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Double Case of Passive Pressure Acting on Wall Rotated About the Top

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ABSTRACT

Basic research of lateral earth pressure based on physical and numerical experiments began in 1998 at the institute of the author and it has continued to the present time. The physical research should prove the behavior of ideally non-cohesive granular mass during three basic types of structure/wall movement towards in active and passive directions. The first research period in 1998-2000 was aimed on active pressure, and in 2001-2002 on the first long-term experiment with passive pressure (E3/0.2). Then new experimental equipment was developed between 2003 and 2009 on a contemporary advanced level. The first long-term experiment with passive pressure E3/0,2 acting on a wall rotated about the top was repeated and as double same long-term experiments, denoted as experiments E5/0,2 (2010) and E6/0,2 (2011). The new equipment is completely under computer control and it has five bi-component pressure sensors in the arbitrarily moved front wall and six sensors in the solid back wall. The velocity of the front wall movement can be arbitrarily *slow* from of 3.684 to of >0 mm/min, the maximal pushing force being about of 2870 kN. The maximal recording frequency is of 1000 Hz and it can accommodate a huge quantity of data of 803 MB/day. The paper presents proof that theoretically considered passive pressure of ideally non-cohesive material on a wall rotated about the top cannot be achieved.

INTRODUCTION

The contemporary theoretical base of earth pressure by European standards and the EUROCODE 7-1 (EC 7-1) (and may be found elsewhere) is very old (see basic works on earth pressure of Terzaghi 1936, Jáky 1944 on the lower limit of pressure at rest). However, a center core of the theory was created steel by ancient Belgian engineers and Coulomb (1776) from an imagination of a solid wedge block or other figure acting on a retaining structure. This was developed during the second half of 19th century by Rankine (in 1856), and an influence of internal friction angle was innovated by Moller and Muller-Breslau in 1857. It was completed during the 20th century by Ohde (in 1938 and 1956). Surprisingly, highly important findings as being Terzaghi´s dependence of earth pressure coefficient *K* on wall movement (1943 – present after by Simpson in 2001), , Pruška`s second limit of pressure at rest (passive pressure at rest, theoretically derived in 1973) and Gudehus`s histories of overall active pressure and overall passive pressure during the three basic movements of the retaining wall (1980) were not considered by theory of the code and standards.

Computers provided new prospects to geotechnical design and their results brought imaginations very distinct from the previous designs and imaginations for standard earth pressure theory. As early as the first results of a Dependent Pressure Method (DPM) (originally the Polygonal Method, developed by Zapletal in 1981, later named "DPM" by J. Barták) exhibited a very dissimilar behavior of numerical models from theoretical suppositions of the conventional standard theory. Discordance between the old standard theory and practice findings had existed before and had been solved in design practice by special different load patterns and some other approaches based on contemporary knowledge.

A great advance in geotechnical design and practice in the following era occurred due to the huge development of both design and site technology and those were recognized as gigantic and dangerous works. Many excellent case reports was presented during the last decade and some important knowledge for the earth pressure theory was developed by, e.g., Desai 2001, Kusakabe 2005, Barbosa 2009, Gutierrez 2009, T. Koudelka et al. 2004, Kruis et al. 2010, P. Koudelka 2000, 2008, Kruis et al. 2007 (advanced program "SIFEL"),, and Krejčí-T.Koudelka 2012. Despite new knowledge and new experiences, the standard EUROCODE 7-1 theory base remains closely unchanged like the theory of the 1950s.

It was at Prague's Institute of Theoretical and Applied Mechanics of the Academy of Sciences of the Czech Republic in 1998 that basic research of earth/lateral pressure based on physical and numerical experiments was inaugurated and is still in progress there. The research is designed to affirm the behavior of ideally non-cohesive granular mass during three basic types of structure movement towards active and passive directions. The research is designed to improve the theory. The focus of the first research period in 1998-2000 was on active pressure and in 2001-2002 on the first long-term experiment with passive pressure (E3/0.2). During the second period (2003-2009) experimental equipment on the second and the third (contemporary) stages was developed. The first experiment with passive pressure E3/0,2 (2001-2) was repeated in the frame of the second research period, such as double same long-term experiments designated E5/0,2 (2010) and E6/0,2 (2011). The passive pressure during rotation the wall about the top was tested of which the experiment E5/0,2 was also a successful long-term operation test of the new experimental equipment (Koudelka P. et al. 2011).

The paper, with the exception of basic information on the experimental equipment and the above mentioned experiments, presents results of a comparative pressure analysis of the both experiments. The analysis proves substantial differences between the earth pressure theory of EC 7-1 (and other standards) and the actual non-cohesive mass.

