Conference Paper, Published Version

Vicari, Marco; Ferraiolo, Francesco

An Innovative Ballasted Geocomposite Filter for the Stabilisation of the Seabed in the Venice Lagoon: Field and Laboratory Test Results

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/100083

Vorgeschlagene Zitierweise/Suggested citation:
Vicari, Marco; Ferraiolo, Francesco (2006): An Innovative Ballasted Geocomposite Filter for the Stabilisation of the Seabed in the Venice Lagoon: Field and Laboratory Test Results. In: Verheij, H.J.; Hoffmans, Gijs J. (Hg.): Proceedings 3rd International Conference on Scour and Erosion (ICSE-3). November 1-3, 2006, Amsterdam, The Netherlands. Gouda (NL): CURNET. S. 684-690.

An Innovative Ballasted Geocomposite Filter for the Stabilisation of the Seabed in the Venice Lagoon: Field and Laboratory Test Results

Marco Vicari , Francesco Ferraiolo
Officine Maccaferri S.p.A., Bologna, Italy
francesco.ferraiolo@maccaferri.com
marco.vicari@maccaferri.com

ABSTRACT

In order to assure the complete defence of all inhabited centres of the Venice lagoon from high waters, including exceptional occurrences, the solution based upon the temporary closure of all the three Venice lagoon inlets through a line of mobile flood barriers, has eventually emerged as the only solution able to fully respond to the required objectives.

The mobile flood barriers are made up of lines of flap-gates built into the inlet canal beds: in normal tide conditions they are full of water and lie flat in their housings built into the inlet canal bed. When tides exceeding predetermined levels are forecast, an emission of compressed air empties the flap-gates of water until they emerge, thus temporarily isolating the lagoon from the sea thereby blocking the flow of the tide. The system is dimensioned to resist a difference in level of up to 2 m between the sea and the lagoon and it will thus also be effective in the event of the predicted significant rise in sea level during the next century.

Similarly to other interventions carried out in the world to regulate tidal floods (Thames, Scheldt), the selected solution for the seabed protection involves a prefabricated mattress, assembled in a plant, wound onto a floating cylinder and transported to the site where it is laid on the seabed by means of a special pontoon.

The 40 mm thick ballasted filtering mattress consists of three basic elements:

- a lower filtering polypropylene, spun-bonded, nonwoven geotextile;
- a polypropylene geomat, reinforced with double twist steel wire mesh, to entrap the ballasting gravel;
- an upper polypropylene, spun-bonded, nonwoven geotextile to contain the material, the total structure is interconnected by steel crews.

The main performance characteristics the filter has to assure are: a submerged weight capable to resist to the pressure gradients due to waves occurring between its installation and the further rockfill covering; the granular material inside the mattress must not be allowed to move during transport and installation; to maintain its tensile strength and filtering properties after the rockfill installation.

In order to verify the hydraulic characteristics of the filtering mattress, a series of laboratory and in-situ tests has been carried out both on the single components and the whole mattress, covering the following aspects: hydraulic properties before and after different energy impact tests carried on 2 soil types (silt and sand); tensile properties (MD, XD) before and after different energy impact tests; lifting tests on assembled units to verify the resistance of both longitudinal and transversal joints.

The paper presents the required characteristics, the test methodology and results which have allowed to select the materials to be eventually adopted for the installation.

I. INTRODUCTION: THE INTERVENTIONS FOR THE SAFEGUARDING OF VENICE

The objective of the legislation to safeguard Venice is to guarantee the complete defence of all built-up areas in the lagoon from high waters of all levels, including extreme events. Ever more frequently, Venice, Chioggia and other historic towns and villages in the lagoon are flooded with water and the lowest lying zones - usually the oldest and most valuable - are now flooded almost daily, particularly during the winter.

