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PROCESS OF LATERAL PASSIVE PRESSURE ACTING IN A SANDY MASS

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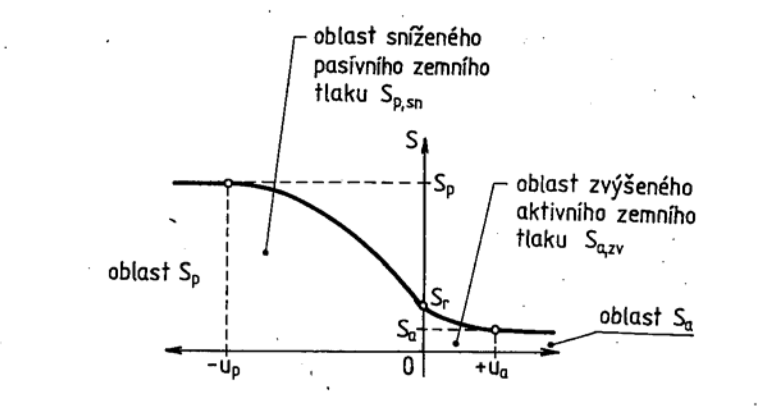
Summary: *The paper presents the results of physical experiment (E3/0+2) both with the passive pressure and the pressure at rest of the ideally non-cohesive sand on a retaining wall rotated about the top. The results are analysed and compared according to relevant requirements and recommendations of the final draft of EC 7-1(2004) and ČSN 73 0037. A preparation state of a next repeated physical experiment E5/0+2 with passive pressure and pressure at rest to prove the results is mentioned.*

1. Introduction

Both the EUROCODE 7-1 “Geotechnical design – Part 1: General rules” (EC 7-1) and ČSN 73 0037 “Earth pressure acting on structures” (ČSN 73 0037) present values of the extreme passive pressure “after mobilization of the full shear strength” and some relative values of movements those should evoke the extreme pressures (EC 7-1, Ann.C, Figs. C1, C2, C3; ČSN 73 0037, Tab.2, Tab.3, Fig.15). The Czech standard also presents a dependence of earth pressure on structure movement (see Fig.1) of which idea is non-linear plastic behaviour of earth pressure both active and passive.



Obr. 1. Schéma průběhu hodnoty zemního tlaku v závislosti na přemístění konstrukce

Fig.1 ČSN 73 0037 – History scheme of earth pressure value depending on structure movement.

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In the light of knowledge from physical experiments at ITAM – ASc. CZR both with active and passive pressure of non-cohesive sand, some theoretical principles of earth pressure theory of the both rulings obviously are not correct and their idea of earth pressure is to a great extent a fiction. A true and veritable behaviour and values of passive pressure during the experiment E3/0,2 are shown in the paper.

2. 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 E3/0,2. 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 (see Fig.2b).

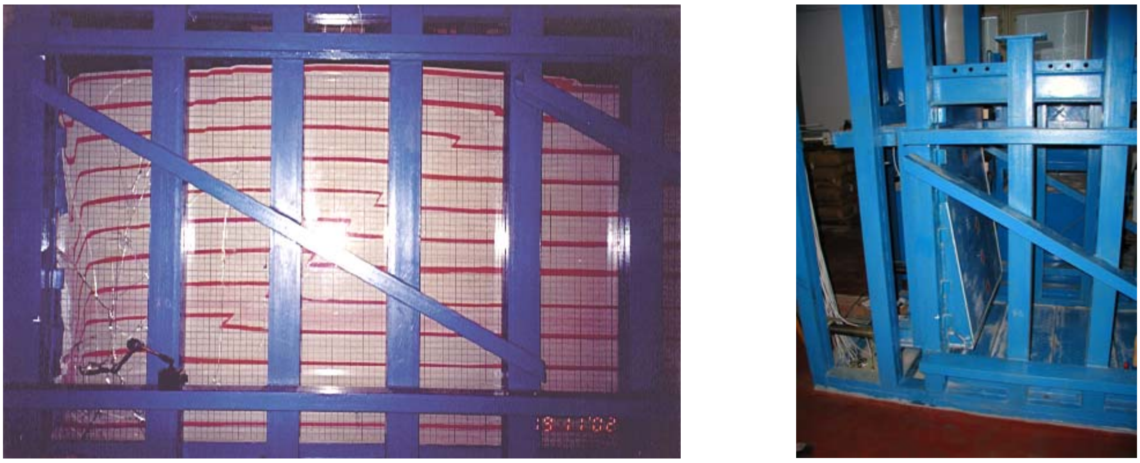


Fig 2.Experiment E3/0,2:

a) Left - The state of the mass and the first glass plate near the moved wall after the toe movement of 134.8 mm before the final toe movement of 159 mm on 18th Nov.2002. The destroyed glass plate resisted the stress state with the pressure up to 160 kPa.

b) Right – The final position of the moved front wall after the experiment.

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 : $\gamma = 16.14$ kN/m^3 (unit weight), w = 0.04 % (water content), $\phi_{ef}' = 48.7^o$ (angle of the top shearing resistance for low stresses), $\phi_r' = 37.7^o$ (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.2b. 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 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.2a.

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 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.

3 Results of experiment E3/0+2

The experiment E3/0+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.

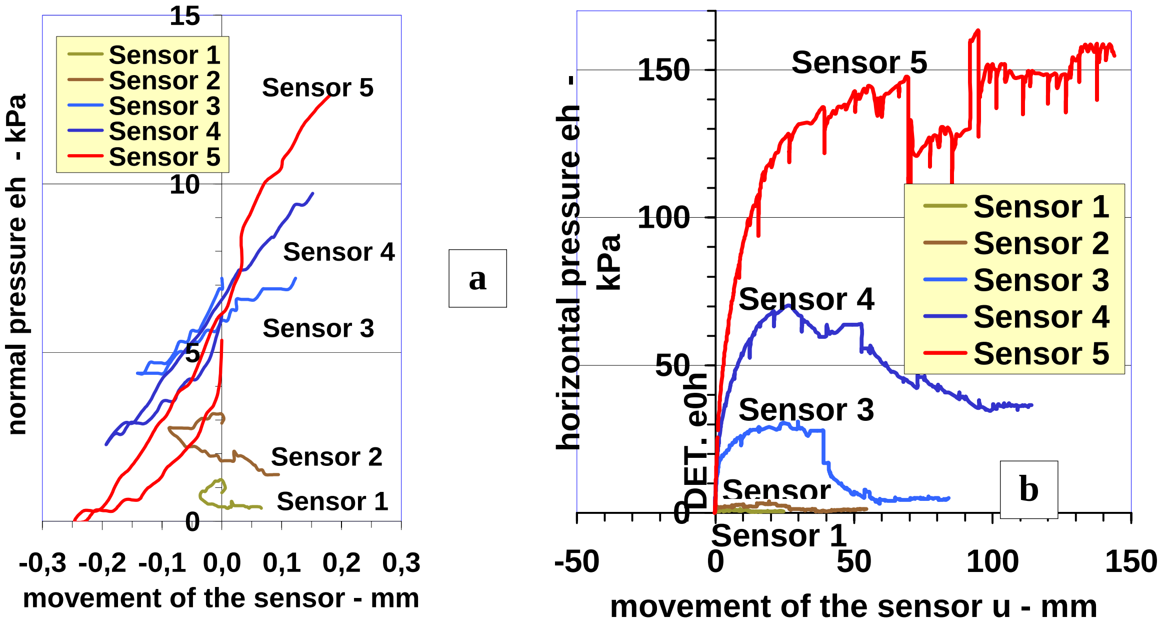


Fig 3: Experiment E3/0+2 - rotation about the top. - History of passive pressure components of the sensors (numbered from upper to lower). a) Pressure at rest in detail (E3/0). b) Whole experiment.