EXPERIMENTAL EQUIPMENT

Former simple experimental equipment for a maximal sample size of 3.0*1.0*1.2 m was designed and constructed in 1997-1998 for basic research of the lateral pressure of multi-phase granular materials and to verify a theoretically derived "*General* Lateral Pressure Theory" (GLPT). The equipment made possible a simple hand-made arbitrary movement of the front wall and took two component data of five excellent bi-component pressure sensors (invented by Šmíd-Novosad) placed in the moved front wall. Two glass sides served for a visual monitoring of processes into the granular mass.

The research using this former stand has produced some obviously new results, some of which can be considered as substantial (e.g., time instability of lateral pressure, proof of interval of pressure at rest and an existence of its limits, proof of increased residual active pressure, existence of a decreased residual passive pressure and others). In addition, it achieved such high passive pressure that nearby glass side tables cracked but while the experiment was successfully completed,, stand renovation and development was necessary.

The second development stage of the stand involved changing the thicker glass sides and because of that a less wide front wall. However, the most important advance has been a motor engine movement of the wall and computer control.

The earlier experiments using the former equipment gave incomplete boarder conditions for 2D numerical analyses. Major aims of the third actual stage of equipment 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 related to up-graded existing hardware and new software. The 3rd stage contains also a very important visual observation and monitoring with continuous registration of the soil mass behavior by a number of cameras under computer control. The experiment E5/0,2 with pressure at rest and passive pressure was simultaneously the operation test of the equipment.

The actual advanced equipment (Figs. 1a,b) is the same size and is totally controlled by two computers (the first for front wall movement and data monitoring and registration, the second for visual monitoring and photo registration). This reaches to very suitable characterizations: max. *active* wall movement of 300 mm, max. *passive* wall movement of 242 mm, arbitrarily *slow* front wall movement of velocity from of 3.684 to of >0 mm/min., max. pressing force cca. 2870 kN, five bi-component pressure sensors in front moved wall, one

Fig. 1. Experimental equipment with transparent glass sides before experiment E5/0,2 with non-cohesive sandy sample into: a) (above) Lateral view at right equipment side. The moved front wall is left. b) (below) Lateral and back view at left equipment side. Front moved wall is right and back solid wall with one three-component and five bi-component pressure sensors is left.

three-component sensor and five bi-component pressure sensors in back solid wall (Fig.1b), two potential movement sensors, one optoelectronic movement sensor, one impulse summator, max. recording frequency 1000 Hz. The equipment can accommodate a huge quantity of data of 803 MB/day. Visual registration data are stored separately. (A detailed description of the equipment can be found in Koudelka P. and Bryscejn J. 2010 and the technical characterizations of the equipment development stages in Tab. 1.) Views at the equipment are shown in Figs. 1a,b.

Table 1. Characterizations of the experimental equipment

Property	unit	1st stage value	2nd stage value	3rd 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	3.684	3.684
Maximal pressure force				
	kN	manual	**2870**	**2870**
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**	-	-

SAMPLES

The same material (quartz sand) under the same compaction is used for samples of all experiments. Principal physical properties of the sample were found as follows: unit weight γ = 15.172 and 15.697 kN/m^3 for E5/0,2 and E6/0,2, respectively, effective angle of shearing resistance ϕ_{ef} = 38.5°, effective cohesion c_{ef} = 0, residual angle of shearing resistance ϕ_r = 31°, structure-ground interface friction angle δ = 12.8°, moisture w = 0.3 %.

EXPERIMENT E5/0,2

The experiments are a part of the set of basic physical experiments with ideal non-cohesive material that verifies the real behavior and pressure of the mass during the wall movement. The set considers cases of all three basic movement types, i.e., rotations about the toe and the top and translative motion, both in active and passive directions. Each of the cases is verified by the same two experiments. Thus, the set consists of the following experiments:

active pressure:

- double of repeated experiments with pressure at rest and *active* pressure during *wall rotation about the toe* (E1/0,1 and E2/0,1 – 1999),
- double of repeated experiments with pressure at rest and *active* pressure during *wall rotation about the top* (E1/0,2 and E2/0,2 – 1999),
- double of repeated experiments with pressure at rest and *active* pressure during *wall translative motion* (E1/0,3 and E2/0,3 – 1998-9),
- double of repeated experiments with pressure at rest and *passive* pressure during *wall rotation about the toe* (E5/0,1 and E6/0,1 – 2012),
- double of repeated experiments with pressure at rest and *passive* pressure during *wall rotation about the top* (E5/0,2 and E6/0,2 – 2010 and 2011, respectively),
- double of repeated experiments with pressure at rest and *passive* pressure during *wall translative motion* (E5/0,3 and E6/0,3; should be carried out in 2013).

