SEDIMENTATION IN DREDGED NAVIGATION CHANNELS

BY

Lars Mikkelsen *

Preben Mortensen *

Torben Sorensen **

1. INTRODUCTION

The feasibility of a harbour project, which involves dredging of an access channel, may to a large extent depend on the future maintenance dredging in the channel. It is therefore important to be able to calculate sedimentation in dredged channels with sufficient accuracy.

In 1974 and 1975 the Danish Hydraulic Institute (DHI) carried out a study of the most feasible access channel to Warri Port situated in the Western Niger Delta, Nigeria. Two alternative entrances were studied and in conclusion it was recommended to improve the existing access channel through Escravos Entrance

* Senior Hydraulic Engineer, M.Sc., Danish Hydraulic Institute, copenhagen, Denmark.

** Director, Danish Hydraulic Institute, Copenhagen, Denmark.

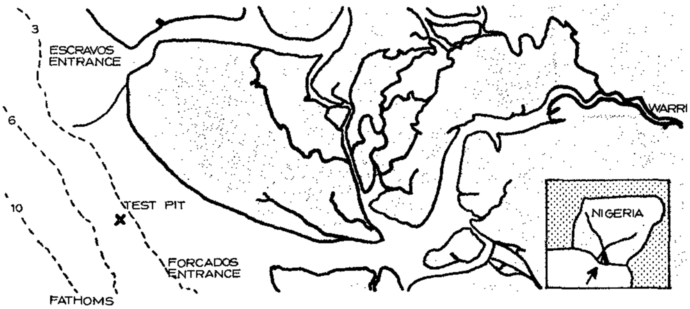

Fig. 1 Location Map

as this solution would yield much smaller maintenance dredging quantities as compared to an access channel through Forcados Entrance, see Ref. /1/

In 1978 it was decided to improve the accuracy of the sedimentation estimates for a dredged channel through Forcados Entrance and therefore it was recommanded by DHI to dredge test pits in the alignment of the channel and to carry out a pertinent monitoring programme.

The paper presents

- The test pit monitoring programme and results including a discussion of measurement techniques.
- calculation of sediment transport in combined currents and waves and comparison with the monitoring results.

- discussion of some important sedimentological aspects.

2. SUMMARY AND CONCLUSIONS

On the basis of the test pit monotoring and the measured current and wave parameters it has been possible to calibrate the sediment transport rates in combined waves and currents. The test pit results has been used to obtain a satisfactory expression for the sediment diffusion coefficient ε_s and hence the concentration profile.

Using the calibrated transport rates, the theoretical sedimentation model and the wave and current statistics it has been possible to calculate the expected annual sedimentation in the dredged channel. Futher, it has been possible to predict the consequences of changes in the depth ratio D_1/D_2 and in the channel width and hence to produce an optimal design of the channel.

In conclusion the sedimentation model has proved itself to be a very useful tool for studies of expected sedimentation quantities, particularly if the transport rates can be calibrated through pertinent field studies.

3. TEST PIT LOCATION AND PLANNING OF MONITORING

A test pit was dredged outside Forcados Bar at an undisturbed depth of app. 7 m MSLW (Mean Spring Low Water), see location map. The aim of the test pit investigation was not to provide a direct estimate of the future annual maintenance dredging quantities. This would be unrealistic due to the following reasons:

1) The test pit experiment took place during a limited part of the year only.

2) The depth in the test pit was decreasing contrary to the maintained depth of the access channel.

3) Suspended sediments would settle from the test pit ends contrary to the settling in a continuous access channel.

4) A continuous channel could tend to "attract" the current in the alignment of the channel.

The aim of the test pit investigation was therefore to calibrate a sedimentation model and thereby be able to understand and control the effects mentioned under 1 through 3.

Based on experiences from channels under similar conditions it was estimated that the effect mentioned under 4 was of minor importance.

In conclusion it was decided to dredge a rectangular test pit with bottom width 200 m equivalent to the future access channel width and bottom length 400 m in order to eliminate the major part of the "artificial" infill from the ends of the pit (effect 3). The test pit volume was about 350.000 m^3

4. FIELD MEASUREMENTS

The test pit was dredged in April 1979 and a monitoring programme was carried out from May to September 1979. Below is briefly outlined the most important hydrographic parameters and the methods of test pit monitoring.

