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IMPLEMENTATION OF LOW PRESSURE INJECTION FOR SOIL REINFORCEMENT AND SEALING – SELECTED APPLICATION

ZASTOSOWANIE INIEKCJI NISKOCIŚNIENIOWEJ DO WZMOCNIENIA ORAZ USZCZELNIENIA PODŁOŻA GRUNTOWEGO – WYBRANA REALIZACJA

Abstract

The paper summarizes the practical aspects of the application of low pressure injection (grouting) for soil hydroinsulation and stabilization. Technical aspects of low pressure injection application and requirements dedicated to soil binders have been described. The paper also contains characteristics of selected investment where low pressure injection technology has been applied.

Keywords: execution of special geotechnical works, low pressure injection, hydroinsulation barrier, clay-cement bingers, grouting

Streszczenie

W artykule przedstawiono praktyczne doświadczenia z zakresu stosowania iniekcji niskociśnieniowej w celu uszczelnienia i wzmocnienia podłoża gruntowego. Scharakteryzowano zagadnienia techniczne związane z wykonaniem iniekcji oraz wymagania dotyczące stosowanych spoiw gruntowych. Scharakteryzowano także wybraną inwestycję zrealizowaną w technologii iniekcyjnej.

Słowa kluczowe: wykonawstwo specjalnych robót geotechnicznych, iniekcja niskociśnieniowa, przesłony hydroizolacyjne, spoiwa iłowo-cementowe, grouting

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1. Introduction

An intensive increase in the amount of new building investments has been observed for several years. Many of them are located in the centers of towns. The high cost of parcels and spatial restrictions determine investors to find flexible and cost efficient design solutions for the projects. Many of them require special and deep foundation or special geotechnical works for sealing or soil reinforcement (e.g. deep underground garage or crossing of underground communication and transport lines). One of the required elements of these projects is a hydroinsulation barrier. Depending on local conditions, the barriers are made in different technologies and to various depths. The basic expectations for waterproof barriers can be determined as follows:
- high insulating properties,
- long-term functionality,
- resistance to hydrostatic pressure,
- resistance to deformation,
- high resistance to corrosion caused,
- no impact on the environment.

One of the allowed ways for reinforcement and sealing is the injection of the binder (agent) into soil or rocks. Depending on injection pressure, we can differentiate between high pressure injection (jet grouting) and low pressure injection (grouting).

2. Low pressure injection

Low pressure injection (grouting) is a standardized method described by ISO Standards ISO-EN 12715 Execution of special geotechnical work. Grouting. Grouting isn't a method for the replacement of natural soil like jet grouting. In the grouting method, liquid agent is pumped by a special drilling hole into soil or rocks using pistons or plungers pump. Injected agent fills free area and decreasing water permeability. Therefore the goal of grouting can be described as modification of natural soil by:
1) filling of soil emptiness (suffosion effect, fractures etc.),
2) filling of porous canals in soil,
3) compaction and moving soil grains by the pressure of agent (binder).

Below (Fig. 1) is shown the theoretical model of soil sealing using water-cement suspensions pumping. The model is based on a column experiment where we can see three stages:
1) water pumping, where porosity and water permeability are constant,
2) agent pumping, where we can see a colmatation effect and
3) water pumping, where we can see partial decolmatation of pores.

In the 2nd stage, when we pump the agent, particle of cement fixes the pores and decreases permeability. During the injection and saturation of soil, we can observe an increase in injection pressure and a decrease flux in injected agent. In practice, the scale of this effect, as well as the distance of agent migration, depends on the soil condition and liquid agent parameters (e.g. viscosity, grain size of suspension). After the injection, the solidification process of the agent starts. If we make an injection into water flow area, a part of the agent can be distributed outside from injected soil, which makes increase permeable (reduced before). It is not a desired effect and we can eliminate it using sped up solidification components.

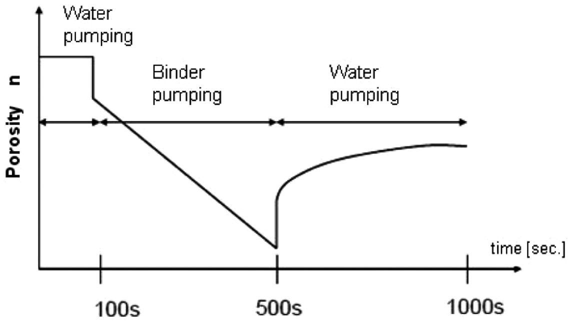

Fig. 1. Theoretical model of injection in porous media (water-cement suspension) [2]

Model Fig. 1 is typical for a liquid agent, similar to Newton's fluid model [2]. Many of the binders (agents) are thixotropic fluids (similar to Bingham's fluid model). The rheology and internal structure of thixotropic fluid is important for the decreasing or elimination of soluble binders, during and after injection. It is an important aspect of the injection design. Samples of quasi Bingham's binders are cement-bentonite solutions or binders based on modified clays.

