# CHAPTER 65

## EXPERIMENTAL STUDY OF THE HYDRAULIC BEHAVIOUR OF INCLINED GROYNE SYSTEMS

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### SYNOPSIS

*This paper presents the results of an experimental study on the behaviour of inclined groynes and a short discussion on the optimization of groyne systems It supplements a paper presented at the XI Coastal Engineering Conference (London, 1968) In the present paper both studies are applied to the design of a groyne system located to the south of the Tagus estuary (near Lisbon), where a serious erosion has been under way*

### 1 - INTRODUCTION

Groynes are one of the most applied coast protection structures because, owing to their transverse position, they detain long shore drift, which is the main cause of serious coastal erosion phenomena (see fig 1) Groynes have practically no influence on transport normal to the coast but this, in addition to being usually small, tends to balance in the annual wave cycle Groynes can be used to stop longshore drift, which may cause undesirable depositions in certain zones (case of beaches in dynamic equilibrium), or to protect beaches where the supply of material is exceeded by the losses. In any case, a single groyne or a group of groynes can be used, the latter - called a groyne system - being particularly important owing to applications in long sand shores

The hydraulic optimization of groyne systems (structural questions, although influenced by the hydraulic behaviour, belong to the stability of maritime structures) is extremely important because groynes must obey economic requirements and simultaneously must provide beach stretches satisfactory for recreational purposes ,

Fig. 1 - Erosion in Caparica beach, January 1970

Fig. 2 - Groyne system tested in the 1st stage of the study

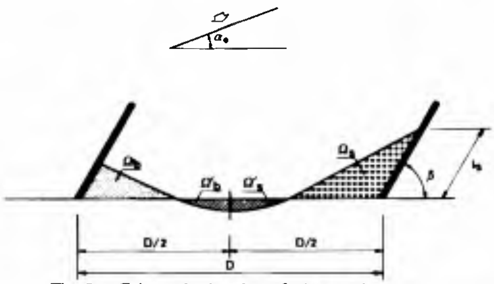


Fig. 3 - Schematic drawing of the testing setup

Fig. 4 - View of a test ($\beta = 50^\circ$; $\alpha_o = 20^\circ$)

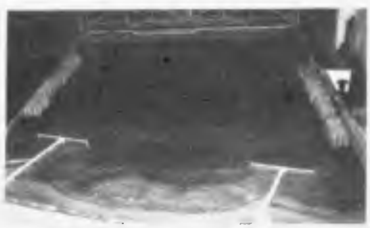

Fig. 5 - Test of T-groynes ($\alpha_o = 20^\circ$)

which, together with coast protection, is their main object This leads to the use of long very spaced groynes, which in addition to affording a satisfactory protection against wave erosion and providing wide beach stretches satisfactory for recreational purposes, improves the landscape of these A groyne system is functional when it meets these requirements

A paper was presented at the XI Coastal Engineering Conference (London, 1968) describing an experimental study of the hydraulic behaviour of systems of groynes normal to the bathymetric curves [1] (see fig 2) This study is now complemented by the present study on inclined groynes, which also contains some consideration on the optimization of groyne systems based on the results of both studies, and an instance of application to a serious case of erosion in the Portuguese coast (Caparica and Cova do Vapor beaches)

## 2 - EXPERIMENTAL TECHNIQUE

The tests were carried out in a tank (with a net area of about 8 m x 18 m), fitted with a translation wave machine The plain sine waves generated had periods from 1 0 to 1 3 s, heights between 3 00 cm and 5 50 cm and obliquities of $20^{\circ}$, $10^{\circ}$ and $5^{\circ}$ ($\alpha_o$ - - obliquity of the breaking wave - see fig 3) The mobile material used was pumice stone with a unit weight of 1 46 gf/cm$^3$ and a median diameter of about 1 5 mm The tests begun with a beach with a transverse slope of $i = 8\%$ The still water level remained constant, i e tides were not reproduced Fixed, high, and impermeable groynes were tested and the beach stretches between them can be considered as independent physiographic units

The testing setup was as extensive as possible so that the evolution of beach stretches between groynes could be studied in detail (see figs 4 and 5) The interference of the tank borders with the transport of sediments was taken into consideration but it was only in one test of very inclined groynes that it was neces sary to reproduce the area near the downdrift groyne with a fixed bed and to remove mobile material beyond this groyne The curve of fig 6, plotted from the quantities removed, represents drift at the end of the groyne versus the duration of the test It should be noted that the conclusions drawn are not invalidated by the absence of updrift feed, which corresponds to the most adverse conditions in the extreme updrift groyne

