Granular Mass Behaviour under Passive Pressure

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ABSTRACT

Actual behaviour of the soil/granular mass under lateral/earth pressure is highly complex and has not been sufficiently described and known to data. In this paper the term "Lateral pressure" is used instead of the customary "earth pressure" to differentiate a new theoretical approach to the problem and because the term "lateral pressure" appears more adequate and less general in this particular problem. A significant characteristic of lateral pressure consists in its continuous variability in time. For this reason a number of objections may be raised against the contemporary earth pressure theory. The paper sums up the present state of knowledge and a new theory acquired by research. It shows the real non-cohesive mass behaviour under passive pressure.

INTRODUCTION

Actual behaviour of the soil/granular mass under lateral/earth pressure is highly complex and has not been sufficiently described and known to data. In this paper the term "Lateral pressure" is used instead of the customary "earth pressure" to differentiate a new theoretical approach to the problem and because the term "lateral pressure" appears more adequate and less general in this particular problem. A significant characteristic of lateral pressure consists in its continuous variability in time. For this reason and due to the little attention paid to the development of lateral pressure theory a number of objections may be raised against the contemporary earth pressure theory. On the basis of theoretical considerations, physical and numerical experiments an advanced General Lateral Pressure Theory (GLPT) is being developed the actual stage of which was presented at last 5th IC CHGE (New York 2004). The paper sums up the present state of knowledge acquired by research and it presents the contemporary actual idea of the real behaviour of an ideally non-cohesive mass under passive pressure. In particular it monitors the relation of lateral pressure to the forming failure (slip) surfaces and other phenomena, as well as the relation of both (normal and shear) components of lateral pressure applied to a retaining wall and its displacement.

MASS AND MONITORED PHENOMENA

As an example of real mass behaviour it is possible to present the final results of the physical experiment E3/2 described at the last Conference (New York, Koudelka 2004). Due to it the following experiment description is given briefly.

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 was 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 every corner of the retaining wall. Five measuring points were situated at the granular mass/retaining wall contact surface at the depths of 0.065 m, 0.265 m, 0.465 m, 0.665 m and 0.865 m. A general view at the experimental equipment shows Fig. 1 .

Fig. 1. General lateral view at the experimental equipment with sample off the ideal (dry) non-cohesive sand inside before the long-term experiment E3/2 (29th Aug. 2001). The moved front wall is left.

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 described in detail earlier (Koudelka 2000, 2004). 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 both lateral glass sides were used for visual monitoring of displacements and deformations in the investigated granular mass, i.e..the state of deformation and failures according to the respective "lateral pressure/structure (front wall) movement state ". The measurements of lateral pressure were based on the Czech invention of bi-component pressure sensors (Šmíd – Novosad) which enable simultaneous continuous measurements of normal and tangential components. As well as the pressure dynamics and the state of failure were monitored. Due to it the right side glass tables are provide with orthogonal net.

