Gabions for Streambank Erosion Control

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Complexity	Environmental Value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

Gabions are cylinders that are filled with earth or stones, which are used in building structures such as dams or dikes. Gabions have been used for several millennia in Egypt and China. Prior to 1879, gabions were constructed with plant materials, which severely limited their useful life. In about 1879 a firm in Italy is . thought to have first used wire mesh in the construction of gabion baskets. This is possibly the first use of the modern wire mesh baskets as used today. Gabions are now used throughout the world for bed protection, bank stabilization, retaining walls, and numerous other purposes.

Gabions come in three basic forms, the gabion basket, gabion mattress, and sack gabion. All three types consist of wire mesh baskets filled with cobble or small boulder material. The fill normally consists of rock material but other materials such as bricks have been used to fill the baskets. The baskets are used to maintain stability and to protect streambanks and beds.

The difference between a gabion basket and a gabion mattress is the thickness and the aerial extent of the basket. A sack gabion is, as the name implies, a mesh sack that is filled with rock material. The benefit of gabions is that they can be filled with rocks that would individually be too small to withstand the erosive forces of the stream. The gabion mattress is shallower (0.5 to 1.5 ft) than the basket and is designed to protect the bed or banks of a stream against erosion.

Gabion baskets are normally much thicker (about 1.5 to 3 ft) and cover a much smaller area. They are used to protect banks where mattresses are not adequate or are used to stabilize slopes (Figure 1), construct drop, structures, pipe outlet structures, or nearly any other application where soil must be protected from the erosive forces of water. References to gabions in this article refer generally to both mattresses and baskets. Sack gabions are rarely

Figure 1. Gabion baskets installed for slope stabilization along a stream

used in the United States and are not within the scope of this technical note.

Gabion baskets can be made from either welded or woven wire mesh. The wire is normally galvanized to reduce corrosion but may be coated with plastic or other material to prevent corrosion and/or damage to the wire mesh containing the rock fill. New materials

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such as Tensar, a heavy-duty polymer plastic material, have been used in some applications in place of the wire mesh. If the wire baskets break, either through corrosion, vandalism, or damage from debris or bed load, the rock fill in the basket can be lost and the protective value of the method endangered.

Gabions are often used where available rock size is too small to withstand the erosive and tractive forces present at a project site. The available stone size may be too small due to the cost of transporting larger stone from remote sites, or the desire to have a project with a smoother appearance than obtained from riprap or other methods. Gabions also require about one third the thickness of material when compared to riprap designs. Riprap is often preferred, however, due to the low labor requirements for its placement.

The science behind gabions is fairly well established, with numerous manufacturers providing design methodology and guidance for their gabion products. Dr. Stephen T. Maynord of the U.S. Army Engineer Research and Development Center in Vicksburg, Mississippi, has also conducted research to develop design guidance for the installation of gabions. Two general methods are typically used to determine the stability of gabion baskets in stream channels, the critical shear stress calculation and the critical velocity calculation. A software package known as CHANLPRO has been developed by Dr. Maynord (Maynord et al. 1998).

Manufacturers have generated extensive debate regarding the use and durability of welded wire baskets versus woven wire baskets in project design and construction. Project results seem to indicate that performance is satisfactory for both types of mesh.

The rocks contained within the gabions provide substrates for a wide variety of aquatic organisms. Organisms that have adapted to living on and within the rocks have an excellent home, but vegetation may be difficult to establish unless the voids in the rocks contained within the baskets are filled with soil.

If large woody vegetation is allowed to grow in the gabions, there is a risk that the baskets will break when the large woody vegetation is uprooted or as the root and trunk systems grow. Thus, it is normally not acceptable to allow large woody vegetation to grow in the baskets. The possibility of damage must be weighed against the desirability of vegetation on the area protected by gabions and the stability of the large woody vegetation.

If large woody vegetation is kept out of the baskets, grasses and other desirable vegetation types may be established and provide a more aesthetic and ecologically desirable project than gabions alone.

PLANNING

The first step in the planning process is to ascertain whether gabions are the appropriate tool to meet project objectives and constraints related to stability and habitat. Team members conducting this assessment should include hydraulic engineers, biologists, geologists, landscape architects, and others that have an understanding of stream restoration, fluvial geomorphology, and vegetation and habitat requirements.

