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LANDSLIDE ROAD PROTECTION AND RIVER TRAINING WORKS WITH GABION STRUCTURES

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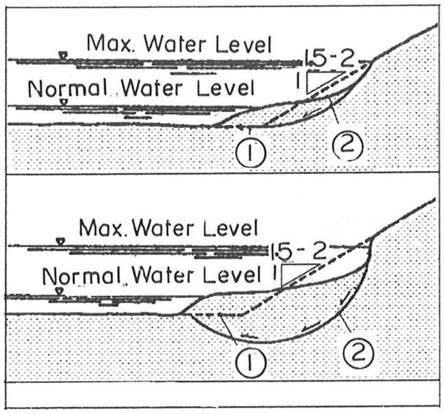
ABSTRACT

The paper pertains to the use of flexible gabion structures for landslide, road protection and river training works. The general phenomena of landslide and erosion can be explained as modification of the equilibrium condition of soil at specific surfaces due to a natural configuration or due to a human activity. The protection works for such cases are categorised as rigid, flexible or loose material structures. Gabion and Reno mattresses being flexible structures have added advantages. The internal structure details of the gabions and Reno mattresses such as opening size, double twist mesh, hexagonal shape, wire diameter, extent of galvanisation, diaphragms and joint details play an important role in the functioning of the structure as a whole. The gabions can be used in the form of weirs or longitudinal protection works for training of rivers whereas for landslide and road protection works they can be used in the form of retaining structures or reinforced earth structures.

GENERAL

To speak about protections against landslides and erosion phenomena means to analyse in general the superficial equilibrium of the soil that can be modified by the combined action of man and the natural atmospheric events, and mainly the water. The erosion of the river bed or of a bank can strongly modify the soil stability both from the geotechnical and the geomechanical point of view: in situations in which rapid longitudinal or transversal currents erode banks or the toes of the banks both slopes and embankments can become unstable. This phenomenon can occur in almost any geological situation and particularly in areas prone to landslides or where undrained strata are present .Typical examples are the failures due to rapid draw down in a situation where a possible slide plane coincides with a toe of a bank (FIG.1) or the stream bed or where an erosion at the toe of the bank creates an instability along a curved slide surface or a vertical plane (FIG.2).

From the geotechnical point of view it can be generally considered that the relationship between the soil characteristics and the presence of water in the subsoil cannot be in equilibrium, due to a natural configuration or to a human activity as for example a road construction or a rehabilitation of a certain area for building or industrial / agricultural purposes. The drainage of the subsoil water is therefore probably the most important aspect to be considered . All this preamble is important because a landslide or an erosion phenomena can not be contained, but has to be restored understanding the source of the problem, considering the most suitable design criteria and using the right kind of materials.



1. Original Bank Profile
2. Probable Failure Surface

Figure I

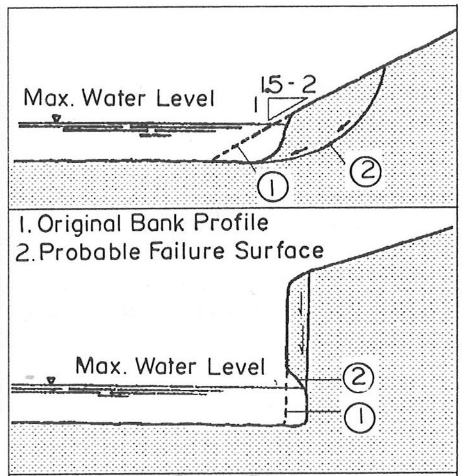


Figure 2

It is useful to group the soil protection structures into the following classes : rigid, loose materials and flexible. The gabions normally defined flexible structures, combine some of the characteristics of the rigid and the loose material structures ac'ded to the structural continuity typical of the rigid structures .Gabion structures can adjust easily to the yielding of the foundation soil and can resist large deformation without being destroyed and without compromising their protective function. In addition to deformability and resistance typical of flexible structures, gabion and Reno mattresses structures convenient in the broad range of hydraulic protection works and soil conservation .