The right Fig. 3b shows the behaviour of the normal pressure components 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 left Fig.3b 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.*

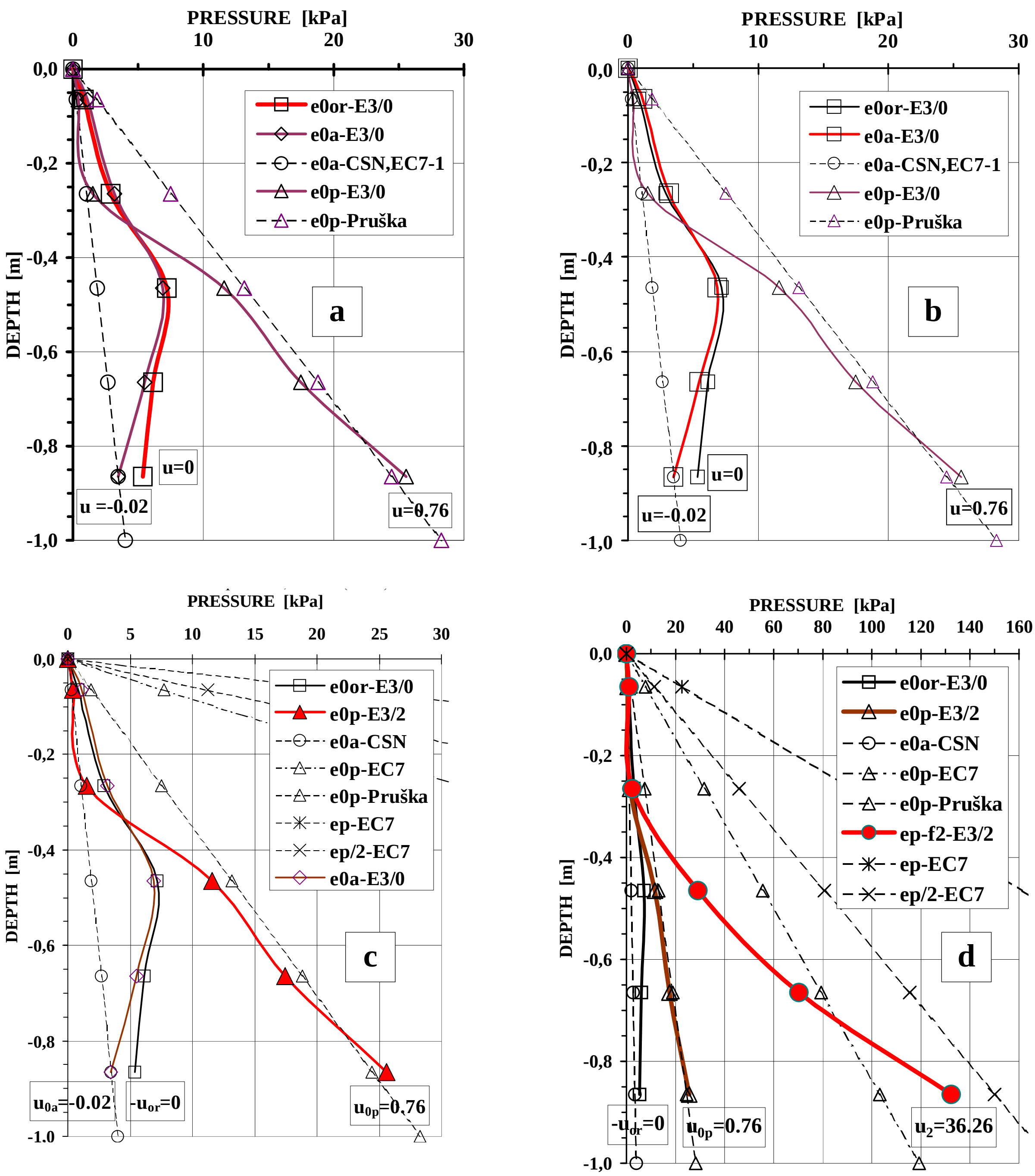
4 Processes of passive pressure - normal components

The experiment brought a large quantity of data. It has been impossible to present all results and a number of them have not been presented yet. The analysis presents a new elaboration of normal component histories of the sensors to be described influences of the processes in the non-cohesive mass. Lower figures are located step by step according the experiment process. The data of Figs.3 afford a possibility to carry out a pressure history for any movement of the front wall (structure), any of a number hundred possibilities. There were chosen some of them those show the pressure processes of deciding movement phases.

