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Results of Measurements of Pore Water and Air Pressure in Model Studies on an Flood Embankment Under Variable Water Saturation Conditions

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1. Introduction

A flood embankment is an artificial earth wall in the form of an escarpment-shaped fill, whose length is one of the characteristic parameters. Flood embankments are an important component of the system of protection of people, animals and material objects from flood. During its exploitation, a flood embankment is exposed to destructive factors – mainly changeable water saturation levels. This results in a rapid escape of air from the inside of an embankment, which is linked to the initiation of the destruction of the whole structure. The research discussed in the article was first conducted as part of the European Union Integrated Project called FLOODsite (*Integrated Flood Risk Analysis and Management Methodologies),* 2004-2009, Fourth Framework Programme of the European Union, coordinator: HR Wallingford, the United Kingdom, contract no GOCE-CT-2004-505420, and subsequently continued under the framework of the TROIAnet network, financed by the Polish Ministry of Science (2009) and a grant funded by the National Science Centre no NN 506 31 70 39 „Studies on changes in the earth microstructure and its influence on process of water flow and transport of pollutants in flood embankments", carried out in 2010-2013. Model tests were performed at the Institute of Hydroengineering of the Polish Academy of Sciences in Gdańsk.

2. Research method

The research station (Fig. 1) was built by Abo Elela in 1996, but it was refurbished in 2006, which is when a system for measuring air and water pressure in soil pores was added (Abo Elela 1996). Another refurbishment took place in 2011, when the pressure recording system was modernized.

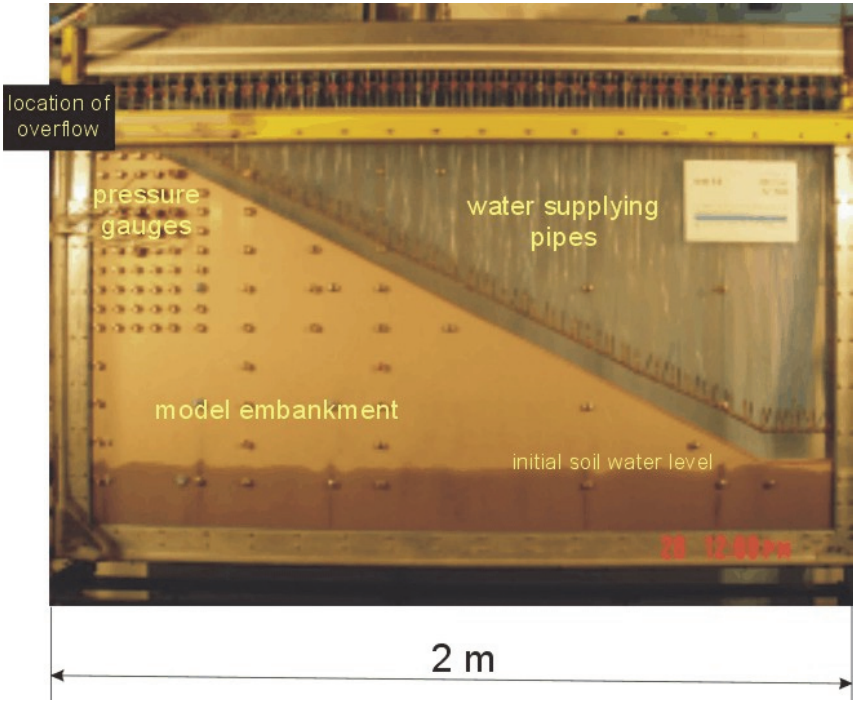

Fig. 1. Component elements of the research station

The knowledge of pressure changes inside the flood embankment model has not been adequately described in the literature. The work is an observation of phenomena occurring during changing hydration conditions with particular emphasis on changes in pore pressures within the model.

The main measurements of pressure were recorded on a model whose geometrical parameters are presented in Fig. 1. It was made of Lubiatowo sea sand, whose characteristics are presented in Table 1. The model was formed with the sand rain method (Kolbuszewski & Jones 1961, Zaradny 1993, 1994). The angle of inclination ($\alpha = 27°$) of the model (Fig. 2) is due to the need to load it in the limit state of load, which facilitated the observation of model degradation. More than 50 tests were conducted. The most representative was test No. 17, the results of which are shown below.

