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PHYSICAL EXPERIMENTS WITH GRANULAR MATERIALS UNDER DIFFERENT GRAVITY

FYZIKÁLNÍ EXPERIMENTY SE ZRNITÝMI MATERIÁLY V RŮZNÝCH TÍHOVÝCH PODMÍNKÁCH

Abstract

A number of physical experiments with lateral pressure of granular material (ideal non-cohesive sand) were performed at the Institute of Theoretical and Applied Mechanics during last ten years in conditions normal gravity 1G using medium samples of the size of 1.0*3.0*1.2 m (passive pressure) or 1.0*1.5*1.2 m (active pressure 1999-2000) [2]. The similar experiments with active pressure were performed in Japan (N.S. Kusakabe et al. 2005)[4] 3 years before under high gravity 50g using smaller sand and silt samples of the size of 0.2*0.4*0.4 m. Experiments with sand materials were performed also by NASA (USA) at the orbit without gravity (1996-1998) [5].

The paper gives basic information on the active pressure research in 1g and 50g gravity and on the research of deformation properties in conditions without gravity. It presents also a comparative analysis of some results of the Japan experimental study in 50g gravity with relevant results of Czech research in 1g gravity. An evaluation of behaviour of the used granular materials in different gravity conditions is comprised.

Abstrakt

V Ústavu teoretické a aplikované mechaniky AV ČR bylo provedeno za posledních 10 let více fyzikálních experimentů s bočním tlakem ideálně sypkého zrnitého materiálu.. Byly vyšetřovány středně velká tělesa o rozměrech 1,0*3,0*1,2 m (pasivní tlak) nebo 1,0*1,5*1,2 m (aktivní tlak 1999-2000)[2] v normálních podmínkách zemské tíže (1g). Podobné experimenty s aktivním tlakem byly provedeny před třemi roky v Japonsku (N.S. Kusakabe et al. 2005)[4] ve vysokém přetížení 50g na vzorcích písku a siltu velikosti 0,2*0,4*0,4 m. Jiné experimenty s pískem provedla NASA (USA) na oběžné dráze ve stavu beztíže (1996-1998)[5].

Příspěvek podává základní informace o výzkumu aktivního tlaku v podmínkách 1g a 50g a o výzkumu přetvárných vlastností ve stavu beztíže. Uvádí také srovnávací analýzu některých výsledků japonské experimentální studie v podmínkách 50g a odpovídajících výsledků českého výzkumu v podmínkách 1g. Je obsaženo i vyhodnocení chování použitých zrnitých materiálů v podmínkách různé tíže.

1 INTRODUCTION

In investigation of granular matter behavior we can distinguish three different approaches concerning effective gravity field acting during experiment. The experiments can be carried out in the earth gravity or gravitational acceleration can be increased or the experiment can be performed in zero/micro gravity. The two last mentioned situations require a special arrangement limiting the size

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and weight of experimental body to a technically feasible value. The technical limitation of the multiple g environment is the force supportable by centrifuge in which the experiment is carried out. On the other hand in zero/microgravity experiments performed during either parabolic flight or on orbit the size limit is implied by economy of delivering payload into orbit. Uniqueness of condition dissimilar to that on earth enables to detect hidden assumption in tested hypotheses. These assumptions work well in the earth-like environment, where gravity is driving force of many phenomena or even triggers some processes. Influence of this kind can be present also in behavior of loosely connected granular matter, a model for dry soil or sand material. If this possibility is overlooked in foundation of theory or in formulation of constitutive equation characterizing the behavior of the material, it may result in loss of generality and validity of the theory. Study of the granular matter in dissimilar conditions can be therefore indispensable tool for evaluation of current state of theory, the valued feedback. On the other hand experiments carried out in bodies of sufficient size yield results directly applicable in construction practice as there is no need to readjust measured properties to some model scale factors. Such arrangement is established in ITAM testing device

2 ACTIVE PRESSURE RESEARCH IN 50g GRAVITY

Kusakabe´s movable earth support apparatus was applied for research of lateral active pressure with 10 divided walls (see Fig. 1). The sheet pile was divided into 10 portions each of which having a strut. Each strut was moved independently at the maximum movement accuracy of 0.00001 mm so

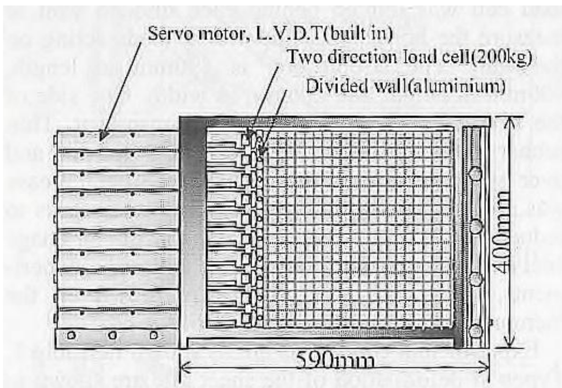


Fig. 1 Movable Earth Support Apparatus by Kusakabe et al. (2005).

that it accurately created a variety of sheet pile deformations. Each strut was connected to a divided wall with a hinge so that the sheet pile could move smoothly. A two-directional load cell was jointed behind each divided wall to measure the horizontal and vertical loads acting on the wall.

