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EXPERIMENT E3/2 - TEMPERATURE INFLUENCE ON LATERAL PRESSURES OF A NON-COHESIVE GRANULAR MASS

EXPERIMENT E3/2 - VLIV TEPLOTY NA BOČNÍ TLAKY SYPKÉHO ZRNITÉHO TĚLESA

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In the framework of the long-term research of passive pressures and pressures at rest of a non-cohesive granular mass that proved existence of internal pressures and residual passive pressures during rotation of movable loading wall about its top, also yielded unexpected results similarly to previous research of active pressures, temperature influence on measured pressures was observed. With the respect to the quantitative evaluation of this temperature influence, the presented paper is devoted to the analysis of time series of measurement records of bicomponent pressure sensors and temperature sensor, and concentrating on the correlation between the two variables in the context of granular mass behavior research.

V rámci dlouhodobého výzkumu pasivních tlaků a tlaků v klidu u sypkých zrnitých těles, jehož hlavním výsledkem je potvrzení existence vnitřních tlaků a residuálních pasivních tlaků při rotaci pohyblivé zatěžovací stěny kolem vrcholu, které přineslo i další nečekané výsledky podobně jako předchozí výzkum aktivních tlaků, se projevil vliv teplotních změn na měřené tlaky. S ohledem na kvantitativní rozbor tohoto vlivu se příspěvek detailně zabývá časovými řadami záznamů dvousložkových snímačů tlaku a snímače teploty a analyzuje korelaci mezi těmito veličinami v kontextu studia chování zrnitých těles v klidu.

Keywords

Non-cohesive granular mass, lateral pressures, thermal expansion

Introduction

Experiment E3 belongs to a series of physical modeling experiments dealing with the research of lateral (earth) pressure of non-cohesive granular masses. Two medium-term experiments with *active* lateral pressure (experiments E1 and E2) of loose sand acting on a retaining wall were performed previously. The experimental stand makes it possible to measure both the normal and the tangential pressure components. Experiment E1 showed some rather unexpected behavior of the granular mass, especially its deformations and failures during three different wall movements. This was the reason for experiment repetition. Two analogous numerical model experiments were made, based on the General Lateral Pressure Theory (GLPT).

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The long-term first part of experiment E3 with *passive* pressure due to *rotation about the top* has been started in the second half of 2001 and carried out during 2002. The part was marked E3/2 according to the second type of the wall movement (rotation about the top).

The history of the component pressure values (particularly of normal components) recorded by individual sensors appeared to be directly dependent on the time of day already during experiment E1. It was assumed it could be due to the influence of temperature, voltage in power mains and perhaps also humidity. Therefore, temperature of the experimental hall environment was measured during experiment E2. The results were analyzed and presented previously [1, 2]. For the first part of the third experiment E3/2 the sensors were changed with regard to higher actual pressures. Instead of the temperature of the hall environment, the temperature of the *steel structure of the stand* was measured. The paper presents the analysis of temperature changes of the stand structure and its influence on the results of the experiment E3/2.

Experiment E3/2

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 accuracy lower than 0.024 mm. The wall is 1.0 m high and perfectly stiff, without any deformations of its own. The contact surface of the retaining wall was 1.0*1.0 m. The wall movements were measured by mechanical indicators in each corner of the retaining wall. Five measuring points were 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.

The lateral sides of the stand were transparent to enable visual observation of the changes in the mass. The granular mass is 3.0 m long, 1.2 m high and 1.0 m wide and consists of the same ideally non-cohesive material (loose very dry sand) like the previous masses. The experimental equipment and tested material were described in detail earlier [3, 4]. Therefore, we shall state merely that the sand had the following basic parameters: γ = 16.14 kN/m^3 (unit weight), w = 0.04 % (water content), ϕ_{ef}'= 48.7^o (angle of the top shearing resistance for low stresses), ϕ_r'= 37.7^o (angle of the residual shearing resistance), c_{ef}'= 11.3 kPa (illusory cohesion), c_r'= 0.

