Reinstallation and upgrade of a 15 g-Ton centrifuge at the University of South Carolina

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A geotechnical centrifuge has been reinstalled at the geotechnical research laboratory at the University of South Carolina in 2011. The centrifuge was used by NASA and donated to the University of Maryland in 1982 before being relocating to USC. The centrifuge is a Genisco 1230-1 device with 1.50 m radius arm and symmetrical platforms. The centrifuge is rated at 15 g-ton (approximately 136 kg payload mass at 100 g and 68 kg at 200 g) and has a speed range of 0 to 400 rpm. The centrifuge can accommodate a model with dimensions of 500 mm in depth, 500 mm in width, and 500 mm in height. In 2014, the USC centrifuge was upgraded with new on-board cameras, data acquisition hardware, and customized LabView based software. The centrifuge is equipped with a variety of sensors and an inflight soil characterization system. Details of the specifications and capabilities of the USC facility will be presented in this paper.

1 INTRODUCTION

The necessity of involving centrifuges in civil engineering research in order to overcome the limitations during the analysis of complex structures and to develop engineering models similar to prototypes and with stress states closer to those observed in-situ was recognized during the late 1980s and early 1990s. Investigations of consolidation processes, slope stability, and soil dynamics were developed considering the role of the self-weight factor during the initial implementation of centrifuge modeling in geotechnical engineering throughout the world. Successful results obtained lead this practical and innovative technique to be recognized as a strong element for increasing understanding of soils and geotechnical structures. Widespread knowledge and investigation techniques have continued to be developed using centrifuge modelling together with the increasing development of technology in electronics, mechanics, and data acquisition. Today centrifuges are available in a variety of configurations, involving different technologies. The centrifuge technique is also used for different purposes including education, research laboratories, and military technology development. Although the first identifiable evidences of centrifuge modelling was at Columbia University in New York, currently only twelve facilities exist in United States. Only two of them are located inside the Southeast region, one at the University of Florida and one at Vicksburg, MS inside the US Army Corp of Engineer facilities. The purpose of this paper is to present the configuration and technologies offered at the upgraded geotechnical centrifuge facility that was relocated to the University of South Carolina in 2011 and discuss future research possibilities.

2 BACKGROUND

The USC centrifuge was originally built and used by NASA until 1982 when it was relocated to the University of Maryland. From 1982 to 2010, several geotechnical modelling research activities were conducted with this device including the evaluation of the effects of backfill properties on the stability of geotextile-reinforced vertical walls (Suah & Goodings 2001), effects of freezing over heave and consolidation of clays (Han & Goodings 2006), sinkhole development using sand and karst limestone (Goodings & Abdullah 2002), behavior of soils subjected to grout bulb injection at different depths (Nichols & Goodings 2000), cratering and soil loosening due to explosive detonations modelled with pentaerythritol tetranitrate (Lin et al. 1994). In 2011, the centrifuge device was transferred and reinstalled at University of South Carolina inside the Civil and Environmental Engineering Department facilities. Upgrades were developed at USC including the installation of a wireless data acquisition system, new data acquisition hardware and software, the installation of rotatory joint, acquisition of new sensors, and inflight soil characterization system. The configuration of this equipment allows classifying it as a small size centrifuge specifically designed for small models with short preparation times, which makes the USC centrifuge is ideal for parametric studies where models are built and tested quickly. This also allows multiple models to be constructed focusing on a broad range of parameters, making this facilities ideal for collaborative research with calibration of numerical methods.

3 FACILITIES

The USC centrifuge is located within the Geotechnical Research Laboratories (Fig. 1) at the University of South Carolina. The laboratories are located in a total area of nearly 9,100 square feet divided in three main sections: geotechnical, materials, and advanced geotechnical laboratories. The laboratories offer a wide range of capabilities for soil characterization, testing and modelling. Soil index testing equipment, 1-D odometers, direct shear test, unconfined compression test, among others, are available inside the geotechnical and materials laboratories. Two GDS triaxial devices (MINIDyn and ELDyn), manufactured by Global Digital Systems Limited, are currently available in the advanced research laboratory and area capable of reproducing static and dynamic tests in UU, CU, CD and CK0 conditions as well as unsaturated tests. Both devices have capabilities to measure shear wave velocity of soil using bender elements. In addition, the Stokoe type combined resonant column and torsional shear system is available for measurement of dynamic soil properties. These facilities were renovated to accommodate the centrifuge device offering additional features related to scaled physical modeling. The equipment was installed in an enclosed 480 square foot room providing enough space for model and test preparation. The control room was located adjacent to the centrifuge area in an isolated location increasing the safety of the operator. A small closed circuit television system with four network cameras was installed providing different views of the centrifuge device during the operation as well as different views of the tested model on the 42-inch display in the control room.

