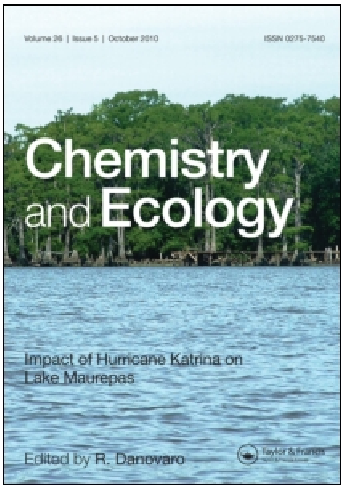

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ARTIFICIAL NOURISHMENT OF THE VESIMA BEACH (GENOA): SEDIMENTOLOGICAL AND MORPHOLOGICAL RESULTS

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In Italy artificial nourishment has been considered as a suitable tool for dealing with the problem of coastal erosion for some years, following successful experimental programmes. In this article, we present some of the results of a case study of a nourishment programme on the beach of Vesima (Genoa). This programme was undertaken to limit the coastal erosion and increase the use of the beach and the littoral near very urbanized areas where there are extensive recreational activities such as sun bathing, swimming, fishing and vacationing. In particular, we studied the evolution of the morphological profiles of the surficial beach and the variations in the sedimentological and morphometric characteristics before and after the nourishment. These profiles represent two different seasonal settings of the beach, during calm (summer) and stormy (winter) weather. The grain size and morphometry of the sediments and the morphological profile of the beach were studied in four seasonal surveys. The elaboration of the data allowed us to correlate the nourishment and the seasonal accumulation of sediments. These studies have been extremely important for our understanding of the movement of sediments and changes in the morphology of the beach due to dynamic nearshore processes and variations to the budget of the littoral sediments. After the nourishment work in March 2000, the width of the dry beach was stable; the estimate of nourishment material (20,000 m^3) and of the material left on the dry beach after 2 years (4800 m^3) indicates that a remarkable quantity of sediment was taken from the shoreface to form the nearshore zone.

Keywords: Coastal erosion; Beach development; Pebbles; Morphometry

1 INTRODUCTION

The beach of Vesima is very important to the city of Genoa, because it is the first stretch of the coast to the west of the city with ample facilities for tourists (Cavallo and Ivaldi, 2000). In fact, the neighbouring beaches are heavily influenced by their closeness to harbours and intense urbanization, which have restricted their use and caused their degradation (Cavallo, 1995). The anthropic development of the coast often interferes with natural variability in that once a house or road is built there is a natural human desire to maintain the property in the face of the natural processes of shoreline erosion (Komar, 1998; Short, 1999).

The beach of Vesima was indicated, in a case study of Liguria, as a suitable site for a requalification of the coast, to maintain the beach that is one of our most important natural resources. The preservation of even more intensely utilized beaches and the protection of coastal properties for an increasing population requires an understanding of nearshore

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processes, such as the movement of beach sediment, and their impact on beach morphology. This study should provide morphological and sedimentological data useful for re-establishing lost beaches and restoring those that still exist but are under threat.

In this article, we present some of the results of our experimental study of a nourishment programme begun on the beach of Vesima in March 2000. In this study we particularly investigated the various properties of the sediments, such as the grain size distribution, including size variations across and along the surficial beach, the degree of roundness and the shapes of sediment grains, in a monitoring program that lasted 2 years (2000–2002).

1.1 Description of the Area and Historical Evolution

The western littoral of Genoa is characterized by a 6-km long coastline with a heterogeneous morphological face (cliff 60%, beach 40%) with sandy–gravely pocket beaches between cliffs. Vesima is one of these beaches, with a length of 400 m and a width of about 20 m, bounded by a riprap revetment to the west, protecting the coast road, and a recent groyne to the east, to reduce west–east littoral drift (Corradi *et al.*, 2000).

