CHAPTER 210

PORT OF LISBON
IMPROVEMENT OF THE ACCESS CONDITIONS THROUGH THE TAGUS ESTUARY ENTRANCE

I. B. Mota Oliveira[1]

ABSTRACT

The Port of Lisbon authority is aiming at the reception of container ships of the fourth generation. For that a deeper and wider artificial channel has to be dredged through the outer bar. The set of studies undertaken (data collection, site investigations, mathematical and physical modelling) put into evidence the importance of the opening of a secondary bar, some 50 years ago, over the general morphological behaviour of the estuary entrance. So a recommendation has been made to close it using an artificial sand dike.

1- INTRODUCTION

The Port of Lisbon takes advantage of the excellent conditions offered by the lower reach of the river Tagus estuary, as a natural harbour.

The port facilities are distributed along the banks of the estuary, mainly along the north bank: 16 km of quays (13 km in the north bank) with depths from 4 up to 17m (CD); 98 ha of reveted embankments; 1100 ha of total dry area under the port authority control (Administração do Porto de Lisboa - APL). In addition the estuary shelters: a major ship repair yard; a navy base; some important industry terminals (steel mill, chemicals, food processing, cement, etc); fishing facilities; small craft (yachting) harbours.

With an annual traffic of 17 million tons (1991), the port of Lisbon is the main portuguese port. General cargo accounts for about 26% of that tonnage, being 39% for liquid bulks and 35% for dry bulks. General cargo is already containerised at a level of 60%, equivalent to about 285 000 TEU.

The Tagus estuary - Figure 1 - affords excellent depths in the lower reach, a "corridor" of some 12 km in length with approximately parallel banks between the entrance and the Praça do Comércio Square in Lisbon. On the contrary, it is very difficult to get here new embankments: on the north side, because of the neighbouring town, namely the historic zone, against which the port is really compressed; on the south side, because of the very steep margins. From Praça do Comércio upstream the situation is reversed: it is easier to get new embankments but natural depths diminish progressively, sedimentation problems in channels and basins worsen and maintenance dredging becomes critical.

[1]Partner, HIDROTÉCNICA PORTUGUESA, Consulting Engineers. Lisboa,
Professor, INSTITUTO SUPERIOR TÉCNICO, UTL. Lisboa, Portugal

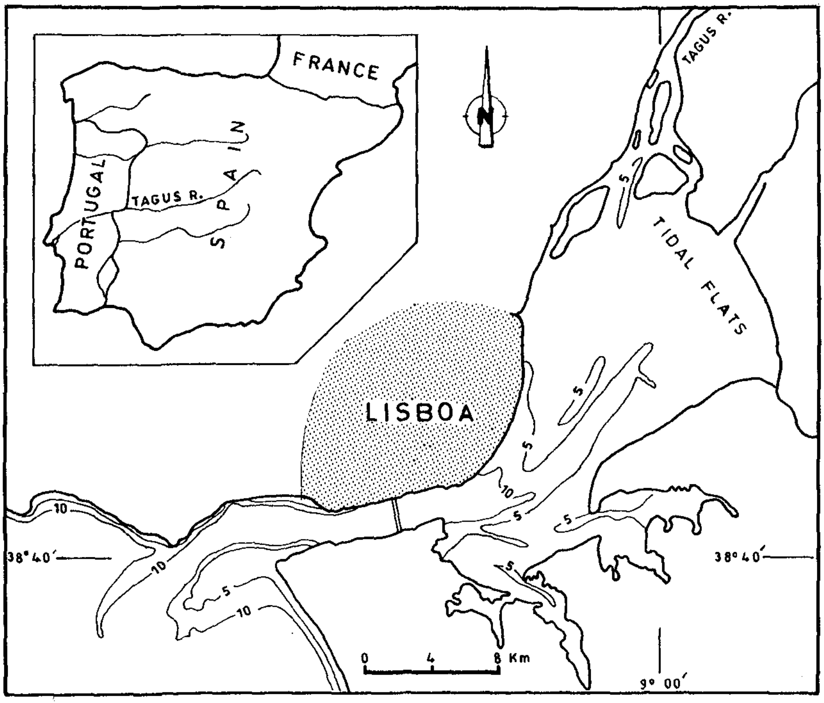


Figure 1 - The River Tagus Estuary

The estuary has a total area of the order of 250 km^2 which, with a spring tide amplitude of almost 4 m, generates a tidal prism around 1 000 * 10^6 m^3. The tidal amplitude varies along the estuary and it is worth mentioning that, on account of a small resonance effect, the amplitude inside the estuary is greater than in the outside, growing continuously from the estuary entrance up to the Praça do Comércio Square.

