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GEOTECHNICAL ASSET MANAGEMENT

How Structural Engineers can exploit Geo-polymer Injection Technology

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Abstract

Geo-polymer injection is a non-disruptive, efficient alternative to conventional underpinning and piling which Uretek has advanced due to over 30 years of research, development, testing and installation. The implementation of the Uretek geo-polymer injection system can be be categorised as proactive (improving the strength of soils to facilitate an increase in loading or combating long term settlement) or reactive (remediation of subsidence).

Introduction

The application of geo-polymer injection can be categorised into two phases:

1. Surface consolidation

2. At depth consolidation

With regards to surface consolidation, geo-polymer is injected into the shallow area beneath a foundation, with the intent of fully re-establishing contact between the underside of the foundation and the underlying soils by filling any voiding within the treated soil.

At depth consolidation relates to soils being treated at greater depth and thus most concerned with the forces provoked by loading. The objective of at depth treatment is to densify the ground via:

• Elimination of voids by filling and compacting/consolidating

• Expulsion of air and water

• Agglomeration of the soil (in granular cases)

Once injected, the geo-polymer will move and expand both horizontally and vertically to a region that allows the material to take the path of least resistance, and thus has the greatest need to be reinforced. Once this has taken place, the geo-polymer will expand vertically and place pressure on the underside of the foundation, eventually ending its liquid phase and becoming solid.

Typically, each injection point will create a zone of influence of approximately 1m radius (depending upon the characteristics of the geo-polymer utilised), resulting in a section of reinforced soil. Injection points are usually placed at 1.0 - 1.5m centres to ensure that the entirety of the area requiring treatment is impacted by the injection works. This spacing can be altered depending upon factors such as soil type, soil strength and loading.

Working with a worldwide leading chemical manufacturer, Uretek has developed a portfolio of over 30 materials for use depending on the project scope and soil properties. Each geo-polymer material possesses different characteristics, making them advantageous in different scenarios. These characteristics include:

Cream Time - The time taken for the injected geo-polymer to begin to change state from a liquid to a solid.

Gel Time - The time taken for the geo-polymer to adhere to a surface, signifying the beginning of the expansive phase.

Tack Free Time - The time taken for the geo-polymer to cease adhering to a surface, thus signifying the end of the expansive phase.

Free Rise Density - The density of the geo-polymer when injected without containment (the level of containment will directly impact the density of the geo-polymer, thus the free rise density is the lowest possible density).

In accordance with Uretek's "non-disruptive" ethos, ground improvement injection works are carried out from self contained mobile workshops, with all plant and equipment necessary for standard projects carried at all times. Depending on a number of factors, Uretek technicians will use either the extraction method, or the multi tube method of injection.

Extraction method

1. 16-50mm diameter hole drilled to the required depth of treatment

2. A single injection tube of required length is inserted into the hole

3. Geo-polymer is injected through the tube, with the flow rate measured together with the rate at which the injection tube is simultaneously extracted.

Multi tube method

1. 16-50mm diameter holes drilled to the required depth

2. Multiple injection tubes of varying lengths will then be inserted throughout the depth of the hole

3. Specified quantity of geo-polymer is injected into each tube.

Materials

Uretek's geo-polymers are formed from multiple components. When these components are combined during the installation process, polymerisation is initiated. This is the process that causes the material to change state from liquid to solid (expanding as this occurs).

The mechanical strength of the geo-polymers have been evaluated by Uretek's material manufacturers by performing compressive strength tests according EN 826 (according to this standard the compressive strength is measured at 10% deformation of the material).

Typically, when installed on site, a geo-polymer will never fully complete the expansion process and possess its specified free rise density, as any strata injected into will offer counter pressure to the geo-polymer; this will limit horizontal deformation. In order to mimic this, compressive strength tests on Uretek geo-polymers are performed using a mold to prevent horizontal deformation.

The compressive strength of a geo-polymer depends on the applied density. Therefore the compressive strength of each material has been measured at different applied densities, in order to provide a range of results that can be used for interpolation if required.

