Fundamentals of Erosion Control on Slopes and the Role of Geosynthetics

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ABSTRACT: Water and wind erosion are the most common and greatest natural harmful effects among all erosion processes. The soil erosion process includes detachment, transportation and deposition of soil particles from a consolidated soil body. Soil erosion can be divided into natural erosion and accelerated erosion. The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land and the nature of the plant cover. Civil engineering projects often result in disturbing on-site slope soil surfaces. The disturbed bare soils on slopes are highly sensitive to runoff and erosion process. The water erosion process on a slope leads to partial or complete loss of the surface soil layer. Such eroded slopes have lower fertility due to the loss of soil particles, nutrients and organic matter, affecting the soil structure, water holding capacity and porosity. The establishment of plants and subsequent development of a protective vegetation cover are hampered. Slopes are therefore exposed to further and more severe erosion processes. The strategies for soil conservation must be based on covering the soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce runoff; improving the aggregate stability of the soil; and increasing the surface roughness to reduce runoff and wind velocity. Various conservation techniques include agronomic measures, soil management and mechanical methods. Erosion and shallow landslides are commonly treated with artificial coverage materials in conjunction with vegetation. Geotextiles, geocells and geosynthetic erosion control products have been demonstrated effective in reducing erosion and subsequent slope degradation processes. The Soil erosion influence factors and mechanisms on slopes are discussed. Laboratory, field and engineering case studies on various geosynthetics for erosion control applications are also reviewed and discussed.

Keywords: Soil erosion, Slope protection, Geosynthetics, Rolled erosion control product, Geotextiles, and Vegetation protection.

1 INTRODUCTION

Soil erosion is a naturally occurring process on all land. The agents of soil erosion are precipitation, runoff, wind, earthquakes, wave, and temperature, each contributing a significant amount of soil loss each year. Water erosion and wind erosion are the most common and greatest natural harmful effects among these erosion processes. The soil erosion process includes detachment, transportation and deposition of soil particles from a consolidated soil body. Since soils consist of rich organic matters and various nutrients, the loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. In addition, the eroded soils flowing into water reservoirs pollute the water and cause dam reservoir eutrophication.

2 AGENTS OF EROSION

Erosion is essentially a smoothing or leveling process, with soil and rock particles being carried, rolled, or washed down by the force of gravity. The main agents that loosen and break down soil particles are wind and water.

Wind erosion is the result of an abrasion process from grains of sand or soil carried in suspension. Water is probably the most important single erosion agent. Rainfall, streams and rivers all scour or carry away soil, waves erode the shores of seas and lakes. In fact, wherever water is in movement it is eroding its boundaries.

When considering natural erosion the passage of time is hardly noticeable. Examples are the cracking and flaking of rock by variations in temperature. Rapid variations between day and night affect only the surface rocks, while the changes due to slower variations between summer and winter penetrate deeper. When temperature changes include frost, the disruption is greatly increased by the expansion of water in rock and soil cracks and crevices.

Some actual destruction may be caused by living organisms, such as lichens and mosses on rocks, but the main effect of living things is any disturbance that speeds up the effects of other agents.

3 TYPES OF SOIL EROSION

Soil erosion can be divided into natural erosion and accelerated erosion. Soil erosion caused by exterior natural agents can be classified as natural erosion. Soil erosion caused by human activities can be classified as accelerated erosion.

Precipitation, wind, temperature changes and living creature activities are the natural agents that produce natural erosion. Precipitation includes rain fall, frost, dew condensation, snow and glacial movement. Precipitation, wind and temperature change are the major agents that cause natural rock degradation into soil. Natural soil erosion is a slow process that continues relatively unnoticed. Generally, undisturbed rock requires around 300 years to generate a soil layer 25 mm thick. Therefore, natural erosion is normal erosion or geological erosion.

However, farm land reclamation and human activities disturb surface soils and soil structures. These activities accelerate the soil erosion process. This accelerated erosion may occur at an alarming rate causing serious loss of topsoil. Disturbed rock requires around 30 years to generate a soil layer 25 mm thick, according to collected research reports. Nearly 300 tons of top soil loss would be induced by farming on 60% slope land without any soil conservation treatment (Wu and Wang, 1996).

