Offshore sediments

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

A new series of fundamental studies has started in the laboratory that will focus on the rigorous characterisation of various aspects of the mechanical behaviour of offshore sediments using element testing protocols. Analysis and understanding of offshore sediments behaviour has also continued through a series of rigorous numerical studies. Likewise, field methods for characterising the behaviour of offshore sediments have been developed further in 2012. A summary of these studies is provided below.

Particle breakage of a soil with crushable grains in one-dimensional compression

Antonio Carraro and Nathalie Boukpeti have started a new series of fundamental studies focused on the rigorous characterisation of various aspects of mechanical behaviour of offshore sediments. The first study of the series is focusing on the effect of particle breakage on the one-dimensional compression of a carbonate sand from Western Australia. Like many other offshore deposits from Western Australia, the sand selected for this research has a significant amount of relatively weak, crushable grains (Figure 55). Shin Chou led the initial study focusing on the evaluation of basic index properties, particle-size distribution, and one-dimensional confined stiffness of the soil for vertical stresses varying from 0.01 to 3 MPa and low to medium relative densities. Yield stresses associated with the onset of particle crushing were found to be considerably lower than what would be expected for silica sands. A fractal analysis (McDowell and Bolton 1998) and determination of the stiffness exponent and modulus number of the soil (Muir Wood 2009) will be conducted next in combination with an additional series of high-quality experiments focusing on wider ranges of stress and density variables as well as other types of boundary conditions.

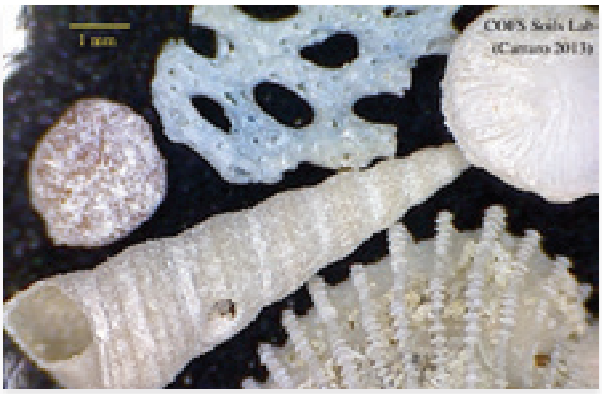


Figure 55: Typical particle shapes of carbonate sand used in the study

Numerical analysis of pipeline-seabed interaction using a constitutive model that considers clay destructuration

Pipelines and risers form an essential part of the infrastructure associated with offshore oil and gas facilities. In deep water environments, the seabed is typically soft clay. Many geotechnical processes regarding offshore foundations and pipelines on clay soils involve cyclic movements that remould and soften the surrounding soil. This disturbance leads to significant changes in the operative shear strength and the basic constitutive properties of the soil such as critical state, which must be assessed in design. Prediction of soil strength and the resulting pipe-soil interaction forces are essential in providing an appropriate idealisation of the soil-structure interaction. However, due to the severity of the cyclic action, it is important to account for the changing constitutive properties of the soil (due to the combined effects of remoulding and reconsolidation) during episodes of disturbance.

The aim of this research is to tackle problems of pipe-soil interaction involving remoulding and reconsolidation, using numerical modelling. To do so, it is necessary to adopt a constitutive model that captures changes in clay soil behaviour after destructuration caused by the cyclic movements mentioned above. A destructuration theory recently proposed in the literature, which is applied to the SANICLAY Constitutive Model, will be used in this research. SANICLAY is a constitutive model for clays within the framework of critical state soil mechanics, employing the new concept of the bounding surface in plasticity theory. In this research, we have written the algorithm for single element test of SANICLAY constitutive model and we are going to add the destruction theory in it and implement it in ABAQUS.

Piezoball penetrometer

Postgraduate researcher Hamed Mahmoodzadeh continued his work on piezoball penetrometers, focusing on prediction for the penetration resistance of the jack up spudcan from a piezoball penetrometer test due to the similarities in the failure mechanism. The differences in the rate of penetration and the size of two objects could lead to different drainage conditions during the penetration of the probe and the spudcan. To solve this problem, methods need to be developed to estimate the drainage condition during ball penetration tests.

