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Experimental research on the filtration properties of an untamped mixture with "PMM" polymer mineral material

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Abstract: Polymermineral material "PMM" has multiple cycles of swelling and drying. It does not decompose under soil, biological and atmospheric influences and is environmentally safe. By adding the proportion of up to 30 g/kg of PMM additive to soil and tamping, we get a waterproofing material that can be used in urban construction and water supply. Taking into account the fact it is not always technically possible to carry out high-quality ramming when repairing channel walls, the task was to conduct an experimental study in order to determine the total moisture content of the mixture of PMM additive with soil. Experimental results of laboratory studies show that when PMM is added to the soil at a ratio of 30 g/kg under evaporation conditions, the mass of excess water in the substrate increases with time.

Keywords: filtration, substrate, humidity, hydraulic structure

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Introduction

In many hydraulic structures, including reservoir bowls, it is not possible to effectively mitigate the problem of filtration. Although a number of effective technological solutions for implementing anti-filtration measures have been developed

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in this direction in recent years, their mass application implies long-term experimental research and the issue is unlikely to be solved in the near future (Borodin et al., 1995; Tokmajyan et al., 2020; Tokmajyan et al., 2021,).

In Japan, for the purpose of disposing of waste from the nuclear disaster at Fukushima, substrates made from a mixture of sea clay, bentonite and zeolite were examined for moisture conductivity and adsorption properties using a series of laboratory tests. Bentonite was added to marine clay to reduce hydraulic conductivity, and zeolite was added to increase the adsorption capacity of the substrate. Most studies have been conducted on unsaturated soil or soil-bentonite mixtures with low water content, since the swelling property of bentonite in unsaturated soil-bentonite mixtures reduces the hydraulic conductivity of the substrate. When zeolite was mixed with marine clay, the pore flow conductivity was almost the same as that of marine clay without the addition of zeolite. The hydraulic conductivity decreased in proportion to the addition of bentonite. Therefore, when mixing a large amount of bentonite into marine clay in order to reduce moisture conductivity, one should take into account the negative effect on the adsorption capacity of the substrate (Kurihara et al., 2018).

In Armenia, in 2019, a pool was built in the form of an upturned truncated cone with a top circle diameter of about 12 m. At the bottom of the tamped pool, 5-6 cm thick sand was first laid and tamped again. Then, a layer of gravel, 5 cm thick, was poured on top, which was sprinkled with material "Natlen" at a ratio of 30 kilograms per 1 m^2 and all rammed again. The gravel was covered by a 5 cm thick sand layer. On top of the layer was put a 10 cm thick layer of soil from a dug-out pit and the layer was tamped down to protect it from mechanical processes (as a waterproofing layer a mixture of gravel and sand with "Natlen" material at a ratio 1:1 was used). Water was gradually poured into the formed basin, which did not pass through the waterproofing layer of "Natlen" and sand with gravel. This new technique is meant for creating a waterproofing mixture from innovative materials "Natlen" and "PMM" for reservoirs and irrigation canals, as well as their repairs (Tokmajyan et al., 2021).

The moisture characteristic curve shows the water-holding capacity of the soil. It can be measured either by drying out or by moistening the soil mass. Most researchers only consider soil drying because it is easy to measure compared to wetting (Albadri et al., 2014).

The "PMM" material is developed at the Institute of Mechanics of Moscow State University after Lomonosov, by employees of the laboratory of natural processes under the direction of A.A. Shakhnazarov. Over the past four years, scientists from the Moscow State University and the Shusha Technological University have been conducting research on the use of the PMM material in order to develop technologies for its use in urban planning, water management (Tokmajyan et al., 2018), waste disposal (Avanesyan, 2021a), agriculture and other sectors of the economy.

