Kuen Lee, who is a postgraduate student under the supervision of Mark Cassidy and Mark Randolph. An illustration of the model is shown in Figure 2. The analytical basis of the conceptual model follows the approach for silo analysis, and accounts for the stress level and dilatant response of the sand. It is therefore an advancement over the punching shear and load spread models advocated in the current industry guidelines SNAME (2002), which do not consider the strength properties of the sand. It has been shown that the new conceptual model agrees well with 47 centrifuge model tests spanning a wide range of foundation diameter and sand layer thickness, while the industry guidelines have significantly under-predicted the experimental values.

This research is supported by an ARC Linkage grant and industry partners Keppel Offshore and Marine Limited in Singapore.
Swiss Cheese Drilling

In 2008, Davene Daley from Vassar College, New York visited COFS for two months. Davene Daley, Shazzad Hossain and Mark Cassidy investigated ‘Swiss Cheese Drilling’ for mitigating punch-through of mobile jack-up rig through an experimental study. The rationale is to reduce the bearing resistance of the stiff layer by perforating it with drill holes. In an attempt to find an effective Swiss Cheese pattern, a series of spudcan penetration tests were undertaken on perforated stiff-over-soft clay. A number of Swiss Cheese patterns were investigated by varying hole spacing, hole depth, number of holes underneath the spudcan, and the density and distance of holes adjacent to the perimeter of the penetrating spudcan. An observed failure mechanism from a half-spudcan test on a similar stiff-over-soft clay deposit was used as the basis to reduce the punch-through potential. The method of producing the holes, whether through drilling or coring, was also explored. Ryan Hannan, a 4th year UWA Engineering student, joined in the research group later and used a purpose designed apparatus to drill holes by water jetting (see Figure 4b).

Figure 3 shows a 31% reduction of peak bearing capacity obtained by drilling 2 mm holes on an equilateral triangular grid with a spacing of 4 mm (this represents holes of 0.05D and spacing of 0.1D). The Swiss cheese drilling was confined to a narrow band around the perimeter of spudcan location, extending 0.25D beyond the spudcan periphery, and down to a depth of 1D into the lower layer. The catastrophic punch-through was nearly eliminated, as also can be seen from the top snapshots of surface soil deformation in Figure 4a and 4c. For no Swiss cheesing, from the start of penetration the soil deformation was directed vertically downwards to the lower layer, with no upward movement (see Figure 4a); conversely on a Swiss cheesed deposit, significant surface heave occurred as a result of general shear failure (see Figure 4c).
Jack-up re-installation near existing footprints

Large footprints often remain on the sea-bed after the spudcan footings of offshore mobile jack-up platforms have been removed. In soft clays, they can be in excess of 10m deep and wide, with large variations in soil strengths below the surface. Reinstallation close to these footprints is often necessary but is extremely hazardous, due to the large horizontal and moment loads induced on the spudcans and subsequently on the jack-up legs. This problem has caused a number of failures and near misses incidents in the past.

The work initiated by Melissa Landon, during her visit in 2007, on the behaviour of jack-up re-installed near existing footprints, in collaboration with Christophe Gaudin and Mark Cassidy was further pursued in 2008. A 1g reduced-scaled model of a three-legged jack-up was used to investigate the influence of the re-installation of a single leg adjacent to an existing footprint when coupled to the interaction of three legs and the jack-up hull (Figure 5).

The study focused on the effect of shape and non-uniform strength on the behaviour of a single leg through offset from spudcan generated and vertical and sloped auger generated footprints in uniform strength soil. Installation offsets of 0.75, 0.89, and 1.0 times the diameter were chosen to compare with and bracket results from literature reported studies comprised of single leg installations with restrained or enabled allowed horizontal motion during installation. During testings, vertical, horizontal and bending moments in the three legs were measured, along with the displacements and the tilt of the hull (Figure 6).