Usually, the injection is made from bottom to top of injection unit of hole, by designed intervals (e.g 1.0 or 0.5 m). In practice, pressure between 2–25 bar and flux 10–45 liters/min is used. The injection parameters depend on the soil or rock condition. For special jobs, injecting by angles and directional holes is possible.

Depending on the configuration of the injection holes kind of agent and agent propagation, grouting can find application in:
– building horizontal and vertical hydroinsulation barriers,
– protection and water inflow reduction for the deep founding excavations,
– modification of the mechanical parameters of soil and rocks,
– underground and open pit mine hydroinsulation,
– *in-situ* immobilization of the contaminants (soil and groundwater),
– contaminated soil and groundwater treatment.

3. Sealing and bonding agents

Depending on the requirements of the design, lots of different mixtures of binders can be described. The most popular, for engineering practice, are: water-cement suspensions; cement-bentonite solutions; silicates solutions (based on liquid glass); cement-clay solutions.

In PRGW (Geological and Drilling Works Company, Poland) practice, binders based on modified clays are the most useful. The main component of cement-clay binders is mono or poly-minerals clays, moved to water solution. The main required parameters of the clays are:
– 5 μm grain size participation > 60%,
– ability to form a thixotropic, colloid solution (Bingham's fluid).

Below is shown the mineral characteristic of clay from Brown Coal Mine in Bełchatów (Poland).

Table 1

Mineralogical characteristics of clay form Belchatow brown coal resources (DTA – differential thermal analysis) [3]

Components	Content [weight %]
Beidellite (Montmorillonite group)	51.3–87.8
Kaolinite	8.7–14.2
Calcite	15.2–2.0
Siderite	0.0–5.0
Organic material	0.0–0.9
Thermal inactive minerals	1.4–18.5

Additional components of the solution based on the modified clay are:
- cement (as source of CSH phase),
- silicates (sodium liquid glass).

Below (Fig. 2) is shown a flowchart of the preparation of a solution based on modified clay [5]. In the first step, a water solution of clay, called base solution are prepared. In the second step, a base solution is modified by cement and silicate, and from this moment, the solidification reaction starts. The prepared binder is a thixotrophic the solution and must be non-stop agitated before application to soil. It's necessary for the hang up solidification process and for the keeping the binders properties as liquid (solution).

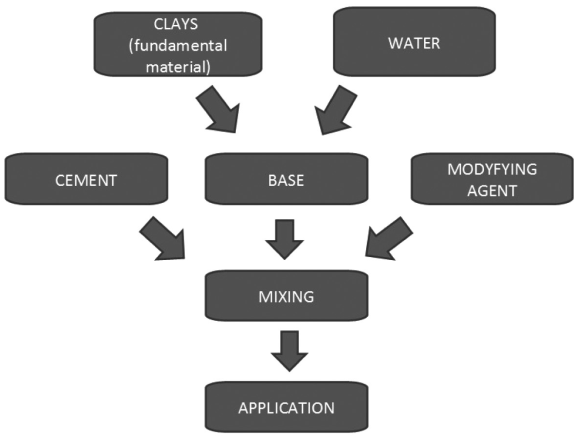

Fig. 2. Flow chart of preparation of the binder based on modified clays [5, 6]

Depending on the content of reagents, solidification can be managed according to the needs and project goals. Below (Fig. 3) are shown the results of the optimization of the solutions' rheological parameters. Depending of the contents of reagents, we can receive different parameters of binders, such as viscosity, thixotropy, etc. By managing the components, we can manage the binders parameters and fit them into the design requirements [6].

