Turf Reinforcement Mattings:
An EPA Recognized Storm Water Best Management Practice (BMP)

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Abstract

While increased development drives our need for an ever-expanding infrastructure, the subsequent construction also exposes a significant amount of soil to the erosive properties of water. These considerations in conjunction with the implementation of the Environmental Protection Agency's National Pollutant Discharge Elimination System Phase II regulations present a very daunting task to reducing sediment/pollutant loads in storm water runoff.

Traditionally, rock of various sizes (riprap) was used with varying success to protect against soil erosion in channels exposed to high shear stress flows, slopes with steep gradients or shorelines exposed to wave action. Rock riprap, however, is quite costly, requires heavy equipment to install, presents a less than appealing aesthetic value, can present a hazard to people and machinery alike while not meeting the specific performance requirements established for a project.

In contrast, turf reinforcement mats (TRMs) have been established by the EPA in their Storm Water Technology Fact Sheet entitled *"Turf Reinforcement Mats"* to provide effective, economical, and aesthetically pleasing alternative to hard armor (e.g. rock riprap) practices for erosion control in areas where forces exceed that capabilities of naturally occurring vegetation and storm water conveyances. Additionally, TRM reinforced vegetation affords a corollary benefit, sediment/pollutant removal from storm water runoff. Despite variations in materials, TRMs have proven their performance capabilities over the past 30 years in field and laboratory channel tests where shear stress can reach 6-10 lbs/ft^2 (288-479 Pascal). Moreover, the use of TRM reinforced vegetation furnishes a value engineered option to hard armor alternatives by effectively reducing construction times, material costs, equipment requirements and most importantly improving water quality, ground water recharge capabilities and other sensitive issues involving water quality.

Keywords: Erosion Control Technology Council (ECTC), turf reinforcement mattings (TRMs), erosion control, storm water, National Pollutant Discharge Elimination System (NPDES), and rolled erosion control products (RECPs).

Introduction

Geological erosion, due to water, is a natural event resulting from both the detachment and transportation of soil particles. Accelerated erosion, due to human activity or the removal of vegetation and cover from the land often results in drastically increased rates of soil loss unless appropriate and effective best management practices (BMPs) are utilized. The potential for amplified erosion due to increased erosive forces must be addressed and negated by appropriate methods to establish a permanent erosion control system. Along with soil being removed from these channels there is also the possibility that attached pollutants will be transported along with the sediment (i.e. fertilizers, pesticides, petroleum products, etc.). The EPA lists erosion as the single largest impairment to water quality in rivers (News Section of CE News, March, 2000).

Historically, a majority of costs and time were used in the design and implementation of sediment control devices. It has been shown repeatedly that while sediment control is reactive, effective erosion control is proactive in reducing the concentration of soil in runoff. If soil particles are not detached it logically follows there is less sediment contained in runoff and an overall reduction in the associated hazards. A good example of this forward thinking is achieved through the use of rolled erosion control products (RECPs) for effective erosion control. RECPs reduce detachment of soil particles and therefore reduce sediment load in runoff, further diminishing demands placed on sediment control devices.

No erosion control

RECPs provide effective erosion control

Figure 1. Effective erosion control methods/best management practices (BMPs) can significantly reduce sediment load contained in runoff.

There are a wide variety of RECPs that afford cost-effective solutions to nearly any erosion problem. Varying from temporary erosion control blankets (ECBs) to permanent turf reinforcement mats (TRMs) RECPs provide a diversity of economical and effective forms of erosion control for any project. Through the combination of these products and vegetation, often termed “Green Engineering” or “soft armor”, the maximum use of living plant systems in conjunction with man-made materials can provide effective erosion control.

Vegetation offers an excellent form of erosion control and cover (Temple, 1980), however, increased concentration of runoff from additional impervious surfaces in a watershed may result in flows exceeding the vegetation’s natural erosion control capabilities. When vegetation alone will not provide the required permanent erosion protection, riprap and concrete were the traditional "hard armor" materials thought to be the only suitable solutions for lining high velocity/shear stress areas. Prior to the advent of TRMs, vegetative linings were simply out of the question for these highly erosive conditions where expected velocities would exceed 6.8 foot per second (2.1 meters per second) (Chow, 1959) or shear stresses topping 3.7 pounds per square foot (177 Pascal (Pa)) (Chen and Cotton, 1988). However, modern turf reinforcement mattings (TRMs) have proven ability to substantially increase the erosion resistance of vegetation, enabling its use in areas where high velocities/shear stresses are prevalent (Hewlett, et al., 1987, Northcutt, 1996).