The first experiment with passive pressure E3/0,2 is not taken into account that it does not appears to be totally comparable.

The experiment E5/0,2 was the first one exploiting the new equipment. It was started in April 8th, 2010 and completed October 13th, 2010. An extraordinarily important factor of the experiments is a velocity of the wall movement. It was the chosen movement of the toe of 0.005 mm/min because this value is near natural phenomena (e.g., 26 times faster than the continental drift or 50 times faster than finger nail growth). A history of the experiment is found in Tab. 2.

EXPERIMENT E6/0,2

The repeated experiment E6/0,2 was the second one of the doublet of the same experiments with passive pressure acting on the wall rotated about the top. It was started in March 25th, 2011 and concluded September 25th, 2011. The velocity of the wall toe movement was also of 0.005 mm/min. A history of the experiment can be seen in Tab.3.

Table 2. History of experiment E5/0,2 – Rotation about the top

E5/0,2	Date			Movement		
Phase [1)] [Note]	Start [d/m/y]	End [d/m/y]	Time [2)] [h/m/s]	Direct ion [1)]	Max. dist. [3)] [mm]	Toe velocity [mm/mi n.]
0a	08.04.10	08.04.10	1:01	a	- 0.270	0.005
recon.1	08.04.10	15.04.10	-	-	- 0.270	0
a0	15.04.10	15.04.10	1:09	p	- 0.083	0.005
recon.2	15.04.10	22.04.10	-	-	- 0.083	0
0p	22.04.10	22.04.10	1:40	p	0.768	0.005
recon.3	22.04.10	03.05.10	-	-	0.768	0
p1	03.05.10	05.05.10	52:11	p	15.601	0.005
recon.4	05.05.10	14.09.10	-	-	15.601	0
p2	14.09.10	13.10.10	703:40	P	226.89	0.005

1) Phases containing zero indicate movement in a branch of pressure at rest, similarly "a" branch of active pressure and "p" branch of passive pressure, Numbered phases "recons" indicate period’s re-consolidation without a movement for research of time stability of the pressure.

2) Time of continuous wall movement.

3) Maximum distance of the wall toe at the phase end from wall original position before the experiment start.

Table 3. History of experiment E6/0,2 – Rotation about the top

E6/0,2	Date			Movement		
Phase [1)] [Note]	Start [d/m/y]	End [d/m/y]	Time [2)] [h/m/s]	Dire ctio n [1)]	Dist. max. [3)] [mm]	Toe velocity [mm/mi n]
0a	25.03.11	25.03.11	0:59:59	a	0.200	0.005
rec.1	25.03.11	31.03.11	-	-	0.200	0
a0	31.03.11	31.03.11	1:14:25	p	0.020	0.005
rec.2	31.03.11	07.04.11	-	-	0.020	0
0p	07.04.11	07.04.11	1:40:16	p	0.292	0.005
rec.3	07.04.11	26.04.11	-	-	0.292	0
p1	26.04.11	03.05.11	163:52:20	p	47.950	0.005
rec..4	03.05.11	01.09.11	-	-	47.950	0
p2	01.09.11	25.09.11	578:02:28	p	205.46	0.005

1) Phases containing zero indicate movement in a branch of pressure at rest, similarly "a" branch of active pressure and "p" branch of passive pressure, Numbered phases "recons" indicate period’s re-consolidation without a movement for research of time stability of the pressure.

2) Time of continuous wall movement.

3) Distance maximum of the wall toe at the phase end from its original position before the experiment start.

EXPERIMENTAL RESULTS

The experiments produced an extreme quantity of data of *4.7* and *1.7 GB* of E5/0,2 and E6/0,2, respectively, (time data and sensor data only without visual monitoring data and photos). The data quantity requires special technology (software, approaches, etc.) of which the development is running. At all events, the size of experimental results does not make it possible to present them complete in the paper. Complete analyses and evaluations of particular aspects of the granular mass behavior in detail will be presented step by step later. The paper is concerned with lateral earth pressure and with a comparative analysis of its normal component to be proved by the real behavior of the non-cohesive mass as follows below.

Data of the Experiments

Data of sensors were monitored and registered in the software format of NEXTVIEW (BMC Messsysteme GmbH) and further translated in format text. A separate problem has been deciding on considered exact fixed values. Further presented values are averages of ten values adjoining to the given moment.

