NEW PRODUCT DEVELOPMENT:
A MULTI-DIRECTIONAL DYNAMIC CYCLIC DIRECT SIMPLE SHEAR APPARATUS

Writing for the Geotechnica this month are the GDS Instruments’ Technical Team. This month GDS turn their focus to their newly developed product, a multi-directional dynamic cyclic direct simple shear apparatus.

What is a multi-directional laboratory test apparatus?

A significant majority of test apparatuses traditionally used in soil laboratories shear soil elements in a single direction only. Examples include the direct shear apparatus, in which a test specimen is sheared in a single horizontal direction following application of normal stress, and the triaxial apparatus, in which soil elements are compressed or extended vertically following completion of saturation and consolidation. Such apparatuses may be termed uni-directional, as the direction of shearing is fixed to one specific axis.

It is however possible to design and build more advanced apparatuses in which soil elements can be sheared in more than one direction – such apparatuses may therefore be termed multi-directional. To highlight this idea, Figure 1 displays a three-dimensional and plan view of a soil element subjected to normal stress and shear stresses applied from two directions (τ_X and τ_Y). Here the application of τ_Y perpendicular to τ_X leads to a resultant shear stress, τ_XY, acting in a direction different to the X and Y components. Further to this, changing the relative magnitudes of τ_X and τ_Y vary the direction in which τ_XY acts, enabling shear in any horizontal direction to be specified and applied.

What effect does multi-directional loading have on soil response?

Although many laboratory test apparatuses are uni-directional, loading conditions in the field are typically three-dimensional in nature. This includes cyclic stresses induced during earthquake shaking, and the cyclic loadings applied to offshore structures as the direction of wind and wave action varies. Recognising this difference between field loading and laboratory simplification, a number of studies reported in the geotechnical literature have investigated the effect of uni-directional and multi-directional loadings on soil strength and deformation. An early example regarding soil response during earthquakes include the shake table tests reported by Pyke et al. (1975), during which dry sand settlements were shown to increase significantly when multi-directional shaking was used in place of uni-directional shaking. More recently, work conducted at the Hamburg University of Technology (TUHH) by Dührkop and Grabe (2008) has shown that laterally-loaded mono-piles used to support offshore wind turbines accumulate larger displacements when the applied cyclic loadings are multi-directional.

With the difference in load directionality between the field and laboratory equipment recognised, a number of multi-directional laboratory apparatuses have been constructed by various institutions at points throughout the evolution of soil mechanics. These include the multi-directional direct simple shear apparatuses reported by Ishihara and Yamazaki (1980), Boulanger et al. (1993), and Rutherford and Biscontin (2013), which were produced to study topics ranging from sand response during multi-directional earthquake shaking, to rate and load direction effects on pore pressure generation in marine clays.

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The direct simple shear apparatus

First built by the Royal Swedish Geotechnical Institute in 1936 and reported by Kjellman (1951), the direct simple shear apparatus (DSS) is a relatively common sight in soil testing laboratories today. “Its popularity stems from a number of practical advantages over traditionally-used devices...”

Its popularity stems from a number of practical advantages over traditionally-used devices such as the triaxial apparatus, including the ability to deform soil elements in plane strain and smoothly rotate the principal stress directions. Such loading conditions are often representative of those observed in the field, including where the soil adjacent to friction piles is deformed, or when approximating the stress state applied to soils underlying offshore structures. Direct simple shear has also been suggested to better represent the soil response to vertically-propagating shear waves generated by earthquakes when compared with the triaxial test. These advantages have therefore made DSS testing an important addition to laboratory investigations during many engineering projects.

Of course the DSS test does come with limitations, as do all laboratory tests. Here an inability to apply complementary shear stresses along the specimen sides (see Figure 2) results in non-uniform stresses being...
may have on soil response, GDS Instruments designed and built a new multi-directional direct simple shear apparatus in cooperation with TUHH. This was done as part of the continued TUHH work investigating the response of offshore mono-piles during multi-directional loading.

**New product development:**

**The GDS VDDCSS**

The variable direction dynamic cyclic simple shear apparatus (VDDCSS), designed and built by GDS Instruments in cooperation with TUHH, and shown in Figure 3, is an SGI-style DSS device based around the GDS uni-directional dynamic cyclic simple shear system (EMDCSS). Here the test specimen is laterally confined using a standard latex membrane...

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The apparatus also contains four load cells for measuring normal and horizontal loads, including one mounted directly above the top-cap to eliminate friction error when taking horizontal load readings. To measure displacements, three low-range LVDTs are positioned around the specimen platen, complementing the displacement readings obtained from the high-accuracy actuator encoders. Many of the apparatus transducers can be seen in Figure 4.

With three electro-mechanical actuators used instead of the two required for uni-directional testing, the VDDCSS operates at frequencies up to 1 Hz via specifically-designed system firmware, applying shear stresses to specimens in any horizontal direction. In addition to its third axis positioned perpendicular to the primary shear actuator, the VDDCSS uses the same rigid frame developed for the EMDCSS, reducing system compliance and relative motion between the specimen platen.

“...the VDDCSS enables complex dynamic cyclic multi-directional tests to be performed with relative ease...”

Figure 3 – The variable direction dynamic cyclic simple shear apparatus (VDDCSS), designed and built by GDS Instruments in cooperation with TUHH.

“Here the test specimen is laterally confined using a standard latex membrane...”

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Figure 4 – VDDCSS platens and transducers (load and displacement). Note some system transducers are not shown in this photo.

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Using the VDDCSS to investigate offshore mono-pile response at TUHH...

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The apparatus also contains four load cells for measuring normal and horizontal loads, including one mounted directly above the top-cap to eliminate friction error when taking horizontal load readings. To measure displacements, three low-range LVDTs are positioned around the specimen platen, complementing the displacement readings obtained from the high-accuracy actuator encoders. Many of the apparatus transducers can be seen in Figure 4.

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Given the usefulness of the DSS test, and the recognised effect multi-directional loads developed during shear, while there is also potential (when using less-rigid test systems) for significant relative motion, or ‘rocking’, to occur between the top and base specimen.

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cycles, $\gamma$ shear strain after 30,000 load cycles. Rudolph et al. (2014). Here the variation has been reproduced from Rudolph et al. (2014). Figure 7 displays the accumulation of shear strain as the angle of loading direction is increased, reproduced from Rudolph et al. (2014).

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The angle of variation in loading direction, $\psi$, was then systematically increased throughout five tests, ranging from 0° (i.e., uni-directional shearing) to 120°.

The response observed during these five tests highlighted an increase in accumulated shear strain, $\gamma$, as $\psi$ was raised from 0° to 90°. This trend is displayed in Figure 7, which has been reproduced from Rudolph et al. (2014). Here the shear strain after 30,000 load cycles, $\gamma_{30,000}$, is normalised by the shear strain recorded after completion of the first load cycle, $\gamma_1$.

In addition to shear strain, Rudolph et al. (2014) also reported an increase in volumetric strains for test specimens where the direction of loading was varied, mirroring the higher settlements observed by Pyke et al. (1975) during multi-directional shake table tests. Such agreement is encouraging to see, and with three other VDDCSS apparatuses currently installed in various laboratories around the world the GDS team look forward to reading further publications discussing the response of DSS specimens sheared in multiple directions.

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References