The tidal prism is the main agent in maintaining the excellent depths across the Tagus outer bar: almost 12 m in spring low water and 15 m in mean high water - Figure 2. That explains why only in the last two or three decades the bar began to cause some significant constrains to the navigation of the largest ships calling the port of Lisbon. As a matter of fact, the first dredging works in the outer bar, at a level of (-13.5 m CD), were carried out only in 1969.

It should be mentioned that this bar was crossed by tankers of the 300 000 dwt class (and even 500 000 dwt), mainly empty ships bounded for the repair yard of LISNAVE, within the estuary.

The port authority (APL) is now aiming at the reception of container ships of the so called fourth generation, almost without navigation restrictions in the outer bar (Length: LOA=290 m; Beam: B=32 m; Draft: D=13 m). Several studies where undertaken, including data collection, site investigations, mathematical and physical modelling, improvements in aids to navigation, etc.

The main purpose was to establish the geometry of an artificial channel through the outer bar (alignment, depth, width) and to estimate the corresponding mean annual volume of maintenance dredging. In addition, the evaluation of the

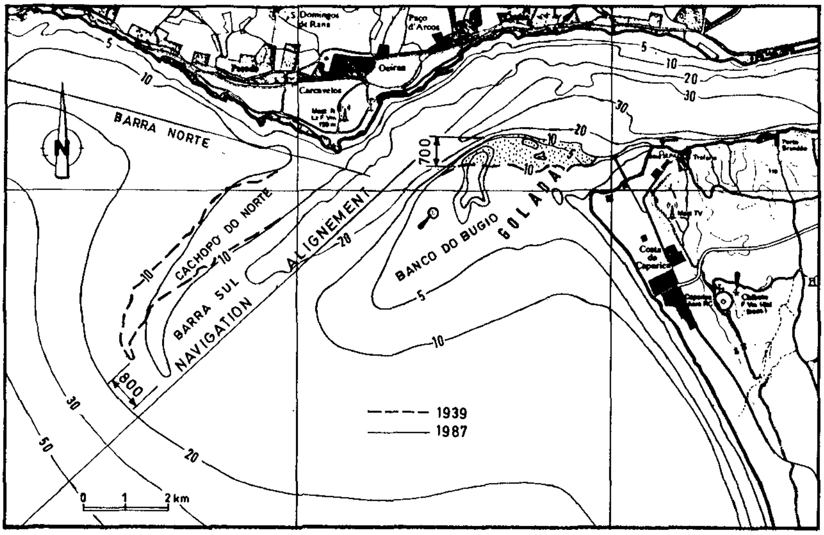


Figure 2 - The Entrance of the Tagus Estuary

general consequences of the closing of the Golada was also considered.

Golada is a secondary bar over the "Banco do Bugio" , this latter being a big shoal that defines the southern bank of the main entrance channel - Figure 2. It is a morphologically very unstable area, with very small depths, which in the beginning of this century had yet the nature of a sand spit that, at least in low water, allowed the pedestrian access to the Bugio lighthouse (in effect a fortress of the last years of the 16th century).

During the forties this secondary bar (Golada) "broke" through the Banco do Bugio. So, another question to be answered by the study was: what have been the consequences of that event over the stability of the main outer bar or, what would be the consequenses of an artificial closing of the Golada, namely upon the maintenance conditions of the artificial channel to be cut through the main bar?

Only a brief summary of those studies and of their main results can be presented in this paper.

2 - ARTIFICIAL CHANNEL THROUGH THE OUTER BAR

2 . 1 - Alignment

It was decided to open the artificial channel according to the "traditional" navigation route, that is to say, the alignment that has been used by pilots for many decades to cross the bar and to navigate along the lower reach of the estuary - Figure 2. In fact, a different alignment would imply:

- a second set of navigation aids ;
- additional steering problems in the transition between the two alignments; the risk of a ship grounding would be particularly high in an outgoing trip during the ebb phase, when ship and tidal velocities add each other; indeed in the area of the channel ebb currents are stronger then flood ones and, in an outgoing manoeuver, the ship passes from an almost unrestricted

navigation area, upstream the channel, to a confined path width.
- the change of navigation habits that has been established for a long time (may be, the main reason).

On the other hand, the advantages of the new alignment (mainly, a somehow shorter length of the artificial channel) seems almost irrelevant in relation to those negative points.

2 . 2 - Cross-Section

2 . 2 . 1 - Depth

In order to obtain the total required depth of the channel the loaded draft of the reference ship must be added to the corresponding "underkeel allowance", that is to say, the clearance between the keel of the standing still ship in calm water and the nominal level of the channel bed. The underkeel allowance faces a number of different ship movements (rolling, pitching, squat), and includes the net clearance which accounts for the minimum allowance under the keel when the ship moves along the channel under the most unfavourable conditions.

