Simulation of the impact of work of heat pumps on the frost heaving of the base soil

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Abstract. The additional deformation of ground bases and foundations, which are located in the ground collectors of the heat pumps, has been identified. It is concluded that the values of these strains have the same order of their limit values which have been specified in the regulations.

Key words: heat Pumps, ground foundation, modeling, soil, foundation.

INTRODUCTION

The aim of the research. The research aims at identifying the value of additional deformations of the base by the frost heating of the soil under the working of heat pumps in the process of heating. In order to receive the desired results the theory of similarity has been used [1].

State of the problem. In this work the heat removal from the surface layer of soil with plastic pipes of large area, that are stacked parallel to the ground, usually in the form of several loops (Fig. 1) is considered. Thus, one loop along its length should not exceed 100 m, because otherwise high power of the pump will be required.

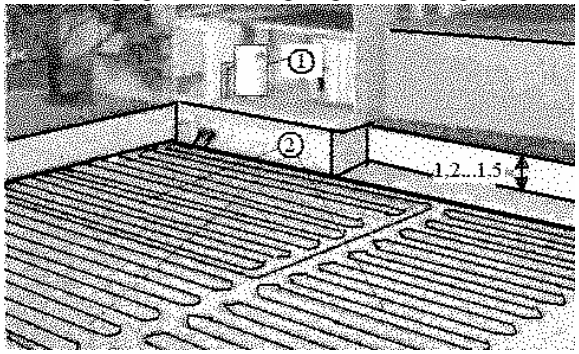

Fig. 1 Heating system of the building with the use of flat collector (scheme): 1 – heat pump; 2 – flat soil collector.

Individual circuits are connected to the dispenser, which should be at the highest point, to allow removal of air from the piping system.

According to the company "Junkers" temporary glaciation of the soil does not have any negative effects on the functioning of the heat collector and on the vegetative coating technological area. If possible, necessary to watch that in the area that is occupied by the soil collector, should not be plants with deep root system. It is also important that the pipes were placed in a sand bed to prevent possible damage by sharp stones. Before performing the backfilling the collector, necessarily recommended to pressurize the piping system. Best of all to keep the pipeline under the test pressure in the process of backfill. Then it is very easy to immediately see the likelihood of damage.

Performing the required displacement of soil is possible without major additional costs especially in new buildings.

The magnitude of the selection of thermal power from the soil depends on many factors, first of all – from the soil moisture. From experiments is known that especially good results were obtained when installing collector in humid loams. At the same time the least suitable for remove heat is dry sandy soils (Table 1).

Table 1. The specific capacities of selection off heat from soil from lot of types of rocks

Name of the soil	Specific capacity of selection off heat q, W/m^2
Dry sand	10
Wet sand	15,0 - 20,0
Dry loam	20,0 - 25,0
Wet loam	25,0 - 30,0
Loam saturated with water	35,0 - 40,0

Ground source heat pumps, in which heat exchange with the base is carried out using flat collectors, have in comparison with analogous heating systems the following advantages:

- low operating costs,
- high annual coefficients of efficiency of operation of the heat pump.

Rules of operation of heat pumps allow the cyclic glaciation - thawing them collectors [2]. Since in freezing pore fluid increases in volume by about 10 percents, and the toughness and modulus of deformation of ice have the same order with the same characteristics of building structures and significantly higher than in conventional soils, when designing basesand constructions, in which heat pump collectors are arranged, must take into account this phenomenon.

Table 2. The dependence of the technological area of surface base on the area of the heated building.

