National Conference with International Participation
ENGINEERING MECHANICS 2003
Svratka, Czech Republic, May 12 – 15, 2003
paper no. 160

HISTORY OF STRUCTURE-GROUND INTERFACE FRICTION DURING ACTIVE MOVEMENTS - EXPERIMENT E1

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Summary: *Physical experiments dealing with the problem of lateral pressure of granular materials proceed some years using medium-size models of the ideal non-cohesive granular masses and bi-component pressure sensors.*
The experiments have brought extraordinary number of data of which is evaluated gradually. The results of the analyses of active normal components were presented previously. The Paper deals with the first results of the tangential pressure component analysis of the experiment E1, i.e. with the interface friction during three basic types of movement towards active side.

Figure 1: Experimental stand inside as seen through transparent lateral sides. The retaining wall is the blue plane inside the structure on the left. Five bi-component sensors placed in the retaining wall cannot be seen behind the steel column. The sample is not finished.

1 Introduction

In the course of the past six years, the research of lateral (earth) pressure has been proceeding by means of physical as well as advanced numerical models. The research has shown that the discrepancy between conventional earth pressure theory and reality is not negligible and that some approaches can be connected with considerable risk. The theoretical concept of the research was concerned with the behaviour of soil and soft rock mass during various types of movement of the retaining structure. The research monitored and analyzed the deformation and failure processes as well as both components of the contact stress at the ground-structure interface., i.e. normal pressure and vertical

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interface friction. It was ascertained that the behaviour of the soil mass was considerably more complicated than that considered by standards and codes in force (Koudelka P. 1996, 1998a,b, 2000a,b,c, 2001, Koudelka P. & Koudelka T. 2002, Koudelka P. & Valach 2000)

Figure 2: Experimental stand with arbitrarily moved front wall (blue). The wall is the plane inside the structure on the left. Four red bi-component sensors can be seen placed in the front retaining wall. The first above is not in place. The sample is not finished.

The main objectives of the physical modelling research were the measurements of both components (normal and tangential) of lateral pressure of a loose granular mass applied to the retaining wall during its various movements. A reliable separation of both stress components was enabled by sensors according to the Czech invention of Šmíd and Novosad (Šmíd et al. 1993, Koudelka P. & Valach 2002) based on a new concept. The experiments were performed with the mass of a loose and really non-cohesive material (very dry flowing sand). The first two experiments (E1 and E2) were concerned with pressure *at rest* and *active* pressure. The third experiment (E3) intent on *passive* pressure and pressure *at rest* is in progress.

Figure 3: Curved slip surface in the mass after *active* front wall rotation (left) about the top (*out* of mass). The toe movement was of 8.75 mm; the mesh size 20/20 mm.

The research has brought a great number of results, data and pieces of knowledge. The major results and achievements of E1 and E2 experiments, referring to the dependencies of the normal pressure component and deformation on movement were presented earlier (see Fig.3). The third and fourth major sets of knowledge – the ground-structure interface friction and the time instability of pressure – as well as the results of E3 experiment have not been published yet.

The paper presents the first information about the interface friction history of lateral pressure of a loose granular mass during the first physical experiment E1. The results prove and quantify the instability of active lateral pressure and pressure at rest due to the movement of the structure. The results can quantify preliminarily the risk of conventional approaches for interface friction especially to deep structures and excavations.

2 Experiment E1

2.1 Model

The physical 2D model consists in a granular mass and a retaining wall which can perform the movements of all three basic types (rotation about the toe and the top, translative motion) with an accuracy of less than 0.024 mm. The wall is 1.0 m high and perfectly stiff, without any deformations of its own (see Fig.1). Five measuring points are situated at the granular mass/retaining wall contact surface 0.065 m, 0.265 m, 0.465 m, 0.665 m and 0.865 m deep (see Fig.2).

The granular body is 1.5 m long and 1.2 m high and consists of an ideally non-cohesive material (loose very dry sand). The experimental equipment and tested material were described in detail earlier (Koudelka 2000a, Koudelka-Valach 2002). Therefore, we shall state merely that the sand had the following basic parameters: γ = 14.88 kN/m^3 (unit weight), w = 0.04 % (water content), ϕ_{ef}' = 48.7^o (angle of the top shearing resistance), ϕ_r' = 37.7^o (angle of the residual shearing resistance), c_{ef}' = 11.3 kPa (illusory cohesion), c_r' = 0.

2.2 Procedure

The possibilities of the arbitrary movements of the retaining wall were used for 3 phases of the previous experiments E1 and E2 with *active* lateral pressures. One of the three basic movement types was active during each phase. Movements needed for an analysis of *passive* pressure are much greater than those applied in case of *active* pressure. Therefore, it is impossible to investigate all three types of movements on the same sample (model mass) as that used during experiments E1 and E2.

