การพัฒนาเครื่องหมุนเหวี่ยงทางวิศวกรรมเทคนิคธรณีขนาดเล็ก เครื่องแรกของประเทศไทย

กิติเดช สันติชัยอนันต์ [1]

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี บางมด ทุ่งครุ กรุงเทพฯ 10140

บทคัดย่อ

เครื่องหมุนเหวี่ยงทางวิศวกรรมธรณีเทคนิค (Geotechnical centrifuge) CTEd-1 ขนาดเส้นผ่านศูนย์กลาง 2 เมตร ถูกพัฒนาขึ้นที่มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี การออกแบบอาศัยหลักการออกแบบที่ใช้ต้นทุนต่ำโดยนำระบบการควบคุมและระบบการตรวจจับแบบไร้สาย หรือ แบบคลื่นวิทยุ ที่มีอยู่ในประเทศมาใช้แทนที่วงแหวนเลื่อน (Slip ring) ที่มีราคาสูง เครื่องหมุนเหวี่ยงได้ใช้งานแล้วในการทดสอบปัญหาพื้นฐานทางด้านการพังทลายของดิน และใช้เพื่องานวิจัยและงานด้านการเรียนการสอนในห้องเรียน เครื่องหมุนเหวี่ยงประกอบด้วยชุดควบคุมและอุปกรณประกอบต่างๆ เช่น ระบบควบคุมระยะไกลแบบอินฟาเรด ระบบจับภาพไร้สาย เครื่องเตรียมตัวอย่างดินเหนียว ตัวตรวจจับน้ำหนัก (Load cell) ขนาดเล็ก ตัวตรวจจับระยะเคลื่อนที่ (Potentiometer) ขนาดเล็ก และอื่นๆ แบบจำลองที่ประสบความสำเร็จในการทดสอบแล้วคือ แบบจำลองการพังทลายของลาดดินเหนียวและแบบจำลองการพังทลายของกำแพงกันดินทราย เครื่องหมุนเหวี่ยงนี้ถือได้ว่าเป็นเครื่องหมุนเหวี่ยง ด้านวิศวกรรมธรณีเทคนิคเครื่องแรกของประเทศไทย และถือได้ว่าเป็นต้นแบบในการบุกเบิกเทคนิคการจำลองแบบหมุนเหวี่ยง (Centrifuge modeling) ด้านวิศวกรรมธรณีเทคนิคของประเทศ

คำสำคัญ : Centrifuge / g-level / Wireless / Retaining Wall / Slip Ring / Consolidometer

---

[1] ผู้ช่วยศาสตราจารย์ ภาควิชาครุศาสตร์โยธา คณะครุศาสตร์อุตสาหกรรมและเทคโนโลยี

Development of The First Small Geotechnical Centrifuge in Thailand

Kitidech Santichaianant [1]
King Mongkut's University of Technology Thonburi, Bangmod, Toongkru, Bangkok 10140

Abstract

A geotechnical centrifuge (CTEd-1) with a diameter of two meters has been developed at King Mongkut's University of Technology Thonburi (KMUTT), Thailand. The design concept was based on using the low cost devices of wireless controlling and monitoring system which were available in Thailand instead of using an expensive signal slip ring. The small geotechnical centrifuge has been used to evaluate and demonstrate classical failure problems that were attractively discussed in undergraduate classes and senior projects. Several controlling and monitoring systems were developed to enable the large variety of test, such as infrared and Bluetooth remotely controlling system, closed circuit cameras, consolidometer, miniature load cells, displacement potentiometers and so on. Several models tested successfully were undrained slope stability and Rankine's lateral earth pressure models. The centrifuge was regarded to be the first pioneer in promoting the centrifuge modeling technique in the engineering society of Thailand.

Keywords : Centrifuge / g-level / Wireless / Retaining Wall / Slip Ring / Consolidometer

---

[1] *Assistant Professor, Department of Civil Technology Education, School of Industrial Education and Technology.*

1. Introduction

In 2002 a development of a small geotechnical centrifuge with a diameter of two meters was started at the Department of Civil Technological Education, King Mongkut's University of Technology Thonburi (KMUTT), Thailand. The device was operational in 2003. The original purpose of the project was to evaluate possibility of new design and construction of a small centrifuge without using expensive multi-channel slip ring. Due to present wireless technology of selected devices, the centrifuge was designed to generate AC power to the centrifuge arm by using only single low cost slip ring. Test models with dimension of 80 x 200 x 150 mm^3 and weight up to 6 kg can be accelerated up to 100 g at swing-up platform. The small geotechnical centrifuge was relatively cheap in use, and the development of the model did not take so much time. To enable the test, the wireless system of data acquisition and the image monitoring system were used instead of using expensive multi channel slip ring. The single air pressure supply line was supplied through a coupling to four channel solenoid valves controlled by wireless infrared (IR) remote controller. Moreover, two close-circuit cameras were installed at swing-up platform and arm to monitored and recorded images of test model and centrifuge operation, respectively. There are two choices to monitor the data obtained from provided sensors. The simplest choice is to use so called in-flight self-reading circuit installed on the centrifuge arm. The readout digit can be observed in-flight at a small LCD panel of the circuit by the wireless close-circuit camera. The second choice is to use a small circuit of data loggers attached at the arms to transmit signals to nearby PC wirelessly by using a pair of serial to Bluetooth adapters. The centrifuge is driven by a DC motor regulated manually by an AC to DC inverter. The operating cost for a test is low and the device is very suitable to perform trial and error testing. The modification for different tests is relatively simple, so that a very flexible operation is obtained. The device was used to inform and to instruct undergraduate and graduate students and others to realize the advantages of this new technique in Thailand.

