Technical notes

Uretek

GEOPLUS®

the super

consolidating

polymer that

provides thrust

of 10,000 kPa

URETEK®

Uretek - Leading
the world in polymer
development

GEOPLUS®

Technical notes and laboratory test results on the latest generation of the Uretek Geoplus expanding resin

Carried out by Uretek Technical
Staff in collaboration with
Padua UniversityIMAGE Department

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1. Introduction

For many years now in the field of geotechnics, we have been concerned with building the reputation of the Uretek Deep Injections method for the consolidation of foundation soils.
In the early stages, the method, invented and patented at European level by Uretek, was met rather coldly by engineers, who considered that it had not been sufficiently tested.

Today, several years on, there is broad consensus amongst engineers and this is based on the very large number of applications carried out successfully by Uretek under the most varied conditions, both in Italy and abroad.

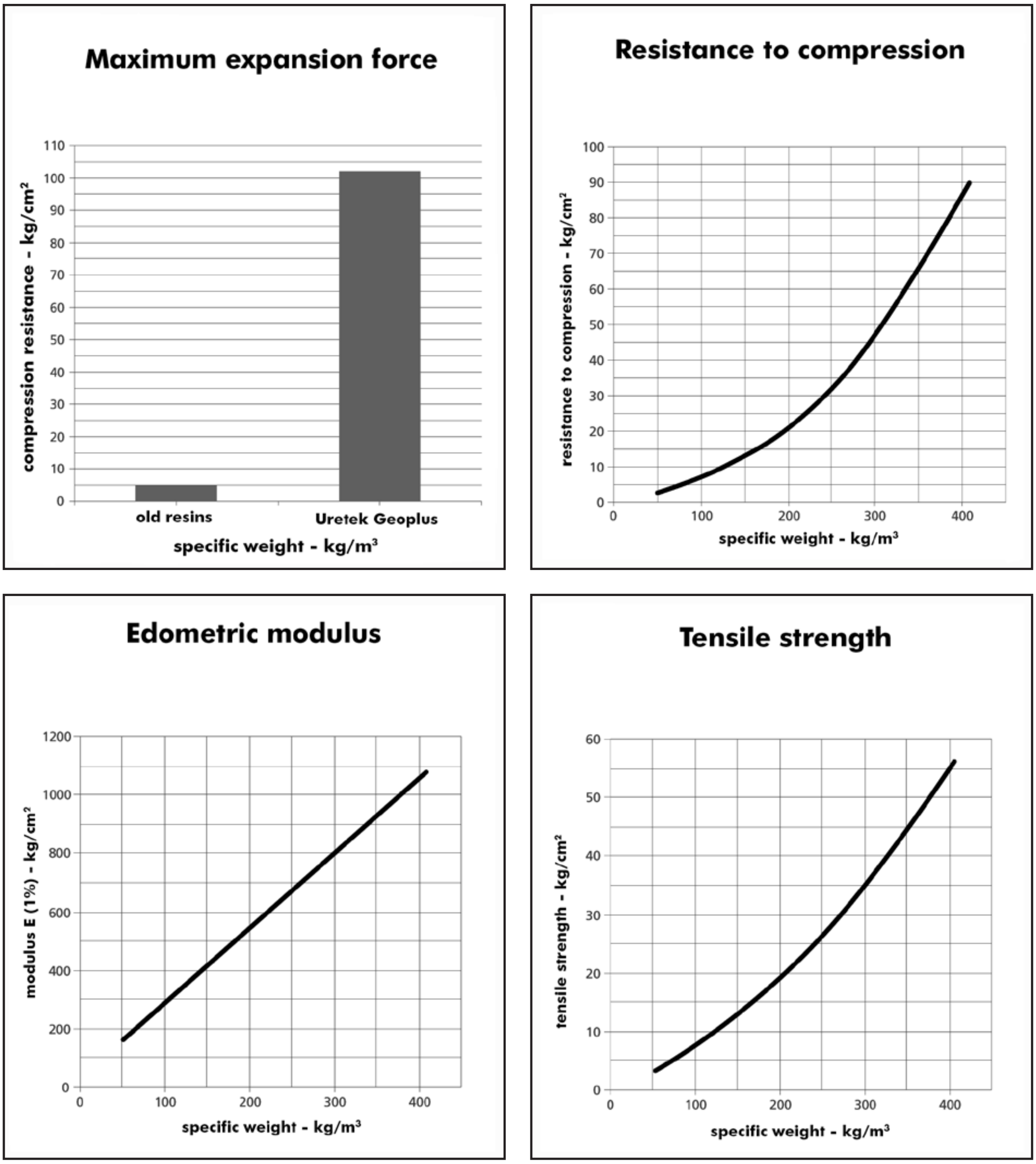
In order to maintain the technological leadership that sets it apart, Uretek has undertaken a series of studies and research, taking advantage of the invaluable assistance of the University of Padua, aimed both at improving application techniques and the products used.
Prompt results were obtained and these have led to a substantial improvement in the application method.