3.1 *Raindrop erosion*

Soil erosion will usually initiate at the beginning of rainfall. Falling raindrops will impact the bare soil surface and cause soil particles to detach from the soil surface. This process is called splash erosion or raindrop erosion. If the rain continuous falling, the surface soils will be saturated and runoff erosion will develop. Runoff will carry the detached soil particles and induced further in depth surface erosion. As the runoff moves from uphill to the downhill on the slop, the amount of runoff flow will also increase and runoff cutting strength will also increase. This type of erosion is called concentrated-flow erosion. In addition, stream-bank erosion and seashore erosion will also develop as the runoff reaches rivers and the ocean. All of these types of erosion are related to the initiated rainfall with different intensity and damage. Water erosion is the common term for all of these types of erosion.

3.2 *Wind erosion*

Wind erosion is induced by wind. It usually occurs in dry and wide open areas with limited rainfall. Wind will gradually erode rock surfaces and transport non-cohesive sand particles. Therefore, wind erosion can cause severe sand dune movement covering farm lands, roadways and houses. However, the effect of wind erosion is not further discussed in this paper.

4 SOIL EROSION INFLUENCE FACTORS

The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land and the nature of the plant cover.

Rainfall erosion potential describes the soil breakage capability from rainfall. Soil erodibility describes the soil resistance quantity index against erosion. Runoff erosion potential is the combination of rainfall erosion potential and soil erodibility.

Rainfall erosion potential is related to the rainfall type and rainfall characteristics. Excluding seasoning rain events, rainstorms, typhoons, thunderstorms, large area soil movement and landslide conditions, rainfall erosion is related directly to the rainfall and soil condition characteristics. Rainfall erosion is a function of rainfall erosivity and soil erodibility. The rainfall characteristics are related to the total amount of rainfall and rainfall duration. Soil erosion potential is therefore directly influenced by the atmospheric environment.

Soil erodibility is influenced by internal and external soil factors. The internal factors include physical and chemical soil influence factors. Soil physical properties include soil material content, structure and permeability. Soil chemical properties include soil organic content and soil cohesion capability.

Soil erodibility external influence factors are directly related to soil erosion resistance ability. These factors include terrain factor, farming products management factor, land management and application factors. Slope degree and slope length are terrain factors. Crop type, plough depth and cropping method are related to the soil disturbance depth. Crop height, crop affixed to the ground and surrounding vegetation conditions are related to the top soil cover conditions and protection capability.

Land use and management are also important factors for soil erodibility. The appropriate use of ditches on hill slopes will provide adequate drainage function and reduce runoff. This application can significantly reduce the soil erosion potential. Therefore, soil erosion loss is function of rainfall erosivity and soil erodibility and can be formulized as follows:

Soil erosion loss = Function (rainfall erosivity and soil erodibility) = Function (rainfall erosivity and soil internal factors, terrain factors, crop management factors, and land use and management factors)

Human activities are the major factors for accelerated erosion. Therefore, soil erosion can be controlled if soil erosion can be reasonably estimated during the project development and planning stage, and appropriate soil water conservation treatment can be designed and implemented during design phase.

5 UNIVERSAL SOIL LOSS EQUATION (USLE)

Monitoring and modeling of erosion processes can help people better understand the causes of soil erosion, make erosion predictions under a range of possible conditions, and plan the implementation of preventative and restorative strategies for erosion. However, the complexity of erosion processes and the number of scientific disciplines that must be considered to understand and model them (e.g. climatology, hydrology, geology, soil science, agriculture, chemistry, physics, etc.) makes accurately modeling soil erosion challenging. Erosion models are also non-linear, which makes them difficult to work with numerically, and difficult or impossible to scale up to making predictions about large areas from data collected by sampling smaller plots.

5.1 *Soil Loss Estimation*

The most commonly used model for predicting soil loss from water erosion is the Universal Soil Loss Equation (USLE). This was developed in the 1960s and 1970s. It estimates the average annual soil loss A (ton/hectare/year) on a plot-sized area as:

$$A = Rm\,Km\,L\,S\,C\,P$$

where Rm is the annual rainfall erosivity factor, Km is the soil erodibility factor, L and S are topographic factors representing length and slope, C is the cover and management factor, and P is the soil water conservation support practices factor.

