E3S Web of Conferences **368**, 02003 (2023)
GeoAfrica 2023
https://doi.org/10.1051/e3sconf/202336802003

Steel mesh geocontainers for coastal protection

Pietro Rimoldi[1*], *Marco* Vicari[2], *Paolo* Di Pietro[2]

[1]Civil Engineering Consultant, Milano, Italy
[2]Officine Maccaferri SpA, Bologna, Italy

Abstract. The paper aims to present the applications of steel mesh geocontainers for coastal protection: the various types of products are introduced, the design principles are shortly explained, and case histories illustrate important projects.

1 Introduction

Geosynthetic container, or Geocontainers, can be defined as a class of Geocomposites assembled from geosynthetics and/or steel meshes, able to contain soil and/or other loose materials, for segregating the loose particles while allowing water or other fluids to escape.

A peculiar family of geocontainers includes gabions and mattresses made up of double twisted steel meshes.

The paper aims to present the applications of steel mesh geocontainers for coastal protection: the various types of these products are introduced, the design principles are shortly explained, and case histories illustrate important projects.

2 Steel mesh geocontainers

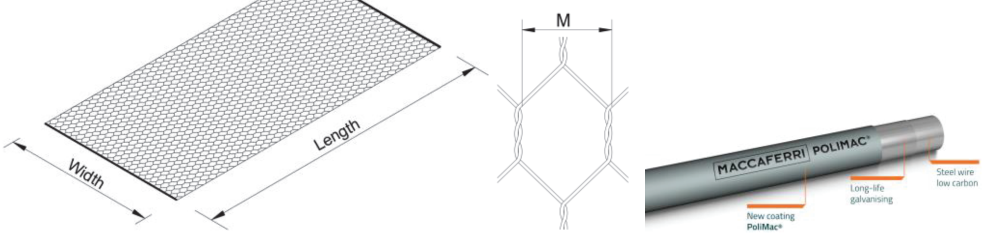
Gabions and mattresses made of double twisted steel meshes have been developed in Italy almost 130 years ago: these pioneering products were made of galvanized wire.

Steel mesh geocontainers have been continually improved over the decades, and nowadays the durability of the whole family of products has been greatly enhanced by protecting the wires with technologically durable advanced metallic and polymeric coatings; moreover, these composite products can be combined with different types of geosynthetics (geotextiles, geogrids, geomats) providing multi-functional performance.

Steel mesh geocontainers are factory manufactured by assembling hexagonal steel wire mesh panels (Fig. 1), having mechanical characteristics in accordance with EN 10223-3. The nominal aperture M of the single mesh (Fig. 1) is 80 mm for gabions and 60 mm for mattresses. The steel wire used in the manufacture of steel wire mesh panels is galvanized with an advanced metallic coating in accordance with ISO 7989-21; a high abrasion resistant polymer coating (Polimac®) is then applied to provide an extended life and additional protection for use in salt or fresh water, and in environments where the risk of corrosion is present. The Polimac® coating has a nominal thickness of 0.50 mm.

* Corresponding author: pietro.rimoldi@gmail.com

 https://doi.org/10.1051/e3sconf/202336802003



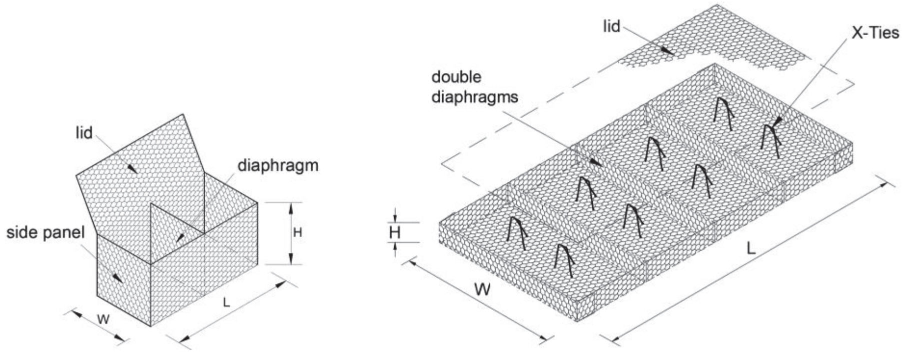
a) b) c)

Fig. 1. a) Steel wire mesh panel, b) single mesh, c) advanced metallic and Polimac® coated wire

Gabions are baskets made of hexagonal double twisted wire mesh panels, filled with stones at the project site to form flexible, permeable, monolithic structures such as retaining walls, channel linings, and weirs for erosion control projects. Gabion units are divided into cells by means of diaphragms positioned at approximately 1 m centres (Fig. 2).

