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EnkaTech *Note*

Tensile Strength — How much is enough?

The Tensile Strength Question

The lack of standardized test protocol and lack of standardized specifications for Turf Reinforcement Mats (TRM's) have led to much confusion in the marketplace. One particular point of confusion lies in the question of how much tensile strength is required of a TRM to provide satisfactory performance? The answer is less than you might think.

For Channel Linings, there are two widely accepted methodologies that allow the designer to examine the permissible velocity or permissible tractive (shear) force to determine the suitability of a given lining. For slope design, some form of the Universal Soil Loss Equation (USLE) is commonly used. It is important to point out that Tensile Strength is not used in any of these design methods.

A secondary consideration of tensile requirement of TRM's depends on the severity of the exposure, primarily related to the depth of flow and the topography, as well as on how frequently the TRM is anchored to the ground surface. The most severe case would involve deep flow within a steep channel with infrequent anchoring of the TRM. Conversely, TRM installations exposed only to rainfall impact and sheet runoff on slopes of modest steepness would require minimal tensile strength.

But what about installation stresses? Generally the greatest tensile stresses that TRM's are exposed to occur during installation. The deployment, edge burial, pinning or stapling, and soil covering (if required) of the TRM may involve pulling on it, walking on it, pounding on it, driving on it, dumping on it, and/or compacting on it. These imposed forces are usually nominal, but they may be important to consider if the installer is inexperienced or careless.

Typical TRM Strengths

TRM's have performed remarkably well since being introduced in the 1970's. This successful performance is perhaps the best indication that typical TRM's provide sufficient tensile strength for typical installations. Table 1 is a sampling of available TRM's and their associated published tensile strengths. Although there are many different levels of tensile properties for the various TRM's, all of the products listed have been successfully used and evaluated in many similar ways — be it test evaluations or real-life applications. Obviously, any stresses that may be encountered (installation or performance-based stresses), must be resisted by the tensile strength of the TRM, but consideration should be given as to how this resistance is developed.

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Typical TRM Strength *(cont.)*

Table 1: TRM Product	Tensile Strength — MD x XD (lb/ft)
Enkamat 7010	150 x 80
Enkamat 7018	160 x 90
Enkamat 7020	175 x 145
Enkamat R45(formerly "S")	3000 x 3000
Pec-Mat	144 x 84
NAG P300	430 x 300
NAG C350	585 x 687
NAG P550	1421 x 1191
SI Landlock 450	400 x 300
SI Landlock 1060	300 x 225
SI Pyramat	4000 x 3000
Miramat TM8	660 x 480

Data from manufacturers literature and GFR Specifiers Guide

Determining the Amount of Imposed Shear

Resistance to Shear – As shown in Figure 1 below, an installed TRM will be exposed to shear forces imposed on it by flowing water.

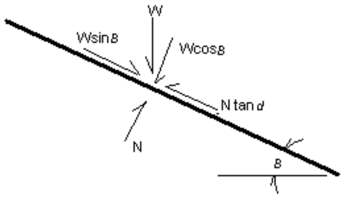

Figure 1. Free-Body Diagram of Shearing Forces

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Calculation of Total Imposed Shear

$\text{Shear}_{\text{Total}} = (W_{water} + W_{TRM})\sin\beta - (W_{TRM}\cos\beta\tan\delta_{TRM}) - (W_{water}\cos\beta\tan\delta_{water})$

Where: $W_{water} = \gamma d$ and $\sin\delta \approx$ slope

$W_{TRM} = (\text{mass/area}_{TRM})(SG_{TRM} - 1)$

SG = specific gravity ($SG_{nylon} = 1.35$; $SG_{PP} = 0.90$)

δ_{TRM} = interface friction angle between soil and TRM

γ_{water} = 62.4 pcf and d = depth of flow

If we neglect W_{TRM} and note that $\delta_{water} = 0$:

$\text{Shear Total} = W_{water}\sin\beta$ Equation 1

Following are two examples of channel bottom slopes commonly designed and constructed.

Example 1 — Shear resulting from 2 ft. of water and a slope of 3%:

$\text{Shear}_{\text{Total}} = W_{water}\sin\beta = (2\text{ ft} \times 62.4\text{ lb/ft}^3)\sin(\tan\text{-}1(3/100)) = 3.74\text{ psf}$

Example 2 — Shear resulting from 2 ft. of water and a slope of 7%:

$\text{Shear}_{\text{Total}} = W_{water}\sin\beta = (2\text{ ft} \times 62.4\text{ lb/ft}^3)\sin(\tan^{-1}(7/100)) = 8.72\text{ psf}$

Tension Resulting from Anchorage

The imposed shear will be resisted either by anchorage at points (i.e. pins or staples) or by anchorage in trenches. [The general usage of anchoring devices such as pins or staples is intended as a temporary means of securely fastening the TRM to the soil to ensure intimate contact between the TRM and the soil until vegetation is established. While anchor trenches are permanent and the pins or staples are temporary, it is prudent to assume these devices will contribute some tensile resistance.] These anchorages prevent the TRM from moving with the flow through developing tension in the TRM. The magnitude of the tension can be determined using Equation 1 and multiplying by the contributory area.

