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The use of soil strengthening techniques in construction

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Abstract

Construction works should be designed, built, maintained and dismantled in accordance with technical and building regulations as well as the principles of technical knowledge ensuring compliance with basic requirements regarding safety, ecology and sustainable use of natural resources. Among these requirements, it is important to secure the foundation of the object on the ground, which is affected by proper recognition of soil and water conditions, knowledge of the behavior of weak soils, selection of the appropriate method of strengthening and improving the subsoil, correct drainage, checking the stability of slopes and slopes, and the selection of appropriate materials for the construction of earthworks.The article describes the basic soil conditions and gives techniques to strengthen the soil, which can be used in the foundation of buildings.

Keywords: soil, construction, reinforcement techniques

1 Introduction

Construction works are buildings, structures and small architecture objects that should be designed to be built, maintained and disassembled in accordance with technical and building regulations as well as the principles of technical knowledge ensuring that the basic requirements regarding safety, ecology and sustainable use of natural resources are met [1, 12, 20]. According to Eurocodes, a building is everything that has been built or is the result of works. This definition refers to building structures with structural, non-structural (finishing, installations) and geotechnical elements [7]. Ensuring the safety of a building object [13] throughout its life cycle requires stable grounding. Therefore, the foundation of the object must be adapted to specific soil conditions, taking into account the type of the object and the loads transferred to the ground. In this respect, the provisions of the construction law impose on the facility designer an obligation to obtain information on the soil conditions of the planned investment [17].

The increase in the demand for civil engineering and transport facilities means that it is increasingly necessary to use areas that were previously considered unsuitable for building because of the weak soil that is not able to transfer the object's load to the ground. Poor soil is a major problem for civil engineers and building contractors, and requires ground testing. When starting the soil analysis, the ground must be clearly defined. According to the guidelines for strengthening the subsoil in road construction, as non-loadable soils, intended for strengthening, it is necessary to understand soil layers that do not meet the requirements arising from the load-bearing or stability conditions or the conditions of suitability for use in relation to a specific object or structure element. [21]. This group includes organic soils, e.g. silts or peat and cohesive soils in plastic and liquid state, as well as cohesive soils with inadequate compaction, which may undergo significant deformations under the influence of loads. In the case of foundation of a building object on such land, its strengthening is required. Reinforcement is a process of monitored change in the physico-mechanical properties of soil, which has a positive effect on its work under the influence of loads and external influences. Thanks to this, it is possible to obtain effects such as: increase in soil strength, reduction of ground deformation, increase in object stability, decrease in soil permeability, reduction or elimination of harmful phenomena (e.g. suffusion or liquefaction) or increase in resistance to dynamic loads [14]. Modern science offers a whole range of ways to strengthen weak soil. The problem is their unequivocal classification, because they differ in many respects, conditioning the effectiveness of gain. Among them the most important, include production technology, depth of interference in the ground and materials resulting from soil conditions used for strengthening.

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2 Ground conditions

A construction soil is a part of the earth's crust that interacts with or forms part of a building object. Separated soil can also be used as material for making all earthworks from it. Lands that are within the range of impact of building objects and interact with each other are referred to as building substrate. Among them are solid rocks (e.g. granite, limestone, sandstone) or soils resulting from rock weathering processes (e.g. gravel, sand, clay, loam). The main feature that distinguishes the soil from solid rocks or continuous media is its fragmentation. The crushed rock material contains separate grains and particles, which are bound by small forces of molecular attraction, clearly smaller than their internal strength and affecting cohesion. For the needs of construction, a division of land was introduced, due to their cohesiveness, into two groups: cohesive and non-cohesive soils.

Cohesive soils are characterized by having so-called cohesion, i.e. cohesion, which consists in close adherence of grains and soil particles, partial and their sticking together by colloidal particles and the tension of water membranes surrounding the grains. Coherence decreases as grain diameter increases and moisture increases. Cohesive soils, as a result of moisture, change their consistency to more plastic, and with moisture corresponding to the liquidity limit they almost completely lose their attraction forces. This phenomenon in cohesive soils significantly reduces shear strength and increases their compressibility.

