Geotextile encased columns for reducing the heave potential of expansive clays

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ABSTRACT: Geotextile encased columns (GEC) includes a high strength, creep resistant, seamless, tubular woven geotextile that confines the compacted sand or gravel column thereby providing easy constructability and high bearing capacity even in extremely soft soil. GEC can resist the radial horizontal stresses in the columns through the circumferential resistance of the high strength geotextile. GEC can also act as large diameter vertical drains, which can speed up the settlement and consolidation process. The capacity of GEC to reduce the heave potential of expansive clays is shown. This problem has not found a proper solution so far. A case history is presented, where the capacities of GEC have been used to solve very difficult geotechnical problems created by the heave of expansive clay in an electrical station in central Italy. Design, installation procedures, and the results of monitoring programs are presented, showing that GEC can be used in one of the most difficult geotechnical applications.

Keywords: geotextile encased columns, expansive clay

1 INTRODUCTION

The distortion and cracking of highway pavements and buildings which are caused by the swelling or shrinking of expansive clay foundation soils create major engineering problems in many areas of the world. Expansive clays create problems involving the service life and riding qualities of highway pavements in areas where unsaturated clay soils and nonuniform rainfall occur. Cracked foundations, floors, and basement walls are typical types of damage done by swelling soils. Damage to the upper floors of the building can occur when motion in the structure is significant. Clay soils with the potential to swell are found in almost any area of the world, but it is in semi-arid regions of the tropical and temperate climate zones that the environmental conditions are most conducive to the development of the problem. The presence of thick layers of expansive clay soils and a wide range of climatic conditions may combine to produce some extreme cases of damage and economic loss (Wise and Hudson, 1971).

Expansive soils contain minerals such as smectite clays that are capable of absorbing water. When they absorb water, they increase in volume. The more water they absorb, the more their volume increases. Expansions of 30 % are not uncommon. This change in volume can exert enough force on a building or other structure to cause damage.

Expansive soils will also shrink when they dry out. This shrinkage can remove support from buildings or other structures and result in damaging subsidence. Fissures in the soil can also develop. These fissures can facilitate the deep penetration of water when moist conditions or runoff occurs. This produces a cycle of shrinkage and swelling that places repetitive stress on structures.

Expansive soils are present throughout the world and every year they cause billions of dollars in damage. The American Society of Civil Engineers estimates that 1/4 of all homes in the United States have some damage caused by expansive soils. In a typical year in the United States, they cause a greater financial loss to property owners than earthquakes, floods, hurricanes, and tornadoes combined.

An expansive clay soil does not change in volume unless it undergoes a change in moisture content, and therefore, it is of prime importance to know how moisture moves in clay soil and how soil properties and climatic conditions affect the speed of moisture flow (Donaldson, 1969). Permeability and soil suction are the important soil properties affecting moisture movement. Climatic conditions such as rainfall, temperature, humidity, and evaporation influence the availability of moisture in the clay soil.

2 EXPANSIVE SOILS

Soils are composed of a variety of materials, most of which do not expand in the presence of moisture. However, a number of clay minerals are expansive. These include: smectite, bentonite, montmorillonite, beidellite, vermiculite, attapulgite, nontronite, and chlorite. There are also some sulfate salts that will expand with changes in temperature. When a soil contains a large amount of expansive minerals, it has the potential of significant expansion.

Expansive foundation soil swells and can cause lifting of a building or other structure during periods of high humidity. On the contrary, during periods of decreased humidity, expansive soil can deflate quickly and may lead to the destruction of buildings. In either case, the damage can be very extensive.

The expansive soil can also exert pressure on the vertical face of a foundation or basement wall or support with consequent lateral movement. Expansive soils that have swollen due to high soil moisture may show a loss of resistance or bearing capacity, resulting in instability that can lead to various forms of foundation problems and slope stability.

The potential for expansion of any particular expansive soil is determined by the percentage of clay and the type of clay in the soil. Clay particles that cause an expansive soil are extremely small. Their shape is determined by the arrangement of their constituent atoms forming thin clay crystals.