4 DETAILS OF THE EQUIPMENT

The centrifuge was designed and manufactured by Genisco Systems. The device is a Genisco 1230-1 G-Accelerator. To the best of our knowledge, there are only a few Genisco centrifuges available for geotechnical application in the United States. In addition to the USC centrifuge, a Genisco device of similar size is located at the University of Colorado in Boulder. The USC centrifuge has two platforms attached by an aluminum alloy arm constituting the symmetrical spinning device that allows testing of two identical models at the same time. This system presents a 1.5 meter radius arm and two baskets with 0.125 cubic meters (500 mm width x 500 mm length x 500 mm height) of available space for each model. Each platform is rated at 15 g-ton capacity (30000 g-lb) with an approximate payload mass of 136 kg at an acceleration of 100 g and 68 kg at 200 g. This piece of equipment is operated using and hydraulic oil drive system Type A-8 manufactured by Oilgear Fluid Powers and controlled using a Model 1220-103 Control Console developed by Genisco Systems. The centrifuge can spin from 0 to 400 RPM allowing an acceleration rate from 1 to 200 g at 107 centimeters radius (42 inches).

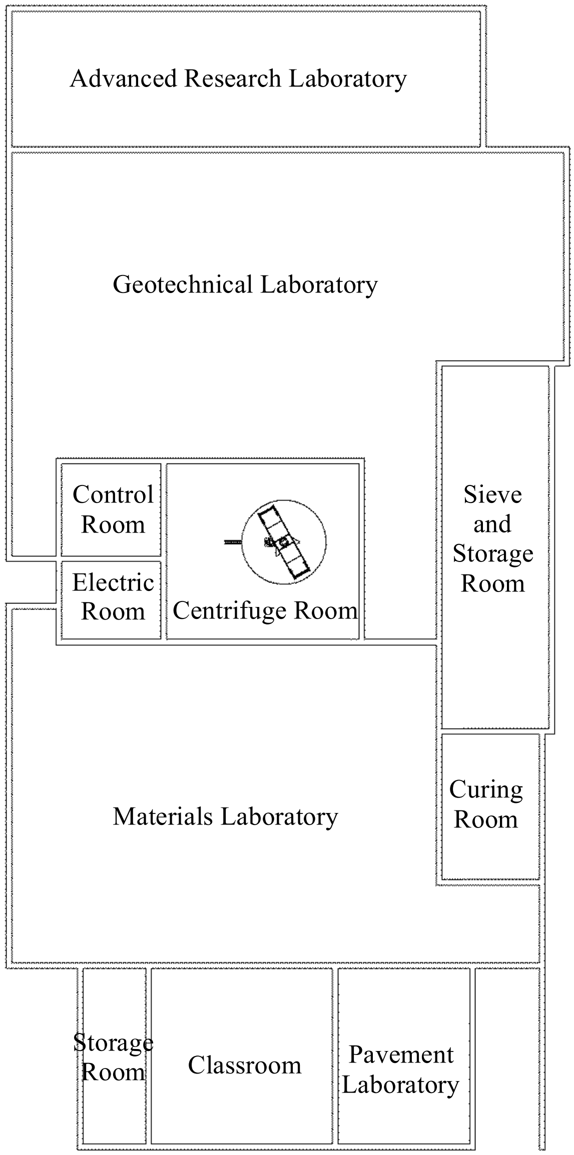

Figure 1. USC geotechnical research facilities. Scale 1:200.