The results of compressive strength testing carried out on two of the Uretek geo-polymers is shown below:

	Free Lateral Expansion			Confined Measurement		
	Density	10% compression	E-modulus	Density	10% compression	E-modulus
	kg/m^3	MPa	N/mm^2	kg/m^3	MPa	N/mm^3
Uretek A	163	2.544	66	164	3.050	66
	229	4.311	97	230	5.004	102
Uretek B	324	4.383	120	325	5.232	123
	402	8.536	219	402	10.926	217

"Environmental impact of the Uretek Resins on soil and groundwater" is a paper written by the Uretek material manufacturer. It discusses the effects of the geo-polymers once injected, along with the testing carried out by the material manufacturer regarding this matter. The summary of this paper states:

"The Uretek material components are injected into soil and could therefore influence the environmental and ecological condition of the soil and surrounding groundwater. Based on several environmental impact studies of Uretek Resin to soil and groundwater, it was concluded that the Uretek Resins have no or little impact."

Hydraulic conductibility tests have been carried out on both pure Uretek geo-polymers and on samples of injected soil utilising an in-situ geo-polymer density of approximately $37kg/m^3$. This density is considered to be low for an in situ geo-polymer density (as in-situ density is affected by numerous factors including counter pressure experienced during the expansion of the geo-polymer). Therefore this is essentially a worst case scenario.

The testing showed hydraulic conductibility values on pure geo-polymer ranging from $1.10\text{-}9$ to $1.10\text{-}8$ m/s, suggesting the existence of reduced interconnected porosity. The hydraulic conductibility of the injected soil sample was approximately $10\text{-}10$ m/s.

On the basis of these results, it was concluded that the structure of the geo-polymer consists almost entirely of closed pores that are impenetrable by water. The very low hydraulic conductibility measured for the injected soil samples was due to the presence of random micro-defects. The summary of the testing concluded with this statement:

"These resins can therefore be considered virtually impermeable and practically unaffected by imbibition of water."

Throughout the Uretek network, and in conjunction with the material manufacturer, multiple laboratory tests have been commissioned with the aim of determining physical and mechanical properties of geo-polymers.

One such test was carried out with the aim of assessing the relationship between expansive force and density. This test was carried out using a specially constructed device that enabled the geo-polymer to be injected inside a rigid metal cylinder fitted with a piston.

Immediately after injection, the geo-polymer started to expand vertically (due to the rigidity of the container, this was the path of least resistance).

Upon expansion, the geo-polymer drove the piston upwards, which after a stroke of a few centimetres, was blocked by a transversal contrast fitted with a manometer. The expansive force was then determined by measuring the pressure that the transversal contrast supplied in order to prevent the piston from moving upwards.

The experiment results have yielded the following relationship:

$P = \exp(0.23(Y_{rf} - 0.36))\text{-}1$

where:

P = expansive force (expressed in MPa);
Y_{rf} = weight of the unit of volume of the expanded geo-polymer (expressed in kN/m^3).

The swelling ratio of the expanded volume of the geo-polymer (Y_{rf}) injected into the soil in a liquid state (V_{ri}) can also be calculated. The mass of the geo-polymer remains substantially unchanged in the transition from the initial liquid state to the final expanded solid state and, therefore, volumes V_{ri} and Y_{rf} can be equated to the specific weight of the expanded, and liquid geo-polymer. As such the swelling ratio can be derived via the following equation;

$10.5/0.36 + (1/0.23) \ln(1+P)$

Where 10.5 relates to a specific weight of liquid Geo-polymer of 10.5 kN/m^3.

Verification

Whether geo-polymer injections are used to combat future settlement, or to increase soil strength, a standard on site check is used by Uretek technicians; structural movement. Throughout the geo-polymer injection process, relevant parts of the overlying structure are monitored using rotary lasers and mounted sensors, with sensors placed in the vicinity of the active injection point. Each injection will be prolonged until a reaction is registered (< 0.5mm). This indicates when a degree of compaction/consolidation has been achieved. This also shows that the treated soil has been reinforced sufficiently enough to carry the load of the structure, as an upward force will be acting upon the underside of the above foundation, causing the upward movement.

In order to quantify the increase in soil strength achieved by geo-polymer injections, Dynamic Cone Penetrometer (DCP) testing is typically used. This testing allows an insight to be gained into treated ground conditions and also to clarify the bearing capacity of the tested soil at 100mm increments. By comparing the results of the testing carried out prior to treatment with the results of the DCP testing carried out after treatment, the improvement in the strength of the soils can be shown.