Hydrographic Parameters

Currents

Recording current meters and float trackings relealed current velocities of 10-30 cm/sec without any dominating direction at the location of the pit. Some deviation between the surface and bottom current directions could be observed.

Waves

The wave trains consisted of swell waves approaching from W-SW with typical periods between 10 sec. and 18 sec. superimposed by local wind waves with periods between 3 sec. and 8 sec.

The wave heights (spectrum derived significant wave height H_{mo}) varied between 0.7 m and 2.2 m. About 70% of the time H_{mo} was between 0.8 m and 1.4 m.

Bottom Material

At the location of the test pit the seabed consisted of course silt with fine sand and minor portions of finer sediments could be found. A median grain size of 0.05 mm was characteristic.

Suspended Sediment Sampling

The suspended sediment sampling was carried out by using a tripod frame, see fig. 2.

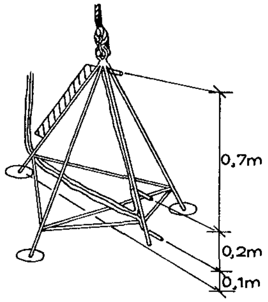

Fig. 2 Tripod Frame

The tripod was lowered to the undisturbed seabed and samples were sucked from fixed levels above the bottom layer, the lowest level being 0.1 m above bed. Results are presented in section 5.

MONITORING OF SEDIMENTATION

Methods

Preliminary calculations had revealed severe potential sedimentation, but even with high sedimentation rates it was foreseen to be difficult to detect the sedimentions with sufficient accuracy due to the swell waves. It was decided to measure the sedimentation by using two different methods:

1) Echo-sounding in lines crossing the test pit. The wave disturbance of the echo-sounding was eliminated by repeating the lines a sufficient number of times, see data processing below.

2) A pressure cell mounted on a sledge was pulled across the pit at the bottom. By averaging over a sufficient period of time the waves were eliminated. The position of the sledge was determined by underwater positioning equipment, see fig. 3.

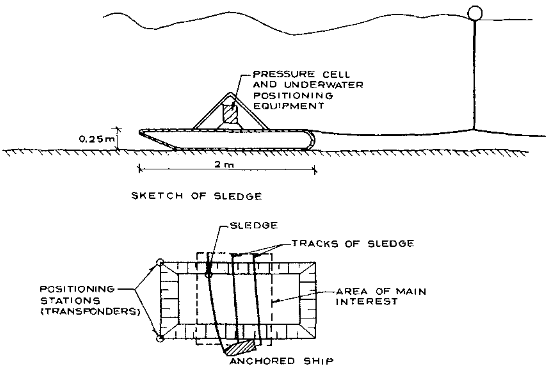

Fig. 3 Pressure Cell Method

DATA PROCESSING

Echo-soundings

The wave disturbed depth soundings of the echosounders (200 khz and 30 khz) were smoothened out for the individual sounding lines, see fig. 4. The repetitions of the same line were plotted to the same scale and an average of the cross section was elaborated, see fig. 5.

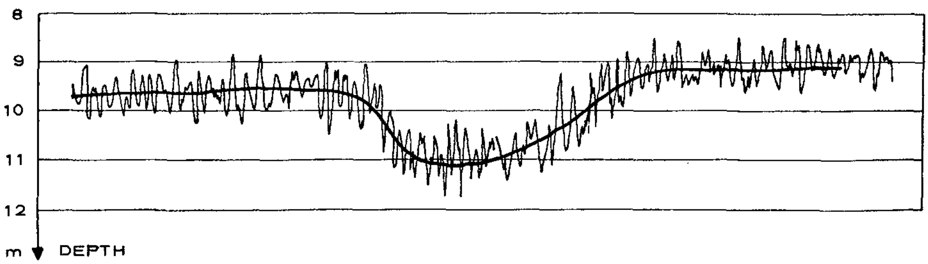

Fig. 4 Echogramme

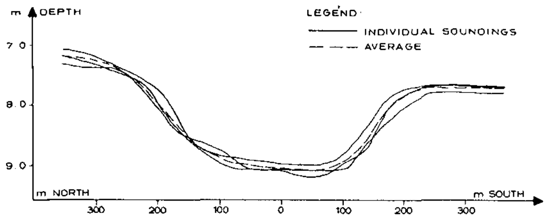

Fig. 5 Characteristic Profiles.

