HYDROSEDIMENTOLOGICAL STUDIES IN BAHIA BLANCA

BY

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1. INTRODUCTION AND SUMMARY

The increasing international grain trade make it necessary to have more deep facilities for large draught ships.

Within the areas of major agriculture developments, Bahía Blanca harbour complex, is one of the most important and consequently also its improvement. In order to achieve this improvement a deeper and wider navigation channel has to be designed.

The actual channel, 100 km. long is limited to bulk carriers up to 37 ft. draught. It is developed along a sandy and silty coast with large bars and islands. Bahía Blanca is located at the southwest of the Buenos Aires Province, within a Bay of trapezoidal shape, where the mean tidal range changes from 3,5 m in the inner part to 1,8 m in the outer part. Trying to improve a so long channel in a complex sedimentological area imply a rather difficult task, which requires a fully investigation programme to achieve an economical and technical solution. To this end, extensive field and desk studies were carried out covering all the influence area and testing different alternatives.

One of the major problems to solve is the sedimentological stability of the channel due to the action of currents and waves.

The use of mathematical models and of large and reliable field surveys, together with a pilot test dredging used as a one to one model for the calibration of the transport formulas, looks as the most suitable method to attack such problems.

The results of this study are part of the navigation channel project carried out by the firm NEDECO-ARCONSULT for the Argentine Government.

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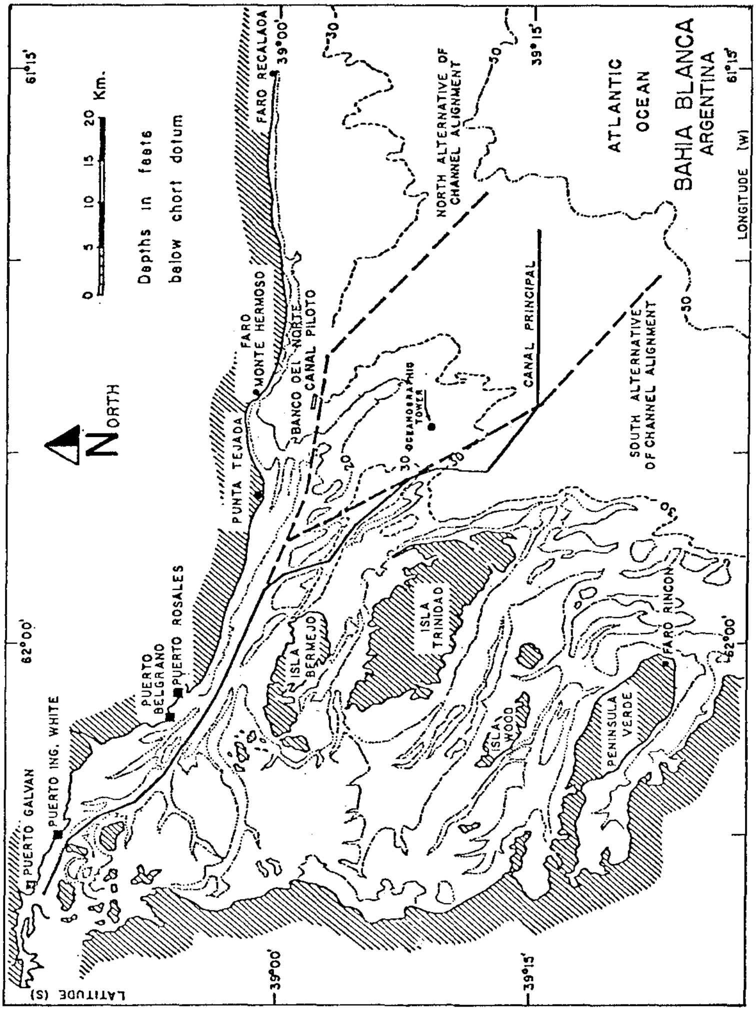

Fig. 1 Bahia Blanca, general view

2. SITE DESCRIPTION

PHISIOGRAPHIC CHARACTERISTICS

From the phisical point of view, Bahía Blanca is characterized by sandy and silty coasts with large bars and islands which show the result of a dentrictic shape. Fig. 1.

