Journal of Coastal Research	SI 39	561 - 564	ICS 2004 (Proceedings)	Brazil	ISSN 0749-0208

The Stability of the Camacho Inlet, Santa Catarina, Brazil

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ABSTRACT

BORDERES DE OLIVEIRA, D.; CARVALHO, J.L.B. and KLEIN, A. H. F., 2006. The stability of Camacho inlet, Santa Catarina, Brazil. Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium), 561 - 564. Itajaí, SC, Brazil, ISSN 0749-0208.

In the south of the State of Santa Catarina lies the Camacho Lagoon (28°36'S and 048°54'W), which is connected to the Atlantic Ocean by a single channel known as the Camacho Inlet. The inlet is not permanently open, which impedes fishing activity inside the lagoon. The State Government therefore decided to build two groins at the mouth of the inlet, with the aim of stabilizing it. However, even with the groins in place, the lagoon still shows an inconsistent profile. This research seeks to analyze the stability of the inlet, the factors at work, and the efficiency of the groins. This study of the stability of Camacho Inlet involved empirical criteria based on (1) the relationship between tidal prism and cross-section area; (2) the relationship between maximum velocity and cross-section area and (3) the relationship between response ability and cross-section area. Taking into account the environmental aspects of the area and its fluctuations, it is clear that the efforts to keep the Camacho Inlet open were in vain. The Camacho Inlet presents a strong profile of instability, with cross-section area and flow velocity values below those necessary to generate stable conditions in the system. The channel is only open during periods of intense river discharge and/or meteorological tides; once the inlet is open, the flow is maintained by the semidiurnal tide, which is not strong enough to remove the sediment deposited in the channel. This condition, associated with the high rate of sediment transport in the region, causes the channel to close completely.

ADDITIONAL INDEX WORDS: *Tidal prism, cross-section area, response ability.*

INTRODUCTION

Coastal lagoons are shallow water bodies connected to the sea by one or more inlets which flow through a sandy barrier. These systems are usually present in areas with a wide continental shelf, intense wave action and a wide microtidal range. According to GOODWIN (1996) the water body may be saline, brackish or fresh, and depending on the tidal exchange through the inlet channel, freshwater inflows and is lost due to evaporation or seepage. KJERVE (1990) sub-divides lagoons into three major types, according to the degree of water exchange with the coastal ocean: (1) choked lagoons, where a single channel connects with the sea; (2) restricted lagoons, which have two or more channels and (3) leaky lagoons, which have wide tidal passes.

To the south of the State of Santa Catarina, between the towns of Laguna and Jaguaruna, is the *Complexo Lagunar Sul-Catarinense*, a lagoon complex (see Figure 1). The Camacho Lagoon forms part of this complex and is connected to the Atlantic Ocean by a single channel, known as the Camacho Inlet.

The Camacho Lagoon is a choked lagoon with an approximate area of 24 km^2 and mean depth of 2 m (INPH, 1993). According to the INPH (1991) the wave action of the ocean region, 98% of the time, consist of wave heights of less than 2 m. NE winds are the most frequent and intense, followed by the NNE, S and SW winds (INPH, 1992). In the nearby area, dune fields of multiple dimensions and heights are formed. This formation is the result of the incident winds in the area, predominantly, the NNE wind (GIANINI, 1993).

Measurements carried out by the DEOH-GEOCO in the Camacho Lagoon, in 1994, show that the average water level is -0.30 m (in relation to IBGE vertical data), but can vary from -0.41 m to +0.46 m, depending on the climatic conditions. The astronomical tide is classified as mixed, predominantly semidiurnal (F=0.84), and suffers strong meteorological influence (INPH, 1991).

The Camacho Inlet presents a history of instability (Table 1), whereby it is closed most of the time and opens only in periods of meteorological extremes. The State Government therefore decided to build two groins in the inlet, to stabilize it and enable fishing activity in the lagoon.