It is seen in fig. 5 that the deviations of the individual soundings from the average is in the order of 10 cm. The pitch and roll of the ship had some effects at the slope of the pit. However, performing echosounding during relatively calm periods it was concluded that repetition of each sounding line three times yielded satisfactory results.

Since the middle of the pit was flat and the velocity of the waves large compared to the speed of the survey vessel, this method was in principle the same as the averaging of the pressure cell at a specific position, see below.

Pressure Cell Method

In fig. 6 the cross section obtained from the average of the three cross sections shown in fig. 5 is compared to the results of pressure cell soundings in a number of check-points.

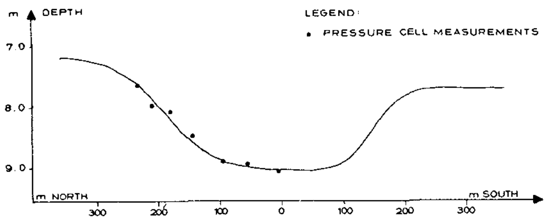

Fig. 6 Comparison of Sounding Methods

It is seen that the differences are small, averagely in the order of 5 cm.

The points were obtained by averaging over 30 seconds which was an adequate timelength, but the method as such turned out to be fairly complicated and time consuming.

Sedimentation Rates

The soundings of the pit took place with app. 3 weeks interal. The cross section of the middle of the pit is presented in fig. 7.

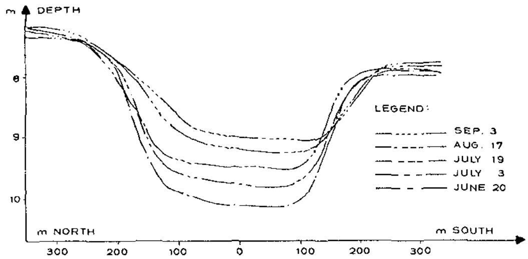

Fig. 7 Sedimentation in the middle cross-section of test pit.

The sedimentation was fairly evenly distributed over the width of the pit indicating slow settling of fine suspended sediments.

During the first period a sedimentation rate of app. 1.7 cm/day was observed, while later on a rate of 1.2 cm/day appeared. Using the sedimentation model this decrease was explaned by the depth reduction in the pit.

Also longitudinal profiles of the pit showed that the sedimentation was fairly evenly distributed, see Fig. 8

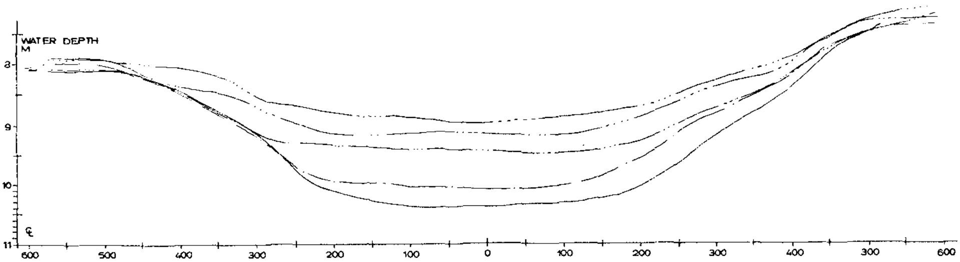

Fig. 8 Longitudinal test pit profile.

Fig. 9 shows the sedimentation rate between two soundings. The rates are seen to be strightly higher along sides of the pit than in the centerline of the pit.

