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EVOLUTION OF THE STABILITY WORK FROM CLASSIC RETAINING WALLS TO MECHANICALLY STABILIZED EARTH WALLS

BY

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Abstract. For the consolidation of soil mass and the construction of the stability works for roads infrastructure it was studied the evolution of these kinds of works from classical retaining walls – common concrete retaining walls, to the utilization in our days of the modern and competitive methods – mechanically stabilized earth walls. Like type of execution the variety of the reinforced soil is given by the utilization of different types of reinforcing inclusions (steel strips, geosynthetics, geogrids) or facing (precast concrete panels, dry cast modular blocks, metal sheets and plates, gabions, and wrapped sheets of geosynthetics).

Key Words: Retaining Wall; Mechanically Stabilized Earth Walls; Reinforced Earth Wall.

1. The Necessity for Technique Evolution of the Retaining Walls

Support structure is a generic term for all the retaining works built for establishing the stability of the slopes and slims. An example for these are the consolidation works made along time in Jassy, which is located in a region with hills, cholines and plateaus that have suffered numerous sliding across time. The solutions applied were complex and even if they have contributed to improving the overall stability of the area, they failed to stop entirely the slip phenomena. An overview of the areas at risk of slipping from Jassy and the work carried out over time is given in Fig. 1.

There were plenty of rehabilitation works which were executed in Jassy, like: works of drainage and regrading (area Dumbrava Roşie, Botanical Garden, Aurora); caisson on Benotto piles (Sărărie); concrete retaining wall on Benotto piles together with collecting drains and culverts for leakage of water (Ţicău, Brânduşa, Bucium, Socola - Nicolina, Galata, Cetăţuia); water discharge caissons (Tătăraşi), retaining walls on piles and adjoins earth supporting vaults (Arcu); retaining walls on Benotto piles (Bucium).

The slope-instability phenomena can be observed today in the following area: Ţicău, Copou, Aurora, Bucium, etc., thus the need to attract the design and execution of new retaining structures in order to solve the slope-stability problems. This is why we present an evolution of stability works methods including the utilization of the reinforced soil structures.

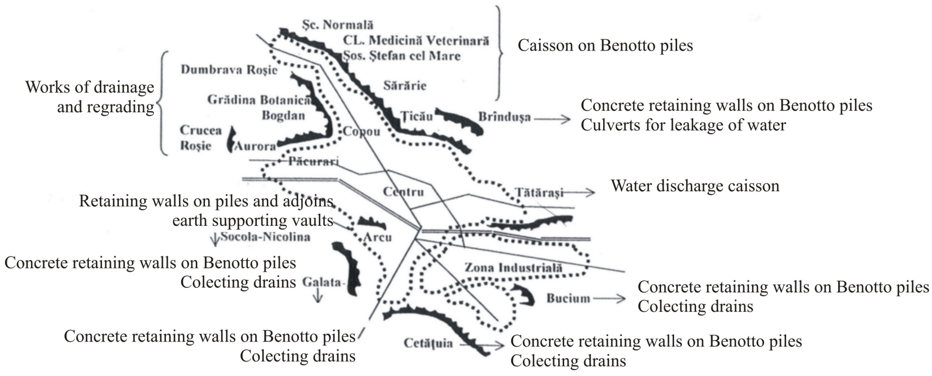

Fig. 1. – Jassy slope-support structures in the sliding-affected areas.

2. The Evolution of the Stability Structures

To solve the problem of the construction of communication routes in areas with restrictions and for the stabilization of adjacent slopes at risk of slipping, over the time it has been seen an evolution of stability works concepts from the classical retaining walls to reinforced or precast concrete retaining wall to various forms of reinforced soil.

In summary, in time, the concept retaining wall sustains all the unstable soil, changed into the concept where the soil sustained itself and the remaining forces are taken by the retaining wall.

2.1. Classical Retaining Walls

The first retaining structures realized was those made in concrete in various forms (Fig. 2) constructed of dry masonry, stone masonry or brick with mortar, concrete no-fines [1]. They ensure the takeover of the earth resistive forces (friction on the foot, etc.) generated by its own weight and a partial mobilization for a possible area of failure, shearing resistance of the earth. Most often, these types of structures become non-economical due to their quite large size. Their use is recommended particularly where masonry material may be found in the construction area.

In order to reduce the size of these retaining walls and especially in the case of large heights, the idea of introducing discharge plates appeared, they being named *retaining walls with consoles* or *discharging plates* (Fig. 3 *a*, *b*).

