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Converting Seawalls into Gravel Beaches

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Abstract

Coastal tourism is a growing industry, relying mostly on the use of beaches. However, a worldwide tendency to coastal erosion may be locally aggravated by some of the very strategies implemented to reverse this pattern. Coastal erosion affecting Italian beaches since the 19th Century induced the construction of several coastal structures that strongly modified the landscape and reduced beach quality. Along the urban coastline, where infrastructures and high value properties needed to be defended, protection was provided under the "hard approach". Nowadays, "softer" shore protection strategies are available, but they are hardly applicable where previous hard structures have strongly modified the nearshore morphology. In such cases, the construction of gravel beaches can provide protection for the settlement whereas also providing a surface for recreation. Several gravel beaches have been created in Italy in recent years and proved to be cost-effective in restoring the waterfront. Whereas the frequent use of hard structures to protect coastal settlements and prevent shoreline retreat traditionally lead to the lack of beaches for residents and tourists, the creation of gravel beaches provides them access to the sea and offers better protection of coastal facilities and buildings. This study examines the creation of gravel beaches in selected Italian locations as a measure of coastal management, and refers to their effects on shore protection as well as the increased potential for beach use by tourists and residents at these sites.

Keywords: erosion, tourism, gravel beach, shore protection

Introduction

Tourism is widely recognised as a growing industry worldwide, particularly in the coastal zone (Kay and Alder, 1999). People have increasingly been driven to the shore due to urbanisation and industrialisation, and beaches are today the preferred site for tourists (Lencek and Bosker, 1998). Beaches are in fact used by more people than any other habitat in the coastal zone, being the focal point for coastal recreation and tourism, and causing the value of the adjacent land to increase due to the large sums of money involved in this activity (Clark, 1996).

Beaches are dynamic landforms which may alter shape and position due to local imbalance between deposition and erosion. The construction of hotels and other facilities on the beach immobilises coastal sediment stocks and may contribute to erosion, threatening the very same buildings, reducing the area for recreation and therefore impacting the whole industry in a specific location (Clark, 1996).

Beach erosion and its effects on tourism-dependent coastal communities can be particularly severe in places already undergoing erosion by other causes, natural or anthropogenic. The beach in its natural form exists in a state of dynamic tension, continually shifting in response to waves, wind, and tide and continuously adjusting back to equilibrium. It is also a fact, for a variety of causes, that beaches are being lost at a rapid rate throughout much of the world. Approximately 30% of the Italian beaches are eroding (CNR/MURST, 1997; D'Alessandro and La Monica, 1999) due to the reduction in river sedimentary input (Pranzini, 1995). This process initiated in the mid 19th Century at the river mouths and continuously expanded onto the adjacent beaches (Pranzini, 1989), at the same moment when urban development reached the coast. This process had been triggered by several factors, such as the end of malaria, the rise of industrial plants, the development of coastal communication and the beginning of bathing tourism.

In the 20th Century, beach erosion along the Italian coasts was amplified by the construction of ports and harbours which had strong downdrift feeding effects. As a result, erosion threatened urban settlements, industrial plants, communication routes and beachfront facilities where the tourism was the main source of income. Therefore protective works were needed, planned and carried out. Coastal stabilization through the construction of seawalls, breakwaters and groins was the instinctive answer. This policy was carried out by the Ministry of Public Works, which, according to a law enacted in 1907, had the duty to protect coastal settlements against shoreline retreat after an official request by the Municipality. The philosophy and the staff of the Ministry strongly relied on harbour construction experience, and the "hard solution" to coastal protection was a natural choice. Hundreds of kilometres of the Italian coast were then covered by breakwaters (Fig 1), which often induced downdrift erosion and prevented proper tourist use of the beach. On the Adriatic coast detached breakwaters border the shoreline for dozens of km (Preti, 2002) and on the Tyrrhenian side some coastal sectors are protected with more than 2 km of hard structures per kilometer of coastline (Cipriani *et al*, 2001).

However, the traditional "hard structures" such as breakwaters, seawalls and groins are often a bargain whereby the structure may hold but the beach is lost: the complex chain of reactions from the secondary effects from these and other popular protection structures, results in major downstream erosion and, quite often, total loss of beach (Clark, 1996). In addition, these structures are known to affect water and sand quality due to the reduced dynamics in the protected area. On most of the Italian coast, the protection of a short coastal sector, lacking the study of the whole physiographic unit, induced a downdrift erosion which, in turn, triggered the construction of other structures, in a positive feed-back process, altering long stretches of coast. The sea-land interface was strongly modified, erosion was not always controlled but the beach value was always reduced, due to the impact of the structures on the landscape and on environmental quality. Groins in particular compartmentalise the coast, occupying part of the beach facing the sea-front promenade in urbanised sites.