The most significant innovation, however, relates to the resin used. Today, Uretek is able to present Uretek GEOPLUS® resin, which has been researched specifically for deep injection and produced exclusively for Uretek. Uretek GEOPLUS® will be analysed in depth in the pages which follow.

In part one, prepared by Uretek technical staff, the main characteristics of the Uretek Deep Injections method and Uretek GEOPLUS® resin are summarised, with reference to the most common applications.

In part two, we present the report prepared for us by the University of Padua, with comments by Prof. Giuseppe Ricceri and Prof. Marco Favaretti of the Geotechnics section of the University of Padua IMAGE department, containing detailed descriptions of the tests carried out on Uretek resin.

Summary table of the main characteristics of URETEK GEOPLUS® expanding resin.



The results given in the table are examined and commented upon in depth in the report by Prof. Giuseppe Ricceri and Prof. Marco Favaretti from the University of Padua, which is presented from page 9 onwards.

The table presented refers to tests carried out specifically on Uretek Geoplus resin and cannot be extended to other resins, as it is possible for very significant variations to occur.

The complete certificates from the University of Padua relative to the tests mentioned are available if required.

2. Part One

a. Uretek Deep Injections technology

Uretek GEOPLUS® resin is injected in liquid state by using the mechanical action of a pump to push the liquid through injection tubes until it is released into the soil which requires consolidation.

The tubes are inserted into holes of less than 20mm diameter, made directly in the foundation, in order that the underlying soil is treated with precision.

The injection pressure is not high and does not play a particularly significant role in order to achieve a successful result.

The degree of obtainable soil compaction is, in fact, a function of the expansion force of the resin and is not related to the pressure at which it is injected.

At the point of injection, the mix undergoes an exothermic chemical reaction, which induces the state change from liquid to solid. It is the consequential increase in volume which produces the dynamic energy and subsequent expansive force.

The resistance encountered by the resin during the expansion phase is inversely proportional to the volume increase.

The chemical reaction is very quick and the immediate resulting solid compound possesses definitive physical and mechanical characteristics.

The reaction, which is confined by the surrounding soil, transfers the energy produced by

compression, depending on the soil type this will produce a dense aggregate.

Once the Uretek GEOPLUS® mix has been injected into the soil, the material behaves in a differing manner and is dependent on the nature of the medium encountered:

- if the soil is granular, the mix permeates the gaps and, acting as an hydraulic binding agent, produces a monolithic conglomerate with significantly improved mechanical characteristics;
- if the soil is of the cohesive type, the mix does not permeate the gaps, but forms a dense lattice of strands similar to a plant root system, thereby producing a mass, which is compressed and strengthened by the strands themselves;

In both cases the resin transfers a strong compressive force, produced by the chemical reaction, to the host soil which is appropriate to its consolidating requirements.

The determinant characteristics of Uretek GEOPLUS® resin, for the operation to be successful, are summarised below.

b. Expansion force

The maximum expansion force of the Uretek GEOPLUS® mix under edometric conditions is 10,000 kPa. This characteristic is essential for Uretek Deep Injection treatment to be successful. Following the chemical reaction, Uretek GEOPLUS® resin transmits a precompression force to the soil which leads to a reduction in the gaps ratio. This application of force also prevents possible future settlement, by over compensation.

The expansion force generated by the chemical reaction reduces in proportion with the progressive reduction in the expansive characteristic of the resin. Thus the degree of expansion regulates itself as a function of the surrounding resistance. In order to simplify the process, you can think of the Uretek GEOPLUS® resin-soil system as two springs interacting with each other: the 'Geoplus' spring and the 'soil' spring.

On exit from the injection tube, the 'Geoplus' spring is completely contracted. Expansion commences at the expense of the host soil. The system will be in equilibrium when the 'Geoplus' spring has reached a degree of expansion such that the force it generates is equal to the opposite reaction of the compressed soil. At this point, the system is in equilibrium and is consolidated by the change in the state of the mix, which becomes solid. The resistance offered by the solid resin is greater than the reaction of the compressed soil, therefore the system remains stable over time.