The mass was slightly compacted by means of a special instrument, which ensured its homogeneity. The whole procedure was designed so as to create an ideal non-cohesive homogeneous mass possible.

2.3 Phases E1/0 and E1/1– Passive pressure art rest and active rotation about the toe

The notation of the phases is taken from time steps of the experiment and is kept for the following experiments. Before the first phase of the experiment, the experiment with the *passive* pressure at rest was made by a small rotation about the toe of 0.19 mm and back to 0 mm and, continuously, the *active* rotation began (22nd Dec.1998). The rotation about the toe followed and the value of top movement of 8.75 mm was achieved on 11th Jan. 1999. Subsequently the mass was left to consolidate for 42 days.

The retaining wall was not moved continuously, but step by step with the periods of re-consolidation between steps. These periods without any movement completed the experiment on the time behaviour. Rotation steps were performed on 28th- 29th Dec. 1998 and on 5th Jan. 1999.

2.4 Phase E1/2 – Active rotation about the top

The rotation about the top followed and the value of toe movement of 8.75 mm (after previous phase also of the whole wall) was achieved 3rd March 1999. The retaining wall was moved in two steps including the period of re-consolidation between steps. This period without any movement completed the experiment on the time behaviour. Rotation step was performed on 22nd Feb. 1999. Then the mass was left to consolidate for 41 days.

2.5 Phase E1/3 – Active translative motion

The phase of translative motion of 8.75 mm was performed on 15th Apr. 1999 in one step. The re-consolidation period without any movement completed the experiment on the time behaviour and terminated on 26th Apr. 1999 after 11 days. The experiment (all phases and reconsolidations) lasted altogether 127 days.

3 Results

The results are presented in the form of diagrams a limited number of which has been selected to represent most faithfully the behaviour of the model ideally non-cohesive mass in time. From the great number of data the values recorded during the movements of the front wall (retaining structure) have been selected which makes the result base very dense to characterize the behaviour of the mass. The records were cleaned of some influences of the long-term acting system of instruments. Some data recorded during reconsolidations form vertical lines in the component graphs.

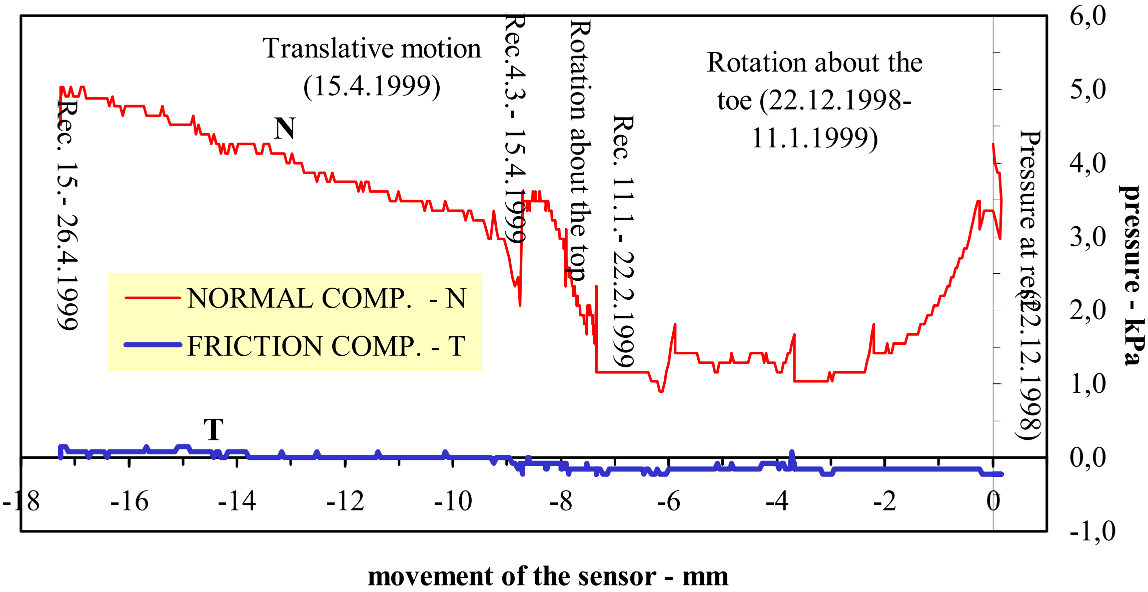

Fig.4: Normal and tangential (friction) components of the active pressure of the bi-component sensor no.1: N – normal stress component, T – tangential (friction) stress component.