Several miniature devices have been developed to enable the performance of simple tests in flight, such as: low cost beam load cells, displacement and pressure transducers and miniature air actuators. There have been developed devices to prepare sand and clay samples. A large consolidation apparatus was developed to prepare a large clay sample trimmed into a model container. In 2004 four different senior research projects were carried out for the centrifuge by undergraduate students, i.e.: active lateral earth pressure of sand against a vertical retaining wall, stability of clay slope, miniature cone penetration test (CPT) and lateral stability of pile in sand. In the last twenty years or so, small centrifuge has been extensively developed as a simple tool to demonstrate and to instruct students to understand the centrifuge modeling technique. Some researchers scaled down their own large centrifuge to a small scale centrifuge and some redesigned new small centrifuges to meet an instructional purpose in the class. A small centrifuge with 0.7 m diameter and maximum g-level at 120 g was developed [1]. The mild steel rotor beam of 15 cm width was used to horizontally hold two 2.5 cm thick containers at both ends. The device was used to demonstrate weekly in terms of experiments including clay model slope, bearing capacity failure, failure around tunnel and so on. A development of small 1.0 m diameter centrifuge with swing-up boxes was developed to provide data for undergraduate theses [2]. As a part of graduate project course, a development of three preliminary “teaching/learning packages” was carried out for the small centrifuge. [3] and [4] also presented an instructional centrifuge with 1.2 m in diameter. A 2.5 cm thick container was laid down on a stainless steel spinning disc. Failure pattern was observed through a small window by helping a stroboscope. Air pressure line was used to manipulate the single small actuator simulating behaviors of a shallow foundation subjected to service loads. The undrained slope stability analysis was successfully performed to obtained g-level while the slope model failed. From experimental results, it was apparent that the slip circle failure patterns performed by the centrifuge were in good agreement the classical theory.

2. Components of the Small Geotechnical Centrifuge

2.1 Mechanical parts

The mechanical part of the CTEd-1 (Fig. 1 and 2) consists of a strong steel frame which is bolted on ground. The frame carries the bearing house of a vertical axis and a driving motor. A pair of hollow square section aluminum beams with length of 1800 mm is hold by a steel plate welded to the axis, so that it is able to rotate in the horizontal plane. The beams were chosen since this design wanted to minimize the dead weight of the beams. A swing-up platform is connected to one end of the beams by means of a basket. The platform is formed by two vertical “A” shape aluminum plates and a bottom plate. The area of the bottom plate is 100 x 200 mm^2. Containers up to 70 mm width are able to be inserted in the platform and hold laterally with four adjustable bolts. The maximum size of the boxes is limited by the working area of the platform.

Another end of the beams equips with a set of counter weight system to obtain balance on the beams during operation. The system allows provided counter weights to be adjusted laterally to balance the moment taking place on the beams. An amount of 25 mm diameter steel rod can be gathered to obtain a balanced weight calculated by means of active moment taking place on the beams.

The potential danger of the spinning parts of the centrifuge is minimized by a protection shield. The iron sheets with a thickness of 3 mm are fold to form a sealed large cylindrical box. Moreover, to minimize air turbulence due to spinning an electric fan is used to suck air out of the box where the centrifuge spinning speed can be enhanced additionally up to about 25%.