Movement of the front wall toe was measured using five independent techniques: potential movement sensor, opto-electronic movement sensor, impulse summator, calibrating micrometer and the maximum distance from the origin after the experiment by electronic micrometer. There were not found significant differences. A position of the front wall top (not moved) was controlled by the second potential movement sensor. Movement values presented in the Paper are data according to the lower potential movement sensor in all experimental phases except of the last one (p2) for which are used data according to the measurement after the experiment by electronic micrometer.

Mass Deformation and Failures

The right glass side wall of the equipment is provided with a black net of 20/20 mm. The sample contains red strips of colored sand in contact with the right side glass wall. The distance of the strips is 100 mm and strip positions in the original state coincides with thick horizontal lines in the net (Fig. 1a)

Figs 2a,b, show a state of the deformed sample and seven slip surfaces self-created after a passive rotation of the front wall about the top (towards the mass) with a toe movement of u = + 154,74 mm. The red strips in the deformed mass very obviously present changes and failures in the mass. The slip failures in the strips are very clear cut and precise, better than

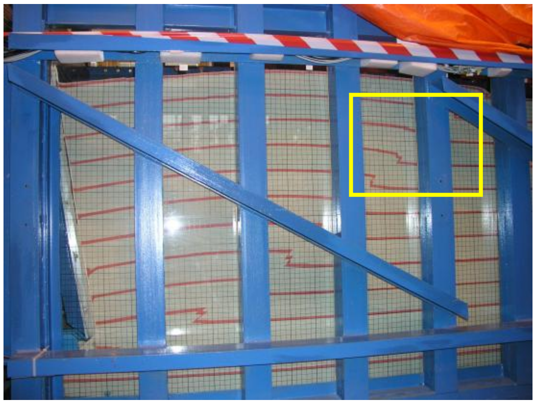

Fig. 2a. Experiment E5/0,2: View on the deformed and failed front section of the mass behind the moved front wall after rotation about the top and toe movement of u=+154.74 mm. A position of the front wall is very obvious on the left.

→

Figure 2b. Experiment E5/0,2: Detailed view of the deformed and failed area marked in Fig. 2a with a zone of a main system of the slip surface after rotation about the top (toe movement of u=+154.74 mm).

Fig. 3a. Experiment E6/0,2: View on the deformed and failed front section of the mass behind the moved front wall after rotation about the top and toe movement of u=+156.25 mm. A position of the front wall is very obvious on the left.

→

Figure 3b. Experiment E6/0,2: Detailed view of the deformed and failed area marked in Fig. 2a with a zone of a main system of the slip surface after rotation about the top (toe movement of u=+156.25 mm).

other methods. Comparing the slip failures to the solid net on the glass side, it is possible to observe displacements and a development of the slip surface exactly (Fig. 4a). Frames in the Figs. 2a and 4a mark the detail of Figure 2b.

Similarly Figs.3a,b prove similar and almost the same behavior of the second sample during the repeated experiment E6/0,2 to E5/0,2 (see seven slip failures in Fig. 3a and the part of the major failure zone in detail in Fig. 3b), after a similar toe movement of *156.25 mm.* Also this is behind the maximal toe movement of *150 mm* considered by the Code (EC 7-1) as needed to achieve the maximal (full) passive pressure. A real state of a normal pressure component in a mass/wall contact is dealt in following Chapter. An obvious view on measured slip surfaces of the experiment E6/0,2 is in Fig. 4b.

The major slip zone divided the mass in two parts: a *failed* part above the slip zone closer to the front wall and a *stabile* part under the zone closer to the back solid wall. A surface of the mass formed simultaneously to the wall movement, however, on the fail part only (Figs. 2a, 3a – upper ends of the slip surfaces and "Visual observation" below). Theoretical shear/slip surfaces according to ČSN 73 0037 (left) and EC 7-1, Annex C (right) are given by dashed lines in Figs. 4a,b. Frames in the diagrams mark the details of Figs. 2b and 3b.

Visual Observation

To capture the relation between slip lines observed on the surface development, the final state of the sample's surface was thoroughly analyzed. A 3D scanner Leica ScanStation C10 was used for precise surface topography determination. The scanner is a sophisticated device utilizing a precisely positioned laser with a femtosecond pulse duration and precise atomic clock for distance measurement via a method called "duration of flight" of laser light. The result of this measurement is a "cloud of points" that is the measured surface.

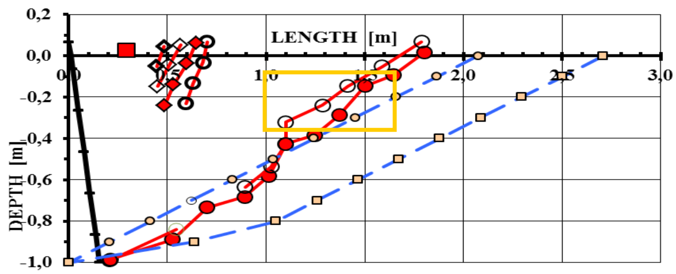

Fig. 4b. Experiment E5/0,2: Seven failure slip surfaces in the sample front part after the toe movement of 154.74 mm derived according to the failed red strips. Major slip zone is created by two surfaces Nos. 1, 2.

