Theme: "Sustainable Environmental Protection & Waste Management Responsibility"
November 19 – 20, 2020 RKK – Óbuda University, Budapest, Hungary
ISBN: 978-963-449-203-0 www.iceee.hu

LABORATORY TEST FOR SAND BOIL FORMATION NEAR A FLOOD PROTECTION DIKE

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Abstract *The sand boil is the first stage of a piping failure of river dikes which may form in either free granular soil surface or in areas covered with a less permeable layer that is not thick enough to maintain a balance with water pressure if the water's exit speed exceeds a given value. The aim of the research is to see whether a laboratory model is capable to the examination of this phenomenon. The reason for it is the sand boil is starting at a hydraulic gradient much less than the critical value and it may be assumed that the equilibrium condition of individual grains forces may explain this. The model test is made using a simplified Hungarian river dike section where a fine sand layer is placed between the impermeable cover layer and the permeable subsoil. It can be clearly observed that while the flood occurs upstream, the stability of the fine sand grains at the downstream side is not ensured after the cover layer is cracking. The sand boil phenomena also appeared. This proved that a laboratory sandbox model is applicable to modeling and examining sand boiling with controlled circumstances.*

Keywords: *flood protection dike, sand boil, piping, sandbox model, hydraulic gradient*

INTRODUCTION

Hungary has the longest river dike system in Europe. Piping (Lampl, 1959, Nagy, 1993-2014) may form in either free granular soil surface if the exit speed of the upstream groundwater exceeds the critical value or can form in flood areas covered with a more or less clayey and watertight layer which is not thick enough to maintain a balance with water pressure, or if it has holes, cracks, so continuity gaps, caused by worms, plants or other conditions, so there are continuity gaps on which the water can break. Such unique piping can be successfully mitigated by surrounded bags ensuring a smaller hydraulic gradient (Figure 1). Dynamic effects due to triggering lateral spread of the downstream part apart from the upstream part, and the cracking of the cover layer may contribute to the development of pipe once the sand boil appears at the or close to the toe of the dike.

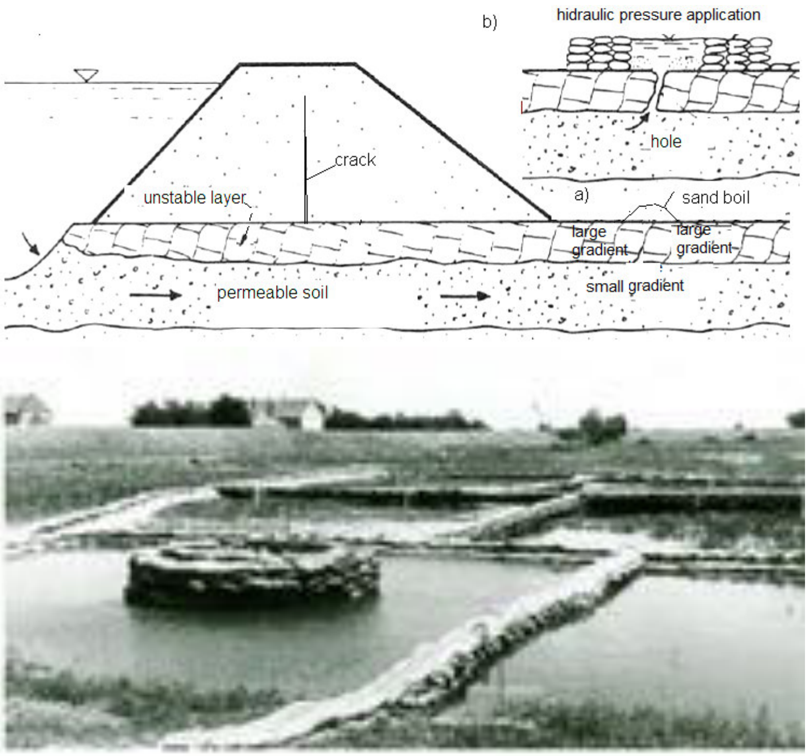

Figure (1) The piping phenomenon during flood at the Hungarian river dike system. (a) The formation of a sand boil due to the crack or a hole in the cover layer, (b) the treatment of the sand boil by decreasing the hydraulic gradient around the boil [after Galli, 1968]. ***Sand boil treatment by decreasing the hydraulic gradient***

However, there is a general experience that the sand boiling due to an upward flow can occur at much lower hydraulic gradients than the well-established theoretical critical hydraulic gradient value. Garai (2016) stated that this discrepancy results from the incomplete equilibrium requirements as follows (Appendix). The sand boiling can be initiated and developed from the removal of single grains at the exit surface. Therefore, the stability of the grain should be ensured. Garai agrees that the grading curve influences the internal stability of the fine sand layer in later stage of piping, also (Imre 1995, Imre et al, 2012, Nagy, 2014).