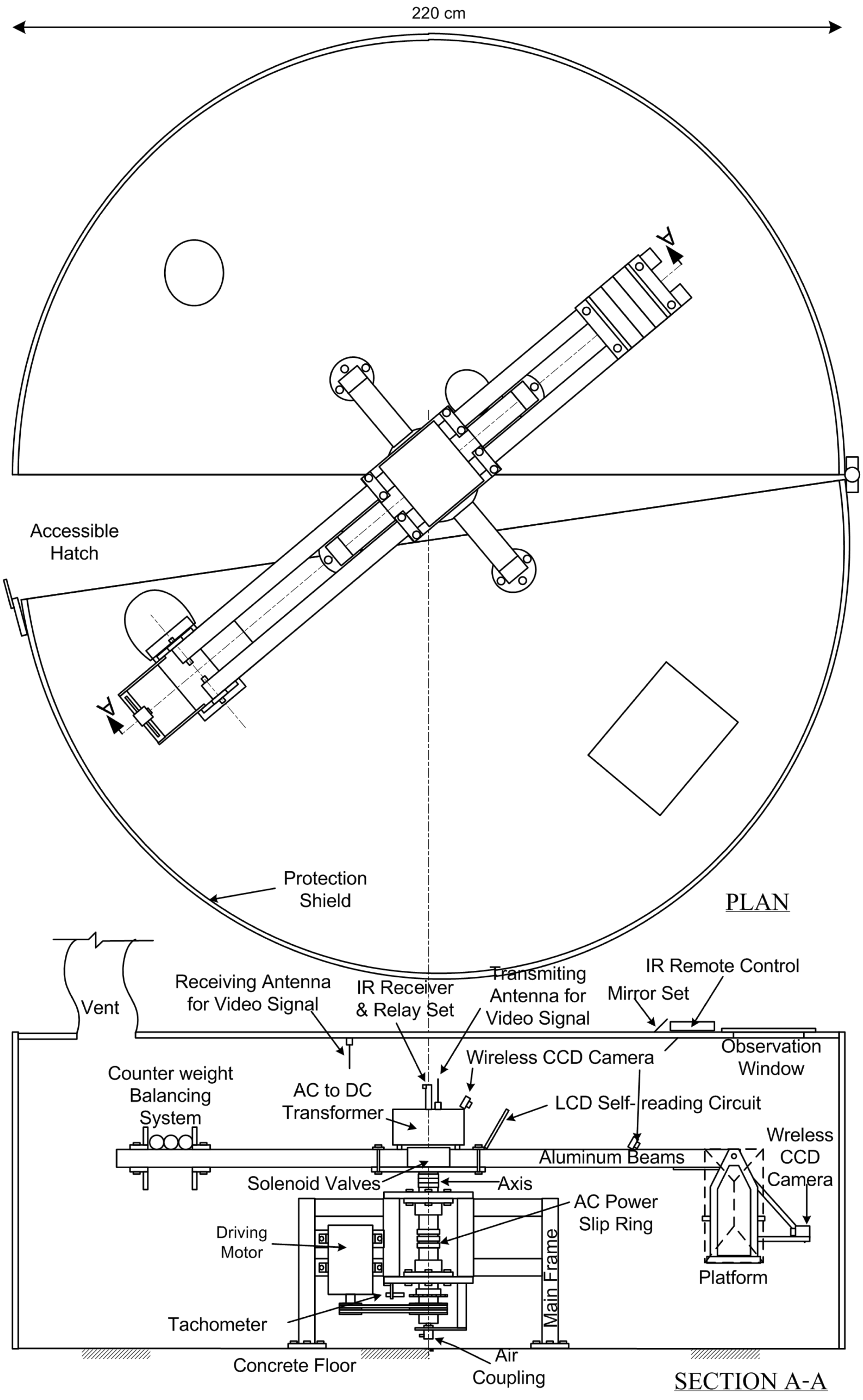

Fig. 1 Centrifuge setup (patent pending).

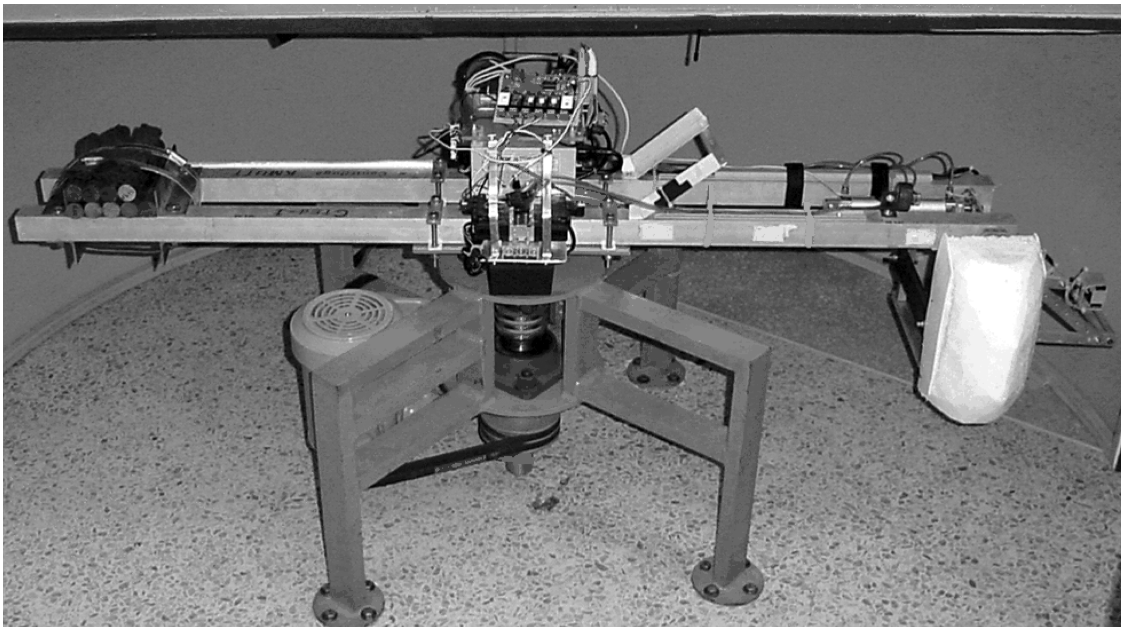

Fig. 2 CTEd-1 centrifuge.

The centrifuge is driven by an electric motor of 1 hp via two driving belts. The speed is monitored by tachometer and manually manipulated by an AC to DC inverter unit via a small knob. Typical specifications are showed in Table 1.