Clay belongs to a family of minerals called silicates. The main elements of clay are silica, aluminium and oxygen. As shown in Fig. 1, silica atoms are positioned at the centre of a pyramidal structure called tetrahedron with an oxygen atom occupying each of the four corners (Fredlund, 1975). Aluminium atoms are located in the centre of an octahedron with an oxygen atom that occupies each of the eight corners. Because of the sharing of electrons, silica tetrahedra are connected together to form thin tetrahedron sheets. The aluminium octahedrons are connected to each other so as to form octahedral sheets. Clay crystals are a set of aluminium and silica sheets that are held together by intra-molecular forces. In expansive clay, the clay crystal clusters capture and retain the water molecules between their crystalline leaves in a sort of "molecular sandwich". The montmorillonite clay mineral, which is the best known in the smectite family, can absorb large quantities of water molecules between its crystalline leaves and thus has a great potential for expansion and contraction. The presence of sodium as the predominant exchangeable cation can result in the clay swelling to several times its original volume.

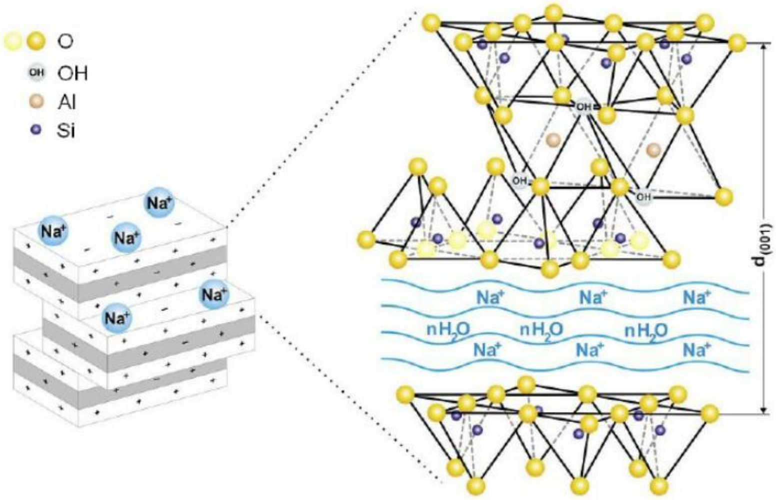


Figure 1. Scheme of sodium montmorillonite structure

When moisture reaches a potentially expansive soil, water dipoles are increasingly pooled between crystalline clay sheets, causing soil volume increase and subsequent swelling. During the periods when moisture is removed from the expansive soil, by gravitational forces or by evaporation or drainage, the water trapped in the clay is released, causing the reduction of the total volume of the soil. When moisture is removed from the soil, the expansive soil may develop large voids or drying cracks.

Expansive clay has the ability to generate enormous pressure on structures such as concrete foundations, which are the key to the destructive power of expansive clay in creating foundation problems.

These pressures may be in the order of 15 MPa or more, although the most common values are 1 to 4 MPa.

By adding water to a solid sample of dry clay, it will cease to behave as solid or semi-solid and begin to assume a plastic behaviour. The percentage of moisture at that point is at the plasticity limit. Continuing to add water, at some point the clay will cease to have a plastic behaviour and will begin to behave like a liquid. This point is called the liquid limit. Since a liquid is incompressible, when expansive clay exceeds the liquid limit, it produces pressures on any structure that limits its volume, while if there is a free surface, the internal pressure causes the clay volume to expand. The same happens when the clay undergoes the decrease of confining stresses, as in the case of excavations of considerable depth extended to a large area. A uniform mass of expansive soil that becomes saturated with moisture will exert pressure in all directions, since each single expansive clay mineral tries to occupy more space. The direction and magnitude of the ground movement depend on the magnitude of the confinement pressure at a given point. The ground movement will be minimized where the confinement pressures are larger, while the movement will be greater when the size of the confinement pressure is smaller. As the depth increases, the weight of the above soil creates an increasing confinement pressure. Therefore, for any particular uniform mass of expansive soil, the resistance to expansion is generally higher in depth than near the ground surface. On horizontal ground, the magnitude of the soil expansion movement will be greater near the surface and in the upward direction. On sloping terrain, the greater amplitude of motion will be even closer to the surface, but the primary direction of motion will also have a horizontal or lateral component. Buildings and other structures that were built on top of an expansive soil mass create a confining pressure that tends to mitigate the ground movement. When the confining pressure of a building or other structure does not exceed the pressure exerted by expansive soil, there will be a movement of the foundation in the form of swelling or upward movement.