In a case like the bar of the Tagus estuary, facing openly the Atlantic Ocean, the most important movements of the ship are by far those resulting from the wave action. In theory, the maximum immersion of the ship due to rolling and pitching could be obtained through the "amplitude response operator" of the ship, relating those movements with the wave period, for a given water depth and angle of wave attack.

Indeed in our case that operator for the "project ship" was not known. Nor physical or mathematical modelling had been foreseen to establish the channel depth.

A bibliographical study was made, taking advantage of the known performance of artificial channels cut in environmentally similar conditions. The main steps of the study were as follows.

Based on data of the "Oceanographic Atlas of the North Atlantic Ocean. Section IV, Sea and Swell" (U. S. Naval Oceanographic Office), the deep water wave climate was defined. By means of regular wave diffraction diagrams, the local wave climate (in the area of the artificial channel) was established in terms of wave heights and angles relative to the channel alignment. In what concerns wave heights, their frequencies have been characterised by height intervals of 0.5 m, from 1.5 m to 4.0 m. In a word , for the mean year it was obtained

$Hs < 1.5$ m	285	days/year	(78.1 %)
$1.5 \text{ m} < Hs < 4.0$ m	77	"	(21.1 %)
$Hs > 4.0$ m	3	"	(0.8 %)

After a careful analysis of some case studies (Richards Bay, South Africa; Ashdod, Israel; Antifer, France; Europort, Netherlands; Inkoo and Tahkoluoto, Finland) the hypothesis was made that the maximum sinkage (s) of the project ship (rolling and/or pitching) due to a certain wave would be equal to its height (H): $s=H$. Taking into account the velocity of the ship and the depth of the channel, a maximum squat of 0.6 m was considered and an underkeel clearance of 0.6 m was accepted. So, the maximum overdraft (underkeel allowance) needed in the presence of a wave height H will be $Z=H+1.2$ m.

"Distribution" of tide levels in the region of the outer bar was defined by means of a level duration curve. If we think of time intervals while the tide levels remain below a certain value (Tl), we have as an example the following "probabilities" pTl = p(tide level < Tl):

Tl = 0.7 m CD, pTl = 2%; Tl = 2.7 m CD, pTl = 75%.

Let C be the channel bottom level and D the draft of the project ship (13m).

In order to cross the bar in the presence of a wave height H a minimum tide level

$$Tl = C + D + Z = C + D + H + 1.2 \text{ m} \qquad (1)$$

will be necessary (C and Tl are referred to Chart Datum; C is negative).

If a given wave height H occurs, the channel will be "inoperative" for any tide level below the value given by expression (1). A measure of the "inoperativeness" (Inop) of the channel can be obtained as follows

$$Inop = \sum_i pHi * pTl \qquad (2)$$

in which pHi is the probability associated to the local wave height interval (Hi-0.5 m) < H < Hi .

Three channel bottom levels were "tested": C = -17; -16; -15 (m CD). The "inoperativeness" can be expressed as a percentage of the total time or, alternatively, it can be though as the percentage of the number of "project ships" that will suffer some waiting time to cross the artificial channel .In effect the arrivals are random. Taking into account that a ship calling the port crosses the estuary entrance twice, the results obtained were

Channel bottom level (m CD)	Inop (%)	Ships suffering some waiting time to cross the bar
- 15	11.1	1 out of 4 or 5
- 16	3.2	1 out of 16
- 17	0.6	1 out of 85

A nominal bottom level C = -16 m CD was recommended to the port authority. For a tide level of 0.7 m CD (98% exceedence), the project ship (D = 13 m) will afford an overdraft of 28.5% (16.7 m/ 13 m = 1.285), which compares with the reference cases: Richards Bay, 35%; Ashdod, 35%; Europort, 32%; Antifer, 10%; Inkoo, 15%.

Of course, the channel has to be built at a somewhat lower level to account for sedimentation between dredging works

2 . 2 . 2 - Width

Considering the small length of the artificial channel (≈4 km) and the relatively small number of ships having to travel within it, a one lane channel was considered suitable in this case. The channel width was assessed preliminary by means of empirical rules. In a second approach, a mathematical model was elaborated to simulate the ship manoeuvring in the channel.

According to CIERGNA (Commission Internationale pour la Reception des Grands Navires) of PIANC (Buletin nº 35, 1980) the width of a one lane channel should not be smaller than 5B, B being the ship beam; in some very severe conditions, for instance strong transverse currents, according to the same commission that width could reach the value of 10B.