Water course losses affect the efficiency of the exploitation of basins. There are many examples of the efficiency of exploitation of hydraulic works being lower due to filtration losses. For instance, the usable storage of the Aparan reservoir is 90 mln/m^3 from which 36 mln/m^3 is lost to filtration (Tokmajyan et al., 2020, Yeroyan, 2007). Being unique, highly effective, ecologically clean and having no comparable substitute, "Natlen" (Galstyan et al., 2020) and "PMM" (Galstyan et al., 2020; Tokmajyan et al., 2021), which is used for waterproofing important facilities and structures (subway tunnels, storage dams, dams, canals, reservoirs, treatment facilities, etc.), has the ability to increase ten times in size when released into an aquatic environment (Galstyan et al., 2020; Tokmajyan et al., 2020). It is advisable to build a new channel from the PMM substrate-soil in a proportion of 30-40 g/kg with a trapezoidal cross-sectional shape, and an angle of inclination of the side walls to the base of the channel of no more than 30 degrees (Tokmajyan et al., 2020).

Contamination of soils with heavy metals is a serious problem because it negatively affects the characteristics of the soil and leads to the limitation of its productive and vital functions. As a result, it is necessary to avoid an "industrial environment" as much as possible. The inclusion of heavy metals in environmental pollutants is due to their stability and ability to accumulate biologically and their accumulation leads to negative effects on ecological systems. Metal waste contributes to the penetration of metal materials into waterways, water bodies, spreads through food chains, appears in dangerous amounts in food products and affects the biodiversity of ecosystems. It is necessary to try to neutralize the harmful effects of industry, or reduce them to a safe level. Reducing filtration processes in water-saturated soils plays an important role in solving this problem. As a result of infiltration of fertilizers, pesticides, domestic and industrial waste water into water bodies, not only surface but also underground water can be polluted (Avanesyan, 2021b). When assessing the indicators of waste pollution, we often confirm the existence of a state of emergency in the environment, which can be regulated by the introduction of modern irrigation technologies (Vartanyan et al., 2020).

Analyses carried out on a 4 m thick compacted substrate showed that hydraulic conductivity is maintained at a level below the norm in order to avoid seepage of environmentally hazardous substances (Ören et al., 2014).

Although the study of the behaviour of the hydro conductivity of zeolite--bentonite mixtures has recently attracted the interest of researchers, the nature of the change in moisture content in the substrate during compaction has not yet been sufficiently studied. Experimental data shows that hydraulic conductivity is not affected by the water content during compaction, but it differs significantly in substrates containing 10% and 20% bentonite. The hydraulic conductivity of the substrate containing 10% bentonite and 90% zeolite gradually decreased as the water content increased. The hydraulic conductivity of such a substrate tended to decrease rapidly when the water content exceeded the optimum value. On the contrary, the hydraulic conductivity of the substrate containing 20% bentonite and 80% zeolite decreased sharply in the early stages of compaction water content and leveled off when the water content was at the optimum water level (Tsuchida et al., 2014).

Soil with the addition of biochar has become a sustainable and alternative material as an ideal waste cover system. Water retention characteristics, gas permeability and water infiltration vary for unsaturated soil depending on soil uptake. Biochar was derived from water hyacinth and mixed with silty sand at a rate of 5%. Water-holding capacity is increased by adding biochar to silty sand. The amount of incoming air almost doubled, while the rate of desorption did not change significantly, which was associated with the capture of clay particles inside the biochar and the subsequent change in soil porosity. Infiltration rate was found to be relatively higher in case of biochar amended soil in comparison to bare soil (Bordoloi et al., 2021).

Numerous experimental studies have shown that the dosed mixing of "PMM" with various soils allows to significantly increase their moisture content. A well--compacted mixture of soil with a thickness of 7-10 cm with a concentration of "PMM"-soil of 30 g/kg and higher acquires good anti-filtration properties (withstands a pressure of 5 atmospheres and higher), and can be used as a waterproofing layer for the construction and repair of reservoirs, tailings, irrigation canals, basements, tunnels and other structures (Danilova et al., 2007).

In low-hazard hydraulic structures, sometimes, depending on the location of the structure, the urgency of liquidation and the lack of financial resources, it is advisable to use soil substrates with the addition of polymeric minerals to reduce filtration losses, the compaction of which, for technical reasons, is not always possible to perform qualitatively.

1. Purpose, tasks, and research methods

In order to develop new technology for the production of waterproofing materials, the task was to conduct laboratory experimental studies to determine the patterns of changes in the moisture content of the non-compacted substrate "PMM-Grunt", at a ratio of 30 g/kg.

