PIPING PHENOMENON AT THE FLOOD CONTROL DIKES IN THE CARPATHIAN-BASIN (II)

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ABSTRACTS. - Piping phenomenon at the flood control dikes in the carpathian-basin. Pipings are the most spectacular phenomena preceding and ultimately leading to breach of flood protection dikes. The piping is close correlation with the geological history of the flood plane. A review of historic data showed that 1 in every 12 to 13 dike failures was the consequence of piping (Nagy, 2002). This paper places particular emphasis on a special feature in the protection against piping directing attention to some important aspects of flood defence and to the need for going into a deeper study of certain details of the phenomenon of piping. Undoubtedly, we know a great deal more about piping than we did just 30 years ago. Research has been pursued in various fields in an attempt to find answers to some peculiar but very real problems, as grading entropy shed light on soils prone to piping from the theoretical side (Lőrincz 1986, 1993, Lőrincz et al., 2004, Imre et al., 2008), but the practical approach revealed that in the vicinity of all the pipings a particular layer prone to piping failure invariably occurred in the stratified soil (Lőrincz, Nagy 1995, 2010). In the case of recorded actual pipings the mean hydraulic gradient only reached a value that was as low as less than one fifth of the allowable value, yet failure conditions did occur (Nagy et al., 1994).

Key words: flood defense, hydraulic failure of dikes, rapid sand boiling/piping, piping sand

3. Identify the sections prone to hydraulic failure along the dikes

The above mentioned dangerous phenomena, including conventional or „slow" piping are expected to develop in special stratification conditions, usually in the three-layered stratification that was shown in Fig. 6. Such conditions are due first of all to the differing stratification of the subsoil within a shorter section from that of the neighboring sections.

Further investigations have proved that these anomalies in the stratification are expected, and all the mentioned hydraulic failures along the dikes occurred in those points, where the track of the dike has intersected ancient river bed that had

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disconnected and silted up several hundred or possibly several thousand years ago. The ancient river beds are easily identifiable in black and white aerial photographs.

An interpretation of ancient river bed system along the Sebes-Körös river (Fig. 9.), as well as the scheme of stratification at the concave bank of a silted river bend can be seen in Fig. 10.

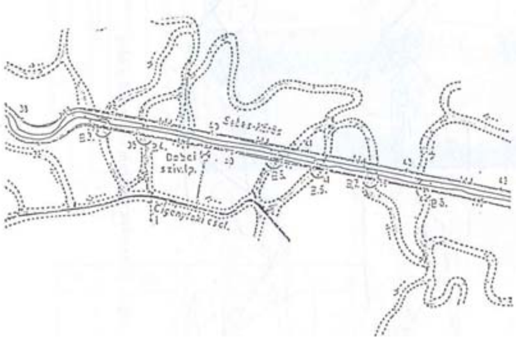

Figure 9. Ancient meanders at Sebes-Körös river.

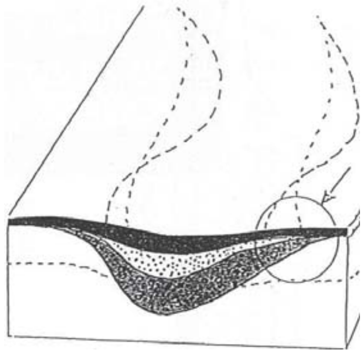

Figure 10. Sandy deposit on the concave bank.

With a help of an interpretation of the ancient river bed we are able to identify the intersections of them with the dikes, as well as to evaluate the weak points of the dike at these intersections from morphological point of view in order to prioritize further investigations and interventions.

The particular characteristics that must be considered are:

- the distance of intersection from the mean bed;
- the shape of the mean bed in the vicinity of the intersection (straight, convex or concave bank, inflexion);
- the shape of the ancient bed in the intersection.

This morphological classification completed with the exploration of continuous stratification of subsoil by the means of horizontal geoelectric probing can be a proper method for identifying and determining the characteristic and individual sections.