In the case of the Lisbon outer bar, ebb and flood currents flow more or less parallel to the navigation channel. On the other hand, strong winds can represent a critical problem on account of the high free-board of the project ship (container ship), in as much as they can occur perpendicularly to the ship path.

The cases mentioned previously (Richards Bay, Ashdod, etc) were carefully analysed, namely the "adimensional" widths (n B) when related to their specific environment conditions. Values between 5 B (Tahkoluoto) and 8.4 B (Antifer) were found.

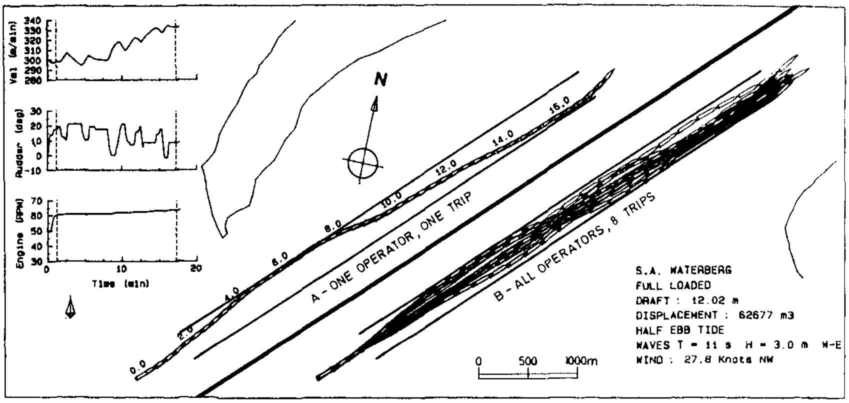


Figure 3 - Ship Motion Controlled by a) One Operator and b) All Operators, for a Given Set of Environmental Conditions

The importance of aids to navigation systems is pointed out by CIERGNA and is put into evidence by the case studies analysed: the poorer the system, the wider the channel has to be.

As a first approximation a width of 300m, corresponding to 9.4 B (B=32 m), was adopted; the capabilities of the present aids to navigation was taken into consideration. It has to be said that pilots claim for an even wider channel (350 m).

A numerical model (SIMNAV) was then elaborated by Laboratório Nacional de Engenharia Civil - LNEC. Its characteristics and capabilities are described by Santos and Rita (1991). It simulates the ship manoeuvring in coastal waters, calculating the time evolution of the ship heading and position, taking into account the motion in the horizontal plane.

The following testing parameters were considered:

- Loading conditions of the ship: fully loaded; in ballast.
- Tide levels: mean tide level; spring low water.
- Currents: tidal currents as obtained from the 2D hydrodynamic model (see item 3.3).
- Local wind: calm; 50 km/h perpendicular to the ship path.
- Local waves: no waves; H=3m, T=11s, α =45°.

The most unfavourable conditions were obtained combining waves 3 m high with transverse winds of 50 km/h.

Four different operators conducted a reasonable number of manoeuvres in the model for each environment situation. The operator controls the ship by varying the rudder angle and the available torque at the propeller axis. Figure 3 presents a single trip and the superposition of all the trips made by the four operators for the same testing conditions.

The variable considered in the verification of the channel width was the maximum distance per trip between the channel axis and the ship's centre of gravity - Y. Curves of probability of exceedence of | Y | were obtained. The conclusion of the model study was: the acceptable channel width will be somewhere between 272 m and 300 m.

2 . 3 - Maintenance Dredging

The navigation channel through the Lisbon outer bar was firstly dredged in 1969 at a

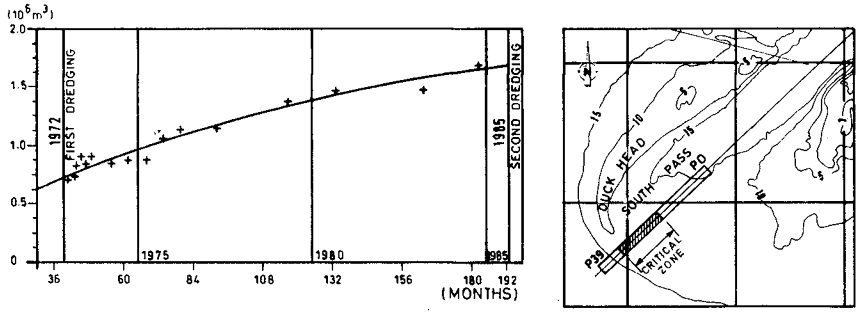


Figure 4 - Infill Process of the Channel Critical Zone

level of (-13.5 m CD); a second and a third dredging took place in 1972 and 1985, at levels of (-15.5) and (-15) respectively.