Comparison of tests results between reinstallation near natural footprints and reinstallation near sloped auger generated footprint show that shear strength changes dominate jack-up installation behaviour rather than soil geometry. Regardless of offset, offset leg penetration into lower strength soil results in rotation of the hull into the footprint direction. Additionally, the offset of 0.89 spudcan diameters resulted in the highest horizontal force and moments at the hull and spudcan levels for the offset leg. With increased offset distance, it appears that the risk of leg failure decreases. Analysis of spudcan installation adjacent to a shallow slope in uniform soil shows that the bearing capacity failure seen in natural footprints does not occur, rather the slope results in hull rotation into the existing footprint for the offsets tested.

Figure 5: Failure by overturning of the jackup during re-installation near natural existing footprint

Figure 6: Example of forces in the legs and displacements of the hull during re-installation
The first stage of Vickie Kong’s PhD study (supervised by Mark Cassidy, Christophe Gaudin and Mark Randolph) on the response of jack-up reinstallation near existing footprint involves the investigation of the three key parameters of the problem: footprint geometry, soil properties and jack-up structural properties.

A set of centrifuge modelling was conducted in 2008 to investigate the footprint geometry. Artificial footprints of conical cavity shape were formed in the overconsolidated clay soil sample to eliminate the effect of remoulded soil strength under the footprint (Figure 7). 17 individual spudcan penetration tests have been performed in artificial footprints in different diameter, cavity depth and slope angle. The vertical, horizontal and moment reaction on the jack-up leg were recorded (Figure 8a and 8b). It was found that the critical offset distance is between 0.5 to 1.0 times the spudcan diameter (D). The peak horizontal force and peak bending moment reduced by 50% when increasing the offset distance from 1.0D to 1.5D. Furthermore, the peak horizontal force reduced by 70% when reducing the footprint cavity depth from 0.33D to 0.16D.

In 2009 the failure mechanism will be investigated using numerical modelling and Particle Image Velocimetry (PIV). In addition, a ‘flexible’ leg-actuator connection is currently under development to investigate the influence of the structural properties of jack-up units to the response of spudcan.
Jack-up push-over capacity

Britta Bienen’s previous work on the three-dimensional physical modelling of the push-over capacity of jack-up rigs was extended in 2008 with the help of Honours student Sally Wong. The experimental set-up was modified to enable testing of more loading directions (Figures 9a and 9b). The horizontal push-over load can now be applied at any angle between 0° and 60° to the hull’s axis of symmetry.

Further numerical work using the integrated in-house fluid-structure-soil interaction analysis program SOS_3D complemented experimental results obtained in the beam centrifuge in the previous year. The comparison of the numerical predictions with the experimental results (with the horizontal footing loads shown in Figure 10) demonstrate that the current state-of-the-art footing model when integrated in a structure-soil interaction program, successfully predicts the global response of a three-legged jack-up as well as the individual footing behaviour. The global failure load, though shown to be significantly underestimated by the current guidelines, was shown to be predicted well.

Figure 9a: Modified experimental set-up for push-over tests

Figure 9b: Modified pulley system

Figure 10: Comparison of horizontal loads measured in an experiment and their numerical prediction
Use of jetting to ease spudcan extraction

Retrieval of jack-up rigs at the end of their operations is common practice in the offshore industry, notably to move the rigs to another drilling location. In some cases, the process is difficult, time consuming and costly because the high extraction resistance on the jack-up’s ‘spudcan’ footings can exceed the capacity of the rig to pull. This is particularly the case in soft clay where significant suction is developed at the spudcan invert. The main option available to operators to ease the spudcan extraction resistance is to use a jetting system at the spudcan invert to attempt to break the suction generated. However, there is a general consensus within the offshore industry that jetting systems, under their current configurations, have a limited efficiency.

Christophe Gaudin, Britta Bienen and Mark Cassidy have performed a series of centrifuge experiments in order to understand the mechanisms taking place during jetting extraction and to provide recommendations to optimise the jetting performance. A reduced scale spudcan model (Figure 11) simulating a 17.11 m diameter prototype spudcan with jets has been tested at 200g. It was extracted from penetrations of up to 1.5 diameters in normally consolidated clay at variable extraction rates and variable jetting flow rates. Measurements of the generated suction and the total extraction resistance after a preloading period have provided insight to the extraction mechanisms with jetting. The study has demonstrated that jetting can lead to significant reduction in extraction resistance, provided that the extraction rate is fast enough to ensure undrained extraction and that a sufficiently high flow rate is applied with respect to the extraction rate (Figure 12).

