# Investigation of the behaviour of nailed sand trenches before failure by geotechnical centrifuge

## Enquête sur le comportement des tranchées de sable cloué échec avant centrifugeuse géotechnique par

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ABSTRACT
The main purpose of this paper is the study of the pre-failure behaviour of loose vertical sand slopes stabilized by nailing system. In this research a series of centrifuge tests have been done and the behaviour of nailed vertical sand slopes has been traced in flight either by instrumentation or by image processing techniques.

By analyzing the behaviour curves of the nailed trenches, it can be inferred that some progressive failure surfaces are formed as the height of stabilized trench increases. During the formation of failure surfaces a kind of hardening is observed in the system, i.e. displacements remain constant or they increase with a lower rate after a sudden increment.

RÉSUMÉ
L'objectif principal de ce document est à l'étude de la pré-défaillance de comportement lâche verticale pistes de sable stabilisé par système de clouage. Dans cette recherche d'une série de centrifugeuses tests ont été faits et le comportement des cloué verticale pistes de sable a été détectée en vol soit par l'instrumentation ou par des techniques de traitement des images.

En analysant le comportement des courbes de la cloué tranchées, il peut être déduit que certains défaillance progressive des surfaces sont formées que de la hauteur de la tranchée stabilisée augmente. Au cours de la formation de surfaces non une sorte de durcissement est observé dans le système, c'est-à-dire les déplacements demeurent constants ou augmentent avec un taux plus bas, après une brusque augmentation.

Keywords :Soil nailing, Centrifuge modelling, Image processing, Failure

## 1 INTRODUCTION

Soil nailing is an innovative and cost-effective technique to strengthen the soil, and has been practiced for many years (Juran, 1985). Some researchers have conducted detailed studies for reinforced earth walls (Rowe and Ho, 1996). However, limited studies have been conducted for soil nailed structures (Sivakumar Babu, 2002). It has been shown in various studies that the performance of a soil nailed structure is significantly influenced by such factors as the construction sequence, the rigidity of facing, the interaction between the soil and the nails, and the details of the load transfer from the nails to the facing.

The main purpose of this paper is to study of the large deformations occurred in loose vertical sand slopes stabilized by nailing system. In this research a series of centrifuge tests have been performed and the behaviour of nailed vertical sand slopes has been traced in flight either by instrumentation or by image processing techniques. The centrifuge tests were done on 17 down scaled models differing in the facing types, nail surface roughness, nail bending properties, nail length, and nailing pattern. In these tests the construction process of a nailed soil wall is simulated by different stages of soil excavation. After different stages of excavation (which are done at 1g) the model is accelerated up to 20g. As the centrifuge acceleration increases the stresses induced in the soil mass and nails are increased. During accelerating the models the horizontal and vertical displacements of the wall and the size of the failure surfaces are investigated. To determine the failure surfaces a mesh of target points is constructed and some white thin horizontal soil lines are placed on the side wall of the model. An image processing technique, based on the shear strain changes in a horizontal profile of the side wall, is used.

## 2 CENTRIFUGE MODEL TESTS

### 2.1 *The new geotechnical centrifuge of Iran University of Science and Technology*

Centrifuge tests of this research program were performed in the Geotechnical Centrifuge Centre of Iran University of Science and Technology. The new centrifuge machine has a radius R=1.0 m to the platform and a maximum capacity of 70kg at 200 gravities (Salehzadeh, et. al., 2005). Table 1 gives the main specifications of the centrifuge facility.

Tabel.1: Main specifications of IUST centrifuge (Askarinejad, 2007)

| specification | magnitude |
|---|---|
| Radius | 1 m |
| Max. payload | 70kg |
| Max. Acceleration | 200g |
| Max. size of strong box | 60cm*20cm*20cm |
| Wireless picture transfer rate | 24 frames per sec. |
| Data acquisition system | 16 channels |
| Data logging rate | 100 Hz. from each channel |

The strong box used in these tests, is 60 cm long, 18.5 cm wide and 14 cm high in size. The main structure of the box is a steel frame, and two longitudinal transparent walls enabling image monitoring of the sample. These walls are composed of two layers. the outer layer is a thin anti-reflex Plexiglas to

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lessen the shadows and light reflections, to have a better quality of pictures. The inner layer of side walls is composed of sheets of glass to reduce the friction between sand and the wall (Bransby, and Smith, 1975, Tie, 1993).