Variable	Value
Median d_{50}	0.25 mm
Filtration coefficient k_s	0.016 cm/s
Volume weight	17.0 kN/m^3

Table 1. Characteristics of Lubiatowo sand

The initial pressures in the unsaturated zone were calibrated to zero. During the modelling, the degree of compaction of the entire model was not verified, but based on previous experiments it was assumed that it was homogeneous. The model was formed in the ultimate limit state. Based on the observations of previous tests, it was found that the determination of the groundwater level had a small and negligible effect on the pore pressure measurements.

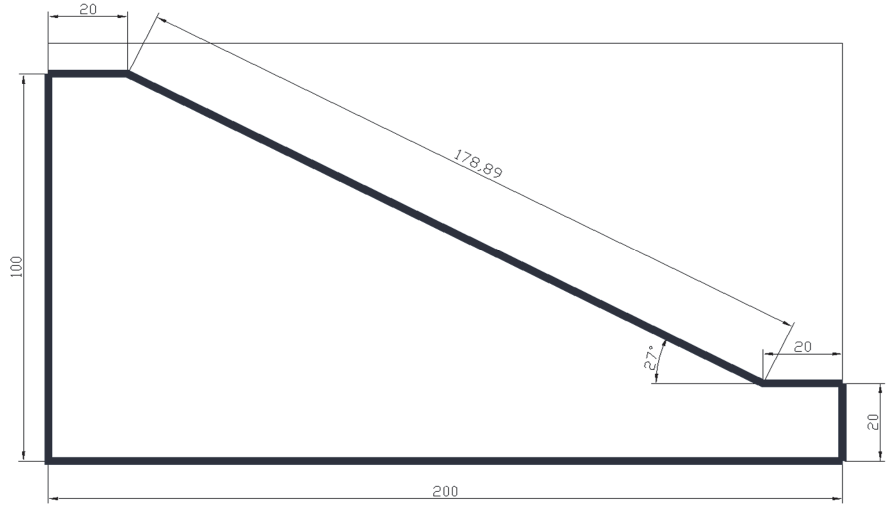

Fig. 2. The geometry of one of the slopes of the flood embankment model, adopted for the study (linear dimensions are given in [cm])

The modelling program included three simulated model irrigation methods:
1. intense rainfall – air slope,
2. water overflow through the crown of the flood embankment,
3. change of water level from the side of the upstream slope.

The type 1 experiment consisted in watering the flood protection model by introducing a rain generator into the measuring box. The type 2 experiment consisted of water overflow through the embankment crown – it was carried out for the air slope and various overflow expenses, and for the full embankment model. The type 3 experiment consisted in changing the water table level at different speeds, simulating a flood surge.

During tests simulating rainfall and overflow through the crown of the embankment (with a correspondingly large expenditure) or rapid lifting of the water table on the upstream side, i.e. in those experiments where the pore air was closed in the areas surrounded by irrigated soil and lost contact with the atmosphere, the appearance of open discontinuities in the form of air-filled gaps was observed in the model body. These fissures are called macropores because their dimensions correspond to a much larger (in the order of several thousand) number of soil grains.

Sensors SSC-3000 (SensorsTechnics, Germany), i.e. piezoresistance sensors (Fig. 3), set within the range of -1.0; +1.0 bar (-1000; +1000hPa), were used to measure the pressure. These sensors were dedicated to measuring overpressure.

Fig. 3. SSC3000 applied in the research, [http://www.sensortechnics.com]

A set of sensors installed in the head panel of a measuring box consisted of:

1. sensors to measure the air pressure in soil pores – no 1 to 6
   (Fig. 4 – yellow colour),
2. sensors to measure the water pressure in soil pores – no 8 to 13
   (Fig. 4 – red colour),
3. sensor to measure the atmospheric pressure – no 7
   (installed outside the measuring box).

The sensors, supplied an electrical current of 1 mA, transmitted a signal indicating the value of measured pressure to the interface connected directly to a PC computer, where the results were recorded in text files.

