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Original Experimental Equipment for Slow Processes of Lateral Pressure in Granular Masses

Petr Koudelka,[1] Jan Bryscejn[2]

Abstract: An original experimental equipment was designed and constructed in 1997-1998 for a basic research of lateral pressure multi-phase granular materials and to verify a theoretically derived theory of "*General* Lateral Pressure". The equipment made it possible a simple hand-made moving with front wall and five two-component pressure sensors (Šmíd-Novosad) placed in it. In 1998-1999 were performed two parallel medium-term experiments E1 and E2 with active pressure which have brought some unexpected and new results. The third long-term experiment E3/0+2 with passive pressure was perform in 2001-2002.

Then design and construction of two following equipment upgrades have been begun. The 2nd upgrade (3rd stage) has been finished at this time and a next parallel experiment with passive pressure E5/0+2 is prepared. The Paper presents the equipment development and its last state and refers also to some problems of the development.

Keywords: Experimental equipment, Granular material, Lateral (earth) pressure, Sensor, Hardware, Software

1. Introduction

The experimental equipment was designed and constructed in 1997-1998 for a basic research of lateral pressure multi-phase granular materials and to verify a theoretically derived theory of "*General* Lateral Pressure". The equipment made it possible a simple hand-made however, arbitrary movement of front wall and took two-component data of five excellent pressure sensors (invention of Šmíd-Novosad) placed in the wall. Two glass sides served for a visual monitoring of processes into the granular mass. In 1998 and the first half 1999 was made the first complete medium-term experiment E1 with pressure at rest and active pressure of very dry flowing sand mass. Then in 1999-2000 the second repeated experiment E2 follows. Both experiments were complete, i.e. they contained al three types of movements: rotation about the toe and top and translative motion. The third long-term experiment E3/0+2 with pressure at rest and passive pressure on the wall rotated about the top was performed in 2001-2002. The research using this stand has brought some obviously new results of some which can be considered as substantial

[1] *DrSc., CEng. Petr Koudelka; Institute of Theoretical and Applied mechanics, Prosecká 76, 190 00 Praha 9, Czech Republic; koudelka@itam.cas.cz*
[2] *MSc. Jan Bryscejn; Institute of Theoretical and Applied mechanics, Prosecká 76, 190 00 Praha 9, Czech Republic; bryscejn@itam.cas.cz*

(e.g. time instability of lateral pressure [1], proof of interval of pressure at rest and an existence of its limits, proof of an increased residual active pressure, existence of a decreased residual passive pressure and oth.).

Among others it was achieved so high passive pressure that the nearest glass side tables cracked but the experiment was successfully finished, however the stand renovation and development was necessary. The first development upgrade of the stand (2nd stage) involved a reconstruction the thicker glass sides and due to them a less wide front wall however, the most important progress has been a motor engine movement of the wall and computer control.

Fig. 1. The first stage of the experimental equipment: **a)** (Left) Preparation of the experiment E1 in 1998 with a sandy mass of the front half of an experimental space. Four red bi-component pressure sensors in the front wall are obvious, The first (upper) sensor is not placed. **b)** (Right) The equipment and the mass before the experiment E3 in 2001. The sandy mass fulfils the all experimental space into the equipment.

2. Concept

The experimental equipment is of original design and both the technology and the equipment are undergoing constant development. The concept is open and is based on limited research resources and envisages successive equipment development in several phases, depending on the results of previous research phase on the one hand and on the funds available on the other.

2.1. Basic concept

The basic concept covered the experimental equipment with the front wall arbitrarily movable in any required direction within 300 mm (+/- 150 mm inwards and outwards). The wall enables rotation at the toe or at the top as well as a regular movement, all three movements in both directions. The outward movements (away from the granular mass) generate active lateral pressures, the inward movements (into the granular mass) generate passive lateral pressures. Both upper (top) and lower (toe) movements of the front wall are measured and recorded.

The granular mass pressure in contact with the movable front wall was monitored by bi-component pick-ups according to the Czech patent of Šmíd-Novosad and a BMC station and amplifier which had proved very well (Koudelka &

Valach 2002). The BMC "NextView" programme took care of recording and evaluation.

