Testing the superblock deck by dynamic loads

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Abstract. Tyumen oil and gas industry province is being developed with the use of complete block construction. Especially increases the importance of building large blocks with installed equipment and superblocks on a floating mobile base. Styrofoam concrete is used to insulate the superblock deck. According to the developed methods, the adhesion strength of Styrofoam concrete to the superblock deck was tested and its characteristics for vibration resistance after the test were studied. The thermal characteristics of Styrofoam concrete used for superblock deck insulation are established, taking into account the vibration effects during transportation and operation. For testing, the deck fragment was installed in a climate chamber, and heat flow and temperature sensors were fixed to the surface of the fragment. As a result, it was found that dynamic loads reduce the resistance to heat transfer by 8-12 % due to the opening of cracks and the appearance of convective heat exchange. It is shown that the actual thermal resistance of the superblock deck with a thickness of 0.25 m and after exposure to dynamic loads remains at a sufficiently high level.

Keywords: superblock deck, deck fragment, Styrofoam concrete, a climate chamber, thermal resistance, compressive strength.

1 Introduction
There are special requirements for construction in the regions of the North of the Tyumen region. In the conditions the soils are not uniform, they are represented mainly by sand and clay rocks, and they have an ice content of 5 % to 80 %. Humidification of the insulation during operation causes a sharp increase in heat costs, and if it is accompanied by phase transitions of steam into water and water into ice, this leads to mechanical destruction of the insulation [1], [2] (it is shown in Figure 1). Of particular importance are the issues of soil protection from the impact of structures during the transition from pontoon to non-pontoon superblocks [3], [4]. The pontoon superblock is operated with a ventilated underground, which is preferable in relation to the impact of heat flows on the ground [5], [6]. The mineral wool plates, foam plastic panels and Styrofoam are used to insulate the basement of the superblock.

Figure 1. Superblock delivery.
Foam plastic panels were widely used. They were installed in the form of a vertical set of plates with a size of 0.1 * 0.25 * 0.05 m.

Mineral wool plates and foam padding have a common drawback - to fix them in the basement of the deck (cell size 15 * 15 * 0.2 m) requires a holding steel sheet thickness 0.0005 - 0.001 m, which increases the consumption of metal 10000 - 25000 kg per superblock, labor intensity and, most importantly, heat loss through cold bridges (deck-blank set-metal sheet) [7]. In addition, mineral wool plates and foam padding during transport and reloading operations, installation and operation of super blocks can collapse, settle and increase voids, which raise heat loss through the deck.

The most appropriate solution to insulate the deck was to use Styrofoam concrete, which has adhesion to the basement of the deck and the blank set. Usage of monolithic Styrofoam instead of foam plastic panels and mineral wool plates for insulation of the superblock deck reduces the labor intensity and cost of work [1], [8]. It reduces the consumption of metal because with sufficient strength of adhesion of Styrofoam to the deck subfloor, sheet metal is not needed for fixing the insulation.

The purpose of this work is to study the influence of dynamic loads (transportation, loading, unloading, operation) on the thermal characteristics of Styrofoam concrete.

2 Materials and methods
We have developed a new type of composite foam plastic whose density increases from the center to the surface. The introduction of fillers allows increase the compressive and bending strength by 3-4 times, to convert the foam plastic into a composite, non-flammable material.

The difference between composite plastics from traditional types of foam plastics is that the more pronounced the unevenness of the density across the cross section of the sample, the better the thermal parameters and strength indicators of this material are.

The advantage of composite foam plastics is the ability to design and manufacture them with specified physical and mechanical properties by optimizing the composition using mathematical methods [6],[9],[10].

Resin FRV-1A is used as a binder for foam plastic. Phenol-formaldehyde resin FRV-1A is a homogeneous mixture of neutralized aqueous solution of the primary products of alkaline condensation of phenol and formaldehyde, which introduced surface-active substance OP-7 or OP-10 and aluminum powder in the following ratio in parts by weight:

- Resin FRV-1A - 100
- Aluminum powder - 1
- OP -7 (OP -10) - 3

Exfoliated vermiculite, free-flowing granular material has flaked structure. Vermiculite the chemical composition is a silicate of magnesium and iron. Vermiculite is heterogeneous in composition and has an ellipsoidal configuration, its density 2.52 * 10^3-2.86 * 10^3 kg/m^3

Flotation reagent-oxal is a byproduct of isoprene production brought to the necessary condition through the stage of dimethyldioxane production. Introduction to the composition of the flotation agent-oxal allows to change the structure of the foam plastic and improve its physical and mechanical properties.

