GRAVEL BEACH STABILIZATION MEASURES
IN THE BAIE DES ANGES, CÔTE D'AZUR, FRANCE.

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Abstract - The Baie des Anges coast of the French Riviera is a densely developed area whose beaches represent a very important tourist attraction. These gravel beaches tend to retreat, mainly as a result of man-induced perturbation of their sediment supply. Although rates of retreat are moderate, the process nevertheless threatens seafront property and infrastructure. Shoreline protection measures have included a wall along the Nice seafront, block armouring, groyne fields and breakwaters. These measures have not been effective enough in stabilizing the beaches as they neglect the basic problem which is one of increasing sediment starvation, and they tend to generate other unexpected problems such as higher wave energy reflection and pollution. Since the 1970's, a project of periodic nourishment using gravel has been implemented along certain sectors and has proved to be effective in stabilizing the beach along the Nice seafront. Erosion still proceeds along much of the rest of the groyne-protected unnourished stretches of beaches of four other communes in the study area. These communities lack a coordinated beach protection scheme. The necessity of a common policy of beach management, using soft solutions such as gravel nourishment, appears evident.

Key-words - French Riviera, gravel beaches, coastal erosion, gravel beach replenishment.

Résumé - Le littoral de la Baie des Anges sur la Côte d'Azur est un espace très développé dont les plages attirent beaucoup de touristes. Ces plages de galets ont tendance à reculer à certains endroits, un fait essentiellement imputable à des interventions anthropiques sur la dynamique sédimentaire. Bien que ce recul soit relativement modéré, il menace néanmoins la route nationale de bord de mer et des infrastructures touristiques. Les mesures mises en œuvre pour la protection du littoral consistent en un mur le long du front de mer de Nice, des enrochements, des champs d'épis et localement des brise-lames. Ces mesures ne se sont pas révélées suffisamment efficaces, exacerbant parfois l'érosion tout en engendrant d'autres nuisances. Elles négligent en fait le problème principal de ces plages qui est celui d'un déficit sédimentaire. Depuis les années 1970, un projet de rechargement périodique en galets a été mis en œuvre sur les plages de Nice, méthode qui s'est révélée efficace dans la stabilisation de ces plages. Le littoral continue de reculer modérément mais inexorablement le long d'une grande partie du reste de cette côte malgré la mise en place de batteries d'épis et de brise-lames. Cette partie menacée du littoral est partagée entre plusieurs communes et ne bénéficie pas d'un programme coordonné de lutte contre l'érosion. La nécessité de mettre en œuvre une politique de gestion commune faisant appel à des solutions souples, comme des rechargements en galets, paraît évidente.

Mots-clés - France, Côte d'Azur, érosion côtière, rechargement de plage.

INTRODUCTION

The extreme southeastern Mediterranean coast of France, known as the Côte d'Azur or the French Riviera (Fig.1) is one of the most densely developed shorelines in the world with tourist revenues constituting the basic cornerstone of the local economy.
Beach recreational activities are an important component of tourist earnings and also provide employment to nearly 2000 people. Although tourism dates back over a century, the last thirty years have seen a tremendous boom in land development, with increasing pressures on the coastal zone both as a result of rural exodus and a continual influx of new residents seeking sea and sun. Such pressures result in a more intensive utilization of the beach and coastal zone in general. Apart from providing recreational space, the coastal belt attracts various types of development projects such as hotels and is the locational zone of the main seafront routes and railway line linking up coastal communities as well as France to Italy.

This paper deals with the gravel beaches bounding the Baie des Anges between Nice and Antibes (Fig.2). These beaches are subject to slow but inexorable erosion and the process, if unchecked, will seriously threaten seafront property and infrastructure in the next years to come. The paper briefly presents the anti-erosion measures implemented in the study area and assesses the consequences of such measures on beach stability. The study is part of a wider on-going project on artificial shorelines in the Côte d’Azur (Anthony, 1992) and the basic conclusions should serve as a guideline for future approaches to beach protection, especially in sectors where past and present schemes against erosion have proved a failure.

![Figure 1. Location of the study area in southeastern France.](image)

**SETTING**

The Baie des Anges is a depression divided into two separate bay units, Nice and Villeneuve Bays, by the Var, a typical Mediterranean-type river with a torrential regime. Material brought down by this river has served to build a Gilbert-type delta that interrupts the concave plan-view pattern of the bay beaches bounded by the rocky headlands of Cap de Nice in the east and Pointe de Belaye in the west (Fig.2).

The beaches consist essentially of limestone granule, gravel and cobble clasts mostly representing existing coastal deposits reworked into two coherent bay barriers as sea level rose to stabilize more or less in the middle Holocene. These sediments were supplied by the Var and smaller coastal streams, stripped in part from outcrops of poorly consolidated coastal Pliocene puddingstone formations (Fig.2) rich in rounded clasts. This part of the Côte d’Azur, as much of the rest of this area of the Mediterranean, is bounded by a steep, narrow shelf cut by several narrow channels that sometimes practically impinge on the beach.

