CHAPTER 252

MODELLING AND MONITORING OF A PERCHED BEACH AT LIDO DI OSTIA (ROME)

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Abstract

A description is given of a new large project of artificial beach nourishment protected by a submerged sill carried out at Lido di Ostia near Rome in 1989-1991. After a review of the main aspects of the design (supported by model tests) and construction, details are given of the ongoing field monitoring program. Collected data has been used to verify the predictions of numerical models of cross-shore and longshore evolution of the perched beach. Useful preliminary lessons have been drawn from this unconventional experience of coastal protection.

Introduction

The sandy beaches of Lido di Ostia stretch along the southern delta cusp of the river Tiber, some 25 km from Rome on the Tyrrhenian Sea, and represent long since a very popular holiday resort for the Roman community (Fig.1). The cuspated delta was formed by alluvial sediments carried by the river, producing a progressive coastline advance of more than 4 km from the Roman age until this century (Fig.2). Then, particularly in the last 25 years, a severe erosion process has been taking place reverting the evolution trend to a recession rate of 1.7 m/year. The main cause has been the strong reduction of river sediment supply (due to upstream dams and extraction of building material from the river bed) with a consequent deficit in the coastal sand budget and a trend towards the cusp straightening and smoothing out.

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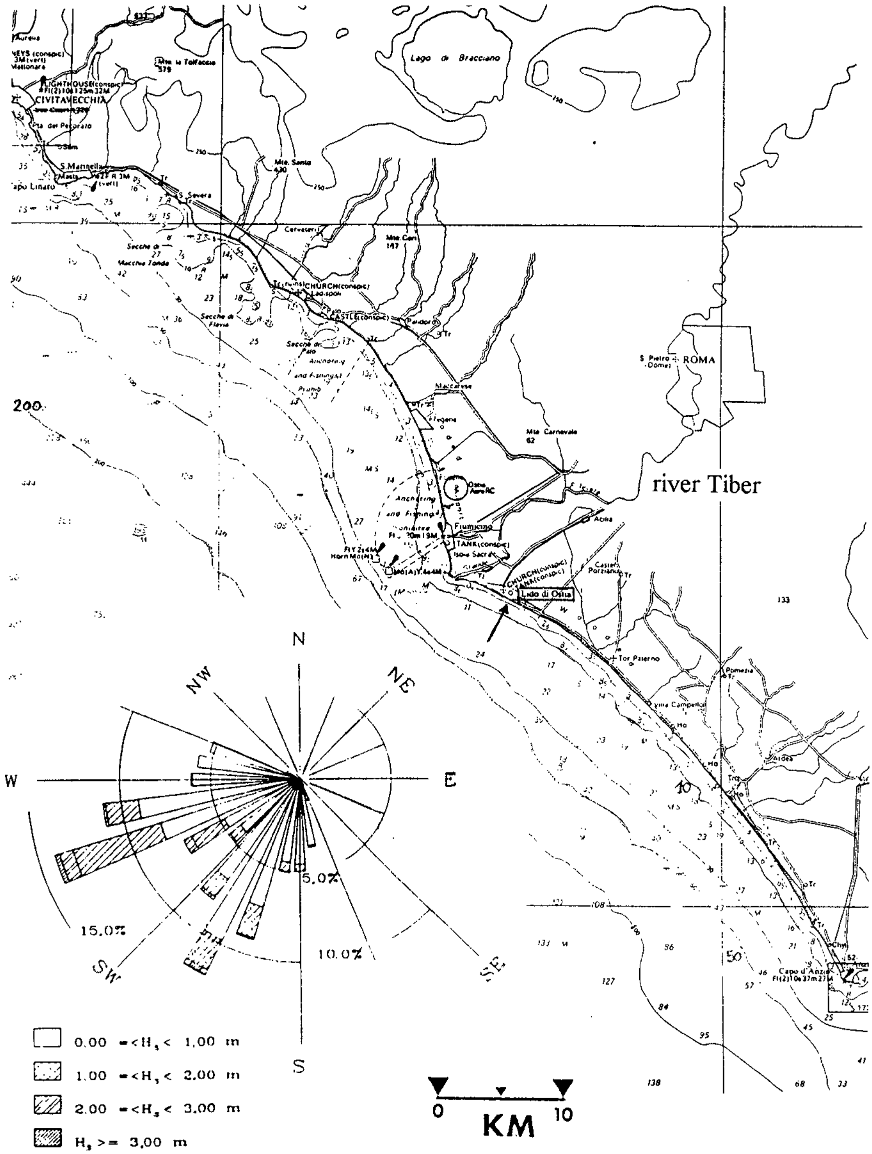