Living area [m^2]	The specific heating load [W/m^2]					
	30	40	50	60	70	80
	Required technological area of surface ground for arranging ground collector heat pump [m^2]					
100	90	120	150	180	210	240
125	113	150	188	225	263	300
150	135	180	225	270	315	360
175	158	210	263	315	368	420
200	180	240	300	360	420	480

In the construction practice currently specified phenomena take into account in such cases:

1. When determining the deformations of frost heaving (in Ukrainian conditions this kind of calculation is performed in the appointment of the depth of the foundation base).
2. In the cyclic freezing – thawing occurs deterioration of properties of the soil [3-5]. This phenomenon currently taken into account in the design of offshore structures by introducing further loads and impacts (in the calculation of stress - strain state) and the reduction coefficients (in determining the the mechanical properties) [6,7].
3. In the cyclic freezing - thawing occurs deterioration of the concrete. This phenomenon currently taken into account when designing by determining the amount of cycles of freezing - thawing of concrete, at which its strength decreases slightly (frost resistance) [8].
4. Concrete elements of building constructions, in which polymer collectors of heat pumps are located have a coefficient of thermal extensions on 1,…,2 decimal orders of magnitude smaller, than in the collectors for close values of deformation properties of concrete and polymer, owing to what when the temperature changes may occur additional thermal deformation in constructions.
5. Collectors of heat pumps may be lower than the level of groundwater, owing to what process of freezing - thawing in this case has a number of other conditions, than when tested in accordance with standard procedure.

During the operation of the heat pumps in the mode of heating, the cooling of the basis is happening whose temperature may take zero values or negative ones [9-11].As a consequence the frost heaving of the soil base takes place [12], which leads to additional moving of the foundation situated on it, for these reasons there are the changes of tensely-deformed condition of the system “the base-foundation-the structure over foundation”.

Since there are no indications connected with this problem in the valid documents [13], we have carried out some experiments to find out the effect of additional deformed foundations which is caused by the working of the soil heating pumps.

Materials and results of the study. In experimental studies we have considered the building on the solid base plate, located on the ground, in which the freeze-thaw of the soil takes place caused by the work of the ground heat pump (Fig. 2). The part of the base, where the freezing and thawing of vapor fluid takes place, was constructed using a water-ground filled flexible container with the walls irresistible to inner pressure (Fig. 3).

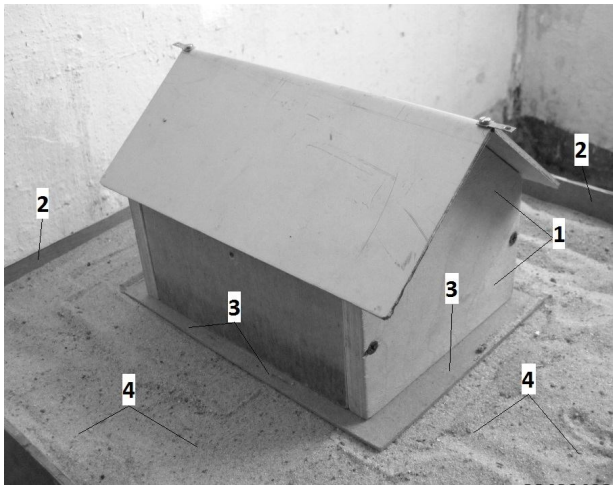

Fig. 2. Scheme of the test: 1 – building model; 2 – subsoil tray; 3 – slab foundation; 4 – ground foundation

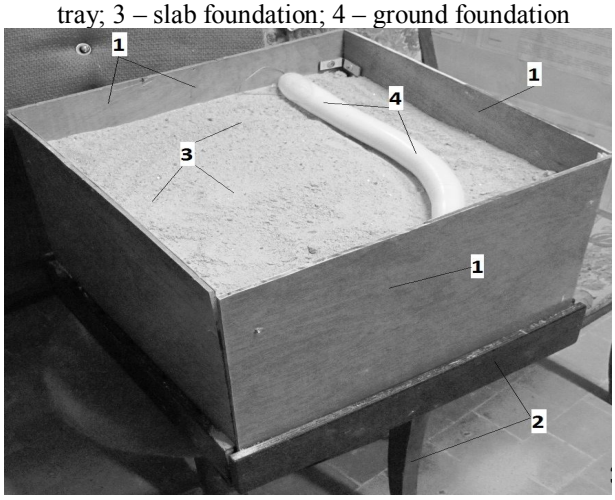

Fig. 3. Preparation of the substrate to the test: 1 – subsoil tray; 2 – bed; 3 – ground foundation; 4 – filled with soil and water rubber sheath

