NUCLEAR TECHNIQUES IN PLANNING AND CONTROLLING DREDGING WORKS IN SÃO MARCOS BAY, MARANHÃO - BRAZIL

Lécio Hannas Salim, Paulo Sérgio P. Minardi, Virgílio Lopardi Bomtempo,
Jefferson Vianna Bandeira & Geraldo Godinho Pinto
Comissão Nacional de Energia Nuclear - CNEN
Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
P.O.Box 941 - 30161-970 Belo Horizonte, MG - Brazil

and

Ronildo Soares de Carvalho
Consórcio de Alumínio do Maranhão S.A. - ALUMAR
BR - 135 KM 18 - Pedrinhas
65095-050 São Luís, MA - Brazil

ABSTRACT

This paper introduces a nuclear gauge developed for "in situ" measurements of bottom sediments density in the state of Maranhão, in the Northeast of Brazil.

Measurements intended to plan and control maintenance dredging works, resulting in a very favorable reduction of annual dredged volumes and in improvement of port operational conditions.

The same instrument was used in tests to evaluate loading operations of hopper dredgers, with valuable results in improving dredging efficiency.

1. INTRODUCTION

ALUMAR Port is located at the Baía de São Marcos, on the west bank of the Ilha de São Luís, 5.5 miles south of the Port of Itaqui, in the northeastern region of Brazil (Figure 1). The Port was built in the confluence of the Rio dos Cachorros with the Estreito dos Coqueiros, which was dredged to permit access to the Baía de São Marcos. The dredged access channel in the Estreito dos Coqueiros is located between the islands of São Luís and Tauá-Mirim (Figure 2).

Most of the brazilian ports located in bays or in estuarial regions are subject to intensive sedimentation processes. ALUMAR Port is no exception. So, since its completion and beginning of operation, in 1983, maintenance dredging works are periodically carried out in the access channel, in the turning basin and in the berthing area.

Local tides are semi-diurnal, with amplitudes ranging from -0,3m to +7,10m during spring tides. Tide level variations induce reversible currents all over the area. During spring tides, approximately three hours before the ebb or the flood slacks, currents may reach extreme values of 5 to 6 knots (2,5 to 3,0 m/s) in Baía de São Marcos. SALIM(1984) has recorded current speeds greater than 1,5 m/s in the access channel during spring tides.

Starting in the middle 1983, CDTN/CNEN developed several studies in the region, aiming at the reduction of dredging volumes and costs, by the application of nuclear techniques based upon radioactive tracers and gauges provided with sealed radioactive sources.

In selecting the dredged material disposal area, techniques of labelling the waste material with radioactive tracers were employed, in order to evaluate the spoil behaviour after dumping. These techniques are solely described in the paper presented during COPEDEC III (AUN et al, 1991).

As an aid in planning and controlling dredging works, with the main goal of reducing the annually dredged volume, CDTN/CNEN designed, constructed and calibrated a nuclear gauge for the "in situ" measurement of the bulk density of the bed sediment, which is the weight of the soil in natural conditions, including water content, by unit of volume. This gauge is constituted basically by a sealed source of Americium-241 (half-life of 458 years; activity of 10 mCi), a scintillation detector and a pressure transducer calibrated for measuring depths. By using this gauge, which yields profiles of density times depth, two kinds of studies could be carried out: 1) to monitor, under natural field conditions, the spatial and temporal evolution of the depth of the bottom until the density of 1200 kg/m^3, adopted as the navigational limit, by punctual measurements in a pre-stablished monitoring net; 2) to evaluate the load and its distribution in the compartment of hopper dredgers.

The maximum depth for navigational purposes may be defined from studies of navigability of crafts in the unconsolidated layers of sediments forming the bed. In this way, the parameter density may be used to indicate the limit (boundary) between consolidated and non-consolidated layers. Based upon such studies, which involve the assessment of relationships between density, viscosity and critical shear stress, the nautical depth of the Port of Rotterdam has been stablished as the one corresponding to the density of 1.200 kg/m^3, rather than the superficial one yielded by the 200 kHz echo-sounder (HELLEMA, 1979, 1981). Although such a study has not been realized for ALUMAR Port, the adoption of this same limit proved to be very adequate for the local conditions, which may be attested by the practical results obtained along 11 years of continuous monitoring of the harbour area.

Data obtained by means of the nuclear gauge, together with those resulting from echo sounding, allowed the port managers to stablish especific dredging techniques in order to reach a considerable reduction in the dredged volumes. Another profitable benefit was the improvement of port operation conditions, in particular as referred to local ships traffic.

This paper intends to describe the gauge and the nuclear techniques applied to the studies, as well as to present results and their interpretation in view of the local sedimentary conditions.

2. PHYSICO-CHEMICAL CHARACTERIZATION OF THE SEDIMENT

Granulometric characteristics of bottom sediments from the turning basin and the access channel, up to Curva Grande, are pretty much the same. Sediments are predominantly clay (MINARDI et al, 1984, 1990).

Heading from the turning basin towards Baía de São Marcos, grain sizes gradually increase, from fine sediments (clay) to coarser sediments (fine sand). Sand contents in bottom sediment samples gradually increase from 2,76% (turning basin) to 86,98% (at the entrance of the access channel). Farther north, and all over the bay, sediments are predominantly well sorted fine sand (~ 100% of sand in every sample).

The transition region from clay to fine sand, with some silt, can be observed between Curva Grande and the entrance of the access channel (Figure 2).

Mineralogical analysis of the sediments, by X-ray difractometry techniques, has identified the presence of quartz, halite, fieldspat and traces of caolinite and muscovite (SALIM et al, 1983).

3. TRANSMISSION OF GAMMA RADIATION

3.1 Principles

The nuclear gauge developed for "in situ" measurement of sediment density is based upon the phenomenon of attenuation of radiation by a physical medium.

The amount of sediment which is to have its density measured is inserted between a radiation source and a detector. The radiation beam emitted by the radioactive source towards the detector undergoes interactions with the atoms of the interposed medium which, in turn, will cause part of the emitted radiation to be absorbed (attenuated) or scattered. Thus, the counting rate (amount of gamma rays striking the detector, by unit of time) decreases exponentially with the linear increase of the medium density, according to the equation:

$$R = R_0 \, e^{-\mu' \rho x} \qquad (1)$$

in wich:

R - true counting rate perceived by the detector (counts per second);
R_0 - counting rate perceived by the detector in the absence of attenuation medium (cps);
$\mu' = \mu/\rho$ - massic attenuation coefficient (cm^2/g);
μ - linear attenuation coefficient (cm^{-1});
ρ - medium density (g/cm^3);
x - distance between source and detector (cm).

The linear attenuation coefficient μ represents the probability, by units of lenght, that gamma rays be removed from the beam. This coefficient varies with the density of the attenuating medium; thus, for practical reasons, the massic attenuation coefficient is more adequate, as long as it does not depend upon density (KNOLL, 1979).

Equation (1) is valid for a parallel and monoenergetic radiation beam, which is achieved in practical applications by the collimation of the source and the detector , or by discriminating the gamma-ray energy during counting. These procedures have the purpose to avoid that scattered rays reach the detector, thus masking the measured grandeur (GARDNER et al, 1967).