The works to stabilize the channel began in 1990. In July 1993, after a long break in the activities, the groins were finally completed. However, even with the presence of the groins, the lagoon still shows a fluctuating profile, and this study seeks to point out the reasons for this instability.

METHODOLOGY

Before analyzing the stability of the Camacho Inlet, a knowledge was needed of the main frequencies of variation in

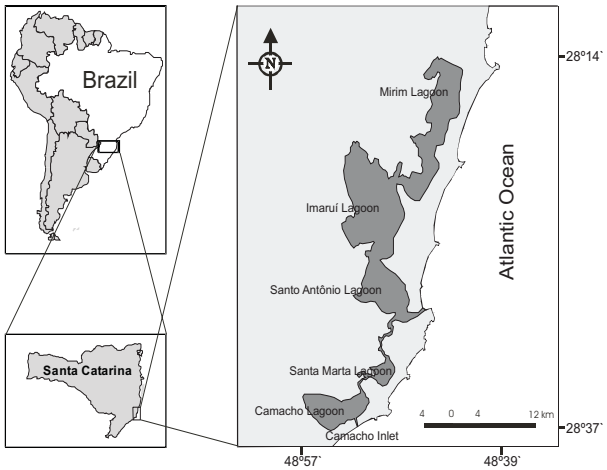

Figure 1. Location of Camacho Lagoon.

the lagoonal system, to determine which agents are active in generating the flows that could keep the channel open. To do this, time series of (1) water levels inside the lagoons, (2) wind, (3) fresh water discharge and (4) tidal levels in Laguna Sea Port were analyzed.

To calculate the water level range in the mouth of the inlet, the tidal components were determined using the PAC software (FRANCO, 1988) for harmonic

The stability study of the Camacho Inlet involved empirical criteria based on:

- Relationship between tidal prism () and cross-section area (A_c) ;
- Relationship between maximum velocity (V_{max}) and cross-section area (A_c) (ESCOFFIER, 1940);
- Relationship between response ability (R_A) and cross-section area (A_c) .

The above relationships were analyzed through analytical solutions, following the methodology proposed by MEHTA and ÖZSOY (1978) for inlet hydraulics and by O´BRIEN and DEAN (1972) for inlet stability.

For the stability analysis, the following dimensional values were used (DEOH-GEOCO, 1995):

- Camacho Inlet length: 1,000 m;
- Camacho Inlet width: 35 m;
- Camacho Inlet depth: 1.5 m;
- Cross-sectional area (A_c) of Camacho Inlet: 59.5 m^2;
- Margin slope: 3:2
- Area of the lagoonal water body: 24 km^2

RESULTS AND DISCUSSION

A certain similarity can be observed between the water level records from the Laguna Sea Port and the Santa Marta and Camacho lagoons. However, there is evidence of phase lag and attenuation in the amplitude of the variation as the water advances towards the lagoonal system. The main variation periods for the Laguna Sea Port (44.05, 18.79 and 12.30 days) are also present in the Camacho Lagoon, showing a phase lag of 3.14, 2.83 and 1.86 days respectively (Figure 2).

The energy spectrum for the water level recorded in the Laguna Sea Port shows that the energy peaks, due to the diurnal and semidiurnal tides, are very significant, but variations with periods of more than 10 days present even more significant peaks.

Although water level measurements in a situation of open inlet do not exist, we believe that the pattern observed for Laguna should also occur when the Camacho Lagoon is open. Carrying out a time scale analysis, the flows generated in the channel by the variations of more than 10 days would be weaker than the flows originated by the diurnal tides, and the flows generated by the semidiurnal tide would be the strongest. This occurs because the volume of water flowing into the lagoon during the semidiurnal tide has to flow off in a shorter period of time (6 hours), which generates a higher flow speed in the channel. This fact allows us to determine the stability criteria of the Camacho Inlet, considering only the flows caused by propagation of the semidiurnal tide.