Non-cohesive soils constitute a group of so-called loose soil. Their most important parameter is the degree of compaction, which determines the suitability of the substrate for construction purposes. The higher its value, the better the properties of a given soil. It is important that in the case of non-cohesive soils any changes in humidity do not significantly affect their strength. It is assumed that, after proper compaction, they show better properties for building buildings on them [15]. The division of construction land is defined by standard [16]. A simplified division of land is shown in Fig. 1.

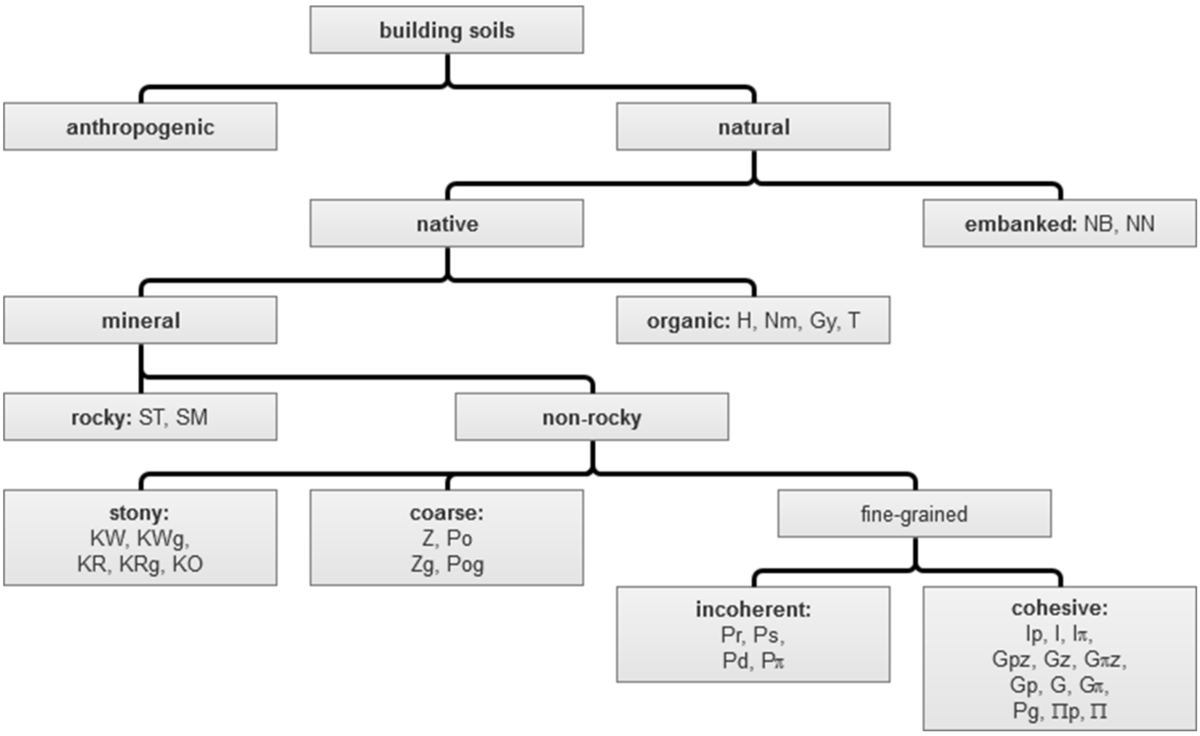

Figure 1. Simplified division of construction soils [16]
NB - construction embankment, NN - uncontrolled embankment, H - humus, Nm - silt, Gy - gytia, T - peat, ST - hard rock, SM - soft rock, KW - weathered, KWg - clay weathered, KR - rubble, KRg - clay rubble, KO - boulders, Z - gravel, Po - gravel mix, Zg - clay gravel, Pog - clay gravel mix, Pr - coarse sand, Ps - medium sand, Pd - fine sand, Pπ - dusty sand, Ip - loam sandy, I - loam, Iπ - loam dusty, Gpz - cohesive sandy clay, Gz - cohesive clay, Gπz - cohesive dusty clay, Gp - sandy clay, G - clay, Gπ - dusty clay, Pg - clayvy sand , Пр - sandy dust , П - dust

Geoengineering is a science dealing with the improvement of rocks and soils. This field has significant development prospects, caused by the increasing number of areas with poor parameters, which are transformed into building substrates with higher strength than in the natural state.

