Development of a 25ton consolidation press at the Centre for Energy and Infrastructure Ground Research

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ABSTRACT: A 1d consolidation frame has been designed and manufactured at the Centre for Energy and Infrastructure Ground Research (CEIGR), University of Sheffield. The consolidation frame allows static consolidation of soil beds. This system comprises of a 25 ton rated press that can accommodate a range of centrifuge payload strong box configurations. The consolidation force is delivered via a hydraulic piston rated to deliver 80 kN force at 10bar supply pressure with a stroke of 500mm. A series of vertical draw-wire transducers are implemented which monitor consolidation settlement. Combined with pore pressure transducers, the user can measure the pore water pressure at the top and at the bottom of the clay sample. A bespoke LabVIEW VI visual display is implemented which offers visual/graphical feedback to the user on the range of sensor information and a live update of consolidation progress; it also incorporates data entry to capture test specific information.

1 INTRODUCTION

An essential part of centrifuge modelling is the ability to produce clay bed profiles of different over-consolidation ratio. In order to understand the consolidation characteristics of the test bed it is necessary to capture and record consolidation information during this process. This will enable knowledge of the consolidation characterises of each test bed and also provide a means of creating reproducible homogeneous clay beds.

It is very common for researchers to develop a series of experimental parametric studies where clay bed models must be uniform across the whole test series (Hakhamaneshi et al. 2012). A non-uniform clay bed model directly affects the performance of many physical model tests in the centrifuge; examples include pile capacity tests, seismic site response, offshore platform response on soft clay. Many researchers also aim to compare their experimental findings with numerical predictions (e.g. Arulanandan and Scott 1993) or the experimental results to be used as a benchmark for calibration of numerical models (e.g. Liu et al. 2013). It is therefore essential for centrifuge facilities to employ a consolidation press capable of producing uniform clay bed models at a wide range of pre-consolidation pressures and over-consolidation ratios accordingly.

