

CHAPTER ONE HUNDRED TWENTY FIVE

SEDIMENTATION IN DREDGED CHANNELS AND BASINS.

PREDICTION OF SHOALING RATES

C.M.Vicente ¹⁾ and L.P.Uva ²⁾

1 - ABSTRACT

A method is presented for predicting shoaling in dredged channels and basins where deposition of finer sediment fractions carried in suspension by tidal currents occurs.

The method is based on the analysis of hydrographic surveys of different dates, which show the hydrographic evolution of dredged areas located in the site or in its vicinity. It can also be applied to experimental dredged pits.

Results obtained from the analysis of surveys are worked out by using mathematical expressions deduced from a simplified hypothesis, empirically based. Parameters are determined which can be used to predict shoaling either when new dredgings are made or when previously dredged sites are deepened.

2 - DESCRIPTION OF METHOD

The basic assumption, of empirical nature, considers that the shoaling rate is proportional to the relative bottom elevation. This proportionality is expressed by

$$dC/dt = K(C_e - C) \quad 1)$$

where:

C is a variable that represents the different bottom elevations at instant t ; C_e is a constant that represents the bottom natural equilibrium elevation in the zone studied, and K is a constant sedimentation coefficient that expresses the proportionality already mentioned.

1) Research Officer, Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101; 1799 Lisboa Codex, Portugal.

2) Research Assistant, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal.

To establish this assumption three aspects were considered which experience in the field of the maintenance of dredged zones in estuaries has shown to be very general:

- Sedimentation occurs whenever dredging is carried out to make deeper a zone previously in natural equilibrium;
- The sedimentation rate increases as a function of the thickness of the dredged layer;
- The bottom tends to shoal back to its natural equilibrium elevation corresponding to the situation prior to the first dredging operation whenever maintenance dredging is discontinued for a sufficient number of years.

When applying the method it is assumed that the natural equilibrium elevation C_e and the sedimentation coefficient K are constant throughout the zone under analysis and do not significantly vary in the course of time. So that this may be true, the following conditions seem to be required:

- The zone analysed must not be too large so that there can be approximate uniformity of the characteristics of sediments in suspension and of hydrodynamic conditions, concentrations and salinities.
- The time interval between two surveys must not be less than one year so that the semidiurnal and fortnightly tidal variations as well as the seasonal variations which hydrodynamic conditions, concentrations and salinities ordinarily present can be eliminated or markedly filtered.

By integrating equation 1), one obtains:

$$C = C_0 + (C_e - C_0) \cdot (1 - e^{-Kt}) \quad 2)$$

This expression is graphically represented by a family of curves, each one giving the time variation of a point of the bottom with the initial generic elevation C_0 (Fig. 1).

The existence of a curve for each initial elevation C_0 enables expression 2) to describe the evolution of a zone with different bottom elevations. The shoaling rate decreases as elevation C increases, the evolution of erosion prone zones located above natural equilibrium elevation ($C > C_e$) being also reproduced.

The family curves have the elevation C_e as asymptote. C_e represents the elevation to which all points at different depths will tend if they are let to evolve naturally during a sufficiently long period.

From expression 2) it may be deduced that, if the evolution of each point in a set follows a family curve, then the mean elevation of that set will also be represented by one of the curves.

It is of interest to compare expressions 1) and 2) with other expressions and empirical methods described in the technical literature on this subject.

A) Lyakhnitsky and Smirnov [2] presented a shoaling coefficient similar to K . It was defined by

$$\varepsilon = \frac{S}{\Delta h}$$

where S is the mean thickness of the silt layer settled to the bottom of the channel during one year, and Δh is the thickness of the dredged layer.

