Flat Dilatometer Tests for verification of Uretek's Resin-Injektions

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ABSTRACT: In 1996, Carlo Canteri, founder of Uretek Italy Srl, patented Uretek Deep Injections®, the technology for ground improvement by injecting polyurethane resins at various depths. This technology, which is currently the company`s "core business", runs alongside the method Uretek Floor Lift® to lift and level tilting shallow foundations. In practice, a verification of the improved bearing capacity of soil is often required by the clients. Usually dynamic probing tests are carried out before and after the injection work. However, the dynamic probing is only an indirect proof by comparing the blow count (blows per 10 cm penetration). In this paper we present an experimental study into the effect of the ground improvement by flat dilatometer tests.

1 THE URETEK DEEP INJECTIONS® METHOD

1.1 *Introduction*

The exploitation of residual areas of the urban system, the fulfilment of buildings in the proximity of existing buildings, the structural and functional transformation of existing constructions, the groundwater level variations in the subsoil and the construction of buildings in contaminated areas are only some of the possible reasons that need consolidation interventions on shallow foundations with systematic injections of polyurethane resin at high pressure expansion.

1.2 *Technology description*

Uretek Deep Injections® is already a well-known technology, consisting in local injections into the soil of a high-pressure expansion resin, named Uretek Geoplus®, whose properties are widely described in Favaretti et al. 2004, in order to produce a remarkable improvement in the geotechnical properties of the foundation soil.

The operation steps do not require invasive excavations or connection systems to existing and new foundation structures, so it is particularly suitable for historic buildings.

Small quantities of expanding materials are injected with precision underneath the foundation level into the soil volume where the stress state reaches its peak. After, injection resin immediately begins to expand and the high expansion pressure of the injection grout guarantees a proper compaction of the soil. The expansion process first leads to the compaction of the surrounding soil and then, in case of light over structures, also to a lift.

This expansion process can be theoretically studied as a spherical cavity (or cylindrical, if several injections are performed very close to one, along the same vertical line) expanding in quasi-static conditions. The soil is modelled as a linear elastic-perfectly plastic material with a non-associated Mohr-Coulomb yield criterion and is considered initially subjected to an isotropic state of stress.

During the first part of the expansion process, when the internal pressure of the cavity increases, the soil exhibits elastic behavior. After reaching a specific value of the internal pressure plastic deformation starts, similarly to the elastic phase, until it reaches the pressure limit (σ_{lim}). It is assumed that as soon as pressure limit is reached, the resin solidifies (Dei Svaldi et al. 2005).

The analytical model of the expansion process together with the resin expansion law obtained in the laboratory were used to develop a software, Uretek S.I.M.S. 1.0, capable of predicting the ground improvement index of a soil injected with Geoplus® resin. Its characteristics are well described in Gabassi et al. 2010.

1.3 *The restoring process phases*

The entire design process must include several phases in order to best apply the intervention technique. It is necessary to know the local conditions through preliminary testing: both the soil profile and its mechanical properties by means of a geotechnical investigation and the geometry of the foundation system must be determined. Then the injection process must be modelled with the analytical model described above and/or a numerical analysis in order to understand how to best perform it in the field.

During the injections the entire procedure must be monitored by electric receivers lit by a laser emitter and anchored to the building whose foundation is to be worked upon in order to measure vertical displacements.

During and after the field intervention, a monitoring system called Easy Crack Monitor® is installed to guarantee an automated control of the relative movement of pairs of check points, which can be the two lips of a crack, and verify that they no longer move significantly.

However, soil properties are to be investigated after the field intervention in order to verify the soil improvement in terms of strength: tests are performed at the end of the injection process to compare results with those performed previously.

2 EVALUATION OF MONITORING METHOD FOR INJEKTION WORK

A screening of different field methods for monitoring the influence of the injections was done by the University of Natural Resources and Life Sciences in Vienna.

The methods were rated to three different kinds of boundary conditions. The first boundary condition covers all geotechnical aspects.

As the Uretek-Method is primary used to reconstruct damages on buildings due to soil settlement, the elastic soil parameters like the modulus of elasticity are interested. The desired method should create a link between the change in soil stress due to the injections and the elastic parameters of the soil.

The second group of boundary conditions deals with specific methodical aspects. Thus means for example the use in constricted working spaces, the use in different soil types, not many adaptions for this application are necessary, cheap and easy use on the construction site.

A third group of boundary conditions covers all device specific aspects like inserting the probe in the ground, the suitability for construction sites, easy on site handling, first evaluation of results on site possible.

As a result of this process a rating matrix including all possible field methods was created. The two best ranked methods were the Flat Dilatometer Test (DMT) and the SASW-method (Seismic Analysis of Surface Waves).