Since the major cause of damage to the dikes at the intersections with ancient river bed is liquefaction of sand layers, construction of counterweight structures as well as decreasing the head to the foundation soil by the means of ground improvement or of lowering the groundwater table during floods were among the countermeasures considered. Of course, further basic requirements were: restoration of the original function of the dikes, applicability to all the dikes, feasible and sustainable solution, including not only the execution, but the maintenance of the construction as well.

4. Piping sand investigation sites

Formerly little attention was paid to the investigation of material washed out of a piping (Nagy, 2000). The grain size distribution of the washed out material was not tested, nor was it compared to the grading of surrounding soil layers. Now, an important question arises: Is it the entire mass of a soil layer or only certain fractions of the soil that are washed out? During the high flood on Danube in 2006, samples were taken from a number of pipings. Tests on these samples form the backbone of the present paper.

The summary of investigated sites grouped according to the rivers and to the years of occurrence is contained in Table 2. Materials obtained from 12 pipings by river Tisza, 7 by Danube and 1 by river Sajó were tested. Based on these samples the effect of a number of factors has also been revealed at the various sites.

Whether grading curves of samples taken from pipings maximum a few metres away from each other (see e.g. Photo 3.) show a different picture? Pipings located close nearby (samples 5 – 8 and 17 – 18 in Table 2.) are supposed to give identical grading curves, yet testing experience indicates a difference in the shape of the grain size distribution curves (Fig. 11).

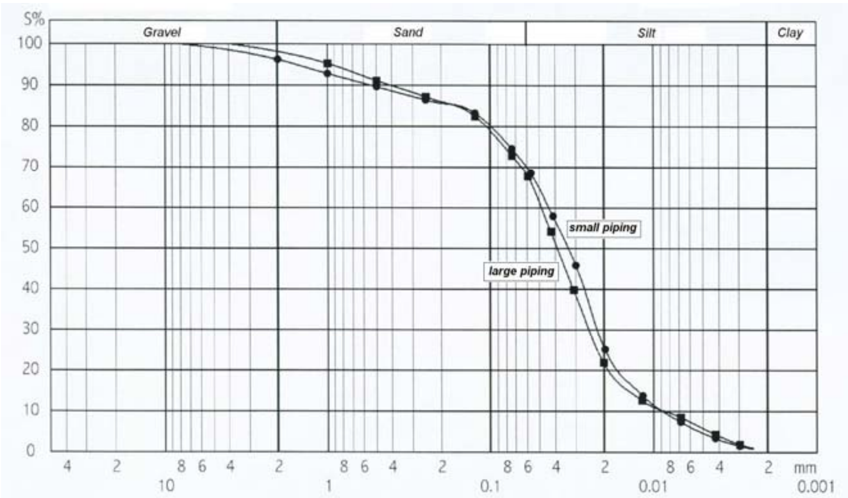

Figure 11. Grain size distribution of two pipings located close to each other (Soils No. 17-18 in Table 2.)

Another question also arises as to what differences if any can be between the grain size diagrams of two samples taken from different parts of the same piping (Samples No. 2-3, 5-6, 14-15 and 19-20 respectively in Table 2.). It can be stated that a difference does exist. Finer particles are conveyed and then deposited by the water farther away radially from the piping. Therefore at the central part where water is issuing in a concentrated flow sedimentation of the coarsest grains is expected, while finer grains settle at gradually increasing distances. As can be seen in Fig. 12., the difference between the grading curves can be relatively great.

