Soil improvement by powder injection

Stabilisation du sol par l'injection de matériaux pulvérulents

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ABSTRACT: Soft and water-sensitive soils are often difficult to improve with common stabilisation methods. The ground situation even becomes worse when water is inserted by fluid injections. An alternative is the injection of dry granular materials such as limestone powder or fly ashes. For this purpose new techniques have been developed to produce column-shaped bodies in the ground consisting of compacted powder. Apart from compaction the surrounding soil is stabilised by the extraction of water absorbed by the columns. The materials are either injected pneumatically or using a screw conveyor. The construction of the injection devices and the technologies are demonstrated. The injection of the powders is largely controllable. By measuring the point pressure during the injection process, and recording the amount of injected material conclusions about the geometry and strength of the produced columns can be drawn. Results of laboratory tests on big samples and of a field test are presented. Furthermore possible applications are shown.

1 INTRODUCTION

The improvement of soft, fine-grained and water sensitive soils requires gentle methods especially when sensitive structures such as historical buildings are in close proximity. Within the scope of a research program dealing with the conservation of historical buildings, methods of soil stabilisation were developed to meet the following (at first glance contradictory) requirements [1]:

- stability is to be improved and further deformations are to be confined;
- the substance is to be preserved as much as possible, even if it is buried underground;
- costs must be justifiable.

Current stabilisation methods imply primarily injection substances and/or construction parts such as piles or anchors, which are brought into the subsoil. Such structures are often unavoidable, but they remain in the subsoil as foreign objects. The spreading of fluid injections with chemicals and suspensions is difficult to control. Moreover, additional water weakens the soil [4]. For that reason we have been trying in the last several years to develop more "gentle" technologies, which meet or surpass the above requirements.

The insertion of dry mineral granulates into the subsoil generally offers several advantages:

- strength and stiffness can be increased relatively uniform;
- the substance buried in the ground is relatively unaffected. At most it will be compressed or slightly displaced;
- the method is reversible, i.e. the stabilising devices can be exchanged or removed without losing or damaging substantial parts of a building;
- the use of chemically neutral granulates avoids unpredictable changes in the ground;
- due to the use of relatively inexpensive materials and small machinery, costs are kept to a minimum.

The following text presents two variations of this new technology: powder injection using a helical auger and pneumatic injection. Particular emphasis is given to the construction, the mechanical operating procedures and the advantages of using this method near sensitive buildings. The details of dimensioning and monitoring can only be touched upon briefly. This aspect is naturally being thoroughly researched and will be the subject of later publications.

2 POWDER INJECTION

Old buildings with flat foundations located on soft water saturated ground necessitate stabilisation from below. This is the case when the settlements increase too much, when the foundation slowly loses its stability and/or the soil condition has been disturbed by nearby construction or traffic. Current methods of stabilisation are primarily based on those of modern civil engineering below ground level construction methods; e.g. the insertion of small piles or injections of cement suspensions with low or high injection pressures. The pros and cons of these methods are known. If it were possible to simply compact the soil under and next to the buildings without damaging them, then the building material and the subsoil could be maintained with almost no changes. Compaction with surcharge, lowering of water, vacuum or vibration is not an option because considerable, unavoidable and irregular settlements would occur that the building could not survive. The thesis of the methods described below is that to compact the soil through the injection of additional soil-similar materials while avoiding unacceptable settlements or settlement differences.

The soil-mechanical principle upon which the method is based is very simple. Through injection and subsequent compression of dry granulates in one area, the surrounding soil is displaced, and obtains a soil similar supplement.

Through capillary action and the excess pore water pressure caused by the injection, the surplus pore water seeps quickly into the granulate body which does not soften due to sufficient density. By withdrawing the injection device and systematic further injections, a column-shaped zone can be produced and the zone surrounding can be hardened. By injecting at several points simultaneously and successively a building can be stabilised from below and even be lifted at chosen points (Fig. 1, (a)). Also a specific sideways displacement behind walls or tunnels can be treated using the same principle, (b). The method can also fulfil the requirements of common site stabilisation by using cheap materials such as fly ash instead of stones (c).