One of the most important physical factors of the area are the tides, which in the range up to 4 m. flood large part of those bars spreading the water surface from 745 Km2. in low water to aproximately 1.880 Km2 in high water; showing at this stage a unique water surface with a few islands.

This means that the difference between low water and high water is of about 1.135 Km2. of land, that is covered with water alternatively within 6 hours and a half.

This behavior has an important influence in the hydrosedimentological aspects of the area.

Other important picture of the area is that there is no fresh water supply, because only small creeks discharge on it.

It is a windy area with a dry climate. The reason of that is due to the fact that the most frequent winds are from the West and North, which induce a typical continental weather.

Eventhough, when this situation is reversed the winds from the South-East produce changes in the Bay behavior with wind set up and ocean waves conditions.

Due to the continental weather and the low depth, the water temperature is affected by the air temperature, making its variation from a maximum of 26°C and a minimum of 9°C.

HYDROOCEANOGRAPHIC CHARACTERISTICS

The Principal Channel has an extention of about 100 Km. long.

This is a natural channel, part of which has a depth of more than 60 feet. But there are other areas where the navegation is restricted by depth of about 30 feet, which imply a yearly mantainance dredging and also to make use of the tide to go in and out of the channel.

Those areas of shallowness are principally located on the outer zone, where, the sand bars movement are due to the combined action of currents and waves.

As a general feature of the channel, we can divide it in three different sections each of them with different geomorphological characteristics.

The inner part, is extended from Galvan Port to Belgrano Port with aproximately 30 Km. Here we find soft rocks on the bed and therefore a very stable situation. On the other hand the flats are muddy convered, and due to the tidal action and wind induced turbulence we find in the water large amount of suspended sediment, getting from the tidal flats.

From Belgrano Port up to an extention of about 20 Km. the channel bed is of fine sand and silt. Here is where largest depth is found.

Out of this area, the channel becomes erratic and shallow. Rather than one defined channel we find several branches which also change in shape and depth due to storm conditions.

As it was said before, the tide characterizes the flow conditions in the area, generating reversible currents in the natural channels of about 0,3 to 1,3 m/s.

These currents induce the movement of large amount of sediment inward and outward the bay during flood and ebb. It can be said that the sediment transport induced by tidal currents has an almost zero net drift.

However under storm conditions, where wind driven currents and waves are present, the dynamic stability is broken.

Particulary in the outer area, the wave climate has a very important role in the sedimentation mechanisms.

Two wave systems are presented, the ocean waves coming from the S and SE and the localy generated wave by anshore winds.

The first one have waves up to 5 m. height and period of 12 seconds, which are strongly effected by the shoals and the second one goes up to 4 m. height but in the period of 7 to 8 seconds.

3. HYDROSEDIMENTOLOGICAL PROBLEM

As it was stated the outer part of the channel represent the major problem due to its sedimentological instability.

As we can see in Fig. 1 the existing channel turn to the south as it reach the end of the island area.

This behavior is somewhat unexpected because the tide and the current shows a symetric pattern in the angle formed by the norther shore and the West island shore.

Nevertheless, only after a good knowleged of the nature of the sediment of Banco del Norte, it will be possible to understand the problem. Previous works in the area, and spetially bottom sounding performed before, show us that this "Banco del Norte" remains identical along the time. The only possible reason for that, it would be that the surface of such a bank were harder than the original southen part.