The monitoring of beach erosion and its implications to and from coastal tourism are among the many issues of planning and management of the coastal zone, and the evaluation and choice of a strategy to be adopted should therefore be considered within a wide technical and political scenario. The needs of local residents and stakeholders, second-home owners and tourists must be mediated (Cipriani *et al*, 2003). As coastal communities face beach erosion it becomes clear that attempts to stabilise the shoreline with hard protective structures might not be enough, and other strategies that call for a retreat from the coastline are increasingly being considered. However, retreat is not always possible, especially in places that have already undergone heavy urbanisation. In such cases, the most promising solution has been rebuilding the beaches. Beach renourishment is an anti-erosion scheme that is relatively low-tech, is competitive with seawalls and breakwaters in terms of cost and helps to improve sea-water quality due to an increase in water circulation and the restoration of a more natural landscape.

After the urbanisation of beaches, coastal tourism redirected towards more natural-looking landscapes (if not authentically, untouched environments). Even in anthropic, urban coastal sites, beach nourisment may free or alleviate the marine landscape from the presence of artificial protection structures, looking less urbanised and meeting the tendence from beach tourism towards a more natural landscape. However, feeding a beach is neither a cheap nor a permanent solution, and where the coast is protected by seawalls, the reçonstruction of a sandy beach is particularly expensive, because of the deepening in the nearshore profile induced by wave reflection on the structure itself. Where erosion rate is high and hard structures are not recommended due to the type of use of the coast or environmental conditions, a gravel beach may be proposed as an alternative to seawalls, providing a functional beach, at a lower cost of implementation and maintenance, and coastal protection against natural forces.

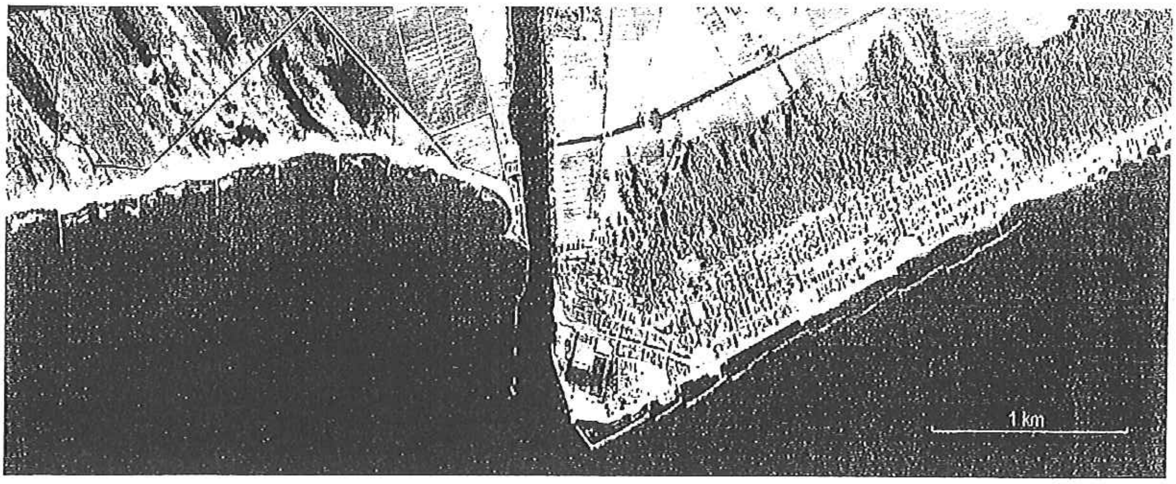


Figure 1: Arno River delta: the segment on the left eroded for 1300 m since mid 19th centrury and was recently protected with groins with submerged extensions; the left side is protected by detached breakwaters facing the seawall at Marina di Pisa and by improvised structures on the downdrift sectors.

Protective gravel beaches

Renourishment can restore the beach to its original appearance and its original function of deflecting the force of the waves. Since 1971, the US Corps of Engineers has embraced the non-structural solutions. During the last decades, beach nourishment was adopted in several countries, mostly using marine sands, which are dredged for tens of millions of cubic meters per year (Hanson *et al*, 2002). It provides a beach suitable for recreational purposes, an effective check on erosion in the problem area, a supply of sediment to adjacent beaches and a feasible, if expensive, answer to beach erosion where large quantities of sediment are available (Clark, 1996). In Italy approximately 20 million cubic meters of marine sands have been used for beach nourishment (Pranzini, 2004) during the last 10 years, most of them in projects carried out along Veneto (Silva and De Girolamo, 1993) and Lazio (La Monica, 1999) coastal areas.