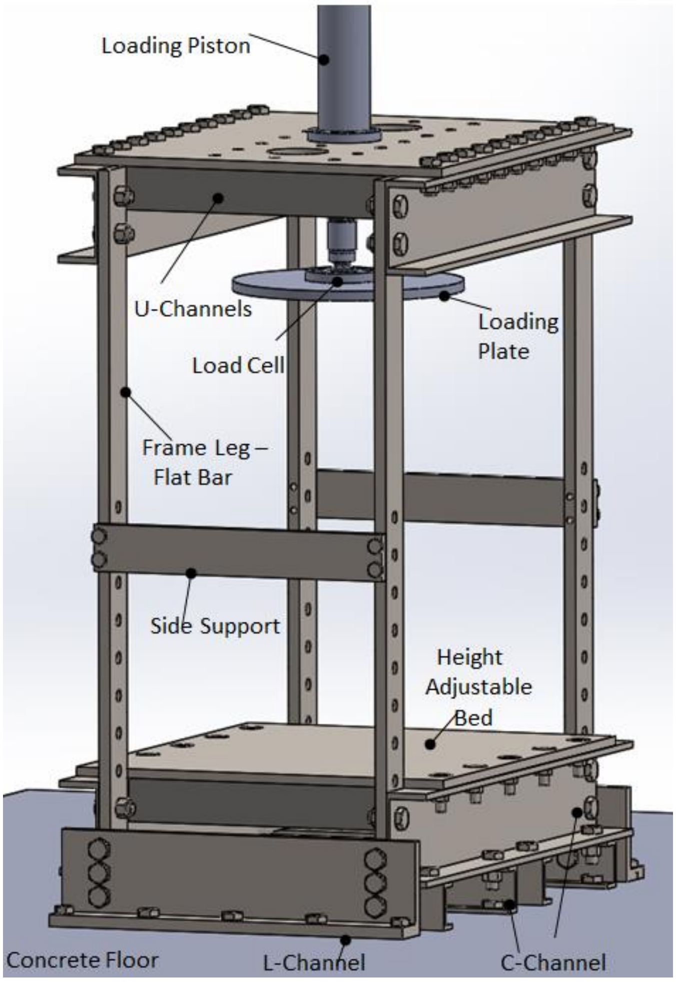
2 CENTRIFUGE FACILITY

A 25 ton consolidation press is developed at the Centre for Energy and Infrastructure Ground Research (CEIGR) centrifuge facility at the University of Sheffield. The centrifuge is a newly established University of Sheffield 50gT geotechnical beam centrifuge located in the CEIGR. The centrifuge was designed and manufactured by Thomas Broadbent and Sons Limited, United Kingdom, and commissioned in 2014. The centrifuge beam has a radius of 2 m to the base of the swing platform, of plan area 0.8 m^2, and can accelerate a 500 kg payload to 100 gravities (Black et al. 2014).

The 25 ton consolidation press is aimed to produce a wide range of over-consolidation ratios (OCR). A typical container employed within CEIGR is a circular tub of 490mm diameter and 500mm height, thus the maximum vertical stress that can be achieved in this configuration is 1300 kPa. It can be assumed that the thickness of a consolidated clay bed will not exceed 350mm. Therefore, the 25 ton consolidation press at full capacity is capable of producing a consolidated clay bed (assuming 350mm height and a unit weight of $18kN/m^3$) of OCR=2 at the bottom of the clay bed when the sample is spinning at 100 times earth's gravity (100g). On the other end of the spectrum, much higher OCRs can be produced by reducing the centrifugal acceleration.

3 DESIGN OF THE CONSOLIDATION PRESS

As shown in Figure 1, consolidation press frame consists of 4 steel flat bars as the main support of the frame, 8 C-channels as top and bottom supports of the frame, 2 L-sections bolted to the concrete floor, two steel plates as the top and bottom platforms, 2 side steel plates and 8 U-channels (4 on top and 4 on the bottom). The steel flat bars are 25mm thick, 1600mm long and 100mm wide made out of high strength carbon steel. The 4 smaller C-channels on the bottom are bolted to the concrete floor to provide additional axial support. The side L-sections are bolted to the floor and provide twisting resistance. The top and bottom larger C-channels provide additional axial and shear resistance to the steel platforms. The top steel platform and 4 U-channels support the loading piston and the reaction forces generated during loading. The bottom steel platform and U-channels support the soil container along with the consolidation loads generated from the piston. A loading plate of diameter 488.5mm transfers to consolidation load to the soil; load is being registered through a 100kN Load Cell rigidly mounted to the loading plate.



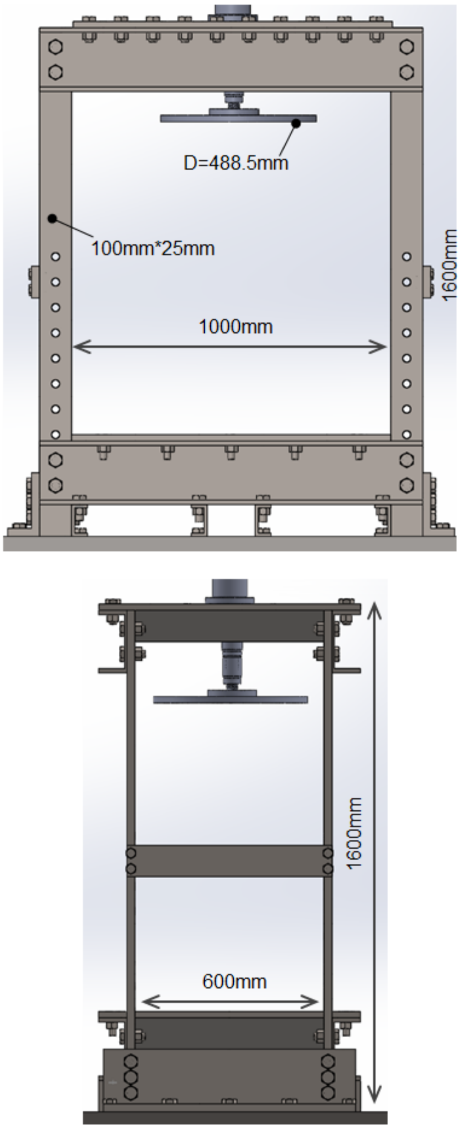


Figure 1. SolidWorks drawings of the consolidation press frame and 3D view.