Both stress components of the sensors no.1 and 4 in Fig.4 and Fig.5 show characteristic changeable histories of the movement dependencies according to the movement types in respective phases. The records softer sensors no.1 and 4 with lower loading interval (SM1-65/40 N) were chosen rather than those of other sensors with the large loading interval (SM2-350/200 N). The presented measurements can be considered more accurate.

Normal components of pressures applied to sensors Nos. 1 and 4 (Fig.4 and 5) show a marked dependence on the movement type of the retaining front wall (retaining structure) described earlier (Koudelka 2000b,c; Koudelka-Valach 2000) the character of which is analogous. The values of the normal components of the pressure at rest and in the phase of rotation about the toe correspond. The values of normal components, however, differ in magnitude during rotation about the top and the translative motion which are not proportionate with the depth below the sample surface. While during the rotation about the top the maximum values are approximately equal, during the translative motion the normal component of the pressure applied to the upper sensor No.1 (at the depth of 0.065 m) increases to a value exceeding the value achieved during the pressure at rest. The normal component of the pressure applied to the sensor No.4 (at a depth of 0.665 m) in the same motion phase remains constant approx. at the value of active pressure during the top shear strength mobilization.

In comparison with the significant dynamics histories of normal lateral pressure components the histories of tangential lateral pressure components (interface friction) are surprisingly insignificant (Fig.4 and Fig.5). The friction components in both sensors are very small, practically constant and negative in case of sensor No.4, and with a mildly rising

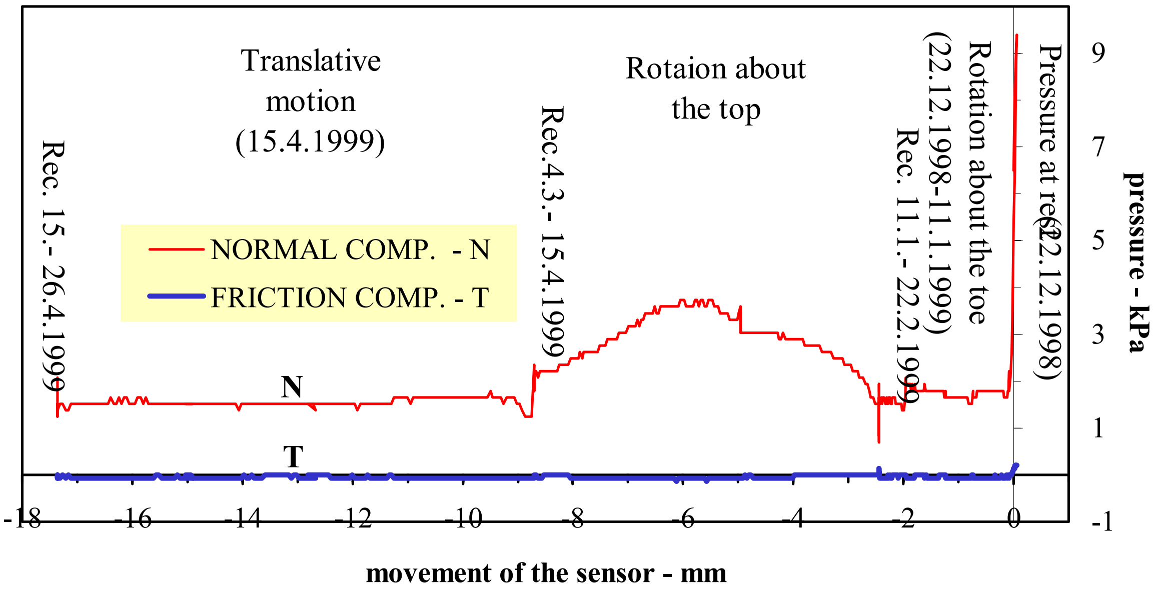

Fig.5: Normal and tangential (friction) components of the active pressure of the bi-component sensor no.4: N – normal stress component, T – tangential (friction) stress component.

tendency from small negative values in the phases of rotation about the toe and top to very small positive values in the phase of translative motion in case of sensor No.1. It should be also noted that in the phase of the pressure at rest the interface friction components approaching zero were observed in all sensors.

A general survey of effect of interface friction is provided by the diagram in Fig.6, showing the angle of structure-ground interface friction δ plotted against the movements of the structure (retaining front wall). The angle δ expresses toe magnitude of *participation* of the friction component in lateral pressure, *not its magnitude*. The diagram differentiates clearly the results of the more sensitive sensors Nos.1 and 4 from others by their stability. A comparison of sensor sensitivity is possible by the observation of minor jumps in their lines. Major singularities are due to the approach of normal components to zero, mostly in the periods of reconsolidation; their maximum values ($\pm 90^{o}$) were eliminated from the diagrams.