When using a small drill bit the initial soil disturbance is minimal and vibrations can be completely avoided. As soon as the powder comes into contact with the displaced soil the latter is stabilised. Advancing with small methodical steps allows for easy monitoring and operation. In addition, blow-outs can be more easily avoided than with liquid injections, and they are not harmful.

We tested and checked different variations of this method in the laboratory and in the field. Several setbacks occurred: powder clogged the supply pipes, leading to insufficient yield of powder.

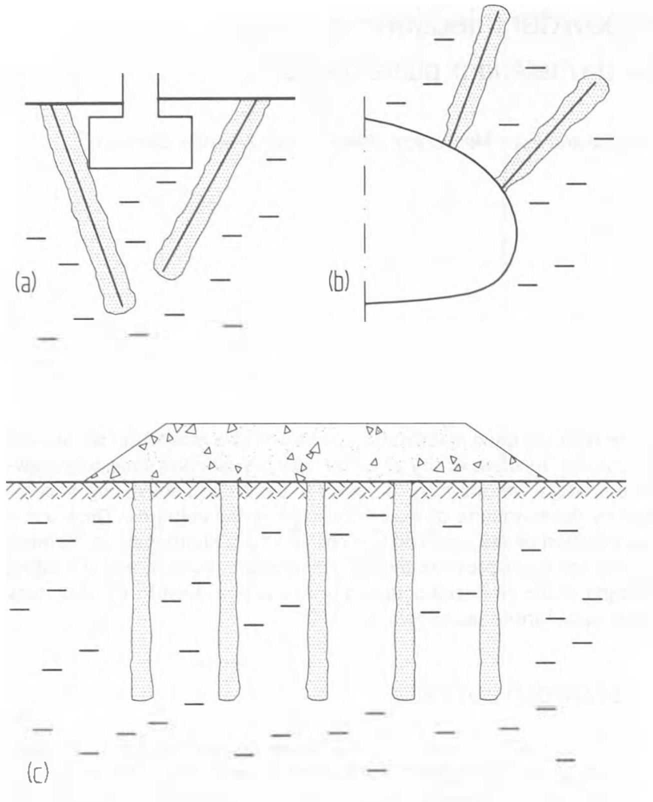

Figure 1: Possible applications of the powder injection

Only a few kinds of soil seemed to be appropriate at first, e.g. peat. Two methods proved to be applicable. Thus we are presenting only them here.

The first uses a helical auger (Fig. 2). The light machine is inserted to the required depth removing soil material with the helical auger or simply displacing it. By reversing the direction of the helical auger powder is filled into the hole and compressed at the end of the pipe. Only a little water can enter the pipe since powder is constantly being filled in. One only uses the amount of powder that the situation calls for. A successive pulling of the pipe and further infilling yields a stabilising column-like zone. Only light tools are necessary, and the required labour is not exceedingly high. The procedure can be controlled by measuring the point pressure during the injection process [5].