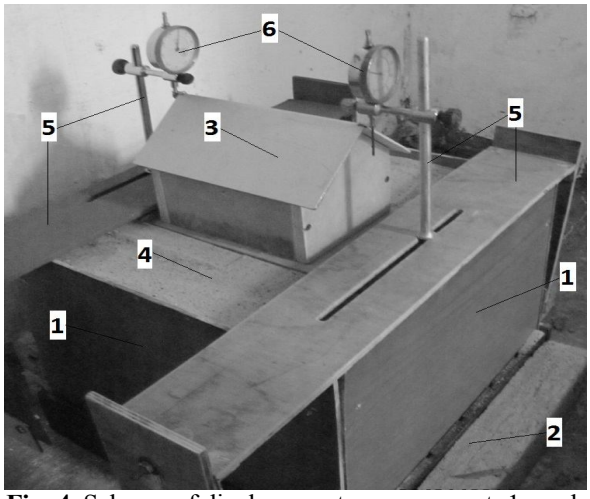

Fig. 4. Scheme of displacement measurement: 1 – subsoil tray; 2 – bed; 3 – ground foundation; 4 – ground foundation; 5 – the reference system; 6 – moving a dial indicator

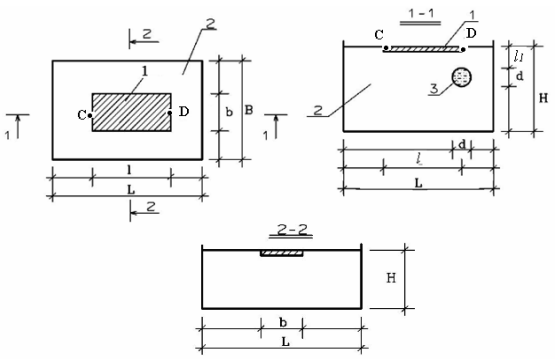

Fig. 5. Scheme of the "Clay tray – Base - a foundation."
Note: In this scheme, there are no dimensions of the over structure.

Vertical movements of the building model were measured using a dial indicator movement, which is attached to a special system of the reference (Fig. 4).

The scheme of the soil tray located on grade building is shown in Fig. 5.

Tests were performed in the soil tray with plan dimensions of 40x40 cm and a height of 30 cm in the following sequence:

1. Firstly, the preparation was carried out to mark the base of the sand bedding soles which freezes and thaws due to the heat pump field (Fig. 3).

2. Further, the rubber sheath filled with the ground and water and the walls which are slightly resistible to the internal pressure was put on the base (Fig. 3).

3. After that, the base was built up to the marked level and the model of the structure made of waterproof plywood and polymer composite material was fitted (Fig.2).

4. To measure the vertical displacement of the building model the special reference system was used (Fig. 4).

5. Next, the model of the building was placed in a dry environment with air temperature t = -14 ° C. The Freezing of water in a rubber container led to frost heaving base and as a consequence - the vertical movement of the points "C" and «D» was placed on the building model. These movements were measured after 7 days after placing the experimental setup in a climatic chamber.

6. Thereafter, the temperature was raised to a value t = + 20 °; in this state structure was kept for 7 days and re-measured vertical displacements of the points ”C” and ”D”

Table 1 shows the properties of the sub grade and some characteristic dimensions [14-16] of the "base-foundation". In the process of the analysis, we used the elements of the theory of dimensions.

