Simple Shear Testing of Sand under Cyclic and Multidirectional Loading

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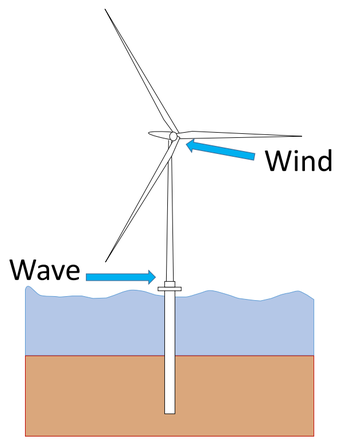
Introduction

- Offshore wind turbines (OWT) are predominantly supported on monopile foundations.
- Monopiles are subjected to a range of complex dynamic loads throughout their lifetime, e.g. wind and wave loads in multiple directions (Abadie, 2015).
- In current design practice, constitutive models are used to capture the soil behaviour under these complex loading conditions.
- To further develop a better understanding of soil response to such loading conditions, high-quality laboratory element tests are required. In this project the simple shear test will be used to create a new laboratory test database.



Multidirectional loading on OWT

Multidirectional cyclic loading caused by wind and wave loads

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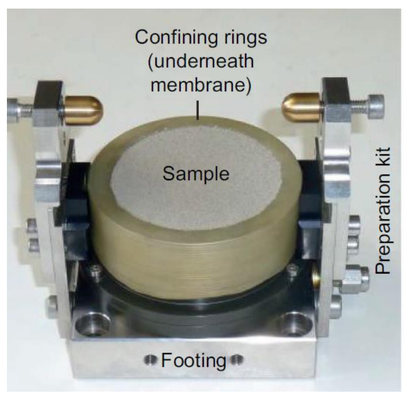
Soil response:
Increase in accumulated shear strain
Changes in soil stiffness
Changes in pore pressure

Research Objective: To develop an accurate and easily implementable constitutive model capable of capturing the behaviour of sand when subjected to complex loads

Sample Preparation

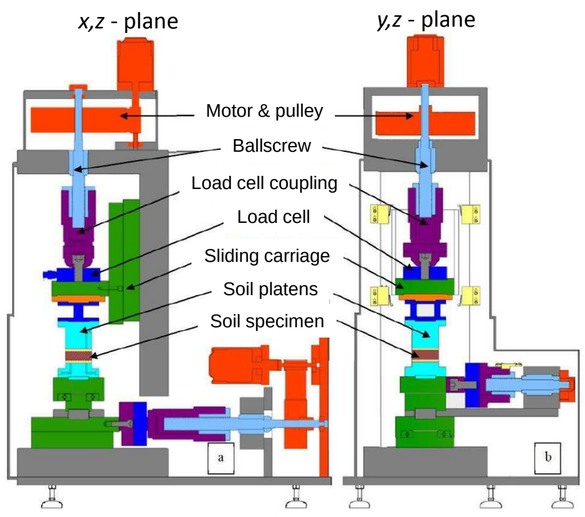
- Test Material: Leighton Buzzard Sand
- Dimensions: 70mm diameter
  17mm height
- Preparation Method:
  - Hopper method / Air pluviation (dry)
  - Slurry deposition / Moist tamping (wet)
- Test specimens are reconstituted to simulate natural deposition processes.



Sample preparation kit by GDS
Source: Rudolph et al. (2014)

Laboratory Apparatus

- Testing will be undertaken using the Variable Direction Dynamic Cyclic Simple Shear (VDDCSS) device manufactured by GDS Instruments Ltd.
- The device allows simple shear of specimen in two directions (*x* and *y*) using two orthogonally positioned actuators. Actuators can be strain or load controlled.



Schematic of VDDCSS operation mechanism
Source: Li et al. (2017)

Sample orientation inside VDDCSS
Source: Rudolph et al. (2014)

Future Work

Stage 1: Develop robust sample preparation techniques

Stage 2: Investigate effects of cyclic and multidirectional loading

Stage 3: Select and calibrate appropriate constitutive sand model.
- Critical state model e.g. *Nor-Sand* (Jefferies, 1993)
- Bounding surface model e.g. *MIT-S1* (Pestana & Whittle, 1999)
- Kinematic-hardening bounding surface model e.g. *Severn-Trent* (Gajo & Wood, 1999)

References:

1. Abadie, C. N. 2015. "Cyclic Lateral Loading of Monopile Foundations in Cohesionless Soils." DPhil dissertation. University of Oxford.
2. Gajo, A. & Wood, M. 1999. Severn–Trent Sand: A Kinematic-Hardening Constitutive Model: the q–p Formulation. Géotechnique. 49(5):595–614.
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4. Li, Y., Yang, Y., Yu, H.-S. & Roberts, G. 2017. Monotonic Direct Simple Shear Tests on Sand under Multidirectional Loading. International Journal of Geomechanics. 17(1).
5. Pestana, J.M. & Whittle, A.J. 1999. Formulation of a Unified Constitutive Model for Clays and Sands. International Journal for Numerical and Analytical Methods in Geomechanics. 23(12):1215–1243.
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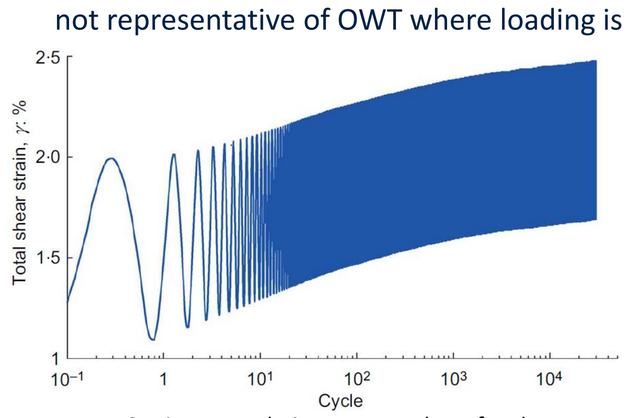
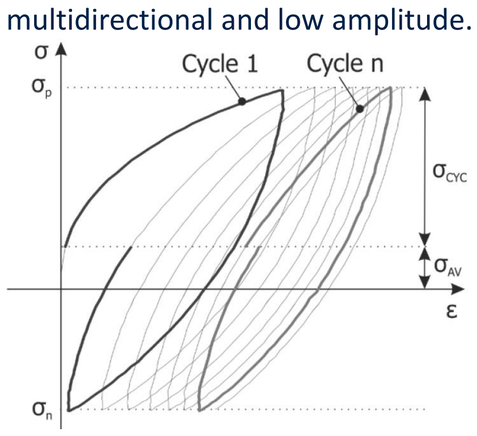
Initial Studies

Cyclic Testing

- Element tests are performed to verify behaviour of sand under cyclic loads.
- The outputs from the tests will allow comparisons between pile testing and element testing experiments.
- Previous testing is unidirectional with relatively high load-amplitude, which is not representative of OWT where loading is multidirectional and low amplitude.



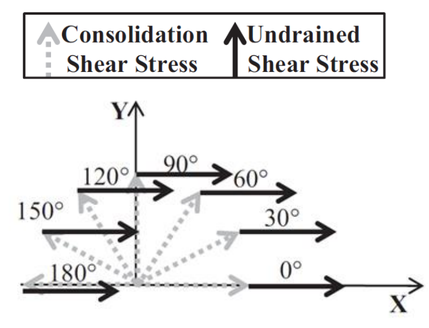
Strain accumulation over number of cycles
Source: Rudolph et al. (2014)



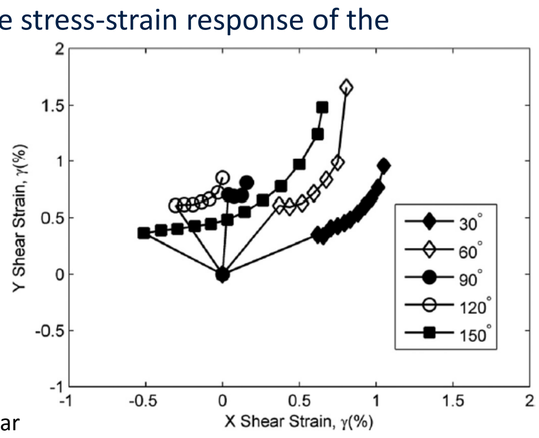
Typical cycle definition for element tests

Multidirectional Loading

- The examples below illustrate undrained loading tests performed under constant volume conditions.
- The direction of the consolidation shear stress with respect to the secondary shear stress, has a significant effect on the stress-strain response of the specimen.



Stress path on soil sample showing first consolidation shear stress followed by undrained shear stress
Source: Li et al. (2017)



Shear strain accumulation in *x* and *y* directions
Source: Li et al. (2017)

Summary

- Preparation of reconstituted sand sample to be carried out using either the hopper or slurry deposition method.
- VDDCSS is capable of applying highly controlled cyclic loading in two different directions orthogonal to one another.
- Selected constitutive model to be calibrated from VDDCSS outputs and readily implemented into 3D FEA.

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