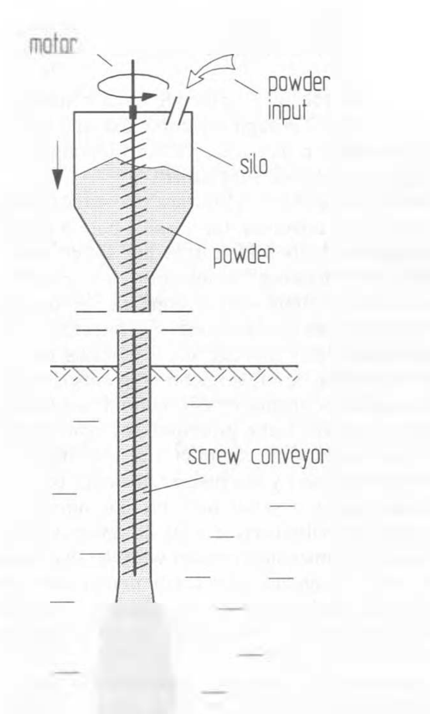

Figure 2: Producing powder columns using a helical auger

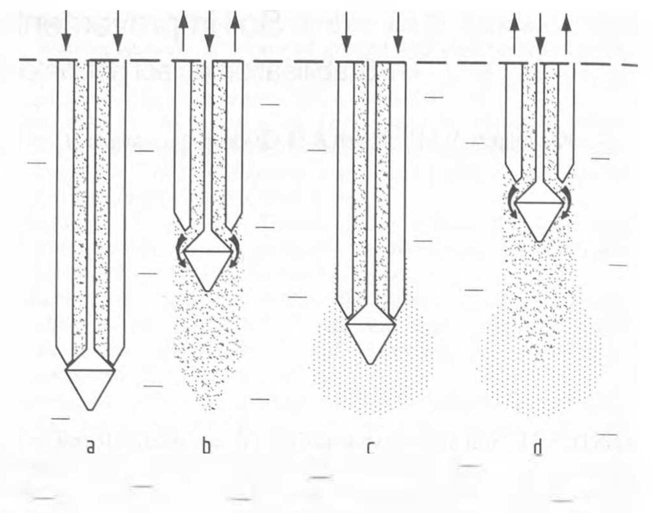

Figure 3: Producing powder columns by pneumatic filling

The main device of the second method is a lance in which a double cone shaped valve is axially movable (Fig. 3). The lance is being inserted to the desired depth (a). A casing may be necessary as previously described for the helical auger for protection of a foundation or an archaeological relevant layer. When carefully pulling the tube, a circular opening appears behind the cone and the powder flows into the created void (b). When the tube is pushed back the opening is closed and the released powder is then compressed (c). This procedure is repeated at a different depth after pulling the tube with the valve shut, yielding a soil stabilising column (d). When operated correctly the powder does not clog and the surplus air can escape along the casing [3]

A pilot powder lance has been built by the company Keller (Renchen, Germany) according to our suggestions and has been tested in large scale experiments (Fig. 4). The lance is inserted into a soil sample of 60cm in diameter and 1 meter in height and

