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SOIL BIOENGINEERING IN SLOPE STABILIZATION: POTENTIAL AND DIFFICULTIES IN TURKEY

Doç. Dr. Hüseyin E. ÇELİK[1)]

Abstract

Soil bioengineering is use of live plants or plant parts to stabilize slopes or riverbanks. Use of soil bioengineering methods for controlling torrent, erosion and shallow mass movements has gained importance since 1930s in the world. Since rapid stabilization of methods is highly dependent on rapid root and leaf out of plants, summer precipitation is essential factor in soil bioengineering. If the methods are performed in arid zones, irrigation is necessary in the first phase of development until vegetation is well established. Due to the fact that only 11% of Turkey takes summer rainfall; soil bioengineering methods seem not applicable in the areas without summer rainfall but in the areas, which have irrigation possibilities, microclimates and natural leakages on slopes.

Keywords: **Soil bioengineering, Biotechnical works, Slope stabilization, Torrent and erosion control**

1. INTRODUCTION

Conventional biotechnical slope stabilization is the combination of structures and vegetation; in other words, it is the mixture of hard and soft measures. Soil bioengineering is also a slope stabilization approach, which is made of more and sometimes only soft measures than biotechnical approach. Society and environmental institutions in the world force professionals to control torrent and erosion by soft methods. Kyoto Protocol requires less CO_2 and other air pollutant emissions and more carbon sequestration. In this context soil bioengineering is more favorable against cement using hard methods.

Soil bioengineering can be regarded as a specialized area or subset of biotechnical stabilization. Soil bioengineering is somewhat unique in the sense that plant parts themselves, that is, roots and stems, serve as the main structural and mechanical elements in a slope protection system. Live cuttings and rooted plants are imbedded in the ground in various arrangements and geometric arrays in such a way that they serve as soil reinforcements, hydraulic wicks (or drains), and barriers to earth movement. Soil bioengineering treatments provide sufficient stability so that native vegetation and surrounding plants can gain foothold and eventually take over this role. Successful implementation of soil bioengineering stabilization likewise requires some knowledge of the factors governing the mass and surficial stability of slopes (GRAY/SOTIR 1996).

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Bioengineering term is often used synonymously with soil bioengineering. Gray and Leiser (1989) define soil bioengineering as quasi-vegetative slope protection. Equivalent of soil bioengineering term in some languages are: *ingenieurbiologie* (engineering biology) in German, *génie biologique* (biological engineering) in French, *ingegneria naturalistica* (natural engineering) in Italian, *bioingeniería de suelos* or *ingeniería naturalística* (soil bioengineering or natural engineering) in Spanish. Yet, the term has not been translated into Turkish. Bioengineering word has connotations with medicine, sanitary and genetics. According to Mediterranean approach and in the sense of taking benefit of natural elements and processes, *doğal mühendislik* (natural engineering) term can be appropriate.

Soil bioengineering techniques are assumed to have the same effective as traditional engineering methods when used on appropriate sites for roadside stabilization and the treatment of runoff. However, since soil bioengineering uses living plants, it has benefits that rock and cement do not have. For example, plants can provide air pollutant uptake and carbon sequestration. Plants also provide visual benefits such as distraction screening, guidance and navigation enhancement, and aesthetic pleasure (LEWIS *et al.* 2001).

Use of bioengineering methods dates back to 12th century China, when brush bundles were used to stabilize slopes. In the early 20th century, similar techniques were used in China to control flooding and erosion along the Yellow River (FRANTI 1996). The age of machines and the development of concrete and steel technology encouraged the use of rigid, inert construction materials in engineered projects. These inert, "hard" systems also promised initially to be more durable, cheaper, and safer. By the 1930s a number of professionals in various disciplines developed successful techniques employing the basic concepts of soil bioengineering. These techniques included the use of green willow as a live construction element, the planting of dry stone wall joints with woody cuttings, and crib wall construction with vegetative inclusions as an integral component of the wall (GRAY/SOTIR 1996). Bioengineering construction techniques have improved immensely since the 1930s. The lack of effectiveness of linear and spot planting methods was recognized and improved methods were implemented which where low in cost and which provided fast erosion protection (SCHIECHTL 1980). In the last 20 years bioengineering has been recognized as a re-emerging technique to provide erosion control, environmentally sound design and aesthetically pleasing structures (WOOLSON 2005)

Biotechnical slope stabilization works started in 1940s but systematically applied in 1950s in Turkey. During the last decade, some methods to be considered as soil bioengineering methods have been also implemented. These methods, however, are not widespread and applied only in limited areas in the country. Torrent and soil erosion are the major problems of Turkey and 78.8% of the country suffer such problems from moderate to very severe degrees. In the condition that some basic problems regarding illegal use of forests and political strategies are overwhelmed, soil bioengineering methods could help in creating new jobs or establishing businesses in Turkey. This paper reviews application potential and difficulties of soil bioengineering methods in the country.

2. SOIL BIOENGINEERING METHODS

Soil bioengineering methods can be used to prevent and control surficial erosion and shallow mass wasting. Different methods or combination of methods can be used on 1) natural hillslopes, 2) cut and fill slopes along roadways, 3) landfill covers, 4) spoil banks, and 5) streambanks. Some methods are better suited than others for particular site conditions and objectives. *Live fascines (wattling)* for example, provide good protection against erosion and are relatively easy to install on both cut and fill slopes. *Brushlayering*, on the other hand, provides better reinforcement and protection against shallow mass wasting but it is more difficult to install on cut slopes. *Live crib wall* provides additional restraint at the base of slopes and also protects the toe. Soil bioengineering methods can be used alone or in combination with structural or conventional methods (GRAY/SOTIR 1996).

