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Improvements to Loose Soil

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Abstract

The terms loose, compressible or organic refer to the soils that comprise the surface layers of the soil, including soil, sludge, peat, organic soils, as well as soils that have come from land fillings with unconcentrated homogeneous or non-homogeneous materials. By the term improvement or strengthening of a soil material, be it natural or breakable, we mean the processing of this material which is aimed at improving its geotechnical properties (durability, erosion, compressibility, permeability, porosity, physical characteristics, mechanical properties etc.). Many degraded areas in terms of soil characteristics, are used for construction works, either due to a lack of space (peri-urban areas) or because of increased requirements for the geometric characteristics of large infrastructure projects. For the use of these soils, in such or other cases, methods of improving and enhancing their geotechnical properties are necessary to be used.

Keywords: loose soils; soil retreats; consolidation methods; condensation; solidification; drainage; soil liquefaction.

1. Introduction

Land subsidence is defined as the widespread phenomena of soil surface concessions caused by the removal of fluids or the collapse of natural and artificial shells. Soil surface recessions (Subsidence) are differentiated from settlements caused by additional (external) charging [4]. Depressions - soil retreats are created where the soil layers are soft / compressible (i.e. low strength), swelling or chemically eroded, resulting in caves and various forms of sinks. In the case of soft / compressible (low strength) soils there are soil settlements and cracks in the works, when they are carried out on loose or soft deposits on the surfaces of mountain slopes. These territories, because they are very vulnerable to erosion by rain and weaken even more when taking heavy rains, form sinkholes that can be transformed into landslides.

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The aim of this paper is to present the causes of territorial concessions, as well as the measures that need to be taken in order to improve and strengthen the resistance of loose soils, so as to protect works based on these soils.

2. Soil Retreats

The main causes of soil retreats are: Physical consolidation of clay formations (also referred to as sedimentation). The removal of fluids from the soil and consolidation due to changes in the geostatic field of stresses. Oxidation of organic soils as a consequence of the degradation of the level of aquifers. The collapse of erosive cavities, mainly in carbonate formations, due to progressive erosion, or due to increased roof loads. The collapse of anthropogenic cavities (e.g. galleries, mining chambers, hydrocarbon pockets, etc.). The main cause of vertical deformations is the natural process of consolidation of clays. The distribution of soil recesses is affected by the thickness of the consolidating materials. Soil settlements may occur in the form of differential or non-differential distortions. Surface cracks reflect the occurrence of differential territorial concessions. Differential soil recessions occur when: The thickness of soil compressors differs due to the anisotropic deposition of sediments. The thickness of soil compressors is varied due to fluctuations in the background depth of the background formations. The thickness of the compressors of soil formations on each side of the cracks is differentiated. The most commonly observed impacts of soil concessions are: Soil cracks. Failures of rigid building structures. Damage to linear networks of utilities (electricity, water supply, etc.) as well as to road works. Advance of the sea inland (along coastal areas). Destruction of water wells [4].

3. Methods of Strengthening Loose Soils

Techniques for improving and enhancing soft soils are comprised of interventions to change the structure of the problematic soil in order to improve its mechanical characteristics and increase its bearing capacity. In general, the strengthening material is applied to soft - loose soils such as:

- loose sands, especially when saturated
- loose and medium density saturated sand and gravel under seismic loading
- uncharged or sub-consolidated clays and mud [3].

The methods utilized are the following:

3.1 Mechanical Soil Compaction

It is the artificial increase of soil density by mechanical means. Mechanical compaction is applied to soil improvement, on which mainly light constructions are to be erected, ones that are rather not affected by large and uneven settlements. This mechanical compaction reaches a small depth, is achieved by charging, through rolling or tampering, driving of stones or piles into the soil, vibration, through a dynamic method or through soil drainage [5].

Soil compaction is applied to:

- stabilize the soil for the foundation of technical works
- create a more durable terrain for walking and general space formation.
- promote homogenization of foundation soil.
- aid in the creation of solid land plots, the construction of roads, etc.
- provide support in the construction of land barriers.
- improve the carrying capacity and reduce the potential settling of soil excavation materials etc.
- increase passive soil resistance in lateral loads.

Soil compaction manages:

- ✓ to increase the shear strength and bearing capacity of the soil.
- ✓ to reduce compressibility and therefore all subsequent soil settling in external load conditions.
- ✓ to bring about a reduction in soil permeability.
- ✓ to increase soil resistance.

A) BY LOADING

The preloading method is applied to fine-grained soft soils (mainly clay), aiming at their consolidation. It is the simplest and most cost-effective way to improve soil, while the time requirement is regarded as a disadvantage. Preloading is mainly applied to road works and building foundations, provided that the construction loads are not highly concentrated. The method consists of accumulating soil material (embankment preload) and placing it in heap on the site that is to be improved, for as long as it is required in order to bring the site to proper strength levels. The method is effective, as long the preloading tension is greater than the soil consolidation tension. In other words, the temporary loads to be applied, must be greater than those that had previously been applied to the ground. The loads commonly used are sand, gravel or stones. The total loads used must not be less than the weight of the completed technical work. It is a common method in port-loading works for boulders. If the soil to be compacted is comprised of sand, compaction occurs rapidly with a reduction in pore volume, but if it is mainly clay, it takes a rather long time to complete. The load is removed, either in part or completely, after compaction of the foundation soil is completed. This method is quite costly and its implementation takes a long time [5].

B) BY CYLINDER OR TAMPERING

This method compacts loose sandy soils but also clayey soils, provided that the latter are not saturated. For sandy soils it is preferable to tamper rather than roll, since the vibrations tampering causes facilitate compaction. This method also applies to the compaction of embankments, but must be carried out in 20 to 30 cm thick layers.