This process takes places over a very short period of time and in a very precise manner in the soil mass. These two characteristics make it reasonable to consider that it is a dynamic action, which induces very low interstitial overpressure and favours dissipation in very short time periods.

c. Reaction time

The chemical reaction, which produces the resin expansion and the state change from liquid to solid, is completed very quickly. This leads to a series of advantages:

- containment of the resin in a maximum area of 2.00 m from the injection point.

This characteristic results in:

- total utilisation of the injected material without waste;
- the possibility of avoiding damage caused by uncontrolled infiltration of materials in the surrounding areas;
- precise localisation in the volume of soil treated;
- transfer of the chemical reaction energy to the soil with a 'dynamic' action.
- This property demonstrates similarity with the dynamic compaction produced by mechanical means.
- very fast working times, in the order of around 10 linear metres of foundation per day for each application team, for soil is treated down to a depth of three metres from the foundation support plane. Obviously, if greater speed is required, then more teams can be utilised.
- Immediate & empiric measurement of successful application. The resin injection is monitored by laser sensors, anchored to the structure. Injection is continued until an upward change in level is noted. This indicates the foundation materials have reached a degree of

compression and compaction which have the capability to resist not only static stresses generated by the structure, but also dynamic stresses, which are far greater than the static stresses, which are generated during the lifting process.

The success of the operation can be checked and assessed with geotechnical tests.

- controllability of the process by means of laser measurers positioned on the structure in such a way as to highlight movement and ensure the safety of the operation.

d. Degree of expansion

- The degree of expansion of the Uretek GEOPLUS® mix varies from 2 to 20 times as a function of the resistance encountered. Therefore, 1 dm^3 of the mix can generate a solid compound of variable volume of between 2 and 20 dm^3. This characteristic enables:
- filling of any gaps present in the foundation soil or at the interface between the soil and the foundation laying plane;
- immediate compensation for the volume lost in the compacted soil by the expanding action of the resin.

e. Modulus of elasticity

The elastic modulus of the Uretek GEOPLUS® mix is comparable to that of foundation soil, varying between 10 and 80 MPa in accordance with the host soil density.

Geotechnical literature indicates that a load induced on the soil by a foundation is distributed downwards with decreasing intensity and increasing impression.

The pressure bulb theory shows how to calculate this variation of stress states at specific depths.

In the case of deep foundations in concrete or steel, which are more rigid than the host soil, the stresses are, for the most part, transferred downwards.

Soil treated with Uretek GEOPLUS® resin does not alter its stiffness characteristics and therefore the distribution of the forces through deeper layers is not changed as a result of the Deep Injection process.

Similarly if the soil volume treated does not coincide with the entire volume involved in the distribution of loads, but is only, in part, subject to induced stresses, the soil layers above the treated zone remain relatively unaffected and remain in an unchanged state.

As the injection of uretek resin does not involve significant redistribution of stresses in the soil, it is possible to utilise the technique in partial or localised treatments.

f. Stress resistance

The mechanical properties of Uretek GEOPLUS® resin have been studied at the Padua University laboratories. The detailed report prepared by the Head of Research is given below.

With regard to resistance to compression, the material demonstrates excellent performance with respect to the purposes for which it is used.

We emphasise that the results obtained refer to resistance to collapse of the samples and not to true resistance to rupture. In fact, at the end of the test and after removal, the samples reassumed their original position.

For the use for which Uretek GEOPLUS® resin is employed, it always proved that compression resistance is greater than the expansion force produced at an equal degree of expansion. This property is essential for the non-reversibility of the Uretek Deep Injections process.

Resistance to tensile strength and bending were also more than satisfactory and although these characteristics do not appear particularly significant in Uretek Deep Injections operations, it can be considered that they contribute to the improvement of the soil treated.

g. Stability over time

Uretek provides a guarantee of the stability of the consolidated product for a period of 10 years for each job carried out. Given the nature of the compound, however, the duration is definitely far greater than the above mentioned period. This is borne out by the fact that the first Uretek applications date back to 1975 and that there are no significant variations in the mechanical and volumetric characteristics of the resin used.

GEOPLUS® resin represents further development of the resins used then and still maintains these fundamental properties.

h. Permeability coefficient

Uretek GEOPLUS® resin has a permeability coefficient of 10^{-8} m/s.

This value, if compared with the soil permeability, is similar to that of clay and is far less than those of sand and gravel.