Numerous questions must be addressed by the team including, but not limited to, the following interrelated items:

1) Are gabions the appropriate tools given the magnitude of the erosion problem?
2) Are stream velocities and shear stresses permissible?
3) Is there danger to the wire mesh from floating debris, sharp bed load, or from vandalism?
4) Will site conditions during construction permit installation?
5) Have consequences of failure been considered and what are they, e.g., what happens if one or several baskets becomes dislodged and move downstream or break open?
6) Can and will the sponsor repair the baskets in a timely manner when necessary?
7) Are there areas that must be protected to prevent erosion damage from the upper bank areas behind the gabions?

8) Are the project costs acceptable?

Costs for gabion projects are among the highest for streambank erosion and bank stabilization techniques. Costs for the baskets vary by size and depth but are on the order of \$1.50 to \$3.20/ft^2 (all figures in 1999 dollars) for 3-ft-deep baskets, \$1.25 to \$2.00/ft^2 for 18-in.-deep baskets, and \$1.10 to \$1.75/ft^2 for 12-in.-deep baskets. Closure items for the baskets are normally included and prices also vary with the gauge of the wire, with heavier wire being more expensive. Baskets can be ordered in custom sizes for a higher price. Keys or tiebacks, if required, stone, backfill, and vegetation plugs, if any, add to material costs but vary with design and availability.

Total project cost is estimated at about \$150.00 to \$450.00/yd^3 of protection. This includes the baskets, assembly and filling the baskets, stone fill (may vary depending on location and availability), and basket closure.

Basket installation does not always require heavy equipment but the filling and closure of the baskets can be very labor-intensive and a good crew should be planned to complete installation in a timely manner.

SITE CONSIDERATIONS

Gabions are suited to a variety of site conditions. They can be used in perennial or ephemeral streams, and installation can occur in dry or wet conditions with the proper equipment. The main concern is the delivery and handling of the baskets and rock fill. If wet conditions exist for long periods of time in the area surrounding the site, the delivery of rock materials may be impossible or extremely problematic.

The most important consideration for the installation of gabions is the stability of the stream. If the stream is undergoing rapid changes in base elevation (down- cutting or deposition) or extreme lateral movement, plans should be made to correct the larger problems that are contributing to the local problem. If the larger problems are not addressed, local protection measures may be overwhelmed or flanked.

Foundation conditions are also important in site selection because the gabions must have a firm foundation. If the substrate is noncohesive material, such as sand or silt, the material may be removed through the gabions and cause settlement or flanking to occur. Installation of a filter material or filter fabric should be considered in every project. Filter material should only be omitted if it is clearly not needed. Some projects may require a filter fabric as well as a gravel filter material to prevent erosion of the underlying bank and bed material. An additional and extremely important consideration is the calculation of the amount of erosion to be expected in a project. This should be calculated to ensure that the foundation for the gabions is not undercut due to scour.

DESIGN

Primary design considerations for gabions and mattresses are: 1) foundation stability; 2) sustained velocity and shear-stress thresholds that the gabions must withstand; and 3) toe and flank protection. The base layer of gabions should be placed below the expected maximum scour depth. Alternatively, the toe can be protected with mattresses that will fall into any scoured areas without compromising the stability of the bank or bed protection portion of the project. If bank protection does not extend above the expected water surface elevation for the design flood, measures such as tiebacks to protect against flanking should be installed.

The use of a filter fabric behind or under the gabion baskets to prevent the movement of soil material through the gabion baskets is an extremely important part of the design process. This migration of soil through the baskets can cause undermining of the supporting soil structure and failure of the gabion baskets and mattresses.

Primary Design Considerations

The major consideration in the design of gabion structures is the expected velocity at the gabion face. The gabion must be designed to withstand the force of the water in the stream.

Since gabion mattresses are much shallower and more subject to movement than gabion baskets, care should be taken to design the mattresses such that they can withstand the forces applied to them by the water. However, mattresses have been used in application where very high velocities are present and have performed well. But, projects using gabion mattresses should be carefully designed.