FINAL EXPERIMENTAL RESULTS

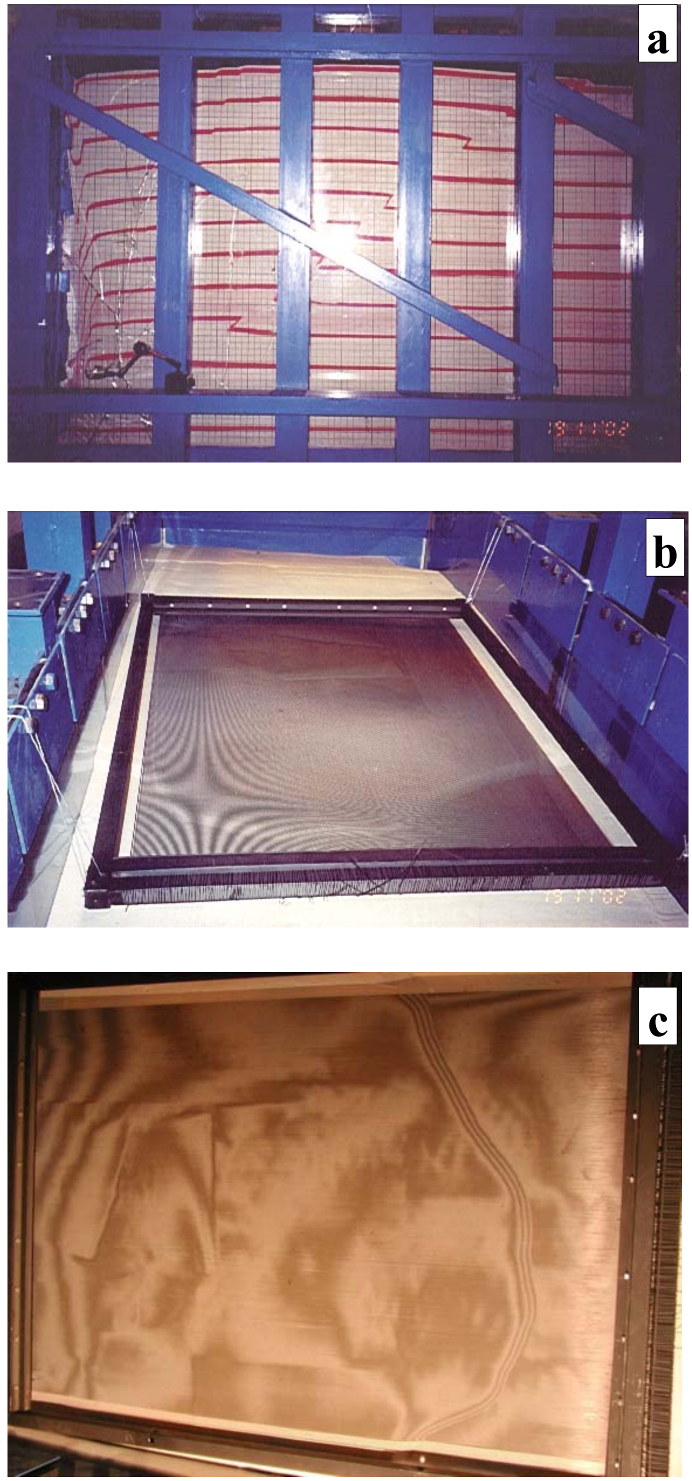
Let us look at the final results of the experiment E3/2 and concentrate our attention to lateral passive pressure only (whole E3/2 involved also an experiment part with pressure at rest E3/2-0).

Structure (front wall) movement

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. The state of the mass after the final movement can be seen in Fig. 2a (slip surfaces in the mass, edge of deformed mass surface) and Fig. 2c (feature of deformed mass surface).

Form changes of the mass

The original form of the mass was performed carefully. Each part of the mass was slightly compacted with regard to the maximal real pressure due to itself weight and each part of the mass received the same quantity of vertical energy. The upper opened surface of the mass was adjusted strictly horizontal.



Figs. 2a,b,c. The final form of the ideal non-cohesive sandy mass after rotation about the top of the front equipment wall (in Figs. 2a, c left, in Fig. 2b before, down) and the toe movement of 159 mm:
a -Left side of the mass with rotated front wall (left), the lifted upper surface and slip failures into (see discontinuities of red strips).
b - Visual monitoring equipment for the "moiré" method.
c - "Moiré" view down at the mass upper surface with curved tracks of the internal slip surfaces.

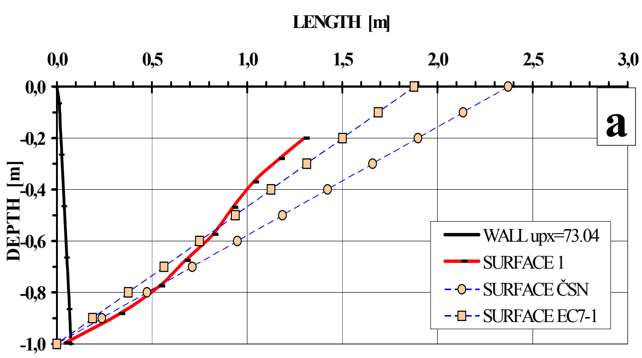
The original form of the mass after the toe movement of 159 mm of the front wall rotated about the top was changed substantially and obviously. The final mass form shoved of course the fore mass part with the sloped front rare according to the rotated front wall (see Fig. 2a) and the lifted fore part of the upper surface (see Figs. 2a,c). Changes of the back part of the mass were visible hardly (firm mass part - see the mass surface in Fig. 2b, above behind "moiré" equipment).