THE STRUCTURE OF GABION

Gabions are rectangular cages made of hexagonal double twisted wire mesh filled with appropriately sized cobbles or quarry stones (FIG.3).The wire used is soft steel, annealed and zinc coated to international standards . Double twisting ties together the wires that form the mesh and guarantees that the mesh will not unravel should one or more wires break. Zinc coating provides long term protection for steel wire against oxidation. The mechanical and qualitative characteristics of the wire, i.e. breaking strength, elongation and quality of zinc coating meet the most rigid international standards. Any stone or any other material may be used to fill the gabion as long as it's density and other characteristics meet the structural, functional and durability requirements of the project . The most commonly used materials are round or quarried stones of high specific gravity, weather resistant, non friable insoluble and sufficiently hard .

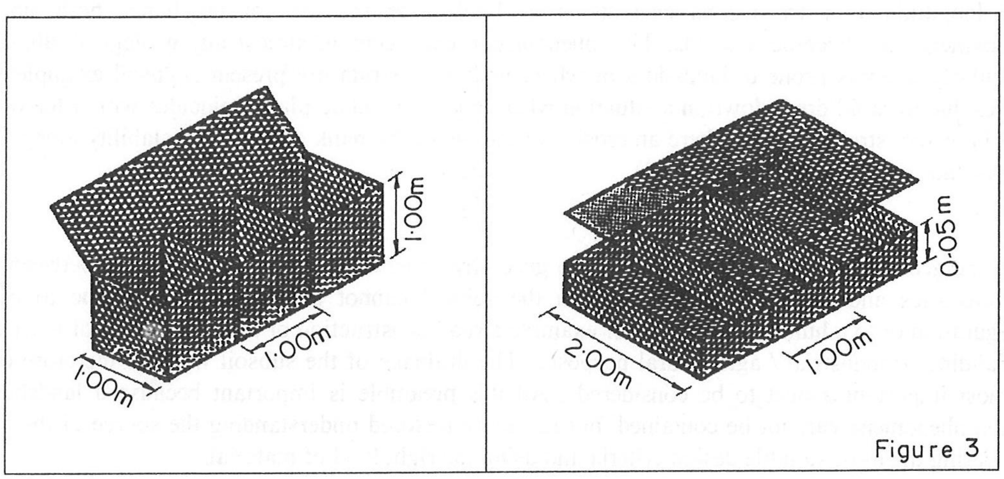


Figure 3

The most appropriate size for stone varies from 1.5 to 2 times the dimension D of the mesh to prevent it's escape through the mesh opening (Fig 4).

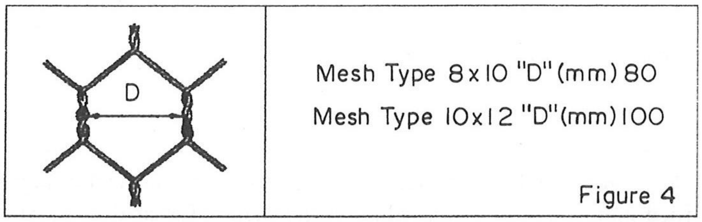


Figure 4

This means that for a mesh type 8x10 the maximum stone diameter to be used is 120 mm, while for the mesh type 10x12 the same minimum is 150 mm which represents an easier value to guarantee.

APPLICATION IN THE RIVER TRAINING WORKS

Where the river bed consists of materials permeable, easily eroded and have low bearing capabilities, the gabion structure offers a more convenient solution than most other materials. In mountainous countries the control of erosion in streams can be of major importance reducing the occurrence of landslides and the deposition of material in lower reaches (Fig 5).

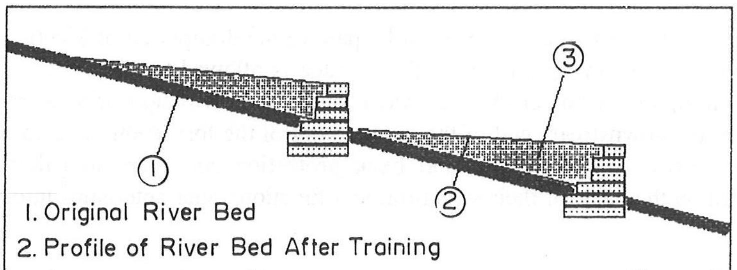


Figure 5

Erosion is checked by lowering the velocity of water to a value which it ceases to move the soil particles forming the bed and the banks . This is achieved by reducing the gradient to obtain a stable velocity and hence equilibrium and in practice such conditions are attained by the construction of a series of weirs.
If a stretch of a river, having a natural slope 'i', is to be trained to a slope 'i_e' by means of a series of weirs at equidistant points (Fig 6).

