SHORE PROTECTION AT VENICE: A CASE STUDY

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ABSTRACT

The lagoon of Venice (N. Adriatic) is the most important in Italy (Fig. 1). Between 1840 and 1933 the tidal entrances facing the lagoon were controlled by six large jetties, after the construction of which more evident erosion phenomena appeared in some tourist resort beaches near the inlets. Detailed historical, movable bed models, and field studies have recently been conducted with the aim of defining a proper defence system for these beaches. The results of these studies are reported here.

HISTORICAL REPORTS

The lagoon of Venice originated nearly 6,000 years ago as a result of slow invasion by rising sea-water over a wide alluvial zone, faced by a large dune system whose position has not significantly changed in time.

The first detailed historical reconstruction of the lagoon describes the site as it was about 1,000 years ago (Filiasi [2]). At that time the lagoon was connected to the sea by nine different mouths, called "ports", i.e. from NE to SW, Jesolo, Lio Maggiore, Treporti, S. Erasmo, S. Nicolò, Malamocco, Porto Secco, Chioggia and Brondolo (Fig. 2).

The following evolution of the northern lagoon area is shown in Fig. 3. In the 16th century five inlets were still present on this side, i.e. Jesolo, Lio Maggiore, Treporti, S. Erasmo and S. Nicolò. One century later, as a consequence of large deposits of river sediment, the port of Jesolo became a branch of the Piave river and that of Lio Maggiore an internal channel called "Pordelio". Sediment deposits continued in front of the Pordelio channel.

Finally, as a consequence of the construction of two big jetties between 1882 and 1910, Treporti, S. Erasmo and

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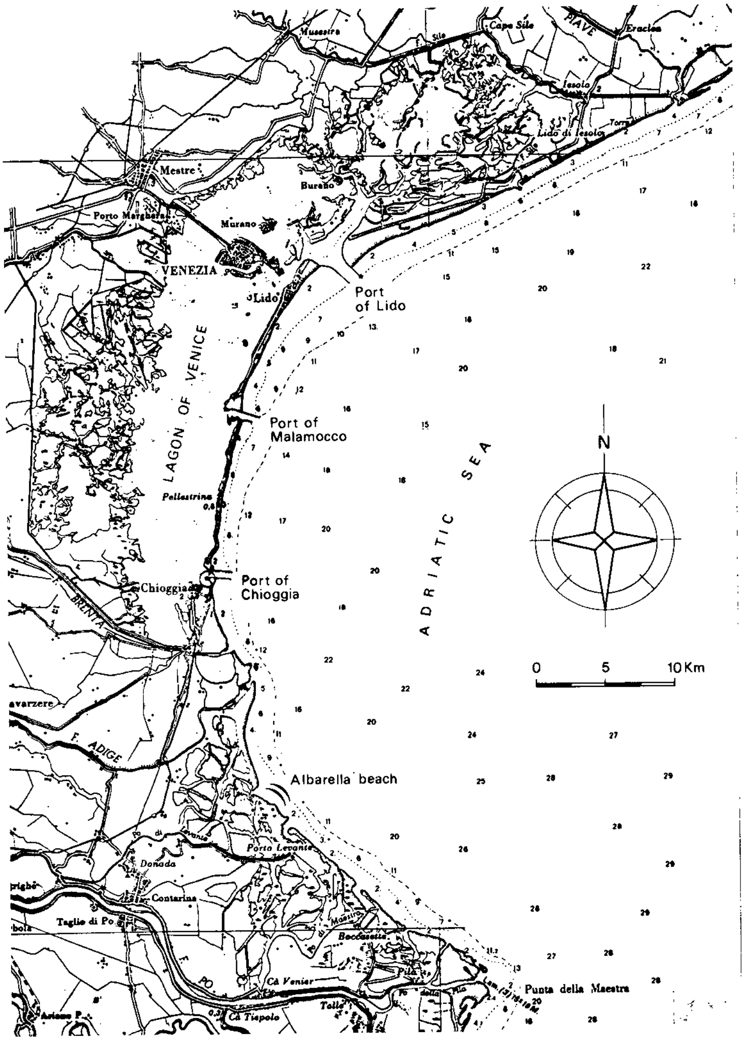

