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Flood Protection Phenomena in the Körös Region

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Since the regulation of the Körös Rivers, and following the construction of the flood protection systems and their development, several phenomena have developed on the embankments as a consequence of the receding flood waves. The following article presents the phenomena developed on the flood protection lines and flood control structures of the Körös Rivers. This information was collected, structured and categorised to better assess the flood protection lines. With the collected data, as well as with data from other sources (such as geomechanics, modelling) recommendations can be made on where and what kind of investment should be made in order to increase flood protection safety.

Keywords: *flood, flood protection, embankments, phenomena, seepage*

Introduction

The Körös region (Romanian: Crișana) is a geographical location in Romania and Hungary, whose water network consists of the Fehér-Körös, Fekete-Körös, Kettős-Körös, Sebes-Körös, Hármas-Körös, Berettyó and Hortobágy-Berettyó watercourses, the geographical location of which is shown in Figure 1.[2] (Hereinafter, the Hungarian river names are used in this article for a better understanding of the location.)

The Körös region flood protection system and the safe drainage of flood waves are provided by embankments made of compacted soil, the current form of which was achieved by increasing their cross-section (height and width). The permanent retreat of flood waters at high peak levels greatly weakens the protective capacity of flood protection facilities. This generates flood phenomena that can occur on the embankment and its subsoil.

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2 Szlávik et al. 1994.

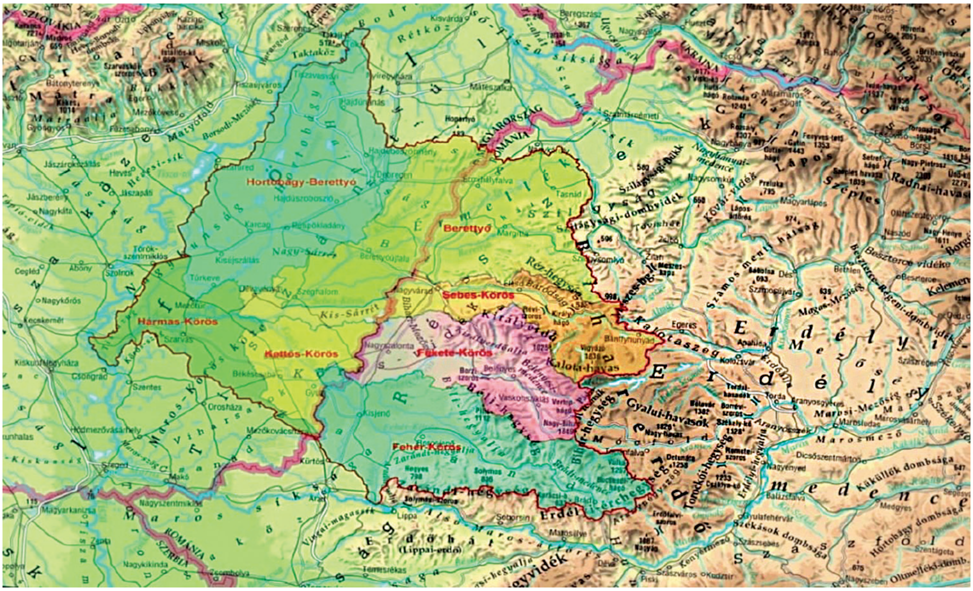

Figure 1: The Körös River Basin and its landscapes
Source: Alföld-Planum Kultúrmérnöki Kft. 2014

Seepages and water flows

For the majority of the levee failures – that are not caused by overtopping – the main reason of the flooding disaster is the water flow that takes place in the soil. Consequently, the damage of the flood protection levee is usually, in absence of overtopping, the consequence of seepage.

In addition to the embankment body, the flood protection levee also includes the part of the subsoil that interacts with the embankment.