3 Techniques for strengthening construction soils

The purpose of strengthening the land is to obtain a proper foundation when building buildings such as buildings, industrial halls, road and railway embankments, underground culverts, retaining walls, earth tanks, breakwaters and sealing partitions. The basis for designing soil reinforcement are in-depth soil tests [4, 5]. By determining the construction - the arrangement of geotechnical layers, in particular the depth of non-bearing soils, and determining parameters such as water conditions, compressibility, permeability, stiffness, bearing capacity, graining or compaction of the soil, you can determine the extent of interference in the ground and choose the appropriate technology for its implementation. The choice of reinforcement methods is also influenced by factors such as: size of designed loads, availability of materials, time and cost of the strengthening works, contractor's technical capabilities and investment location [2, 3].

Over the centuries, soil strengthening techniques have evolved along with technological progress [9, 10]. The availability of new, specialized machines and increasingly more perfect materials meant that today much better results are achieved in a much shorter time. This encourages engineers to reach for innovative solutions that more and more companies offer on the Polish and global market. Soil strengthening techniques can be divided due to a change in the condition and composition of a given subsoil [11]. The change in soil condition results in an improvement in strength properties as a result of increasing its compaction, reducing humidity or stabilizing it by means of an appropriate temperature. The change in composition, on the other hand, is characterized by the introduction of additional substances or materials stabilizing and reinforcing the soil as a result of transferring tensile and shear loads. Among the methods of strengthening and sealing the subsoil, two basic groups are noted [14] in which it stands out:

- traditional methods: soil compaction, land exchange, preloading of soil, soil cementation, soil stabilization, soil reinforcement,
- modern methods: dynamic compaction, dynamic exchange, vibroflotation, vibrational exchange, pre-consolidation using vertical drains, soil injections, deep soil mixing (Deep Soil Mixing) and soil reinforcement [18].

The article characterizes contemporary methods of the Keller company - the leader of the geotechnical market in Poland and North-Eastern Europe [8].

Dynamic compaction, also called impulse compaction, finds application among cohesive soils, especially those with low humidity and anthropogenic soils. It consists in the compaction of a given soil center by means of high-energy impacts falling from a considerable height. The weight of the rams used can reach the value of 40 tons, and the height up to 40 m. The effectiveness of the dynamic compaction method is determined by the value of impact energy, and the factor limiting its use are significant shocks dynamically affecting nearby buildings [11, 14, 19]. The scheme of the method is shown in Fig. 2.

Dynamic exchange is a variation of dynamic compaction. The method is used when cohesive soils in the liquid and soft plastic state as well as organic soils occur in the substrate. Technological differences between dynamic compaction and dynamic exchange begin at the moment of crater breaking during the initial impacts of the compactor. In the case of cohesive soils, it is covered with coarse-crumb material, from which as a result of further compaction, large-diameter columns stiffening the soil are formed. Currently, the diameters of such poles can reach up to 4.5m. If it is not possible to introduce specialized heavy equipment to a given area, it is necessary to create a working platform with a thickness of max. 1.5 m from cohesive soil [11, 14, 19]. The scheme of the method is shown in Fig. 3.

Vibro-compactoin is a method that uses soil strengthening technology with a special vibrator called a vibrocomact. The method is used to compact loose soil, also below the groundwater table. The whole process is reciprocating vibrocompact, introduced into the ground with the help of pushing or compressed air. The energy of vibration reduces the friction forces between the grains of the soil, and when the device is lifted, it compacts. This method is associated with a loss of soil volume, during the performance of works, therefore it is necessary to provide for supplementing the deficiencies with appropriate non-cohesive soil. The maximum depth of reinforcement reaches the level of 50 m. Thanks to modern technologies in which modern vibrocompacts are equipped, it is possible to constantly control the strengthening process. The data is recorded and the device operator is able to correct any deviations from initial assumptions. [11, 14, 19]. The scheme of the method is shown in Fig. 4.

