

On the effect of pre-stressing using micro-pile injection

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When damages occur on structures due to their base giving in, strengthening of that base, i.e. of the foundation soil, is performed. One possible method of strengthening is through the use of pipe micro-piles and pressure injection, which is the subject this paper deals with. The effect of pipe micro-pile injection, the process and successful repair are described below. Keywords: micro-piles, pressure, injection.

Introduction

Small diameter piles (micro-piles) have low rigidity and bearing capacity, but carry a very specific and important role, and can be repaired using supplementary injection.

Injecting the injection mixture leads to pre-stressed surrounding soil, and after the mixture hardens, to compression pre-stressing of the hardened mixture next to the micro-pile pipe.

This type of pre-stressing results in favourable features in low-permeation high-deformity soil. A considerably lower air pollution in the cities, and a lower greenhouse gas emissions require considerably smaller investments and efforts in developing the charging infrastructure.

There are also more modern methods of strengthening the soil below structures, such as expansion resin (also used for soil pre-stressing). Injecting this resin into the area below the foundation has numerous advantages: no digging/excavation is necessary, there is a safe laser-based movement control, the operation is quick, efficient, and simple, it does not pollute the environment, there is a direct contact between the soil and the construct, there are no dynamic effects, etc.

About micro-pilots and injecting

About the micro-pilot and injection process

The steel pipe is outfitted with a sharp point at the top and lateral perforations approximately 1.0 m (depending on the length of the micro-pilot) from the top of the pipe, in order to allow seepage of the injection mixture (Figs. 1 and 3).

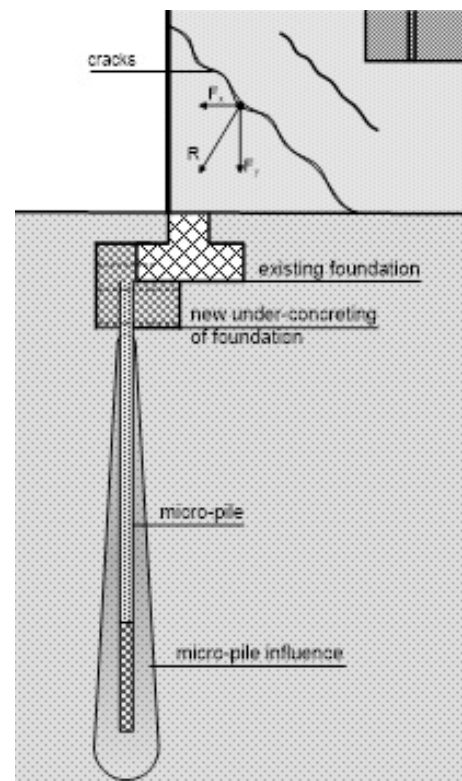


Figure 1. Some of possible micro-pile applications:
- prevention of the soil creeping under load, - decrease of settling, - prevention of differential settling

Spiking the sharpened micro-pile pipe or its placement into a drilled bore-hole 4-5" in diameter, when faced with a low-permeation high-deformity soil is quite simple. When the steel pipe reaches the planned depth, spiking is ceased, and the operation of sealing the ring-shaped area between the pipe and the surrounding soil on a segment approximately 1 m below the surface of the soil now begins. The most important operation before injection is setting the appropriate packer (Fig. 2) in the upper portion of the pipe so that the seepage of the injection mixture to the surface during the injection is prevented. Next, injection is used to facilitate injection pre-stressing of the contact zone between the pile and the surrounding soil.

Under pressure, the injection mixture exits the pipe through the perforations, but due to high density (and thereby high viscosity), the injection mixture, being a pressed-in fluid, cannot propagate through filtration into the surrounding soil (because the soil is not permeable enough). Instead, there is an effect of compaction grouting, i.e. injected surface being created in the soil.

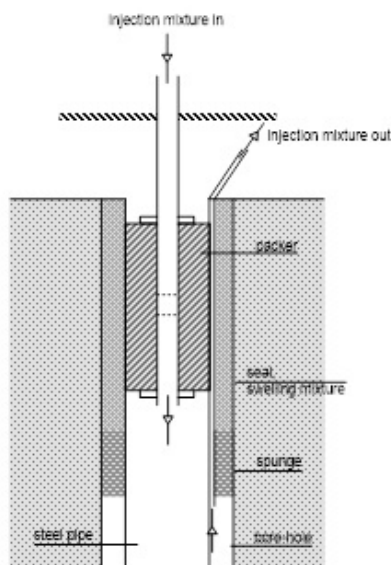


Figure 2. Detail at the outlet of the bore-hole injection

Pipe micro-pile injection characteristics

This type of soil pre-stressing appears due to the inability of filtration seepage of the injection mass into the surrounding soil (due to low soil permeability and high density, i.e. very high viscosity of the injection mixture). Soil pre-stressing in this case also appears due to high level of deformity of the surrounding soil and due to forces seepared by high