Table 1 Specifications of CTEd-1 centrifuge.

Specifications	Description
Centrifuge Type:	Beam centrifuge with swing-up platform.
Radius:	1 m.
Maximum Speed:	350 rpm (about 100 times of normal gravity).
Payload:	6 kg.
Capacity:	0.6 g-ton.
Transducer Type :	Pressure, load and displacement.
Data Communication System:	LCD self-reading circuit and wireless serial to Bluetooth based data acquisition.
Slip Ring:	1 power slip ring (3 channels), 1 pneumatic coupling.
Driving System :	1 hp AC motor with an electronic inverter.
Observation System:	2 close-circuit wireless CCD color cameras.
In-flight Loading System:	4 channel pneumatic solenoid valves for up to 4 pneumatic actuators.
In-flight Control System:	4 DC relays controlled by IR remote transmitter.

2.2 Electrical Supply and Control

The centrifuge is equipped with a design of simple electrical supply system. The diagram of the system is presented in Fig. 3. To minimize the number of slip ring to be only single 3-channel power slip ring, the system allows an AC to DC transformer to locate on the beams at the center of rotation. The power slip ring is used to pass 3 AC power lines to the transformer to provide two voltage supplies of 5 and 12 volts which are needed by wireless close-circuit cameras and other instruments installed on the beams.

To control air actuators in flight, single pressurized air supply line is passed through a coupling to supply 4 solenoid valves. An electronic circuit of IR receiver with 4 relays is used to manipulate the valves independently in controlling up to 4 air actuators in different direction via an IR remote controller. The receiver is installed to maintain the receiving LED to be at still and clear position at the center of rotation as much as possible. Therefore, the controller can send IR signals effectively to the receiver by reflecting of two small mirrors through a small hole on the top of the shield.

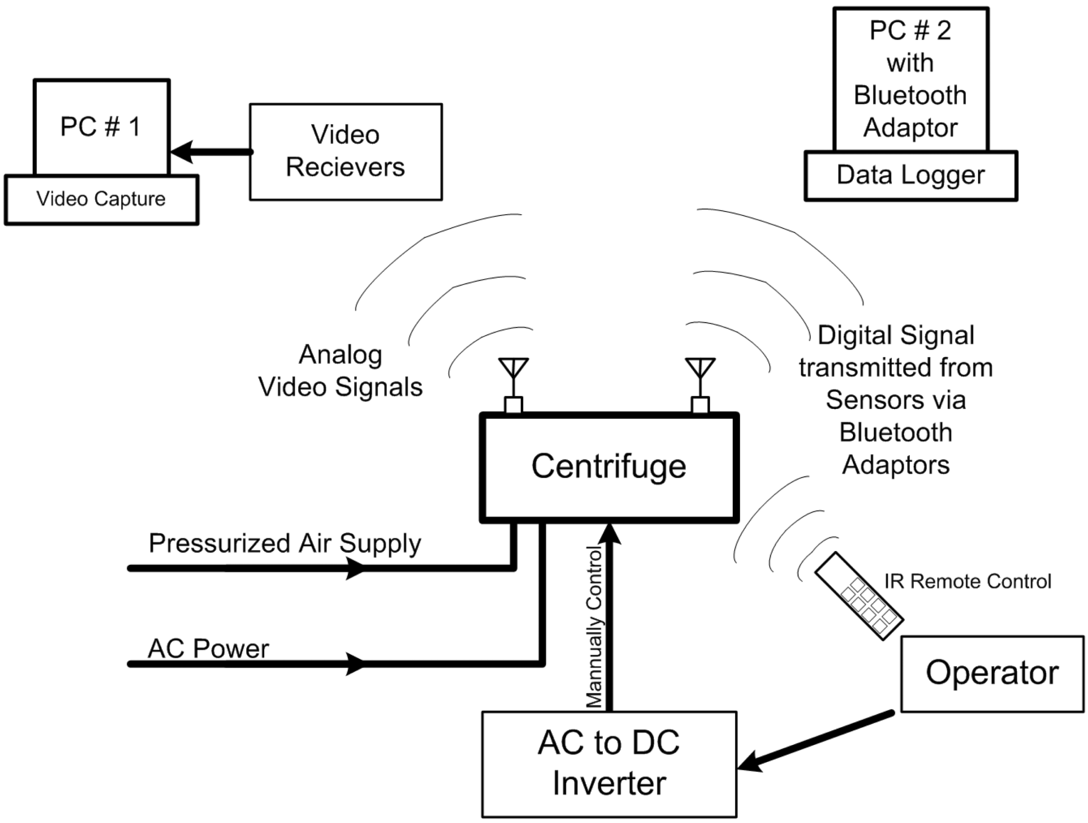

Fig. 3 Schematic diagram of control system.