Figure 11: Model jetting spudcan in action

Figure 12: Reduction of suction at the spudcan invert with filling ratio defined as the jetting flow rate divided by the extraction rate time the spudcan area
Pushover analysis for fixed offshore platforms and Jack-ups

Mehrdad Kimiaei and M.M. Memarpour (PhD student from Iran University of Science and Technology) are working on ultimate strength analysis of fixed offshore platforms. Quasi static pushover analysis is commonly used in offshore engineering for assessment of Reserve Strength Ratio (RSR) of offshore platforms. In reality, the forces imparted by the waves traversing the offshore structures are in dynamic mode and hence it seems that dynamic ultimate strength analyses can provide better estimation of platform’s RSR. General view of the numerical model of a typical fixed platform, developed for pushover analysis using USFOS software, is shown in Figure 13. Pushover results for a quasi static and a dynamic pushover (using shake down concept) analysis are shown in Figure 14. It was shown that it can not be said that static pushover analysis will always lead to conservative estimations of the platform’s RSR. The main objective of this study is to compare the results of static and dynamic pushover analyses for fixed platforms and to find a more precise way of showing ultimate strength of fixed platforms. Results of this study will be presented in OMAE 2009 conference, Hawaii, USA.

Mehrdad Kimiaei continued working on numerical models for 3D pushover analysis of jack-up platforms. Using USFOS package, a 3D model of a sample jack-up platform was developed (Figure 15) in order to investigate nonlinear behaviour of jack-ups under extreme environmental loading. In a series of quasi static pushover analyses, the effects of boundary conditions (hinged or fixed supports at spudcans) on the overall structural behaviour of this platform were studied (Figure 16). Using this model, the effects of joint flexibilities, joint strength, fabrication imperfections and dynamic pushover analysis will be studied further. Based on these results, sensitivity of the jack-up’s RSR (Reserve Strength Ratio) to main structural inputs can be investigated. In the next stage, this model will be used for verification of the results of a comprehensive ABAQUS nonlinear 3D model for jack-ups which was initially developed last year (and can handle nonlinear soil-structure interaction behaviour of jack-ups using soil plasticity models based on using a user defined element developed by Mark Cassidy).
Figure 15: General 3D view of a sample jack-up used for pushover analysis

Figure 16: Comparing structural nonlinear behaviour for hinged and fixed supports
Installation of Subsea Modules

Installation of offshore platforms has always been a major issue in engineering of offshore platforms. Deployment of subsea platforms represents one of the highest risk activities in subsea engineering and that is why it has acquired increasing importance these days.

Since 2006, Mehrdad Kimiaei, as a member of WA:ERA’s project on Compact Sub-sea Gas Processing Technology, has been working in COFS on numerical models for installation of subsea modules using Conventional Installation Method (CIM) and Pendulous Installation Method (PIM). He has developed two numerical models (CIM and PIM) for installation of subsea platforms, using Orcaflex software.

Mehrdad Kimiaei and Master students Xu Jiajing and He Yu extended previous works on CIM model in 2008 (Figure 1). Results of this numerical model were compared with DNV guidelines (existing code of DNV-1996 and draft revision of new code, DNV-2008). Sensitivity of the results, mainly DAF (Dynamic Amplification Factor), to main input parameters such as wave data, winch lowering speed, dimension and weight of subsea module were investigated in this study. It was found that always DNV guidelines lead to very conservative DAF results comparing with numerical (Orcaflex) results (Figure 2). It was also observed that new DNV code (DNV-2008) will usually lead to better agreement with numerical results than existing DNV code (DNV-1996). Results of this study will be presented in OMAE 2009 conference, Hawaii, USA.