A series of SolidWorks simulation under static load are conducted to evaluate the performance of the critical parts of the press frame under 25 ton of static loading. Figure 2 plots the simulation results for the steel flat bar legs and the top platform. It can be seen that the flat bars undergo a displacement of 0.02mm while the platforms deforms by 0.38mm (strain of less than 0.1% for both parts). The frame assembly is then trustfully capable of carrying 25 ton of axial loads.

4 CONSOLIDATION OF KAOLIN CLAY

4.1 *Mix preparation & instrumentation*

The circular tub of dimensions previously specified is used to perform a 1g consolidation test on Kaolin Clay using the consolidation press. A 30mm layer of dense sand is poured on the bottom of the container to create a uniform free draining surface. Kaolin Clay is mixed at a water content of 100% (approximately 1.3 times the liquid limit) and poured to an initial height of 450mm (measured from bottom of the container). The slurry was covered with a vinyl sheet and allowed to self-consolidation for 24 hours.

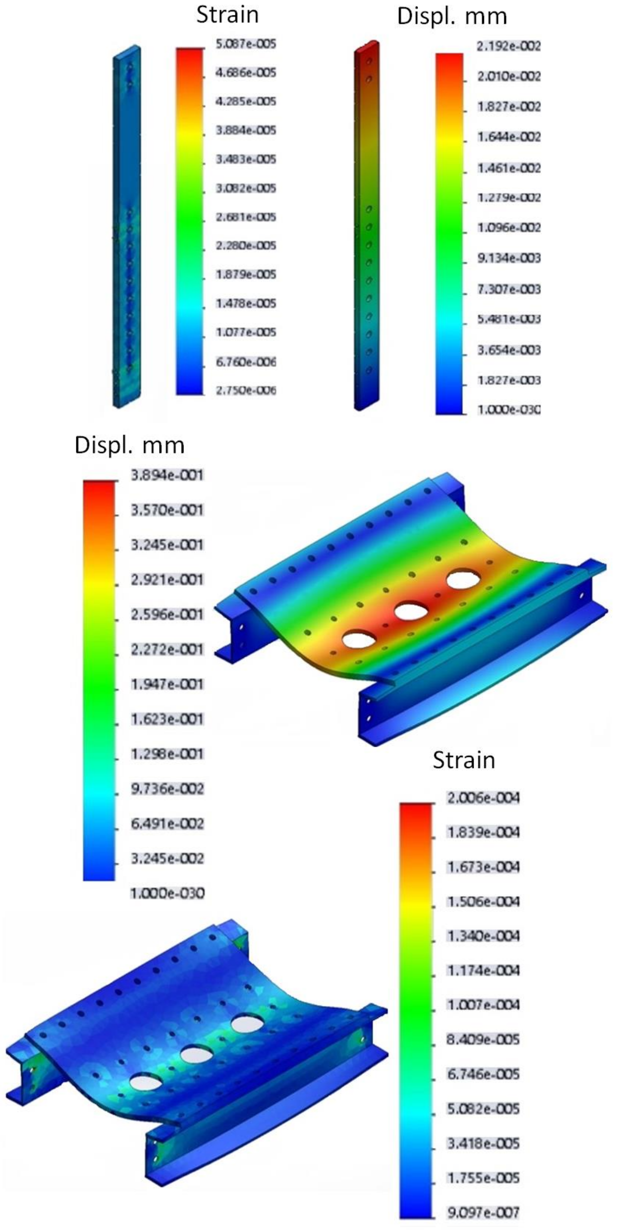


Figure 2. SolidWorks simulation results for 25 ton of static loading.