Figure 2. Where the turf reinforcement mattings stop erosion begins. The removal of vegetation and extensive erosion occurred in portions of the same channels where TRMs were not installed. However, those portions of the channel protected by vegetation reinforced with TRMs resulted in exceptional erosion control and turf reinforcement.

Design Considerations

It is human nature to resist change because of familiarity with another way of designing and the comfort that comes from this knowledge. However, designing and fully achieving the required performance from a material in the field when installed is another matter. This is very true when it comes to replacing rock riprap with TRMs. TRMs not only protect against erosion better then riprap but have a greater environmental, installation, cost advantage and provide additional pollutant removal unheard of by riprap.

Water flowing over a surface causes tractive force or shear stress (units of pounds per square foot or Pascal) between the water and the soil surface. When shear stress exerted by the flow exceeds the permissible shear stress of the surface material (e.g. riprap, soil, matting or vegetation) the movement or loss of these materials is likely. Additionally, the possibility of significant damage to the channel within a few hours is possible. The level of shear stress generated by a flow is dependent on the discharge, depth of flow, slope or energy gradient, surface geometry, hydraulic roughness of the liner, and underlying soil type. While there are numerous methods used to assess or determine the erosive force of water, some of the primary means utilize of the following equations and methods:

1. Manning's Equation
2. Continuity Equation
3. Shear Stress Equation
4. Revised Universal Soil Loss Equation

It is well documented that during flow, shear stress at a given velocities does in fact predict performance or when erosion will occur, and that shear stress is superior to velocity in predicting this failure. Therefore, the standard hydraulic test to determine performance properties of a product is related to permissible shear. For more extensive detail on design materials and considerations in selecting and use of turf reinforcement mattings and reinforced vegetation please review information available at www.ectc.org.

Any erosion control materials permissible shear stress/performance must be established by large-scale research. Typically in the establishment of performance values on TRMs, the flumes utilized are normally 2 to 4 foot wide (0.61 – 1.2 m), 15 to 85 foot (4.5 – 25.9 m) long and can create shear forces of 0.5 to 20 lbs/ft^2 (24 – 960 Pa) for durations of 30 minutes to 60 hours. Several of the laboratories that have been used to establish TRM's permissible shear stress and design values for RECP manufacturers include Utah State University, Logan Utah and Colorado State University, Fort Collins, CO. Bench scale-testing programs are also available to determine index/physical parameters through laboratories such as TRI, Austin Texas.

Figure 3. Research being conducted on TRMs to establish performance/permissible design values (Images in order from left to right. High shear stress flow over reinforced vegetation in vertical walled flume, reinforced vegetation after flow, reinforced vegetation in trapezoidal channel before flow, measuring velocity during flow over reinforced vegetation)

General Discussion Of Riprap

The purpose of rock or any erosion control system for that matter is to reduce the energy (velocity, shear stress and/or impact) of water during concentrated flow and to minimize soil erosion or soil displacement. Depending on the diameter of rock used and its hydraulic roughness, rock may significantly reduce flow velocities but increase shear stress due to the subsequent increase in flow depth from the slowing of the water. The use of riprap that is not well-graded will result in discontinuous contact with the soil and this has shown to be ineffective in minimizing erosion or soil displacement.

A filtering system, such as a woven or non-woven geotextile is also required beneath the rock in an effort to minimize soil displacement. In this instance the planar fabric is the erosion control and the rock is generally considered “ballast” for holding the fabric in place. However, if the riprap is not well graded or there are minimum contact points with the geotextile the tendency is a lifting of the fabric from the ground surface due to hydraulic loading. Once the fabric is separated from the soil surface then the soil begins to move or be removed.

Figure 4. Rock riprap may be a permanent material but this does not mean it will provide the appropriate level of erosion control. Another concern is the potential for piping of soil from between and/or through rock riprap (far right image).

Typically, riprap gradation design will fall in the range of D_{100}/D_{50} and D_{50}/D_{20} with a riprap thickness of 1.5 to 3.0 times the mean riprap diameter. The subscripted number in this riprap nomenclature denotes the percentage of rock that must be at the noted diameter. While rock size is an important consideration, the shape of rock must also be considered in its selection. Because of its interlocking capabilities, angular rock allows greater resistance to flow than rounded stones. More importantly, rounded rock should not be placed on slopes stepper then 3:1 because of geotechnical stability reasons (Chen and Cotton, 1988).

What Is A Turf Reinforcement Matting?