Although the DMT is an indirect site investigation method, conclusions concerning the mechanical soil properties can be made with the help of the so called index parameters I_D, k_D, E_D. These parameters are directly calculated from the measured Values A and B. For a first evaluation of the test results the dilatometer modulus was chosen as the main parameter for a verification of the injection success. This parameter can easily be calculated from the Values A and B and contains no correlation to soil type and its stress history. As the injections causes a change in the horizontal stresses, these changes can be measured with the flat dilatometer. Marchetti (1981) stated that the dilatometer modulus cannot be seen as an elastic soil parameter like the modulus of elasticity. But in a first approach it seems to be sufficient.

The SASW-method was chosen because of its easy handling on the job site. The interpretation of the results is done by special processing software which calculates the shear modulus versus depth below ground surface. The seismic excitation is done by a hammer blows, the induced seismic waves are measured with six geophones. In the basic approach an influence of the injections on the shear velocity of the soil is supposed.

In the next step of the evaluation process both methods were tested on real job sites. On the first two job sites the SASW-method showed no reasonable and evaluable results. No significant correlation to the injection work could be found, so this method was dropped.

In the following, the three test sites and the results of the flat dilatometer tests are presented.

3 RESULTS OF FIRST FIELD TESTS

On three test sites flat dilatometer tests were carried out before and after the injection work. Before the job sites were started a normal ground investigation was done to determine soil type and ground properties. Indirect surveys were done by dynamic penetration tests, in test pits and percussion borings the soil under the footing was disclosed. For driving the flat dilatometer blade in the ground

Fig. 1. Special rod with adapter for blade

special rods and an adapter for the blade were made, see Fig.1. With this equipment the test can be made with a normal dynamic penetration hammer. As the rods are hollow the air wire safely runs inside the rods.

3.1 *First test site*

The first test site is situated in the eastern part of lower Austria. Cracks appeared in an old building after the ground water level was lowered artificially. The soil under the strip foundations consist of a mixture of silt and clay. The consistency down to a depth of 3.0 m can be described as stiff, below a change to weak could be observed. The dynamic penetration tests (DPH) show less blows, especially between 2.0 and 4.0 m depth. The first injection level was situated directly under the shallow strip foundation in a depth of one meter. The first DMT was carried out before the injection works started. The blade was driven in the ground with the help of a driving rod, measurements were made every 0.2 m. A second test was made after the first injection level was finished; the results of both tests are shown in Fig.1. The horizontal distance between the injection points and the blade sized 0.3 m.

The calculated dilatometer modulus of the second test after the first injections shows significant higher values around the injection level at 1.2 m depth. As the injected resin causes an expansion process the soil stresses in all three main directions raises till they reach the pressure limit. The influenced area can be seen in Fig. 2. It reaches from the injection point down to about one meter under this point. Below this depth the dilatometer modules show normal values compared to the test before the injection. The increase of the measured modulus is about three times of the normal value; this can be explained by the very small distance between injection level and test level.

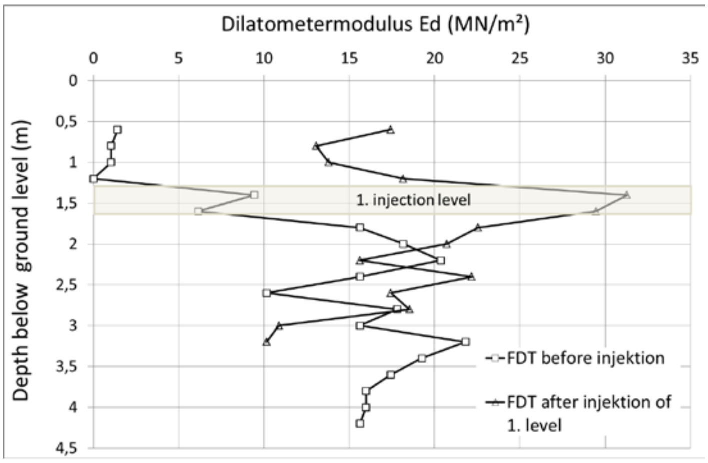

Fig. 2. Results of dilatometer tests, first test site

3.2 *Second test site*

The second test site is situated in the south-eastern part of Austria near the Hungarian border. On a little fire station cracks in the northern external wall appeared some years after completion. The disclosed soil beneath the strip foundation was a fine grained backfill in a weak consistency. In 2.7 m depth the in situ soil in form of a sandy silt in a stiff consistency was explored. To stabilize the building and to reduce further settlement injections were done in two different depth levels. The first level was situated directly under the strip foundation in about one meter; the second level was about one meter deeper. One flat dilatometer test was made after finishing all injection work in a distance of 1.5 m from the building. In Fig. 3 the measured values in form of the dilatometer module versus depth are shown.