C) BY INSERTING GRAVEL, STONES, OR STAKES

Gravel and stones are pushed into the soil, through tampering or pile driving, resulting in its surface compaction. In order to compact the soil to a greater depth, wooden piles are used to open holes in the soil, which are then filled with compacted gravel. This method is mainly applied to types of soils (as in silty and argillaceous lands), in which vibratory compacting has no remarkable results. It is characterized by compound action as it achieves:

- an increase in cargo loading capacity,
- an increase of the equivalent shear strength,
- an acceleration of subsidence on argillaceous soils due to consolidation,
- a promotion of compaction of sandy soils [5].

The root piles are used in cohesive soils, usually broken up, and are characterized by high construction speed. For the intubation of the opening a pipe is not used, resulting in the pile sustaining abnormalities and rhizomes, to which its characterization is due. The diameter of the piles is between 75 and 250 mm and the reinforcement consists of a single central rod when the diameter is less than 140 mm, or a cage when the diameter is greater. Stronger compaction and particularly in greater depths, is achieved through the insertion of concrete compaction piles [3].

D) BY VIBRATION

Loose sandy soil, with the vibration caused by a vibrating apparatus in operation on the soil surface, or within holes in the ground, with simultaneous impregnation with water, undergo rearrangements of their grain, becoming significantly denser. Any nascent funnel is filled with gravel (Sandpiles).

E) BY DYNAMIC METHOD. MENARD METHOD

In 1970 Louis Menard applied a new soil compaction technique, which he initially called "heavy tampering", with the scope of application on artificial deposits or natural, sandy soils. It was quickly proven that the method can also be applied to saturated clays or alluvial deposits. Henceforth, this method has been known as "Dynamic Compaction". Dynamic compaction improves the mechanical properties of compressible soil, up to a depth of 10 to 30 m. This is achieved by the repeated drop from a relatively large height of 15 to 40 meters, of a specific weight of several tons, based on a predetermined drop schedule, in terms of time and positions, depending on the project (Figure 1).

Figure 1: Application of the dynamic compaction method, which consists of dropping large weights onto the ground. (Source: Kaltsios 2012) **[3]**

Dynamic compaction is implemented on large construction sites and requires heavy equipment. The application of the method is avoided in the case of existing structures at distances less than 30 m, as the vibrations of the ground may cause cracking. Dynamic compaction is particularly suitable for granular (loose sandy) soils; but it can also be applied to mixed terrain of granular and cohesive materials.

The vibrations caused by the drop of the weight are relatively large and require attention in the design and implementation of this method. Before the decision on the application or not of the method for a specific plot, the following should be considered:

a. Detailed soil investigation, which includes on-site compressibility tests, Vane tests, compressibility and penetration tests.

b. Accurate determination of Atterberg limits, water content and particle size composition, for all layers affected by compaction.

c. Complete determination of soil layering, with dense drilling so as to reveal any existing local lenses.

d. Compressibility tests on the dynamic "compressor meter".

The area to be compacted must be properly prepared for the machine, which weighs 60 to 200 ton, and should have very good drainage of both rainwater and any water that will rise to the surface because of compaction. The evaluation of compaction is done with a compression and penetration meter, radioisotope methods, measurement of apparent weight, or other suitable methods [5]. Table 1 shows the effectiveness of compaction methods on different types of soils. Table 2 includes methods for stabilizing road paving soils.

3.2. Soil Drainage

After removal of water from unstable soils, such as wet loamy or clayey ones, their strength is improved. The drainage is usually done through natural flow, or through pumping, but it can also be achieved by direct current in one-inch iron piping driven into the ground, as positive poles, close to adjacent tubular drainage shafts of 210 mm diameter, as negative poles. The flowing electric current drives the water through the very thin soil pores into the well. Preloading is most effective when combined with the use of vertical drainage, which consists of creating vertical columns of increased permeability in the soil, in order to accelerate the consolidation phenomenon (Figure 2). The drains communicate with a horizontal high permeability layer (e.g. a granular layer on the ground surface under the preloading embankment). In this way the water within the pores flows horizontally toward the nearest drainer and then vertically to the drainage layer (Figures 3, 4, 5). The method is applied to fine clay soils, in which settlement from secondary consolidation is not significant. The drains may consist either of sandpiles or gravel piles with a usual diameter of 0.50-1.0 m or by geocomplex strip drains, with a usual width of 10 cm.

Table 1: Areas of efficiency of improvement methods, depending on soil type. (Source: Kaltsios 2012, [3] Platis-Vgenopoulou 2016, [7]).

Efficiency areas of improvement methods				
Soil type / particle size	**Gravel 30 - 2,5 mm**	**Sand 2,5 - 0,07 mm**	**Silt 0,07 - 0,0017mm**	**Clay 0,0017 - 0,0001mm**
Precharging	✓	✓	✓	✓ (> 0.0002 mm)
Dynamic compaction	✓	✓	✓	✓ (> 0.0005 mm)
Concrete injections	✓	✓ (> 0.7 mm)	X	X
Clay injections	✓	✓ {> 0.17 mm)	X	X
Chemical additives injections	✓	✓	✓	✓ (> 0.0006 mm)
Displacement or compaction injections	X	✓ {> 0.2 mm)	✓	✓ (> 0.00014 mm)
Column vibration	✓	✓	✓ (> 0.03 mm)	X
Pile compaction	✓ (<9 mm)	✓	✓ (> 0.07 mm)	X
Explosives	✓ (< 14 mm)	✓	✓ (> 0.016 mm)	X
Electric osmosis	X	X	✓	✓ (> 0.00014 mm)
Heating	X	X	✓ (<0.016 mm)	✓ (> 0.00014 mm)
Layered compaction (wet only)	✓	✓	✓	✓
Layered compaction, by cement or chem. additives	✓ (< 11 mm)	✓	✓	✓ (> 0.00026 mm)
Armed soil	✓ (< 30 mm)	✓	✓ (> 0.00026 mm)	X

Table 2: Stabilization of paved soil (Source: Kaltsios 2012) [3].