To best assess the status of a flood protection line (whether it is safe of not), it is vital to understand the seepages occurring in the surrounding of the protection line (both embankment and subsoil) as precisely as possible.[3]

Seepages in embankments

The flood protection embankments of the Körös Rivers were built – without exception – from both ditch material and the materials of bound top soils indiscriminately. In the 1970s, the levee reinforcement was done with the same process. This construction procedure entails

[3] Völgyesi 2004: 61.

that the inside of the embankments is almost without exception of heterogeneous nature. According to measurements made during flooding, considering seepage, the heterogeneity of embankments may occur in three forms: Seepage in heterogeneous embankments (Figure 2); Seepage in the subsoil (Figure 3); Complex seepages in heterogeneous embankments and subsoil (Figure 4).[4]

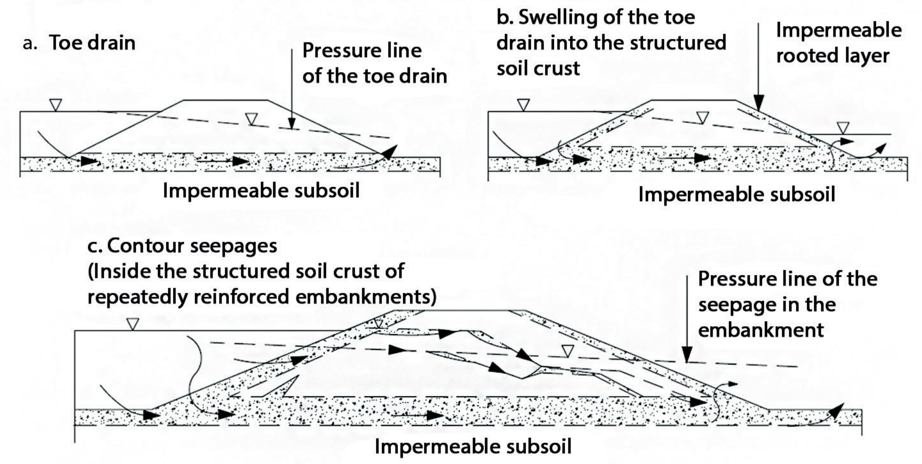

Figure 2: Seepage in heterogeneous embankments
Source: Galli 1976

Seepage in the subsoil

Regarding seepages, the subsoil in the flood protection lines may always be divided into multiple groups. Firstly, the subsoil can be single-layered, which is either a homogeneous aquiclude or aquifer. Alternatively, according to the general rules of sedimentary sequences, it can also be some sort of a simple-bound layer or a two-, three-layered subsoil covered with bound and fine sand.

From the perspective of seepages, a multi-layered subsoil is also considered a naturally impermeable subsoil given that its bound top soil is so thick that the hydraulic soil failure on the protected side as well as the seepages under the embankments regarding the underseepage are negligible. Seepages may occur both in embankments and in the subsoil.[5]

[4] Galli 1976: 49.
[5] Galli 1976: 52.