FIG. I : Study area

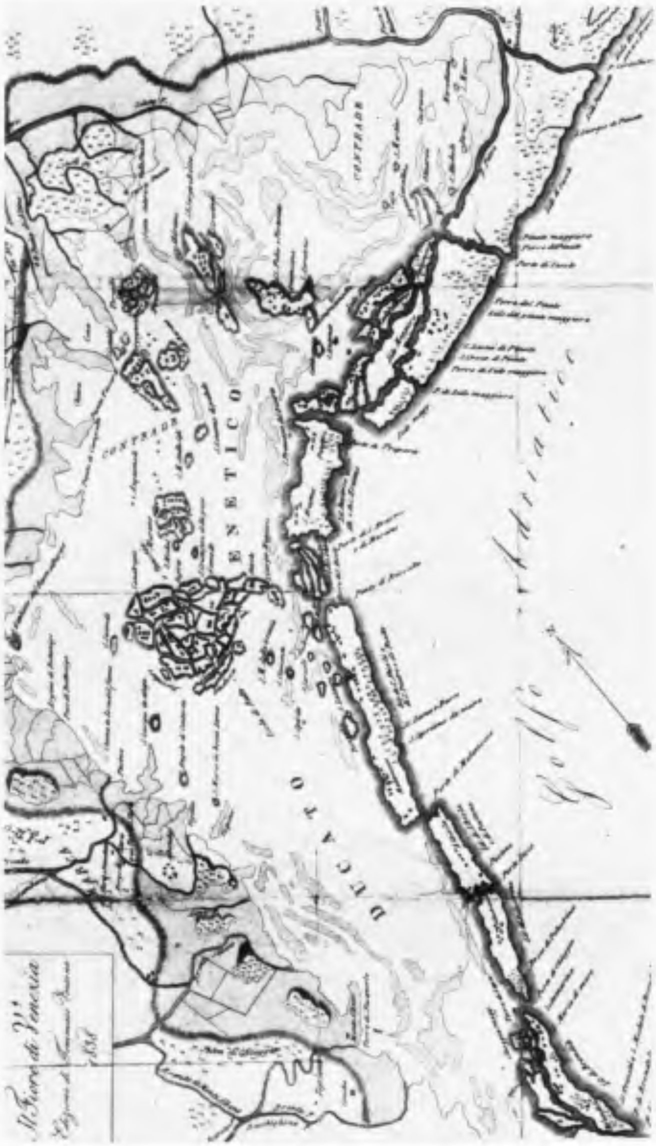

FIG. 2 : The lagoon of Venice one thousand years ago

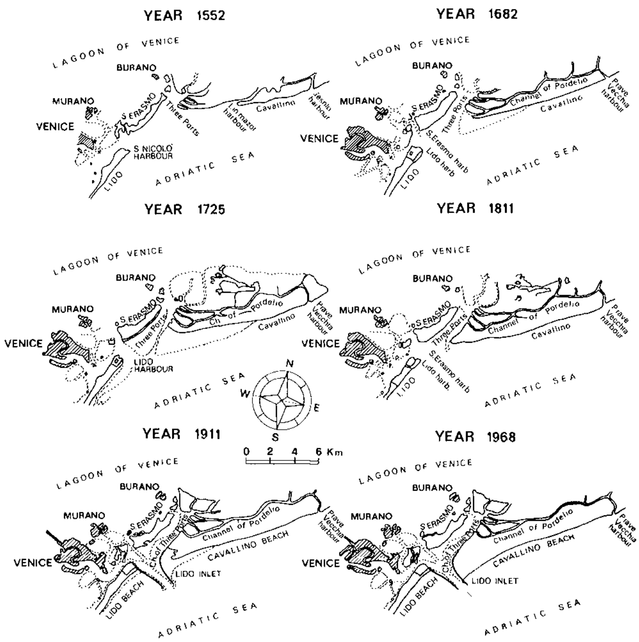

FIG. 3 : Topographic change of N-E lagoon area
(after Miozzi [3])