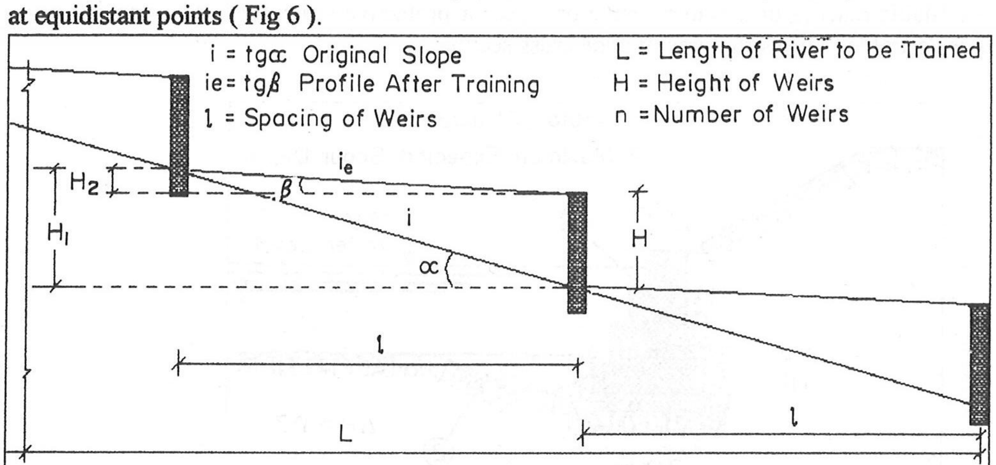


Figure 6

The height h and the distance 'l' between the two weirs are connected by the relation

$H = H1 - H2 = (i - i_e)\, l$

Consequently, the number n of weirs necessary for the training of the considered length L is

$n = L/l = L\,(i - i_e) / H$

In general, it is preferable to build small and closely separated structures instead of high ones.
Gabion weirs are classified into three types, according to the shape of their downstream face at the centre of flow:

- Vertical weirs
- Stepped weirs
- Sloped weirs

In the vertical gabion weir, the nappe is not only aerated, but separated from the downstream face. Since this means that the weir mesh is protected against abrasion and impact by heavy bed material carried in spate conditions, it is a type recommended for training works on mountain torrents . The only mesh which is exposed to abrasion is the crest, which must be protected . Suitable materials are : timber or steel sheets securely fastened to the wire netting, or concrete capping.

In the design of vertical weirs, maximum attention must be paid to the dissipation of kinetic energy of the cascade at the toe of the structure . In certain cases, the cascade is allowed to scour the bed and form a pool where the energy is dissipated in the cushion of water and in the formation of a hydraulic jump. A secondary weir is placed at the downstream end of the pool to control the formation of jump and to restrict the extension of the pool downstream. Longitudinal bank protection structures in gabions and Reno mattresses can be classified on the basis of their structural and functional characteristics into the following types :

- massive structures
- linings
- combined structures

<u>Massive structures (Fig 7)</u>

Within the more unstable reaches of a water course or where a protective structure has to provide also earth retention, it is desirable to use structures of wide cross section .