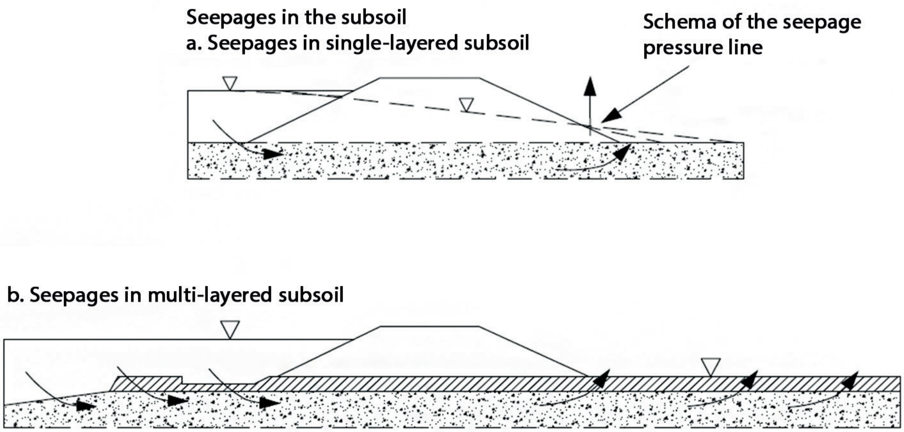

Figure 3: Seepage in the subsoil
Source: Galli 1976

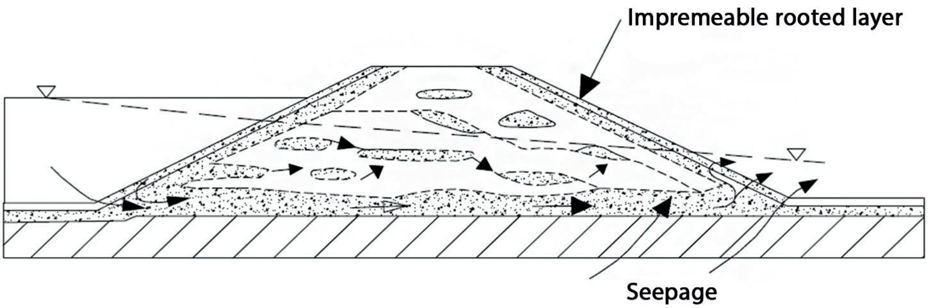

Figure 4: Complex seepages in heterogeneous embankments and subsoil
Source: Galli 1976

Development of flood phenomena

The water load in different zones of the flood protection dikes leads up to seepages, the intensity of which is often different and also changes over time.

The intensity of the flood phenomenon itself is also changing, nevertheless when examining the risk of a dike break due to seepages, only the flood level is taken into consideration (standard flood level, height of the embankment, or level that can be protected by embankment elevation during flood). However, understanding the duration of the flood or the velocity of the rising and falling phases is also important.[6]

[6] Völgyesi 2004: 64.

Experiences show that the failures caused by seepage has four main characteristics, occurring in four critical locations:

- subsoil stability in terms of topsoil breach
- subsoil stability in terms of sand boil formation
- subsoil stability in the aquifer
- slope stability on the protected side

Embankment and subsoil seepages – apart from the possible damages caused by underseepage – are not necessarily dangerous events. Even if the slope shows separate stains or leakage, or soaking on a continuous surface or even if there is surface wetting and seepage in the safety zone, the stability of the protection line is only compromised if these phenomena cause certain geomechanical processes in the embankment or subsoil that lead to the breach of the flood protection line. The stability of the protection lines and the need for flood protection interventions and possibly the subsequent strengthening of the protection lines must therefore not be based on the occurrence of the seepage, but rather on the expected consequences of the seepage.

Flood protection sections

The flood protection settlements and areas in the Körös region are protected and exempted from floods by flood protection sections, including flood protection embankments (Figure 5).

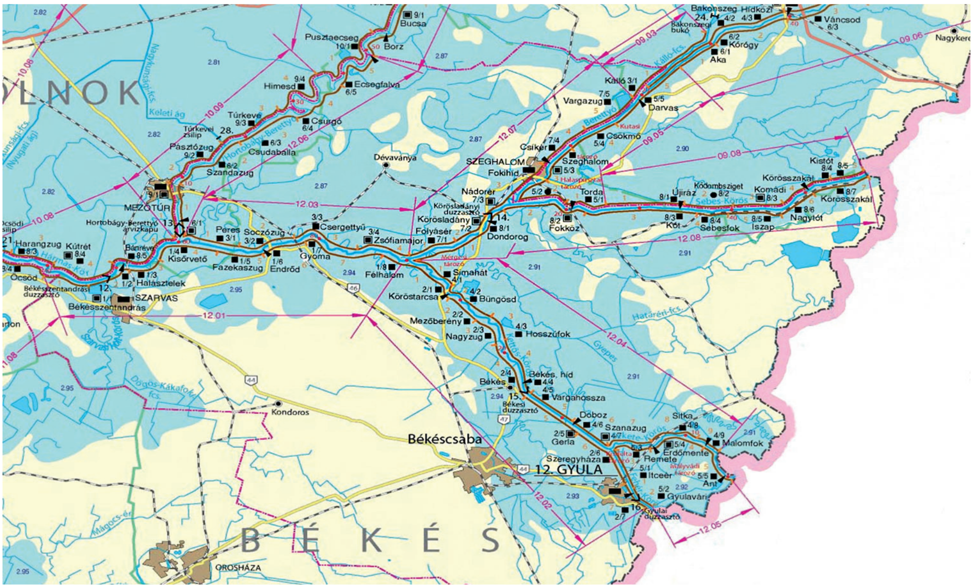

Figure 5: Flood protection system of the Körös Region Water Management Directorate
Source: General Directorate of Water Management 2014

The flood protection sections and lengths of protection lines in the Körös Region Water Management Directorate (hereinafter KÖVIZIG) area are summarised and presented in Table 1.