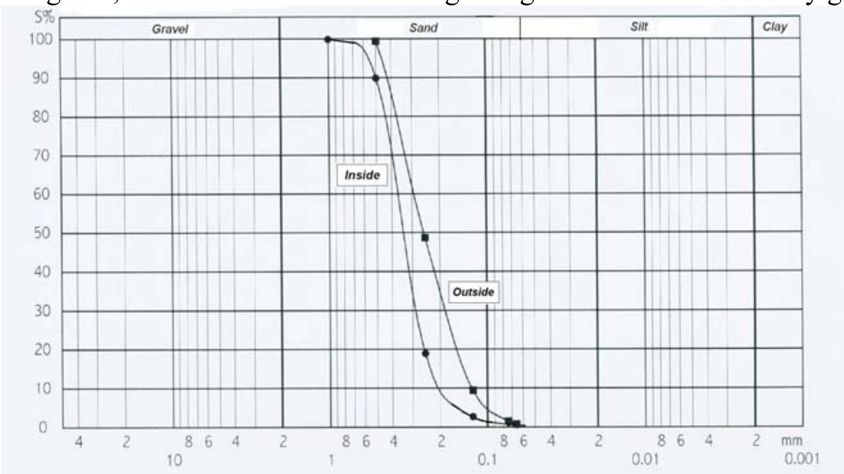

Figure 12. Grain size distribution curves of two samples taken from different parts of the same piping (Soils No. 19-20 in Table 2.)

Table 2. Sites of piping investigations**.**

Number	Year	River, location	Remarks	d_{10}	Uniformity coefficient (C_U)	Description of soil
1	1998	Tisza, right bank	Tivadar, inner side	0,08	3,25	Fine sand
2	1998	Tisza, right bank	Tivadar, outer side	0,025	8,4	Silty sand
3	1998	Tisza, right bank	Dombrád	0,036	4,6	Silty sand
4	2006	Duna, right bank 12+150	Abda	0,0071	17,8	Silty sand
5	2006	Duna, right bank. 41+206	Dombori, small piping	0,007	13,9	Silty sand
6	2006	Duna, right bank 41+206	Dombori, small piping, crater	0,041	2,4	Sand
7	2006	Duna, right bank 41+206	Dombori, big piping	0,026	4,3	Sand
8	2006	Duna, right bank 41+206	Dombori, big piping, crater	0,006	15,2	Silty sand
9	2006	Duna, right bank 79+420	Bölcske, ox-bow	0,026	6,5	Silty sand
10	2006	Duna, right bank 79+420	Bölcske, ox-bow	0,016	10,8	Silty sand
11	2006	Tisza, right bank 61+075		0,056	2,1	Fine sand
12	2006	Tisza, right bank 71+300		0,049	3,5	Silty sand
13	2006	Tisza, left bank 13+250	Tiszasas, marshy bushland	0,106	2,2	Fine sand
14	2006	Tisza, left bank 13+580	Tiszasas, edge of crater	0,073	2,3	Fine sand
15	2006	Tisz, left bank 13+580	Tiszasas, centre of crater	0,051	2,6	Fine sand
16	2010	Sajó, left bank 6+266		0,007	12,6	Silty sand
17	2010	Tisza, Millér	Small piping	0,007	6,1	Silty sand
18	2010	Tisza, Millér	Large piping	0,0083	5,9	Silty sand
19	2010	Tisza, Tiszakürt	Outer part of crater	0,17	2,2	Sand
20	2010	Tisza, Tiszakürt	Inner part of crater	0,13	2,3	Sand

It is a common premiss that any test is worth as much as the reliability of the underlying data. In Geotechnics, determination of the grain size distribution is a routine test and as such can be relied upon for correctness of test results. Yet, any theoretical conclusion is of no use if the determination of the grain size distribution curve is unreliable. The laboratory tests referred to in this set of tests were carried out at different laboratories, though the majority of the samples was tested at the Geotechnical Laboratory of the Budapest University of Technology

4. 1. Shape of the grain size distribution curve

The grain size distribution curves of the material ejected from pipings have continuous smooth shape characteristic of natural soils. When the grain size distribution curves of all the samples tested are plotted in the same graph they clearly define a distinct zone. The types of soil located within this zone (silty sand, fine sand, sand) exhibit no considerable cohesion, and at the same time the mass of their individual soil particles is small enough allowing them to be readily removed from their position by seeping water (Fig. 13.). It should be noted that under sufficiently high hydraulic gradients any type of soil (or even rock) can be washed out by piping. What is significant in this respect is that for soils within the domain in Fig. 13. the lowest hydraulic gradient is necessary.