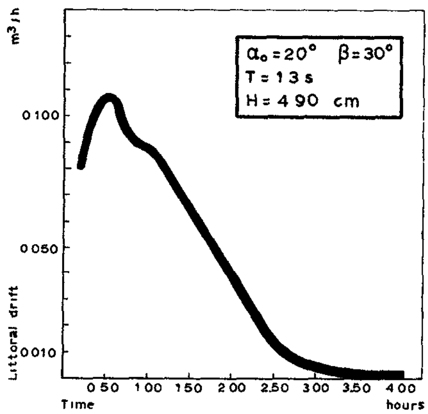


Fig 6

The inclinations considered were those affording the best protection to groyne roots, inclinations symmetrical of these were not tested as they obviously are of no practical interest The study was completed with tests of T-groynes for comparison with the former results

The measurement and bottom surveying methods used were those described in {1} Fresh water was used and the flow can be considered as turbulent Systematic tests to no particular scale were also carried out as the testing setup represents no specific case

## 3 - EXPERIMENTAL RESULTS

On the whole inclined groynes (see fig 3) operate roughly as normal groynes ($\beta = 90^{\circ}$), i e beaches initially with a uniform transverse slope of 8 % reach final equilibrium conditions essentially depending on the characteristics of the wave for each value of $\beta$ The characteristic parameters of the operation of groynes are those indicated in {1} , but the following are particularly relevant in the present study accretion areas $\Omega_s$ and $\Omega_b$, total accretion area $\Omega = \Omega_s + \Omega_b$, evolution $l_s$ of the beach near the downdrift groyne, spacing D between groynes, length c of the groynes, and value

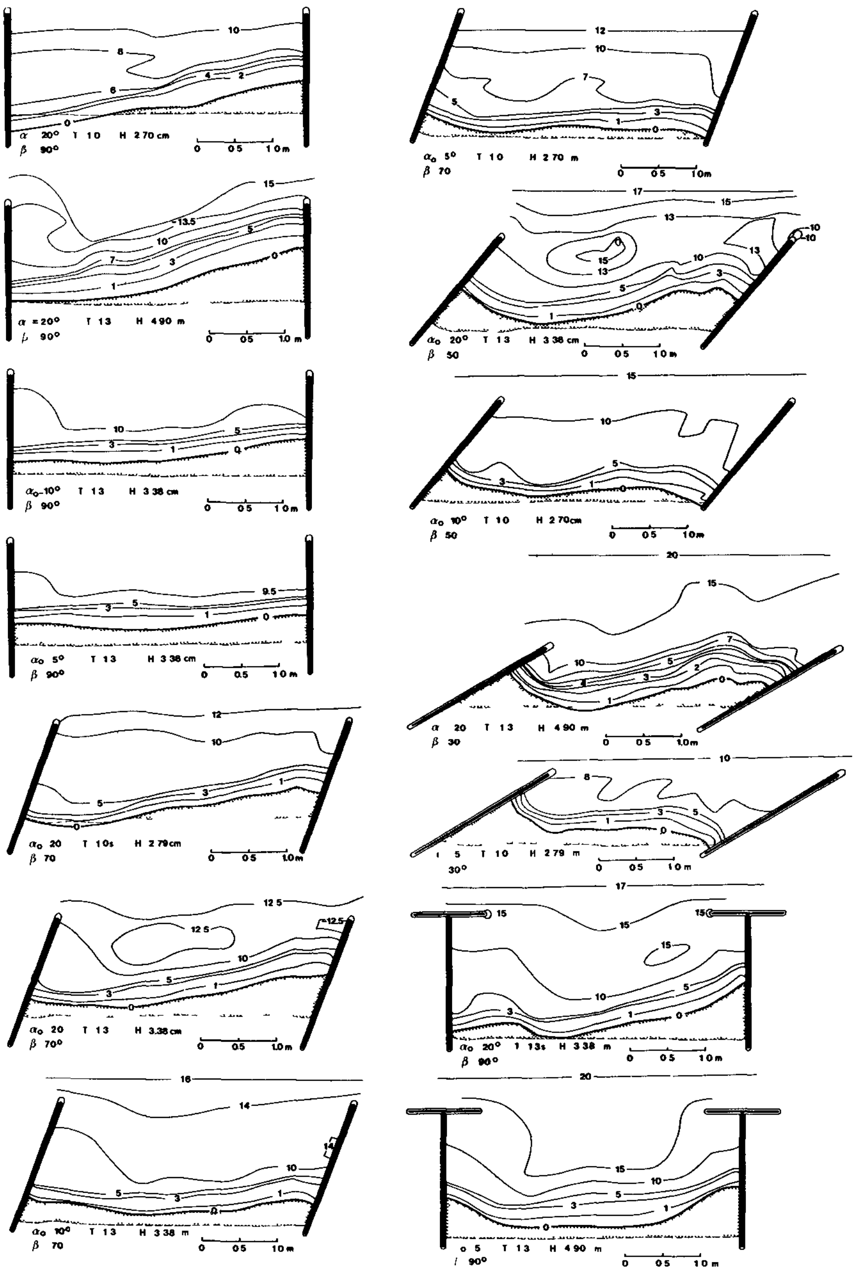

Fig 7 - Typical plans of final equilibrium conditions of the tested cases

$H_o^2 C_o$ proportional to the transmitted wave power ($H_o$ and $C_o$ are the wave height and the wave speed in infinite depth, respectively) Detail characteristics of the evolution of beach stretches will be taken into consideration and the efficiency of inclined groynes will be defined in function of these characteristics

