Numerical and comparative analysis of earth passive pressure acting

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ABSTRACT: The paper presents the results of physical and numerical experiments (E3/0+2, N3/0+2) both with the passive pressure and the pressure at rest of the ideally non-cohesive sand on a retaining wall rotated about the top. The numerical experiment repeats the physical experiment. The results are analysed and compared according to relevant requirements and recommendations of the final draft of EC 7-1 and ČSN 73 0037.

1 INTRODUCTION

Objections to the recent theory of earth pressure resulting from its weak points have led to the research of non-cohesive granular masses, concentrating both on physical and numerical modelling. They were presented previously, see e.g.

Two medium-term experiments with active lateral pressure (experiments E1 and E2) of loose sand acting on a retaining wall were performed. The experimental stand makes it possible to measure both the normal and the tangential components of pressure. The experiments showed some rather unexpected behaviour of the granular mass, especially its deformations and failures during three different wall movements. This was the reason of experiment repetition. The measurements included both components of the pressure of the mass. Two analogous numerical model experiments were made, based on the General Lateral Pressure Theory (GLPT).

Recently, a long-term research of passive pressure (experiment E3) has been carried out. The rotation about the toe of the physical model sized 3.0*1.0*1.2 m has brought unexpected results similarly as the previous research of active pressure. The research contains among others the investigation of time (in)stability of both pressure components. An analysis of this experiment forms the subject of this paper.

2 SKETCH OUTLINE OF GLPT

The problem of lateral (earth) pressure can be characterised according the approaches to four basic forms of the pressure or the states in the granular (soil) mass, i.e.:

– pressure at rest,
– acting of extreme pressure values (active and passive),
– intermediate values and
– residual pressures (active and passive).

GLPT is a non-conventional theory and the presented research of passive pressure forms one part of the proof of this theory. The theory is characterized in Fig. 1.

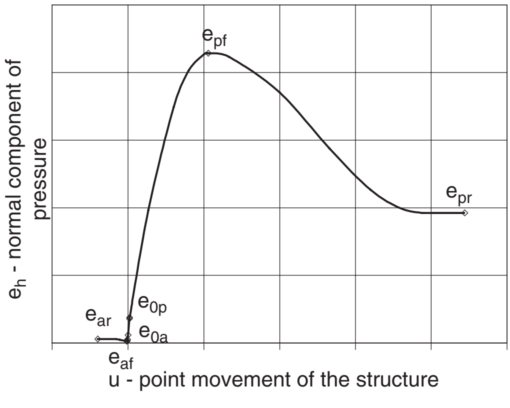


Figure 1. Theoretical relation between the normal component of lateral pressure and the structure rear face point at the depth of 0.465 m, or in the location of No.3 tensor.

3 EXPERIMENT WITH PASSIVE PRESSURE AND PRESSURE AT REST

At the end of 2001 and during of 2002 the first part of the third experiment E3 was made, denominated 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 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 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 was 3.0 m long, 1.2 m high and 1.0 m wide and consisted of the same ideally non-cohesive material (loose very dry sand) as in the previous cases. The experimental equipment and tested material were described in detail earlier (Koudelka 2000a). Therefore, we shall state merely that the sand had the following basic parameters: $\gamma = 16.14\,\mathrm{kN/m^3}$ (unit weight), w = 0.04 % (water content), $\phi'_{ef} = 48.7°$ (angle of the top shearing resistance for low stresses), $\phi'_r = 37.7°$ (angle of the residual shearing resistance), $c'_{ef} = 11.3$ kPa (illusory cohesion), $c'_r = 0$.