Mattresses are double twisted wire mesh containers uniformly partitioned into internal cells with relatively small height in relation to other dimensions, having a small mesh opening (60 mm) than the mesh used for gabions. The base, diaphragm, front, end and sides of the units are manufactured from one continuous mesh panel. The base is folded onto itself at regular intervals to form double diaphragms, which are secured with spirals at the production facility. To secure tighter packing of the filling material, and to improve the hydraulic performance, units are supplied together with vertical ties (X-Ties) connecting the base panel to the lid and toe. Mattresses are filled with stones at the project site to form flexible and permeable, monolithic structures and they are generally used for riverbank protection and channel linings for erosion control. The original mattresses are internationally named Reno Mattresses, from their first installation along the river Reno in Italy, while the improved products are internationally called Reno Mattresses Plus.

Both gabions and mattresses are produced in compliance with the European Regulation (EU) No 305/2011 and have a CE marking in compliance with EAD 200019-00-0102.

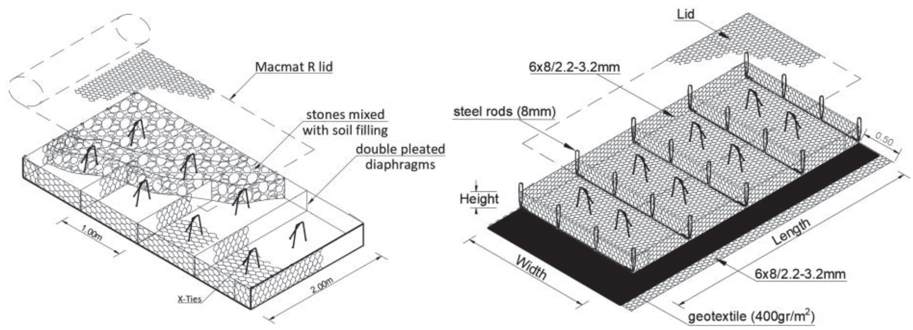


a) b)

Fig. 2. a) Gabion, b) Reno mattress Plus

Reinforced geomats are three-dimensional products composed of UV stabilized synthetic fibres directly extruded either onto a steel wire mesh or a polymeric geogrid (Fig. 3). Reinforced geomats can be combined with gabions and mattresses to enhance their multifunctional performance.

Fig. 3. Reinforced geomats with steel wire mesh (left) and polymeric geogrid (right)



a) b)

Fig. 4. a) Combo Mattress Plus, b) Renomac Plus (underwater installation)

Reinforced geomats and Reno Mattresses Plus may be combined to form the Combo Mattresses Plus (Fig. 4a), where the reinforced geomat is placed as the top lid of Mattresses Plus, to improve resistance to shear stresses and wave actions. Shall the mattress be vegetated, the top part can be filled with topsoil, which get protected against erosion by the reinforced geomat.

Reno Mattresses Plus can be designed for being installed underwater (Renomac Plus). Renomac units are equipped with a wire mesh base panel and a geotextile to prevent erosion underneath the unit (Fig. 4b), as well as side bands to allow for continuous protection between adjacent units. The side bands are 0.5 m wide and made from Polimac® coated wire mesh and a nonwoven geotextile on top. Renomac units are provided with Ω-shaped lifting rebars to allow for their lifting once the units have been properly filled. The units are assembled with stones and covered with lids at the project site prior to their underwater installation.

3 Coastal erosion and protection

Coastal erosion is an important problem throughout the world, since some degree of coastal erosion is experienced in almost all countries that have coastlines.

A variety of alternative methods, traditional and recently developed, are available to combat the coastal erosion problems. Broadly speaking, they fall under two categories:

- structural and engineering methods, that is, involving construction of coastal structures or creation of beaches
- non-structural methods.