The median stone size for a gabion mattress can be determined from the following equation:

$$d_m = S_f C_s C_v d\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{0.5} \frac{V}{\sqrt{gdK_1}}\right]^{2.5} \qquad (1)$$

The variables in the above equation are defined as:

C_s = stability coefficient (use 0.1)
C_v = velocity distribution coefficient = 1.283-0.2 log (*R/W*) (minimum of 1.0) and equals 1.25 at end of dikes and concrete channels
d_m = average rock diameter in gabions
d = local flow depth at V
g = acceleration due to gravity
K_1 = side slope correction factor (Table 1)
R = centerline bend radius of main channel flow
S_f = safety factor (1.1 minimum)
V = depth-averaged velocity
W = water surface width of main channel
γ_s = unit weight of stone
γ_w = unit weight of water

Table 1. K1 versus Side Slope Angle

Side Slope	K1
1V : 1H	0.46
1V : 1.5H	0.71
1V : 2H	0.88
1V : 3H	0.98
<1V : 4H	1.0

This equation was developed to design stone size such that the movement of filler stone in the mattresses is prevented. This eliminates deformation that can occur when stone sizes are not large enough to withstand the forces of the water. The result of mattress deformation (Figure 2) is stress on the basket wire and increases in resistance to flow and the likelihood of basket failure. The upper portion of Figure 2 shows an undeformed gabion, while the lower portion shows how gabions deform under high-velocity conditions.

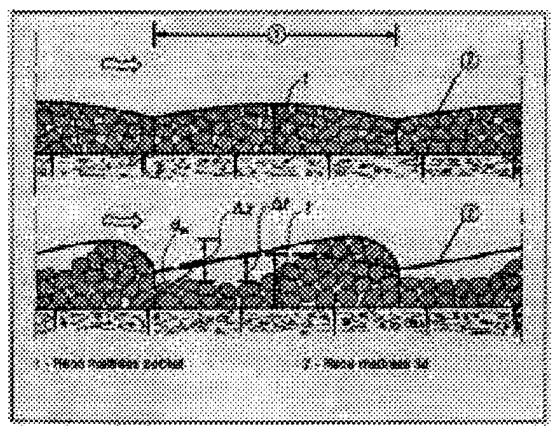

Figure 2. Gabion mattress showing deformation of mattress pockets under high velocities (courtesy Maccaferri Gabions)

Maccaferri Gabions offers a table in their materials giving guidance on sizing stone and allowable velocities for gabion baskets and mattresses. This is shown in Table 2.

Table 2. Stone Sizes and Allowable Velocities for Gabions (courtesy of and adapted from Maccaferri Gabions)

Type	Thickness (ft)	Filling Stone Range	D50	Critical* Velocity	Limit** Velocity
Mattress	0.5	3 - 4"	3.4"	11.5	13.8
	0.5	3 - 6"	4.3"	13.8	14.8
	0.75	3 - 4"	3.4"	14.8	16
	0.75	3 - 6"	4.7"	14.8	20
	1	3 - 5"	4"	13.6	18
	1	4 - 6"	5"	16.4	21
Basket	1.5	4 - 8"	6"	19	24.9
	1.5	5 - 10"	7.5"	21	26.2

When the data in Table 2 are compared to Equation 1, if $V = 11.5$, $C_s = 0.1$, $C_v = 1.0$, $K_1 = 0.71$, $\gamma_w = 150$ and $S_f = 1.1$, the local flow depth must be on the order of 25 ft in order to arrive at the stone diameter of 3.4 in. shown in Table 2. Designers should use Equation 1 to take the depth of flow into account. Table 2 does, however, give some general guidelines for fill sizes and is a quick reference for maximum allowable velocities.

Maccaferri also gives guidance on the stability of gabions in terms of shear stress limits. The following equation gives the shear for the bed of the channel:

$$\tau_b = \gamma_w S d \qquad (2)$$

with the bank shear τ_m taken as 75 percent of the bed shear, i.e. $\tau_m = 0.75\tau_b$. (S is the bed or water surface slope through the reach.) These values are then compared to the critical stress for the bed calculated by the following equation:

$$\tau_c = 0.10(\gamma_s - \gamma_w)d_m \qquad (3)$$

with critical shear stress for the banks given as:

$$\tau_s = \tau_c \sqrt{1 - \frac{\sin^2\theta}{0.4304}} \qquad (4)$$

where θ = the angle of the bank rotated up from horizontal.