The risk of an event representing a danger to the city, such the dramatic flood of 4 November 1966, is ever greater. The so-called MOSE protection system has been designed to protect the whole Venice lagoon and includes mobile flood barriers, realised at the lagoon inlets (fig. 1) in order to isolate the lagoon from the sea in the case of tides higher than the pre-established height of 110 cm, whose frequency is approx. 12 times per year, together with complementary measures capable of abating the level of the most frequent tides. Furthermore, at the Malamocco inlet, a navigation lock is under construction to allow the transit of large ships [1], [2], [3].

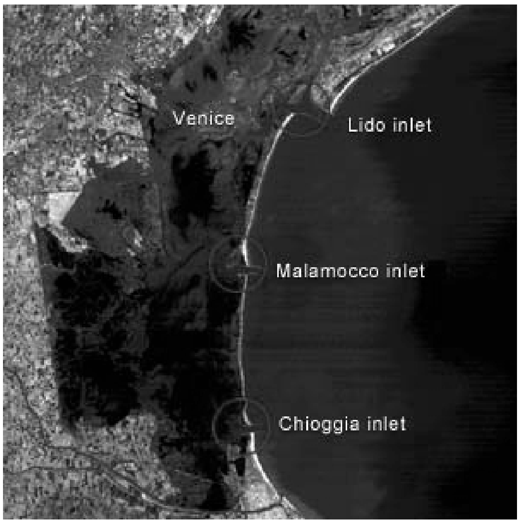

Figure 1. The Venice lagoon

The mobile flood barriers are made up of lines of flap-gates built into the inlet canal beds. They are "mobile" because in normal tide conditions they are full of water and lie flat in their housings built into the inlet canal bed (fig. 2).

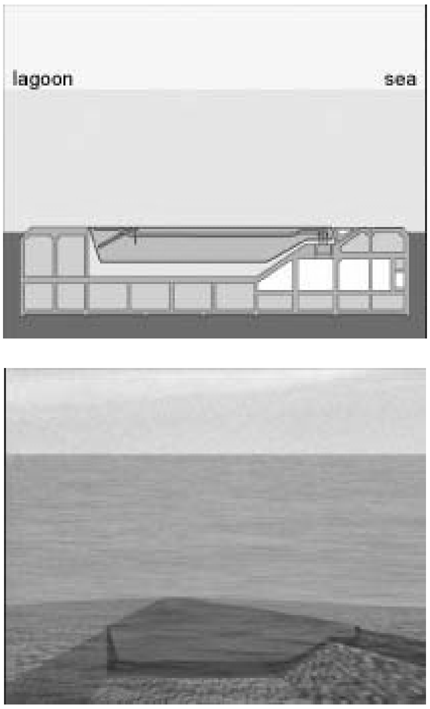

Figure 2. The floodgates at rest

When tides exceeding predetermined levels are forecast, an emission of compressed air empties the flap-gates of water until they emerge (fig. 3).

The inlets remain closed for the duration of the high water and for the time it takes to manoeuvre the flap-gates. The system is designed to resist a difference in level of up to 200 cm between the sea and the lagoon, thus being effective also in the event of the predicted significant rise in sea level during the next century.

Each oscillating buoyant floodgate consists of a box-shaped metal 'flap' attached to its housing by two hinges;,at rest they are "folded-away" into their housings buried at the bottom of the lagoon inlets. The housing consists of prefabricated concrete caissons which are located into the sill, built up of graded layers of stones installed above a mattress filter applied to protect against erosion by scour and migration.

The total amount of approx. 600.000 m^2 surface of filter mattress, to be installed on the 3 inlets within 2008, is therefore an essential part of the whole foundation structure, which is designed to prevent settlement of the caissons.