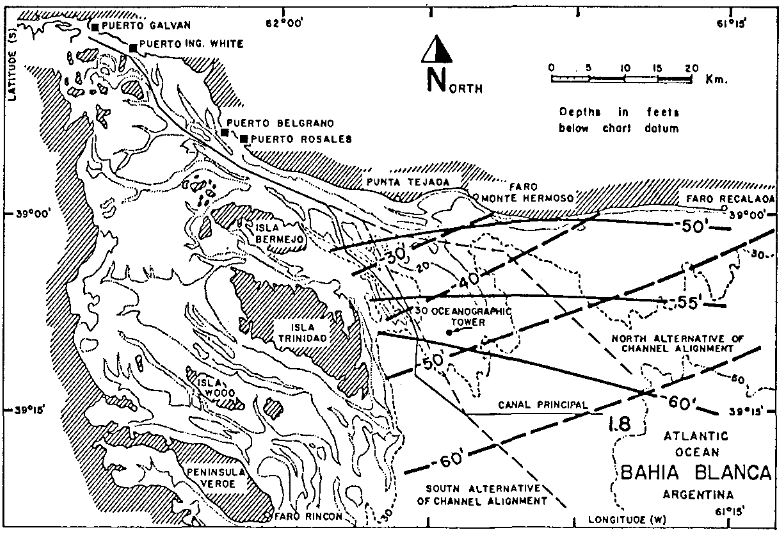

Fig. 2 Cotidal lines for high and low water

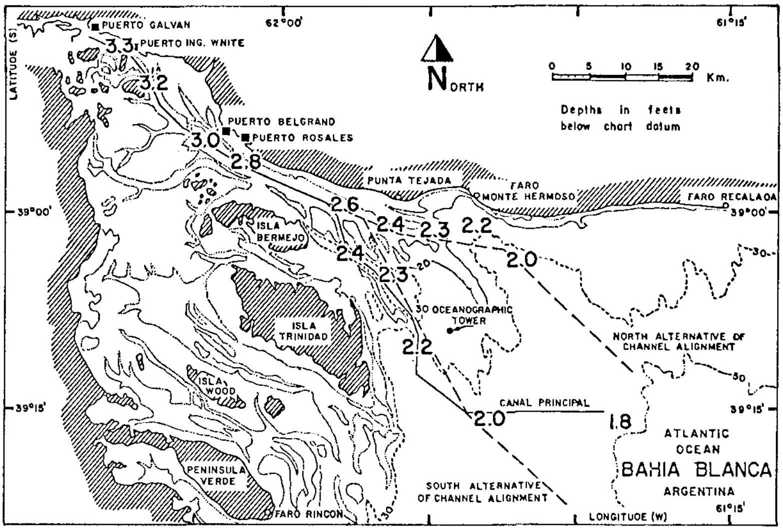

Fig. 3 Mean tidal amplitude

Moreover, if we consider in such alignment a new channel cutting Banco del Norte, it would be a good solution because the current will increase keeping the channel almost free of sedimentation.

For this reason we include the norther alignment in order to provide a new and shorter alternative for the access channel to the harbor complex.

The present paper deal with the hydrosedimentological studies carried out in this outer area.

What it was done and the resulting test carried out shows the difficulties with what we have to deal in order to estimate the sedimentation rate on a navegation channel dredged through a bank in an area with large waves and tidal currents.

4. FIELD SURVEY

The field survey was rather extensive and covered all the major aspect of the hydrosedimentological parameters.

The first work was a complet sounding of the area following the existing channel and the new alternative of alignments, previously selected from the existing data. The sounding extended over more than 1000 Km. was taken as a reference sea bottom level for all the future works.

Previously to the bottom sounding, 11 tidal gage station were installed adding to the two existing ones, which were recovered after the one mouth survey. The tidal data was first analized to get the chart datum level and to reduce the soundings.

Moreover determination of sea levels, tidal amplitudes, phase lags and harmonic analysis were carried out to provide information for navigation and hydrodinamic studies. Cotidal lines for high and low water are shown in Fig. 2 and the averaged tidal amplitudes in Fig. 3. As it can be seen the tidal flood go tinto the bay from south to north and the tidal ebb from NW to SF, also a large change in amplitude is recorded from the inner part to the outer part as a result of the funnel shape of the canal principal.

Current velocities and directions were measured at hourly intervals generally during 13 hours periods, at different points of the vertical at 22 stations, repeting most of them during both spring tide and neap tide conditions.

The variation of the current velocities in magnitude and direction under different tidal and meteorological conditions, were measured, generally during 14 days periods, using a non wave afected self-registered current meter, positioned at 10 stations.