3.2 Density Meter Nuclear Gauge

The nuclear gauge developed by CDTN/CNEN for "in situ" density measurements presents the shape of the letter "H" (Figure 3). One of the legs houses a sealed Americium-241 radioactive source, the other leg houses a scintillation detector - NaI (Tl) crystal. An important complement is a depth sensor (pressure transducer based in a strain-gauge).

Figure 4 presents a block diagram of the apparatus, in which its main components, described as follows, can be observed:

- radioactive source - activated ceramics pad, with a double encasement of tungsten and stainless steel, produced by Amersham in 1971. Nominal acitivity of 10 mCi ($3{,}7 \times 10^{-8}$ Bq), half-life of 458 years and maximum gamma energy of 59,5 keV;
- ratemeter - BASC Portable Battery Scaler produced by NEA (Nordisk Elektrisk Apparatfabrik, with linear amplifier, temperature compensation and pulse heigh analyser;
- detector - BASC Gamma Probe, with EMI/THORN photomultiplier, HARSHAW 1" x 1" NaI(Tl) scintillation crystal and transistorised pre-amplifier;
- high - voltage supply - Hewlett Packard Model 6110A;

- two-channel graphic recorder - Hewlett Packard Model 7100B;
- depht sensor (pressure transducer) - TELEDYNE TABER Model 2403;
- low voltage supply - Hewlett Packard Model 6218A.

3.3 Calibration Curve

The relationship between the counting rate and the density is obtained by the calibration of the instrument which consists in obtaining a large series of counting rates corresponding to a large series of known density values. These data allow for the construction of a calibration curve, which is used to assess unknown values of density from known values of counting rates.

Calibrations are usually performed in a laboratory, employing containers with mixtures, in several different concentrations, of water and sediments from the site where the field measurements are to be realized. The density of each experimental point of the calibration curve is a mean value of the densities of several aliquotes, determined in the usual way by the relationship between weight and volume.

The calibration curve has a similar shape to that of Equation (1); nevertheless, the determination of R_0 is rather difficult. Thus, a mathematical artifice is employed: all terms of that equation are divided by Rs, which is the response of the equipment in a standard medium, usually fresh water. Therefore, the calibration curve will present the following shape:

$$\rho = K_1 - K_2 \, ln\, R/Rs \qquad (2)$$

where K_1 and K_2 are known constants and Rs is the count rate observed by the ratemeter for the standard medium.

4. FIELD EXPERIMENTS AND RESULTS

4.1 Bottom Monitoring in Natural Conditions

During the time interval spanning from July 1983 to July 1994, CDTN/CNEN performed 77 field monitoring campaigns in the surrounding of ALUMAR Port to measure the density of sediment layers below depths recorded by the 200 kHz echo-sounder.

The information so obtained was used to plan and control dredging works, keeping in mind the need to maintain costs as low as possible without endangering navigational safety.

The measurements were intended to define the thickness of layers of sediments corresponding to values of density lower than 1300 kg/m^3, from the bottom recorded by the 200 kHz echo-sounder. The depth of the interface water - mud was simultaneously recorded by the nuclear gauge and by the echo-sounder.

When measurements started, in 1983, about 50 points, distributed over the access channel, the turning basin and the berthing basin, were monitored during each campaign. The methodology then employed for the measurements can be described: for every point to be monitored, the embarcation was anchored and had its position registered by an electronic positioning system (Motorola Mini Ranger III); the gauge was lowered down by means of a manual winch. This procedure was time consuming because the anchor should be thrown a bit way from the measuring point; speed and direction of tidal currents not being known for sure caused the craft to be miss positioned and, in this way, all the procedure had frequently to be repeated.

Later on, in 1986, a new type of craft went into operation, namely a small-sized tugboat equipped with powerful enough engine to keep it in place during the measurements. Points to be monitored were previously marked with buoys positioned by two theodolites and the electronic positioning was discarded. The efficiency of the field works was greatly increased and about 170 points could be monitored during each campaign.

Due to the extremely punctual characteristics of each measurement there was a permanent concern about the representativity of the results obtained.

In this way, each point was profiled at least three times, five or six being the limiting number when large discrepancies were observed for neighboring points. This allowed for the construction of a mean profile representative of the region around each point. A typical profile of density for the bottom sediment in the turning basin, recorded by the density gauge, can be seen in Figure 5.

Final results were mean values of thickness corresponding to discrete values of densities 1100, 1150, 1200, 1250 and/or 1300 kg/m^3, for each monitored point. The thickness is defined as the height of the sediment layer until a determined density, measured from bottom recorded by the 200 kHz eco-sounder. In order to obtain the total depth for a given density, it is necessary to add the value of the thickness corresponding to this density with the local water depth recorded by the echo - sounder, for instance. The experimental standard deviations associated to the mean values of density refer predominantly to uncertainties resulting from horizontal displacements of the embarcation associated to a non-homogeneous distribution in plant of the sediments constituting the bed.

Isothickness curves for a given density can be constructed, as can be seen in Figure 6 for the 1200 kg/m^3 density. In this figure values between parenthesis are the mean values, in centimeters, of the thickness of the mud layer until the density of 1200 kg/m^3, under the bottom recorded by the 200 kHz echo-sounder. By linear interpolation of these values it was possible to draw the geometric locus of points with the same thickness. These curves are particularly useful in guiding dredging works and in determining nautical depths, for the figures presented by them, added to those obtained in echo soundings, yield the nautical depth limited by the 1200 kg/m^3 value of density.

Figures 7a and 7b presents sucessive density profiles recorded in points located in the turning basin and in the access channel. Increases in depth can be observed, due to the action of the hopper dredger and, partially, due to the action of the cutter and suction dredger operating in the berthing basin. The hopper dredger was in operation in the access channel between July and September 1987 and during February and March 1988. This same dredger was in operation in the turning basin during May and June 1987. The operation of a cutter and suction dredger in the berthing area, started in December 1987, has, in a certain way, influenced the behaviour of neighboring areas.

4.2 Evaluation of Loads in a Hopper-Dredger

Next, some comments will be made about the study performed in the "Boa Vista I" hopper dredger owned, at that time, by Companhia Brasileira de Dragagem (CBD), a subsidiary of the now extinct PORTOBRÁS S.A. (MINARDI, 1984).

The experiments, applying the nuclear gauge developed by CDTN/CNEN, had the following objectives:

- to evaluate the dredger load and its distribution;
- to evaluate the mean density of the mixture water-mud;
- to optimize the time of "overflow";

to calibrate the dredger's loadmeter.

This dredger used to operate in the access channel and in the turning basin of the ALUMAR Port.

The dredged material was predominantly fine (clay and silt), with higher sand contents in the access channel than in the turning basin.

The nuclear gauge was used to obtain discrete profiles of density in the dredgers compartment, by measurements every meter along the vertical. The option for the discrete procedure for measurements was due to the fact that direct values of depth could be obtained from the instrument lifting cable, adequately graduated. The depth sensor was discarded because its use would imply in iterative calculations to obtain the depth, for it had to be taken into account the variable pressure contribution of the sediment layers above it.

