CHAPTER 111

NATURAL FLUSHING ABILITY IN TIDAL INLETS

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1 - ABSTRACT

The main object of this work is to study the relation between the flushing ability of tidal inlets with the degree of shoaling, assuming that water-level fluctuations in the lagoon are uniform all over.

It was assumed that natural flushing ability is proportional to the bed-load capacity of tidal currents and that this capacity can be characterized both by the hydraulic power consumed in the connecting channel and by the 3rd or 6th power of the mean velocity. Influence of the slope of the lagoon banks and of the inner head losses was also analysed.

2 - INTRODUCTION

In 1951 E. H. Keulegan [1] undertook the analytical study of the hydrodynamic behaviour of the inlet-lagoon system, but some restricting hypotheses were assumed which diminish the practical interest of the results obtained. For instance, he assumed the relationship between the depth of the inlet channel and the tidal range to be very great (and therefore he considered the flow section constant during a tidal cycle). Also the banks of the lagoon were considered vertical, and the level variation law the same for all points of the lagoon.

The hydrodynamic behaviour of the system could thus be characterized by the equations

$$\frac{dh_1}{d\theta} = K\sqrt{h_2 - h_1} \quad \text{when } h_2 > h_1 \text{ (flood)} \qquad \text{and}$$

$$\frac{dh_1}{d\theta} = K\sqrt{h_1 - h_2} \quad \text{when } h_1 > h_2 \text{ (ebb)}$$

where (see Fig. 1),

$h_1 = \frac{H_1}{H}$, $h_2 = \frac{H_2}{H}$, H being the ocean tide amplitude, H_1 and H_2 sea and lagoon levels respectively referred to the mean sea level, $\theta = \frac{2\pi}{T}t$,

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T the tidal period, t the time variable, K a dimensionless parameter which the author has called repletion coefficient, and which condenses the influence of several parameters, namely, lagoon and channel dimensions, channel roughness, and sea tide amplitude and period

Owing to the simplifying hypotheses made, the coefficient K is constant all along the tidal cycle and, consequently, the mean level of the lagoon is equal to the mean sea level, the behaviour of the level law in the lagoon is symmetrical with respect to that level, and the flood velocities and rates of flow are symmetrical to those at the ebb In the study of natural flushing ability of a tidal inlet we cannot make use of the results of such a simplified scheme, since the most interesting cases to be analysed are obviously those which are characterized by faulty inlets needing correction, which present small values for the channel depth/tidal range ratio

In the first studies it was sought to analyse the influence of the channel flow section variation and that of the lagoon area during a tidal cycle, subsequently, the influences of head losses in the lagoon were also analysed for a very schematic case

3 - INFLUENCE OF FLOW SECTION VARIATION OF INLET CHANNEL AND OF BANK SLOPE

3 1 - Characteristic equation of the system

Assuming the inlet channel to be well shaped, to have constant width and depth over its entire length, and the level variation in the lagoon to be uniform, we obtain similarly to Keulegan

$$\frac{dH_1}{dt} = \frac{a}{A} \sqrt{\frac{C^2 r}{L + \frac{C^2 r}{2g}}} \sqrt{H_2 - H_1} \qquad (1)$$

where

A - lagoon area

a - flow section area of the inlet

L - length of inlet channel

r - hydraulic radius of inlet channel

C - Chezy coefficient ($C^2 = \frac{r^{1/3}}{n^2}$)

n - Strickler coefficent

Assuming further that the hydraulic radius (r) is equal to the depth of the channel, that this depth corresponds to the arithmetic mean of sea and lagoon levels, and that the lagoon area varies linearly with its level, we get

$r = d + \frac{H_1 + H_2}{2}$, where d is the depth referred to the mean sea level (Fig 1)

$a = br$, b being the width of the channel,

$A = A_o(1 + N\frac{H_1}{H})$, A_o being the area of the basin corresponding to the mean sea level (Fig 2)

Parameters H_2, H_1 r and d were reduced to a dimensionless form by relating them to the sea tidal amplitude

$$h_2 = \frac{H_2}{H} = \sin\theta,\quad h_1 = \frac{H_1}{H},\quad r_o = \frac{r}{H} = d_o + \frac{h_1 + \sin\theta}{2}$$

Besides, $\theta = \frac{2\pi}{T}\, t$, so that equation (1) will be

$$\frac{dh_1}{d\theta} = \frac{Tb}{\pi A_o}\sqrt{\frac{gH}{2}}\;\frac{1}{1+Nh_1}\;\frac{r_o^{3/2}}{\left(\frac{2gn^2L}{H^{4/3}r_o^{1/3}} + r_o\right)^{1/2}}\;(|h_2-h_1|)^{1/2} \quad (2)$$

Making $D = \frac{Tb}{\pi A_o}\sqrt{\frac{gH}{2}}$ (3)

$$E = \frac{2gn^2}{H^{4/3}}\,L \quad (4)$$

we get $\frac{dh_1}{d\theta} = j\,\frac{D}{1+Nh_1}\;\frac{r_o^{3/2}}{\left(\frac{E}{r_o^{1/3}} + r_o\right)^{1/2}}\;(|\sin\theta - h_1|)^{1/2}$ (5)