Systems inside the centrifuge chamber are supplied power through 24 available connections attached to a set of electrical slip rings placed in the vertical main axis of the device. The rotary joint has been replaced with a new stainless steel GPS 140 system, manufactured by Dynamic Sealing Technologies Incorporated, allowing four passages for air, water or vacuum flow. The system has a static-dynamic balancing system with an unbalance pendulum sensor capable of identifying in-flight unbalance of 5 kg at 300 RPM. An aerodynamic clean steel enclosure is placed over the centrifuge in order to increase the safety during flights and reduce the aerodynamic effects. A general sketch of USC centrifuge is presented in Figure 2.

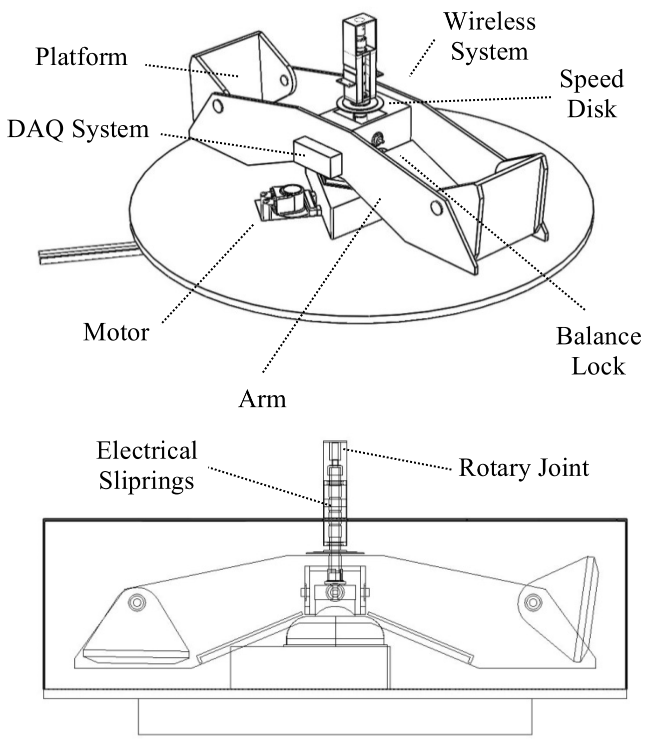

Figure 2. USC reinstalled geotechnical centrifuge.

5 FEATURES

As mentioned before, several upgrades have been integrated into the centrifuge equipment since the installation at the University of South Carolina in order to improve the capabilities and increase the possibilities for geotechnical research. Renovations and upgrades related to data acquisition, control systems, and instruments are presented in this section.

5.1 *Data Acquisition System*

The Data Acquisition System was completely renovated using National Instrument chassis and modules. An NI cDAQ 9188 chassis was placed in the center of the arm providing eight slots for different modules (Fig. 3). In addition to integrate several different sensors in the same interface, this device presents a slim rugged design ideal for small centrifuges and is capable of operate in a wide range of temperatures (from -22 to 55 Celsius degrees) and resists impacts up to 30 g. Moreover, this high-speed device allows an acquisition rate of 1 million samples per second in both analog and digital domain. A wide range of modules are available for in-flight centrifuge modelling including NI9263 and NI9205 for simultaneous analog output and input signal processing currently used for bender element analysis and voltage measurement based sensors, an NI9403 module for bidirectional digital signal management currently used for control purposes of a full flow penetrometer (TBar), an NI 9237 employed as analog input terminal for pore pressure sensors and strain gauges, and an NI 9234 analog module available for accelerometer. An additional set of NI cDAQ 9171 chassis and NI-9402 analog module has been included for centrifuge speed monitoring. This system is connected to the PC located in the control room through a new wireless communication system adapted for the centrifuge equipment.

