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Calculation of the Height of Capillary Rise of Water in Soils

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Abstract: ***Rain and melt water will form temporary accumulations of surface water on the surface. When they seep into the ground, temporary streams of leaky filter water are formed. If a limited section of water-resistant soil layer or the roof of an underground structure is encountered in the path of these waters, a temporary aquifer-the upper layer of ground water-may form above them. In temporary and permanent aquifers, the soil pores are completely filled with gravitational water, the degree of water saturation is equal to one, and there is pressure under the surface of underground water. Above this surface is a zone of capillary moisture, while the level of capillary rise is determined by the granulometric composition of the soil and ranges from tens of centimeters in sand to several meters in dusty and clay soils. Capillary water rises in the ground on free canals formed by mutually communicating pores, or is kept in them in limbo.The lifting of the liquid in the capillary continues until the gravity acting on the column of the liquid in the capillary becomes equal to the resulting force. Capillary water penetrates from the ground into the walls and rises to a height of up to 2 meters. The normal moisture content of the brick walls is 0.02...0,03, and in the case of unprotected contact with moist soil is increased to 0.15...0.25. On the inside of the walls there is a damp, mildew. Evaporating water increases humidity in the room, and the salts released when it evaporates from salt solutions lead to peeling paint, destruction of plaster and wall material.***

Keywords: ***Water penetration protection (waterproofing), chemically bound water, water vapor, hygroscopic water, film water, capillary water.***

I. INTRODUCTION

In order for the Foundation to serve for a long time and also protect the basement, ground floor and house from dampness, it first of all itself requires protection – from ground, rain and melts water. Moreover, not only the underground part of the Foundation needs protection, but also the above ground-the plinth.

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Waterproofing should not only resist the flow of water during the spring melting of snow or heavy rains, but-last but not least! - protect the walls of the Foundation from capillary moisture; prevent water absorption by its surfaces.

Moisture penetrating into building structures is a serious cause of their destruction.

In conditions of high humidity, wooden structures are destroyed by rotting for 2-3 years, steel structures lose strength due to corrosion in 10-12 years, stone, concrete and reinforced concrete structures are destroyed after 40-50 years of operation. Therefore, protection against water penetration (waterproofing) is an important factor in the safety and durability of buildings [6].

The capillary moisture rising on pores in the massif of the base and a plinth from a damp ground, can extend and in a lying of walls of the lower floors. And in case of aggressiveness of groundwater materials of the Foundation and underground parts of the building can be destroyed. To protect the building from groundwater, provide measures to combat the movement of groundwater and the penetration of precipitation. In a ground of the basis and arrange a protective waterproofing from penetration of soil moisture in a building design.

To protect against penetration of soil moisture in the structure of the building in the new construction is usually performed external insulation of structures from the impact of water.

The soil always contains a certain amount of water, fully or partially filling the cracks and pores between the particles.

The state of moisture in the soil can be solid (ice), liquid (water) and gaseous (steam). All moisture, in any state, is in constant physical and chemical interaction with soil particles [1].

II. THEORY

The waters contained in the ground were first classified By V.Bogdanov in 1889. Later, in 1918, the classification of water in the ground was proposed by A. F. Lebedev, who developed on the basis of experimental studies a coherent theory of the state and behavior of groundwater. Studies of water properties were continued and significantly expanded by our contemporaries A.A.Raza, B.V.Deryagin, B.F.Reltov.

At temperatures above 0^0C in the soil can distinguish the following types of water:

- Crystallization or chemically bound water;
- Water vapor;
- Hygroscopic water;
- Film water;
- Capillary water;
- Gravitational water.

Crystallization, or chemically bound, water is part of the crystal lattices of minerals. It can be removed by calcinations and, in fact, is an integral part of the substance of which the particles of the soil are composed.

Water vapor fills the voids of the soil, is released from water, moves from zones with high pressure to zones with low pressure, condenses, and contributes to the replenishment of groundwater.