Fig.1. Location map of Ostia Lido and nearshore wave climate recorded in 1990-91

The local tidal range is very small (below 0.5 m), but deepwater waves may exceed a significant height of 5 m and a period of 10 s. Recent coastal protection works have been partially successful, such as the system of detached breakwaters constructed near the river mouth: erosion was shifted downdrift, mainly affecting the southern beach between the Vittoria Pier and the Pescatori Canal,causing damage to the beach clubs and even to the littoral road during storm periods.

An innovative beach nourishment project was then designed in 1988 by the competent Authority, the Office of Civil Engineers ("Genio Civile") for Maritime Works - Rome of the Italian Ministry of Public Works. A preliminary description of the project was given by Toti et al.(1990).

Project objectives and constraints

The aim of the project was to re-create a wide protective beach with an efficient technical defence solution complying with the economical, managing, political and environmental requirements. In fact the local community rejected any traditional emerging coastal structure to favour tourism, aestethics and ecology. Indeed the project represents a new approach of the Administration toward a global view in coastal defence, also taking into account the environmental aspects. Financial constraints restricted the project area to the most vulnerable 3 km stretch of coast.

Given the existing high deficit of the littoral sand budget, the proposed beach nourishment needed to be protected by some coastal structure able to dissipate part of the wave energy and reduce the littoral transport, and to retain the new fill material. The most suitable solution then included an offshore underwater rock barrier "fixing" the natural dynamic sandy bar, as a "perched beach" scheme. The submerged bar should hold the artificial beach at a shallower slope, reducing both offshore sand losses and longshore transport, enhancing the development of marine fauna, without endangering bathing and leisure navigation.

Important constraints were also resulting from the scarcity of marine sand for nourishment. The native beach sediments at a depth of MSL-10 m (on a 1% slope) have a too fine grain size with D_{50} = 0.1 mm. Fill material needed to be quarried inland on the alluvial Tiber delta at 20 km distance from the beach: the available material is a poorly sorted mix of well rounded sands and gravels.

Design scheme and problems to be studied

The protection scheme covers a beach length of 3 km (Figs.3-4) and basically consists of:

a) a sill made with a submerged rubble mound parallel to the shoreline at a distance of some 150 m, with toe level at MSL -4.0/-5.0 m, a 15 m wide crest berm at -1.5 m, seaward slope of 1:5, a multilayer rock mound (maximum stone weight of 1 t) placed above a geotextile and a 5 m wide rock toe protection in a 1 m deep trench;

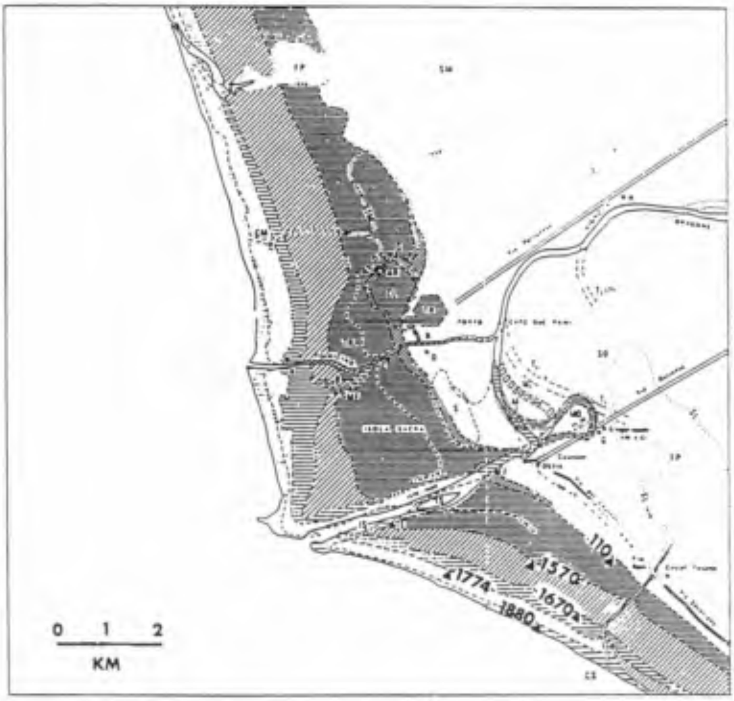

Fig.2. Historical evolution of the river Tiber delta from year 110 a.C. (Segre,1950)

