Strengthening of supporting ground of a damaged building by high-pressure injection of a moving cement-sand mixture

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ABSTRACT: The article describes a set of activities undertaken to enhance the supporting ground of a damaged building in the city of Nadym of Yamal-Nenets Autonomous District, Russia. Works on strengthening were implemented by the high-pressure injection of the moving cement-sand mixtures. Design algorithm is formulated, standard operating procedures are described, and criteria for quality control are given.

1 INTRODUCTION

Currently, the strengthening of the foundation bases of damaged buildings and buildings under refurbishment is one of the most common types of engineering works in an urban environment. They should result in a damping and the subsequent absence of post-repair sedimentary deformation of a building. One option that will ensure the fulfilment of this condition is a method of high-pressure injection of cement-sand mixtures into the ground.

Figure 1. View of Nadym, it geographical position and climatic conditions.

This method was used in the strengthening of the supporting ground of the residential house № 39 on Naberezhnaya Orudzheva Street in the city of Nadym in Yamalo-Nenets Autonomous District. The building consists of four entrances made of built-up concrete structures with dimensions in the plan of 64.8 ×13.2 m and has five floors. Recently, the building began to show above-standard non-uniform deformations, which led to the emergency condition of supporting constructions of the building.

2 GEOLOGICAL CONDITIONS

Silt sands of small and medium size interbedded with sand clay and clayey loam take part in the geological structure of the base. The ground water level is between 2.8 and 3.2 m below ground level. Seasonally-frozen ground underlays from the surface to a depth of 1.9 to 2.6 m, relics of permafrost ground underlay at depths of 14.8 to 20.2 m to 21.8 to 22.7 m. Relics force is varied considerably, ranging from 0.2 m to 7.7 m.

Comparison of the results of additional engineering and geological surveys conducted in the late 90s with old materials showed a significant change in permafrost conditions during the period since 1985. During this time, the thawing of frozen earth and its redistribution on adjacent grounds were evidenced due to the long-term technogenic impacts under the building. This, obviously, was the main cause of non-uniform deformations, significantly exceeding the limit values. Aggravating factors were unsuccessful structural diagram of the building, heavy flooding of the supporting ground, as well as the lack of depth of the foundation base.

3 PROJECT OF STRENGTHENING GROUND BASE

According to obtained engineering and geological data and research materials of the "Center of research analysis, inspection, planning and implementation" of Novosibirsk State University of Architecture and Civil Engineering (Sibstrin) the project on strengthening the base of a dangerous building was drafted. It was based on the assumption that the concentration of heat flow in the circuits of the residential building led to a complete thawing of the underlying subgrade soils, and continuing precipitation is determined by long-term consolidation process of thawed soils and restructuring of the entire deformable thickness into a new equilibrium state. The aim of the project was to limit the vertical deformations of the building under refurbishment and transferring of the vertical setting into the decaying phase by artificial acceleration of the consolidation processes through the excessive pressure transmitted to the consolidated ground by way of layer-by-layer high-pressure injection of plasticized cement-sand mixture.

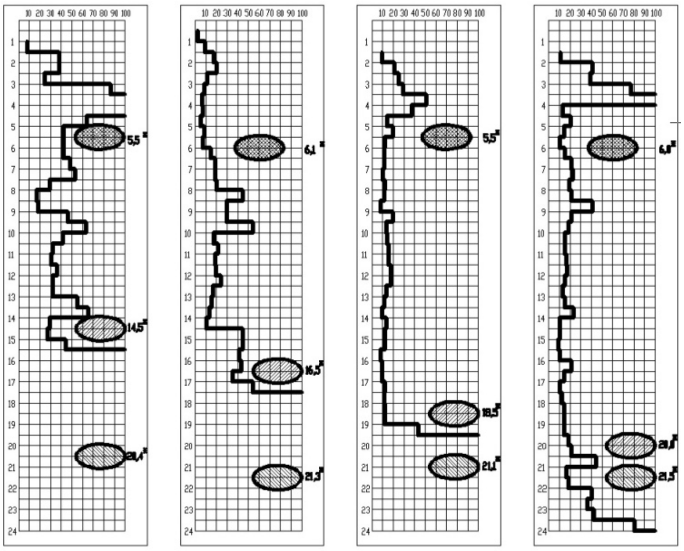

Figure 2. The original purpose of injection horizons according to results of the static probing of soils.

