The use of a special ballasted geocomposite filter for seabed stabilisation and other coastal engineering applications

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ABSTRACT

The Modulo Sperimentale Elettromeccanico (MOSE) is a solution adopted in Venice to protect the town from high water by way of mobile flood barriers. For this system to be effective, the fine material on the sea bed requires protection against scour and erosion. A 40 mm thick ballasted filtering mattress (BFM) was designed and installed between the silty sand foundation soil and the upper rock protection layers. Due to the large sizes of these BFM units and the complex installation requirements, an innovative system utilising specially adapted pontoons, was employed to lay the units on the seabed. Based on this experience gained at Venice, smaller BFM units were designed for use as filters for foundation protection and retention of the sand nourishment material on the onshore side during rock breakwater construction, utilising traditional installation techniques, at other coastal sites. This paper describes the BFM characteristics, installation procedures used and illustrations of the actual process.

1. THE UNIQUE COASTAL ENGINEERING SOLUTION AT VENICE

In order to protect Venice from the effects of high water during tidal activity, an innovative system utilising mobile flood barriers has been designed and is under construction at the lagoon inlets. The primary purpose of this system is to separate the lagoon from the sea in the case of extraordinary high tides. Each oscillating buoyant floodgate consists of a box-shaped metal flap attached to its housing by two hinges. Whilst at rest they are folded-away into their housings which are buried at the bottom of the lagoon inlets. These mobile flood barriers under normal tide conditions are full of water and lie flat in their housings in the canal bed. When tides higher than normal are forecast, an insertion of compressed air empties the flap-gates enabling water to be emptied from the barriers, thus enabling them to raise towards the surface. The inlets will remain closed for the duration of the high water and for the time it takes to manoeuvre the flap-gates (Brotto and Gentilomo 1998, Cecconi 1997, Gentilomo and Cecconi 1997). Figure 1 below shows the flood barriers in the central portion of the illustration.

Graded layers of rockfill, installed above a 40mm thick ballasted filter mattress, are placed on both the lagoon and sea side of the barriers, in order to protect the seabed from hydrodynamic loads occurring during gate closure manoeuvring. The filter mattress is laid between the silty sand foundation soil and the rock layers in order to prevent erosion by scour and migration of the foundation soil. This filter mattress constitutes an essential part of the design for the whole seabed protection plan, which integrates a prefabricated mattress, assembled at a remote plant, wound onto a floating cylinder and then transported to the site where it is laid on the seabed by means of a special pontoon.

2. PHYSICAL CHARACTERISTICS OF THE BALLASTED FILTER MATTRESS

In the MOSE project, one of the main purposes of the ballasted filter mattress is to separate the upper graded rockfill layers from the silty sand foundation soil, and in the process to prevent erosion as a result of by scour and migration of the foundation soil. This component is shown in Figure 1 below.

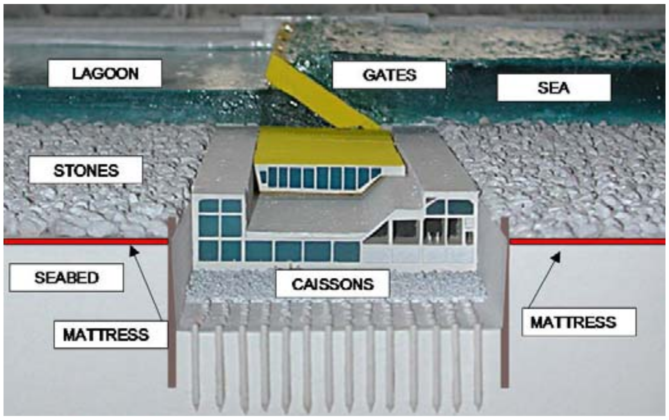

Fig. 1: The mobile flood barriers and BFM for the MOSE project

The total weight of the mattress in air is approximately 50 daN/m^2. This results in a submerged weight not less than 25 daN/m^2. The 40 mm thick ballasted filtering mattress (BFM) consists of the following basic components (see also Figures 2 and 3):