The notation of the described 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 terminated 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 after the final movement can be seen in Fig. 2. The state inside the mass was characterized by the slightly curved major slip surface separating the *active* mass part from the *passive* one. The *active* part

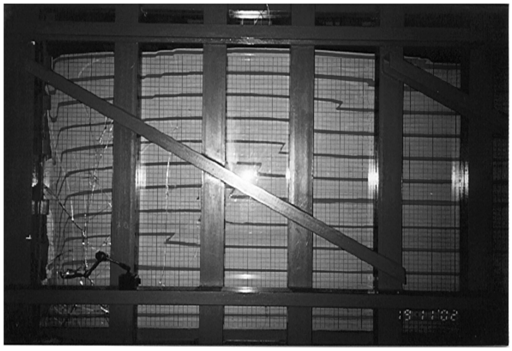


Figure 2. The state of the mass and the first glass plate near the moved wall (left) after the toe movement of 134.8 mm before the final movement of 159 mm on 18th Nov. 2002. The destroyed glass plate resisted the stress state with the pressure of 150 kPa.

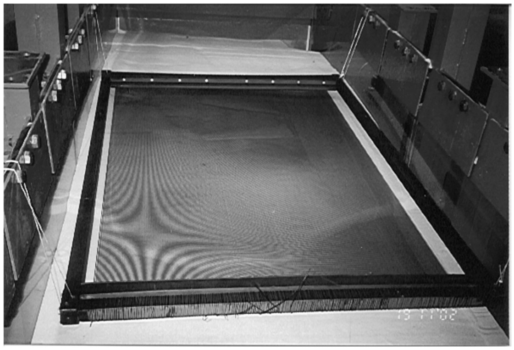


Figure 3. Deformed surface of the experimental mass from the back of testing equipment after the toe movement of 134.8 mm on 18th Nov. 2002 before the final movement of 159 mm. The top of the moved front wall is above (blue).

Table 1. Tested movements and standards limit movements for supposed mobilization of active pressure {peak strength}.

					Standard active limit movements			
		Wall height	Max. increment experiments E1, E2		EC 7-1 (final draft 10/2001)		ČSN 73 0037	
Phase	Type of movement	H (m)	max u (mm)	u/H –	u/H –	u_{lim} (mm)	u/H –	u_{lim} (mm)
1	Rotation about the toe	1.0	8.75	0.009	0.001–0.005	1–5	0.001–0.002	1–2
2	Rotation about the top	1.0	8.75	0.009	0.002–0.010	2–10	0.002–0.004	2–4
3	Translative motion	1.0	8.75	0.009	0.0005–0.002	0.5–2.	0.0005–0.001	0,5–1

was heavily deformed and further divided into a system of others slip surfaces. The pressure near the rotated wall toe (maximally over 150 kPa) destroyed both nearest glass plates; one of them can be seen in Fig. 2. The deformed surface of the mass is shown in Fig. 3.

The retaining wall was not moved continuously, but step by step with the periods of reconsolidation between individual steps. These periods without any movement completed the experiment on time behaviour. The data of sensors were read and recorded also during the periods of reconsolidation.

4 RESULTS OF EXPERIMENT E3/0+2

The experiment E3/2 has yielded considerable information which has not been analysed fully yet. Due to its scope the paper presents only some results of the lateral (earth) pressure components. The results of visual monitoring and some others are beyond the range of the paper.

The following diagrams show (on their *x* axis) the toe movement and 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.

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 other hand, the experiment breaks in the area of *passive* pressure are characterized by pressure *decreases.*