The analysis presents also at rest and passive pressures according ČSN 73 0037 and EC 7-1and so it makes it possible to compare the real measured values and processes to the values and images of the relevant rulings. The analysis aims differences between the real processes and values and the images and values of rulings. A discuss of these results is given in the next chapter.

Horizontal axes of the Figs.4 give values of pressure in *kPa*, vertical axes mark the depth from surface of the mass and thus also the locations of the sensors.

The curves in the lower graphs are marked by following types of lines and lower indexes: thick full color lines - results of the experiment, thin dashed black lines - pressure values of the rulings; a - minimal active pressure, 0or - original pressure, 0a - lower limit of pressure at rest (active), 0p - upper limit of pressure at rest (passive) , p - maximal passive pressure, p-fi (i=1, 2, 3, 4, 5) - phases of passive pressure, pr - residual passive pressure.



Figs.4: Process of passive pressure and its histories according the physical experiment E3/0+2 and relevant rulings, i.e. EC 7-1 and ČSN 73 0037:

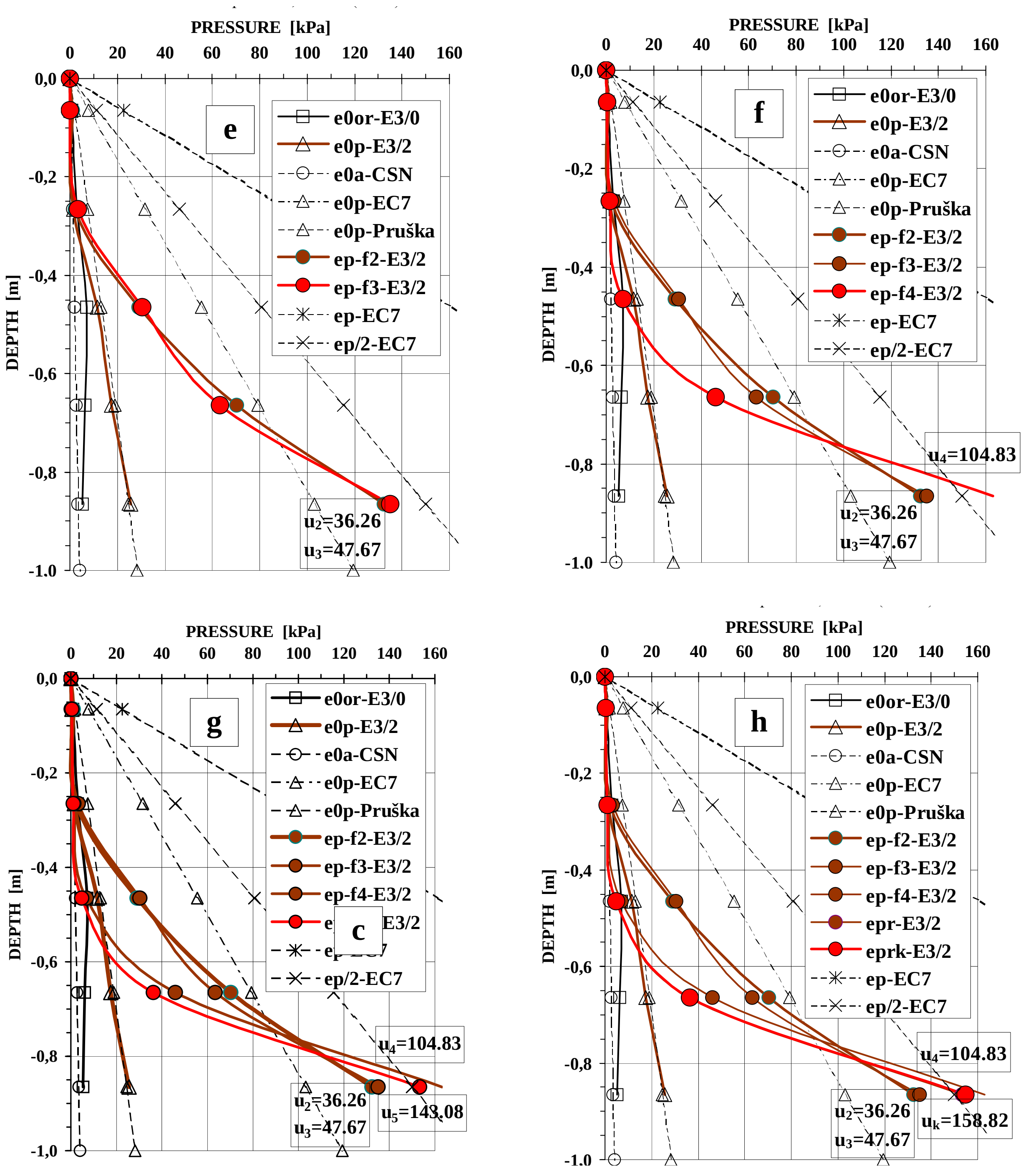
a) The original state before the experiment (u=0 mm).