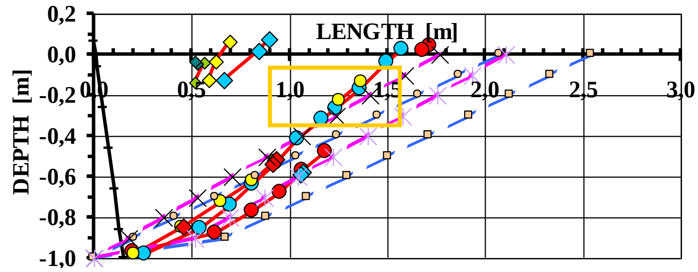

Fig. 4b. Experiment E6/0,2: Seven failure slip surfaces in the sample front part after the toe movement of 156.25 mm derived according to the failed red strips. Major slip zone is created by three surfaces Nos. 1, 2 and 3. The zone can be compare to theoretical slip surfaces according to ČSN 73 0037 (blue) and EC 7-1 (purple).

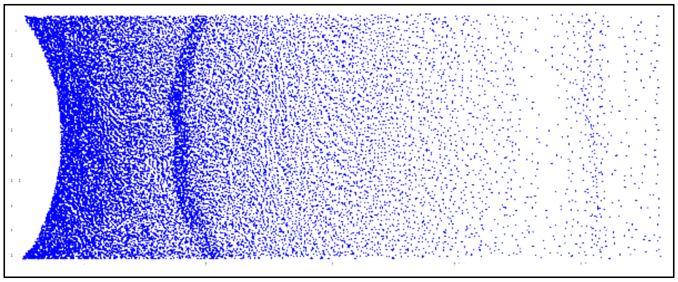

Figure 5. Experiment E5/0,2 - Reverse view on the final state of the sample upper surface after the toe movement of 226.85 mm (the moved front wall is right and the solid back wall is left). Cloud of points acquired by laser scanner can, as in this example, be unevenly distributed (length is 3 m, width is 1 m).

This cloud of points is in an extensive and time-consuming post-processing stage converted into a smooth surface; incorrectly determined points are excluded. The surface can be visualized and manipulated with several software tools. The result of the procedure in Fig. 5 is in a reverse position (the moved front wall is right, the solid back wall is left).

ANALYSIS OF PASSIVE PRESSURE

This comparative analysis of results of experiments E5/,02 to E6/0,2 concentrates on a *normal component* pressure acting on the *moved front* wall in accordance [or, compliance?] with the Code (EC 7-1) theory of passive earth pressure. Both components of pressure on the solid back wall were registered and while also interesting they do not play a role in the analysis. Regarding the given case of wall movement, the Code gives toe movement values to be achieved at half of the total passive pressure and the total passive pressure. They are given in relative values to the height of the wall for loose soil of *1.0-1.5%* and of *6-15%*, respectively, then for dense soil of *0.5-1.3%* and of *5-6%*, respectively. These values can be transformed to absolute values of the experimental equipment for rotation about the top of *10-15 mm* and of *5-13 mm* for half of the passive pressure and of *60-150 mm* and of *50-60 mm* for the total passive pressure, respectively. The experimental samples were compacted a bit more than slightly [or, were slightly compacted and their density can be considered as intermediate between loose and dense. Then intervals of the toe movement by the Code mentioned are of *5-15 mm* and of *50-150 mm*. The analysis has been carried out through the full scales of the toe movements of the experiments. The paper presents from point of the Code concept view the most important cited states of the masses.

Each graph in the following figures shows histories of pressures (horizontal axis) of both experiments acting on the wall and depending on the depth (vertical axis). The histories of the pressures are thick in solid red (E5/0,) and purple (E6/0,2) curves. Each graph also contains original pressure histories before the experiments colored red or purple and dashed, respectively. Lines distinguish theoretical pressures, i.e, both active (Jáky) and passive (Pruška) pressure at rest, half full passive and full passive. The letter *u* and the value in the text field denote the respective toe movement to the pressure curve.

<u>Half Full Passive Pressure</u>

The states adhering to the Code supposed for a half of passive pressure are shown in Fig. 6 to be closely to the lower values for loose and dense soils. Fig. 6 demonstrates a normal component pressure of E5/0,2 (red curves) original and after toe movement of *10.11 mm* (loose soils) as well as both pressures of E6/0,2 (purple curves), the full curve representing the state after toe movement of *6.42 mm* (dense soils).