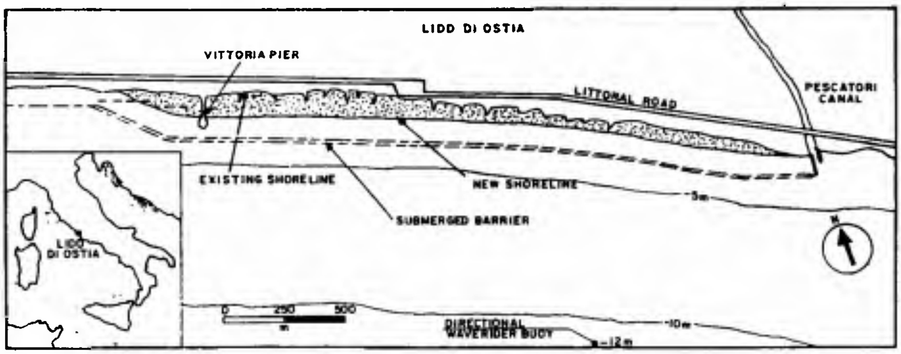

Fig.3. Design plan of the nourishment project

b) a fill with a double layer of quarry material: a lower layer of mixed sandy gravel with a wide grading of 0.08-120 mm, and a 1.0 m thick upper layer of sand with grading 0.3-1.3 mm; the underlayer also acts as a 5 m thick filter between the sand and the rock bar; the beach equilibrium slope is 2.5% and the berm crest located at MSL +1.0 m. The average design shoreline advance is about 60 m.

The main problems to be studied were related to the prediction of: the average losses of beach material due to longshore and cross-shore transport; the effects on the adjacent beaches; and the profile deformation during storms (which should not expose the underlayer). The sill hydraulic stability also needed to be verified.

Model tests

The above design problems were solved with the support of physical and mathematical model studies carried out by Delft Hydraulics (1989). The one-line mathematical model simulated the long term evolution of the whole shoreline planshape, finding a dynamic equilibrium position just 5 years after construction. A cross-shore numerical model was also used to check the morphological changes of the beach profile. Annual sediment volume losses were estimated in 4-10 m^3/m for the first year (depending on wave climate severity), reducing by 50% within three years. A minor erosion effect along the initial 700 m of downdrift beach was predicted. A 2-D mobile-bed hydraulic model at a scale 1:15 showed a remarkable stability of both the rock barrier and the artificial beach profile. A maximum 0.3 m vertical erosion was observed, together with an expected steepening of the beach slope at the shoreline and a horizontal recession of 5 m.

Construction features

The execution of the works was carried out by Condracos, a consortium of specialized Italian contractors. The works started in May 1989 with a 3-month stop in the tourist summer season; in June 1990 a 2150 m beach portion was built, while the final 850 m were completed in the following spring, for a total construction period of only 14 months. The works progressed from the Pescatori Canal to the north against the net littoral drift direction with the following sequence:

a) construction of longshore and cross-shore causeways to provide access for land-based equipment to build up the offshore barrier (initially emerging);

b) dumping and shaping of beach granular material with both land-based and marine equipment; some native dark beach sand (iron-rich) was temporarily stockpiled to be mixed with the yellow quarry sand as toplayer .

The construction equipment consisted of one hopper suction dredger, three 600 m^3 capacity barges, one tug, one pontoon, four dumpers, two bulldozers, three excavators and many trucks for material transport from the quarry. The total material quantities were about 1,3600,000 m^3 of sand and selected mixed sandy-gravel and about 300,000 m^3 of rock (basalt and limestone from different quarries).