The key role of the fine grains at the start of the sand boiling is supported by the tests of Lampl (1959, who reports on the experiments carried out to determine how the presence in different % of the silt fraction between 0.01 and 0.1 mm affects the predisposition of soils to piping formation and the percentage of silt content that no longer forms a piping. Lampl found that sands with silt content of around or larger than 7% are generally no longer dangerous for the formation of piping.

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Garai: Assuming that the grains are spherical the relevant equation can be derived from employing Stokes law. Critical diameter, corresponding to grain size destabilized at the critical hydraulic gradient, is introduced (Figure 2). This diameter separates the grains of the soil into two parts. The grains, which size exceeds the critical diameter, lose their stability at the critical hydraulic gradient derived from “global/overall” equilibrium condition (Terzaghi’s criterion). Smaller grains loose stability at smaller hydraulic gradients.

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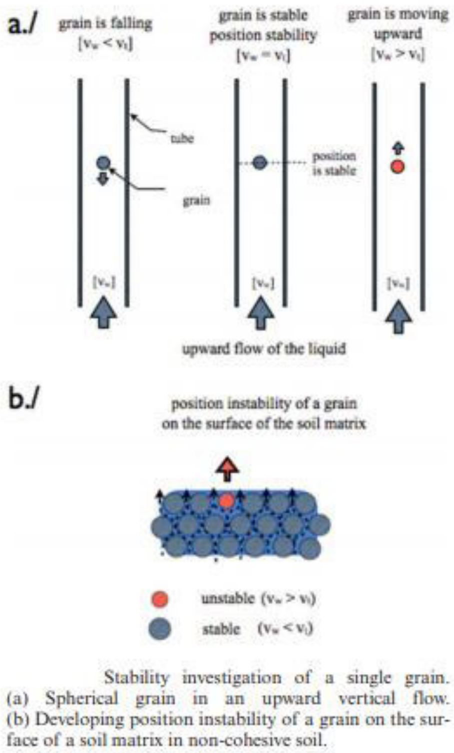


Figure (2) Garai's analyses of single grain

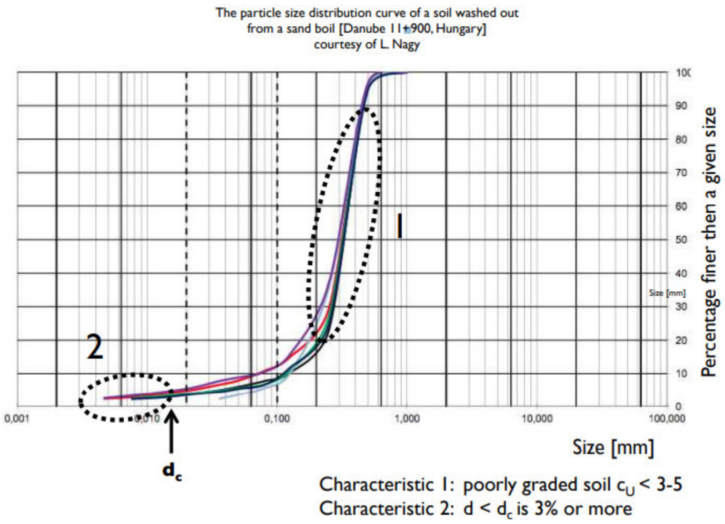
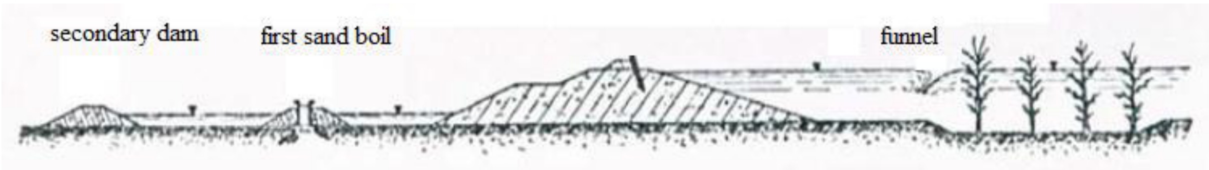