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

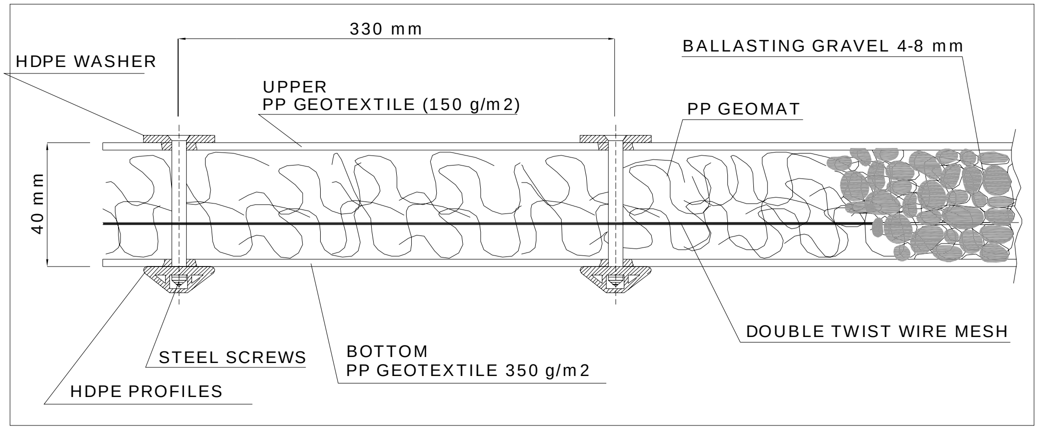

Fig 2: Section through the BFM


Fig 3: The BFM components

2.1 Design requirements of the filter mattress

The main performance requirements that the filter mattress has to assure are divided into short and long term. The short term requirements deal with manufacturing, placing and then finally, covering the mattress with rock. The BFM must assure adequate resistance to manufacturing and installation forces; stability during the process of laying the mattress on the seabed whilst contending with wave uplift forces; stability of the mattress edge which is subject to tilting forces generated by prevailing currents; resistance to the impact of the rockfill being dropped into place.

As far as long term performances is concerned, the mattress in its final configuration, once covered by the rockfill protection, must be able to assure: suitable filter properties in order to prevent settlement of the bed protection; limited sensitivity to flapping induced by wave cyclic loads; meet the durability requirements of at least 100 years in the particular environmental conditions.

2.2 Test methodology

In order to verify compliance of the specific mattress design with the performance requirements, a series of tests were carried out on each of the individual component parts as well as on the fully assembled mattress itself (Mayerle et al., 2006).

Hydraulic properties: In order to evaluate the hydraulic properties before and after energy impact tests, a semi-dry test was set up where the design stone 300 daN weight was dumped onto the mattress from various fall heights and different water content conditions (dry and saturated), for a total of 3 test conditions. For each falling test, a thorough survey of the impact area was carried out to evaluate the final elongation of the geotextile. To compare the hydraulic properties after impact with those of the virgin material, 5 samples for each of the 3 test conditions were extracted for a total of 15 samples.

Submerged weight: A select number of BFM samples of 0.8 x 0.8 m dimension were weighed during their immersion in a water tank. The results showed that values of 28 and 48 daN/m^2 respectively were obtained for the submerged and dry conditions.

Tensile strength: All of the mattress components were subjected to tensile strength tests. Tests were carried out on samples extracted from the BFM. The results showed that all materials used proved to be well above the values required before and after impact.

Lifting and shaking tests: In order to verify both the resistance of the reinforcement and the stability of the ballasting gravel within the mattress, a sample measuring 10 x 2 m was lifted up completely and subjected to shaking movements. During this test on the BFM very limited movements of the infill material were observed.

3. MANUFACTURING AND INSTALLATION OF THE VENETIAN BFM

3.1 Manufacture in a mobile factory and delivery using a shuttle pontoon

For the MOSE project in Venice, a total of 600 000 m^2 of the Ballasted Filtering Mattress was required for the 3 lagoon inlets needing protection. Manufacture took place at a mobile factory situated close to the area to be protected. The completed BFM was wound onto a floating drum at a width of 11.20 m, including a purely geotextile side band of 1,2 m, and to lengths varying from 100 up to 200 m approximately, depending upon the inlet zone to be protected (Figure 4). Following manufacture and the rolling operation onto the drum, a shuttle pontoon delivered the BFM units to the installation pontoon which was anchored in the area to be covered with the mattresses.

Figure 4: Mattresses being rolled onto the drum

3.2 Installation procedure

The installation pontoon (Figure 5) was able to transfer the drum loaded with the mattress from the shuttle pontoon. Then, the drum was lowered close to the seabed and eventually allowed to unroll at the designated position under the direct control of continuous positioning system. The drum was connected to hinges at the edges of two arms attached to the pontoon. On the inside of the drum, a series of watertight compartments were designed to be filled or emptied with water to ensure a constant vertical load on the controlling arm winches of about 10 tonne.This constant load is required to obtain a controlled sinking of the drum and maintain the correct distance from the seabed. The addition of water into the drum enables it to maintain constant weight during operation of unrolling the mattress. The installation pontoon is able to operate at a wave height lower than 0,5 m and is equipped with a positioning control system which ensures that the mattress is installed within the 40 cm tolerances required. The pontoon is equipped with six cable winches each fixed to an anchor in a specific position. The winches are controlled by an automated system which governs the positioning and movement of the pontoon.

