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Article

Foundation for waterlogged bases with conical void design

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Abstract. The article presents hollow foundations that play a multifunctional role: drainage to accelerate the process of consolidation of weak water-saturated cohesive foundation soils, drainage in case of obvious underflooding, anti-barrage in case of latent underflooding, as well as compensating for possible swelling or frost heaving of the clay soils. The adopted design solution makes it possible to transfer the load from the foundation to the soil foundation that includes loose cavity filling material through a more developed support area than a foundation with a flat footing. Unlike the solid foundation, the hollow foundation has a higher bearing capacity by 120 N more, and in the intervals of high loads (> 400 N) the settlement of the hollow foundation develops with an occasional lag from the settlement of the solid foundation. The use of hollow concrete foundations makes it possible to expand the area of application of prefabricated foundations, simplify their manufacture, increase their bearing capacity and ensure their strength and durability, while reducing the material intensity and cost of construction.
Keywords: hollow foundations, resource-saving methods, sediment, roll, existing foundation.

1. Introduction

The use of traditional foundations with a solid waterproof sole causes artificial flooding of the territory (barrage effect), does not ensure operational reliability, since when poorly permeable foundation soils are flooded under unfavorable drainage conditions, there can be a risk of losing the building stability [1].

So far, shallow solid foundations used in construction practice are not economically profitable when building in conditions of heaving soils, swelling clays, especially for relatively light low-rise buildings and engineering structures (power line supports, pipelines, etc.). At this, it is necessary to use traditional labor-intensive, material-intensive sand cushions and other energy-intensive inefficient technologies: replacing the swelling layer, increasing the depth of foundations, arranging pile foundations, etc. The known methods of strengthening foundations and walls with reinforced concrete belts or simple mesh reinforcement in mortar joints are not used due to complexity, labor intensity and high cost for normal construction conditions.

Traditional methods of protecting buried parts of buildings against groundwater using “backfilling of hollows” are not effective in flooding urban areas [2].

In present day conditions of the rapid growth of scientific and technological progress, signs of the ecological crisis of cities have become especially noticeable due to the hidden factors of anthropogenic geological processes, the negative consequences of which have not been considered in advance in traditional methods of surveys, design, technologies of erecting buildings and their operation [3].

For these reasons, in recent years, accidents in residential buildings have occurred in several countries, resulting in the death of people, which indicates the failure of traditional design methods and the need to adopt fundamentally new design, technological solutions to improve the reliability and safety of housing. There is known a foundation including extended downward shaft with a through vertical cavity filled with bulk material [4]. The disadvantage of such a foundation is its acceptability for use only for tower structures erected on rocky soils.

There are known schemes of foundations of rectangular and trapezoidal shape with longitudinal and transverse cavities. The disadvantages of such schemes include the complexity of manufacturing and the unreliability of the foundations, due to the irrational shape and orientation of the cavities in space.

There are known foundation including a rectangular base plate with a through vertical cavity [5]. However, this design is also unreliable in operation, since the area of the sole of the base plate is reduced by the area of the base of the cavity (the sum of the cross-sectional areas of the holes), which leads to decreasing the bearing capacity of the foundation. In addition, the design is difficult to manufacture, uneconomical and requires high material consumption.

There is known a typical prefabricated foundation including a base plate without voids and holes. The disadvantages of this design include its high cost, high resource consumption, bulkiness, and irrational distribution of the specific reactive pressure of the base.

The idea of developing biopositive and environmentally protected buildings adapted to the adverse effects of built-up areas of natural and man-made nature in such a comprehensive target formulation is put forward for the first time and is a major unresolved problem of modern construction, which is of great scientific and practical importance [6].

In the proposed reinforcement method, unlike analogues, there are used elements already present in the design of buildings under construction lintel beams of window and balcony openings, which are a continuous stiffening belt located on each floor along the perimeter of the outer walls of the building.