The Baie des Anges beaches experience a low tidal range (< 1 m at spring tides) and are exposed to fetch-limited wind waves. The dominant wave approach directions embrace a wide sector stretching from NE to SE, resulting in variable longshore drift. Peak period is 6-7 s and mean wave height 0.6 m. Significant wave height is 0.96 m. Expected wave heights at various return intervals are 3.1, 4.6 and 6.2 m respectively for $H_{1yr}$, $H_{10yr}$ and $H_{100yr}$. Globally, the low wave energy regime is punctuated by storm conditions (H up to 3 m) five to ten days a year, sometimes associated with a barometric increase in sea level of several cm. It is during such events, which occur mainly between late autumn and early spring, that beach reworking is most intense, the beach profile exhibiting very little mobility the rest of the year.

**BEACH EROSION**

Apart from the immediate vicinity of the Var delta, the beaches show no signs of past progradation (Anthony, 1991). Barrier morphology and available stratigraphic data suggest moderate retreat and probably stabilization in historic times. It is thought that the resumption or exacerbation of beach retreat is largely due to man-induced modification of the sediment budget through damming of coastal streams, aggregate extraction, reduction of beach width through increasing land development and urbanization, back-barrier wetland reclamation and the construction of static structures on the upper beach, such as walls and embankments to protect coastal installations. Moreover, the morphology of the steep, deep nearshore zone is such as to favour beach and coastal sediment losses seaward and is an important factor in explaining the particularly fragile status of these beaches when cut off from their usual sediment sources.

The beaches are extremely narrow in places and although their retreat is slow and sporadic, this process threatens coastal infrastructure and residences and in places calls for cumbersome gravel recovery operations over impermeable surfaces such as routes and promenades installed along the seaboard. Landward dispersal of gravels during storm waves generally leads to route closure in certain areas.
BEACH STABILIZATION MEASURES

The two bays forming the Baie des Anges show contrasting modes of coastal management and in this regard, it is enlightening to examine, in turn, the schemes adopted in each bay. The importance of beaches, in economic terms, is such that none of the five coastal communities in the study area can afford to reject the issue of beach stability. Furthermore, since decentralized administration was voted by the Central Government of France in 1984, it has become incumbent on each commune to provide most of the finances for coastal management. Solutions adopted to stabilize and enhance beaches are also dependent on resources available, generally dependent in turn on communities size and the degree of past development and investment, the latter being an important factor in attracting bathers and holidays-makers. Moreover, each commune has its priorities regarding coastal management policies, and it has become clear in certain cases that perception of the problems of beach erosion and protection is not as urgent as it should be in an area reputed for being a tourist Mecca.

Nice Bay

In this bay, coastal defence schemes predate beach stabilization measures. Several "hard" structures have been emplaced on the upper beach over the last decades, basically to protect seafront property and the walk and drive (the famous Promenade des Anglais) from flooding and gravel accumulation. The earliest structure constructed was a wall, progressively extended between 1930 and 1967 along over 80% of the 4.6 km-long beach seafront, the rest consisting of a stretch of block armouring using limestone boulders. These structures have proved efficient in retaining beach gravel projected landwards during storms and in protecting the drive from storm wave flooding (Perez, 1991). Gravel accumulating at the foot of the wall after each storm season is raked down to restore beach width. Block armouring is the standard protection measure along the entire Nice airport waterfront, partly built on land reclaimed from the sea. A series of short, closely spaced groynes was also implanted in the 1970’s and 80’s along the more exposed western part of the beach. This groyne field was not directly intended for beach stabilization but to protect a number of conduits that link up the Nice sewage system with a sewage treatment plant constructed next to the airport. Such groynes have been effective in limiting longshore drift in this part of Nice bay.

None of the above structures has prevented beach retreat related to sediment loss offshore during storms. They may even have exacerbated such losses in places although the softer beach protection measures implemented in the last fifteen years have, as discussed below, tended to stabilize the beaches.

Beach nourishment has been carried out since 1976 (Fig.3), material being injected at various points of the coast, at intervals of from 1 to 5 years with injections of the order of 17000 to 52000 m³, giving an annual rate of 15000 m³. In terms of cost-benefit, this solution appears to be the most interesting. Nice has the rare advantage of having readily available stocks of gravel and cobble clasts from the unconsolidated Pliocene puddingstone formations surrounding the city (Fig.2). Gravel extraction is associated with building sites and terracing operations. Profiling has not been carried out to assess the efficiency of this solution but an acceptable surrogate is provided by measurements of beach width carried out by the technical works department of Nice.
Figure 3. Volumes of gravel beach nourishment in Nice from 1976 to 1986. The gravel comes from waste material excavated by building contractors from the Pliocene puddingstone formations that surround Nice.