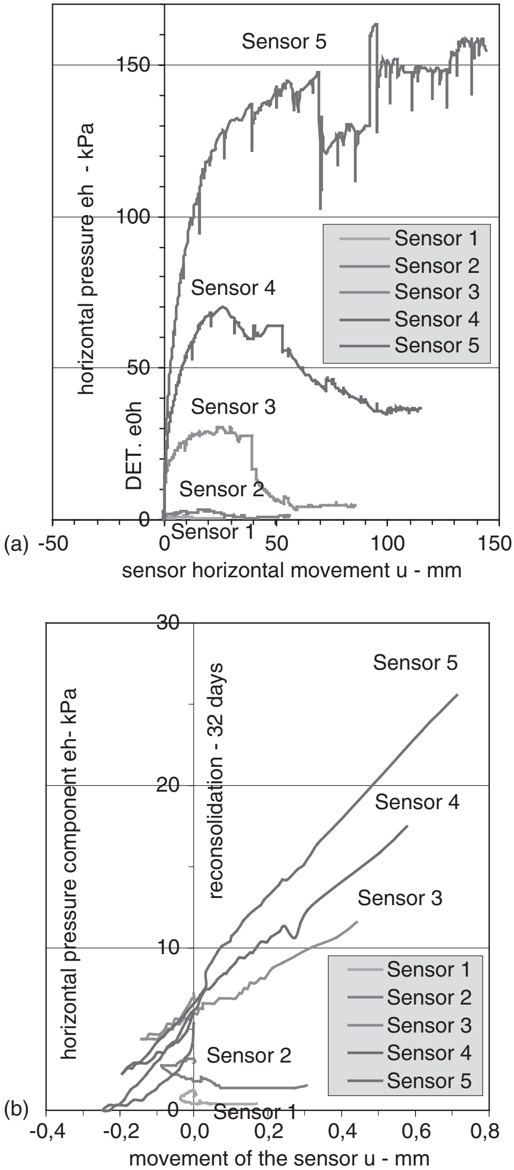


Figure 4. History of horizontal pressure components of the sensors during experiment E3/0+2: (a) In general (above); (b) In detail (bottom).

5 NUMERICAL EXPERIMENT N3/0+2

The previous numerical experiments N1/0+1+2+3 and N2/0+1+2+3 with *active* pressure used the numerical model for *active* pressure which has made it possible to calculate structure movements relevant to the pressures. The limit pressure values according to ČSN 73 0037 or EC7-1 were used for comparison.

A use of the *active* pressure numerical model 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.

6 COMPARISON OF DIFFERENT PROCEDURES

The analysis compares the results of experiment E3/0+2 with the results based on the final draft of EC7-1 (10/2001), ČSN 73 0037 and results of the adequate numerical experiment N3/0+2 (see Figs. 5 and 6 on this and following pages).

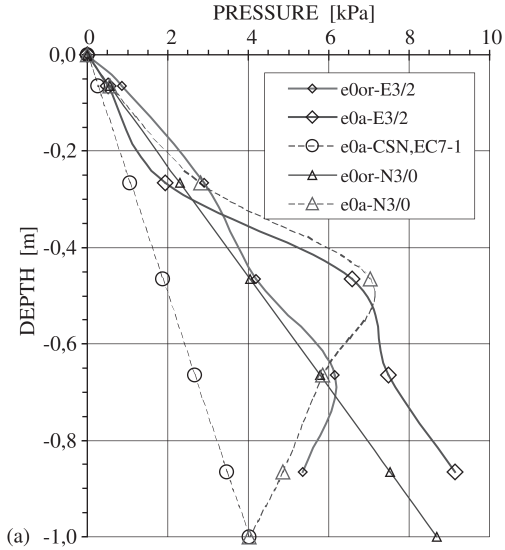
Figs. 5a,b show the good agreement of the physical and the numerical experiments (E3/0, N3/0) in the area of pressure *at rest*, both *active* and *passive*. The differences between physical experiment and results according to standards (both EC7-1 and ČSN 73 0037) are not relevant and show the weakness of the standard concepts of the area of pressure at rest.

Figs. 6a,b,c,d present comparisons with regard to the limit movements (standard or real) in the area of *passive* pressure. The first after toe movement of 10.1 mm (according to standards) should show the achievement of half the top passive pressure. It is obvious that the envisaged 1/2 standard values are too high, numerical model (using the top passive pressure values) including. The result nearest the real values of E3/2 is that according to ČSN 73 0037 which uses a type movement correction for rotation about the top.