B) The Balanin formula presented by Djunkovski and Smirnov [1] describes the time variation of shoaling in a dredged channel. It can be expressed through

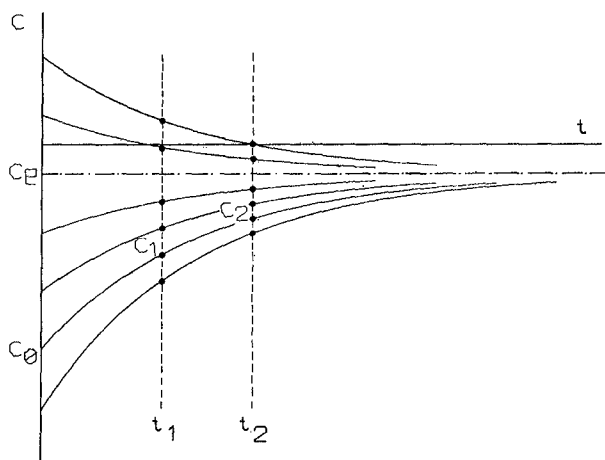


Fig. 1 Family of curves $C = C_0 + (C_p - C_0)(1 - e^{-Kt})$

$$h_t = \frac{1-(1-p)^t}{(1-p)^t} \cdot (H-H_0)$$

where

h_t is the thickness of the sediment deposit after t years;

H is the channel depth;

H_0 is the initial natural depth;

p_0 is a coefficient characteristic of sedimentation at the place in question.

If $t=1$ year, we obtain

$$\frac{h}{H-H_0} = \frac{p}{1-p}$$

which shows that with Balanin's formula the shoaling rate (h) is proportional to the thickness of dredging, that is, to its depth with reference to the bottom natural equilibrium elevation ($H-H_0$), as established in 1).

C) Perestrelo [3] in his studies of shoaling of dredged basins in the Tagus estuary empirically fitted exponential curves expressed as in 2), to the points that showed the time evolution of the mean bottom elevation.

This author used this expression only to characterize dredged zones of approximately constant depth. He also considered that, contrary to the present method, the shoaling coefficient depends on the dredged depth.

D) One of the empirical procedures used in USA and cited by Trawle [4] considers the shoaling rate to be proportional to the area of the dredged channel section, measured below the bottom natural equilibrium elevation. This procedure agrees with expression 1) if the section can be considered nearly rectangular, i. e., when the channel bottom width is much larger than the width of its side slopes.

From the analysis of expression 2) it can be concluded that there are two procedures to obtain the values of K and C_e which characterize the family of curves (Fig. 1):

- a) From the evolution of mean elevation of a deep zone;
- b) From the variation between times t_1 and t_2 , of the elevation of a set of points of a zone with varied depths.

Using procedure a) one immediately extracts parameters K and C_e from the exponential equation which best fits the evolution of bottom mean elevation.

Using procedure b) parameters are obtained as follows: let t_1 and t_2 ($t_1 < t_2$) be the dates of the two surveys, and C_1 and C_2 elevations at times t_1 and t_2 respectively. Then from 2) we have:

$$C_2 = C_1 + (C_e - C_1) \cdot (1 - e^{-K(t_2 - t_1)}) \quad \text{i.e.}$$

$$(C_2 - C_1) = A C_1 + B$$

In case the basic assumption holds, the straight line indicated should fit shoaling at different depths. The straight line coefficients are:

$$A = e^{-K(t_2 - t_1)} - 1$$

and

$$B = (1 - e^{-K(t_2 - t_1)}) \cdot C_e$$

From coefficients A and B one obtains parameters K and C_e .

3 - APPLICATIONS

Both procedures were applied. Procedure a) was applied to the evolution of the mean elevations of two zones. Data concerned Macao outer harbour in the south coast of China (Fig. 2) and a dredged basin in the Tagus estuary in the west coast of Portugal.

Both sets of data correspond to periods during which no main tenance dredging was carried out. To these data could be fitted exponential regression curves such as those already mentioned, and high correlation coefficients were obtained (Figs. 3 and 4). Data used in Fig. 4 were taken from Perestrelo's work [3] referred to above.