As a result of experimental studies based on simplex planning [9], the composition of foam plastic was developed. The composition of the foam plastic [% mass:

- phenol-formaldehyde resin 50-57 [%]
- granules of polystyrene foam 3-5 [%]
- flotation reagent-oxal 2-6 [%]
- vermiculite 26-31 [%]
- the product of condensation of sulfadimidine with formaldehyde and orthophosphoric acid (VAH-3) the rest
Foam plastic composition includes flotation reagent-oxal, which reduces the wetting angle of vermiculite with phenol formaldehyde resin by 2 times (from 30° to 14°).

Formation of crusts on the surfaces of the foam plastic causes its high mechanical properties [11], [12], [13].

The reactive composition merges into a mixer, where it is mixed with granules of polystyrene and vermiculite. From the mixer activated heat-insulating mass is discharged into the cassette and leveled. In the period of time from 180 to 600 seconds, the foaming reaction of the foam plastic occurs, during which hydrogen is released. Vermiculite particles can move in a liquid medium only in those first five minutes after the start of the foaming reaction, when the mixture is in a liquid state, then the foam is cured.

The multiplicity of the foaming reaction mixture is equal to 20. The gas bubbles released during the reaction join the vermiculite particle, an effective particle is formed, the volume of which significantly exceeds the volume of the vermiculite particle (the volume of the PP composition is doubled, which is due to the bubbles of the released gas).

The mass of the effective particle is almost equal to the mass of the vermiculite particle.

The mode of movement of a single particle in reaction Eq. (1)

$$m_p \frac{dv_p}{dt} = F_{Arch} - F_{r} - m_p g,$$  \hspace{1cm} (1)

where $m_p$ - the mass of the particle, $v_p$ - the speed of movement of the particle,

$\frac{dv_p}{dt}$ - acceleration of particle, $F_{Arch}$ - the lifting force of Archimedes,

$F_{r}$ - the force of resistance to motion of a particle.

The bulk of vermiculite a minute after the beginning of foaming will be in the areas of formation of foam crusts. Microscopic analysis of the foam PP showed that only 12-18% vermiculite is distributed in the middle part of the product. The density of crust is more than 200 kg/m³. The density of the foam plastic in its middle part is 380 kg/m³.

The technology for producing integral foams based on polyurethane and phenolic oligomers differs in a number of features caused by exothermic effects of the foaming-curing reaction. As a result, the cooling mode of the surface crust and core of the product changes, which leads to a change in the structure of the material [4], [6], [7].

Styrofoam is made on the basis of Portland cement (M400), sand and polystyrene granules. The mixture of components with water is mixed in a concrete mixer and placed in the basement of the deck. After seven days of exposure in natural conditions, the block pontoon can be turned and used for preparation and installation of equipment.

Determination of the adhesion strength of Styrofoam concrete to the basement of the deck was carried out by testing for breaking the anchor from the mass of the insulation. The experiments were made on fragments of ceiling deck size 1.5*1.5*0.2 m. Styrofoam laid in fragments corresponded to the mark 350. Anchors were installed in the mass of insulation at a distance from the flooring of the fragment. They consisted of a sheet of steel, in the middle of which is welded a pin with a ring (L = 0.41 m, D = 0.012 m). Fragments were tested on a special stationary stand in a horizontal position. Using four bolts, the fragments were attached to the frame of the stand. The experiment was performed till those states in which the Styrofoam in the sample did not meet the requirements under the applied load.
In the same conditions, in parallel with the formation of fragments and making the mixture, cubes 0.1\times0.1\times0.1 m were created for control. After twenty-eight days of natural hardening, both fragments and cubes were tested. Loading of the anchor was performed in stages that made up 10 % of the standard load. After each stage, 600 seconds of exposure were given, during which the dynamometer reading were taken. Dynamometer DPU-50-2-U2 was installed according to the scheme: anchor-dynamometer-loader boom hook. During the test, the condition of the fragment was visually assessed and cracks were detected. As a load, the force applied by the autoloader was used. The standard load was applied, and the duration of exposure reached 1800 s. After reaching the standard loads, cracks appeared in the samples in the area of the anchor. In the process of pulling out the anchor, the cracks grew diagonally from the center to the corners.