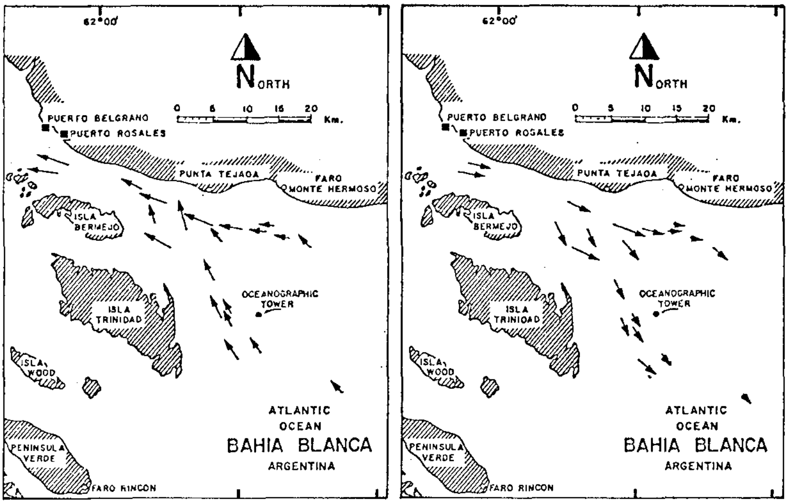

Fig. 4 Mean current pattern

The currents patterns, Fig. 4 shows in the inner part a larger velocity during ebb flow than during flood flow, ranger in the order of 0,7 - to 1,0 m/s. In the outer region the velocities decrease to the order of 0,3 m/s and the direction remains almost reverse within an angle of 10-15°. Further off shore the current directions rotate rather than reverse.

The climatological conditions at Bahía Blanca were obtained from the Servicio Meteorológico Nacional. Local winds statistic was obtained from Comandante Espora Station of the Navy.

A proper description of the wave climate in the estuary was required to design the navigation channel and for the hydrosedimentological computations. Since no wave measured data were available for the project, a Datawell waverider were first installed at the entrance of the bay for a six month period.

It was later moved to Banco del Norte, where is recording since more than one year. A wave staff was also installed on the measurement tower near buoy 8 (See Fig. 1)

Until the processing and analysis of the wave data of at least one year record has been completed other information had been used. For that the wave climate was divided in 2 categories: waves generated locally from onshore winds blowing from SW to NE directions and incoming ocean waves (swell) originating off shore from E-S directions.

The wave characteristics for onshore wind conditions were determined from the JONSWAP sepectrum (Ref. 1)

The ocean waves offshore Bahía Blanca were estimated by hindcasting on the basis of a mathematical model for the Argentina Sea developed by the Argentina Navy Meteorological Service.

On a 90 m. depth and for a period from May 1976 to January 1981, daily waves heights, periods and directions were computed, adding up a record of about 1700 data.

The ocean waves were refracted to get the shallow ocean waves climate for different points along the channels alternatives.

To this end, a mathematical model was used based on linear wave theory (Ref. 2)

SIGNIFICANT WAVE HEIGHT - H_s (m) \ SIGNIFICANT WAVE PERIOD - T_s (Sec.)	0–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	OCURRENCE FREQUENCY OF SIGNIFICANT HEIGHT PERIOD
OCCURRENCE FREQUENCY OF SIGNIFICANT WAVE PERIOD		4,17	12,85	18,40	11.0	10,65	9,14	9,03	7,99	7,41	3,47	3,36	1,39	0,58	0,35	0,12	0,12	100
2.5–3.0						0,12	0,12			0,12								0.35
2.0–2.5					0,12	0,23	0,35	0,58	0,12	0,46	0,23	0.12						2.31
1.5–2.0					0,46	1,04	0,58	0,35	0,23	0,12	0,23	0,23						3.24
1.0–1.5			0,69	1,74	1,04	1,74	0,46	0,23	0,46	0,58	0,12							7,06
0.5–1.0		0,58	7,06	8,10	4,63	3,01	2,55	3,47	2,43	1,04	0,12	0,23	0.12			0,12	0,12	33.56
0.0–0.5		3,59	5,09	8,56	4,75	4,51	5,09	4.40	4,75	5.09	2,78	2.78	1,16	0,58	0,35			53.47

Fig. 5 Waves dispersion diagram

After the comparison with the one year measured data, a rather good correlation was verified, spetially in the local wind waves.

