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THE ROLE OF MICROORGANISMS IN ELEVATING THE TURBIDITY OF DAM SEEPAGE WATER

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Studies at one of the earthen dams of the Volga – Kama cascade of dams revealed an elevated removal of suspended particles in seepage water, resembling the process of mechanical erosion. Comprehensive studies show that active microbiological processes occur in dam bodies. Elevated turbidity of seepage water was caused by microbiological processes. Microorganisms are also capable of adversely affecting the physical and mechanical properties of soil and promote the risk of reducing the stability of hydraulic engineering installations. In this regard, there is a need to develop a method to study the extent of microbiological process hazard and to incorporate it into regulatory documents.

Keywords: hydraulic engineering installations; safety; erosion; microorganisms; soil properties; regulatory documents.

Safety issues for hydraulic engineering installation earthen dam operation require periodic measurement of various facility parameters [1 – 3]. One of the important monitored parameters is water turbidity at the drainage system outlet [4], which permits erosion processes to be identified at the early stage of development. Suffusion process development is an extremely negative development that leads to reduced facility stability and even failure. Thus, for example, at the Unmun dam in the Nakdong river basin (South Korea), the erosion process led to the formation of three sinkholes at the dam crest [5]. However, as practice shows, increased water turbidity after seepage through a dam embankment may be related not only to erosion processes, which places the objectivity of this factor into question.

A study of this problem was carried out on one of the dams of the Volga – Kama cascade via the collection of seepage water that had passed through the body of an earthen dam. This resulted in the discovery of an ocher-colored deposit on the wall lining and on the bottom of the discharge drainage channel. A chemical analysis of the specimens was carried out in the operating organization's laboratory in accordance with internal procedures, and these showed that the seepage water turbidity index exceeded that of reservoir water by more than 6 times. In this regard, we carried out a set of activities to study this phenomenon, which included laboratory chemical, mass-spectrometric, and mineralogical analyses of water and soil specimens, as well as an on-site inspection with geochemical testing of subsurface gas and drainage system gas composition [6].

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Field study results

Up to a height of 19 m, the dam was constructed of sand-gravel soil via hydraulic mining, with a built-up shield made of fine-grain sand on river-borne deposits; the river deposits are up to 14 – 17 m thick. The river-borne deposits are represented by clay and heavy clay loam, fine-grain sand, and gravel-pebble bodies. The entire stratum of river-borne clay and clay loam contains sand interlayers. Clay and clay loam are layered, powdery, dense and moist, and contain some plant residue. Clay soil exhibit high physical and chemical activity and contain a significant quantity of organic substances (up to 8%) and trace nutrients. Drilling has shown that the dam soil located below the seepage water level has a blue-gray-to-gray hue, and is up to 8 m in overall thickness. Blue-gray, green, bluish, and mottled (ocher-blue-gray, etc.) hues are typical of soils that have undergone gleyification, which occurs as a result of the development of anaerobic microorganisms; at the same time, microorganism waste products-carbon dioxide, methane, and organic acids-appear in the water [7]. The gleying process-which is one of the most widespread in the saturated zone-consists in the reduction of trivalent iron to a divalent state with subsequent removal of iron (II) from gleyed horizons [7, 8]. A typical sign of gleyification is trivalent iron hydroxide, which is formed during gleyification in sections of somewhat higher oxidation potential or during subsequent oxidation processes, when former gleyed horizons are exposed to an environment conducive to oxidation [7]. When cores of gleyed soil are brought to the surface, ocher spots of trivalent iron hydroxide start to gradually appear on the core. Gas geochemical tests of subsurface gas within the earth dam embankment reveals

Fig. 1. Potential sources of organic substance inflow into a dam embankment.

pockets of elevated carbon dioxide, methane, and volatile organic compounds [6, 9, 10].

Laboratory study results

Precipitate from seepage water specimens was ocher in color and consisted of finely dispersed mineral particles, while the precipitate from a reservoir water specimen was of a dark-brown color, and consisted primarily of flaky particles and organic debris particles. The precipitate from seepage water specimens dissolved when boiled in a 4 N HCl solution, and the solution assumed a yellow hue; the precipitate from the reservoir water specimen partially dissolved and partially decomposed into smaller brownish-black particles when boiled in a 4 N HCl solution, and the solution assumed a brown color. The seepage water precipitate was represented by trivalent iron hydroxide.