The available data reveal that the shore is characterized by sandy–gravely sediments with a slope between 4 and 13% and is fed by a littoral drift from west to east and by weak fluvial contributions from the following minor watercourses: the Vesima, Agugia and Lupara (Provincia di Genova, 2002; Piccioni, 2003).

For some decades, the beach has been subject to a strong erosive trend. The evolution of the coastline, analogous to that of other coastal zones of Liguria, shows a close relationship between human activities and erosion. The construction of a coastal road, the main railway line, and some breakwaters, to protect fragile coastal areas, has changed the coastal dynamics and the equilibrium of this stretch of the coast (Corradi *et al.*, 1994). In fact, from 1800 to 1960, there was increasing erosion along the entire shoreline, due to the quarrying of sandy sediments from the rivers and the beaches. This process culminated in the 1950s and 1960s with the additional impact of demand for beachside housing and holiday structures.

On the contrary, in the 1970s there was a period of temporary and limited progradation of the beach due to the beginning of new dumping, which was carried out for the building of a new railway and a motorway (Corradi *et al.*, 1994). During the 1980s and 1990s, the beach showed a new and greater erosional trend, essentially because of reduced contributions made by the local watercourses and littoral drift. The present coastal situation, already highlighted in *The Atlas of the Italian Beaches* (Piccazzo *et al.*, 1990), is one in which certain areas of the beach are in retreat and the sedimentary budget is balanced only through intervention.

In March 2000, the Ligurian regional authorities carried out a nourishment program on the beach of Vesima, depositing 20,000 m^3 of sediment from the Cerusa Torrent. This nourishment was planned using selected sediments that could be monitored to verify the morpho-sedimentary dynamic of the beach and the durability of the intervention. Generally, the material of the nourishment was characterized by sandy gravel, as in other nourishment case studies in Italy (Pacini *et al.*, 1999; Pranzini, 1999).

1.2 Wind/Wave Climate

The offshore wind/wave climate of the study area was carried out by KNMI (Koninklijk Nederlands Meteorologisch Instituut), which made about 17,000 observations of wind and wave motion between 1986 and 1999. The dominant wind, on an annual basis, comes mainly from the direction 240° N, with a frequency of 14.5% and an average velocity of about

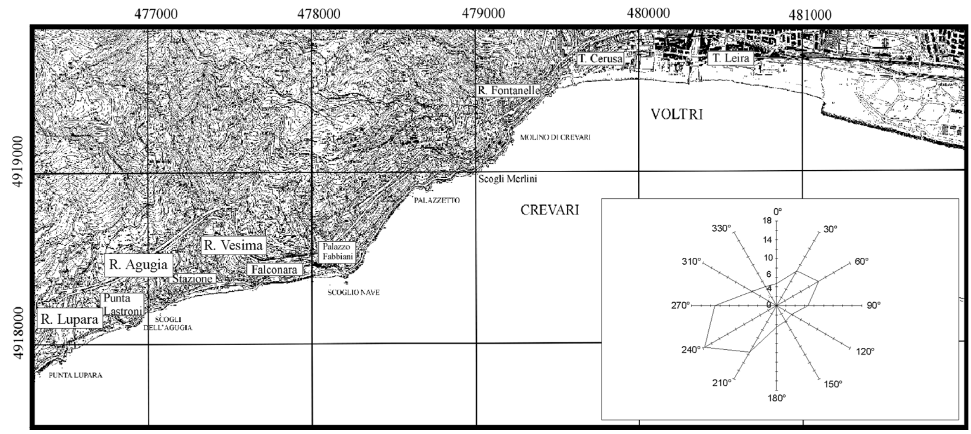

FIGURE 1 Map showing the area studied and the frequency diagram of the wave motion (KNMI, 1986/1999).

13 knots. The winds from the northeast sectors are also quite important, especially those between 30 and 60° N, whose frequency is close to 10%.

The frequency of the wave motion shows clear analogies with the data on the wind. The dominant sea comes from the direction 240° N, with a frequency of 17.6% and an average height of 1.4 m (Fig. 1).