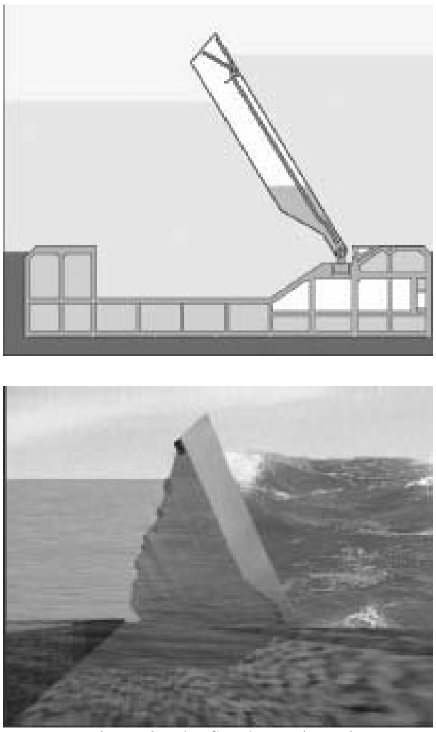

Figure 3. The floodgates in action

Similarly to other interventions carried out in the world to regulate tidal floods such as the Eastern Scheldt Project [4], [5] the selected solution for the seabed protection involves a prefabricated mattress, assembled in a plant, wound onto a floating cylinder and transported to the site where it is laid on the seabed by means of a an accurately positioned pontoon (fig. 4).

Immediately after the start of the ebb-tide the mattress is unwound from the cylinder in a direction parallel to the current at a speed of approx. 4 m per minute in the same direction as the current. At both end of the mattress ballasting beams are fitted to assure the required stability with respect to currents and waves.

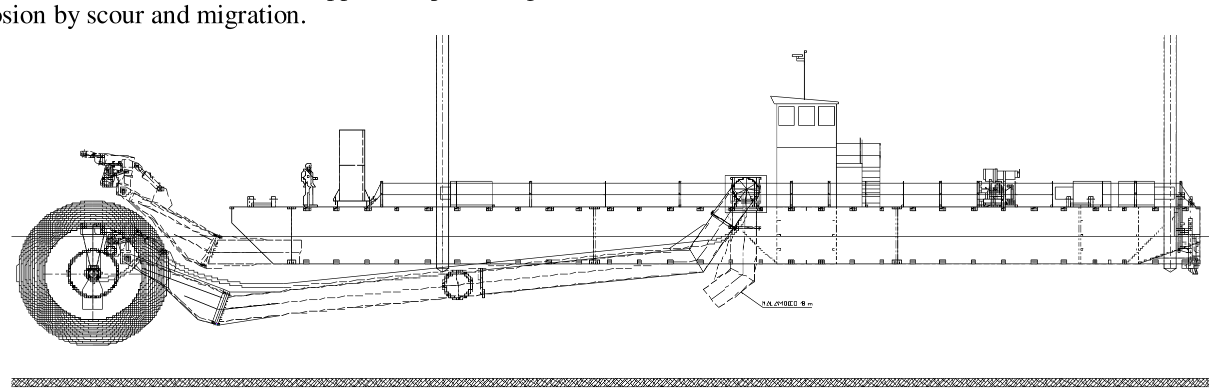

Figure 4. The pontoon for the mattress installation

II. THE FILTER MATTRESSES

The solution of the problem has requested the study, the design, the realization and the execution of performance tests of a brand new product, suitable for the bathymetric and meteomarine conditions of the Venetian site, characterized by a water depth variable between 6 and 15 m, a maximum wave height of 1.5 m and a current on the seabed up to 1.5 m/s.

For such scope, the Client has requested a solution with an optimal filtration capability, flexibility, resistance, durability with respect to the mechanical stresses imparted during the rip-rap installation.

A. *Design of the Filter Mat*

The fundamental role of the geotextile filter is to prevent the erosion of the existing soil foundation while allowing easy dissipation of hydraulic pressures and avoiding that pressures which can force up the filter should develop (uplift criterion).

The equation used to design the ballasting of the filter layer is the one used for the calculation of the unit lifting force p_w through the surface of the geotextile:

$$P_w = i\, k_s\, t_g / k_g \qquad (1)$$

where:

- i is the hydraulic gradient on the soil
- t_g is the geotextile thickness
- k_g is the geotextile permeability
- k_s is the soil permeability

In the case of the Venice inlets, the lifting force on the surface unit results:

$$p_w(\Delta H) = 8.2 \text{ daN/m}^2$$

By applying a safety factor equal to 3 we obtain a minimum design value for the ballasting in submerged conditions equal to 25 daN/m^2.

