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Laboratory and field tests on a ballasted geocomposite filter for the stabilisation of the seabed in the Venice lagoon inlets

Mayerle, G.
Magistrato alle Acque di Venezia, Venezia, Italy (mayerle@magisacque.it)

Cazzuffi, D.
CESI, Geosynthetics and Environmental Geotechnics Division, Milano, Italy (cazzuffi@cesi.it)

Greco, P.
Technital, Milano, Italy (p.greco@technital.it)

Sarti, L. & Vicari, M.
Consorzio Maccaferri Progetto Venezia, Bologna, Italy (l.sarti@impresasarti.it and marco.vicari@maccaferri.com)

Usan, G.
Ing. E. Mantovani S.p.A., Padova, Italy (usan@mantovani-group.it)

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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 (Lido, Malamocco and Chioggia) through a line of mobile flood barriers, has emerged as the only solution able to fully respond to the required objectives. Similarly to other interventions carried out in the world to regulate tidal floods (as Oosterschelde in the Netherlands and Thames barriers in UK), 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 will be laid on the seabed by means of a special pontoon. The 40 mm thick ballasted filter mattress consists of the three following components: a lower filtering polypropylene nonwoven geotextile; a polypropylene geomat, reinforced with double twist steel wire mesh, to incorporate the ballasting gravel, and an upper polypropylene nonwoven geotextile. All the mattress components are interconnected by steel crews. In order to verify the mechanical and hydraulic characteristics of the filter mattress, a series of laboratory and field tests has been carried out, both on the single components and the whole mattress. The paper presents the test methodologies and the test results useful to select the materials to be adopted for the installation, which will last from 2006 to 2008.

1 INTRODUCTION

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, Lido, Malamocco, Chioggia (Fig. 1) 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, particularly during the winter. The risk of an event representing a danger to the city, such as that of 1966, has to be avoided. The system includes mobile flood barriers, realised at the lagoon inlets in order to separate the lagoon from the sea in the case of tides higher than the pre-established height, together with complementary measures capable of abating the level of the most frequent tides and, at the Malamocco inlet, a navigation lock to allow the transit of large ships.

The mobile flood barriers are made up of lines of flap-gates built into the inlet canal beds. They are

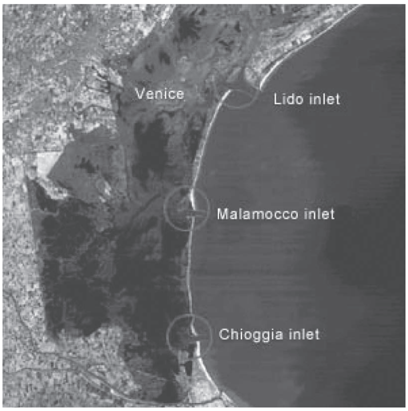

Figure 1. The Venice lagoon, with the three inlets.

"mobile" because 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. The inlets will be 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). The system is designed to resist a difference in level of up to 2 m 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. Graded layers of rockfill, installed above a filter mattress, are realised on the lagoon side and on the sea side of the barriers, in order to protect the seabed from hydrodynamic loads occurring during gates closure manoeuvrings. The filter mattress is applied between the seabed foundation soil (silty sand) and the rock layers to protect against erosion by scour and against migration of the silty sand and it will constitute an essential part of the seabed protection.

Similarly to other interventions carried out in the world to regulate tidal floods, as Oosterschelde in the Netherlands (Dorr and de Haan, 1982) and Thames barriers in UK, the selected solution for the seabed protection involves a prefabricated filter mattress, assembled in a plant, wound onto a floating cylinder and transported to the site where it will be laid on the seabed by means of a special pontoon.

2 THE FILTER MATTRESS

The 40 mm thick ballasted filter mattress (BFM) consists of four layers (Fig. 2):

- A: a lower filtering polypropylene nonwoven geotextile (mass per unit area: 350 g/m^2);
- B: a polypropylene geomat, reinforced with
- C: a double twist steel wire mesh to incorporate the ballasting gravel (Fig. 3);
- D: an upper polypropylene nonwoven geotextile (mass per unit area 150 g/m^2).

All the components are interconnected by steel crews every 330 mm.

Figure 3. The filter mattress ballasted with the 4-8 mm gravel, together with a detail of the PP geomat reinforced with the wire mesh.

The main performance requirements the filter mattress has to assure are:

- a reliable filter against migration of silty sand;
- a submerged weight capable to resist to the pressure gradients due to waves occurring between its installation and the further rockfill covering;
- the ballasting gravel inside the mattress must not move during transport and installation;
- to maintain its tensile strength and filtering properties after the dumped rock installation.

In order to verify the mechanical and hydraulic characteristics of the filter mattress, a series of laboratory and field tests (Cazzuffi and Villa, 2005) 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 two different foundation soil types (silt and sand); tensile strength and strain (MD, CMD) before and after different energy impact tests; lifting tests on assembled units, to verify the resistance of both longitudinal and transversal joints.

3 REQUIRED CHARACTERISTICS OF THE FILTER MATTRESS

The BFM has been designed to comply with the requirements hereafter specified.

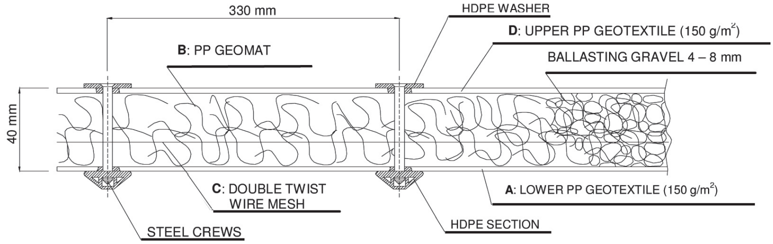

Figure 2. Cross-section of the filter mattress.