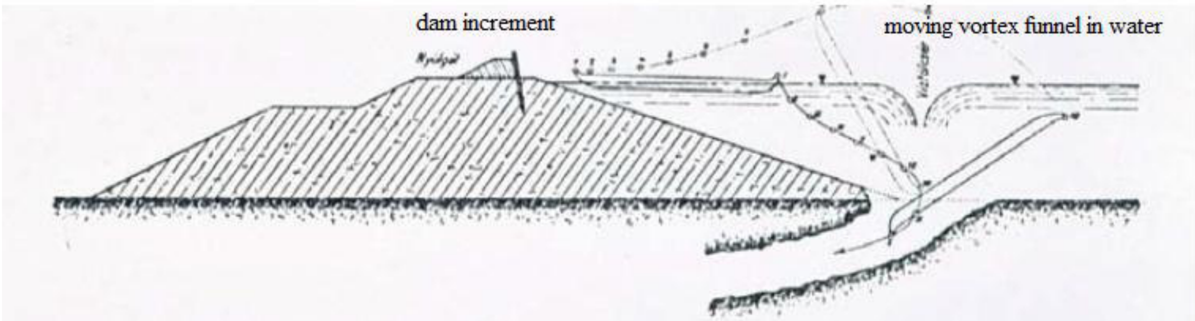
Figure (3) Garai's representation oof critical grain size

REVIEW: CASE STUDY

In 1926, there was a very high and long flood on the estuary section of the Danube Dráva. Therefore, on the downstream side, a dike increment was created (Figure 74).
A few days before the dam breach, a spring was spotted 10-12 meters from the saved side leg of the

embankment, which also brought sand with it. According to their well-established method, a barrel was put on the spring, and the barrel was surrounded by a ground block, by which time the water rose in it and was at the same height for two days.
On the third day the water in the barrel started to oscillate: landed and rose. The change in the water color in the barrel clearly showed that a cavity had formed in the subsoil, and the cavity is temporarily blocked for the path of the water by earth which is washed out afterwards.
Therefore, he immediately had protective material (sacks, planks, piles, etc.) carried there and at the same time put on standby a boat about 10 meters long and 2 meters wide to be charged and settled it if necessary.
Over the next 24 hours, the rise and drop of the water level continued in the barrel.
During this time, on the downstream side, 2-3 volcanic sand boil happened and these were already stronger than the first. At first, the boat sank nicely, his buttocks with load more than his nose. After a minute or two, the boat was arrived the upstream side, turning his bottom upwards. The dike stood for a few more minutes, after which its crown began to crack. At one time, the embankment breached at a length of 8-10 meters, the water began to protude into the saved area, and the dam burst soon widened to 80-100 meters. The depth of pipe at the site of the rupture was 24 meters below the flood level.
The next day, the spring suddenly erupted in the form of a mud volcano. A water funnel about 30 meters on the upstream side appeared, which was constantly approaching the embankment (Figure). Meanwhile, the water funnel on the upstream side was constantly approaching the embankment. When he approached the embankment at 15-20 meters, the boat suddenly began to tilt, his nose up and made the path dived under water.