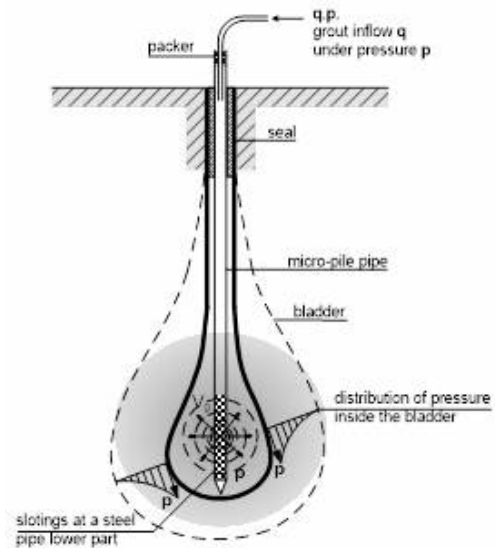


Figure 3. Effect of pressure pre-straining of hardened contents (ideal case diagram)

working pressures (prad) during the injection into the pipe and the underground space surrounding the pipe, especially around the top of the pipe, where perforations were made in order to facilitate injection mixture seepage. An estimate of the successful creation of pre-stressed soil around the pipe micro-pile is determined by measuring return pressures (ppov), and the volume can be ascertained according to the quantity of the injection mixture used. The total volume of the mixture used (V_u) for the pile in question contains two components: V_o = volume of the mixture contained within the steel pipe and V_g = volume of the mixture outside the pipe, with the ratio being:

$$V_u = V_o + V_g \quad (1)$$

Coefficient of realized injection volume K may be formulated as follows:

$$K = \frac{V_s}{V_o} = \frac{V_s - V_o}{V_o} = \frac{V_g}{V_o} - 1 \quad (2)$$

In theory, the coefficient may have values between: $0 \leq K \leq \infty$ (most often 2 to 10).

If the return pressure is very low and the coefficient K is close to zero, that means the soil features low deformability (semi-hard or hard clay). If the return pressure is low and K is high, the soil is very deformable, which may mean:

- The soil contains cracks or other paths (for example, holes along dead roots, groundhog holes, etc.)

- The soil contains intercalations (or thicker layers) of high permeability
- The injection mixture entered the holes (in some underground areas, etc.)
- Due to overly high pressure, the ground fractured (fracturing hydro-fracture grouting), and the injection mixture filled the cracks
- In very soft, non-consolidated and water-saturated dusty/muddy layers there exists a high probability for the injection mixture, heterogeneously mixing with the muddy materials (creating round, bubbly accumulations).

The effect of stress in the soil is partially transformed and weakened, although the coefficient K may carry a high value. The quality of the above process is shown through increased density and total stiffness of the injected zone, decreasing the total soil deformability along the micro-pile pipe. The average strain effect surrounding the pipe micro-pile is estimated using two parameters: $p_{pov} > 1$ bar (better: $p_{pov} > 5$ bar) $K > 1$ (better: $K > 3$)

The effect of soil strain due to injection

When the injection mixture is allowed to solidify, i.e. become properly dense (a minimum of 30 minutes, usually around 60 minutes), packers are taken down from the micro-pile pipe.

In order to prevent the rising seepage of the mixture due to return pressure, it is necessary to hold initial pressures in the soil (especially those in contact with the surrounding soil) to levels as high as possible.

After a few days the injection mixture hardens, and fluid pressure fills the stress area. However, the area of the contact with the surrounding soil will keep the pre-stress effect, manifesting in the surrounding soil increasingly pressuring the hardened contents within the pre-strained area. The said phenomenon has a positive effect on the pile bearing capacity from two aspects:

- The hardened injection mixture is exposed to increased spatial pressure stress (pre-stressing), increasing its resistance to rifts in the pipe
- Soil around the stress contour is in a high-compression state, resulting in decreased porosity and deformability, and increased bearing capacity.

An example of salt silo foundation repair

A large number of silos have been constructed lately, only by installing them on standard foundations and only with a visual examination of the foundation soil, without any pre-construction geotechnical examinations (Fig. 4). After filling the silos up with 100 tons, or 80% of their capacity, settling and leaning of the silos was noticed, both phenomena increasing significantly in a short time period. Counter-measures were introduced right away: surveying of settling and geotechnical investigations. The silo foundations at the depth of 1.3 m were set on hard clay, but from the depth of 2 m (where the water level is), there was soft clay. After geotechnical investigations, a means of repair/improvement (i.e. preventing further settling) was suggested – driving a micro-pile into the foundation soil to below the present foundations, then injecting and thereby improving the soil, as will be shown below.