Table 1. Main characteristics of the BFM components, as measured in the laboratory tests.

Layer	Mass per unit area EN ISO 9864 g/m^2	MD tensile strength EN ISO 10319* kN/m	Permeability EN ISO 11058 m/s	Pore size EN ISO 12956 μm
A	350	26.5	1.2 x 10^{-3}	59.5
B	650	1.8	n.r.	n.r.
C	1490	36.2	n.r.	n.r.
D	150	10.3	1.8×10^{-3}	76.5

n.r.: not relevant
* for the wire mesh a specific methodology has been used

3.1 *Filter properties*

To prevent the migration of the subsoil particles (silty sand) 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, maximum geotextile pore size O_{90} = 60 μm was required.

3.2 *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 foundation soil is approx. 10^{-5}-10^{-6} m/s, while the permeability of the filter had to be at least equal to 1×10^{-3} m/s. Therefore the uplift pressures occurring during the installation period, with frequent waves, are in the range of 8 kg/m^2 and applying a safety factor of 3 the required submerged weight become 25 kg/m^2.

3.3 *Resistance to impact*

The application of the seabed rip-rap protection can pose a severe threat to the condition of the filter mattress, as rockfill, whose weight is in the range 60-300 kg, is dumped from barges directly onto the mattress. Consequently, a 300 kg rockfill has been assumed to evaluate the impact energy in water and a test, where the rockfill is 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 filtering geotextile after impact, had to be checked to assure their acceptability as follows:

- pore size after impact ≤ 1.05 Pore size on the virgin material;
- MD tensile strength after impact >70% MD tensile strength on the virgin geotextile;
- permeability after impact >1×10^{-3} m/s.

3.4 *Resistance to installation forces*

The ballasted filter mattress is subjected, during the various phases of construction, wounding and final placement onto the seabed, to important mechanical forces: therefore, according to design calculations, the metallic reinforcement placed in between the mattress shall have a tensile strength of at least 35 kN/m. Furthermore, the ballasting gravel inside the mattress must not be allowed to move; to verify its stability, a series of lifting tests on the mattress to check the possible gravel movement inside its thickness was performed.

4 TEST METHODOLOGIES

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

4.1 *Hydraulic properties*

To evaluate the mechanical and hydraulic properties before and after energy impact tests, a semi-dry test was set up where the design rockfill 300 kg mass was dumped onto the mattress from various fall heights (Fig. 4). The tests were done using two soil types (silt and sand) as foundation layer commonly found in the inlets seabed and placed in two trenches 8 m × 8 m × 1 m. The impact test with the sandy soil has been carried out with two different water content conditions (dry and fully saturated, i.e. submerged), for a total of three test soil types (Tables 2 and 3).

Figure 4. Impact tests on the filter mattress placed on the sandy foundation soil in dry conditions (on the left) and in submerged conditions (on the right).

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

To compare the hydraulic properties after impact with those of the virgin material, 5 samples for each of the three test conditions have been extracted for a

Table 2. Impact test: different types of the foundation soils.

Soil type	Water content (%)	d_{50} (mm)
Sand (dry)	5.3	0.125
Sand (submerged)	100.0	0.125
Silt	12.4	0.040

Table 3. Falling heights of the dumped 300 kg rockfill.

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

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 and EN ISO 11058 for the permeability.

4.2 *Submerged weight*

Some BFM samples 0.8 m × 0.8 m have been weighed by immersing them in a water tank, to check their actual submerged weight, obtaining 28 kg/m^2 and 48 kg/m^2 respectively for the submerged and the dry conditions (Fig. 5).

Figure 5. Determination of the BFM submerged weight.

4.3 *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 of 10 m × 2 m has been completely lifted and subjected to shaking movements (Fig. 6). The BFM has showed no visible movements of the infill material, confirming the suitability of the chosen gravel and the positive effect provided by the pinning system, adopted to mechanically join the components.

Figure 6. Lifting test on a 10 m × 2 m sample.

5 CONCLUSIONS

The results of the laboratory and field test campaign have shown the full conformity of the designed filter mattress with the technical specifications.

The first units have been installed in May 2006 by means of the special pontoon (Fig. 7) and the installation works on the total surface of 600.000 m^2 will continue up to 2008.

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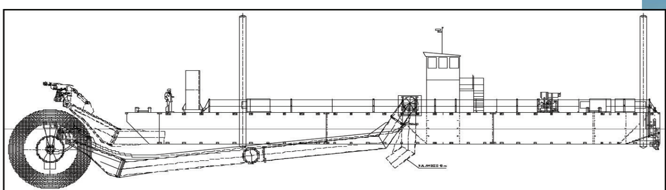

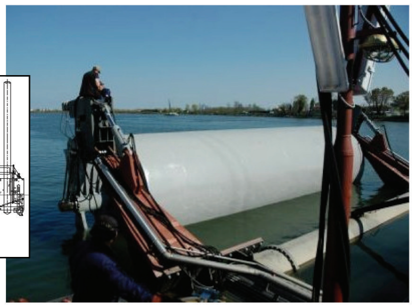

Figure 7. The pontoon for the filter mattress installation in the Venice lagoon.