Table 1: Flood protection sections and protection lines in the KÖVIZIG area

Protection section number	Dike location (River)	Dike length (m)	Embankment length (m)
12.01	Hármas-Körös left bank	49,117	49,117
12.02	Kettős-Körös left bank, Fehér-Körös left bank	9,286–35,040	44,326
12.03	Hármas-Körös right bank	28,413	28,413
12.04	Kettős-Körös right bank, Fekete-Körös right bank	16,059–36,193	52,252
12.05	Fehér-Körös right bank, Fekete-Körös left bank	9,475–20,490	29,965
12.06	Hortobágy-Berettyó left bank	43,210	43,210
12.07	Sebes-Körös right bank, Berettyó right bank	14,013–21,313	35,326
12.08	Sebes-Körös left bank	57,966	57,966

Source: 12.01.–12.8. KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [KÖVIZIG Flood Protection Sections. Technical Description] Körös Region Water Management Directorate

Flood protection phenomena

In the past 57 years, there have been 20 flood waves in the river basin of the Körös Region Water Management Directorate (on 8 flood protection lines) when a flood phenomenon occurred.

According to the registry data, a total of 3,798 phenomena were documented over nearly six decades, which is equivalent to 1,283,806 metres on all the 8 flood protection lines.[7]

Table 2 shows the data per protection lines:

[7] Árvízvédelmi tervek. Észlelt árvízi jelenségek JEL-12.01–12.08 [Flood Protection Plans. Observed Flood Phenomena JEL-12.01–12.08]. KÖVIZIG [Körös Region Water Management Directorate].

Table 2: Distribution of flood protection phenomena per protection lines

Protection section number	Total length of phenomena occurred (57 years) (m)	Average total length of phenomena occurred (1 year)	Total number of phenomena occurred (57 years)	Average total number of phenomena occurred (1 year)
12.01	304,486	5,342	685	12
12.02	179,730	3,153	488	9
12.03	91,821	1,611	371	7
12.04	292,057	5,124	776	14
12.05	158,521	2,781	434	8
12.06	122,779	2,154	511	9
12.07	65,982	1,158	302	5
12.08	68,430	1,201	231	4

Source: 12.01.–12.8. KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [12.01–12.08 KÖVIZIG Flood Protection Sections. Technical Description] Körös Region Water Management Directorate

The table above (Table 2) shows that over the 57 years, more than 500 phenomena with high values have developed on the 12.04, 12.01, 12.06 defence lines, which means an average of 9–10 phenomena per year. By observing the length of the phenomena that have developed, it can be stated that phenomena have developed on the 12.01, 12.04 defence lines for a length of more than 5 km per year, which greatly weakened the defence lines and made defence more difficult.

Categorisation of the phenomena

The data on the phenomena was documented separately, using 5 different categories, as shown below:

- seepage in the embankment (seepage, stream, drenching)
- seepage outside of the embankment (spring water, subsoil seepage, footing seepage)
- wave action (protection against waves caused by wind)
- sand boil (hydraulic soil failure)
- levee break

Table 3 shows the distribution of the number of documented phenomena by categories per protection lines:

Table 3: Distribution of flood protection phenomena per protection lines

Phenomenon group	Flood protection line								Total
	12.01	12.02	12.03	12.04	12.05	12.06	12.07	12.08	
Number of seepages in the embankment	108	117	51	135	113	140	40	40	744
Number of seepages outside of the embankment	558	369	318	600	295	324	262	178	2,904
Number of wave actions	10	1	0	0	0	46	0	13	70
Number of sand boils	9	1	2	39	17	1	0	0	69
Number of levee breaks	0	0	0	2	9	0	0	0	11
Total	685	488	371	776	434	511	302	231	3,798

Source: 12.01.–12.8. KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [12.01–12.08 KÖVIZIG Flood Protection Sections. Technical Description] Körös Region Water Management Directorate

Table 3 above shows the number of types of phenomena that developed on the protection lines, where it can be shown that the number of leaks outside the embankment (water seepage, subsoil seepage, bedrock seepage) was the highest on each protection line. Observing the data series, it can be stated that the most phenomena developed on the protection lines 12.04, 12.01, 12.06.

The following table (Table 4) shows the distribution of the number of phenomena according to the length of the protective conductors.