Unintentional lateral form changes of both fore side tables happened in areas near to the front wall toe due to glass cracking and buckling (see Fig. 2a).

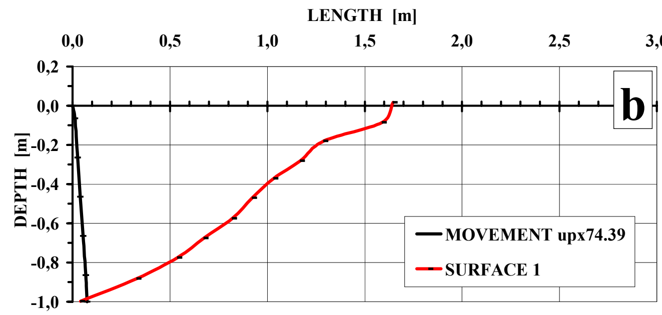
<u>Failures</u>

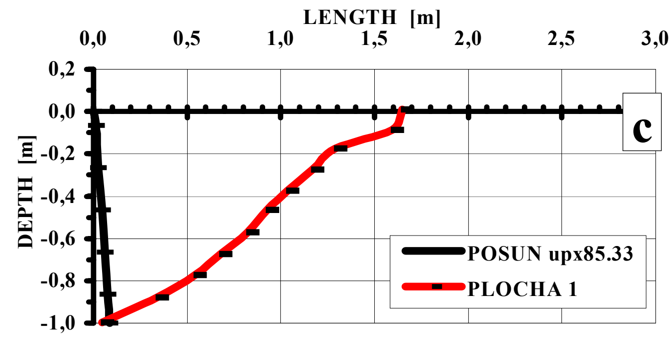
The state inside the mass was characterized by the slightly curved major slip surface dividing the *active* mass part from the *passive* one. The *active (upper fore)* part was heavily deformed and further divided on a system of others slip surfaces. The pressure near the rotated wall toe (more of 150 kPa maximal) destroyed the both nearest glass plates, right of them is seen in the Fig. 2a. The deformed surface of the mass with curved tracks of slip surfaces is shown in Fig. 2c. It can be seen that the slip surfaces *into* the mass are more inclined than near to lateral glass sides.

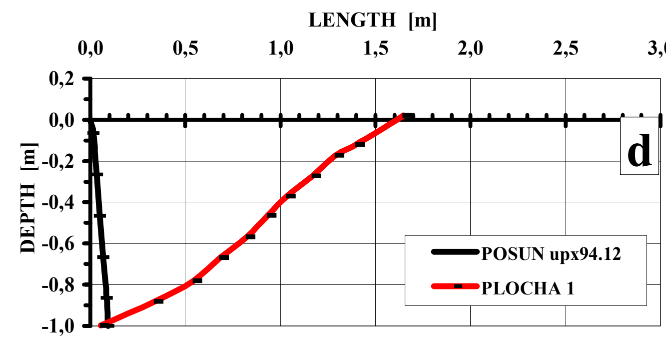
Let us look more in detail at the failures development in dependence on front wall rotation. A mass deformation (a tendency to the convex form of 3-4 mm) was observed from the wall toe movement of about u_{px}= *12.6 mm*. This value is near or within the recommended limits of ČSN 73 0037 or EC7-1 or for the achievement of the half of the top passive pressure value. The first sharp real slip surface began forming at the wall toe movement of about u_{px}*=73 mm* and completed whole by inflex and concave parts at u_{px}*=74.4 mm* (Figs.2b, 2c, 2d).

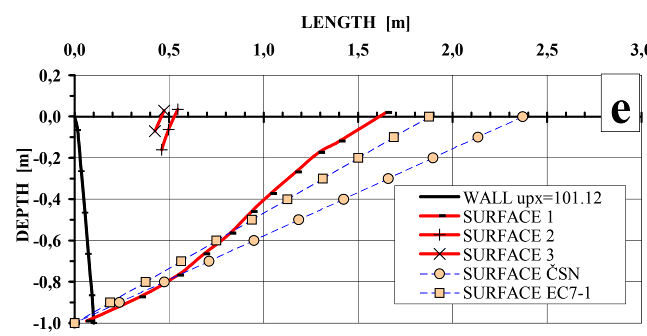


Figs. 3a, b, c, d, e, f, g, h. Development of the failures (slip surfaces) into the mass in dependence on front wall rotation about the top and theoretical critical shear surfaces according to EUROCODE 7 - Part 1 and ČSN 73 0037:
a - after the toe movement of 73.0 mm
b - after the toe movement of 74.4 mm
c - after the toe movement of 85.3 mm
d - after the toe movement of 94.1 mm
e - after the toe movement of 101.1 mm