Procedure b) was applied in three sites: three applications in a channel of Aveiro lagoon (Mira channel) located in the west coast of Portugal (Fig. 5); one in a dredged channel in the Tagus estuary (Fig. 6); one in Macao, in the Ka-Ho experimental dredged pit (Fig. 2).

The calculation was as follows: a mesh was established with about one thousand points, equally located in the two hydrographic surveys of dates t_1 and t_2 to be compared; the points were grouped according to the elevation ranges of the earlier survey; in each range the mean values of elevations C_1 and of the corresponding shoaling ($C_2 - C_1$) were determined; the regression line best fitting the set of points so defined was determined; parameters K and C_e were determined from the coefficients of the lines following the expressions indicated.

In Figs. 7 to 11 the results of instances of application corresponding to such grouping are presented. The amplitude of each range is 0.20 m.

The number of points in each range varied; that is why weighted values were considered in the linear regression. This aspect is clearly shown in the example of Table 1. Notice that the largest deviations from the fitted line were found in ranges to which corresponded a small number of bottom points.

The hydrographic surveys were made at time intervals varying between 1 and 6 years. During those intervals no maintenance dredging was made.

Linear regression was also established between variables C_1 and $(C_2 - C_1)$ by considering the points not grouped (Examples in Figs. 12 and 13).



Fig. 2 Location map of Macao - Macao outer harbour and Ka-Ho experimental dredged pit.

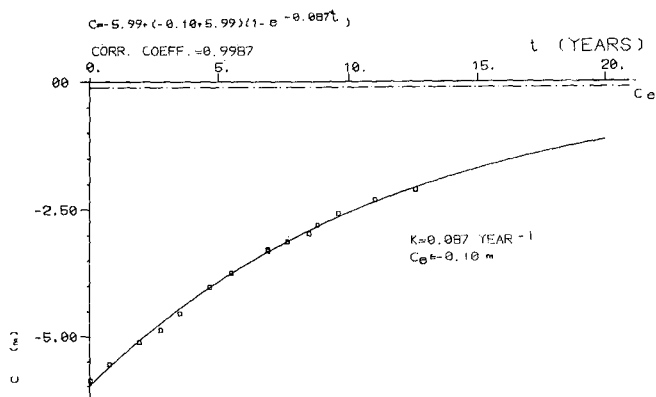


Fig. 3 Application of procedure a). Macao outer harbour.

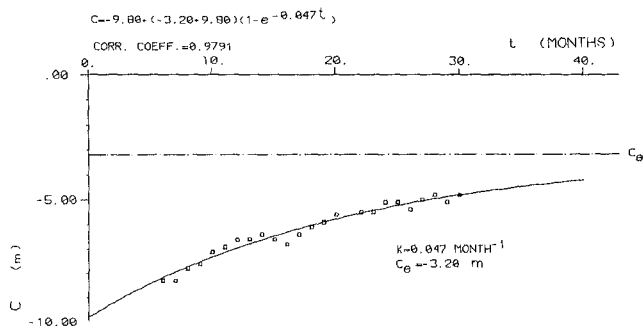


Fig. 4 Application of procedure a) to a dredged basin in the Tagus estuary.

Application of the procedure b) brought to light the following aspects:

- It was always possible to establish a good linear correlation between the mean values of depth C_1 and shoaling ($C_2 - C_1$). From the line obtained one could deduce with close approximation the mean shoaling for sets of points contained in each depth range.
- Higher correlations were obtained when surveys were made at larger time intervals.
- In the case of Aveiro lagoon for which three surveys of the same zone were available, K and C_e were found to take very close values in the two successive time intervals defined by these three surveys. In the periods 1975-80 and 1980-81, K values were found to amount to 0.108 and 0.121 year^{-1} , whereas C_e values were 1.39 and 2.00 m.

