Dependence of stress-strain state of hydraulic structures on infiltration moistening of foundation soils

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Abstract. As is known, loess subsidence soils are widespread on the globe; their area in Europe and Asia is more than 13 million sq. km. Many of the loess rocks are also located in Central Asia, including the Republic of Uzbekistan. The practice of irrigation development of loess lands shows that the disruptions that have occurred so far in the operation of hydraulic structures (HTS) are due to insufficient knowledge and neglect in designing the features of joint work and interaction structures with their subsidence foundations. The design of hydraulic structures also does not fully consider these features. To ensure the long-term, reliable, and economical operation of hydraulic structures on subsiding soils, it is necessary to improve their design and construction methods, considering the peculiarities of interaction with loess foundations. This article deals with the features of infiltration soil moistening from channels and structures on them.

The article deals with the features of the infiltration moistening of soils from canals and structures on them. Based on the analysis of previous studies, the specificity of infiltration in loess soils is considered a serious factor affecting the stress-deformed state of hydraulic structures and their foundations.

1 Introduction

At present, large-scale measures are being taken in the country to extend the service life of hydraulic structures on irrigation systems that are built and are being built on subsiding loess soils to reduce damage from their breakdowns and failures, as well as to develop safety criteria. In solving these problems, it is important to carry out research work aimed at developing rational methods for designing and efficient operation during a period of shortage of water resources based on taking into account the factors of damage, failures, and accidents, as well as stress-strain processes in the operation of hydraulic structures of irrigation systems on subsiding soils.

The problem of ensuring the reliability and safety of hydraulic structures of irrigation systems was dealt with by some scientists, including M.A. Bandurin [3], M.R. Bakiev [1-

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2], A.B. Veksler [4], V. A. Volosukhin [5], V. A. Dokin [13-14], S. V. Zasov [15-17], B. D. Kaufman [12], A. A. Kirillov [24], Yu.M. Kosichenko [18], Ts.E. Mirtskhulava [1], F.V. Matveenkov [19], A.A. Sozaev [20], B.U. Urishev [25], R. Khuzhakulov [7-11], S.S. Eshev [27], V.M. Federov [1], N .N.Frolov [26] , etc.

One of the most important tasks of designing and constructing reclamation network structures on loess subsidence soils is to ensure their long-term trouble-free operation. Improving the methods of designing hydraulic structures on subsidence bases requires further study of very complex physical processes occurring in the foundations of structures during their construction and operation. This is confirmed by the fact that even if all the requirements and recommendations of regulatory documents on the design of irrigation systems on subsidence soils are met, deformations of the foundations of structures often significantly exceed the calculated ones, which can cause loss of operational suitability of irrigation structures.

This determines the need for further study of the features of the interaction of irrigation facilities with their subsidence bases.

The processes of deformation and moistening of subsidence soils are closely related to each other. On the one hand, the deformations of the subsidence soil depend on the degree of its humidity. On the other hand, they seriously affect the regularities of the moistening process of the massif. In this regard, improving methods for calculating deformations of loess bases of GTS requires a thorough study of the process of moistening the massif and the influence on this process of the specifics of the impact and irrigation facilities on the ground [7,14,20].

The nature of the humidification of the loess bases of the GTS depends both on the ground conditions of the site and on the type of structure, its dimensions in the plan, the pressure transmitted by the structure to the ground, the width of the water mirror and its pressure, etc. Two types of structures can be distinguished by the nature of the humidification of their bases [7,14,20]:

Type I - structures, during the operation of which their bases are moistened constantly or for a long period. Such structures should include drops, fast currents, and other structures on the channels and the channels themselves. In the process of co-operation of such structures, a significant amount of moisture enters their bases.

Type II - structures from which water enters the ground only by accident for a short time due to damage to their structures. These are pipes, trays, channels in anti-filtration clothes, etc., and other water sources with a very small water mirror area that work periodically.