Mehrdad Kimiaei and Final year student Charles A Simmons continued working on PIM model (Figure 3). Several installation simulations were conducted and the effect of the main operational installation parameters (such as distance between cargo and lifting barges, additional floaters on the lifting wire, environmental data, etc) on the overall installation system’s behaviour were investigated in series of case studies (Figure 4). It was shown that the initial configuration of the main installation wire before starting the pendulous motion, and the hydrodynamic forces on the subsea module in early stages of the pendulous motion can significantly affect the installation results. Experimental tests are planned to be conducted at UWA’s hydrodynamic laboratory in the future.

In an industrial collaboration between WA:ERA and WEL (Woodside Energy Ltd), Mehrdad Kimiaei, and Hemlata Wadhwa (PhD student from the School of Mechanical Engineering) and Krish P Thiagarajan (WA:ERA, facilities research program leader) are now working on the development of a specific software for installation of subsea modules, using DNV guidelines. This software would be able to determine DAF at different installation stages (water surface zone, fully submerged and retrieval from seabed). This software would also be able to check the integrity of the rigging items in all installation stages.
Figure 2: Comparing CIM results of numerical model and DNV guidelines

Figure 3: General view of PIM model, using Orcaflex

Figure 4: Tension load in main lifting wire for PIM (effect of distance between cargo and lifting barges)
Most materials behave differently under static and dynamic loads. High speed impact testing is often conducted to define the dynamic material properties. The drop-weight rig, Split-Hopkinson-Pressure Bar (SHPB) or light gas gun are the common equipments used for such tests. All these equipments occupy large laboratory space because they need a large distance to accelerate the impact mass to achieve a large velocity. The primary limitation of a drop-weight rig is the relatively low impact velocity. A very high impact velocity can be generated using a light gas gun, but the amplitude of the impact force is limited. Moreover the specimen size used is usually small which often makes a complete representation of the different components of a composite material not possible. The impact velocity of a SHPB is usually less than 30 m/s, and the impact force it can generate is also limited. For these reasons, reliable dynamic concrete material properties are only available to strain rate up to approximately 100/s to 200/s.

Many researchers have spent a lot of effort to develop devices being able to generate high-speed impact force on relatively large specimens, but this problem remains unsolved.

An innovative blast simulator was recently developed by Boris Tarasov and Hong Hao. A new principle of the energy release accumulated in highly compressed fluid was realized in this apparatus. Compared with the traditional impact test machine, this design has some clear advantages. It can generate large impact force without sacrificing the impact velocity. It does not need a large distance to accelerate the piston to achieve a large velocity, therefore only a small laboratory space is needed. With properly designed air or liquid bag, this blast/impact simulator will also be able to simulate air blast force to test structural components to blast loads. This small scale simulator is designed to generate an impact velocity of about 100 m/s and an impact force of more than 100 tonnes. It can be used to perform impact tests on specimens of various sizes and to small scale structure components.

The capacity of the simulator has been tested in hundreds of experiments. Despite the fact that these experiments were conducted with about half of the design maximum pressure, the created impact force exceeded 100 tonnes, the impact velocity generated was higher than 50 m/s and the largest strain rate achieved was about 2000 /s. At the full pressure capacity an impact velocity of 100 m/s is achievable. This successive testing demonstrates that the designed apparatus represents a new generation of impact machines and will find a wide range of applications. The patent application process on the new idea is in progress.
Awards

The following are awards that were presented to COFS staff during 2008:

**Mark Randolph** became an “Honorary Overseas Member” of the Japanese Geotechnical Society.

**Susan Gourvenec, Mark Randolph** and our former 4th year student **Oliver Kingsnorth** were awarded the 2008 ASCE International Journal of Geomechanics Excellent Paper Award for their paper “Undrained Bearing Capacity of Square and Rectangular Footings”.

**Mark Cassidy** was elected as a Fellow of the Australian Academy for Technological Sciences and Engineering.

**David White**, along with co-authors **Johnny Cheuk** (Hong Kong University) and **Malcolm Bolton** (Cambridge University) were awarded the R.M. Quigley Honourable Mention (see Figure 1) which is the runner-up prize in the Canadian Geotechnical Journal's best paper competition. Their paper, “Large scale modelling of soil-pipe interaction during large amplitude movements of partially-embedded pipelines”, was published in the August 2007 edition of the journal.