The prevailing winds from the south have important effects on the coastal dynamic as they present the greatest geographical fetches: about 485 n.m. for the southwestern sector and 120 n.m. for the southeastern (Papa, 1992; Gamboni, 2000).

2 MATERIALS AND METHODS

The sedimentological and morphological data were collected from the beach at Vesima (Figs 2–5) during six surveys from February 2000 to June 2002 and allowed us to delineate

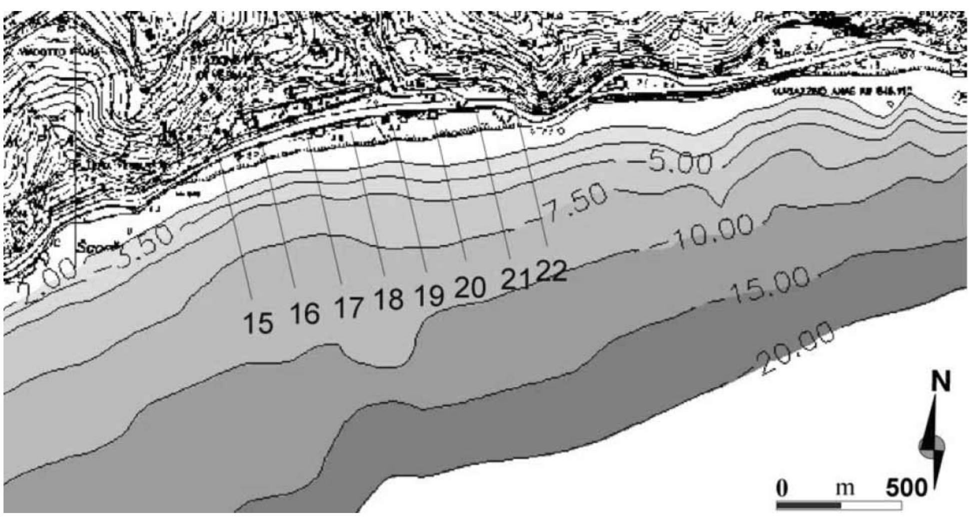

FIGURE 2 Sites of beach profiles and bathymetry map (Corradi *et al.*, 2000, modified).

FIGURE 3 View of the beach of Vesima looking eastwards (in February 2000) before the nourishment.

the characteristics of the shore evolution induced by storms with high recurrence time. In particular, eight beach profiles (from 15 to 22, Fig. 2) were surveyed from the dry beach down to the depth of the trough (mean depth 0.5 m), with suitable timing, during data collection over the 3 years, to evaluate seasonal changes and the contribution of the nourishment work. During this period beach sediment samples (in total 455) were collected from the storm berm, the swash zone and the trough and grain size analyses and statistical measurements were made for each ones.

Morphometric measurements were carried out on pebbles collected along only two beach profiles (17 and 21). In particular, the sampling of 120 pebbles with varying length from 40 to 60 mm was carried out in June 2000, 2001, 2002 and February 2001 and 2002, with two samplings for every cross-section near the dumping site. We analyzed the most important parameters and indices (Cailleux and Tricart, 1959) to determine the shape of each pebble for the further evaluation of the indices for the determination of shape elaboration (Bluck, 1967;

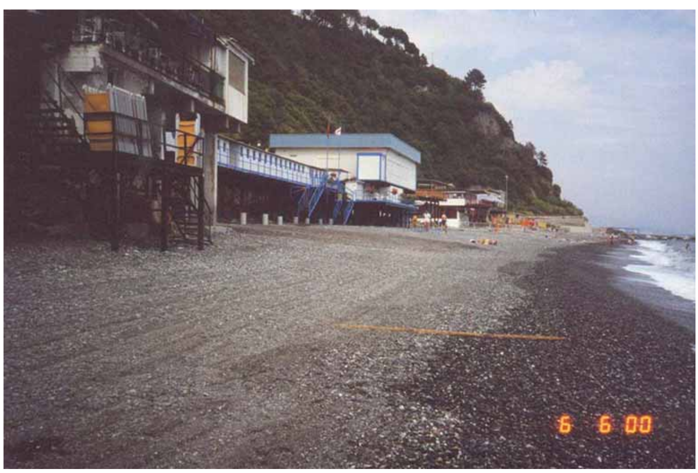

FIGURE 4 View of the beach looking eastwards (in June 2000): 3 months after the nourishment.