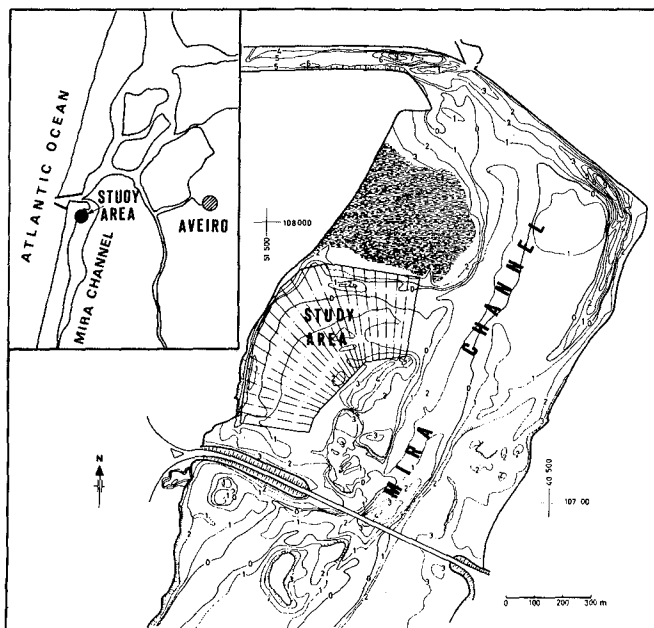


Fig. 5 Location map of Mira channel - Aveiro lagoon.

- A study of the distributions of deviations between shoaling values observed and those calculated by the regression line, considering points not grouped, showed that distributions were similar in all cases analysed regardless of the place and of the time interval between two surveys (Examples in Figs. 14 and 15).

Ninety per cent of the deviations fell in a range of ± 50 cm. It is assumed that ± 25 cm is the range of deviations corresponding to inaccuracies in surveys and in their comparison. The remainder is believed to be due to the approximations inherent in the basic assumption which disregards the influence of other variables besides depth influencing the shoaling rate.

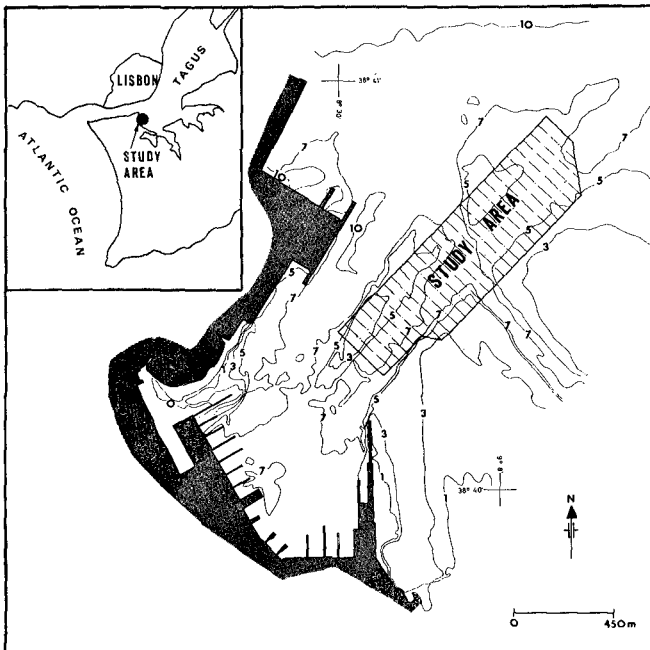


Fig. 6 Location map of a dredged channel in the Tagus estuary.

Table 1 Application of procedure b). Mi-
ra channel (Aveiro lagoon). Sur-
veys: Sep.-Oct.1975 and Sep.1981.
Range 0.20 m.