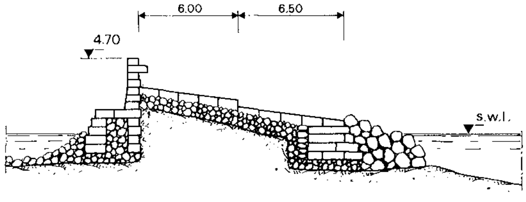

FIG. 4 : Seawall built between 1744 and 1782

the Lido (S. Nicolò) were united to form the Lido inlet. In the meanwhile, fewer modifications took place on the southern side of the lagoon, where the sediment supplied by river floodings had the effect first of closing the Porto Secco inlet and then of confining the Brondolo inlet to the border of the lagoon itself.

From the beginning of the 13th century, man's contribution became gradually more important. The Venetians generally followed three main directions while aiming at preserving the singular aspect of their lagoon:
1) they avoided large river sediment deposits inside the lagoon and preserved the activity of the inlets;
2) they favoured predominance of salt water over fresh in the lagoon;
3) they assured an efficient shore defence system to the islands composing the littoral belt.

To satisfy the first two needs (points 1 and 2), from the 14th century onwards, the main rivers formerly entering the lagoon were diverted outside it. Longshore sediment supply consequently increased at the borders of the lagoon.

Shore defence had been important since the 11th century, when the first artificial sand movements were performed, whereas the first structures were built around the 14th century. These consisted of groins and sea-walls, built of several lines of generally transversally connected wooden piles. Stones were also placed between the lines of the groins and at the foot of the sea-walls. The effect of these structures was, however, often unsatisfactory and the Venetian government was frequently obliged to remove or modify them. Between 1774 and 1886, about 20 km of large sea-walls were built. The first 5 km were built between 1774 and 1782 to protect positions between the Malamocco and Brondolo inlets, where beach extension was insufficient to avoid flooding during heavy storms. Although these structures, where concrete was used to increase the stability of the stones, represent an incredible technological level for those times (see Fig. 4), they underwent serious damage and the bottom erosion rate increased in front of the sea-walls. Parts of these structures were destroyed in November 1966, during a storm in which the sea rose approx. 2 m above normal levels. On that occasion, it was noticed that, two hundred years after their construction, damage to the sea-walls was mainly due to cavities which had formed under the stone covering, rather than to structural weaknesses.

EFFECTS OF JETTY CONSTRUCTION

Between 1840 and 1933, both to improve navigation facilities and to increase sea/lagoon water exchange, six large jetties were built, thus causing the present configuration of the lagoon. Fig. 5 shows this configuration: of the nine tidal inlets active 1,000 years ago, only three still remain. They are:

- the Lido, whose jetties were built between 1882 and 1910. The N jetty is 3,635 m long, the S one 3,155 m; the inlet channel is 900 m wide;
- Malamocco inlet, whose jetties were built between 1840 and 1872. The N jetty is 2,120 m long, the S one 930 m. This inlet is 470 m wide and separates the littoral of the Lido from that of Pellestrina;
- Chioggia inlet, whose jetties were built between 1911 and 1933. The N jetty is 1,800 m long, the S one 1,500 m; the inlet channel is 550 m wide.

To analyze the effects produced by the long jetties on the adjoining beaches, bathymetric charts up to 1810 have been collected and compared with the present situation.

As Figs. 6 and 7 show, large offshore bars were present in front of Malamocco and the Lido inlets before jetty construction: their orientation testifies to a net southward littoral drift. These bars were quickly eroded as a result of jetty construction and steady deepening of the bottom appeared in the central parts of Pellestrina and the Lido beaches.

