Experimental study results of the strip foundation fragment action underpinned by a drill-injection pile with widening low end

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Abstract. The article presents the results of static load tests of a strip foundation fragment (bearing plate) underpinned by a drill-injection pile, which has a widening low at its lower end. The static load tests were carried out at the experimental site in the city of Tyumen. A drill-injection pile with widening low end is an injector that has a rubber membrane-glass at its lower end. With the help of a hydraulic packer, the solution is injected into the rubber membrane-glass. After the solution has cured, a widening low end of the required volume is formed at the lower end of the injection pipe. To assess the results obtained, static load tests were also carried out both for a strip foundation fragment without underpinned using a drill-injection pile with widening low end, and a separately located drill-injection pile with widening low end. Based on the data obtained during static load tests in the course of the experimental study, graphs of dependencies were formed: the settlement of a strip foundation fragment on the pressure under its base and the settlement of the drill-injection pile with widening low end on the static load. As a result, it was found that the use of a drill-injection pile with widening low end to underpin a strip foundation fragment allows increasing the bearing capacity by an average of 30%.

1. Introduction
Currently, a large number of technologies for strengthening foundations, in particular strip foundations, are known in the world practice [1-4]. However, not all of them can be used to strengthen the foundations of buildings and structures of historical buildings and cultural heritage. According to the requirements of regulatory documents, the development of additional building tilt and deformations is unacceptable for such buildings [5]. The most popular methods for strengthening the foundations of buildings and structures of historical buildings and cultural heritage are methods without dynamic loading [6-8]. One of the ways to strengthen the foundations is a drill-injection pile installment with widening low end. The study is relevant due to the insufficiency of studying the interaction of the drill-injection pile with widening low end with the strip foundation, as well as its bearing capacity as part of the strip foundation.

2. Aims and tasks of the study
The aim of the study is to conduct a field testing site to establish the dependence of the interaction of a strip foundation fragment (bearing plate) underpinned by a drill-injection pile, which has a widening low end.
Study tasks:
- to determine the maximum value of the vertical static load, which can be perceived by a strip foundation fragment underpinned by a drill-injection pile with widening low end, 2.0 m long and a broadening volume of 50 liters;
- carry out a static load tests both of the strip foundation fragment without underpinned by a drill-injection pile with widening low end, and a separately located drill-injection pile with widening low end, 2.0 m long and a broadening volume of 50 liters in order to assess its bearing capacity in the geological conditions of the experimental site, to analyze the underpinned effect of the strip foundation fragment by a drill-injection pile with widening low end.

3. Ground conditions of the experimental site
The study was carried out in September 2020 at the testing site in the city of Tyumen. In the course of in-situ soil tests was revealed that at the base of the testing site are cohesive soils: loam and clay. The physical and mechanical properties of the soils of the base of the testing site are presented in table 1. The established groundwater level for the survey period was recorded at a depth of 0.7 m.

| Engineering and geological element | Depth H, m | Fluidity index I, | Specific weight \( \gamma \), kN/m\(^3\) | Angle of internal friction \( \varphi \), degrees | Specific cohesion \( c \), kPa | Deformation modulus \( E \), MPa |
|-----------------------------------|-----------|------------------|------------------|------------------|------------------|------------------|
| 1 Low-plastic loam                | 0.4-1.5   | 0.42             | 18.7             | 19               | 27               | 9                |
| 2 Very soft loam                  | 1.5-5.5   | 0.81             | 17.9             | 15               | 18               | 5                |
| 3 Semi-solid clay                 | 5.5-10.0  | 0.22             | 17.8             | 15               | 35               | 10               |

4. The process of making the object of study
The process of making a strip foundation fragment underpinned by a drill-injection pile with widening low end.

A strip foundation fragment was a bearing plate with dimensions in plan 1000x1000 mm, 200 mm high, reinforced with reinforcing meshes with a 175 mm cell made of reinforcing steel of class A400 with a diameter of 10 mm.