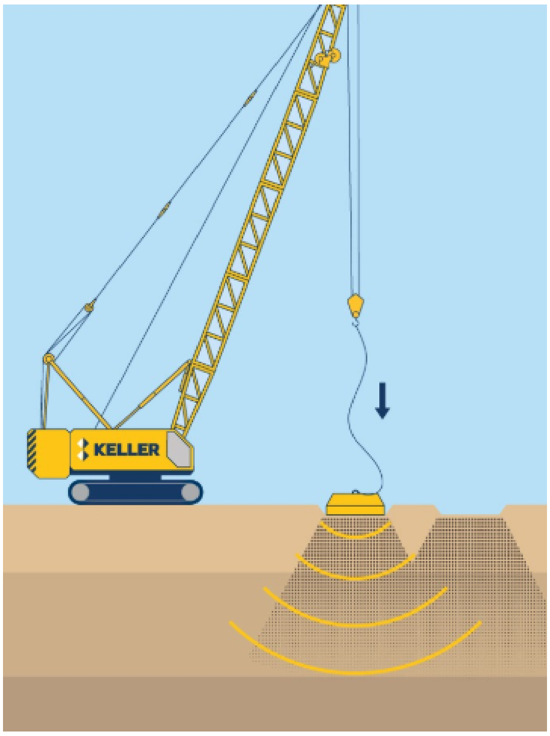

Figure 2. Diagram of the dynamic compaction method [8]

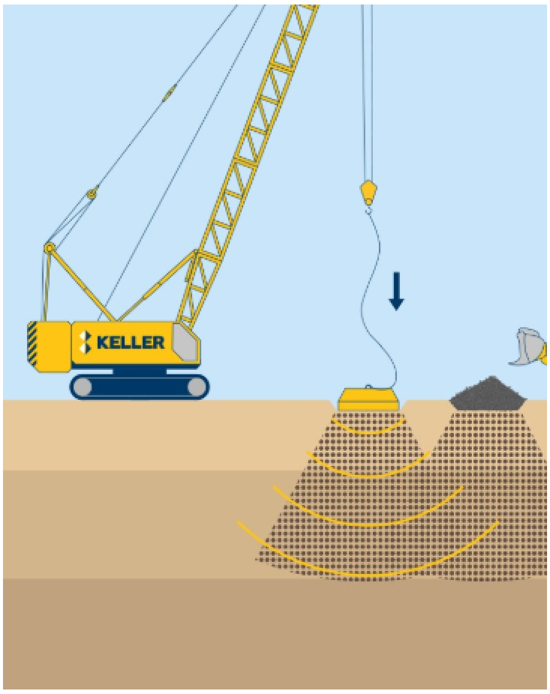

Figure 3. Diagram of dynamic exchange method [8]

Vibro concrete columns is a similar method to vibro-compaction, except that in the case of vibrations, as a result of vibro-compaction operation, columns of aggregate - gravel are additionally formed in the ground, which strengthen the soil around them both in cohesive soils (dusts, clays) and cohesive soils, mainly in a loose state . Such columns are characterized by high strength parameters and significant stiffness. Additional reinforcement results in the use of a geosynthetic cover. In addition to gravel columns, it is possible to make cement columns that use hydraulic and concrete binders using dry structural concrete instead of aggregate.[11, 14, 19]. The scheme of the method is

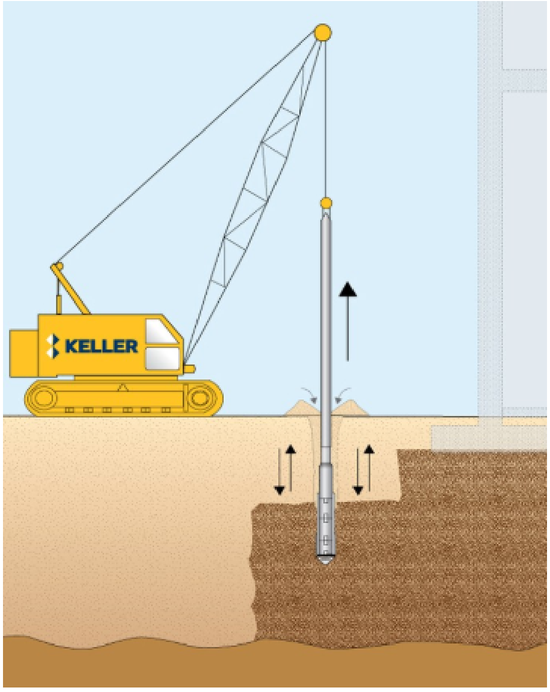

Figure 4. Diagram of the vibro-compaction method [8]

presented in Fig. 5.