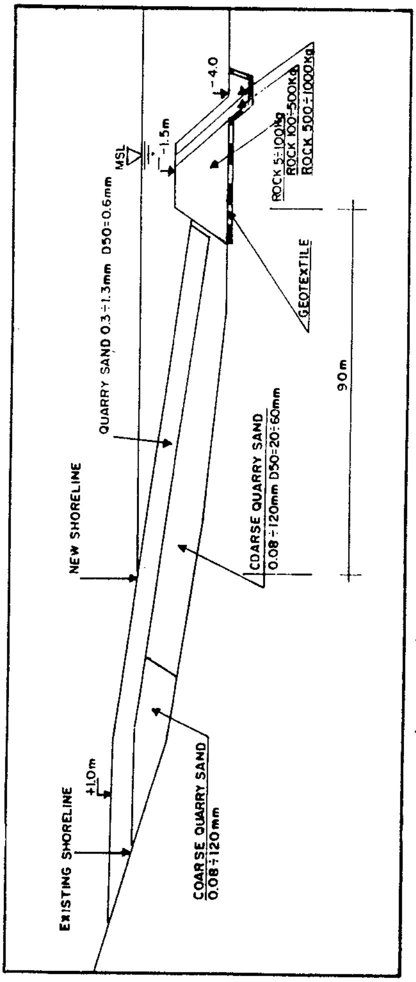

Fig.4. Design cross section of the perched beach

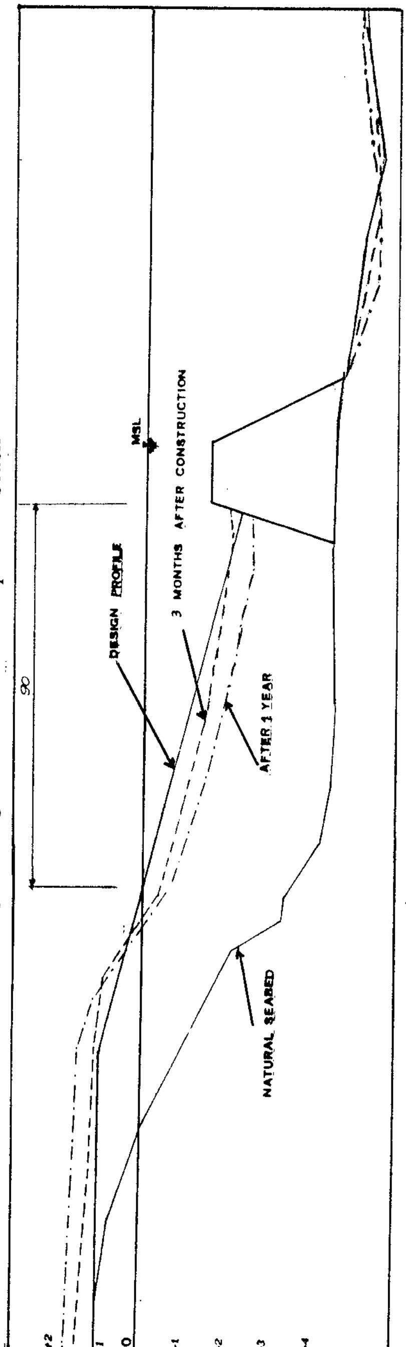

Fig.5. Measured average perched beach profiles

Monitoring program and analysis of field observations

Given the innovation of this technical solution and the unusual length of nourished beach without groynes, the Supreme Council of the Ministry of Public Works attributed an experimental character to the works and imposed the setup of a monitoring program since the construction start in mid 1989.

The periodic acquisition of field data includes: aerial photographs (twice a year), beach profile surveys (four per year), sediment sample analysis and directional wave recordings (starting on 3 Jan 1990). Beach profiles are surveyed up to MSL -7.0m at 100 m intervals, while 5 samples are collected across sections spaced 250 m. Local wave activity is recorded by a directional Datawell Waverider buoy moored in a depth of 12 m at 2 km distance from the coast, where a station easily receives the radio signals, supplying wave data in real time. Eigth samples of 200 s (26.6 minutes) are processed with FFT and spectral results displayed every half hour. Records are stored every 3 hours unless a threshold of 2.5 m significant wave height is exceeded. Site surveys and underwater inspections were carried out also by the Authors.

The analysis of the topographical surveys has shown a general stability of the new beach with predicted maximum 20-30 m shoreline advance (at southern end) and retreat (at northern end), due to the southbound littoral drift. This sediment transport is reduced by the presence of coarser material and of the fixed bar in the surfzone. Dredging volumes smaller than before were infact required to open the inlet of Pescatori Canal. No adverse effects have been observed on the adjacent beaches.

Photo 1 shows the original dark beach before the intervention and photos 2,3,4 the new large artificial beach, with gravel ridges typically forming near the cuspated shoreline (which also shows an active 3-D inshore circulation).