Figures 8 e 9 present profiles of density versus depth for two dredging cycles of the dredger; twelve cycles in the total have been monitored. In this figures points 2BB and 4BB are situated at portside, in the stern and in the bow, respectively; point 2BE is situated at starboard, in the stern.

For a better understanding of the results obtained some definitions seem to be necessary, having in mind that the equipment never reached the bottom of the hopper because the lower layers of sediment were compacted to a greater degree. About 7,7% of the total volume could not be monitored. The definitions are as follows:

- <u>minimum load</u>: total weight of the mixture considering, for the unpenetrated layer, a constant density with the same value as the last one obtained in the profile;

- <u>maximum load</u>: total weight of the mixture, considering a linear variation of the density from the last value obtained in the profile up to the value of 1850 kg/m^3, which has been adopted for the bottom of the hopper based on the greatest value measured during the campaign. Should the material remain in rest, the compactation law would be exponential. As long as this is not the true situation, the linear approximation was adopted, since the true law is unknown;

- <u>loading time</u>: time interval, in minutes, between the beginning of loading and the instant in which the mixture begins to overflow;

- <u>dredging time</u>: time interval, in minutes, between the beginning of loading and the end of overflow;

- <u>consolidation time</u>: time interval, in minutes, between the end of loading and the beginning of the measurements;

- <u>measurement time</u>: time interval, in minutes, between the beginning of the overflow and the beginning of each measurement;

- <u>loadmeter weight</u>: weight of the mixture as recorded by the dredger loadmeter, based upon the phenomenon of upthrust.

The mean density profile, representative of the material loaded in the hopper, being known, mean density may be given by:

$$\bar{\rho} = 1 / V \int_0^H \int_{So}^S \rho \, . \, s \, . \, ds \, . \, dh \qquad (3)$$

where:

ρ - density in depth h;
s - hopper cross section, transversal to the profile, at the depth of density ρ;
H - total thickness of the mixture layers;
V - total volume of the mixture;
So - hopper cross section, transversal to the profile at the depth h = 0;
S - hopper cross section, transversal to the profile at the depth h = H.

For a same dredging cycle experiments have shown that there were no significant differences among profiles obtained in the stern and in the bow of the hopper, the same being observed for those in the port and starboard sides. Loads calculated using these profiles have presented discrepancies of about 5% for a given cycle and lower than 3% for the others. Based upon these observations it was concluded that the dredged material was uniformily distributed in the hopper and that, for this reason, just one of the profiles could be considered as representative of the load in its totality.

Considering that the profiles have been obtained in a discrete manner, an approximation of the integral of Equation (3) was used, by introducing the volume curve of the hopper:

$$\bar{\rho} = \left(\sum_{i=0}^{n} \rho_i \, \Delta V_i \right) / V \tag{4}$$

The volume differential ΔV_i is the part of the total volume corresponding to the density ρ_i and can be assessed by calculating the difference between two volumes: volume corresponding to the intermediary position between ρ_{i-1} and ρ_i minus the volume corresponding to the intermediary position between ρ_i and ρ_{i+1}. The total load relative to the mixture is given by $\bar{\rho}$ V.

Table 1 presents a summary of the experiments performed. In this table, the last two columns present the dry weight of the material considering, respectively, minimum and maximum loads. The equation used for this calculation was:

$$W_s = (W - \rho_a V) / (1 - \rho_a/\rho_s) \tag{5}$$

where:

W_s - dry weight of the solids;
W - total weight of the mixture (minimum load or maximum load);
ρ_a - density of the salt water (sea water);
ρ_s - dry density of the solids;
V - total hopper volume.

Analyses realized by the sedimentology laboratory of CDTN/CNEN, using the picknometer method, resulted in mean values of dry density of 2267 kg/m^3 and 2407 kg/m^3 for the material dredged in the turning basing and in the channel, respectively.

With respect to the aditional dredging time with overflow, experiments have shown that, for a 10% increase in the load, it would be necessary a minimum over-dredging of 37 minutes in the channel and of 40 minutes in the turning basin (Figures 10 e 11). The graphs show that, due to the nature of the sediments, with high contents of fine material both in the basin and in the channel, a very long period of time is necessary to allow for sedimentation in the hopper and, consequently, for an increase in load.

Comparing loads measured at the end of dredging with those measured after the consolidation time, it can be concluded that the hopper's gates were well tight; no significant losses due to sealing failures were observed.

Relationships between loads measured in the hopper and those recorded by the loadmeter can be put as:

$$Y = 0.9553\ X + 4635 \quad \text{for the maximum load} \tag{6}$$

and

$$Y = 0.\ 9423\ X + 4670 \quad \text{for the minimum load} \tag{7}$$

where X is the hopper load in tons and Y is the value recorded by the loadmeter.

5. SOME CONSIDERATIONS ABOUT ERRORS

Main causes of errors associated to "in situ" measurements of density, and interpretation of results, include:

a) statistical nature of radioactive desintegration. In this case the error estimated by analogical records of counting rates was around 1% for the dynamic measurements of the real bottom, and practically negligible for measurements performed in the hopper dredger. This error depends basically on the time constant selected.

b) instability of the electronic circuitry, mainly due to fluctuations in the high voltage supply and to temperature variation. Error resulting from these two factors can be considered negligible, according to the manufacturers of the equipments employed, which has been confirmed by tests conducted in CDTN.

c) calibration accuracy, estimated in 0,3%.

With respect to depth measurements, simultaneous to those of density of the bottom, it was concluded that the associated error is estimated in no more than 20 cm, taking into account that the equipment lowering rate is around 20 cm/s or less and time constant is 0.2s.

6. CONCLUSIONS

The technique of "in situ" measurement of the density of unconsolidated bottom sediments, by means of the attenuation of gamma radiation by the medium, has proved to be extremely adequate in planning and controlling dredging works. The same is true for the stablishment of nautical depth, as 11 years of monitoring in ALUMAR Port and surroundings have demonstrated.

Obtaining continuous profiles of density versus depth, directly in the field, with no need to collect samples for further analysis in laboratories, is a valuable technique, introducing the versatility and flexibility wich are detrimental in taking decisions when dredging works and port operationality are under concern.

Two other advantages of the nuclear technique are the confiability of the results and the great strenght of the equipments.

Experiments performed at the hopper dredger allowed for important conclusions about decisive factors as: distribution of the dredged material in the hopper, assessment of the mean density of the mixture, increase in load versus overflow time, tightness of gates and relationship between the load in the hopper and that registered by the loadmeter.

The "in situ" monitoring of the bottom sediments, associated with the experiments in the hopper dredger and echo sounding data, allowed the managers of ALUMAR Port to implement specific dredging techniques that resulted in a considerable decrease of the dredged volumes. Around 2.8 millions of cubic meters were dredged annually before the nuclear monitoring started. Presently, no more than 1.5 millions of cubic meters are dredged annually, an outstanding reduction of 54% per cent in volume.