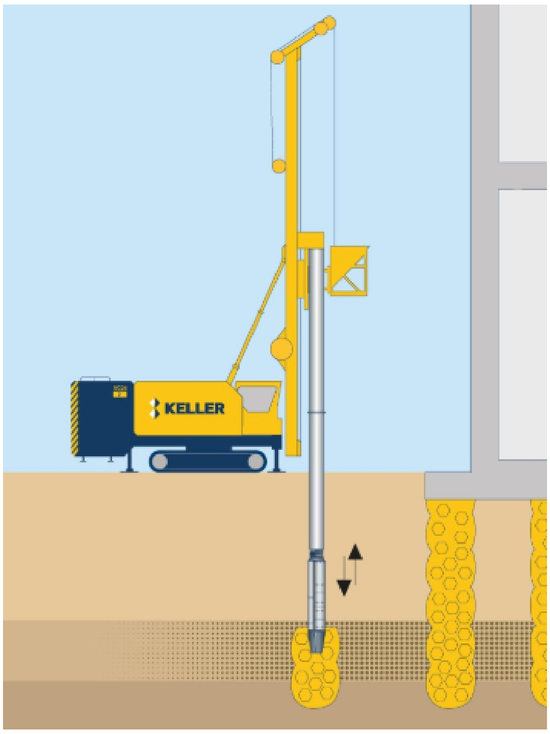

Figure 5. Diagram of vibro concrete columns method [8]

Pre-consolidation using vertical drains is a method in which initial consolidation and vertical drains have been used. Pre-consolidation is usually used in very compressible, cohesive and organic soils. It consists in loading a weak soil with ballast, as a result of which excess water is squeezed out of the soil pores. The increase of stress reduces the volume of pores, and the result of this phenomenon is the settlement of the embankment and strengthening of the ground. This process, usually long, can be significantly accelerated by using vertical drains. Nowadays, prefabricated (plastic) belt drains are the most common. Their advantage is the high speed of implementation and the ability to use low-bearing soils (up to 50 m) with considerable thickness. These drains are in the form of specially shaped tapes surrounded by a filter layer of paper or geotextile. This ensures better filtration and also much greater reinforcement of the substrate. [11, 14, 19]. The scheme of the method is presented in Fig. 6.

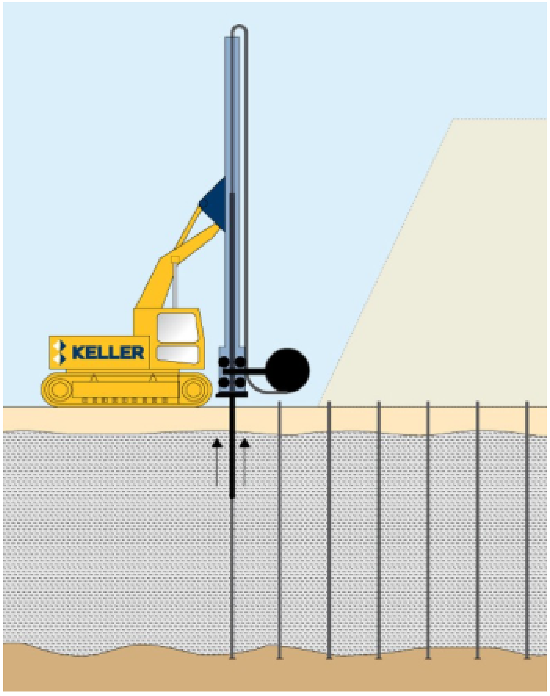

Figure 6. Scheme of the pre-consolidation method using vertical drains [8]