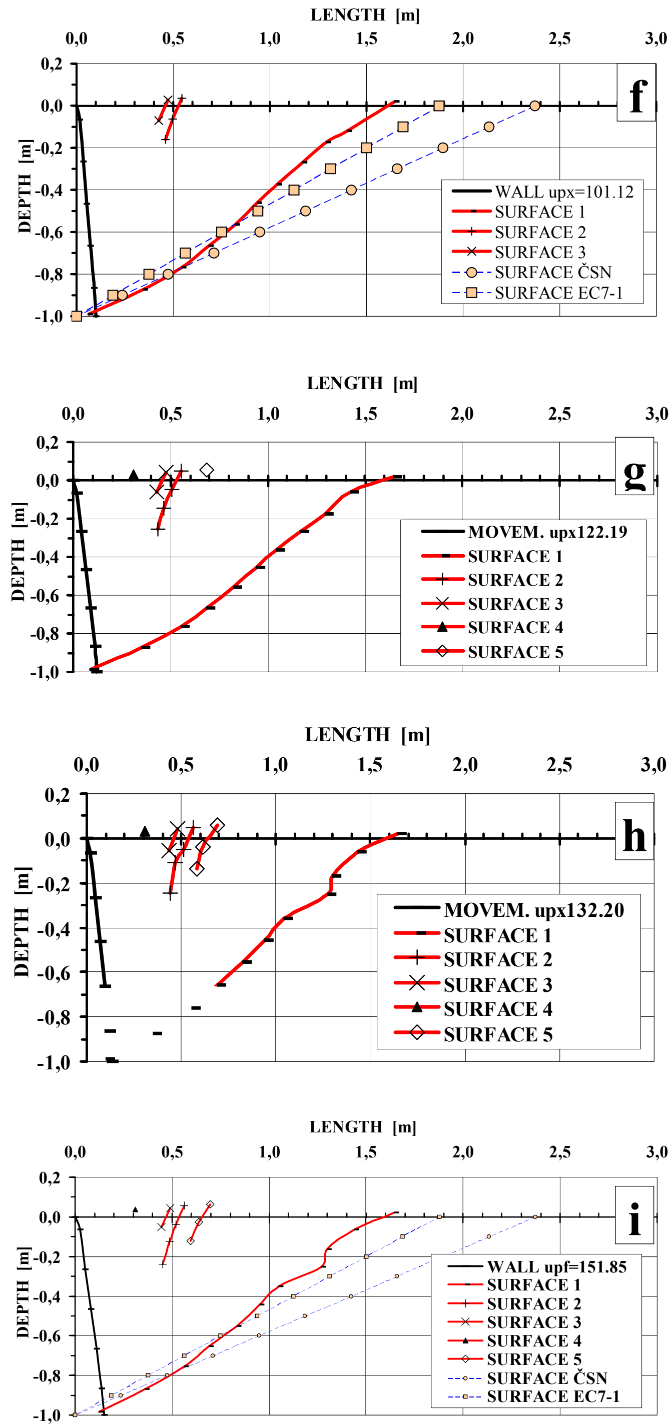






Next failures began emerging above the first slip surface in the upper part of the mass near the mass surface. The short second and third failures appeared at u_{px}*=101.1 mm (Fig. 2e)*, the fourth and fifth followed from u_{px}*=122.2 mm (Fig. 2f)*. Further mass development characterized the displacements along the described slip surfaces continued till the toe movement u_{px}*=132.2 mm* (Fig. 2g,). Following changes of the slip surface system till the final movement were small and hardly visible (Figs. 2h, i).