In the new foundation, unlike analogues, instead of a mesh reinforcement system, there are proposed closed reinforcing loops that work only in tension; moreover, the saved part of the reinforcement is used to reinforce the reinforcement belt, which combines all the elements of the foundation into a single whole and thereby ensures spatial rigidity of the foundation-basement part of the building [7]. Hollow foundations including loose material inside, can be considered as foundations placed on distribution pads, which play a multifunctional role: water discharging to accelerate the process of consolidation (strengthening) of weak water-saturated cohesive base soils; draining with obvious flooding; anti-barrage with hidden flooding; compensating for possible swelling or frost heaving of clay base soils. Moreover, the inner cushions of hollow foundations, unlike traditional soil cushions, have the minimum consumption of the bulk material, since their dimensions are taken constructively. Thus, the method of complex protection of a building developed by the authors, which has an anti-barrage, adaptive effect, is a synthesis of the potential possibilities of the method of strengthening building envelopes, a foundation with a filtering sole and a stiffening belt, as well as the known design solutions for the arrangement of an artificial base layer and near-wall, reservoir drainage [8].

The use of the proposed foundation designs with a filter base guarantees high reliability and environmental protection of the facilities under construction.

The use of hollow foundations instead of traditional solid foundations is also economically beneficial when building in conditions of heaving soils, swelling clays, especially for relatively light low-rise buildings and engineering structures (power line supports, pipelines, etc.). At this, the internal filling of hollow foundations of coarse sand or fine gravel, in addition to the draining function, can also play the role of a compensating (anti-rock) cushion and eliminates the use of traditional labor-intensive, material-intensive sand cushions and other inefficient technologies [9].

The commercial attractiveness of the innovative method of "integrated protection" is to ensure operational reliability of buildings in all possible cases of basement soil flooding: hidden flooding, emergency leaks from utility pipelines, rising groundwater levels [10].

2. Methods

Based on the analysis of the design features of the known prefabricated concrete strip foundations, the authors have developed a concrete hollow foundation design, the essence of which is as follows (see Figure 1). Its dimensions: the height, length, and width of the support block, which has a square shape in plan, are assigned depending on the angle of rigidity, as for rigid foundations. In the central part of the concrete block, where compressive stresses mainly occur, a through cavity is made that expands downwards and is provided with an internal backfill of a loose hard material of dense addition. Moreover, the slope of the side surface of the cavity to the horizontal plane of the base is taken not less than the angle of internal friction of the bulk material. The adopted shape of the hole of the support block contributes to the denser packing of the bulk material grains in the process of filling the foundation cavity and ensures uniform transfer of the load to the soil base including the backfill. The ratio of the area of the lower hole to the total area of the sole of the support block is accepted considering the rational use of the strength characteristics of the foundation materials in the range of 0.5...0.6.

Figure 1a and 1b shows the view of a hollow concrete foundation in plan and section, respectively.

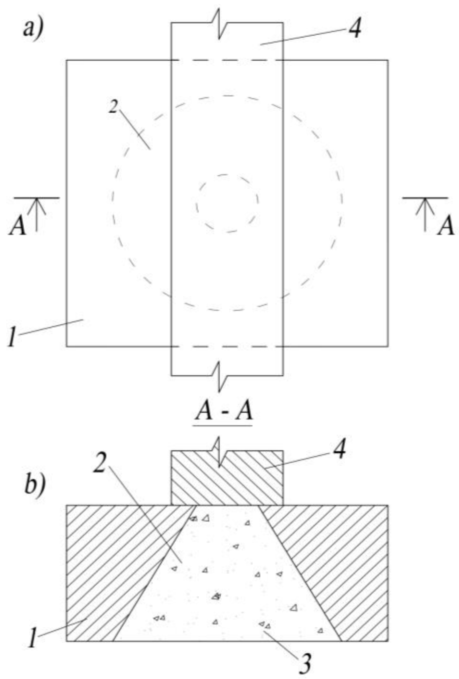


Figure 1 – Hollow concrete foundation: a) Plan; b) Section.

As shown in Figure 1, in the process of manufacturing support block (1), the angle of inclination of the generatrix of cavity (2) to its base is taken as large by 1.1...1.3 of the angle of internal friction of bulk material (3), which can be gravel or wood soil. In this case the area of the base of cavity 2 is assigned within 0.5...0.6 of the total area of support block 1 (which means the entire area of the sole of the support block that does not have a cavity). Support blocks 1 are placed on the sand preparation of the soil base, then cavities 2 are filled with loose material (3), after which foundation blocks (4) are laid.