Following the tendency towards a softer approach in defending the coastline, some projects converting hard structures into gravel beaches have been carried out or have been proposed in recent years in Italy. Some allow for the construction of new gravel beaches in front of old seawalls, others plan the lowering of the detached breakwaters and the absorption of the higher wave energy reaching the coast by a coarse-grained beach.

Gravel beaches are characterised by sediments of a diameter ranging from 4-64 mm (pebbles), 64-256 (cobbles) and from 264 mm upwards (boulders), according to the classification by Wentworth (1922). Since the size of these sediments is larger than sand (which may range from 0.0625 to 2 mm) and as a function of hydraulic properties, gravel beaches are characterised by a steeper slope than sandy beaches. Coarse grained sediments show a great stability both on natural beaches and in those artifically created, as an effect of the higher weight of the single grain, which require higher energy to be moved, and of the greater porosity and permeability of the beach (Pranzini, 1999). These two characteristics favour water infiltration during the wave uprush, and this water returns to the sea through subsurface fluxes reducing the backwash energy and the removal of grains. On-shore fluxes drop grains on the beachface and on the berm crest producing very high berms (Orford, 1977; Orford and Carter, 1985). This process is shown also by numerical models (van Hijum and Pilarczyk, 1982; van der Meer, 1998). One of the main issues relates to the relationship between the borrow coarse sediments and the fine sediment that form the natural profile. In natural mixed sand and gravel beaches the coarsest elements are found on the step (Miller and Zeigler, 1958), where the last breaking occurs, whereas fine sand lays on the nearshore. Field observations lead to the conclusion that under severe storm events a flat sandy beachface forms, and gravel returns on the swashzone under swell conditions producing a steeper profile, but very little is known on the process acting during the storm when any sampling is impossible. On the cases studied, in spite of the evident use of the new gravel beaches for tourism and leisure (Fig 2), these observations lack qualitative and quantitative assessment of user perceptions on the quality of this use (due to the steeper profile and angularity of gravel-size beaches) as these studies have not yet been carried out.

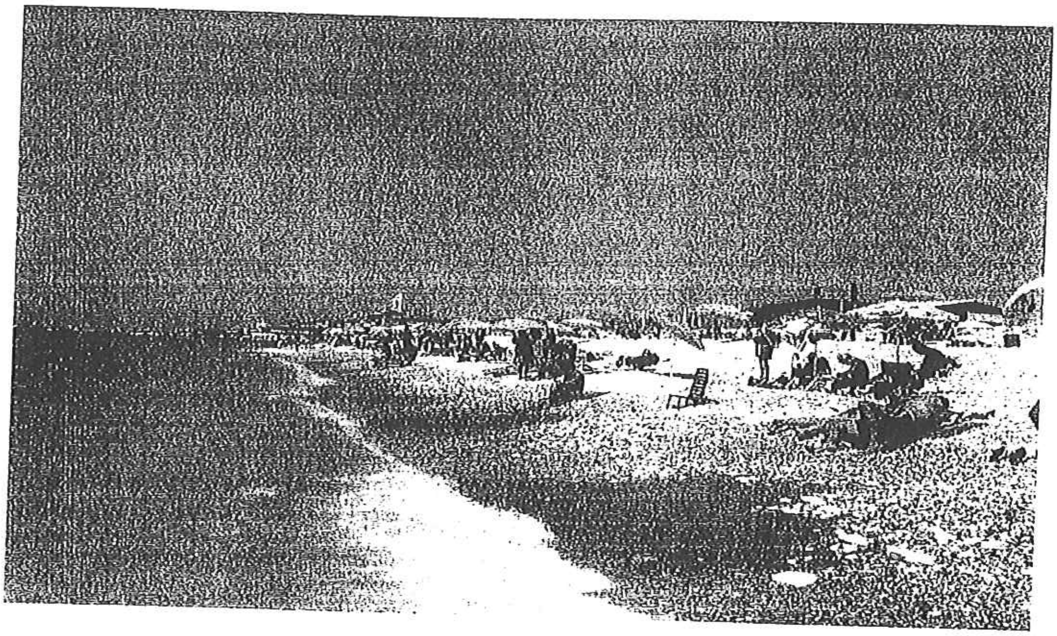


Figure 2: Recreational use of an artificial gravel beach (Marina di Pisa)

Case studies

Cala Gonone (Sardinia)