Jet grounting, i.e. soil injections, are one of the oldest ways to strengthen and seal the substrate. Today, due to the significant development of this methodology, they are very often used. Undoubtedly, one of the most effective is jet grouting technique, which uses a high-pressure fluid stream, which cuts and crushes the soil, thereby destroying its natural structure and leads to mixing and partial replacement with a binding medium. The process of destruction is made possible by nozzles located in a drill rod inserted into the ground to the required depth, from which the material is extracted, usually in the form of cement paste. The reinforcement consists in mixing cement with the soil, which creates a new composite called cement-soil. Depending on its shape, it can be a column (cylindrical element) or a wall (flat element). The diameters of columns created in this technology reach values from 50 cm to even 400 cm. The effectiveness of this method is noticeable in all types of soil, including even the most unfavorable organic soils for construction purposes. The scope of its applicability is very wide not only because of the soil conditions in the ground. An important feature of jet injection and the equipment used for it is the ability to form columns in strictly limited spaces, e.g. around obstacles, etc. [11, 14, 19]. The scheme of the method is presented in Fig. 7.

Deep Soil Mixing - DSM is a method of strengthening a weak substrate consisting in mixing soil with a cement paste. There are two variants of mixing: dry (mainly in heavily irrigated soils) and wet, depending on the form of the binder used. As a result of chemical reactions occurring between the stabilizer introduced and the ground, and above all ground water, the process of forming columns or their systems as cement-ground structures takes place. The deep mixing technique can be used even with a significant depth of weak soil layer [11, 14, 19]. The scheme of the method is shown in Fig. 8.

Soil reinforcement is currently a widely used method of soil strengthening in all areas of construction. This is possible thanks to the continuous development of the materials and technologies used, and increasingly accurate methods for dimensioning such soil. A reinforced soil mass is a construction material created as a result of incorporating elements cooperating with the surrounding soil in the ground to transfer loads, mainly tensile and shear loads, thereby increasing the load capacity and rigidity of the ground. Among the many reinforcement techniques, reinforcement: bar, skeleton and geotextiles. The most commonly used rod and skeleton methods are soil nails, soil anchors, micro piles and gabions (Fig. 9, 10).

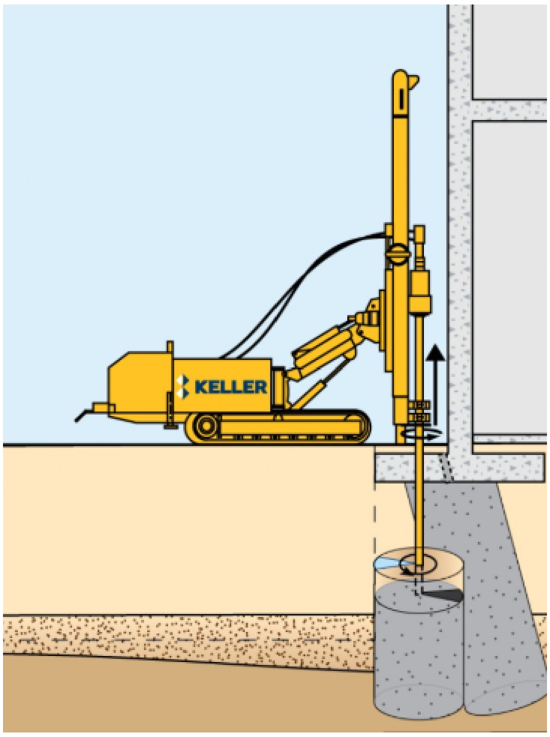

Figure 7. The scheme of jet grounting method [8]