In conventional foundations, continuous perimeter beams and internal plinths are based at greater depths and are more heavily loaded than slab foundations. Consequently, the expansive soil that acts evenly on the foundations of a building will generally encounter more resistance from continuous beam or plinth foundations and less resistance from slab foundations. On the other hand, with beam or plinth foundations, away from beams or plinths the soil is slightly loaded, hence differential heave will occur below the foundation and away from it. This phenomenon, called "differential lifting", can be observed and measured with a topographical survey.

The results of numerous research programs confirm that the potential expansion of the clay is nearly exhausted when the confinement pressure is 100 - 120 kPa; for an expansive soil with free upper surface this means that expansion expires at about 6 - 8 m depth.

2.1 *Moisture movement in clays*

Moisture movement in a clay soil is the direct cause of swelling (Wise and Hudson, 1971). When moisture migrates into one of the more active clay soils, the soil increases in volume and the surface will heave vertically. Unless a clay soil undergoes an increase in moisture content, it will not swell.

Moisture movement is generally divided or classified as either saturated or partially saturated flow, the flow mechanics being quite different in the two cases (Lytton, 1969). Moisture flow in saturated soil takes place mainly in the large soil pores; in unsaturated soils the large pores are filled with air and the moisture moves primarily into the smaller capillary pores. The moisture content of saturated soil does not normally vary enough to cause serious swelling problems.

A soil-water system tends to reach an equilibrium between the soil, water, and air. Any disruption of this equilibrium will cause a movement of moisture and a corresponding change in volume until equilibrium is again reached. Rain, drought, humidity, wind, temperature, vegetation, load decrease, and construction work often change the soil system equilibrium, mainly near the surface.

Moisture movement in clay can be classified as hydrostatic, capillary, vapor, or osmotic flow (Lytton, 1969). They cannot be separated in the natural state.

Hydrostatic flow is caused mainly by the forces of gravity. When water is introduced at the surface of a soil, by rainfall or some other means, it is moved down through the soil by gravitational force. During irrigation or ponding, hydrostatic flow is increased as the layer of water increases the pressure, causing the moisture to go deeper into the soil.

Capillary flow is the moisture movement in the liquid phase caused by the surface tension forces that exist between water and soil. Water will migrate vertically downward in the capillary pores of a soil which is in contact with a source of free water. This downward migration of water will continue until the surface tension forces between the water and the soil are balanced. In addition, moisture in a clay moves upward to the surface, where it evaporates and dries out the clay. When the surface is sealed by a pavement or a waterproofing barrier the capillary paths are blocked and deep seated moisture will move upward and collect beneath the surface.

Vapor flow contributes greatly to the movement of moisture in soil. As the larger voids in a soil are filled with air, some equilibrium must exist between this soil – air system and the moisture in the soil. The moisture contained in soil is evaporated into the soil - air system and condensed out of it so that a state of equilibrium is continually maintained. If moist air reaches cooler soil, water will condense and cause an increase in water content of the cooler region.

Osmotic flow tends to occur between aqueous solutions having different solute concentrations. Due to the nature of the water adsorbed on clay particles the adsorbed phase will have a specific solute concentration. The clay type, the nature of the adsorbed cations, their position in the water structure, and other unknown factors determine the solute concentration in a soil.

Soil particles are negatively charged due to their molecular structure while the surrounding free moisture film is positively charged. However, since the soil particles are not free to move, the positively charged water moves towards the negative charge when there is an electrical potential difference in a clay soil.

2.2 *Possible remedies to the expansive clay problem*

For expansive soils to cause foundation problems, there must be fluctuations in the amount of moisture contained in the soil. If the humidity of foundation soil can be stabilized, foundation problems can often be avoided.

The main objective of remedial techniques is to allow the subgrade soil to reach a condition of moisture equilibrium and then prevent rainfall moisture from migrating into the drier clay strata to cause swelling.

Many different methods for controlling the expansive nature of certain clays have been tried with varying degrees of success (Wise and Hudson, 1971). Many of the methods currently used to control expansive clay soils can generally be sorted into the following three categories:

(1) prevention of moisture variation in the clay;

(2) removal of the dry soil and replacement with soil of desired and uniform moisture content; depending on the severity of potential expansion, non-expansive soils can be mixed with expansive soil to lower the potential for expansion to an acceptable level;

(3) wetting the dry soil in place to bring it to the same moisture content as adjacent soil;

(4) contrasting the pressure produced by clay: such method includes the use of concrete beams, piles, threaded rods and tendons. All these systems must be designed taking into account the tremendous pressure that an expansive soil can oppose to every attempt to compress or reduce volume with mechanical systems.

