แบบจำลอง CENTRIFUGE ในงานวิศวกรรมธรณี

CENTRIFUGE MODELLING IN GEOTECHNICAL ENGINEERING

Thanadol Kongsomboon [1], Dr. Tan Thiam Soon [2], Dr. Warakorn Mairaing [3]

Dr. Yong Kwet Yew [4]

[1] Research Scholar, [2] Associate Professor, [4] Professor

National University of Singapore

[3] Associate Professor

Kasetsart University

บทคัดย่อ: แบบจำลอง Centrifuge ได้ถูกนำมาใช้ในการจำลองขนาดของการทดสอบทางด้านวิศวกรรมธรณีมานานหลายปีแล้ว เนื่องจากดินเป็นวัสดุที่มีคุณสมบัติซับซ้อน และประวัติการรับน้ำหนักของตัวอย่างดินในแต่ละพื้นที่มีความสำคัญอย่างยิ่งต่อการทดสอบ ซึ่งไม่สามารถจะกระทำได้ด้วยแบบจำลองขนาดเล็กภายใต้สภาพแรงโน้มถ่วงของโลก นอกเสียจากว่าจะทดสอบบนดาวเคราะห์ที่มีสภาพแรงโน้มถ่วงที่สูงกว่าโลก ด้วยหลักการของเครื่อง Centrifuge คือการจำลองสภาพแรงโน้มถ่วงสูงบนกระเช้าหมุนด้วยคานเหวี่ยงรอบแกนหมุน เครื่องทดสอบนี้สามารถศึกษาพฤติกรรมของโครงสร้างทางวิศวกรรมปฐพีได้อย่างถูกต้องด้วยแบบจำลองที่ถูกลดขนาดลง ในส่วนของข้อมูลที่ตรวจวัดได้จะถูกขยายค่าขึ้นตามสัดส่วนของแรงโน้มถ่วงที่สูงขึ้นด้วยเช่นกัน อย่างไรก็ตามในการที่จะจำลองปัญหาทางวิศวกรรมได้อย่างถูกต้องนั้น จะต้องมีความแม่นยำในการเตรียมตัวอย่างแบบจำลองชั้นดินในสนาม รวมทั้งจำลองกระบวนการก่อสร้างจริง บทความนี้ได้แสดงตัวอย่างผลการทดลองแบบจำลองงานขุดดิน และงานวิจัยในโครงสร้างอื่นๆที่น่าสนใจด้วยแบบจำลอง Centrifuge

ABSTRACT: Centrifuge modelling has been used for many years to carry out correctly scaled physical model tests in geotechnical engineering. This is necessitated by the fact that soil is a highly non-linear material, and that stress history plays an important role in all prototype problems. An associated problem is that in the field, gravity plays an important role and this is almost impossible to simulate in a small model unless the experiment is conducted in a high gravity planet. The central idea of centrifuge testing is in fact the simulation of that high gravity environment at the end of a large revolving centrifuge. This allows prototype soil behaviour to be simulated in the model and model data can be scaled to prototype values in a rigorous and self-consistent way. However, to conduct such an experiment well, there are many details to ensure; from the preparation of samples to realistic modelling of actual field construction process. In this paper, the application of centrifuge modelling to deep excavation will be used to illustrate the approach and power of this method. Other interesting examples will also be given.

KEYWORD: Centrifuge model, Geotechnical centrifuge

***For further details, contact** Thanadol Kongsomboon, Department of Civil Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260*

1. Introduction

Civil engineers are responsible for the safe and economical construction and satisfactory performance of tremendous structures. To achieve this task, rigorous prediction of the behaviour of structure during its expected life must be carried out with sufficient accuracy by means of theoretical, numerical, or experimental approach. In practice, engineers will choose a suitable analysis procedures usually from various alternatives available in manuals or codes of design. Ordinarily, these procedures are described in the form of theoretical formulae, tables or design diagrams. However, such procedures are always based on simplified assumptions and hence are valid only within the validity of the assumptions.