The Data Acquisition System (DAQ) consisted of a National Instruments 6001 USB device capable of measuring 8 analogue input channels. The DAQ device is packaged inside an enclosure along with sensor and signal conditioning power supplies. The sensor outputs are amplified, using amplifier Printed Circuit Boards built into the cable plugs, such that the amplified signal magnitudes (at full scale output) is a significant proportion of the input signal range, hence increasing the signal to noise ratio. The sensors used in the consolidation process are: a 100kN capacity load-cell for measuring plate load (and deriving consolidation pressure); two 500mm displacement draw-wire sensors for measuring plate movement and a pressure transducer sensor for measuring the pump pressure. The other 4 channels are spare for connection of test specific sensors (e.g. Pore Pressure Transducers). A front Virtual Instrument (VI) was developed in the LabVIEW programming environment in order to acquire data, convert voltages to engineering units, plot and record the sensor data.

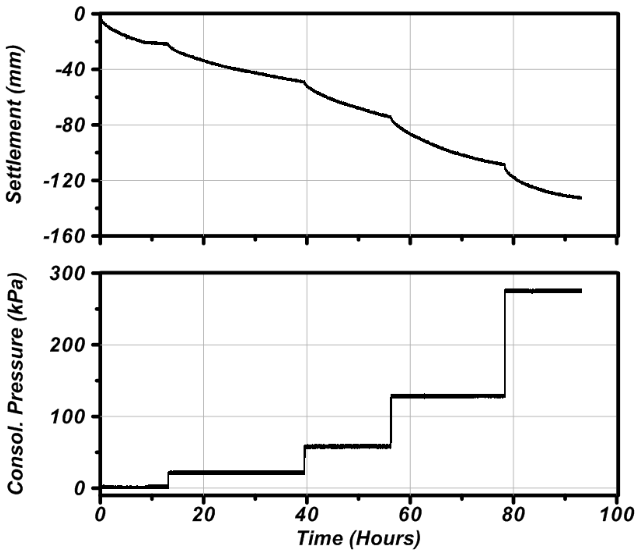


Figure 3. Settlement and consolidation pressure time history.

4.2 *Consolidation test results*

Figure 3 plots the settlement and consolidation pressure time history of the slurry mix. This plot does not include the settlements incurred during the self-weight consolidation of the specimen being under its own weight for 24 hours. After self-weight consolidation, initial seating pressure was set to about 13kPa and consolidation pressured was doubled during each stage increment. The achieved seating pressure without loss of material during loading is larger than seating pressure applied in typical oedometer testing (6kPa). A maximum pre-consolidation pressure of 280kPa was registered by the load cell. The weight of the steel plate is neglected in the calculation of the consolidation pressure as it is negligibly small compared to the applied axial stresses. Settlement time history plot in Figure 3 demonstrates that the sample settled 133mm (volumetric strain of about 32%). Bauer and El-Hakim (1985) reported an axial strain of 16% and 24% for Kaolin Clay slurry of 48% and 62% water content, correspondingly.

Figure 4 plots the incremental clay sample height with respect to the square root of time; the final sample height is measured to be about 287mm. Taylor (1948) method using the square root time method is used to evaluate the time required for 90% of consolidation at each stage (t_{90}). End of primary void ratio for each stage is further calculated and the resulting Normally Consolidated Line (NLC) line is shown in Figure 5. A separate oedometer testing of normally consolidated Kaolin Clay (of the same slurry mix) is performed and results are also plotted in

Figure 5. The seating pressure in the oedometer testing was set to be 6kPa and doubled for each following stage until a maximum consolidation pressure of 200kPa was achieved.