These measurements have been systematically carried out since March 1978 along 50 transects regularly covering the entire 4.6 km-long stretch of beach. Average beach width between March 1978 and October 1990 has tended to remain stable (Fig.4), suggesting that the gravel quantities injected on the upper beach and spread out by bulldozers make good the losses to the nearshore zone. The average beach width per transect over the period 1978 to 1990 however shows that there are a number of persistent erosional “holes” where beach width has not been improved by nourishment (Fig.5). The factors responsible for these holes are presently being studied.

Villeneuve Bay

The most threatened sectors concern Villeneuve Bay (Fig.6). The spatial variations in coastal retreat in this bay depend on such miscellaneous factors as clast fining or coarsening, residual gravel accumulation in the vicinity of stream mouth groynes, proximity of the seafront route and embankments, beach surface “sealing” from the construction of marina facilities, motels, car parks, and on-going illegal extraction of gravels.

The solutions implemented to counter erosion have been varied, but lack the harmony of those in Nice Bay. The problem basically is that coastal management along this seafront does not depend on one coordinated scheme but on the choices of each community (Jagoudet, 1991) and even on individual initiatives along portions of beach that are privately administered.
In this part of the French Riviera, much less urbanized than Nice Bay, tardy development accompanied by hasty shoreline management schemes by communities keen on not missing the tourist bandwagon have led to the sprouting of marinas and aquatic sports centres with little or no consideration of their impact on beach dynamics.
Beach protection structures include an important groyne field of limestone blocks on the Cagnes Sur Mer seafront and a series of breakwaters on beaches of St Laurent du Var (Fig.6). Whereas groynes effectively hinder longshore drift, they do not restore a negative sediment budget and erosion still proceeds unabated (Fig.7). Breakwaters essentially serve to provide protection for an aquatic sports leisure centre and have had a negative environmental impact by completely dissipating the small amount of wave energy left after considerable refraction and diffraction of the dominant easterly waves by the Nice Airport complex.

![Figure 6. Presently eroding sectors and hard beach protection structures (groynes and breakwaters) in Villeneuve Bay.](image)

This in turn has led to the progressive sedimentation of fine sediments and pollutants flushed out by the Var river, especially after thunder showers, although no serious study has as yet been carried out on such pollution. Paradoxically, these breakwaters do not appear to be efficient buffers against directly impinging southerly waves which tend to erode sectors between the breakwaters. Sediment losses during storms are probably enhanced by strong seaward directed flows between breakwaters as preliminary field observations have tended to show.

The failure of beach protection along the less urbanized gravel shoreline of the communes of Villeneuve-Loubet and Antibes farther south is illustrated by the state of neglect of parts of the beaches in this part of the bay (Fig.8). These beaches often serve as waste dumps, neglected by both the community authorities concerned and bathers. The attitude of the communities is probably deliberate as there are projects for constructing pleasure ports. In certain limited sectors, episodic sand injections are carried out and have
proven inappropriate in view of the highly reflective nature of the natural gravel shoreline. Sands are dispersed both landwards over pavements and seawards onto the deep shoreface zone. The most severely eroded sectors are protected by block armouring, dismantled in places by storm wave attack. Near Pointe de Belaye, where the beach has all but disappeared, block armouring has had to be reinforced by concrete in order to protect the highly threatened coastal route.

CONCLUDING REMARKS

The foregoing brief presentation has highlighted both the fragile status of beaches in the study area, reputed for its summer tourist resorts, and the inadequacy of most beach protection and rehabilitation methods. It is evident, as is now classically admitted elsewhere, that sole reliance on hard engineering solutions is inappropriate, especially in view of the nature of the clasts composing these beaches. Gravel beaches have a generally "tight" budget and in the French Riviera where coastal streams and cliff outcrops no longer supply beach sediments, this budget is even more delicate because of the propensity for slow but inexorable sediment losses onto the steep nearshore zone. Given the high pressures exerted by land development schemes in this part of the Mediterranean where space is considerably limited, one should expect increasing demands on these gravel beaches. The maintenance of beaches of acceptable width for recreation will necessitate recourse to the only remedy that seems viable, given the sediment budget situation, that of beach nourishment using clasts from surrounding puddingstone formations or from the numerous quarries in the mountains that hem the study area. Periodic gravel nourishment has been successfully practised on beaches of Nice since 1976.

The other four communities, which share a common bay-beach system, lack a coordinated coastal management programme. Each community has implemented (or not) its own coastal defence programme, with little or no consideration of its impact on beach dynamics. Often, while simple beach profile adjustments appear adequate in areas where the beach is wide and where cobbles dominate, providing more efficient protection against waves, the other more threatened areas require more expensive beach protection measures including nourishment and beach restoration programmes. The four communes need to work in concert in order to implement an efficient coastal management project.

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References