Figure 4. Salt silo: a) Silo photograph
b) Silo foundations at the depth of 1.3 m, diagram of the foundations and driven-in micro-piles

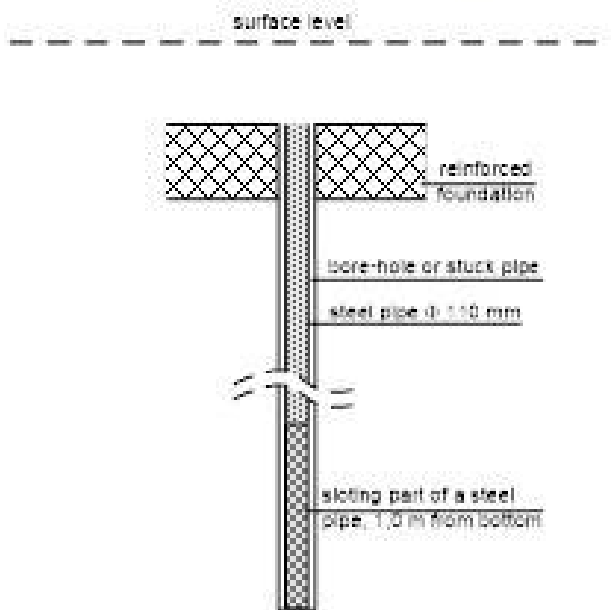


Figure 5. Foundation, bore-hole, steel pipe

The chosen repair method using micro-piles is the simplest, fastest and the most economical means of improvement for the presented situation.

The following was performed on 4 foundation footings (4 micro-piles per foundation): pre-drilling and driving in the pre-perforated steel pipes 6.00 m long, 101 mm in diameter, with a wall thickness of 3.60 mm, installation of rubber packers and injection of a certain quantity of cement suspension under pressure, thereby forming return pressure (Fig. 5).

The entry pressure (pre-injection) was 12 bar. Through the measurement of return pressure, it was ascertained that injection was successful and yielded

the pressure of 3 bar, while the volume of used mixture was approximately 2.5 times larger than the volume of the drill-hole.

The contents and the characteristics of the injection mixture per 100 kg of dry cement: water (42 kg), bubbling additive - "Interplast - A" (0.5 kg or 0.17 l). The average mixture density, based on the formed injection mixture, was 1.9 t/m³.

The operation also called for filling in the area between the pipe and the footing wall using an appropriate adhesive with a bubbling additive in order to ensure a long-lasting bond.

Settling is coupled with surveying equipment monitoring. The diagram of the time-based settling of the silo (i.e. the 4 foundations) was drawn according to the collected data.

The diagram shows that the repair of the soil was successful, i.e. further settling was stopped (Fig. 6).

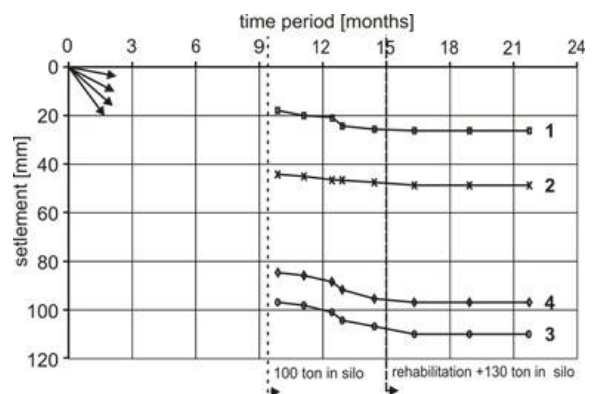


Figure 6. Time-based diagram of silo settling

An estimated calculation (not taking in consideration the pre-stress) of the pile at the depth of 6 m and estimated diameter of 0.2 m, using the alpha method with non-drained stiffness, gave us the total bearing capacity of one pile of $Q_t > 230$ kN, which is a significant increase per foundation.

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O efektima prednaprezanja metodom injektiranja mikrošipovima

SAŽETAK

U slučaju oštećenja konstrukcije zbog slabljenja podloge, izvodi se ojačavanje te podloge, tj. temeljnog tla. Jedna od mogućih metoda ojačavanja tla i tema ovog rada je upotreba cjevastih mikrošipova i ubrizgavanjem pod pritiskom. Opisani su efekti ubrizgavanja mikrošipovima, postupak i uspješno ojačavanje tla.

Ključne riječi: mikrošipovi, pritisak, ubrizgavanje.