STABILIZATION OF SOILS BY THE USE OF CEMENT, LIME, BITUMEN OR PLAIN COMPACTION (KOLIAS 1979)			
Type of stabilization	**Affected soil qualities**	**Results of stabilization**	**Position of stabilized layer on the road surface**
Mechanical stabilization	- Grain size grading - Plasticity - Moisture content	Improvement of compaction capacity and other properties of the mixture that depend on the original properties of the materials.	Base - Sub-base (insufficient for heavy traffic roads).
Stabilization by the use of lime	- Moisture content - Atterberg limits - Soil structure	Ability to compact at increased moisture conditions. Permanently reduce of vulnerability to water and frost effects. Increase in strength.	Subsoil - Sub-base. Rarely used in light traffic roads.
Bitumen stabilization	-Strength	Creation of a flexible layer, with increased bearing capacity, resistant to water and frost influence	Mainly used for base construction, rarely for sub-bases
Cement stabilization	- Strength - Soil structure	Creation of a flexible layer, with increased bearing capacity, resistant to water and frost influence	Base, sub-base, subsoil, self-supporting lightweight road surfaces with fine asphalt coating

Figure 2: Geocomplex vertical drains are placed in the ground by using a special crane with a vertical guide, in close in-between distances of 2-4 m (Source: Kaltsios 2012) [3].

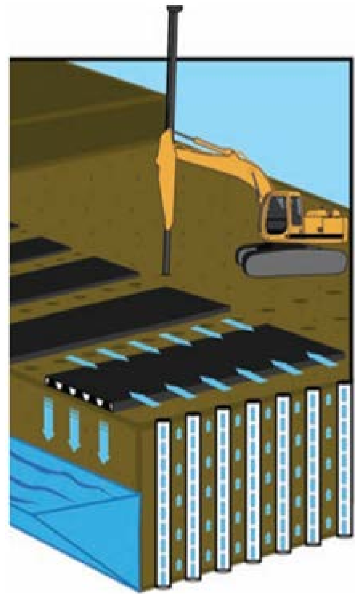

Figure 3: Increased horizontal permeability and the short distance between the piles greatly limit the time of consolidation (Source: Kaltzios 2012, **[3]** Platis-Vgenopoulou 2016, **[7]**)

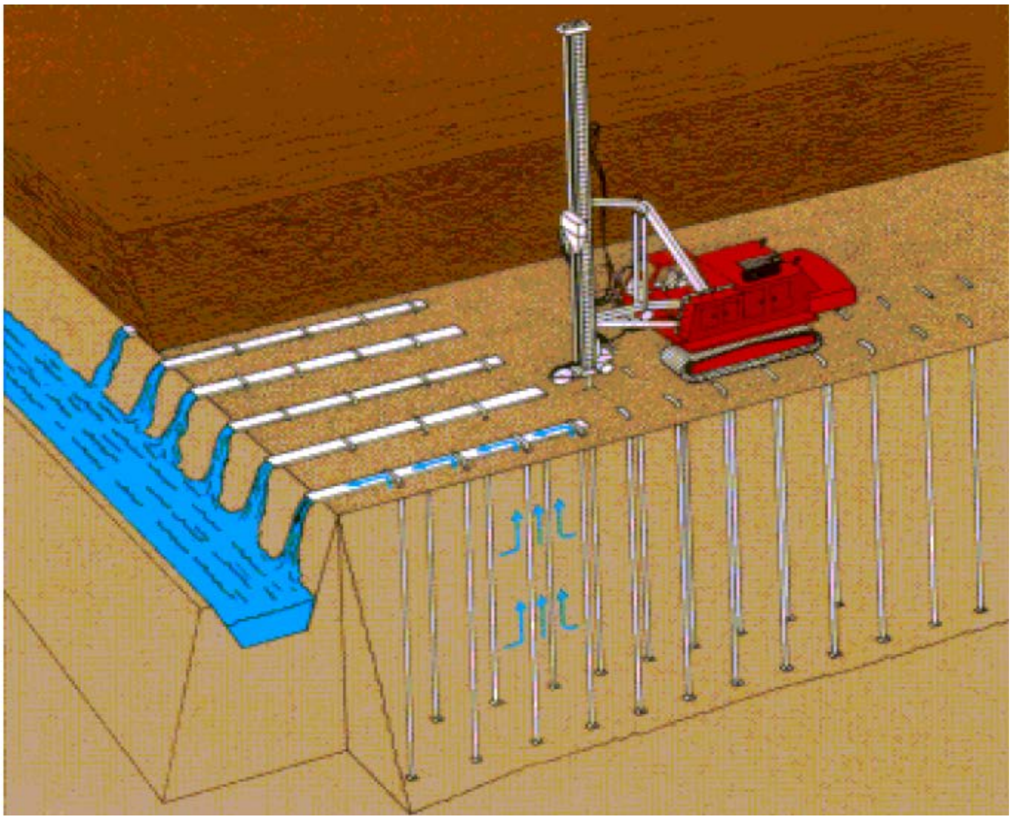

Figure 4: Schematic arrangement and mode of operation of the vertical synthetic drainage systems. (Source: PETEP 2006) [6].

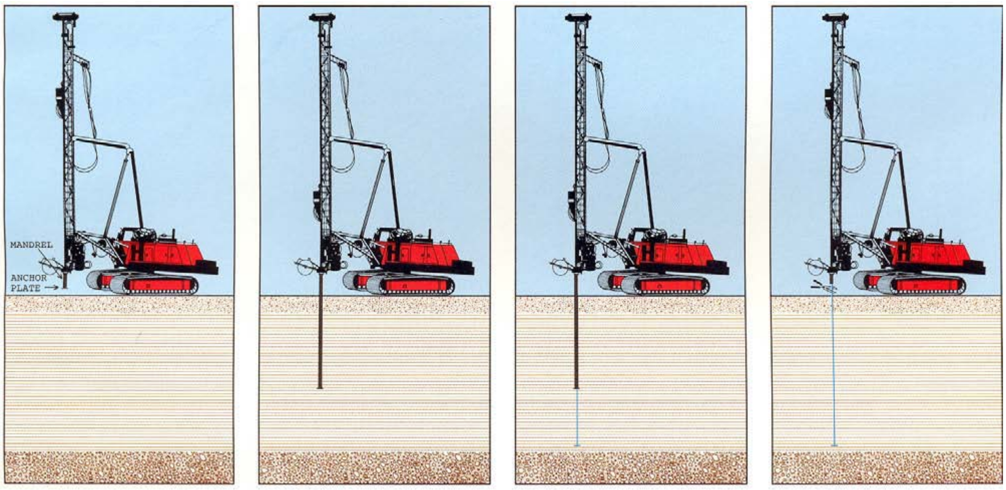

Figure 5: Schematic illustration of the process of placing vertical geocomplex drains in the ground (Source: Platis A.D. 2007) [8].