The strong box was 590 mm in length, 400 mm in height and 200 mm in width. One side of the box was detachable and transparent. Thin rubber membranes were put over the sheet pile and over two large sides of the box. Silicon grease was used between those walls and membranes to reduce lateral friction. From the whole research study, it is chosen a case of rotation about the toe with the medium dense sand sample of following properties: angle of internal shearing resistance ϕ_{ef} = 38°, void ratio e = 0.81 , relative density D_r = 45-50 % . The horizontal components of lateral pressure are compared in Fig.3a in which two theoretical lines are drown along with the experimental data. For these theoretical lines, Jaky´s equation (1) [1] was applied for horizontal pressure at rest σ_0 and Rankine´s equation (2) was applied for active pressure (extreme/minimal values) as follows:

$$\sigma_0 = (1 - \sin \phi_{ef})\, \sigma_v \tag{1}$$

$$\sigma_A = (1 - \sin \phi_{ef})\, \sigma_v / (1 + \sin \phi_{ef}) - 2c_{ef} \cos \phi_{ef} / (1 + \sin \phi_{ef}) \tag{1}$$

where σ_v - vertical stress component, ϕ_{ef} - angle of effective internal shearing resistance, c_{ef} - effective cohesion.

3 ACTIVE PRESSURE RESEARCH IN 1g GRAVITY

Two medium-term (nearly 6 and 4 month) practically the same experiments E1 and E2 with the very non-cohesive flowing sand (Koudelka 1999, 2000) showed the very different behaviour of the tested granular mass according to the three different types of the retaining structure movement (rotation about the toe and the top, translative motion). The size of samples was 1.0*1.5 m, height 1.2 m, height of the retaining wall 1.0 m. These physical experiments revealed also the physical base of objections to the present earth pressure theory. Experiment E1 was repeated as experiment E2 and the little expected results of E1 were confirmed. The paper presents a part of comparison analysis of the second experiment E2/0,1 on active structure rotation about the toe (top movement 8.75 mm) and preceding very little passive translative motion (0.49 mm).

The basic properties of the E2 mass follow below and Fig.2 shows the experimental equipment with the sample and the normal pressure components according the experiment E2/0,1:

- unit weight γ = 14,38 kN/m^3
- water content w = 0,04 %
- compaction - medium dense e = 0.878

Shear strength : Deformation properties:

- angle of top shear.resist. ϕ_f' = 48,7° - deformation modulus E_{def} = 12 MPa
- top cohesion c_f' = 0 kPa - Young´s modulus E = 35 MPa
- angle of residual shear. resi. ϕ_r' = 37,7° - Poisson´s ratio ν = 0.35
- residual cohesion c_r' = 0 kPa

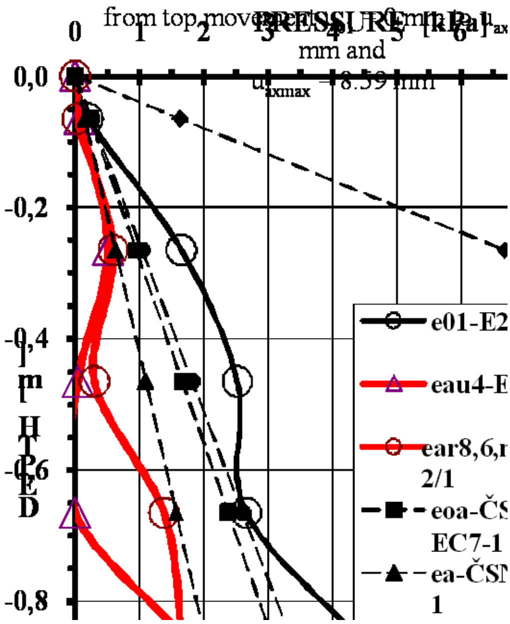
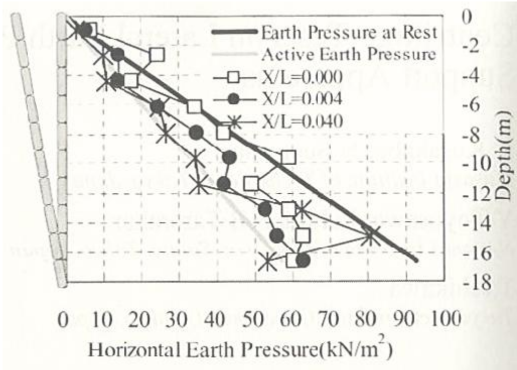


Fig. 2 Experiment E2.
a - (left) Internal space of the experimental equipment and arbitrarily moved front wall with 5 bi-component pressure sensors (red)..
b - (right) Measured normal and theoretical pressure components acting due to respective wall movements

4 COMPARISON RESULTS OF EXPERIMENTS IN 50 g AND 1g GRAVITY

The 50g experiment found good agreement of the case without movement (x/l=0) with the theoretical calculations applying Jaky´s equation (1). On the other hand, the 1g experiment E2/0,1 showed pressure at rest above the Jaky´s calculation but under the upper limit pressure at rest according to Pruška (1973)[6].