Obviously, an important consequent benefit of this decrease in dredged volume was a substancial cut of operational costs, guaranteed the nautical depth for safe traffic of ships of great drafts.

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Figure 1 - General Location Map

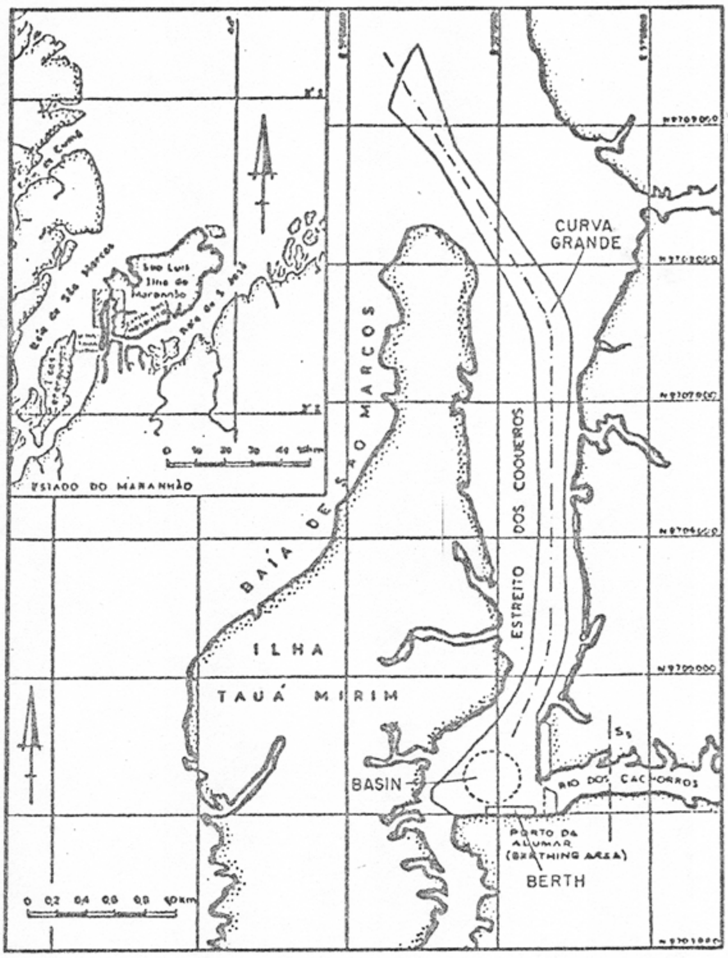

Figure 2 - Key Map - ALUMAR Port

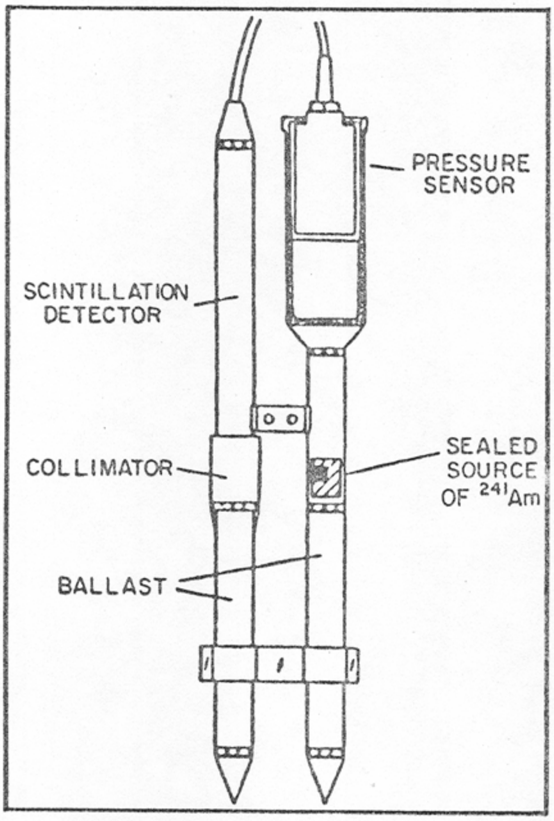

Figure 3 - Density Gauge

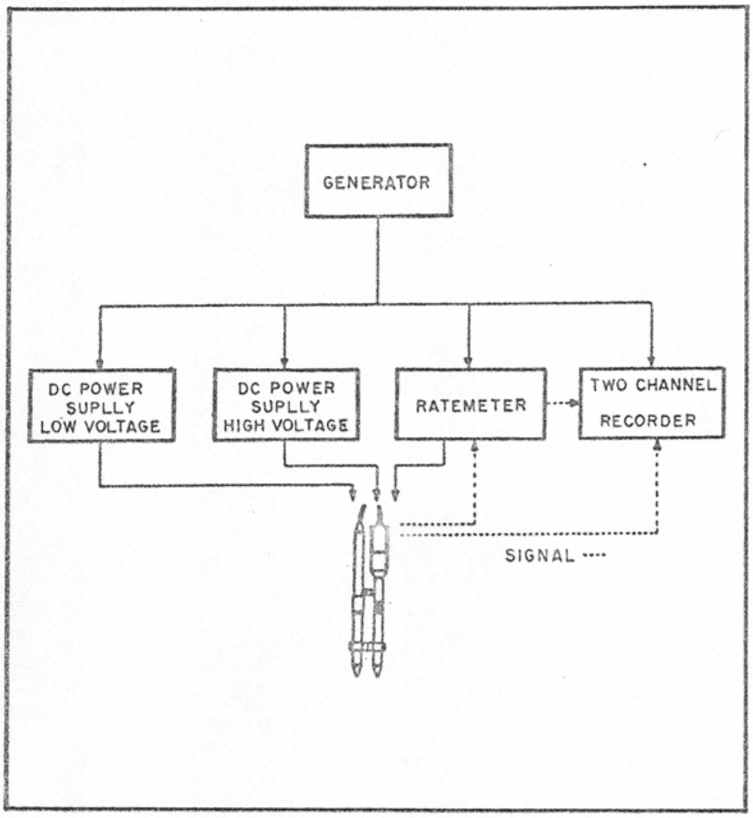