As mentioned in table 1, this centrifuge has an internal data logger with maximum logging frequency of 100 Hz from 16 channels in which data can be access at the end of each test. During the test only the image data can be transferred to the laboratory computer.

## 2.2 *The soil*

The sand used in these tests is fine silty sand from the city of Mahan located in central south east of Iran. The properties of this soil are summarized in table 2.

Table 2: Sand properties (Roostazade, 2007)

| Soil parameter | Magnitude |
|---|---|
| Gs | 2.56 |
| D50 | 0.18mm |
| USCS Category | SM |
| Optimum water content | 9.8% |
| $\gamma_{d\max}$ | 16.7 KN/m3 |
| $\varphi$ | 35 |
| $C_{dry}$ | 0 |

According to the grading and hydrometery tests, the soil is composed of 85.5% sand, 12% silt, and 2.5 % clay. The grading curve has a Cc=3.3and Cu=0.7.

As it could be seen in the table 2, the dry sand is non-cohesive, but in these tests the soil is mixed with water to have 5% water content, and this will cause apparent cohesion in the soil, which was measured to be 0.9 kPa (Shahnazari, et. al, 2008). The unit weight of the sample after the compaction stage is $\gamma = 15.6 \ {KN}/{m^3}$. According to the following equations the saturation of the sample can be estimated.

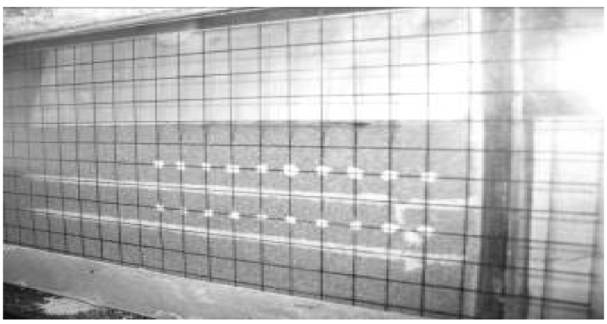
$$\begin{cases} \gamma = \dfrac{(1+\omega)\times\gamma_w\times G_s}{1+e} \\ \omega\times G_s = S\times e \end{cases} \Rightarrow e = 0.78, S \cong 17\% \tag{1}$$

It should be mentioned that before the compaction stage of acceleration, the height of samples is 13cm and after compaction stage the samples settle to 11.5cm.

## 2.3 *Sample Preparation and test procedure*

To prepare samples the sand is poured from a constant height of 30 cm from the surface of the soil. At different stages, target points are progressively installed. The colour of these points is such that a proper visual contrast is achieved. To prepare the same samples the compaction is applied by a 20g centrifugal acceleration. During this stage the face of cut is supported against lateral displacement. After this stage, in the lateral supports are removed (excavation). This process is performed at 1g, then, again the model is accelerated to the failure.

Figure 1. The reference grid, and installing the target points and lines during model preparation



The horizontal displacement of the slope crest is measured by an LVDT and the logged data is stored in a computer attached to the arm of the centrifuge near the main vertical shaft. After the test, the data is analyzed. Different stages of excavation and acceleration are done in the same way until failure.

## 2.4 *Nails and facings properties*

*Nails*

Since one of the parameters studied in this research project, was the effect of nails properties, 5 different types of circular nails were used as follows:

1. Steel nails, with smooth surface and a diameter of 2mm
2. Aluminium nails, with smooth surface and a diameter of 2mm
3. Aluminium nails, with rough surface and a diameter of 2mm
4. Plastic nails, with smooth surface and a hollow circle section of 0.4mm internal and 2.9mm external diameters
5. Steel nails, with smooth surface and a diameter of 0.8mm

The 2mm diameter of the rough nails does not include the 0.4mm thickness of the rough part; therefore the rough nails have a total diameter of 2.8mm.