Table 4: Distribution of flood protection phenomena by categories per protection lines

Phenomenon group	Flood protection line								Total (m)
	12.01	12.02	12.03	12.04	12.05	12.06	12.07	12.08	
Seepage in the embankment (m)	30,755	44,221	9,394	45,396	37,758	50,295	9,994	4,847	232,660
Seepage outside of the embankment (m)	269,737	135,358	82,425	246,395	119,400	58,923	55,988	61,169	1,029,395
Wave actions (m)	3,985	150	0	0	0	13,560	0	2,414	20,109
Sand boil (m)	9	1	2	150	1,363	1	0	0	1,526
Dike break (m)	0	0	0	116	0	0	0	0	116
Total	304,486	179,730	91,821	292,057	158,521	122,779	65,982	68,430	1,283,806

Source: 12.01.–12.8. KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [12.01–12.08 KÖVIZIG Flood Protection Sections. Technical Description] Körös Region Water Management Directorate

Table 4 shows the duration of the types of phenomena that developed on the protection lines during the 57 years, where it can be shown that on each protection line, the number of seepages outside of the embankment was the longest-lasting phenomenon, followed by seepage in the embankment, wave action, sand boil and dike break phenomena in the embankment. Observing the data series, it can be stated that phenomena that weakened the protection lines developed the longest on the 12.01, 12.04, 12.02 protection lines.

Examining the data, it can be seen that seepage outside the embankment accounts for the most documented phenomena, both in terms of number of cases and length.

The following graph below shows the danger and load of the protection lines as the specific average length of the flood protection phenomena per protection line. The specific average length is the average of the length of the phenomena developed so far and the quotient of the length of the protection line, expressed in percentage.

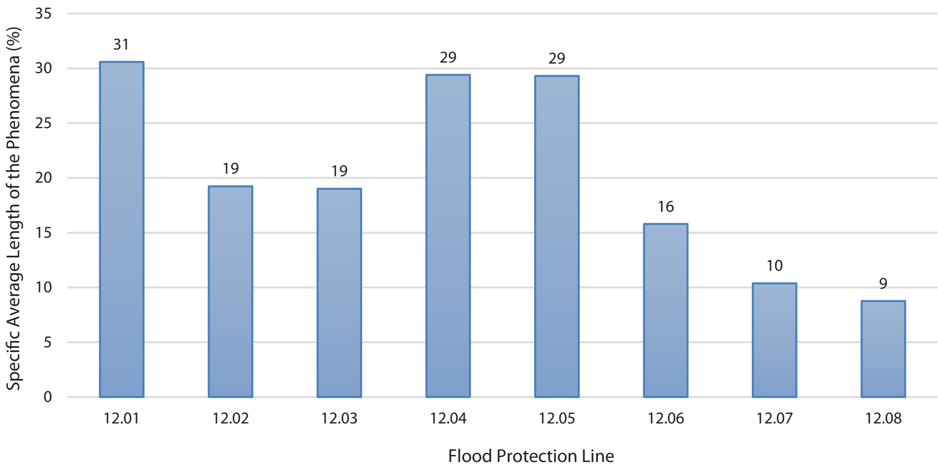

Figure 6: The specific average length of the phenomena occurring at the protection lines (%)
Source: Compiled by the author based on 12.01–12.08 KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [12.01–12.08 KÖVIZIG Flood Protection Sections. Technical Description] Körös Region Water Management Directorate

As shown in the chart (Figure 6), considering the already occurred phenomena, the protection line 12.01, i.e. the Hármas-Körös section is the most overloaded with its specific average length of 31%. This is followed by the 12.04 line of the Kettős-Körös and the Fekete-Körös section with 29%, then the 12.05 line of the Fekete-Körös and Fehér-Körös section with 29%.

The outlier value on the 12.01 line can be explained by the permanent floods (may last 2 to 12 weeks, with an average duration of 37 days) occurring on the Hármas-Körös (because of the backwater effects of the Tisza), during which several phenomena can develop since the flood greatly burdens the protection line.

On the 12.04. flood protection line, the soil properties of the embankment can influence the number of phenomena occurred (average duration of floods is 21 days). Contemporary records already confirm that a significant number of seepages in the embankment and subsoil have been developed on this protection line due to the saline soil of the embankment. This is also confirmed by the fact that this was the first section where a brick wall (Figures 7 and 8) was built into the embankment as a protection against seepage.