The discharging plates and the consoles have a double role: to reduce the values of active forces and to increase the stability of the earth wall, with the raising of the soil weight on to console to the weight of the wall. In addition, there have been realized retaining walls with shafts and niches [2], (Fig. 3 *c*, *d*).

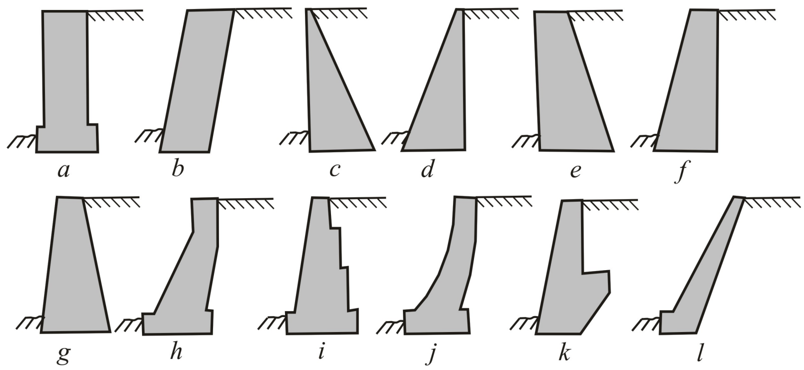

Fig. 2. – The classical retaining walls in various forms.

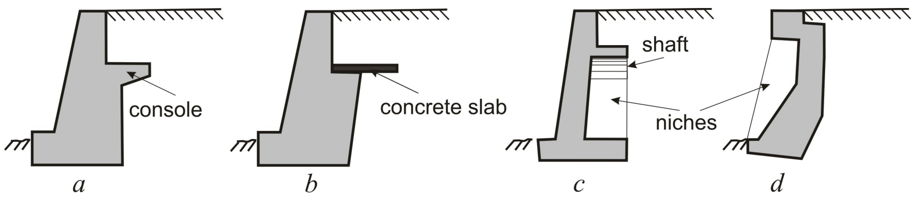

Fig. 3. – Retaining walls with discharging consoles / discharging plates and niches.

2.2. Concrete Steel Retaining Walls

It appeared the possibility of reducing the size of the retaining walls using by then, along with the emergence of the concrete steel in area of constructions; through the use of structural forms that have helped to increase the share of soil's own weight in ensuring its stability, reduction of active earth pressure and the mobilization of a part of the resistance to shearing on foot (Fig. 4). The cross-section of these walls consists of a foundation plate that is embedded in the front wall [3], [4]. To increase the stability to the sliding wall, a heel key is appropriate to develop at the footing level.

Reinforced concrete walls were developed from simple cross section to complex ones. Thus, in order to reduce the active earth pressure and to increase the strength and stability of these structures were introduced counterforts or buttresses and/or discharging plates (Fig. 4 *d*). In the case of high heights for retaining walls (over 5 m) the bending moments become very high and the use of the concrete steel retaining walls becomes unreasonable, and therefore has resorted to placing pretension reinforcements in the stretched areas of the retaining wall (Fig. 4 *e*) [4].

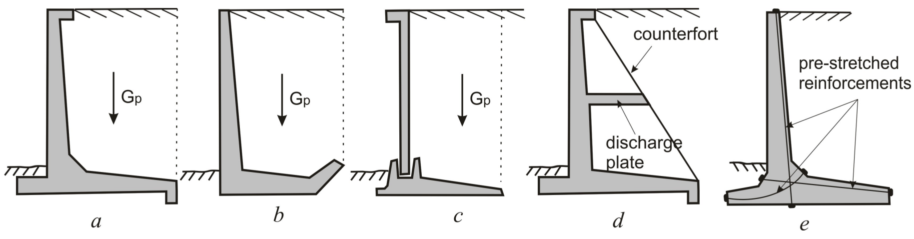

Fig. 4. – Active and passive reinforced concrete retaining walls.

2.3. Anchored Retaining Walls

The appearance of concrete steel and the pre-stretched elements favoured the emergence of new forms for the construction of the retaining walls, and the development of *anchored retaining walls* (Fig. 5) [5].

