CHALLENGERS IN THE DEVELOPMENT OF ADVANCED GEOTECHNICAL LABORATORY EQUIPMENT

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Overview: GDS Instruments are no stranger to developing advanced laboratory equipment for geotechnical engineers. The company was created in 1979 for exactly that purpose. For the first 25 years of their life, GDS created advanced computer controlled testing systems primarily for use in Universities by research engineers. In April this year, the Hong Kong University of Science and Technology took delivery of GDS's latest creation, the True Triaxial Apparatus.

INTRODUCTION

GDS Instruments are no stranger to developing advanced laboratory equipment for geotechnical engineers. The company was created in 1979 for exactly that purpose. For the first 25 years of their life, GDS created advanced computer controlled testing systems primarily for use in Universities by research engineers. GDS estimate at least 500 Phd's have been obtained through the direct use of their equipment. In April this year, the Hong Kong University of Science and Technology took delivery of GDS's latest creation, the True Triaxial Apparatus (see Fig. 1).

Fig. 1: GDSTTA, True Triaxial Apparatus.

The defining characteristic of a True Triaxial Apparatus (TTA) is that, unlike conventional triaxial apparatus, all three principal stresses can be controlled independently. In conventional triaxial apparatus, the radial stress applies equal pressure around a cyclindrical sample in the σ_2 and σ_3 axes, and an axial ram takes care of any load control requirements for the direction of σ_1 (see Fig. 2a). A True Triaxial apparatus is designed to independently control stresses on a soil sample in the σ_1, σ_2 and σ_3 axes (see Fig. 2b), allowing a wider range of complex stress paths to be performed.

First developed by Kjellman in 1936, the idea behind the True Triaxial Apparatus was to enable researchers to investigate stress paths beyond that which could be investigated in conventional triaxial apparatus. As with many testing devices developed before the availability of low cost electronics (or even the existence of electronics), the TTA has been reborn as a viable testing system, albeit more likely to be used at present as a research tool. Kjellman's instrument utilised a fixed boundary approach whereby 6 platens would slide across each other to create the 3 axes of stress (see Fig. 3a). GDS have designed a system using a more typical approach to the application of stress by using a mixture of boundaries, 2 fixed (σ_1 and σ_2), with the final axis (σ_3) being applied using a constant hydraulic pressure. One of the greatest challenges for GDS with this new TTA was that it would be designed to perform dynamically with loading frequencies up to 10Hz, whilst maintaining the ability to load quasi-statically for low strain shear testing.

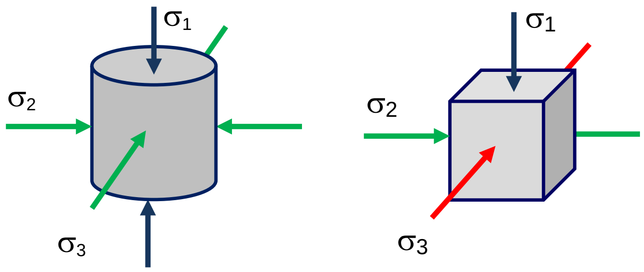

Fig. 2: a) Stress conditions on a conventional triaxial sample ($\sigma_2 = \sigma_3$), b) Stress conditions on True Triaxial Apparatus sample ($\sigma_1 \neq \sigma_2 \neq \sigma_3$).

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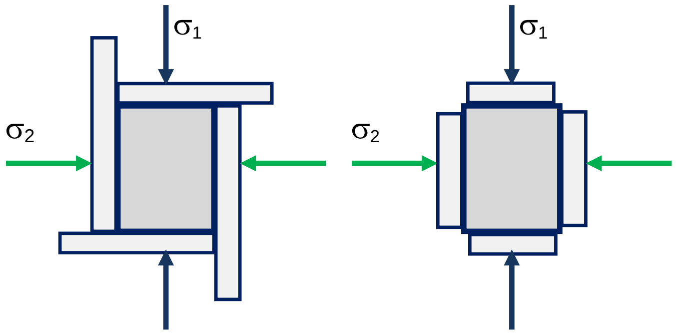

Fig. 3: a) Cross section of fixed boundary method, b) Cross section of the GDS approach which uses mixed boundaries, but does not suffer with friction problems associated with fixed boundaries.

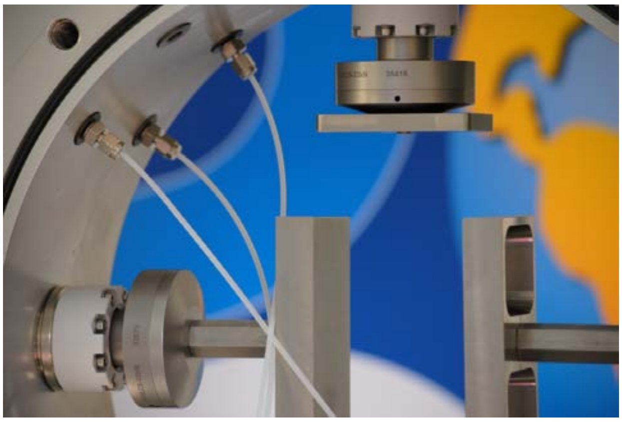

Fig. 4: Unlike conventional triaxial testing, vertical and horizontal platens have the potential to collide.