Photo 3 . Piping at Dombori as seen from the crest of the dike. Washing out of soil first occurred some 20 metres away from the toe of the dike (Areas No. 5-8 in Table 2.).

The zone of grain size distribution curves of all the soils tested is shown again in Fig. 15. This zone shows a striking similarity to the zone representing the limits of granular soils liquefied by earth quakes. The grading limits shown in Fig. 13. are copied onto a graph presented in Smoltczyk's book (2002) defining various degrees of hazard for liquefaction due to earth quake. (Zone 1: moderately susceptible, Zone 2: highly susceptible). This apparent correspondence already formerly raised the hypothetic question of whether piping occurring during high flood can be simulated by shape to similar surface liquefaction phenomena experienced during earth quakes, as in both cases a volcanic cone is formed through the crater of which water is constantly issuing, dragging away solid particles. The apparent similarity of the zones of grain size distribution curves in the two cases (Fig. 14.) strongly suggest that the two phenomena should indeed be closely related.

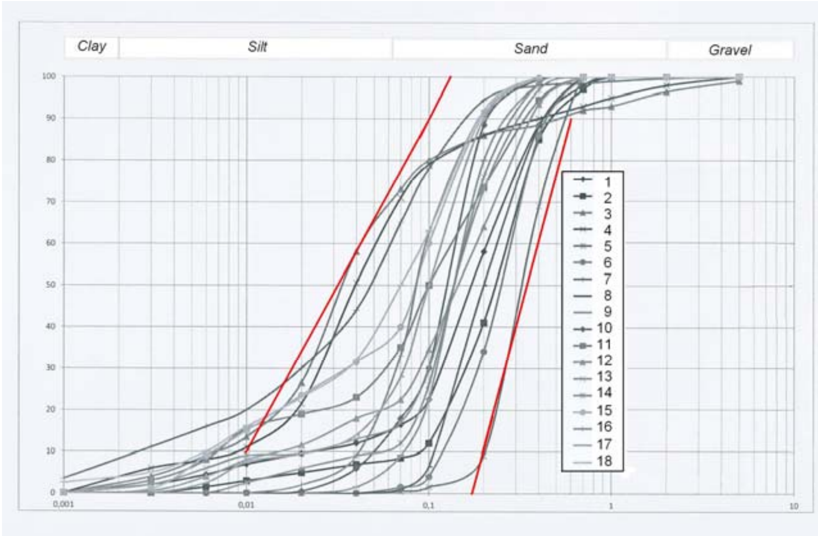

Figure 13. Grain size distribution curves and limiting envelops of the critical zone.

Following this reasoning one cannot help raising a question concerning the similarity of surface phenomena observed in both cases and the similarity of grading: i.e. **whether piping constitutes a pseudo-static liquefaction or liquefaction (e.g. one triggered off by earth quake) constitutes a dynamic piping**.

It should be noted that several expert's reports have recently been prepared dealing with failure of tailing dams where breach of the dam was judged to have been caused by liquefaction but in none of those cases was failure attributable to earthquake effect. This means that liquefaction may also occur under static loading conditions.