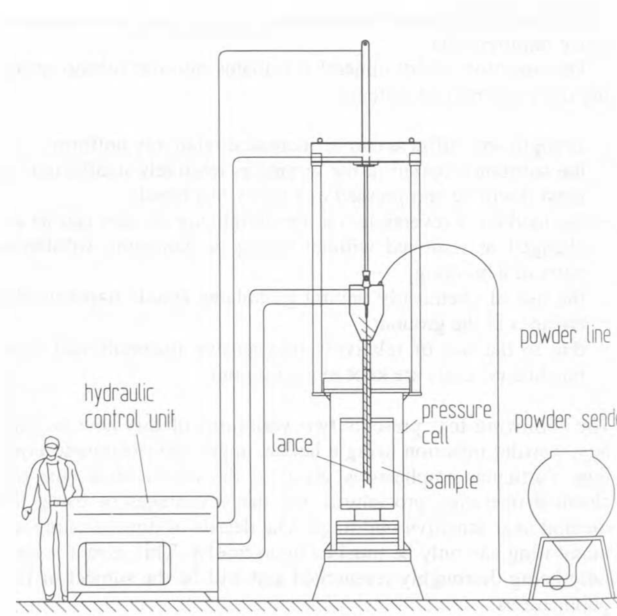

Figure 4: Large scale powder injection tests on big samples

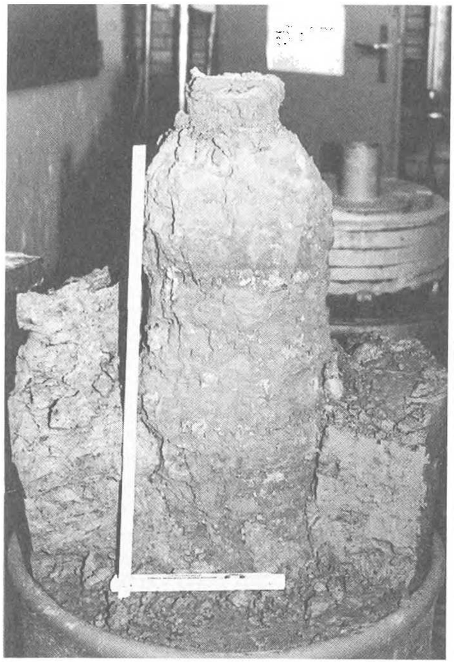

Figure 5: Result of a powder injection test on big samples (clayey silt) using the screw conveyor

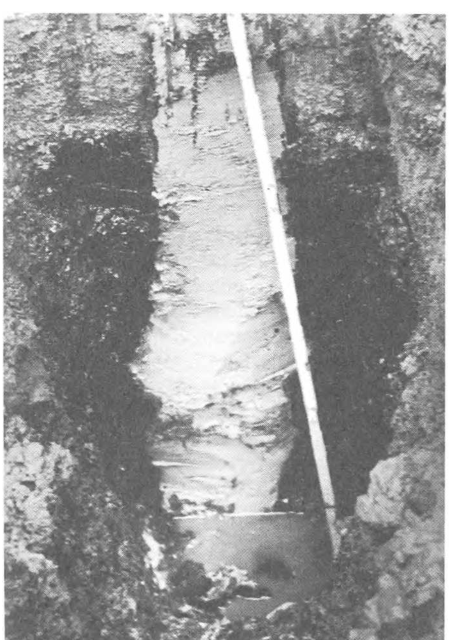

Figure 6: Result of a powder injection test in situ (peat, organic clay) using the powder lance

is subjected to external pressure. The powder is injected from the top with air pressure through a pipe. An oil-hydraulic aggregate drives the tube as well as the cone valve in axial direction. Pressure and injected amounts of powder are electronically controlled.

Figure 5 provides an impression of the experiments. When tested in a sample of saturated clayey silt a pear-shaped body is formed, as can be seen when cutting the sample after the experiment.

The method has also been successfully applied in the field (Fig. 6). When operated with the appropriate valve adjustments clogging can be avoided so that a satisfactory production process can be obtained.

The soil-mechanical effect is identical to the one explained before, which is also obtained using a new theoretical soil-mechanical model [2]. The appropriate dimensioning is based on the balance between solid material, water and air, which allows an estimate of possible mean strength and stiffness. Settling rates and pore water pressures have to be monitored at characteristic points. The advantages are obvious.

- Sensitive buildings are gently stabilised;
- when using a dry and chemically neutral
- granulate, similar to soil, neither the soil nor the groundwater will be affected;
- stability of the building can be estimated and monitored;
- the method is very versatile and economical because of inexpensive material and the light tools necessary.

We note that the powder lance can also be applied inside a building and from the sides. Thus a specific lifting and straightening of partially dilapidated stonework is feasible to a satisfactory degree. It has to be considered that powder injections in comparison with other modern geotechnical technologies can better protect neighbouring edifices.

3 CLOSING REMARKS

The research and development of dry granulate for soil improvement could only be briefly presented here and has not been concluded yet. It is evidently possible to combine it with known methods; i.e. reinforcing rods can be inserted after injecting a powder column like a pile providing an additional support to the soil. At this point we cannot elaborate on the mechanical engineering and construction of this method, which are essential for safety and economic viability. The soil-mechanical assessment is embedded into a general concept hence allowing a comparison between the new and other methods in terms of serviceability and bearing capacity. The basic monitoring methods according to the draft design EC7 can be applied consequently taking into consideration the concerns of sensitive buildings and ground protection. Other applications for the powder injection are the stabilisation of sludge deposits or the improvement of huge dumping areas consisting of loose packed wastes left behind by open pit mining. When traffic routes or other constructions have to be built on such ground, the method allows to adapt to the local requirements. The use of cheap material for the improvement offers the possibility for an economic stabilisation of even such extended areas.

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