The toe movement of E6/0,2 conforms more closely to the lower Code value for reaching the half passive pressure of dense soils *(5 mm)* and the toe movement of E5/0,2 is adequate for the lower value of loose soils *(10 mm)*. However, it is necessary to take into account that the samples do not represent exactly dense or loose soils but both samples are of the same type of soil and compacted approximately in the same way. The difference between the pressure histories was due to this difference between the toe movements. The

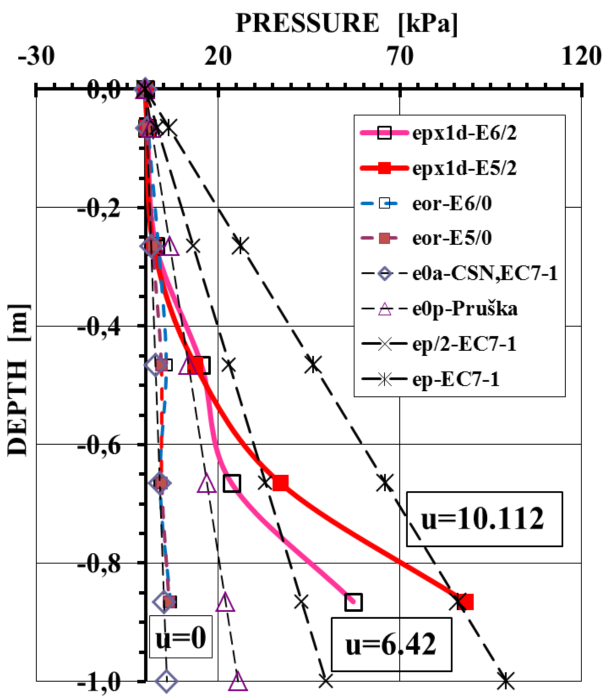

Fig.6. Histories of passive pressures of both experiments (red E5/0,2, purple E6/0,2): full curves - after marked toe movements, dashed before the experiments. The movements are in accordance to the lower toe movements of EC 7-1 for the half passive pressure values.

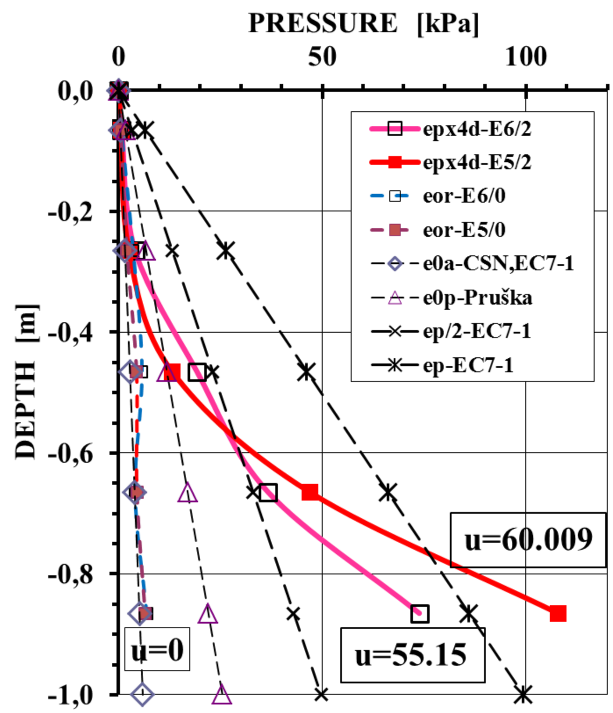

Fig.7. Histories of passive pressures of both experiments (red E5/0,2, purple E6/0,2): full curves - after marked toe movements, dashed before experiments. The movements are in accordance to the lower toe movements of EC 7-1 for the full passive pressure values.

pressure curve of E6/0,2 could be put near to E5/0,2 if the movement continues. It can be stated the pressure does not achieve the half passive pressure values through the whole depth interval as far as to of *- 0.665 m,* but the pressure around the toe in a deeper area touches (E5/0,2 - *u=10.112 mm*) the full passive pressure value.

The toe is a singular wall point of the case and a pressure acting on it could not be investigated due to a size of pressure sensors. The pressure courses were investigated as far as to a depth of 0.865 m but a further course is problematic. Probably it cannot be considered as a simple extrapolation.

<u>Full Passive Pressure</u>

A formal adjustment of graphs in Figs. 7 and 8 showing histories of normal components of the real full passive pressures and denotation are the same like Fig. 6 in the previous sub-chapter.