3.3 Soil Consolidation with Chemical Methods

Soils composed of non-cohesive components, such as sandy and sand-gravel, may be improved by filling the gaps and sticking of grains substances as set out below. In this way the soils acquire the properties of a rock and no longer suffer deformations under the action of the loads thereon. This method is also called fossilization of the soil. Additionally, this method is applied in order to make the wet cuttings between sheet pile walls for drying, more watertight, since by the fossilization of the soil below the bottom of the trench the influx of water in the pit will be significantly reduced. The emulsion or cement mortar injection is done through tubes perforated on their lower end and that are driven into the ground either through impact or rotation. The smaller the pores of the soil are, the finer the components the injection should contain. Thus, a cement mortar is used in a ratio of about 1:4 for sandy soils and a cement emulsion for sand. For fine sand and clay-sand soils, the implementation of the method is done under certain conditions, following extensive investigative work. Wolfsholz in the case of sandy soils recommends an injection with tube, bearing fins along its lower edge, which during rotation by punching, loosen the soil, while at the same time pressurized water is pumped into the tube. During lifting by rotation, the place of the water is taken by cement mortar, further contributing to consolidation. Another method consists of the injection of water under pressure to loosen the soil, and then, through the same tubes, a cement emulsion is injected under a pressure of usually 5 to 7 atmospheres, while other intermediate tubes at the same time pump out groundwater to facilitate the spreading of the cement emulsion [5].

A) BY CHEMICAL SUBSTANCE BINDERS

The deep soil mixing includes the pressurized injection of special fluids, the coagulation of which leads to the reinforcement of soils.

Depending on how the binder acts, there are the following categories:

- Dampening injections, through which the binder penetrates the soil and fills up the soil pores.
- Injections of displacement or compaction.
- Embedding injections, by which the binder welds cracked rock mass.
- Land filling injections, through which karst, holes or gaps of artificial embankments are filled.

Usual types of binder injections are cement suspensions or a mixture of soil (e.g. betonies, sand) and cement, or even soils in water, as well as chemical solutions, usually silicate or polymeric materials. If stabilizing of the properties of soil-cement mixtures is required, stabilizing or other additives are used, such as accelerators and retarders. The reinforcement with injections can be applied in almost all range of soils (coherent and non-coherent) and in soft rocks, provided that the rock is fractured, with communicating cracks. On the other hand, it cannot be applied to soils with low permeability, such as clays. The advantages of the method are the high speed of application, the relatively low cost and the absence of noise and vibrations during application. The choice of the binder material depends on the type of soil and its granulometric classification. In general, cement stabilization has the widest range of application. In the case of permeable sandy soils, cement suspensions with high cement to water ratios are used if high strength is pursued, while chemical solutions of special silicates or polymer products are preferred when the permeability is lower, as is the case with clay soils.

This category includes the Joosten method, which consists in the fossilization of sand layers by injection, initially by dissolving silicic acid and then through the same tubing by dissolving of a salt, which finally forms within the soil pores a silica gel which adheres to grains and fossilizes the soil. The dissolution of the silicic acid is compressed within the induced tubing at a pressure of 1.5 atmospheres in succession and per inch of 0.50 m insertion, until the tip reaches the lower surface of the layer to be consolidated. The dissolution of the salt is similarly compressed during the lifting of the tubing. These dissolutions expel the water from the soil pores; make it possible to fossilize ground filled with groundwater. The presence of clay within the layer makes it difficult and often impossible to fossilize. With regard to the compressive strength of the fossilized soil, it depends on its composition and for fine sandy soils roughly amounts to 10 to 30 kg/cm^2 and in gravel at 40 to 90 kg/cm^2.

B) BY INJECTION OF BITUMEN MATERIALS

While the two previous methods, apart from significantly improving the strength of the soil, also reduce its permeability, the present method achieves only a reduction in the permeability of the bitumen injected ground. Because the bitumen price is higher than cement, it should be used only when cementing is not possible, as is the case with fine sand. The Shellperm-made asphalt emulsion has the fluidity of water and therefore penetrates the thin pores of the permeable soil as well as water. The injection is carried out by pipelines embedded in the soil similar to the method of paragraph A. The bitumen emulsion, when pressed with relatively little pressure, displaces water from the soil pores without being mixed therewith. In the emulsion there are substances added during preparation, which cause its coagulation within a certain period of time. Thus, around the tip of the tube a sealed volume of soil is formed, which is approximately spherical in shape. When the tube is moved by retraction, the volumes are approximately cylindrical in shape. With proper spacing of the injections, the formation of a water-impermeable wall is achieved.

C) INJECTIONS OF SUSPENSIONS OF MILLED FLY ASH (MFA) [9]

Fly ash is mainly used by the cement and concrete industries, but it is also used in impregnation injections to improve soil reinforcement. Upon investigation of I.N. Markou (Laboratory of soil mechanics and Foundations DUTH) the results obtained regarding the improvement made by soaking with suspensions of fly ash on the characteristics (shear strength and permeability) and at deflection parameters of sand showed that: the improvement of permeability of sand caused by impregnation with MFA suspensions is comparable with or better than that resulting from the soaking of sands with other types of binder type suspensions. Impregnation with MFA suspensions leads to an increase in stiffness and a reduction in the deformability of the sand while at the same time a satisfactory increase in the consistency of impregnated sand is observed.