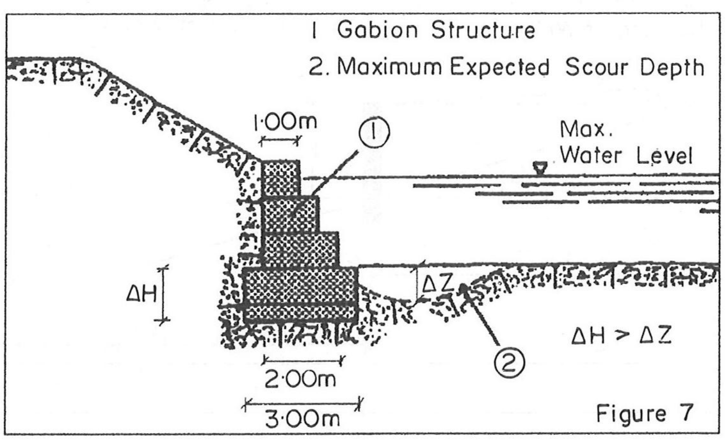


Figure 7

Gabion protections in addition to their flexibility and their superior drainage characteristics have an excellent ability to function as gravity structures. The wall must be founded at a level that is not affected by water scour problems. Generally a direct foundation is appropriate in mountainous regions and especially in the more wild torrents where the heavy bed load could damage the elements such as aprons protruding into the stream bed . The depth of foundation (ΔH) has to be obviously higher than the max. scour conditions (ΔZ).In alternative a properly sized apron can extend horizontally beyond the vertical front face of the protection into the river bed 1.5 to 2 times the maximum depth of expected scour . This ensures that under normal maximum scour conditions the apron will fold down along a slope that is not excessively steep, forestalling any propensity to slip. The thickness of the apron needs always to be proportionate to it's function and needs to have sufficient weight to be able to adjust down to adhere to the bottom as this is eroded away. For this reason the recommended thickness is 0.5 m. If it is not possible to build the foundation of a river bank improvements in the dry conditions, a platform can be built of loose rocks : it is particularly important to choose a rock size to ensure it's stability and with a size that has to be large and well assorted so as to prevent movement and washing away of fines. In some cases the use of cylindrical gabions can be very beneficial because of their size (2 to 3 cum) and weight which prevent the water from carrying them away. At the same time the fill can be relatively of small size, thus reducing the voids and the need for filter layers between the foundation and the river bed .

River/Canal Lining

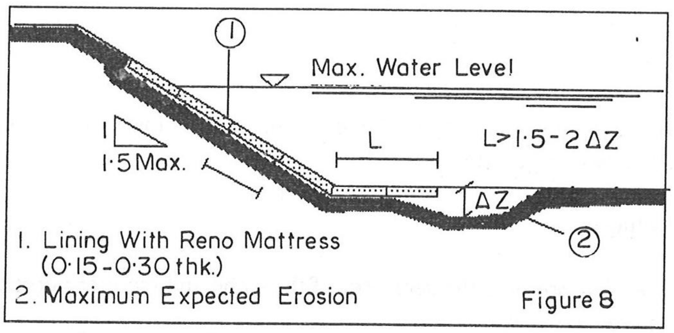


Figure 8

Linings are simply laid on the slopes to be protected (Fig 8). The thickness of the protective layer is dictated by the hydraulic conditions of the water course and it may vary from 0.15 to 0.30 m . Such small depths encourages vegetation growth in a short time. Again the best toe protection is to extend the lining for a length 1.5 to 2 times the expected erosion at the most critical section. The flexibility of this apron allows it to maintain intimate contact with the scoured profile thus preventing the scour to advance toward the bank.

For the purpose of identifying design criteria for gabion and Reno mattress lining a research programme has been carried out at the Laboratories of Colorado State University in Fort Collins, Colorado, USA. The test results have established values of resistance to both shear forces and water velocities (Table-1).

Table-1 Indicative gabions and Reno mattress thickness related to water velocity

Type	Thickness (m)	Rock fill size (mm)	thickness d_{50} (m)	Critical Velocity (m/sec)	Limit Velocity (m/sec)
Reno mattress	0.15 - 0.17	70 - 100	0.085	3.5	4.2
		70 - 150	0.110	4.2	4.5
	0.23 - 0.25	70 - 100	0.085	3.6	5.5
		70 - 150	0.120	4.5	6.1
	0.3	70 - 120	0.100	4.2	5.5
		100 - 150	0.125	5.0	6.4
Gabions	0.5	100 - 200	0.150	5.8	7.6
		120 - 250	0.190	6.4	8.0

It was possible also to determine the ability of Reno mattress structures to resist deformation due to major movement of the rock fill without impairing their function as linings.