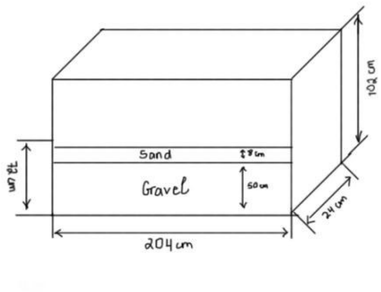


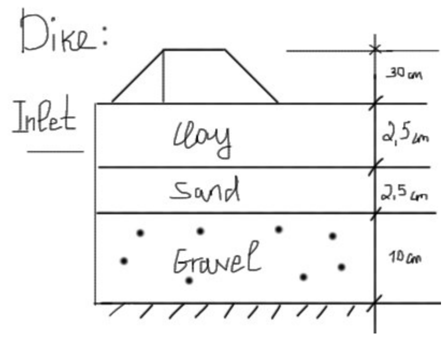


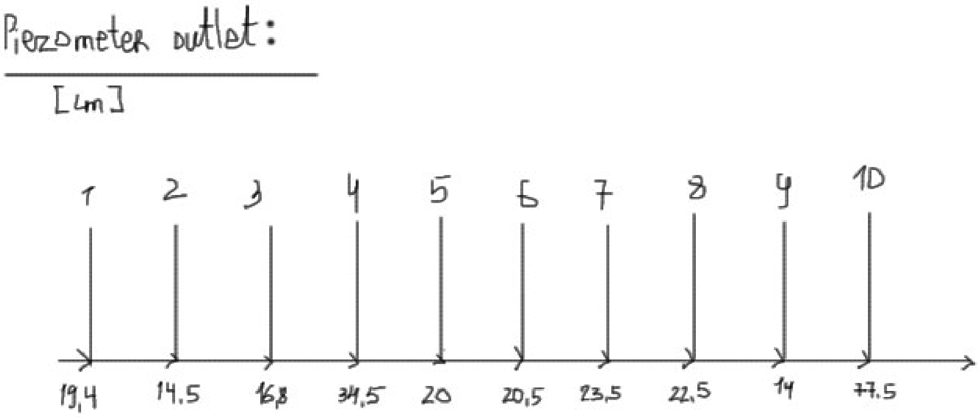
A piping's cavity level to the water side elevated. Tiszasas, no breach.

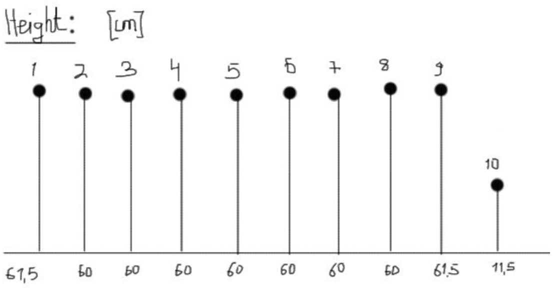
MATERIALS AND METHODS

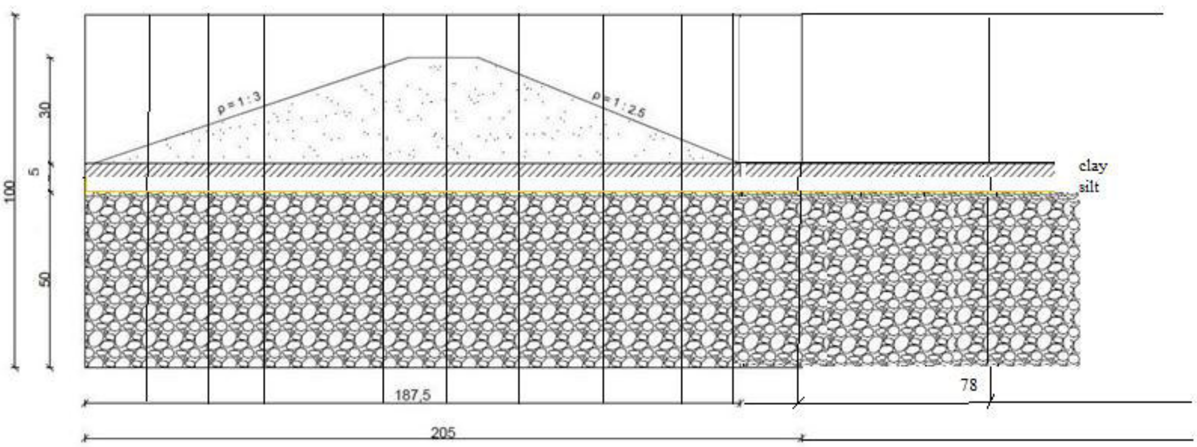
The laboratory experiment was done on dike failure due to the impact of seepage force have been carried out in the water laboratory in a horizontal channel, with transparent plexiglass wall. A sketch of the experimental facility is illustrated below:











Materials used for dike:	Calculation [cm]
Gravel	V=W*L*A=24*204*10=48960 cm (~50 liter)
Sand	V=W*L*A=24*204*2.5=12240 cm (~13 liter)
Clay	

Measurement steps of dike experiment

⇒ Prepared sand, gravel and clays to fill the dike.