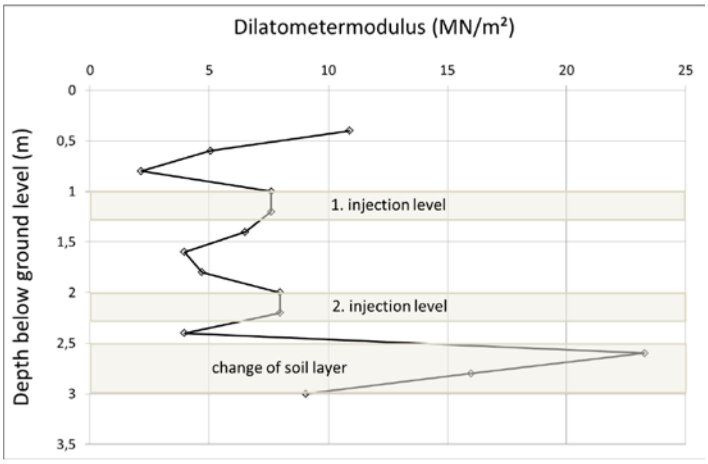

Fig. 3. Results of dilatometer tests, second test site

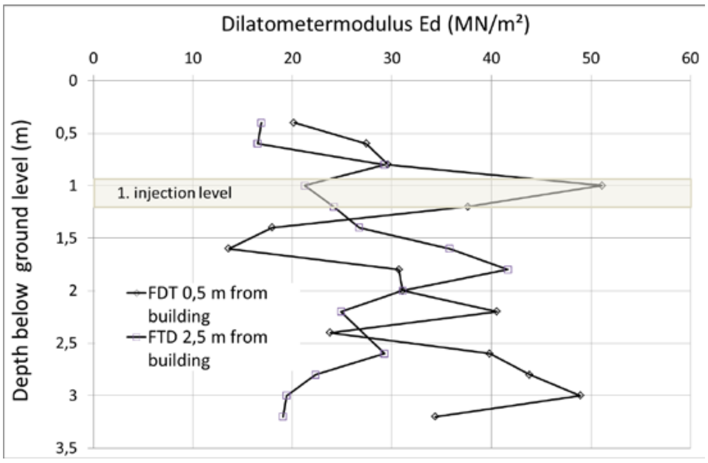

Fig. 4. Results of dilatometer tests, second test site

The values of the dilatometermodulus show a slightly increase in the depth of the injection levels, a significant peak is visible by the change of the soil layer in 2.6 m depth. Obviously the distance between the injection point and the test point was too big to measure a significant increase. The change in the horizontal stresses due to the expansion of the resin could be measured at the test point 1.5 m away from the injection point, but the change is not as significant as in the first test site.

3.3 *Third test site*

The third test site is located in the northern part of lower Austria. A sixty year old residential building was sold. The new owner wants to renovate the house including the cracks in the external walls. The soil beneath the strip foundation consists of a mixture of fine sand and silt in a weak to stiff consistency. The differential settlement can be due to the high loads of the strip foundations in some areas. Injections were done under the strip foundations of the external walls in three different depth levels. Two different flat dilatometer tests were made after the grouting work was finished at two different distances from the building (0,5 and 2,5 m). In Fig. 4 the measured values in form of the dilatometer module versus depth are shown for both tests. On this test site the influence of the distance between test position and injection point was investigated. The obtained results confirm these from the first two sites. At a distance of 0.5 m a significant increase of the values can be seen. In contrast at a distance of 2.5 m no change appears.

4 CONCLUSION

We have carried out a literature recherche where different field testing methods were evaluated concerning different boundary conditions. The two best methods were the Flat Dilatometer Test and the SASW-method (Seismic Analysis of Surface Waves). Both methods fulfil the requirements of the company Uretek. In our field tests both methods were used under field conditions. The SASW-method was discarded because no reasonable results could be obtained.

The results of the flat dilatometer tests from three different test sites show significant correlation between the grouting works and the dilatometer modulus. Obviously the expansion of the injected resin causes an increase in the horizontal stresses in the soil. This increase can be measured and expressed by the dilatometer modulus. The modulus depends on the horizontal distance between the grouting point and the point of measurement. The first tests show that this influence can be measured up to a distance of about 1.5 m.

In these first tests a qualitative correlation between the influence of the grouted resin could be demonstrated. Further tests are needed to establish a quantitative relationship.

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