Hygroscopic water is attracted by soil particles from the air and condenses on their surface. The amount of hygroscopic water depends on the properties of the soil substance and humidity. The dried soil in moist air will increase in weight until the humidity corresponding to the maximum hygroscopicity is reached, which has approximately the following values: for sand – about 1%, for dust – about 7% of the weight of the dry substance of the soil, for clay – about 17%.

Hygroscopic water can move in the soil, passing into a vaporous condition, and can only be removed by drying.

Film water is retained on the surface of ground particles by molecular attraction. Soil moisture corresponding to the maximum thickness of the molecular films of water is called the maximum molecular moisture capacity. The molecules of the film water are attracted and held on the surface of the soil particle by huge forces of electric attraction in specific magnitude.

Film water does not obey the laws of hydrostatics and hydrodynamics and moves from particles with a large shell thickness to particles with a smaller shell thickness, regardless of the relative positions of these particles. The high viscosity of the film water causes its very slow movement in the soil. The amount of film-molecular-bound-water and its properties affect the physical and mechanical properties of the soil [3].

The greatest force of attraction, acting directly on the surface of the particles, causes the formation of a layer of strongly bound water, with the distance from the surface of the particle gravity weakens and the water goes into a condition of weakly bound, where the gravitational forces of the particles cease to act, the water is in a free condition.

Strongly bound water, as shown by studies conducted by B.V.Deryagin, is in a particularly solid condition it is essentially combined with a system of solid mineral particles.

For physics and mechanics of soils is of great importance water loosely bound. Its density, viscosity and freezing point are different from free water and the greater the smaller the thickness of the films. The immobility of this type of water in narrow pores explains the low permeability and slow compressibility of fine-grained soils.

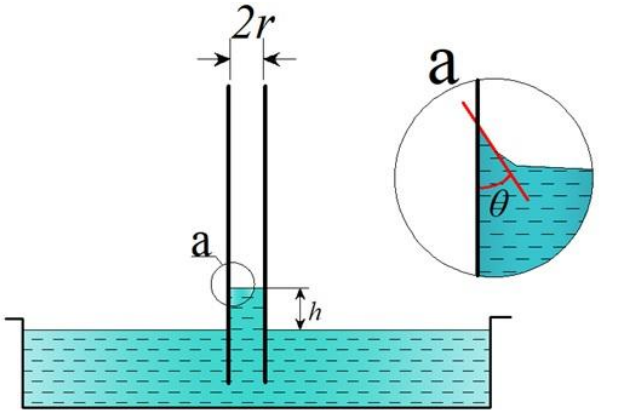
Film water can be removed from the soil by evaporation.

Capillary water rises in the soil through free channels formed by mutually communicating pores, or is held in them in a suspended condition.

Physical processes such as surface tension and wetting are at the heart of the question of fluid behavior in vessels. The capillary phenomena caused by them are studied in a complex.

III. RESULTS AND DISCUSSION

Under the action of surface tension, the wetting liquid in the capillaries is above the level at which it should be according to the law of communicating vessels (Pic.1) [1]. So, water in a glass tube (wetting liquid) rises to the greater height, the thinner the vessel. In addition, as shown in the picture, the wetting fluid forms a concave meniscus shape.



Pic.1. Capillary phenomena

Wetting occurs at the boundary where the liquid comes into contact with the solid. This is due to the special interaction of molecules at the boundary of their contact. Full wetting means that the droplet spreads over the surface of the solid. The surface of the droplet has a spherical shape and the reason for this is the law acting on the liquid-surface tension.

Capillary phenomena are associated with the fact that the concave side of the liquid in the tube tends to straighten to a flat condition due to the forces of surface tension. This is accompanied by the fact that the outer particles carry up the bodies under them, and the substance rises up the tube. However, the liquid in the capillary cannot take a flat surface shape, and this process of lifting continues until a certain moment of equilibrium. To calculate the height to which the column of water will rise (fall), you need to use the formulas that will be presented below.

The moment of stopping the rise of water in a narrow tube occurs when the force of gravity $\mathrm{P}_{Тяж}$ the substance will balance the surface tension force F .

This moment determines the height of the liquid lift. (Pic.2) [1]. Capillary phenomena are caused by two opposite forces:

- Gravity $\mathrm{P}_{Тяж}$ causes the liquid to fall down;
- The surface tension force F moves the water upwards.