The detail characteristics of the evolution of beach stretches are presented in fig 7, which shows the final equilibrium condition for the different typical cases studied, the dotted line represents initial conditions in the beach for a zero water level, the indicated value of the wave height, H, concerns the depth where the wave generator is placed Groynes with $\beta = 90^o$ may cause erosions near the updrift groynes for the maximum obliquities tested, whereas accretions extend throughout the width of the beach stretch for lower obliquities, in which transverse movements predominate For $\beta = 70^o$ the overall behaviour of the groyne system is not changed, but erosion hazards near the updrift groyne decrease, and for obliquities of $\alpha_o = 20^o$ there is even deposition throughout the beach stretch, owing to the shelter afforded by the updrift groyne, for smaller obliquities, the beach retreats near the downdrift groyne and the area $\Omega_s$ decreases For $\beta = 50^o$ the increase in the accretion area $\Omega_b$ and in the protection afforded by the root of the up drift groyne grow more marked For smaller obliquities regression increases near the downdrift groyne and the areas $\Omega_s$ decrease For $\beta = 30^o$ the beach stretch can hardly be considered as a physiographic unit for large obliquities, for smaller obliquities considerable erosions occur in the root of the downdrift groyne and the areas $\Omega_s$ are appreciably reduced T-groynes operate roughly as normal groynes but the protection afforded to the groyne roots is present in all cases and the symmetry of areas $\Omega_b$ and $\Omega_s$ is more marked

The two most relevant parameters for the definition of the efficiency of groynes (accretion areas and evolution of the beach near the downdrift groyne) are defined in fig 8, which represents