The elevation of the emerged beach has increased up to MSL+1.5/+2.0 m, while the submerged beach profile generally deepened, as shown in fig. 5. In the first months after construction stagnant water ponds formed on the upper beach due to poor drainage of wave uprush, caused by this shoreline ridge and by the initial impermeability of the mixed surface layers (also compacted by truck transit). However natural wind and wave action later redistributed the sediment avoiding this problem.

Minor scour has been observed at the barrier seaward toe, but some deposition in deeper water may indicate small offshore sand losses. Some fine material has penetrated into the rock sill, thus reducing its permeability, but not the stability.

As far as wave measurements are concerned, the local climate of two years is shown in fig.1. It shows a typical bimodal distribution and the resultant of the wave energy vector is just directed from 225 N, still quite angled to the coastline normal oriented at 210 N, thus confirming the southbound littoral drift. These nearshore wave records have also been correlated with those taken at the deepwater directional station off Ponza island, finding a good correspondance. The main wave direction is typically refracted inshore with a rotation of 25-30 degrees and the directional spread reduced from 30 to 10 degrees. An annual average of 7 storms with a peak significant wave height H_s > 2.5 m was recorded, with a maximum H_s of 4.4 m. The corresponding offshore significant wave height of 5.8 m has an estimated return period of 10 years. This was indeed a severe positive test for the just completed perched beach.

Post-construction computation of beach deformation

The field data collected during the monitoring program has been used for hindcast computations of beach plan evolution and beach profile deformation, which have been performed with the "Unibest" software suite of Delft Hydraulics.

a) Profile development

Hindcast computations of the beach profile developments have been performed with "Unibest-TC". In this program the principal processes (wave asymmetry, undertow, gravity) underlying the cross-shore sediment transport are taken into account. The surfzone dynamics are computed by a built-in random wave propagation and decay module (Battjes and Stive, 1984). It includes the wave energy changes due to bottom refraction, shoaling and dissipation due to bottom friction and wave breaking. The secondary currents due to the vertical non-uniformity of the driving forces in the nearshore zone are modelled according to the formulations of Stive and De Vriend (1987). The cross-shore sediment transport along the coastal profile is calculated according to the formulations given by Bailard (1981), which include the transport due to the combined actions of steady current, wave orbital motion and bottom slope effect. The related bottom level changes of the cross-shore profile are computed from the mass balance.

For the computation of the perched beach profile morphodynamics at Ostia the local wave data from the directional Datawell Waverider buoy has been used in chronological sequence. The original wave data has been averaged per day on the basis of wave energy. The computation has been performed for the typical measured cross-shore profile as shown in Fig.5, but only the upper fill layer consisting of 0.3 - 1.3 mm was taken into account. The effect of coarsening of the beach material at the surface due to mixing of the upper and lower fill layer was just considered by increasing the D_{50} from 0.6 to 0.8 mm. In Figure 6 the computed beach profile developments after 3, 6 and 12 months are shown together with the distribution of the cross-shore transport Sy at the time step of 3 months. For the computed profile situated below MSL a similar erosion pattern can be observed in comparison with the profile developments which have been measured in nature (see Fig.5), although the calculated erosion seems to be slightly underestimated. Near the waterline the computation also show the formation of a ridge similar to the natural development. However, above MSL, at the emerged beach face, a large difference between calculated and natural development can be observed. In the model the accretion of the upper beach profile does not occur. One explanation for this may be the poor description in "Unibest" of the effect of wave up-rush on ridge formation at the

