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METHODS FOR PROTECTING BUILDINGS AND CONSTRUCTIONS FROM HARMFUL EFFECT OF GROUNDWATER IN THE SOUTH OF UKRAINE

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The South of Ukraine, characterized by its unique geological and hydrological conditions, poses significant challenges to the stability and longevity of buildings and constructions due to the harmful effects of groundwater. The excessive presence of groundwater and fluctuating water tables can lead to a range of issues, such as foundation instability, structural weakening, and corrosion, which in turn increase maintenance costs and reduce the safety and lifespan of buildings. This research article explores and evaluates modern and effective methods of protecting buildings from these harmful effects, taking into account the specific conditions in southern Ukraine.

Groundwater impact on buildings and construction is an increasingly urgent issue, especially in regions with a high water table or areas prone to seasonal floods, which are common in the southern parts of Ukraine due to its proximity to water bodies like the Dnipro River and the Black Sea. The variability of climate conditions, combined with human activity, has altered the natural water regime, exacerbating the problem.

This article presents a comprehensive overview of the most prevalent methods of groundwater protection used in building construction in southern Ukraine. It addresses both traditional and innovative techniques, highlighting their effectiveness, costs, and long-term sustainability. Among the methods examined are drainage systems, waterproofing technologies, soil stabilization, and foundation insulation.

In conclusion, the article emphasizes the importance of choosing an appropriate combination of groundwater protection methods based on the specific environmental conditions and the type of building or construction project. A combination of drainage, waterproofing, soil stabilization, and insulation offers the best protection against the harmful effects of groundwater, ensuring the safety and longevity of structures in the challenging climatic and hydrological conditions of southern Ukraine.

This research contributes to the ongoing dialogue about sustainable construction practices in regions prone to groundwater-related issues and provides practical recommendations for engineers, architects, and construction professionals working in southern Ukraine. By adopting these methods, it is possible to minimize the adverse effects of groundwater on buildings, thereby increasing their durability and reducing maintenance costs.

Key words: *groundwater, buildings protection, drainage systems, waterproofing, soil stabilization, foundation insulation, South of Ukraine.*

Аверчев О.В., Ладичук Д.О., Аверчева Н.О., Нікітенко М.П., Ладичук В.Д. Способи захисту будівель і споруд від шкідливої дії підземних вод на півдні України

Південь України, що характеризується унікальними геологічними та гідрологічними умовами, які створюють значні проблеми для стійкості та довговічності будівель і споруд через шкідливий вплив підземних вод. Надмірна присутність ґрунтових вод і значне коливання їх рівнів можуть призвести до низки проблем, таких як нестабільність фундаменту, ослаблення конструкції та корозії, що, у свою чергу, що збільшує витрати на технічне обслуговування та зменшує безпеку та термін служби будівель.

У цій роботі досліджуються та оцінюються сучасні та ефективні методи захисту будівель від цих шкідливих впливів з урахуванням специфічних умов півдня України. Негативний вплив ґрунтових вод на будівлі та споруди стає дедалі актуальнішою проблемою, особливо в регіонах з високим рівнем грунтових вод або на територіях, схильних до сезонних повеней, які є поширеними у південних регіонах України через близькість до водойм, таких як річка Дніпро та Чорна море. Мінливість кліматичних умов у поєднанні з діяльністю людини змінила природний водний режим, загостривши цю проблему.

У цій статті подано комплексний огляд найбільш поширених методів захисту ґрунтових вод, які використовуються при будівництві на півдні України. Він розглядає як традиційні, так і інноваційні методи, підкреслюючи їх ефективність, вартість і довгострокову стійкість. Серед розглянутих методів – дренажні системи, технології гідроізоляції, стабілізації ґрунту, утеплення фундаменту.

Крім того, у статті розглядаються такі методи утеплення фундаменту, як використання ізоляційних панелей, мембран і композитних матеріалів, які захищають конструкції від проникнення води. Ці методи часто поєднуються з вищезазначеними підходами для забезпечення більш комплексної стратегії захисту від впливу грунтових вод.

Також в статті підкреслюється важливість вибору відповідної комбінації методів захисту від шкідливої дії підземних вод, виходячи з конкретних умов навколишнього середовища та типу будівлі або будівельного проекту. Поєднання дренажу, гідроізоляції, стабілізації ґрунту та ізоляції забезпечує найкращий захист від шкідливого впливу ґрунтових вод, забезпечуючи безпеку та довговічність конструкцій у складних кліматичних та гідрологічних умовах півдня України.