$j = 1$ for $\sin\theta > h_1$ (flood)

$j = -1$ for $\sin\theta \leqslant h_1$ (ebb)

Since $r_o = d_o + \frac{h_1 + \sin\theta}{2}$, it follows that the inlet-lagoon system is well characterized by the dimensionless parameters D, E, d_o and N On the other hand, it is easy to see that Keulegan repletion coefficient is related to these parameters by the expression

$$K = \frac{D\, do^{3/2}}{\left(\frac{E}{do^{1/3}} + do\right)^{1/2}}, \quad N=0 \tag{6}$$

The numerical integration of equation (5) was made in the NCR-Elliott 4100 computer of the Laboratório Nacional de Engenharia Civil, using one of its library programs An integration step $\Delta\theta = 0\ 1$ radians was adopted, to which corresponds, in the case of a semi-diurnal lunar type tide ($T = 12$ h 25 min), $\Delta t \simeq 11$ min 52 s The numerical integration of equation (5) was effected starting from a situation in which the level inside and outside the basin were equal to the mean sea level After some attempts it was concluded that the second tidal cycle no longer depended on initial conditions, so that integration was made to comprehend two tidal cycles, of which the first was discarded While integrating equation (5) the computer also calculated the other parameters necessary for the study of the natural flushing capacity of the inlet, namely, rate of flow, velocity, 3 rd and 6th power of the velocity and consumed power

3 2 - Rate of flow

From the continuity equation

$$Q = A\frac{dH}{dt} = \frac{2\pi H Ao}{T}(1+Nh1)\frac{dh1}{d\theta}$$

we get

$$Q_a = \frac{Q}{\frac{2\pi\ H Ao}{T}} = (1+Nh1)\frac{dh1}{d\theta} \tag{7}$$

where Qa is the dimensionless rate of flow, whose term of comparison

$$\frac{2\pi H Ao}{T} = \frac{2H\ Ao}{T/2}\ \frac{\pi}{2}$$

represents the peak discharge corresponding to the sinusoidal flow of the lagoon's maximum admissible prism ($2H\ A_o$)

3 3 - Mean velocity

From $Q = a\,V = A\frac{dH1}{dt}$ there results

$$V_a = \frac{V}{\frac{2\pi\ Ao}{Tb}} = \frac{1+Nh_1}{r_o}\ \frac{dh_1}{d\theta} \tag{8}$$

where Va is the dimensionless velocity whose comparison term

$$\frac{2\pi A_o}{T b} = \frac{2 H A_o}{T/2} \frac{\pi}{2} \frac{1}{bH}$$

represents the mean velocity of flow, through section bH, of the peak sinusoidal discharge corresponding to the lagoon's maximum admissible prism (2 H Ao)

Another dimensionless velocity (V'_a) was further considered, in which the comparison term adopted was $\sqrt{2gH}$ It is easy to prove that

$$V'_a = \frac{V}{\sqrt{2gH}} = \frac{1 + N h_1}{D r_o} \frac{dh_1}{d\theta} = \frac{Va}{D} \tag{9}$$

In Keulegan's study a coefficient C was determined, which relates the maximum flow with the one that would occur if the effective prism Pr (and not the maximum possible one 2 H Ao) would flow out sinusoidally As this author considers the flow section (bd) invariable, constant C also gives the relationship between the maximum velocity and the peak velocity corresponding to the sinusoidal flow of the effective prism Pr In our case, as we take into account the variation of the flow section, there are reasons for the determination of a value C_1 for the rates of flow and of a value C_2 for the velocities, adopting as term of comparison for them the maximum velocity corresponding to the sinusoidal flow of the effective prism Pr through the mean sea level section

We will then have

$$C_1 = \frac{Q_{max}}{\frac{Pr}{T/2}\frac{\pi}{2}} = \frac{Q_{max}}{\frac{\pi}{T} A_o (H_{1\,max} - H_{1\,min})} = \frac{Q_{max}}{\frac{2\pi H A_o}{T}} \frac{1}{\frac{H_{1\,max} - H_{1\,min}}{2H}}$$

From expression (7) we will thus get, for N=0 (vertical banks)

$$C_1 = \frac{2}{\Delta h_1} Q_{a\,max} \tag{10}$$

where Δh_1 represents the lagoon tidal range in the dimensionless form

In the same way

$$C_2 = \frac{V\,max}{\frac{\frac{Pr}{T/2}\frac{\pi}{2}}{bd}} = \frac{V\,max}{\frac{2\pi A_o}{Tb} \frac{1}{d_o} \frac{H_{1\,max} - H_{1\,min}}{2H}}$$

Thus, from expression (8) there results for N=0 (vertical banks)

$$C_2 = \frac{2}{\Delta h_1} d_o V_{max} \tag{11}$$

We must say that the comparison of C_1 with the value of C obtained by Keulegan seems to be more logical than the comparison of C_2 In fact C_2 relates the maximum effective velocity which, as a rule, will occur for a level other than the mean one, with the peak velocity corresponding to the sinusoidal flow through the section fixed arbitrarily for the mean level On the other hand, in the calculation of C_1, and since we are relating rates of flow, it is not necessary to take into account the value of the flow section This comes close to the Keulegan scheme, in which this section was considered invariable

