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Internal erosion or (fast) liquefaction? Some interesting dyke failures

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Abstract

Some unusual case studies are presented in relation to very fast piping damage leading to dyke failure in about 5 minutes. Soil mechanical information is only available for one (Hosszúfok) case study. A hypothesis of fast, liquefaction piping is made with a vortex in the waterside and a geyser on the safe side. It is likely that advanced continuum/discrete approaches coupled with continuum fluid dynamics may explain these failures, including dynamic effects such as the vortex being in contact with the riverbed. Research is ongoing.

Keywords: dyke, liquefaction, piping, failure, flood protection dam

1. Introduction

Hungary has the longest river dyke system in Europe along the two big rivers (Danube and Tisza) and their connecting parts. The main characteristics are as follows. The Danube valley has a 0.5-6.0 m thick silty fine soil cover, which is prone to piping and liquefaction. The river bed is lying in granular soils. The dyke material is sand in the northern part and silt in the southern part. The most frequent flood damage is piping.

Dykes of the Duna river have the following leading dimensions. The height is about 6 to 8 m; the crest width is 4 m, the waterside slope is 3:1, and the landside slope is 2:1. The dykes have been built of silt (IP=12-20%), sand, or sandy gravel. The stratification under dykes comprises a sandy, silty cover overlying a highly permeable gravel bad.

The subsoil of the Tisza-Kőrös valley varies from the granular (northern part) to the highly plastic (southern part). The dyke material is granular soil in the north part and plastic soil in the south part. The surface is generally covered by plastic soil.

In some case studies (Danube, 1926, 1954 and 1965 Csicsó, Hosszúfok in 1980) are presented in relation to a very fast piping damage leading to failure in about 5 minutes. Soil mechanical information is available for the Hosszúfok case study only. A hypothesis of fast, liquefaction piping is made with a vortex on the waterside and a geyser on the safe side.

2. Case descriptions

The first specific, recorded case study of failure by internal erosion in Hungary at the river Danube was first reported by eyewitness Benedek in 1932 [1] and is referred to more recently by Nagy in 2014 [2]. The embankment failed (rapidly) approximately five days after the first sand-boil was observed 10-12 m from the downstream side toe of the embankment. According to well-established practice, a barrel was put on the spring and then reinforced by a protective material. At the same time, a boat/canoe about 10 m long and 2 m wide was put on standby. Two days before the breach, the water level in the counterpressure basin started to oscillate, indicating pipe formation. Therefore, preventive materials (boat to sink if needed, piles, sand bags, piles, etc) were prepared. The breach happened within minutes, and a mud geyser appeared at the location of the sand boil. Seeing this, the chief engineer immediately ran up to the embankment crest and glanced at a vortex about 30 m from there, which was constantly approaching the embankment. When it approached the levee at 15-20 m, the boat began to tilt into the vortex, its nose up, dived under the dike, and reached the other side of the dike (see [1]) due to a kind of sink-hole effect. Subsequently, the crest began to crack, the embankment settled 8-10 m, the water began to flow into the saved area, and the breach widened to about 100 m. The depth of the washout at the rupture site was 24 m below the level of the flood.

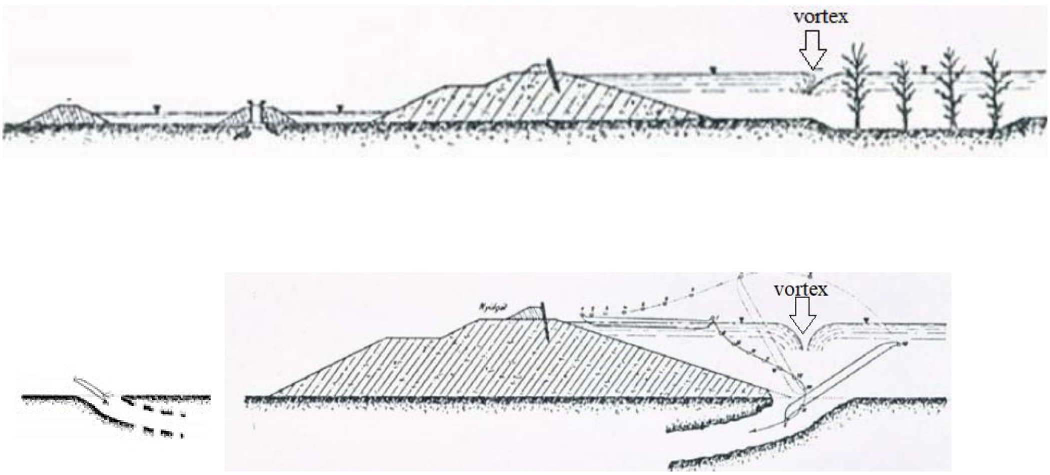

Figure 1. Illustration of the boat diving to the pipe, (a) condition some minutes before breach, (b) the path of the boat, which ended on the land side at around the first sand-boil spot. (after [1])

A similar failure occurred later at the river Danube on 15 July 1954 at Ásványráró which was referred to by Szepessy in 1983 [3] and more recently by Nagy in 2014 [2]. The formation of the dam break is quoted from the report of the witness, chief expert engineer László Marek, government commissioner, as follows. “During my inspection trip ...quite unexpectedly, about 5 m from the foot of the embankment in the saved field, a column of water broke up with a diameter of 1 m, a slightly cloudy color to a height of 1.4 m. At the moment of breaking, the surface of the river water was smooth, but approx. 2 seconds later, from the dam crown about 10 m away, a *huge vortex appeared*, which soon reached the embankment crown, and in its center, the watercolor sunk deep like a funnel. The geysir *widened to 1.50 m* in about a minute and a half and then suddenly stopped (probably due to the collapse of the embankment body). *The dyke crown was in the original position*. Then after half a minute, the column of water with a diameter of 1 m originally widened to approx. *4 m in diameter*, the water column became 0.5 m high, with extremely cloudy, dark-colored water, and then another half minute later, the crown of the embankment and its crest suddenly collapsed deeply, and above the water began to flow above the collapsed dyke."

