The Possibility of Local Soils Use for Levees Construction as Part of Flood Protection

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Abstract **– The levee is an important part of the complex of flood protection measures, which is direct a barrier against high water levels. At the same time, it is the most voluminous and time-consuming structure, the construction of which requires a significant amount of material and transport costs. For their construction, soil from local quarries can be used, which will significantly reduce the costs of their construction and speed it up. But before the possibility of their use, it is necessary to check their suffusion characteristics to ensure their seepage stability.**

Keywords **– levee; seepage flow; suffosion; erosion; eroding soil.**

I. Introduction

Floods are among the most frequent and destructive natural disasters globally, causing significant economic, environmental, and social impacts. Floods have become more intense and frequent in recent years due to a combination of natural and human factors, including climate change, urbanization, and inadequate flood management systems.

The floods in 2023 were particularly severe, affecting several countries across the continent. Slovenia, Greece, Turkey, Bulgaria, and Spain experienced some of the most devastating floods, with torrential rainfall overwhelming river systems and infrastructure. In Slovenia, August floods led to widespread damage, with thousands displaced and significant losses in agriculture and infrastructure [3]. Similarly, Greece, Turkey, and Bulgaria were hit by catastrophic flooding in September, with record rainfall causing fatalities and disrupting daily life [7].

Floods are not only driven by extreme weather events but are also exacerbated by human activities like deforestation, construction in flood-prone areas, and insufficient flood protection measures. As European nations continue to grapple with these disasters, the role of flood protection infrastructure, such as dams and levees, has come into focus. While these structures can reduce the risk of floods by controlling water levels, their failure either due to aging or extreme conditions can lead to catastrophic consequences [6].

The recent floods underscore the urgent need for a comprehensive approach to flood management that includes both structural measures like dams and levees, and non-structural measures such as improved early warning systems and sustainable land use planning. As climate change continues to intensify rainfall patterns across Europe, the pressure on existing flood defenses will only increase, making it crucial to enhance resilience to future floods.

This sets the stage for a deeper exploration into how dams and levees function as key elements of flood protection, and how their design, maintenance, and management need to adapt to changing environmental conditions.

Climate change is already impacting peoples` daily lives and will continue to do so for the foreseeable future. For example, Europe is expected to get warmer, some regions getting drier, while others wetter [1]. These changes will not only impact our health but also the ecosystems we depend on. The EU is preparing to live with a changing climate through various adaptation measures.

Catastrophic consequences of inundation with floodwaters are becoming more and more common in Ukraine. The mountain and foothill regions of the Ukrainian Carpathians (Zakarpatya, Ivano-Frankivsk, Lviv, Chernivtsi regions), Polissia (Volyn, Rivne regions), the Danube and Dnieper territories suffer the greatest damage. Floods cause significant damage to industry, agriculture, and the population of this regions. Their reason lies in the peculiarities of the natural conditions of the Carpathians and adjacent territories, as well as human economic activity in this region.

The territory of Zakarpattia Region, due to its geographical position and climatic conditions, belongs to the zone of developed torrential activity, where during the year the level of precipitation reaches 100 millimeters or more in short periods of time, which is the reason for the formation of significant floods, often catastrophic in their consequences. Rain and snow-rain floods are characterized by frequency, intensity of flow and simultaneous coverage of large areas.

Several rain floods are observed in the Carpathians throughout the year, from 5-8 to 20-23 in certain high-water years. In recent years, floods have become catastrophic and have led to the flooding of large agricultural areas and settlements. Therefore, the issue of protection of territories adjacent to rivers from flooding is acute. The results of the analysis of the causes of emergency situations with catastrophic consequences indicate the need for a comprehensive approach to solving this problem.

II. STATEMENT OF PROBLEM

The levee (barrier dam) in the flood protection system is the most expensive and time-consuming element, and the most vulnerable to damage. Significant volumes of soil material are needed for its construction. This soil can be extracted from local quarries in the valleys of the Carpathian rivers. The construction of an embankment dam depends on its height, the soil of the foundation and body of the dam, engineering and geological conditions.

The main feature (and the difference from embankment dams) of levees is that they hold the estimated water level for a short period of time - the time of the high flood level. In some cases, floods with elongated hydrographs may form, although not of maximum flow. In such cases, despite pressures that are lower than calculated, it is advisable to perform seepage calculations.

The second feature of levees, which significantly affects its operation, is that seepage flow during flood is non-stationary. In case of a short-term flood and a sufficiently low filtration coefficient of the embankment, water percolation to the downstream slope may not occur. In this case, with appropriate soil characteristics and pressure gradients can lead to particle movement and internal suffusion can occur, which may lead to changes in levee profile.

Depending on the structure of the levee and its elements, on the gradation of the soils of the body and foundation, their suffusion characteristics, under the influence of the seepage flow in the structure, seepage and suffusion deformations may occur both in the body and foundation of the levee or in other structural elements.

Flood protective levees can have a significant length and, accordingly, require a significant volume of material for their construction. Soil material from local quarries can be used for their construction, which will significantly reduce the cost of the dam itself, as well as transportation and production costs. In order to check the possibility of using these soils in the body of levees, they should be checked for suffusion resistance and seepage stability.

But regardless of their size, every embankment dam creates a hazard potential from the stored energy of the water they impound. Examples, such as Kelley Barnes Dam, which failed suddenly in 1977, show the destructive power of water when it is released suddenly from behind even a small embankment dam. This embankment dam was less than about 12m high and about 120m long, but when it failed, it released water downstream at an estimated flow rate of over 340 m^3/s, killing 39people [4].