An artificial gravel beach was created at Cala Gonone, Sardinia, in front of the retaining wall next to the promenade (Fig 3), to provide summer tourists with a beach in front of the village, preventing them from crowding Cala Luna, which is a valuable and ecologically sensitive site located a few miles from this study area, along a rocky coast. Part of the new beach project was also aimed to protect a cliff made by unconsolidated quaternary deposits on top of which a tourist resort was located. From Autumn 1994 to Spring 1995, 23.000 m^3 (less than 30 m^3/m) of crushed quarried white limestone was fed along the coast and an additional 57.000 m^3 (to reach a fill of approximately 100 m^3/m) of crushed pink granite rock were added from Autumn 1996 to June 1997. The interruption of the work and the change in fill material were due to a break of the contract by the company who had started the work. The limestone gravel used in the renourishment project at Cala Gonone had a mean size within 0.5 and 32 mm, with a modal value of 16 mm; granite gravel, which covered it later, had a mean size between 0.5 and 22 mm with a mode at 8 mm. It is the granite gravel that nowadays forms the berm. Limestone grains were rapidly rounded and in one year roundness passed from 0.9 to 0.5 - 0.6, according to the visual scale proposed by Krumbein (1941). Granite reached the same value later (monitoring was interrupted after two years). The area has a high environmental value and the landscape was to be maintained as close as possible to its original look. Therefore, the fill material was not stabilised with groins or breakwaters, but with artificial shoals, formed of loose rounded stones that had the same characteristics of those naturally present along the coast. The shoals position was planned to reduce wave energy and to correspond or harmonize the shoreline with the cliff morphology. Their efficiency is proven by the formation of cusps and by the reduced height of the berm on the sheltered sectors (Pacini *et al*, 1997). The rounding of limestone allowed the use of the beach by tourists immediately after the end of the first work phase. This project had to consider the need to obtain a beach that was open to waves allowing for good water circulation, the need to redefine the hard structures in order to keep the natural characteristics as unaltered as possible, and the wish to protect the *Posidonia oceanica* prairies which are present beyond the 10 m isobath. The completion of the project resulted in an increased beach use and better economic returns, as it extended the summer bathing season for two more months. In 2000 the project was awarded the Mediterranean Prize for Landscape, which aims at recognizing good practices in landscape planning and design (Junta de Andalucia *et al*, 2001).

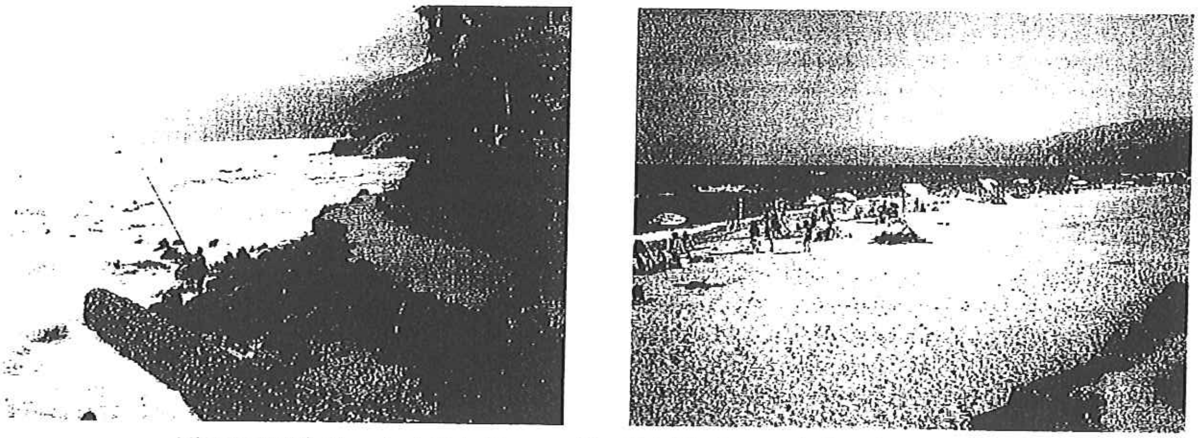


Figure 3: The beach at Cala Gonone (Sardinia) before and after the gravel fill

Marina di Pisa (Tuscany)

Marina di Pisa was born as a touristic "new town" on the southern lobe of the Arno River delta, where erosion started in the mid 18th Century and several hard structures (groins, seawalls and detached breakwaters) were constructed for the sake of protecting the coast; now as many as 2.2 km of breakwaters protect each kilometer of this coast (Aminti *et al*, 1999a). The coastline was stabilised, but the nearshore is still eroding and in the offshore side of the detached breakwaters a depth of up to 7 m is attained (Cipriani *et al*, 2001). Scarce energy dissipation occurs due to shoaling in the deep nearshore, and waves break on the structure itself. The poor longshore sediment transport, originated at the river mouth, is diverted offshore as demonstrated by a convex profile that is formed approximately 150 m away from the structures. Downdrift beaches had no more longshore sediment feeding and their erosion induced local tourist operators to build improvised, and sometimes abusive, structures (Fig 4).

An experimental gravel beach was created in 2001 south of Marina di Pisa where no offshore structure flanks the seawall (Aminti *et al*, 1999b). The primary objective was not to create a recreational beach area but an efficient and less reflective form of coastal defence in order to prevent flooding of the coastal road during severe storms. A gravel beach approximately 20 m wide and 300 m long was constructed (Fig 4).

