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# Centrifuge model tests on foundation on geosynthetic reinforced slope

## Essais en centrifugeuse d'une fondation sur une pente renforcée par géosynthétique

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ABSTRACT: Centrifuge modelling is a powerful tool for physical modelling of reinforced slopes and offers the advantage to observe the failure mechanisms of the slopes. In order to replicate the gravity induced stresses of a prototype structure in a geometrically 1/N reduced model, it is necessary to test the model in a gravitational field N times larger than that of the prototype structure. In this paper, a series of model tests in a geotechnical centrifuge on reinforced slopes is presented. The geotextile reinforced slopes have the same height of 270 mm and is built with soil layers of the same properties. Photographs with high resolution are taken in short time intervals through the glass wall during flight and the soil deformations of geotextile reinforced slopes loaded with a footing are evaluated with Particle Image Velocimetry (PIV). The experimental results of reinforced slopes are presented. The test data provide interesting insight into the failure mechanisms and the progressive failure characteristics of geo-synthetic reinforced slopes.

RÉSUMÉ : La modélisation en centrifugeuse est un outil puissant pour la modélisation physique des pentes renforcées et offre l'avantage d'observer les mécanismes de rupture des pentes. Pour reproduire les contraintes induites par la gravité d'une structure prototype sur un modèle réduit à l'échelle 1/N, il est nécessaire de tester le modèle dans un champ de gravitation N fois plus grand que celui de la structure prototype. Dans cet article, une série d'essais sur modèle dans une centrifugeuse géotechnique sur les pentes renforcées est présenté. Les pentes renforcées de géotextiles ont la même hauteur de 270 mm et sont construites avec des couches de sol de mêmes propriétés. Des photographies haute résolution sont prises à des intervalles de temps courts à travers la paroi de verre pendant le vol et les déformations du sol de pentes renforcées de géotextiles chargées par une semelle filante sont évaluées en vélocimétrie par images de particules (PIV). Les résultats expérimentaux de pentes renforcées sont présentés. Les données d'essai donnent un aperçu intéressant sur les mécanismes de rupture et les caractéristiques de rupture progressive de pentes renforcées.

KEYWORDS: centrifuge, reinforced slope, foundation, PIV (Particle Image Velocimetry).

## 1 INTRODUCTION.

A wide range of geotechnical problems can be investigated using physical modeling techniques. Centrifuge modelling has become a powerful technique in geotechnical engineering for studying the stability of prototype slopes. In order to replicate the gravity induced stresses of a prototype structure in a geometrically 1/N reduced model, it is necessary to test the model in a gravitational field N times larger than that of prototype structure (Viswanadham and König, 2009). Substantial research demonstrated the effectiveness of centrifuge modelling for studying the behaviours of geosynthetic reinforced walls and slopes, as reported by Porbaha and Goodings (1994, 1996), Zornberg et al. (1997; 1998a,b), Zornberg and Arriaga (2003), Viswanadham and Mahajan (2007), Chen et al. (2007) and Viswanadham and König (2004, 2009).

Foundations are sometimes built on slopes or near the edges of slopes. Knowledge of the treatment of reinforced slopes loaded with a surface footing is of practical importance to geotechnical engineers. Although there are several research studies on reinforced level ground, investigations of footings on reinforced slopes are rather limited (Selvadurai & Gnanendran, 1989; Omar et al., 1993; Huang et al., 1994; Lee & Manjunath, 2000; Yoo, 2001; El Sawwaf, 2007; Alamshahi & Hataf, 2009).

In this paper, a series of reinforced slope models with a slope inclination of about 65, 75 and 85 degrees were tested in a geotechnical centrifuge. The aim is to investigate the effect of the foundation on the geotextile reinforced slopes. Moreover, a technique called Particle Image Velocimetry (PIV) is used in this research to reveal the failure mechanisms of the geotextile reinforced slopes. The experimental results provide reproducible database for rational design of geosynthetic reinforced slopes.

## 2. MODEL DESIGN

### *2.1. Centrifuge*

The geotechnical centrifuge at the Institute of Geotechnical Engineering, University of Natural Resources and Life Sciences (BOKU) in Vienna was manufactured by Trio-Tech, USA and was put into operation in 1990 with partial financial support from the Austrian Science Foundation (Trio-Tech 1988). The beam centrifuge has the following components: a swinging basket, a balancing counterweight, a DC motor and aerodynamic enclosure. It is equipped with 56 electrical slip rings for process control and data acquisition. By using the dual platforms, two models can be tested at the same time. However, it is usual to have only one swinging basket carrying a model, while a balance weight is loaded on the other platform. The centrifuge has been used to investigate various problems in geotechnical engineering, such as retaining wall, shallow foundation and pile foundation. Recent development in digital image processing offers excellent possibilities to study strength of geosynthetic reinforced slopes. The technical specifications of the centrifuge are listed in Table 1 and illustrated in Figure 1.