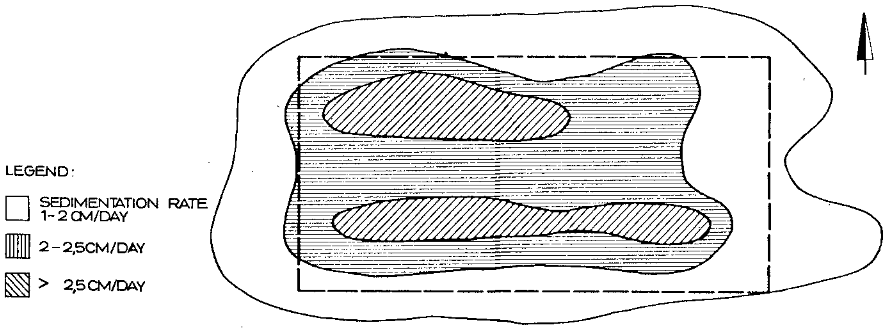

Fig. 9 Sedimentation between two soundings

5. SEDIMENTATION MODEL

In Ref /1/ it was shown that the sedimentation in a dredged channel, q_r, originating from settling of suspended sediments could be calculated as follows

$$q_r = \left\{ q_{10} \left(1 - e^{-\frac{W}{\varepsilon} \frac{W}{V} \frac{D_1}{D_2} \frac{B}{\cos\alpha}} \right) - q_{20} \left(1 - e^{-\frac{W}{\varepsilon} \frac{W}{V} \frac{B}{\cos\alpha}} \right) \right\} \cos\alpha$$

where:

q_{10} = transport of suspended sediments, equilibrium conditions at depth D_1

q_{20} = transport of suspended sediments, equlibrium conditions at depth D_2

w = settling velocity of suspended material

ε = eddy viscosity

v = current velocity

B = channel (test pit) width at the middle of the slope

α = angle between the direction of the current and normal to the test pit alignment

D_1 = undisturbed depth

D_2 = channel (test pit) depth

The calculation of the equilibrium transports q_{10} and q_{20} of suspended sediments in combined currents and waves has mainly been based on parameters calculated from field data. Further, the measured sedimentation in the test pit has offered a possibility to determine the unknown sediment diffusion coefficient ε_s near the bottom. In the following some of the basic parameters are discussed.

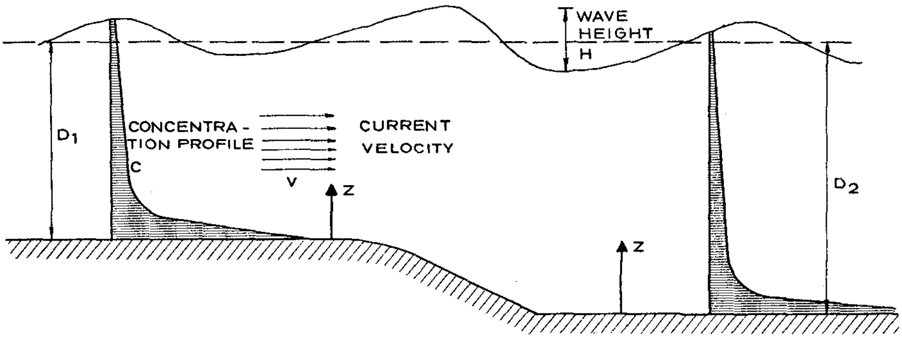

Fig. 10 Parameters

Wave Parameters

The thickness ∂ of the wave boundary layer was calculated by formulae given in /2/. In the calculation it was assumed that the wave amplitude a and the horizontal particle velocity U_w could be determined by sinusoidal wave theory.

Current Velocity Profile

The description of the current velocity profile at the bed is essential as the concentration of suspended sediment near the bed increases enormously.

The friction velocity $U_f = \sqrt{\frac{\tau}{\rho}}$ (where τ is the shear stress and ρ the density of water) in combined currents and waves can bee determined by iteration in the following way:

1. The instantaneous particle velocity U_∂ just above the wave boundary layer is determined by adding the current velocity U_c and the wave particle velocity U_w vectorially
2. The instantaneous shear stress is found by using U_∂ and Johnsons wave friction factor f (/2/) calculated from:

$$\frac{1}{4\sqrt{f}} + \log \frac{1}{4\sqrt{f}} = -0.08 + \log \frac{A}{k}$$

where k is the bed roughness. The amplitude A may be taken as one half of the maximum excursion of a particle in the combined currents and waves.

3. The instantaneous shear stress projected in the current direction is integrated over a wave period yielding an expression for U_f.