D) BY ELECTROCHEMICAL METHOD. CASAGRANDE METHOD

By directing a continuous electric current through an aluminum electrode into clayey soil, permanent consolidation of the soil between the electrodes is achieved, as well as a reduction in the moisture thereof, by the formation of aluminates. Of particular interest is the technique of electrical osmosis, which aims to the soil consolidation, consisting in the generation of electrical potential that causes the flow of groundwater to the cathode. Cathodes are usually made of perforated iron pipes designed to remove water.

3.4 Soil Removal

The replacement of "soft" soil with suitable material (gravel, crushed quarry, etc.) can be carried out in a variety of ways, such as excavation and embankment, displacement under the same weight of decontamination or displacement by means of explosives.

Unsuitable soil bearing direct foundation, without room for improvement, should be removed. If the thickness of the inappropriate layer is small, then it shall be excavated and the foundation will be grounded on the underlying resistant layer. However, if the thickness of the inappropriate layer is large and the soil is very unstable, then, in order to reduce the cost, instead of digging it will be displaced by the accumulation of gravel or stones on it. These materials by their own weight overcome the resistance of the unstable soil, displace it laterally and substitute it. This method is common in the construction of port projects. Occasionally, this displacement of the soil is assisted by small explosions, which occur under the surface of the unstable layer through penetrated tubes. Scheidig proposed, in some cases, instead of seeking to improve, to aid in the deterioration of the subsoil, with partial soil removal and interference of a more compressible layer, to equalize settlements. The replacement method is advantageous only when the unsuitable ground is characterized by a limited depth layer.

3.5 Thermal Action

A) GROUND HEATING

This method is the less economical than the previous ones and is applied to loose soils with high permeability and consists in the creation of pin holes and insertion of a very hot air and fuel mixture into the ground. The pressure is 1.5 times the atmospheric pressure. Temperature range from 300^oC to 1000^oC resulting in compaction due to water loss and increased of active stresses [5]. At temperatures of 550^oC the ability of clay to swell is destroyed while at 1000^oC sand grains melt and create artificial cementation.

B) COOLING

The cooling method results in the creation of frozen water blocks outside the surface of the structures. Figure 6 presents a soil cooling layout for stabilization.

Figure 6: Soil cooling layout for stabilization. (Source: Platis-Vigenopoulou 2016) [7].

Soil cooling is a construction technique used in cases where the soil needs to be stabilized so as not to collapse, when next to excavations. Tubes are placed in the soil and then coolants run the pipes, thereby freezing the ground. Frozen ground is in some cases as hard as concrete. Typical applications of this method include vertical wells, deep excavations (Figure 7), tunnels, construction support and confinement of hazardous waste [7].

Figure 7: Application of the cooling method in a deep excavation. (Source: Platis-Vgenopoulou 2016) [7].

3.6 Strengthening with Arming

The soil can be improved by introducing local arming components. This can be done by inserting metallic strips in the ground (reinforced ground), using geotextiles, and inserting steel rods or by riveting (soil nailing) or by inserting root piles [2].

A) ARMED EMBANKMENTS AND ARMED SOIL

Construction of sizeable embankments has now become a standard procedure for roadworks. To the extent that the environmental conditions allow it, and their anti-seismic design is acceptable, the height of the embankments may be large. Embankments of up to 50 - 60 m in height have been built, either by benches or armed. Prerequisites for the proper construction of an embankment are the right choice of materials, the proper preparation of the bearing ground, the optimization of the compaction process and the general assurance of suitable conditions to achieve the stability of construction and to minimize embankment and subsoil deformations. In modern times, the first to use reinforced earth to build a retaining wall was the French Architect Henri Vidal. In 1963 he internationally patented the method Terre Armée or Reinforced Earth, the method based on the frictions that develop between the tendons and the grains of the soil material **[11].** More specifically, their construction is based on the simple principle, which is due to the significant friction between the soil molecules and the reinforcement plates, which, when brought into contact, in combination with similarly distributed reinforcement plates and banking material, produce the armed earth, a composite material with many advantages as shown below (Figure 8): [17]

- High resistance to static and dynamic forces.
- The structures are flexible and for this reason they are efficiently adapted to deformations under the surface of the soil.
- The application is fast and simple, offering significant savings, in time and cost.
- Armor plates are made of galvanized steel, or synthetic carpets, with typical horizontal layers, per 80 cm.
- Facade elements are made of concrete, and are separated by joints, offering flexibility, which is one of the determining factors for the use of armed land.
- These elements are connected to the reinforcement plates and are placed alternately. This provision ensures the coherence of the elements in the event of a significant subsidence, and also serves to place the prefabricated facade elements.
- Prefabricated facade elements can be replaced with alternative materials, such as special mesh, in specific applications.

B) GEOTEXTILES-GEOGRIDS

This concerns the soil improvement with the introduction of geotextiles, geogrids, or by inserting steel rods and root piles nailing. It applies to large engineering projects (roads, landfill construction, etc.), as well as in building construction projects. Geotextiles and geogrids act as reinforcement through their shear and anchoring mechanism in the surrounding soil. Geogrids are made of polypropylene or high-density polyethylene. Geotextiles are made of thermoplastic materials such as polyamides, polyethylene, polyesters, polypropylene, polyvinyl chloride (PVC) and polyethylene chloride and are distinguished in woven and non-woven fabrics.