2.3 Measuring Facilities

As mentioned, the simplest choice is to use so called in-flight self-reading circuit installed on the centrifuge arm. The readout can be observed in flight from a small LCD panel on the circuit (Fig. 4) by a wireless closed-circuit camera. Only two circuits and sensors are used in case of a simple test. However, for more sophisticated test with a number of sensors needed, two small light weight circuits of data loggers of 12 bits A/D converter and a signal conditioner (B&B Electronics®) are used to be able to communicate wirelessly to a nearby PC by a pair of serial to Bluetooth cable replacement adapters. This technique is very simple for computer technology today and can be applied to use with any data logger which has a basic RS232 communication port. Although quality and precision of the circuit are not comparable to the other complete data acquisition systems, with the benefit of light weight and disregarding the expensive high quality slip ring, the circuits are fairly acceptable.

Two video signals are transmitted wirelessly from two transmitters whose antennas are located on the beams to outside receivers whose antennas are attached inside the centrifuge chamber. The video lines are connected to video surveillance PCI card installed in another PC. Up to 4 cameras (depending on the number of card installed) are able to be used simultaneously and their signals can be viewed and recorded simultaneously by a frame grabber program. Image processing can be used to visualize and digitize the deformation of the model samples. This mentioned technique has proven to be very effective and useful to develop a setup of low cost small geotechnical centrifuge.

3. Measuring and Model Preparation Equipments

3.1 In-flight Self-reading Circuit

Two self-reading electronic boards made by Acsensor® (Fig. 4) are able to be attached to the beams. The boards are capable of measuring voltage difference from typical resistance bridge circuits used in typical transducers. The boards can be moved out of the beams and used to calibrate transducers anywhere. Additionally, two knobs of zero reading and sensitivity adjustments are provided. A transducer can be connected to a board by a four-wire connector. A LCD display on the board displays value of voltage difference due to the detection of the transducer, and a wireless close-circuit camera simultaneously monitors the value shown at the nearby PC outside the chamber. This technique is simple and effective for this type of centrifuge, especially in case of demonstration the operation. Therefore, any setup of simple model tests requiring transducers less than two will be provided easily. However, for this setup the voltage difference is needed to be recorded manually by an operator.

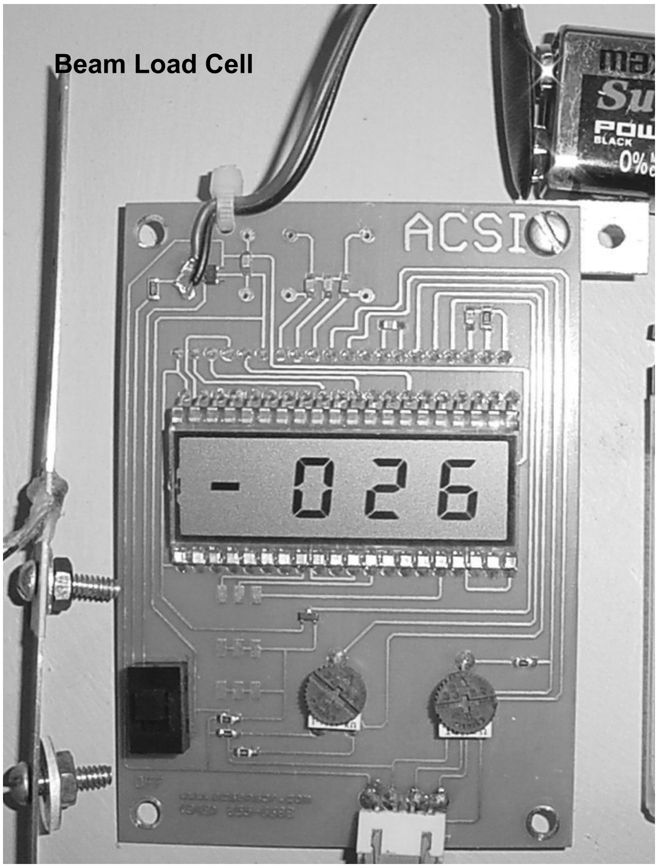

Fig. 4 In-flight self-reading circuit and low cost beam load cell.