TRMs have been effectively used for over 35 years with the general purpose being to improve vegetations resistance to erosion by increasing the permissible shear of the vegetative cover. The Erosion Control Technology Council (ECTC), an organization with the mission to develop performance standards, uniform testing procedures, and guidance on the application and installation of rolled erosion control products defines TRMs as:

> *Turf reinforcement mat (TRM), A long term non-degradable RECP composed of UV stabilized, non-degradable, synthetic fibers, nettings and/or filaments processed into three dimensional reinforcement matrices designed for permanent and critical hydraulic applications where design discharges exert velocities and shear stresses that exceed the limits of mature, natural vegetation.*

Figure 5. TRMs are constructed from a variety of materials that impart different performance characteristics, however, the one thing in common among all TRMs is the presence of a permanent three-dimensional structure for effective vegetation reinforcement.

It is important to make special note that TRMs must contain a permanent three-dimensional structure for stem and root reinforcement and further enhance the vegetation's erosion control performance. Those materials containing only a permanent two-dimensional structure (e.g. geogrid) do not provide reinforcement but only maintenance of the vegetation's natural performance levels as noted in the CIRIA 116 Report, *Design of Reinforced Grass Waterways* (Hewlett, et al., 1987).

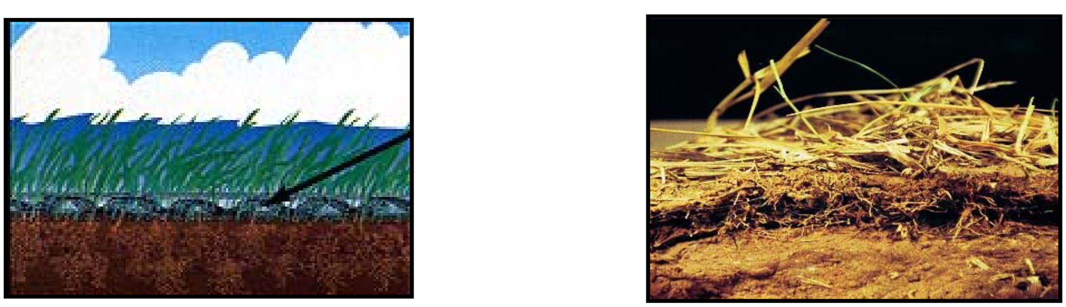

Figure 6. The one thing in common among all TRMs is the presence of a permanent three-dimensional structure for effective vegetation reinforcement. Image on left is a schematic depicting vegetation and TRM interaction and reinforcement (EPA's Storm Water Technology Fact Sheet, 1999). Image on right shows root and stem reinforcement afforded by a TRM five years after installation.

How TRMs Work

The effectiveness of TRMs has been established by the EPA in their Storm Water Technology Fact Sheet entitled *"Turf Reinforcement Mats"* to provide effective, economical, and aesthetically pleasing alternative to hard armor (e.g. rock riprap) for erosion control in areas where erosive forces exceed the capabilities of naturally occurring vegetation. TRM reinforced vegetation also affords a corollary benefit, sediment/pollutant removal from storm water runoff.

Despite variations in materials, TRMs have proven their performance capabilities over the past 35 years in both qualitative field applications and quantitative laboratory research. The vegetation and permanent three-dimensional structure of TRMs form a symbiotic interaction that provides reinforcement to the stem and root structures. Even with these important benefits afforded by TRMs, it is important to emphasize that TRMs, should not be used under constant, high velocity flow conditions or in any location that will not allow vegetation establishment. TRMs only work in conjunction with vegetation (Sprague, 1999). With permissible shear stresses up to 10 lbs/ft^2 (478 Pa) as noted by the ECTC, geosynthetically reinforced turf can provide similar erosion resistance as 30-inch (0.76 meter (m)) rock riprap (FHWA, 1988).

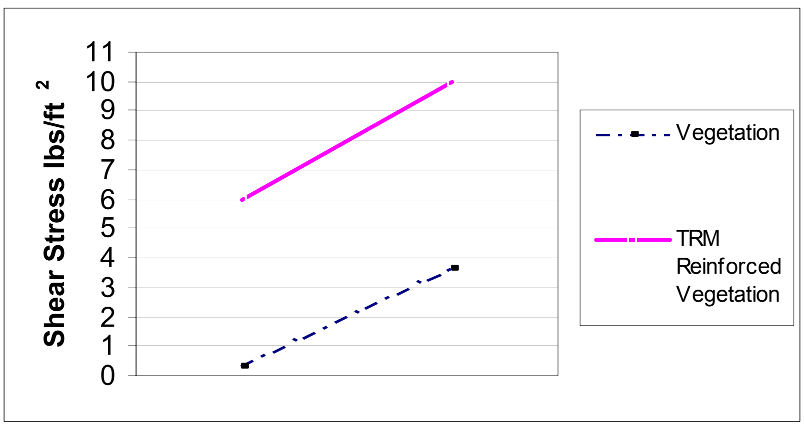

Figure 7. Adapted from "Green Engineering Optimizing Erosion Control with Vegetation and RECPs" (Sprague, 1999).