Category 1 methods are perhaps the most difficult since they require the use of geomembranes and/or a specific drainage system to maintain constant the moisture level. Category 2 is perhaps the easiest for a small structure, but it would be uneconomical for a large area such as a highway pavement. Category 3 may be a reasonable solution but much research remains to be done on such possible methods as ponding, water injection with a system of wells, and dry land farming. Category 4 may be suitable when the pressure produced by expansive soil is known to be relatively small.

It is possible to build successfully and safely on expansive soils if stable moisture content can be maintained or if the construction can be insulated from any soil volume change that occurs. The procedure should be as follows: a) Testing to identify any problems; b) Design to minimize moisture content changes and insulate from soil volume changes; c) Build in a way that will not change the conditions of the soil; d) Maintain a constant moisture environment after construction.

Category 1 methods consider that, for the expansive soil to cause swelling problems, there must be fluctuations in the amount of moisture contained in the foundation soil. If the humidity of the foundation soil can be stabilized, swelling problems can be avoided or minimized. Moisture control is an essential and potentially very cost-effective approach to managing problems associated with expansive soils. When using this approach, the existence of expansive soil is accepted and corrective work is focused on drainage strategies to keep the soil within acceptable moisture content values (Wise and Hudson, 1971). This approach has the dual aim of intercepting excessive moisture that could cause soil saturation but also to protect the soil from evaporation and other factors that would lead to excessive dehydration.

All forms of drainage control can help alleviate the negative effects of expansive soil. A system of French drains (a trench filled with gravel, with a perforated pipe at the bottom) or deep drainage systems can be particularly effective if high ground levels or low drainage conditions make large amounts of moisture in the foundation soil.

It is also necessary to consider that the expansive soils show particularly fine matrices and therefore produce significant capillary ascending heights, of the order of a few meters, which may saturate the soil well above the actual ground. Moreover, since vapor flow contributes greatly to the movement of moisture in soil, the drainage system shall afford a relatively large volume of voids, where the vapour can migrate without affecting the moisture of soil.

In Literature the fact is mentioned that no currently available technique can guarantee the success of a contrast action of the negative effects caused by the presence of expansive clays.

2.2.1 *Geosynthetic barriers*

Since swelling in expansive soils is caused by an increase in the soil water content, an impervious membrane on or near the surface which prevents moisture access to the soil will prevent swelling (Brakey, 1969). But if the moisture flow is upwards due to a relatively high water table, an impervious membrane will prove rather detrimental. Little research has been done with membranes and most of the information available is generally unfavorable from the economic and long-range point of view. This method seems to work well when first installed, but after a period of time the moisture content of the soil begins to increase and some heaving occurs again.

Hence a geosynthetic barrier should always be associated to a drainage system below it.

2.2.2 *Water injection in clay with a system of wells*

Some research has been carried out to find a method to accelerate the flow of water in a clay soil (Brakey, 1969). This can be done by reducing the length of the maximum flow path, and the most obvious way is to construct a grid system of vertical wells or drains to accelerate the vertical entry of water. The water is then given rapid entry deep into the clay where it can migrate laterally along a shorter flow path. As the spacing of the wells should be 3 m or less, the cost of such a system of many drilled wells will be very high. The results of pre-construction flooding in conjunction with a grid of vertical wells was reported by Blight and DeWet (1965): a grid of 100 mm diameter wells, 6 m deep, with a spacing of 3 m, was used.

Results in controlling clay heave with this system are controversial. Anyway from this solution came the opposite idea of using a system of wells for draining the water deep into the expansive soil.