The described slip surfaces development could be affected partially due to cracking of the fore glass tables which began



Figs. 3 f, g, h, i. Development of the failures (slip surfaces) into the mass in dependence on front wall rotation about the top and theoretical critical shear surfaces according to EUROCODE 7 - Part 1 and ČSN 73 0037:

f - after the toe movement of 101.1 mm
g - after the toe movement of 122.2 mm
h - after the toe movement of 132,2 mm
i - after the toe movement of 151.9 mm

from the toe movement u_{px}*=9.8 mm* (10th Oct. 2001). The affect was reliably negligible to the toe movement about of 18,0 mm (18th June 2002) and slightly significant, but slowly increasing, after the movement about of 31.8 mm (2nd July 2002).

<u>Passive pressure</u>

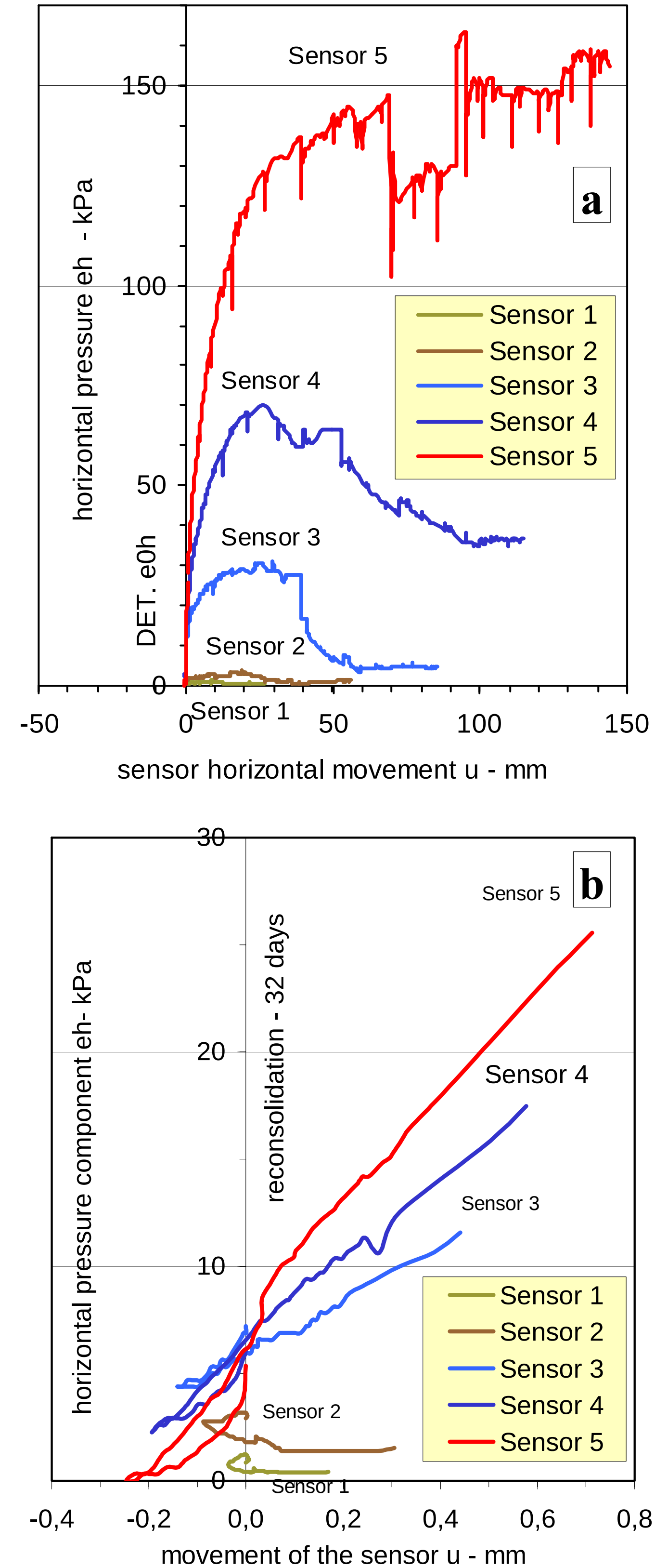
Both pressure components, i.e. normal and tangential (shear), were monitored individually. The following diagrams show (on their *x* axis) the toe movement or the absolute movements. The toe movement is defined as the horizontal movement of the centre of the lower wall edge. The toe movement is the same for all sensors. The absolute movements are defined as the horizontal movement of the contact surface centre of the given sensor.

