VEGETATED WATERWAY LININGS REINFORCED WITH GEOMATRIX MATTING -DESIGN METHODOLOGY AND PERFORMANCE-[1]

by

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Abstract. Design of vegetative erosion control linings for waterways has become an emergent and frequent engineering practice over the past decade. To assess and support performance consistency, several independent field and flume studies are featured, deriving correlations strongly suggestive of a maximum shear restraint performance criteria. A comprehensive baseline design methodology is also proposed to further enhance consistent performance over a range of design and installation variables.

Additional Key Words: Enkamat, linear flow velocity, tractive force, Manning equation, intermittent flow, geotextile, sod, growth curing.

Introduction

Over the past decade several independent studies have been conducted to quantify the design requirements and performance of vegetated waterways permanently reinforced with synthetic geomatrix linings. The empirical results derived from these studies correlate strongly, suggesting defined application parameters for the subject lining category. A standard design methodology is therefore proposed to further quantify and enhance performance of geomatrix reinforcement installations.

Previous Research

The use of permanent synthetic materials for erosion control and vegetation reinforcement originated in the late 1960's. At that time Dutch Akzo engineers began exploring end uses for a unique three-dimensional nylon matrix they had developed. The concept was later formalized. Geomatrix matting vegetation reinforcement products soon became available, initially under the Enkamat trade name.

During 1979 two independent groups studied the reinforcement concept in field and flume trials. A government group, The Pennsylvania Department of Transportation, installed, monitored, and evaluated a roadside diversion channel having a steep flow line slope of 22.5

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[1] Paper presented at the 1989 Joint Meeting of the Canadian Land Reclamation Association and the American Society for Surface Mining and Reclaimation, Calgary, Alberta, Canada, August 27-31, 1989.

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Proceedings America Society of Mining and Reclamation, 1989 pp 249-254
DOI: 10.21000/JASMR89010249
https://doi.org/10.21000/JASMR89010249

percent. Their study concluded that geomatrix reinforced vegetation could endure flow velocities up to at least 20 linear feet per second, at greater than 7.5 pounds per square foot tractive force[3], three times the capability of typical unreinforced grass (Hoffman and Adamsky, 1982).

Also during 1979, Western Canada Hydraulics Laboratories of British Columbia conducted flume tests to determine a maximum permissible shear stress value for channelways lined with Bermuda sod reinforced by geomatrix matting. Their results indicated that the system would consistently endure nominally 8.5 pounds per square foot of shear stress over a two hour flow duration (WCHL, 1979). Seven years later similar results were obtained from an exhaustive field evaluation in Great Britain sponsored by the Construction Industry Research and Information Association. They determined an 8.9 pounds per square foot shear resistance over a one hour flow duration (Hewlett et al., 1987).

All three of the studies occurred in temperate climates with adequate precipitation. To date the only comprehensive evaluation conducted in an arid environment is a 1985 Simons and Li effort in Colorado sponsored by the US Federal Highway Administration and US Department of Agriculture Forest Service. The Simons and Li vegetated flume trials evaluated a lightweight geomatrix reinforcement with sparse vegetation development. Their results indicated an ultimate shear capability of 6.9 pounds per square foot (Chen and Anderson, 1986). Given the conditions of the Colorado study, the results correlate strongly with performance expectations derived from the other three evaluations.

Tractive Force Design Criteria

In practice, designs of permanently reinforced vegetated erosion linings have become reasonably predictive over the past several years as civil engineers and landscape architects have gained experience with the lining concept. A majority of these professionals will typically base their vegetative lining selections on a velocity criteria as derived from Manning's equation. Whereas this practice appears adequate, it does not provide the additional degree of design accuracy necessary for selective engineered usage of erosion control materials, except on a intuitive and qualitative basis.

For example, the design of a vegetated spillway in Columbia, South Carolina required a lining reinforcement that could withstand a linear velocity of 14.7 feet per second, a discharge up to 12,100 cubic feet per second, and a flow depth of up to 10 feet. Intuitively the lining of choice would be a heavyweight geomatrix material. However, given that the channel slope is extremely shallow, approaching 0.5 percent, the maximum design shear stress developed on the lining would be only 3.1 pounds per square foot.