The harmonic tidal analysis revealed that the components that more influence the system are M2, S2, O1, and K1 respectively (Table 2).

In the simulations for the stability criteria, 0.22 meters maximum amplitude was used. This value was determined as the highest level variation between the ebb tide and the flood tide found in a tidal forecast using the four harmonic constants.

Relationship Between Tidal Prism and Cross-Section Area

A tidal prism value of 1,660.000 m^3 was achieved using the methodology proposed by MEHTA and ÖZSOY (1978).

A stable cross-section area of 175 m^2 was calculated using the methodology described by O´BRIEN (1969).

According to the methodology described by JARRET (1976), the Camacho Inlet is stable when 56 $m^2 \leq A_c \leq 327$ m^2, where 127 m^2 is the mean recommended value ($Ac= 1.57 \times 10^{-4} \Omega^{0.95}$).

Considering the values presented above, it is clear that the actual cross-section area of the Camacho Inlet (59.5 m^2) is highly unstable.

Relationship Between Maximum Velocity and Cross-Section Area

According to the methodology described by MEHTA and ÖZSOY (1978) the value for maximum velocity in the inlet is 0.12 m/s (for a semidiurnal tide, with an amplitude of 0.22 m). However, to be stable, the inlet would need to show a V_{max} of 0.85 m/s.

The Principle of ESCOFFIER (1940) applied to the Camacho Inlet (Figure 3) shows stability conditions for several cross-section areas A_c and tidal amplitudes a_0. The figure shows that

Table 1. *Oscillating pattern of Cam*acho´*s inlet (modified from KLEIN et al.(1998)).*

Period	Inlet Characteristics	Environmental Conditions
1927	Open and remained so until the mid 30s	A major storm, with flooding in the region of Itajaí River Valley
From mid 30s to beginning of the 70s	No records of a significant opening	Occurrence of floods in 1957 and 1961
From March 1974 to October 1980	Open for 6 years and 8 months	Higher than normal rainfall in the Tubarão River's Valley
From July 1983 to December 1990	Open	Intense conditions caused by "El Niño"
At the end of 1990	Closed	Start of works to open and stabilize the Camacho inlet.
From July/10th/1993 to August/23rd/1993	Open	Artificially open in June/15th/1993 due to flooding of the Congonhas River. In July/25th/1993 a storm associated with a rise in sea level damaged the groins. Soon after, the inlet had to be closed to repair the groins.
From September to December 1995	Closed	Natural conditions
May/15th/1994	Open	Inlet opened due to flooding of the Congonhas River
December/23rd/1995	Open	Inlet opened due to a major flood. Water level reached + 0.7 m. The inlet remained open for 3 months
From August 1996 to April/12th/1997	Closed	Naturally open. CTTMar´s research group visited the area in October and April