<u>Norma components.</u> The upper Fig. 4a shows the behaviour of the horizontal pressure component during the whole experiment E3/0+2, i.e. both during small retaining wall movements in the area of pressure at rest and during the following movements in the passive course. The lower Fig.4b shows horizontal pressure components of sensors in the area of the pressure at rest in detail. The history of the pressure at rest is obviously close to linear, but different at *active* side (from $u_{or} = 0$ to u_{0a}*=-0.01 to –0,05 mm*; next curves parts pass to the *active* pressure values) and at *passive* side (from the extreme *active* position with sensor movements u_{ax}*=-0.04 to –0.25 mm* to the limit of *passive* pressure at rest at approximately u_{0p} *= 0.55 to 0.75 mm*). Both parts of the curves are very sheer but the *active* one is almost vertical, i.e. the reaction of the mass at rest to any *active* structure movement is very sensitive. On the other side the reaction of the mass at rest to a *passive* movement is slightly less expressive, but also very sensitive.

The histories of the *passive* pressures of sensors Nos. 2, 3, 4 show two very important facts, i.e. very expressive drops after the maximal values and the closely constant *residual passive* pressures at the ends. Sensor no.1 was placed closely under the surface of the mass (0.065 m) and its pressure values are very low. The sensor no.5 monitored some other behaviour with an increasing tendency during almost the whole tested interval of *passive* movement.

Let us turn our attention to the behaviour the mass during the breaks of the experiment. The breaks are characterized in Figs.4a and 4b by vertical abscissas. The abscissas of *passive* pressure at rest in Fig.4a near the origin distinguish the pressure *increase* during 32 days of reconsolidation. On the the other hand, the experiment breaks in the area of *passive* pressure are characterized by pressure *decreases.*

The vertical break abscissas in the histories of the sensor pressures proved and shoved the phenomenon of time pressure

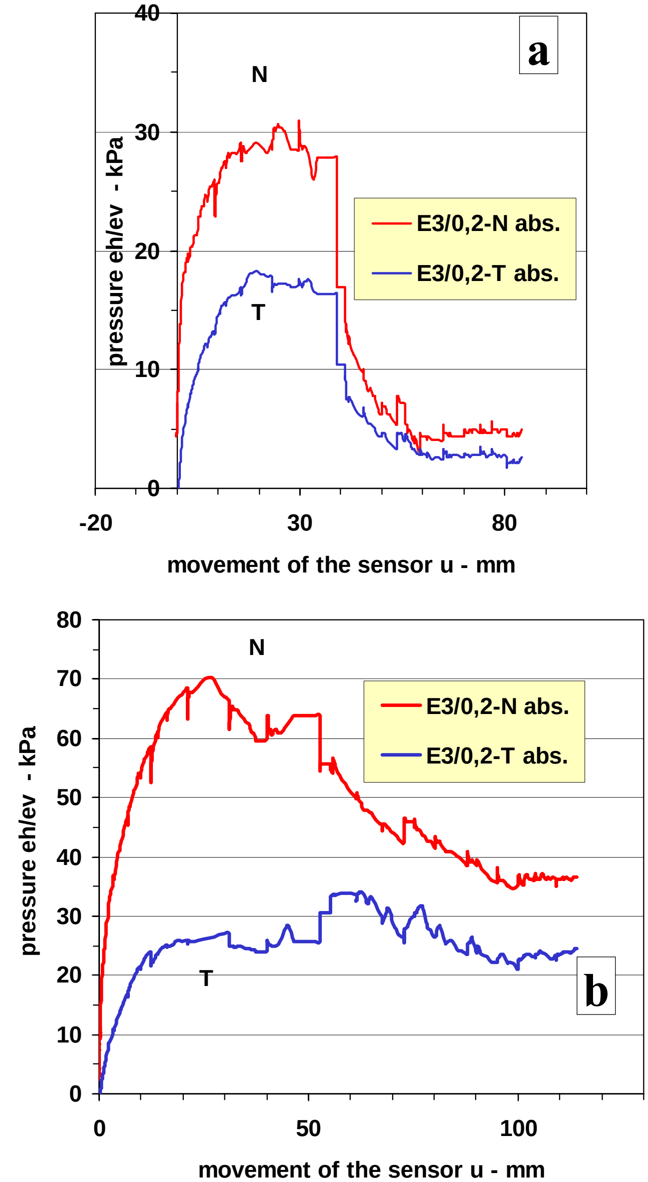


Figs. 4a, b.. History of horizontal pressure components of the sensors during experiment E3/0+2 :
a In general
b In detail

instability during constant surrounding conditions and also its magnitude. Of course, the magnitude depends above all on length of a time interval.