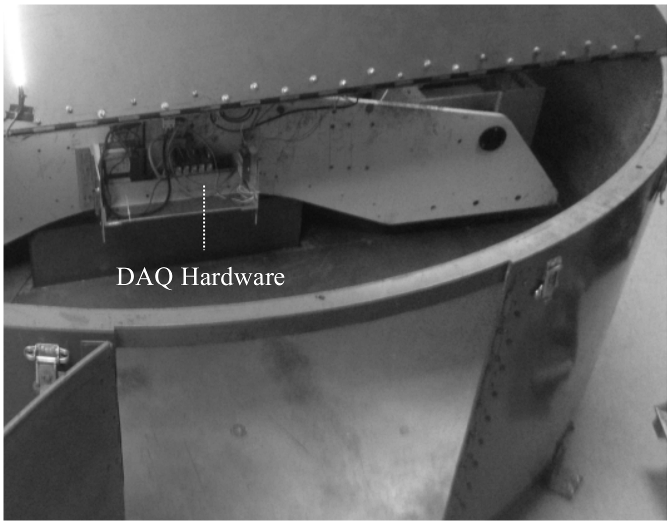

Figure 3. NI instruments location in the USC centrifuge.

In order to provide control of the data acquisition system as well as sensors and test management before and after centrifuge experiments, an NI LabView software package designed specifically for this setup was developed by Bloomy Co. together with the Geotechnical Research Group of the University of South Carolina. Configuration of modules and sensors can be developed with this interface allowing setting up several different devices at the same time. This software has been programed to identify any type of module or data acquisition assistant automatically as well as designed for an easy configuration. Device properties can be configured directly and the user is allowed to enable or block any sensor during before acquiring and recording data. One of the most important functions available is the possibility of saving configurations and storing data separately by project. Furthermore, during flight the user is capable of defining the sampling rate before recording data as well as selecting any parameter evolution to be displayed alone or in groups. Real time measurements can be observed during flight allowing the user to monitor test evolution. Pictures of the software interface are presented in Figure 4.

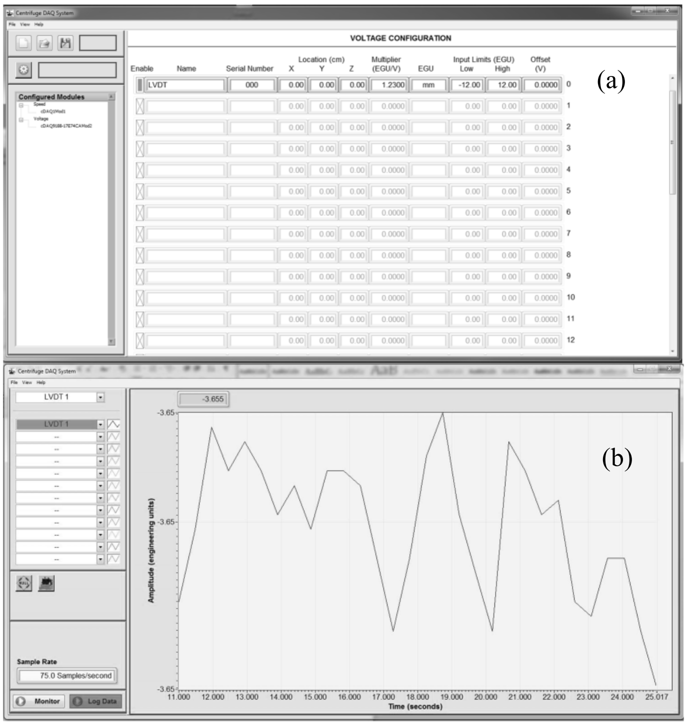

Figure 4. General views of the specialized USC centrifuge software. (a) Configuration interface and (b) data acquisition interface.

5.2 *Instrumentation*

In addition to the centrifuge device, the advanced research laboratory at the University of South Carolina is equipped with a wide variety of electronic sensors including linear variable differential transformers (LVDT), ultrasonic displacement devices, pore pressure sensors, load cells, accelerometers, water content sensor, TBar penetrometer, and bender elements. All instrumentation has been adapted to develop readings during flight under different g levels and sampling rates.

As mentioned before, a closed circuit television system has also been adapted in order to increase the safety of the user during tests but also in order to provide continuous observation of both the centrifuge and model. Up to four AXIS P1204 Network Cameras are available with full frame rate HDTV 720p providing high quality video and image captures with 1280x720 pixels resolution. The frame rate of 25 to 30 frames per second and the shutter time of 1/24500 seconds available with these devices are ideal for centrifuge modelling where details must be captured in short time intervals. Specialized software and hardware developed by Bluecherry have been integrated allowing recording any image or video from the cameras at the same time and continuously using an IP based technology. An eight channel Network Video Recorder device allows 1 TB of recorded files with a RAM memory of 4 GB supporting up to 8 cameras.