FIGURE 5 View of the beach looking westwards (in June 2002): 2 years after the nourishment.

Cortemiglia, 1989, 1992a, b). We also defined the shape of every pebble using Rosfelder's classification (1961).

3 RESULTS AND DISCUSSION

The twice-yearly collection of on-site morphological survey data revealed a general profile variation showing the sloping beach face, the berm and the trough. By comparison with the morphological cross-sections of the backshore, it is possible to note that, after the nourishment of March 2000, the beach showed a general progradation (Fig. 6).

In particular, in February 2001, the western sector showed a marked progradation, after the first sea-storm from the southeast, which redistributed the deposited material along the beach.

However, it was possible to observe a loss of material in the eastern sector, due to littoral drift, after the progradation which followed the nourishment (in June 2000). The profiles

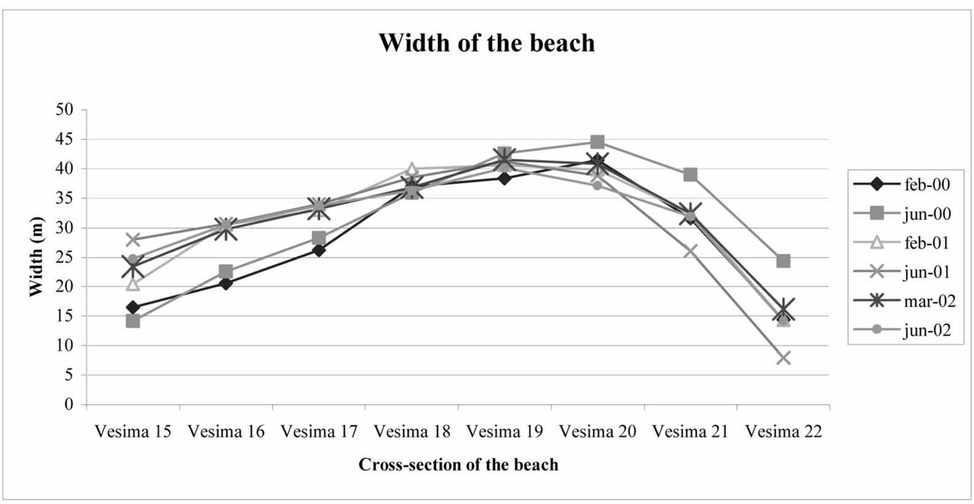

FIGURE 6 Variation in the width of the beach of Vesima (February 2000–June 2002).