Long-term profile changes (Fig. 8) show this behaviour (for location, see Fig. 5). The evolution of section 16 clearly reveals the process of bar destruction, while more gradual bottom erosion is seen in section 21. In profile 29, surveyed at the middle of Pellestrina beach, erosion actually increases at a slower rate, probably due to the presence of a steeper slope resulting from the construction of the sea-walls since the 18th century. However, the long-term trend of bottom evolution shows strongest erosion occurring between the 3- and 10-m depth contours in the central part of the Lido.

It is worthy of note that, while generally accretion or stability of the submerged beach has been noticed close to the jetties, clear-cut erosion has developed to the SE, close to the Malamocco inlet: this phenomenon may be partly ascribed to the limited extent of the jetty, which is the smallest of all.

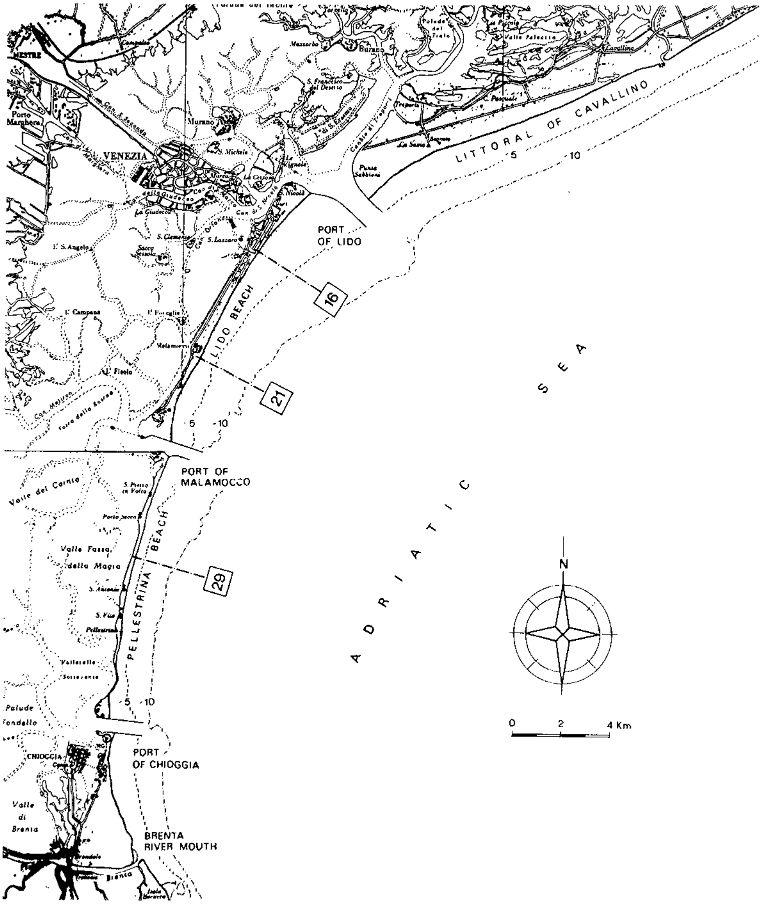

FIG. 5 : Venice coastline and profile location

FIG. 6 : Shoal orientation in front of Malamocco

FIG. 7 : Shoal orientation in front of Lido

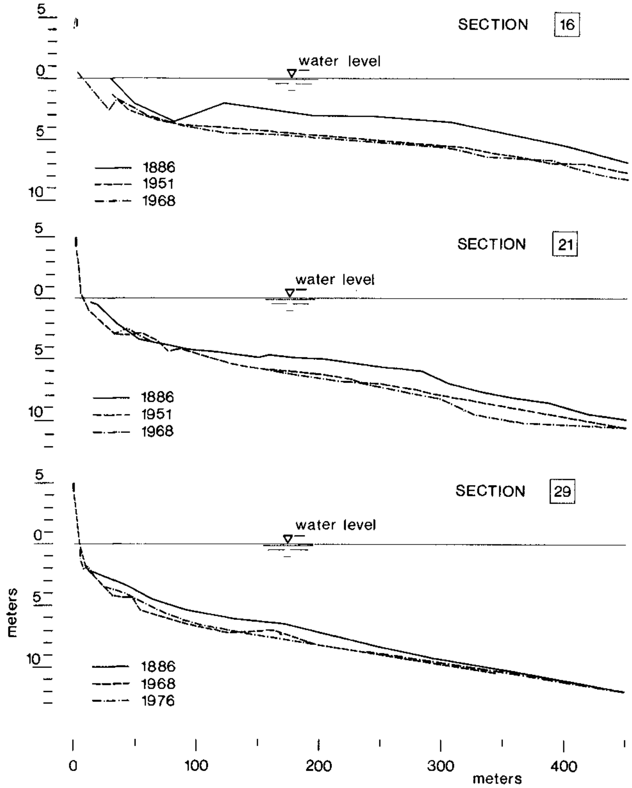

FIG..8 : Beach profile changes in front of Lido and Pellestrina islands

Shoreline variations are shown in Fig. 9. Shoreline advance is evident close to the updrift jetty of the Lido inlet and reveals a southward net littoral drift. From the beginning of this century the average rate of shoreline advance (updrift side of jetty) was more than 10 m a year; the interrupted littoral drift has been evaluated between 350,000 and 400,000 cubic metres a year. Thus, this area represents a potential borrow site from which large quantities of sand could be dredged. Between the Malamocco and Lido inlets, net littoral drift was probably southward before jetty construction (see Figs. 3 and 6): shoreline variations