The adhesion strength ($R_{28}^0$) of the anchor to the Styrofoam concrete should not be greater than the strength of the monolith Styrofoam $\sigma_{28}$ in the deck subfloor (it is shown in figure 2). In this case, we should not attach Styrofoam to the deck. Stability condition of the monolith Styrofoam in the deck subfloor: $R_{28}^0 \leq \sigma_{28}$.

Adhesion strength of the anchor to the Styrofoam of the monolith is determined by the formula Eq. (2):

$$R_{28}^0 = \frac{P^0}{A},$$

where $R_{28}^0$ - the adhesion strength of the anchor with Styrofoam of the design strength, $N/m^2$;

$P^0$ - the value of the tearing load on the anchor, $N$;

$A$ - the total area of separation of Styrofoam concrete, $m^2$.

![Figure 2. Adhesion strength of the anchor to Styrofoam.](image)

The main characteristic of the strength properties of Styrofoam is the compression strength mark (cubic strength), which is used for the compression strength of reference samples 0.1\times0.1\times0.1 m tested after the set of the design strength. Samples were tested on the P-10 press. The compressive strength of Styrofoam ($R_{28}$) was determined for each tested sample (it is shown in figure 3) according to the formula Eq. (3).
\[ R_{28} = \frac{P}{A}, \]  

(3)

where \( R_{28} \) - the design strength of Styrofoam concrete, \( N/m^2 \);

\( P \) - the breaking load, \( N \);

\( A \) - the average working area of the sample, \( m^2 \).

\[ \sigma_{28} = \frac{6P(\mu + 1)a^2}{47h^2}, \]  

(4)

where \( \sigma_{28} \) is the strength of the monolith Styrofoam in the deck subfloor, \( N/m^2 \);

\( P \) - is the weight of the Styrofoam slab per unit area, and \( a \) is the side of the slab, \( kg \);

\( \mu \) - Poisson's ratio (\( \mu = 0.2 \));

\( h \) - plate thickness, \( m \).

**Table 1. The strength of the monolith Styrofoam.**

| № fragments | mass of Styrofoam per unit area [kg/m²] | Strength (stress) of Styrofoam [N/m²]|  |
|-------------|---------------------------------------|-------------------------------------|--|
| 1           | 91                                    | 23.128                              |  |
| 2           | 88                                    | 22.344                              |  |
| 3           | 95                                    | 24.108                              |  |
| average     | 91                                    | 23.226                              |  |

Calculations have shown that when the anchor is pulled out, the Styrofoam is destroyed, and not the contact layer. Therefore, the adhesion strength is greater than that of Styrofoam. The binding strength of the anchor with Styrofoam is less than the strength (stress) of the monolith Styrofoam in the deck subfloor. Therefore, it is not necessary to attach Styrofoam to blank sets with sheet metal [14], [15], [16].

To test the Styrofoam under operational and transport loads, six fragments of the superblock deck subfloor were used, which were insulated with Styrofoam grade 300 with a thickness of 0.0025 m. The Fragments were tested after twenty-eight days of natural hardening of the Styrofoam.

When performing the experiment, the IV-24 vibrator was used. The vibrator was fixed to a crosspiece mounted on a fragment of the deck. The fragment was examined for operational loads over a period of 6.0 hours. The struts of the deck fragment were fixed. Readings of vibration displacement and vibration resistance were taken with a VIP-2 Vibrometer at the corners and in the center of the fragment with a time interval of 0.5 hours.
From the data obtained, as well as from the type of surface, it follows that no deformation and destruction of Styrofoam was observed, that is, long-term time tests were successful. This means that Styrofoam can withstand operating loads [5], [17], [18].

The fragment was tested for multiple cyclic transport loads, provided that the two diagonal racks were free. The first stand had vertical oscillation amplitude 0.006 m, and the third one had vertical oscillation amplitude 0.008 m. A crack appeared on the fragment in length 1.17 m and width 0.0018 m (norm 0.0015 m) after 63·10³ cycles, it is shown in Figure 1.

This number of cycles that the sample has sustained is 70 times greater than the Styrofoam loading cycles that it is subjected to when moving the "drag" method over a distance. With sufficient reason, it can be argued that the composite material in the basement of the superblock deck can withstand cyclic transport loads [17], [19], [20].

The behavior of samples under concentrated load was investigated by applying force with a hydraulic Jack DG-25. Load values were taken with a DOSM 20-3 dynamometer. The results obtained as a result of testing the sample under a concentrated load in the center of the flooring are as follows: the value of the deflection is greater than the control one by 3.9 % (norm 15 %); there was a crack with a width 0.0014 m (norm 0.0015 m), a length 1.9 m on the surface of the Styrofoam at a load 7500 kg.