In Fig. 5 the dispersion diagram is illustrated which was prepared on the basic of the Draper analysis and wave spectrums.

Suspended sediment measurement were done by means of a turbidity meter and water samples at six points in each vertical, at the same locations of the current meter stations. Seabed samples were taken at several locations and at all current meter stations.

The grain diameter D50 varies from 30μ to 300μ showing three types of sediment in the full area. There are zones with full sand with D50 = 200μ , other areas with a mixture of sand and silt with D50 = 100μ and some small areas in which the sediment is composed basical by fine sand, silt and clay.

Other measurement related with the subbottom characteristics were also done, like subbottom seismic profiles by uniboom and sparken technics, and vibrocoring in different location from which were obtained 6 m of samples and in some special points like the area of installing of the measurement tower a case drill hole up to 20 m. soil depth.

Most of this information, also usefull for sedimentation studies, was related with the dredgability of the soil in the channels alternatives.

5. THE PILOT DREDGE

After the analysis of the data collected from all the area along the existing channel and the alternatives was concluded, the pilot dredge was located. The selected area was the so called northern route because for the southern alignment other areas could be take as a control area, like channel sections between buoys 13-14 and 7-8.

Therefore a test channel of 2000 m long and 70 m wide, having a minimum depth of 13,5 m below datum, was dredged during December and January 1981-1982.

Fig. 1 shows the location of the pilot test dredge.

After the channel was completed, a bathymetric survey were done as well as current measurement both on the bank and on the channel by means of twoself recording meter during 15 days.

The wave climate was controlled by the wave gage installed at Banco del Norte.

All this information together with a regular sounding each three mont, let us to check the sedimentation estimation rate providing a proper tool for the calibration of the sedimentation formula. An spetial measurement programm for the one year survey was carried out in January 1983, which includes measurements of currents, suspendend sediments and bed samples of 1 m core.

6. SEDIMENTATION ESTIMATES

A sedimentation estimates metodology was developed on the basis of the existing knowledge for areas were the combined action of currents and waves acts on the sea bottom sediment. With this metodology an estimation of the sedimentation rate were carried out for all the different sections of the channel, taking into account the different wave action and current patterns that are present in each of them.

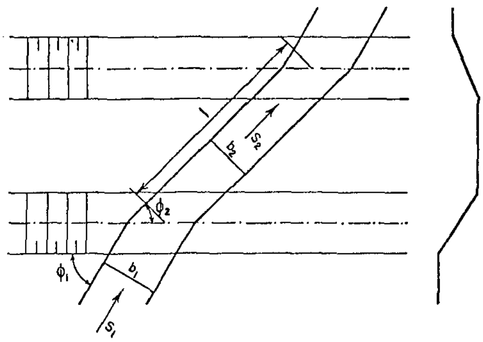

Fig. 6 Channel, definition sketch

Change in the current filled when the flow cross a dredged channel with a given angle, was estimulated on basis of the current refraction research conducted at HRS Wallingford (Ref. 3)

That approach was used for every section and for the pilot channel, where the previous estimation was obtained.

The sedimentation in a channel section can be determined by the difference in sediment transport entering and leaving this section.

Looking to the sedimentation mechanism it can be distinguish ed into the following three groups of processes.

1. Sedimentation due to the combined effect of waves and cu rrents.

2. Sedimentation due to gravity infill at channel slope.

3. Sedimentation or erosion due to an extra inflow which re sults from changing hydraulic boundary conditions along the channel alignment.

From the three mechanism recalled, the first one is the most important, particulary in the outer area.

Therefore in the following only we will refer to this one.