Due to the additional shear stress analysis, permanent reinforcement requirements were found to be less than expected, so a lightweight geomatrix was specified and installed. Consequently the project exhibited proper value engineering. Also, the client had the satisfaction of a quantified and prudent design safety factor, which would have been unavailable if velocity had been the only design criteria.

Velocity, however, has evolved in practice as a design surrogate for tractive flow forces acting on the

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(3) 1 LB/FT^2 = 4.88 KG/M^2

channel lining. The criteria is severly limited because velocity is only approximately constant over a narrow range of channel shape (R) and roughness (n) (Chen and Cotton, 1988). It is, furthermore, the force developed by the flow, not the flow velocity itself, that determines erosion lining failure and success.

The tractive forces acting on the lining will typically create a discrete level of shear stress which defines a constant design parameter virtually independent of randomness due to channel shape and roughness. Furthermore, the higher stresses developed in channel bends can be quantified by simplified shear stress calculations, providing a higher level of design confidence than otherwise possible.

The formula for maximum shear stress is:

$$\tau_c = \gamma DS \tag{1}$$

In practice, flow depth (D, feet or meters) and channel slope (S, percent, e.g., .1 equals 10 percent) are directly quantifiable. Also the unit weight of water is defined for most conditions, (γ, 62.4 pounds per cubic foot or 863.7 kilograms per cubic meter). In contrast, channel roughness is a more arbitrary range value determination, varying with grass development, flow regime, and slope steepness (Hewlett et. al., 1987).

Since maximum shear stress is virtually constant over a channel section, it provides an umbrella lining criteria for a wide range of flow conditions, and solely allows for the development of implicit design safety factors over that range. The critical shear stress criteria furthermore readily facilitates simplified comparisons of lining performance from site to site.

The critical shear stress determinations are meant to be used in tandem with velocity calculations for pre-screening of channel lining designs. Manning's equation will undoubtedly remain as a primary hydraulic design tool. However, as the FHWA, and everyday practice have determined, a focused simplified screening criteria for channel lining selection (such as maximum shear stress) is necessary to continually ensure properly engineered design (Chen and Cotton, 1988).

Design Methodology

Prescreening

From results of the independent evaluations previously mentioned and other field experience, the conservative permissible shear stress values for permanent geomatrix reinforced vegetated linings e.g., Enkamats, are 6.0 pounds per square foot for lightweight geomatrix reinforcement and 8.0 for heavier matting reinforcement. Comparatively, riprap with a mean diameter of two feet also has a permissible shear stress of 8.0 pounds per square foot, and the maximum shear capability of class A unreinforced vegetative stands is only 3.7 pounds per square foot (Chen and Cotton, 1988). For class A vegetation, typical design values under sustained flow would be 3.0 or less pounds per square foot.

Thus over the flow-induced shear stress range of 3.0 to 8.0 pounds per square foot (14.7 to 39.1 kilograms per square meter), permanent geomatrix reinforced linings have reasonable design applicability. Additional design considerations would be local climate and soil type.

Performance Factors

Flow Frequency. Vegetative linings are appropriate for conditions of intermittent flow. In a channel flow line, vegetation will not become established when the zone is continually wet for long periods. On some occasions, therefore, the necessity arises to design a non-vegetated solution for the flow line in tandem with reinforced vegetation on the side slopes.

Flow Duration. Flow duration influences the shear restraint capabilities of geomatrix reinforced and other vegetated lining systems. As example, the parameter of 8.0 pounds per square foot for heavyweight geomatrix lining systems is a conservative figure based on a two hour flow duration. Between two and ten hours duration the system will loose up to eleven percent of design strength, and up to an additional thirteen percent at fifty hours of flow (Hewlett et. al., 1987). The trend of strength versus flow duration is similar among both reinforced and unreinforced vegetated linings, with the reinforced categories retaining much higher performance capabilities over all flow durations.