Figure 5: The installation pontoon

3.3 Shuttle pontoon

The task of the shuttle pontoon is to transfer the drums from the production area to the installation pontoon. In the process, the shuttle pontoon removes the unloaded drum from the installation pontoon, deposits it at the production site and from there collects a newly loaded drum before returning to the installation pontoon.

Figure 6: The shuttle pontoon

3.4 Drums

The drums, having a 5 m diameter and a 13 m length (Figure 7), were designed to be loaded with up to 2500 m^2 of mattress and equipped with all the necessary devices required for: transfer from the shuttle pontoon to the installation pontoon; immersion into the sea; lowering into position; and finally unrolled. In order to assure an adequate stock of BFM units ready for installation, a total of three drums were made available for this project.


Figure 7: The drum before the BFM is wound

3.5 Working phases

3.5.1 Rolling of the BFM onto the drum

It was essential that this operation should be carefully controlled. Any mistake made on the rolling alignment would cause an amplified incorrect positioning of the unrolled units on the seabed.

3.5.2 Transporting the drums

Once the shuttle had taken the full drum from the production site, the drum had to be kept partially submerged in order to increase the stability of this mode of floating transport. Effective and prompt delivery to the installation pontoon had to be assured at all times.

3.5.3 Installation

The drum had to be filled with water so that a residual weight of approx 10 tonnes could be maintained. This filling process was controlled via a system which recorded the tension on the winches. This system also facilitated the continuous adjustment of the water quantity inside the drum and placement of the drum at the specified short distance from the seabed (Figure 8). The installation of the mattress was obtained by moving the pontoon along a straight line parallel to the current at a speed of approximately 4 meters per minute. During the BFM unrolling operation water was pumped into the drum in order to compensate for the resultant loss of weight.

Figure 8: The BFM unrolling operation

3.5.4 Positioning controls during installation

Prior to the commencement of the works on each area selected for the laying down a scan of the seabed had to be carried out for the purpose of assuring the theoretical working depth at that location. During the installation phases the pontoon's crew, in addition to the sailors, was composed of a captain and an engineer who took responsibility for the pontoon positioning. An on board positioning system was used for laying the mattress in place. This consisted of a DGPS type based on the GPS satellite signal corrected by a differential system which enabled maximum precision of the data to be reached. This system consisted of 2 satellite receivers and a high frequency aerial capable of receiving the differential signal from a land station. The receiver was connected to a navigation computer which was capable of defining the correct positioning of the satellite receiver on the ground surface.

The software controlling the system permitted a constant plot on the screen of the actual route of the pontoon and also maintained a full record of the routing data. The pontoon movement during the laying process was guided by a navigation program which controlled the operation of the servo-motors driving the 6 winches on board. This multidimensional system enabled the pontoon to follow the designed route as follows: the navigation program controlled the DGPS input data and automatically corrected the routing in the case of mismatchings from the theoretical route. The depth of the drum at which the BFM was unwound was constantly controlled by means of a visual control on the deck panel.

The effective integration of each of these systems during the laying operation assured that the mattress was positioned and installed correctly within the required 40 cm tolerance allowed.

4. NEW APPLICATIONS OF THE BFM

The experience of the Venice project has suggested the use of the BFM as an effective solution for the protection and stabilization of breakwaters foundations (Fig. 9) or the retaining of the nourishment material behind a breakwater (Fig. 10).

4.1 Breakwater at Sant'Alessio Siculo in Italy

On this project the mattress was the same as that used on the Venetian project. However, it had been manufactured in smaller sizes to allow for handling and installation using traditional marine equipment and methods. This required the provision of longitudinal loops for lifting each unit which was 2,60 m wide with a variable length up to 12 m. The mattresses were fitted with geotextile side bands of 0,60 m width in order to ensure adequate overlapping between units and to avoid exposure of the seabed (Figure 11).