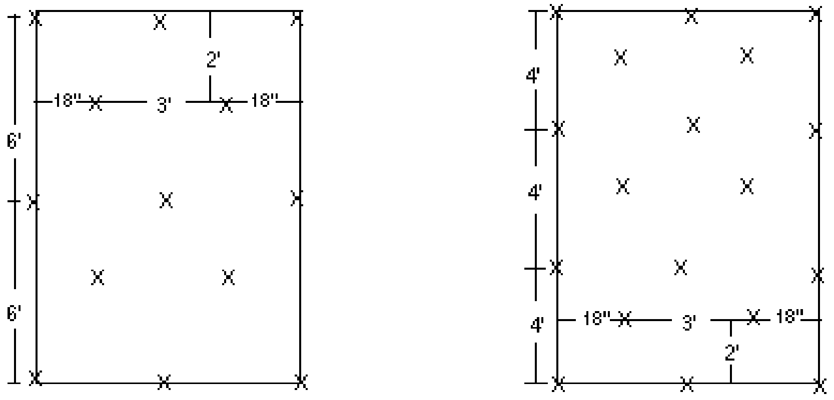
Tension Resulting from Anchorage

Calculation of tension resulting from point anchorage. The total required tension to be resisted by each anchorage point can be determined by multiplying the required tension by the contributory area for each anchorage. The contributory area is determined by anchorage spacing.

Calculation of tension resulting from trench anchorage. The total required tension to be resisted by an anchor trench can be determined by multiplying the required tension by the contributory area. The contributory area is the unanchored length of TRM below the trench.

Available Anchorage

Maximum Point Anchorage. The maximum resistance to pullout at anchorage points is a function of the type of soil, the length of pins or staples, and the frequency of anchorage. Rather than try to determine the anchorage on a project-by-project basis, it has become standard practice to rely on empirically derived charts — such as Chart 1 below, that relate anchor frequency to slope and channel conditions.



1.5 Staples / SY

2 Staples / SY

Example — Anchorage resulting from 8" staples in soft silty/clay soil:

Using short pile theory, the force, P, resisted by a single anchor, can be calculated from:

$$P = k_h y d$$

Where: k_h = coefficient of horizontal subgrade reaction ≈ 300 lb/in^3

y = allowable deflection ≈ 0.25 in.

d = diameter ≈ 0.125 in.

Available Anchorage *(cont.)*

Therefore, $P = 300 \times 0.25 \times 0.125 = 9.375$ lb/in length of leg of staple

x 8 inches deep = 75 lbs per leg of staple

x 2 legs to the staple = 150 lbs per staple

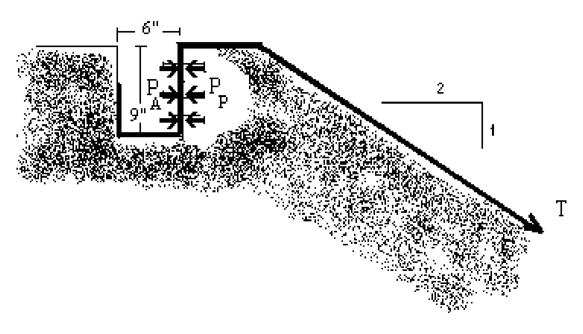
Maximum Anchorage in Trench — The maximum resistance to pullout and, therefore, the maximum tensile strength that can be imposed upon the TRM can be determined by Equation 2.

$$T \cos\beta = P_A + P_P \qquad \text{Equation 2}$$

$$P_A = (0.5\gamma_{AT} d_{AT} + \sigma_n)\, K_A\, d_{AT} \quad \text{and} \quad P_P = (\gamma_{AT} d_{AT} + \sigma_n)\, K_P\, d_{AT}$$

$$P_A = (0.5\gamma_{AT} d_{AT} + \sigma_n) \tan^2(45\Phi/2)\, d_{AT} \quad \text{and} \quad P_P = (\gamma_{AT} d_{AT} + \sigma_n) \tan^2(45\Phi/2)\, d_{AT}$$

Example — Anchorage available from 6" wide x 9" deep trench with no overburden (sn=0) and back-filled with compacted competent soil (f=30° & g=100 pcf). Adjacent side slope = 2:1 (26.5°): [Consider only these forces – Ignore Runout]



$P_A + P_P$

$$(0.5((100\text{pcf})(.75\text{ft})+0)\tan^2(45-30/2)(0.75\text{ft}) + (0.5((100\text{pcf})(.75\text{ft})+0)\tan^2(45+30/2)(0.75\text{ft})$$

$$9.375 + 84.375$$

$$T = (9.375 + 84.375) / \cos 26.5 = 105 \text{ lb/ft}$$

Shown above is the capacity of the anchor trench and the pins or staples. Compared with the tensile strengths found in Table 1, it becomes obvious that high tensile strengths are of little use since the pullout capacity of the anchoring system is really the controlling factor. This further explains why the hydraulic design protocols deal with shear stress and velocity and omits tensile requirements.