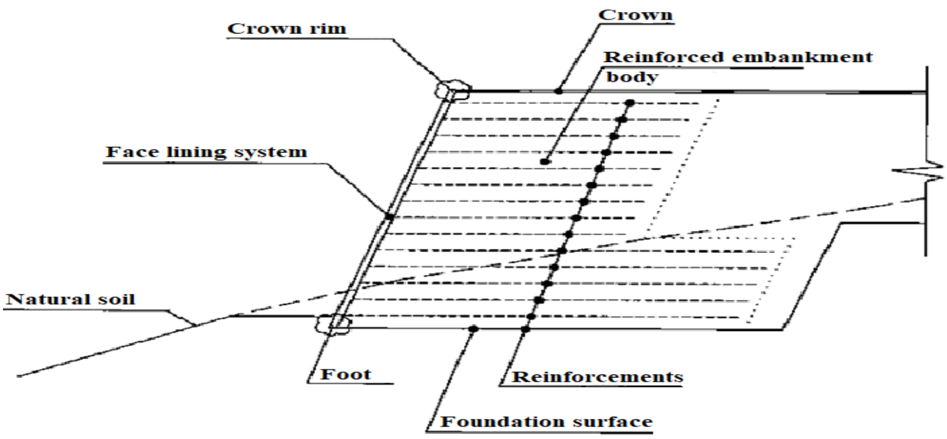

Figure 8: Construction method of reinforced embankment (Source: Naskos 2007) **[12]**

Their weight ranges from 70-350 gr/m^2 [13]**.** Geotextiles have significant mechanical and hydraulic properties and are therefore commonly used:

- in transport network projects (roads, airports, railways, etc.), where they act as separators and / or filters in areas facing groundwater hazards.
- as basic materials in the design and construction of a variety of marine and hydraulic engineering structures such as overlays, reefs and other breakwaters, tubular structures and deposition structures of organic and chemically infected mud.
- as materials in the reinforcement of structures, such as foundations, retaining walls, slopes and embankments, in which they provide elastic resistance to the soil, enhancing its characteristics. Soil stabilization using rigid biaxial geogrids is a modern, fast and economical method that takes place completely on the surface of the weak soil without the need for excavation or any other disruption of the existing, "weak", soil material. Layers of biaxial geogrids are placed directly on the surface of the weak soil and then covered with layers of compacted granular material of appropriate size and good grading (Figure 9) [7].

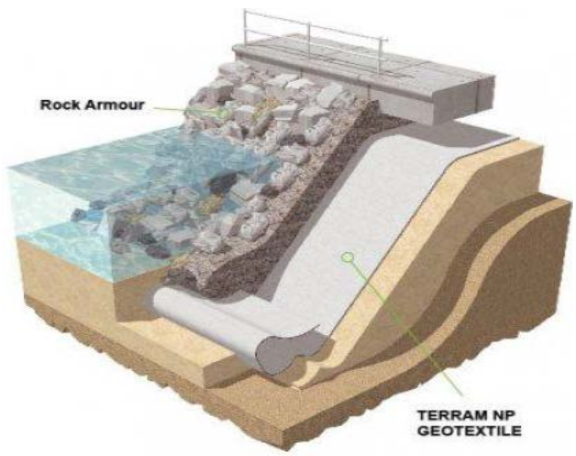

Figure 9: Geotextiles in the construction of a breakwater (Source: Platis-Vgenopoulou 2016) [7].

C) GEOFOAM

The use of geofoam EPS in geotechnical applications in conjunction with soil materials began in Europe and the US in the early 1970s and involves the use of expanded EPS polystyrene foams in the form of prisms, because it has a very small specific weight (about 1/100 compared to soil materials) and a very high strength to density ratio. According to Hovart (1995, 1997) EPS geofoam prisms are currently used, amongst others in many geotechnical applications such as:

1. Thermal insulation, 2. Lightweight embankment, 3. Compressible insert 4. Shock damper, as well as in the following project categories:

- Foundations of road projects in loose-small strength soils
- Improving slope stability
- Replacement of soil embankments in retaining walls
- Support of structures
- Replacement of foundation preloading process.
- Light fillings behind bridge abutments (transitional embankments).

These applications ensure the long life of the project resulting in minimizing maintenance cost~~s~~, bringing it down to even ¼ of the maintenance cost~~s~~ of conventional methods [14].

4. Soil Liquefaction - Reinforcement and Improvement Methods

Non-coherent saturated soil formations, when subjected to direct loading under undrained conditions, tend to compact, but due to their inability to change their volume there is an increase in the pressure of their pore water with simultaneous reduction (or zeroing) of their shear strength. In the above process, the state of these soil layers is converted from the solid into the liquid phase, that is, liquefaction thereof is induced. In order for a soil to be considered potentially liquefiable, it must meet certain conditions, which need to be considered before final assessment of the likelihood of liquefaction for the soil formation under consideration.

Tables 3 and 4 below show criteria for soil classification based on the likelihood for liquefaction. Table 5 presents the methods of reinforcement and improvement of liquefiable soils. Figure 10 illustrates the equipment and various deep soil mixing devices and in Figure 11 the composite action of grinders in liquefiable soil [15].

Table 3: Classification of soils based on geomorphological criteria (Iwasaki, 1986) (Source: Papadimitriou 2010).

Category	Geomorphological modules	Liquefaction potential
A	Recent riverbed bottom, old riverbed, swamp	High likelihood of liquefaction
B	Ripples, river silting, flood plains	Likelihood of liquefaction
C	Hills, mountains	Non-liquefiable

Table 4: Susceptibility to liquefaction of soil formations depending on depth of aquifer level (Youd, 1998). (Source: Papadimitriou 2010).

