The Technology for Manufacturing High-Strength Pipe-Concrete Bearing Elements to Increase the Stability of Underground Structures

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Abstract. It is proposed to use high bearing small-size pipe-concrete units in the construction of underground geotechnical structures instead of large-sized reinforced concrete units (support blocks, pylons, columns, etc.). The analysis of the methods of manufacturing pipe-concrete units, their advantages and disadvantages is conducted. The process flowchart for manufacturing pipe-concrete units with barothermal pre-stressing of a concrete mixture in a steel pipe was developed to ensure the collaboration of a steel pipe and a concrete core and increase its strength. Experimental research in barothermal treatment of a concrete mixture in a steel pipe was performed using the laboratory model of a pipe-concrete unit, which showed the efficiency of the proposed technological scheme for the production of pipe-concrete units. The lines for further research in the development of a method for determining the optimal parameters of the technological scheme for manufacturing pipe-concrete units with barothermal pre-stressing of a concrete mix are planned.

1 Introduction

Geotechnical structures - coal mines, mines, tunnels, subways, industrial enterprises, etc. - are widely used for various purposes in the industries of the Russian Federation.

The feature of the construction and operation of underground geotechnical structures are high static and dynamic operating loads on their lining. With that, particularly significant operational loads act on linings of large cross section underground chambers of various geotechnical purposes. Such underground chambers are usually fixed by reinforced concrete lining, leaving large reinforced concrete bearing units - supporting blocks, pylons, columns, etc. - in sections of chambers and their junctions. A large amount of concrete and reinforcement is required for the production of such supporting elements, besides they occupy a lot of space in the underground structure, preventing its rational use.

Nowadays, bearing pipe-concrete units are currently used as an alternative to bearing reinforced concrete units in the construction of surface and underground geotechnical structures for various purposes [1, 2, 3, 4, 5].

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Many scientists [6, 7, 8, 9, 10, 11,12, 13, 14, etc.] were engaged in researches in the field of calculation, design, and technology for manufacturing pipe-concrete bearing units. The essence of the method of manufacturing a pipe-concrete bearing unit is that a concrete solution is poured into a metal mantle pipe, which performs the functions of both permanent formwork for a concrete solution, and that of reinforcement of a concrete core, providing its longitudinal and transverse rigidity; a concrete solution shrinking when hardened in the formwork, and expanding in a metal mantle pipe.

It is known that a pipe-concrete bearing unit can withstand much greater loads in comparison with the usual reinforced concrete unit, both in the vertical and in the horizontal planes. A metal pipe, collaborating with a concrete core in a pipe-concrete unit, provides a significantly higher resistance coefficient than that in an open reinforced concrete bearing unit. In a reinforced concrete bearing unit, cracks are formed; the disclosure of which increasing with time. In a pipe-concrete unit, due to the load acting on it, only closed microscopic cracks of a concrete core can form, which practically do not expand, and the steel pipe, reinforced with concrete, accommodate various loads much more efficiently [1, 3, 4, 6, 10].

It was established that, compared with reinforced concrete load-bearing units, pipe-concrete units make it possible to reduce the consumption of metal and concrete by 1.5-2.0 times, to reduce by 2-3 times the size of sections of elements and, as a result, their mass and labor costs due to significant decrease in the volume of welding and reinforcement works, as well as the complete elimination of formwork works. A pipe-concrete unit, having a steel outer shell, is easily mounted and has a significantly greater fire resistance compared to reinforced concrete and metal structures [1, 3, 4, 6, 7].

However, in addition to numerous advantages, pipe-concrete bearing units also have a serious drawback, which consists in the difficulty of ensuring collaboration of a concrete core and a steel mantle pipe under workloads. As a result, a steel mantle pipe starts to behave as a reinforcing element only after the start of the formation of micro cracks in a concrete core, which negatively affects the bearing capacity of a pipe-concrete unit.

To increase the bearing capacity of pipe-concrete units, two methods were proposed for pre-stressing of a concrete core in a steel mantle pipe in the transverse direction [1, 3, 6]:

1) mechanical pre-stressing of a concrete mixture in a steel pipe by means of void formers of various designs at a pressure of 2-3 MPa;

2) manufacturing of a concrete core from expansive-cement 1.5-2.0 MPa or more self-stressing concrete.