The adopted design solution allows transferring the load from the foundation to the soil base including the loose material filling the cavity through a more developed bearing area than the foundation with a flat sole. In this case, there is achieved increasing the contact area of two bodies of different rigidity: the hollow concrete block and the soil medium, by more than 20 %. It obviously leads to decreasing the intensity of reactive pressures because of their redistribution within the developed bearing area of the hollow foundation, hence, to the unloading of the concrete block body. For this purpose, based on the experimental data, it is recommended to keep the ratio of the deformation moduli of the backfill material and the base soil within, which will significantly reduce the concentration of contact reactive pressures arising in the peripheral zone of the hollow foundation block base. One of the main advantages of this design is that the base reaction is manifested not only in the form of vertical frontal resistance, as is typical for traditional foundations with a flat sole but also in the form of friction resistance along the inclined side surface of the inner cavity of the support block. Moreover, the frontal resistance of the soil base during the operation of the foundation occurs in the plane of the sole and top of the support block, as well as along the side surface of the cavity. The geometric parameters (the wall thickness and height) of the hollow support block in two mutually perpendicular directions are taken as variables depending on its stress-strain state for a more complete use of the construction material strength characteristics.

In general, the foundation works as follows. From the beginning of the process of loading the foundation, the work mainly includes the lower horizontal part of the sole of the hollow block (about ~50 % of the bearing area), therefore, the settlement occurs due to compression of the natural foundation soil. As the load on the foundation increases and it subsides, the work will also gradually include the inner side surface of the hollow block (about ~48 % of the bearing area) and the upper horizontal area (~2% of the bearing area). After the foundation is fully loaded and redistributed, stabilization of the reactive pressures of the settlement occurs due to the additional compaction of the backfill material and mainly because of deformation of the natural foundation soil.

The pattern of development of the hollow foundation settlement with increasing the load will differ significantly from that for the traditional solid foundation with a flat sole, which is explained by the absence of a compacted core (wedge) under the center of the loaded area. It is known that the formation of the specified zone of the base is the main reason for the development of uplift of the soil leading to the loss of stability of conventional foundations.

Hollow foundations that include loose material inside, can be considered as foundations placed on distribution pads, which play a multifunctional role: water discharging to accelerate the process of filtration consolidation (compaction) of water-saturated clay soils of the base; draining with obvious flooding; anti-barrage with hidden flooding; compensating for possible swelling or frost heaving of cohesive base soils. Moreover, the internal distribution pads of hollow foundations, unlike traditional soil pads, have the minimum consumption of the bulk material since their dimensions are taken constructively.

The body of a hollow base plate filled with the bulk material, under the action of the reactive pressure of the base soil acts like a rigid retaining wall having a distributed load on the surface of the retained backfill. The correctness of this assumption was confirmed by the results of numerical studies and comparative calculations performed according to the method of designing pile heads.

2.1 Experimental studies of the hollow foundation operation

The purpose of the model experiments is to identify the features of interaction of a hollow foundation with the ground base by carrying out comparative tests. According to the purpose of the studies, when carrying out parallel experiments under identical conditions with models of solid (ordinary) and hollow base plates, the following tasks were set:

1) To fix the settlements of experimental foundations under increasing load.

2) To measure the settlement of the ground surface outside the foot area of the loaded stamps.

3) To reveal the nature of the base deformation dependence on the shape of the model foundation base.

2.2 Analyzing the results of model experiments

In the experiments, two types of foundation models were tested:

a) the first type simulated the work of a traditional solid foundation with a hard sole and played the role of a reference sample.

b) the second type was a model of a light-weight hollow foundation with a complex sole design including a rigid and a ground part.

The general view of the model test bench is shown in Figure 2 below.