The basic concept involves also a visual observation. According to the initial idea a visual observation was intended as a supplementary activity. In the course of the experiments, however, it brought about a number of new information and, consequently, was developed from plain irregular photographing of changes in the red strata to continuous observation and documentation on both sides (red strata on one side, a 40/40 mm grid of black points consisting in glass beads made by Ornela a.s. on the other side - Koudelka & Valach 2000) and the monitoring of the deformation of the upper free surface of the granular mass (Valach & Koudelka 2005). The last concept and description of the 2^{nd} upgrade (3^{rd} stage equipment) will be presented separately.

2.2. The Second Development Stage (1^{st} upgrade)

This phase of development of the equipment comprised initially only the provision of front wall motor drive. However, due to the defects of lateral glass walls on both sides of the equipment and the necessity of their strengthening it was necessary to provide also a new, narrower front wall. The concept of this phase was expanded subsequently to include all necessary and possible modifications required for the optimization of the equipment (Figs.2), e.g. upgrade hardware, new software, safety arrangement. The equipment at this stage was tested by the experiment E4/0+2.

Fig. 2. a) (Left) Overall view of the computer-controlled front wall motor drive after the first development part and restructure of the moved front wall. The motor is on the left; the linear incremental position pick-ups near the skids cannot be seen. **b)** (Right) Motor drive in detail with hardware and computer behind.

2.3. The Third Development Stage (2^{nd} upgrade)

The experiments using the stand of the previous stages gave not total boarder conditions for 2D analyses. Major aims of the second stand upgrade have been a complementation of five bi-component pressure sensors and three-component one in the back solid wall to afford missing data and of course, also hardware accessories. This concept was connected with upgraded existing hardware and new software.

3. Upgrades

3.1. The first upgrade - 2nd Development Stage

Lateral glass wall thickness was increased from 10 mm to 20 mm. The new front wall required by this thickness was redesigned to that it could be modified easily in case of further increase of wall glass wall thickness was increased from 10 mm to 20 mm. The new front wall required by this thickness was redesigned to that it could be modified easily in case of further increase of wall thickness, if required in the future. The front wall was also provided with special seal at the sides, as the ideally loose sand used in experiments behaves as a fluid around even very small openings and gaps. Also new high-precision movement screws were provided.

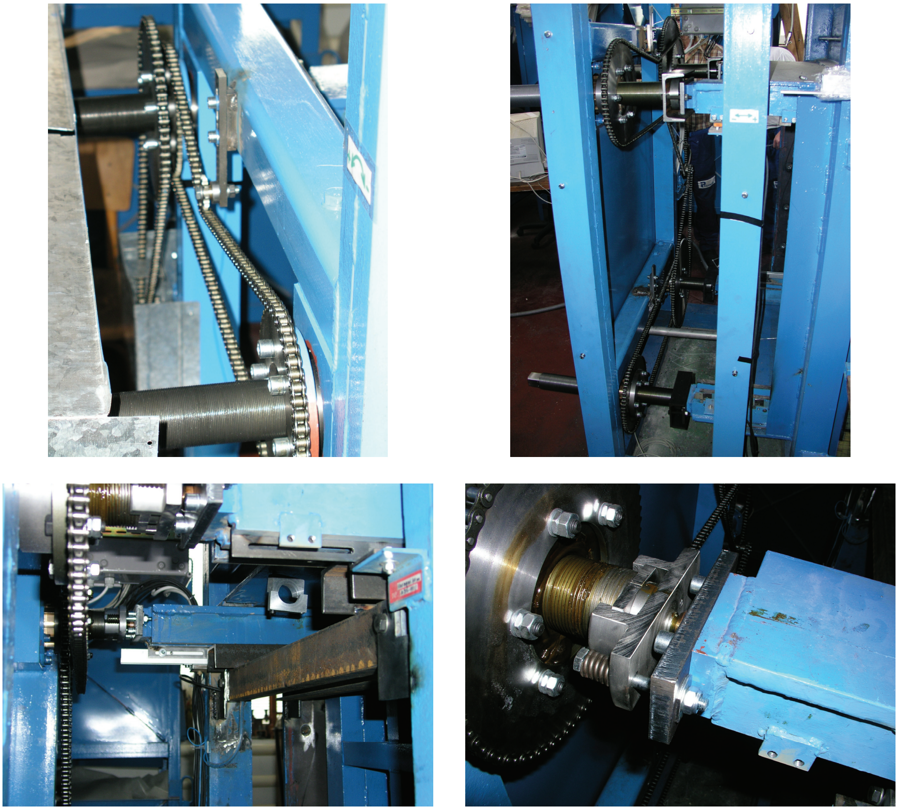

Fig. 3. a) (Above left.) Detail of upper screws and driving chain system (the motor is right down) in 31.7.2006. **b)** (Above right) Detail of upper screws for front wall movement with skids and linear incremental position pick-up (left side view in 19.9.2006) and **c) d)** (Below - views above and down resp.) after the development in Apr.2007 due to the rupture of the little plate off very hard steel under a bearing steel globe (Pictures in 4.6.2007.).