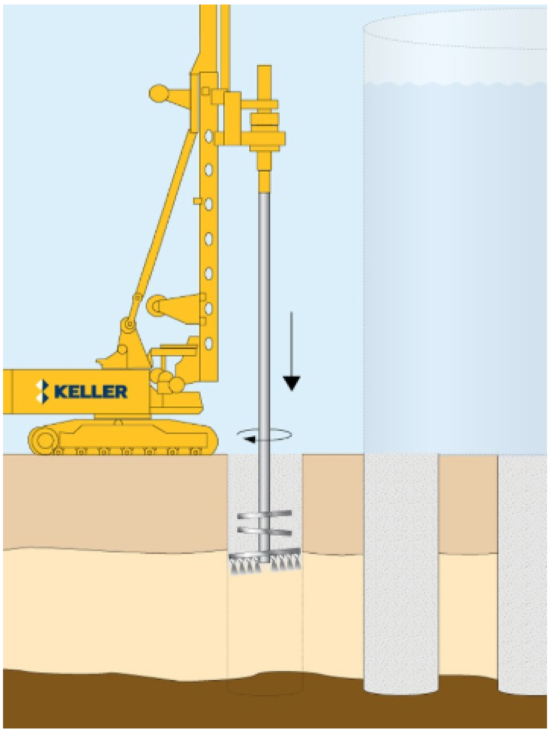

Figure 8. Scheme of the Deep Soil Mixing method - DSM [8, 18]

Geosynthetics are products that, working with soil, improve its properties, and at least one of their components has been made of polymer. Substrate reinforcement with these materials in engineering practice is a fairly modern but increasingly common method of strengthening low-bearing soils. Their processing is possible thanks to textile, thermal and chemical methods. Permeable geosynthetics are mainly used for reinforcement [11], which include: geotextiles, geogrids, geogrids and geogrids. Types of geosynthetics are shown in Figure 11.

Figure 9. Frame construction of gabions at the Zambrów bypass

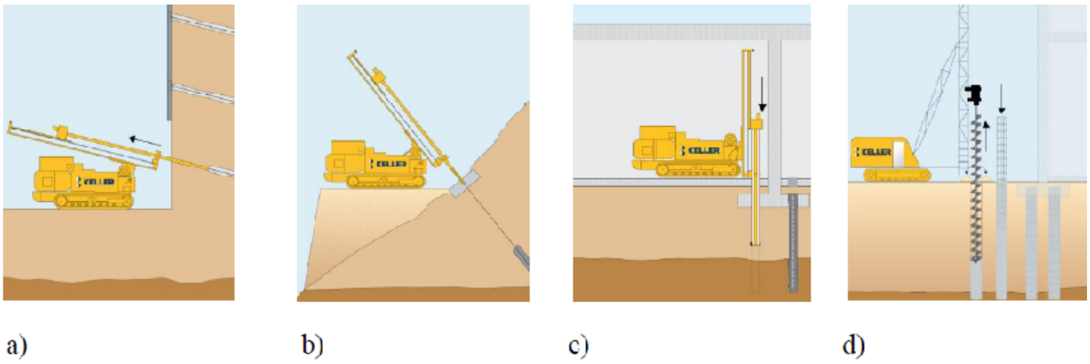

Figure 10. Reinforcing the soil mass using bar methods: a) nails, b) anchors, c) micropiles, d) CFA micropiles [8]

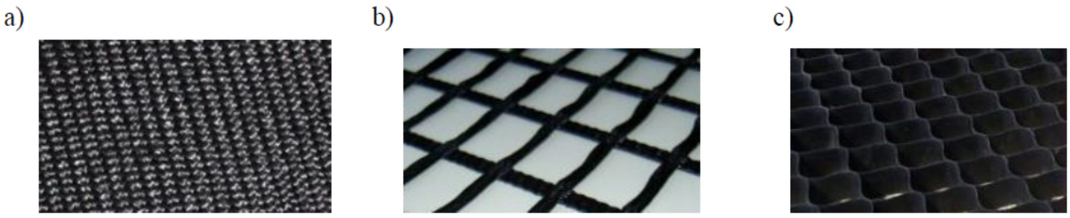

Figure 11. Types of geosynthetics: a) geotextile, b) geogrid, c) theocrat [6]

4 Conclusions

In today's construction practice, unfavorable soil or soil-water conditions are more and more often encountered, because attractive areas in this respect are usually already developed. They occur in areas with native land as well as in areas previously used for construction purposes, where e.g. uncontrolled embankments are created as a result of the liquidation of old facilities or excavations. Areas of retention of low-bearing, highly deformable and diversified soils in the plan and cross-section require strengthening and soil strengthening becomes an important stage of the investment process.

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