Grant Winners

COFS was awarded four Australian Competitive grants in 2008:

ARC discovery grant: Dr S. Gourvenec; Prof. M.F. Randolph, “Shallow foundation solutions for offshore oil and gas facilities”.

ARC Linkage grant: Dr C. Gaudin; Prof. M.J. Cassidy; Dr B. Bienen; Dr O.A. Purwana; Dr M. Quah, “A novel foundation to extend the operation of mobile structures into deeper water”, Collaborating/Partner Organisation(s): Keppel Offshore and Marine Pte Ltd.

ARC Linkage grant: Prof. L. Cheng; Prof. D.J. White; Prof. M.F. Randolph, “On-bottom stability of large diameter submarine pipelines”, Collaborating/Partner Organisation(s): Woodside Energy Limited.

Group of Eight/DAAD Australian-German Research Co-operation Scheme: Dr B. Bienen, Prof. M.F. Randolph, Prof. D.J., White, Prof. J. Grabe, and Mr J.Duehrkop from the University of Technology, Hamburg, Germany, “The use of winged piles to optimise the foundations for offshore energy production”.

Figure 1: Johnny Cheuk collecting the R.M Quigley Honourable Mention at the Canadian Geotechnical Society’s annual conference

Figure 2: Grant winners (L-R): Christophe Gaudin, Mark Randolph, Arcady Dyskin (Civil Engineering), Ming Zhao, Elena Pasternak (Mechanical Engineering ) and Britta Bienen
National Youth Science Forum

Figure 3: Conveying the excitement of offshore foundations with baby photos?

Early in 2008 Mark Cassidy was invited to be the after dinner “inspiration” speaker at the National Youth Science Forum (NYSF), a two-week annual science camp for 144 students about to enter Year 12. Held in Canberra the camp promotes science to future scientific leaders, providing them with exposure to guest lectures, experiments, laboratory visit, field excursions and development of their own scientific networks. Mark looks forward to the development of a NYSF program in Western Australia, which is planned to run a full program in Perth in 2010.

Graduation Ceremony

April 2008 Graduation Ceremony was well attended by those who were awarded their PhDs. Congratulations to COFS students Britta Bienen, Nina Levy and Chin Chai Ong.

Soccer

The 20th of November was the date of this years COFS v Civil Soccer match for 2008.

As some of you may remember the first of these encounters was won by COFS in 07, and as a result Civil were keen to make amends, and this they did in style.

The only highlight for COFS was in scoring the first goal of the match after 10 minutes, which sent a shiver through the Civil camp, but they quickly regrouped and equalised in a matter of minutes and by half time were leading 2–1.

As the second half progressed the raw talent of the likes of Helinski, Doherty & Leane and not mention Liang Cheng who was absent from the previous year came to bear along with several others in finishing with a score line of 5–1 to Civil.

COFS looks forward as always to the next encounter when we will once again face difficult challenge of Civil.

Thanks to all those who participated whether it was on or off the pitch.

Figure 4: Graduation ceremony Back Row (L–R): Liang Cheng, Chin Chai Ong, Britta Bienen, Nina Levy, Andrew Deeks, Boning Li, Mark Cassidy, Steve Chidgzey Front Row (L–R): Mark Randolph, Kervin Yeow, Nawawi Chow

Figure 5: COFS soccer team

Figure 6: Civil soccer team
2008 Journals


Gourvenec, S. (2008), Shape effects on the capacity of rectangular footings under general loading, Geotechnique 57(8): 637-646.


**2008 Conferences**


Gaudin, C., K. H. Tham and S. Ouahshine (2008), Plate anchor failure mechanism during keying process. *International Symposium on Offshore and Polar Engineers (ISOPE)*.