When planning experimental studies, it should be taken into account that the total moisture capacity of the substrate during short-term exposure to water is higher compared to soil without additives, since the PMM additive particles swell and absorb a large amount of moisture. As a result of evaporation and filtration, the difference between the moisture content of the substrate and the soil is subsequently maintained. However, with a longer exposure of the substrate in the pool (several days), the picture changes and the water permeability of the mixture decreases.

PMM created by polymer-mineral materials based on natural components of b-powder less than 1 mm in size with specialized polymer-mineral additives of organic origin. The created mixture is environmentally friendly, stable, retains its properties for ten years, is frost-resistant and withstands temperatures up to 90°C. Polymer additives have a long molecular structure, dissolved in water, significantly increases the viscosity of the liquid, which makes it possible to accumulate in the soil additionally from 10-304% and significantly reduces the filtration coefficient.

2. Results and discussion

Laboratory experiments started at the Institute of Water Problems and Hydraulic Engineering, named after Yehiazarov, on the 19th May 2022.

The laboratory studies were carried out according to the theory of experiment planning. It is known that the sample mean is an estimate for the average value of the measured value and can serve as a characteristic of one or another quality indicator. Dispersion describes the spread of experimental values and serves as a measure of accuracy. The mass of substrates was determined by the Explorer EX10202.

The studies were carried out indoors, since the evaporation rate is significantly affected by wind and temperature changes, that is, only changes in the collected water in the substrate were analysed, which affect the dynamics due to evaporation and filtration of water from the tank. The moisture capacity of the soil and the mass of water in the substrate were determined, over time, depending on the method used and the amount of PMM, consisting of a polymer-mineral concentrate and bentonite of the same mass.

To determine the moisture capacity of the substrate, a container with a mixture of soil and PMM was placed in a water bath until it was filled to the maximum in order to achieve a volume of liquid corresponding to the total moisture capacity of the soil. The substrate of natural moisture content was preliminarily weighed. Next, the container was placed on a surface to drain excess water and reach the field container. When the flow of water from the holes in the bottom of the container stopped, the difference between the results of measurements of the mass of the "dry" mixture and thus impregnated mixture in the tank was determined by the absolute and relative values of the collected water.

After soaking in the bath to the field capacity, containers with substrate without PMM and with PMM collected water, which was retained throughout the time. The masses of the containers were measured until the scales showed a mass close to the value corresponding to the masses of the containers before the start of the experiment (water in the containers evaporates at a rate depending on the temperature and humidity of the air in the room, and the thickness of the substrate layer in it). The tests were carried out multiple times.

In two containers with the same mass of 390 g, 1000 g of soil and substrate by mass was placed: 970 g soil + 30 g "PMM" additive (total 1000 g mass). The temperature in the laboratory was 21°C: The bottom of the containers had holes for draining water. The containers were kept in the pool for 5 hours. The water penetrated into the soil through the holes in the bottom of the container and rose up through the microscopic pores and capillaries. The higher the porosity of the soil, the more water and air it can hold. The maximum amount of water collected in the soil corresponds to the soil water holding capacity criterion (total soil moisture capacity), which must be distinguished from the soil's water-holding capacity (soil field moisture capacity), which is determined by the amount of moisture remaining in it after complete water saturation until the final free squeeze. The total moisture content of the soil was 768 g, and the substrate was 1075 g. After one day, their field wettabilities were measured. The field moisture content of the soil was 570 g, and the substrate was 705 g. In other words, the substrate had additionally stored about 20% more water. On the 14th day, it was 44%.

The performance of the second experiment began on the 2nd June 2022: 500 g of water was added to each container of the first experiment. The temperature in the laboratory was 27°C: The field moisture content of the soil (determined after draining the excess water) was 516 g, and the substrate was 609 g. In other words, the substrate had additionally stored around 15% more water.