Soil is a highly non-linear stress-dependent material. As a result, behaviours of geotechnical systems tend to be highly complex and even rigorous analysis such as finite element computations employing highly sophisticated constitutive models may not necessarily give accurate solution. In that case, the best way is to observe the behaviour of the actual structure and check the accuracy of an existing procedure or establish a new design technique base on new assumptions derived from observations of full-scale instrument structure. However, a full-scale test to observe the behaviour of an actual structure is almost always very costly, takes a long time, and sometimes is very dangerous. Furthermore, it is almost impossible to carry out a parametric study and to check the reproducibility of the test results. There is therefore a necessity to carry out correctly scaled physical modelling to replace such full-scale observations. That is the role of centrifuge modelling.

2. Scaling principles for centrifuge testing

To simulate the self-weight effect in a large earth structure, a small-scale model has to be tested in a high gravity (high-G) environment, which is approximated by the centrifugal field at the centre of a soil model that is put on a large rotating arm as shown schematically in Fig.1. This allows homologous points in the model to be subjected to the same stress levels as the prototype and enables prototype soil behaviour to be correctly simulated within a reduced scale model as shown in Fig.2. If the model is geometrically similar to the prototype, then the ratio of prototype size to model size can be characterised by N where N is the ratios of prototype to model dimension, and is referred to as the scale factor.

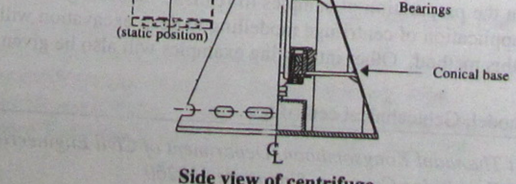


Fig.1 Side view of NUS Geotechnical Centrifuge

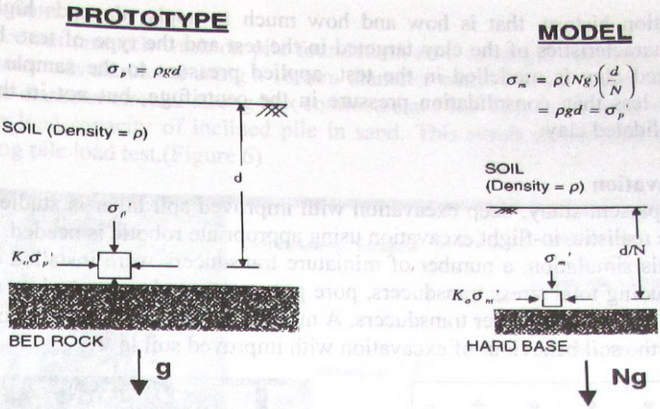


Fig.2 The stress field between prototype and centrifuge model.

Table 1 The scaling relations of various parameters between model and prototype

Parameter	Prototype	Centrifuge model at NG
Linear dimension	1	1/N
Area	1	$1/N^2$
Volume	1	$1/N^3$
Density	1	1
Mass	1	$1/N^3$
Acceleration	1	N
Velocity	1	1
Displacement	1	1/N
Strain	1	1
Energy	1	$1/N^3$
Stress	1	1
Force	1	$1/N^2$
Time (seepage)	1	$1/N^2$

3. Applications of centrifuge modelling

With this approach, it can be shown rigorously that the soil in the model is subjected to the same stress level as in the prototype, thus ensuring that the correct soil characteristics are modelled. In this way, the prototype soil behaviour is simulated in a strong box model. Such models are easily amenable to repeated tests and appropriate parametric studies.

Preparation of soil sample

The initial stress condition of a soil model is one of the most important characteristics, which will strongly influence the subsequent behaviour. Thus samples need to be carefully prepared in terms of void ratio and other mechanical properties. The consolidation history applied to the sample in the laboratory is one of the determining factors on the characteristics of sample. The selection of an appropriate consolidation history, that is how and how much to apply, depends highly on the desired characteristics of the clay targeted in the test and the type of test. If normally consolidated clay is modelled in the test, applied pressure to the sample in the lab should be less than consolidation pressure in the centrifuge, but not in the case for overconsolidated clay.