3 4 - 3rd and 6th powers of the mean velocity

According to Colby [3], "the relationship of bed-material discharge to mean velocity is the most convenient to apply The computations are simple, and the energy gradient is not required The relationship may be as accurate as any of the other three [which relate bed load capacity, respectively, with shear velocity $\sqrt{\frac{\tau}{\rho}}$, shear velocity relative to the particles $\sqrt{\frac{\tau'}{\rho}}$ and stream power] unless antidunes extend across much of the flow "

From the curves presented by this author it can be concluded that bed-load capacity of an unidirectional current varies almost linearly with a very high power of the mean velocity In the present work it was assumed that for the velocity range occuring in a given inlet, this variation was in fact linear with the 3rd or 6th power of the mean velocity and that natural flushing ability of the inlet was proportional to the integral value, during the ebb and flood periods, of that bed load capacity Again, it was logically assumed that for a given natural flushing ability the more the integral ebb bed load capacity exceeds that of the flood, the better would be conditions offered by the inlet

While integrating equation (5) the computer therefore calculated the values of function $V^3_a(\theta)$ and $V^6_a(\theta)$ (see expression (8)) and then obtained the integral value of these parameter by the trapezoidal rule

3 5 - Hydraulic power consumed in the inlet channel

It was sought to relate natural flushing ability of the inlet with the hydraulic energy consumed in it during a tidal cycle

To achieve this, and in accordance with the hypothesis made when deducing the expression (5), it was assumed that the kinetic energy of flow $\frac{V^2}{2g}$ is totally dissipated in the sea or lagoon, in a turbulent expansion process, and that, therefore, the hydraulic power consumed in the channel can be calculated through the expression

$$W = \gamma\ Q\,(|H_2 - H_1| - \frac{V^2}{2g})$$

It was deemed unnecessary to present here the deduction of the consumed power in its dimensionless form, which is as follows

$$Wa = \frac{\gamma Q\,(|H_2 - H_1| - \frac{V^2}{2g})}{\frac{2\pi\ \gamma\ A_o H^2}{T}} = Q_a\left[|\sin\theta - h_1| - (V'_a)^2\right] \qquad (12)$$

where the comparison term, which may be written,

$$\frac{2\,\pi\gamma\,A_o H^2}{T} = \frac{\gamma 2 H\ A_o}{T/2}\ \frac{\pi}{2}\ H$$

represents the power developed, under a difference o levels equal to the sea tide amplitude, by the peak discharge corresponding to the sinusoidal flow of the maximum prism admissible in the lagoon

The expression of W_a may also be given as

$$W_a = \frac{E}{D^2}\ \frac{V_a^3}{r_o^{1/3}} \qquad (13)$$

from which it is concluded that the behaviour of the $W_a(\theta)$ function should be analogous to that of the 3rd power of the dimensionless velocity (V_a) This similarity will increase with the mean depth of the channel, considering the smaller relative fluctuation of the dimensionless hydraulic radius (r_o) during the tidal cycle

3 6 - Results obtained by the computer

Through its plotter out put and for each of the cases studied, the computer gave in graphic form all the functions just mentioned $\sin(\theta)$, $h_1(\theta)$, $Q_a(\theta)$, $V_a(\theta)$, $V^3_a(\theta)$, $V_a^6(\theta)$ and $W_a(\theta)$ Fig 4 shows the results concerning a lagoon-inlet system characterized by D=0 2 E=10 0 d_o=6 0 N=0 0 as given by the plotter, the curves $V_a^3(\theta)$ and $V_a^6(\theta)$ regarding the system characterized by

D = 0 2 E=10 0 d_o=6 0 N=0 2

being added only to illustrate the effect of the lagoon bank slope, which only differs from the previous system in so far as parameter N is concerned, which charac terizes the slope referred to (Fig 2)

4 - INFLUENCE OF HEAD LOSSES IN THE LAGOON

4 1 - Equations used in the study

It can be concluded, by mere energetic considerations that head losses through friction in a lagoon will bring about a decrease in natural flushing ability of its inlet In fact, the tidal wave energy dissipated in the inner basin will cease to be available to remove the littoral drift material which tends to obstruct it

As, however, flushing ability of an inlet depends not only on the integral bed load capacity of the tidal currents but also on the difference between the flood and ebb capacity, and considering that the friction damping effect of the tidal wave inside the lagoon causes the displacement of the discharge curve with respect to that of the levels in the inlet, so that for the same discharge the ebb flow section will be smaller than that for the flood, one cannot a priori and in a general way state that head losses in the lagoon impair the natural flushing ability of its inlet

A very simple mathematical model was therefore prepared, mainly to eva luate the change in the relation between the ebb bed load capacity and that of the flood, as a result of interior head losses

