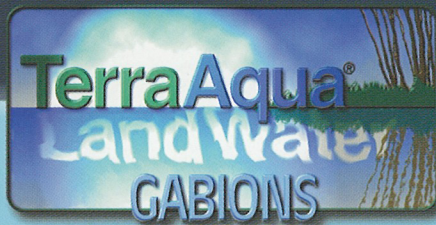


TERRA AQUA GABION SYSTEMS

GABION AND RENO MATTRESS CHANNEL LINING



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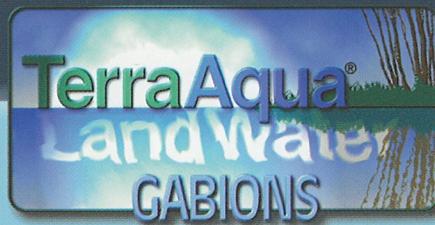
Terra Aqua Gabions and Reno Mattresses offers designers, engineers, contractors and development planners numerous unique advantages for channel lining applications. Gabions and Reno Mattresses will allow the designer to stabilize the channel base and banks, predetermine the value of roughness for the channel base and banks, prevent soil erosion, increase the capacity of the channel, promote vegetation, reduce seepage of the channel and most important determine the soil movement under the lining. Terra Aqua Gabions and Reno Mattresses are generally placed directly on cut grade soil conditions with little or no foundation preparation prior to placement. A permeable geotextile filter fabric should be placed between the Gabion or Reno Mattress and the foundation soil. This shall prevent fine soils from leaching through the lining. Due to the limited foundation preparation required, and given the hydraulic applications Gabions and Reno Mattresses are typically used, they are subjected to various stresses and must have the ability to settle, twist, and conform to sub surface ground settlement. At the same time the Gabions and Reno Mattresses must have sufficient strength to contain the weight of the rocks with which they are filled and any additional gabions or reno mattresses that may be placed on them. As well as withstand the impact force of hydraulic flows and soil pressure while maintaining structural integrity. This combination of flexibility and strength requirements determines that the Gabions and Reno Mattresses used for channel linings must possess a Double Twisted Hexagonal Mesh pattern conforming to ASTM A975-97.

PLACEMENT AND LAYOUT

Placement of the Gabions or Reno Mattresses on the base of the channel shall be such that the length dimension of the unit is laid parallel to the water flow with the internal diaphragms running perpendicular to the water flow. For placement on the side slope or banks the Gabion or Reno Mattress shall be placed such that the length dimension of the unit is laid perpendicular to the water flow so that the internal diaphragms are running parallel with the water flow. This type of placement will minimize stone fill migration within the Gabion or Reno Mattress confinement system. It is best to provide a slope angle on the banks of 1:1.5 or 1:2 depending on the nature of the ground, using the maximum gradient for normal soils of medium consistency and the minimum for non cohesive fine sands. A toe wall may be placed below sub grade for additional stability of the revetment on the slope, and a cut off wall may also be used on the base at the beginning and ending of the revetment to eliminate lifting or scouring and to provide additional stability.

DESIGN CONSIDERATION

The overall stability of the Gabion or Reno Mattress channel lining depends not only on the strength of the double twisted mesh, but also on the thickness of the lining and the grading of the stone fill material used. The proper thickness of Gabion or Reno Mattress lining to use depends on the type of material through which the water flows, the flow velocity, the sediment and bedloads, the gradient of the channel and the curvature of its trace. The thickness of the lining may be increased at the curved sections or where the side slopes are inclined up to 45 degrees. The following information is intended as a guide for designers to determine thickness of the Gabion or Reno Mattress channel lining required for specific applications.



DESIGN CALCULATIONS

GABION AND RENO MATTRESS CHANNEL LINING

FLOW VELOCITY

The hydraulic analysis and calculations are based on uniform flow in open channels, and *Manning formula* is commonly used to estimate the flow velocity in open channels.

$$V = \frac{1.486}{n} \cdot R^{2/3} \cdot S^{1/2}$$

Where

- V = velocity in ft/s
- n = Manning coefficient (see Table 1)
- R = Hydraulic radius in ft
- S = Slope in ft/ft

Table 1 – Reference Values of Manning Coefficient

Products	Thickness	Stone Size	Manning Coefficient
Reno Mattress	6"	3"-6"	0.0277
	9"	3"-6"	0.0277
	12"	3"-6"	0.0277
Gabion	1'	4"-8"	0.0301
	1.5'	4"-8"	0.0301

The Froude number can be calculated as:

$$F = \frac{V}{\sqrt{g \cdot y}}$$

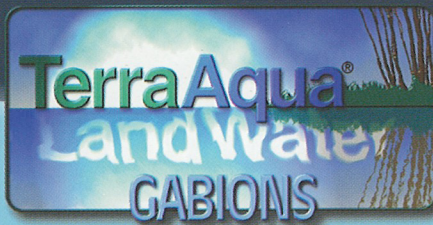
Where

- V = Velocity in ft/s
- g = Acceleration due to gravity (32.2 ft/s²)
- y = Flow depth in ft

For stone fill Gabion and Reno Mattress channel linings, *critical velocity* is the velocity at which the gabion or reno mattress revetment will remain stable without movement of the stone fill; *limit velocity* is the velocity at which is still acceptable although there is some deformation of the Gabion or Reno Mattress due to movement of the stones within the internal compartments or cells.