The normal pressure state in a movement area of the *lower* toe movements presented in EC 7-1 (*50-60 mm*, dense and loose soils, respectively) is given in Fig. 7 for real toe movements of *60.009 mm* (E5/0,2) and *55.15 mm* (E6/0,2). Normal pressures of both experiments are somewhat higher but not by much. The pressures on more than an upper half of the wall are lower

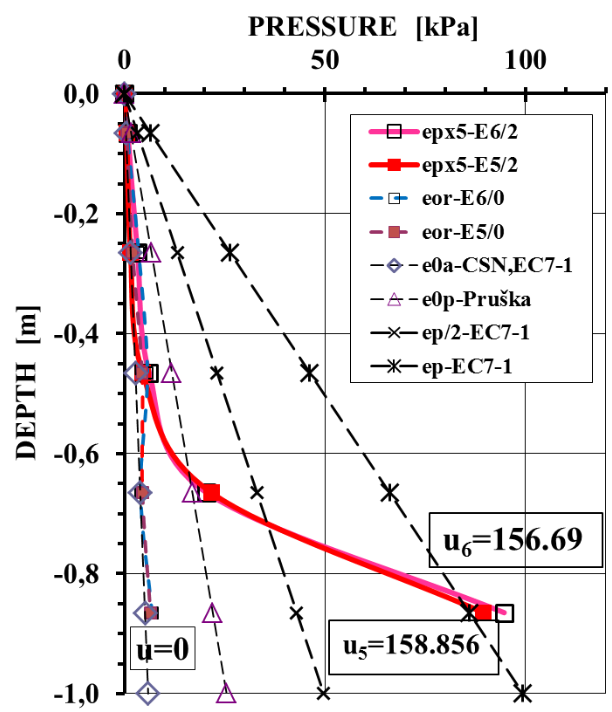

Fig.8. Histories of passive pressures of both experiments (red E5/0,2, purple E6/0,2): full curves - after marked toe movements, dashed before experiments. The movements are in accordance to the upper toe movements of EC 7-1 for the full passive pressure values.

than the half passive pressure values. Only at around a depth of *0.865m* does the curve of E5/0,2 increase to and across the value of the theoretical passive pressure. The history of E6/0,2 does not achieve the theoretical value.

The normal pressure state after crossing the *upper* toe movements presented in EC 7-1 (*130-150 mm*, dense and loose soil, respectively) is given in Fig. 8 for real toe movements of *158.856 mm* (E5/0,2) and *156.69 mm* (E6/0,2). Normal pressures of both experiments are higher somewhat but not much. The pressures on more than an upper half of the wall are lower than the half passive pressure values. Only around depth of *0.865m* the curve of E5/0,2 increases to and across the theoretical passive pressure value. The history of E6/0,2 does not achieve the theoretical value.

The normal pressure state after crossing the *upper* toe movements presented in EC 7-1 (*130-150 mm*, dense and loose soil, respectively) is given in Fig. 8 for real toe movements of *158.856 mm* (E5/0,2) and *156.69 mm* (E6/0,2). *The histories of both experiments are nearly the same and pressures are substantially lower than in Fig. 7. Differences to the full pressure are extremely high in more than the upper half of the wall in which the pressure is mostly in the interval of the pressure at rest. Both pressures on the lower wall part under a depth of 0.665 m increase simultaneously through the interval between a half of the passive pressure and the full passive pressure however, the full pressure value is touched in depth only of 0.865 m.*.

Figs. 6, 7 and 8 obviously demonstrate the pressure histories of both experiments and are not in accordance to the EC 7-1 presuppositions and both pressure histories cannot afford the supposed total full pressure. The following subchapter contains a quantified evaluation of the results

Normal Pressure Evaluation

The evaluation is carried out by integrating all investigated pressure histories of both experiments and by a pressure calculation in accordance with the Code in which it is not defined as the curve of pressure/movement. The curve is substituted by a combination of line and parabola. Comparative graphs for the total normal force and a total moment of the force to the toe are in Figs. 9 and 10.

Full blue curves in the graphs represent values of the Code's supposed effects and the red and purple ones give the real total effects of both experiments E5/0,2 and E6/0,2, respectively. The major difference of behavior can be seen between the Code course and the real courses of the experiments. While the Code considers a constant (full) value after the supposed toe movement (ideal plastic behavior), the real behavior is something else. The pressures of both experiments decrease after reaching the maximal values to residual values due to the creation of a number of *failure surfaces* and deformations of masses *closer* to the wall.