Soil bioengineering methods include, but are not limited to: *live staking, live fascines, live fascines used in pole drains, fascines with subsurface interceptor drain, brushlayering, vegetated geogrids, live gully repair fill, vegetated (live) crib walls and live slope grating.*

Descriptions of these methods according to GRAY and SOTIR (1996) are: **Live staking** involves the insertion and tamping of live, rootable vegetative cuttings into the ground (Figure 1). They can be used alone to repair small earth slips and slumps that are quite wet. The procedure is simple, economical and fast.

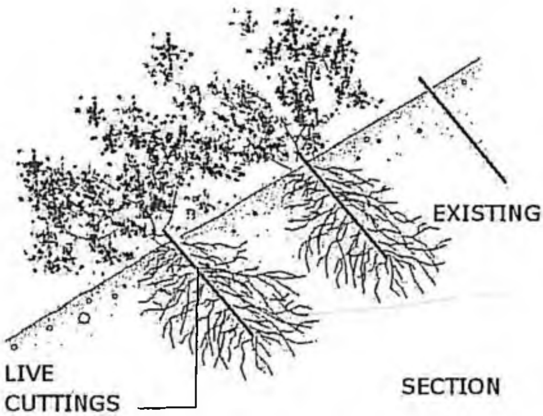

Figure 1 : Live staking
Şekil 1 : Canlı kazık

Live fascines: Stems and branches of rootable plant material (e.g., willow, dogwood, alder) are tied together in long bundles and placed in shallow trenches. The bundles are tied together with twine and anchored in the trench with wooden construction stakes and/or live stakes (Figure 2). The trenches are typically excavated by hand and normally follow the contour of the bank or slope. After the live fascines are secured with stakes, the trench is backfilled with soil until just the tops of the live fascine bundles are exposed.

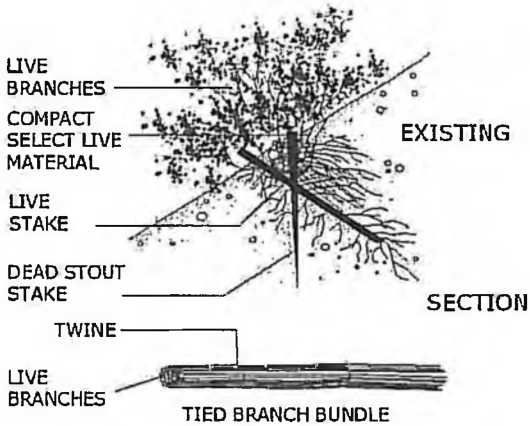

Figure 2 : Live fascines
Şekil 2 : Canlı dal demeti tesisi

Live fascines used in pole drains: Rows of live fascines are installed chevron-fashion connecting to a central drain. Typically the side chevron sections are composed of single, live fascine bundles, whereas the central drain, which serves as the primary collector drain, is constructed with three fascine bundles grouped together (Figure 3).

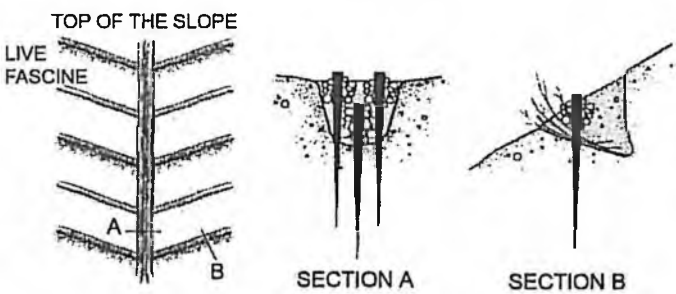

Figure 3 : Live fascines used in pole drains
Şekil 3 : Drenajda kullanılan canlı dal demeti

Fascines with subsurface interceptor drain: Rows of fascines are installed on contour on a slope in the conventional manner. In addition, a subsurface drain, oriented downslope and perpendicular to the fascines, is placed in an axial trench beneath the rows of fascines to intercept and collect seepage (Figure 4).

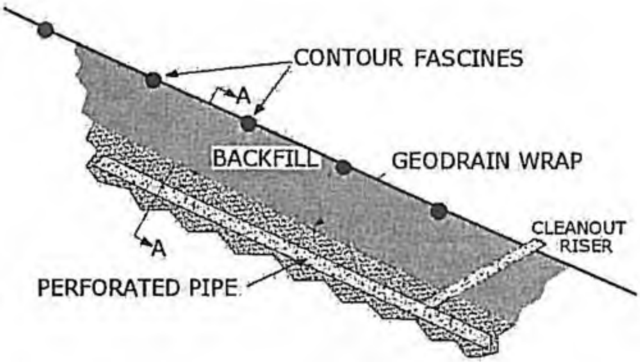

Figure 4 : Profile view of a fascine system constructed over a subsurface interceptor drain
Şekil 4 : Yeraltı drenaj sisteminin üzerine tesis edilen dal demetlerinin profil görünüşü

Brushlayering: Brushlayering consists of live cut branches interspersed between layers of soil (Figure 5). The brush is placed in a crisscross, or overlapping pattern, so that the tips of the branches protrude just beyond the face of the fill, where they retard runoff velocity and filter sediment out of the slope runoff. The stems extend back into the slope in much the same manner as conventional, inert reinforcements, for example, geotextiles and geogrids. Unlike conventional reinforcements, however, the brushlayers root along their lengths and also act immediately as horizontal slope drains.