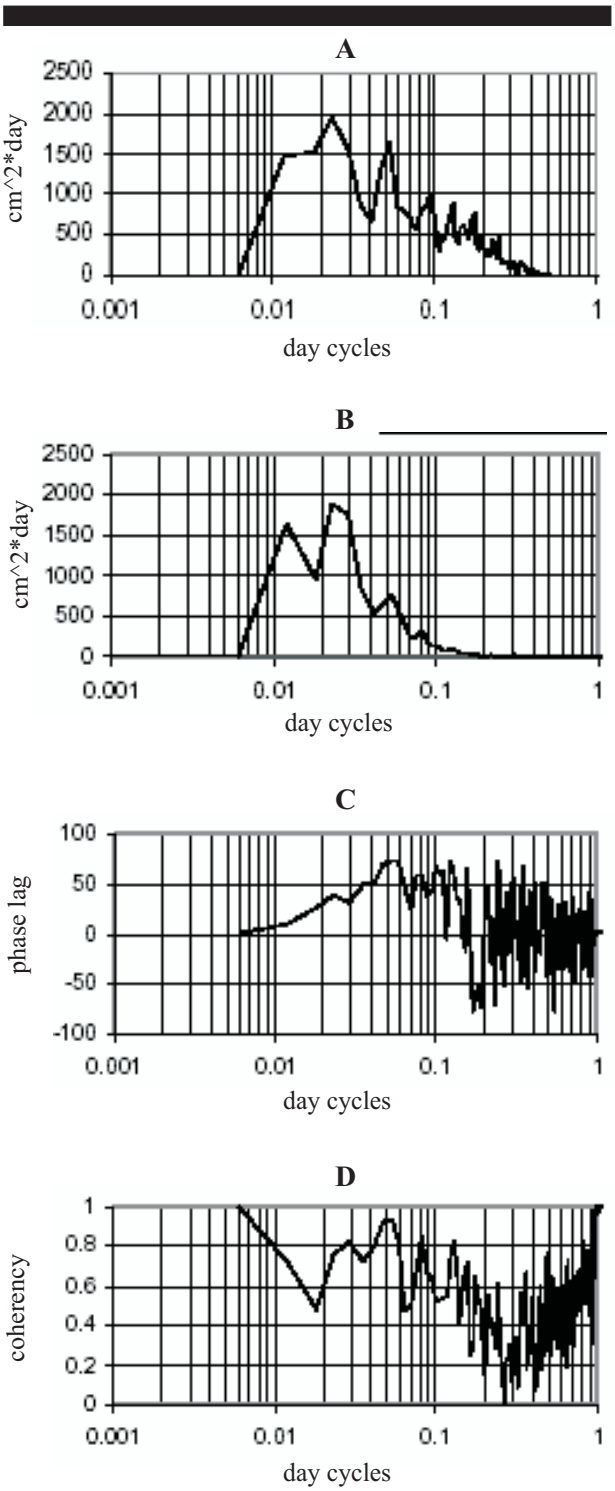

Figure 2. **A**: Power spectrum from the water level record in Laguna Sea Port; **B**: Power spectrum from the water level record in Camacho Lagoon; **C**: Phase spectrum between the water level records from Laguna Sea Port and Camacho Lagoon; **D**: Coherency spectrum between the water level records from Laguna Sea Port and Camacho Lagoon.

Table 2. *Main harmonic tidal components for Laguna Sea Port.*

	Amplitude (m)	Phase (s)	Period (s)
M_2	0.0746	3.780	44.720
S_2	0.0583	24.404	43.200
O_1	0.0688	49.289	92.970
K_1	0.0434	84.509	86.170

there is no stability when (1) the cross-section area A_c is less than 200 m^2 and (2) the maximum velocity V_{max} is less than 0.4 m/s.

Relationship Between Response Ability and Cross-Section Area

The response ability R_A, calculated by means of an analytical solution, is shown in figure 3 (the full line), which shows clearly that even with a small a_0, and A_c of 280 m^2 is needed, to ensure conditions of equilibrium in the inlet.

The criterion of maximum velocity states that ideal flow conditions, and consequently stable A_c, will only be achieved when the V_{max} is approximately 0.8 m/s. The calculations made in this study show that the inlet rarely presents these values of velocity, a fact which contributes to the silting up of the channel.

The criterion of ESCOFFIER (1940) (Figure 3) shows that the actual inlet (Ac = 59.5 m^2) is far from presenting stable conditions. The stability curves for the different tide amplitudes show that the cross-section area would become stable at a minimum value of 200 m^2; when a_0 is 0.03 m. For an extreme situation like that of the Camacho Inlet, with a_0 of 0.22 m, a stable Ac would be 350 m^2.

Therefore the Camacho Inlet, for any amplitude of operating tide, shows cross-section area dimensions smaller than those necessary to maintain a stable condition.

CONCLUSIONS

According to the environmental history of the region and the results of this research, it is clear that the construction of the groins in the Camacho Inlet was misguided. The groins were not effective in maintaining the water exchange between the ocean and the lagoon.