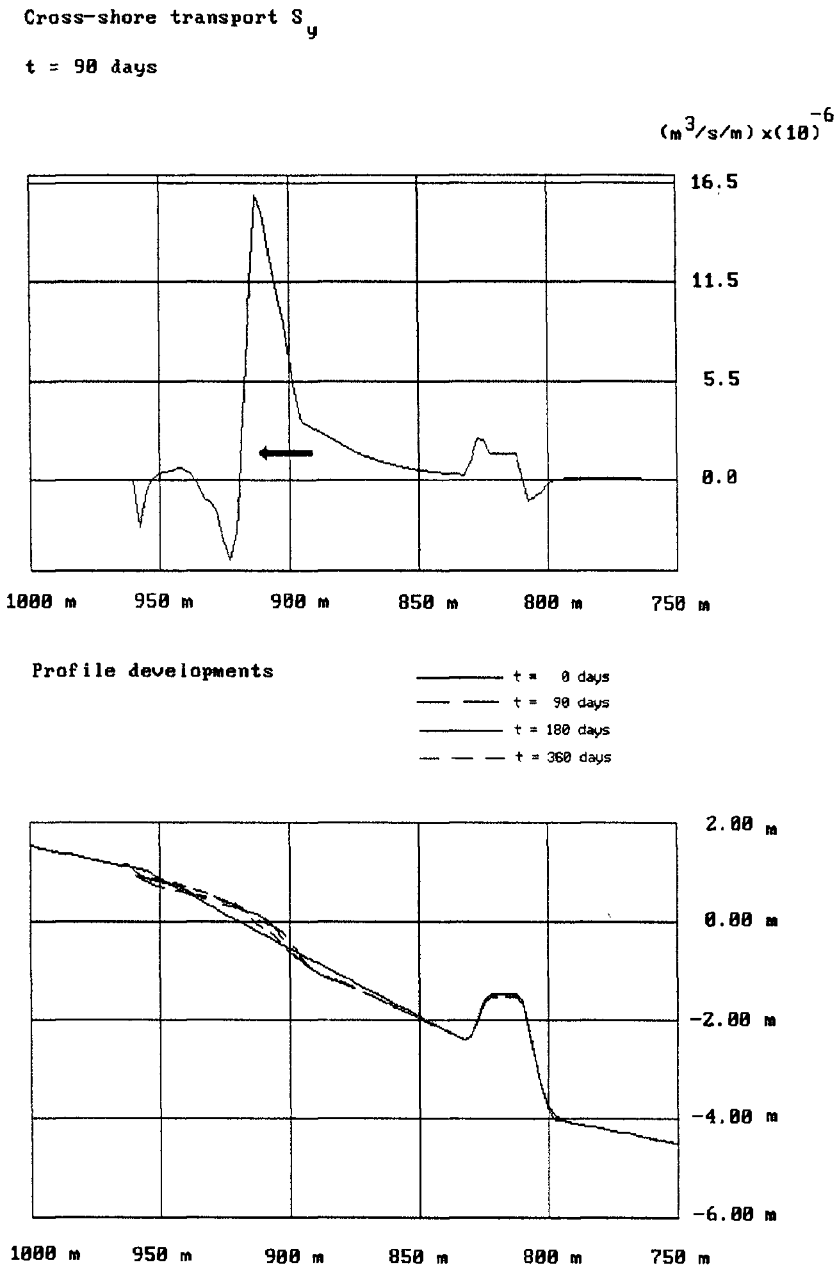

Fig.6. Cross-shore transport and profile developments computed with UNIBEST-TC (Delft Hydraulics)

waterline. Possibly, aeolic transport along the dry beach face may be another explanation for this difference.

b) Beach planshape evolution

Computation of the beach planform shape have been performed with the program "Unibest-CL". This program computes the coastline changes due to longshore sediment transport gradients and cross-shore sediment losses/ gaines on the basis of the one-line schematization. The model is based on the well known single line theory, which was first presented by Pelnard-Considère (1956). The profile characterizing the beach is assumed to move horizontally over its entire active height as a result of accretion or erosion. The beach slope therefore does not change. An equation of motion and a continuity equation are used together with specified initial and boundary conditions.

The basic input data for the module "Unibest-CL" is generated with the module "Unibest-LT" which computes tide- and wave-induced longshore currents and sediment transports on a beach of arbitrary profile. The surfzone dynamics are derived from the same built-in random wave propagation and decay model as used in the model "Unibest-TC". The distribution of the longshore current is computed from the momentum equation alongshore taking into account the radiation stress gradient, the bottom friction under combined current and wave action and the tidal surface slope alongshore.

The longshore transport computations have been carried out for the design profile of the beach nourishment with the same grading assumptions. The computations are based on a statistical description of the local directional wave recordings. The longshore transport computation are carried out with the Bijker formula (Bijker, 1971).

For the computation of beach planform development it has been assumed that the active profile extends down to the toe of the submerged rubble mound barrier. At the updrift boundary of the coastline model a zero transport has been imposed; at the downdrift boundary of the model the current transport has been modelled.

Figure 7 shows the results of the coastline computation after approximately 1 year. The initial coastline in January 1991 is also shown. The results display a retreat of the beach in the area south of Pontile della Vittoria due to the southward directed longshore transport and a small accretion in the area north of Canale dei Pescatori. From the computational results it can be noticed that the beach-line fluctuations which are present in the initial situation are slightly smoothed by the model. The reason for this is that longshore transport has been computed in the model for only one typical cross-shore profile. In nature, however, local deviations of the beach profile and nearshore area may cause small differences in beach response. In Figure 7 the corresponding net sediment transport distribution alongshore is shown as well. The sediment transport rate varies between 5,000 and 15,000 m^3/year.