Let us imagine a lagoon constituted by two basins, in both of which levels vary uniformly over their entire area, and which are connected to one another by a channel with well defined morphological characteristics (section, length and roughness) These basins are connected to the sea by a singla inlet in which the bed load capacities of tidal currents will be studied The channel connecting the two basins is the energy dissipating factor (Fig 3) In this study the lagoon banks are considered to be vertical

Index 2 will denota the sea, index 1 the basin directly connected to the sea and the inlet, and index 3 the inner basin and the channel connecting the two basins

The equations characteristic of the system were derived from the equations ralative to flow in the inlet and inner channel, and from the continuity equa tions relative to the inner basin and the entire lagoon, that is

$$V_1 = \sqrt{\frac{2\,g\,r_1}{\frac{2g}{C_1^2}L_1 + r_1}}\ \sqrt{H_2 - H_1} \qquad Q_1 = a_1 V_1 = A_1\frac{dH_1}{dt} + A_3\frac{dH_3}{dt}$$

$$V_3 = \sqrt{\frac{2\,g\,r_3}{\frac{2g}{C_3^2}L_3 + r_3}}\ \sqrt{H_1 - H_3} \qquad Q_3 = a_3 V_3 = A_3\frac{dH_3}{dt}$$

After some manipulations whose presentation can be dispensed with, a system of two differential equations of the 1st order, identical in form to equation (5), is obtained, which characterizes the hydrodynamic behaviour of the inlet-lagoon system, namely

$$\frac{dh_1}{d\theta} + e\,\frac{dh_3}{d\theta} = i\,\frac{D_1\,r_{1\,0}^{3/2}}{\left(\frac{E_1}{r_{1\,0}^{1/3}} + r_{1\,0}\right)^{1/2}}\,\left(|\sin\theta - h_1|\right)^{1/2}, \text{ with } r_{1\,0} = d_{1\,0} + \frac{h_1 + \sin\theta}{2}$$

(14)

$$\frac{dh_3}{d\theta} = j\,\frac{D_3\,r_{3\,0}^{3/2}}{\left(\frac{E_3}{r_{3\,0}^{1/2}} + r_{3\,0}\right)^{1/2}}\,\left(|h_1 - h_3|\right)^{1/2}, \text{ with } r_{2\,0} = d_{3\,0} + \frac{h_1 + h_3}{2}$$

where

$i = 1$ for $\sin\theta > h_1$ $\qquad j = 1$ for $h_1 > h_3$ $\qquad e = \dfrac{A_3}{A_1}$

$i = -1$ for $\sin\theta \leqslant h_1$ $\qquad j = -1$ for $h_1 \leqslant h_3$ $\qquad A = A_1 + A_3$ = Total area of the lagoon

and

$h_1 = \dfrac{H_1}{H}$, $h_3 = \dfrac{H_3}{H}$, $r_{1\,0} = \dfrac{r_1}{H}$, where H is the sea tide amplitude

The numerical integration of system (14) was made in the NCR Elliot 4100 computer of the Laboratorio Nacional de Engenharia Civil, using one of its library programs [2]

The integration step was $\Delta\theta = 0.1$ radians, the initial situation was characterized by equal levels in the sea and inner basins, so that to obtain results independent of initial conditions, the 1st calculation cycle, corresponding to a tidal period, had to be discarded

Together with the numerical integration of system (14) the computer also calculated other quantities with interest for the study of the natural flushing capacity of the inlet

As in item 3 2 and following, these quantities, in their dimensionsless form, were calculated by means of the following expressions which, for the sake of brevity, will not be deduced here

- Flow

$$Q_{1\,a} = \frac{Q_1}{\frac{2\,\pi\,H\,A}{T}} = \frac{1}{1+e}\,\frac{d\,h_1}{d\,\theta} + \frac{e}{1+e}\,\frac{d\,h_3}{d\,\theta} \qquad (15)$$

- Velocity

$$V_{1\,a} = \frac{V_1}{\frac{2\,\pi\,A}{T\,b_1}} = \frac{1}{r_{1\,0}}\,\left(\frac{1}{1+e}\,\frac{d\,h_1}{d\,\theta} + \frac{e}{1+e}\,\frac{d\,h_3}{d\,\theta}\right) \qquad (16)$$

- 3rd and 6th power of the velocity

$$V^3_{1\,a} = V^3_{1\,a}(\theta) \quad , \quad V^6_{1\,a} = V^6_{1\,a}(\theta)$$

- Power consumed in inlet channel

$$W_{1\,a} = \frac{\gamma Q_1\left(|H_2 - H_1| - \frac{V_1^2}{2\,g}\right)}{\frac{2\,\pi\,\gamma\,A\,H^2}{T}} = Q_{1\,a}\left[\,|\,\mathrm{sen}\,\theta - h_1| - \left(\frac{1+e}{D}\right)^2 V^2_{1\,a}\right] \qquad (17)$$

which may be written

$$W_{1\,a} = \frac{E_1}{D^2}\,\frac{V^3_{1\,a}}{r^{1/3}_{1\,0}}$$

where D is the dimensionsless parameter relative to the total lagoon basin with area A ($A = A_1 + A_3$) and its inlet width b_1