Beach monitoring revealed that the gravel fill did not move offshore but remained within the -1 m isobath. Poor sorting was observed up to the -1 m depth in response to the input of the new coarse fractions. No significant changes in textural characteristics were observed in the nearshore seaward of the 1 m isobath. Visual observations of sediments on the backshore surface and at depth (in trenches) were made in May 2002. Despite the presence of a steep beach gradient at that time, patches of sand were observed on the dry beach and trenches made on the backshore revealed the presence of sand below the surface, creating an interstitial sand-matrix in the gravel deposit. Results indicated that deposition of gravel to create a sub-aerial beach provides a mechanism for the transportation of sand from the nearshore to the nourished foreshore and that a beach created using only gravel can begin to take on hydraulic characteristics of mixed sand and gravel beaches (Cammelli *et al*, 2004).

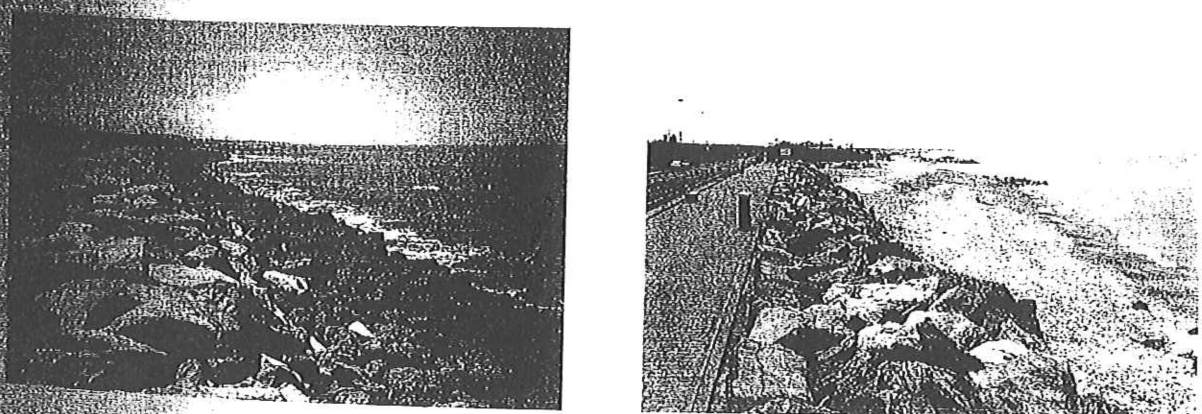


Figure 4: Marina di Pisa southern coast before and after the nourishment

A coastal protection project is currently being developed at Marina di Pisa which foresees, after full completion, the lowering of the detached breakwaters down to -0.50 m below m.s.l. and the construction of a gravel beach bordering the seawall to absorb the energy of the waves overtopping the lowered external structure. The beach will be 30 m wide and groins to be connected to the breakwater by submerged segments will interrupt the longshore sediment transport. Flume (Aminti and Pranzini, 2000) and wave-tank (Damiani *et al*, 2002) experiments together with numeric modelling were performed to forecast the nearshore dynamics and optimise the project. It is expected that a reduced wave reflection on the breakwater will favour the elevation of the nearshore profile and a more effective wave energy dissipation; this will permit further lowering of the structure and, possibly, a decrease in the grain-size of the beach fill.

Unfortunately, a 30-year recurrence-time storm hit the study area in October 2003 when the first phase of the project was still being carried out, during which a 6.4 m significative wave height (Hs_0) and single wave heights of 10 and 11 m have been recorded at the national wave buoy of La Spezia, located approximately 29 nautical miles north-west of Marina di Pisa, at a waterdepth of 70 m. As it had been previously observed in the physical models, the limited fill volume that had so far been loaded onto the proposed beach was insufficient and could not give rise to a concave profile with a full developed berm crest. A convex profile formed instead, as a consequence of the water set-up generated in the area between the two existing hard structures, from where water overtopping the detached breakwater cannot exit. As a result gravel was transported inland over the adjacent coastal road and the project faced strong opposition from residents who had to deal with this unpleasant and even hazardous situation (Fig 5). However, by the completion of the Marina di Pisa project, the proposed gravel beach shall have the full volume of gravel required to reach a profile equilibrium compatible to the average wave conditions but also capable to support high energy storm events such as the one from October 2003. This will allow for an extended use by tourists and for a more effcient defence of the coastline.