Це дослідження сприяє постійному діалогу про практику сталого будівництва в регіонах, схильних до проблем, які пов'язані із підземними водами, і надає практичні рекомендації для інженерів, архітекторів і будівельників, які працюють на півдні України. Застосовуючи ці методи, можна звести до мінімуму негативний вплив ґрунтових вод на будівлі, тим самим підвищивши їх довговічність і зменшивши витрати на їх технічне обслуговування.

Ключові слова: *підземні води, захист будівель, дренажні системи, гідроізоляція, стабілізація ґрунту, утеплення фундаменту, південь України.*

Problem statement. Over the past decades the process of flooding has become widespread in Ukraine causing losses not only to agricultural lands but settlements as well.

According to the expert assessment of the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine, annual economic losses make about 500 UAH per hectare. In extremely humid periods losses increase several times [1].

At the 5th World Water Forum (Istanbul, 2009), the group established a list of the main types of harmful effects of water and its consequences in the act entitled "Prevention and Action to Minimize Death and Destruction: Building Resilience Toward Sustainable Development" [2]. They are:

1 – consequences of flooding, leading to flooding of lands and human settlements;

2 – destruction of shores, protective dams and other structures;

3 – waterlogging, flooding and salinization of lands caused by an increase in the level of groundwater due to irregular water supply during irrigation, water leakage from water supply and sewerage systems and overlapping groundwater flows when large industrial and other structures are located;

4 – land drainage caused by the groundwater abstraction in a volume exceeding the established volumes for their selection;

5 – pollution (salinization) of land in areas of mining, as well as after the end of field operation and conservation;

6 – erosion of soils, formation of ravines, landslides and mudflows.

Due to global climate changes, the frequency and amplitude of natural fluctuations in river flow increases, it increases the risks of manifestations of the harmful effects of water, the damage from which for Ukraine is estimated approximately of 1,5-2,0 billion hryvnas per year [3].

The analysis of recent research and publications. The most active dangerous exogenous geological processes (EGP) include landslides, karst, underflooding, abrasion, processing of the banks of reservoirs, and subsidence of the earth's surface. All these processes are typical for the South of Ukraine (Kherson, Nikolaev, Odessa region and Autonomous Republic of Crimea). Kherson region was chosen as a key research area, which is typical for the South of Ukraine.

For this territory, the carrying out of water management activities, which has such negative consequences as: filtration losses from irrigation systems, reservoirs, canals, loss of water from communications, the creation of ponds in the ravine-girder system and the like, is of decisive importance. This led to the fact that on the territory of research up to date there is a regional flooding that has arisen as a result of significant, prolonged anthropogenic impact on both agricultural and urbanized agrolandscapes, which necessitates the development of new methods for protecting agrolandscapes, as well as artificial objects, built in them, from underflooding. Therefore, the tasks of the research are:

1 – determination of causes of flooding for the study area;

2 – development of technical solutions for ensuring reliable and long-term operation of foundations and in-depth parts of structures in the flooded land zone.

Analysis of recent research and publication. The use of anti-filtration systems is based on the following scientific facts.

Since water is in a gravitational field, part of its free energy depends on the location of a given volume. The free energy of any volume of soil moisture, due to the position of the latter in the gravitational field, is measured by the water level in the state of comparison.

So, if the expansion of the surface of the liquid is adiabatic, the fluid loses the amount of heat [- T ($\delta\sigma$ / δT)] and its temperature falls back. When a new surface is formed isothermally, this amount of heat is supplied from the environment to the surface layer to compensate for cooling [10].

All liquids tend to move so that their potential decreases. For example, water spontaneously flows from the z_1 level to a lower level of z_2. The water potential per unit mass decreases by g ($z_1 - z_2$), and this change of the potential corresponds to the sum of the energies (mechanical, thermal, etc.) that water can give in its fall [11, 12].

S. Taylor, J. Carry [13] note that in all experiments the influence of the temperature gradient caused an immediate rise in water in the water-measuring tube at the warm end of the column and a decrease in the level at the cold end. After 8-10 hours, this level difference disappeared, after which the water continued to move, but now from the hot to the cold end, creating a difference in the hydraulic head.