A drill-injection pile with widening low end [9] was used as an underpin element of the strip foundation fragment. A drill-injection pile with widening low end is an injector which made of a steel tube 2000 mm long, 57 mm in diameter, with a wall thickness of 3.5 mm, that has a rubber membrane-glass at its lower end (figure 4). The rubber membrane-glass is put on top of three rows of through bore holes with a diameter of 8 mm for the solution exit (figure 1) and is fixed to the injector with two clamps.

The process of forming a widening low end consists in injecting the solution into the rubber membrane-glass using a hydraulic packer, and the formation of the drill-injection pile shaft consists in injecting the solution into the annular space between the injection pipe and drilled formation wall.

The succession of technological operations for modelling underpinned process of the strip foundation fragment is:
- in the soil massive, a well is drilled to the design mark at the location of the strip foundation fragment center its base (figure 1);
- an injection pipe is installed in the drilled well with a rubber membrane-glass hermetically fixed at the lower end. In the lower part of the injector, a spherical pipe closer is welded to eliminate the possibility of back-ingress of the solution. The bore holes are closed with rubber cups that act as a check valve and are fixed to the injector with a tying wire (figure 2 and 3);
- after installing the injection pipe, a concrete plug is placed in its upper part to exclude the exit of the solution from the wellhead during the formation of the drill-injection pile shaft;
under the strip foundation fragment base, an artificial base is formed from a 200 mm thick sand fill and a 100 mm thick crushed-stone bed;

- a reinforcing mesh and a concrete form are installed for concreting of the strip foundation fragment (figure 6);
  - the injection pipe is rigidly fixed to the reinforcement mesh by means of additional metal rods welded to the injection pipe;
  - is carry out a multilayer concreting of the strip foundation fragment with consolidating concrete by vibration. To prevent concrete from entering the injection pipe, a plastic plug is installed in the upper part of it (figure 7);

- is carry out a technological break equal to 28 days, which is necessary for development of strength in concrete;
  - after the concrete strength development is set, a thrust structure and jack are mounted on the strip foundation fragment to load transfer to the tested a strip foundation fragment;
  - is carry out a reference system, on which the displacement measurement sensors are fixed in the amount of 11 pieces;

- is carry out loading of the strip foundation fragment static load in stages of 20 kPa (20 kN load);
  - after stabilizing the deformations of the strip foundation fragment at the 5th stage of loading (pressure under the strip foundation fragment base of 100 kPa), a widening low end is formed at the lower end of the injection pipe by injecting a solution into the rubber membrane-glass in a volume of 50 liters, while the effective load on the strip foundation fragment of 100 kN is preserved;
  - after the formation of the widening low end, a technological break was arranged equal to 1 day, necessary for the hardening of the injection solution;

- after the technological break the drill-injection pile shaft was formed by injecting the solution into the annular space between the injection pipe and drilled formation wall
  - after the formation of the drill-injection pile shaft, a technological break was arranged equal to 7 days, necessary for the hardening of the injection solution;

- after the technological break, the static loading of the strip foundation fragment continued to the ultimate load until its «failure».

The injector with a rubber membrane-glass is installed in the soil foundation in a pre-drilled well (figure 5) until the strip foundation fragment is concreted (figure 6 and 7). The well is drilled to the design mark by using the TRAILER 80 drilling rig in the core-drill method with the drilling screw, diameter of 90 mm.

The process of making a separately located drill-injection pile with widening low end.
For the making a drill-injection pile with widening low end, an injection pipe with a rubber membrane-glass was used, the assembly process of which is shown in figures 1 to 4.

![Figure 5. Drilling a well for the immersion of the injector.](image)

![Figure 6. Strip foundation fragment before concreting.](image)

![Figure 7. Concreting a strip foundation fragment.](image)

To prevent the drill-injection pile from being squeezed out during the formation of the widening low end, a concrete plug was placed in the upper part of the drill-injection pile. The concrete plug serves as a stop for the uprights that prevent it from leaving the soil (figure 8-9). Before testing the drill-injection pile, the concrete plug was destroyed with a pneumatic hammer (figure 10).