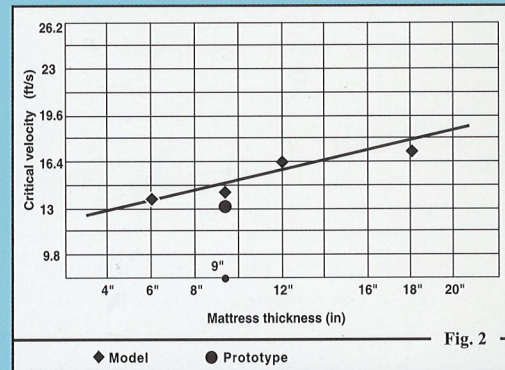
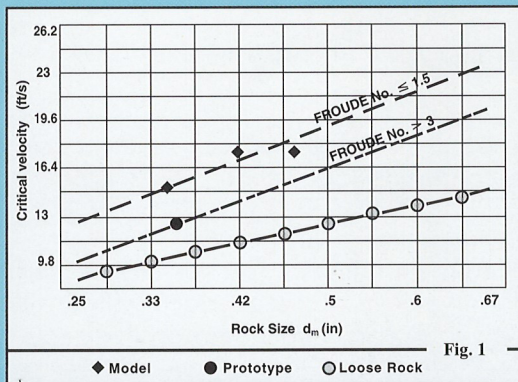
Table 2 – Reference Values of Flow Velocities

Products	Thickness (in)	Stone Size (in)	d ₅₀ (in)	Critical Velocity (ft/s)	Limit Velocity (ft/s)
Reno Mattress	6	3 - 6	3.4 - 4.3	11.5 - 13.8	13.8 - 14.8
	9	3 - 6	3.4 - 4.7	11.8 - 14.8	18.0 - 20.0
	12	3 - 6	3.9 - 4.9	13.8 - 16.4	18.0 - 21.0
Gabion	18	4 - 8	5.9 - 7.5	19.0 - 21.0	24.9 - 26.2



In addition Figure 1 indicates the critical velocity as a function of the Froude number and the stone sizes. It shows that, given the same stone size, the critical velocity on the Reno Mattress is much greater than the loose rip rap; given the same critical velocity, for a stable revetment, the stone size in the Reno Mattress is much smaller than for rip rap.

Figure 2 shows the critical velocity versus Reno mattress thickness.



SHEAR STRESS ANALYSIS

A stone revetment is considered stable when there is no movement of the individual stones whether the stones are dumped loose rip rap or confined in Gabions and Reno Mattresses. The point at which the stones are about to move is defined as the limit of revetment's stability.

The shear stress acting on the revetment is: $\tau_b = \gamma_w \cdot y \cdot S$

And the shear stress on the bank or side slopes is computed as: $\tau_m = 0.75 \cdot \gamma_w \cdot y \cdot S$

Where

- τ_b = Shear stress on inverts in lb/ft²
- τ_m = Shear stress on banks and side slopes in lb/ft²
- γ_w = Unit weight of water (62.4 lb/ft³)
- y = Water depth in ft
- S = Slope in ft/ft

The shear stress on the invert, in the critical condition when the stone movement is about to start, is calculated as: $\tau_c = C_* \cdot (\gamma_s - \gamma_w) \cdot d_m$

And the critical shear stress on banks is computed as: $\tau_s = \tau_c \cdot \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}}$

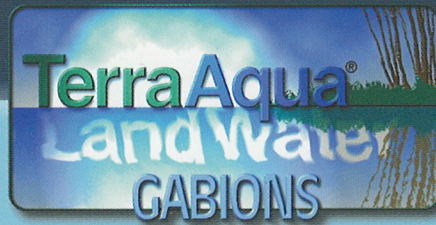
Where

- τ_c = Critical shear stress on inverts in lb/ft²
- τ_s = Critical shear stress on banks and side slopes in lb/ft²
- C_* = Shield's parameter (0.10 for gabions and mattresses)
- γ_s = Unit weight of stones in lb/ft³
- d_m = Median size of stone rocks in ft
- θ = Bank side slope angle in degree
- ϕ = Internal friction angle of stone fill in degree

The revetment is stable if $\tau_b \leq 1.2\tau_c$

The lining on the banks or side slopes of channel is stable if $\tau_m \leq \tau_s$

With limited deformation, it may be accepted if $\tau_m \leq 1.2\tau_s$



VELOCITY AT LINING/FILTER (or Base Soil) INTERFACE

According to *Manning equation*, the velocity under Gabions or Reno Mattresses, at the interface with the base soil or the filter is expressed as:

$$V_b = \frac{1.486}{n_f} \cdot (d_m)^{2/3} \cdot S^{1/2}$$

Where n_f is the Manning coefficient (0.02 lining with a geotextile filter or not filter; 0.025 lining with a gravel filter).