Despite the USLE's plot-scale spatial focus, the model has often been used to estimate soil erosion on much larger areas, such as watersheds or even whole continents. This is scientifically controversial for several reasons. One major problem is that the USLE cannot simulate gully erosion and so erosion from gullies is ignored in any USLE-based erosion assessment. Yet erosion from gullies can be a substantial proportion (10-80%) of the total erosion on cultivated and grazed land.

6 SOIL CONSERVATION PRINCIPLES

The aim of soil conservation is to obtain the maximum sustained level of production and safety from a given area of land while maintaining soil loss below a threshold level which, theoretically, permits the natural rate of soil formation to keep pace with the rate of soil erosion. In addition, there may be a need to reduce erosion to control nutrient loss from agricultural land or developed areas to prevent the pollution of water bodies, decrease rates of sedimentation in reservoirs, rivers, canals, ditches and harbors, limit crop damage by wind or by burial beneath water and wind transported sediments and increase the stability and safety of developed areas. In the longer term erosion must be controlled to prevent the land from deteriorating in quality until it has to be abandoned and cannot be reclaimed, thereby limiting options for future use. Since erosion is a natural process, it cannot be prevented but it can be reduced to a maximum acceptable rate or soil loss tolerance.

The strategies for soil conservation must be based on covering the soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce runoff; improving the aggregate stability of the soil and increasing the soil surface roughness to reduce the velocity of runoff and wind. The various conservation techniques include agronomic measures, soil management and mechanical methods.

Agronomic measures utilize the role of vegetation to protect the soil against erosion. Soil management is concerned with ways of preparing the soil to promote plant growth and improve its structure so that it is more resistant to erosion. Mechanical or physical methods, often involving engineering structures, depend upon manipulating the surface topography, for example by installing terraces or wind breaks, to control the flow of water and air. Agronomic measures combined with good soil management can influence both the detachment and transport phases of erosion whereas traditional mechanical methods are effective in controlling the transport phase but do little to prevent soil detachment. Various geosynthetics are also widely used for soil erosion control applications. This mechanical method can influence soil detachment and erosion transportation processes.

7 APPROACHES TO SOIL CONSERVATION

Erosion control is dependent upon good management which implies establishing sufficient crop cover and the selection of appropriate tillage practices. Thus, conservation relies strongly on agronomic methods combined with sound soil management while mechanical measures play only a supporting role. A soil conservation strategy for cultivated land is shown in Figure 1 (Morgan, 1996). In addition, agronomic measures, soil management systems and mechanical methods are needed for non-cultivated land, as shown in Figure 2 (Morgan, 1996). Similarly, agronomic measures and soil management with some mechanical methods are commonly used for urban area soil conservation systems, as shown in Figure 3 (Morgan, 1996).

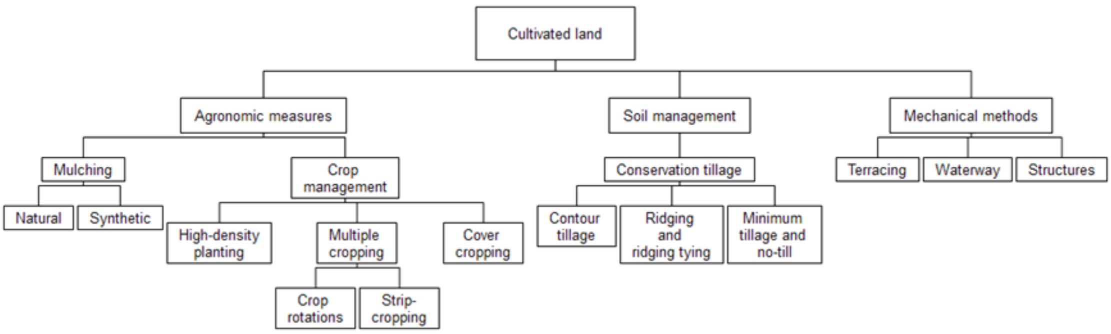

Figure 1: Soil conservation strategies for cultivated land (Morgan, 1996)