The gradient of the electric potential and the temperature gradient are capable of causing an electric current, or a gradient of the moisture potential and a temperature gradient can cause a moisture flux in the soil. Irreversible phenomena are expressed by a linear phenomenological relationship of a general type

$$I_i = \Sigma L_{ik} X_k, \quad (1)$$

where

I – flow;

L – a phenomenological coefficient, or a constant, which depends only on the physical state and geometry of the system;

X – function that acts as an acting force;

i, k – indices for the designation of components, which states that the total flux can be created with the participation of all force fields (i = 1,2 … n).

As applied to the heat flux, this means that the change in temperature along the mean free path, which has an average length, should be much less than the average temperature itself. This expression shows that the difference in pressure in water arises in a porous medium under the pressure of a constant temperature difference depends on the enthalpy of water and on the ratio of the moisture transfer coefficient in the same material.

The motion of the soil solution occurs when the chemical potential of the particles and the temperature are equal in the different parts of the solution. The known conditions for such an equilibrium are the constancy of the chemical potential of molecules, ions, and temperature: μ = const, T =const.

Under conditions of incomplete saturation of the soil with moisture, or the presence of an evaporation front of the soil solution that fills the pores completely, the basic forces determining the movement of moisture are usually capillary forces that manifest themselves as capillary pressure, depends on the curvature of the water-air interface and on the surface tension on this boundary [14].

Ladychuk D.O., Ladychuk V.D. (2023) proved that the relative contribution of the steam flow to the total moisture flux increases with decreasing soil moisture. These conclusions are valid under the condition that for different soil moisture the concentration of salts in the soil solution does not change. With an increase in the concentration of salts in the soil solution, the relative contribution of the vapor stream decreases.

It should be noted that the effect of the concentration of salts on the rate of evaporation is much less if they do not take into account the value of α, which characterizes the decrease in the effective evaporation surface.

A significant role is assigned to the moisture film during the evaporation of liquid from thin capillaries. If the radius of the capillary is small, then the evaporation rate is determined not only by the diffuse vapor flux, but also by the flow that is carried by the liquid film, when it flows under the influence of the film thickness gradient. As the diameter of the capillary decreases, the role of liquid transfer increases. The role of fluid transport also increases with increasing relative air humidity.

Problem statement. The purpose of article to establish the causes and factors of regional flooding of agricultural and urbanized landscapes in the South of Ukraine, and to develop measures to protect against the harmful effects of ground and surface water to ensure reliable and long-term operation of foundations and buried parts of structures in this zone.

Materials and research methods. The methodological basis of the study is a long – term experiment based on ecological – reclamation monitoring. The methodology of substantiation and technical decisions on the protection of landscapes from the harmful effects of groundwater and surface water is based on the principles of heat pumps.

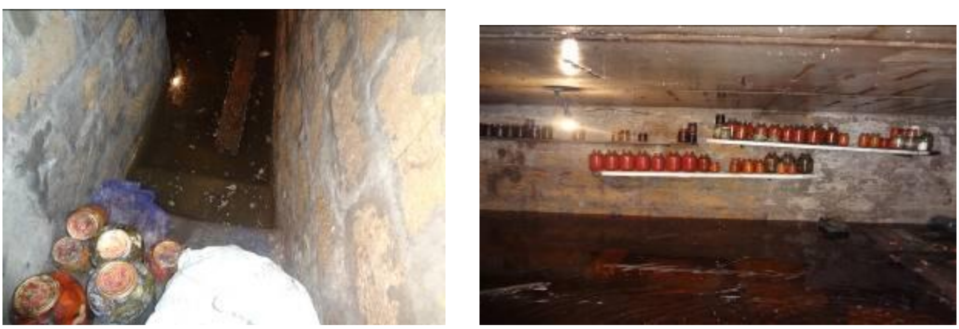
Results and discussion. The facts, published on the Dnipro Public Forum on July 6-7, 2012 by specialists and scientists of Ukraine, have shown a continuous deterioration of the hydrological regime throughout the basin, especially affecting the situation in Ukraine. Given the global climate change, the catchment area of the basin has grown today and in the conditions of free flow to the Black Sea, the Dnieper should make 63-67 billion cubic meters of water – but the drainage in the sea is only 35-38 billion cubic meters. Due to water abstraction for drinking and technical needs (up to 5-6 billion cubic meters) and filtration processes in Kiev, Kanev, Kremenchug and former Kakhovka reservoirs (up to 25 billion cubic meters), the Dnipro with the dam cascade practically "undermined" most of the adjacent territories and he himself became a marsh, where natural biological productivity in the last 30 years has decreased by 32 times.