Also the front wall movement was totally redesigned. The wall displacement is generated by the rotary movement of four screws located in the corners of the wall. The motion of only the upper pair or of only the lower pair of screws can produce the wall rotation about the lower and the upper edge respectively. The screws are driven by a single two-phase stepping motor with a 1:30 worm gearbox. The torque is distributed to the screws by a roller chain with 1:5 transmission ratio. The overall transmission ratio between front wall displacement and the motor drive is 0.35 mm/rev., which makes it possible to produce a pressure force of as many as 40 kN for the maximum stepping motor torque of 3.25 Nm.

The stepping motor is controlled by a programmable unit which can be controlled by simple commands of the control software of an external PC. In this way it is possible to achieve any front wall movement within the velocity scope of 0–20 mm/min. incl. cyclic movements. The control of front wall position is derived indirectly from the inner position links of the stepping motor. For the measurements of the front wall position the equipment is provided with four linear incremental position sensors with a 10 μm resolution situated near the screws.

3.2. The Second Upgrade - 3rd Development Stage

The upgrade has concentrated on the complete data set of the mass boarder conditions. There have been placed six pressure sensors in the back solid wall perfectly in the opposite to the sensors in the front wall (if it has been possible) numbered from upper to lower. Component scopes are marked as normal (N)/friction (T) in the unit [N], :

No.11 – SM NTM -10/8/0.15 (scope in N, N, Nm resp.) very sensitive three-component sensor at the topmost position,
No.12 – SM 1 - 65/40 medium scope bi-component sensor (new),
No.13 – SM 1 - 65/40 medium scope bi-component sensor (new),
No.14 – SM 1 - 65/40 medium scope bi-component sensor (new),
No.15 – SM 2 - 350/200 high scope bi-component sensor,
No.16 – SM 2 - 350/200 high scope bi-component sensor.

Due to it the equipment has had to be provided with a corresponding new hardware set and carried out new software projects.

The equipment is able to record an incredible quantity of data (see Tab.1) thus, it has been necessary to prepare a data storing and a data processing. It has been looked for some procedures and software enabling an appropriate data reduction and their compatibility to usual software (e.g. Excel). The simple solution has appear in an application of the program system NextView (BMC) which involves a reduction procedure.

It has been appeared that four former placed incremental sensors of movement could not be applied and that it is necessary to complete two secondary ensuring sensors (above and down). A solution of this requirement is in gear and the wall movement at the beginning of the next experiment will be recorded by two potential movement sensors and one digital micrometer.

Fig. 4. Views of the solid back wall with six pressure sensors placed in and with the sample into.

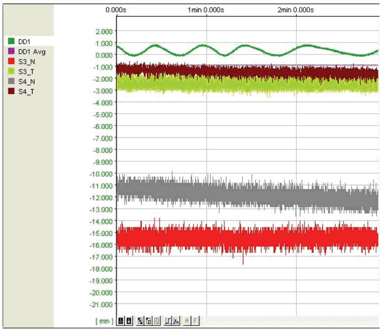

Fig. 5. History of an interference of the sensor signals.

Table 1. Characterizations of the experimental equipment.

Property	unit	1^{st} stage value	2^{nd} stage value	3^{rd} stage value
Equipment - length	m	3.920	3.920	3.920
- width	m	1.400	1.400	1.400
- height	m	2.386	2.386	2.386
Specimen - length	m	1.5-3.0	1.5-3.0	1.5-3.0
- width	m	1.000	0.980	0.980
- height	m	1.200	1.200	1.200
Max. active wall movement	mm	- 150	**- 300**	**- 300**
Max. passive wall movement	mm	+ 150	**+ 242**	**+ 242**
Movement resolution	µm	**10**	**17**	**17**
Min. wall movement velocity	mm/min	man. stepping	**> 0**	**> 0**
Max .wall movement velocity	mm/min	man. stepping	20	20
Maximal pressure force	kN	manual	**40**	**40**
Number of sensors	1	6	12	16
Max. frequency of record	Hz	manual	**1000**	**1 000**
Maximal data size per day	MB	-	487	803
Max. measured pressure	kPa	**163.16**	-	-

4. Hardware and Software

The stepper motor is controlled by a control unit. The system is equipped with transmission, chain gearings and an acting screw. Changing the chain gearings, one could configure the system to move upper, lower or both parts of the wall.