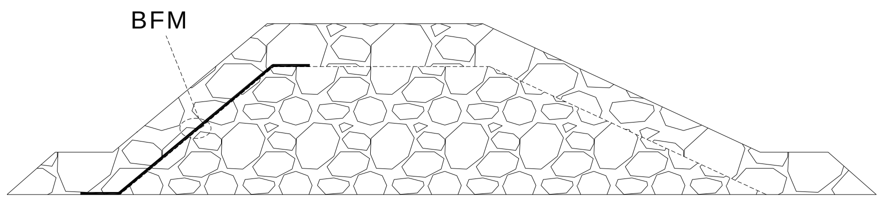

Figure 9: Breakwater filter against the sand nourishment loss with the special BFM

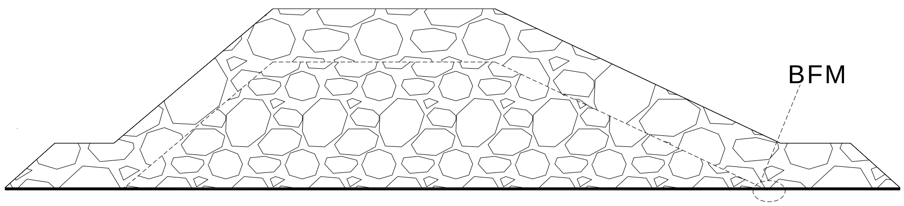

Figure 10: Breakwater foundation protection with the special BFM

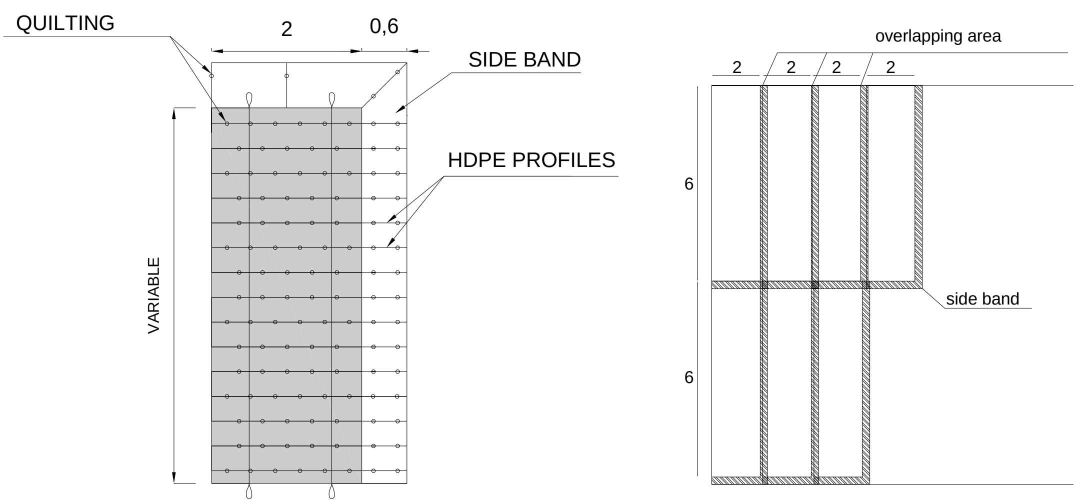

Figure 11: The special BFM units and their overlapping

4.1 The BFM application in Sant'Alessio Siculo

Sant'Alessio Siculo is a village located in North Eastern Sicily on the Ionian Sea, where problems relating to erosion of the beach frontage have been faced since 1967. Following the heavy 2003 storms and a general reduction of beach width of approximately 70 m, the attraction of tourists and in some situations even the stability of building structures adjacent to the beach, has been adversely affected.

In order to reconstruct the beach profile, the following measures have been planned: a submerged breakwater 1.3 km long, perpendicular groynes every 100 m, a revetment to protect the toe of the existing seawalls and a beach gravel nourishment.

The original breakwater design (Figure 12) has been modified to ensure the highest capacity of retention of the nourishment material, without affecting the permeability requirements of a graded rockfill. In the process, BFM units of 6 x 2.6 m for a total quantity of approximately 3,500 m^2 have been inserted in the breakwater cross-section above the 50 – 1000 kg stone layer. Then this component of the redesigned breakwater is to be covered with an upper layer consisting of a rockfill layer made up of 7 - 10 tonne units. See Figure 13.