The notation of the phase is taken from previous experiments in which rotation about the top was called “phase 2”. Before this (first) phase of the experiment, the experiment with the *active* pressure at rest was made by a small rotation about the top of 0.27 mm and back to 0 mm (6th Sept.2001 – E3/2-0). Then the mass was left to consolidate for 32 days and the *passive* part of the experiment began (8th Oct. 2001); the initial part of E3/2 ended on 10th Oct. 2001. The final part of E3/2 began on 18th June 2002 and the final toe movement towards the *passive* side attained about 159 mm on 3rd Dec. 2002.

Figure 1 The state of the mass and the first glass plate near the moved wall (left) after the toe movement of 134.8 mm before the final movement of 159 mm on 18th Nov.2002. The destroyed glass plate resisted stress state with the pressure of 150 kPa.

The state after the final movement can be seen in Fig. 1. The state inside the mass was characterized by the slightly curved major slip surface dividing the *active* mass part from the *passive* one. The *active* part was heavily deformed and further divided into a system of other slip surfaces. The pressure near the rotated wall toe (maximally over 150 kPa) destroyed both nearest glass plates; one of them can be observed in Fig. 1. The deformed surface of the mass is shown in Fig. 2.

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 with time behavior. The data of sensors were read and recorded also during the periods of re-consolidation.

The first movement step E3/2 began on 8th Oct. 2001 and the movement of the toe of 15.63 mm was attained after 3 days (10th Oct. 2001). The maximal velocity of the toe movement was approximately 0.05 mm/min. The following re-consolidation without any movement of the front wall lasted 251 days (until 18th June 2002) and is denoted T1. The movements of the sensors differed in accordance with their distance from the top of the moved retaining front wall (depth under the surface). The respective (initial and also final during this phase) movements from Sensor 1 to Sensor 5 were *2.84 mm, 5.93 mm, 9.03 mm, 12.12 mm and 15.21 mm* respectively. The first (most important) 60 days

Figure 2 Deformed surface of the experimental mass from the back of the equipment after the toe movement of 134.8 mm on 18th Nov.2002 before the final movement of 159 mm. The top of moved front wall is above (blue).

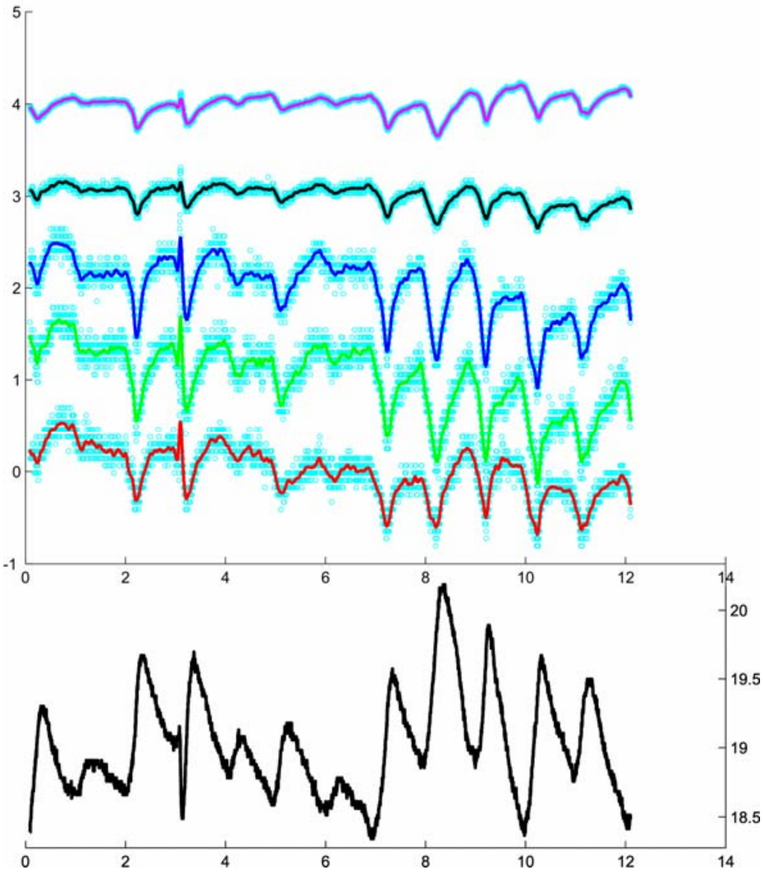

Figure 3 Pressures recorded in 12 days period of measurement (upper part of the plot, vertical axis in kPa – the data series are transposed in order to exclude their overlapping, the first serie was measured by sensor 1, the lowest serie by the sensor 5) compared to the record of temperature development (bottom part, vertical axis in degrees C)