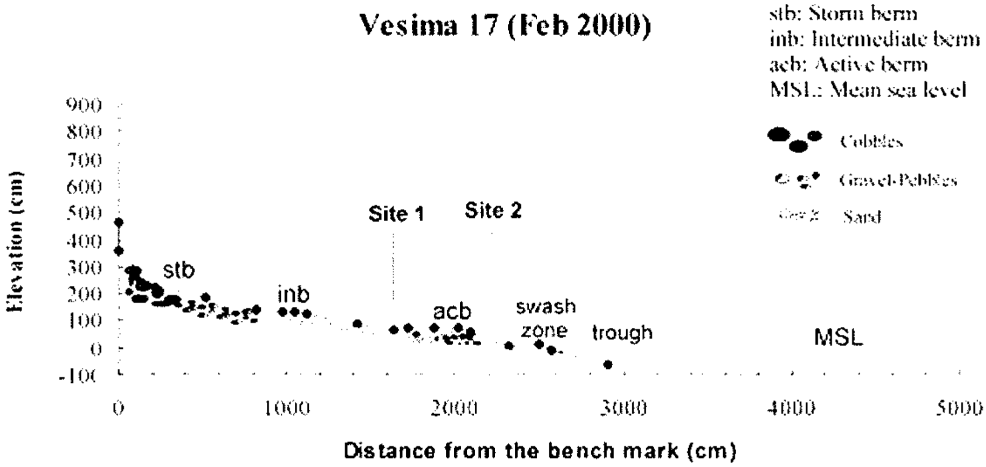

FIGURE 7 Morphological and textural characteristics of profile 17 (in February 2000) and the morphometrical sediment sample sites (site 1 and 2).

acquired after the nourishment work had unstable profiles in comparison to the profiles obtained after a major winter sea-storm. In fact, some factors that control the morphology profile (Fig. 7), such as the sediment grain size, were already determining the beach-face slope and wave conditions. In response to the increasing energy level there was a systematic increase in grain size and in the eastern beach slope (Tab. I).

The results of the sedimentological and morphological study showed that the beach slope was characterized by a general decrease after the nourishment work. In fact, only profiles 18, 20 and 22 showed an increasing trend, probably caused by the prevailing sea-storms from the southeastern sector, its closeness to the dumping site and the grain size sediments in this zone. In particular, the sea-storms did not generate strong rip currents near the eastern groyne boundary of the beach. In general, the beach of Vesima was characterized by sandy–gravely sediments with pebbles or cobbles in high-energy morphologies such as the berm.

The sediment samples collected from the swash zone revealed moderate sorting and negative skewness. This skewness was caused by the removal of fine sediments from this zone and their reworking by wave motion.

The morphometric analysis was carried out on pebbles sampled near the nourishment site, to verify the characteristics of the nourishment material and to check its selection

TABLE I Beach-face slope of the beach of Vesima.

	Beach-face slope (%)					
	February 2000	*June 2000*	*February 2001*	*June 2001*	*March 2002*	*June 2002*
Vesima 15	11.5	10.7	8	7	6.8	6.4
Vesima 16	10.1	8.9	6.5	8.1	6.3	6.5
Vesima 17	6.3	8.3	5.9	7.1	6.5	6.8
Vesima 18	2.4	3.3	3	4.6	4.7	5.4
Vesima 19	5	4.6	5.2	5.7	5.2	5.4
Vesima 20	4.8	3.6	6.9	6.2	5.2	5.8
Vesima 21	6	4.9	5.8	8.7	6.6	6.6
Vesima 22	13.9	8.1	12.2	8.7	17.6	19.1

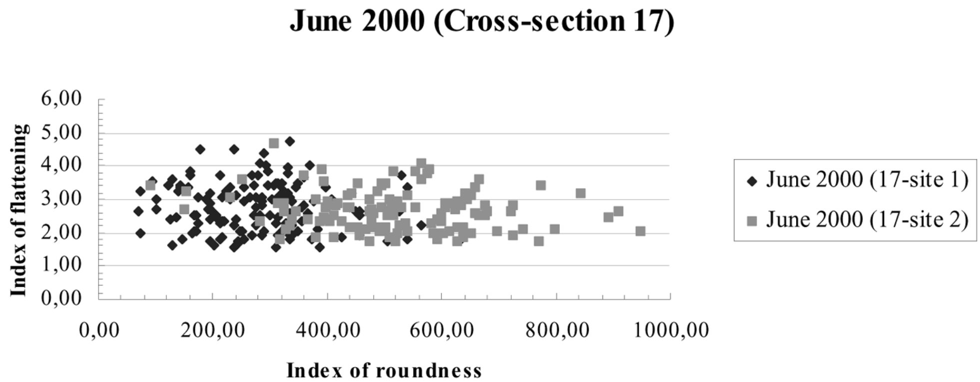

FIGURE 8 Diagram of index of roundness *vs*. index of flattening – 2 months after the nourishment.

after elaboration by wave motion for 2 yr. Using Rosfelder's diagram (1961), it was possible to obtain useful indications on the stablest shapes in the dynamic stretch of the backshore.