The first 7 mm of the length of nails was bent vertically and a 10mm diameter circular plastic piece with a thickness of 4mm is glued to the nails. This plastic head was finally pasted on the faces, to transfer the face displacements and earth pressure to the nails.

In order to roughen the nail surfaces, a thin layer of liquid glue was rubbed on the nails, and then from height of 10cm, sand was poured on the rotating nail.

*The Facings*

In order to investigate the effect of face wall rigidity on stability of nailed slopes, 3 types of facings were used to cover the cut face as shown in table 3.

Table 3.Facings properties

| Facing type | Material | Thickness | $\rho$ |
|---|---|---|---|
| Very flexible | Nylon | 0.01 mm | 1.3E7 |
| Flexible | Perspex | 0.1 mm | 1.3E4 |
| Rigid | Perspex | 5mm | 0.112 |

In the 4th column of table 3, $\rho$ is used to quantify the flexibility of the facing walls. Row (1951) and Milligan (1974) illustrated that a number named "Flexibility Number" is a useful parameter to compare the full scale tests results with those of the model tests (Tie, 1993), as defined bellow:

$$\rho = \frac{H^4}{EI} \tag{2}$$

where

H is the height of the wall, E is the young's modulus of the facing material and $I$ is the second moment of inertia of the face section.

## 2.5 *Determination of the failure zone using image processing method*

During the in-flight condition, the positions of lines and target points are transferred by a wireless camera system to the laboratory computer and are saved for post processing. After locating the target points, according to a reference mesh drew on the transparent side of the strong box, the coordinates of the points are determined. By tracking every point in subsequent images the displacement vectors and strains can be defined. The side wall is triangulated and every target point is part of a triangle element. Knowing the coordinates of the element nodes, a 2*3 matrix is formed for each triangle. The same triangle in two successive frames has enough data to calculate the direct and shear strain within that element. By analyzing the strain distribution in a horizontal line on the side wall of a sample, the failure zones are detected (Askarinejad, et. al, 2008).

As an example the distorted location of target points and lines show two slip surfaces, as shown in figure 2. After triangulation of the target points in the upper part of the side wall, and performing the shear strain calculations, the peek points are located. These peek points of the curve have good consistency with the failure zones distances formed by target lines and points (figure 3).

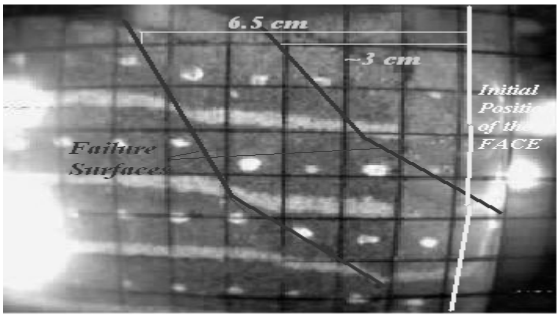



Figure 2. The first and second failure surfaces according to the target points and lines

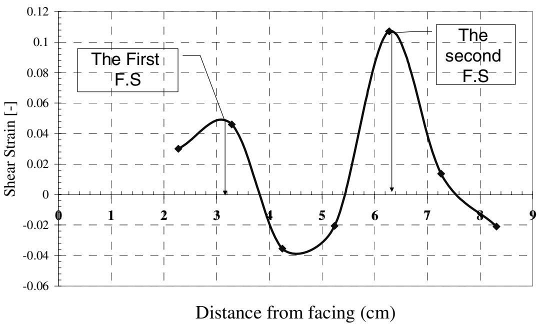



Figure 3. The shear strain change with distance on the side of the sample

## 3 RESULTS AND DISCUSSION

Over all 17 centrifuge tests were performed on the down scaled nailed walls. Each of the samples differed in one or some parameters, (e.g. the nail type, length, pattern, or facing) with the other ones. As mentioned before samples were accelerated to 20g first to be compacted and then after excavating the soil in front of the face to the defined level either to failure or up to max. 20g.