(from 10th Oct.2001 to 11th Dec. 2001) were analyzed and described in [5, 6]. The analysis proved the time instability of lateral pressure and its analytical formulation. The following analysis deals with the results of the re-consolidation period T1 with regard to temperature influence in the time interval from 11.11h. 23rd Oct. 2001 to 10.53h. 5th Nov. 2001.

Analysis of time series

The set of 3100 pressure (normal and tangential pressures of the five sensors) and temperature records acquired in 300s time step, representing in total approximately twelve days, was analyzed in detail. The set is a small fraction of the experimental data to be evaluated. As mentioned above due to ambient temperature change the temperature of the steel structure changed as well. The change was accompanied by thermal expansion of the structure. As the temperature difference (ΔT) between the highest and lowest recorded temperature is roughly 2° C, the deformation of the structure can be derived from the simple formula neglecting other factors involved in the experiment. Taking into account the size of the structure (L=3m), the coefficient of thermal expansion of steel ($\alpha = 15\cdot10^{-6}$ K^{-1}) the elongation is roughly equal to the size of sand grain 0.1mm

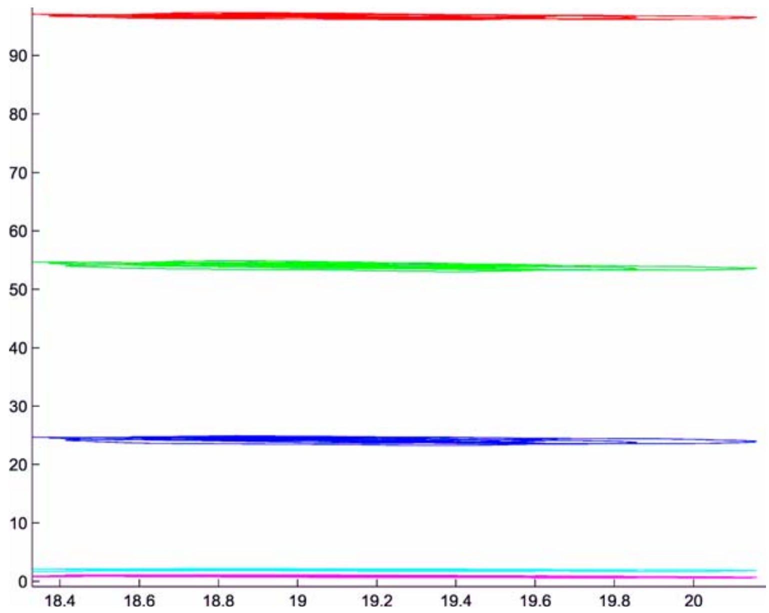

Figure 4 Plots of dependence between measured temperature and normal pressure for each of the five sensors

($\Delta L = \alpha\cdot\Delta T\cdot L = 15\cdot10^{-6}*2*3=8\cdot10^{-5}$[m].)

Figure 3 shows time record of sensors‘ reading with strikingly similar pattern of peaks and valleys suggesting either effects of thermal expansion or AC power instability. The voltage instability can be rather excluded as there are no pronounced workday and workweek periods. Recorded points are overlaid with smoothed curve for each set of data. The smoothing procedure is based on floating average taking into account points in the vicinity. It is clearly observable from the image, that lower three records were acquired using wider sensor range which at the same number of steps results in lower resolution.

The range in which measured variables varied is shown in the Table 1. It suggests that observed effect is very fine in comparison to overall pressures.

Table 1 Pressure sensors' reading for the extremal temperatures in the studied records, difference between maximum (20.167° C) and minimum temperatures is 2.09° C.