Once injected, the resin notably reduces the permeability of the granular mass, avoiding subsequent elutriation action. In fact, elutriation is a function of the quantity of filtration water and the flow rate.

i. Specific weight

The Uretek GEOPLUS® mix has a variable specific weight which varies with the degree of expansion.

The empirical evidence shows that, once it is consolidated in the foundation soil, it has a variable specific weight of between 150 and 300 kg/m^3. This value is around 6-12 times lower than the specific weight of a soil and 3-6 times lower than water.

Uretek Deep Injections treatment does not, therefore, increase the load of the soil treated.

j. Reaction stability

The Uretek GEOPLUS® resin chemical reaction has attained a maximum level of stability. In fact, in contrast to resins used to date, as can be verified by comparison with our previous documentation, the characteristics of Uretek GEOPLUS® resin are far less variable for a given density, leading to more precise and accurate forecasting of the properties assumed by the resin once injected into the soil.

3. Part Two

a. Introduction

- URETEK GEOPLUS® resin has been subjected to laboratory testing for the purposes of evaluating the main physical and mechanical characteristics. In particular, the following were carried out:
- vertical compression tests with free lateral expansion
- vertical expansion tests under edometric conditions
- simple tensile stress tests
- bending tests

The tests were carried out in the geotechnical laboratory and the health and environmental engineering laboratory of the Department of Hydraulic, Maritime, Environmental and Geotechnical Engineering (IMAGE) at the University of Padua, and in the materials laboratory of the Construction and Transport Department at the University of Padua.

The following methods and standards were used as a reference:

- UNI Standard 6350-68 "Rigid cellular plastic materials - Determination of compression characteristics"
- UNI Standard 8071 "Rigid cellular plastic materials - Determination of tensile stress characteristics"
- UNI Standard 7031-72 "Rigid cellular plastic materials - Determination of bending load"

The results of these experiments and some processed data, which enable the true behaviour of the resin to be described more completely, are presented below.

b. Vertical compression tests with free lateral expansion

The testing was carried out at the University of Padua IMAGE Department Geotechnical Laboratory, with reference to UNI Standard 6350-68.

A press capable of maintaining a preset, constant advancement speed of 0.5mm/minute during the course of the test was utilised for application of the vertical load.

Testing was carried out on cube shaped samples, with a 50mm side and specific weight of between 0.5 kN/m^3 and 3.3 kN/m^3. 5 samples were tested for each density investigated.
The maximum compression resistance has been defined as the ratio between the maximum load encountered during execution of the test and the initial surface area of the section normal to the load direction.

Figure 1 shows the vertical compression stress trends as a function of vertical strain of the sample and the initial density of the mix. The diagram shows the test curves obtained during the course of 10 tests conducted on different mix samples. The mix displays simple compression resistance, which is highly dependent on its initial density. The maximum resistance condition is characterised not by a true rupture of the sample, but by a loss in alignment between the vertical axis of the sample and the load piston axis, which made it impossible to continue the test. In fact the sample bent towards the area of lowest resistance, as it was not perfectly homogenous internally.

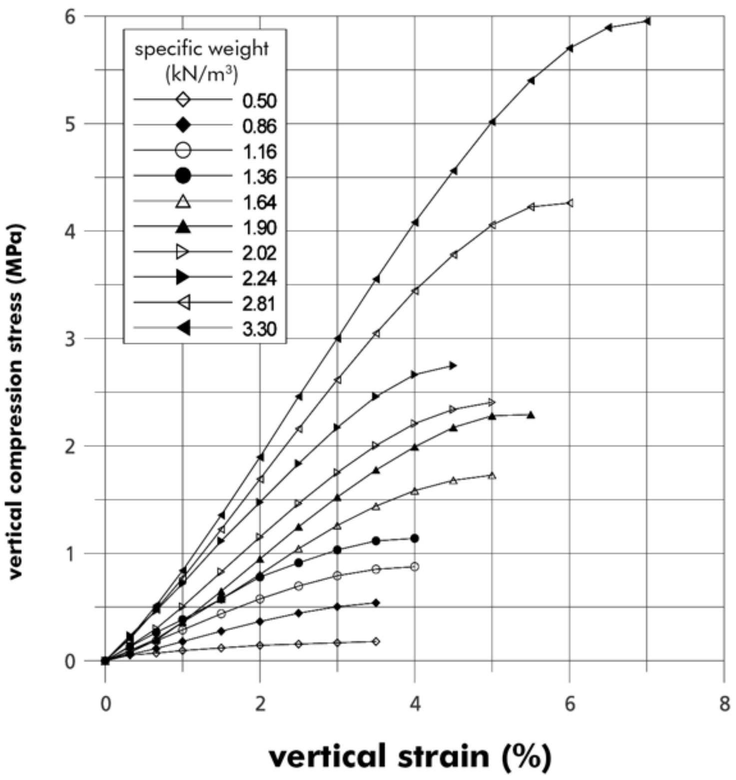


Fig. 1 - *Vertical compression test with free lateral expansion: average vertical stress trend as a function of vertical strain and the specific unit weight of the sample*