Depth of aquifer level from the surface	Susceptibility to liquefaction
<3 meters	Very high
3 to 6 meters	High
6 to 10 meters	Moderate
10 to 15 meters	Low
> 15 meters	Very low

Table 5: Methods of strengthening and improving liquefiable soils (Source: Papadimitriou 2010)

MECHANISM	METHODS OF STRENGTHENING-IMPROVEMENT
Reduction of shear deformation imposed by earthquake	• Diaphragm walls • Deep Soil Mixing
Increase of soil density	• Surface compaction • Deep vibratory compaction • Deep vibratory replacement
Facilitation of rapid relief of water overpressures	• Gravel piles - drains

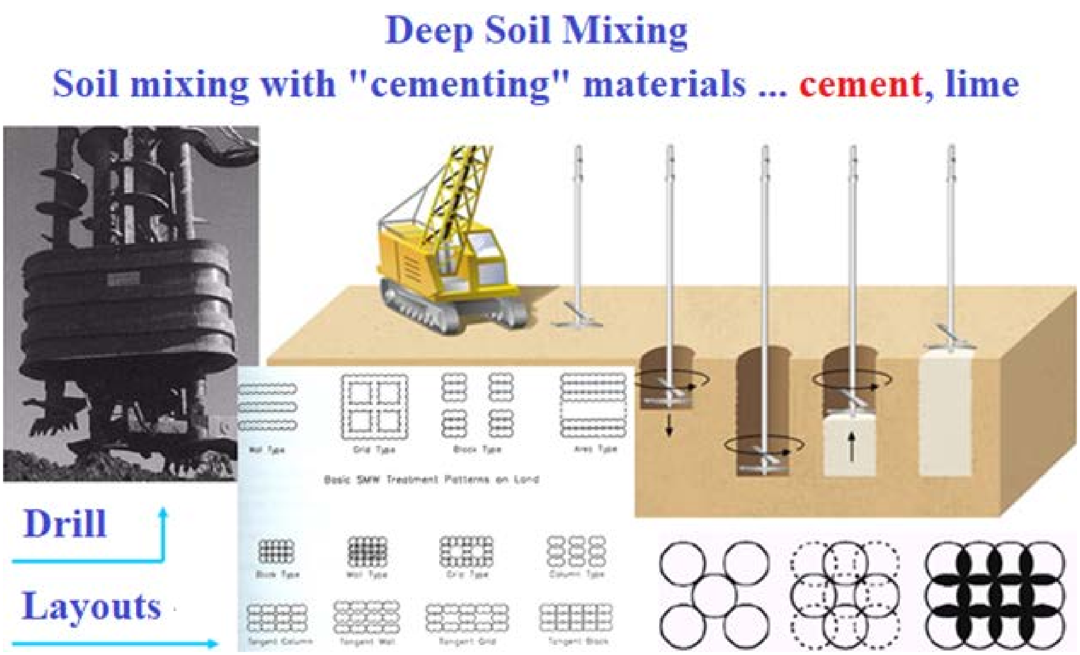

Figure 10: Deep soil mixing in liquefiable soil (Source: Papadimitriou, 2010)

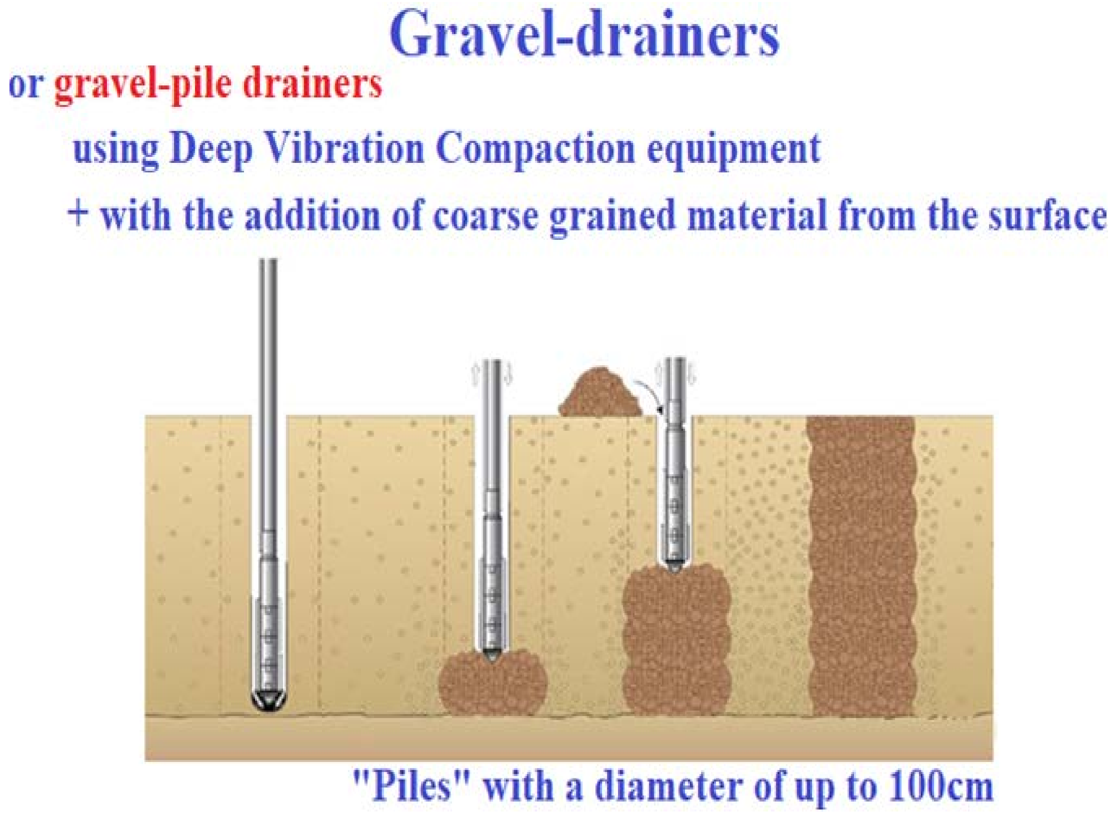

Figure 11: Complementary action of gravel drains in liquefiable soil. (Source: Papadimitriou 2010) [15].

Significant improvement of the liquefied soils is achieved by using gravel-drainage. Their complex action contributes to:

- Acceleration of drainage of water overpressures.
- Soil compaction (sands).
- Load bearing capacity.
- Increase of the equivalent shear strength.

5. Conclusions

On the above presented methods and technics for loose soil improvements, the following conclusions can be pointed out:

1. The process and method of implementation of soil improvement and reinforcement depends directly on the quality of the soil (sandy, cohesive or expanding soil), the (physical or mechanical) property to be improved, the type and size of the geotechnical project, but also on the corresponding construction.