A secondary and temporary function of TRMs is to collect sediment and act as a barrier to minimize soil displacement/erosion during hydraulic flows prior to and while vegetation is being established. The performance provided by TRMs increases as the vegetation becomes established and the vegetation's stem and root structures become entangled within the permanent three-dimensional structure of mattings.

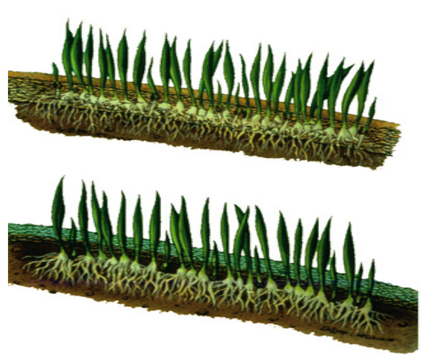

Figure 8. Depending on manufacture installation recommendations, TRMs are normally surface applied after seeding or soil filled.

Benefits Afforded by Reinforced Vegetation

Having discussed the general properties, mechanism and performance of riprap and TRMs, we now need to discuss the true comparison of using riprap and TRM reinforced vegetation. There are many additional advantages and objectives that can be satisfied using a TRM versus standard riprap then just meeting the permissible shear requirement. The advantages of using reinforced vegetation over riprap include:

1. Aesthetics

People have very different viewpoints when it comes to aesthetics but one commonality is often shared among all that live in areas where there are large expanses of hardscapes (e.g. buildings, concrete, asphalt, etc…), the desire and need for "green" areas. As our infrastructure continues to expand the areas occupied by hardscapes (rock, concrete, asphalt, etc…) also continues to increase. Reinforced vegetation offers a softer, much-needed green, natural looking relief to the topography of a populated area while also providing exceptional erosion control.

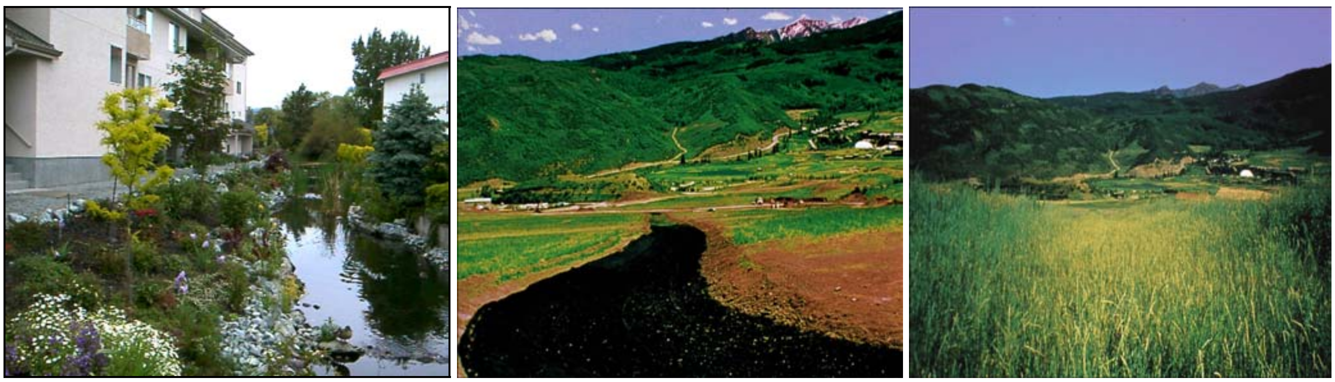

Figure 8. TRMs improve the performance of vegetation, allowing the use of "green solutions" to meet a diversity of erosion control needs with aesthetically pleasing results.

2. Water quality & aquatic/wildlife habitat

While vegetation adds to the aesthetics of a site, "green" areas can also provide habitat for wildlife and improve aquatic habitat by the removal of sediment and other pollutants from runoff. Vegetation provides natural areas for wildlife to include cover, food source, and nesting areas.