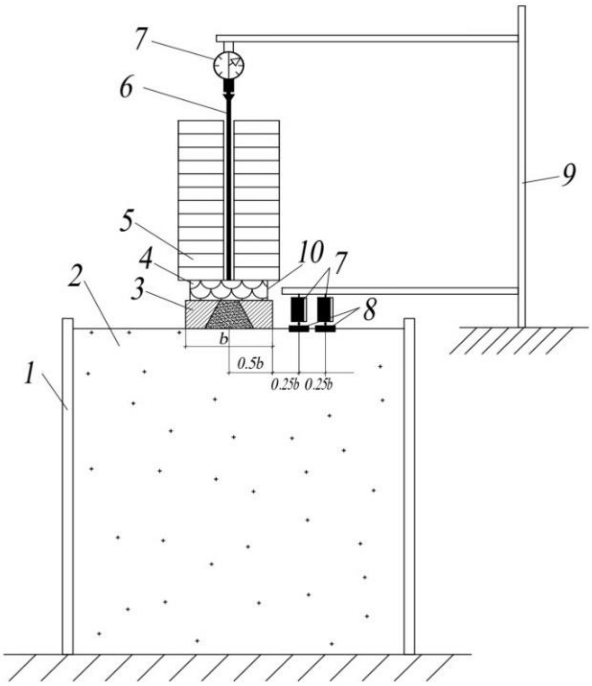
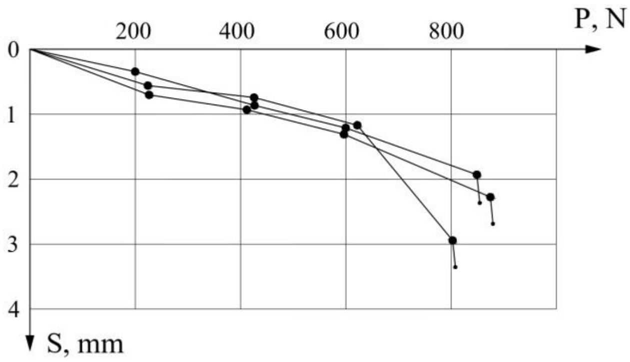


Figure 2 – General view of the model test bench: 1 – Tray; 2 – Soil (fine sand); 3 – Foundation model (stamp); 4 – Wooden gasket; 5 – Weights on the stamp; 6 – Steel string; 7 – Indicators; 8 – Surface marks; 9 – Reference system; 10 – Filling material (coarse sand)

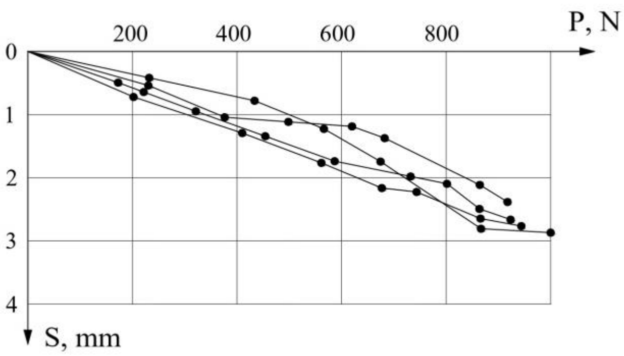
According to the purpose and objectives of the experiment, the loaded stamps were measured, as well as the ground surface near the stamps at the distance of 0.25 b and 0.5 b from their outer edge, where b is the width of the stamp sole. In the experiments, the stamps were loaded in stages until the bearing capacity of the base was completely exhausted.

3. Results and Discussion

The settlement of hollow and solid foundation models' dependences on loads are shown in Figure 3a and 3b. Summary graphs of the development of settlements of experimental foundations with increasing vertical load on the base are shown in Figure 4.