The sediment transport by waves and currents approaching a channel under an angle ϕ in general decrease due to the decrease of turbulence in the channel.

The mathematical formulation for the adaptation of the suspendend sediment in the channel has been given by Fredsøe (1976) Ref. (4) and Bijker (1980) Ref. 5.

As a general approach, sediment transport can be classified in bed load and in suspended load. The suspended load could be of two origen: the fine sediment from the bed putted in suspension by the current and the wash load which is very fine sediment(fine silt and clay)already in suspension.

Looking to the channel scheme Fig. 6 the volume of sedimentation in the time Δt, can be estimated as:

$$V = (S_1 - S_2\ (\ell)\ \frac{b_2}{b_1}\ b_1)\ \Delta t \qquad (1)$$

where

S_1= total load in the bank in equilibrium

$S_2(\ell)$ = total load at a distance ℓ along the streamline from the upstream side slope

in which assuming that the bed load adapts instantaneously to the hydraulics characteristics in the trench, we can write:

$$S_1 = S_{f_1} + S_{s_1} \qquad (2)$$

and

$$S_2(\ell) = S_{f_2} + S_{s_2}\ (\ell) \qquad (3)$$

where

$S_{f_{1\ 2}}$ = bed load in equilibrium in bed and trench

S_{s_1} = suspended load in equilibrium in the bank

$S_{s_2}(\ell)$= suspended load at a distance ℓ along the streamline from the upstream side slope

Following Bijker, the suspended load in a trench due to currents and waves, can be written as:

$$S_s\ (\ell) = (S_{s_1}\ \frac{b_1}{b_2} - S_{s_2})\ \exp\ (-\ \frac{wE\ell}{V_2 h_2}) + S_{s_2} \qquad (4)$$

where

S_{s_2} = suspended load in equilibrium in the trench

$$E = \frac{h_{*1}(h_{*2} - h_{*1})}{h_{*2}(1 - \exp\ (-h_{*1})) - \beta h_{*1}(1 - \exp(-h_{*2}))} \qquad (5)$$

and h_{*1}, h_{*2}= value of h_* outside and in the channel respectivily = $\frac{wh_1}{\varepsilon_1}$ and $\frac{wh_2}{\varepsilon_2}$

where

$$\varepsilon = 1/6\ V_{*cw} h \qquad (6)$$

and

V_{*cw} = shear velocity under combined effect of wave and current according to Bijker (1967)

$$V_{*cw} = V_{*c}\left(1 + \frac{1}{2}\left(\xi \frac{U}{V}\right)^2\right)^{1/2} \qquad (7)$$

$$V_{*c} = \text{shear velocity under current alone} = \frac{Vg^{1/2}}{C} \qquad (8)$$

w = fall velocity of sediment

h_1, h_2 = depth in the bank (1) and channel (2)

ℓ = distance from the channel boundary along the flow trajectory.

U' = maximum orbital wave velocity at the bottom

V = depth averaged current velocity

$$\xi = (fw/2g)^{1/2}\ C \qquad (9)$$

fw = wave friction coefficient =

$$= \exp\left(-5{,}977 + 5{,}213 \left(\frac{A}{r}\right)^{-0{,}194}\right) \qquad (10)$$

(if $A/r \leq 1{,}47$, $fw = 0{,}32$)

A = orbital excursion at the bottom

$$\beta = \frac{Cb_1}{Cb_2} \qquad (11)$$

Cb_2, Cb_1 = bottom concentration outside and in the channel respectively.

For the calculation of the suspended and bed load in equilibrium, on the bank and in the channel, we can use different formulae. The first approach used, was to estimate the total load by means of the Engelund-Hansen formulae and then divided the result in to bed and suspended transport by means of the so call Bijker-Einstein, so

$$S = \frac{0{,}05\ (V_{*}cw)^4\ C}{g^{5/2}\Delta^2 D_{50}} \qquad (12)$$

where

C = Chezy coefficient = $18 \log \left(\frac{12\ h}{r} \right)$ (13)

r = bed roughness

Δ = relative density of bed material = $\left(\frac{\rho s - \rho w}{\rho w} \right)$

D_{50} = particle diameter (50% by weight)

and according to Einstein modified by Bijker since

$$S = S_f + S_s$$

$$S_s = 1{,}83\ S_f \left(I_1 \ln \frac{33h}{r} + I_2 \right) \quad (14)$$

where I_1 and I_2 are the well known Einstein integral.