In relation to the long term performance of the geotextile, a further check has been conducted through a finite element modelling, which allows to analyze the fields of filtering motion under saturated and not saturated conditions, both as steady or as transitory.

Considering a configuration in which the rocks are sunk in the water (fig. 5) and that the filter settles as represented in fig. 6, the tension induced by the filter settlement has been calculated assuming that the under-pressure resultant ΔU, produced by the passage of the wave, is balanced by the stress generated in the geotextile N (fig. 6).

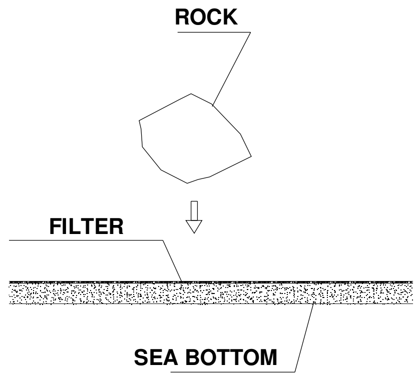

Figure 5. Rip-rap installation

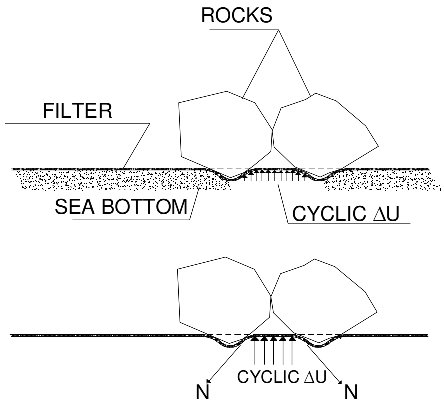

Figure 6. Filter settlement and corresponding reaction force N

B. *Composition of the filter mat*

The 40 mm thick ballasted filtering mattress (BFM) consists of the following basic elements (fig. 7):

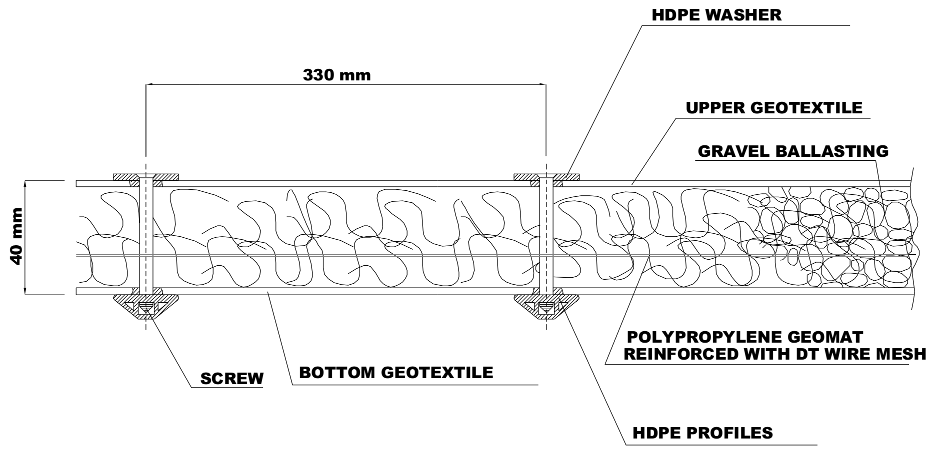

Figure 7. Cross-section of the filter mattress

- a geotextile as bottom filter;
- a central body consisting in a geomat in polypropylene filaments, internally strengthened with a double twist wire mesh;
- a ballasting of the central body with small crushed rock , grading 4-8 mm;
- a geotextile for the upper closure;
- a side band in filtering geotextile;
- a quilting with HDPE profiles and steel screws.

The total weight of the mattress in air is approx. 50 daN/m^2, such to guarantee a submerged weight not less than 25 daN/m^2. The filter mattresses are 11.20 m wide and their length is 150/200/250 m depending upon the inlet zone to be protected.