Figure 4 -Block Diagram

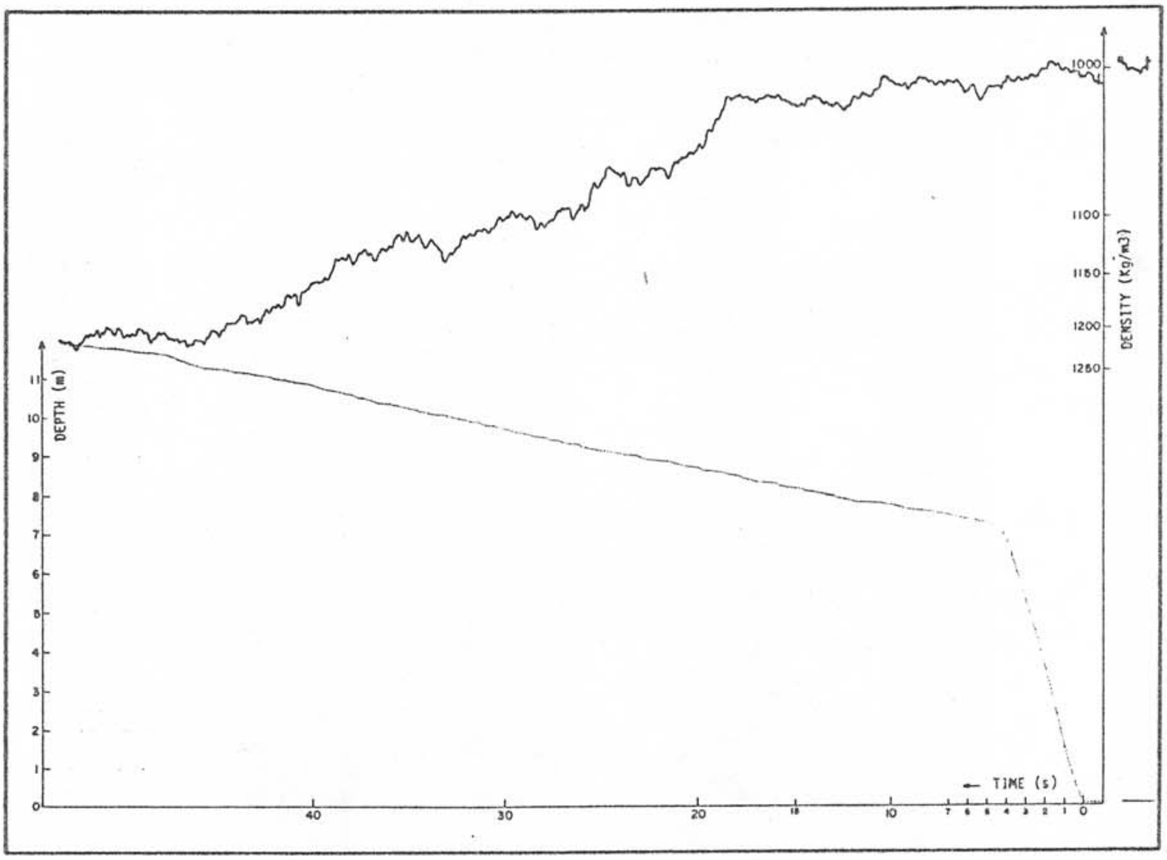

Figure 5 - Typical Profile of Density (Turning Basin)

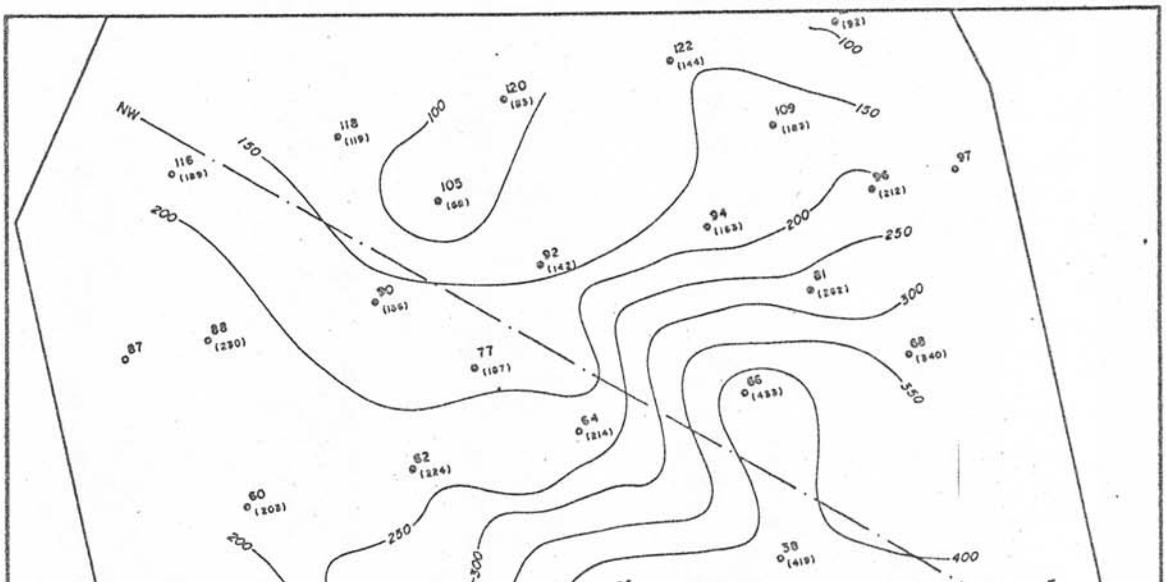

Figure 6 - Isothickness Curves for 1200 kg/m^3 Density Bellow the Bottom Recorded by the 200 kHz Echo-Sounder in the Port Area (August/87)

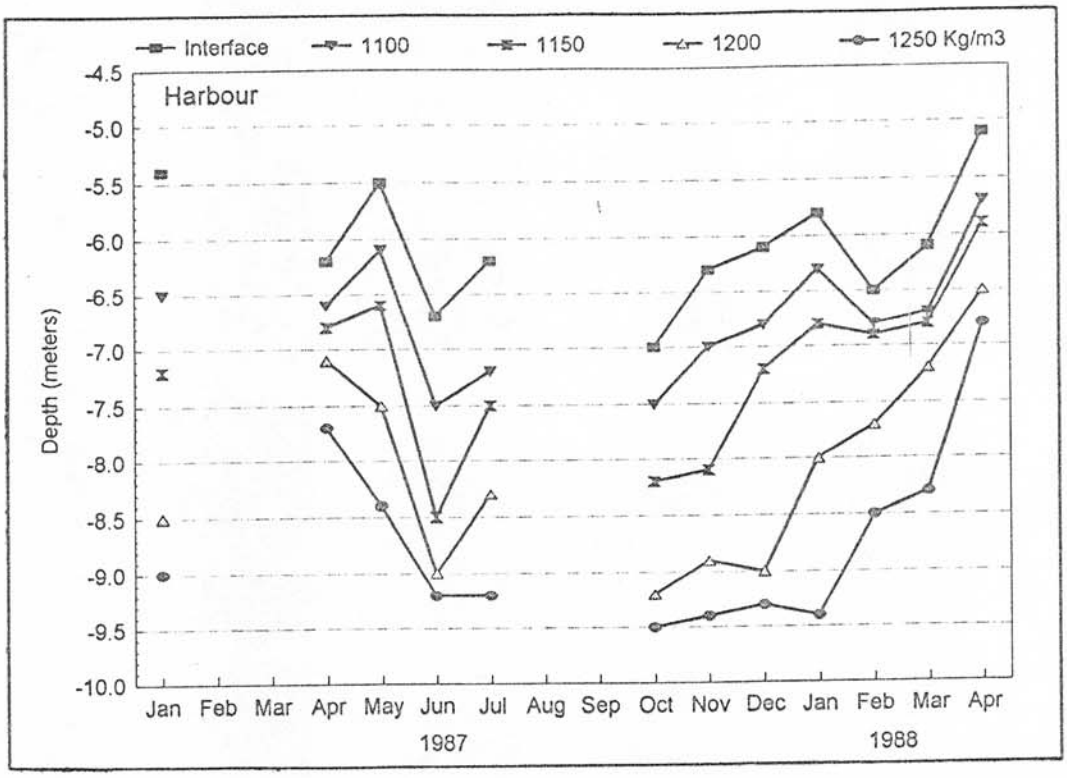

Figure 7a - Successive Density Profiles (Turning Basin)
(Depths are referred to the Brazilian Navy Datum (DHN)