Following this approach it was estimated the sedimentation along the different alignment of the designed channel, taking into account the different wave and current influence for each section, so waves and current where schematized in group, with their associated percentage of occurrence. Therefore, the following formulae was applied

$$V_s = \sum_{w,c} V_{wc} p_w(H,T)\ p_c(V,\phi)$$

where

V_s = total yearly sedimentation

$p_w(H,T)$ = Wave percentage of height H and period T

$p_c\ (V,\Phi)$ = Current percentage of speed V and direction ϕ

V_{wc} = sedimentation volume due to waves and currents.

This approach was applied to the pilot dredge taking in to account, because their short lenght compared with the navegation channel, the sediment input from the both ends of the same and taking the field measurement current data for the bank and channel.

The result of this calculation, show an average value for the yearly sedimentation of about 0,80 m.

After seven month from the basic sounding of the pilot dredge, the sedimentation was higher. Fig. 7 and Fig. 8 shows some cross

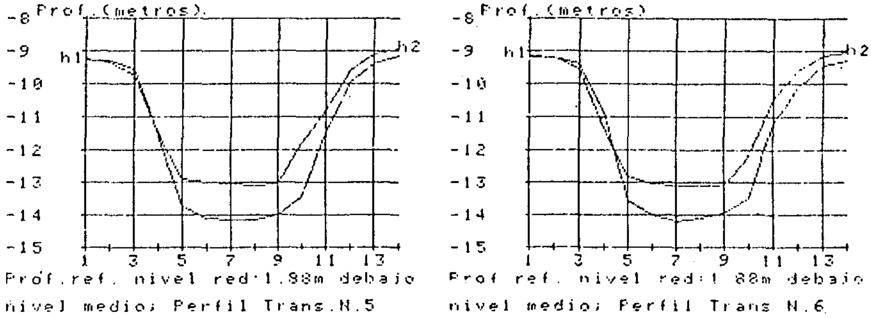

Fig. 7 Pilot dredge, comparison of cross sections after seven months.

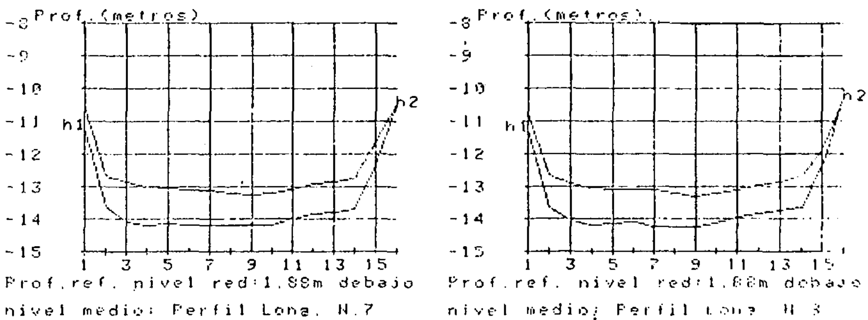

Fig. 8 Pilot dredge, comparison of longitudinal sections after seven month.

and longitudinal section of the channel. The averaged sedimentation observed in seven month is about 1 m.

After this dissapointment, we went back to ower estimation formulae and reanalized them.

First we found that the Engelund-Hansen formula it is very sensitive to the roughness of the bottom, parameter very difficult to estimate.