The formation of the widening low end was carried out by means of a hydraulic packer located at the lower end of the high-pressure hose (figure 11) connected to the drilling pump NB 4-160/6.3.
The widening low end, with a volume of 50 liters at a depth of -1.8 m, located at the lower end of the drill-injection pile, was formed in 5 stages with a duration of 14 seconds each and technological pauses equal to 5 minutes (figure 12). The composition of the solution for injection was adopted according to the results of the studies presented in the paper [10].

**Figure 8.** Plug in the upper part of the drill-injection pile.

**Figure 9.** Concreting the plug in the upper part of the drill-injection pile.

**Figure 10.** Dismantling of a concrete plug.

**Figure 11.** Marking of the high-pressure hose.

**Figure 12.** Injection of a solution for the formation of a widening low end.

After the formation of the drill-injection pile with widening low end, a technological break was provided, equal to 14 days, associated with the development of strength in concrete.

**5. Performing static tests**

Static load tests of the strip foundation fragment without underpinned with a drill-injection pile with widening low end, 2.0 m long and a broadening volume of 50 liters, were also performed to compare the results obtained at the end of the static load tests of a strip foundation fragment underpinned by a drill-injection pile with widening low end.

The number and value of the increment of load, the criterion of conditional stabilization and the criterion of failure when static load testing of the strip foundation fragment (figure 14 and 15) were accepted according to GOST 20276-2012, and when static load testing drill-injection pile with widening low end (figure 16) – according to GOST 5686-2012.
As a thrust structure for the jack during the static load tests, an innovative development of a mobile small-sized unit was used [11], which is a collapsible, on bolted connections, spatial structure in form of geodesic dome and anchors (figure 13).

**Figure 13.** A small-sized mobile unit for static pile load tests and plate bearing tests.

**Figure 14.** Static load test of the strip foundation fragment.

**Figure 15.** Static load test of the strip foundation fragment underpinned by a drill-injection pile with widening low end.
6. Results of in-situ testing
Based on the data obtained during static load tests in the course of the experimental study, graphs of dependencies were formed: the settlement of the strip foundation fragment on the pressure under its base and the settlement of the drill-injection pile with widening low end on the static load.

7. Conclusions
In conclusion, it should be noted that when static load testing of a strip foundation fragment underpinned by a drill-injection pile with widening low end, the formation of the widening low end was carried out after transferring a load on the bearing plate equal to 100 kN, while the pressure under its base was 100 kPa. After that, additional loading of the bearing plate was carried out, until it reached the ultimate subsidence of 40 mm.

Figure 16. Static load test of a drill-injection pile with widening low end.

Figure 17. Bearing plate test schedule.

Figure 18. Graph of testing a drill-injection pile with widening low end length of 2.0 m with a heel volume of 50 liters.
The analysis of the graphs allowed us to draw the following conclusions:
- on the dependence graph of the settlement of the strip foundation fragment on the pressure under its base (figure 18) two sections are set: 1 - a section with a linear deformation zone (at a load of 0 to 40 kN), 2 - a section with a non-linear deformation zone at a load of 40 to 80 kN.
- the bearing capacity of a 2.0 m long drill-injection pile with widening low end \( V = 50 \) l was 70 kN, ultimate load («failure») of the drill-injection pile with widening low end occurred at the load of 80 kN, while the settlement was 44.7 mm, recoverable deformation were 4.9 mm;
- on the dependence graph of the settlement of the drill-injection pile with widening low end on the static load (figure 17) a linear deformation zone is observed at the pressure under the strip foundation fragment base of 0 to 180 kPa, a non-linear deformation zone is observed at the pressure under the strip foundation fragment base of 180 to 280 kPa.
- ultimate load («failure») of the strip foundation fragment without underpinned by a drill-injection pile with widening low end occurred at the pressure under the strip foundation fragment base of 260 kPa, while the deformations were 120.2 mm.
- ultimate load («failures») of the strip foundation fragment underpinned by a 2.0 m long drill-injection pile with widening low end \( V = 50 \) l occurred at the pressure under the strip foundation fragment base of 300 kPa, while the deformations were 108.1 mm.
- the use of a 2.0 m long drill-injection pile with widening low end \( V = 50 \) l to underpin the strip foundation fragment allows increasing the bearing capacity by an average of 30% and reducing its deformations by an average of 43%.

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