The state of pressures after the toe movement of 38 mm is shown in Fig. 6b. This state corresponds to the top pressure on the sensors no.2,3,4. The comparison gives similar relations as that for the movement of 10.1 mm in Fig. 6a. The total passive force on the structure is probably highest.

Fig. 6c presents the stress state of the rear face after the toe movement of 100 mm which corresponds to the residual *passive* pressures according to the experiment E3/2 on sensors no.1,2,3,4 and an intermediate value of passive pressure on sensor no.5. The values of the real pressure acting on the sensors greatly differ from the values based on standard procedures, including the numerical model N3/2 using standard top values.

The final passive pressure values in the last Fig. 6d approach the real pressure values of E3/2 and the numerical model values of N3/2. This phenomenon is due both to almost the top values of pressure around



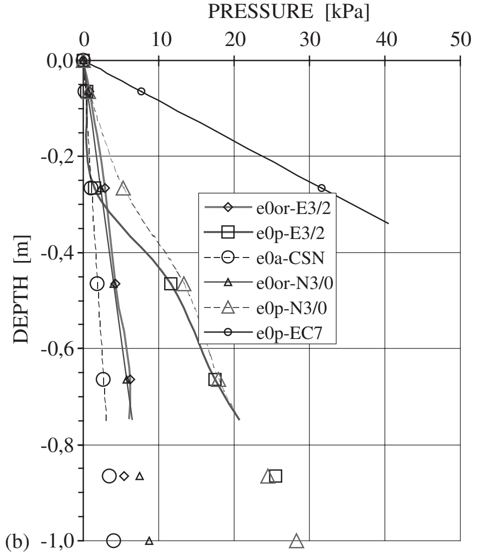


Figure 5. Histories of horizontal pressures at rest acting on moved structure (height of 1.0 m) after toe movements: (a) u = −0,116 mm – active pressure at rest; (b) u = 0.76 mm – passive pressure at rest.