Table 1. Technical specifications of the centrifuge.

| | |
|---|---|
| Diameter [m] | *3.0* |
| Radius of the swinging basket [m] | 1.3 |
| Maximum radial acceleration [g] | 200 |
| Maximum model weight [kg] | 90 |
| Maximum model height [cm] | 56 |

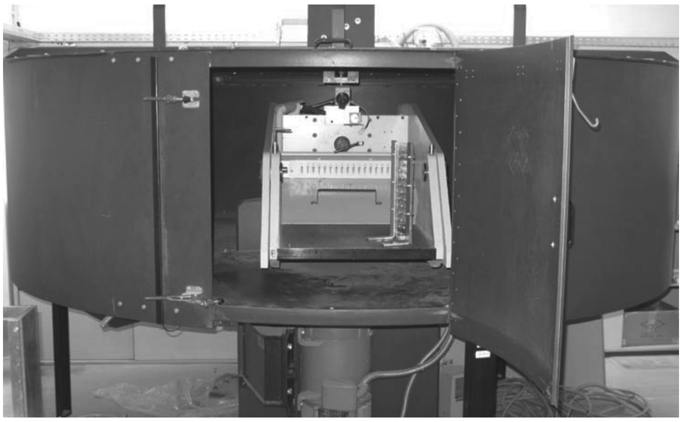

Figure 1. Photo of the centrifuge and its swinging basket.

### 2.2. *Model box*

The model box (Figure 2) has the dimensions of 440mm*400mm*155mm in depth. A transparent Plexiglas plate with a thickness of 30mm was used on one side of the box to enable digital images to be taken during testing. The other walls of the box were aluminum plates with a thickness of 15mm. The box is sufficiently rigid to maintain plane strain conditions in the model.

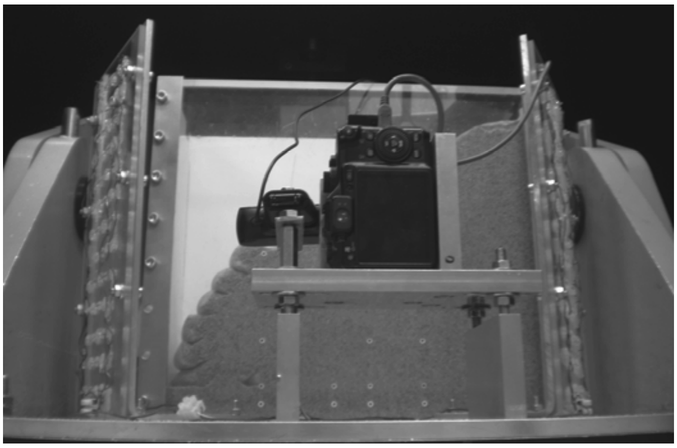

Figure 2. Geotextile reinforced slope model with a digital camera in the front and LED lights on the left and right sides.

### 2.3. *Slope model and model textiles*

Reinforced slope models have a slope inclination of about 65, 75, and 85 degrees. The geotextile reinforced slopes had the same height of 270mm and was built on a soil layer of the same properties. The slope models were loaded with a surcharge of the same soil on the top of the slope. Due to the inherent symmetry of the slope, only half of the slope was modelled.

### 2.4. *Soil*

The soil used in the experiments was uniform coarse sand (Table 2), Standard Sand II (DIN 1164/58). The sand was not compacted but each layer had the same weight for all three models.

Table 2. Properties of soil

| | |
|---|---|
| Specific weight $\rho_s$ [g/cm³] | 2.644 |
| Density range $\rho_{min}$, $\rho_{max}$ [g/cm³] | 1.44 – 1.65 |
| Void ratio $e_{min}$, $e_{max}$ | 0.607 – 0.844 |
| Coefficient of uniformity | 1.4 |
| Friction angle $\varphi$ [°] | 34 |
| Cohesion c [kN/m²] | 0 |

### 2.5. *Instrumentation*

The displacement of the geotextile reinforced slope models was measured by PIV (White et al. 2001; 2003). For this purpose, a 14.7 MP Canon G10 digital camera was used to obtain high resolution digital images of the sand grains behind the Plexiglas wall. Black dots surrounded by white circles were applied to the Plexiglas as can be seen in Fig. 2, and were used as reference points for monitoring displacements within the soil. Two panels of 33 LED lights were used on both sides of the model box for lighting the centrifuge during testing. A laptop computer was mounted close the rotating axis of the centrifuge and connected to the main computer in the control room to save the photos during centrifuge testing.