4 2 - Results obtained in the computer

Fig 5 shows, as an example, the different curves studied for a system characterized by

$D_1 = 0\ 4 \qquad E_1 = 10\ 0 \qquad d_{1\,0} = 6\ 0$

$D_3 = 0\ 4 \qquad E_3 = 10\ 0 \qquad d_{3\,0} = 3\ 0$

which can be compared with the system shown in Fig 4

In view of expressions (3) and (4) defining parameters D and E, and moreover assuming that one considers the same outside tide (equal values of T and H) and an inlet channel with the same width and roughness (equal values of b and n), one may in fact conclude that the systems to which Figs 4 and 5 refer have lagoons with the same total area Nevertheless these lagoons differ in that the lagoon of the latter system is formed by two basins with the same area (e=1 0) connected by a channel half as deep as the channel of the outer inlet, with reference to the mean sea level

5 - ANALYSIS OF THE RESULTS

The studied cases were characterized by the set of the following parameters (in order to make clearer the prototype cases referred to, it is convenient to enclose in parentheses the lagoon area A_o, the length L and the depth d of the inlet channel referred to the mean sea level, that are compatible with these parameters and with the following conditions semi-diurnal lunar tide with an external amplitude H=1 0 m, inlet b=200 m wide and n=0 0226 rough)

N=0 0

I - D=0 5 (A_o=12 6 km^2), E=19 (L=1 900 m), d_o=2,3,4,5,6,8,10 (d =2,3,4,5,6,8,10 m)

II - D=0 2 (A_o=31 6 km^2), E=10(L=1 000 m), d_o= idem

III - D=0 2 (A_o=31 6 km^2), E=19(L=1 900 m), d_o = idem

N=0,1, 0 2 for D=0 5, E=19, d_o=4 0

D=0 2, E=10, d_o=6 0

D=0 2, E=19, d_o=6 0

Although this work was mainly directed to the study of the bed load capacity of tidal currents in the inlet channel other results were obtained that should be compared with those obtained by Keulegan

It has been shown that an inlet-lagoon system can be well defined only by the set of parameters D, E, d_o and N (expression (5)) Hence, the great variety of possible cases As an attempt to reduce such a variety of cases, it was tried to make use of the Keulegan's coefficient of repletion which, in some way, condenses the influence of the first three parameters This parameter has proved satisfactory for the interpretation of some of the studied quantities

Thus Fig 6 gives the variation of the tidal prism against the parameter K in a vertical bank lagoon

$$Pr = A_o(H_{1\,max} - H_{1\,min}) = A_o H(h_{1\,max} - h_{1\,min}) = A_o H \,\Delta h_1$$

the following function is represented in that figure

$$\Delta h_1 = \Delta h_1(K)$$

and compared with Keulegan's results (upper continuous curve) The effective prism is found to be well defined by the parameter K, although it is slightly superior to the one obtained by that author The same figure also shows the functions $h_{1\,max} = f_1(K)$ and $|h_{1\,min}| = f_2(K)$ which are similarly compared with Keulegan's results (lower continuous curve), it being concluded that both the parameter K and Keulegan's scheme are less satisfactory in this case In fact since the connecting channel is not "many times deeper than the tidal range" (Keulegan's hypothesis) a rise of the lagoon mean level results, which is better explained in Fig 7

Fig 8 illustrates the variation of the flood and ebb times against the coefficient K It may be concluded that ebb is always longer than flood and the difference between them increases as the entrance conditions of the tidal inlet grow worse (lower K values)

Fig 9 illustrates the variation of C_1 and C_2 with the coefficient K This variation is compared with the results obtained by Keulegan As was shown in 3 3, C_1 and C_2 respectively relate rates of flow and maximum velocity values with those of the sinusoidal flow of the effective prism From the figure it may be derived that in any case the function $C_2(K)$ satisfactorily agrees with the function C(K) obtained by Keulegan, that is not the case with the function $C_1(K)$, concerning the rates of flow, which is clearly different from C(K) In the zone of small K values, the behaviour of the curves obtained seems rather anomalous and, thus, it is intended to carry out laboratory experiments in order to verify them

Fig 10 presents, for the case of a lagoon having vertical banks (N=0 0), the variation of the integral bed load capacities of the flood and ebb currents against the coefficient K, which are assumed to be proportional to V^3 and V^6, It should be noticed firstly, that the general conclusions to be derived from this figure are practically independent from the power that affects mean velocity in its relation with bed load capacity

The most evident indication given by the figure is that the bed load capacity of tidal currents (which we assimilate to natural flushing ability in the tidal inlet) reaches a maximum for values of the coefficient of repletion K within the range

$$0\ 6 < K < 0\ 8$$

Then it may be stated that a tidal inlet characterized by a K value greater than 0 8 has an extra natural flushing ability that will allow it to overcome an occasional increase of the littoral drift In fact, as the entrance conditions of the tidal inlet worsen as a consequence of that increase, the coefficient of repletion K decreases and then the natural flushing ability of the tidal inlet improves In other words, it can be said that a tidal inlet characterized by a coefficient of repletion $K > 0\ 8$ is in a condition of steady alluvial equilibrium On the other hand, following a similar reasoning, we can state that a tidal inlet characterized by a coefficient $K < 0\ 6$ is in a condition of non-steady alluvial equilibrium, which means that shoaling may be in progress there