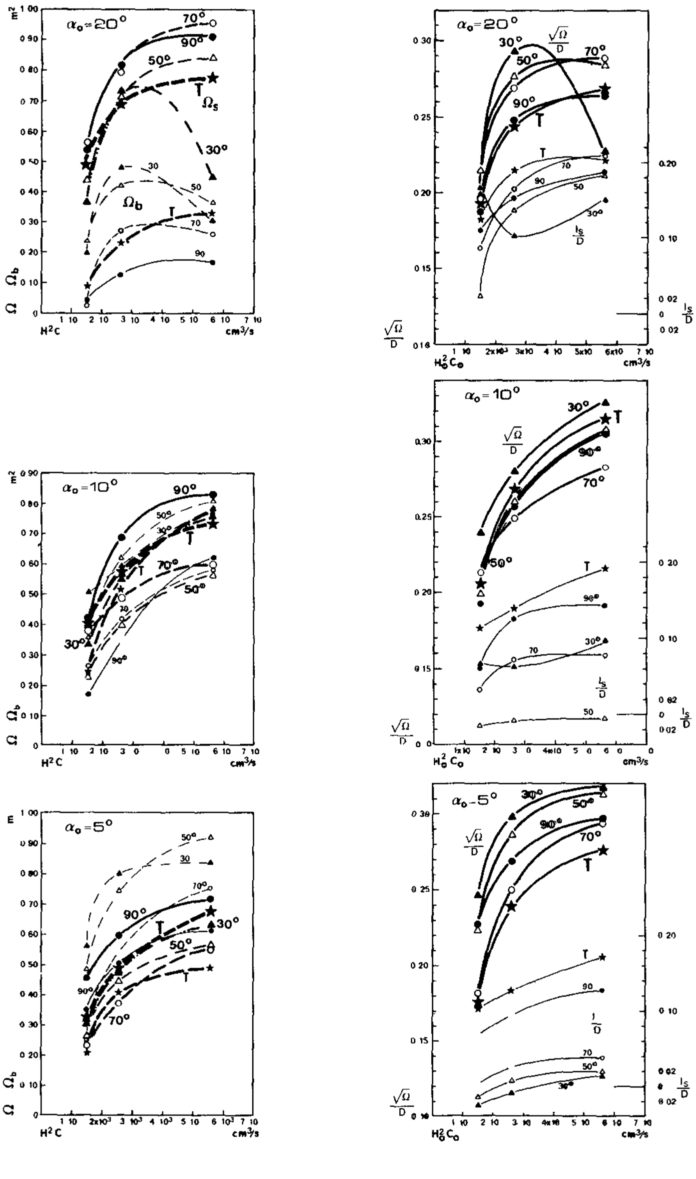


Fig 8 - Curves of the parametere defining the efficiency of groynes in function of the transmitted wave power the curves of $\Omega_s$ and $\Omega_b$ (thick and thin lines respectively) with dimensions which give an idea of the values observed in the model tests, and the curves of $\sqrt{\Omega}/D$ together with those of $l_s/D$ (dimensionless values suitable for practical applications) The figure also presents the curves of these parameters in function of the value $H_o^2C_o$ proportional to the transmitted wave power for each obliquity $\alpha_o$ of the breaking wave It is from these dimensionless values that the efficiency of the groyne types tested will be defined For $\alpha_o = 20^o$ the maximum efficiency corresponds to $\beta = 70^o$, if the increase not only of $\sqrt{\Omega}/D$ but also of $l_s/D$ is taken into account For $\alpha_o = 10^o$ the groynes with $\beta = 90^o$ are the most efficient taking into account the fact that $l_s/D$ is larger for $\beta = 90^o$ although the values of $\sqrt{\Omega}/D$ are higher for $\beta = 30^o$ For $\alpha_o = 5^o$, groynes with $\beta < 90^o$ yield values of $l_s/D$ which are very low or correspond to erosions, so that the maximum efficiency is obtained for $\beta = 90^o$ T-groynes are not more efficient than normal groynes ($\beta = 90^o$), their only advantage being the absence of erosions in the groyne roots

The efficiency of the different groyne types was defined for the maximum transmitted wave power

These results agree with Prof Nagai's {2} , as regards both the inclinations of the groynes and the values of the ratio c/D

## 4 - PRACTICAL APPLICATION

Portuguese beaches are extremely valuable assets for our economy due to their variety and remarkable natural conditions, so that they must be improved, and protected against the serious phenomena of erosion which endanger them

One of the most serious erosion phenomena in the Portuguese coast occurred in the beaches of Cova do Vapor and Caparica, a long sand expansion south of the Tagus estuary near Lisbon From the situation presented in fig 9, which prevailed in 1929, erosion begun due to the collapse of the natural protection afforded by the sand formation north of the beaches, which ends at the

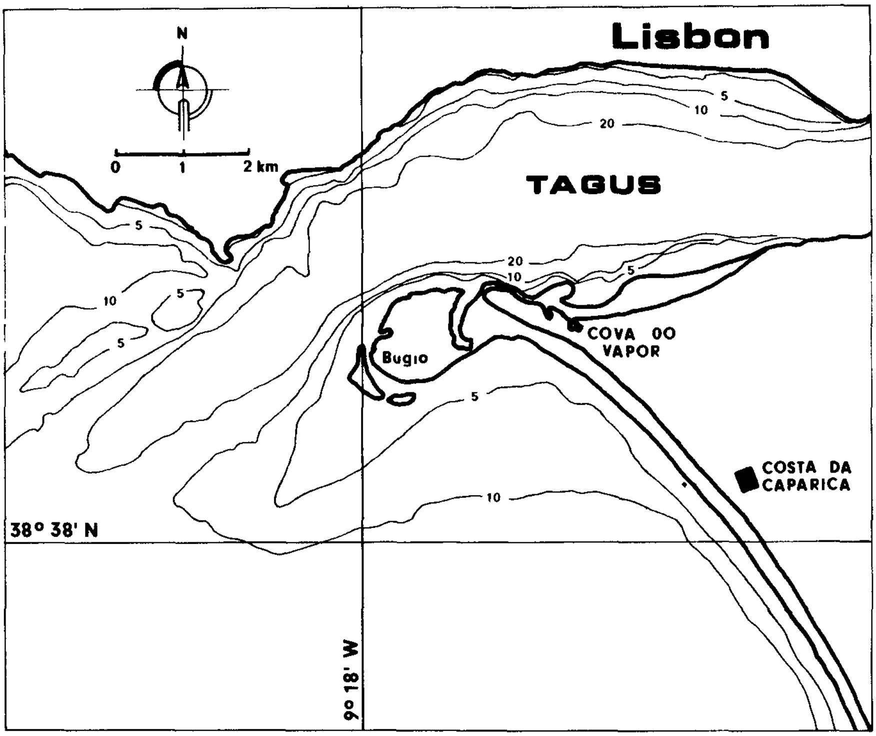


Fig 9 - Caparica and Cova do Vapor beaches (1929)