5.3 *Control Room*

As mentioned before, 110 square feet isolated space next to the centrifuge room has been designated for control and operation. The control room has been equipped with two computers remotely connected to the centrifuge and DAQ devices, a 42-inch TV screen. and the centrifuge control panel (Fig. 5). Interface between the user and the general equipment is provided in this room as well as the power and spinning controls, emergency brake and centrifuge main gear.

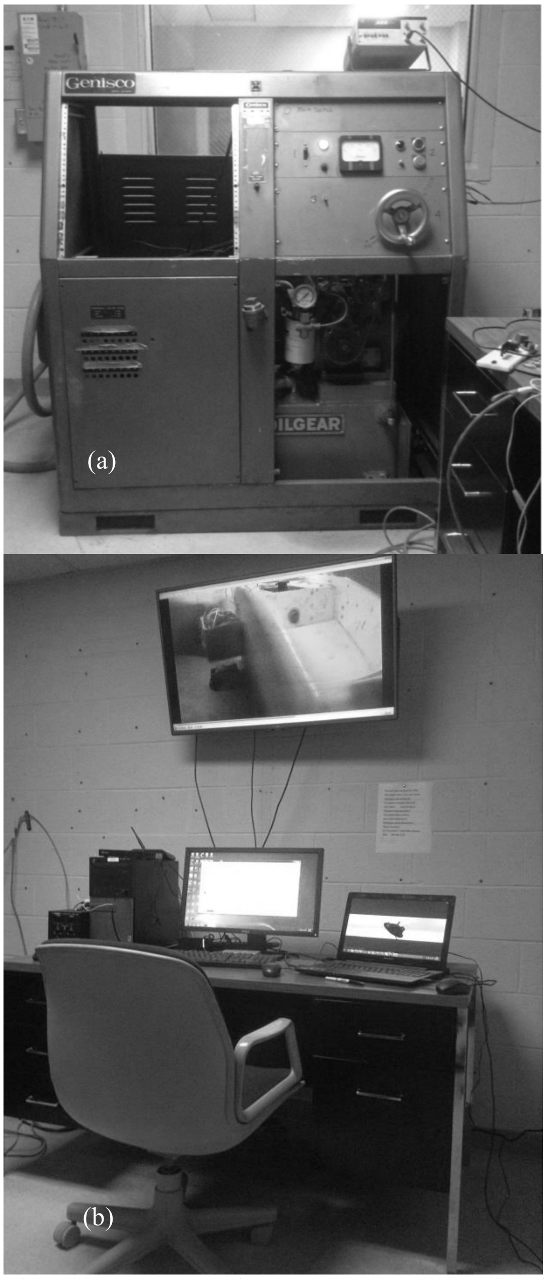

Figure 5. USC control room: (a) control panel and (b) interface of operation.

5.4 *Communication System*

Excluding the speed control system, data transmission between the centrifuge devices and the user interface is managed remotely. This is possible due to the installation of a wireless communication network capable of supporting all centrifuge devices transmitting 100 megabytes per second. Information from DAQ systems, instrumentation and onboard cameras is delivered directly to the user within this system, reducing the required amount of wires, as shown in the flowchart presented in Figure 6.