4. The current velocity profile U = U(z) near the bottom is then determined by

$$U_f^2 = \varepsilon \frac{\partial U}{\partial z}$$

where ε is the total turbulent eddy viscosity in the current direction and z the distance above the bottom. The eddy viscosity for waves has been determined from /3/.

5. Finally current velocity U_c just above the wave boundary layer is used in 1. for the determination of U_f and the "circle" is closed.

Above the wave boundary layer the current velocity profile has been assumed to be logarithmic.

Suspended Sediment Concentration Profile

Bottom Concentration

The bottom concentration has been assumed to be a function of the dimensionless shear stress (Shield's Parameter):

$$\theta = \tfrac{1}{2} f \frac{U_\partial^2}{(S-1)\ gd}$$

where U_∂ is the instantaneous particle velocity just above the wave boundry layer, f the friction factor, S the relative density, g acceleration of gravity and d the grain diameter. By using formulae in /4/ and integrating over a wave period the average bottom concentration were obtained.

Concentration at the bed (wave boundary layer)

The time-averaged concentration C of suspended sediment a distance z above the bed was determined by

$$\varepsilon_s \frac{\partial C}{\partial z} + WC = 0$$

W being the settling velocity of the grains and ε_s the sediment diffusion coefficient.

Laboratory experiments have indicated that for specific conditions ε_s is constant near the bed. However for the present study conditions none of the experiments were pertinent and instead another approach was needed.

Since no ripples were present it was natural to assume that ε_s at the bed basically could be expressed as a product of a characteristic length, a, characteristic velocity, U_f, i.e.:

$$\varepsilon_s = n_1 \ (aU_f)^{n_2}$$

n_1 and n_2 being constants, n_1 nondimensionless.

n_1 and n_2 were then determined from the results of the test pit monitoring as they should satisfy the following conditions:

1. Integration of the sedimentation with current and wave statistics should yield measured sedimentation.

2. The calculated sediment concentration profiles should correspond with the measured profiles.

n_1 has been calculated to be 2.4×10^{-4} $(m^2/s)^{0.45}$, n_2 to be 0.55

Concentration above the wave boundary layer

Above the wave boundary layer the sediment diffusion coefficient has been assumed to be equivalent to the momentum exchange coefficient

$$\varepsilon_s = 0.4 \ U_{fcw} \ z(1-\frac{z}{D})$$

U_{fcw} being the time-integrated "friction velocity" without projection in the current direction.

6. DISCUSSION

Suspended Sediment

Fig.11 shows the suspended sediment concentration as function of wave height and current velocity as well as the theoretical concentration lines. A large scatter is observed but it can be concluded that

- The current has no significant effect on the amount of sediment in suspension.

The amount of sediment in suspension increases with increasing wave height (determining n_2, discussed above).