In the foundations of type I structures, the subsidence layer is soaked intensively and, as a rule, completely. In case of accidents of type II structures, the soil mass is not moistened to full water saturation, and usually, a suspended humidification circuit is formed.

Within the humidification circuit, the soil moisture varies from natural (at the border of the humidified zone) to full water saturation close to the water source.

2 Methods

The process of filtration moistening of soils, including subsidence, has been studied by many authors [1,2,5,8,9,10,13]. In particular, it is noted that for humidification sources of any shape in terms of having approximately equal filling depth, the rate of soil soaking is proportional to their transverse dimensions. At the same time, when soaking the soil from moisture sources having approximately the same width and depth of filling but a different shape in plan (in one case compact, imitating construction pits, and in the other elongated, representing sections of the structure with the base changes the stress state of the GTS structures, reducing their reliability.

Regulatory documents [6] recommend using the method of electrodynamic analogies (EGDA) for filtration calculations of GTS bases of classes I and II. However, this method necessitates using analog computers or complex calculations that require the exact solution of hydrodynamic equations.

In other cases, it is allowed to use simpler methods based on the principles of the generalized Darcy law - methods of resistance coefficients, fragments, etc. When performing calculations using these methods, the structure of the porous medium of the soil is considered ordered, which does not correspond to reality. In addition, it is difficult to consider the changes in the filtration characteristics of loess soil during its subsidence and changes in the degree of water saturation of the massif [3,15,16,17,18,19].

In this regard, several scientists have attempted to determine the regularities of the moisture movement in the soil by a statistical method. The disadvantage of statistical models of the soil moistening process is that due to the wide variety of soil properties, such models are not universal, which makes it difficult to use such solutions for practical purposes. Thus, A.A.Mustafayev [16-17], based on the results of studies of the dynamics of the process of moistening loess soils, indicates its complex nature, which is associated with the mutual influence of the processes of moistening and deformation of subsidence soils. Based on the analysis of var

Dzekzer E. S. and Pevsner L. M.[14] provides a mathematical model of moisture movement in saturated soils with and without subsidence properties. At the same time, three zones separated by movable boundaries are distinguished in the moving flow of moisture:

1. The zone of full (maximum) saturation, the movement of water which occurs under the influence of gravitational forces.
2. Capillary saturation zone – the movement of water is carried out under the action of capillary and partial gravitational forces.
3. The zone of film saturation, where the movement of the liquid occurs under the action of sorption forces.

The calculation of moisture zones in loess subsidence soils, proposed in the work of Rabinovich I. G. [4;12], is based on the theory of moisture transfer with incomplete soil saturation. One of the advantages of this technique is the use of graphical modeling elements, which greatly simplifies the practical use of this calculation method.

However, these methods of modeling the process of moisture movement in loess soils also cannot be considered universal. This is explained by the peculiarities and a wide variety of properties of subsidence soils (porosity, subsidence, natural importance, layering, continuity violation, etc.).

3 Results and discussions

With this in mind, the regulatory document [6] recommends determining the filtration and other characteristics of the construction area loess soils by soaking them in the field. With such a study of the properties of the soil mass, it is possible to determine its filtration subsidence and other characteristics most fully. However, the experimental soaking of many pits requires considerable labor and time.

Of undoubted interest is the methodology proposed in the work of A. A. Kirillov [24] for determining the necessary timing of the preliminary soaking of loess soils and the amount of water required for this, based on the results of field experiments. In the course of field work, the author [8, 9, 21, 22] studied the process of moistening loess soil through pits of various sizes, based on which a methodology for determining the timing of the preliminary soaking of loess soils was developed. This technique compares favorably with comparative simplicity but requires further clarification because the experimental data used by the author are available only in one region.