Both pre works and post works DCP testing is carried out using the same equipment; Pagani DPM 30 - 20 penetrometers with 30kg falling weights. By measuring how many "blows" are required to drive a rod 100mm into the soil to be tested, a measurable indication of strength can be gained.

When converting the DCP test data, Uretek utilised a realistic conversion of N(300) = N(100) x 1.25.

This allows Uretek to relate the pre and post treatment Dynamic Cone Penetrometer (DCP) testing to the surrounding Standard Penetration Test (SPT) values and allow conversion of these results using standard geotechnical formulae and parameters. Once an equivalent SPT value has been obtained at the test depth, this information is utilised to derive a shear strength value using the worst case scenario (that the soils are entirely cohesive and are subject to shearing failure). This is achieved by again utilising the familiar methodology from Stroud relating the SPT to shear strength. Again using the worst case assumption that the soils are completely cohesive, it provides a function relating these two parameters with varying plasticity index. Thus, it is possible to anticipate the following relationship:

Shear strength: Cu = 5.0 x N(300).

In the final stages of the conversion calculations, Uretek is required to derive a bearing capacity - using traditional bearing capacity theory this equates to 6Cu.

Uretek will then apply a factor of safety depending upon the aim of the works. In cases when geo-polymer injections are carried out to facilitate a new build construction, a factor of safety of 3 is utilised. In cases where geo-polymer injections are carried out to facilitate a refurbishment, a factor of safety of 2 is used.

Geo-polymer injection works have also been verified using a number of different testing methods, including plate load testing, CBR testing and GPR Surveys (depending upon the client's requirements).

Conclusion

Uretek is constantly striving to make developments both in terms of geo-polymers (developing existing materials and creating new geo-polymers) and of best practice for installation/verification. As a result of this Uretek is able to adapt to meet the requirements of both our clients and the sites we work on. This ensures that Uretek's non-disruptive ethos is upheld, as well as enabling Uretek to continue to demonstrate the main benefits of geo-polymer injection. These are:

• Speed

• Lack of disruption

• Efficiency

• Minimal plant

• Minimal environmental impact

• No need to excavate.

For a structural engineer, a key benefit of utilising geo-polymer injection over traditional methods is the efficiency of the system. The wider economic impact of invasive methods caused by disruption and lengthy timeframes is becoming more accountable. By having the option to reinforce soils and increase load bearing capacity within days using geo-polymer injection, stakeholders can focus on the long term goals of the overall project.