3 GEOTEXTILE ENCASED COLUMNS (GEC)

Soft soils can be improved by various means, like sand columns, prefabricated vertical drains (PVD), vacuum consolidation, stone columns, concrete piles, etc. Stone column is one of the proven techniques to improve ground. However, stone columns construction requires certain minimum undrained strength of the soft soil to form columns, otherwise the bored hole collapses and the column cannot be formed. These limitations of conventional stone column are overcome by providing encasement in the form of seamless tubular geotextiles and these columns are called Geotextile Encased Columns (GEC). GEC include a high strength, creep resistant, seamless tubular woven geotextile encasement that confines the compacted sand or gravel column, as shown in Fig 1, thereby providing easy constructability and high bearing capacity even in extremely soft soil. GEC can resist the radial horizontal stresses in the columns through the circumferential resistance of the high strength geotextile. GEC have intrinsic flexibility and can support dynamic loads (like in railway embankments) without damage. GEC can also act as large diameter vertical drains (equivalent to a well), which can speed up the settlement and consolidation process.

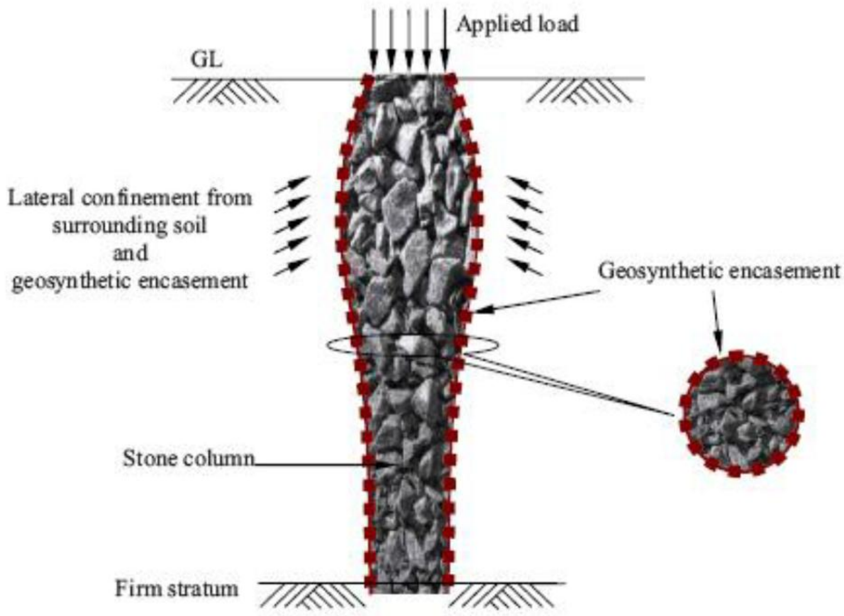


Figure 2. Schematic of geosynthetic encased stone column

4 CASE STUDY OF GEC IN EXPANSIVE CLAY AND DESIGN INDICATIONS

In the electrical substation (SSE) of Monteferrante, in Central Italy, in the year 2000, a green face geogrid reinforced soil wall, with a maximum height of 13.20 m and inclination of 70° on horizontal, was built to support the slope that was cut to get the space for the yard of the SSE (Rimoldi, 2017). The natural slope on which the SSE had to be built consisted of a powerful bank of grey clay to a depth of over 30 m, whose geotechnical properties are shown in Fig. 5. Two years after the SSE was completed, the pavements of the yard were lifted at the toe of the reinforced soil structure and a large tilt of two light poles was observed (Fig. 3). Few months later, a further significant increase in yard pavement lifting was observed, which reached a value of 400 mm; all the asphalt pavement of the yard was heavily cracked. The soil heave extended in amplitude, as if the outer surface had swollen, retaining the shape of an enlarged bell. This movement also affected the insulators poles, which have undergone a rotation of 10 % from the vertical. To get control of the situation three inclinometers were installed, with a depth of 24 m, and regular surveys were carried out. The surveys and the inclinometric measures substantially confirmed the results of the FEM model that was specifically developed:
- the displacements in a proximity of the toe of the reinforced soil structure were relatively small;
- displacements increased until 12 - 15 m away from the toe of the reinforced soils, ie in correspondence of the first transformer tank, and then decreased to essentially zero at 45 - 50 m away from the toe;
- the transformer tank, 70 tonnes in weight, positioned 10 m off the toe, was lifted approx. 200 mm. This gives the idea of the expansion force of the clay;
- vertical and horizontal movements increased after rainfall events, especially in the fall, while slowing down or even regressing in the dry and hot months;
- the soil showed the behaviour of expansive clays;
- the clays were already potentially swelling in the natural state, but the discharge of the stresses resulting from the cutting of the slope to form the yard, and the subsequent wetting by rainfalls, triggered the heave potential of expansive clays;
- the water table was at 24 m below the ground surface of the yard, hence the variation of humidity took place both for capillary rise and by infiltration of rainwater (including the snowmelt);

Figure. 3. Heave of the pavements of the yard in the electrical substation (SSE) of Monteferrante

- the major expansive effects were found in the area where the cutting of the slope had a greater height than 6 m, where confining pressures larger than 100 kPa were removed;
- the extension of the yard (100 m x 50 m), totally exposed to rainfall, made the entire surface and volume of the clay undergo a significant variation in the moisture content over the years, which has triggered the swelling behaviour of the expansive clay.