A design is acceptable if $\tau_b < \tau_c$ and $\tau_m < \tau_s$. if either $\tau_b > \tau_c$ or $\tau_m > \tau_s$, then a check must be made to see if they are less than 120 percent of τ_b and τ_s. If the values are less than 120 percent of τ_b and τ_s, the gabions will not be subject to more than what Maccaferri defines as "acceptable" deformation. However, it is recommended that stone size be increased to limit deformation if possible.

Research has indicated that stone in the gabion mattress should be sized such that the largest stone diameter is not more than about two times the diameter of the smallest stone diameter and the mattress should be at least twice the depth of the largest stone size. The size range should, however, vary by about a factor of two to ensure proper packing of the stone material into the gabions. Since the mattresses normally come in discrete sizes, i.e. 0.5, 1.0, and 1.5 ft in depth, normal practice is to size the stone and then select the basket depth that is deep enough to be at least two times the largest stone diameter. The smallest stone should also be sized such that it cannot pass through the wire mesh.

Stability of Underlying Bed and Bank Materials. Another critical consideration is the stability of the gabion foundation. This includes both geotechnical stability and the resistance of the soil under the gabions to the erosive forces of the water moving through the gabions. If there is any question regarding the stability of the foundation, i.e. possibility of rotational failures, slip failures, etc., a qualified geotechnical engineer should be consulted prior to and during the design of the bank/channel protection. Several manufacturers give guidance on how to check for geotechnical failure (see Maccaferri Gabions brochure as an example).

Stacked gabion baskets used for bank stability should be tilted towards the soil they are protecting by a minimum of about 6 deg from vertical. Gabions are stacked using two methods. These are shown in Figure 3. While the gabions can be stacked with no tilt, it is recommended that some tilt into the soil being protected be provided.

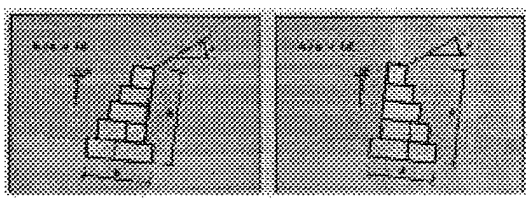

Figure 3. Front step and rear step gabion layout (courtesy of Maccaferri Gabions)

One of the critical factors in determining stability is the velocity of the water that passes through the gabions and reaches the soil behind the gabion. The water velocity under the filter fabric, i.e. water that moves through the gabions and filter fabric, is estimated to be one-fourth to one-half of the velocity at the mattress/filter interface. (Simons, Chen, and Swenson 1984) The velocity at the mattress/filter interface (V_b) is estimated to be

$$V_b = \frac{1.486}{n_f}\left(\frac{d_m}{2}\right)^{2/3} S^{1/2} \qquad (5)$$

where n_f = 0.02 for filter fabric, 0.022 for gravel filter material and S is the water surface slope (or bed slope) through the reach. If the underlying soil material is not stable, additional filter material must be installed under the gabions to ensure soil stability. Maccaferri also provides guidance on the stability of soil under the gabions in terms of velocity criteria.

The limit for velocity on the soil is different for each type of soil. The limit for cohesive soils is obtained from a chart, while maximum allowable velocities for other soil types are obtained by calculating V_e, the maximum velocity allowable at the soil interface, and comparing it to V_f, the residual velocity on the bed, i.e. under the gabion mattress and under the filter fabric.

V_e for loose soils is equal to $16.1d^{1/2}$ while V_f is calculated by:

$$V_f = \frac{1.486}{n_f}\left(\frac{d_m}{2}\right)^{2/3} SV_a^{\ 1/2} \qquad (6)$$

where V_a is the average channel velocity and d_m is the average rock diameter.