Bottom geotextile

The bottom layer, with the main function of filtering element and containment of the crushed rock, is made of a 350 g/m^2 spun-bonded, non woven, polypropylene geotextile without added resins and adhesives, resistant to the attack of bacteria and fungi, and UV rays.

Central body

It has the function to contain the ballasting material, preventing its migration and is constituted by a geomat in polypropylene filaments extruded on a double twist 6x8 wire mesh, wire diameter 2.2 mm with Zn/Al corrosion coating and external protection in PVC. The pre-assembled product (fig. 8) used for the site production is constituted by a geocomposite formed by the bottom geotextile coupled, by thermal welding, to the reinforced geomat having a nominal thickness of 40 mm.

All the geocomposite rolls are protected from rain and UV by a cover with a black PE film both during the transportation and the storage in the yard.

Ballasting inerts

The inerts, whose principal function is to ballast the mattress, is a calcareous crushed rock with apparent specific weight 14.4 kN/m^3 and a 4-8 mm granulometry, (fig. 9) which responds to both the requirements of easily penetrating inside the geomat and of avoiding segregation during the installation.

Upper geotextile

The upper geotextile, with the main function to contain the inerts, is a spun-bonded, non woven polypropylene geotextile with the same characteristics of the bottom one. To minimize the sewing operations, the rolls of the upper geotextile are 5.20 m wide.

Quilting

The mechanical connection of the upper geotextile layer to the ballasted mattress is realized by profiles in HDPE with trapezoidal section, placed transversally every 33 cm on the lower side of the mattress, with washers of the same material on the top side, and joined with metal screws (fig. 10).

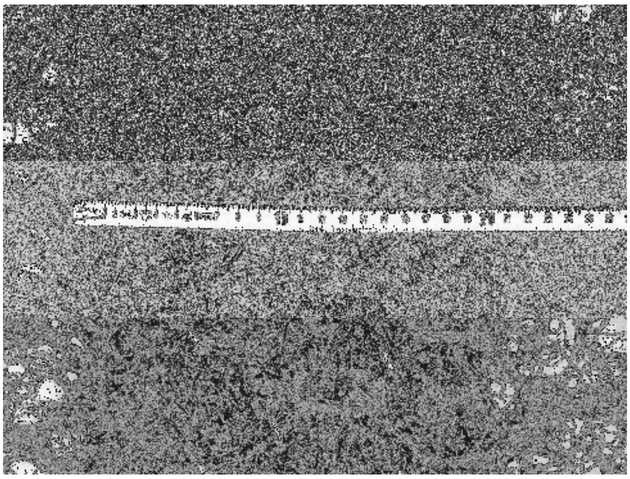

Figure 8. The PP geomat reinforced with wire mesh

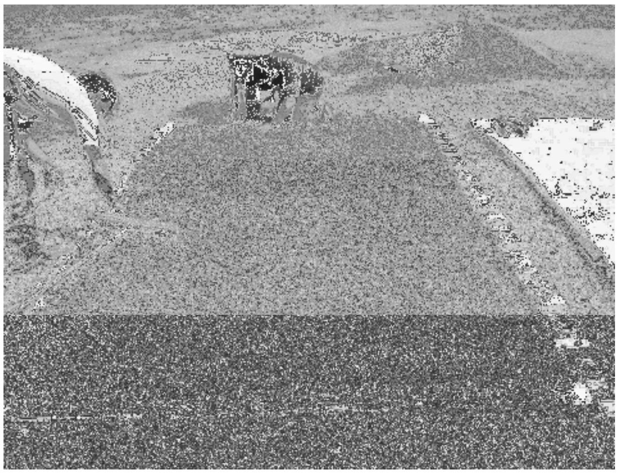

Figure 9. The mats ballasted with 4-8 mm gravel

Side band

The side band 1.20 m wide (fig. 10) is present for the whole length of the mattress and is realized with the same type of geotextile used for the bottom filter layer and its functions are:

- to guarantee the resistance to the impact due to the high tenacity of the filter geotextile;
- to supply a transversal rigidity against the lifting actions through the transverse HDPE section placed with a 33 cm spacing;
- to avoid the need of doubling the thickness of the filtering mattress at the overlaps;
- to reduce the weight of the mattress on the launching roll assembly, with equal surface, minimizing the loading problems.