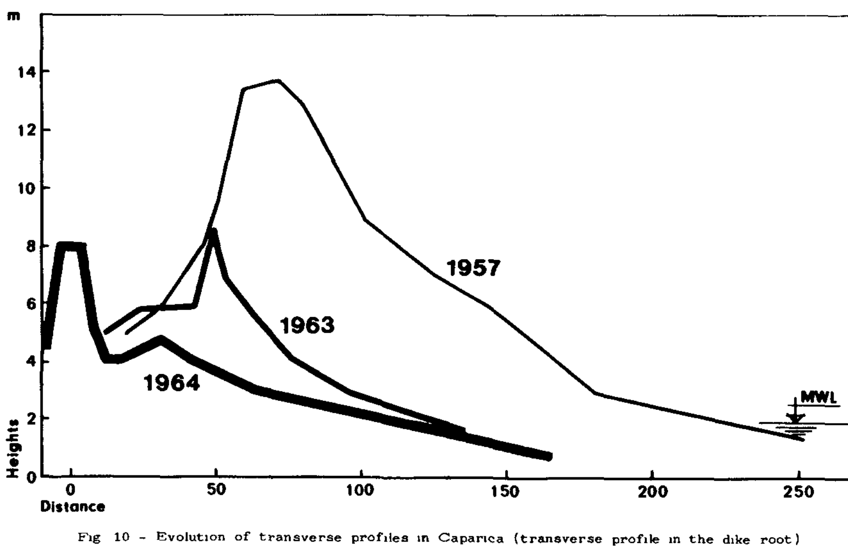


Fig 10 - Evolution of transverse profiles in Caparica (transverse profile in the dike root) zone of the Bugio lighthouse The very oblique approach of the waves caused northward sand movements from the central zone of Caparica beach, where the obliquity of the wave action was very reduced or even normal to the coast so that the beach south of Caparica was very stable

When the natural protection to the north collapsed an intense longshore drift begun that formed a spit in the root of the existing formation, this spit was fed in part by the sands carried northward, the remainder being deposited in the channel of the Tagus estuary, the great depth of which avoided serious disturbances This phenomenon begun to affect Caparica practically in 1960 in the form of the erosion mechanism illustrated in fig 10 The first emergency measures, taken in 1959, consisted in the construction of a groyne (see fig 11, E3) and were followed by a frontal protection structure and groynes $E_1$ (1962) and $E_2$ (1963) at Cova do Vapor When the waves cut the sand dunes between Cova do Vapor and Caparica a dike with a light structure was built (1959) to protect the urban areas in the neighbourhood, located below the mean level of the sea, against the runup of spring tide waves

The situation grew worse after 1964 when serious destructions occurred in the central zone of Caparica, so that the dike was strengthened and a frontal protection core was built at its root, together with a short groyne, which, of course, proved entirely useless Obviously the influence zone of the groyne built at Cova do Vapor was too small to protect the southern beach and the other protection works in the same site merely helped to form a resisting core that prevented the entire destruction of the zone and of the small village in it Other emergency measures were taken after 1964, so that the situation evolved to the state presented in fig 12 (a comparison of which with fig 11 shows the evolution in 1963-1969) after the groyne $E_2$ was extended and the beach between Cova do Vapor and Caparica was entirely eroded except for a small zone protected by the first groyne built, the northern spit moved under the influence of the waves up to the NATO jetty

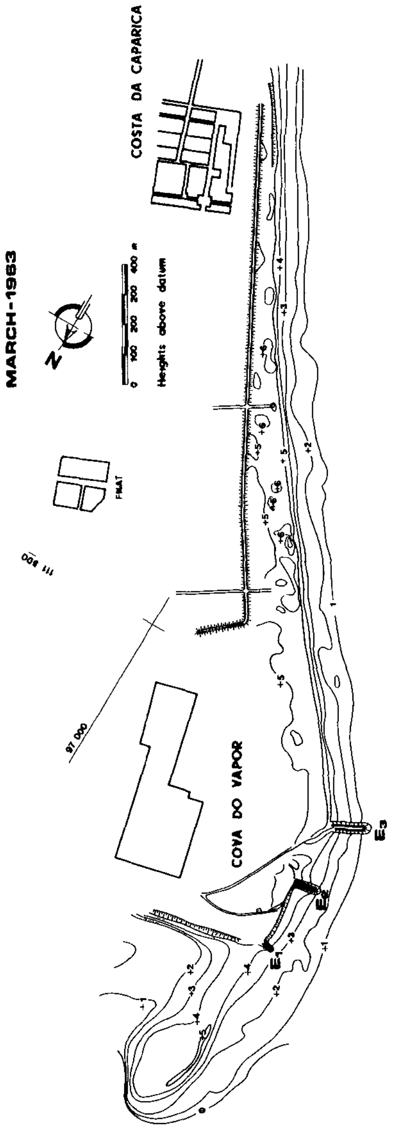


Fig 11 - Plans of Cova do Vapor and Caparica beaches (March 1963)