Vegetation is an effective form of erosion control because of its hydraulic roughness characteristics and the cover it provides the soil surface. Depending on the vegetation's characteristics that influence hydraulic roughness (e.g. height, density and growth habit) vegetation dissipates energy of flow and therefore results in the slowing of flow. As water slows, its energy is reduced and the water is less able to keep material entrained. Vegetation can also play a key roll in the phytoremediation of various pollutants attached to sediment as it settles out of the flow.

Slowing of the flow also allows for increased infiltration and natural percolation through the soil profile with the added benefit of ground water recharge. Removal of pollutants from runoff means that there are less contaminants carried into receiving waters and the improvement or maintenance of aquatic habitat. As compared to rock or concrete, vegetation also provides a natural system to reduce thermal heating of runoff. Because vegetation does not heat and maintain thermal radiation like hard armor reinforced vegetation does not transmit heat into runoff that is then conveyed through the system and into receiving waters (EPA's Storm Water Technology Facts Sheet, 1999).

Even thought TRMs do not directly provide improvements in the aforementioned qualities, mattings do increase the erosion resistance of vegetation and therefore allow its use in many areas it previously may not have been applicable. Therefore, increasing the benefits afforded by the vegetation by increasing the areas where vegetation is used.

Figure 9. TRM reinforced vegetation offers beneficial wildlife habitat.

3. Construction impact

Riprap is typically placed on a prepared soil surface by large equipment like a front-end loader or an excavator when larger boulders are required. For riprap to be effective erosion control, a well-graded mass with minimum voids is essential. In contrast, erosion control provided by vegetation reinforced with TRMs can reduce or eliminates the need for heavy equipment during the installation process. TRMs are normally sold in light weight rolls that at are easy to hand and can be installed using manual labor.

Figure 10. TRMs are easily installed without the need for heavy equipment (Images in order from left to right. A TRM being installed in a channel. The same channel after vegetation establishment).

4. Economic & performance comparison

Providing a service that is both functional and economically sound is the basis for the fundamental theory of value-engineering. Through the use of TRM reinforced vegetation instead of rock riprap, designers and engineers can achieve effective erosion control while reducing their total project costs. The economic comparison for individual projects may differ, due to variations in geographic location, labor rates, and material costs but the following table provides an approximate representation of the performance and dollar costs for comparison.

Material	**Performance lbs/ft^2 (Pa)**
Unreinforced vegetation	0.3-3.7 (14.4-177.6) [1]
Fully vegetated TRM	6-10 (287-478) [2]
30 in (60.9 cm) Riprap[3]	383.0[1]

[1] Empirical value from FHWA HEC #15 (1988) data

[2] Performance value provided by ECTC

Figure 11. Performance comparison of erosion control systems.

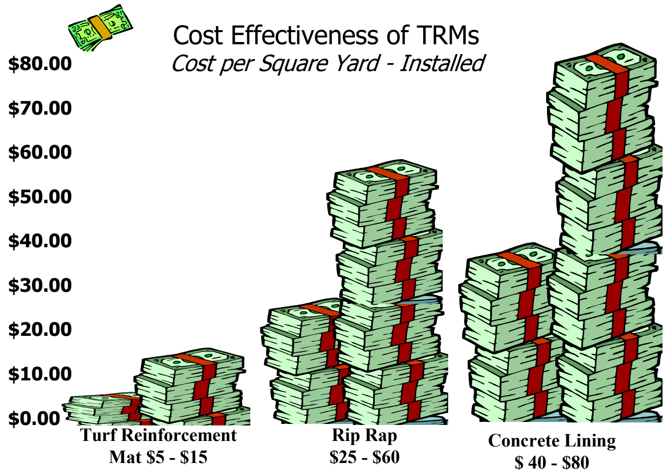

Figure 12. Economic comparison of erosion control systems. All values are provided by the ECTC for approximate installation costs in U.S. dollars.

Summary

Traditionally, rock of various sizes (riprap) was used with mixed success to protect against soil erosion in channels exposed to high shear stress flows, slopes with steep gradients or shorelines exposed to wave action. Rock riprap, however, is quite costly, requires heavy equipment to install, presents a less than appealing aesthetic value, can present a hazard to people and machinery alike while not meeting the specific performance requirements established for a project. Conversely, vegetation when armored with turf reinforcement mats has been shown through field and university research for the past 35 years to provide cost-effective, aesthetically pleasing, natural solutions to storm water management and erosion control. TRMs are an EPA recognized best management practice that also provides a natural filtering medium for some pollutant contained in storm water runoff at one-third to half the cost of rock riprap.

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