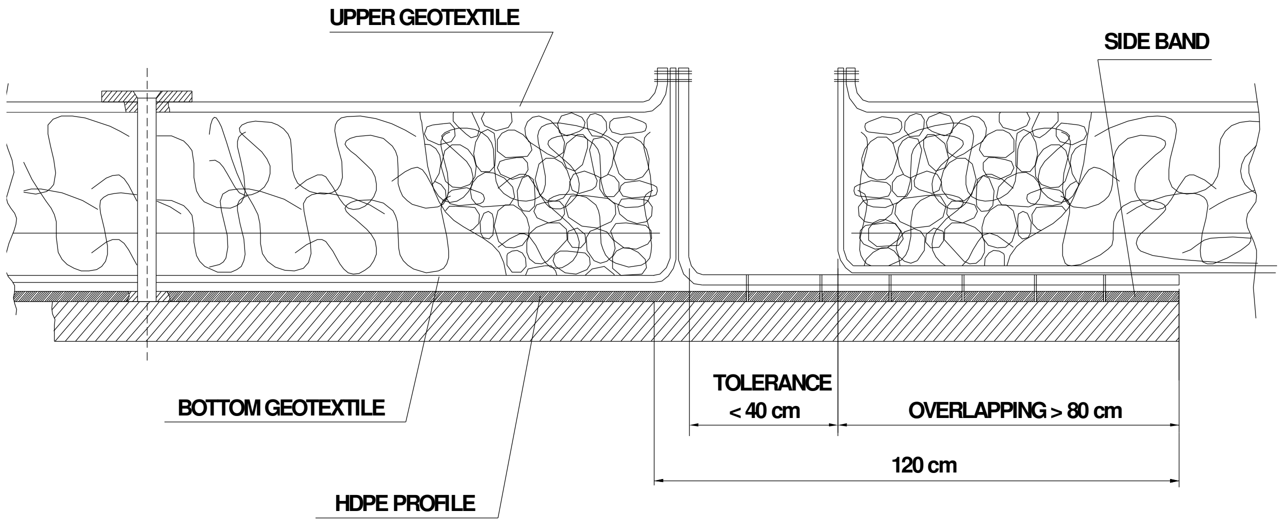

Figure 10. Overlapping of the mattress onto the side band

The band can be placed on the right or left side of the mattress, depending on the laying direction.

In order to verify the hydraulic characteristics of the filtering mattress, laboratory and in-situ tests have been carried out both on the single components and the assembled mattress, covering the following aspects: hydraulic properties before and after different energy impact tests carried on 2 soil types (silt and sand); tensile properties (MD, XD) before and after impact tests; lifting tests on assembled units to verify the resistance of both longitudinal and transversal joints.

III. REQUIRED CHARACTERISTICS OF THE FILTER MATTRESSES

The main performances the filter has to assure are:

- a submerged weight capable to resist to the pressure gradients due to waves occurring between its installation and the further rockfill covering;
- the granular material inside the mattress must not be allowed to move during transport and installation;
- to maintain its tensile strength and filtering properties after the dumped rock installation.

The specific required characteristics are shown hereafter.

A. Filter properties

To prevent the migration of the subsoil particles (sands and silts) through the filter layer and to assure the retention of the base material without the generation of unacceptable excess pore water pressure, at the dredging water depth, a maximum geotextile pore size O_{90} = 60 μm was required.

B. Resistance to uplift

The submerged weight of the filter mattress must be adequate to prevent its uplift due to the wave cyclic loads occurring after the filter installation and before its complete covering with the rock layers.

The permeability of the seabed silts and sands is approx 10^{-5}-10^{-6} m/s, while the permeability of the filter had to be at least equal to 10^{-3} m/s. Therefore the uplift pressures occurring during the installation period with frequent waves and calculated with equation 1, are in the range of 8 daN/m^2 and applying a safety factor of 3 the required submerged weight became 25 daN/m^2.