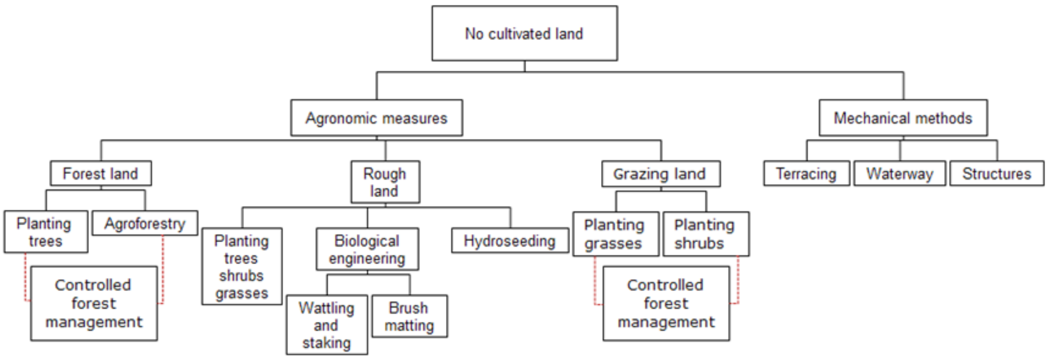

Figure 2: Soil conservation strategies for non-cultivated land (Morgan, 1996)

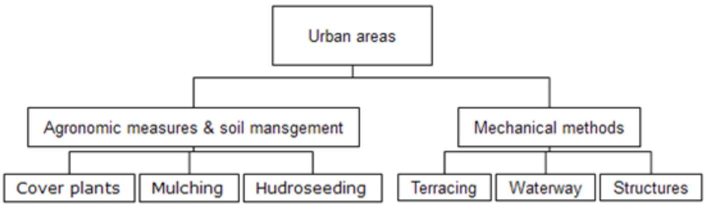

Figure 3: Soil conservation strategies for urban areas (Morgan, 1996)

7.1 *Vegetation measurements*

Vegetation acts as a protective layer or buffer between the atmosphere and the soil. The above ground components, such as leaves and stems, absorb some of the energy of falling raindrops, running water and wind, so that less erosion is directed at the soil. The below-ground components, comprising the plant root system, contribute to the soil mechanical strength. Agronomic measures for soil conservation use the protective effect of vegetation covers to reduce soil erosion. The use of geotextiles for vegetation is also a useful protection application for erosion control.

7.2 *Erosion control mechanical methods*

A range of techniques is available and the decision as to which to adopt depends on whether the objective is to reduce the velocity of runoff and wind, increase the surface water storage capacity or safely dispose of excess water. Mechanical methods are normally employed in conjunction with agronomic measures. The most common traditional mechanical erosion control methods include contouring, contour bunds, terraces, waterways, stabilization structures and windbreaks.

Carrying out plowing, planting and cultivation on the contour can reduce soil loss from sloping land compared with cultivation up-and-down the slope. The effectiveness of contour farming or land use varies with the length and steepness of the slope. It is inadequate as the sole conservation measure for lengths greater than 180 m at 1o steepness. The allowable length declines with increasing steepness to 30 m at 5.5^{o} and 20 m at 8.5^{o} (Morgan, 1996).

Contour bunds are earth banks, 1.5 to 2.0 m wide, thrown across the slope to act as a barrier to runoff, to form a water storage area on the upslope side and to break up a slope into segments shorter in length than is required to generate overland flow. The banks, spaced at 10 to 20 m intervals, are generally hand-constructed. There are no precise specifications for their design and deviations in their alignment of up 10% from the contour are permissible.

Terraces are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non-erosive velocity, and shorten the slope length. They differ from contour bunds by being larger and designed to more stringent specifications. Terrace can be classified into three main types: diversion, retention and bench. The primary aim of diversion terraces is to intercept runoff and channel it across the slope to a suitable outlet. Retention terraces are used where it is necessary to conserve water by stringing it on the hillside. Bench terraces consist of a series of alternating shelves and risers and are employed where steep slopes, up to 300, need to be cultivated.