By removing the vertical force applied, the sample reassumed its initial geometrical dimensions and cube shape. The material, even in the presence of certain obvious heterogeneities and at least in the stress range tested, demonstrated a good degree of isotropy, given that the compression resistance values determined turned out to be independent of the placement of the sample cube on the press.

Definitions

- SPECIFIC WEIGHT: ratio between the total weight and total volume of the sample (in kN/m³);
- VERTICAL STRAIN: percentage ratio between vertical height reduction and initial height of the sample (in %)
- VERTICAL STRESS: ratio between the vertical force applied and the initial surface area of the section normal to the load direction (in MPa)
- COMPRESSION RESISTANCE: ratio between the maximum vertical force applied and the initial surface area of the section normal to the load direction (in MPa)
- MODULUS OF ELASTICITY: ratio between vertical stress and vertical strain recorded in relation to a vertical strain of 0.33% (E1), 0.67% (E2) and 1% (E3), (in MPa).

Within the specific weight range γ investigated, between 0.5 kN/m^3 and 3.3 kN/m^3, average resistances to simple compression were determined varying from 0.2 MPa and 6 MPa.
The maximum resistance values have been obtained in relation to vertical strain ϵ of between 3.5% (low initial sample density) and 7% (high initial sample density). The resistance values at higher compression, determined by subjecting the denser samples to compression, are characteristic of soft rocks and are far superior to those of loose soils.

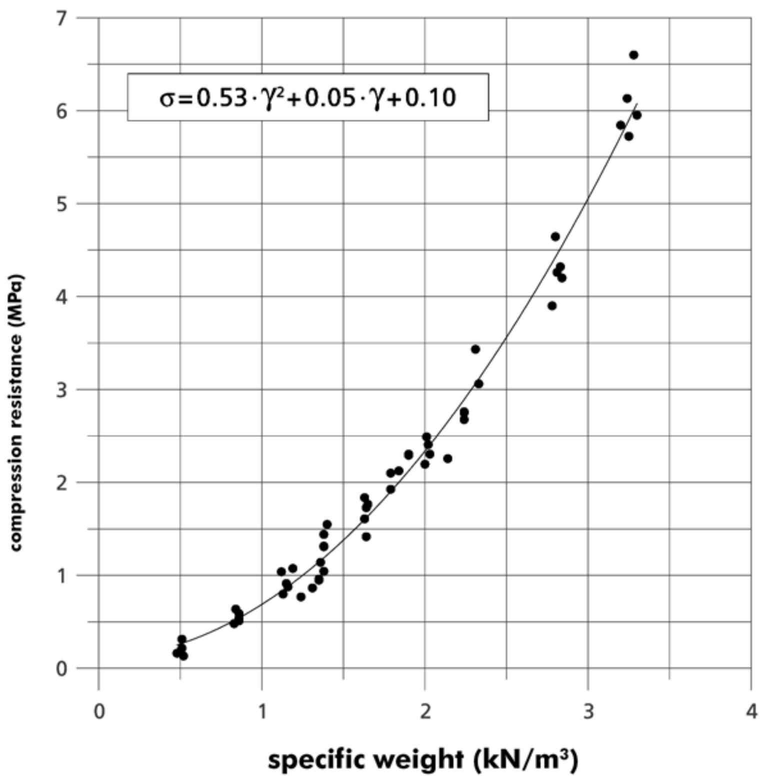


***Fig. 2** - Vertical compression test with free lateral expansion: vertical stress trend as a function of vertical strain and the specific weight of the sample*