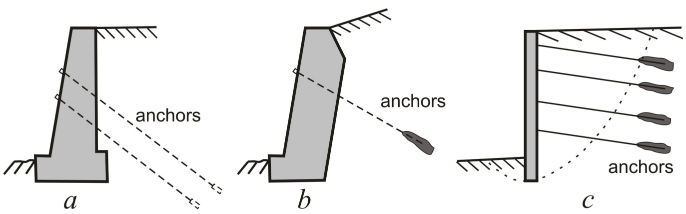

Fig. 5. – Anchored retaining walls

These structures are composed of a reinforced concrete element that is intended to convey the equivalent of the active or rest pressure to the land mass as possible tensions in the pre-stretched anchors. This sustain mainly comes from the mobilization of the resistance through anchors.

2.4. Mechanically Stabilized Earth Walls

Starting from the idea of concrete steel and from the idea that the soil is self-sustainable in the slope to some extent, it appeared the concept of *reinforced soil* [6]. Thus, the basic idea of reinforced soil is using reinforcements in the form of bands, bars, wires and sheets inserted between layers of soil and they are likely to take up significant stretching efforts.

However, as in reinforced concrete, they are forming an assembly in which the reinforcements are located on land in the direction where the soil is solicited on stretching. In this solution, the retaining wall does not add additional efforts: the weight of the material from which the wall is made, the stability being given by the weight of the reinforced soil mass and reinforced efforts stretching over the reinforcements.

The first modern system of soil reinforced was conceived and promoted since 1966 by French engineer Henri Vidal, known as ”Terre Armée” (reinforced soil), (Fig. 7 *a*), [7], ..., [10]. As reinforcement elements, Vidal used metallic bands and the facing was made from metallic elements.

3. Mechanically Stabilized Earth Walls Evolution

3.1. Terminology

A retaining structure of reinforced soil consists of several items whose presentation is given in Fig. 6 [7], [11].

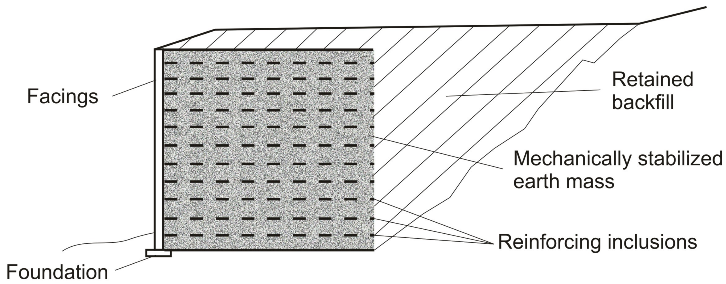

Fig. 6. – Reinforced soil cross-section.

Reinforced soil: it is the term used for all types of reinforced soil, created using multiple layers of inclusions, reinforcements.

Reinforcements: generic term that defines all kinds of items made by humans, which incorporated into the soil, improve its characteristics.

Facing: it is part of reinforced soil systems, used to prevent collapse of soil layers of reinforcement.

Filling soil: the soil, usually uncohesive where the reinforcements are placed for reinforcement.

Retained backfill: the material located behind the reinforced soil.

Foundation: ensure the verticality of the facing, used only for the facing of reinforced concrete plates.

3.2. Facing

As we said, the facing is used to maintain the land between two layers of reinforcement. The facing should be fairly resistant to retain local granules of soil that is between two reinforcements near the surface [11]. Also must be flexible as a whole to follow all the strains of massive reinforced soil without introducing additional efforts.

The main types of facing used for reinforced soil are the following:

Metallic facing is made of galvanized steel in the form of a cylinder cut in half. Such type of facing can be positioned on the horizontal direction, specifically for the first reinforced soil structures made in the 60's, (Fig. 7 *a*), or vertically specific for the reinforced soil Ter-voile, (Fig. 7 *b*).