The same Fig 10 supplies further information that may be useful to the interpretation of the evolution of such tidal inlets In fact, for K values greater than 0 8 bed load capacity is found to be higher in the flood than in the ebb which may contribute to introducing littoral drift into the lagoon and to the corresponding formation of shoals and inner bars Both facts would bring about a continuous reduction of the coefficient of repletion Conversely, in a tidal inlet where $K < 0\ 6$, though the inlet is located in a zone of non-steady alluvial equilibrium, ebb currents overcome the flood ones as regards bed load capacity, which may represent the last resort of the tidal inlet in order to fight against its increasing obstruction

It should be emphasized that the above remarks concern lagoons with vertical banks and in which the fluctuation of levels is uniform over their entire area Nevertheless actual lagoons always deviate more or less from this theoretical condition In fact banks are never truly vertical, sometimes the water successively overflows and withdraws from the surrounding land in accordance with the tidal cycle, the extent of the lagoon and the head losses inside it do not allow the hypothesis of a uniform law of levels to be valid

In Figs 11 and 12 it is tried to evaluate the influence of bank slopes and of the internal head losses over the bed load capacity of tidal currents

Fig 11 shows that the slope of banks, given by the parameter N (see Fig 2), and thus the existence of large zones that the tide overflows or uncovers, improves the ebb bed load capacity in detriment of that of the flood

In Fig 12 the most significant results of the study relative to lagoons with internal head losses are condensed In 4 1 it has been shown that these head losses are artificially introduced by considering an inner channel that connects the two basins in which the lagoon is divided This inner channel is characterized as an energy dissipating factor by means of the parameter

$$F = \frac{E_3}{d_{3\,0}} = \frac{2\,g\,L_3}{d_3\,C_3^2}$$

If there are no head losses in the lagoon ($L_3 = 0$, d_3 or $C_3 = \infty$), F equals 0 The variation of F was obtained only by varying $d_{3\,0}$, that is, a study was made of four different cases characterized by an inner channel with progressively lower depth

$$d_{3\,0} = 6,\ 5,\ 4,\ 3$$

Fig 12 shows the general decrease of the bed load capacity of the tidal currents in the outer inlet as the internal head losses increase, which is the result logically expected Nevertheless the same figure also shows the increase of the relative importance of the ebb bed load capacity as compared with that of the flood This figure also shows the percentage with which a capacity overcomes the other for each case considered Such a percentage is found to reach very significant values in some cases which will favourably influence the natural flushing ability of the inlet

Summing up the main conclusions drawn from this work, we have

- The natural flushing ability of the inlet of a vertical bank lagoon where the law of levels can be assumed uniform, reaches a maximum for values of the coefficient of repletion of about 0 6 to 0 8,

- The slope of the lagoon banks or the existence of areas overflowed and uncovered during tidal cycle, increase the bed load capacity of the ebb currents as compared to the flood ones, and thus improve the natural flushing ability of the inlet,
- The existence of head losses in the lagoon or the effect of propagation of the tidal wave decrease the tidal prism and the integral bed load capacity of the tidal currents, but improve the ebb capacity as compared to that of the flood which has a favourable influence on the natural flushing conditions of the inlet

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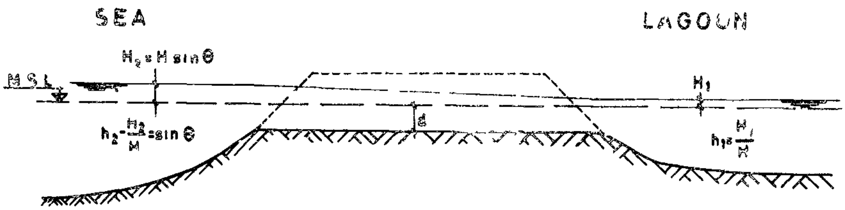