The subsequent morphological evolution was monitored regularly through a reasonable number of hydrographical surveys. While analysing this evolution we looked into nature as a one to one scale model of itself.

The channel infill process is governed by a complex interaction of tidal currents and a rough and varied wave climate. We have assumed that a exponential law can characterise such a process as a whole, when time scales of several years (at least two or three) are considered. Such a law states that, if a morphological situation is artificially driven away from its natural equilibrium, the difference will diminish exponentially with time. Accordingly we can write

$$V(t) = Ve - (Ve - Vo) \exp(- C t) \qquad (3)$$

where: V(t) is the channel infill volume at time t; Ve is the volume corresponding to the natural equilibrium situation; Vo is the volume at t=0, in principle immediately after the conclusion of the dredging work.

The sand volume at the date of each survey, laying on the volume to be occupied by the artificial channel (bottom: -16 mCD; width: 300 m; side slopes: 1/20), was evaluated. Due to its longer duration (13 years) and to its deeper initial bottom level, only the period between the second and the third dredging was considered in this study.

In theory we would have known Ve and Vo, the only unknown to be determined being C. Indeed, owing to the great scatter of data obtained (reflecting the normal morphological instability of an outer bar controlled by a rough and varied wave climate), we only had first approximations to those values.

The following approach was used: several Ve values where considered and, for each one of them, several Vo values where taken; the pair Ve, Vo determining the best fit of the theoretical curve to the "experimental" points (highest correlation coefficient) was chosen.

The "critical" zone (a 1400 m long reach facing the tip of "Cabeça do Pato" (Duck Head) where the infill rate is the highest), and the whole channel where considered separately. Figure 4 pertains to the critical zone only.

The following values where obtained:

	Ve (m^3)	Vo (m^3)	C ($month^{-1}$)	Correlation Coefficient
Total channel	3 800 000	790 000	$5.4*10^{-3}$	0.924
Critical zone	2 200 000	254 000	$7.0*10^{-3}$	0.980

Some comments:
- the "best" value of Ve for the critical zone compares quite well, and the one of the whole channel compares fairly well, with those measured in the last survey done before the first dredging (1969);
- the higher correlation coefficient obtained for the critical zone is in agreement with its greater physiographical homogeneity when compared with the diversity encountered along the whole channel
- as expected, the C value is higher in the critical zone than in the whole channel .

After some manipulations over the expression (3), with the corresponding values of Ve,Vo and C, the following results were obtained

	Over dredging (m)	Initial bottom level (m CD)	Infill volume after 39 months (m^3)
Critical zone	1.00	-17	680 000
Outside the critical zone	0.5	-16.5	300 000

A final conclusion could be drawn: the artificial channel, with a nominal bottom level of (-16 mCD), will require a maintenance dredging of the order of one million cubic meters every three years.

3 - THE TAGUS ESTUARY ENTRANCE. HYDROMORPHOLOGICAL ANALYSIS

3 .1 - Past Evolution

The most important event in this century of the Tagus entrance morphological evolution has been the opening, some 50 years ago, of a secondary bar named the Golada over the "Banco do Bugio" - Figure 2. Despite the fact that some people charge the borrow dredgings in the Bugio with being the cause of that event, the analysis of old hydrographic surveys shows that the Golada has passed through narrowing and widening phases in the last 140 years.

If we characterise the amount of closing of this secondary bar looking at the total area over the "Banco do Bugio" above CD level, Figure 5 shows that over the last 140 years the situation has been more of instability than of equilibrium. As a matter of fact, during the last few years an important shoal has been growing in the middle of this secondary bar above low water level.

In the Golada flood currents and waves largely prevail over the ebb currents in what concerns sand transport capacity. As a consequence, a volume of sand of $36*10^6$ m3 has been accumulating over the northern slope of the "Banco do Bugio" since 1939, forcing it to advance northwardly some 700 m - Figure 6. In the meantime, the estuary main channel was narrowed and its tidal current pattern was changed. Accumulation rates in (m^3/year) are shown in Figure 6.

The accumulation process has been the result of two opposite actions: the "bringing in" action of flood currents and waves entering through the Golada, and the "flushing out" action of ebb currents in the main entrance channel, more or less parallel to the northern slope of the shoal, "sweeping" the sands downstream in the direction of the main outer bar. So, the sand transport rate through the Golada can be seen as the sum of two parcels: the shoal accreting rate and the ebb flushing rate over the same shoal.