Studies of the fragment on the vertical movement of one of the supports showed that the Styrofoam did not collapse under load up to 6200 kg, which was 1.65 times greater than the control value 3750 kg. A load to the support of more than 6200 kg was not applied according to safety requirements. Tests to determine the adhesion strength of Styrofoam to the superblock deck revealed that the force at which the composite was detached is equal to 9000.

This strength is 21 times the mass of Styrofoam in the cell multiplied by the dynamic coefficient. The results of experiments allow make the following conclusion: the composite material–Styrofoam M300 in the deck subfloor meets the requirements for it, it can withstand the transport and handling and operating loads of the superblock (it is shown in figure 4).

![Figure 4. Styrofoam after testing for cyclic transport loads.](image)

The thermal parameters of the superblock deck are theoretically determined with large assumptions [21],[22]. These assumptions distort the picture of heat and mass transfer through it [11], [23]. The presence of metal inclusions (reinforcing mesh, stiffeners of the idling set of the deck subfloor) leads to an unreliable assessment of the temperature field through the deck, insulated with Styrofoam. Reliable thermophysical studies of natural fragments of the superblock's insulated deck were carried out experimentally (it is shown in figure 5).

The climate chamber Ilka was used for conducting experiments. The subject fragment of the ceiling of the deck was mounted in the doorway of the chamber. The size of the image coincides with the size of the cell ceiling deck. Two samples were made 0.5×0.5×0.2 m. The metal frame was filled with Styrofoam grade 300. After twenty-eight days of exposure, the mixture had the design strength, and the test sample was mounted in a climate chamber.
Figure 5. Heat engineering tests of fragments the superblock deck.

The experiment was performed following the requirements of GOST 25380-2014. The temperature on the inner and outer surfaces of the sample was measured; the density of the heat flow passing through the sample. The internal and external air temperature was measured at a distance from the fragment surfaces. Chromel-Copel thermocouples and glass thermometers were used to measure the temperature. Disk heat meters were used to measure heat flows. The V7-2F voltmeter was a secondary device (it is shown in figure 5).

The locations of heat-conducting inclusions on the sample were determined as points for measuring the required parameters (it is shown in Figure 4). To achieve a close contact of the heat meter with the sample, the surface of the heat meter was smeared with technical Vaseline. The experiment was performed following the requirements of GOST 25380-2014. The temperature on the inner and outer surface of the sample was measured; the density of the heat flow passing through the sample. The internal and external air temperature was measured at a distance from the fragment surfaces.

Thermometers and thermocouples were fixed on the sample using plasticine. The tests were performed at a temperature of outdoor air $-35^\circ C$, and indoor air at level $+27^\circ C$. The experiment was performed when stationary heat transfer was set through the sample. The values of the temperature and heat flow sensors were obtained after 1.5 and 7 days. The value of 7 days was applied because the design of the sample has a significant thermal inertia.

3 Results

The thermal inertia of the superblock's D deck was determined by the formula Eq.(5), (6):

$$D = R_1 S_1 + R_2 S_2 + R_3 S_3,$$

where $R_1$, $S_1$ - thermal resistance and coefficient of heat absorption of steel flooring; $R_2$, $S_2$-thermal resistance and heat absorption coefficient of the thermal insulation layer of Styrofoam M 300; $R_3$, $S_3$ - thermal resistance and heat absorption coefficient of the reinforcing layer of the concrete screed.

$$D = \frac{0.004}{58} - 126.5 + \frac{0.26}{0.079} - 1.95 + \frac{0.05}{1.51} + 16.77 = 0.009 + 6.17 + 0.56 = 6.74.$$

Based on the results of measuring the temperature and density of heat flows, the thermal parameters of the experimental fragment of the superblock deck are calculated [24],[25],[26].

4 Discussions

Dynamic loads experienced by the superblock during transportation, installation and operation do not significantly affect the physical and mechanical characteristics of the Styrofoam insulation in the superblock deck. The heat transfer resistance of a deck with Styrofoam is 1.2-1.5 times higher than required even after dynamic testing.
When the deck is insulated with Styrofoam, its heat transfer resistance $R = 3.24 \, m^2 \cdot \degree C / W$ is greater than the required heat transfer resistance of the deck $R^c = 2.73 \, m^2 \cdot \degree C / W$, therefore, in this case, the heat engineering deck will meet the design requirements.

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