The situation worsens every year, and the latest "realities of constantly progressing manifestations of flooding" are demonstrated by the following video facts of recent years (Fig. 1, 2, 3).

The natural conditions of the Kherson region and water-meliorative measures determine the wide development of the flooding process. Over the past decades, the process of flooding is actively developing and has reached a critical state capable of leading to the withdrawal of large land masses from economic use.

Up to date, the area of flooded land in the Kherson region is 11300 km^2, which is 39,7% of the area (and this is only according to official data). According to the research data, the area of submerged lands in the region, depending on the critical level of groundwater and their normative values, can reach 69%. The most affected by this disaster are the territories of the south-western and north-western regions. The determining factor in the development of the flooding process here is intensive and long-term reclamation work, which was accompanied by external water supply and construction of man-made water bodies. In addition, under the threat of flooding are about 300 settlements and about 100 thousand hectares of agricultural land.

The process of development of underflooding is conditioned by two main factors:
– the degree of natural flooding (natural flooding and drainage)
– the degree of man-caused (water-economic) factor.



2015 2021

Fig. 1. Underfloor flooding in the village Nova Mayachka, Kherson region

The areas of flooding and the intensity of the process are constantly changing. In recent years, the largest areas of flooding have been recorded in the southern regions such as Kherson, Mykolayiv, Odessa, where the process develops not only within the floodplains, above-floodplain terraces and the bottoms of large beams, but also on watersheds that are characterized by very poor natural drainage. In general, for the southern regions of the territory of Ukraine, the process of flooding, first of all, is connected with the technogenic conditions for the formation of the position of groundwater levels [4].

April 2015

April 2021

Fig. 2. Exit to the surface of groundwater in the village Nova Mayachka, Kherson region

A rise in the average annual level of groundwater over a long period of time is observed at an average rate of 0,1-0,3 metres per year.

Further expansion of the flooding zone here will grow due to the technogenic factor in conditions of irreversible violation of the water balance of the territory.

It is also alarming that due to limited funding, field work on monitoring exogenous processes on the territory of the Kherson region has not been conducted in recent years [5].

Prior to this, today, global climate changes have also significantly influenced the amount of precipitation in the southern region – in the last decade their average annual amount is already 420-480 mm.

The most intensively flooded areas adjacent to river floodplains, areas in the zones of influence of reservoirs, canals, irrigation system. For urban areas, the most frequent reason for raising the level of sources from the water supply system, the rise of groundwater in the foundations of buildings and structures, the absence of storm sewerage, the formation of closed depressions that serve as surface water receivers.

To ensure the prevention and control of flooding, various measures must be taken. But they boil down to one thing – to reduce harmful water entry and increase sanitation.

Consider, as an example, drainage systems. To prevent flooding in the territory of agricultural landscapes, drainage should be used. But the drainage systems built 30-40 years ago, especially with pumping drainage, do not always perform their functions to the full [6].

In urbanized landscapes, an increase in the level of groundwater contributes to the water saturation of the soils of the aeration zone, worsens their physico-mechanical properties, which leads to the development of negative phenomena (such as karst, landslides, loess soil compaction, subsidence of soil strata, etc.) that affect state of buildings and structures, increase the seismicity of sites by 1-2 points.

The level of groundwater under buildings and structures should be located below the foundation of the basement not less than 0,5 m. At the same time, the protection of foundations and basements from capillary moisture is carried out by means of a suitable waterproofing. But if there are negative phenomena caused by the flooding process, it is possible to violate the structural elements of the buried parts of buildings and structures in the space, and any reliable waterproofing of the surfaces of the in-depth parts, it will not save from underflooding inside the building or structure.