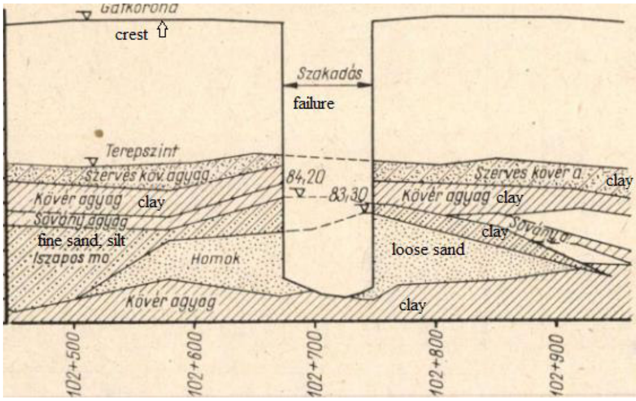

Figure 2. Kettős Körös river, Hosszúfok in 1980, loose, thick sand layer prone to liquefaction [3].

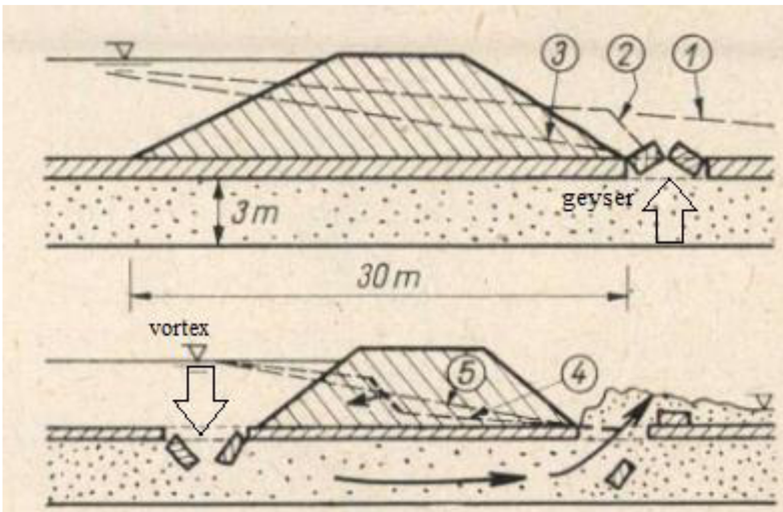

Figure 3. The hypothesis of fast, liquefaction piping in [3] completed by the vortex.

3. Discussion, conclusion

The evaluation: the piping mechanism is possibly liquefaction of the extremely loose and thick sand lens at the thickest dimension of the layer (Fig. 2). The cause was assumed to be a dynamic effect caused by liquefaction. The possible dynamic effect was the tearing off the very plastic clay cover layer (typical for this part of Hungary) at the first geyser spot (Fig. 2) and the sudden displacement of the dyke body due to the increased horizontal load.

In these three reported cases, failure may be attributed to regressive erosion and/or concentrated leak erosion (while contact erosion is not possible according to existing filter criteria). It is, however, more likely that static or dynamic liquefaction occurred. This is supported by the occurrence of sand boils, the formation of geysers from below a plastic clay surface layer after being torn off suddenly, and the loose state of the deposit of silty sand in Hosszúfok (Fig. 2). With similar observations, the occurrence of a vortex in the first failure reported may also indicate that there is a hydraulic component in these failures. It is hypothesized that a kinematically admissible path was formed below the embankment comprising the entire layer.

Hence the occurrence of liquefaction is more likely. It is likely that advanced continuum/discrete approaches coupled with continuum fluid dynamics may explain these failures, including dynamic effects such as the vortex being in contact with the river bed. Research is ongoing. The possibility of the high energy impact of the vortex at the river bed and its effect on the liquefaction process of a deeper sublayer of soil may also need sophisticated numerical modeling for understanding. The liquefaction may be caused by the following effects: high pore water pressure in the dike base, the tear off of the clayey cover layer (i.e., sudden shear strain increment of the dike base, due to the increased load, cracking of the dike), the dynamic effect due to the advance of the saturation front in the dike material, and may be enhanced by the effect of the vortex reaching the river bed. Fast piping may occur in the case of a thick layer of extremely loose and poorly graded fine sand, generally in the vicinity of some old river bend crossings. The breach may happen within seconds/minutes of observation of the first muddy geyser on the land side and simultaneously appearing vortex funnel in the river. The vortex in the river water is moving towards the dyke, touching the river bed.

The membrane problem of Mechanics is identical to the fluid problem in terms of optimum model and numerical solution. A uniaxial problem is needed to be solved. The suggested literature is related to the optimization parts of Fluid Mechanics (see, e.g., Borrvall and Petersson, 2003 [5], Papadopulos and Süli, 2021 [6], Vásárhelyiné, 2002 [7], Lógó, 2021 [8]).

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