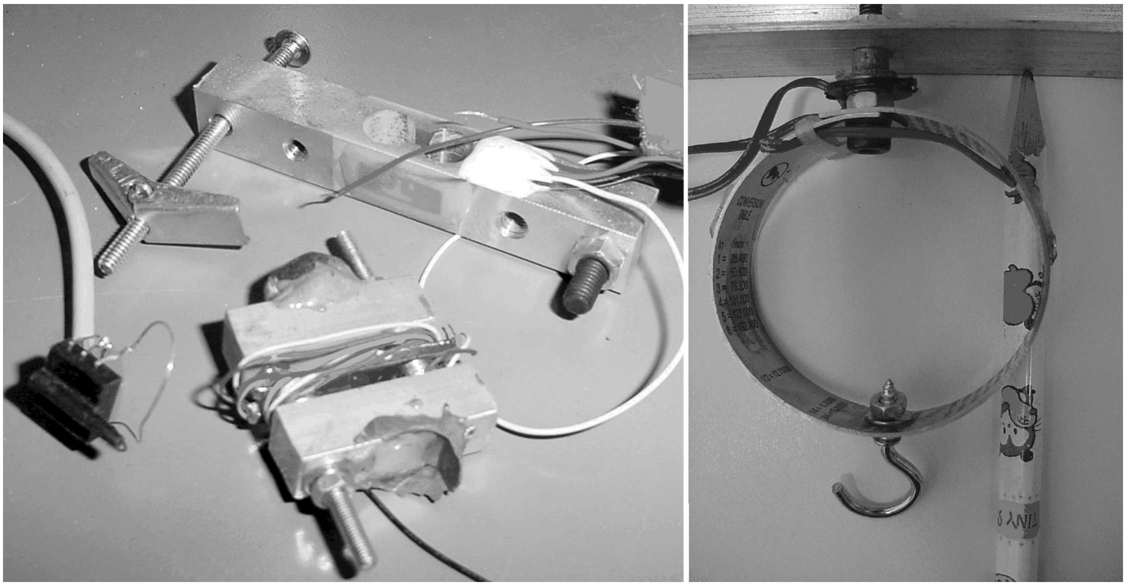

Fig. 5 Various types of low cost transducer.

3.2 Low Cost Beam Load Cell

Based on using foil strain gauges connected together as a Wheatstone bridge circuit, a number of simple low cost beam load cell is constructed. Fig. 4 presents a 1 mm thick stainless steel plate with 1.5 cm wide. There are four strain gauges glued on both sides of the plate. Other transducers are also custom-made and also shown in Fig. 5. The voltage difference can be transmitted to the in-flight self-reading circuit by the four-wire connector. This simple load cell is able to monitor any low forces on the centrifuge platform. The load cell is needed to be initially calibrated with known loads before using. The first use was to calibrate g-level and rotational speed at the middle height of the platform. The calibration was performed simply by hanging a known weight on the load cell. The result is illustrated in Fig. 6. The second use was to measure total active earth pressure thrust of dry sand backfill acting to a vertical plain strain retaining wall. With the flexible behavior of the load cell, active earth pressure condition behind the wall was developed.

3.3 Large Consolidometer

To prepare a clay sample for a centrifuge test, the sample has to be large enough to fit the size of the model container which is 20 cm long. Therefore, a new consolidometer (Fig. 7) made of 20 cm diameter plastic cylinder was build to consolidate kaolin clay for undrained slope stability model. A pneumatic actuator attached to a strong frame is used to apply continuous pressure on the clay slurry. Very soft to medium clay can be artificially created under 5 days of consolidation period. Ten slices of sample for undrained slope stability model can be prepared by one time of consolidation.

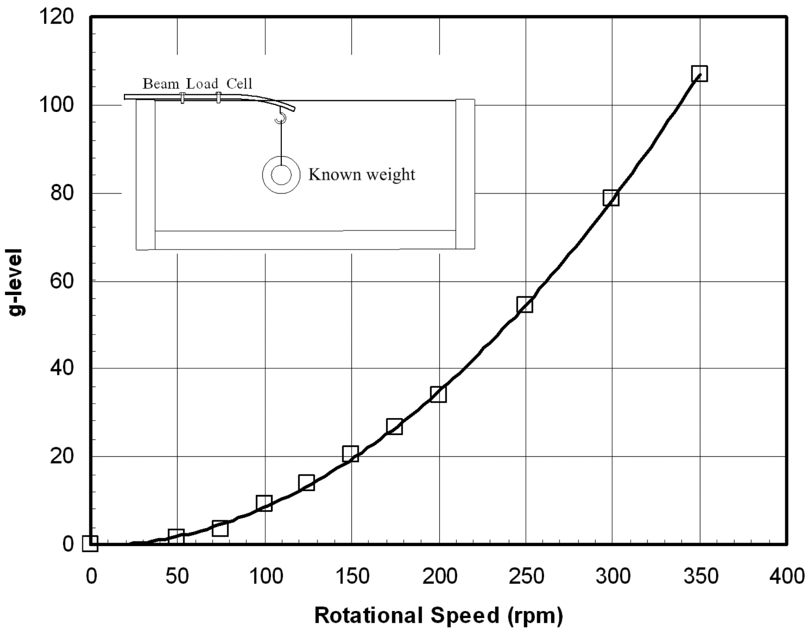

Fig. 6 Calibration of rotational speed and g-level.

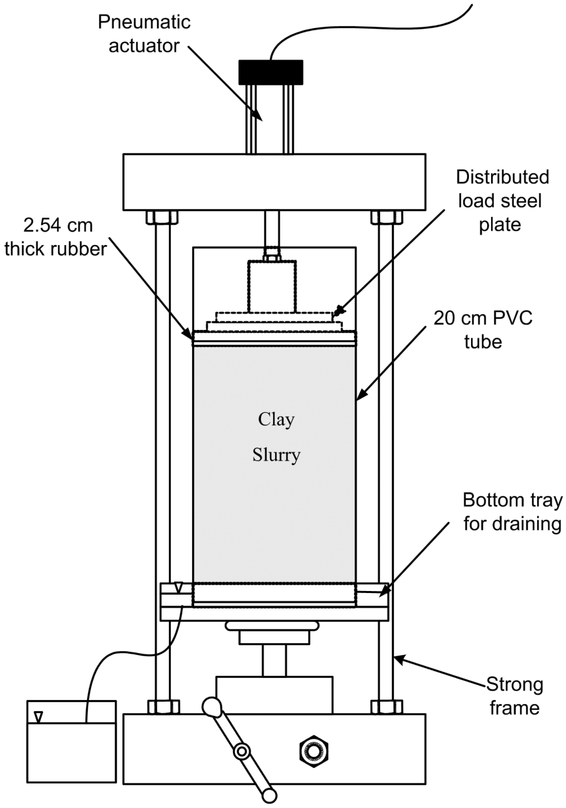

Fig. 7 Large consolidometer.