April 2015

April 2021

Fig. 3. Destruction of buildings as a result of floodingy Nova Mayachka village, Kherson region

Also devices of anti-filtration curtains and screens of foundations of buildings and structures are known [7, 8]. The disadvantage of these design solutions is that they protect the foundation from the inflow of groundwater from the outside, do not provide foundation protection from below, do not take into account the capillary rim, do not reduce the aggressive influence of groundwater on the foundation and the deeper parts of structures, and reduce their effectiveness [9]. Therefore, to protect the buried parts of buildings and structures from the harmful effects of water, options are offered for anti-filtration systems.

The solution of the task of work is achieved by the fact that the deeper parts of the structures along the perimeter and from below are protected by a continuous clay screen and a water basin is placed with a system for removing the water accumulated in it [16].

Figure 4 shows a schematic diagram of the anti-filtration system (version 1) in the plan and a cross-section of A-A.

Anti-filtration system foundation (1), recessed parts of the structure (2), which are protected from the outside along the perimeter and from below by a continuous clay screen (3) from groundwater (4). Between the side walls of the deepened part of the structure (2) and the protective clay screen (3) along the perimeter of the deepened part of the structure (2), a water basin (5) is created, filled for three-fourths with a water-permeable soil (filler) (loams) electric cable (6), the number of which and the mark depends on the depth of the deepened part of the structure (2) and is set by heat engineering calculation, and the upper part of the header (5), has an air cushion (9), is covered by the blind area (7), which has air exchangers (8).

The anti-filtration system (version 1) works as follows. A continuous clay screen has a low filtration coefficient, but groundwater penetrates through it to a deeper part of the structure after a certain time, accumulate in a water basin.

The voltage of the filament of the heat-conducting electrical cable is applied.

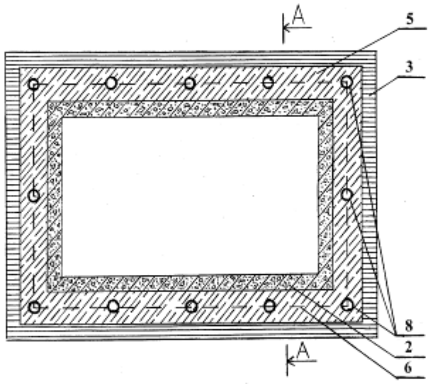
The electric current passing through the cable heats it, after which there is heating of the soil-filler of the header and transformation of the water accumulated in it into a vapor-like state, followed by the raising of this substance before the pillow, and then removing it from the compartments located in the viewport beyond the catchment area. After drying the sump, the voltage to the cable stops.

Significant disadvantages of the proposed system are:

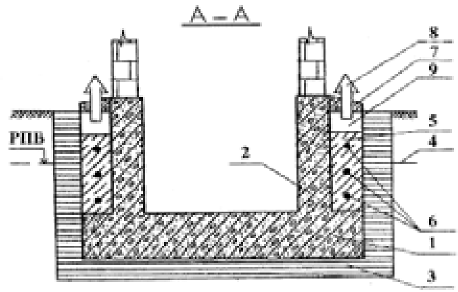
– impossibility to clearly determine the amount of air cushion;

– completely drain the water collector;

– decrease in strength of the blind area due to the presence of a significant amount of air exchangers.



Scheme of the anti-filtration system for in-depth parts of structures



Cross section A - A of the anti-filtration system

Fig. 4. Scheme of the anti-filtration system (version 1) (numbers are given in the text)

An alternative solution to the problem posed in the study may be an antifiltration system (version 2) (for distinguishing variants, it is called the system for ensuring the dryness of the deepened part of the structure). The diagram of the system for ensuring the dryness of the deepened part of the structure is shown in Fig. 6. The schematic diagram of the system for providing dryness in the plan and cross-section A-A is shown in Fig. 7 [17].

The system for ensuring dryness has a recessed part of the structure (1), protected from the outside along the perimeter and from below by a continuous clay screen (2), a water basin (3), the volume of which is filled with water-permeable soil-filler and contains several threads of a heat-conducting electric cable (4), parameters which are determined by heat engineering calculation.

In the upper part of the header (3), perforated in the upper part of the horizontal drain (6), the parameters of which are determined by hydraulic calculation, and the drainage water is collected in a standard drainage well (7), arranged along the perimeter of the deepened part of the structure (1).

The dryness maintenance system works as follows.