Injection wells were placed in the plan under the condition for ensuring the uniformity of compaction of structurally unstable strata according to the geometric dimensions of the injectable body (a compaction lens). The original purpose of injection horizons was based on the results of the static probing of soils, dilatometric tests and the data obtained due to the drilling of technical wells. The projected compression zone of the supporting ground was designated in the depth interval from 6 to 22 m at the lower resistivity of the probe cone (Fig. 2). The volume of injected mixture per well and per one injection horizon was taken from the experimental selection based on the provision of the maximum compaction uniformity of the structurally unstable supporting ground strata. The project considered the construction of a proving ground with similar engineering and geological conditions in order to develop the workflow technology and determine the discharge modes required for effective solidification of the supporting subsoils.

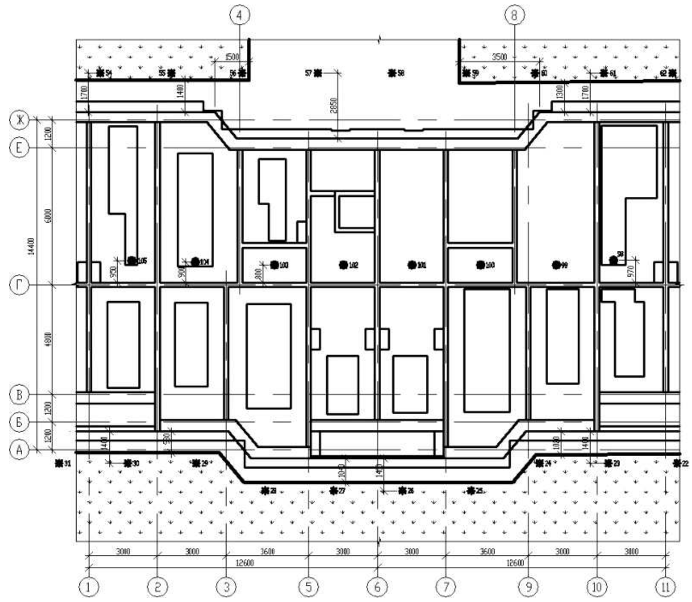

Figure 3. Example of injection points positions on the building plan.

4 EXPERIMENTAL WORKS

The proving ground was equipped in close vicinity to the building under refurbishment. Research at the proving ground was carried out before the start of works on the injection compaction of the deep lying structurally unstable soils. During the tests, the possibilities of the main technological machinery were investigated, as well as their use in combination with other mechanisms facilitating the immersion of injectors into the ground. The dependence of the immersion rate of injection tubes on the soil density (fixation of the depth of the top and bottom of the softest soils to clarify the injection horizons) was determined, the roof level of permafrost was confirmed, and control procedures on the degree of compaction of soft soils were worked out. Besides, the injection modes were investigated and injection volumes of cement-sand mixtures were specified, taking into account the adjusted density of addition of natural soil and drainage conditions of intrastratal waters outside the compacted zone.

According to the research results, some corrections, clarifications and amendments aimed at improving the quality and reducing the turnaround time were introduced into the project on strengthening the supporting ground.

5 MAIN WORKS

Main works on the subgrade compaction were carried out in summer 2002. The injection was carried out along the building envelope through the vertical wells under the foundations of external walls, and, with the help of inclined holes, under the foundations of internal load-bearing wall.

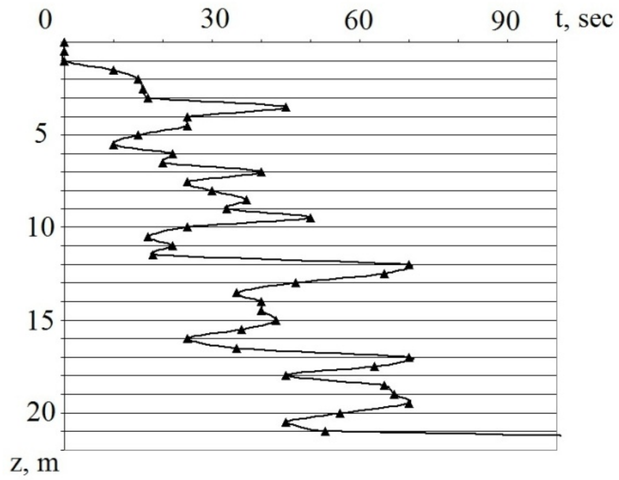

Figure 4. Schedule of a dynamic sounding of soils during the workflow (dependence of the injector sink rate on the density of the soil composition).

The injection tube with a lost tip was hammered on a roadbed note with AVB-2M assembly. While hammering, we measured the speed (depth and time) of its immersion (Figure 4) to clarify the injection horizons notes (they were appointed in places with the highest speed of injector dive). Before starting the injection, the tube was lifted on 100...150 mm to release the lost tip, protecting the injector from clogging with the soil and serving for creation of a drainage layer that facilitates the removal of groundwater due to the increased outer diameter. Discharge of injection mixture was carried out from the bottom upwards - on the bottom, and then on the upper levels.