As it can be seen in Figure 5, the NCL lines from the oedometer and consolidation press are somewhat different. The difference at lower consolidation pressures is small (3% difference) and the difference gets larger with increasing consolidation pressures (up to 8%). The increased in the difference can be contributed to the variation in side friction and geometry aspect ratio between the centrifuge tub and oedometer test ring; while a thin layer of silicon grease was applied to the sides of the oedometer ring, the centrifuge tub was not treated similarly Sarsby and Vickers (1985) also discussed the effects of the side friction to the on the consolidation results and showed that the side friction can be up to 50% of the applied pressure, even when the sides were smeared with grease.

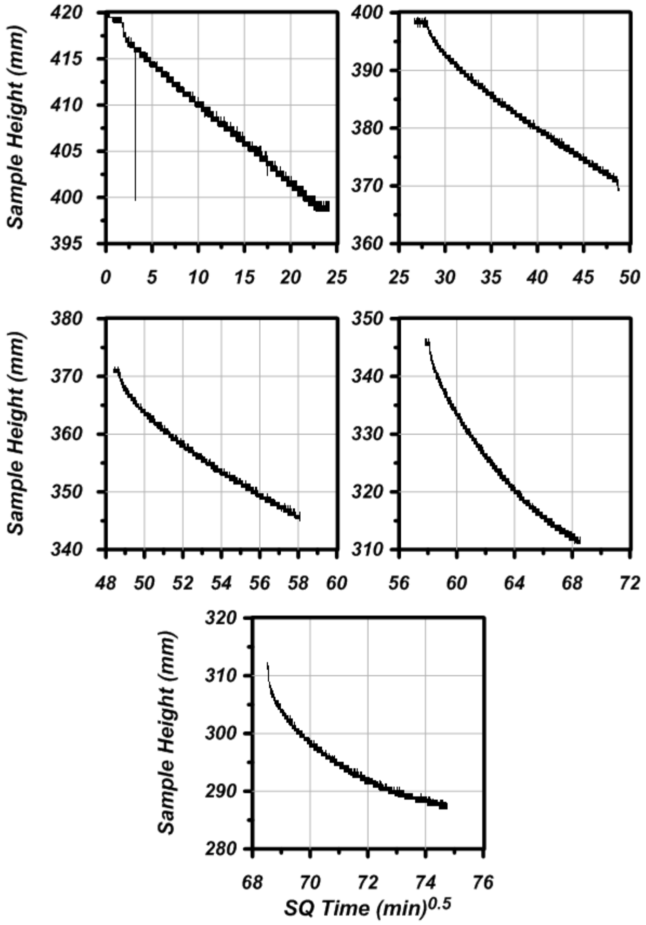


Figure 4. Caption of a typical figure. Photographs will be scanned by the printer. Always supply original photographs.

A series of water content, hand shear vane, oedometer and triaxial tests were performed on the consolidated sample produced using the consolidation press to evaluate the uniformity of consolidation within the consolidated sample. A Shelby tube sampler was used to extract a continuous sample of the entire clay profile. Water content was measured every 20mm throughout the sample. Figure 6 plots the water content of the entire profile of the consolidated clay bed. After consolidation water content varied between 45% and 49% with the minimum water content recorded towards the middle of the clay.

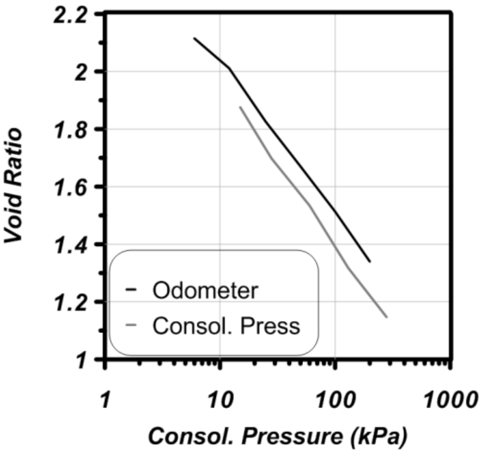


Figure 5. Void ratio versus log of consolidation pressure of Kaolin clay obtained from oedometer and consolidation press.