Soil Preparation. The compactive effort on a soil can raise site shear strength by up to .4 pounds per square foot (Chen and Cotton, 1988). In soil media where ultimate compaction and inherent soil cohesion are negligible e.g., dune sands and some mine spoils, soil amendments are available to raise the level of both qualities. Should soil fertility pose a significant barrier to vegetation, ferilizers and mulch amendments may be required.

Geomatrix Underlays. An underlay of biodegradable mulch or of porous geotextile may become necessary. If the climate is semi-arid or arid, a moisture retaining mulch blanket may provide the necessary retention media to facilitate growth. A mulch or geotextile underlay also will provide added durability if the system is developed over highly erodable soils. The geotextile, being permanent, will contribute design strength to the lining, up to an additional 1.0 pound per square foot of shear restraint. Whenever employing a geotextile underlay, the overlaying geomatrix should be filled with fertile, cohesive soil to facilitate plant growth.

Seeding. Local seeding experts are available for consultation through private firms, universities, and government agencies. Since indigenous seed types tend to be best suited for local sites, local experts are the most qualified to comment on seeding. There are, however, two criteria which are vital to the selection of a vegetative cover. Of primary importance the vegetation mix should be able to germinate quickly during the season when the lining is installed. Secondly, the selected vegetation should develop a dense root system capable of extensively knitting with the geomatrix reinforcement matting. Usually the higher the documented maximum shear strength of the selected vegetation, the more appropriate it is for a permanently reinforced system. Where sod is available and cost effective it often provides a more aesthetic alternative to seeding, especially in the early growth curing stage of installation.

Installation. The primary relevant installation variables are grading, laydown, and staking. When the contractor fine grades a site, meaning that he leaves a smooth surface conforming to the local terrain, he facilitates the opportunity to create intimate contact between the geomatrix and soil surfaces, thus preventing undercutting of the system. The subsequent laydown effort is similar to that of placing roof shingles, as the crew unrolls the geomatrix matting from the downstream end up the channel, allowing the geomatrix mat to "shingle" down the flow line of the channel.

During laydown, staking should take place on three foot centers, preferably with triangular wooden stakes. They create local zones of compaction and anchorage. Wooden stakes will also resist frost heave since they tend to swell and lock into adjacent soils when introduced to moisture. Metal staples are not usually recommended because they do not create localized compaction anchorage, and they are highly susceptable to frost heave.

In-Situ Performance

The first six months after installation constitute a period when the system "growth cures," or develops to full strength. The seed germinates and grows while the matting becomes filled with sediment. Overall, a fertile substrate is being developed which enhances further and denser growth.

Upon installation a reinforced vegetative lining provides up to 5.0 pounds per square foot of shear restraint for the lightweight geomatrix, up to 7.0 for the heavyweight. During the growth curing period additional strengths develop with vegetation emergence. Ultimate maximum design strengths of 6.0 and 8.0 respectively result from the synergistic combination of soil, grass, and geomatrix matting. Even higher strengths (an additional 1.0 pound per square foot) are obtainable with a permanent porous geotextile underlay.

As the reinforced system cures and evolves, lining roughness will inherently change. Upon installation the unfilled geomatrix mat has a characteristic surface roughness determined by its dimensional stability and profile height. As the mat fills with sediment to create a viable fertile substrate, roughness begins to decrease. The growth of emergent grasses will cause a gain in surface roughness until the grass blades later become long enough to lay down and create a smooth surface. Over the system design life further minor roughness variations will occur coincident with the growing seasons.

Conclusions

Independent formal studies in North America and Europe conducted over the past decade provide strongly correlative results regarding the design performance of permanent, geomatrix reinforced vegetative linings for waterway erosion control. These findings readily suggest a discrete value design window for this lining category conservatively ranging from 3.0 to 8.0 pounds per square foot of flow-induced shear stress (14.6 to 39.0 kilograms per square meter). Furthermore, proper design and installation of the permanently reinforced vegetative linings has resulted in positive, repeatable performance over a vast range of climatic, soil, vegetative, and flow conditions.

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