From the stability criteria used in this work, it is clear that the inlet is highly unstable. The Camacho Inlet shows cross-section area and flow velocities that are below those necessary to create stable conditions in the system.

The Camacho inlet is only open during extreme events of river discharge and/or meteorological tide; when the inlet is open, the flow is driven by the tidal motion. Since the flow in the channel is maintained by the action of astronomical tides, the velocities generated are not strong enough to remove the deposited sediment. In addition, this region presents high rates of sediment transport, coming both from the land and from the ocean. This fact contributes to the complete closure of the channel.

ACKNOWLEDGEMENTS

The authors would like to thank DEOH, in particular , Engineer Milton Sant'Anna, for the information about the Camacho Lagoon, without which this study would not have been possible.

LITERATURE CITED

DEOH-GEOCO, 1994. *Relatório de Acompanhamento dos Níveis d' Água da Cheia Ocorrida na Bacia Hidrográfica do Rio Congonhas em Maio de 1994*. Florianópolis, 76p.

DEOH-GEOCO, 1995. *Relatório a Respeito das Obras de Fixação e Abertura da Barra da Lagoa do Camacho*. Florianópolis, 42p.

ESCOFFIER, F.F., 1940. The stability of tidal inlets. *Shore and Beach*, 8 (4), p. 114-115.

FRANCO, A.S.,1988. *Tides: Fundamentals, Analysis and Prediction.* São Paulo: FCTH, 250 p.