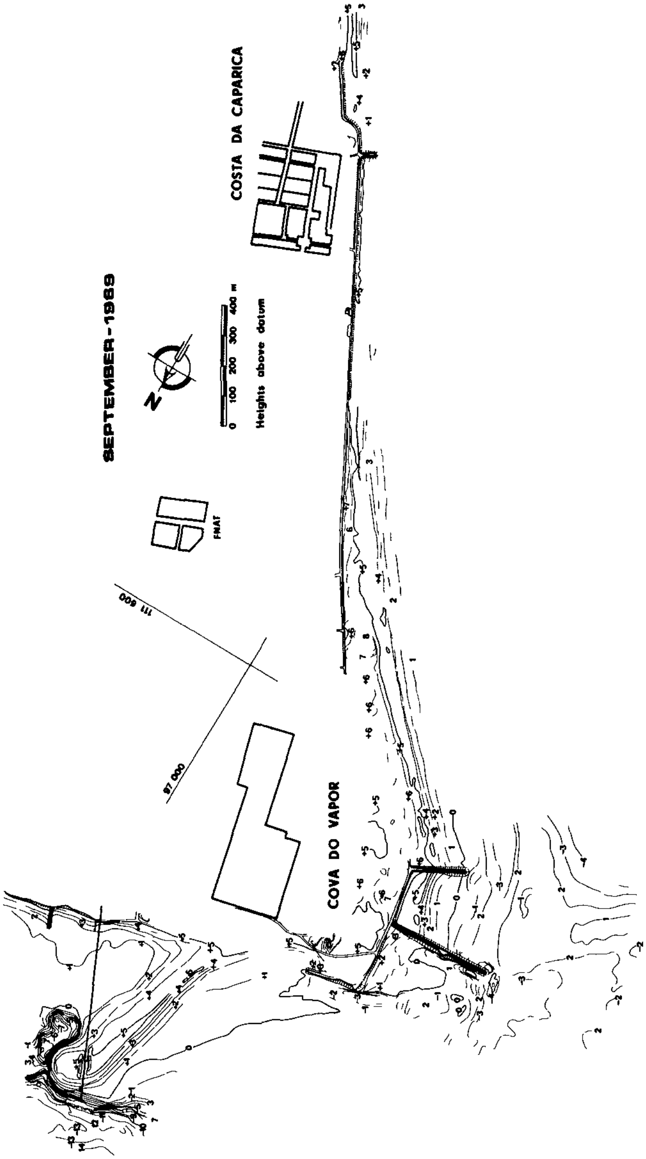


Fig 12 - Plans of Cova do Vapor and Caparica beaches (September 1969) also shown in fig 12 According to the studies carried out {3} the littoral drift in this zone is estimated in 1 000 000 $m^3$/year At the same time, owing to changes in the sea-bottom relief and their in fluence on the wave action, a rapid erosion started in the central zone of Caparica particularly serious in the beaches to the south (see fig 1) Another emergency structure for frontal protection was built and subsequently strengthened in the central zone of Caparica

The main physiographic characteristics of the beaches of Cova do Vapor and Caparica have been very rapidly presented Many comprehensive studies of this case were carried out by official and private bodies charged with and interested in the development and exploration of marine zones Owing to insufficient means, deficient policies of beach protection and development, and uncoordinated activities of the different official and private bodies involved emergency structures — some of which entirely unsuited — were resorted to, but did not prevent the loss of one of the best Portuguese beaches

Figures 13 and 14 give an idea of conditions in Caparica beach before the erosion begun and now (July 1970) The groyne $E_2$ (fig 11 and 12) is now being extended, and the construction of a groyne system and the strengthening and extension of the frontal protection structure {4} are in preparation The groyne system is made up of units which, although very long, have a reduced effective length and a small spacing and are located at very high elevations With such a system, the restoration of the beach is out of question, as the existing groynes to the north cannot operate efficiently for lack of supply from the south due to the disappearance of the beach On the other hand the southern stretch of the beach will tend to be eroded away up to the extended frontal protection structure, which will have to be exaggeratedly strengthened These measures, planned a long time ago for hydrographic conditions no longer prevailing, are unsuited to the present needs and will never

Fig. 13 - Caparica beach before erosion begun

Fig. 14 - Caparica beach in July 1970 (low water level)

Fig. 15 - Scheveningen beach (The Hague, Netherlands)

provide a beach with real recreational and touristic interest As an instance of a system of functional groynes, the one built at Scheveningen beach (The Hague, Holland) is presented, the construction was very expensive owing to the extraordinary structural perfection of the groynes, but the results were excellent (see fig 15)