Determining the coefficient of consolidation (c_v) is the key point to estimate the degree of consolidation during penetration. This parameter could be estimated from a dissipation test. The effect of the degree of consolidation on the results of ball penetration test and following dissipation test was first studied through centrifuge modelling using two miniature pizoballs with different pore pressure measurement positions and a piezocone. Previously, in the absence of analytical and numerical solutions for ball dissipation tests, results of piezoball dissipation tests were interpreted based on the solutions for cone dissipation tests. To overcome this shortage, Hamed and Dong Wang replicated ball and cone centrifuge tests numerically using ABAQUS software. Coupled consolidation analyses were performed using modified Cam-clay model, and both cone and ball penetrometers were modelled using modified small strain and LDFE approaches. The penetration resistance and the following dissipation test were compared to the centrifuge test results and previous studies. After verification of the method, the effect of penetrometer's geometry (ball size and shaft to ball area ratio) and soil permeability were studied. Based on the parametric studies, a method to interpret the ball dissipation test was proposed. This method considers the effect of ball geometry and the coefficient of consolidation of the soil.

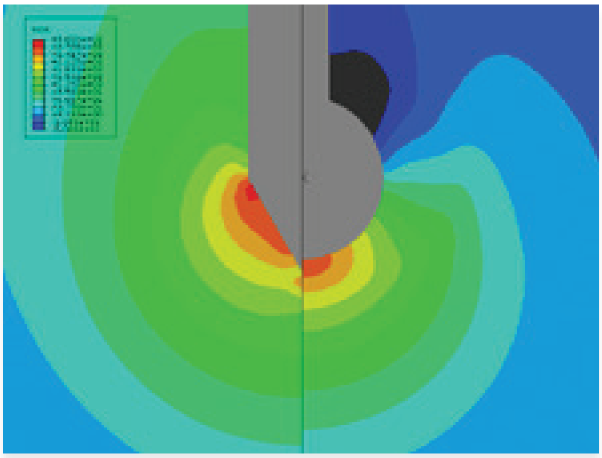
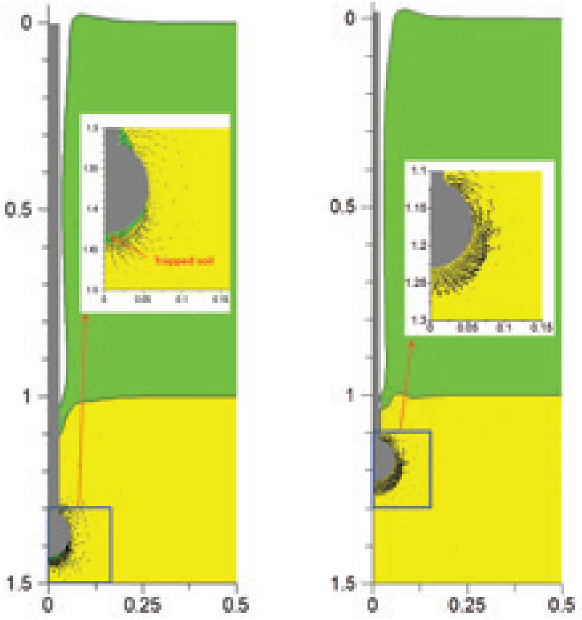


Figure 56: Excess pore pressure field around the ball and cone penetrometer

Behaviour of ball penetrometer in uniform single and double layer clays

The spherical ball penetrometer is used increasingly for profiling the undrained shear strength of soils in centrifuge and offshore site investigations. Mi Zhou, Shazzad Hossain and Yuxia Hu investigated undrained vertical penetration of ball penetrometers in uniform and stratified clay deposits through large deformation FE (LDFE) analysis. The LDFE analyses have simulated continuous penetration of ball penetrometers from the seabed surface. The results were validated against centrifuge test data and plasticity solutions prior to undertaking a detailed parametric study, exploring a range of normalised soil properties and layer thickness and roughness of soil-ball interface. The influence of the shaft (or area ratio) was also identified. It is found that the evolving soil failure patterns in single and double layer soils revealed two interesting aspects including (a) soil backflow above the penetrometer and (b) trapping of the stronger material beneath the penetrometer. A framework has been proposed to account for these effects, which will allow accurate interpretation of soil undrained shear strength from the ball penetration resistance.



(a) Punch-through pattern for smooth ball on stiff-over-soft clay

(b) Rough ball on stiff-over-soft clay

Figure 57: Soil failure mechanisms in double layer clays

Numerical investigation of cone and ball penetrometers in multi-layered soils using LDFE/RITSS method

Hongliang Ma joined COFS as a PhD candidate in July 2012 researching "Numerical investigation of cone and ball penetrometers in multi-layered soils using LDFE/RITSS method." Cone and ball penetrometers are site investigation tools for soil characterisations. When multilayer soil is encountered, interpreting site investigation data obtained from penetrometers becomes challenging because there are no existing design guidelines for the accurate extraction of soil parameters from the site data. The successful completion of this project will provide such guidelines to assisting in foundation design.