Given the geometric and stratigraphic situation, the Author, playing the function of Design Engineer for the restoration of the SSE yard, decided that one only option for eliminating the deleterious bulging effect of the expansive clay was technically feasible: build a control system to decrease and control the moisture of the clay, by means of GEC.

The design included:

- GEC of 800 m diameter, encased by a woven polyester geotextile with tensile strength of 300 kN/m in circumferential direction and 100 kN/m in longitudinal direction, filled with gravel mix soil, to a depth of 10 m;
- a prefabricated vertical drain (PVD) inserted in each column;
- all the area of GEC lined with a Geosynthetic Clay Liner (GCL);
- small drainage trenches (300 x 300 mm cross-section) below the GCL, connected to the outflow of PVDs;
- on top of the GCL: new yard pavement, with a granular base stabilized with biaxial geogrids of 40 x 40 kN/m tensile strength, and 70 mm thick asphalt layer.

Fig. 4 shows the cross section of the final design layout.

The rational for this solution is the following:

- Moisture in the expansive clay shall initially be decreased by GEC to eliminate / minimize the heave;
- Thereafter moisture shall be controlled to obtain an equilibrium state of the expansive clay;
- There shall be enough void volume in the draining system to allow vapor to migrate without affecting the moisture equilibrium of the expansive clay: hence relatively large columns are required;
- The GCL at ground surface shall provide the barrier at top for avoiding further flow of rainfall into the saturated clay and desiccation of clay in hot temperature periods;
- Water shall not collect and pond at the bottom of the columns: hence PVDs shall be inserted in each column, with the function of carrying the water at top of the columns;
- Drainage trenches shall be provided below the GCL for collecting the water carried upwards by the PVDs and the moisture moving upward from the clay in between the columns, thus avoiding that moisture concentrate below the surface barrier;
- Loads on the pavements from moving vehicles shall be distributed evenly: hence the pavement shall feature a granular base stabilized with biaxial geogrids.

The solution was analyzed by developing a finite element model with the PLAXIS 8.2 code, which took into account the behaviour of the expansive clay (Fig. 5). The model included four rows of GEC with a diameter of 800 mm and a depth of 10 m, at 3.0 m centres in square pattern.

In summary, the following results were obtained:

the introduction of gravel columns is actually able to reduce practically to zero the soil bulging in the yard area between the toe of the reinforced soil and roughly the transformer position (10 m off the reinforced slope), after about one year from installation of the columns (Fig. 6).