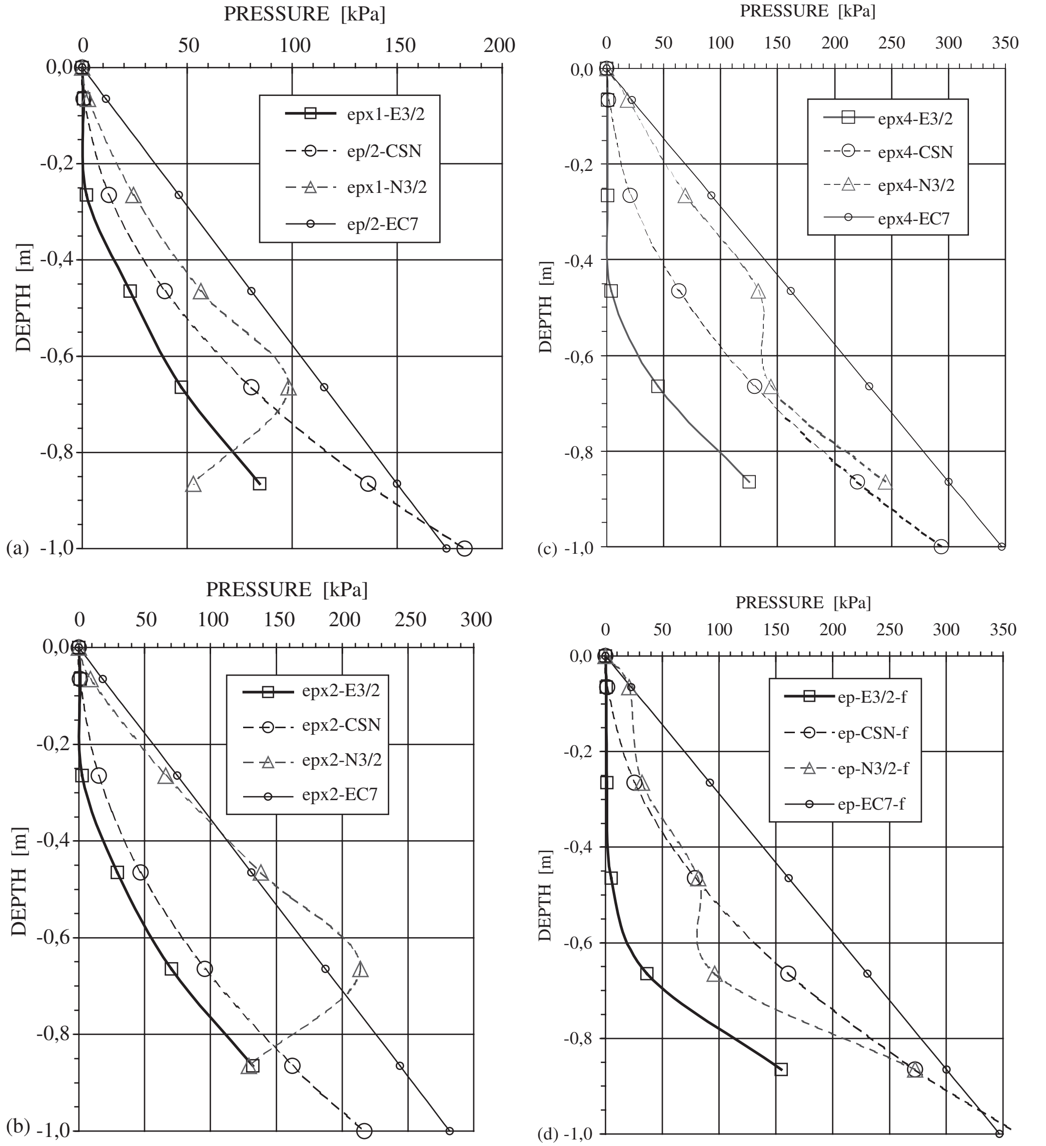


Figure 6. Histories of horizontal passive pressures acting on moved structure (height of 1.0 m) after toe movements: (a) u = 10.1 mm – half of top passive pressure (according to standards); (b) u′ = 38 mm – about top values according to sensors 1,2,3,4; (c) u = 100 mm – residual passive pressure according to sensors no. 1,2,3,4; (d) u′ = 166.7 mm – top passive pressure according to sensor 5, the end of the experiment.

the toe and the decrease of the residual pressure values on the upper part of the structure.

7 CONCLUSIONS

An analysis and numerical modelling are not the object of the paper, which cannot show a number of other diagrams, results of visual monitoring of displacements into the mass, more detailed information and time instability, either. Despite these limitations it is possible to state *for the case of retaining structure rotation about the top*:

a) The experiment has proved the existence of the decrease of passive pressure to the *residual values*, thus proving simultaneously the whole contemporary theoretical basis of GLPT.

b) The theoretical basis of GLPT is not in discordance with other new knowledge.
c) Both compared standard values (EC7-1 and ČSN 73 0037) of the top horizontal *passive* pressure appear as *too high*.
d) The calculation procedure according to ČSN 73 0037 is more accurate than that according to EC7-1. In spite of that both procedures are unacceptable.
e) The new knowledge has shown the necessity o include into the developed theory also lateral pressure *values* with greater accuracy.
f) The monitored time instability extends the validity of general pressure values and the theory into the very important time-space.
g) The results have confirmed the different behaviour of the normal and the shear components of lateral pressure in the range of *passive* pressure as well as in the range of *active* pressure.
h) Some contemporary knowledge leads to the conclusion that the natural state of granular mass is the state at rest and the mass appears to have the tendency to get into it.
i) This fact would lead to an important conclusion statement that the natural values of lateral pressure are within the interval of the pressure at rest and the mass seems to have the tend to get its lateral pressure into this interval.

These conclusions should be verified and extended to other types of structure movement. The continuation of the research is necessary.

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