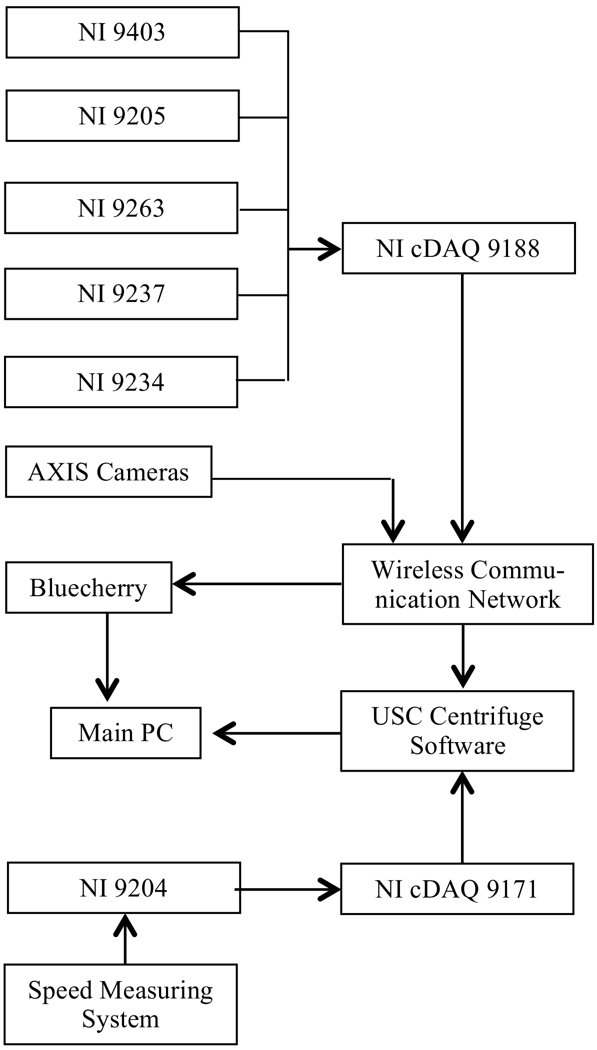

Figure 6. USC centrifuge communication flowchart.

5.5 *Speed Control and Monitoring System*

The g-level of the centrifuge is controlled manually from the control panel inside the control room. The original handwheel is used to control centrifuge speed as the system has been kept in good working condition as shown previously in Figure 5. Once the centrifuge is powered and ready to operate, the speed handwheel is rotated until the desired spinning speed is reached. In addition to the NI cDAQ 9171 chassis and the NI-9402 analog module, the speed measuring system is composed by an ultrasonic displacement sensor and a ticked steel disk attached to the center axis of the centrifuge (Fig. 7), and a LM324N voltage amplifier. Hence, the steel disk spins with the centrifuge while the ultrasonic sensor counts the number of ticks for a specified time interval in terms of voltage variations. This voltage signal is amplified and digitized through the LM324N voltage amplifier and then acquire and processed by the NI instruments. An example of frequency of ticks during flight obtained from the ultrasonic sensor and before being processed to gravity level is presented in Figure 8. The translated signal is continuously presented in terms of g-level in the USC centrifuge software interface. In this way, the USC specialized software is considered the main tool for speed monitoring. However, a backup system composed by a National Instruments 5314A Universal Counter is also attached to the speed system providing an additional monitoring system, thus increasing the safety during flight. As mentioned before, communication between the speed system and the interface is developed physically using a direct connection from the center of the equipment and the main computer.

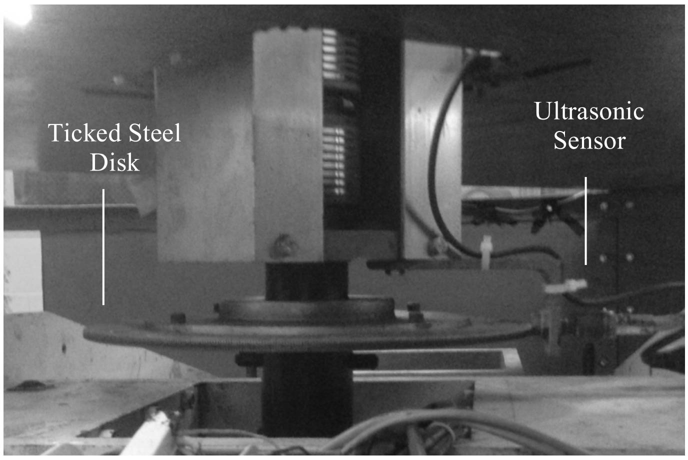

Figure 7. Speed measuring system.