ELEVATION RANGE	MEAN ELEVATION	MEAN SHOALING	NUMBER OF
FIRST SURVEY (M)	FIRST SURVEY (M)	(M)	POINTS
-3.40	-3.35	3.31	1
-3.20	-3.09	1.93	1
-3.00	-2.91	1.79	4
-2.80	-2.71	1.72	1
-2.60	-2.59	2.11	1
-2.40	-2.27	1.58	4
-2.20	-2.08	1.62	11
-2.00	-1.91	1.71	13
-1.80	-1.69	1.33	27
-1.60	-1.50	1.44	22
-1.40	-1.30	1.40	32
-1.20	-1.09	1.29	37
-1.00	-0.92	1.22	31
-0.80	-0.71	1.11	41
-0.60	-0.54	1.09	41
-0.40	-0.31	0.94	35
-0.20	-0.12	0.86	33
0.00	0.03	0.75	33
0.20	0.28	0.45	33
0.40	0.49	0.59	37
0.60	0.71	0.46	46
0.80	0.90	0.33	82
1.00	1.11	0.18	73
1.20	1.30	0.14	88
1.40	1.48	0.04	66
1.60	1.71	0.06	96
1.80	1.99	-0.06	98
2.00	2.08	-0.21	38
2.20	2.27	-0.27	8
2.40	2.44	-0.31	8
2.60	2.60	-0.13	4
2.80	2.87	-0.98	4
3.00	3.50	-0.60	2
3.20	3.33	-0.60	1
3.40	3.60	---	0
3.60	3.65	---	0
3.80	4.00	-1.00	1

TOTAL NUMBER OF POINTS 1025

$C_2-C_1=0.454C_1+0.778$
CORR. COEFF.=0.9929

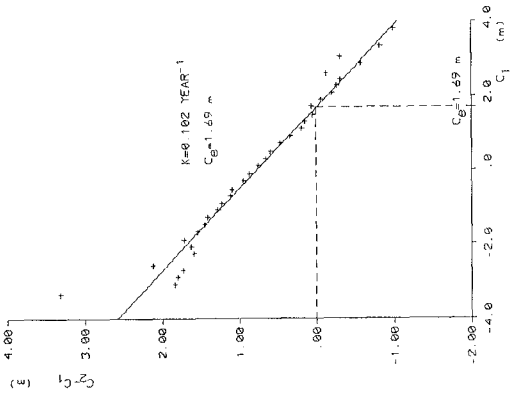


Fig.7 Application of procedure b). Mi-
ra channel (Aveiro lagoon). Sur-
veys: Sep.- Oct.1975 and Sep.1981.
Range 0.20 m.

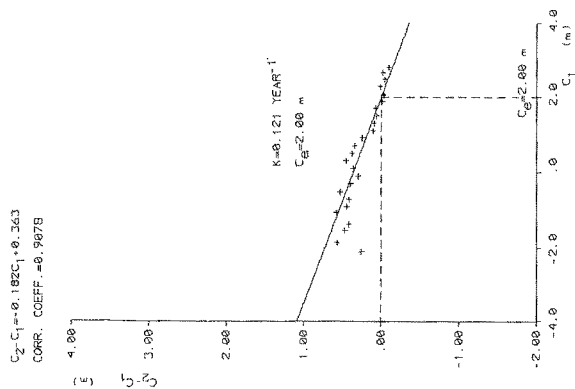


Fig. 8 Application of procedure b). Mira channel (Aveiro lagoon). Surveys: Sep.-Oct. 1975 and Jan. 1980. Range 0.20 m.

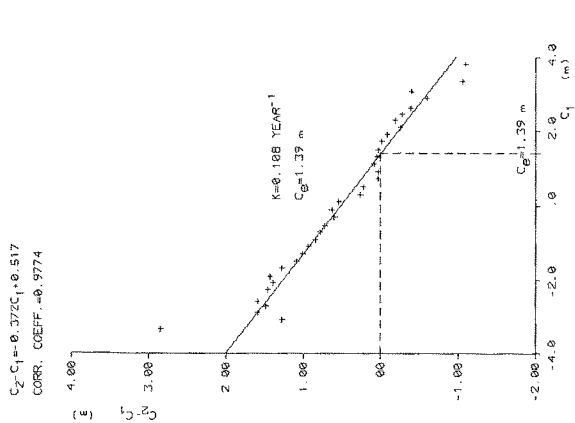


Fig. 9 Application of procedure b). Mira channel (Aveiro lagoon). Surveys: Jan. 1980 and Sep. 1981. Range 0.20 m.