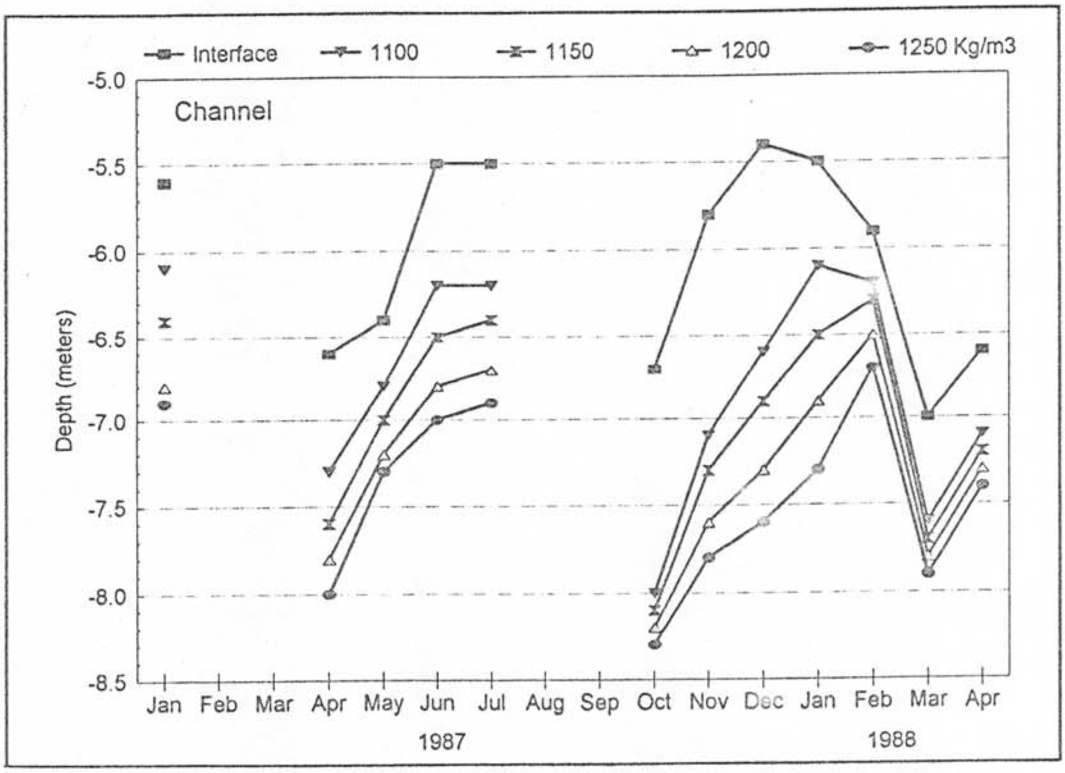

Figure 7b - Successive Density Profiles (Access Channel)
(Depths are referred to the Brazilian Navy Datum (DHN)

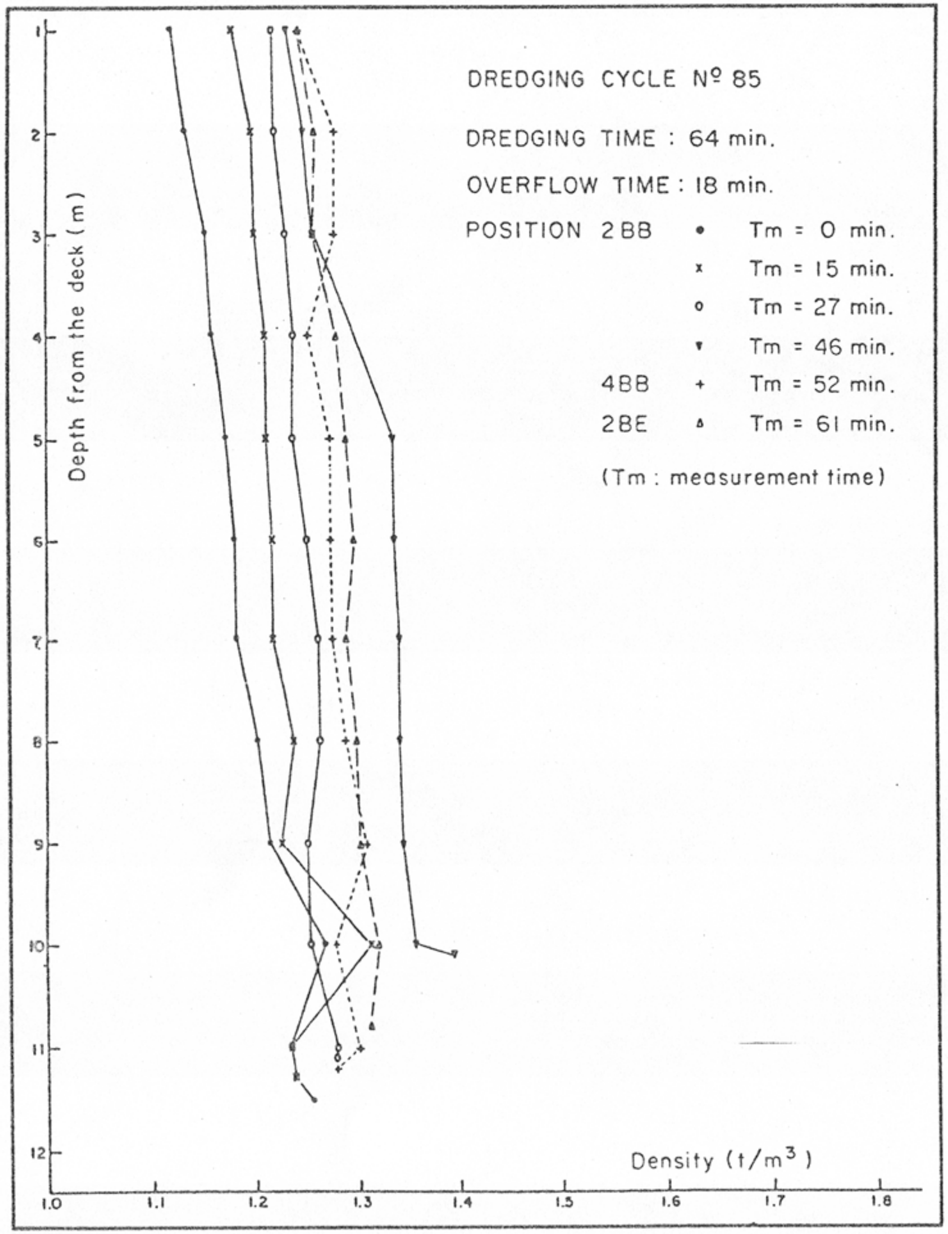

Figure 8 - Bulk Density Profiles in the Hopper of "Boa Vista I" Dredger (Turning Basin Sediment) - June/84.