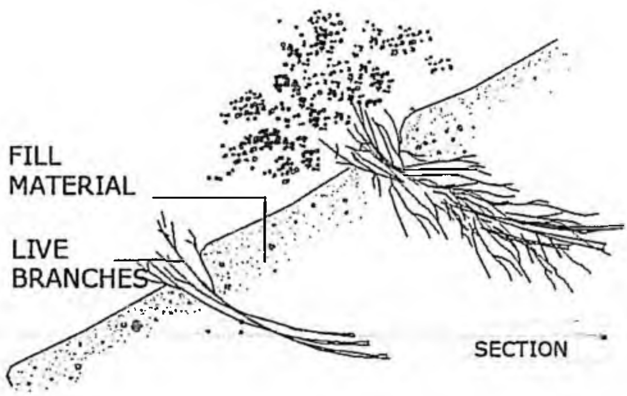

Figure 5 : Brushlayering on fill slopes
Şekil 5 : Dolduru şevlerinde canlı çit tesisi

Vegetated geogrids[2]: A vegetated geogrid installation consists of live cut branches (brushlayers) interspersed between layers of soil and wrapped in natural or synthetic geotextiles materials (Figure 6). The brush is placed in a crisscross or over-lapping pattern so that the tips of the

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[2] Geogrids are net-shaped synthetic polymer-coated fibers that are used to reinforce earth-fill slope, wall and base layer construction.

branches protrude just beyond the face of the fill, where they retard runoff velocity and filter sediment out of the slope runoff. The stems extend back into the slope. The brushlayers are living and root along their lengths and also act as horizontal slope drains.

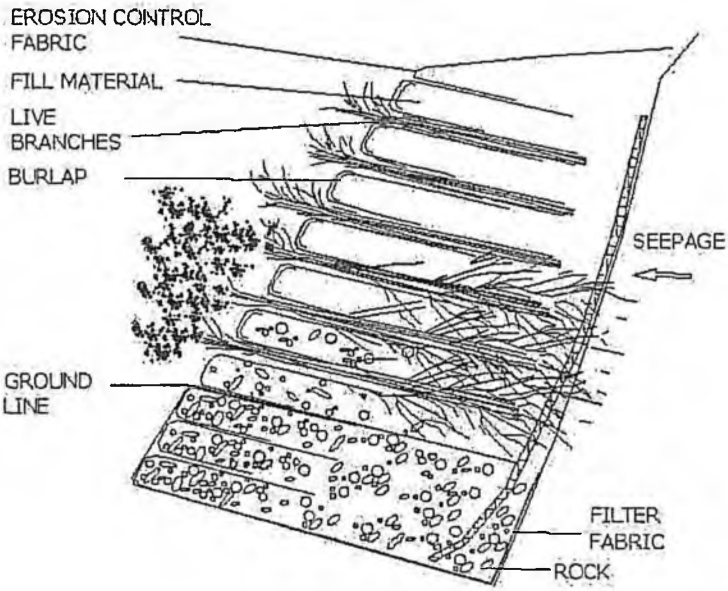

Figure 6 : Vegetated geogrids
Şekil 6 : Bitkilendirilmiş jeogridler

Live gully repair fill: A live gully repair fill consists of alternating layers of live branch cuttings and compacted soil. This reinforced fill can be used to repair rills and small gullies. The method is similar to branchpacking but is more suitable for filling and repairing elongated voids in a slope such as gullies (Figure 7).

Vegetated (Live) Crib Walls: A vegetated crib wall consists of a hollow, box-like interlocking arrangement of structural beams. In live crib walls the structural members are usually untreated log or timber members. The structure is filled with a suitable backfill material (or cribfill) and layers of live branch cuttings, which root inside crib (Figure 8).

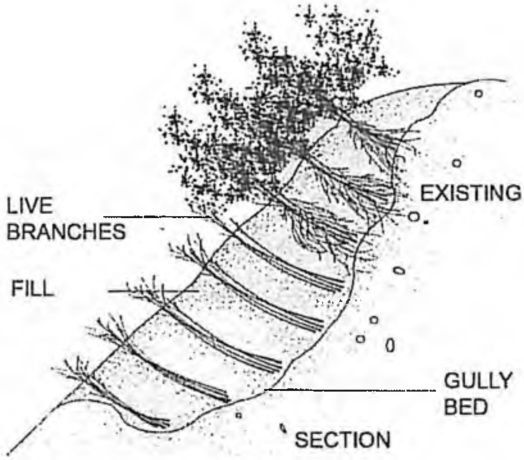

Figure 7 : Live gully repair
Şekil 7 : Canlı oyuntu onarımı

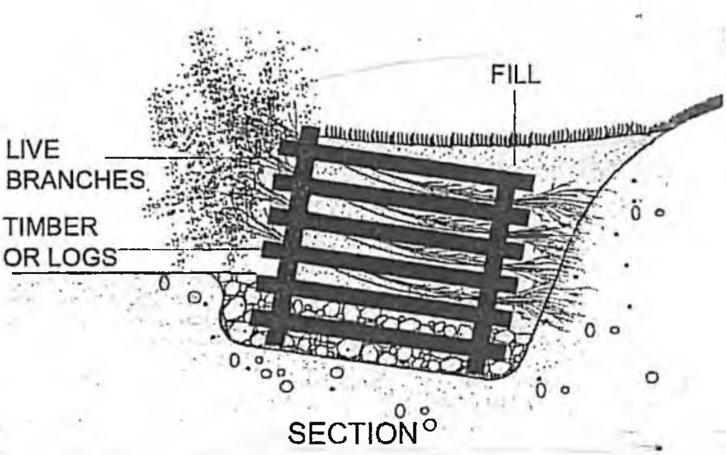

Figure 8 : Vegetated (live) crib wall
Şekil 8 : Bitkilendirilmiş (canlı) tomruk çatma duvar

Live Slope Grating: A live slope grating consists of a lattice-like array of vertical and horizontal timbers that are fastened or anchored to a steep slope. The structural members are typically untreated log or timber members. The grating is constructed in such a manner so as to support itself from the bottom. The openings in the structure are filled with a suitable backfill material and layers of live branch cuttings, which are placed in a similar manner to brushlayering (Figure 9).