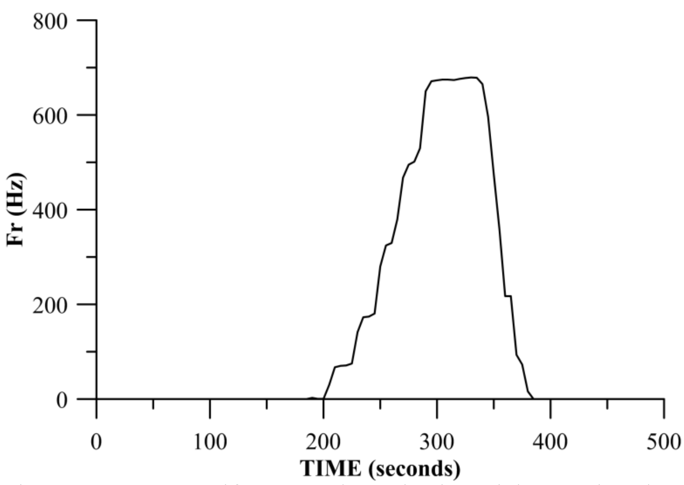

Figure 8. USC centrifuge speed monitoring: tick counting during flight.

5.6 *In-Flight Soil Characterization*

The University of South Carolina geotechnical centrifuge currently has an in-flight soil characterization device in addition to the basic measurement systems. A TBar penetrometer originally developed by Prof. Mark Randolph (Stewart & Randolph 1994) at the University of Western Australia has been implemented with a stepping motor actuation system allowing the measurement of soil shear strength while the centrifuge is spinning (Fig. 9). A relay circuit has been designed and manufactured to provide complete control over the displacement transducer allowing the user to control the penetration test in terms of depth, rate and period. Main characteristic of this system is the total control of the user over the penetration device motion during flight. In other words, the user is allowed to introduce, release or hold the TBar into the model at any time during the test. The USC centrifuge software has the capability to control this feature during flight. From the main interface of this program, the user is able to activate the stepping motor and control the penetration test using the NI 9403 module as communication link.

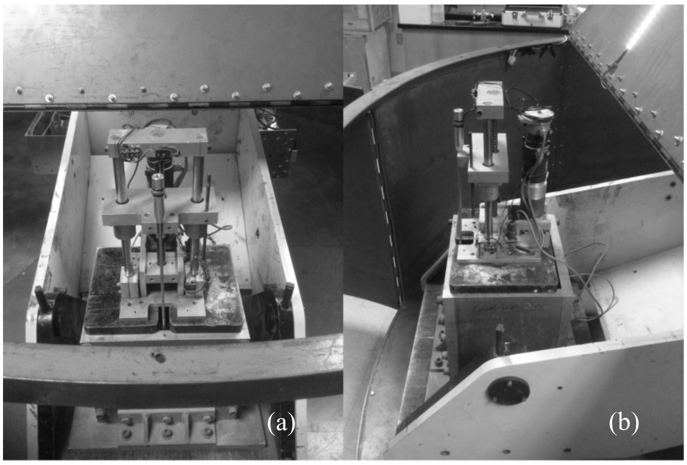

Figure 9. TBar test setup: (a) front view and (b) side view.

6 FUTURE WORK

The reinstalled geotechnical centrifuge at the University of South Carolina has been recently upgraded and is currently fully operational. Nevertheless, new improvements are expected to be developed to increase future centrifuge research capabilities. New containers are currently being designed in order to allow more onboard cameras and sensor locations. Rainfall simulators are being developed to improve the in-flight characterization possibilities involving the effect of rainfall and weather factors. Future research possibilities include modelling of dams, embankments, landslides, pipe culverts, contaminant transport, among others, involving fundamentals of saturated and unsaturated soil mechanics. To accomplish, advanced sensor developments are expected to be developed including shear strength, shear wave velocity, water content and suction measurement during flight.

7 CONCLUSION REMARK

The reinstallation and upgrade of a geotechnical centrifuge at the University of South Carolina has been successfully completed and multiple upgrades to systems, software, sensors and equipment have expanded the centrifuge facility capabilities and increase potential for future work. The 1.5 m radius, 15 g-ton, Genisco 1230-1 centrifuge presents a double-platform arm capable of accelerating a payload mass of 136 kg at 100 g. This equipment provides new opportunities for academic and research projects in the Southeast regions of the United States and particularly in the state of South Carolina. It is anticipated that the facility will become a credible means to foster collaborative research in the area of sustainable and resilient infrastructure systems as well as hazards and vulnerability.

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