Fig 1 - SECHEMATIC LONGITUDINAL SECTION OF INLET CHANNEL

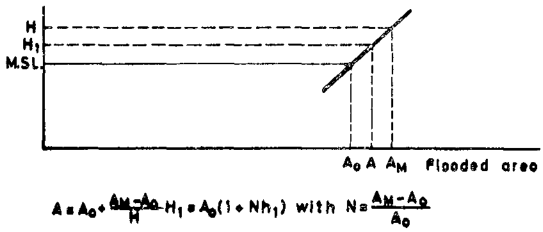

Fig 2 - LINEAR VARIATION OF FLOODED AREA IN LAGOON BASIN

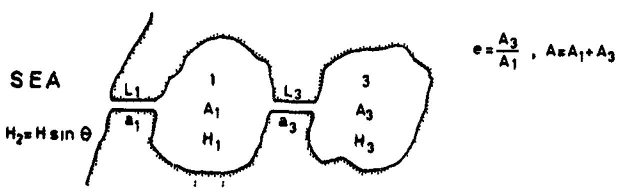

Fig 3 - TWO CHANNEL-LINKED BASINS FORMING A LAGOO

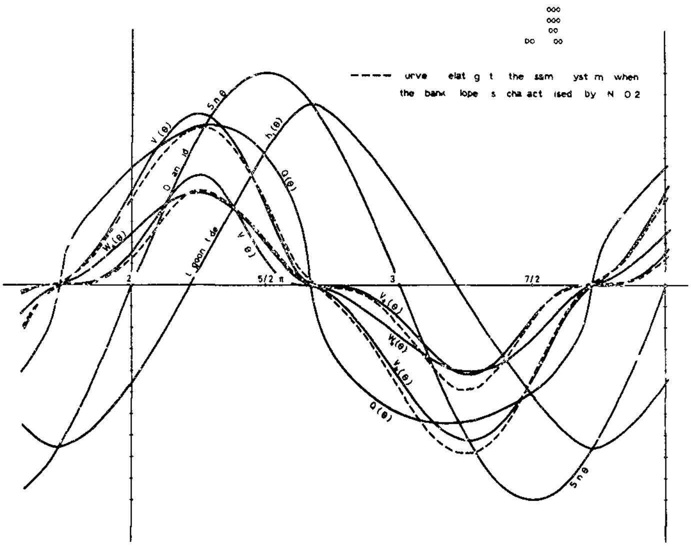

Fig 4 - CHARACTERISTIC CURVES OF AN INLET-LAGOON SYSTEM WITH VERTICAL BANKS, AS OBTAINED FROM THE COMPUTER

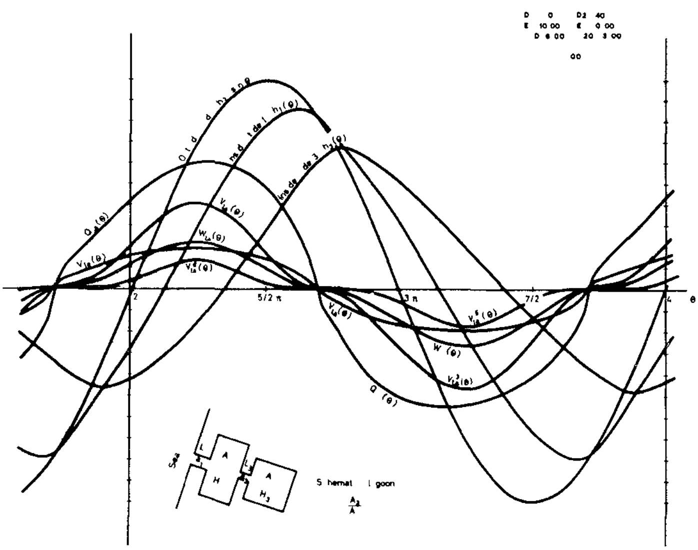

Fig 5 - CHARACTERISTI CURVES OF A TWO-BASIN LAGOON INLFT

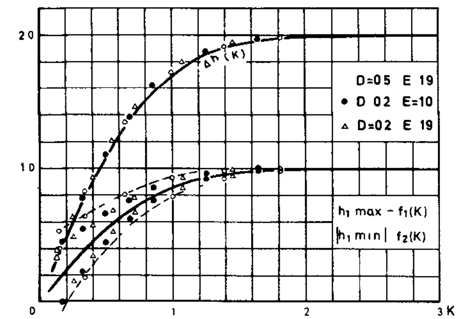

Fig 6 - TIDAL PRISM VARIATION AS A FUNCTION OF THE COEFFICIENT OF REPLETION K

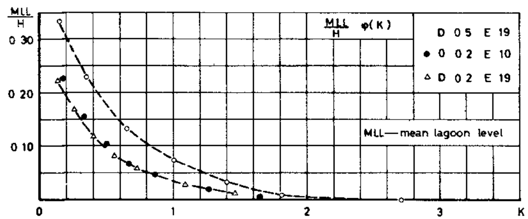