Lessons from field experience and conclusions

After nearly three years of monitoring and the occurrence of many severe storms, the behaviour of the new perched beach at Lido di Ostia has been satisfactory. The observed alongshore and cross-shore redistribution of sediments are in good agreement with the design predictions. Volume losses appear to be small and correspond fairly well with the model predictions for a relatively bad wave climate. Negligible effects are observed on the downdrift and offshore beach morphology. Therefore the design choice to avoid groyne construction seems to be correct.

Ecological and aesthetical impacts are also acceptable: the quality of beach sediments and of seawater is satisfactory, as confirmed by the large tourist crowds in summer. The submerged rubble sill is stable and does not affect the beach recreational activities (a part from surfing). It is easily seen as a dark blue strip in the sea, marked with buoys. The rock barrier has favoured the development of marine fauna, being now fully covered with mussels and stimulating leisure fishing.

The experience gained so far from this innovative large-scale project can give some useful technical indications for the design of other perched beaches in similar hydro-morphological conditions.

The rock bar could be composed by a reduced number of gradations and the stone toe protection enlarged and laid directly on the geotextile above the seabed, thus saving the trench dredging. A proper filter layer of small stones should separate the fill toe from the barrier to avoid intrusion of fines into the sill.

The natural beach profile reshaping can be favoured and the construction eased by dumping the fill material on a steeper slope and keeping the cheaper coarse sediments on the submerged profile and the blanket of precious fine sand on the emerged beach face, which can be designed with a higher crest level.

However, final conclusions will be drawn after a longer monitoring period.

Field data has also been used to perform an interesting hindcasting of the beach profile and shoreline development with advanced mathematical models. The models could also be further calibrated to achieve more reliable predictions for the future evolution of the perched beach.

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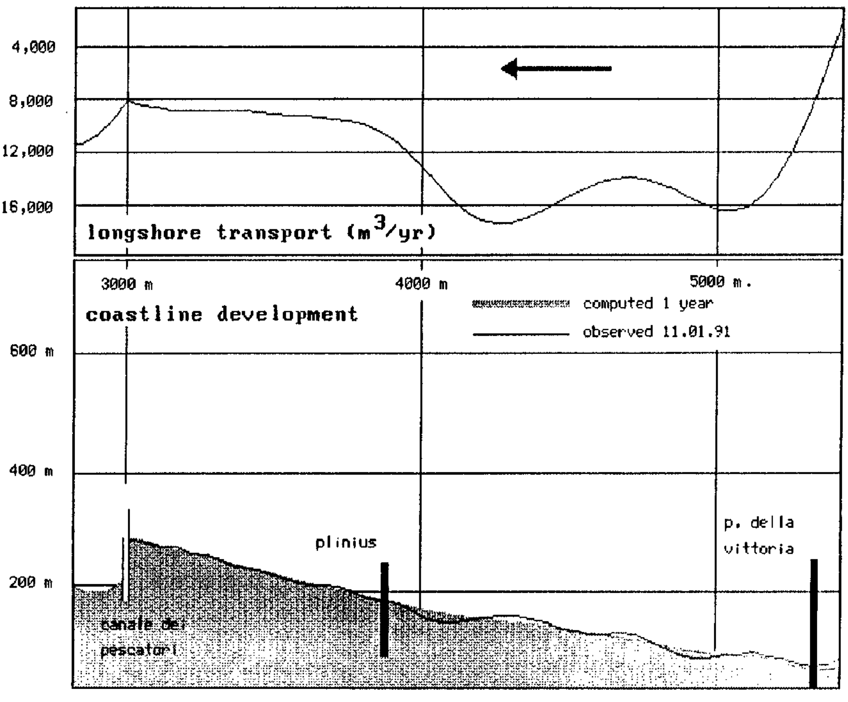

Fig.7. Longshore sediment transport and shoreline development computed with UNIBEST-LT/CL (Delft Hydraulics)

Photo 1-2. The beach before and after the nourishment
(Plinius club and jetty seen in the far field)

Photo 3-4. Aerial views of the new beach at Ostia (1991)