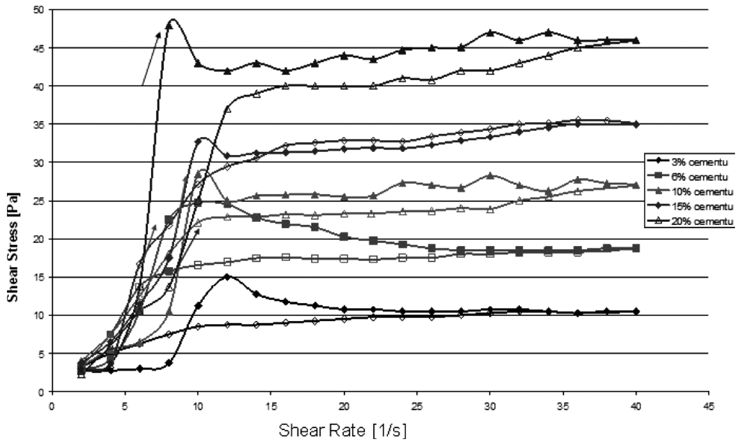

Fig. 3. Sample of rheological parameters optimization of liquid agent based on viscosity analysis [5]

Solidification is a highly expected attribute of soil binders which gives modified soil expected qualities. In Fig. 4 is shown SEM (Scanning Electron Microscope) view of a solid binder based on the modified beidellite clay form Bełchatów Field (Poland). In the picture we can see silicates and the aluminosilicates frame (phase CSH) filled with clay mineral packages. Silicates frame decide about mechanical parameters of solid binders and clay minerals about their permeability [6].

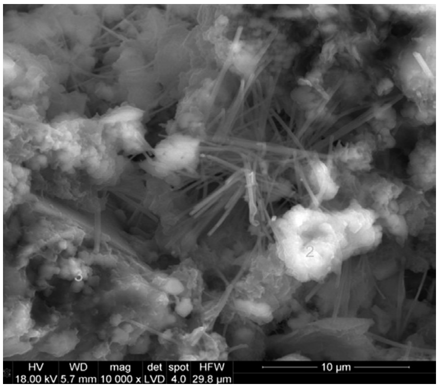

Fig. 4. SEM view of solid structure of agent based on modified clay [4, 5]

Selected parameters of the solid binder based on modified clay are [4, 5]:
- resistance to water soluble,
- no contraction during the solidification process,
- filtration coefficient of the binder – k~10^{-9} m/sec,
- Californian Bearing Ratio CBRd > 20%,
- shearing strength (resistance) ~190 kPa (after 28 days),
- bending strength (resistance) > 400 kPa (after 28 days),
- compression strength (resistance) > 500 kPa (after 28 days).
- full freeze resistance after 42 days (according to Transport and Road Research Lab. TRRL – UK).

4. Selected application – Horizontal hydroinsulation barrier for PROSTA Tower founding in Warsaw

A horizontal hydroinsulation barrier using low pressure injection was made for the protection and water inflow reduction of the deep founding excavation of PROSTA Tower in Warsaw. The Project was realized in the close center of the city, between already existing tall buildings. The reason for using the injection method was because it was a cost effective solution. The main goal of injection was:

- water inflow reduction,
- protection of water displacement of excavations bottom (–17,6 m below ground level and 13m hydrostatic buoyancy),
- no impact of groundwater drainage on neighboring buildings and area.

The whole area was enclosed by a 29,0 m deep diaphragm wall, suspended on permeable soil (medium and fine sands, ID ~0,6–0,8; k~ 8 × 10^{-5}–4 × 10^{-4} m/sec.). The area of the building was over 800 sq.m.

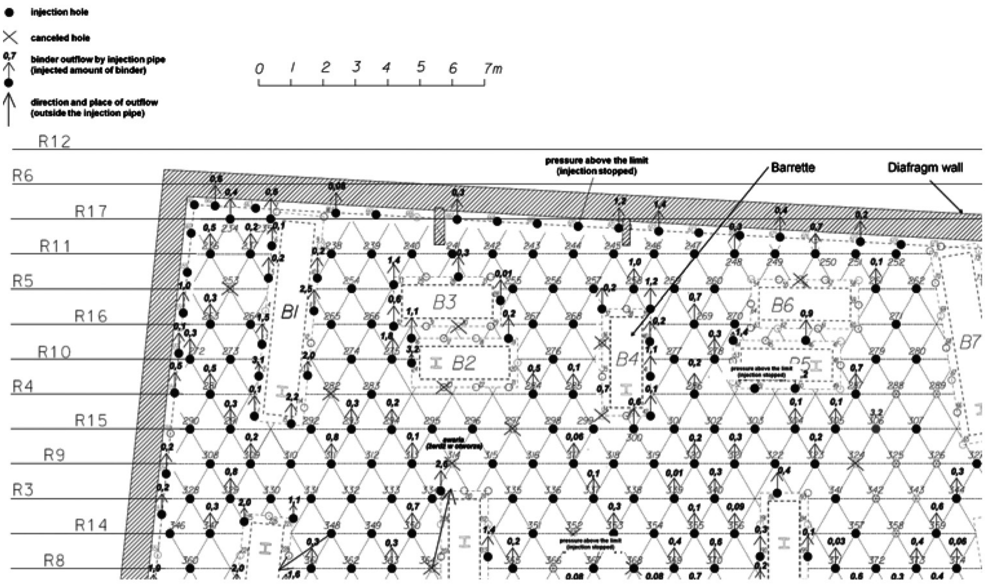

Fig. 5. Injection holes network – horizontal flow barrier

Based on geological investigation and filtration modeling, as well as on stability analysis, a horizontal barrier inside diaphragm wall was designed. The thickness of the barrier was 5.5 m. The barrier was constructed 24.0–29.5 m below ground level. For low pressure injection method and binder based on modified clay were selected for job execution.