C. Resistance to impact

The application of the seabed rip-rap protection can pose a severe threat to the condition of the filter mattress, as stones, whose mean weight can is in the range 60-300 daN, are dumped from barges directly onto the mattress. Consequently, a 300 daN stone has been assumed to evaluate the impact energy in water and a test where the stones are dumped dry by modifying the dry fall height was required.

The geotextile must be elastic enough to deform and stretch along the contact surface soil rock to maintain the tensile forces far from breaking, thus assuring its filter properties. For this reason the required elongation at peak strength of the geotextile was set to 50%.

Furthermore, the main characteristics of the filter geotextile after impact had to be checked to assure their acceptability as follows:

Pore size after impact	≤ 1.05 x 60 μm
Tensile strength after impact	>70% NBL
Permeability after impact	>10^{-3} m/s.

D. Resistance to installation forces

The ballasted filter mattress is subjected, during the phases of construction, wounding and final placement onto the seabed, to forces which could cause elongations or breakages. For this reason, the reinforcement placed in between the mattress shall have a minimum tensile strength of 35 kN/m.

Furthermore, the granular material inside the mattress must not be allowed to move. To verify its stability, a lifting test of a fully assembled mattress 10x2 m, to check the possible stone movement inside its thickness, was required.

E. Durability

All the materials composing the ballasted filter mattresses have to comply with a minimum required lifetime of 100 years.

IV. TEST METHODOLOGY

In order to verify the compliance of the adopted mattress with the performance requirements, a series of laboratory and in-situ tests has been carried out, both on the single components and the mattress.

A. Hydraulic properties

To evaluate the hydraulic properties before and after energy impact tests, a semi-dry test was set up where the design stone 300 kg weight was dumped onto the mattress from various fall heights (fig. 11).

The tests were done using two soil types (silt and sand) commonly found in the inlets seabed and placed in two trenches 8x8x1 m. The impact test on the sand soil has been carried out with two different water content conditions (dry and saturated), for a total of 3 test conditions (table 1 and 2).

Figure 11-a. Impact tests on sand before impact

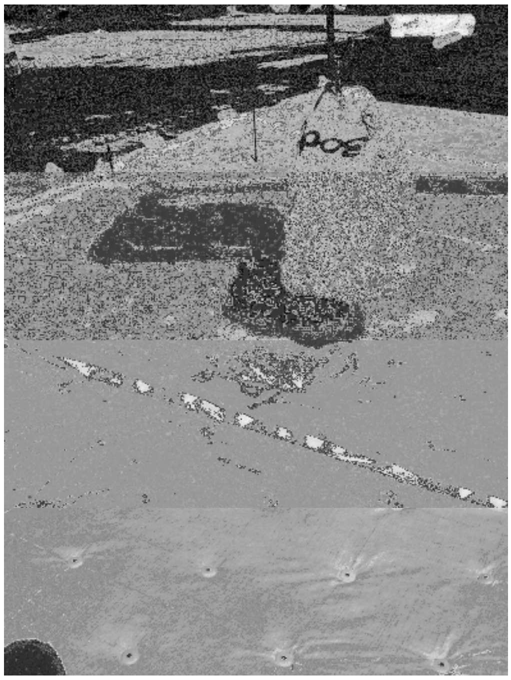

Figure 11-b. Impact tests on sand after impact

For each falling test, a thorough survey of the impact area has been registered, both in terms of superficial size and depths, to finally evaluate the elongation of the geotextile (fig. 12).

To compare the hydraulic properties after impact with those of the virgin material, 5 samples for each of the 3 test conditions have been extracted for a total of 15 samples. As per the specific test methodologies, reference has been made to the following standards: EN ISO 12956 for the pore size under hydraulic loads, EN ISO 11058 for the permeability.