⇒ Estimated the dike model structure


⇒ Add the materials into the model

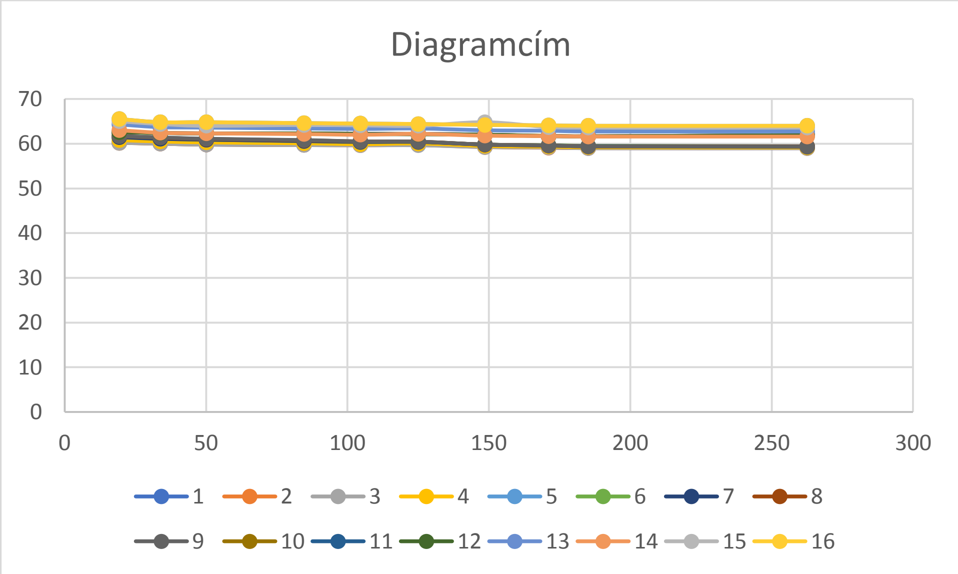

We put cameras on the top and from the front view, in order to record the evolution dike erosion process.

OBSERVATION

- ⇒ Increase in flood level
- ⇒ Originally steady-state piezometer level changed immediately
  Then changed with time
- ⇒ Measurement of outflow (discharge) [v]
  Outflow level was kept constant during the stage.
- ⇒ Measurement of piezometer level

Measurement steps for constant head permeability test

	1	2	3	4	5	6	7	8	9	10	mean i [-]
	19.4	33.9	50.2	84.7	104.7	125.2	148.7	171.2	185.2	262.7	
5.1h40	60.25	60	59.8	59.7	59.7	59.8	59.3	59.15	59	59	0.005
5.2h	60.2	60	59.8	59.7	59.65	59.7	59.25	59.1	59	59	0.0048
5.2h15	60.2	60	59.8	59.7	59.65	59.65	59.25	59.15	59	59	0.0048
5.2h45	60.8	60.5	60.3	60.1	59.9	60.05	59.5	59.35	59.2	59.15	0.0066
5.2h45	65.5	64.8	64.8	64.6	64.5	64.4	64.2	64.1	64	64	0.006
5.3h	61.5	61.15	60.9	60.6	60.4	60.4	59.8	59.65	59.5	59.4	0.0084
5.3h	61.45	61.1	60.9	60.6	60.4	60.4	59.8	59.6	59.45	59.4	0.0082
5.3h45	61.7	61.35	61.05	60.75	60.5	60.45	59.8	59.6	59.4	59.35	0.0094
5.4h	61.7	61.4	61.1	60.8	60.5	60.45	59.8	59.6	59.4	59.3	0.0096
6.2h10	62.55	62.4	62.3	62.3	62.2	62.2	62	61.75	61.65	61.9	0.0026
6.2h25	62.6	62.4	62.3	62.3	62.2	62.2	62	61.7	61.65	61.9	0.0028
6.2h40	62.6	62.4	62.3	62.3	62.15	62.1	62	61.7	61.65	61.9	0.0028
6.2h30	64.3	63.7	63.6	63.4	63.3	63.4	63	62.9	62.75	62.75	0.0062
7.2h05	63	62.45	62.3	62.15	62	62.2	61.8	61.7	61.6	61.6	0.0056
7.2h40	65	64.4	64	64.2	64.1	64	64.8	63.7	63.6	63.6	0.0056
7.2h45	65.5	64.8	64.8	64.6	64.5	64.4	64.2	64.1	64	64	0.006



N=2 fractal gradings were tested (Figure 1 and Table 1) with constant head permeability tests. The four fractions (*N* =1) were: 0.25-0.5 mm, 0.5-1 mm, 1-2 mm 2-4 mm, (uniform distribution was assumed within the limits). The tested optimal 2-fraction soils are shown in Figure 1.

CONCLUSION

A sand boil was cause due to an upward flow can occur at much lower hydraulic gradients than the well-established theoretical critical hydraulic gradient value.

Acknowledgements

Thanks to the Kvarc-Ásvány Kft. 8256 Ábrahámhegy-Kisörs provided the sand.Thanks for the great support of dr. Rita Bodáné Kendrovics, Director of Institute of Environmental Engineering and Natural Sciences, Óbuda University; the great support of the rector of BME. The research is done in the form of a joint research of Obuda University, Budapest, Hungary; BME, Budapest, Hungary; Edinburgh Napier University, U.K; Università di Roma Tor Vergata, Italy, Politecnico di Milano, Italy; Ruhr-Universität Bochum, Germany; SZIE, Budapest, Hungary; University of Bristol, U.K.

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