Plasticized cement-sand mixture was used as an injection, which was prepared according to the following weight ratio: M200 cement - 1 part, bentonite powder - 1 part, fine or medium-grained sand - 7 parts, water - to the desired plasticity level of the mixture. The solution was consistent with the M10 strength and had the mobility meeting the requirements of injection equipment. After injection of each horizon, the flush of the pressure line with water volume of 0.02 - 0.03 m^3 was made to avoid the setting of the mixture in the tube.

Injection was carried out under high pressure (more than 10...15 atmospheres), an occasioned soil gap was fixed by the initial pressure drop until a stable value due to the income rate of the mixture into soil. With a further increase of the mixture income, a crack was observed - both in plan and through-thickness; a single lenticular body consisting of two cones of the volume specified in the project was formed in the ground.

Subgrade support was injected at all possible horizons at depths of 6 m to 23 m from the daylight surface. In some cases, test injection of the mixtures was performed in addition to the actual ones at another 3-4 horizons, where the highest rate of the injector immersion was recorded. However, in general, there were small amounts of injection (less than 0.1 m^3), and the bulk of the injected mixture fell to a depth of 16...21 m, which corresponded to the thawed water-saturated layers of light sandy low-plastic and high-plastic clay-loams and soft fine and medium-grained sands.

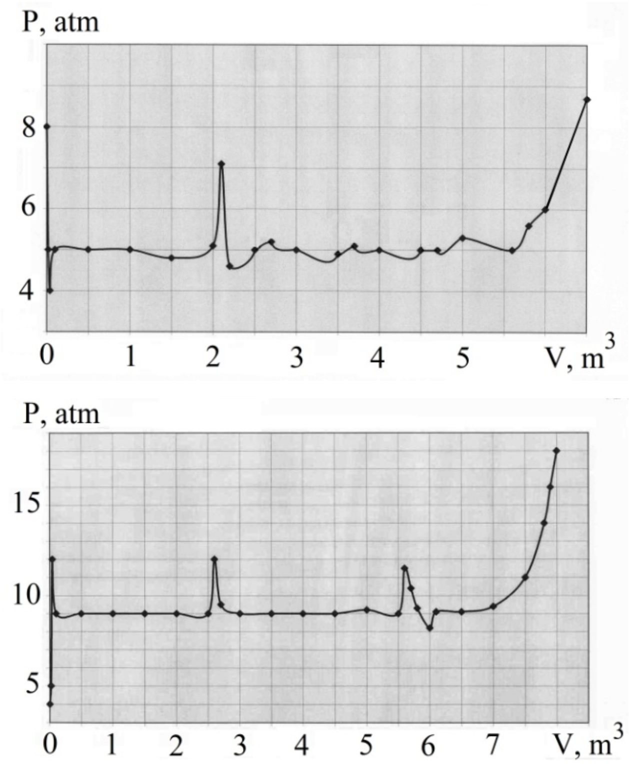

Figure 5. Typical dependences of the pressure on the volume of injection.

Dive and extraction of injection columns were carried out by self-propelled AVB-2M mount for vibratory drilling. The injection was carried out until the pressure increase by 40% in the supply mains was reached compared to the initial steady-state pressure. In specific situations, it was observed due to the great volumes of the mixture injected - more than 15%. The pressure increase was recorded throughout the entire process of injection. Short-term increase in pressure (less than for 0.1 m^3 of the mixture) was not considered a ground for termination of the injection (Figure 5). If it was found impossible to increase the pressure, the injection of maximum technologically possible mixture volumes - more than 8 m^3 – was made.

After the end of the work, the control probing was carried out along the entire perimeter of the building to determine the compacted areas of the supporting ground. This was done to assess the need for additional injection and determine the size of the injection area. In addition, re-testing of soil by dynamic probing was carried out by experienced and closely spaced thereto reference points for quality control of soil compaction. In all cases, a significant decrease in the speed of immersion of the probe in the horizon areas of executed injections is registered. In addition, the change regularities of the packing effect are specified in the injection horizon area as one moves farther from the test hole.

The overall quality of the protective works was evaluated according to the results of geodetic observations for settlements of the building under refurbishment in post-repair period. The measurement data confirmed the stabilization and fading nature of deformations of the supporting ground.

Figure 6. Experimental and main works.

6 CONCLUSION

The practical experience of carrying out of these works allows us to recommend the high-pressure injection method for a wide application to enhance the supporting ground. Application of this method is quite productive and has significant benefits. High-pressure injection to create concrete bodies, reinforces and consolidates the surrounding soil base massif. Currently, further research to improve the effectiveness of this method is performed.

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