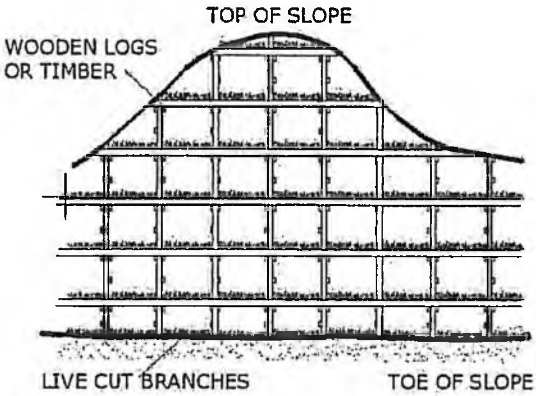

Figure 9 : Live slope grating
Şekil 9 : Canlı yamaç ızgarası

2.1 Selection Criteria

Soil bioengineering methods can be selected according to their utility of suitability for two main slope types, namely upland slopes/hillsides versus streambank/coastal bluffs. The main difference in these two cases is the requirement for some type of toe protection or shoreline defense in the latter to guard against scour and undermining of the slope. Suitable soil bioengineering measures, or combinations of measures, can also be selected based on soil and site conditions (GRAY/SOTIR 1996).

Soil bioengineering measures should be planned according to the:

- Ecological conditions,
- Technical and ecological effectiveness of the individual building methods as they relate to the live building material that exist in the landscape,
- Extend the problem,
- Required aesthetic effect,
- Economic considerations.

In practice this will make it necessary to secure the unstable locality through technical preparation works (SCHIECHTL 1980). Soil bioengineering methods can also be selected according to their environmental and recreational aims. Because of CO_2 emission and carbon sequestration, soil bioengineering methods are more appropriate than structural measures.

2.2 Application

Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install plants and it often coincides with a time when other construction work is slow. The requirement of dormant materials also limits the use of soil bioengineering to seasons; as a result cold storage and refrigerated transportation may be necessary.

Some woody plants used in soil bioengineering projects include, but are not limited to: willow *(Salix* spp.*)*, dogwood *(Cornus* spp.*)*, alder *(Alnus* spp.*)*, poplar *(Populus* spp.*)*, viburnum *(Viburnum* spp.*)*, maple *(Acer* spp.*)*, spruce *(Picea* spp.*)* and cedar *(Cedrus spp.)*. Certain species maple *(Acer* spp.*)*, spruce *(Picea* spp.*)* and cedar *(Cedrus spp.)*. Certain species are difficult to propagate vegetative method, for example *Salix caprea* and *Populus tremula* (SCHIECHTL 1980). Generally, plants with greater water consumption capacity are used in soil bioengineering.

2.3 Attributes and Limitations

Soil bioengineering is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment, for example, grass seeding and hydro mulching, works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system alone or possibly in combination with soil bioengineering. The following can be cited as important attributes of soil bioengineering systems (GRAY/SOTIR 1996):

Labor/Skill Requirements: Soil bioengineering measures tend to be labor/skill intensive, as opposed to energy/capital intensive. Soil bioengineering requires the use of hand labor. In spite of the relatively high use of labor, soil bioengineering work often costs less than conventional treatments because it is normally performed in the dormant season, a time of year when labor is often more available.

Utilization of Natural and/or Indigenous Materials: Soil bioengineering relies primarily on the use of native materials such as plants and plant stems or branches, rocks, wood, and earth. Appropriate vegetation can often be obtained from local stands of species such as willow, alder, dogwood, and others. This stock is already well suited to the climate, soil conditions, and available moisture of the area, and is therefore better suited to survival.

Cost effectiveness: Field studies have shown instances where combined slope protection systems have proven more cost effective than either vegetative treatments or structural solutions alone. The use of indigenous material accounts for some of the cost savings because plant costs are generally limited to labor for harvesting, handling, and transportation to the site. Where construction methods are labor intensive and labor costs are reasonable, the combined systems may be especially cost effective.

Environmental Compatibility: Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. Over time, systems themselves are visually non-intrusive and blend into the natural surroundings. These are favorable attributes in environmentally sensitive areas such as parks, woodlands, riparian areas, and scenic corridors, where aesthetic quality, wildlife habitat, ecological restoration, and similar values are important.

Self-Repairing Characteristics: Unlike conventional, inert systems, soil bioengineering systems become stronger with time as the vegetation roots and become well established. Vegetation has the ability to regenerate when subject to stress that dose not kill the plants. Replanting and infill planting can be used to repair damaged areas as well.

Planting Times: Soil bioengineering systems are most effective when they are installed during the dormant season; usually the late fall, winter, and early spring. This ordinarily coincides with a slowdown it other construction work. Constraints on planting times or the availability of the required quantities of suitable plant material during the allowable planting time may limit the usefulness of soil bioengineering methods in certain circumstances. This time constraint can be partly circumvented by placing cuttings or live plant materials in cold storage until ready for use.

Difficult Sites: Soil bioengineering is often a useful alternative for highly sensitive or steep sites where the use of machinery is not feasible and hand labor is a necessity. On the other hand, usefulness of soil bioengineering methods may be limited by a poor medium for plant growth, such as rocky or gravely slopes that lack sufficient fines or moisture, or by extreme acidity or other toxic conditions in the soil. The biotechnical usefulness of vegetation is also limited on slopes that are exposed to periodic, high-velocity flow or constant inundation. The former constraint can be circumvented to some extent, however, by using structural reinforcement or augmentation with biotechnical ground covers.