Two groups of injection holes were designed (Fig. 5):

- based holes in triangle network (1.25 m spacing),
- special holes, parallel to diaphragm wall and barrettes lateral surfaces.

The goal of based holes was the creation of regular and continuous layer of stabilized and water-proofed soil. Special holes were designed for the additional sealing of contact between soil and lateral surfaces of the diaphragm walls sections and barrettes.

The Injection was made at 0.5 m intervals, from bottom to top of injected thickness.

The order of injection was based on the sequential spatial densification of holes and it was fixed during the job, based on analysis of recorded injection data. Fig. 6 shows sample data recorded during the job. Depending on injection progress and soil condition, different relationships between the injection flux and pressure can be observed. The natural relationships occurs when pressure increase flux is directly proportional. But in reality, we can observe many different relationships (Fig. 6). Such differences can be caused by:
– rheological parameters of the binder,
– consolidation and moving of particles of soil,
– open and filling canals or free spaces formed during the diaphragm wall execution.

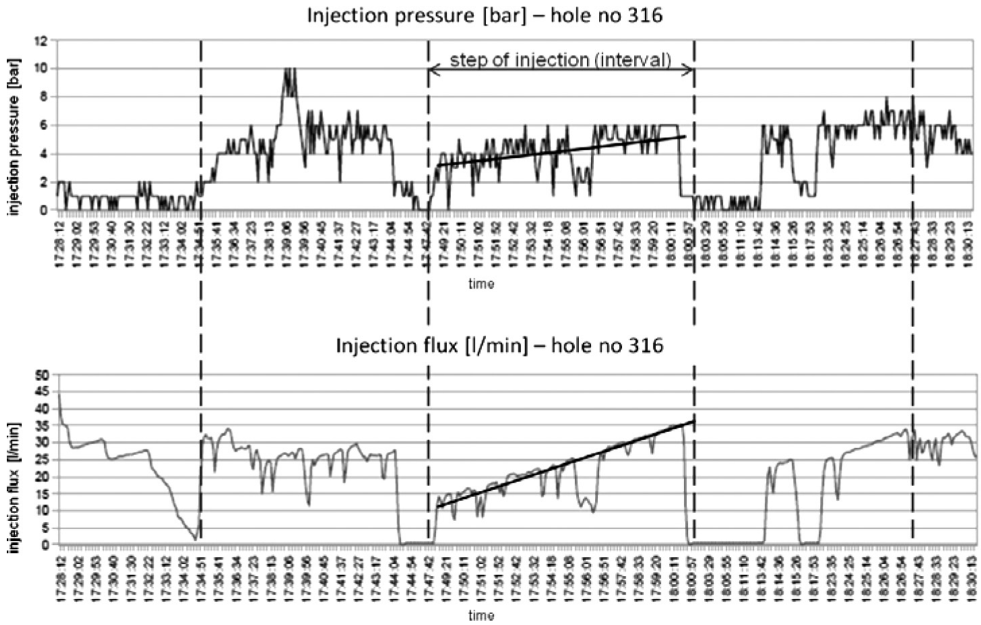

Fig. 6. Sample of main injection parameters fluctuation

All technical data have been collected a during the job progress and can be used for analysis and job correction. Fig. 7 and 8 show sample of the 3D model of soil saturation by the binder. As input data recorded information about the amount of the binder injected in each 0.5 m interval were used. Points data can be estimated to spatial continuous 3D model using geostatistical methods.

In case of the Prosta Tower, the input data was estimated using the krigging method (Gaussian semi-variation function) and normalized for accordance which total binder consumption. Such analysis was made during the whole injection works and it is the basis for managing the works.