From June 2000 to June 2002, the river pebbles used for the nourishment were selected by wave motion and the ellipsoidal shape proved to be the stablest (Figs. 8–10). In fact, the morphometric measurements of all the pebbles sampled in each profile showed that flat and lamellar shapes prevailed during the summer surveys and elongated pebbles during the winter surveys.

The calculation of areal variations indicated an increase of the surface from a first value of about 5260 m^2 (in February 2000) to a value of 11,695 m^2 after the nourishment (in June 2000). In June 2002, the area was even larger (12,350 m^2). The greatest increase was observable along the western sector, while the variations were limited in the eastern part (Figs. 11 and 12).

The comparison of the survey made before the nourishment and that carried out in June 2001 showed a positive volume variation of about 4800 m^3 in the backshore and in the swash-zone while the comparison of the bathymetric data showed an increase of about 14,000 m^3. The following surveys, during the monitoring period, indicated a generally stable beach favoured by the wave-wind climate opposite to the eastward longshore transport; in particular the backshore and the swashzone is characterized by a negative variation in winter and an increase in summer.

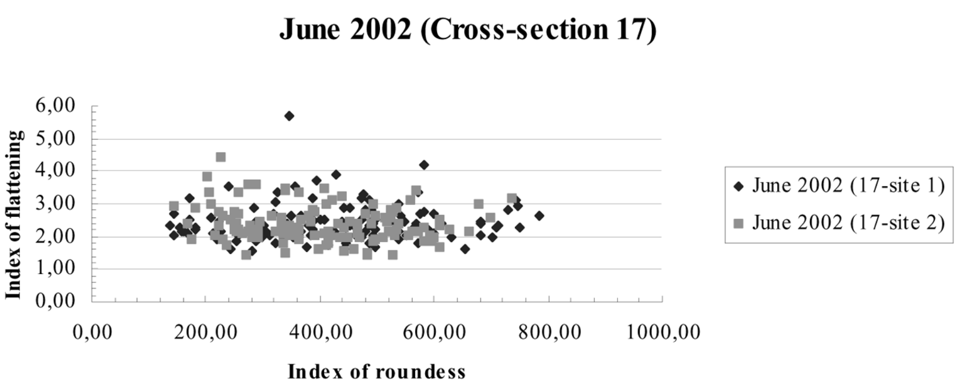

FIGURE 9 Diagram of index of roundness *vs*. index of flattening – 26 months after the nourishment.

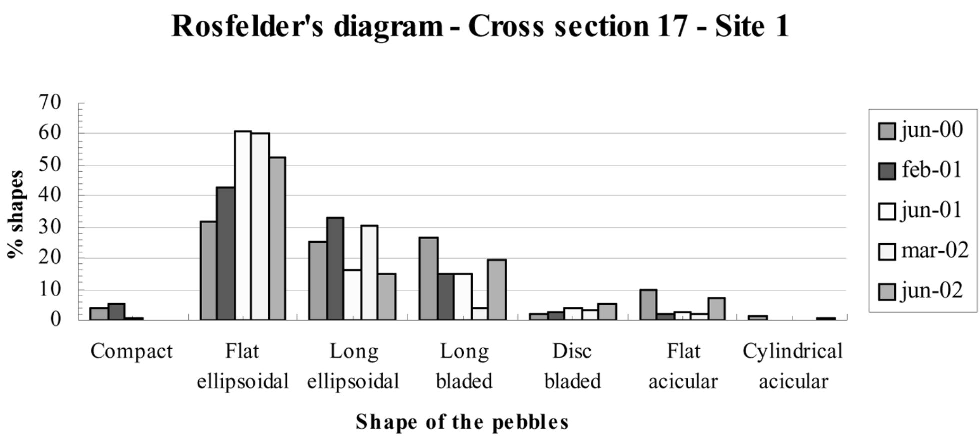

FIGURE 10 Rosfelder's diagram (1961, modified): shape of the pebbles in summer and winter surveys.