Arid zones restrict the use of bioengineering methods somewhat. Usually it is necessary to adjust the bioengineering method to the specific characteristics of the arid zones. Both suitable plant species and the correct building method have to be chosen. The use of live building materials in arid and semi-arid zones is very limited if there is no irrigation. Artificial water supply is necessary only in the first phase of development until vegetation is well established. Very often annual plants replace perennial grasses and forbs. These annuals survive the dry periods as seeds. In semi arid and arid areas it is best to use succulent plants, which survive for a long time in dry zones because of their water-retaining tissue (SCHIECHTL 1980).

According to a study, the average benefit to cost ratio demonstrates that soil bioengineering is a favorable economic alternative than traditional geotechnical solutions in roadside management (LEWIS *et al.* 2001).

Soil bioengineering needs intensive maintenance; cuttings should be inspected regularly for insufficient moisture, dead cuttings, insect infestation etc.

3. SOIL BIOENGINEERING POTENTIAL AND DIFFICULTIES IN TURKEY

Since biotechnical slope stabilization methods have been applied for nearly 60 years in torrent and erosion control in Turkey, the country has a lot of experience in vegetative slope stabilization. There are many nurseries established and site corrected plants used in biotechnological projects throughout Turkey. Some big nurseries have cold storage units for keeping plants dormant. Therefore, this knowledge can be used in soil bioengineering as well.

Unemployment rate in Turkey is relatively high and young accounts for half of the nation's population. Since most soil bioengineering methods require hand labor and no heavy machinery and large investment are needed, such operations could create new employment opportunities for the young in the country.

There are some examples of applications to be considered as soil bioengineering methods combined with biotechnical works in Turkey. Büyük Menderes Riverbanks, for instance, have been reinforced with double lined stakes with willow bundles and willow stakes in between bundles. Although this application of a mixture of biotechnical and soil bioengineering methods was in the riverbed, the success in operation laid on the irrigation for one vegetation season. Çubuk river levee stabilization is another example made by vegetated riprap by willow stakes. Brushlayering with broom and reed behind wattle fences or in terraces on slope and retaining structures on toe were successful in Büyük Menderes river basin for landslide control.

Soil bioengineering methods alone are not sufficient in controlling mass movement due to slow vegetation growth in arid zones. Since there is no surface and mass stabilization in slopes in most areas with severe and very severe erosion risk, it is vital that stabilization be maintained first by hard engineering before soil bioengineering methods are applied.

According to the applications in some countries, soil bioengineering methods are generally more cost effective than some conventional methods.

Turkey is divided into seven geographical regions according to distribution the annual precipitation, which varies between 250-2500 mm. The rainiest regions in the country are outer aspects of mountains in Black Sea, Marmara, and Mediterranean regions, which lay parallel to the sea, and these regions take rainfall roughly ranging between 1000-2200 mm. However, only in the outer aspects of Marmara and Black Sea region and some part of eastern Anatolia, precipitation is distributed throughout seasons and this area take sufficient summer rainfall. Outer aspects of mountains in Mediterranean region also take 600-1000 mm precipitation however summer precipitation is relatively low despite high temperatures. Outer aspects of Marmara and Black Sea region and some part of eastern Anatolia form only 11% of surface area of Turkey and in the rest (89%) annual precipitation is low, seasonal distribution of rainfall is not uniform with very little or no precipitation in summer (Figure 10). Since soil bioengineering methods use generally rapid growing, in other words, water loving plants, survival or growth and stabilization effect of plants are not adequate and the methods are hardly performed in the country except for Marmara and Black Sea regions if other ecological conditions permit. The methods can be applied only on slopes in other parts of the Turkey, which have microclimate, natural drainage or leakages and irrigation possibility in the early phase of plant growth. The ratio of 89% was calculated from meteorological records and real figure can be found considering other ecological conditions, microclimates and application tests.

Use of some water harvesting systems such as terraces can increase applicability of soil bioengineering methods. But application should be considered in the context of adequate soil moisture in summer. Although there are plants, which have the ability to survive in arid areas, root and leaf out degree can be very slow and stabilization functions of these applications can also be inadequate.

Moderately, severely and very severely eroded areas form 78.8% of surface area of Turkey (TOPRAKSU 1981). Moderate soil erosion states absence of 75% topsoil however in severe erosion all topsoil and 25% of subsoil also is disappeared. Very severely eroded areas on the other hand, comprise no topsoil and most parts of the subsoil are vanished. Since soil and nutrition matter is as vital as precipitation in soil bioengineering, lack of nutrients in soil is another factor preventing normal plant growth, development, protection and stabilization effects by vegetation.

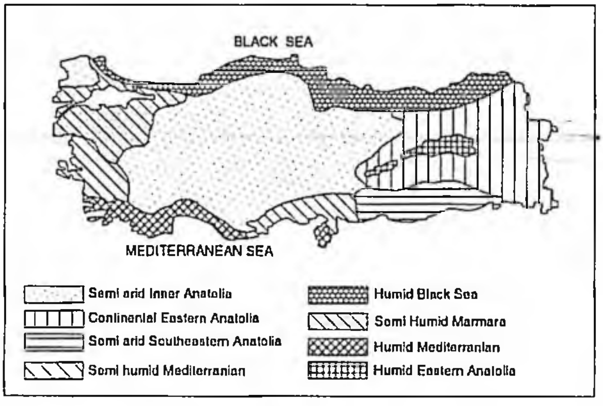

Figure 10 : Climate types in Turkey
Şekil 10 : Türkiye'deki iklim tipleri

Since cold storage is necessary against the shortness of working period in dormant seasons, refrigerated depots in nurseries and refrigerated vehicles for transportation are needed.