Fig 7 - MEAN LAGOON LEVEL VARIATION AS A FUNCTION OF THE COEFFICIENT OF REPLETION K

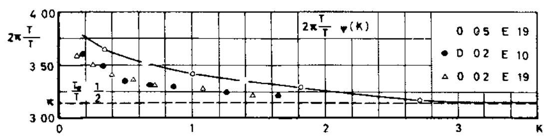

Fig 8 - EBB PERIOD VARIATION AS A FUNCTION OF THE COEFFICIENT OF REPLETION K

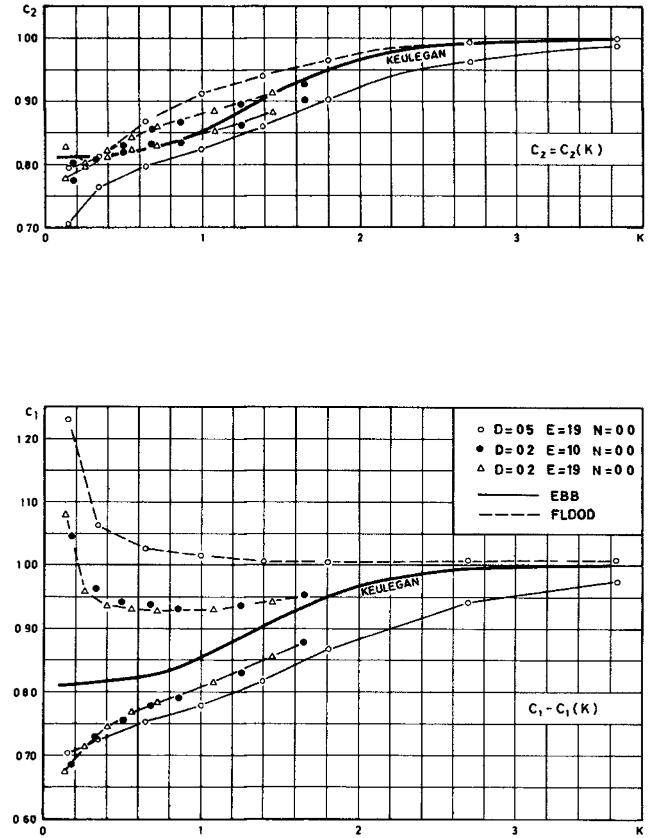

Fig 9 - C_1 AND C_2 VARIATION (VD ITEM 3 3) AS A FUNCTION OF THE COEFFICIENT OF REPLETION K

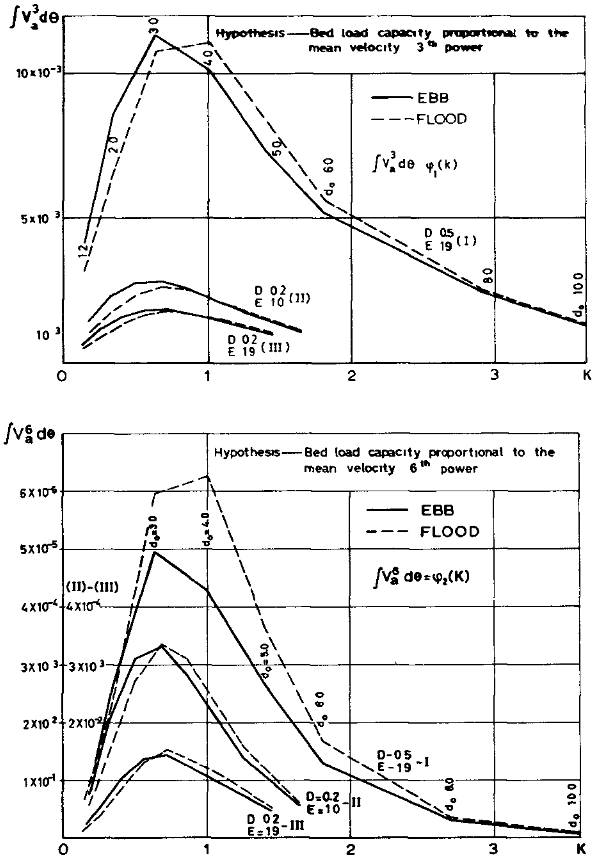

Fig 10 - VARIATION OF TIDAL CURRENT BED LOAD CAPACITY WITH THE COEFFICIENT OF REPLETION

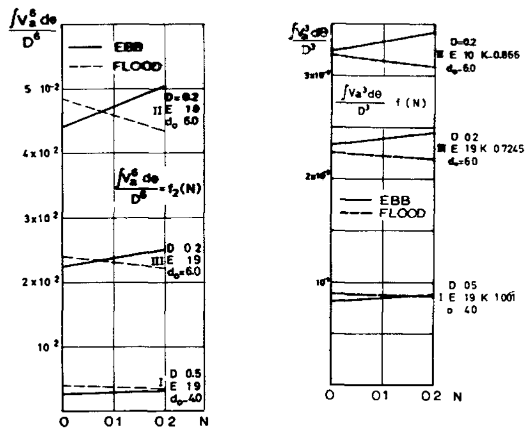

Fig 11 - INFLUENCE OF LAGOON BANK SLOPE

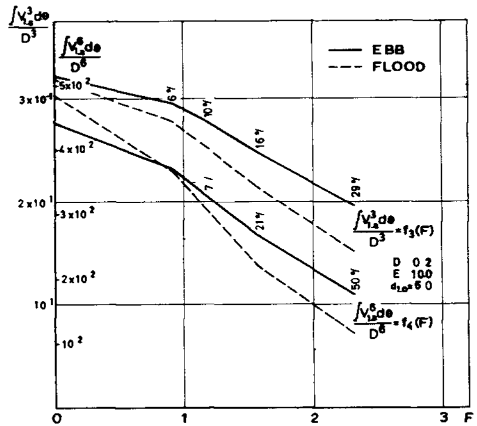

Fig 12 - INFLUENCE OF HEAD LOSSES IN THE LAGOON