In most of the samples two or tree different failure surfaces were observed, as shown in figures 2 and 4.

During each test the horizontal and vertical displacements of top of the wall and the position of the slip surfaces are measured.

The increasing rates of centrifuge acceleration in all of the tests were fairly the same to apply the same stress history on the samples. In figure 5 the acceleration increase during the 2nd and 3rd stage of excavation in four samples are shown.

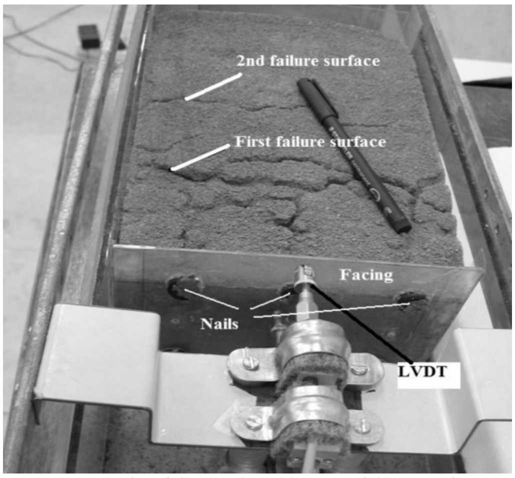



Figure 4. One model after failure – in which two failure surfaces can be seen

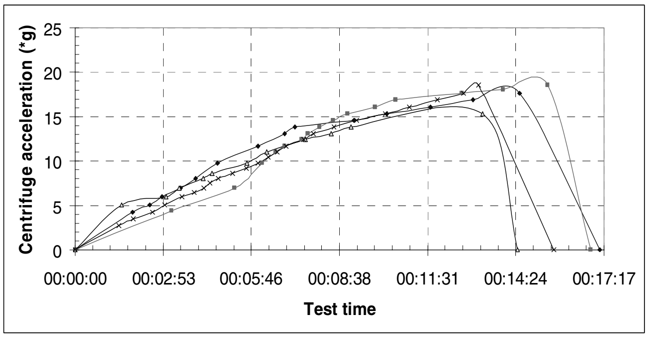



Figure 5. Centrifuge acceleration change during the tests

In figures 6 and 7 the horizontal and vertical displacements of the crest are shown. As it could be seen at lower accelerations the curves have moderate slopes and after being steady for a certain increase in acceleration (or applied load), the displacements increase at a greater rate.

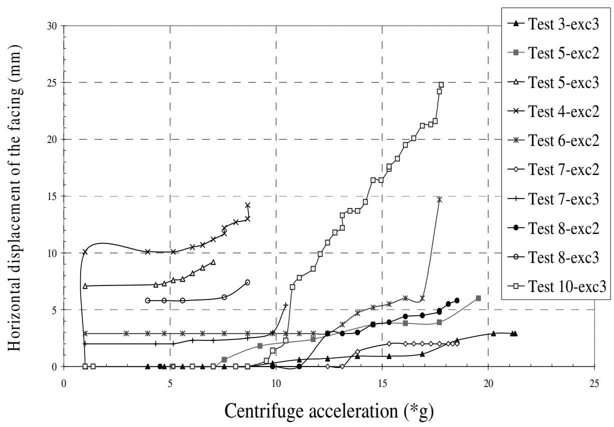



Figure 6. Horizontal displacements of the wall with increase of centrifuge acceleration

As it can be seen in figures 8 and 9, in most of the tests two progressive failure surfaces are generated as the acceleration increases. According to these figures, the first (the smaller) failure surfaces are generated at lower levels of the acceleration, and in some of them it is observed that the distance to the initial position of the facing is decreasing, e.g. tests 8, and 10. This is