Soil bioengineering methods need interdisciplinary coordination, experienced hand labor and continuous maintenance. Biotechnical methods are applied with relatively less skilled hand labor and less maintenance in Turkey. Besides, in some areas, only fencing and protection are seen as an effective erosion control method. Therefore this is another constraint in soil bioengineering methods in the country.

One of the basic problems preventing torrent and erosion control works in Turkey is ownership problem. While 99.99% of forests are belong to state (DPT 2001), cadastral limitation of forests has not finished yet (76% finished). There is conflict between government and villagers for utilization from forestlands. Illegal uses such as grazing, fuel wood collection etc. in forest area cannot be prevented. Since mean income level of villagers especially in mountainous-forested areas is lower than the average; they are dependent on forests by mostly illegal use. Young generation migrates to cities and forest dependant population has declined during last two decades but it is not adequate to eliminate harmful activities against forests.

Some soil bioengineering methods are not applicable; for example crib walls, due to easy rotting and value of wood as fuel in Turkey.

4. RESULTS AND CONCLUSION

Biotechnical and soil bioengineering methods greatly expand our range of options for stabilizing and protecting slopes against erosion and shallow mass movement. More to the point they allow us to carry out this mission in a cost-effective, visually attractive, and environmentally sensitive manner. Questions still remain with regard to quantification and performance evaluation; but answers to these questions will emerge as we gain experience with biotechnical and soil bioengineering stabilization works.

While soil bioengineering is an effective tool, it should not be viewed as a sole solution for all sites and situations. On large landslide features, for example, a geotechnically engineered system alone, or in combination with soil bioengineering should be used. Retaining walls, gabions, road realignment/relocation, and temporary sediment control, erosion mitigation strategies and techniques, cut and fill slope stabilization, and outsloping are alternate and complementary practices to bioengineering applications.

For rapid protection and stabilization by soil bioengineering methods, appropriate climate conditions and especially summer precipitation are essential. Precipitation is not the only factor for plant survival; local climates, tests etc., should be considered, but if only precipitation is taken into consideration, except for outer aspects of mountains of Marmara and Black Sea regions and some part of eastern Anatolia, 89% of Turkey takes low or no summer precipitation. Even if plants or plant parts survive, they cannot grow fast to stabilize the slope unless a leakage in the slope or irrigation possibility.

Soil bioengineering methods are sophisticated and need interdisciplinary team effort, continuously involved in the project and qualified hand labor is critical for success. In contrary, conventional biotechnical works are relatively easy to apply in torrent and erosion control projects. However, soil bioengineering methods should be used in roadside stabilization and urban areas for general public and can be used in some landscape projects, with irrigation possibilities.

Due to the fact that cadastral limitation of forests has not finished yet (76% finished) and some socio-economic problems, such as illegal use of forests, grazing, fuel wood collection etc. go on. Mainly due to these problems, even biotechnical slope stabilization projects are hardly applied because 89% of Turkey has dry summers. Generally speaking, it is relatively hard to apply the soil bioengineering methods throughout the country. In the areas taking enough summer rainfall, soil bioengineering methods can be applied after conflictions on the use of forest area etc. are solved.

YAMAÇ STABİLİZASYONUNDA DOĞAL MÜHENDİSLİK: TÜRKİYE'NİN POTANSİYELİ VE ENGELLERİ

Doç. Dr. Hüseyin E. ÇELİK

Kısa Özet

Doğal mühendislik (soil bioengineering), yamaçları ve nehir kıyılarını stabilize etmek amacıyla canlı bitki veya bitki parçalarının kullanılmasıdır. Sel, erozyon ve sığ kütle hareketlerini kontrol etmek amacıyla doğal mühendislik yöntemlerinin kullanımı 1930'lardan beri dünyada önem kazanmıştır. Yöntemin hızlı stabilizasyon sağlaması, bitkilerin hızla köklenmeleri ve yapraklanmalarına bağlı olduğu için yaz yağmurları temel faktördür. Yöntem kurak bölgelerde uygulanırsa, bitki gelişiminin ilk devresinde sulama gereklidir. Türkiye'nin sadece % 11'inin yeterli yaz yağmuru alması nedeniyle diğer ekolojik koşullar hariç tutulduğunda, ülkenin geri kalan %89'unda doğal mühendislik uygulaması mikroklimaya, yamaçlardaki su sızıntılarına ve bitkinin en azından ilk gelişme devresinde sulanmasına bağlıdır.

Anahtar Kelimeler: Doğal mühendislik, Biyoteknik çalışmalar, Yamaç stabilizasyonu, Sel ve erozyon kontrolu.

1. GİRİŞ

Soil bioengineering terimi *bioengineering* terimi ile eş anlamlı olarak kullanılmaktadır. Soil bioengineering teriminin bazı dillerdeki karşılıkları şunlardır: Almanca'da *Ingenieurbiologie* (mühendislik biyolojisi), Fransızca'da *génie biologique* (biyolojik mühendislik), İtalyanca'da *ingegneria naturalistica* (doğal mühendislik), İspanyolca'da *bioingeniería de suelos* veya *ingegnieria naturalistica* (toprak biyomühendisliği veya doğal mühendislik). Terimin Türkçe'de henüz genel kabul görmüş bir karşılığı bulunmamaktadır. *Bioengineering* terimi tıp, hijyen, genetik gibi bir çok konuda çağrışımlar yaratmaktadır. Doğal elementler ve işlemlerden yararlanılması nedeniyle ve bazı Akdeniz ülkelerinin yaklaşımına paralel olarak terimin Türkçeye *doğal mühendislik* şeklinde çevrilmesinin daha uygun olacağı düşünülmüştür.