It should be noted that the nature of moistening of subsidence soils in the foundations of network structures on channels largely depends on the design of the underground circuit of the GTS and the conditions of interaction between the structure and the base [2;14;20]. In the process of subsidence, separation cavities may form between the flatbed and the loess base, contributing to accelerated water penetration into the ground and increasing the likelihood of contact erosion of the base.

As research has shown [2, 5, 7, 9, 11, 15], the development of deformation can be divided into two stages when moistening the soil under a loaded stamp. In the first stage, the deformation increases due to an increase in the volume of the deformable zone during the advance of the humidification front into the depth of the array. In the second stage, the development of the deformation zone into the depth of the massif occurs simultaneously with the further compaction of the upper layers of the soil and the appearance of horizontal deformations in them. It should be noted that lateral deformations of the soil in the bases of the stamps were recorded only in cases when the soil moisture reached 25-28%. If the amount of water supplied to the pit did not provide such humidity, then lateral deformations were either absent or insignificant and took place only under the edges of the stamps.

In the case of pressure transfer to the pre-moistened soil, the deformation zone is almost completely formed within 1-2 hours. The subsequent growth of deformations is mainly caused by further compaction of all the layers involved in the deformation.

The regularities of the deformation process of moistened loess soil of undisturbed structure were studied by us when working with the device described in [15-17] in the conditions of the south of the Republic of Uzbekistan [7-11].

In Fig.1. The contours of the deformed zone at the base of a semicircular stamp having a diameter d = 35 cm and transmitting a pressure P = 0.1 MPa to the ground are shown. A few hours before the stamp was installed, the investigated soil mass was moistened with a limited amount of water.

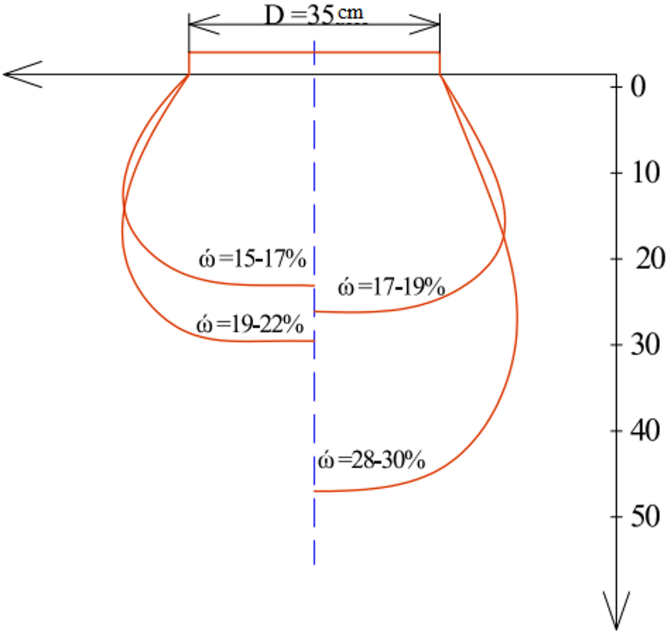


Fig. 1. Contours of deformed zone of subsidence soil of stamp base at pressure at contact of stamp and soil $P = 0.1$ MPa.

Evaporation of moisture from the ground surface was prevented with the help of temporarily laid waterproofing materials. This made it possible to obtain a sufficiently evenly moistened volume of soil.

To obtain different values of the final moisture content of the soil, the volume of water supplied for humidification was changed, as well as the time interval between the dates of moistening the soil and installing the stamp. After the experiment, the soil moisture was clarified by sampling.

As can be seen from the figure, the depth of the deformed zone of the soil is greater the greater its humidity, and the angle α limiting this zone decreases with increasing humidity.

Figure 2 shows a graph of the dependence of the angle α, which limits the zone of soil deformation caused by the action of compressive pressure on the weight humidity. The graph is based on the results of the study of subsidence soils of the research area by stamp tests and using the device [17;18] at a pressure on the soil P = 0.05 - 0.2 MPa.