show that sand tends to accumulate close to both updrift and downdrift jetties, while no variations are logically present in front of those stretches protected by sea-walls. Between Malamocco and Chioggia inlets, sand accumulates again close to both jetties, but this behaviour is less evident due to the great length of the sea-walls.

South of Chioggia inlet, both shoreline advance and orientation of the mouth of the Brenta river clearly show northward net littoral drift. The opposite net littoral drift direction existing at both extremities of Pellestrina leads to the hypothesis that an inversion of net longshore transport probably occurs along this shoreline. If this had also taken place in the past, due to the particular direction of the stretch of coast in question, the consequent sand transport deficit would explain the great "thinning" in time of this area compared with nearby stretches like the Lido.

SHORE DEFENCE PROJECT

In the last century, the Lido has become a very important tourist resort. In order both to arrest bottom erosion and to satisfy the need for improved tourist facilities, artificial beach nourishment represents the proper solution. As mentioned above, the area close to the updrift jetty of the Lido inlet represents a suitable borrow site, and a quantity of sand could be dredged from it sufficient to renourish the whole of the Lido. Moreover, the presence of the two jetties at the ends of the beach would assure good stability with respect to longshore transport: as a consequence, both in order to reduce the initial quantity of fill material and to increase its stability, a perched beach scheme was first considered.

Studies were conducted in a two-dimensional movable bed model to investigate the behaviour of different types of submerged structures (ref. [1]). Scale ratios for crushed