Doğal mühendislik yöntemlerinin Çin'de 12. yüzyılda kullanıldığı görülmektedir (FRANTI 1996). Makine çağında beton ve çelik kullanımının gelişmesi, yapısal mühendislik yöntemlerini teşvik etmiştir. 1930'lardan beri doğal mühendisliğin temel kavramlarını kullanan başarılı teknikler geliştirilmiştir. Doğal mühendislik klasik biyoteknik stabilizasyonun bir parçası veya özel bir alanı olarak görülmektedir. Doğal mühendislik bitki kök ve gövde parçalarının yamaç stabilizasyonunda ana yapısal ve mekanik elementler olarak hizmet etmesi bağlamında tek yöntemdir. Canlı çelikler ve köklü bitkiler öyle bir düzen ve geometrik sırada dikilir ki bitkiler toprak donatısı, drenaj ve toprak hareketini engelleyici unsur olarak hizmet ederler (GRAY/SOTIR 1996).

Bitkilerin ve yapıların birlikte kullanıldığı yamaç stabilizasyonuna biyoteknik stabilizasyon denmektedir. Biyoteknik yamaç stabilizasyonu Türkiye'de 1940'larda başlamış ama sistematik olarak 1950'lerde uygulanmaya başlamıştır. Son 10 yıl içinde sınırlı alanlarda doğal mühendislik olarak kabul edilebilecek çalışmalar bulunmaktadır. Yazıda doğal mühendislik tanımlandıktan sonra Türkiye'nin potansiyeli ve engelleri incelenmiştir.

2. DOĞAL MÜHENDİSLİK YÖNTEMLERİ

Doğal mühendislik yöntemleri yüzeysel erozyon ve sığ kitle hareketlerini kontrol etmek ve önlemek amacıyla kullanılır. Farklı yöntemler veya yöntemlerin kombinasyonu, doğal yamaçlar, yolların kazı ve dolduru şevleri, moloz döküm alanlarının kaplanması, malzeme alınmış kıyılar ve akarsu kıyıları gibi alanlarda kullanılabilir (GRAY/SOTIR 1996).

Bazı doğal mühendislik yöntemleri şunlardır: *Canlı kazık, canlı dal demeti, canlı dal demetleriyle drenaj, yer altı drenaj sistemiyle kullanılan canlı dal demetleri, canlı çit tesisi, bitkilendirilmiş jeogridler*[3]*, canlı oyuntu onarım dolgusu, bitkilendirilmiş (canlı) tomruk çatma duvarlar* ve *canlı yamaç ızgarası* (Şekil 1-9). Ancak bu yöntemler sayılanlarla sınırlı değildir.

Doğal mühendislik yöntemleri yamaçta veya akarsu kıyılarında uygulandığına, ekolojik koşullara, sorunun boyutuna, istenen estetik etkiye ve ekonomik düşüncelere göre seçilir (SCHIECHTL 1980, GRAY/SOTIR 1996).

Doğal mühendislik projeleri geç sonbahar ile erken ilkbahar arasındaki bitkilerin durgun döneminde (vejetasyon dönemi dışında) uygulanır. Durgun dönemde bitki kullanma zorunluluğu uygulama mevsimini sınırlayabilir, örneğin çalışmanın yapılacağı yükseltide henüz kar varken, fidanlığın bulunduğu yükseltide bitkiler vejetasyon dönemine girebilirler; dolayısıyla bitkiler durgun dönemdeyken sökülüp soğuk depolara alınarak vejetasyon dönemine girmesinin önlenmesi ve uygulama alanına soğutma düzenekli taşıtlarla taşınması gerekebilir.

Doğal mühendislik projelerinde kullanılan bazı odunsu bitkiler şunlardır: Söğüt *(Salix* spp.*)*, kızılcık (*Cornus* spp.), kızılağaç (*Alnus* spp.), kavak (*Populus* spp.), kartopu (*Viburnum* spp.), akçaağaç (*Acer* spp.), ladin (*Picea* spp.) ve sedir (*Cedrus spp.*). Bazı türleri vejetatif yöntemle üretmek zordur, örneğin *Salix caprea* ve *Populus tremula* (SCHIECHTL 1980). Bu türlerle sınırlı olmayan bitkilerin genel özellikleri hızlı gelişmeleri ve su sevmeleridir.

Doğal mühendislik her yere ve duruma uygun değildir. Yerine göre klasik bir bitkisel yöntem, örneğin ot ekilmesi az maliyetle doyurucu sonuç verebilir. Doğal mühendislik yöntemlerinin bazı özellikleri ve sınırları şunlardır (GRAY/SOTIR 1996):

- Yöntemler emek yoğun niteliktedir. Daha çok el işçiliği gereklidir.
- Uygulamada yakın çevreden elde edilebilecek bitki ve bitki gövde ve dalları, kayalar, odun ve toprak kullanılır.
- Yöntemler tek başına bitkisel veya yapısal çözümlerden daha maliyet etkindir.
- Yöntemler çevreye uyumludur.
- Yöntemlerin kendi kendini onarma-yenileme özelliği vardır.
- Yöntemlerin vejetasyon dönemi dışında uygulanmaları gerekir.
- Yöntemler makineli çalışmanın mümkün olmadığı çok eğimli alanlarda uygun bir seçenek oluşturur.

Kurak ve yarı kurak zonlarda sulama yoksa doğal mühendislik uygulaması çok sınırlıdır (SCHIECHTL 1980). Doğal mühendislik yoğun bakım gerektirir, topraktaki nem miktarı, böcek

[3] Toprak dolgu yamaç, duvar ve temel tabaka inşaatını güçlendirmek amacıyla kullanılan, ağ şeklindeki sentetik polimer kaplı liflere jeogrid denir.

istilasının bulunup bulunmadığı sürekli kontrol edilmeli, kurumuş bitkiler veya bitki kısımları çıkarılmalı ve tamamlanmalıdır.