The standard deviation of the experimental scenes from the proposed parabolic curve is ± 3 (%). Figure 3 shows the dependence of the depth of the deformation zone on the area of the stamp and the pressure transmitted to the ground by it. Curves 1 and 2 are constructed based on the results of experiments conducted using the above device, and curve 3 is based on the data of soil tests with stamps with a diameter of 112 cm, followed by opening their bases. The weight humidity of the soil that served as the base of the stamps was 25-30%.

As can be seen from Figure 3, the depth of the core increases with increasing die diameter; however, its relative depth H/ D does not change significantly. As a result of observations of soil deformations in the bases of stamps, it was found that horizontal deformations occur only when the pressure on the soil reaches a certain value, which depends on the properties of the studied soil and the stamp size. Despite vertical deformations, horizontal movements in the ground were not recorded at pressures lower than this critical value.

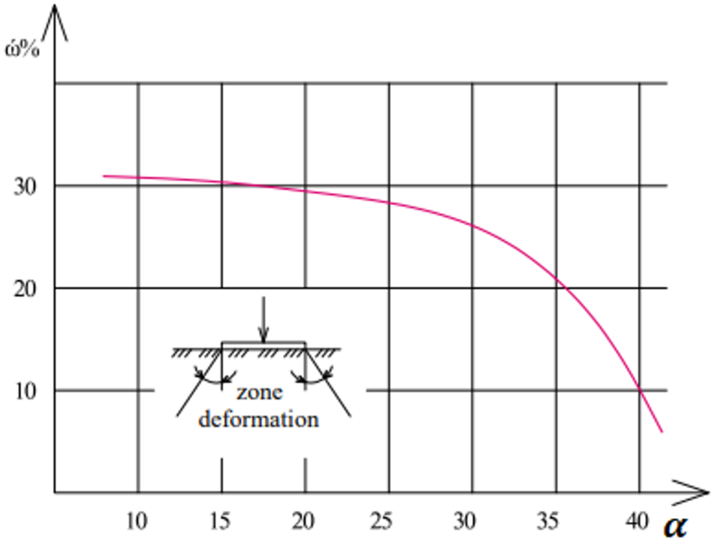


Fig. 2. Graph of dependence of angle α on soil moisture. o is based on results of working with the device [16]; + is based on the results of stamp tests

The greatest lateral deformations were observed under the stamp's edges at a depth depending on the size of the stamp and the pressure transmitted to the ground by it. This depth varied within 0.7-1.0 of the stamp radius in our experiments.

The coefficient of lateral expansion of the soil was determined by the well-known formula:

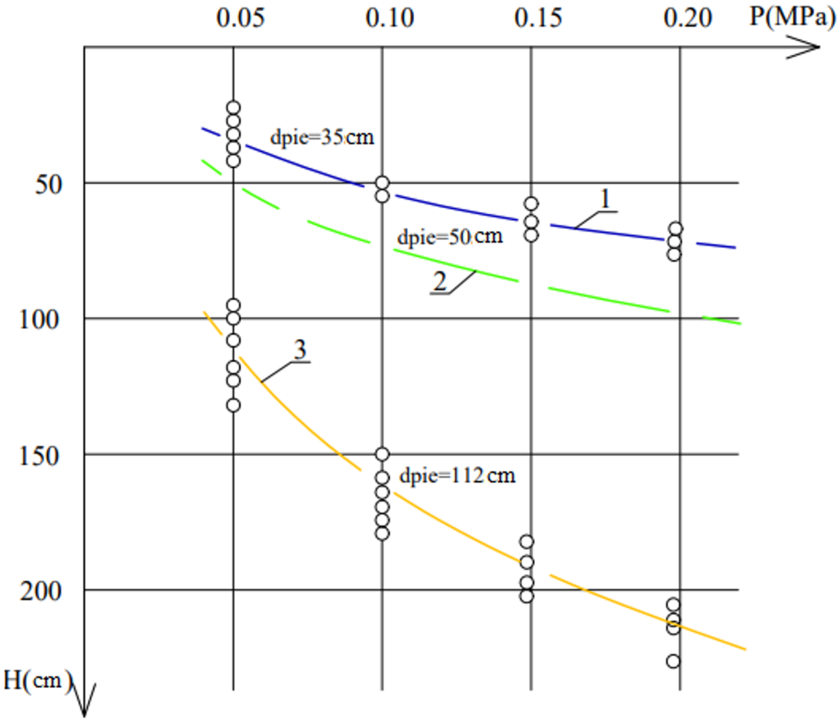
$$\mu = 0{,}5 - \frac{V_0 - V}{2V_0} * \frac{h_{cд}}{S} \qquad (1)$$