We can assume that the latter equals the rate of erosion of the shoal northern slope registered in the 1929/39 period, when the Golada was almost closed

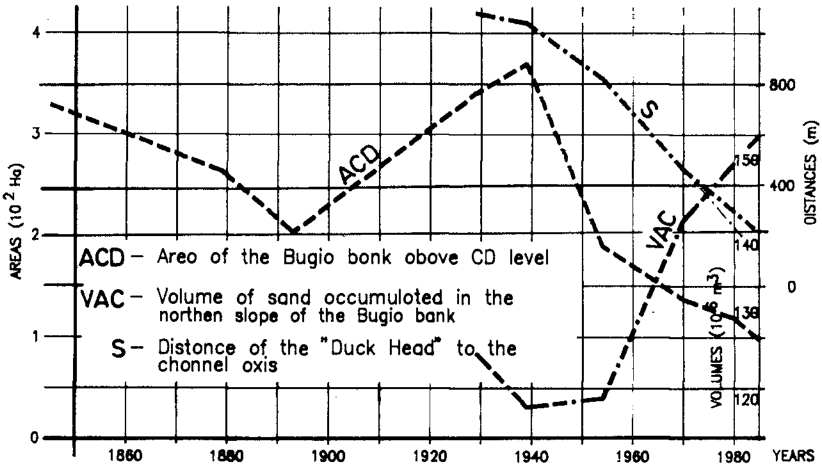
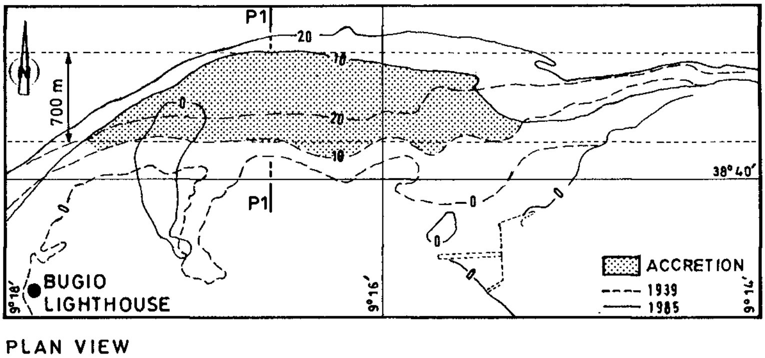
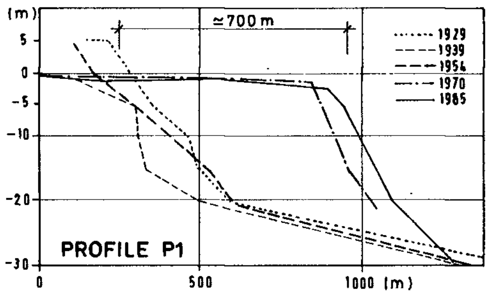


Figure 5 - Morphological Evolution of the Estuary Entrance. Characterization by means of three parameters





DATE	V ($10^6 m^3$)	ΔV ($10^6 m^3$)	r ($10^6 m^3$/Year)
1929	124,5		
		-7,0	-700
1939	117,5		
		+1,2	+ 80
1954	118,7		
		+23,3	+1450
1970	142,0		
		+ 7,5	+750
1980	149,5		
		+ 3,8	+760
1985	153,3		

Figure 6 - Northern Slope of the Bugio Bank. Evolution after 1929

(700 000 m^3/y) - Figure 6 . Some impressive results are then obtained: the sand inward transport rate through the Golada was at least of the order of $2.2*10^6$ m^3/y in the 1954/70 period and, during the most recent times (1980/85), has been still of the order of $1.5*10^6$ m^3/y.

Over the same period (1929/1985) the tip of the "Cachopo Norte" (northern shoal of the outer bar - Figure 2) advanced 800 m in a direction almost perpendicular to the navigation channel - Figure 7. It seems that, if there had been no dredgings, the bathimetric (-10), which we considered the best one to characterize the position of that shoal, would have already overpassed the axis of the navigation channel to the south.

In Figure 7 the advancing rates of the "Cachopo Norte" are presented. It is worth mentioning the value of 22.5 m/y during the 1954/70 period. In this period the accreting rate in the "Banco do Bugio" northern slope was the highest.

3 . 2 - Interpretation

If an entrance outer bar is in a stable morphological condition, this means that a dynamic equilibrium exists everywhere between the opposite actions (transport capacities) of flood currents and waves, on the one hand, and ebb currents, on the other hand.

Assuming that the wave climate has not changed in the last few decades, the advance of the "Cachopo do Norte" is most likely related to the weakening of ebb currents. Indeed, a part of the tidal prism started to flow through the Golada after its opening, and no longer through the main channel. The contribution of the Golada to this flow has been changing with time; according to physical model results, it would have been of the order of 8% and 12% for the ebb and for the flood mean spring tidal prism, respectively, in a morphological situation similar to the one registered in 1985.