Figure 2 gives the values of compression resistance determined over 55 samples of different density as a function of the specific weight of the mix. It is observed from this how the compression resistance increases with the specific weight of the mix. The dependence on compression resistance σ (MPa) of specific weight γ (kN/m^3) has been expressed by means of calculation of a quadratic equation parabola:

$$\sigma = 0.53 \cdot \gamma^2 + 0.05 \cdot \gamma + 0.10$$

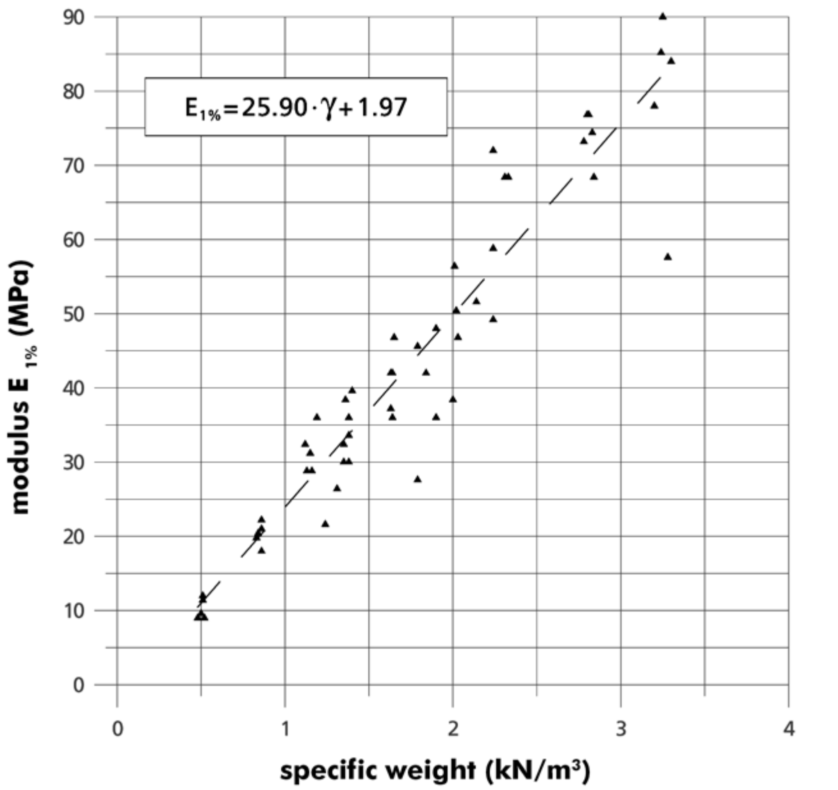


***Fig. 3** - Vertical compression test with free lateral expansion: modulus of elasticity trend determined by an axial strain of 1% as a function of the specific weight of the sample*

The initial moduli of elasticity E have been determined from the test curves "vertical strain ϵ - vertical compression stress σ", considering, respectively, reference vertical strains ϵ of 0.33%, 0.67% and 1%. The moduli $E_{0.33\%}$, $E_{0.67\%}$, $E_{1\%}$, have been thus determined by obtaining the following average value for the moduli E:

$E_{0.33\%}$ = 15 ÷ 70 MPa $E_{0.67\%}$ = 10 ÷ 75 MPa $E_{1\%}$ = 10 ÷ 85 MPa

Figure 3 gives the trend for the modulus of elasticity $E_{1\%}$ as a function of the specific weight of the sample. Dependency of the modulus $E_{1\%}$ (MPa) on the specific volume γ (kN/m^3) has been expressed by means of calculation of a straight-line equation:

$$E_{1\%} = 25.90 \cdot \gamma + 1.97$$

For comparison purposes, ***Table 1*** gives the value ranges of the modulus of elasticity E for various types of soil. It can be seen how the URETEX GEOPLUS® mix assumes values for the modulus E, which are comparable with those of loose soils. This means that, in a soil subjected to treatment with the URETEX GEOPLUS® mix, the average stiffness of the mass will not undergo significant changes.

In conclusion, it can be affirmed that the strong dependence of compression resistance and the modulus of elasticity on the initial density of the mix, and the comparability of the moduli of elasticity of the mix with those of loose soil, constitute extremely interesting properties.

In fact, since the density of the mix utilised in professional applications can be regulated by means of injection times and the quantity of the mix injected, it seems possible to obtain coding of site operations based on the mechanical properties which it is desired to obtain in the treated mass. This is all without altering the overall average stiffness of the same mass, which would involve abnormal redistribution of the stresses applied.

Soil Type	E (MPa)	E (MPa) Uretek GEOPLUS®
Loose sand	10 ÷ 25	15 ÷ 85
Average density sand	15 ÷ 30	
Dense sand	35 ÷ 55	
Limy sand	10 ÷ 20	
Sand and gravel	70 ÷ 180	
Soft clay	2 ÷ 5	
Average consistency clay	5 ÷ 10	
Hard clay	10 ÷ 25	

Table 1 *- Initial modulus of elasticity of various types of loose soil (Das, Principles of Foundation Engineering, 2nd Edition, PWS-Kent, Boston USA, 1990, page 161)*

c. Tensile Stress Tests

The testing was carried out at the University of Padua Department of Construction and Transport Materials Laboratory.