### 2.6. *Method*

The soil displacement analysis was carried out with GeoPIV8 software, developed by White & Take (2002). The first image is divided into a grid of test patches. Each test patch consists of a sample of the image matrix of size 20 * 20 pixels and the images were captured in 6 s intervals until the failure of the model. The recorded photographs are used to reveal the failure mechanisms of the slope after testing.

## 3. RESULTS

The slope deformations before and after the slope failures are evaluated with PIV analysis. The shear strain in the model slopes with inclinations of 65, 75, and 85 degrees are shown in Figures 3-5.

In Figures 3a and 3b, the slope has an inclination of 65 degrees. The failure surfaces can be clearly observed (Fig. 3b). The failure surface does not pass through the toe as is often observed in unreinforced slopes but emerges from the lower part of the slope.

Figures 4a and 4b show the strain distribution in a steeper slope with an inclination of 75 degrees. When compared with the slope having an inclination of 65 degrees, the shear strains especially in front of the shear surface are more pronounced than in the previous slope (Fig. 4b).

Steeper slope (Figs. 5a and 5b) shows larger shear strain than flatter slopes. Larger shear strain is observed not only in the top of the slope but also along the whole surface of the slope (Fig. 5b).

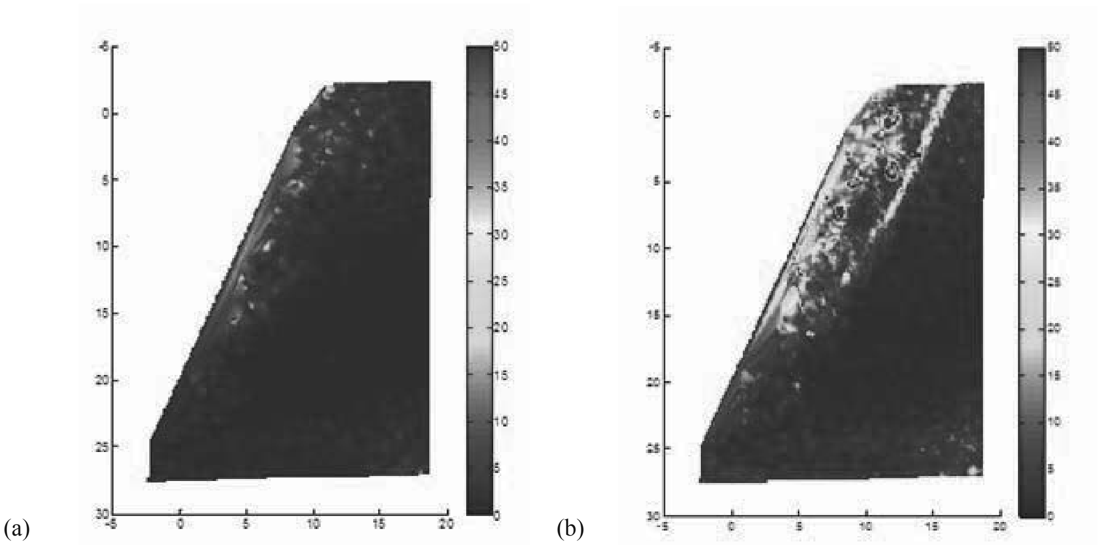


Figure 3. (a) Beginning of slope failure of geotextile reinforced slope with a slope inclination of 65 degrees, (b) Failure surfaces of geotextile reinforced slope with a slope inclination of 65 degrees.