The purpose of water ways in a conservation system is to convey runoff at a non-erosive velocity to a suitable disposal point. A waterway must therefore be carefully designed. Normally its dimensions must provide sufficient capacity to confine the peak runoff from a storm with a ten-year return period.
Stabilization structures play an important role in gully reclamation and gully erosion control. Small dams, usually 0.4 to 2.0 m in height, made from locally available materials such as

earth, wooden planks, brushwood or loose rock, are built across gullies to trap sediment and thereby reduce channel depth and slope.

Windbreaks are placed at right-angles to erosive winds to reduce wind velocity and, by spacing them at regular intervals; break up the length of open wind blow. Windbreaks may be inert structures, such as stone walls, slat and brush fences and cloth screens or living vegetation. Living windbreaks are known as shelterbelts. In addition to reducing wind speed, shelterbelts result in lower evapotranspiration, higher soil temperatures in winter and lower in summer, and higher soil moisture. In many instances, these effects can lead to increases in crop yield. In addition, geotextiles, geocells and various erosion control products are also widely used in erosion control applications. The applications of geosynthetics for erosion control will be discussed in the following section.

8 GEOSYNTHETICS FOR EROSION CONTROL APPLICATIONS

Various geosynthetics (geo-composites) are also widely used for soil erosion control applications. Geosynthetics can be in the form of a mat, sheet, grid or web of either natural fiber, such as jute or coir, or artificial fiber, such as polyester, nylon or polypropylene. Several products are commercially available for use in erosion control where they interact as a composite with the soil and vegetation. The general goal of erosion-control geo-composites is to protect the soil from sheet, rill, or gully erosion either indefinitely or until vegetation can establish itself. They are supplied in rolls, unrolled over the hill slope from the top and anchored with large pins. The natural fiber types are biodegradable and are designed to be laid over the surface of the slope to provide temporary protection against erosion until a vegetation cover is established. The synthetic fiber types, which include geotextiles, geomembranes, geocells, geogrid, as well as rolled erosion control mats, are buried and designed to give permanent protection to a slope by reinforcing the soil; once a vegetation cover is established, the plant roots and the fiber act together to increase the cohesion of the soil and the fiber provides a back-up resistance should the vegetation fail. The interaction of the water or air velocity and the size of soil particles give rise to the soil erosion sequence shown in Figure 4 (Koerner, 2012). As shown in the figure, water is somewhat more severe than air in causing erosion.

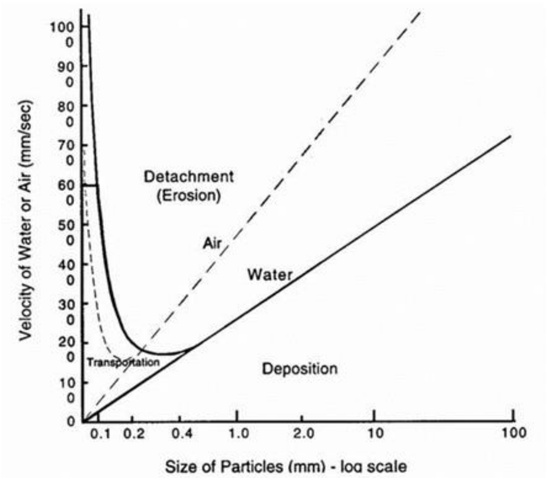

Figure 4: Comparison of detachment (erosion), transportation and deposition responses due to air and water (Koerner, 2014)

The International Erosion Control Association (IECA) is an organization that focuses on erosion control practices, materials conference, publications and standards. Most of the products dealt with by erosion control specialists use geosynthetic materials in whole or in part. The relatively large number of erosion control products can be broadly separated into temporary and permanent materials. The uses for geosynthetic erosion control products as erosion protection in water runoff channels or steep side slopes are shown in Figure 5.