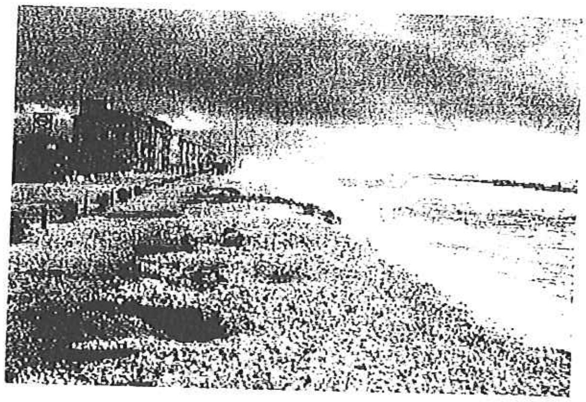
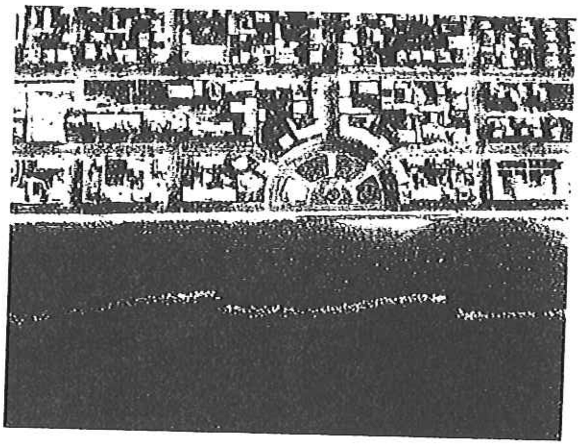


Figure 5: Marina di Pisa during the extreme storm on 5 October, 2003

For Marina di Pisa the completion of this project will offer the possibility to boost tourism, since the absence of a beach, the poor water quality and the coastal road right next to the seawall prevented any revitalisation of the waterfront. Facilities for bathers such as restaurants will be set where a wider beach will be formed by groins; here, exedras will be a seaward expansion of the squares which are part of the 19th Century structure of the town (Fig 6) (Aminti *et al*, 1998).



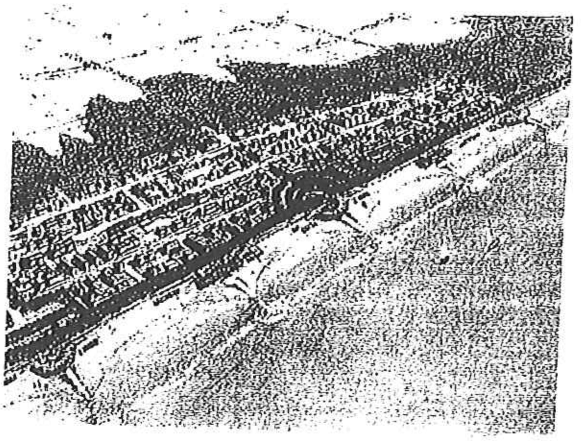


Figure 6: Left: Current configuration of a shoreline section at Marina di Pisa. Note the limited available beach area. Right: Rendering of shoreline configuration for the proposed project (J. Oneto design)

Other experiences

Other renourishment projects using gravel have been completed in different parts of the Italian coast, but some technical issues have not yet been fully understood, such as the mixing of new gravel with native sand. Often the two grain-size populations remain apart and limited gravel fill can produce the armouring of the beach, as occurred at Lido di Policoro (Basilicata) (Fig 7), where cobbles and pebbles were discharged onto the swashzone and then flowed alongshore for several kilometres reducing the quality of adjacent beaches.

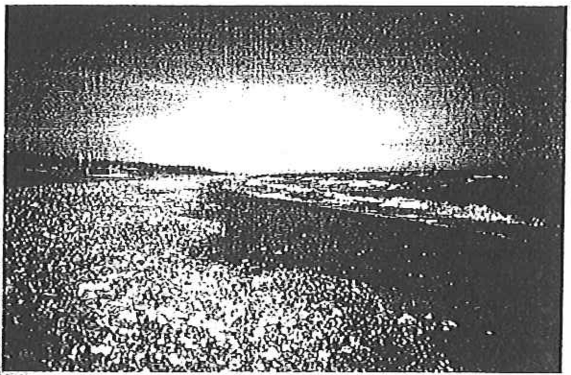


Figure 7: Lido di Policoro: Coarse material transported longshore onto a fine sand beach without defence structures

At Fondi-Sperlonga, on the Lazio coast, the gravel nourishment project that was completed reduced wave reflection on buildings and favoured onshore sand flux, producing a mixed sediment beach: the material originally fed at the beginning of the works in May 1996 was shown to be covered by native fine sands in May 1997 (Berriolo, 1999) (Fig 8).