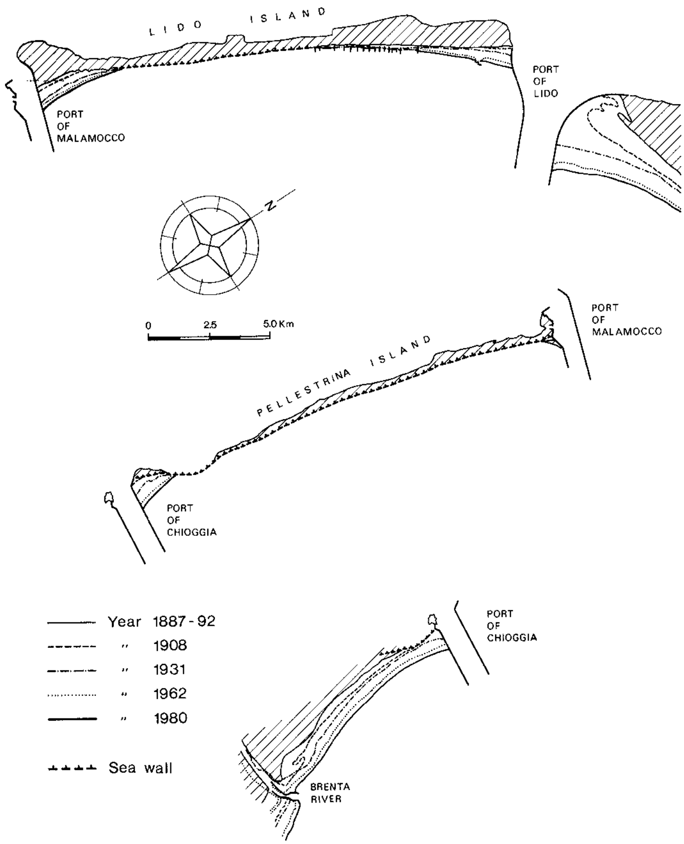

FIG. 9 : Shoreline changes (after Zunica [5])

bakelite as model material were first determined as reported by Noda |4| and applied as follows:

horizontal scale = 1:30
vertical scale = 1:20
median diameter of bakelite = 0.75 mm.

In order to calibrate the model, the initial nearshore slope was changed until an equilibrium profile similar to the natural one was experimentally achieved.

Different configurations of piled sandbags plus a concrete obstacle (see Fig. 10) were tested and summer and winter equilibrium beach profiles were reproduced in the laboratory. These experiments proved that piled sandbags were more stable and allowed less fill material to be transported offshore during winter wave attack. It was also found that the problem of scouring on the landward side of the obstacle could be successfully solved if one or two extra lines of bags were placed on the bottom (Fig. 10; configurations B and D). On a distorted scale, Fig. 11 shows the laboratory behaviour of the submerged structure with and without two extra lines of sandbags (Fig. 10; confs. C and D). The scouring phenomenon on the landward side of the obstacle clearly decreases if configuration D is applied.

Finally, the perched beach solution was tested in prototype conditions. Artificial nourishment stopped by a submerged obstacle was placed at Albarella, a partly eroding tourist beach close to Venice (Fig. 1).

One hundred cubic metres of fill material were placed along a 700-m segment of shoreline and a piled sandbag barrier was placed about 170 m offshore, at an average depth of 1.8 m. A groin of piled sandbags was also placed at the SE extremity to increase the stability of the fill material (Fig. 12). The size of typical filled bags was approx. 2.2 x 1.5 x 0.25 m. They were carefully placed on the bottom by a crane working from a pontoon; divers checked the crane's manoevers.

A comprehensive engineering analysis of the behaviour of the perched beach was carried out. Data evaluated include repetitive beach profiles, bathymetric surveys, visual observation of sea state, wave gage records, aerial photography, and refraction studies.

Unfortunately much of the fill material was removed, especially northwards, during the winter.

Analyses indicate that this behaviour was mainly due to the limited extent of the fill area: as a consequence, the

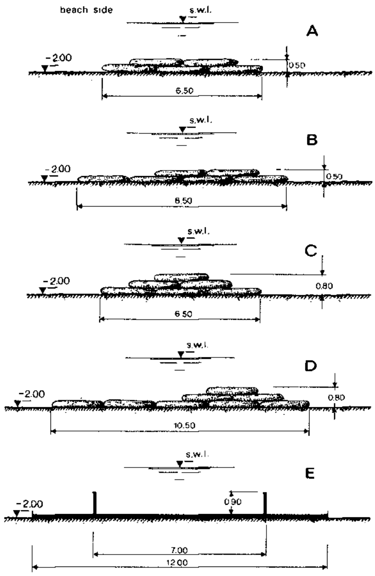

FIG. IO : Submerged structures tested in the model (prototype dimensions)