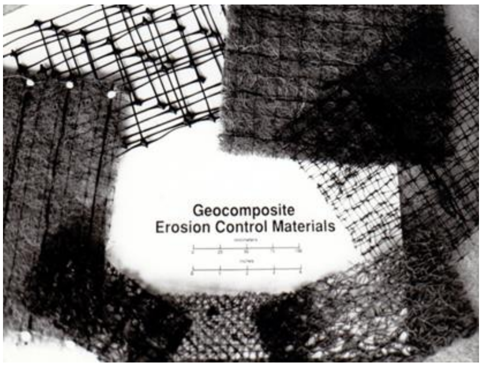

Figure 5: Geo-composites used in erosion control (Koerner, 2012)

Experimental data found that natural fiber surface laid mats are the most effective in controlling soil detachment by raindrop impact because they provide good surface cover, high water absorption, thick fibers able to intercept splashed particles from their point of ejection and a rough surface in which water is ponded, thereby further inhabiting the splash action on the soil (Rickson, 1988). Similar results were also observed for synthetic rolled erosion control products by Jien and Hsieh (2015). Erosion resulting from runoff was also significantly lower for slopes protected by surface-laid jute mat (Rickson, 1992) and synthetic rolled erosion control products (Jien and Hsieh, 2015) because of the higher roughness they imparted to the flow.

In small plot studies with both rainfall and runoff simulations, Morgan and Rickson (1988) found that surface-laid jute mats offered the best protection, reflecting their ability to control both soil detachment by raindrop impact and the transport capacity of the runoff. Cazzuffi et. al. (1991) found that surface-laid jute and buried artificial fiber mats gave very similar soil loss reduction results. In addition it should be noted that the above mentioned studies were carried out immediately after geotextile materials installation. Over time, the natural fiber mats will become less effective as they biodegrade whereas the artificial fiber mat performance is likely to remain constant. The installation procedure for Geosynthetic erosion control products and long term erosion control performance are important research topics and need further investigation.

8.1 *Geotextile silt fences*

Silt fences consist of above-ground textiles attached vertically onto posts to prevent sediment sheet runoff from entering into downstream creeks, rivers or sewer systems. Construction activities are associated with sedimentation and erosion control applications. This concept is used regularly and has replaced bales of straw, hay, and other makeshift methods. The bottom of the silt fence is embedded into a small anchor trench. The posts, to which the geotextile is attached, are usually spaced at 1.5 to 3.0 m. Sometimes a geogrid backup is required on the geotextile to provide additional support. Since the geotextile is exposed to sunlight, it must be UV-stabilized. A typical geotextile silt fence example and suggested design manner are shown in figure 6 (Koerner, 2004).

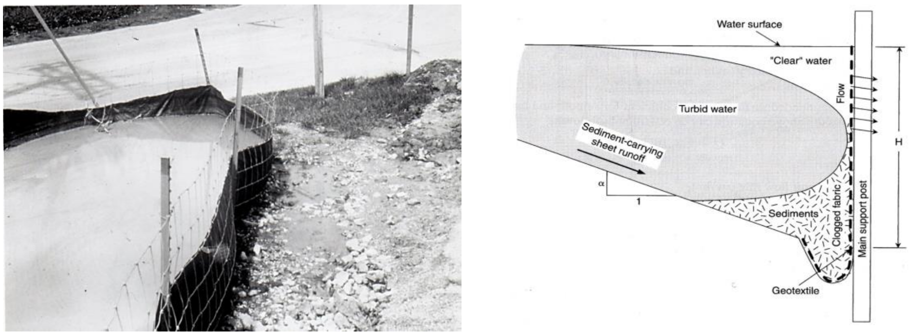

Figure 6: Cross section and field application of silt fence (Koerner, 2012)

8.2 *Temporary erosion and re-vegetation materials*

Temporary erosion and re-vegetation materials (TERMs) consist of materials that are wholly or partly degradable. TERMs provide temporary erosion control and are either degradable after a given period or only function long enough to facilitate vegetative growth. After the growth is established the TERM becomes sacrificial. The natural products are completely biodegradable, while the polymer products are only partially so.