Standard UNI 8071 was taken as a reference, except for the shape of the samples' cross-sections, which were circular, not rectangular. Samples were used with a variable cross-section along the axis with tapering at the centre of the sample. The diameter of the reduced cross-section, at the centre of the sample, was equal to 25 mm +/- 0.5 mm. The diameter of the enlarged cross-section, at the two ends of the sample, was equal to 40 mm.

Definitions

- SPECIFIC WEIGHT: ratio between the total weight and total volume of the sample (in kN/m^3);
- TENSILE STRESS: ratio between the vertical tensile force T applied and the initial surface area (diameter ø) of the section normal to the load direction, measured in relation to the tapered area (in MPa)
- TENSILE STRESS RESISTANCE: ratio between the vertical tensile force T MAXIMUM applied and the initial surface area (diameter ø) of the section normal to the load direction, measured in relation to the tapered area (in MPa)

Test equipment was used, for application of the vertical tensile stress load, which was capable of maintaining a constant advancement speed of 5 mm/minute during the course of the test. 14 samples of variable density were used. A specific weight range included between 0.7 kN/m^3 and 5 kN/m^3 was investigated.

Tensile stress resistance, as with compression, demonstrated a strong dependency on the density of the mix, increasing with the initial density of the mix itself. The test results given in Figure 4 show tensile stress resistance σ_{tens} of between 0.5 MPa and 8 MPa corresponding to specific unit weights of between 0.7 kN/m^3 and 5 kN/m^3.

Dependency of tensile stress resistance σ_{tens} (MPa) on specific weight γ (kN/m^3) is expressed by means of calculation of a quadratic equation parabola:

$$\sigma_{tens} = 0.21 \cdot \gamma^2 + 0.55 \cdot \gamma - 0.01$$

For the current applications anticipated by Uretek, the tensile stress resistance seems to have less relevance with respect to the other mechanical properties investigated. Nevertheless, in view of new applications, this parameter may become important as it allows provision or increasing of a form of resistance (tensile stress) in the soil treated.

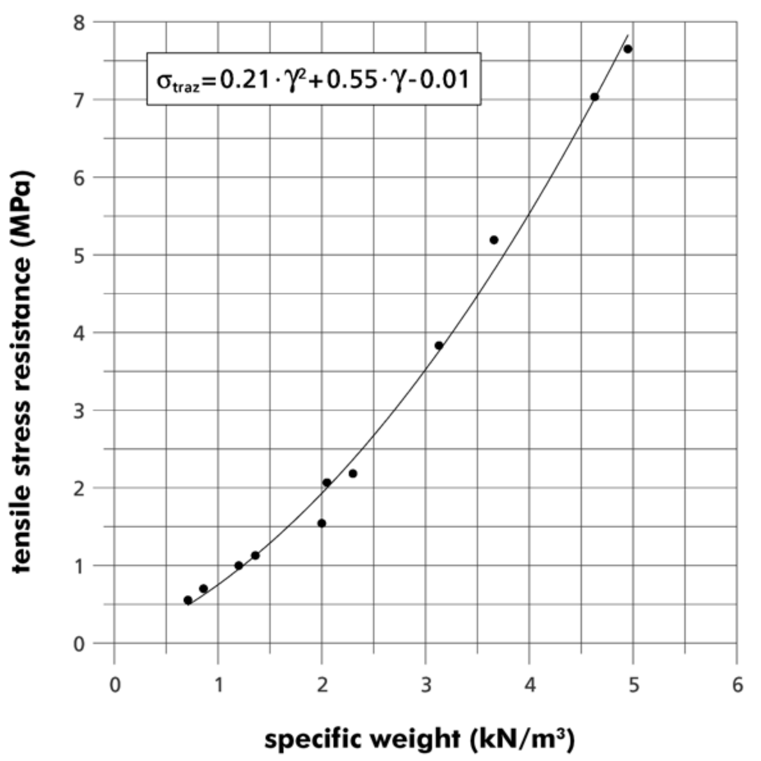


***Fig. 4 -** Simple tensile stress test: tensile stress trend as a function of the specific weight of the mix*

d. Expansion tests under edometric conditions

(Uretek Geoplus® resin has a maximum expansion force under edometric conditions of 10,000 kPa. It is not possible to fully reproduce the results of the Uretek Geoplus® resin expansion tests as they are an integral part of Uretek know-how and the subject of an industrial patent).

e. Bending tests

The testing was carried out at the University of Padua Department of Construction and Transport laboratory. Standard UNI 7031-72 was used as a reference. A bending test machine was used, which was able to apply a preset and constant movement speed to the load application bar. The test equipment has a load application bar and two fixed supports set at a distance of 80 mm. The cross-section of the samples tested was rectangular in shape with a width of 25 mm (+/- 0.4 mm) and height 20 mm (+/- 0.4 mm).