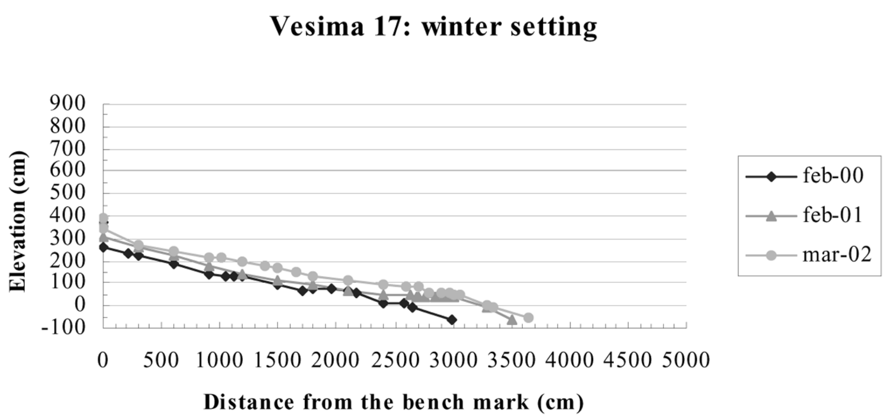

FIGURE 11 Morphological cross-section 17 (February 2000, 2001 and March 2002).

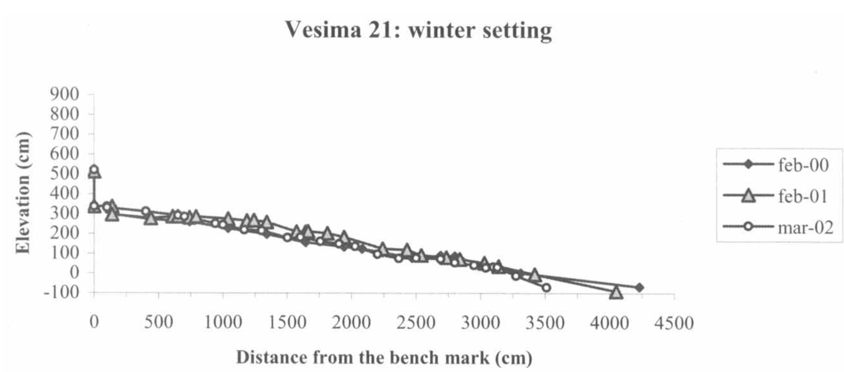

FIGURE 12 Morphological cross-section 21 (February 2000, 2001 and March 2002).

4 CONCLUSIONS

Among the various shore protection strategies, the nourishment of a beach with mixed sediments has been demonstrated to be an efficacious and innovative method for Vesima. This study contains results useful for solving practical problems for a future beach intervention plan with coarse sediments along this sector of the coast. The monitoring program carried out showed a break in the erosive trend along the beach of Vesima after the nourishment work in March 2000. During the next 2 years, the width of the dry beach was stable.

The estimate of nourishment material (20,000 m^3) and of the material left on the dry beach after 2 years (4800 m^3) indicates that a remarkable quantity of the sediment was taken from the shoreface to form the nearshore zone.

The nourishment allowed the width of the backshore to be maintained over the following years. The stability of the beach in those years confirmed the suitability of the material deposited and its good integration with the natural sediment. A sharp separation occurred between gravel migrating on the berm and sand that lay offshore of the trough. The limited loss of sediment and the apparent stable situation during the period of monitoring were also favoured by the action of sea-storms from the southeast, which moved the sediment westwards, so making the action of littoral drift, which is from west to east in this sector, less incisive.

The sedimentological and morphometric characteristics of the pebbles sampled during the nourishment and after 2 years indicated a concentration of the stablest shapes (ellipsoidal) with little difference between seasons.

Acknowledgements

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