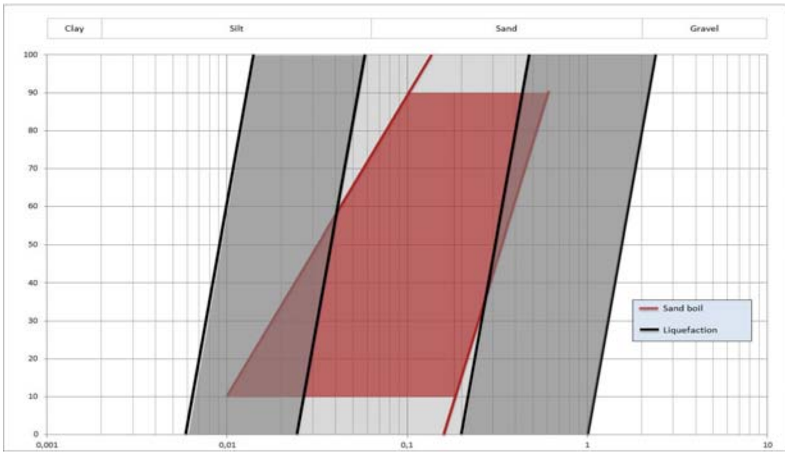

Figure 14. Zones of soils most susceptible to liquefaction (Smoltczyk, 2002) with limiting lines for the zone of piping added.

4. 2. The grain size pertaining to 10 percent passing

In the study of the grain size distribution a crucial point is the determination of the grain size pertaining to 10 percent passing (See Table 2.). This grain size is determinant in respect of seepage phenomena and also in assessing the uniformity of grading. As can be seen in Fig. 15., in none of the tests on material washed out of the pipings were grain sizes $d_{10} > 0,33$ or $d_{10} < 0,0033$ identified. This means that a domain of grain sizes d_{10} spanning over two orders of magnitude is affected in respect of washing out by piping. Frequency values should normally decrease towards both sides of the histogram but probably because of the relatively small number of elements and the few number of categories this tendency does not appear here.

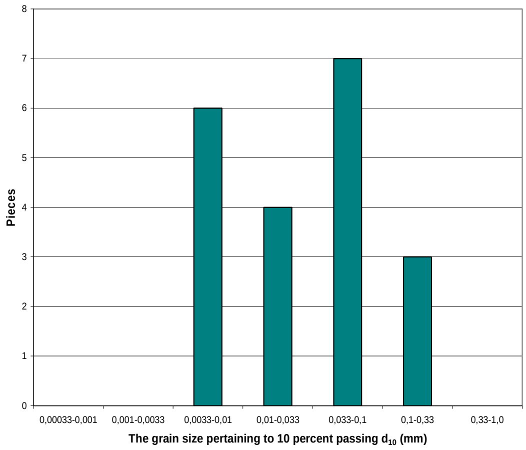

Figure 15. Frequency distribution of d_{10} values in the material washed out by piping .

Photo 4. Piping at dombrádi (1998), some 20 m away from the dike toe after flood (Area No. 3 in Table 2).

4. 3. The uniformity coefficient

Uniformity coefficient (C_U) values of the washed out soils are shown in Table 2. The highest value was C_U = 17,8, and the mean value was C_U = 6,4. No soil with C_U < 2,0 was identified. The frequency distribution of the uniformity coefficients can be seen in Fig. 16., where the category of C_U = 2-5 is the most populous, containing more than half of the samples tested. Fine grained soils with low coefficient of uniformity are the ones that can be most readily washed out or removed from their position, since they have no cohesion and the mass of their grains is small.

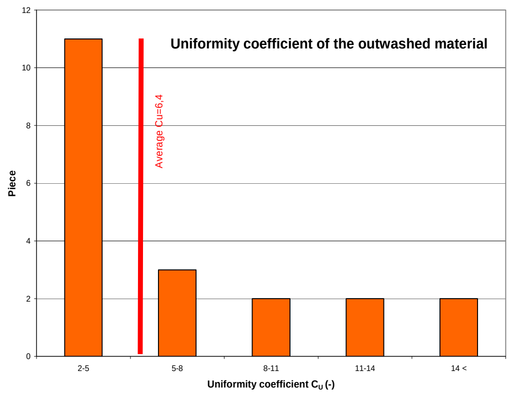

Figure 16. Frequency distribution of uniformity coefficients in the material washed out by piping.