The control unit is placed independently and it is connected with PC by serial port. A program “InMotion” installed on the PC enables to control the unit. Two functional modes are enabled: the manual mode is used for system settings (higher speeds, etc.) and the program mode is used for running an experiment. A typical program consists of phases of slow motion and phases of waiting. This program is written in proprietary control unit’s language.

Transfer coefficient between the number of stepper motor revolutions and linear moving of the wall is crucial and obtained from transmissions’ and screw-thread parameters; m_r = 3/(30 *114/14) = 0.0123418 mm per revolution. One revolution of the stepper motor corresponds to 200 control pulses, which can be divided into some micro-steps. Micro-steps are used in the experiment control.

Front and rear walls are equipped with multi-component pressure sensors of different sensitivities. Sensitivities are chosen due to presumed pressures in different depths of the experimental sand body. The sensors provide us with tangential and normal pressure components; one of the sensors is three-axial and measures torque in addition. Temperature and displacement are measured, too. Two displacement sensors, measuring upper and lower displacement of the wall, are currently installed, both of potentiometer type. Used displacement sensors are relatively nonlinear, which is corrected by a calibration curve obtained during system setting. An additional sensor has been intended to use one of digital incremental type, for which there are no problems with analog noise. In the standard connection of this sensor, though, some severe problems occurred at the very slow speeds used in the experiment.

All analog sensors are equipped by signal amplifiers for signal conditioning. The modules are grouped together and the signals from each group are connected to A/D converters units. These units communicate with PC via USB ports. A/D converters are of 16-bit precision and there are three 16-channel converter modules installed. Signal amplifying modules are fed by small external power supplies and A/D converters are fed from the USB ports.

For recording and basic analyzing of collected data, we use program called NextView, running on PC parallel to program InMotion. This software allows automatic data storing of many channels sampled at custom sample rate, using a row of files generated for each day of experiment running. Also it shows collected data in live display (graphically and numerically). The program has ability to compute other “virtual channels”, e.g. muving averages or formula channels, from input data; these can be also stored to output files. Although there are various capabilities for analyzing of stored data directly built into the program, it is more practical to export stored data for analysis in external tools. Currently, two such tools are in use, these are Microsoft Excel and Wolfram Mathematica. The latter was also extensively used during settings and calibrating phase, e.g. for on-line evaluating of calibration curves and also as some type of “intelligent diary”. To achieve some level of security for logging the experiment’s data, it is used several external data storage devices for backups. At hardware level, the power supply for PC is protected by an UPS.

5. Problems

Here are shortly mentioned some problems, which were encountered during setting up the entire stand. One of them was sudden loss of communication between step motor control unit and InMotion software. This was corrected by resetting the control unit, but the origin of this behavior remains unknown to us; it is possible and even likely that it was caused by electric interference. Next, the starting phase of a program that should be running in the step motor control unit is unreliable; at some cases, the program will not start. Also, if there is a longer period (say one day) without any communication between InMotion program and the control unit via serial link, one has to close and restart the program. We did not reveal causes of this behavior yet, and have to take it as if it were a feature of the system.

Another big issue is interference and noise in general. which is shown in Fig. 5 by a typical output of several sensors. The length of the record is about three minutes; sampling rate is 500 Hz. The green curve corresponds to motion sensor; vertical axis is calibrated in mm and the wall stands still. One could see that overall interference has two components: a slow one and a high frequency noise. Curves of other colors show records from selected pressure sensors at the same time; vertical axis does not apply here.

The exact origin of the two interference components is not known. The higher frequency noise is successfully reduced by means of a moving average computation; the higher sampling rate we use, the better results are achieved. This issue requires further analysis, which is planned to be done soon, with an expert in electrical systems involved.

6. Conclusion

The 3rd upgrade has been carried out at the beginning of this year and a next parallel experiment with pressure at rest and passive pressure E5/0+2 is prepared.

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