Retaining Walls

Retaining walls are designed to provide resistance against the lateral earth thrust (FIG. 9).

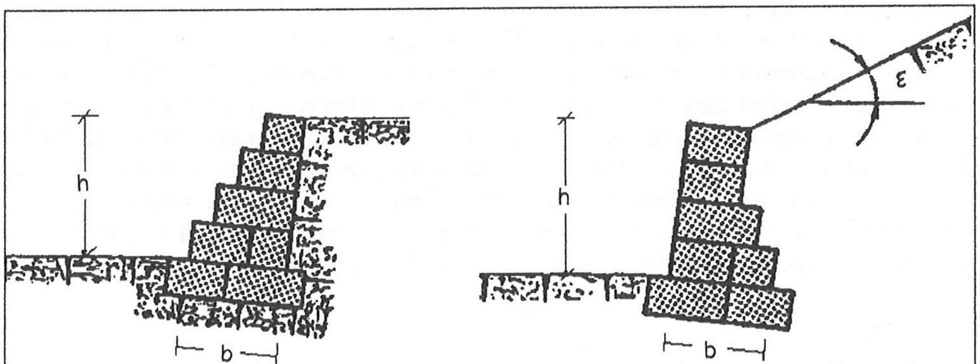


Figure 9

In cases in which the instability of slope is caused by superficial or deep landslides, possible courses of action fall into two large categories.

The first includes :

- Measures that preserve the geometry of the slope and therefore protect it from erosion, degradation etc. that tend to modify it.
- Works for stabilising slopes include gravity structures, sheet piles and diaphragm walls.

The second category of measures includes :

- Works to collect surface water from various sources and rapidly dispel it particularly in an area subjected to land slides.
- Works to collect and dispose of the water present in the soil. These consist in either installing relatively superficial drains such as trenches filled with granular materials and drainage pipes of various types, or deep draining walls in which the function of earth support is subordinate to that of intercepting soil the subsoil water that is too deep to be reached by trenching.

As mentioned, for the erosion control measures, a gabion structure due to the main characteristics of high resisting weight and high permeability can be considered an ideal solution for both category of mentioned retaining structures. A gabion wall is a gravity structure and the resistance is given from the combination of the hexagonal wire mesh and the stone filling. The performance of both components have to be known and need to meet particular requirements that are fundamental in the statical design structure.

The steel mesh from which the gabions are made must get specific properties to guarantee an adequate performance with regard to both structural strength and durability. Tests to check the mechanical properties of the mesh were carried out at "strength of material" laboratory of the Engineering Department of bologna University, the Colorado Tests Centre Inc., Denver, USA 1983. The breaking load in these tests was assumed to be that which caused the first wire to fracture.
Table-2, gives average values of tensile loads of hexagonal mesh in the direction of the weave.

Table-2 **Ultimate failure loads on hexagonal woven steel wire mesh (kg/m)**

Mesh Type	Ultimate Loads (kg/m)				
	Wire diameters (mm)				
	2.0	2.2	2.4	2.7	3.0
6 x 8	....	3500	....	4700	....
8 x 10	....	....	....	4300	5300
10 x 12	....	....	....	3500	4300

The mechanical resistance of the gabion structure have been analysed in the Structural Science Laboratory, of the University of Bologna. Three series of tests were made : simple compression, compression with lateral expansion restrained on two opposite side, and shear.
Based on the results obtained from the laboratory it was possible to extrapolate the allowable stress (σ_{am}) which is the function of the density γ_g of the gabions, and the type of rock fill. The allowable stress is :

$$\tau \leq \sigma_{am} \tan\phi^* + C_g \qquad (1)$$

where σ_{am} is the allowable normal stress shown in the table.
ϕ^* is the internal "fictious" angle of friction of the filling, deduced from the angle of friction of the soil in order to take into account the effect of the compaction of the gabion fill; ϕ^* is related to the density γ_g (t/m^3) of the filled gabions by the empirical expression :