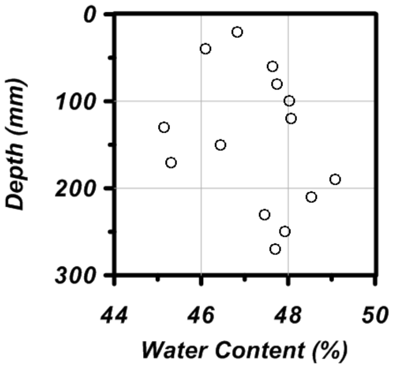


Figure 6. Water content measurements of the entire consolidated clay profile.

Figure 7 plots the results of the shear vane and triaxial tests performed at different surficial locations of different depths (triaxial samples were only taken from the middle of the clay sample). Hand vane shear tests were performed towards the middle and corners of the clay bed at a depth of 50mm followed by penetrating the vane and testing at a depth of 190mm. The undrained shear strength at a depth of 50mm varied from 23 to 28kPa while at 190mm recorded values were in the range of 24kPa and 36kPa. The measured undrained shear strength towards the middle of the container was greater than the shear strengths away from the center, with the smallest values recorded at the periphery of the chamber. The undrained shear strength of the clay bed increased with depth for samples near the center of the container. At the edges, no significant change was captured with the increase in depth. Load distribution and side friction are therefore affecting the shear strength results closer to the boundaries.

Four different triaxial test specimens (38mm in diameter) were taken from the middle of the container and at the top and bottom of the clay bed.

Tests were carried out at confining pressures of 50kPa and 200kPa. Results shown in Figure 7 reveal undrained shear strength of 26kPa for the samples taken from the surface and 37kPa for the deeper sample. These values are consistent with the undrained shear strengths recorded using the hand vane apparatus and towards the middle of the container. Effect of side friction on the samples taken from the middle of the container is minimal and therefore effect of sample surcharge on the shear strength is more pronounced in the samples taken towards the middle of the container.

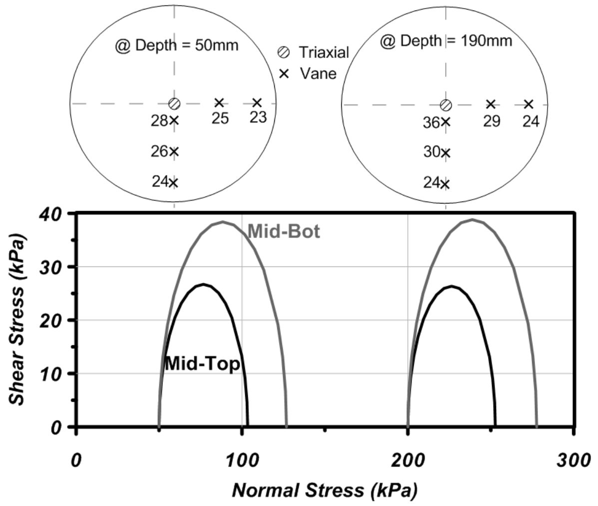


Figure 7. Hand shear vane and triaxial test results of the consolidated clay bed.

A series of 4 oedometer tests were also performed on samples at different depths and surficial locations. Two samples were taken towards the middle of the container at the surface and the bottom of the clay bed; the other samples were taken accordingly but towards the corner of the container. A maximum consolidation pressure of 800kPa (beyong their pr-consolidation pressure of 280kPa) was applied and settlement response of the samples were recorded. Taylor (1948) method was used to calculate the t_{90} and H_{90} values at each consolidation pressure stage. Figure 8 plots the void ratio of the samples versus the log of the applied consolidation pressure. The Casagrande (1936) method for determination of pre-consolidation pressure is used to evaluate the variation of this parameter at different locations of the container.