Deep excavation

In the present study, deep excavation with improved soil layer is studied. For the study to be realistic, in-flight excavation using appropriate robotic is needed. In order to evaluate this simulation, a number of miniature transducers were installed in the clay model including total stress transducers, pore pressure transducers, strain gages on the model wall and potentiometer transducers. A number of studies have been conducted to understand the soil behaviour of excavation with improved soil layer.

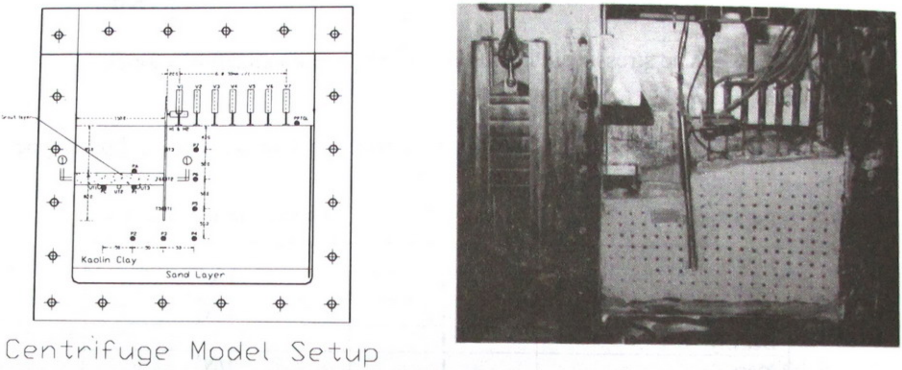


Fig.3 Centrifuge modelling in excavation.

The experiment is conducted at 100G. For the centrifuge at NUS with a nominal radius of 2.0m, this means the centrifuge is spinning at 309 rpm. The size of prototype construction simulated is using a 15 x 40 x 45 m and a 0.4 m thick reinforced concrete diaphragm wall can be simulated strong box of 150 x 400 x 450 mm and an aluminium alloy model diaphragm wall of 3.5 mm thick. The relations of lateral wall movement with depth of excavation and surface settlement behind the wall were shown in figure4

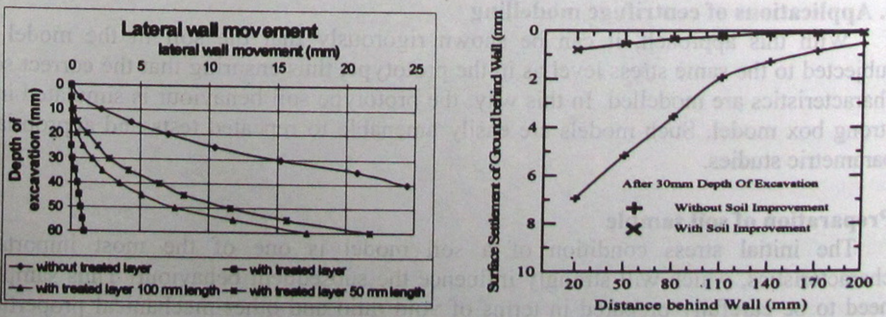


Fig.4 Lateral movement and surface settlement of model wall (in model scale)

Pile foundation

In the present research work on pile foundation, an 8 m length prototype pile with 0.5 m diameter was simulated using a 16 mm diameter with 160 mm length model pile in a 400 mm diameter circular strong box conducted at 50G. This test was to investigate the ultimate load capacity of inclined pile in sand. This result shows load settlement curves during pile load test.(Figure 6)