The horizontal pressure tendency of the 50g experiment is decreasing with increasing movement. Two presented rotation position (x/l=0.004 and 0.040) appear after the limit movements for the (extreme/minimal) active pressure. On the contrary, according to the experiment E2/0,1 in 1g the pressure decreases to the rotation x/l=0.0041 and then increases (see the curve e_{ar} for x/l=0.0086).



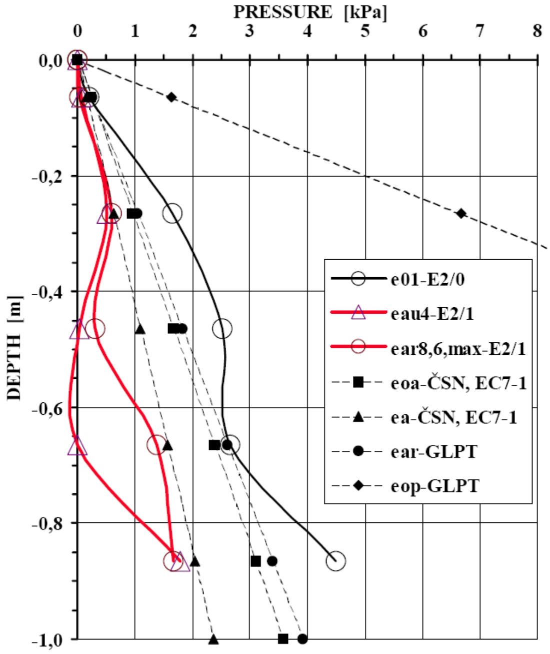


Fig. 3 Comparison of the results in conditions of 50g and 1g gravity:
a - (left - 50g) Lateral horizontal pressure at rest and after rotation quotients 0.004 and 0.040 (top movements 1.6 and 16 mm resp.).
b - (right - 1g) Normal pressure components according to experiment E2/0,1 respective to those in Fig.3a. x/l=0.0041 and 0.00859 .

5 EXPERIMENTS WITHOUT GRAVITY

NASA supported a Microgravity Research Program in the range of mechanics of granular materials (MGM). Here is very brief information on the second round of space experiments to better understand the behaviour of soils, powders, and other particles under very low confining pressures.

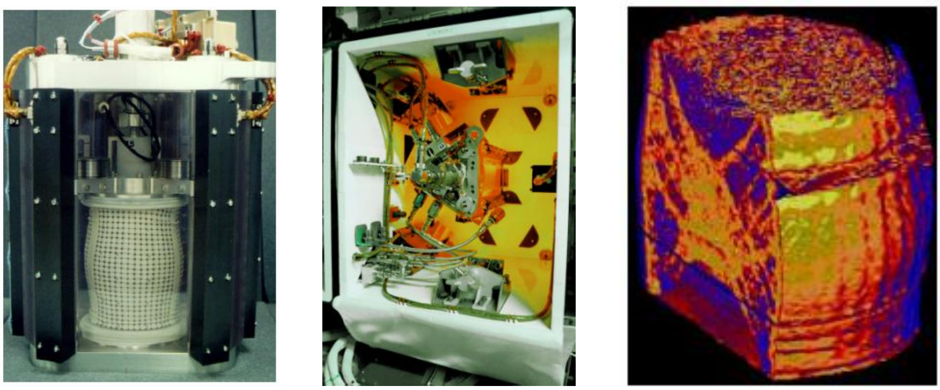


Fig. 4 by NASA **a,b** (left and center) Loading device using aboard space shuttle STS-79 flight in 1996. The loading cell is made from transparent material in order to carry out optical observation. Full set-up of the experiment is seen on the left image (top view). (Images courtesy of NASA, for further information see: http://science.msfc.nasa.gov/newhome/headlines/msad06jan98_1.htm)
c (right) Slip bands were observed not only visually but also full 3d image was rendered using computer tomography. Loci of lower density – associated with the presence of slip band are lighter in the image.

6 CONCLUSION

It cannot be made a general valid conclusion on the base of three cases. Despite it, it appears the laws of granular material mechanics are valid generally more or less independent. Of course, different conditions need different technology from which the differences of the experiment procedures follow.

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