It was determined that seepage water at the outlet from the drainage system is initially transparent, and that a precipitate forms either as a result of incomplete closure of the sample-collection container, or in the laboratory during specimen filtration, i.e., the ocher precipitate formed in the seepage water specimens as a result of long-duration contact with air. Thus, the precipitate is not a result of erosion-related removal of dam soil particles, but iron (III) hydroxide that forms when iron (II) ions dissolved in water is oxidized by oxygen in the air. In this regard, the question occurs: Where do the iron (II) ions dissolved in water come from?

One such source could be corroded metal structures of the drainage system itself. An analysis of the trace nutrient composition of water and of the precipitate from specimens of seepage water and water from the reservoir showed that the principal source of iron (II) ions dissolved in the water is not corroded metal drainage system structures. Without completely rejecting this source, we must acknowledge yet another source, which may be the soil of which the dam embankment is composed, in which the gleyification process is ongoing.

A chemical analysis of water specimens revealed the pocket-like nature of the occurrence of NH_4^+, NO_2^-, NO_3^-, as well as Fe^{2+}. Here, the pocket of elevated NH_4^+ ion content distribution more or less coincided with the pocket of distributed Fe^{2+} ion content distribution. The HCO_3^- ion content in this zone was also elevated. The presence of spatially coincident pockets of elevated NH_4^+ and Fe^{2+} ion content distribution suggests the occurrence of microbiological processes that anaerobically decompose organic substances. That said, the source of NH_4^+ ions is an organic substance, while Fe^{2+} ions come from iron-containing minerals and rock in the dam embankment. It is known that under anoxic conditions, even well-ordered crystals of trivalent iron are capable of undergoing microbiological reductive dissolution [11]. Thus, the existence of a pocket of elevate Fe^{2+} ion content may be evidence of a microbiological transformation of minerals and dam embankment rock that results in the reduction of Fe^{3+} ions present in rock into Fe^{2+} ions that actively migrate in water and fall out as a precipitate in the form of trivalent iron hydroxides with gleyed water emerges onto the surface. This explains the significant increase in the turbidity of water seeping through the dam embankment, as compared to water from the reservoir.

Laboratory studies have confirmed the presence, in dam embankment soil, of a viable microbial community capable of affecting the liquid, solid, and gas phase of the soil as life-sustaining activities become more intensive, for example, as a result of elevated levels of organic substances [9, 10, 12, 13]. Water seeping through a dam embankment, was characterized by an elevated level of organic substances dissolved in water (the Corg content was from 108 to 122 mg/dm^3), while at the same time, Corg for surface water and water with low mineral content did not exceed 30 – 40 mg/dm^3, attaining 60 – 70 mg/dm^3 in individual instances. Mass-spectrometer studies showed that the organic substance dissolved in water is of primarily man-made origin. In our opinion, one of the potential sources of the man-made organic substance entering the reservoir and dam embankment is waste-water discharge from an upstream pulp-and-paper plant and storm water drainage from the city, as well as from streams whose catchment basins lie within residential areas (see the figure). The intensity of microbiological processes increases with increased organic substance content in the water seeping through the dam embankment. This process may start spontaneously. We also note that microorganisms that populate the dam embankment may exert a significant influence on the solid, liquid, and gas components, thus significantly changing the physical and mechanical properties of the soil [6, 9, 10, 12, 13], entailing all of the ensuing negative consequences.

CONCLUSIONS

1. Increased turbidity of waters seeping through the body of an earthen dam may not be related to erosion processes, but caused instead by microbiological processes that have become active as a result of the entry of organic substances from the reservoir, i.e., the turbidity index may serve as an indicator not only of erosion, but also of microbiological activity.

2. Microorganisms, together with increased turbidity in seepage water, are capable of exerting an adverse influence on the physical and mechanical properties of soil and the risk of reducing hydraulic engineering installation stability, which makes it necessary to develop a method to study the extent of microbiological process hazard and to incorporate it into regulatory documents.

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