a) graphs of the solid foundation model settlement



b) graphs of the hollow foundation model settlement

Figure 3 – Dependence of hollow and solid foundation model settlement on loads

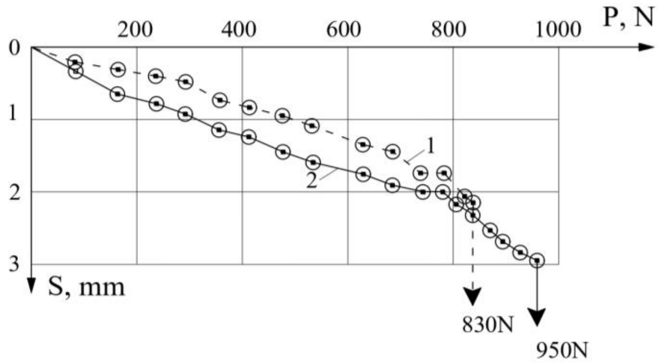
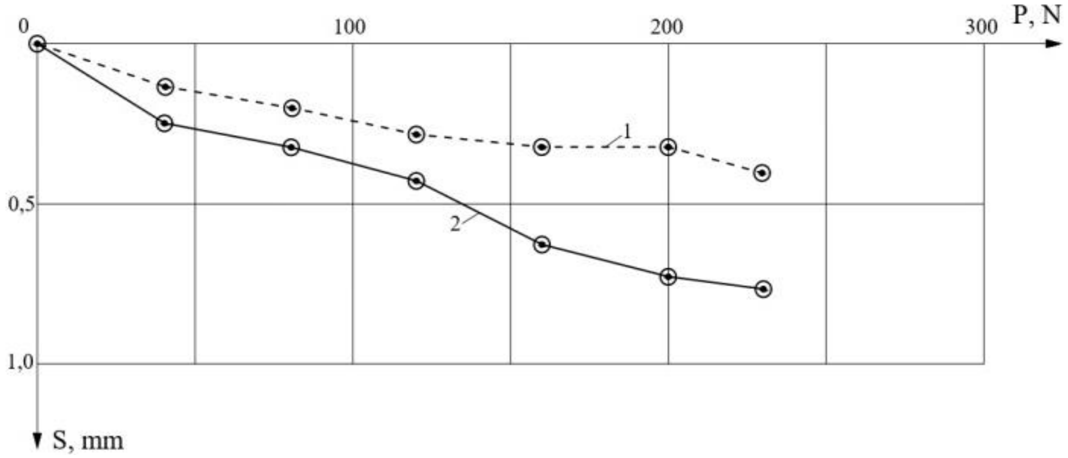
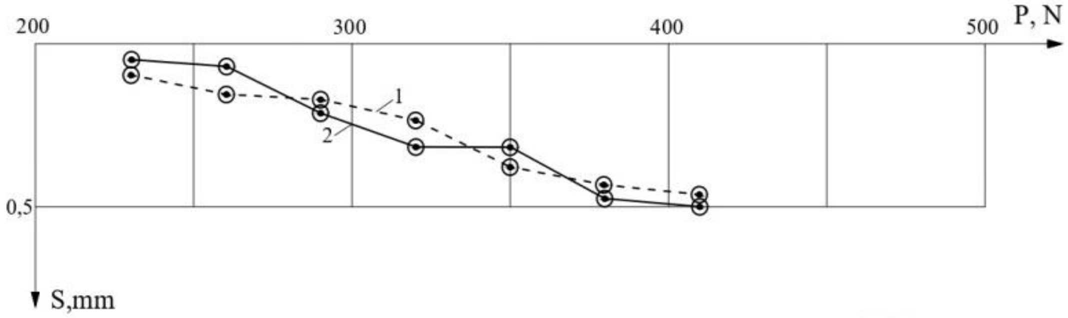


Figure 4 – Dependence of hollow and solid foundation model settlement on loads**:** 1 – for the solid foundation model; 2 – for the hollow foundation model

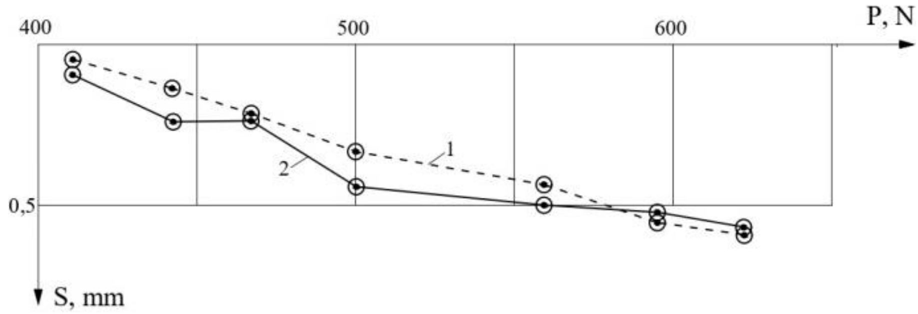
The graphs of the settlements of stamps and the soil surface of the base development outside the area of their foot at individual stages of loading are shown in Figures 5 and 6.