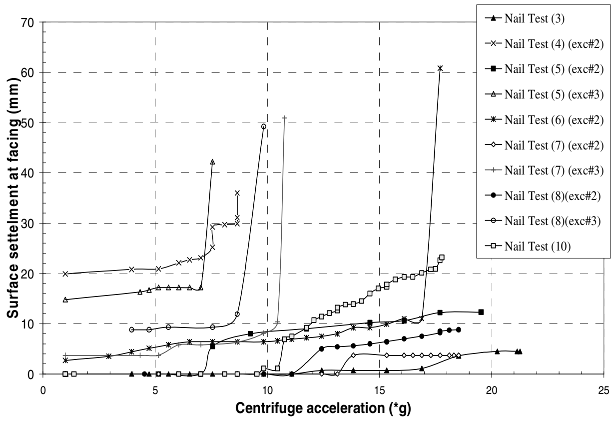



Figure 7. Settlement of top of the wall with increase of centrifuge acceleration

a sign of the formation of the second failure surface which affects the first one. However, in some tests these larger surfaces of failure are also affected by a third surface, because the distance curve of it has a decline in trend, e.g. tests 5 and 13. According to the size of the largest surfaces of failure in most of the tests the effective length of the upper nail rows just before failure is fairly more than 25% of the total length.

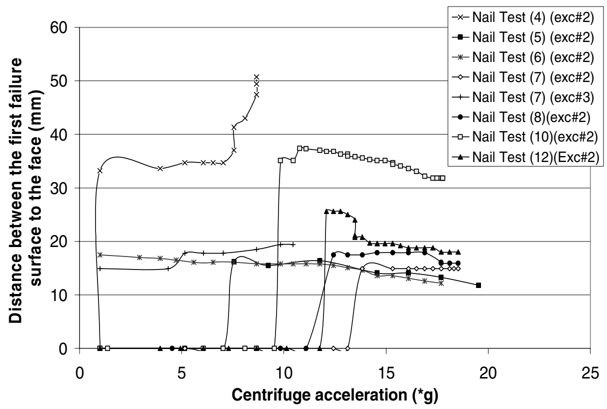



Figure 8. Variation of the first failure surface distance to the initial position of facing with acceleration

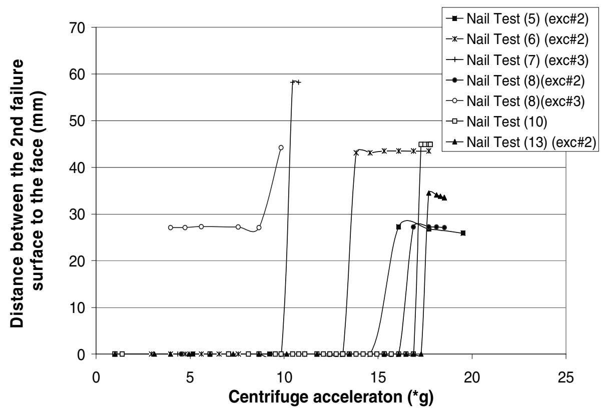



Figure 9. Variation of the second failure surface distance to the initial position of facing with acceleration

## 4 CONCLUSIONS

The centrifuge tests were done on 17 down scaled models differing in the facing types, nail surface roughness, nail bending properties, nail length, and nailing pattern. In these tests the construction process of a nailed soil wall is simulated by different stages of soil excavation. After different stages of excavation (which are done at 1g) the model is accelerated up to 20g. As the centrifuge acceleration increases the stresses induced in the soil mass and in the nails are increased. During accelerating the models the horizontal and vertical displacements of the wall and the size of failure surfaces are investigated. By analyzing the behaviour curves of the nailed trenches, it can be inferred that some progressive failure surfaces are formed as the height of stabilized trench increases. During the formation of failure surfaces a kind of hardening is observed in the system, i.e. displacements remain constant or they increase with a lower rate after a sudden increment

The main results are as follows:

1. As the excavation stages progress, some different failure surfaces are detected.
2. The ratios of horizontal distance $D_h$ of the failure surface at the upper ground surface from the initial position of the face to the wall height H are observed to be:

$$\frac{D_h}{H} = 0.45 \sim 0.53$$

3. According to the size of the largest surfaces of failure in most of the tests the effective length of the upper nail rows just before failure is fairly more than 25% of the total length.
4. At lower applied stresses the deformations rate of nailed walls are lower and as the stress increases this rate gets higher

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