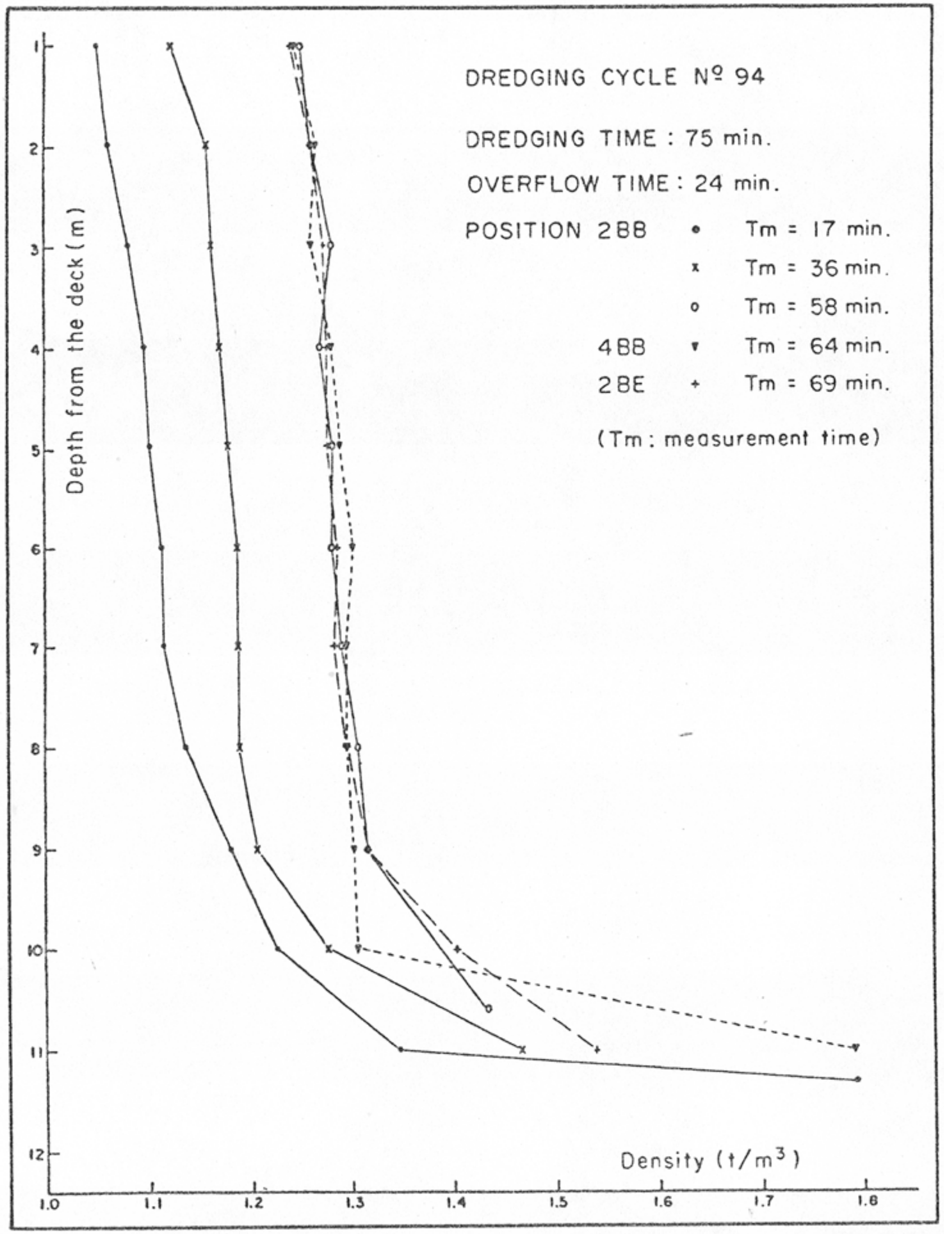

Figure 9 - Bulk Density Profiles in the Hopper of "Boa Vista I" Dredger (Access Channel Sediment) - June/84

DREDGING CYCLE	REGION	POSITION	DREDGING TIME (MINUTE)	OVERFLOW TIME (MINUTE)	MEASURING TIME (MINUTE)	MINIMUM LOAD (TON)	MAXIMUM LOAD (TON)	LOADMETER (TON)	MEAN BULK DENSITY (MINIMO) (TON/M^3)	MEAN BULK DENSITY (MAXIMO) (TON/M^3)	DRY SEDIMENT LOAD (MIN.) (TON)	DRY SEDIMENT LOAD (MAX.) (TON)
84	Channel	2BB	69	17	0	6285	6356	10.600	1,175	1,189	1400	1524
		2BB			15	6264	6335	10.700	1,171	1,185	1364	1487
		2BB			32	6473	6500	10.850	1,211	1,216	1728	1775
		2BB			52	6974	7021	11.450	1,304	1,313	2600	2682
		4BB			58	6876	6939	-	1,286	1,298	2430	2539
		2BE			65	6919	6960	-	1,293	1,302	2504	2576
85	Basin	2BB	64	18	0	6356	6425	10.600	1,189	1,202	1597	1723
		2BB			15	6547	6632	10.800	1,224	1,240	1946	2101
		2BB			27	6676	6781	11.000	1,249	1,268	2181	2373
		2BB			46	7107	7271	-	1,329	1,360	2968	3267
		4BB			52	6818	6910	-	1,275	1,292	2440	2608
		2BE			61	6889	6984	-	1,288	1,306	2570	2743
92	Basin	2BB	60	29	0	6353	6410	-	1,188	1,199	1592	1696
		2BB			15	6573	6627	10.900	1,229	1,239	1993	2092
		2BB			29	6732	6810	11.000	1,259	1,274	2283	2426
		4BB			36	6833	6915	-	1,278	1,293	2468	2617
		2BE			49	6792	6879	-	1,270	1,287	2393	2552
93	Channel	2BB	82	33	0	6468	6542	10.600	1,210	1,223	1719	1848
		2BB			14	6652	6735	11.000	1,244	1,260	2040	2184
		2BB			33	6684	6727	11.200	1,250	1,258	2095	2170
		2BB			49	7193	7193	11.450	1,345	1,345	2982	2982
		4BB			54	7043	7066	-	1,317	1,321	2721	2761
		2BE			60	6998	7072	-	1,309	1,323	2642	2771
94	Channel	2BB	75	24	17	6293	6300	10.450	1,177	1,178	1414	1426
		2BB			36	6788	6838	11.050	1,269	1,279	2276	2363
		2BB			58	7012	7104	11.450	1,311	1,329	2667	2827
		4BE			64	7194	7201	-	1,345	1,347	2984	2996
		2BE			69	7070	7110	-	1,322	1,330	2768	2837
95	Basin	2BB	44	19	0	6297	6384	10.800	1,178	1,194	1489	1648
		2BB			15	6381	6451	10.950	1,193	1,206	1643	1771
		2BB			25	6434	6520	10.950	1,203	1,219	1740	1896
		4BB			32	6443	6543	-	1,205	1,224	1756	1938
		2BE			43	6407	6508	-	1,198	1,217	1690	1875