4. Test Models

4.1 Retaining Wall Model

A preliminary test on retaining wall was performed to measure active thrust on the wall and to observe the wedge failure pattern behind the wall [5]. The setup shown in Fig. 8a is a simple model which consumes a short time in preparation. To verify validity of the setup, water pressure acting on the wall was measured at different g-level up to 34 g by means of measuring resultant force via a copper wire stretched between the load cell and the wall. The force calculated and measured were in good agreement during spinning up the centrifuge as shown in Fig. 9. Afterward, the sand backfill was tested by means of two testing steps. First step, the resultant force of active condition was measured without actuator (by observation at the in-flight self-reading circuit.) Second step, the actuator was installed in front of the wall to activate wall's movement at a certain g-level to observe the failure pattern. With several treatment cases of minimizing wall friction, the best result of total force on the wall was obtained with 15% error comparing to the calculation (Fig. 10).

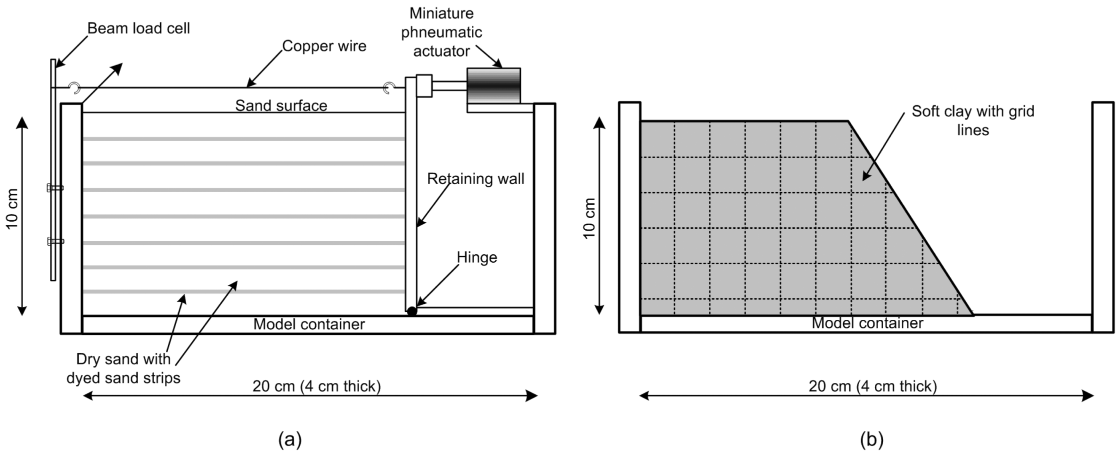

Fig. 8 (a) Retaining wall and (b) undrained slope stability model.

4.2 Undrained Slope Stability Model

Undrained slope stability models were tested follow [4] to evaluate stability numbers for different slope angle. Soft clay samples were prepared by the large consolidometer and trimmed to be fit the container. The undrained shear strength was determined by using unconfined compression test. The setup is shown in Fig. 8b. The slope model was spun to observe and record both failure surface and failure g-level. The experimental failure surface was in good agreement with the failure surface determined by using Taylor's solution. However, for undrained slope stability model where failure g-level was determined, the undrained Taylor's stability numbers obtained from the centrifuge tests were not correspond well to the purposed stability number chart. The possible error may involve treatment of reducing friction between walls and samples and also difficulty in determining an exact g-level at corresponding failure stage. On the other hand, the clear curve failure pattern was observed during the tests which were usefully demonstrated in undergraduate class to understand the mechanism of slope failure.

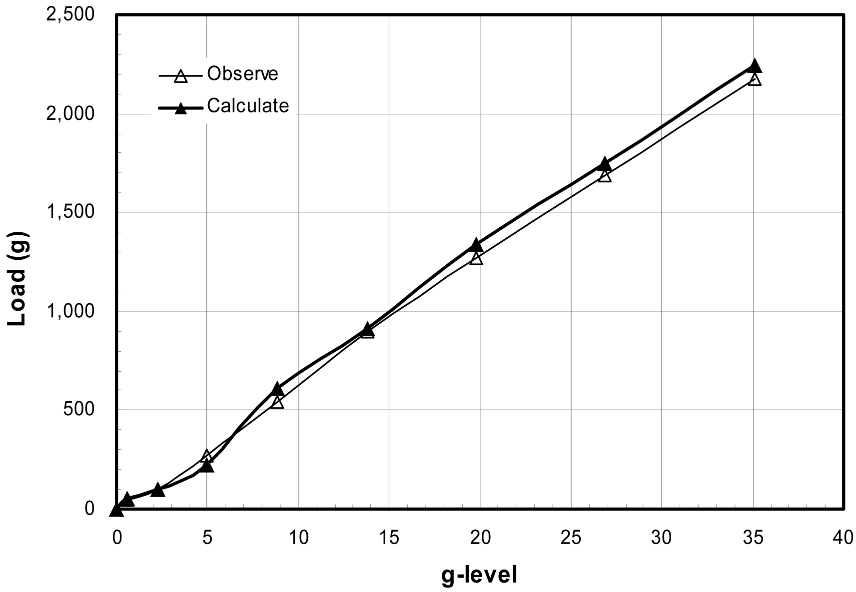

Fig. 9 Test results of water behind retaining wall models. [5]