where, V_0 is the volume of the studied soil under the stamp before the experiment, $h_{cд}$ is the height of the soil column under the stamp within the shear zone, V is the volume of the same soil after the experiment, S is the vertical draft of the stamp.

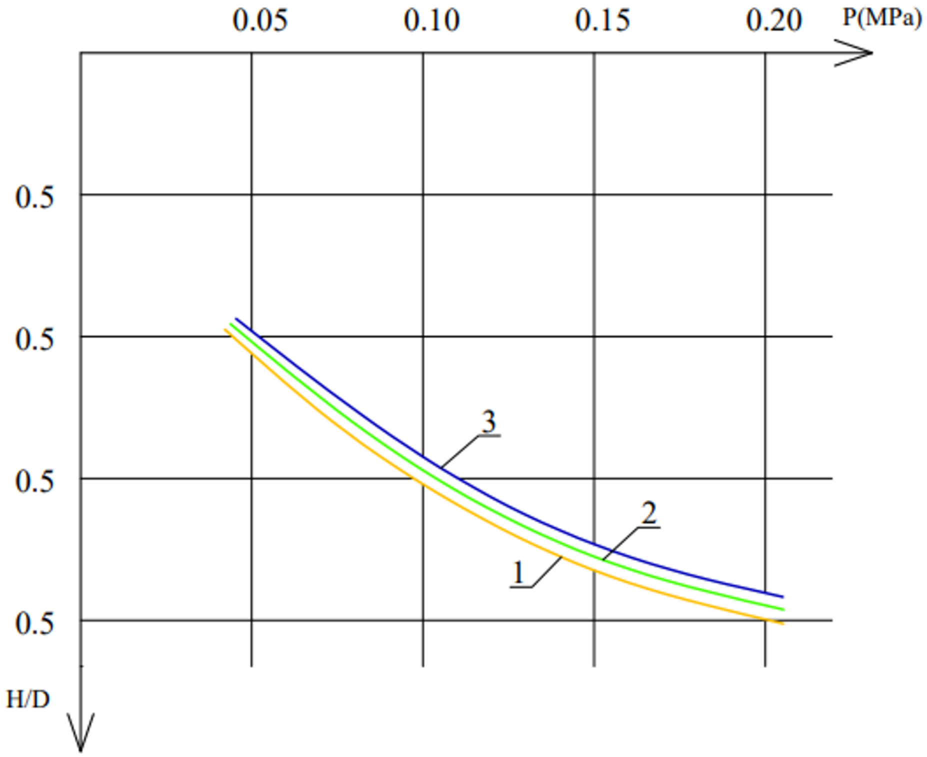
At the same time, in the absence of lateral deformations in the ground ($\frac{\Delta V}{V} = \delta_1 > 0$, and $\delta_2 = \delta_3 = 0$), $\mu = 0$ In the case of deformation only due to the flow of the shape of the material under study at a constant volume ($\Delta V/V = 0$), $\mu = 0{,}5$.
The validity of these limiting values of μ is proved in the work of Troitskaya M.N. [8] for the expression easily deducible from formula (1)

(= δ1> 0, and δ2 = δ3 = 0), μ = 0. (ΔV / V = 0), μ = 0.5.

$$\frac{\Delta V}{V} = \delta_1 (1\text{-}2\,\mu) \qquad (2)$$



a)



b)

Fig. 3. Dependence of power of deformed pressure zone on ground: a) depth in centimeters; b) depth in fractions of stamp diameter.