The Prosta Tower Project was a very difficult but successful job. During this Project, 816 injection holes were drilled (21 021 m of drilling) and ~430 m^3 of binder was injected. The maximum amount of binders injected into holes was ~7.2 m^3 (designed 0.75 m^3/hole). Probably, it was an effect of the anthropogenic changes of soil structure during a barrettes and diaphragm wall execution. The effects of the executed injection were as follows:

- groundwater table drawdown S~13 m (inside excavation),
- average filtration coefficient of barrier k~6 × 10^{-8} m/sec.,
- total water inflow to excavation Q~2.9 m^3/h,
- no groundwater table drawdown outside diaphragm wall,
- guarantee of stability of excavation bottom.

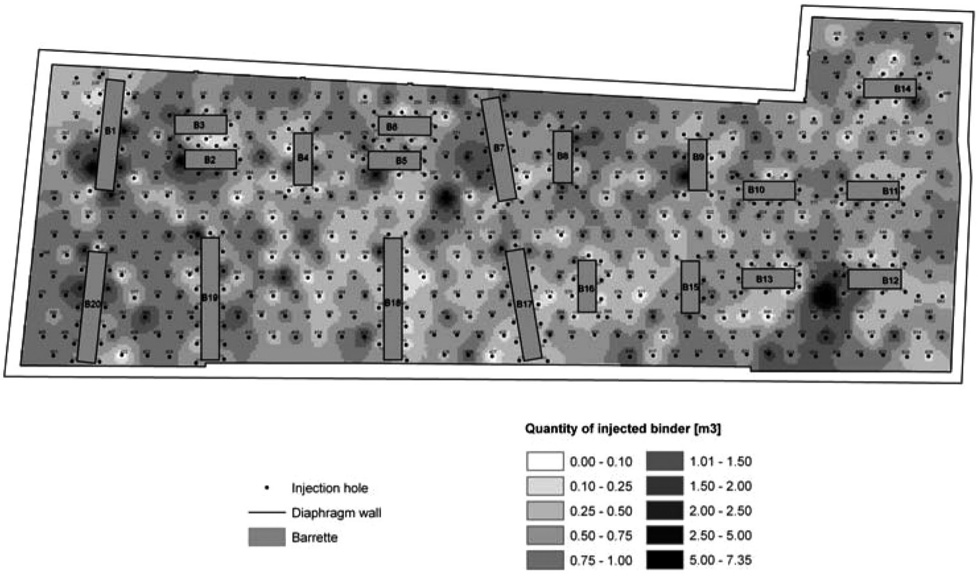

Fig. 7. Spatial distribution of soil saturation by binder as amount of binder injected to whole thickness of barrier (geostatistical model of barrier)

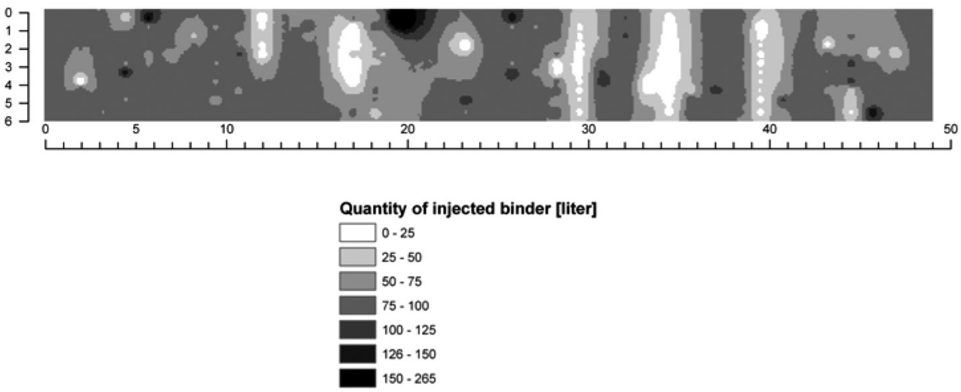

Fig. 8. Sample cross-section of the 3D model of spatial distribution of soil saturation by binder (geostatistical model of barrier)

5. Conclusions

1. Although grouting isn't the most popular method, it is a very flexible and effective method for the reinforcement and sealing of soil and rocks. Grouting can find an application in many solving engineering problems, where other methods cannot be used.
2. The most important aspect of injection is the good selection of liquid and solid binder parameters, dedicated to job requirement and soil or rocks conditions.
3. Limitations of grouting application in Poland are connected with problems of accessibility to good methods and tools for soft and easy designing of injection. There are no effective and certainly mathematical models, well described injection phenomena. Development of such tools will make this method more popular and understand.
4. In engineering practice, the uncertainty of the grouting method can be managed by:
   – good and precise investigation of water-soil conditions,
   – permanent analysis of the technical parameters of injection, during job progress,
   – flexible approach to grouting design, allowed current correction of the designed assumptions.

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