4.4. Correlation between uniformity coefficient and grain size d_{10}

An evaluation of the relationship between the uniformity coefficient (C_U) and the grain size pertaining to 10 percent by weight passing leads to an inverse relation, that is the value of C_U tends to decrease with the increase in d_{10}.

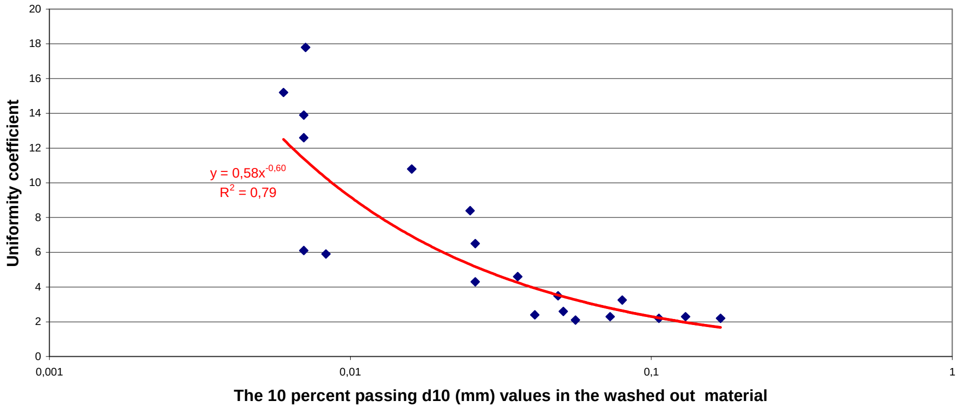

Figure 17. The relationship between the uniformity coefficient and the grain size pertaining to 10 percent by weight passing.

In other words: the more coarse- grained the washed out soils, the more closely they are to a perfectly uniform single-grained soil. The most astonishing fact is the very tight correlation giving a value of nearly R = 0,9 !! (See Fig. 17.), in spite of the fact that the samples originated from various regions of the country and were tested in several laboratories.

5. Summary

Flood defence counter measures to conquer pipings are well established and proven, (Péch 1892, Polgár et al. 1974, Nagy 2009), while theoretical treatment of ground failure due to piping is not satisfactorily profound. It is an undisputable fact that we know a great deal more about piping than we did say 30 years ago, but continued research must go on even by resorting to practical experience if necessary.

Neither hydraulic criteria, nor structural criteria of piping are known deeply enough. We are surely aware of certain parameters that contribute to the build-up of pipings, but their effect cannot yet be quantified. In the case of fully developed pipings the average hydraulic gradient normally has a value hardly reaching one fifth of the allowable threshold value, yet ground failure does occur. Density conditions have not been properly dealt with, and also little attention has been paid to the testing of material ejected by piping.

This paper looks at the process of piping from the aspect of material structure by focussing on the grain size distribution of the material washed out from the piping. Using 20 samples originating from different regions of Hungary, the grading characteristics of these samples were investigated on the basis of some selected grain sizes and the uniformity gradients. Based on these investigations it has become possible to identify which grain size fractions are likely to be washed out, and to characterise those fractions whose washing out is not expected. Based on the grain size distribution curves it has been made possible to define the boundaries of the zone susceptible to piping. The investigations provided useful results concerning values of the uniformity gradient and the grain size pertaining to 10 per cent and the relationship between them.

Photo 5. Piping at the initial section of a trench drain near Tiszakürt in 2010 (Areas No. 19 – 20 in Table 2).

In order to obtain a deeper understanding of the process of piping the question whether the washed out material consists of the entire mass of a layer or only of a grain size fraction within the layer needs be investigated. To this end a more profound knowledge of the environment of the piping would be very important.

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