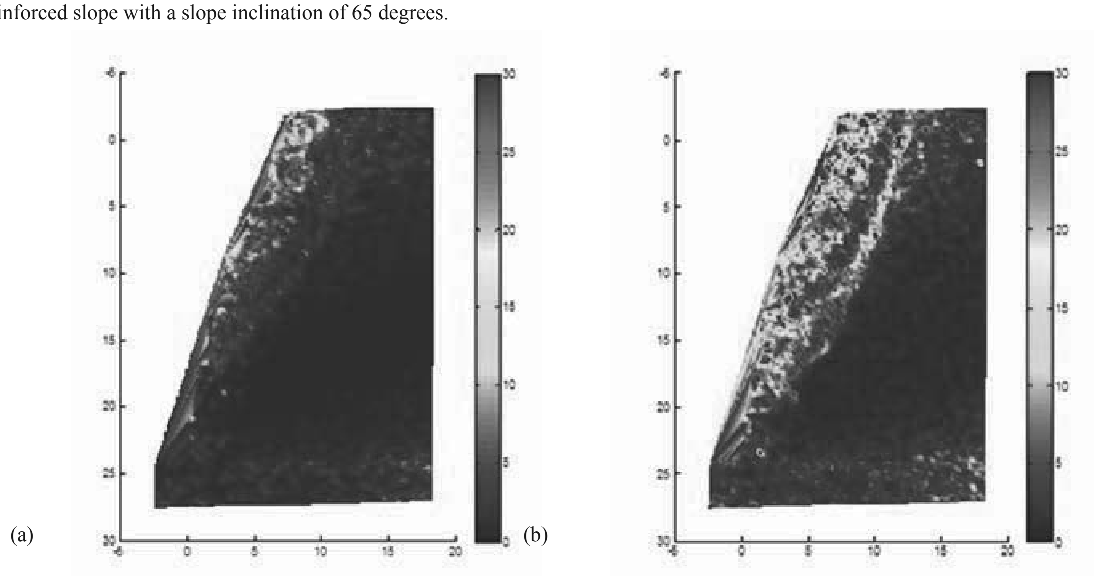


Figure 4. (a) Beginning of slope failure of geotextile reinforced slope with a slope inclination of 75 degrees, (b) Failure surfaces of geotextile reinforced slope with a slope inclination of 75 degrees.

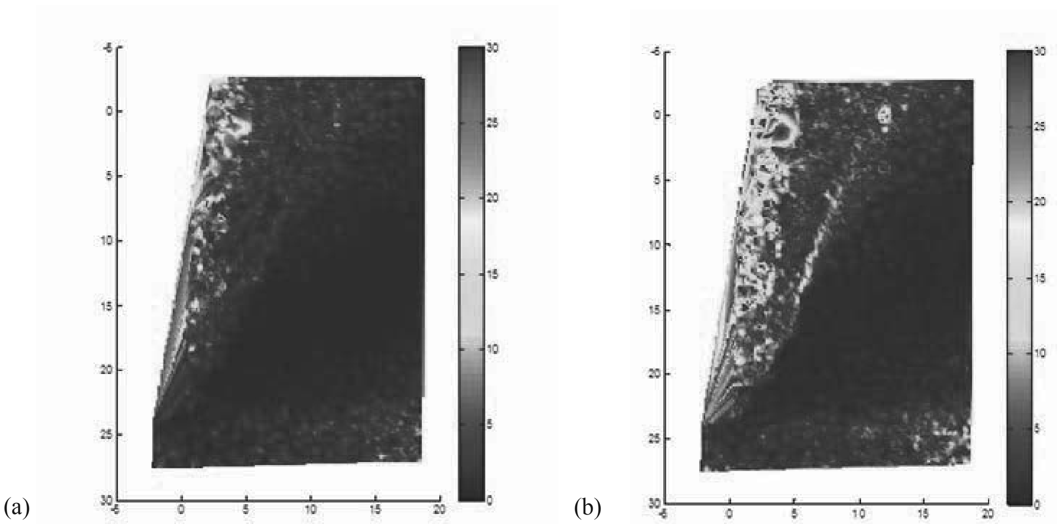


Figure 5. (a) Beginning of slope failure of geotextile reinforced slope with a slope inclination of 85 degrees, (b) Failure surfaces of geotextile reinforced slope with a slope inclination of 85 degrees.

An important parameter in geotextile reinforced slopes is the vertical spacing between the reinforcement layers. There are 6 layers in the slope having 65◦, 7 layers in the slope having 75◦, and 8 layers in the slope having 85◦ slope inclinations. The slope failure is induced by breakage rather than pull-out of the reinforcement. The spacing between adjacent reinforcements is not investigated in the present study. This will be studied later.

## 4. CONCLUSIONS

The failure mechanisms of geosynthetic reinforced slopes are investigated in a geotechnical centrifuge. The failure surfaces emerge from the lower part of the slopes rather than from the slope toes. Slope failure is mainly dictated by the tensile strength of geotextile when geotextile is intersected by the failure surface. PIV is an efficient tool to instrument the soil deformation of model slopes in geotechnical centrifuge.

## 5. ACKNOWLEDGEMENTS

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