Table 1 summarizes typical TERMs and PERMs geosynthetic erosion control materials (Theisen, 1992). Straw, hay, or mulch loosely bonded by asphalt or adhesive are traditional erosion control products. Geo-fibers in the form of short pieces of fibers or micro-grids can be mixed into soil with machines to aid in lay-down and continuity. The fiber or grid inclusions provide for greater stability over straw, hey, or mulch simply broadcast over the ground surface. Erosion-control meshes and nets (ECMNs) are bi-axially oriented nets manufactured from polypropylene or polyethylene. They do not absorb moisture, nor do they dimensionally change over time. They are lightweight and are stapled to the previously seeded ground using hooked nails or U-shaped pins. Erosion-control blankets (ECBs) are also bi-axially oriented nets manufactured from polypropylene or polyethylene, but these are now placed on one or both sides of a blanket of straw, excelsior, cotton, coconut, or polymer fibers. The fibers are held to the net by glue, lock stitching or other threading methods. Fiber roving systems (FRSs) are continuous strands, or yarns, usually of polypropylene, that are fed continuously over the surface that is to be protected. They can be hand placed or dispersed using compressed air. After placement on the ground surface, emulsified asphalt or other stabilized soil is used for controlled positioning. Figure 7 illustrates the application of continuous fiber reinforced soil layer for slope protection (www.nittoc.co.jp).

Table 1. Geosynthetic erosion control materials (Theisen, 1992)

TERMs	PERMs	
	Biotechnical-Related	Hard Armor-Related
Straw, hay, and hydraulic mulches	UV stabilized fiber roving systems (FRBs)	Geocellular containment systems (GCSs)─concrete filled
Tackifiers and soil stabilizers	Erosion-control revegetation mats (ECRMs)	Fabric formed revetments (FFRs)
Hydraulic mulch geofibers	Turf reinforcement mat (TRMs)	Vegetated concrete block systems
Erosion-control meshes and net (ECMNs)	Discrete-length geofiber	Concrete block systems
Erosion control blankets (ECBs)	Geocellular containment systems (GCSs)─vegetated	Stone riprap
Fiber roving systems(FRBs)		Gabion

Figure7: Continuous fiber reinforced soil layer for slope protection (http://www.nittoc.co.jp)

8.3 *Permanent erosion and re-vegetation materials – Biotechnical related*

Biotechnical related permanent erosion and re-vegetation materials (PERMs) furnish erosion control, aid in vegetative growth and eventually become entangled with the vegetation to provide reinforcement to the root system. As long as the material is shielded from sunlight, via shading and soil cover it will not degrade. The seed is usually applied after the PER is placed and is often carried directly in the backfilling soil.

The polymers in FRSs can be stabilized with carbon black and/or chemical stabilizers, so they can be sometimes considered in the PERM category. Erosion-control re-vegetation mats (ECRMs) and turf reinforcement mats (TRMs) are closely related to one another. The basic difference is that ECRMs are placed on the ground surface with a soil infill, while TRMs are placed on the ground surface with soil filling in and above the material. Thus TRMs can be expected to provide better vegetative entanglement and longer performance. Other subtle differences are that ECRMs are usually of greater density and lower mat thickness. Seeding is generally done prior to installation with ECRMs, but it is usually done while backfilling within the structure of TRMs. Flexible TRM systems were used for erosion protection on steep slopes, as shown in Figure 8.

Figure 8: Steep slope erosion protected by TRM (www.quicksupplydm.com, 2015)

Discrete-length geo-fibers are short pieces of polymer yarns mixed with soil for the purpose of providing a tensile strength component against sudden forces for facilities such as athletic fields, trafficked slopes, and so on.

Geocellular containment systems (GCSs) consist of three-dimensional geomembrane or geotextile cells that are filled with soil and are vegetated when used for erosion control. Geocells also can provide reinforcement capabilities. The Geocellular system applications for highway embankment erosion control are very commonly used in the USA and Canada, as shown in Figure 9.

Figure 9: Vegetated geocellular slope protection system (www.prestogeo.com, 2008)

8.4 *Permanent erosion and re-vegetation materials – Hard armor related*

Clearly, fabric-formed revetments (FFRs), which are hard armor materials, clearly recognize that erosion control is the major feature of this system. Numerous concrete block systems are available for erosion control. Hand-placed interlocking masonry blocks are very popular for low-traffic pavement areas. Alternatively, the system can be factory-fabricated as a unit, and placed on prepared soil. The prefabricated blocks are either laid on or bonded to a geotextile substrate. The finished mats can bend and torque by virtue of the blocks being articulated with mechanical jointed weaving patterns, or cable. Pre-fabricated articulating concrete block mats with filter fabrics underneath were used for suburban dam spillways and beach protection projects, as shown in Figure 10 (www.contechES.com, 2016).