In order to prevent such disasters, it is necessary to carefully select the material for the construction of dams. Therefore, a gradation analysis of soil samples taken from quarries possible for use in the construction of dams from the regions of Zakarpattia region near the Tisza River, where levees are especially relevant, was carried out. Based on this analysis, the suffusion resistance of these soils was verified.

III. DISCUSSION OF RESULTS

According to [4] nonsuffusion soil is soil in which mechanical suffusion is impossible, even under the influence of significant pressure gradients, removal of fine particles from the soil will not occur. In suffosion soils, mechanical movement of soil particles can occur and develop when critical seepage rates are reached. The suffusion of soil samples was determined according to the methodology for embankment dam filters design [4]. Practice shows that when removing small particles from the soil, no more than 3…5% of the mass, the strength and stability of the soil is practically not disturbed. Accordingly, the soil from which the smallest particles of no more than 3…5% of the weight can be removed can be considered practically nonsuffosing soil. The soil should be considered (according to the geometric criterion) practically nonsuffosible if its parameters satisfy the following condition

$$\frac{d_5}{d_{17}} \geq N \tag{1}$$

$$N = 0,32\sqrt[6]{C_u}\left(1 + 0,05C_u\right)\frac{n}{1-n} \tag{2}$$

where d_5, d_{17} – diameter of soil particles, the smaller of which is contained in its composition 5 and 17% by mass, respectively, cm; C_u – coefficient of soil heterogeneity; n – soil porosity, in fractions of a unit. If condition (1) is not fulfilled, then the soil should be considered suffosible.

Internal suffusion in sand and gravel soils will develop when it contains particles with a diameter smaller than the diameter of the largest seepage pores in the soil d_0^{max}, at seepage speeds greater than the critical one $V>V_{cr}$. Soil particles that are smaller than the diameter of the largest seepage pores in the soil are called eroding particles, as they can be washed out by the seepage flow from the soil.

$$d_{ci} < d_0^{max} \tag{3}$$

d_{ci} – diameter of eroding particles.

Estimated diameter of seepage pores in loose soils d_0 can be determined with the formula

$$d_0 = C\frac{n}{n-1}d_{17} \tag{4}$$

where $C = 0,455\sqrt{C_u}$.

The diameter of the maximum seepage stroke is determined according to the following dependence (taking into account soil segregation)

$$d_0^{max} = \chi d_0 = \chi C\frac{n}{n-1}d_{17} \tag{5}$$

χ – the coefficient of uneven placement of particles in the soil or the coefficient of locality of suffusion.

Maximum particle size d_{ci}^{max}, which can move in the soil and can be washed out from it

$$d_{ci}^{max} < 0,77\ d_0^{max} \tag{6}$$

Results of the suffusion analysis are shown in table 1.

TABLE I. SOIL SUFFOSION ANALYSIS

Sample	d_{max}, mm	C_u	*n*	d_5 mm	d_{10} mm	d_{17} mm	d_{50} mm	d_0 mm	$d_0^{макс}$ mm	d_{ci} mm	*Suffosion*
Plot No. 1 - village Dubove, Tyachiv district, river Tisa											
S1-1	95,0	81,88	0,21	0,231	0,379	0,833	20,69	0,21	0,82	0,63	+
S1-2	104,0	50,10	0,23	0,267	0,429	0,856	12,90	0,22	0,72	0,56	+
S1-3	132,0	77,77	0,21	0,303	0,707	1,588	37,66	0,40	1,55	1,19	+
S1-4	80,0	61,11	0,22	0,255	0,399	0,636	10,56	0,16	0,57	0,44	+
S1-5	58,0	9,95	0,30	0,125	0,158	0,238	0,91	0,07	0,10	-	-
Plot No. 2 - village Tyachiv, Tyachiv district, river Tisa											
S2-1	102,0	204,29	0,17	0,181	0,299	0,883	45,95	0,20	1,15	0,89	+
S2-2	79,0	173,09	0,18	0,148	0,241	0,425	30,45	0,10	0,53	0,41	+
S2-3	121,0	101,50	0,20	0,281	0,602	16,028	52,59	3,92	16,96	13,06	+
S2-4	94,0	52,49	0,23	0,267	0,522	0,958	15,40	0,25	0,82	0,63	+
Plot No. 3 - villageTernove, Tyachiv district, river Tisa											
S3-4	80,0	425,02	0,14	0,077	0,093	0,451	28,775	0,09	0,71	0,55	+
S3-5	129,0	19,00	0,27	0,917	4,395	17,32	72,169	4,81	9,39	7,23	+
S3-6	120,0	32,95	0,25	0,344	1,401	4,741	32,516	1,28	3,51	2,70	+
S3-4a	132,0	26,03	0,26	1,056	3,148	11,092	69,402	3,03	7,63	5,87	+
S3-5a	82,0	40,85	0,24	0,285	1,272	4,669	38,034	1,24	3,70	2,85	+

According to the gradation analysis of the soil samples of the soils belong to gravel soils with large rock fragments, with a high degree of heterogeneity (Tab. 1) C_U = 30...120. Practically all soil samples turned out to be potentially suffusive. In order to use them as material for levees, it is necessary to carry out seepage calculations, to arrange special filters and drains as a means of controlling and directing the flow of seepage water through dams. Filters are used to prevent movement of soil particles from or between various zones and foundations of embankment dams.

Levees can be constructed with the use of the soils from quarries located directly near rivers. Their cross-sectional parameters must be sufficient to withstand the flow gradient without internal erosion of few grains of soil or they must be equipped with filters used as a defensive measure to protect these structures from the less than desirable conditions that may exist or develop over the life of the structure.

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