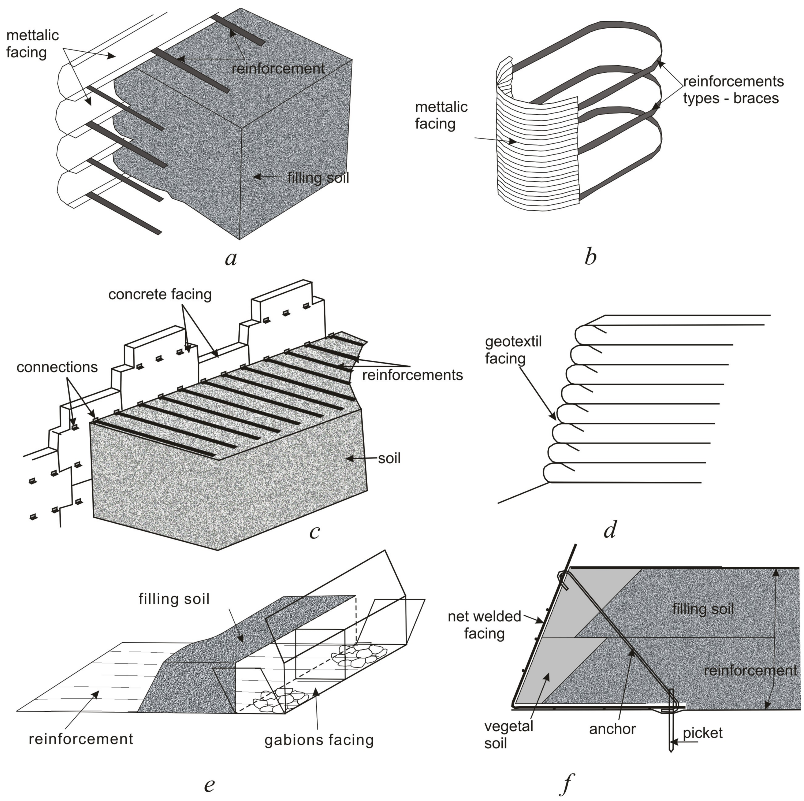

Fig. 7. – Types of facing.

Ter-voile [12] is relatively new used as a method of reinforced soil and the basic idea in this method was the use of waste (metallic barrels) in construction materials, the facing made by cutting the barrels in two on vertical and reinforcements made in the form of braces.

Due to the possibility of corrosion of metallic facing, it occurred the idea of using concrete for the facing in form of panels or precast concrete blocks (Fig. 7 *c*). They are relatively small and were designed and built especially for the construction of reinforced soil walls. The weight of these blocks usually is between 10 and 15 kg. This type of facing is used for the soil reinforced with metallic strips and the connection between blocks and reinforcements are made by metallic connecting elements like safety catch pins and grooves.

Years later, in the early 70's, they have been proposed the use geosynthetics for reinforced soil structures due to fear to a possible corrosion of metal reinforcements in the soil [13]. In France, the first geosynthetics reinforcements works were made in 1971. Were used the non-woven geotextiles for the construction of a retaining wall of 4 m high located on a soft and compressible soil and that's why the need to make a supple structure. A section for this type of support structure is shown in Fig. 7 *d*. For this type of structure was used a geosynthetic facing and the main advantage of this the method is that there are no additional loads on the wall.

Another type is gabion facing, which can be used as a front to the reinforced soil with reinforcements of wire, metal bars, geogrids, geotextiles and the reinforcements are linked on the gabions in various ways. One of the reinforcement works that uses this type of system facing is Terramesh [14] (Fig. 7 *e*). The particularity of this type of reinforcement system of the earth is the unit between the facing and the reinforcements, being used in this case the wire mesh, which at one end can be shaped executing the gabions.

The facing of welded mesh is used for the reinforced soil named Textomur [15], (Fig. 7 *f*). The facing elements of Textomur are 5 m long and are made of steel bars with a diameter of 8...10 mm and the length reinforced is determined according to the design. The angle of inclination may be from 55° to vertical. Another way is the net bending edge welded to the wall to form the front.

The structures were the metallic facing is used have the disadvantage of corrosion. In the case of gabions or welded mesh facing for prevent the corrosion and erosion the metal can be galvanized. The advantage of such facing is low cost, rapid assembly, effective draining, which provides increased stability.

The geosynthetics facing are advantageous due to the elimination of corrosive factor and due to the potential reintroduction into the natural structure by growing grass on the facing.

3.3. Reinforcement

Taking into account that any material which has high resistance to stretching can improve the properties of the soil, we can state that the palette of materials used for reinforced soil is very large. Such reinforcements may be: flat steel, geosynthetics, grid or metal, plastic, steel bolts. Depending on the material used and the direction of manifestation of stretching resistance of reinforcements, we can analyse several ways of reinforcing the soil.

a) Reinforced soil with randomly distributed elements

Practical applications of reinforced soil with randomly distributed elements are closely related to technology implementation. Since the end of the 60's, there were made considerable efforts to find a specific use for them, but the results have remained unconvincing. However, the solution of this type of reinforcement has came later as Texsol which consists in reinforced soil with continue fibres [16].