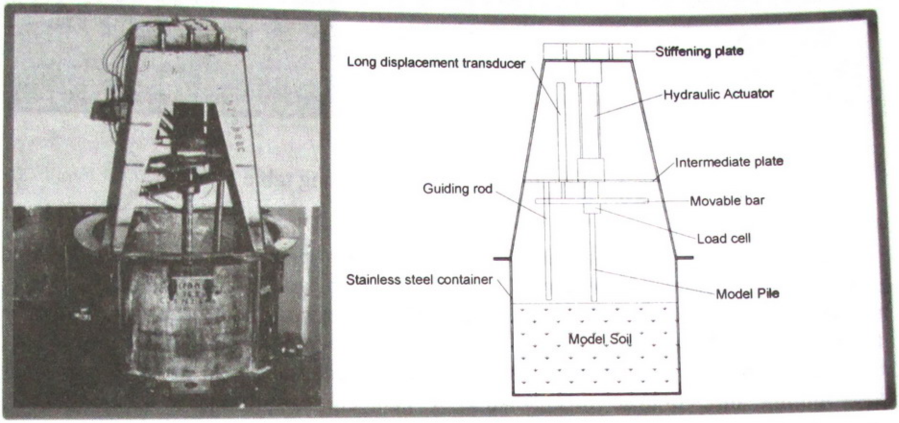
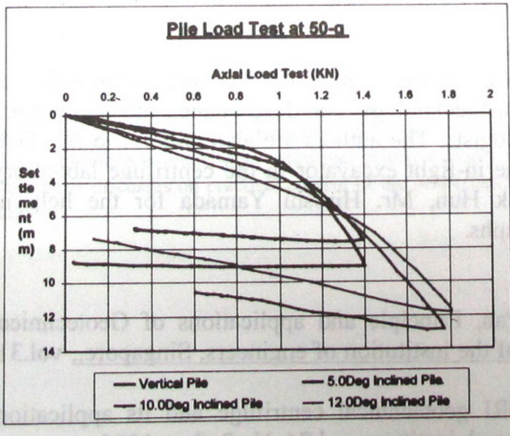


Fig.5 The pile load test in centrifuge model setup



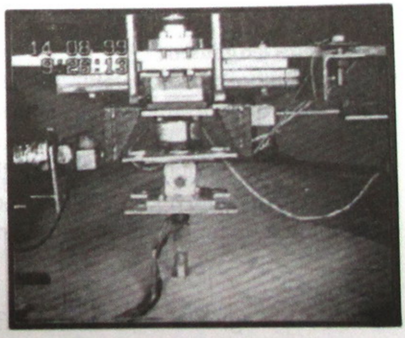


Fig.6 load and settlement curve in centrifuge testing. (model scale)

Earthquake Simulation

Centrifuge tests have also been performed to simulate the behaviours of gravity caissons using a newly developed servo-hydraulic shaking table. Design criteria for the new electro-hydraulic shaking table was conducted in 300mm x 526mm x 310mm laminar box with maximum lateral acceleration 20G and maximum frequency 100 Hz

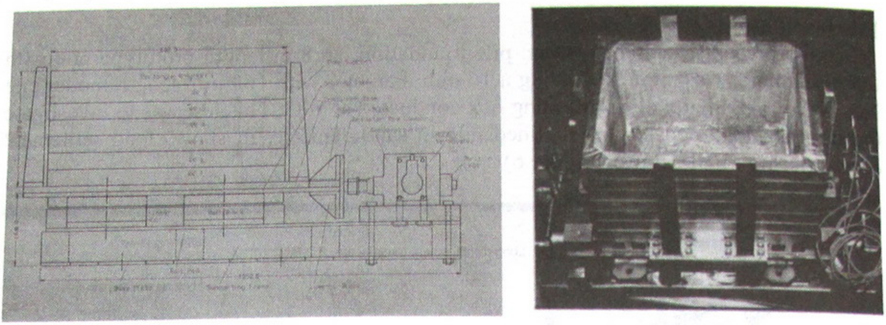


Fig. 7 The electro-hydraulic shaking table

4. Conclusion

Centrifuge modelling is widely used in many parts of the world to study geotechnical problems. Some potential problems that can be investigated include the behaviour of pile foundation, excavation, retaining structure, soil improvement, slope stability, dam engineering and behaviour of geotechnical structures subjected to dynamic loads. The centrifuge is extensively recognised as a major tool for investigating the collapse mechanisms of geotechnical structure. It is ideal for engineering study in the sense that it demonstrates real failure mechanisms and its effect on soil structure. Furthermore, it is amenable to repeated tests and parametric study, something a full-scale test can not emulate.

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