With the body of research substantiating the use of geo-polymer injection and over 200,000 projects delivered by Uretek alone in the last 30 years, the use of geo-polymers is now a mainstream consideration for consultant engineers around the world.
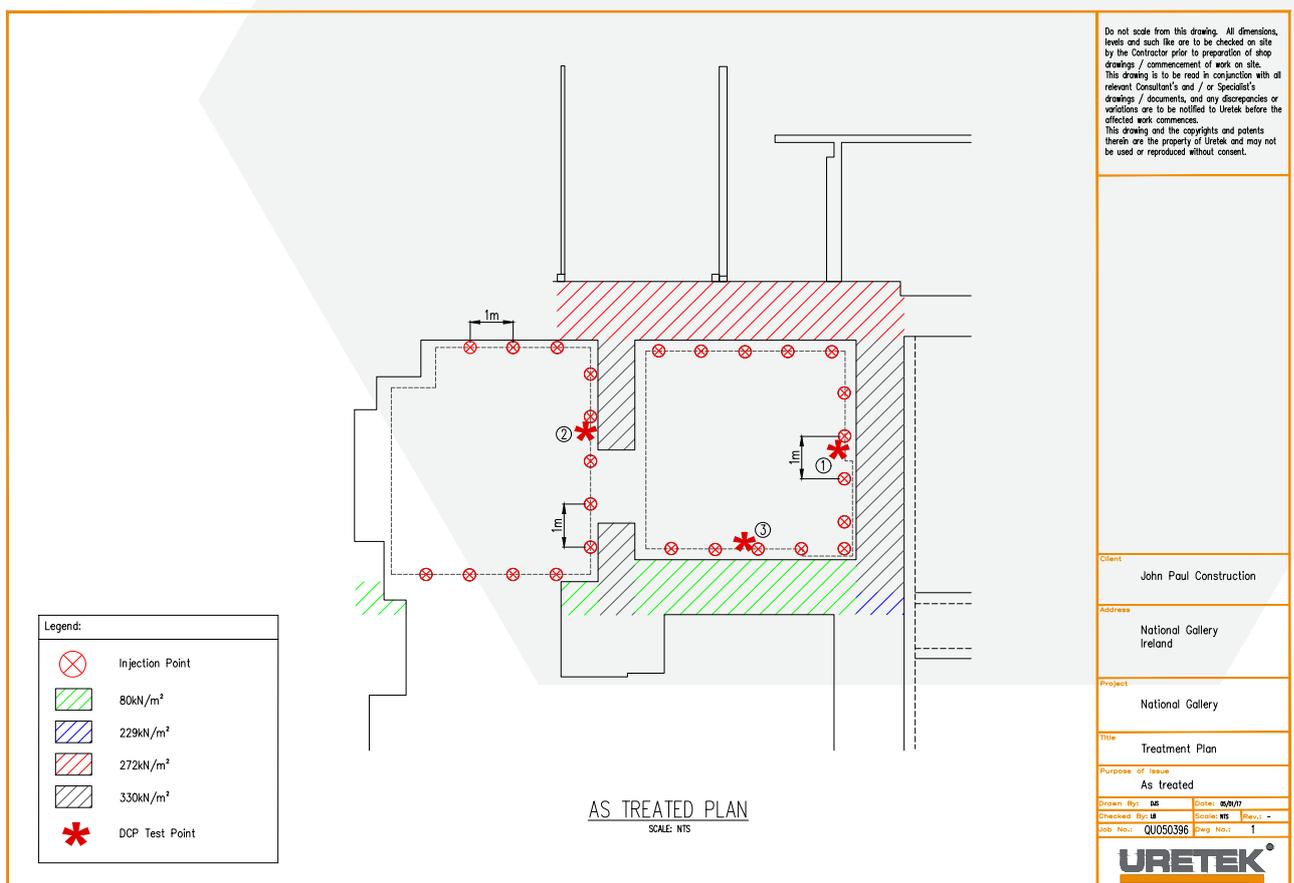
Case Study - National Gallery, Ireland

It was proposed that the National Gallery of Ireland would be refurbished as part of a scheme to alter the layout of the Dargan and Milltown wings at Merrion Square, Dublin. As part of the refurbishment works, it was decided that the soils underlying 28 linear metres of walling (see drawing) did not possess sufficient strength to safely transfer the proposed loading conditions of $80kN/m^2$, $229kN/m^2$, $272kN/m^2$ and $330kN/m^2$ respectively.

Therefore, Uretek was approached by John Paul Construction to improve the soils in the relevant areas of the site in order to facilitate the proposed refurbishment.

After reviewing the site investigation report provided by the client, and taking into account the maximum load of $330kN/m$ (along with relevant foundation dimensions), Uretek specified that geo-polymer injections should take place to a maximum depth of 2.5m below ground level at the walling to be treated. On average, at this point the relevant probe tests within the investigations showed the soils to become competent and able to safely transfer the relevant load.

Upon completion of the works, Uretek carried out post works Dynamic Probe Testing, in order to provide verification of the works (see below):

Site drawing:

AS TREATED PLAN
SCALE: NTS

Legend:

⊗	Injection Point
▨	$80kN/m^2$
▨	$229kN/m^2$
▨	$272kN/m^2$
▨	$330kN/m^2$
✳	DCP Test Point

Client
John Paul Construction

Address
National Gallery
Ireland

Project
National Gallery

Title
Treatment Plan

Purpose of Issue
As treated

Drawn By:	DJS	Date:	05/01/17	
Checked By:	LB		Scale: NTS	Rev.: -
Job No.:	QU050396	Dwg No.:	1	

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Site test result

Site address: National Gallery, Ireland.

Depth below ground level	Number of Strokes Before	Bearing Capacity kN/m²	Number of Strokes After	Bearing Capacity kN/m²
0.1m				
0.2m				
0.3m				
0.4m				
0.5m				
0.6m				
0.7m				
0.8m				
0.9m	11	206.25	19	356.25
1.0m	9	168.75	19	356.25
1.1m	9	168.75	22	412.50
1.2m	7	131.25	23	431.25
1.3m	8	150	31	581.25
1.4m	11	206.25	33	618.75
1.5m	10	187.50	36	675.00
1.6m	10	187.50	40	750.00