Hossain, M. S., M. J. Cassidy and D. Daley (2008). Experimental investigation of Swiss cheese drilling in stiff-over-clay. 2nd Jack-up Asia Conference, Singapore, CD:

Hossain, M. S. and M. F. Randolph (2008). Overview of spudcan performance on clays: current research and SNAME. 2nd Jack-up Asia Conference and Exhibition, Singapore, CD:


### Upcoming Publications


Gaudin, C., B. Bienen and M. J. Cassidy (2009), Centrifuge experiments investigation the use of jetting in spudcan extraction, xvth International Conference on Soil and Foundation Engineering (ISOPE), Osaka, Japan, accepted.


Gaudin, C. and D. J. White (2009), New centrifuge modelling techniques for investigating seabed pipeline behaviour, xvth International Conference on Soil Mechanics and Geotechnical Engineering Alexandria.


Govoni, L., S. Gourvenec and G. Gottardi (?), Centrifuge modeling study of bearing capacity of circular surface footings on sand under general planar loading: submitted June 07.


Hodder, M. S., D. J. White and M. J. Cassidy (2009), Effect of remoulding and reconsolidation on the touchdown stiffness of a steel catenary riser: observations from centrifuge modelling. 41st Offshore Technology Conference, Houston, USA, CD: OTC19871.


Hossain, M. S. and M. F. Randolph (2009), New mechanism-based design approach for spudcan foundations on stiff-over-clay, Offshore Technology Conference, Houston, USA, OTC19907.


Low, H. E., T. Lunne, K. H. Andersen, M. A. Sjursen, X. Li and M. F. Randolph (?), Estimation of intact and remoulded undrained shear strengths from penetration tests in soft clays, Geotechnique: submitted February 2009. 


Randolph, M. F. and P. Quiggin (2009), Non-linear hysteretic seabed model for catenary pipeline contact. 28th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2009), OMAE2009-79259.


Tran, M. N. and M. F. Randolph (2009), Closure discussion of "Variation of suction pressure during installation in sand", *Geotechnique* 59(1).


# STATEMENT OF FUNDS AND EXPENDITURE
for the year ended 31 December 2008

## FUNDING

<table>
<thead>
<tr>
<th>Source</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008 Funds Carried Forward</td>
<td>$1,660,498.01</td>
</tr>
<tr>
<td>Commonwealth Government Funds</td>
<td></td>
</tr>
<tr>
<td>Research Quantum</td>
<td>$583,251.16</td>
</tr>
<tr>
<td>ARC Grants</td>
<td>$609,730.00</td>
</tr>
<tr>
<td>CSIRO Flagship Collaboration Fund</td>
<td>$503,338.71</td>
</tr>
<tr>
<td>Department of Innovation, Industry, Science &amp; Resources</td>
<td>$36,600.00</td>
</tr>
<tr>
<td>State Government</td>
<td>$648,859.13</td>
</tr>
<tr>
<td>Host Institution Support</td>
<td>$410,972.51</td>
</tr>
<tr>
<td>Industry/Private Funds</td>
<td>$2,128,208.99</td>
</tr>
<tr>
<td>Other Funds</td>
<td>$157,674.96</td>
</tr>
<tr>
<td><strong>TOTAL FUNDS AVAILABLE</strong></td>
<td><strong>$6,739,133.47</strong></td>
</tr>
</tbody>
</table>

## EXPENDITURE

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salaries</td>
<td></td>
</tr>
<tr>
<td>Academic Staff</td>
<td>$1,969,138.62</td>
</tr>
<tr>
<td>Non-Academic Staff</td>
<td>$1,324,589.99</td>
</tr>
<tr>
<td>Scholarships and Scholarship Supplements</td>
<td>$229,342.36</td>
</tr>
<tr>
<td><strong>TOTAL EXPENDITURE</strong></td>
<td><strong>$4,896,482.37</strong></td>
</tr>
<tr>
<td>Equipment</td>
<td>$675,207.55</td>
</tr>
<tr>
<td>Travel &amp; Conference Expenses</td>
<td>$196,338.43</td>
</tr>
<tr>
<td>Consumables</td>
<td>$36,054.52</td>
</tr>
<tr>
<td>Other Expenses</td>
<td>$465,810.90</td>
</tr>
<tr>
<td><strong>TOTAL EXPENDITURE</strong></td>
<td><strong>$4,896,482.37</strong></td>
</tr>
</tbody>
</table>

