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A new experimental setup to investigate the cyclic response of soft soils under induced earthquakes

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Energy technologies, which work by extracting or injecting fluids in the ground, such as geothermal energy systems or underground liquefied gas storage, may induce seismic events, see e.g., [1]. In the Netherlands, induced earthquakes are continuously recorded from the Groningen gas field, with the largest magnitude ever recorded of M_L 3.6 at Huizinge. Even though the magnitude of these events is not high, compared to natural earthquakes, damage to the built environment is still caused because of the shallow depth of the events and site amplification, especially where soft soils are encountered [2]. Proper quantification of the induced seismic risk requires better understanding of the response of soft soils to these repeated short events, covering a range of frequencies from 1 to about 20 Hz. This motivated the development of a new advanced dynamic equipment to experimentally investigate the coupled response of soft organic clays and peats from the typical deltaic areas of the Netherlands.

Direct simple shear (DSS) apparatuses are preferred usually to investigate the soil behaviour under cyclic and dynamic loading. Among them, a number of multi-directional DSS setups have been developed to investigate the soil behaviour under multidirectional loading [3, 4, 5, 6, 7, 8]. Applying multi-directional loading to soil specimens in the laboratory is a keystone for elucidating the cyclic and dynamic soil response, as several studies have shown that the cyclic and post-cyclic response of soils is affected by multiple loading directions [6, 9, 10, 11, 12]. However, traditional DSS devices have a number of shortcomings, which are inherited by multi-directional DSS devices. The main deficiency of the DSS device is that the shear stress acting on the lateral side of the specimen cannot be controlled, and hence, a homogeneous stress state cannot be achieved, in spite of the common assumptions. Lateral stresses cannot be measured either in traditional setups, which leaves a knowledge gap on the stress state and the stress path of the sample.

In addition, the majority of laboratory element tests are performed by imposing “slow” undrained cyclic loads, to try to guarantee uniform water pressure distribution within the sample, for the sake of interpretation and modelling. However, seismic events encompass much higher loading frequencies than typically available, with loading rate effects playing a key role in the response of soft soils such as organic clays and peats. In order to fully understand the cyclic behaviour of soft soils, “fast” cyclic tests are crucial.

The innovative multidirectional shear device, developed in the section of Geoengineering at TU Delft (Cyclic-Dynamic shear simulator for Organic Soft Soils, CYC-DOSS), was designed to overcome some limitations of previous equipment. The underlying idea is to abandon the homogenous stress-strain state assumption and monitor the response with local sensors, which allows conditioning a numerical back-analysis of the test data. The new device shown in Figure 1 is characterised by (1) servo-hydraulic control; (2) multi-directional loading in 3 axes; (3) bender elements to measure both P-wave and S-wave velocity; (4) fully controlled cell pressure and back-pressure; and (5) possibility to reproduce the full acceleration time history of seismic events. The device is capable to apply loading frequencies up to 25Hz and a wide variety of multidirectional cyclic loading patterns. The apparatus is equipped with advanced sensors, also developed at TU Delft, including local pressure, displacements, and accelerations devices. The sensors are installed to reduce a priori assumptions on the soil response, better interpret the experimental results as a small-scale physical model and further investigate in depth the soil response under a variety of cyclic loading histories. The experimental

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information from the setup will be used to develop and calibrate an advanced bounding surface constitutive model for soft organic soils.

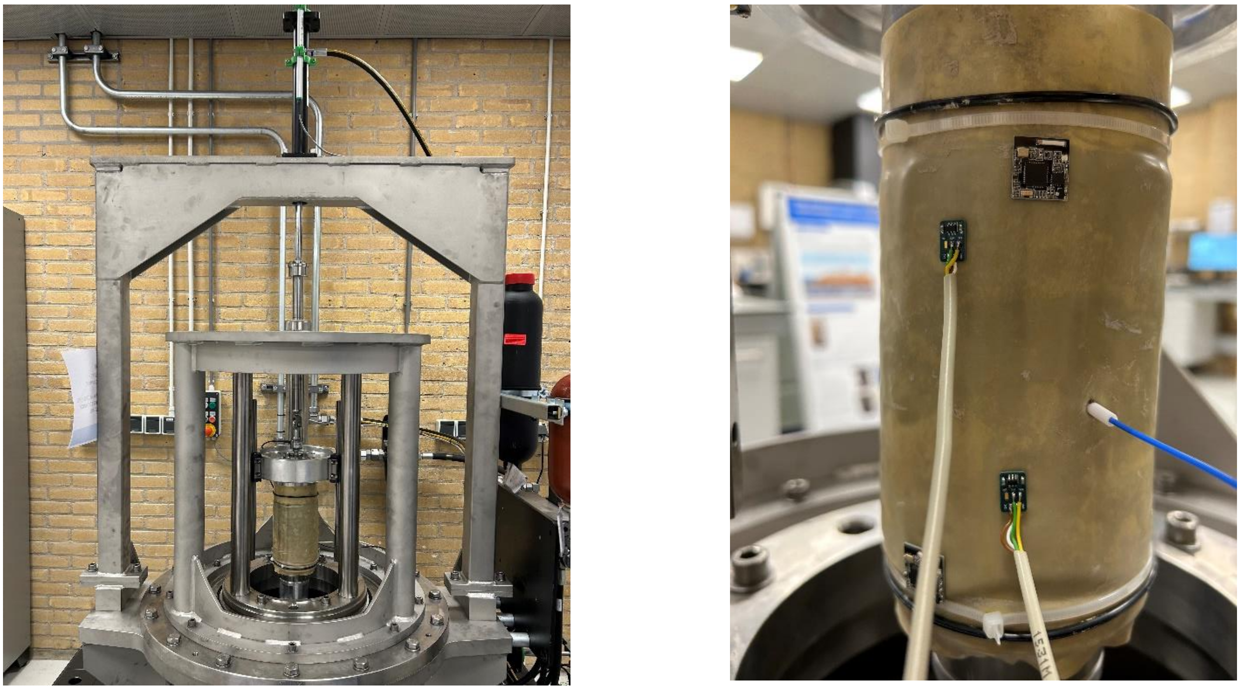

Figure 1: The CYC-DoSS apparatus and the local response sensors.

Contributor statement

Ching-Yu Chao: conceptualisation, design, laboratory work, writing; Wout Broere: conceptualisation, supervision, revision; Cristina Jommi: supervision, revision

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