$C_2 \cdot C_1 = -0.291 C_1 - 1.321$
CORR. COEFF. = 0.9991

$C_2 \cdot C_1 = -0.069 C_1 - 0.316$
CORR. COEFF. = 0.9388

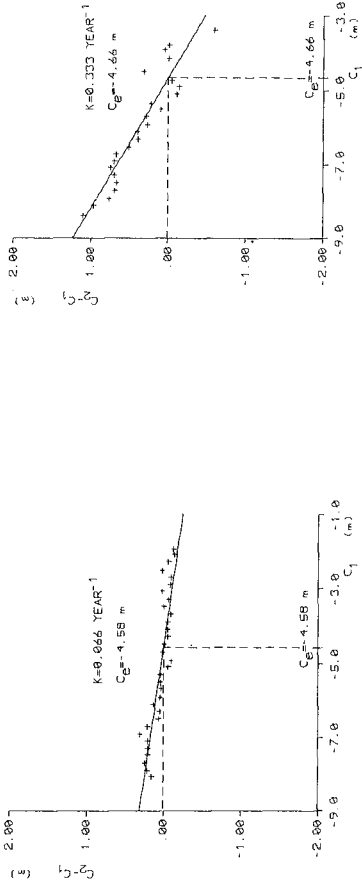


Fig.10 Application of procedure b) to a dredged channel in the Tagus estuary. Surveys: Oct. 1978 and Nov. 1979. Range 0.20 m.

Fig.11 Application of procedure b). Ka-Ho (Macao). Surveys: Apr. 1974 and Apr. 1975. Range 0.20 m.

$$C_2/C_1 = -0.282C_1 - 1.312$$

CORR. COEFF. = 0.5259

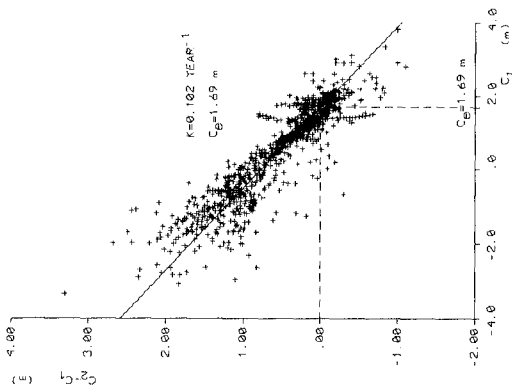


Fig.12. Application of procedure b). Mira channel (Aveiro lagoon). Surveys: Sep.-Oct. 1975 and Sep. 1981. Points not grouped.

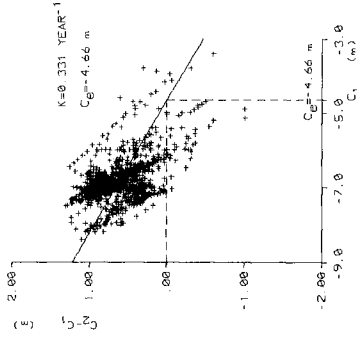


Fig.13 Application of procedure b). Ka-Ho (Macao). Surveys: Apr. 1974 and Apr.1975. Points not grouped.