On the thread of the thermal conductive electrical cable (4), gradually starting from the uppermost one, a voltage is applied. The electric current passing through the filaments of the cable (4) heats them, after which a layerwise (top-down) heating of the soil-the filler of the header (3) and the conversion of the ball water accumulated in each into a vapor-like state occurs, followed by the lifting of this substance along the water header (3) upwards.

Reaching the blind area (5), the vapor-like substance turns into water, due to the decrease in the temperature gradient and under the action of gravitational forces, it starts moving down the water basin (3), where it is intercepted by a horizontal drain (6) perforated in the upper part and diverted to the drainage pit (7) (see Figure 6,7).

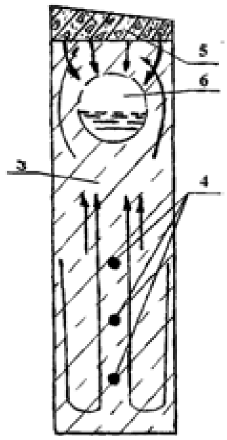
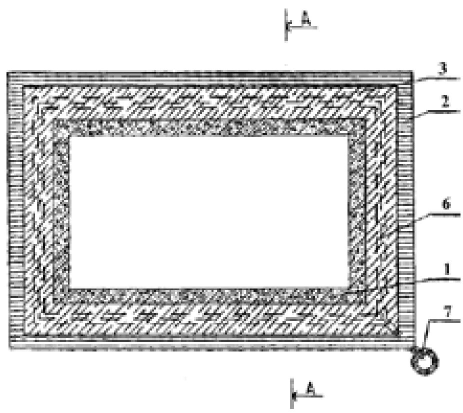
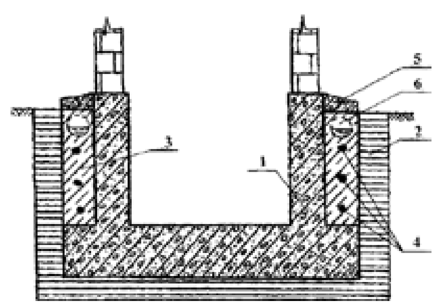


Fig. 6. Scheme of operation of the security system of the in-depth parts of structures

After drying the sump (3), the voltage in the cable (4) stops. If necessary, the cycle is repeated.



System for ensuring the dryness of the in-depth part of the structure



Cross-section A - A of the supply system dryness of the in-depth part of the structure

Fig. 7. Scheme of the anti-filtration system (version 2) (numbers are given in the text)

The means of “green” energy can be used as an energy source for water collectors. It is enough to use small-scale wind energy with the capacity of wind turbines up to 100 kWh with the pitch of installed capacity 4kWh. Moreover, it is possible to use solar panels, located on the roof of a building or construction to be protected.

Conclusions. The construction of the Kakhovka reservoir has turned the valley of the Dnipro river from the zone of unloading of groundwater into the zone of their support and back feeding.

On the territory of the Kherson region today there is a regional flooding, which has arisen as a result of significant, prolonged anthropogenic impact, both on agricultural and urbanized agrolandscapes.

The filtration losses from the reservoirs of the Dnieper cascade reach 25 billion cubic meters. On each hectare of irrigated land, 960 – 990 m^3 of irrigation water is lost every year to replenish groundwater.

The area of submerged lands in the Kherson region is 11300 km^2, which is 39.7% of the area, under threat of flooding are about 300 settlements and about 100 thousand hectares of agricultural land. The most affected by this disaster are the territories of the south-western and north-western regions.

In urbanized landscapes, an increase in the level of groundwater contributes to the water saturation of the soils of the aeration zone, worsens their physico-mechanical properties, which leads to the development of negative phenomena (such as karst, landslides, loess soil compaction, subsidence of soil strata, etc.) that affect condition of buildings and structures.

In the event of negative phenomena caused by the flooding process, it is possible to violate the structural elements of buried parts of buildings and structures in the space, and any reliable waterproofing of the surfaces of the buried parts, it will not save from underflooding inside the building or structure.

Today there is a need to develop new methods of protecting urbanized landscapes, as well as artificial objects built in them from flooding.

One of the solutions of the problem can be proposed method that provides that the deeper parts of the structures along the perimeter and from below are protected by a continuous clay screen and place a water basin with a system for removing the water accumulated in it of various modifications.

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