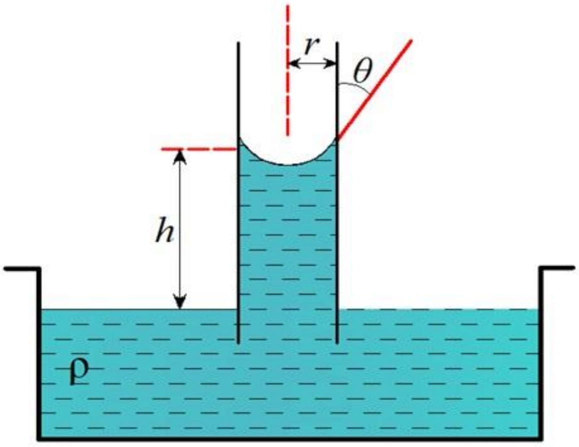
The surface tension force acting around the circumference where the liquid comes into contact with the tube walls, equal:

$$F = \sigma \cdot 2\pi \cdot r, \quad (1)$$

Where r - is the radius of the tube, σ - is the surface tension of the water.

The force of gravity acting on the liquid in the tube is

$$\mathrm{P}_{Тяж} = \rho \cdot \pi \cdot r^2 \cdot h \cdot g, \quad (2)$$



Pic.2. Capillary phenomena

Where ρ- is the density of the liquid; h - is the height of the liquid column in the tube.
Thus, the substance will cease to rise, provided that

$$P_{Тяж} = F, \qquad (3)$$

This means that

$$\rho \cdot \pi \cdot r^2 \cdot h \cdot g = \sigma \cdot 2\pi \cdot r, \qquad (4)$$

Hence the height of the liquid in the tube is equal to:

$$h = \frac{2\sigma}{\rho \cdot g \cdot r}, \qquad (5)$$

As can be seen from the formulas, the height at which the water rises in a narrow vessel (falls) is inversely proportional to the radius of the container and the density of the liquid. This applies to wetting fluid and non-wetting fluid.
As already noted, the liquid in the narrow tubes behaves in such a way that it seems to violate the law of communicating vessels. This fact is always accompanied by capillary phenomenon. Physics explains this by using Laplace's pressure, which is directed upwards in the wetting fluid. Lowering a very narrow tube into the water, observe how the liquid is drawn to a certain level *h*. According to the law of communicating vessels, it had to be balanced with the external water level (Pig.1).

This discrepancy is explained by the direction of Laplace pressure $p_Л$:

$$p_Л = \frac{2\sigma}{R}, \qquad (6)$$

In this case, it is directed upwards. The water is drawn into the tube to the level where the equilibrium with the hydrostatic pressure $p_Г$ of the water column comes:

$$p_Г = p \cdot q \cdot h, \qquad (7)$$

And if $p_Л = p_Г$, then we can equate the two parts of the equation:

$$\frac{2\sigma}{R} = p \cdot q \cdot h \qquad (8)$$

Now the height h can be easily derived as a formula:

$$h = \frac{2\sigma}{p \cdot q \cdot R} \qquad (9)$$

When the wetting is complete, then the meniscus that forms the concave surface of the water has the shape of a hemisphere, where ϴ=0.In this case, the radius of the sphere R will be equal to the inner radius of the capillary r.
Hence get:

$$h = \frac{2\sigma}{p \cdot q \cdot r} \qquad (10)$$

And in the case of incomplete wetting, when ϴ ≠ 0, the radius of the sphere can be calculated by the formula:

$$R = r / \cos\theta \qquad (11)$$

Then the desired height, adjusted for the angle, will be equal to:

$$h = \frac{2\sigma}{p \cdot q \cdot r} \cos\theta \qquad (12)$$

From the presented equations it can be seen that the height h is inversely proportional to the inner radius of the tube r. The greatest height of water reaches in vessels having the diameter of a human hair, which are called capillaries. As you know, the wetting liquid is drawn up, and not wetting-pushed down.
The height of capillary water is determined by the lifting force of the meniscus, the value of which depends on the wet ability of the soil, the size of the pores and the properties of the water (its temperature, degree of mineralization).
The resulting action of capillary forces is conventionally considered as the surface tension force of the meniscus holding the water column.
As is known from the Laplace formula, the lifting force of the meniscus is inversely proportional to the radius of curvature equal to the radius of the capillary: $p_Л = \frac{2\sigma}{R}$, depending on the value of the radius of curvature given in table.1.
Where σ - is the surface tension of water equal to 7.7 mg / mm.
For example, with a pore diameter in fines and d =0.01 cm and a radius r =0.005 cm, the capillary tension force $p_Л = 0{,}03 кг/см^2$, i.e., is negligible in magnitude.

For clay at R=0,00025 cm $p_Л = 0{,}6 кг/см^2$, and at R=0,00001 cm $p_Л = 15 кг/см^2$.

Table 1.

Types of soil	Fine-sand	Dustysand	Sandy loam	Loams	Clays
σ – the surface tension of water, mg/mm	7,7	7,7	7,7	7,7	7,7
r – the radius of the pores, cm	0,005	0,001	0,0005	0,0001	0,00001
$p_Л$ – the strength of capillary tension, kg/cm²	0,03	0,15	0,3	1,5	15

Capillary moisture in the soil can be in a disjointed condition (at the grain joints), in a suspended condition (not associated with the groundwater level, held by the tension of the meniscus) and in a propped state (directly above the groundwater level).

The force $p_Л$ causes the water to rise until the weight of the raised column of water height hmax is balanced by the lifting force of the meniscus:

$$\frac{2\sigma}{R} = p\cdot q\cdot h \text{ and } h = \frac{2\sigma}{p\cdot q\cdot r} \qquad (13)$$

Where $\Delta = \rho\cdot q$ is the specific gravity of water, hence?

$$h_{\max} = \frac{2\cdot\sigma}{r\cdot\Delta} \qquad (14)$$

The considered regularities of capillary phenomena are peculiar to dusty and clay soils with significant limitations. The height of the maximum capillary rise in the soil almost reaches 2-3 meters, whereas according to the above formula, with a capillary diameter of less than 0.005 mm, the height should be hundreds of times greater.

In fact, as shown by the research of Professor A.V. Dumansky [3], at a pore size of 10-7 cm or less, the formation of capillary menisci is impossible, since all the water contained in the pores is influenced by much greater forces – the forces of molecular attraction of soil particles. Therefore, capillary phenomena are more common in silt soils, sandy loam, loamy than in clays.

If water does not completely fill the pores of the soil, the free part of the pores is occupied by gas. In sandy soils, coarse pores are open and the composition of the gas contained in the pores does not differ from the composition of atmospheric air. In clay soils, due to the peculiar shape of the particles and the presence of viscous film water, the pores may be closed and the gas trapped in them in its composition may differ significantly from the surrounding air [4].

Trapped gases increase the elasticity of the soil, its water permeability decreases and significantly complicate all the phenomena occurring at the interface of the media. In addition, the water that fills the pores of the soil always contains a certain amount of dissolved gas that can be released in the form of bubbles when the pressure or temperature changes.

IV.NOMENCLATURE

$P_{Тяж}$ - gravity causes the liquid to fall down;

F - the surface tension force moves the water upwards;

r - the radius of the tube;

σ - is the surface tension of the water;

ρ - is the density of the liquid;

h - is the height of the liquid column in the tube;

$p_Г$ - the level where the equilibrium with the hydrostatic pressure;

$p_Л$ - Of Laplace pressure.

V. CONCLUSION

The rise of the liquid in the capillary continues until the force of gravity acting on the liquid column in the capillary becomes equal in modulus to the resulting force.

The height of the liquid in the capillary is directly proportional to its surface tension and inversely proportional to the radius of the capillary channel and the density of the liquid.

Thus, the degree of water saturation in the capillary zone varies from a unit at the surface level of groundwater to the molecular humidity at the upper boundary of the zone. The pressure of capillary water is negative, since it is affected by tensile stresses from surface tension forces in contact with air and wetted surfaces of solid particles.

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