Most non-structural methods are management tools primarily used to regulate or lessen the problems caused by erosion, rather than to prevent, halt or retard erosion.

3.1 Structural and engineering methods

Shore-line-hardening structures are commonly classified according to their intended function or use. In terms of the functional classification, nearly all of these structures fall into one of three groups: seawalls; revetments; bulkheads. All these structures can be built using steel mesh geocontainers (Fig. 5).

Seawalls are structures whose function is to protect the land and property behind them from damage by heavy wave action. They usually rely on their own weight to hold them in position and can thus serve the secondary purpose of retaining landfill behind them.

Revetments are lighter structures than seawalls, are designed to protect the land from light wave and current attack, and are most often constructed with a sloping surface facing the sea. They are usually not heavy enough to retain fill and are not suitable as docks.

The function of a bulkhead is to retain fill or prevent the land from sliding into the water. As a secondary purpose it can also protect the land from wave action.

3.2 Process-altering structures

Groins are protective structures designed to alter long-shore drift in such a way as to build or maintain a beach. They are relatively narrow in comparison with their length which may vary from less than 30 m to some hundreds of m. Groins may be partially or fully constructed of steel mesh geocontainers (Fig. 5). These materials may be used individually or in combination. The materials selected for a site will depend on availability, cost and the technical expertise required for installation.

A breakwater is a shore-protection structure that acts as a wave barrier. By blocking waves a breakwater creates a zone of reduced wave energy in its lee – a calm, safe area for ships or for development and operation of harbour facilities. By reducing wave energy, breakwaters also protect the leeward shore-line from wave erosion. Breakwaters for erosion control are smaller and depend on strategic placement relative to littoral forces to be effective. Breakwaters may be partially or fully constructed of steel mesh geocontainers (Fig. 5).

Fig. 5. Examples of revetments, groins and breakwaters built with steel mesh geocontainers

3.3 Revetment design

In coastal structures the effects of reducing water depths and coastal forms on the incoming (deep-water) waves must be considered. These factors lead to transformation of the incoming waves and eventually to wave breaking, which results in significant dissipation of energy.

Wave breaking occurs mainly due to the two criteria, depth or steepness, each limiting the maximum wave height. The breaking criterion due to water depth is normally given by a useful non-dimensional parameter called the breaker index (γ_{br}), defined as the maximum wave height to depth ratio (H/h):

- Steepness criterion: $$\frac{H}{L} \leq 0.14\, tanh\left(\frac{2\pi h}{L}\right) \quad (1)$$

- Regular waves: $\frac{H}{L} \leq 0.78$ (2)
- Irregular waves: $\frac{H}{L} \leq 0.5 \div 0.6$ (3)

General design rules for the geometrical design of the cross section will be given here.

The crest width is normally determined by the used construction methods (access on the core by trucks or crane) or by functional requirements (road/crown wall on the top). Where the width of the crest can be small, a minimum width, B_{min}, should be provided, where [1]:

$$B_{min} = (3 \div 4)\, D_{n50} \tag{4}$$

where D_{n50} is the average diameter (m) of an individual armor unit in the primary cover layer. The bottom elevation of the armour layer should be extended downslope to an elevation below minimum still-water level of at least one wave height, if the wave height is not limited by the water depth. Under depth-limited conditions the armour layer should be extended to the bottom and supported by a toe.

About the armour layers, many methods for the prediction of rock size of armour units designed for wave attack have been proposed in the last 50 years. The most commonly used is the revised Hudson formula [1], which is written as:

$$W_{50} = \frac{(w_r\, H^2)}{(K_D\, \Delta^3\, cot\alpha)} \tag{5}$$

where:

W_{50} average weight (N) of an individual armor unit in the primary cover layer
w_r unit weight (saturated surface dry) of armor unit (N/m^3)
H design wave height at the structure site (m) equal to H1/10
Δ relative buoyant density of the material, e.g. for rock is (ρr/ρw)-1
α angle of structure slope measured from horizontal in degrees
K_D stability coefficient considering all other variables. K_D values suggested for design correspond to a “no damage” condition where up to 5 % of the armour units may be displaced:
K_D 2.0 for breaking waves
K_D 4.0 for non-breaking waves