3. TÜRKİYE'DE DOĞAL MÜHENDİSLİK POTANSİYELİ VE ENGELLERİ

Biyoteknik yamaç stabilizasyon yöntemleri yaklaşık 60 yıldan beri Türkiye'de sistemli olarak uygulanmaktadır. Dolayısıyla yeterli bilgi birikimi, amaca uygun bitkilerin üretimi için fidanlıklar, bazı büyük fidanlıklarda da soğuk hava depoları bulunmaktadır. Bu alt yapı doğal mühendislik için kullanılabilir.

Doğal mühendislik ağır makinelerden çok, iş gücüyle uygulanmaktadır. Bu yöntem işsiz genç nüfusun işlendirilmesinde yardımcı olabilir. Yöntemin bitkinin durgun döneminde uygulanması nedeniyle bu dönemdeki ucuz işgücünden yararlanılabilir.

Türkiye'de doğal mühendislik kapsamında değerlendirilebilecek bazı uygulamalar bulunmaktadır. Örneğin Büyük Menderes kıyıları, çift sıra kazık arasına söğüt dal demetleri yerleştirilip demetlerin arasına söğüt çelikleri dikilerek güçlendirilmiştir. Bu uygulama biyoteknik ve doğal mühendislik yöntemlerinin bir karışımıdır. Ancak çalışma nehir kıyısında olmasına rağmen ilk vejetasyon döneminde sulama gerekmiştir.

Doğal mühendislik yeterli yaz yağmurlarına gereksinim duymaktadır. Ülkemizde Karadeniz bölgesi ve Marmara Bölgesindeki kıyıya paralel dağların kuzey bakıları ile Doğu Anadolu'nun bir kısmından oluşan ve Türkiye yüzölçümünün % 11'ini meydana getiren alanda yeterli yaz yağmurları yağmaktadır (Şekil 10). Dolayısıyla sulama, yerel iklim koşulları ve yamaçta mevcut su sızıntısı dışında, teorik olarak ülke yüzölçümünün geri kalan % 89'unda doğal mühendisliğin uygulanma şansı azdır. Pratikte diğer ekolojik koşullar, mikroklima, yamaç sızıntıları, sulama vb. bu oranı değiştirebilir.

Türkiye yüzölçümünün % 78,8'inde orta, şiddetli ve çok şiddetli erozyon hüküm sürmektedir. Erozyonla üst ve alt toprakla birlikte organik madde ve besin maddeleri de taşınmaktadır. Dolayısıyla erozyonla kaybedilen toprak ve besin maddeleri doğal mühendislik uygulamalarını olumsuz yönde etkileyebilir.

Yöntem bitkilerin durgun döneminde uygulanabilir. Fidanlıkta bitkilerin vejetasyon döneminin başladığı ancak proje alanında iklimsel nedenlerle henüz başlamadığı durumlarda, kullanılacak bitki materyalinin durgun dönemde tutulması için fidanlıklarda soğuk hava depolarına ve soğutma düzenekli taşıtlara gerek vardır.

Doğal mühendislik disiplinler arası işbirliği, deneyimli işgücü ve devamlı bakım istemektedir.

Türkiye'de ormanların % 99,99'unun devlet mülkiyetinde olmasına karşın henüz % 76'sının kadastrosu tamamlanabilmiştir. Kadastrosu tamamlanmış ormanların kullanımında bile otlatma, usulsüz yararlanma vb. şekillerde orman köylüsüyle sorunlar yaşanmaktadır. Yamaç stabilizasyon projeleri ancak vatandaşla anlaşmazlık yaşanmayan alanlarda uygulanabilmektedir. Ayrıca orman köylülerinin yıllık geliri ülke ortalama yıllık gelir düzeyinin çok altındadır. Orman köylerindeki nüfus son yirmi yılda azalmakta ise de orman tahribi halen devam etmektedir.

4. SONUÇLAR VE TARTIŞMA

Doğal mühendislik yöntemi, erozyon ve sığ kitle hareketlerine karşı yamaçları korumak için maliyet etkin, emek yoğun, görsel niteliği yüksek ve çevre dostu bir uygulamadır. Ancak doğal mühendisliği her yöre ve durumda etkin bir çözüm olarak görmemek gerekir. Gerektiğinde biyoteknik yöntemlerle kombine edilmeli veya sadece ot ekimi ve koruma ile yetinilmelidir.

Yöntemin hızla etkin hale gelebilmesi için uygun iklim koşulları ve ilk planda yeterli yaz yağmurları temel koşuldur. Diğer ekolojik koşulların dışında sadece yaz yağmurları dikkate alındığında, Marmara ve Karadeniz bölgesindeki sıradağların denize bakan yamaçları ile Doğu Anadolu'nun bir kısmı yöntem için uygun alanlar olarak gözükmektedir. Ancak mikroklimalarda, sulama olanağının bulunduğu yerlerde, özellikle şehirlerde ve kamuoyunun oluşması amacıyla yerleşim alanlarının yakınında gerekli koşullar sağlanarak yöntem uygulanabilir. Türkiye'nin bu alanlar ve koşullar dışında kalan kısmı için doğal mühendisliğin uygulama zemini bulunmamaktadır.

Türkiye'de doğal mühendislik ve diğer sel ve erozyon kontrol uygulamalarını kısıtlayan önemli etkenlerden biri de orman kadastrosu ile sosyo-ekonomik sorunlardır. Ülkenin kadastrosu hızla bitirilmeli, biten alanlardaki anlaşmazlıklar hızla çözümlenmelidir. Orman köylüsünü ormandan yasadışı yollarla yararlanmaktan vazgeçirecek önlemler alınmalıdır.

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