If V_f is larger than two to four times V_e, a gravel filter is required to further reduce the water velocity at the soil interface under the gabions until V_f is in an acceptable range. To check for the acceptability of the filter use the average gravel size for d_m in Equation 6. If the velocity V_f is still too high, the gravel size should be reduced to obtain an acceptable value for V_f.

Other Design Considerations

It may be possible to combine gabions with less harsh methods of bank protection on the upper bank and still achieve the desired result of a stable channel. Provisions for large woody vegetation and a more aesthetically pleasing project may also be used on the upper banks or within the gabions (Figure 4). However, the stability of vegetation or other upper bank protection should be carefully analyzed to ensure stability of the upper bank area. A failure in the upper bank region can adversely affect gabion stability and lead to project failure.

CONSTRUCTION

A gabion project is installed by first smoothing the area to be protected to the desired final slope. The filter fabric and any required gravel filter are then installed according to the design plans.

The gabions are next assembled and tied together, folded flat, stacked, and bundled by the supplier. They are bent into the design form, and all ends and diaphragms are laced into place. The assembled gabions are then placed in their proper location and laced (tied) to all surrounding gabions. It is important that all adjacent gabions be laced together. This prevents movement and the failure of a project due to the loss of one basket out of a protected area. Lacing should occur in accordance with the manufacturer's recommendations.

After a sufficient number of gabions are assembled, filling can start. The fill should be placed carefully in the gabions to prevent damage to the diaphragms and edges. Filling should be done in lifts of no more than 12 in. and some hand adjustment may be required to obtain a smooth attractive face. For gabion baskets with heights greater than 12 in., tie wires or stiffeners are recommended after each lift to prevent exposed faces from bulging (see Figure 5).

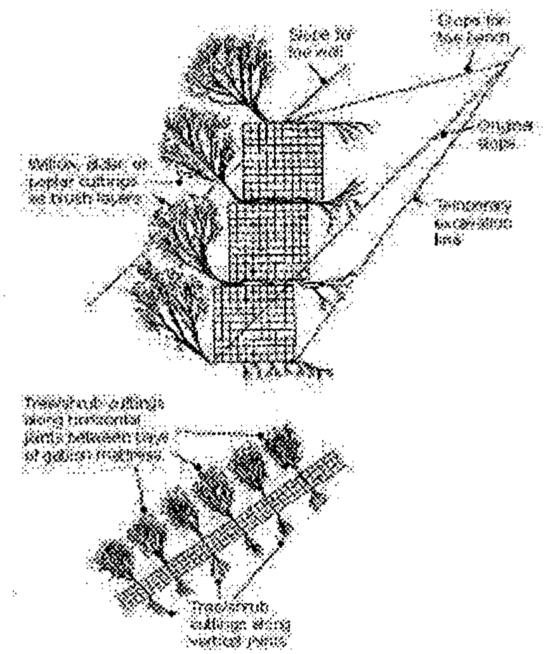

Figure 4. Woody vegetation used within the gabion architecture (Coppin and Richards 1990)