CHALLENGE 1: Mechanical Design

The main challenge in the mechanical design of the system was to produce reliable actuators that can operate at the high frequencies required. Design of the hydrostatic bearing arrangement required the use of exotic materials and multiple finishes, as well as extremely tight control of sizes, concentricity's and their tolerances. Each hydraulic actuator is controlled by an individual high-response servo valve that is required to operate at the high frequencies that we need to achieve. Keeping all hydraulic lines as short as possible is necessary in this sort of high-speed hydraulic system as the oil back pressure needs to be maintained to provide instant responses – to this end the shortest pipe runs need to be calculated as well as the use of accumulators and hydro-cushions such that hydraulic drag and pressure drop is reduced to an absolute minimum.

Four such hydraulic actuator units were mounted around the pressure-cell body, which was constructed with 2 sample access doors. Easy access to the sample via the doors was of paramount importance, as was the requirement to see the sample at all times when shut, therefore large windows that could take the internal pressure were also a design consideration.

The sample is mounted via platens (see Fig. 4 and Fig. 5), and various user-tools such as a datum setting kit had to be designed to help set the sample up in a nominal central position. The sample restraining membrane arrangement was a new design challenge for GDS as the square sample proved more difficult to hold and seal than the conventional normally cylindrical sample. The top caps were designed to taper away from the sample in order to keep their weight to a minimum, as with a high frequency system, the moving items need to be as light as possible to keep their inertia to a minimum.

CHALLENGE 2: Synchronising Paired Rams

When development started it became obvious that GDS existing hardware solutions could provide excellent control on a single axis, but were not a suitable solution in a multi-axis dynamic scenario. The existing firmware/software simply wasn't designed to deal with this. GDS has always controlled all aspects of its products - mechanical, electronic, firmware and software – and are not restricted by dependence on 3rd party products - so they took some of their existing hardware modules and then used them in an entirely new way to solve the problem. In doing so GDS rewrote their firmware and created brand new support software so it could achieve what was needed.

The GDS TTA solution utilises one dynamic controller per hydraulic ram – these are linked together by a high speed real time local bus network which allows each dynamic controller to share real-time (sub millisecond) information about what it is doing with all the other dynamic controllers on the local bus network. Firmware uses this information to ensure the dynamic controllers all remain synchronised and work together as a team to perform the test and prevents platen collision should a sample fail under load tests. PC based software co-ordinates the overall behaviour of each individual controller informing it of what role it should play in an overall test and collecting and collating data that each controller has collected.

CHALLENGE 3: Keeping the Sample Central

Even with full software and firmware co-ordination in place – the control of the rams themselves is a challenge in itself. Displacement control of paired rams was relatively easy. If the left hand actuator moved by 1mm, then so does the right hand actuator, thus maintaining the sample central. When trying to apply load control, there was always the possibility that even very slight differences in calibration between for example the left and right hand load cells, that the central position of the sample could shift. For example if exactly 2kN is applied to the left hand ram but 2.01kN is applied to the right hand ram perhaps due to very slight but inevitable differences in calibration, the sample would drift off to the left.

In load control mode, one ram was dedicated as the load control master, whilst the opposite ram moves under position control, mirroring the displacement of its opposite in real-time, thus keeping the sample in the central position. At lower frequencies this worked perfectly, however above 1Hz it is simply not possible to just follow the measured position due to the time it takes for a hydraulic ram to actually respond – there is always a time delay (albeit small) between targeting a position and reaching that position. With this simplistic approach one actuator will always be playing “catch-up” – however what the application demands is that they both maintain mirrored displacements with full synchronism, whilst controlling the master load value.

The TTA solves this problem by using an intelligent nested feedback approach so when a ram is under load control it is really under *both* load and position control – this means that the feedback process itself generates the correct reference position which can be shared with the ram tasked with mirroring displacement. Utilising this strategy both rams can remain perfectly synchronised in terms of displacement even though one is targeting load and the other targeting displacement.

CHALLENGE 4: Collision Prevention

The GDS TTA design required four hydraulic rams to be operated with perfect synchronism at up to 10Hz whilst ensuring the machine is protected by making it impossible for platens to collide with one another. To avoid collision, the position of each controller had to be resolved in real time such that the sample and the machine cannot be harmed. The collision reference point around the platens always lags behind the actual position, therefore a variable virtual safety zone is generated around the platens which triggers as any platen approaches potential collision. Fig. 5 shows the software collision state form which clearly informs the user when a platen is in the potential collision zone, and which platen is the offender.

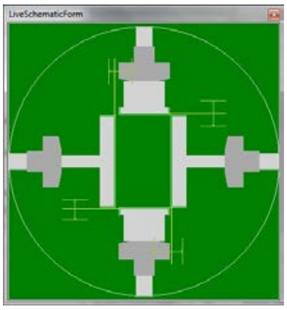

Fig. 5: Platen status window displays collision status at all times (green for not in collision), b) Cubical sample can be viewed through the specimen viewing window.

Predicting when a potential collision may be about to occur, also takes significant logic. A collision resolution mechanism ensures the path of least resistance is taken to resolve the potential collision before it can occur by looking at and then actioning the axis that needs to move the least to ensure platens will never collide.

CONCLUSION:

The TTA is probably the most complex and sophisticated machine that GDS has ever designed and built posing new challenges in multiple areas – mechanical, electronics, firmware, control algorithms, sample preparation and software, allowing a wider range of complex stress paths to be performed over and above conventional apparatus.

Further information about the TTA can be seen at www.gdsinstruments.com, or by contacting Karl Snelling on karl@gdsinstruments.com