This way it came that the construction of reinforced soil wall from a mixture of powdery material reinforced with simple wire, made from textile or synthetic material (disperse reinforcement – Fig. 8 *a*), by mixing them and obtain a distribution of wires in all directions, which results in the emergence of apparent cohesion in any direction in all mass produced.

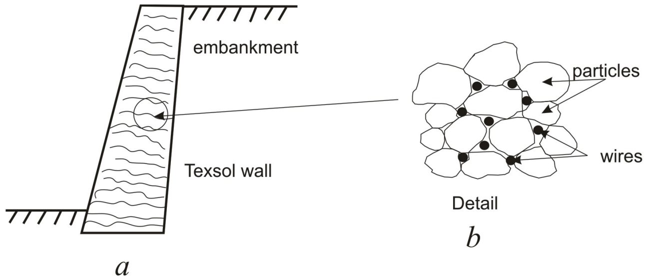

Fig. 8. – Reinforced soil with randomly distributed elements – Texsol.

The construction of these kinds of reinforced soil structures requires a large work area because the technology takes place from the base of the wall to the top, which coincides with the necessity of previous excavations and often use adding material.

b) Linear reinforcements

In addition to random placement of reinforcements in the ground, the construction of reinforced soil the linear reinforcements can also be used too (Fig. 9 *a*). Their basic feature is the form of a bar or strip and the linear effects of reinforcements (Fig. 7 *a*...*c*). This type of reinforcement is specific for reinforcements of metal materials. The practical advantage in using linear reinforcements is that the construction is very easy.

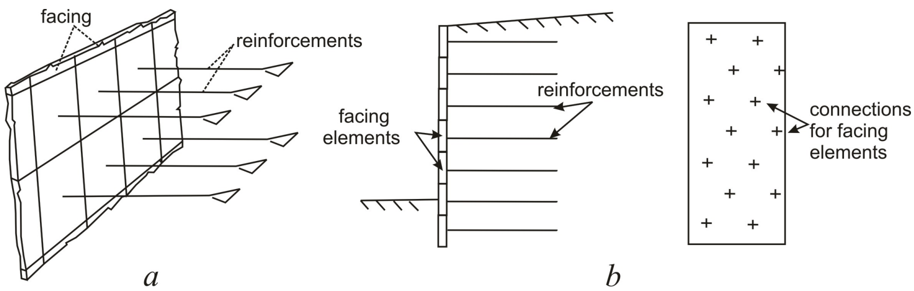

Fig. 9. – Linear reinforcements.

If the soil must be preserved in its natural state, the easiest solution is to introduce bars in holes drilled in soil. With minor changes to the technology of making anchorages, the inclusions bars may be introduced in the ground and they interact on their entire length.

This method is applied for the Clouage type of reinforced soil [17] (Fig. 9 *b*). Using this method, in the massif of soil that we want to maintain in place are placed steel bars, which are fixed by cementing or with synthetic resin. On the outside of the bolt body is fixed a plate of monolithic or prefabricated concrete, forming the facing of the reinforced soil and aims to take over the earth pressure and to transmit forward to the bolt, which works to pluck. The main advantage consists in enhances the adherence soil–reinforcement's thanks to the unchanged structure of sustain soil.

An essential advantage of linear reinforcing is the reduction of the possibility of corrosion, due to the geometry of these inclusions. The surface exposed to corrosion being minimal compared to any other solution of reinforcements. On the other hand, this section is not very efficient because the contact between soil and reinforcements decreases significantly, thereby reducing the friction between the soil and the reinforcements.

c) Continuous reinforcements

Mechanical behaviour of the reinforcements located on levels fits very well the geometry and construction of practical use in soil structures. However, using reinforcements from geosynthetics materials (geogrids or geotextiles, Fig. 7 *d*,*f*) [18], in the form of sheets placed in parallel planes, reinforcing being made on two directions (Figs. 7 *a*, 10 *a*). It can also be used metal reinforcements in the form of welded wire mesh, which also have resistance to stretch in two directions (Figs. 7 *e*, 10 *b*).

Among systems that use metal reinforcements, which have two directions of shearing, we have already reminded the Terramesh system, which has the particularity of using wire-welded meshes as reinforcements and gabions as facing elements.

Another system that uses continuous reinforcing is Polyfelt [19], which is using geosynthetics reinforcements (Fig. 10 *c*). The stages in construction of a reinforced soil wall with Polyfelt are similar to those of any wall of this type, the difference appear in the use of recoverable casings that allow vertical positioning of the layers and ensuring the inclination of the facing that is made from the reinforcements material.