The behaviours of cone and ball penetrometers on multi-layer soils are being investigated, penetrating the objects continuously from the mudline. The main achievement thus far is the completion of validating the numerical model for a cone penetrometer in uniform clay (Figure 58 illustrates soil failure mechanism at a stage of penetration). Results have showed good consistency with existing analytical solutions, LDFE results and laboratory test data.

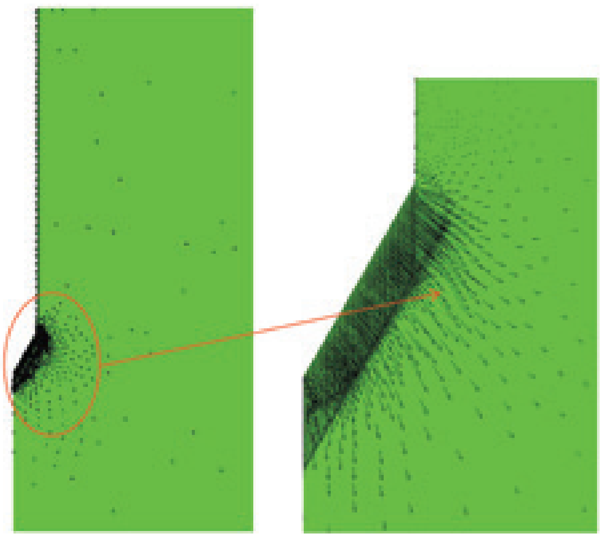


Figure 58: Flow mechanism of cone penetrometer

Seabed penetrometers

Yue Yan continued her PhD studies of toroidal or hemisphericalnovel seabed penetrometers. These devices are tailored to provide characterisation data for the upper half metre of the seabed, to suit pipeline design. They are actuated vertically and torsionally. Yue performed coupled finite element analyses to study wedging effects during different phases of pipe and the toroid/ball penetrometer movements. The wedging effects must be understood if the device measurements are to be converted to fundamental soil parameters, such as interface friction coefficients. It was found in this study that the wedging effect is influenced by the interface properties and loading history.

Figure 59 compares wedging factors calculated after excess pore pressure dissipation (ζ' post-penetration) with values after slow sliding (ζ' post-sliding) for a toroid and pipe, and rough and smooth cases. The post-penetration wedging factor is somewhat affected by overloading ratio for the rough case, but these differences are ironed out by a phase of drained sliding. The ultimate wedging factor is generally close to the analytical solution that is commonly used in practice.

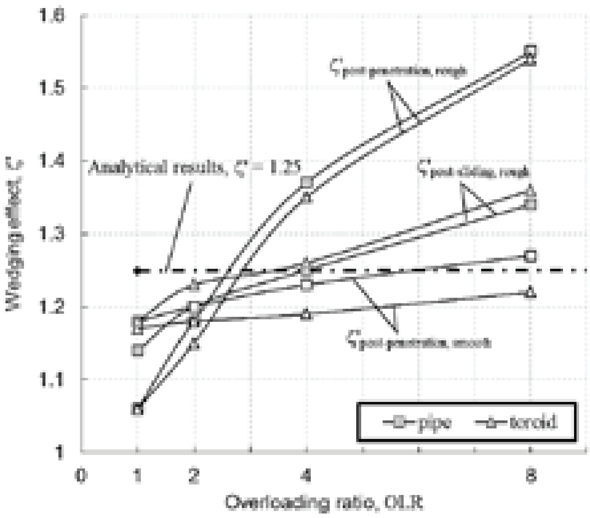


Figure 59: Wedging effect for toroid and ball (w/D = 0.4)

David Russell-Cargill, supervised by Dave White, designed a full scale hemiball device suitable for deployment in the field, as part of his honours project. The device was carefully designed using CAD with a set of 5 surface pore pressure transducers, to detect the presence and distribution of excess pore pressure around the hemiball surface. David is currently trialling the device in the laboratory, before it will be deployed in the field.