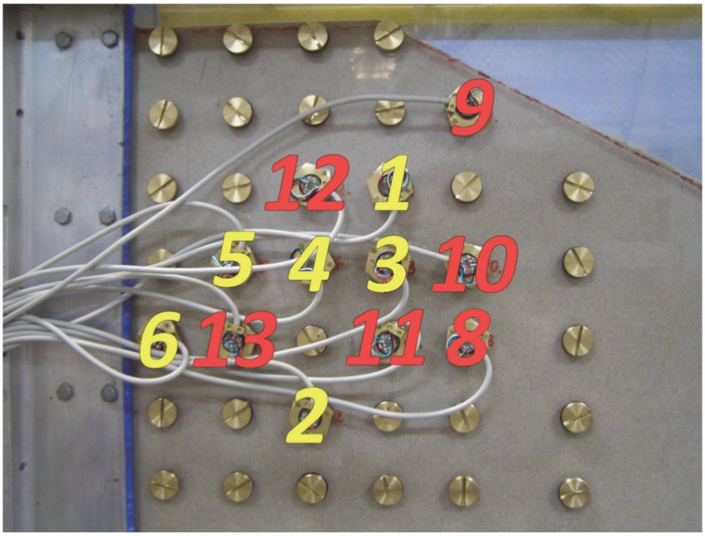

Fig. 4. Position of air and water sensors in the measuring box

3. The results of observations of physical model

The geometry of a model (physical model) corresponding to the landward or riverward (Fig. 2) part of the flood embankment was used in the first part of the research. One advantage of such a shape of the model was the ability to increase its height to 1 m; its disadvantage being the introduction of an impermeable border inside the body – which did not correspond to the factual working conditions of the most frequently observed flood embankment types. The physical model met the conditions described in the literature on geotechnical modeling (Wood 2004).

In some of the tests, when the level of water in the flood embankment model was changed, the air entrapment was observed in some zones, which remained dry for some time, despite being surrounded by saturated soil (Bogacz et. al. 2008, 2017, Kaczmarek et. al. 2010, 2011). The further evolution of these areas resulted in the appearance of open discontinuities, which evolved into variously shaped fissures filled with air. In some tests (e.g. test no 17 – overflow of water through the crown of the flood embankment with the output q ~ 9.25 ml/s), discontinuities occurred in the immediate vicinity of the pressure sensors, which enabled us to record changes in pressure, which were sometimes very abrupt. In most cases, changes in recorded pressures can be associated with the occurrence of a discontinuity in the soil structure, which had been previously described as a macropore (Bogacz 2017).

The diagram shown in Fig. 5 reveals a sudden increase in the air pressure at 58 minute. The peak in the pressure diagram appeared approximately at the moment of taking photo 0433, in which the opening of a macropore denoted with the number 1 can be seen (Fig. 7).

The subsequent increase in pressure is probably caused by the appearance of a zone supplying the discontinuity – a macropore which formed in the immediate vicinity of a sensor (Fig. 7).

Values recorded in the diagram representing water pressures – sensor 11 – Fig. 6 – indicate an increase, caused by the occurrence of the discontinuity mentioned above.