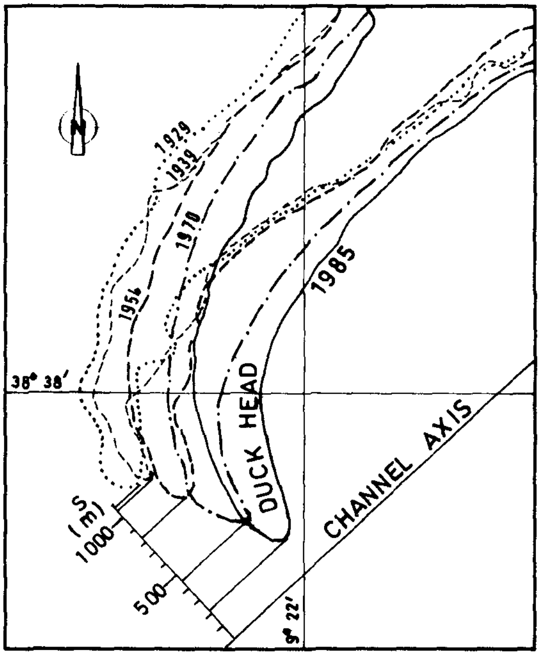
Indeed, a fairly good correlation was verified between the opening of the Golada (wet area of the cross section) and the rate of advance of the "Cabeça do Pato" (Duck Head, as it is known the tip of the "Cachopo do Norte"). In Figure 5 the curve ACD (area above CD level) characterizes the degree of closing of the Golada; the smaller ACD, the greater the opening of this secondary bar. If we consider a sudden opening of the Golada, the resulting physiographical desiquilibrium over the main outer bar area will determine the shoreward advance of the "Duck Head" at a rate that will be "proportional" to the importance of that desiquilibrium, that is to say, to the degree of opening of the Golada. So, in Figure 5 the curve ACD(t) must be compared not with the curve s(t) - s is the distance of the "Duck Head" to the channel axis - but with its derivative.

On the other hand, the critical infill rate zone of the artificial channel is located just in front of the "Duck Head"; as a result of its continuous advancing, the channel infill rate will be aggravating. So, in order to reduce the maintenance dredging effort in the future artificial channel, a decision to close the Golada using a sand dike was made by the port authority (APL). This dike should be built with dredged material from the artificial channel.

It should be stressed that the closing of the Golada would afford some other "secondary" advantages, namely the sheltering of the lower reach of the estuary against the wave energy entering through this secondary bar.

3 . 3 - Physical and Mathematical Modelling

In order to assess the general "functioning" of the Tagus estuary entrance, a study program was initially set up in which a vertically integrated 2D finite element model of the lower reach of the estuary (including a near-field ocean zone) would be used in connection with a physical model. Mathematical and physical model would be matched at the Lisbon bridge cross-section, that is to say, upstream boundary conditions of the mathematical model would be obtained from the physical model.



DATE	$-\Delta S$ (m)	RATE OF ADVANCE (m / y)
1929		
	40	4
1939		
	220	14,5
1954		
	360	22,5
1970		
	230	16,4
1985		

Figure 7 - Advance of the "Duck Head" after 1929

Due to operational reasons the use of the existing physical model had to be abandoned for that purpose, and the initial plan had to be changed: the 2D finite element model was then extended to the whole estuary. However, a strong schematization of the upper estuary region was made. Even so, levels and currents were correctly reproduced in the Lisbon bridge cross-section; velocities and levels were recorded in nature during several tidal cycles.

Three main situations were simulated: the present (reference) situation; the situation immediately after the closing of the Golada; the situation in the long run after the closing. In this third case it was admitted that, after the closing, the northern slope of the "Banco do Bugio" will recede naturally or/and artificially, to its position in the forties, that is to say, some hundred meters to the south. The artificial navigation channel through the outer bar was not considered; in fact, it was assumed that the influence in the hydrodynamics would only be felt locally.

Hourly velocity fields for two tidal periods and tide level curves in some reference stations were obtained, as well as residual currents in some restricted areas. Assuming as a first approximation that the bed load transport capacity depends on V^3 (V - depth mean velocity), integral values of V^3 were also obtained for the ebb and for the flood tidal periods in some grid points over the outer bar.

Some important results are:

a - over the outer bar ebb currents significantly prevail over flood currents, as it could be expected;

b - the predominance of ebb over flood currents will increase as an immediate consequence of the closing of the Golada;

c - that predominance will increase even more in the long term with the natural or artificial receding of the shoal accumulated in the northern slope of the Bugio;

d - with the closing of the Golada, the estuary global tidal prism will increase slightly (3%).

The last result is rather unexpected; indeed, how can the parcial closing of the estuary entrance improve its tidal prism?