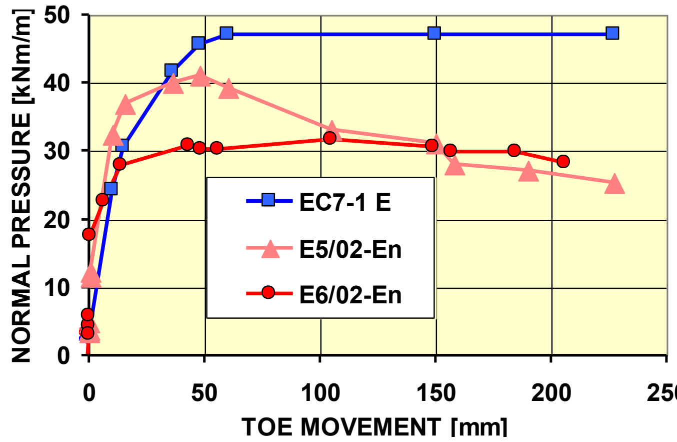

Fig. 9. Histories of the experimental total normal forces and total full passive force according to EC 7-1.

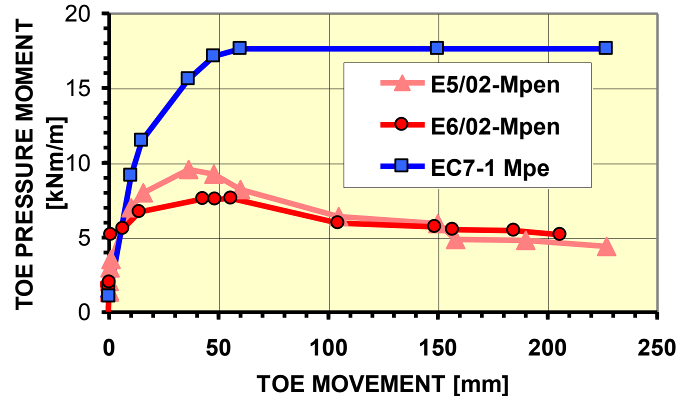

Fig. 10. Histories of moments of the experimental total normal forces and the total full passive force to the toe are according to EC 7-1.

Figs. 9 and 10 clearly show that the total normal pressure effects are less than those presupposed in the Code. The total full normal force of the Code should be of values of around *47.09 kN/m (u=from50 to 150 mm)*, but the maximal values of experiments E5/0,2 and E6/0,2 are *41.09 kN/m (u=47.704 mm)* and *31.67 kN/m (u=104.56,)* respectively. The moment to the toe of the total full force of the Code should be of *17.64 kNm/m (u=from50 to 150 mm)*, however, the adequate maximal values of the experiments E5/0,2 and E6/0,2 are *9.56 kNm/m (u=36.298 mm)* and *7.61 kNm/m (u=55.59 mm)*, respectively.

The above mentioned pressure effect differences between both experiments and EC 7-1 presuppositions are more instructive expressing them in relative values to the EC 7-1 effects as follows:

- reached maximal total normal forces *87% (E5/0,2)* and *67% (E6/0,2)*,
- residual total normal forces after toe movement more than of *150 mm* decreased on of *60% (E5/0,2)* and of *64%*

(E6/0,2),

- reached the maximal moments of the total forces to the toe of *54% (E5/0,2)* and of *43% (E6/0,2)*,
- residual moments of the residual total normal forces after toe movement more than of *150 mm* decreased on of *28% (E5/0,2)* and of *31% (E6/0,2)*,
- residual moments of the residual total normal forces after toe movement more than of *200 mm* decreased on of *25% (E5/0,2)* and of *29% (E6/0,2)*,

This comparison supports the theoretical concept of earth pressure theory that the statement of EC 7-1 (Annex C) is not accurate.

CONCLUSION

The double experiments with passive pressure of the wall rotating about the top prove the similar real behavior of the non-cohesive sandy samples and the similar real histories of the normal pressures. On the basis of this proof, some summaries valid for the analyzed type of wall movement can be made, as follows:

- The Code's concept of achieving full passive pressure along a whole wall, i.e., a full passive force, due to the toe movement, *is highly optimistic, very dangerous and risky*, based independently on an absolute toe movement quantity.
- An old engineering byword not to utilize more than half passive pressure force is not exactly accurate, but mostly correct.
- The real moment effect of passive pressure is relatively less than the force effect. The real moment effect is only somewhat more than a quarter of the effect as, the EC 7-1 supposes.

The paper does not deal with the time instability of lateral earth pressure. The pressure changing during the time of rest (without movement) appears to be a tendency of less favorable values. This phenomenon and the demonstrated results of both experiments lead to the conclusion that the earth pressure theory in EUROCODE 7-1 should be revised.

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