Figure 10: Pre-fabricated articulating concrete block mats underneath by filter fabrics were used for suburban dam spillway and beach protection project (www.contechES.com, 2016)

Stone riprap can be a very effective erosion control method whereby large rock is placed on a geotextile substrate. A geotextile placed on the proposed soil surface before rock placement serves as a filter and separator. Canals and waterfront property are often protected from erosion using stone riprap. Galvanized steel hexagonal wire mesh gabions which consist of discrete wire netting cells filled with hand placed stone. Geogrids can be used to replace wire mesh in some cases. Gabions require that a geotextile be placed behind them, acting as a filter and separator for the backfilled soil. Geobag with gabion system and RECPs can be used for slope stability and erosion control applications as shown in Figure 11 (www.jcep.com.tw, 2016).

Figure 11: Geobag gabion system and RECPs for slope stability and erosion control applications (www.jcep.com.tw)

8.5 *Design consideration*

As discussed earlier, beginning with the impact of a raindrop on the soil, a splash mechanism is set up whereby the shear strength of the soil can be exceeded. Once detachment occurs, surface flow transports the individual particles in a gravitational manner until the hydraulics and topography results in final soil particle deposition. There are an incredible number of variables involved in the three basic mechanisms of detachment, transportation and deposition. Design is distinguished between either slope erosion or channel/ditch erosion. Universal Soil Loss equation (USLE) developed by Wischmeier and Smith (1960) is the most common used formula to estimate the soil loss in the design.

The Erosion Control Technology Council (ECTC) has recommended that the C factors for the various previously described products be analyzed using the above equation. The design procedure is to first calculate the bare soil loss and then compare this value to a calculated soil loss value with the candidate geosynthetic erosion control material. However, there are many limitations with this equation, such as gully-type runoff, small localized sites, steep slopes, seasonal variations and short term water surges. Note that a modified USLE for point source erosion is also available.

9 SUMMARY AND CONCLUSIONS

1. The soil erosion process includes detachment, transportation and deposition of soil particles from a consolidated soil body. The main agents that loosen and break down soil particles are wind and water. Water and wind erosion are the most common and greatest natural harmful effects among these erosion processes.

2. Soil erosion can be divided into natural erosion and accelerated erosion. Precipitation, wind, temperature changes and living creature activities are the natural agents that cause natural erosion. Generally, undisturbed rock requires around 300 years to generate a soil layer 25 mm in thickness from the natural degradation process. However, farming land reclamation and human activities disturb surface soils and soil structures. These activities accelerate the soil erosion process. Disturbed rock requires around 30 years to generate a soil layer 25 mm thick.

3. The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land and the nature of the plant cover. The soil erosion loss function includes rainfall erosivity, soil internal factors, terrain factors, crop management factors and land use and management factors.

4. The most commonly used model for predicting soil loss from water erosion is the Universal Soil Loss Equation (USLE). The average annual soil loss A (ton/hectare/year) on a plot area can be formulized as: A = Rm Km L S C P, where Rm is the annual rainfall erosivity factor, Km is the soil erodibility factor, L and S are topographic factors representing length and slope, C is the cover and management factor, and P is the soil water conservation support practices factor. The Erosion Control Technology Council (ECTC) has recommended that the C factors for various previously described geosynthetic products be analyzed using the above equation.

5. The strategies for soil conservation must be based on covering the soil to protect it from raindrop impact; increasing the soil infiltration capacity to reduce runoff; improving the soil aggregate stability; and increasing the soil surface roughness to reduce the runoff and wind velocity. Various conservation techniques include agronomic measures, soil management and mechanical methods. Erosion control is dependent upon good management which implies establishing sufficient crop cover and selection appropriate tillage practices. Thus conservation relies strongly on agronomic methods combined with sound soil management while mechanical measures play another supporting role.

6. Extremely porous geosynthetics could be used as a ground surface cover from the prevailing atmospheric conditions (wind, rain, snow, etc.). Special geo-composites have been developed for this specific erosion control purpose. Various geosynthetics are widely used for soil erosion control applications. Geosynthetics can be produced in the form of a mats, sheets, grids or webs of either natural fiber, such as jute or coir, or artificial fiber, such as polyester, nylon, or polypropylene.

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