**CARRIED FORWARD TO 2009** $1,842,651.10
### COMMONWEALTH GOVERNMENT FUNDS

#### Department of Education and Training
Operating Grant – Research Quantum $583,251.16
Australian Postgraduate Awards* $15,454.58

#### ARC Programs
- Cassidy, Randolph & Hu – Investigation of Potential Spudcan Punch Through Failure LP0561838 $26,604.00
- Gaudin – Follower embedded plate anchors to underpin economic development in ultra deep water DP0771348 $55,474.00
- Merifield – Rigorous 3D Plasticity Solutions for Soil and Rock Slope (Transferred to Newcastle University) -$17,823.00
- Randolph – Deep Penetrating Anchors – A cost effective anchoring solution for mooring oil and gas facilities in deep water LP0562561 $25,520.00
- Randolph – Federation Fellowship – Geotechnical Engineering Solutions for Deep Water Oil & Gas Development FF0561473 $329,078.00
- Randolph – Application of field penetrometer data to offshore geotechnical design in deep water DP0665958 $190,877.00

#### CSIRO Flagship Cluster
Cassidy, Randolph, Cheng, Gaudin, White, Hao, et al – Subsea Pipelines for Reliable and Environmentally Safe Development of Ocean Hydrocarbon Resources $503,338.71

#### Department of Innovation, Industry, Science & Resources
International Science Linkages Program – International Symposium on Frontiers in Offshore Geotechnics 2010 (ISFOG) $36,600.00

### STATE GOVERNMENT FUNDS

#### Department of Industry and Resources – Centre of Excellence $286,589.00
WA Energy Research Alliance – Subsea Gas Processing $302,077.96
MERIWA – Modelling of Submarine Landslides and Their Impact on Pipelines $30,192.17
MERIWA Postgraduate Scholarships $30,000.00

### HOST INSTITUTION SUPPORT
University Postgraduate Awards* $255,480.07
Research Matching Funds $376,331.27
University Strategic Funds $109,982.51
Whitfield Fellowship $277,500.00
Postgraduate Travel Awards $15,990.00

### PROJECT AND INDUSTRY SUPPORT
$2,128,208.99

### OTHER FUNDS
$157,674.96

### TOTAL FUNDING
$5,725,901.38

* Denotes notional funds
COFS Funding 2008

- Industry/Private Funds: $2,128,209 (34%)
- University Postgraduate Awards: $376,331 (6%)
- Research Quantum Awards: $583,251 (9%)
- Scholarships and Scholarship Supplements: $229,342 (5%)
- Equipment: $675,208 (14%)
- Travel & Conference Expenses: $196,338 (4%)
- Consumables: $36,055 (1%)
- Other Expenses: $465,811 (10%)
- Other Funds: $157,675 (2%)
- In Kind Salary Support: $255,480 (4%)
- CSIRO Flagship Collaboration Fund: $503,339 (8%)
- State Government: $648,859 (10%)
- Department of Innovation, Industry Science & Resources: $36,600 (1%)
- Host Institution - In Kind: $631,811 (10%)
- Host Institution - Cash: $410,973 (6%)

COFS Expenditure 2008

- Academic Staff: $1,969,139 (39%)
- Non-Academic Staff: $1,324,590 (27%)
- Scholarships and Scholarship Supplements: $229,342 (5%)
- Equipment: $675,208 (14%)
- Travel & Conference Expenses: $196,338 (4%)
- Consumables: $36,055 (1%)
- Other Expenses: $465,811 (10%)
- Other Funds: $157,675 (2%)
- In Kind Salary Support: $255,480 (4%)
- CSIRO Flagship Collaboration Fund: $503,339 (8%)
- State Government: $648,859 (10%)
- Department of Innovation, Industry Science & Resources: $36,600 (1%)

COFS Funding 2008

COFS Expenditure 2008