TABLE 1 - Partial Results of Experiments in the Boa Vista I Hopper Dredger - June/1984

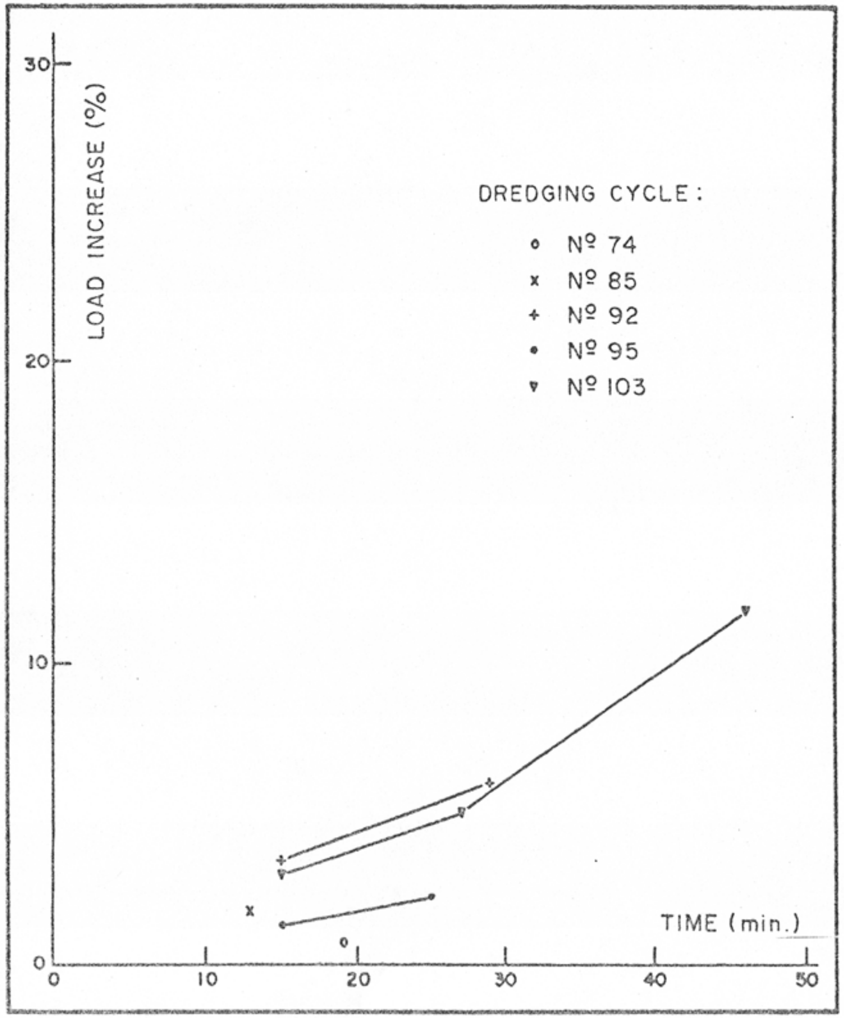

Figure 10 - Load Increase Related to the Load at the Beginning of Overflow versus Overflow Time (Turning Basin Sediment).

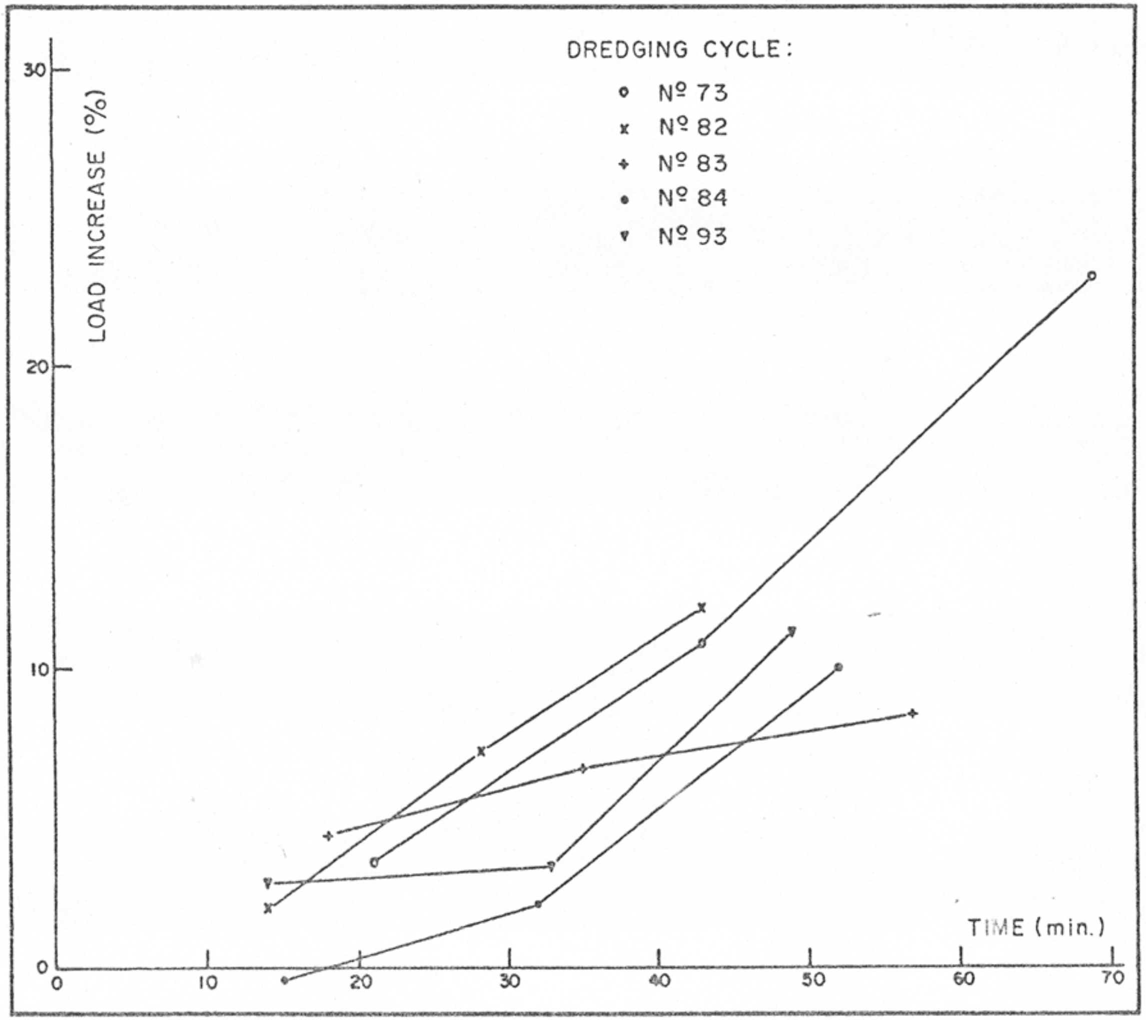

Figure 11 - Load Increase Related to the Load at the Beginning of Overflow versus Overflow Time (Access Channel Sediment)