Sensor #	Normal force [N] / pressure [kPa]			Tangential force [N] / pressure [kPa]		
	Min	Max	Diff.	Min	Max	Diff.
1	1.0795 0.549789	2.2629 1.152495	1.1833 0.602655	-0.0723 -0.03682	0.7521 0.383045	0.8244 0.419867
2	3.2552 1.657873	4.6115 2.348637	1.3563 0.690764	-2.2814 -1.16192	-1.2258 -0.6243	1.0556 0.537617

3	45.3372 23.09024	49.9478 25.43841	4.6106 2.348179	22.9416 11.68416	24.1401 12.29455	1.1985 0.610396
4	103.594 52.76042	108.837 55.43068	5.243 2.67026	43.2963 22.05081	44.9777 22.90714	1.6814 0.856337
5	188.373 95.93837	191.936 97.753	3.563 1.814636	3.3628 1.712674	4.1194 2.09801	0.7566 0.385336

The presented plots deal solely with normal pressures, as the properties and behavior of tangential ones are very similar, however not so pronounced.

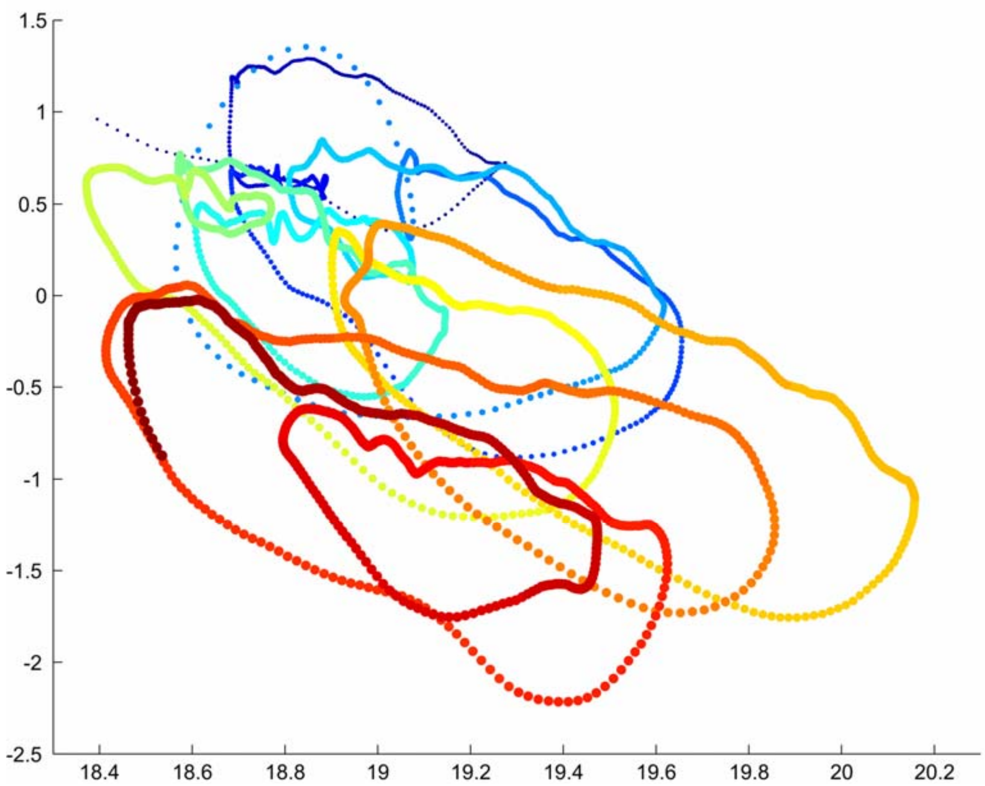

Figure 5 Hysteretic curve of temperature vs. pressure record of sensor 4 shown with time information encoded into growing markers and their color transition

Discussion, Conclusions

In spite of its appearance in figure 4 there is a weak correlation between the measured temperature and pressures. This fact can be explained by hysteretic nature of the granular mass behavior during day cycle accompanied with temperature variation. A complex relation between temperature and pressure can be recognized from Figure 5. It appears that granular mass body or steel frame thermal inertia can influence the process ‘smearing’ simple linear relation.

On the other hand, the possibility to fully separate temperature influence on the pressure would allow an innovative insight into granular mass consolidation phenomenon, which is worth trying in future.

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