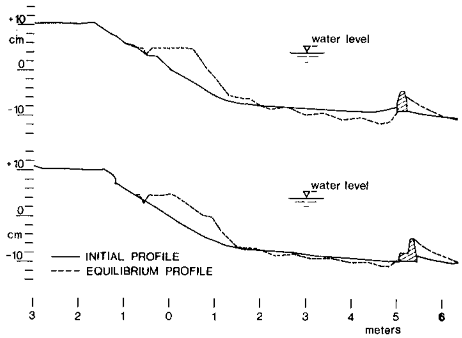

FIG. II : Comparison of equilibrium profiles (confs. C and D)

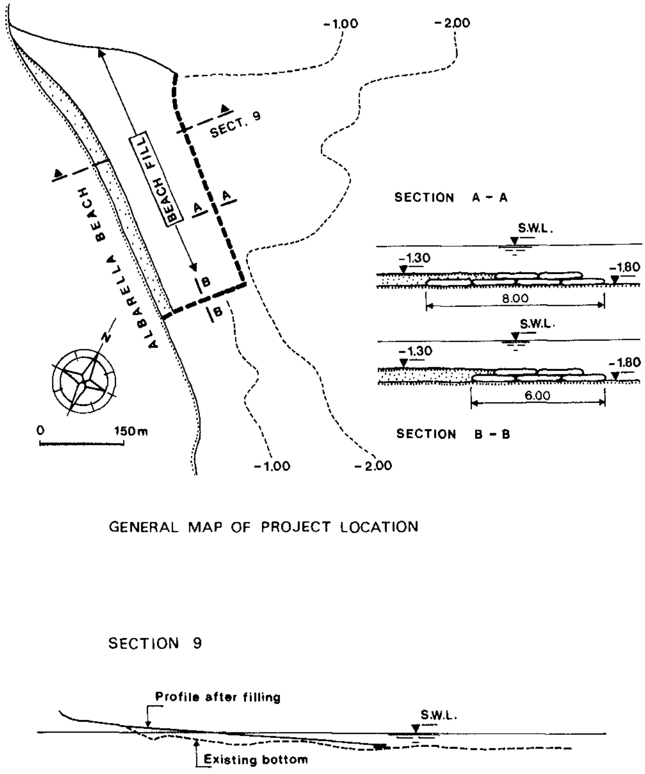

FIG. I2 : General features of perched beach construction effect of both longshore littoral drift and lateral spreading of artificial sand prevailed, and the submerged obstacle did little to increase fill stability.

However, two years after construction of the artificial beach, the piled sandbags showed satisfactory behaviour: no sinking of the submerged structure was observed and no scouring occurred on the landward side, but sand tended to accumulate on the seaward side.

In any case, the above prototype experiment cannot be considered completely significant for the beaches of Venice: in fact, in front of the Lido, the fill area will be much larger and the long jetties bordering the shoreline will probably reduce the influence of longshore littoral drift. For these reasons, some doubts remain regarding the suitability of using submerged obstacles. Further three-dimensional laboratory studies will be conducted.

SUMMARY AND CONCLUSIONS

After jetty construction, the beaches situated between the three Venice tidal inlets have shown two main types of beach behaviour:

1) deposit of sand close to both updrift and downdrift jetties;

2) large-scale erosion of the bottom, with the rapid removal of offshore shoals.

Artificial beach nourishment is considered to be the proper solution both for the problems of bottom erosion and increased tourist facilities, and a perched beach scheme was tested both in the laboratory and <u>in situ</u>. Further research is still needed to evaluate the opportunity of complementary structures to increase the stability of the fill material.

If a submerged obstacle is to be used, a structure composed of piled sandbags has shown itself to be stable, both in the laboratory and <u>in situ</u>.

ACKNOWLEDGEMENTS

Part of the data presented in this paper was kindly supplied by the Genio Civile delle Opere Marittime of Venice and Albarella S.p.A. Permission to publish this information is appreciated. Acknowledgments is also due to Prof. Liberatore, University of Florence, for suggestions.

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