The restoration and protection of these beaches requires an artificial feeding and a system of functional groynes, i e long very spaced groynes The artificial feeding would restore e g. 1963 conditions, as shown in fig 16 The northern spit is represented in the figure, because studies on the touristic development of Cova do Vapor carried out in 1966 for the TECHINT project {3}, recommended the construction of a long groyne in the northern end and the creation of an extensive beach mainly at the cost of sand dredged from the spit, in which a pleasure boat port (represented by the dotted line in the figure 16) would also be built The solution recommended here for the present conditions would require the straightening and protection of the bank, upstream of the root of groyne $E_o$, the artificial restoration of the beach being necessary to the south of $E_2$ alone This location of groyne $E_o$ is preferable to the one shown in fig 12, which would leave two groynes very near one another disturbing the operation of groyne $E_o$

By means of the plan presented in fig 16 it would be possible not only to recover the beaches and protect the coast to the south of Caparica but also to avoid the extension and strengthening of the frontal protection structure Obviously a more detailed study of this plan (which is no more than a typical solution), could yield a better and more economical solution A single very long groyne to restore the natural connexion with Bugio together with a large volume of sand to restore the beach (a natural restoration being impossible owing to lack of supply and the irreversibility of erosion) would leave a long stretch of beach without protection making possible local erosions, so that the solution presented is preferable

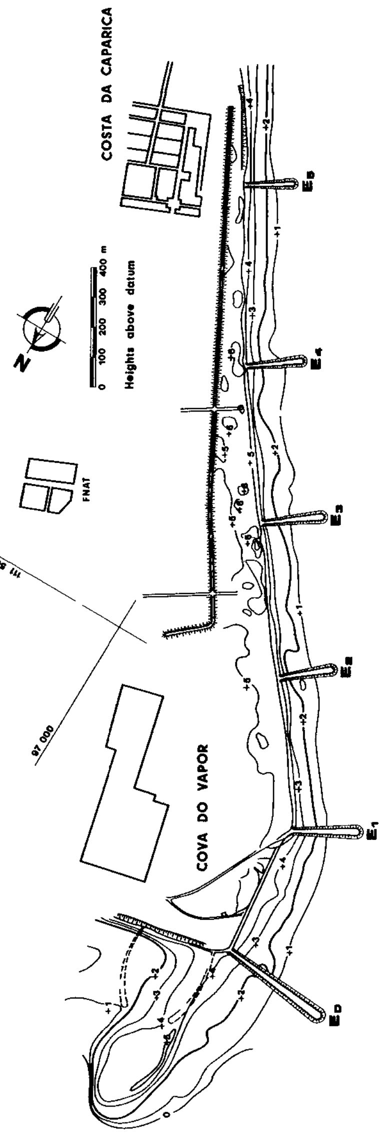


Fig 16 - Groyne field drawn on the March 1963 survey (Cova do Vapor and Caparica beaches)

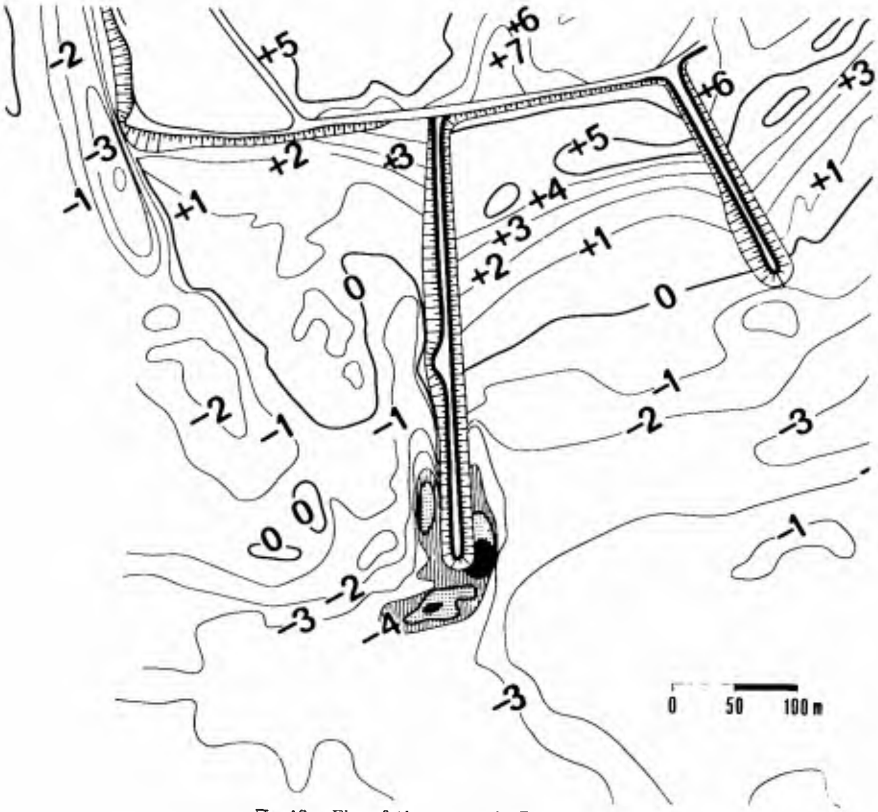


Fig. 17 - Plan of the groynes in Cova do Vapor (September 1969)