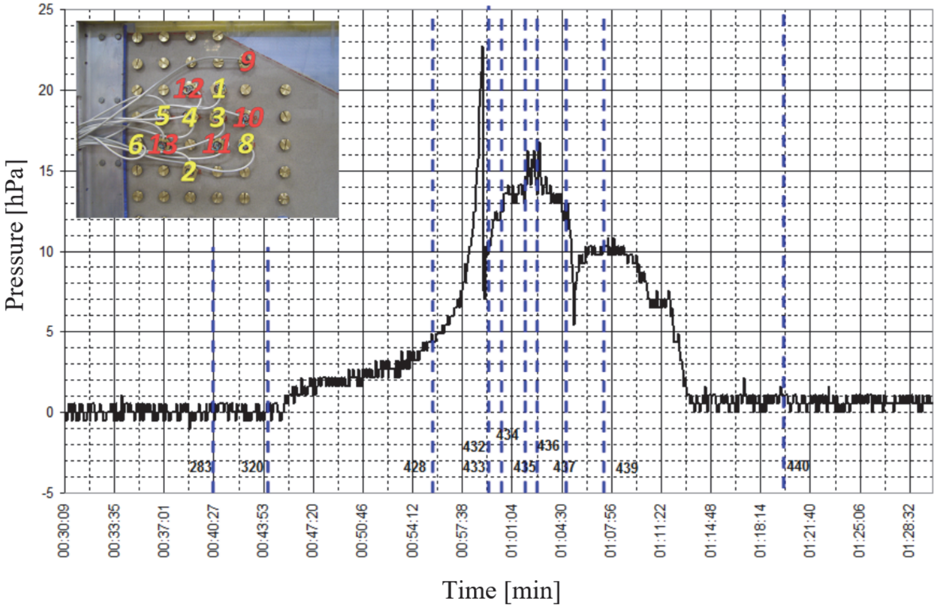

Fig. 5. Diagram of pressures – air sensor no 6 – test 17

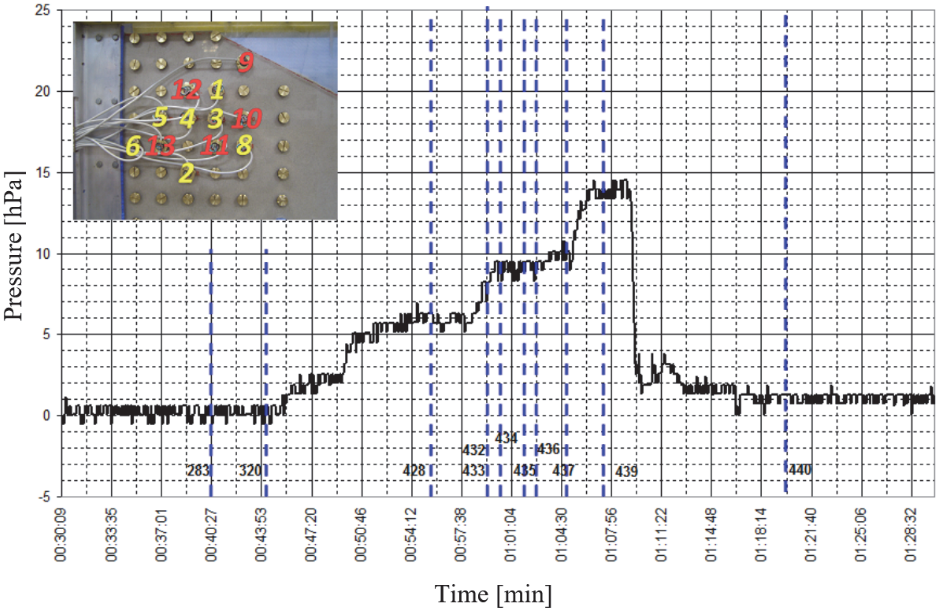

Fig. 6. Diagram of pressures – water pressure sensor no 11 – test 17

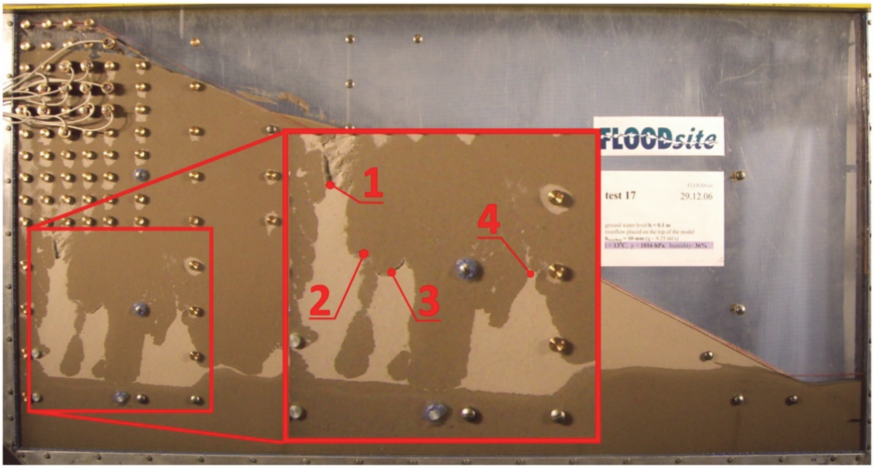

Fig. 7. Test 17 – a photo taken at the moment of a rapid increase in the pressure (Fig. 5), no of photo: 0433.