If we do not consider the singularities and, on the other hand, if we do consider the influence of sensor sensitivity, we can assess the history of the interface friction components as relatively regular, except for the friction on sensor No.5 (depth of 0.965 m) in the phase of translative motion. The friction participation is due here to the drop of normal component to a very small value. Distinct is also the fluctuation of interface friction participation within certain boundaries during structure (retaining front wall) movement participated in to a certain extent (in case of low sensed values) also by the offset of the sensing system.

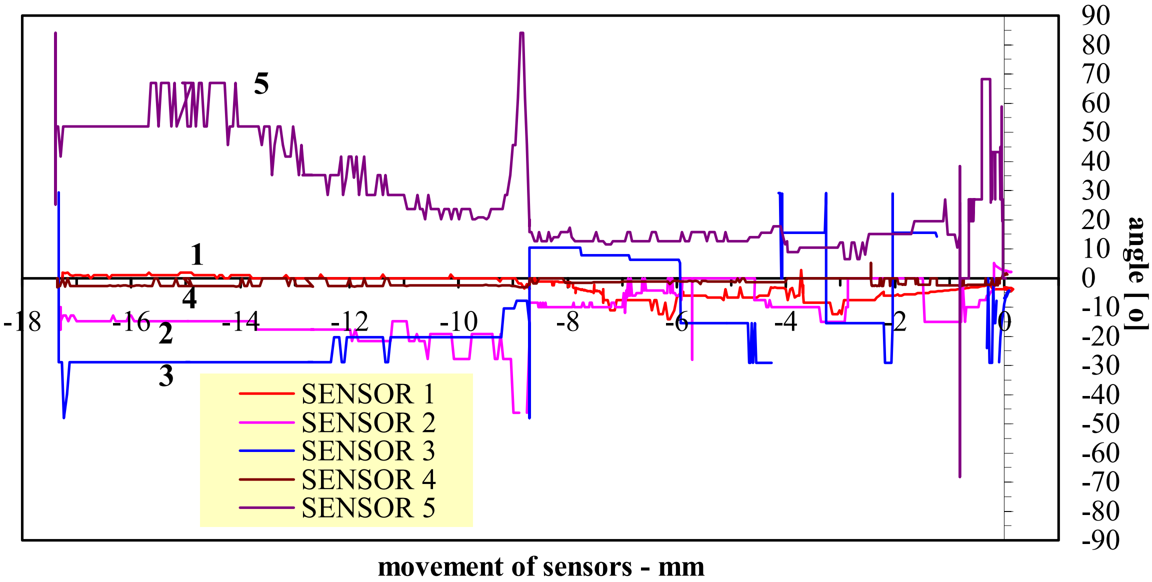

Fig.6: Angle δ of the ground-structure interface friction according to normal and tangential (friction) components of the *active* pressure. Bi-component sensors no.1-5 are noted by their numbers.

4 Conclusions

The results have shown the history of structure-ground interface friction, i.e. the tangential component of lateral pressure of the ideal non-cohesive granular material, in non-stationary conditions (during different types of the retaining structure movement). The instability of lateral pressure is practically never considered either in engineering practice or in theory. Therefore, the following conclusions may be useful for both fields:

4.1 The normal components of lateral pressure of non-cohesive granular materials have not been stable even during structure movements in time in otherwise constant conditions. Relatively high pressures recorded in sensor no.1 could be due to the transfer of stresses and deformations after the structure movements (see the slip surface arch in Fig.3).

4.2 The friction components have appeared more stable according to normal components even during structure movement even in time in otherwise constant conditions.

4.3 The relative stability of friction components is not absolute and their minor dynamics should be assumed.

4.4 It appears from the aforesaid that the structure-ground interface friction plays more or less feeble role, perhaps smaller than assumed so far.

4.5 The results are in accord with the General Lateral Pressure Theory (GLPT) which assumes that lateral pressure after *active* movements of the structure *drops* from the value of pressure at rest to the minimal value of *active* pressure. After further *active* movements the value of lateral pressure *rises* to the value of *residual active* pressure. The presented analysis points to the major role played by the normal component of lateral pressure.

5 Aknowledgement

The Grant Agency of the Czech Republic and the Grant Agency of Academy of Sciences of the Czech Republic provided financial support of the connected research (GP no.103/2002/0956 and no. A2071302 resp.). Petris Ltd. afforded the computing program FORESTR. The authors would like to thank them all for support and co-operation.

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