About stability against ship wave attack, for preliminary design, energy considerations indicate that ship waves of height H should be conservatively assumed to be equivalent in effect to random waves of significant height H_s, as:

$$H_S \geq 1.5\ H \tag{6}$$

The stability of random quarried rock can be substantially improved by using rock as part of a system, e.g. steel mesh geocontainers. For gabions and mattresses the hydraulic stability is based on a general empirical formula from Pylarczik’s approach [2] (Tab. 1), valid for $\xi_m < 3$ and cot $\alpha \geq 2$:

$$\frac{H_S}{\Delta D} \leq \frac{F_1\, F_2 \cos\alpha}{\xi_m^b} \tag{7}$$

The equation (7) can be simplified as:

$$D \geq \frac{H_S \cdot \xi_m^b}{2.25\, F_1 \cdot \cos\alpha \cdot \Delta} \tag{8}$$

where:

F_1 = system determined (empirical) stability upgrading factor (F_1 = 1.0 for rip-rap as a reference and $F_1 \geq 1$ for other revetment systems);
b = Exponent related to the interaction process between waves and revetment type, with $0.5 \leq b < 1$. For rough and permeable revetments such as rip-rap, b = 0.5. For various other revetments b = 0.66 is a typical value;
H_s = significant wave height (m)
α = slope angle (°)
ξ_m = surf similarity parameter = 1.25 tan(α) T_p $H_s^{-0.5}$
T_p = peak wave period
D = Specific size or thickness of protection unit (for gabions/mattresses: D = d = thickness);
Δ = Relative mass density of a system = $\left(\frac{\rho_s - \rho_w}{\rho_w}\right)$ for gabions and mattresses, where the voids are filled with water, we have $\left(\frac{\rho_s - \rho_w}{\rho_w}\right) \cdot (1 - n) \cong 1$
For $\xi_m > 3$ the size calculated at $\xi_m = 3$ can still be applied.

Table 1 - Indicative stability limits for steel mesh geocontainers [2]

Criterion	$\frac{H_s}{\Delta D} = F_1 \cdot F_2 \frac{\cos\alpha}{\xi_z^b} = F_1\, 2.25 \frac{\cos\alpha}{\xi_z^b}$			Limits	$\cot\alpha \geq 2$ $\xi_m \leq 3$	$N = 3000$ waves $P = 0.1$
Gabions	d $b \approx 0.5$	Δ mattress	2	Gabion/mattress as a unit	G+S/	$H_s < 1.15$ m (max. 2.0 m)
	D_n	Δ stone	2	Stonefill in a basket	(G)+C	$d_{min} = 1.8 D_n$

Notes: Gr = granular, G+S = geotextile on sand, G+C = geotextile on clay.

The primary requirement for a gabion or a Reno mattress Plus of given thickness "*d*" is that it will be stable as a unit.

The thickness of the mattress can be related to the stone size D_n. In most cases it is sufficient to use two layers of stones in a mattress (d = 1.8 D_n) and an upgrading factor in the range $2 < F_1 < 3$ is recommended.

The second requirement is that the dynamic movement of individual stones within the basket shall not be too high, to avoid undesirable deformation effects of the baskets and excessive stress in the wire mesh.

To avoid that excessive fine material in the basket move or migrate through the mesh opening, a different formulation for D_n shall be used, assuming an associated loading level for the individual stones to be approximately limited to F_1= 2 - 2.5 times the loading at the incipient motion condition with b ≅ 0.5.

Thus the requirement for the mattress stability may be summarised as:

$$d \geq \frac{H_s \cdot \xi_m^{0.5}}{5.625 \cdot \cos\alpha} \qquad (9)$$

In a multi-layer gabion or mattress system (more than two layers) it is preferable to use a finer stone below the top layers (i.e. up to 1/5 D_n) to create a better filter function and to reduce the hydraulic gradients at the surface of the underlying subsoil.

The stability formulation for gabions and mattresses are only valid for waves with a height up to H_s = 1.5 m, or for less frequent waves up H_s = 2.0 m.