As it can be seen from Figure 8, the pre-consolidation pressure of the samples taken towards the middle of the container (both surface and deep samples) is estimated to be about 250kPa; this estimate is close to the applied 280kPa of consolidation pressure registered by the load cell. The pre-consolidation pressure of the samples taken from the edges measure equal to or less than 200kPa. The lowest value of pre-consolidation pressure is obtained from the sample taken from the edge and bottom of the clay bed. This can be correlated to combined effects of load distribution and skin friction on the actual pressure at this location. Black 2007 also reported the effects of side friction in a large oedometer test on the reduced pressures with depth.

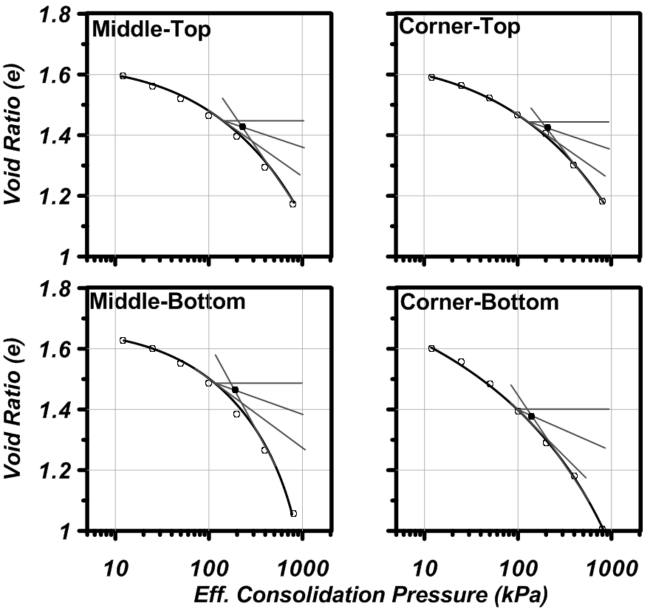


Figure 8. Oedometer testing of four samples taken towards the middle and corner of the container and at two different depths.

5 CONCLUSIONS

This paper outlines the design of a 25ton consolidation press frame. The press can be used for centrifuge testing of over-consolidated clay beds. Kaolin clay was mixed at a water content of 100% and consolidated and settlement time history of the specimen was recorded for different amplitudes of consolidation pressure. A maximum consolidation pressure of 280kPa was applied to the sample and a total axial strain of about 32% was measured at this pressure. The resulting NCL line obtained from the consolidated sample in the press was compared against an oedometer testing of a sample taken from similar initial slurry. Reasonable agreement was obtained between the two NCL lines with smaller differences in the smaller values of consolidation pressure. Effect of side friction is believed to affect the results at larger consolidation pressures. A series of shear vane, triaixal and oedometer testing was performed on the consolidated clay bed and at different surficial locations and varying depths. The undrained shear strength of the sample towards the middle of the container was measured to be greater than those measured towards the corners. There was good agreement between the hand vane and triaxial testing results throughout the cay bed. A series of 4 oedometer testing was performed from samples taken from middle and corners of the container and at different depths. The Casagrande method for determination of pre-consolidation pressure was used to estimate and compare this parameter amongst the samples taken. It was concluded that the samples taken from the middle of the container have larger pre-consolidation pressures than those taken from the corners. This was attributed to the side friction along the container wall and the load distribution leading to smaller pressures distributed to the corners.

6 ACKNOWLEDGEMENTS

Funding support provided by the Engineering Physical Sciences Research Council (EPSRC) to establish CEIGR is gratefully acknowledged. Continued technical support by Thomas Broadbent and Son Ltd. is also appreciated. The authors would like to acknowledge the contribution by the Department of Civil & Structural Engineering technical staff for in-house technical support.

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