<u>Shear components</u> Shear behaviour of passive pressure appears much more complex than behaviour of the normal component, especially problem of shear angle on the rear face of retaining front wall . Here be shown a relation between both components in Figs. 5a, b.

It is obvious the histories both component of the sensor No.3 are rather similar (Fig. 5a), the components similarity of the



Figs. 5a, b. Dependence both pressure components on movement of the sensor:
a - pressure sensor No.3, depth 0.465 m
b - pressure sensor No.4, depth 0.665 m

sensor No.4 is less. The differences could be caused due a proximity to the front wall toe.

Numerical experiment

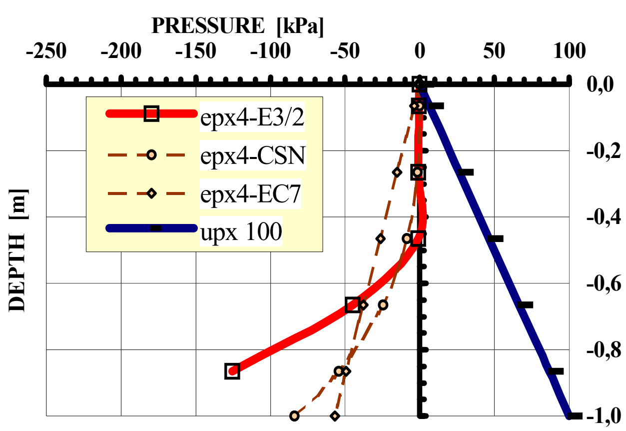
A use of the previous *active* pressure numerical model (for experiments E1 and E2) for the mass loaded with *passive* pressure or *passive* movements did not bring well acceptable results; the same applies to other numerical models. The used numerical model N3/0+2 for both *passive* and *active* pressure was based on the General Lateral Pressure Theory (GLPT) and on the limit movements according to the results of E3/0+2 and the limit values of top passive pressure component according to ČSN 73 0037. The correction for rotation about the top was not considered. This conception provides a better possibility of comparing.

Results of the numerical experiment N3/2-0 and comparative analysis of European and Czech standard procedures was presented separately (P. Koudelka 2005).

Comparison measured pressures with standard values

It appears useful, especially with respect to an European large discussion on EUROCODE 7, Part 1 (EC7-1) contra national standards, to compare and evaluate the measured values of passive pressure to the values calculated according to standard procedures. The comparison with procedures according to EC7-1 and Czech standard ČSN 73 0037 is presented in Fig.6.

Fig. 6. Comparison the real passive pressure on the



investigated mass under the rigid (front) wall rotated about the top with the toe movement of 100 mm and the calculated values according to EC7-1 and ČSN 73 0037.

All three pressure curves in the graph are based on the same toe movement of 100 mm after rotation about the top (10 % of the movement to the wall height). The toe movement of 10 % represents average of the maximal passive pressure according to EC7-1 or about 75 % of the maximal passive pressure according to ČSN 73 0037. The sloped line on the right is scheme of the retaining wall and its movement.

CONCLUSIONS

The presented results make it possible to create an imagine about history of the real process of the mass reform also in dependence on the acting pressure. For research it is very worth that the failures/slip surfaces created themselves in natural conditions (1G). Here given conclusions are preliminary, it is necessary to repeat the experiment E3/2-0 and prove its results by the same following experiment E4/2-0 that is prepared. Some main conclusions can be specify as follows:

a) Displacements into the mass proceed on the one (main) slip surface only from the beginning to a special limit of rotation. Then the other slip surfaces are created step by step.

b) The maximal value of passive pressure is reached before the main slip surface appears. Probably, a decreasing pressure process leading to the residual stress state and the residual passive pressure begin relatively early after the limit movement of passive pressure at rest.

c) It is probable the similar history of the shear component of passive pressure to the normal component. However, there were monitored many times a disconnected behaviour of this shear component.

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