On the 12.05 protection line, many phenomena may develop due to the large water column formed as a result of increased flooding tendency (average duration of floods is 21 days).

The documented phenomena captured above weaken the stability of the flood protection lines (levees), thus endangering flood safety. Because of this reason, it is important to have a good protection against it.

Protection against such phenomena always require at least monitoring but may also involve intervention. In any case, this demands great human and material resources.

Protection against phenomena

There are two ways to protect against flooding: during the flood itself or learning from prior flood protection experiences. Flood protection efforts often comprise of the establishment of temporary protection facilities that help ensuring stability (during the water load period). These structures are usually dismantled after the flood. The need for such structures is later recorded and marked as flood protection experience. Learning from these experiences and scenarios helps to rationally design all the structures that are necessary to strengthen the dikes. Building these structures before a flood is developed one can avoid the recurrence of a critical flood phenomenon that would often require heroic human intervention. These structures can be built both in the embankment and possibly in the subsoil as well with the aim of increasing flood safety and mitigating flood risks.

The built-in flood protection facilities may be divided into two groups:

- active (limiting the harmful effects of water entering the seepage area to a tolerable level)
- passive (mitigating and/or preventing leaking water to penetrate the seepage area)

As far as their location is concerned, the flood protection facilities may be divided into the following categories:

- Structures built into embankments: the purpose of this is to actively or passively protect the area from the seepage process that occurs within the embankment.
- Structures built into the subsoil: the purpose of this is to actively or passively protect the area from the seepage process that occurs within the subsoil.

The following table (Table 5) demonstrates the distribution of built-in flood control structures:

Table 5: Built-in flood control structures

In the embankment		Subsoil	
Active	**Passive**	**Active**	**Passive**
Drainage system Sand drainage layer Stone drainage layer Drainage blanket Stone retaining wall	Slurry wall Sheet pile Foil Cut-off wall	Relief well	Damping mat Slurry wall Sheet pile

Source: 12.01–12.08 KÖVIZIG árvízvédelmi szakaszok. Műszaki leírás [12.01–12.08 KÖVIZIG Flood Protection Sections. Technical Description]; Árvízvédelmi tervek. Észlelt árvízi jelenségek JEL-12.01–12.08 [Flood Protection Plans. Observed Flood Phenomena JEL-12.01–12.08]. KÖVIZIG [Körös Region Water Management Directorate]

The most common way of passive protection against seepage inside the embankment is the construction of a cut-off wall in the embankment, which can be either a brick wall, a slurry wall or even a sheet pile. These engineering solutions will be briefly presented below with illustrations.

Cut-off walls inside embankments

In an attempt to protect against seepage, flood protection facilities were built in embankments already between 1885 and 1914. This flood protection initiative included impermeable brick walls that were built into the right side of the embankment of the Kettős-Körös river. At that time, this was a novel solution that protected the area against the wetting and soaking of the saline soil and the embankment.[8]

The following figures show the current status of the exposed brick wall that was uncovered during the fixing of the embankment (Figures 7 and 8).

[8] Góg 1983: 7–8.

Figure 7: The right side of the embankment on the Kettős-Körös between 18 + 350 – 18 + 650 tkm
Source: compiled by the author

Figure 8: The right side of the embankment on the Kettős-Körös between 18 + 350 – 18 + 600 tkm with the exposed brick wall
Source: compiled by the author

Self-hardening slurry wall

When creating (Figure 9) a self-hardening slurry wall, a rift is made with a scraper chain in which the biding agent is delivered into the different depths of the planned slurry wall either by gravity or by injection. It is then mixed with the soil and solidifies into a self-hardening slurry wall. This type of wall helps preventing seepage.

Figure 9: Building a slurry wall on the embankments of the Hármas-Körös
Source: Körös Region Water Management Directorate

Sheet pile wall

The sheet pile walls – put down with hydraulic sheet plier one after another – prevent water seepage both in the embankment and the subsoil (Figure 10).