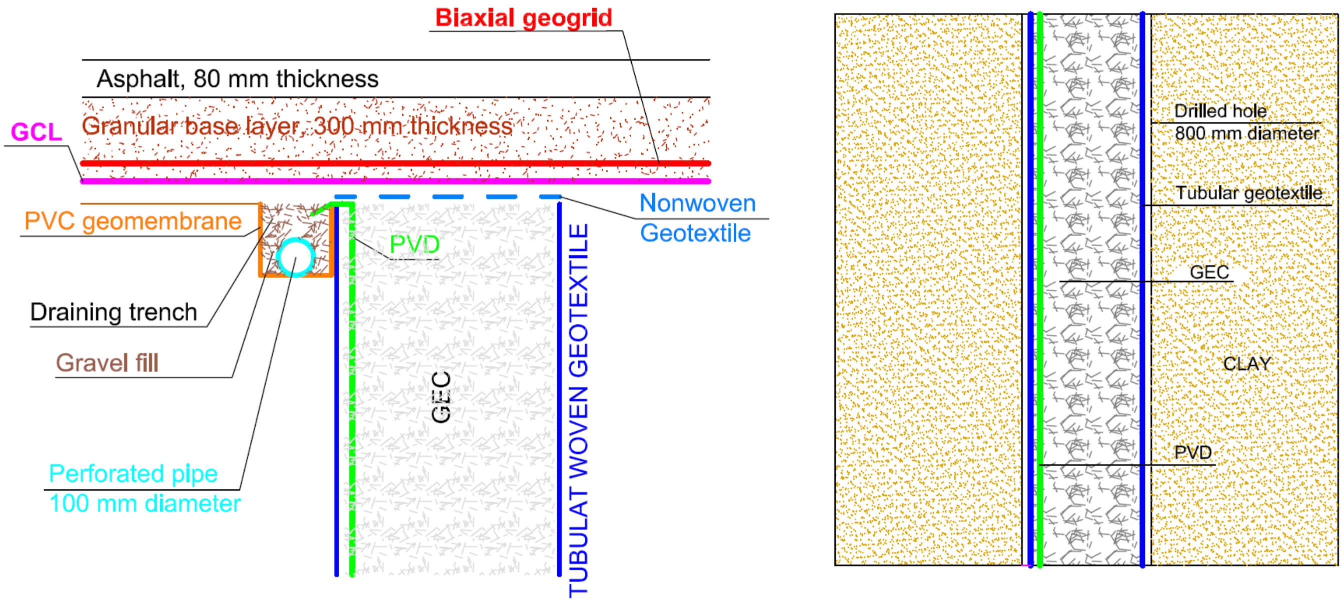
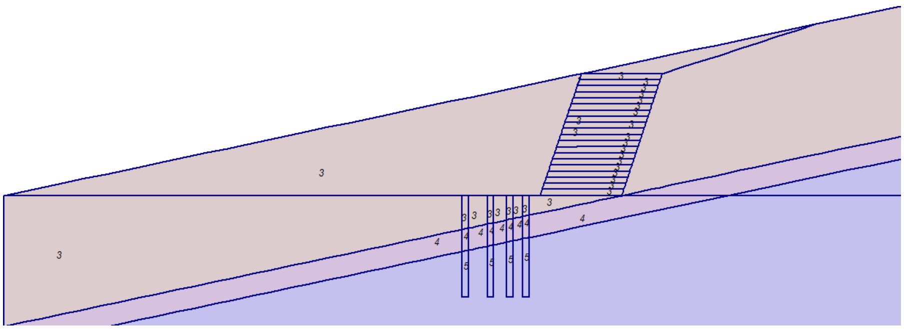


Figure. 4. Cross section of the final design layout



Dry unit weight	γ_{dry} = 17 kN/m³
Saturated unit weight	γ_{sat} = 20 kN/m³
Permeability	k = 8,640E-05 m/day
Drained cohesion	c' = 20 kN/m²
Undrained cohesion	c_u = 200 kN/m²
Drained friction angle	φ' = 20°
Undrained friction angle	φ_u = 9°
Dilatancy angle	ψ = 0°
Young modulus	E = 7,000 kN/m²
Poisson coefficient	ν = 0.35
Shear modulus	G = 2,590 kN/m²
Oedometric modulus	E_{oed} = 11.200 kN/m²

Fig. 5. FEM model of the solution with GEC and clay properties used in the model

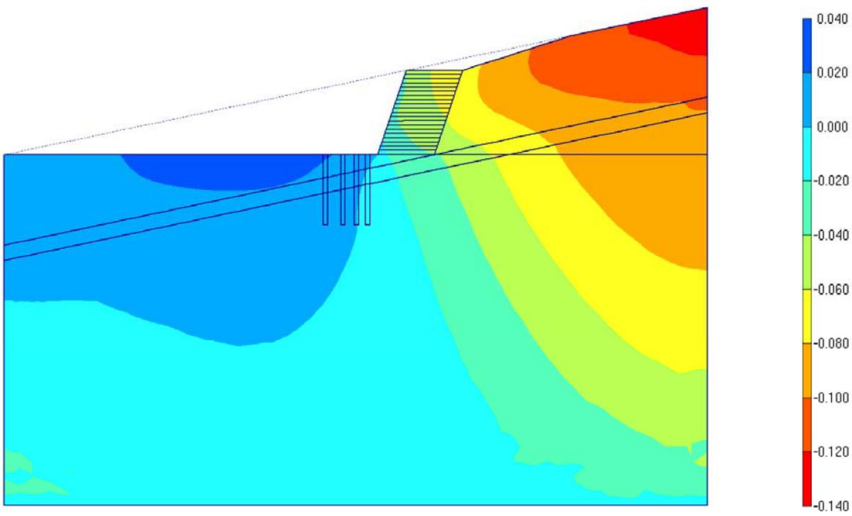


Fig. 6. Results of FEM model: plot of vertical displacements after 1 year

4.1 *Design indications*

The following design indications can be derived for GEC used to control the heave potential of expansive clays:

- the area showing expansive clay activity shall be treated with the installation of GEC;
- parallel rows of GEC shall be installed, with a diameter of 600 - 1000 mm and a depth of 8 - 10 m, at 2.0 - 4.0 m centres in square pattern; GEC spacing shall be smaller were expansive behaviour is more intense and/or where larger discharge of stresses (from slope cutting, removal of heavy loads, etc.) occurred;

- the area treated with GEC shall be lined with a GCL to avoid further rainfall flow into the expansive clay and desiccation of clay in hot temperature periods;
- a draining system, possibly including PVDs inside the columns and small trenches below the GCL, shall be provided;
- when a pavement has to be built, a granular base stabilized with biaxial geogrids is recommended.

4.2 *Installation method*

Since the first development of GEC, two installation methods have been mainly used.

The first option (Alexiew, 2005) is the displacement method, where a closed-tip steel pipe is driven down into the soft soil followed by the insertion of the tubular geotextile and sand or gravel backfill. The tip opens, the pipe is pulled upwards under optimized vibration designed to compact the column. The displacement method is commonly used for extremely soft soils (e.g. cu < 15 kN/m²).

The second option (Gniel and Bouazza, 2010) is the replacement method: an open steel shaft is driven deep into the bearing layer and the soil within the shaft is removed by auger boring. The replacement method is preferred for soils with relatively higher penetration resistance or when vibration effects on nearby buildings and road installation have to be minimized.

In the present project a third installation method was used, which is a simpler variation of the replacement method without using the open steel shaft: in fact in this case the clay featured high undrained cohesion, hence drilled holes were not collapsible at short time. According to design level, excavation was carried out. The excavated surface was cleaned and smoothened. The tubular geotextile was cut as per the design length of the column. A circular loop, made up of 10 mm steel rod, was fixed to the one end of the tubular geotextile. The geotextile was wrapped around the circular loop and locked. The PVD was inserted inside the tubular geotextile. The other end of the tubular geotextile was stitched with steel wire. The column was excavated with drilling machine to the required diameter and depth. The tubular geotextile was inserted into the excavated column by hanging it with the help of the steel loop. In order to ensure that the tubular geotextile had reached the bottom of the column a weight of stones was added into it. Coarse gravel and sand mix was poured from top with the aid of a hopper in lift of 1 m and compaction of gravel was carried out by tamping. At the end, the top of the column was covered with a nonwoven geotextile to achieve separation. Draining trenches were formed and the PVDs top ends were connected to the trenches. GCL was laid. The granular base stabilized with biaxial geogrids was made. The asphalt was spread and rolled. The construction sequence is shown in Fig. 7.

4.3 *Monitoring results*

After two years from GEC installation no more cracks in the asphalt were observed, while the vertical heave of the yard, periodically measured, was reduced from 400 mm to 10 – 20 mm, and further decreasing in time.

These actual results are in very good agreement with the expansive clay and GEC behaviour anticipated by the FEM model.

Such excellent results show that GEC were very effective not only in controlling the moisture content of the expansive clay but, due to GEC drainage capacity, initially the water flowed off the saturated clay into GEC, thus deflating the already occurred heave.

5 CONCLUSIONS

The capacity of GEC to reduce the heave potential of expansive clays have been discussed.
Through a successful case study it has been showed that GEC can be very effective in reducing or eliminating the heave potential of expansive clays by controlling their moisture and by draining the water saturating the clay close to the ground surface.
Simple design criteria have been provided and a simple installation method has been shown, which allow to include GEC in the design of these difficult geotechnical problems.

Figure. 7. The construction sequence (from right to left and top to bottom): excavation up to desired level; fixing the circular steel loop to tubular geotextile; excavation with drilling machine; lowering GEC in the drilled hole; filling through hopper; filled column; covering end of column with nonwoven geotextile; rows of completed GEC; placing the GCL on top of GEC.

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