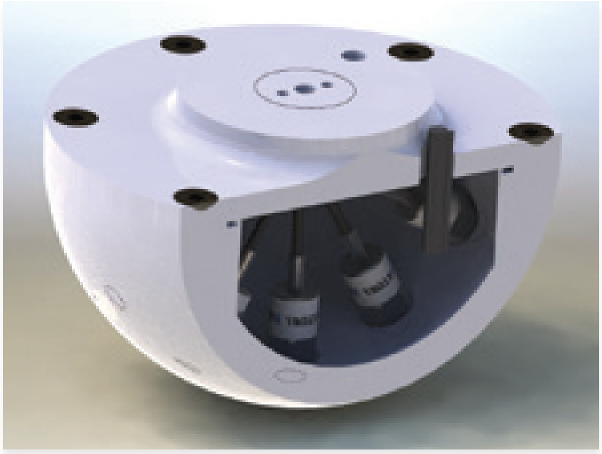


Figure 60: A CAD drawing of our hemispherical penetrometer for shallow seabed characterisation

Figure 61: Manuel and David consulting their crystal hemiball

Understanding the processes associated with dynamic penetration of rigid streamlined bodies from water into soft soil is challenging. In order to simplify this problem, PhD student John Morton has been dropping an instrumented sphere through water into soft clay in field sites in Northern Ireland and off the coast of Scotland. The 250 mm diameter sphere impacts the soil at velocities of up to 8 m/s, causing strain rates in the soil that are several orders of magnitude higher than those typically measured in soil element strength tests in the laboratory.

Instrumentation housed within the sphere measures acceleration on three orthogonal axes and tilt around the same three axes, which permits tilt compensated acceleration in the vertical plan to be measured during free-fall in water and embedment in soil. This data can be used to determine the velocity of the sphere with depth, which is then compared with corresponding theoretical profiles formulated in terms of strain rate enhanced shearing resistance and fluid mechanics inertial drag resistance.

It is hoped that these comparisons will provide insight into the processes taking place during dynamic penetration of rigid bodies into soil. This has widespread applications for a variety of soil structure interaction problems including dynamically installed ‘torpedo’ anchors, free-fall gravity core samplers and free-fall penetrometers for measuring undrained shear strength.

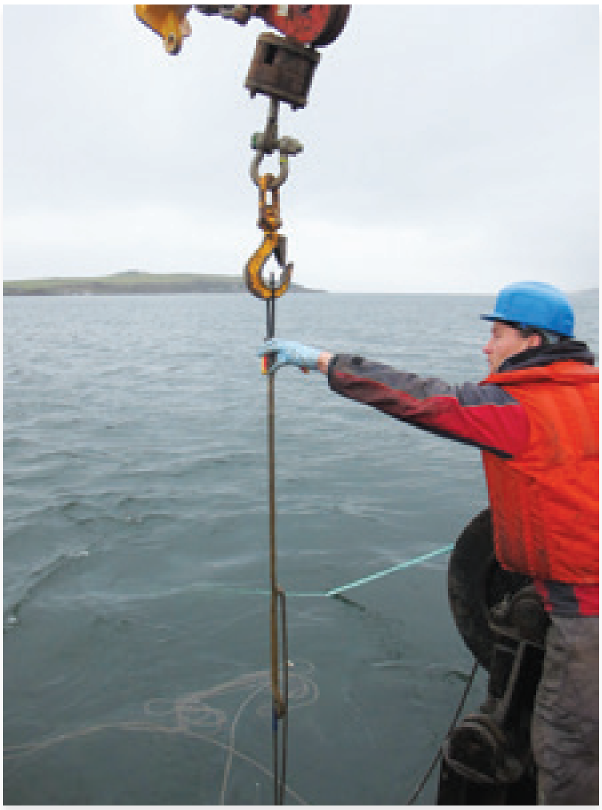


Figure 62: Testing off the coast of Scotland

Figure 63: Underwater photograph of a cavity left in the soil after dynamic penetration

Cathal Colreavy joined us 2012 after transferring his PhD studies from Ireland to COFS. Cathal is investigating the use of the piezoball penetrometer in soft soil characterisation. In 2012, Cathal conducted field tests at a number of onshore and offshore sites in the UK and Ireland.

A key aspect of Cathal's work is to examine the influence of the piezoball diameter on the pore pressure dissipation response. Field tests, conducted offshore Scotland (Figure 64), were conducted using two sized piezoballs of 80 mm and 113 mm diameters (Figure 65). These tests investigated the response of the two piezoball sizes during dissipation tests. Times for dissipation for the smaller piezoball were found to be comparable to that of the conventional piezocone. This confirms that if the piezoball diameter is reduced, it may be a viable alternative to the piezocone for assessing soil consolidation characteristics in the field.

Figure 64: Cathal Colreavy carrying out piezoball tests off the west coast of Scotland

Figure 65: 80 mm and 113 mm diameter piezoballs