$$\phi^* = 25\,\gamma_g - 10° \qquad (2)$$

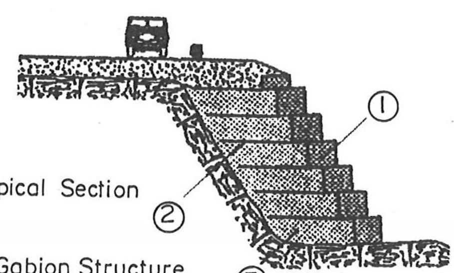
The term C_g represents the overall cohesive effect of the wire mesh on the gabion structure. The value of C_g depends on the ratio of weight of mesh to the volume of gabion structure, and it increases as the gabion depth decreases, with gabion fitted with diaphragms, and with gabion constructed of heavier mesh. It is possible to compute the representative C_g value using the empirical expression :

$$C_g = 0.03\,P_u - 0.05 \qquad (3)$$

where P_u is the weight of the metallic mesh per cubic meter of wall and C_g is expressed in kg/cm^2 .

Reinforced Earth Structures

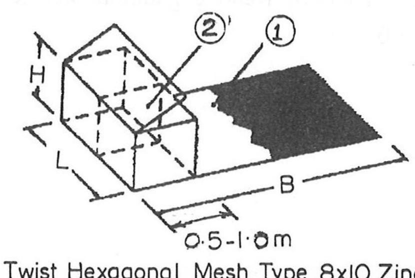
When an embankment has to be contained in several situation a reinforced soil structure can be realised (FIG. 10). The experience acquired and the wish to ensure optimum performance from the finished structure simplifying installation, have led to the development of a product in PVC coated and galvanised double-twist woven wire mesh specially produced for this application (FIG. 11).



Typical Section

1. Gabion Structure
2. Mesh Reinforcement
3. Compacted Soil

Figure 10

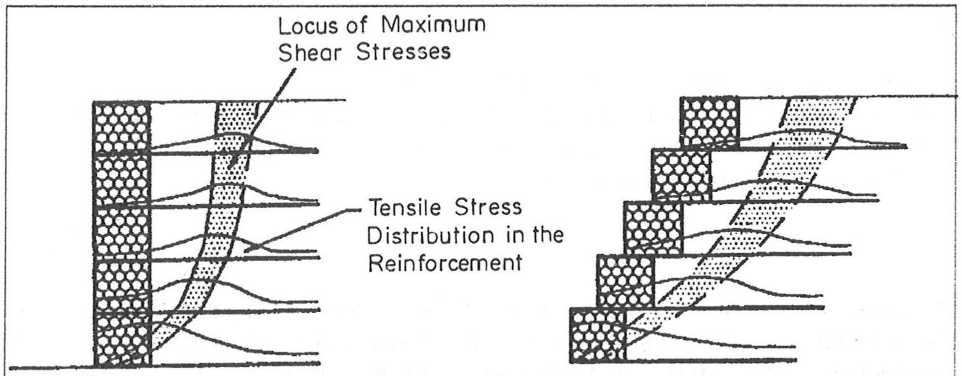


1. Double Twist Hexagonal Mesh Type 8x10 Zinc and PVC Coated Wire Dia. 2·7mm(3·7mm o/d)
2. Diaphragm made With Double Twist Hexagonal Mesh Type 8x10 Zinc Coated and PVC Coated Wire Dia.2·7 Dia.2·7mm(3·7mm o/d)

Figure 11

The main advantage of this system is based on the fact that the units are already in size and at the job site no additional cutting or connecting operations between the different component are required : this means that a great advantage is offered from the reduced installation cost.

In order to determine the tensile resistance and the anchoring capacity of the double-twist mesh in compacted soils and the overall behaviour of reinforced earth walls, a series of tests both on mesh samples and on full-scale structures were carried out in Australia, at the Australian Defence Force Academy, Canberra, and in USA within a research program of the Federal Highway Administration. From these tests it was possible to determine the anchoring and the breaking characteristics peculiar to the Maccaferri double-twist mesh. The test carried out have shown that the stress in each layer of reinforcement reaches a maximum at a point (FIG. 12) the locus of which, and the corresponding shear stress in the soil may approximate to a log spiral, with a more rounded shape, similar to a circular arc in the case of an inclined front face.



Stress Distribution in the Reinforcement

Figure 12

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