Figure 10: Construction of the sheet pile wall at the toe of the dyke and embankment of the Hortobágy-Berettyó river system
Source: Körös Region Water Management Directorate

Drainage systems (infiltration galleries)

The drainage system is a method of active protection against seepage, which collects the water leaking through the embankments at the toe of the dyke on the protected side of the embankment. The water is then directed into the seepage canal.

When the purpose of the system is to drain the water out of the subsoil, the structure is called a gallery (Figure 11).

Figure 11: Construction of a drainage system at the toe of the dyke on the protected side of the embankment on the Fekete-Körös river
Source: Körös Region Water Management Directorate

Relief well

A pressure relief well (Figure 12) is a protected side tapping system that lowers the seepage pressure loss line by removing water seeping through the subsoil due to flood column pressure, thereby reducing the buoyancy force on the protected side to a tolerable (non-hazardous) level and thus significantly reducing hydraulic fracturing.

Figure 12: Relief well at the protected side forehead on the Fehér-Körös river
Source: Körös Region Water Management Directorate

The installation status of the aforementioned flood protection facilities on the protection lines managed by the Körös Region Water Management Directorate are described in the following table (Table 6).

Table 6: Installation status of the flood protection facilities by categories per protection lines

Number of flood protection facilities per protection line									
Category	**12.01**	**12.02**	**12.03**	**12.04**	**12.05**	**12.06**	**12.07**	**12.08**	**Total**
Passive protection in the embankment	48	11	4	14	2	2	1	7	89
Active protection in the embankment	8	9	10	16	4	11	2	3	63
Passive protection in the subsoil	0	0	0	3	0	1	0	0	4
Active protection in the subsoil	0	1	0	5	0	0	0	0	6
Total	56	21	14	38	6	14	3	10	162

Source: Árvízvédelmi tervek. Észlelt árvízi jelenségek JEL-12.01–12.08 [Flood Protection Plans. Observed Flood Phenomena JEL-12.01–12.08]. KÖVIZIG [Körös Region Water Management Directorate]

The most commonly applied method of protection against seepage is passive protection, which accounts for 89 of the 162 structures (slurry walls, sheet piles, foils and cut-off walls), the combined length of which is also the largest.

The categorisation of the built-in structures per protection lines are described in the following table (Table 7).

Table 7: The categorisation of built-in structures by protection lines

Length of flood protection facilities (m)									
Category	**12.01**	**12.02**	**12.03**	**12.04**	**12.05**	**12.06**	**12.07**	**12.08**	**Total**
Passive protection in the embankment	8,352	3,488	4,290	4,640	184	741	233	1,362	23,290
Active protection in the embankment	2,479	5,215	5,325	7,485	526	4,889	179	313	26,411
Passive protection in the subsoil	0	0	0	340	0	85	0	0	425
Active protection in the subsoil	0	86	0	1,093	0	0	0	0	1,179
Total	10,831	8,789	9,615	13,558	710	5,715	412	1,675	51,305

Source: Árvízvédelmi tervek. Észlelt árvízi jelenségek JEL-12.01–12.08 [Flood Protection Plans. Observed Flood Phenomena JEL-12.01–12.08]. KÖVIZIG [Körös Region Water Management Directorate]

Summary

The flood protection embankments of the Körös region are gradually exposed to the soaking effect of the floods during each event. The consequences of these phenomena include, among others, hydraulic soil failure and the reduction of the shear strength of the bound soils affected by seepage to a critical extent resulting in loss of stability (slope slide, levee break).

In addition to the weather conditions (precipitation and temperature), the extent of seepage is also heavily dependent on the water level as well as the duration of the flood wave (number of days spent under flood).

This article focused on the presentation of data collected on flood phenomena since 1969 until today, with special attention to the built-in flood protection facilities, the length and number of occurrences, the protection lines and the rivers as well. It is noteworthy that – based on the length of both the built-in structures and the phenomena – there are still several locations and sections along the protection lines that require intervention.

In order to determine the necessary improvement opportunities, it is recommended to carry out a practical and statistical study regarding the occurrence of flood phenomena on each protection line in question. During the study, experiences gained from the previously built-in stability enhancing structures should also be taken into consideration.

When planning these interventions, seepage tests and stability models may be carried out, leveraging the characteristics and geomechanics data of previously observed flood phenomena. Based on the evaluation of prior experiences, such studies will result in a more realistic and economical safety enhancement.

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