A – an area where discontinuity (a macropore) appeared

4. Conclusions

Numerous physical phenomena were observed during the research. One of them was a change in the pore pressure values recorded by the sensors. Observations of changes occurring in the model (appearance of macropores, discontinuities of the soil center) in association with the pressure graphs show that air transport is carried out within the shaft model. It is variable. The repetitive part of most tests was the appearance of the macropores mentioned, which were powered by the transported air. The appearance of macropores can depend on the method and the rate of irrigation of the model. The observations show that the main cause of soil discontinuity is the increase in pore pressure.

The phenomena related to the air flow in the opposite direction to the pore water flow, the influence of the settlement of the soil loaded with water and the effect of the model walls on its behavior cannot be ruled out.

The connection of the maximum recorded pressure of 22.5 hPa with the observation of the model's behavior allows us to state that a sudden increase in pore pressure initiates the formation of air spaces inside the model. The evolution of discontinuities became the initiator of the observed phenomenon of the destruction of the flood embankment model.

References

Abo Elela, M. M. I. (1996). *Filtration phenomena in earth dike during intensive precipitation*. PhD Thesis, Polish Academy of Sciences, Institute of Hydro-Engineering, Gdansk.

Bogacz, P., Kaczmarek, J., Leśniewska, D. (2008). Influence of air entrapment on flood embankment failure mechanism – model tests. *Technical Sciences, 11*, 188-201.

Bogacz, P. (2017). Degradation of flood embankments – Results of observation of the destruction mechanism and comparison with a numerical model. *Open Engineering – De Gruyter, 7*, 237-243.

Kaczmarek, J., Leśniewska, D. (2010). A flood embankment under changing water level conditions – a comparison of physical and numerical model. *Technical Sciences, 13*, 53-63.

Kaczmarek, J., Leśniewska, D. (2011). Modelling events occurring in the core of a flood bank and water initiated by changes in the groundwater level, including the effect of seepage. *Technical Sciences, 14*(2), 143-152.

Kolbuszewski, I. J., Jones, R. H. (1961). *The preparation of sand samples for laboratory testing*. Proc. Hidland Soil Mechanics and Foundation Engineering.

Wood, D. M. (2004). *Geotechnical modeling*. Spon Press London.

Zaradny, H. (1993). *Physical modeling of infiltration into dikes for stability purposes*. The second term – 1993, Report IBW PAN, Contract No. DWW-510, 1993.

Zaradny, H. (1994). *Physical modelling of infiltration into dikes for stability purposes*. The final report., Report IBW PAN, Contract No. DWW-510, 1994.

Abstract

This paper contains results of measurements of the pore water pressures in a model flood embankment exposed to different water saturation levels. The pressure of air and water was measured, and the recorded values were referred to the atmospheric pressure value. Correlation of the variables corresponding to the recorded pressures was observed, with the appearance of discontinuous in the soil structure of the model.

Keywords:
flood embankment, pore pressure, variable water saturation

Wyniki pomiarów ciśnień w badaniach modelowych wału przeciwpowodziowego w zmiennych warunkach nawodnienia

Streszczenie

W pracy przedstawiono wyniki pomiarów wartości ciśnień porowych w modelu wału przeciwpowodziowego w zmiennych warunkach nawodnienia. Dokonano pomiaru ciśnień powietrza i wody, a zarejestrowane wartości odniesiono do wartości ciśnienia atmosferycznego. Zaobserwowano zbieżność zmienności zarejestrowanych wartości ciśnień z powstawaniem nieciągłości w strukturze gruntowej modelu.

Słowa kluczowe:
wał przeciwpowodziowy, ciśnienie porowe, zmienne warunki nawodnienia