The first method allows more significantly increasing the bearing capacity of pipe-concrete units, since mechanical pre-stressing of a concrete mixture in a steel pipe with the help of void formers allows increasing by 25-40% the strength of a concrete core and reducing the voidness and creep deformation of a concrete [1, 2]. In the process of mechanical pre-stressing of a concrete mix, water which has not entered into the cement hydrotation is filtered out of it, and as a result of the pre-stressing of a concrete mix, pre-stretching of a steel mantle pipe and subsequent compression of a concrete core are occurred, which increases its adhesion to a steel pipe, ensuring their collaboration [1, 3, 6].

However, it is quite obvious that the method of mechanical pre-stressing of a concrete core with the help of void formers of various designs allows effective compacting of a concrete mix in a steel mantle pipe only in the manufacture of small-sized - both in diameter and length - pipe-concrete units. In addition, the implementation of this method requires the manufacture of special pre-stressing machines and void formers, the design of which will differ significantly depending on the size and shape of the pipe-concrete unit.

Therefore, the development of an effective way to ensure collaboration of a concrete core and a steel mantle pipe of pipe-concrete units of various dimensions under workloads remains relevant today.

It is known that when concrete is being autoclaved, a concrete mix in an autoclave is acted upon by excess pressure of water vapor, which presses the concrete mix and heats it. Autoclave (barothermal) treatment of the concrete mixture is carried out at a saturated water vapor pressure of 0.9-1.2 MPa and a temperature of 174.5-187°C, respectively, which significantly reduces the time it takes for concrete to harden, increases its strength and other physical and mechanical characteristics by heating a concrete mixture, its pre-stressing by the vapor-air medium and "autoclave synthesis" - the formation of new phases and compounds in concrete. With that, the strength of autoclaved concrete in comparison with air storage concrete of the similar composition increases on average by 60-200% for heavy and light concrete respectively.

Considering the above, it can be assumed that due to the barothermal treatment of a concrete solution in a steel pipe of a pipe-concrete unit, it is possible to ensure collaboration of a concrete core and a steel mantle pipe in pipe-concrete units of various dimensions under workloads.

2 Results and discussion

The process flowchart for the manufacture of concrete elements with barothermal pre-stressing of a concrete mixture in a steel pipe of a pipe-concrete unit to ensure the collaboration of a concrete core and a steel pipe of a pipe-concrete unit was developed in T.F. Gorbachev Kuzbass State Technical University. The proposed scheme is based on the patent for the method of autoclave (barothermal) treatment of concrete mixes in the sealed form through steam wells [15].

Fig. 1 shows the flowchart of the technology for manufacturing pipe-concrete units with barothermal pre-stressing of a concrete mix in a steel pipe. The steel pipe 1 of the pipe-concrete unit is insulated with the heat-insulating material 2 and is equipped with the hermetic upper 3 and the lower 4 covers. The steam well 5 is mounted in the steel pipe with the fixed lower cover and the concrete mix 7 is placed in the space between the steam well 5, the walls of the steel pipe 1, and the upper cover is hermetically closed. Water steam 8 is supplied under pressure through the steam injector 6 into the steam well 5 and barothermal pre-stressing of the concrete mix 7 is performed.

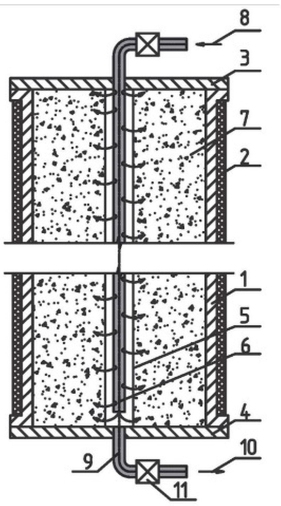

Fig. 1. Process flowchart of the manufacture of pipe-concrete units with barothermal pre-stressing of the concrete mixture in a steel pipe.

After barothermal treatment of the concrete mix 7 and cooling of the concrete in the steel pipe 1, the cover 3 is removed from it, the steam injector 6 is removed from the steam well 5 and the steam well into which a reinforcing element can be placed before concreting is cast.

The parameters of barothermal pre-stressing of the concrete mix depend on the density of the concrete produced and are prescribed according to the known recommendations for the autoclave treatment of concrete mixes.

The steam well is a tubular structure made of reinforced cage with metal mesh walls, impermeable to concrete aggregate, but permeable to water vapor.

To test the possibility and efficiency of barothermal treatment of a concrete mixture in a steel pipe of a pipe-concrete unit, preliminary experimental studies were carried out using a model of a pipe-concrete unit. In fig. 2 the design of a physical model of a pipe-concrete unit with barothermal pre-stressing of a concrete mix is shown.