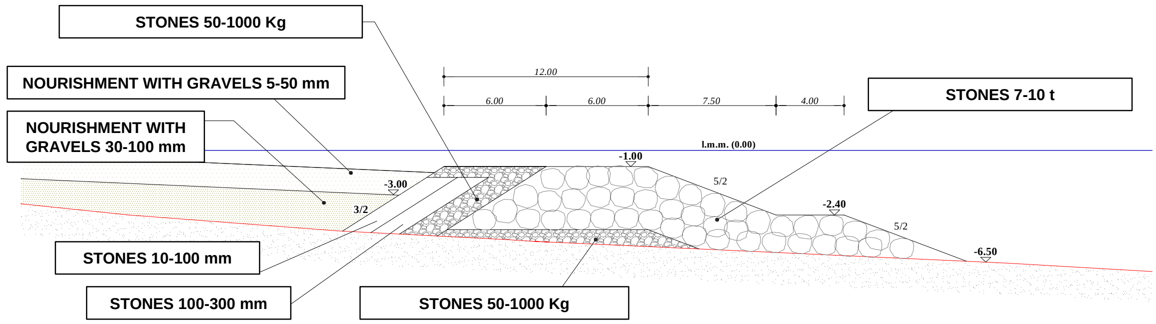

Figure 12: The original breakwater design

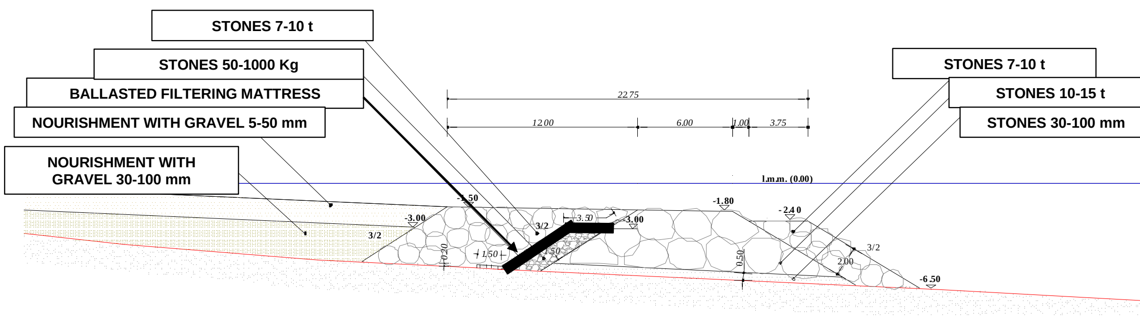

Figure 13: The adopted breakwater design with the BFM within the core

4.2 Installation methods and positioning controls

The installation is conducted by means of a pontoon on which the mattresses are stockpiled and then placed under water in position on the breakwater by the utilising a specially designed frame, which lifts the BFM units on 4 polyester loops placed along the short sides (Figures 14 and 15). The laying down operation is controlled by a team of divers who confirm the positioning and manually unhook each mattress. The two side bands built into each mattress assure adequate overlapping and a total covering of the area which must be protected.

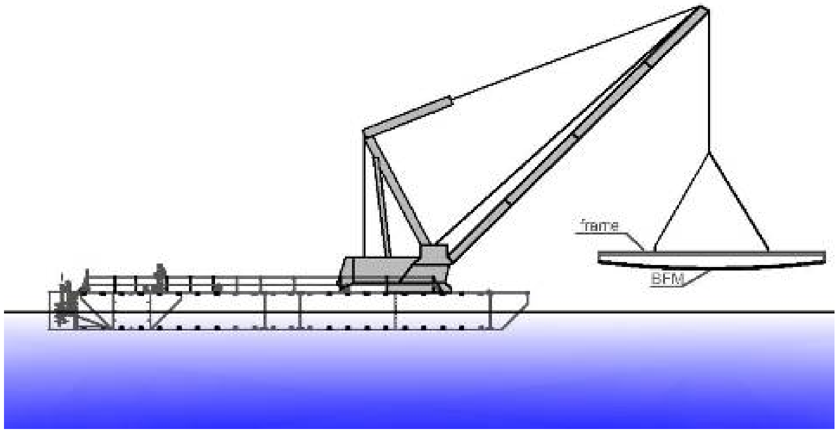

Figure 14: Scheme of the BFM installation


Figure 15: Special BFM laying down phases

5. CONCLUSIONS

The BFM experience on the Venice project, where 400 000 m^2 have been installed to date and a further 200 000 m^2 are scheduled during 2010, has made it possible to optimize the benefits achieved due to the characteristics of the filtering mattress for its effective use in other coastal works applications. This system is designed to perform better as an alternative to the traditional solutions in use for the stabilisation of breakwaters and erosion protection of the seabed.

This paper has presented an innovative application of the BFM in Sant'Alessio Siculo where the filtering mattresses have been used to assure retention of the beach nourishment material behind a submerged rockfill breakwater. Their rapid and proper installation was made possible by using traditional techniques and devices normally associated with maritime works of this nature.

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