The coefficient of lateral expansion was calculated based on the results of experiments with a device for studying the physical and mechanical properties of the soil [16]. During the experiments, semicircular stamps with an area of 480, 980, and 1920 sm2 were used. At the same time, it was believed that the processes occurring through the contact of the ground with the screen are similar to those occurring under the diameters of round stamps with an area of 960,1960 and 3840 sm^2, i.e., an axisymmetric problem was solved experimentally.

Fig. 3 shows graphs of the dependence of the coefficient of lateral expansion μ on the pressure transmitted by the stamp to the base.

It should be noted that when the pressure is transferred to the ground by a stamp sufficient for the appearance of lateral deformations, lateral expansion satisfies the requirement of $0.5 > \mu > 0$ in all cases.

At relatively small pressures transmitted by the stamp to the ground, the dependence of $\mu = f(P)$ is rectilinear. With increasing pressure, as seen from the graphs in Fig. 3, the μ tends to its limit, depending on the size of the stamp, less than 0.5. At the same time, the larger the area of the stamp transmitting the load to the ground, the smaller the value of this limit.

It can be seen from Fig. 3 that lateral deformations of the soil in the foundations of structures, which significantly affect the subsidence, occur at pressures exceeding 0.05 MPa. The coefficient μ characterizing these deformations at a given pressure is the greater, the smaller the area of the structure's flatbed.

Thus, considering lateral deformations when calculating the second group of limiting conditions of irrigation facilities that transmit a pressure of fewer than 0.05 MPa to the loess soil is apparently not mandatory.

Based on the above, we can say:

In connection with the above, the following conclusions can be drawn:

the forecast of the soaking time and the nature of the wetting of the loess bases of the GTS is a complex task and requires considering many different factors to solve it. This makes it difficult to develop simple and reliable methods for calculating the parametrization of the moistening process of the soil mass.

As a rule, the existing methods for calculating the process of moisture infiltration into the soil mass are narrow and complex. In this regard, it is interesting to develop other techniques and methods for predicting the process of soil moistening, which could replace existing mathematical models with sufficient accuracy for practice.

Despite the many studies conducted on this topic by many specialists, there are still some unresolved issues. Loess soils, as the bases of hydraulic structures, require further experimental and theoretical study to identify their moisture infiltration features, which seriously affect the stress-strain state of structures and their foundations**.**

4 Conclusions

The article discusses the studies of the stress-strain state of subsidence based on models of hydraulic structures' flatbeds, and the results obtained allow us to draw the following conclusions In the process of moistening the subsidence soils that serve as the basis of hydraulic structures, a transformation of the stress state occurs in them with the appearance of stress concentration zones;

The stress concentration on the contact of the GTS flatbed with the base takes place in areas with a large value of the soil deformation modulus. For a loess subsidence base, these are zones of unmoaked or low–moisture soil;

According to the depth of the moistened array of bases of hydraulic structures, the stress concentration occurs due to the anisotropy of the strength and deformative properties of loess soils and the influence of a rigid yet wetted layer. The maximum values of normal stresses in the soil layer occur when it reaches the critical humidity ω at the boundary with the soil of natural humidity;

The final value of the subsidence of the soil layer at the base of the hydraulic structure can be due to both the maximum stresses arising in the soil of critical humidity and stresses stabilized at a lower level but at an optimal for the process of subsidence of increased humidity;

Lateral deformations of subsidence soils in the foundations of structures transmitting a pressure of fewer than 0.05 MPa to the ground are insignificant, and, as a rule, there is no need to take them into account when calculating deformations of irrigation structures.

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