The most likely explanation lays on the enhancement of the resonant effect within the estuary, which is responsible for a tidal range inside the estuary greater than in the outside. In fact, the estuary can be hydrodynamically interpreted as a great tidal basin connected to the ocean by a relatively straight and narrow channel - Figure 1. The closing sand dike of the Golada will make this channel somewhat longer; as a consequence, the estuary natural period will increase (Baines, 1957), becoming closer to the tidal forcing one (M2) and so intensifying the existing resonant phenomenon.

The results b) and c) mentioned above mean that the tendency of the "Duck Head" to advance in the direction of the artificial channel will be reversed if the Golada is closed. So a decision was taken to close it.

4 - THE "CHANNEL DREDGING AND CLOSING OF THE GOLADA" PROJECT

The dredging of an artificial channel with the geometric characteristics presented in Chap. 2 (length: 4km; width: 300m; bottom level: -16.5 and -17m CD; slopes: 1/ 20) will produce a volume of sand of $3.5*10^6$ m^3. This sand would be used either in the building of a closing sand dike of the Golada or in the nourishment of the Caparica beaches, just to the south of the estuary entrance - Figure 8.

In order to adjust the sand dike to the present morphology of the Bugio bank, it would have a somehow sinuous outline. The total sand volume would amount to $4.5*10^6$ m3 of which approximately $1.0*10^6$ m^3 would be deposited around the Bugio lighthouse. The Bugio bank itself would be the borrow area for this building sand or, alternatively, the sand removed from the artificial channel would be used for the same purpose.

The sand volumes resulting from future maintenance dredgings of the artificial channel would be deposited on the seaward (westward) tip of this dike, that is to say, around the Bugio lighthouse in order to compensate for the sand losses due to currents and wave erosion. In the long term the south face of this closing dike would evolve to a continuous sand beach from the Bugio lighthouse to Caparica, resembling the morphological situation of some decades ago when the Golada was almost closed naturally.

5 - ENVIRONMENTAL ASSESSMENT

In the final stage of the studies an Environmental Impact Study was made. Environmental authorities raised a lot of questions. Even the influence of the artificial channel through the outer bar over the estuary hydrodynamics had to be analysed to conclude, as expected, that it will have no practical effect. A lot of additional analysis were performed, namely:

- hourly fields of V = V1 - V2 in all the entrance area (velocity differences after (Af) minus before (Bf), after being in the short term (Af1) and in the long term (Af2); Af1 - immediately after the closing; Af2 - after the receding of the northern slope of the Bugio bank to the 1939 position)
- residual values (Vr) of the velocity vector V (Bf, Af1, Af2)

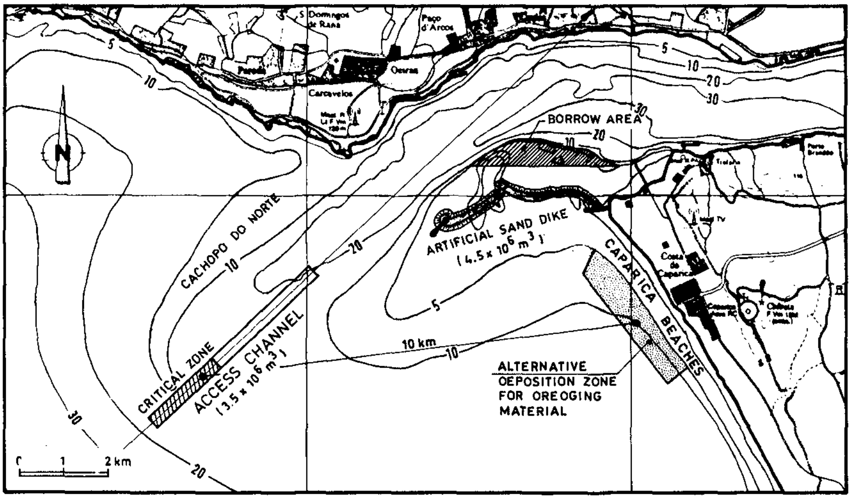


Figure 8 - The "Channel Dredging and Closing of the Golada" Project

- differences of Vr (Af1 - Bf ; Af2 - Bf)
- hourly fields of V^3 (Bf, Af1, Af2)
- residual values (Vr3) of V^3 (Bf, Af1, Af2)
- lagrangean simulation of the dispersion of particles emitted every 20 min in three points of the estuary lower reach (Bf, Af1, Af2).

Very recently the dredging of the channel has been approved. On the contrary, the closing dike of the Golada was rejected on the basis that its beneficial effects on the natural maintenance conditions of the artificial channel were not clearly demonstrated.

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