A new gravel beach nourishment project has been recently proposed at Rio Marina (Elba Island, Tuscany), where the only beach available to the villagers had disappeared due to the construction of a harbour for the mining industry. The beach that is now being proposed would have a double role: it would absorb wave energy near the harbour entrance improving safety for ships navigation, and, in addition, it would recreate a beach that would again be available to residents and tourists as the only town beach in Rio Marina (Fig 9). This would be of particular importance as Rio Marina's economy is now moving towards tourism after the end of the mining activities in 1970's.

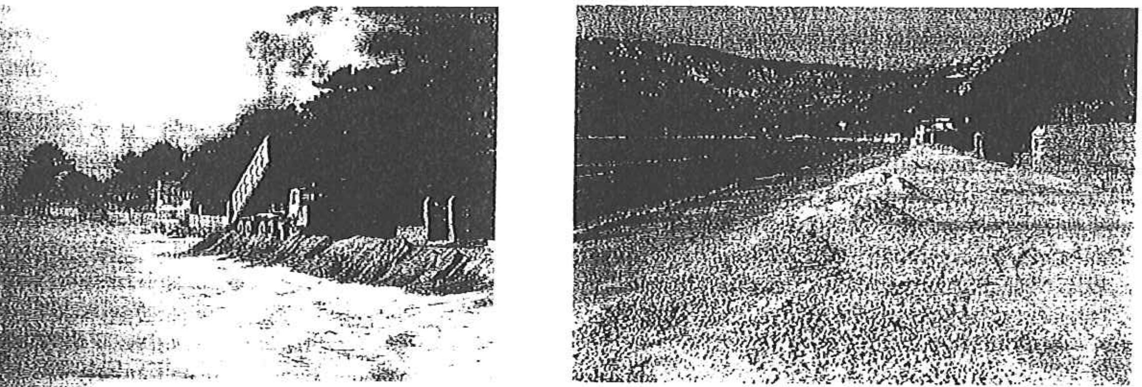


Figure 8: Gravel nourishment on the beach of Fondi-Sperlonga

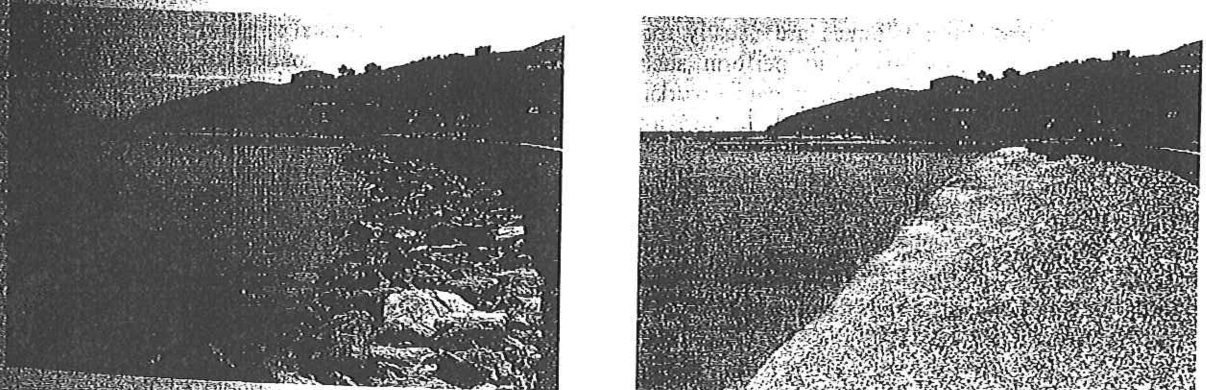


Figure 9: Project proposed for Rio Marina

Discussion

Tourism is an important source of income to coastal areas, and planning and management can contribute to solving some of the problems that usually derive from this use of coastal resources. The growth of coastal tourism inevitably causes environmental changes that need to be kept within acceptable limits, since good beaches are worth billions of tourist dollars, but degraded beaches are worth little (Clark, 1996). Beach management, coastal erosion control and reduction of coastal hazards are therefore among the many issues to be addressed by coastal management programs, and the choice of strategy to be implemented on a particular site in order to control beach erosion must be considered within a wider technical and political scenario, where the effects from and to tourism are considered along the many existing stakes.

Beach erosion is a major threat in Italy, and after many years of the predominance of hard structures as a solution, renourishment has been proposed as a new approach. Beach management in Tuscany has, in recent years, undergone a slow but effective process of change, due to the new legislation. The new strategy proposes to quit building hard structures as a strategy to defend coastal settlements and infrastructures from shoreline retreat, and to enhance the following: beach erosion prevention, use of soft engineering (beach renourishments), and the abandonment of the existing hard structures. A morphological and sedimentological beach monitoring is presently being conducted along the entire coastal length of Tuscany, with particular attention where coastal restoration has been applied. This will give enough information to ensure a correct beach management and to evaluate the effectiveness of the new restoration strategies.