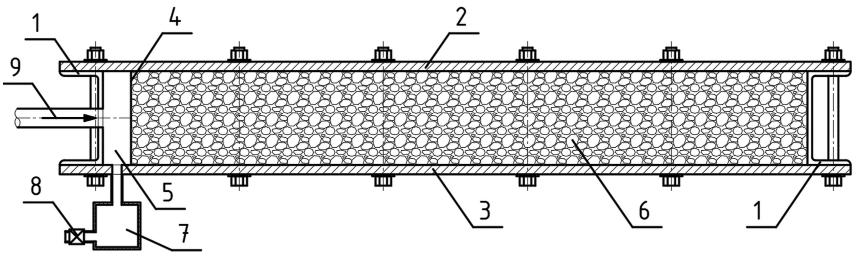

Fig. 2. The design of the model of a pipe-concrete unit with a pre-stressing crimp of concrete mix.

The model of the pipe-concrete unit is made in the form of a sector with an apex angle of 30^0, a radius of 1.1 meters and a height of 0.15 meters. The model consists of the casing 1 with the upper removable cover 2 and the lower non-removable cover 3. The radial wall 4 of the steam well 5 is made of steel armature mesh. Removal of the steam condensate (water) from the steam well 5 in the process of barothermal treatment of the concrete mix 6 in the model is performed in the tank 7 equipped with the drain valve 8. Water vapor 9 is supplied under pressure into the steam well 5 by a steam generator equipped with a pressure gauge.

The barothermal treatment of the concrete mix 6 in the casing of the radial model was carried out as follows. The concrete mix of the required composition was prepared and the radial chamber of the experimental model was filled with it (see Fig. 2), the top cover 2 was installed and bolted to the frame. The steam supply hose was connected to the steam well 5 and barothermal treatment in accordance with the specified modes was performed. After cooling the hardened concrete mixture in the model chamber to room temperature, the top cover 2 was removed from it. The effective radius of the barothermal treatment of the concrete mixture was determined removing from the steam well 5 by changing the strength of the hardened concrete solution, which was determined by the length of the radial chamber by non-destructive method by means of the strength meter "ONYX 2.5" according to the State Standard (GOST) 22690. The tests were carried out for $2{,}32 \cdot 10^3$ kg/m^3 density B30 grade cement concrete. Parameters of barothermal treatment: maximum pressure - 10 MPa, duration of pressure rise to maximum - 2 hours, curing at maximum pressure - 6 hours, pressure descent to atmospheric - 2 hours.

The results of preliminary experimental studies to verify the feasibility and efficiency of barothermal treatment of a concrete mix in a steel mantle pipe using the model of a pipe-concrete unit are presented in the table.

Table 1. The results of preliminary experimental studies.

Steam well diameter, mm	Barothermic treatment radius, m	Concrete strength without barothermal treatment, MPa	Concrete strength after barothermal treatment, MPa
70	0,19	38,6	48,3
150	0,41	38,6	47,2

3 Conclusion

Experimental studies have shown the efficiency of the proposed process flowchart for the manufacture of concrete units with barothermal pre-stressing of a concrete mixture in a steel pipe through a steam well.

For the development of the methods for determining the optimal parameters of this technology, laboratory studies are currently conducted at T.F. Gorbachev Kuzbass State Technical University to determine the relationship between the parameters of a concrete mix, and its barothermal treatment, steam well diameter, radius of distribution of barothermal treatment of a concrete mix from a steam well, the strength of the resulting concrete core and its adhesion to a steel pipe of a pipe-concrete unit. At the same time, the strength of concrete and its adhesion to a steel pipe are taken as optimization criteria, the other parameters mentioned above are variables in the objective optimization function.

The proposed process flowchart for the manufacture of pipe-concrete units by means of barothermal pre-stressing of a concrete mixture and its autoclave synthesis will allow manufacturing pipe-concrete units with improved physical and mechanical characteristics, ensure the collaboration of concrete and a steel mantle and reducing the time for hardening concrete in a steel pipe from 28 to 1.0-1,5 days.

The use of small-sized supporting pipe-concrete units with barothermal pre-stressing of the concrete mixture can be used in cramped conditions for the construction of underground geotechnical structures as an alternative to large-sized supporting reinforced concrete units in the form of pylons, pipe concrete columns, supports, foundations, etc.

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