It should be noted that the combination of the above, leading to the selection of the most appropriate method, is also a function of the cost of the overall construction project in relation to the cost of the method of improvement and reinforcement of the soil as shown in the following Table 6:

Table 6: Modern categorization of soil improvement methods (Source: Platis-Vgenopoulou**,** 2016) **[7].**

Category	Method	Principle
A. Ground improvement without admixtures in non-cohesive soils or fill materials	Al. Dynamic Compaction	Densification of granular soil by dropping a heavy weight from air onto ground.
	Λ2. Vibrocompaction	Densification of granular soil using a vibratory probe inserted into ground.
	A3. Explosive compaction	Shock waves and vibrations are generated by blasting to cause granular soil ground to settle through liquefaction or compaction.
	A4. Electric pulse compaction	Densification of granular soil using the shock waves and energy generated by electric pulse under ultra-high voltage.
	A5. Surface compaction (including rapid impact compaction)	Compaction of fill or ground at the surface or shallow depth using a variety of compaction machines.
B. Ground improvement without admixtures in cohesive soils	B1. Replacement/displacement (including load reduction using lightweight materials)	Remove bad soil by excavation or displacement and replace it by good soil or rocks. Some lightweight materials may be used as backfill to reduce the load or earth pressure.
	B2. Preloading using fill (including the use of vertical drams)	Fill is applied and removed to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B3. Preloading using vacuum (including combined fill and vacuum)	Vacuum pressure of up to 90 kPa is used to pre-consolidate compressible soil so that its compressibility will be much reduced when future loads are applied.
	B4. Dynamic consolidation with enhanced drainage (including the use of vacuum)	Similar to dynamic compaction except vertical or horizontal drains (or together with vacuum) are used to dissipate pore pressures generated in soil during compaction.
	B5. Electro-osmosis or electro-kinetic consolidation	DC current causes water in soil or solutions to flow from anodes to cathodes which are installed in soil.
	B6. Thermal stabilization using heating or freezing	Change the physical or mechanical properties of soil permanently or temporarily by heating or freezing the soil.
	B7. Hydro-blasting compaction	Collapsible soil (loess) is compacted by a combined wetting and deep explosion action along a borehole.
C. Ground improvement with admixtures or inclusions	Cl. Vibro replacement or stone columns	Hole jetted into soft, fine-grained soil and back filled with densely compacted gravel or sand to form columns.
	C2. Dynamic replacement	Aggregates are driven into soil by high energy dynamic impact to form columns. The backfill can be either sand, gravel, stones or demolition debris.
	C3. Sand compaction piles	Sand is fed into ground through a casing pipe and compacted by either vibration, dynamic impact, or static excitation to form columns.
	C4 Geotextile confined columns	Sand is fed into a closed bottom geotextile lined cylindrical hole to form a column.
	C5. Rigid inclusions (or composite foundation)	Use of piles, rigid or semi-rigid bodies or columns which are either premade or formed in-situ to strengthen soft ground.
	C6. Geosynthetic reinforced column or pile supported embankment	Use of piles, rigid or semi-rigid columns/inclusions and geosynthetic girds to enhance the stability and reduce the settlement of embankments.
	C7. Microbial methods	Use of microbial materials to modify soil to increase its strength or reduce its permeability.

2. From the literature review and analysis, measurement and monitoring of the behavior of many projects in Greece, to which the method of preloading to improve the mechanical characteristics of the foundation soil has been applied, showed that:

a) The use of vertical geotextile drains on both sides to accelerate settling and completion during construction, and to improve the shear properties of foundation soil, is an effective method which offers speed, economy and less impact on the environment than the sandpile method.

b) Drain-to-ground compatibility tests or similar experience as well as appropriate on-site testing are considered to be essential for the successful economic and technical implementation of vertical geosynthetic drains in each project.

c) it is considered necessary to build a test embankment before the construction of the project in order to take timely instrumental measurements of soil behaviour and contribution of drains, in order to properly financially decide on the choice of grid systems of drains and to plan efficiently the various phases of construction of the project, particularly in the case of large-scale projects.

3. Freezing of the soils is resulting in a very large increase in strength, consistent with the formation of a rigid ice skeleton. This increase depends exclusively on the amount of water contained in the mass of the specimens. The higher the water content, the higher the values of mechanical strength. Considering that strength increases with the decrease in temperature, then it is easily understood that the method of cooling with liquid nitrogen (-196 ^{o}C) can lead to the creation of much greater soil strength compared to that observed in laboratory tests in frozen specimens at -14 ^{o}C, similar to that of concrete, as a substantial and secure solution in many geotechnical problems and structures [10].

4. When mixing asphalt and soil, there is no chemical reaction but only improvement of the mechanical characteristics of the soil due:

- To the increase of coherence between grains of soil, resulting in a corresponding increase in load bearing capacity.
- To the decrease in hydro permeability of soil material [16].

5. The use of gravel piles will greatly increase the degree of consolidation and the safety factors of the final construction and final consolidation.

6. There are many methods of improving seismically hazardous soils, but the most commonly used ones are compaction, stabilization and drainage methods. More precisely: all the above methods are used in non-coherent soils (sands, silts, gravels or mixtures), while stabilizing and compacting via gravel piles are used are used in cohesive soils (soft clays, organics).

6. Recommendations

It is apparent that methods to improve loose soils as described in detail above, can prove to be substantially damaging to the flora and fauna of the area being processed, sometimes bringing about such change in the local environment, that subsequent recovery of the habitat becomes difficult or, in some cases, extremely unlikely. It is therefore imperative that civil engineers take these effects unto the local environment into consideration and employ methods of soil cohesion improvement that have a low local impact and allow for a swift return of local plant.

Furthermore, in the opinion of the authors, research into measures to improve loose soils should be continued because the soil either as a load bearing medium, or as a building material, plays a major role in all constructions. Of particular interest is the method of enhancing-improving fluidizable soils which, as known under the effect of a recirculating charge, exhibit very low to zero density, creating serious issues with the stability of overlying structures.

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