Restoring sandy beaches would however involve very high volumes of sediment in order to reconstruct the beach profile from the backshore to the nearshore, and these volumes are usually too costly, making it unsustainable to perform such projects as well as subsequent maintenance works. The use of gravel beaches, as an alternative to hard structures, both in new projects and to replace seawalls in older ones, is effective in protecting the coast and in producing areas to support coastal tourism and recreation. The creation of gravel beaches in Italy is proving to be an interesting alternative to providing tourism-dependent coastal communities with a protective, more stable, and less expensive space for tourism and recreation when compared to beaches that are artificially renourished with sand.

The use of coarse material such as gravel for the construction of artificial beaches, or cheaper coarse material for the nourishment of the sea-bottom behind the hard structures may allow for the reduction in the height of such structures, and, in the best scenario, their complete removal, which contributes to landscape recovery and may promote the use of a stretch of land that has high economical value (e.g., allowing the creation of new bathing facilities). The cascading-effect created by the construction of hard structures as means of defence against coastal erosion may therefore be interrupted, with the return to a beach profile that is more natural, in which wave energy is dissipated more gradually.

Numerical and physical modelling helps the design of gravel beaches, although several problems remain in predicting the beach profile in coarse grain beaches and, particularly, in mixed sand and gravel beaches. These models and field data show that gravel does not flow offshore but remains near the shoreface; although strong longshore transport is known to occur and may cause gravel to move away, this can be limited with short groins. However, the mixing of new gravel with native sand is not fully understood. The first results from the monitoring surveys conducted, seem to support the cost-benefit analysis when compared to traditional defence structures. The construction of gravel beaches represents an interesting study case also because there are a few hundred of kilometres of the Italian road system in urban and extra-urban coastal environments which are affected by the erosive processes caused by wave energy, where it could be possible to perform restoration works at low cost and limited impact on adjacent coastal stretches.

Conclusions

Gravel beaches seem to be particularly adequate for urbanised areas, such as Marina di Pisa. It is important to keep in mind that the impossibility of use of beaches in coastal stretches near urban areas may lead to the occupation of adjacent natural beaches and the installation of the new facilities usually needed in response to the growing demand of spaces for tourism. Due to its high efficiency and lower costs, artificially created gravel beaches may also prove an alternative where mass tourism needs to be redirected away from more environmentally sensitive beaches, as happened in Cala Luna, Sardinia.

The replacement of hard structures by gravel beaches may provide a gradual return towards a more natural (if not the original) landscape, and has been internationally referred to under the slogan "Back to the Beach" (Aminti *et al*, 1999a). In spite of the observed use that tourists have been having of these beaches, this process will require a long period of time and a high degree of trust by residents, local authorities and all stakeholders. As any other issue in coastal management, the choice of a coast protection strategy against erosion must be weighted in the planning process, and the interests of all stakeholders be taken into account along with expert technical matters. This must be a transparent, participatory and educative process. Public opinion support is crucial for a measure to be taken at the administrative, political level. The distrust of some residents of Marina di Pisa when the exceptional 30 -year return storm reached the area in 2003 and caused the beach gravel to move and reach the adjacent road could be best dealt with by explaining that the project had not yet been finalised and therefore could not yet provide full protection as originally planned. Without proper communication between planners, politicians, technicians, scientists, residents and tourists, measures that have the potential to be efficient when finalised, such as an artificial gravel beach, may be condemned before its final completion due to some unexpected hard conditions being faced during execution, and what could result as an efficient measure against erosion when finalised could have to be aborted along the way, with its consequences to tourism and therefore impact on local economies.

However, in spite of its high technical and economic efficiency, the choice of creating a new gravel beach to protect the coastline and improve coastal tourism should not be considered without considering the more complex scenario of coastal management, where the tourism industry is one among many stakeholders and all interests must be carefully examined along with the environmental impacts. Even in tourism-dependent coastal communities, the protection of infrastructure that has been built too close to the coastline and the (re)creation of spaces for tourism and recreation must be mediated with the interest of other stakeholders that may be in minority, such as fishermen.

Gravel beaches may be a particularly good choice in places that have already undergone high urbanisation such as Marina di Pisa, where a return to natural conditions would be unlikely to succeed. In less urbanised areas, it may alleviate the pressure over more sensitive beaches (such as happened in Cala Cottone), offer the possibility to defend a coastal protected area or allow for the restoration of sensitive habitats such as a dune environment, but this may have to be considered as a possible trade-off in the full coastal management process.

Tourism is a very important industry and may offer a viable economic solution to coastal communities, but it must be planned as part of the larger process of coastal management, where environmental quality must be considered along with economic returns. It is necessary to conduct further research regarding the creation of gravel beaches as a viable option for this process. Studies on the perception of beach users and on ecological issues must be considered further and followed closely by an educational component, as they could help develop this important political process.

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