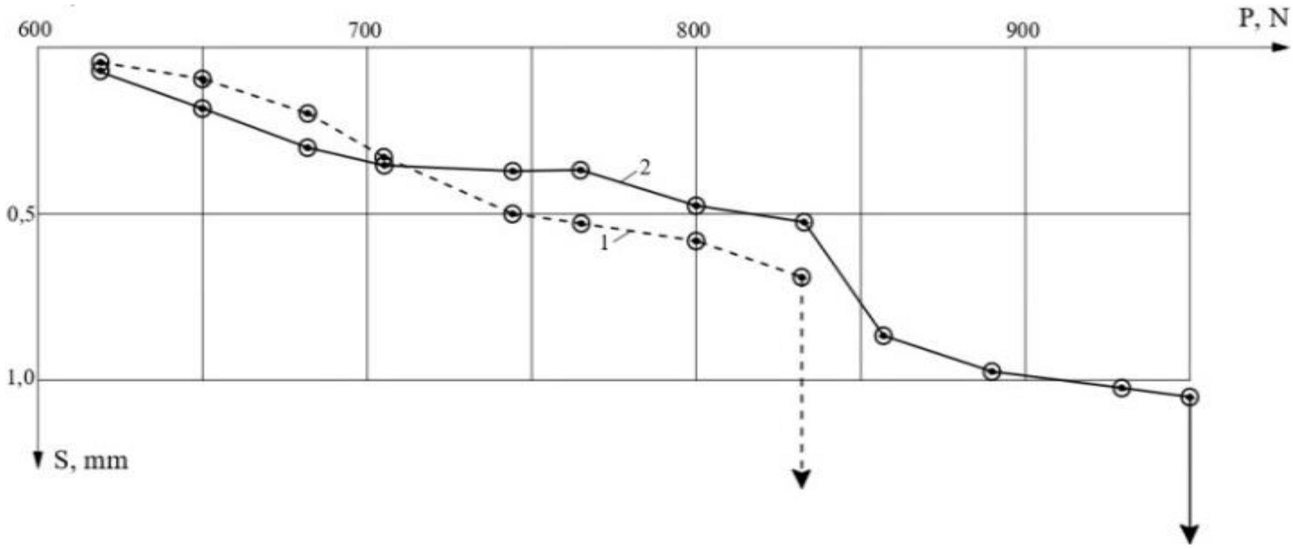
a) At the load range of 0...230 N



b) At the load range of 230...410 N



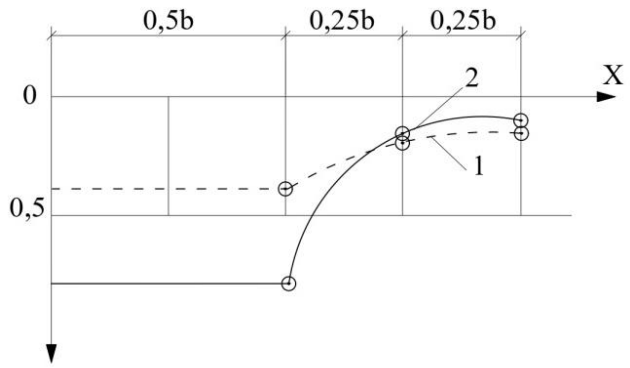
c) At the load range of 410...620 N



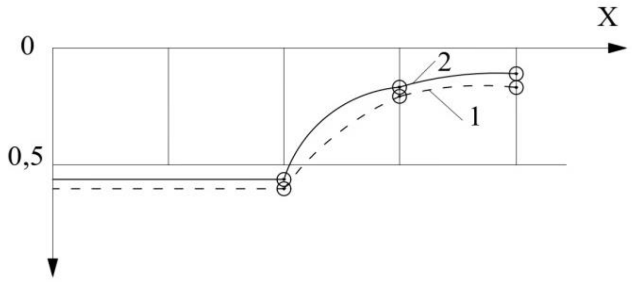
d) At the load range of from 620 N to buckling