In either case it is important that both the subsoil and the stone filling inside the gabion or mattress baskets be adequately compacted. Where the design wave height exceeds 1 m or the current exceeds 3 m/s then a fine granular sublayer (about 0.2 m thick) should be provided between the mattress or gabion and the subsoil. Elsewhere it is satisfactory to place the mattress directly onto the geotextile and compacted subsoil.

4 Case histories

In Abidjan, Ivory Coast, Africa: part of the port rehabilitation was due to the need to increase navigation capacity, and this required to build a 450 m long, 16 m wide jetty, where boats could dock the quay in 8 to 10 m deep waters. The design required a protection of the seabed along the quay wall against scour generated by boat propellers. Renomac mattresses were selected as the solution. Units were prefilled on the shore and then launched using a suitable frame (Fig. 6 left).

Sabetta Port, in Arctic zone of Russia, is a key infrastructure for the transportation of liquefied natural gas and for navigation along the Northern Sea. A protection of the quay wall was deemed necessary due to the frequent action of propellers docking the port, causing erosion of the soft soils on the foundations. Operating in the Arctic, without a developed infrastructure in a remote area, the project implementation was a real challenge. Renomac mattresses were assembled in the temperature-controlled environment of a warehouse and transported to the site by truck for their placement underwater (Fig. 6 right).

Other examples of installation of Reno mattresses at the port of Luanda, Angola, and for erosion protection of a berthing structure in Saudi Arabia, are shown in Fig. 7 left and right, respectively.

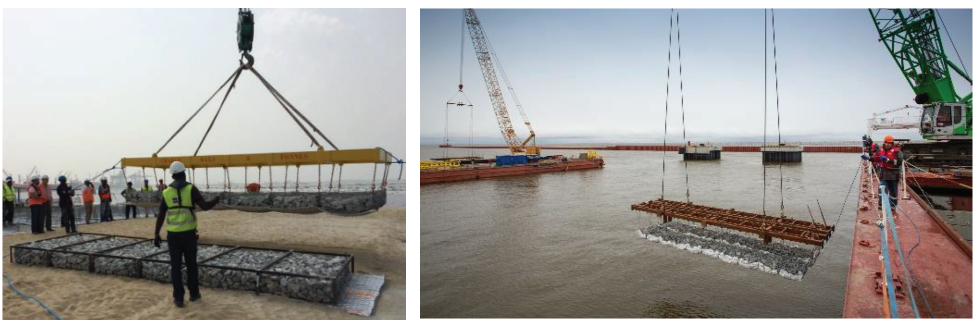


Fig. 6. Installation of prefilled Renomac mattresses for the protection of port of Abidjan, Ivory Coast (left); protection of jetty in the Sabetta port, Arctic zone of Russia (right)

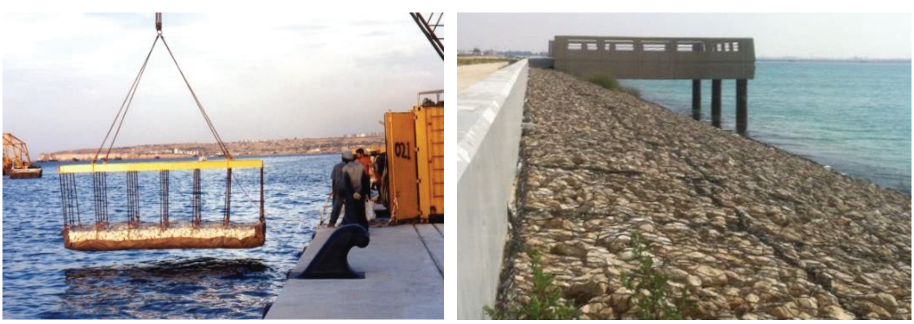


Fig. 7. Installation of Reno mattresses at the port of Luanda, Angola (left) and of Reno mattresses for erosion protection of a berthing structure in Saudi Arabia (right)

References

1. SPM, *Shore Protection Manual*, Coastal Engineering Research Center, U.S. Army Corps of Engineers (1984)
2. K.W. Pilarczyk, *Coastal Protection*, A.A. Balkema Publisher, Rotterdam, Netherlands (1990)