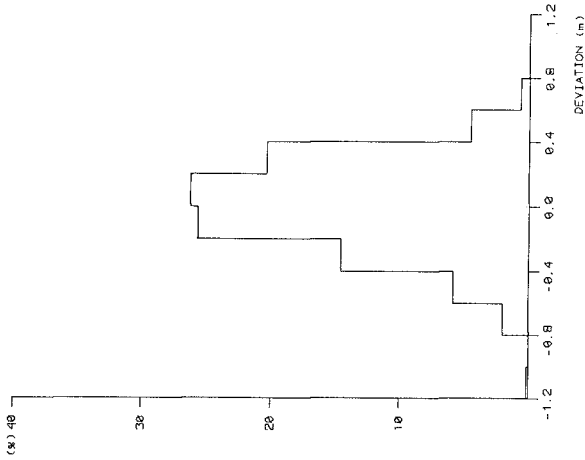


Fig. 15 Deviation histogram. Ka-Ko (Macao). Surveys: Apr. 1974 and Apr. 1975. Points not grouped.

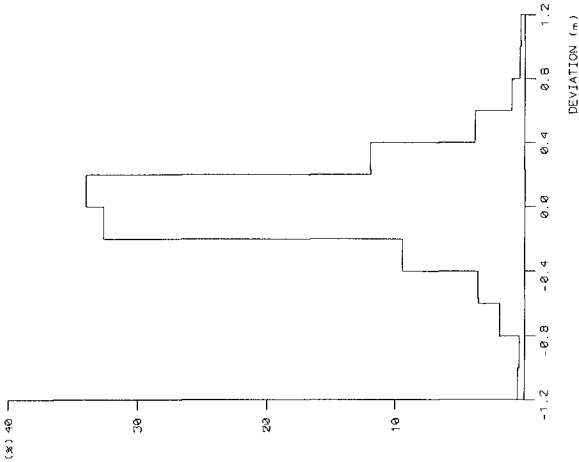


Fig. 14 Deviation histogram. Mira channel (Aveiro lagoon). Surveys: Sep. Oct. 1975 and Sep. 1981. Points not grouped.

The occurrence of identical deviation distributions in all the cases analysed explains why the correlation coefficient improved as the time interval between two surveys increased. With large time intervals shoaling takes higher values, and the relative value of deviations decreases. This aspect is shown in Figs. 12 and 13.

- The fact that high correlations are usually not found except when referred to mean values of the two variables will not permit as a rule to predict shoaling accurately enough at a given point but only in a zone or at a numerous set of points of the bottom. This limitation does not seem to be very inconvenient since the practical purpose of the method is to predict the evolution either of reaches only or of the whole of dredged channels and basins.

4 - CONCLUSIONS

High correlations could be established between mean values of depth and of shoaling in different dredged zones where deposition of finer sediment fractions carried in suspension by tidal currents occurs. In every case data were fitted by empirically based expressions that were worked out to represent the variation of bottom elevations with space and time.

The results of the comparison of surveys can be used to predict volumes of maintenance dredging of channels and basins to be established or deepened in the zone under study. It is assumed that this zone will not be subjected to long term variations of sedimentation characteristics.

The procedure to be used for this prediction consists in the definition of the sedimentation coefficient K and equilibrium elevation C_0 , based on the analysis of two or more surveys. Once these parameters are known, annual maintenance rates for different alternative dredging elevations C_0 can be estimated by using the expression derived from 2), with $t = 1$ year.

It is worth mentioning that procedure b) requires only two surveys provided they are carried out within an interval of at least one year during which no dredgings are made. Such a feature makes it largely adequate to practical use due to ordinary limitations as regards field data to characterize shoaling conditions.

5 - REFERENCES

[1] - Djunkovski, N.N. and Smirnov, G.S., 1957: XIX International Navigation Congress. London. 1957. Section II. Communication 3.

[2] - Lyakhnitsky, V.E. and Smirnov, G.S., 1961: XX International Navigation Congress. Baltimore, 1961. Section II. Subject 2.

[3] - Perestrelo, J.F., 1971: Comportamento de canais e baías dragados em fundos lodosos de estuários. Instituto Superior Técnico. Lisboa.

[4] - Trawle, M.J., 1981: Effects of depth on dredging frequency. Report 2. Methods of estuarine shoaling analysis. U.S. Army Waterways Experiment Station. Technical report H-78-5.