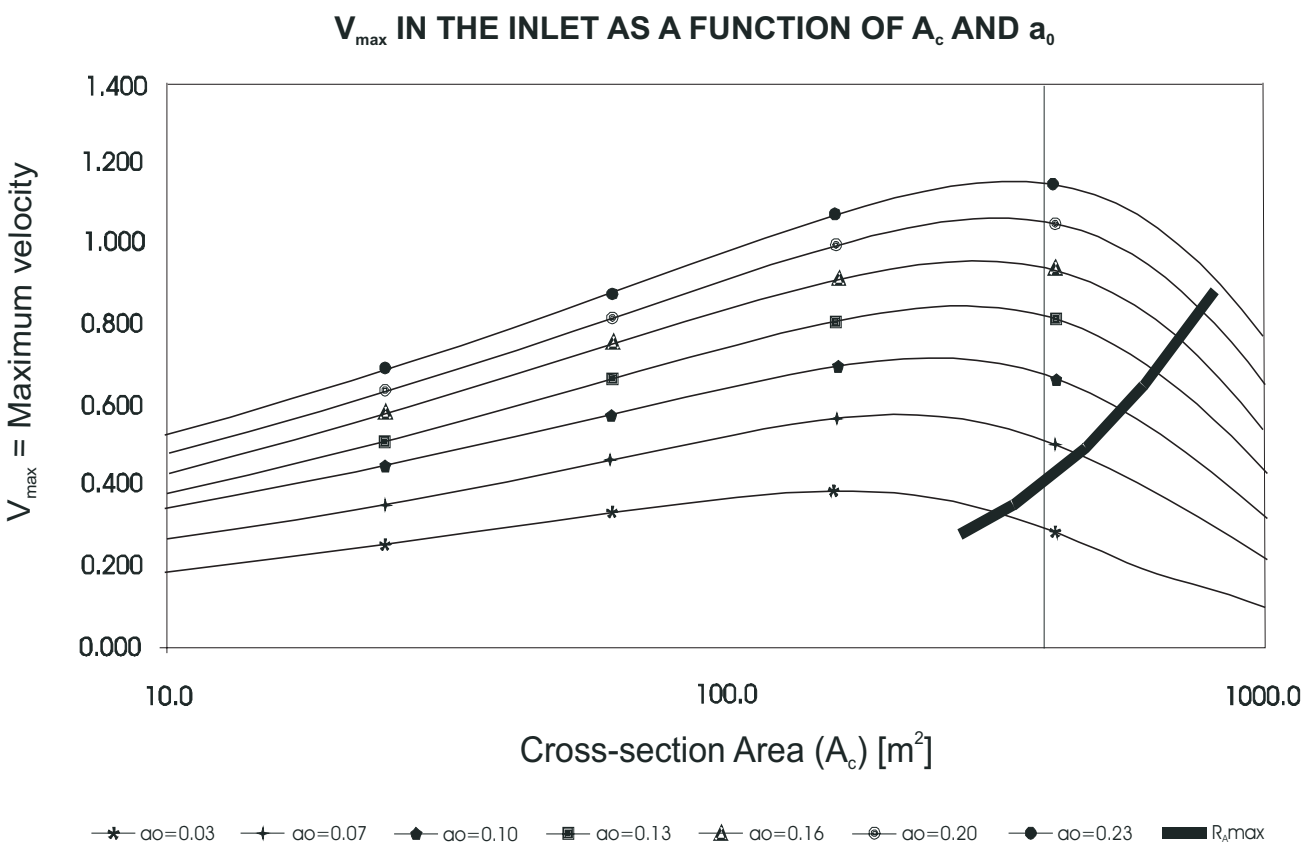

Figure 3 . Stability curves and response ability for Camacho Inlet.

GIANINI, P.C.F., 1993. Sistemas Deposicionais no Quaternário Costeiro entre Jaguaruna e Imbituba, SC: Universidade de São Paulo, tese de Doutorado, vol. 1, 278p.

GOODWIN, P., 1996. Predicting the stability of tidal inlets for wetland and estuary management. *Journal of Coastal Research*, SI(23), 83-101.

INPH, 1991. *Parecer Técnico Quanto aos Aspectos Hidráulicos-Sedimentológicos Relativos à Obra de Fixação da Barra do Camacho*. Rio de Janeiro, 92p.

INPH, 1992. *Monitoramento Ambiental do Complexo Lagunar da Região Sul Catarinense Medições de Níveis d' Água e Vento*. Rio de Janeiro, 125p.

INPH, 1993. *Simulação do Escoamento de maré e das Concentrações de Sal nas Lagoas do Camacho e Garopaba do Sul, Santa Catarina*. Rio de Janeiro, 73p.

JARRET, J.T., 1976. *Tidal Prism-Inlet Área Relationships*. Fort Belvoir, Virginia: U.S. Army Corps of Engineers, G.I.T.I Report 3.

KJERVE, B., 1990. *Manual for Investigation of Hidrolological Processes in Mangrove Ecosystems.* Paris: UNESCO, 72p.

KLEIN, A.H. da F.; SCHETTINI, C.A.F.; CARVALHO, J.L.B. de; and DIEHL, F.P.,1998. Implications of Inlet Stabilization on the Camacho Lagoon, Southern Brazil. .*Journal of Coastal Research*, SI (26) (ICS '98 Proceedings), 150-155.

MEHTA, A.J. and ÖZSOY, 1978. Inlet Hydraulics: flow dynamics and nearshore transport. *In:* BRUUN, P., *Stability of Tidal Iinlets Theory and Engineering.* Amsterdam, The Netherlands: Elsevier Scientific Publishing Co, pp. 83-161.

O´BRIEN, M.P., 1969. Equilibrium areas of inlets on sandy coasts. *Journal of the Waterways and Harbors Division,* ASCE. Vol. 95, pp. 43-52.

O´BRIEN, M.P. and DEAN, R.G., 1972. Hydraulics and sedimentary stability of coastal inlets. *Proceedings of the 13th Coastal Engineering Conference* (Vancouver), Vol. II, pp. 761-780.

SKOU, A., 1990. On the geometry of cross-section areas in tidal inlets. Technical University of Denmark, Licentiata Technices' report, 109p.