The performance of the third experiment began on the 22nd May 2022. In two containers with the same mass of 70 g, 1000 g of soil and substrate by mass was placed: 970 g soil + 30 g "PMM" additive (only 1000 g mass). The temperature in the laboratory was 28°C: The bottom of the containers had holes for draining the water. The containers were kept in the pool for 5 days. The total moisture content of the soil was 554 g, and the substrate was 515 g. After one day, their field wettabilities were measured. The field moisture content of the soil was 410 g, and the substrate was 428 g. In other words, the substrate had additionally stored about 5% more water. In the following days, that difference began to increase significantly. On the 15th day, it was 44%.

The following function can be used to construct the curves of the meliorant effect factor (Avanesyan, 2022):

$$\sigma = \frac{\Delta m_i}{m_{gi} - m_{g0}} \tag{1}$$

where Δm_i is the difference between the substrate mass and the soil mass without PMM at the time of observation (that is, how much water the substrate under observation accumulated/stored compared to the soil containing no PMM), m_{gi} is the mass of the soil without PMM at the time of observation, m_{g0} is the mass of the substrate, that is, the same as that of the soil without PMM (they are equal) at the start of the experiment.

During the second experiment, it was also found that when water was added to the container, the field wettability of the substrate continued to be higher than that of the soil without additives. Meanwhile, the data from the third experiment show that when the container is kept in the water basin (for 5 days in the third experiment) and water infiltration is done from the bottom, the total wettability of the substrate (515 g) is less than that of the soil without additives (554 g). This is explained by the fact that, due to the small water permeability of the substrate, it absorbs less water. But after that, the humidity ratio changes diametrically and the amount of excess water in the substrate increases compared to the soil without additives (Fig. 1).

Testing infiltrometer techniques to determine soil hydraulic properties is necessary for specific soils (Alagna et al., 2016). Direct determination of a wetting water retention characteristics curve is time-consuming and needs destructive sampling and invasive sensor placement, and, at times, it is difficult to measure due to rapid wetting (Naik & Pekkat, 2023).

The results of our research is shown in Figure 1.

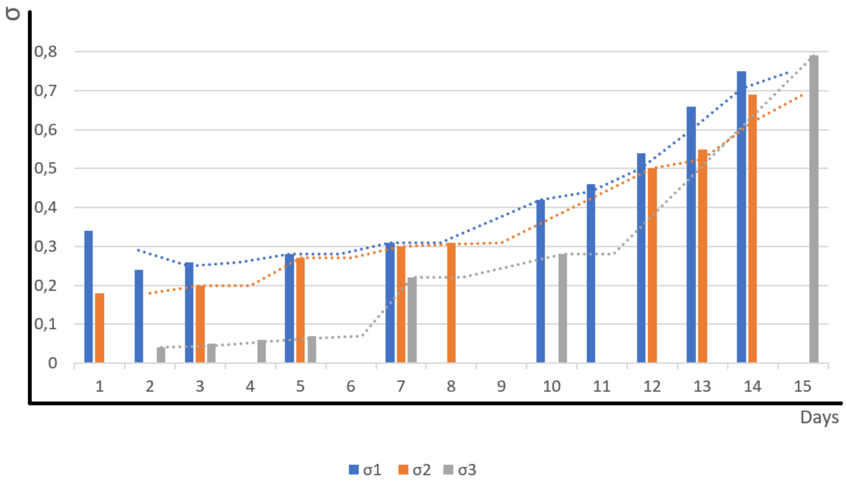

Fig. 1. The curves of the meliorant effect coefficient σ1, σ2, σ3: for the first, second, and third experiments conducted by ourselves, respectively (*own research*)

The experiments indicated the possibility of acquiring an increased volume of water in the substrate with PMM in contrast to the substrate without, as well as how it varies over time due to evaporation.

Conclusions

The dynamics of changes in the moisture content of the PMM additive mixture with soil at a ratio of 30 g/kg shows that in the presence of evaporation, the amount of excess water in the substrate increases with time.

Further experimental works are proposed to be carried out in containers closed from the top, in the absence of evaporation, in order to determine the change in moisture content of the "PMM" additive-soil mixture with a proportion of 30 g/kg and more. The filtration behavior of the substrate under conditions of water supply from above should also be investigated, which will make it possible to model soil hydraulic structures and develop new calculation methods.

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