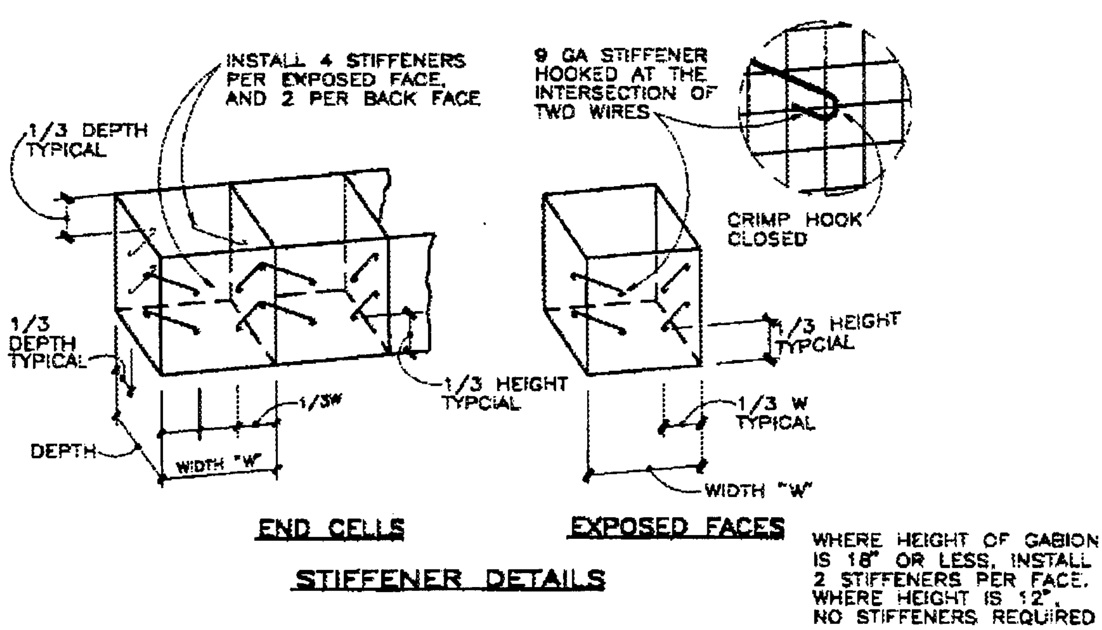

Figure 5. Stiffener installation to prevent bulging faces (courtesy Hilfiker Retaining Walls)

After filling, the covers are placed on the gabions and secured with tie wires (laced). The gabions can be seeded with grass or other cover vegetation if the soil is intermixed with the lifts of stone and if the hydrology is not limiting. Again, large woody vegetation should be avoided in the area protected by gabions.

Care should be taken to determine soil properties if the gabions are to be covered. If the soil is saline or acidic, deterioration of the gabion wire can occur rapidly, leading to project failure.

If the soil has a lower permeability than the underlying bank material, water may not be able to move readily through the gabions, resulting in hydrostatic pressure behind the gabions. This can cause a sliding or rotational failure of the gabions. If the soil that is placed on the gabions is porous enough to allow easy passage of water through the gabion, it may not retain enough water to support the desired vegetation.

If a grass cover can be established over gabions, it is possible that the grass will remain stable during high flows since the root system will be firmly attached to the gabion mesh and underlying rock fill. The problems of adequate moisture and sufficient permeability of the soil need to be carefully investigated.

While gabions may be able to support some types of vegetation, care should be used when recommending covering and filling the gabions with intermixed soil and rock to support vegetation.

OPERATION AND MAINTENANCE

Gabions need to be checked for broken wires and repaired if necessary to protect stone contained in the gabions from being removed by the force of water passing the cage.

Any large woody vegetation that has started to grow in the gabions should be removed and any damage to the gabions repaired. This may include replacing lost stone and repairing any damaged wire with wire similar to that used in the construction of the cages.

The project area should be monitored for signs of erosion. If erosion is occurring at the toe of the gabion structures, measures should be taken to protect the gabions from undercutting and subsequent failure. If water is eroding soil from behind a gabion wall, either the water needs to be diverted or measures need to be taken to eliminate the erosion of soil from behind the gabions. This often occurs where surface runoff enters the stream at a location that is protected by gabions.

The project should be monitored for any signs of geotechnical failure. If any of the gabions have shifted or appear to be bulging away from the bank, measures should be taken to evaluate the seriousness of the problem. If proper geotechnical evaluations and measures are taken during the design and construction stages, there should be little chance of a major problem due to geotechnical failures.

APPLICABILITY AND LIMITATIONS

The aesthetics of gabions are not as desirable as some other types of protective measures such as re-vegetation, but where the damages and dangers associated with failures is high, or where serious erosion problems exist that cannot be controlled with other methods, gabions are a viable alternative.

Caution should be exercised in using gabions in areas where there is a high likelihood of vandalism or damage from in-stream debris including moving cobble, etc., that can harm the wire by impact and scour. Under these conditions, the wire containing the rock fill can be damaged and the protection lost. Gabions must also be protected against impact from large woody debris and sharp objects. These materials tend to distort and break the gabions.

If large woody vegetation is desired in an area to be protected by gabions, it may be possible to use gabions or other methods such as peaked stone toes to protect the lower bank and a vegetative treatment on the upper banks. This can provide for large woody vegetation on the upper bank and yet provide highly effective protection of the toe of the bank.

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