To satisfy the design, V_b must be equal to or less than the allowable velocity of the base soil beneath the lining. The allowable velocities the soils can withstand without being eroded are shown in Table 3.

It is recommended that the geotextile filter be used beneath the linings. The velocity of the flow passing through the geotextile fabrics is reduced, and the velocity at the interface with the base soil may be assumed as 1/2 - 1/4 of the value of V_b given above, depending on the geotextile characteristics.

Table 3 – Reference Values of Allowable Velocities of Soils at River Bed

Soil Materials	Velocity (ft/sec)	
	No material carried in suspension	Colloidal material carried in suspension
Fine sand (non-colloidal)	1.5	2.5
Sandy clay (non-colloidal)	1.7	2.5
Soft clay	2.0	3.0
Mud	2.5	3.5
Coarse sand	2.5	5.0
Stiff clay	3.7	5.0
Gravel	4.0	6.0
Shingle	5.0	5.5
Very Stiff Clay	6.0	6.0

ESTIMATION OF POTENTIAL DEFORMATION

When the shear stress reaches the critical value of the conditions of "initial movement", the stone fill in the Gabion or Reno Mattress moves downstream inside each compartment. With the shear stress increasing and more stone movement development, the deformation of the Gabion or Reno Mattress occurs (Figure 3).

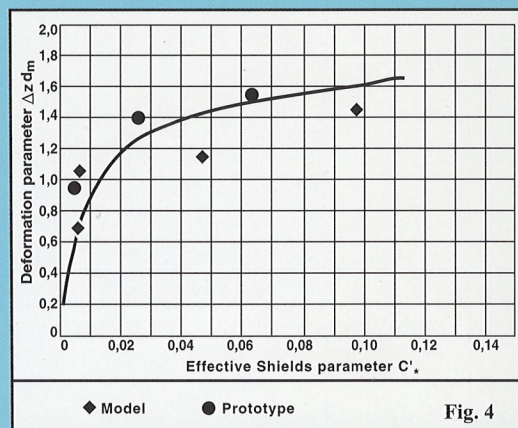
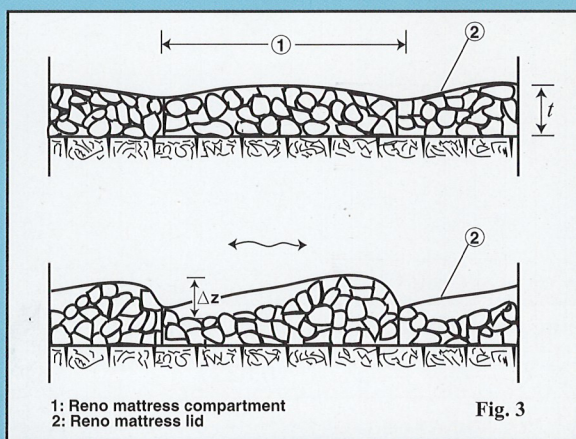
To evaluate the degree of deformation, a parameter D_z / d_m is used, where D_z is the height difference between the highest and lowest stone surface within a cell. Figure 4 shows the relationship between D_z / d_m and "effective Shield's parameter" C_*' which is defined as:

$$\text{For the bed; } C_*' = \frac{\tau_b - \tau_c}{(\gamma_s - \gamma_w) \cdot d_m} \quad \text{For the bank; } C_*' = \frac{\tau_m = \tau_s}{(\gamma_s - \gamma_w) \cdot d_m}$$

The reduction in the stone fill thickness in the upstream portion of the Gabion or Reno Mattress cell is $D_z / 2$; Therefore, to protect the soils beneath the Gabion or Reno Mattress from being directly exposed to the flow current, the deformation may be acceptable if,

$$D_z / d_m \leq 2 \cdot (t / d_m - 1)$$

Where t is the mattress thickness.



LINING DESIGN WITH WAVE ACTION

The banks of channels, canals, irrigation basins etc. are subject to wave action generated by wind; and the banks of navigation canals and rivers are subject to wave action caused by vessels. The major parameters in designing revetment to resist the wave action are the wave height (H_s) and bank slope angle (θ).

The following equations on the minimum lining thickness (t_m) may be utilized to analyze the stability of the lining against the wave action.

$$\text{For } \cot \theta \leq 3 \quad t_m = \frac{H_s}{2 \cdot \cot \theta} \quad \text{For } \cot \theta \geq 2 \quad t_m = \frac{H_s}{4 \cdot (\cot \theta)^{1/3}}$$

The equations are only valid for both wind-induced waves lower than 3 ft and frequent waves 4.5 ft high (e.g. navigation rivers).

COMPARISON OF GABION OR RENO MATTRESS LINING AND RIP RAP

The Shields coefficient for rip rap is approximately 0.047, while for rocks contained in double twisted hexagonal mesh Gabions or Reno Mattresses it is approximately 0.10 double that of rip rap.

In accordance with the shear stress analysis, we can conclude that for any given hydraulic condition the average size of the stones needed in Gabions or Reno Mattresses is half that required for a dumped loose rip rap revetment.