TABLE 1.
Impact test: soil types

Test condition	Soil type	Water content %	D_{50} (mm)
A	Sand	5.3	0.125
B	Silt	112.4	0.040
C	Sand	100	0.125

TABLE 2.
Falling heights of the dumped 300 daN stone

Falling height (m)	Simulated weight (daN)
0.10	75
0.26	150
0.66	300
0.93	390
2.84	900

B. Submerged weight

Some BFM samples 0.8x0.8 m have been weighed by immersing them in a water tank, to check their actual submerged weight, obtaining 28 and 48 daN/m^2 respectively for the submerged and the dry conditions (fig. 14).

C. Tensile strength

For all the mattress components tensile strength tests have carried out, in compliance with EN ISO 10319; for the wire mesh, due to its specific geometry and opening size, a specific methodology has been adopted.

All the materials have proven to be well above the required values both before and after impact.

D. Lifting and shaking tests

To verify both the resistance of the reinforcement and the stability of the ballasting gravel within the mattress, when placed vertically, a sample 10x2 m has been completely lifted and subjected to shaking movements (fig. 15).

The BFM has showed no visible movements of the infill material, confirming the suitability of the chosen gravel D_{50} and the positive effect provided by the quilting system adopted to mechanically join the components.

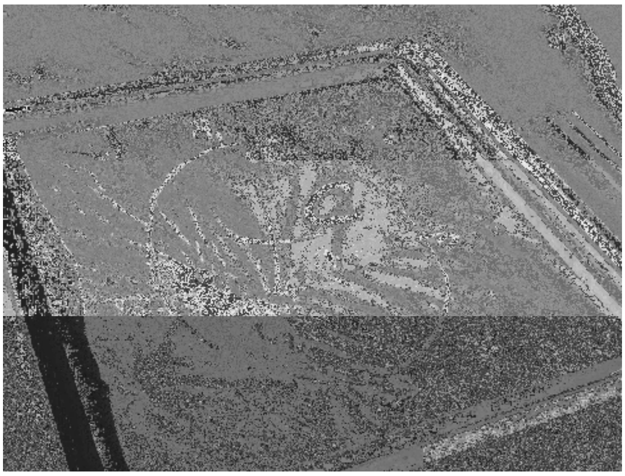

Figure 12. Measurements on the deformed area after impact

Figure 13. Extraction of samples for laboratory testing

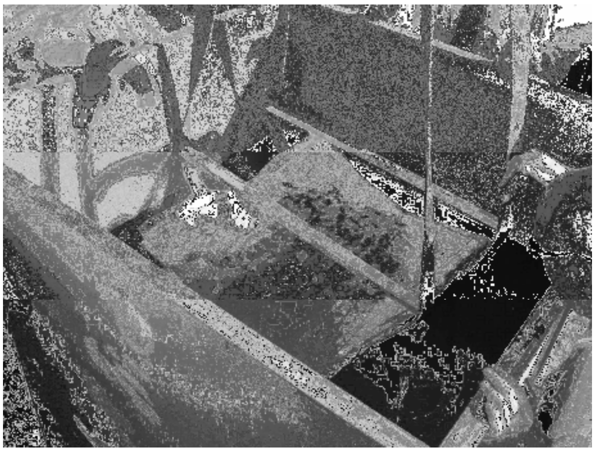

Figure 14. Determination of the BFM submerged weight

Figure 15. Lifting test on a 10x2 m sample

At the end of the test campaign on virgin and damaged samples, it has been verified that all the components comply with the requirements (table 3).

Table 3: main characteristics of the BFM components

Material	Mass per unit area	Tensile strength	Permeability	Pore size
	EN 965	EN 10319	EN 11058	EN 12956
	g/m^2	kN/m	m/s	μm
Filter GT	350	26.5 18.7 (a)	0.0012 0.0018(a)	59.5 49(a)
Geomat	650	1	-	-
Wire mesh	1490	36 (b)	-	-
Upper GT	150	10.3 8.6 (c)	0.0018	76.5

(a) = value after impact tests (900 daN) on silt

(b) = for the wire mesh a specific methodology has been used

(c) = value after impact tests (900 daN) on saturated sand