We considered dimensionless π-complex of the form:

$$\pi_1 = \frac{\sum_{i=1}^{n} \varepsilon_i k_i h_i}{W} = \frac{\varepsilon_l k_l d_{reg}}{W}; \pi_2 = \frac{dreg}{b}; \quad (1)$$

$$\pi_3 = \frac{l}{b}; \pi_4 = \frac{l_1}{b};$$

where: $\pi_1,...,\pi_4$ – dimensionless Pi – complexes; W due to the freezing (thawing) ground rise (subsidence) of the base; ε_i – relative deformation of i-th layer of soil due to freezing (thawing) soil; h_i – it’s thickness; $k_i = 0.6,...,0.8$ – coefficient of working conditions; d_{reg} – the effective diameter of the field of frozen soil; l and b – respectively the length and width of the foundation sole; b – the distance from the base of the foundation to the foot of the basement to the top of the frozen region of the base.

Calculated using the presented data in table 3, Pi – complexes are shown in table 4.

Table 3. Calculating results

№	The names of the characteristics	Symbol	Units of measurement	Meaning
1	The modulus of the base deformation	E	MPa	
2	The degree of humidity of no water-base part	S_r	d. un.	0,02
3	The degree of humidity of water-base part	S_r	d. un.	0,99
4	The length of the foot of the basement	l	m	0,22
5	The width of the foot of the basement	b	m	0,18
6	Diameter of freezing (thawing) area	d_{reg}	m	0,03
7	The distance from the top of the field to the freezing foun-dation base	l_1	m	0,04
8	Lifting point "C" during freezing	$S_{3,A}$	$m \cdot 10^{-3}$	1,32
9	Lifting point "D" during freezing	$S_{3,B}$	$m \cdot 10^{-3}$	0,07
10	Draft terms of the foundation «C» in the process of thawing	$S_{O,A}$	$m \cdot 10^{-3}$	1,25
11	Draft terms of the foundation «D» in the process of thawing	$S_{O,B}$	$m \cdot 10^{-3}$	0,12

Table 4. Pi – complexes

№	Meaning of π-complexes	
1	π_1	0,90,…,34,32
2	π_2	0,17
3	π_3	1,22
4	π_4	0,22

Presented in table 4 data were used by us to determine the strain caused by freeze-thaw real soil bases.

For the foundation slab width of 7 meters with the formulas (1) and presented in table 4 data were calculated due to freezing - thawing soil foundation deformation of the base (Table 3). It was found that the recovery and deposition of base in this case varies in a range of 3, ..., 138 mm.

The following conclusions have been made:

1) the operation of the ground heat pumps leads to the cyclic freezing and thawing of the soil basements. This in turn leads to the rising (when the pore fluid freezes) and settling (when the pore fluid thaws) located on the basis of this foundation,
2) the rise or the subsidence of the slab foundation which is caused by the working of ground heat pump equals to 138 mm. These measurements have the same order with a maximum permissible deformations of the soil bases. [17- 20]. Thus, the deformation is caused by freezing or thawing of vapor base fluid in which the ground heat pump collectors are situated .It is important to take into account while projecting the foundation of the buildings and structures.

Table 5. The results of modeling

№	The names of the characteristics	Calculated formula	Unit of measurement	Meaning
1	The width of the foundation sole	-	m	7
2	The length of the foundation sole	$l = \pi_3 \cdot b$	m	8,54
3	Diameter of the frozen area	$d_{обл} = \pi_2 \cdot b$	m	1,19
4	The distance from the top of the frozen ground to the sole of foundation	$l_1 = \pi_4 \cdot b$	m	1,55
5	The rise (or subsidence) of the slab foundation	$W = \frac{\varepsilon_1 \cdot k_1 \cdot d_{обл}}{\pi_1}$	mm	4,…,138

CONCLUSIONS

In conclusion, we want to note that at the present time on the territory of Ukraine in the existing regulatory base are indicated the problem of accounting for the design effects of frost heaving caused by the heat pumps.

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