In this type of reinforced soil we will include the Textomur system (Fig. 7 *f*), where the geotextiles reinforcements are placed in layers at a vertical distance of 500 mm; between them is placed and compacted the cohesive or granular filling material. The advantages of this system is that local material can be used as filling material and there can be made curves, corners or terraces in varying lengths and the construction is done without support.

A special type of reinforced soil is Pneusol [20], (Fig. 10 *d*), that represents the result from the combination of two elements: tires and soil. The term ”tire” refers to all the waste tires (the sides and roll band), or whole tires. They are placed in layers and filled with compacted soil. The term ”soil” includes all types of cohesive or noncohesive soil, naturally or artificially made. We include Pneusol in the continuous reinforced soil because the connexion between the tires forms continuous reinforcements.

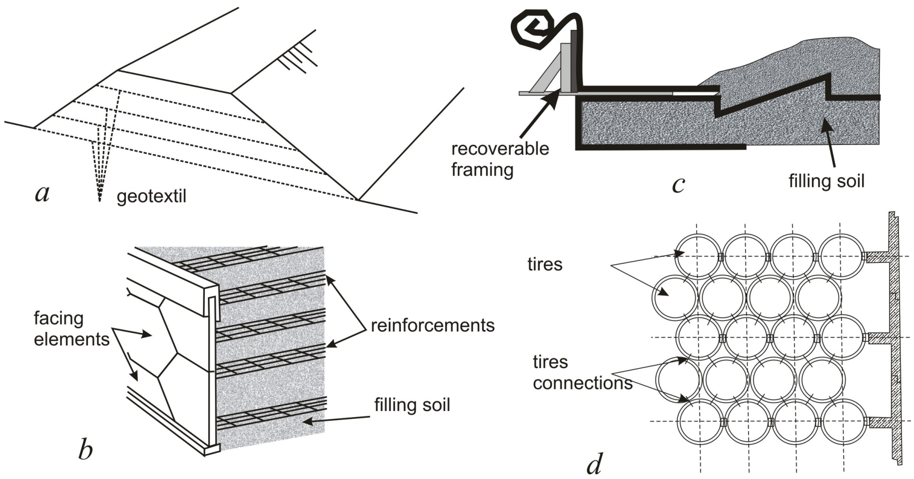

Fig. 10. – Reinforced soil with continuous reinforcements.

The main advantage of this system is economical because there are used waste tires and the filling material does not require special characteristics. The circular shape of tires also allows easily making of curve walls with small radius of curvature.

4. Advantages of Using the Reinforced Soil Walls

The reinforced soil walls presents a number of advantages in comparison with traditional methods due to the materials used and the technologies applied. Among them we may mention the use of simple and fast technologies of construction, which does not require a broad set of machines and also do not require a special qualification of the construction workers. For making the reinforced soil structures we need a small working space, except for Texsol system, which needs a large working area. Because the structures of reinforced soil take over the strains is not necessary the use of rigid foundations. As the main construction material is soil, it can be easily used materials on the spot, which reduces costs considerably. Another advantage is the possibility to reintroduce this kind of structure into the nature by growing grass on the facing.

5. Conclusions

The evolution of conceptual work to support the mass of soil was dictated to both the material and the permanent search for the mobilization of shearing resistance of the soil to ensure its stability. The most of the use of reinforced soil is in the field of retaining walls. The walls of reinforced soil behave like any types of retaining walls and they can replace the classical solutions used to make the retaining walls, bridge abutment, etc. In some cases it might result a large economy, and sometimes the technology used for reinforced soil, taking in account the flexibility of structures, may be the only possible solution.

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EVOLUŢIA LUCRĂRILOR DE SPRIJINIRE DE LA ZIDURILE DE SPRIJIN CLASICE LA STRUCTURILE DIN PĂMÂNT ARMAT

(Rezumat)

Pentru consolidarea masivelor de pământ şi realizarea structurilor de sprijin ca lucrări de artă în infrastructura căilor de comunicaţii s-a observat evoluţia acestora de la lucrările de sprijiniri clasice – ziduri de sprijin din beton simplu, la utilizarea în zilele noastre a unor metode moderne şi competitive – pământul armat. Ca moduri de execuţie varietatea metodelor de realizare a pământului armat este dată de utilizarea diferitelor tipuri de armături (metalice, geosintetice, geogrile) sau de parament (blocuri prefabricate din beton, structuri metalice, geogrile întoarse sau geosintetice).