b) Active pressure at rest (u=-0.02 mm).

c) Passive pressure at rest - phase 1 (u=0.76 mm).

d) Passive pressure -- phase 2 (u=36.26 mm).

Relevant *toe* movements *u* of relevant phases in absolute values in millimetres are presented in black frames near to toes of the relevant curves. The thickest red curves accord to the given phases.



Figs. 4: Process of passive pressure and its histories according the physical experiment E3/0+2 and relevant rulings, i.e. EC 7-1 and ČSN 73 0037:

e) Passive pressure -- phase 3 (u=47.67 mm).

f) Passive pressure -- phase 4 the maximal value of sensor 5 (u=104.83 mm).

g) Residual passive pressure -- phase 5- (u=149.08 mm).

h) Final residual passive pressure (u=158.82 mm).

There can be watched in Figs.4 the process of the red curves step by step depending on the *absolute* movements of sensors. Relations of the real experimental pressures to the fictions according to rulings are also possible and obvious.

5 Discussion

The results of the experiment with pressure at rest E3/0 are evaluated in Figs.4a,b,c. According to Fig.4a the original pressure is close to active pressure at rest but a bit more. The origin state is in interval pressure at rest. The history of active pressure at rest in Fig.4b creates a limit fo the area of pressure at rest, of which sum is obviously more than theoretical one (e_{0a}). The relevant movement is imperceptible. Very good agreement is obvious in Fig.4c at the second (passive) limit of pressure at rest between the experimental history and Pruškaˇs theoretical formula, the relevant movement is also little..

The results of the experiment with passive pressure E3/2 are evaluated in Figs.4d,e,f,g,h. These figures show very obviously a large difference between the maximal passive pressure even its half values considered in the rulings and between real values achieved during the experiment. The real maximal pressure appears that in Fig.4d after the toe movement of 36.26 mm. Then, after following movement a pressure on central wall part decreases on the contrary to a pressure on the toe which increases till the toe movement of 104.83 (Fig.4f). A total residual passive pressure can be considered according to the Fig.4g and the final Fig.4h. A decrease of the summed residual pressure is obvious.

6 Conclusions

It is not possible to 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 a new theory of lateral pressure (see Figs 3b, 4f,g,h).
b) The experiment E3/0 and previous experiments E1 and E2 have proved the Pruškas´s theoretical derivation of the interval of pressure at rest in the very close area about zero movements (Figs.3a, 4a,b,c).
c) The theoretical basis of the both rulings (EC 7-1 and 73 0037) is in discordance with reality and it is necessary to change it according to new knowledge.
d) Both compared standard values (EC7-1 and ČSN 73 0037) of the top *normal (horizontal)* component of *passive* pressure appear as *too high*.
e) It is very necessary to eliminate the Tables C1, C2 and Fig.C3 from EC 7-1 similarly like Figs. 1 and 15 and Tabs. 2 and 3 from ČSN 73 0037.
f) 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.
g) The new knowledge has shown the necessity to include into the developed theory also lateral pressure *values* with greater accuracy.
h) 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.
i) 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.
j) 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.

The conclusions on passive pressure should be verified and extended to other types of structure movement. The continuation of the research is necessary. Contemporary a next parallel experiment with passive pressure acting on the wall rotated about the toe E5/0+2 is prepared and will be start in the near future.

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