35 samples of variable density were subjected to bending tests. A specific weight range of between 1.19 kN/m³ and 4.81 kN/m³ was investigated. The bending load was assumed to be equal to the value of the load applied at the point of rupture.

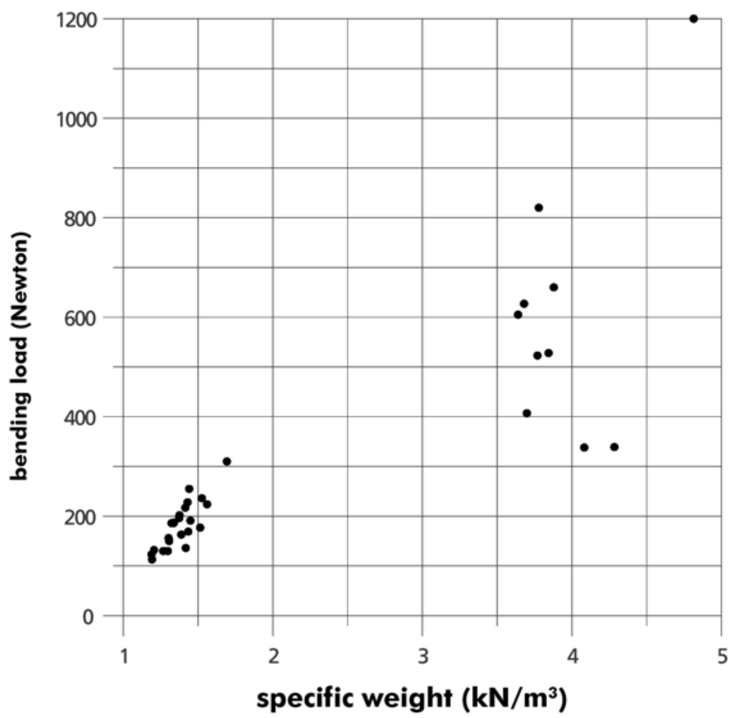


Fig. 5 - *Bending load test*

Figure 7 gives the values of the bending load expressed as a function of the specific weight of the mix. It is observed, as in the previous cases, that on increasing the density of the mix, the bending load also increases in value.

Definitions

1. SPECIFIC WEIGHT: ratio between the total weight and total volume of the sample (in kN/m³);
2. BENDING LOAD: load applied to the centre line of the sample at the point of rupture (in N)

With respect to other test observations, increased data dispersion was seen in relation to the higher test densities. It is considered that this situation is linked to the effect on the type of test undertaken of samples not being perfectly homogenous.

For the current applications anticipated by Uretek, the bending resistance seems to be of less relevance with respect to the other mechanical properties investigated. Nevertheless, in view of new applications, this parameter may become important as it allows provision of or increasing of a form of resistance (bending) in the soil treated.

f. Final observations

On completion of this first phase of laboratory experiments carried out on URETEK GEOPLUS® mix samples, it can be emphasised that all the mechanical properties investigated (compression, tensile stress and bending resistance) have recorded an improvement in their own maximum values on increasing of the mix density.

Another aspect worth considering comes from the fact that the injected mix produces an increase in the overall resistance in the soil, without it altering the stiffness in any significant way.

With respect to the tensile stress and bending properties of the mix, it is stressed that loose soil is practically devoid of both these characteristics and that an injection of the mix can provide or increase the tensile stress and bending resistance of the mass subjected to consolidation with the URETEK GEOPLUS® mix.

The test methodology utilised for execution of the expansion test under oedometric conditions and the results obtained are, for the moment, confidential documents as they are the subject of an industrial patent. The material has a maximum expansion force under oedometric conditions of around 10 MPa. This represents an indicative value for the maximum compression force, which the mix can produce in soil subjected to consolidation operations by means of injection of the URETEK GEOPLUS® mix.

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