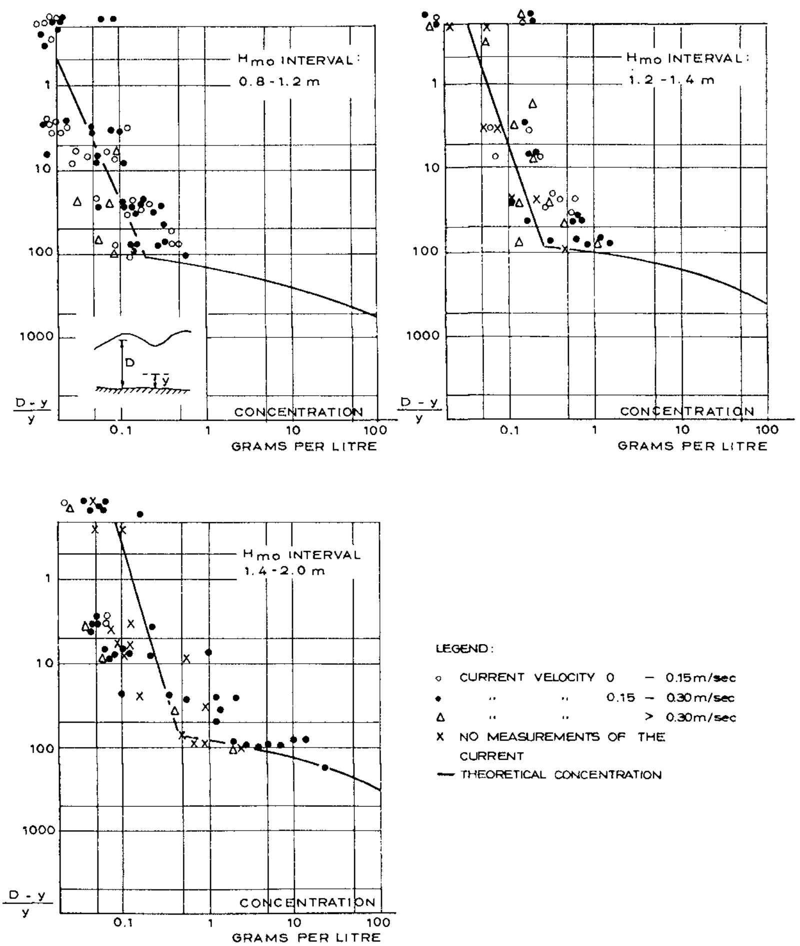

Fig. 11 Suspended Sediment

On the basis of the information that

> the field measurements revealed that fairly large quantities of sand was settling in the pit and practically no sand in suspension was found above level 0.1 m above the bed and the concentrations of suspended sediment above this level were too small to explain the sedimentation -

it was concluded that very large concentration gradients exist at the bed in the wave boundary layer (5-10 cm thickness) and that it is essential to have a description of the suspension within and above the boundary layer.

Fig. 12 shows theoretical concentration profiles. The extreme concentration gradient at the boundary layer clearly proves the importance of the waves as the determining parameter.

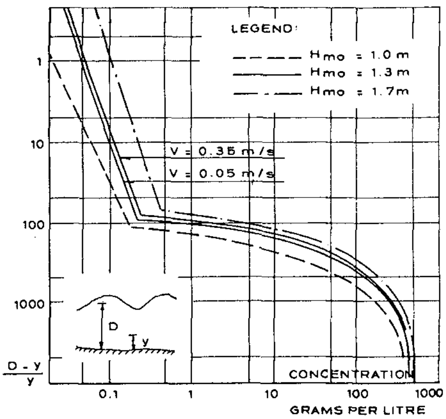

Fig. 12 Theoretical concentration lines

Sedimentation in the Test Pit

The rates of sedimentation as function of wave and current parameters calculated from the sedimentation model is shown in Fig. 13 (only one current direction shown).

The sedimentation model yielded that the current was hampered by the waves at the bed mostly when current and wave particle motion was parallel. Hence the sedimentation in the pit was significantly largest when the current was perpendicular to the alignment of the pit and the wave direction parallel to it.

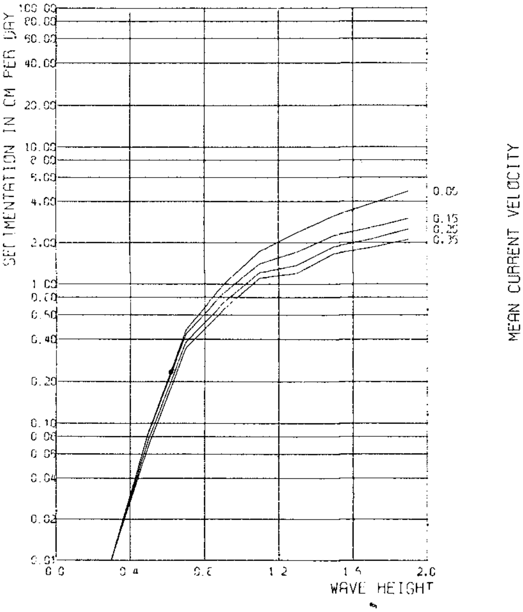

Fig. 13 Sedimentation Rates

Using the sedimentation model the decrease of the sedimentation rate in the pit in the monitoring period was very satisfactorily explained as caused mainly by the depth reduction of the pit and not because of changes of wave and current climate.

7. ACKNOWLEDGEMENT

The test pit investigations has been carried out on the demand of the Nigerian Ports Authority, whom we thank for the opportunity of working with a very interesting programme.

8. REFERENCES

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