Figure 5 – Graphs of the stamp settlements: 1 – For the solid foundation model; 2 – For the hollow foundation model

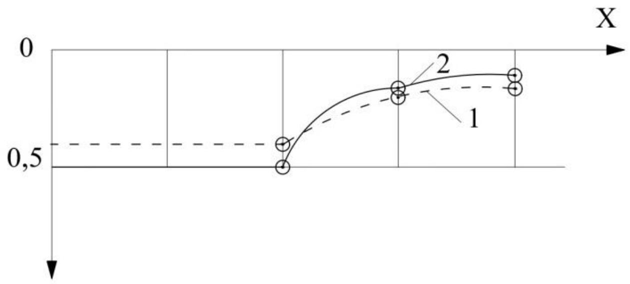
It is seen from the comparison of curves 1 and 2 (Figure 4 and 5d), the bearing capacity of a hollow foundation is 120 N greater than that of a solid foundation. At the same time, the settlement of a lightweight foundation slightly exceeds that of a solid foundation. To find out the reason for this phenomenon, it is of interest to compare for both models the graphs of the development of stamp settlements and the base surface around them at separate stages of loading.



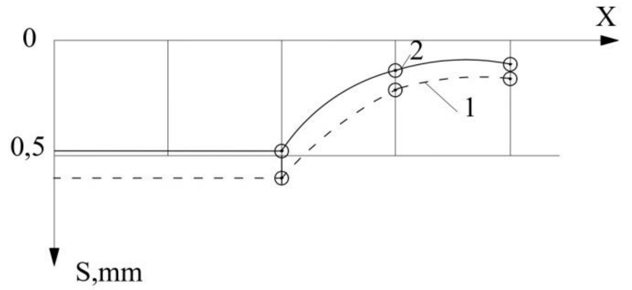
a) At the load range of 0...230 N



b) At the load range of 230...410 N



c) At the load range of 410...620 N



d) At the load range of 620…800 N

Figure 6 – Graphs of the soil surface settlements: 1 – For the solid foundation model; 2 – For hollow foundation model

A comparison of the graphs presented in Figures 5a and 6a show that increasing the settlement of the hollow foundation is caused by the additional compaction of its soil part (filling material) in the initial period of loading in the load range of 0...230 N.

This is clearly seen from the comparison of curves 1 and 2 (Figures 5a and 6a). It is known that the development of a sinkhole around the foundation is one of the main signs of the gradual involvement of the deepest layers of the subgrade into the work. Hence, the position of curve 2 in Figure 6a that is rather different from Figures 6b, 6c and 6d is explained by the cutting into the ground of the rigid peripheral part of the hollow foundation sole as a result of additional compaction of the filling material.

At the next loading stages, the settlement of a hollow foundation develops almost the same as compared to a solid one, which can be seen from the comparison of curves 1 and 2 in Figures 5b, 5c and 5d. It should be noted that at significant loads over 400 N the settlement rate of a hollow foundation is uneven. This is clearly seen from the comparison of curves 1 and 2 in Figures 5c and 5d in the load ranges of 440 N...470 N, 560 N...590 N and 710 N...770 N where the settlement of the hollow foundation (curve 2) practically dies out. This phenomenon is apparently explained by the peculiarities of the nature of interaction with the base of the lightweight foundation, which has a complex shape of the supporting area and the soil part within the base.

4. Conclusions

The analysis of the above phenomena occurring at the base of loaded experimental foundations allows drawing the following conclusions.

1. The total settlement of a hollow foundation, other things being equal, is greater than the settlement of a solid foundation.

2. A slight increase in the settlement of a hollow foundation compared to a solid foundation is due to additional compaction of the material filling the internal cavity in the initial period of loading (in the load range of 0...230 N).

3. Unlike a solid foundation, a hollow foundation has a greater bearing capacity (120 N more).

4. In the intervals of high loads (over 400 N), the settlement of the hollow foundation develops with episodic lagging behind the settlement of the solid foundation.

5. Compared with a solid foundation, the size of the sinkhole around a hollow foundation is smaller.

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Aigul Kozhas – visualization, editing.

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