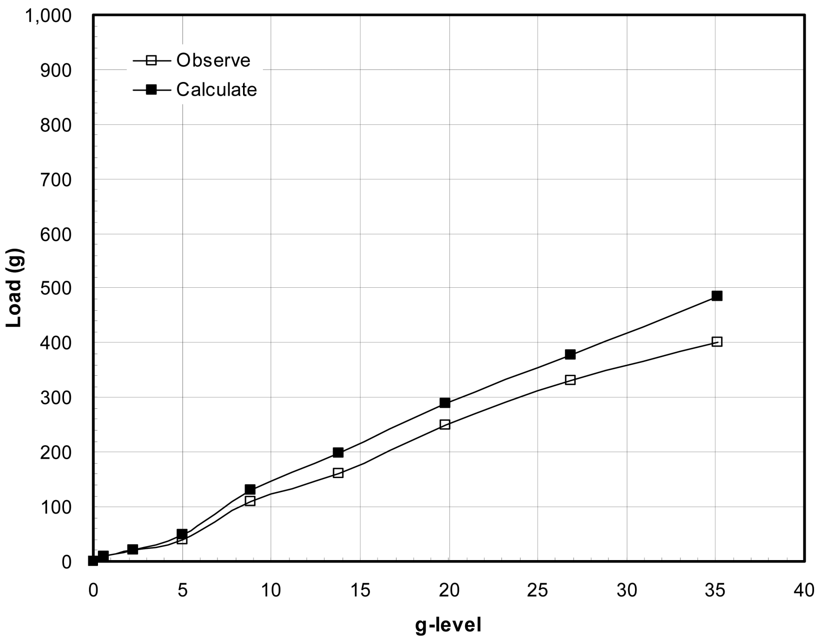

Fig. 10 Test results of sand back fill behind retaining wall models. [5]

5. Discussion and Conclusion

Many techniques are introduced here in order to improve a small geotechnical centrifuge, for example, wireless technology can be used to replace traditional slip ring and to reduce overall construction cost; the air suction technique is able to reduce the air turbulence and the structural vibration and to provide the higher spinning speed; the in-flight self-reading circuit is a low cost and the simplest solution for simple model tests in case of number of sensors are limited; and the IR remote control with reflecting mirrors is also a simple way to control actuators. Disadvantages of the small centrifuge are still remain, such as, in the use of heavy or large sensors and other instruments, since there are not enough provided space on the platform and the arm. The small centrifuge still need to be run extensively to evaluate overall consistency and stability of spinning for a long period of time, for example, in-flight preparation of clay sample from slurry.

The small geotechnical centrifuge is presently capable of demonstrating many centrifuge models and modeling technique itself with the cost as low as a setup of triaxial test apparatus.

Furthermore, the centrifuge is interesting to be applied to develop or produce lessons, media or instructions to enhance any traditional geotechnical engineering classes, especially in undergraduate level. Due to its small size and compact, the centrifuge has been moved place to place to demonstrate the modeling technique to public and the civil engineering society in Thailand in which the technique was not well known before.

According to the first prototype and the mentioned techniques, a bigger geotechnical centrifuge will possibly be custom-made in Thailand as a full-scale research geotechnical centrifuge instead of purchasing a whole expensive setup from aboard.

6. Acknowledgments

Partial financial support for this research, provided by the Department of Civil Technology Education, KMUTT, Thailand, is gratefully acknowledged. Author also thanks Mr. Ong-art Meesawat, Wee Media Ltd., Thailand, for his valued advices and assistances in development.

7. References

1. Craig, W. H., 1989, "The Use of a Centrifuge in Geotechnical Engineering Education", *Geotechnical Testing Journal,* Vol. 12, No. 4, pp. 288-291.

2. Mitchell, R. J., 1994, "Centrifuge Modeling as a Teaching Tool", *Geotechnical News,* Vol. 12, No. 3, September, pp. 30-31.

3. Collins, B., Znidarcic, D., and Goddery, T., 1997, "A New Instructional Geotechnical Centrifuge", *Geotechnical News,* September, pp. 10-12.

4. Dewoolkar, M. M., Goddery, T., and Znidarcic, D., 2003, "Centrifuge Modeling for Undergraduate Geotechnical Engineering Instruction", *Geotechnical Testing Journal,* Vol. 26, No. 3, pp. 201-209.

5. Santichaianant, K., 2005, "The Instructional Centrifuge Modeling of Retaining Wall in Active Condition", *Proceeding of the 10th National Convention on Civil Engineering,* Vol. 3, pp. 201-206.