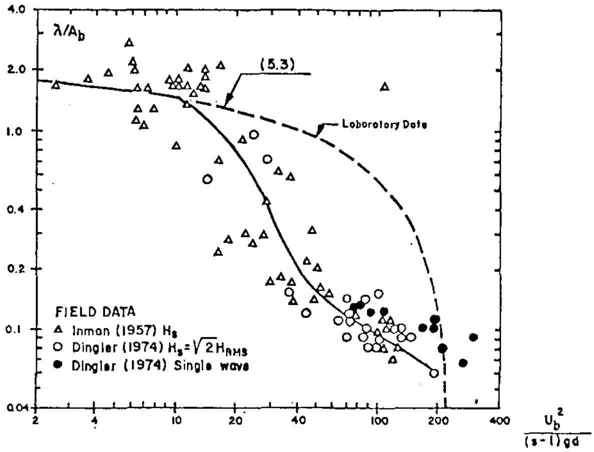

Fig. 9 Ripples height due to waves

Few data from the nature are obtained about the ripples height and wave length from the wave action.

Inman and Dingle data Fig. 9 shows that the prototipe result does not follow the laboratory test. Therefore the first thing to do was to change to another formulae, like the Bijker bed load for current and waves.

$$S_f = \frac{5\ D_{50} V\ \sqrt{g}}{C} \exp\ (- \frac{0,27 \Delta D_{50} g}{\mu V_{*\ wc}^{2}}) \qquad (16)$$

where

μ = ripple coefficient = $(\frac{C}{C'})^{3/2}$

C' = Chezy coefficient for the grain size D_{90}

and taking, according with Einstein the suspended load, for which the bed concentration can be computed as:

$$Cb = \frac{S_f C}{6,34V\ r\sqrt{g}} \qquad (17)$$

with a suspended vertical concentration distribution as follows:

$$C\ (z) = Cb\ \left(\frac{h-z}{z} \cdot \frac{r}{h-r}\right)^{z_*} \tag{18}$$

where

$$z_* = \frac{w}{k V_{*cw}} \tag{19}$$

k = Von Karman coefficient

The result of this calculation shows a less dependence with the bed roughness but now an overestimation of the sedimentation.

Looking to the results got from the Engelund-Hansen, and the Bijker approach, we come to the conclution, that the problem were located in the fact that in both methods the suspended load were overestimated.

The reason of that is because the calculation of the turbulent diffusion coefficient out of the wave boundary layer, is made as produced by the combined effect of the wave and current.

As it was shown by Kennedy experiments and by ISVA measurements, the sediment concentration due to waves decrease very fast as we go up from the bottom, confirmed that out of the wave boundary layer the turbulent diffusions is very small.

On the other hand, also the bed concentration could be overestimated if we consider that it came from the bed load by wave and current. Therefore, we also modified the bed concentration for the suspended load, taking it as due to the current alone. So the wave and current action only affect the bed load.

ROUGHNESS r (m)	BIJKER – EINSTEIN			FIELD DATA
	$\varepsilon = \varepsilon_{cw}$ $C_b = C_{b,cw}$	$\varepsilon = \varepsilon_c$ $C_b = C_{b,cw}$	$\varepsilon = \varepsilon_c$ $C_b = C_{b,c}$	
.012 $r = < \eta >$	7.5	2.6	0.9	
.02	6.2	2.4	0.8	1.00
.04 (Swart)	4.8	2.0	0.6	

Fig. 10 Sedimentation estimate in the pilot dredge, using different aproach, after seven months

In Fig. 10 we can see the result of these different approach, for different roughness criteria applied to 7 month for the pilot dredge from February to September 1982.

7. CONCLUTIONS

From the result got up to now, we can conclude, that for the estimation of the sedimentation in a channel in the open sea, it is still necessary to have a test channel.

It is also very important to have a complete picture of the hydrodynamic behaviour of the area, for which a simultaneous and complete field survey its neccesary.

We point out, also that in order to follow up in the knowledgement of the sedimentation by waves and currents an effort it has to be done in field measurements, like the ripple formations and suspended sediment concentration.

In such a way, we have planning to make careful measurement of concentration in the field, near the bottom, both on the banks and in the channel.

The formula currently applied has to be checked, but in the mean time we can conclude that the Bijker formula can be used but taking for the suspended load the turbulent diffusion coefficient as derived from the current alone.

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