Fig. 18 - Detail of the construction of groynes in Cova do Vapor

Fig. 19 - Erosion at the ends of the groynes obtained in the models

The typical solution presented for the groyne system takes into account the two studies carried out As wave conditions are variable, groynes with $\beta = 90^{\circ}$ were chosen The obliquities $\alpha_o$ considered are $10^{\circ}$ in the zone from Cova do Vapor to the middle of the dike, and $5^{\circ}$ from this point to the central zone of Caparica The reference line for calculating the length of tne groynes will be the bathymetric curve + 2 00 m For $\alpha_o = 10^{\circ}$, c/D = 3 5 and for c = 150 m, D = 520 m (groynes $E_1$ to $E_4$), for $\alpha_o = 5^{\circ}$, c/D = 4 0, which for c = 150 m yields D = 600 m($E_5$) Groyne $E_5$ may be shorter (c = 100 m, above + 2 00m) because the zone updrift of this groyne would be stable and obliquities are very small, an inversion to the south being even possible with small obliquities

It should also be noted that an efficient system does not depend on the location of the groynes alone Their structure and certain constructional details are also essential As an instance, the case of groyne $E_2$ (fig 11 and 12) is presented excavations shown in the fig 17, occurred at its end, in concentric zones at depths -4, -5, -6, the darker zones corresponding to the last depth These peculiarities seriously interfered with the construction of the groynes and caused an exaggerated use of rockfill An adequate base of the groynes protecting the adjacent sea floor against erosion is essential but, as shown in fig 18, these groynes lack such a special base As can be seen in fig 19 erosions at the end of the groynes occur even in the model tests, those shown having been observed in tests carried out in the first stage of these studies

## 5 - CONCLUSIONS

— The angle of the groynes with the shore line is a function of the obliquity $\alpha_o$ of the waves For high obliquities ($\alpha_o = 20^{\circ}$) the maximum efficiency corresponds to inclined groynes with $\beta = 70^{\circ}$ For intermediate ($\alpha_o = 10^{\circ}$) and low ($\alpha_o = 5^{\circ}$) obliquities, normal($\beta = 90^{\circ}$) groynes are preferable to inclined groynes

In variable wave conditions efficiency will be defined in func tion of the range of obliquities of the waves present In this case normal groynes ($\beta = 90^{o}$) are recommended

It should not be forgotten that inclined groynes are longer (increased c) for the same spacing D For $\alpha_{o} = 20^{o}$, groynes with $\beta = 70^{o}$ are 30 % longer than normal groynes ($\beta = 90^{o}$), whereas the increase in the area $\Omega$ of the inclined groyne is 20 % only The fact that groynes with $\beta = 70^{o}$ protect the root of the updrift groyne against erosion should be taken into account.

– T-groynes are not more efficient than normal groynes, except for $\alpha_{o} = 10^{o}$, and even then the difference is small (see fig 8) Their only advantage lies in preventing erosion near the roots of the groynes Nevertheless they are not recommended because, in addition to their construction being more expensive, they disturb the utilization of the beaches for sea baths

– The hydraulic optimization of groyne systems must take into account not only the ratio c/D, the values of which were defined in {1}, but also the inclination of the groynes according to the criteria presented above A judicious application of these results must obviously be based on a knowledge as complete as possible of physiographic conditions in the involved zone, and other questions must also be taken into account such as the stability and the crest elevation of the groynes (the latter basically depends on the transverse profile of the beach and its evolution)

Another basic point to be borne in mind when designing systems of functional groynes and which may help to reduce the volume of the structure is that its object is not, as a rule, entirely to stop the littoral drift occurring in zones of the beach variable under the action of tides, but to preserve a certain area of the beach On the other hand littoral drift is more marked for high tide levels, precisely the conditions in which groynes operate most efficiently This leads to adopting groynes, which although long, do not extend to very low levels

— The cooperation of the different official and private bodies interested in the exploration of marine zones seems extremely important Protecting structures should be thoroughly studied and designed, and constructed without delay, emergency or experimental structures are strongly disapproved, all the more so as the present knowledge in this field makes them entirely unnecessary

— In the case of Cova do Vapor and Caparica, the essential solution for the restoration and improvement of the beaches is their artificial feeding and a functional compartimentation of the beaches by means of a system of groynes

LITERATURE

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