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MUD CAPTURE INSTALLATION AT THE SEA LOCK OF ZEEBRUGGE

J.BERLAMONT and M.THIENPONT, K.U.Leuven, Hydraulics Laboratory,
B.VERNER, Atlas Copco Airpower, Wilrijk
A.VAN BRUWAENE, L.NEYRINCK and L.MAERTENS, Algemene Ondernemingen S.B.B.M., Brussel, Belgium

Since the early sixties siltation has been a source of trouble for many Port Authorities. Indeed, by deepening and widening of the approach channel the cost of maintenance dredging increases exponentially.

A similar and specific problem arises at the harbour of Zeebrugge, which is linked with the navigable passes 'Scheur' and 'Wielingen' off the Belgian coast, by the 'Pas van het Zand'. This approach channel has been dredged through the former 'Bank van het Zand'.
While the natural bottom was 6 to 7 meters below the L.L.W.S. (low low water spring), these days the 'Pas van het Zand' goes down to 11 to 12 meters below L.L.W.S.

Many reasons for the siltation of the 'Pas van het Zand' may be put forward, as there are : the existence of a mud concentration in the close by estuary of the river Scheldt, the orientation of the 'Pas van het Zand' perpendicular to strong tidal currents (approx. 1.5 m/s and increasing to 2.0 m/s due to harbour extension), as well as the pronounced deepening of the natural seabottom.

The 'Pas van het Zand' is like a semi-infinite mud trench, causing mud supply to all deeper parts of the outer harbour of Zeebrugge (turning basin, Western Peninsula -(Westhoofd) and in the near future, also the access channel to the new lock).

As the access channel to the new lock has been dredged two meters lower than the bottom level of the 'Pas van het Zand', serious mud supply problems may be expected at this location (Fig.1).

With a view to a better understanding of the dynamic behaviour of mud from the North Sea, found in the outer harbour of Zeebrugge, a number of preliminary tests were ordered by the Entreprises S.B.B.M. and carried out at the Hydraulics Laboratory of the University of Leuven.

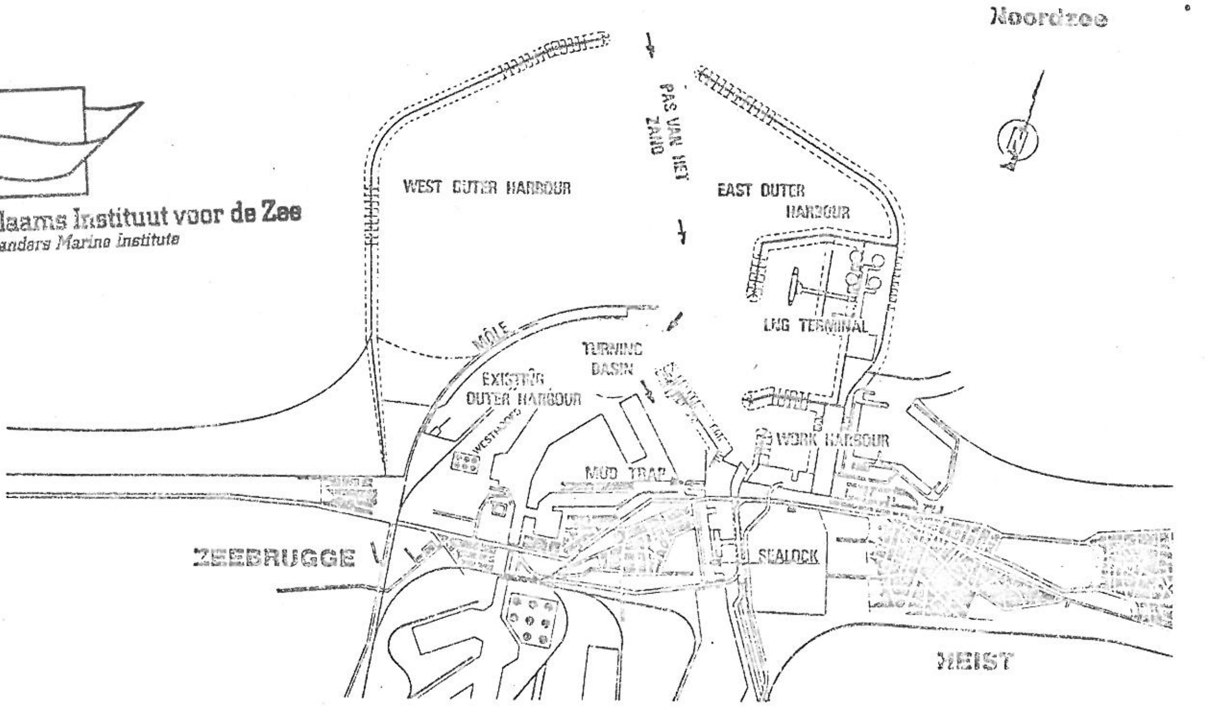

Fig. 1 general lay-out of the outer-harbour at Zeebrugge, the entrance channel and the sea lock.

The hereafter reported tests were carried out in order to check whether it will be possible to keep the entry of the lock and partially the access channel, free of mud by the installing a permanent mud trap.
A mud trap is a fixed pumping plant, working according to simple rules and provided with automatic steering.
By these means the cost of mud removal may be kept much lower compared to the use of suction hopper dredges or cutter dredges. As such a plant is installed below the channel bottom, mud removal may proceed without disturbing navigation.

One may imagine other applications wharfs, piers, dry docks etc...
For many years Atlas Copco has similar plants in operation at different locations (Terneuzen, Canvey Island, etc...). Some other applications are e.g. mud removal from underneath permanent car-ferry pontoons, mud removal in marinas without having to evacuate all yachts.

At present, it is too early to present definite results, because of the complexity of the tests involved and the heterogeneity of the mud samples.

Samples taken at the same site, but at different times behave in a different way according to the history of the mud (stormy weather or a quiet summer time). Even in a limited area such as the outer port of Zeebrugge, mud samples may differ from place to place. Therefore it is not surprising that the samples tested during these experiments behave in a different way from the samples taken in the 'Pas van het Zand' and off the Belgian coast. (Ref. 1).

The differences may be made up of

- different mineralogic composition
- different grain-size distribution especially a different "silt" content (< 40 µ)
- different density or density gradient
- different "rigidity" (yield shear stress, or static shear), due to different consolidation times, the thixotropy and thus the time history of the mud.

Moreover, during its stay in the Laboratory, the properties of the mud may change with time, due to oxidation of the (organic material in the) mud (which, while performing pumping tests, has to be pumped quite frequently, and thus becomes mixed with air) and fermentation, which in one case caused the mud in a "settling column" to swell up and raise, thereby increasing the total volume of mud and water and, apparently denying the law of conservation of mass !

This means that all the tests should be carried out with "fresh" (non aerated) mud, causing important costs, since 5 to 6 m^3 are needed to fill the flume in which the pumping tests are carried out.

Part of the rheologic tests consisted of measuring the "rigidity" (τ_y) of the mud as a function of density (δ) and consolidation time (T_C) (thixotropic effect).
The "rigidity" is defined as the shear stress needed to initiate a shear motion (Ref. 1).
The tests were carried out with the help of a Brookfield viscometer : a cilindrical spindle is forced to rotate in the mud.
The spring torque is measured at the beginning of the rotation, from which the mean shear stress on the surface of the spindle can be calculated.

The density was measured with a γ-densimeter, specially developed by Prof. Schonken (K.U.L.), and having a resolution of 10 kg/m^3 while the density is measured in a layer of thickness 3 mm.

Fig. 2 shows in a speculative way, τ_y as a function of density and consolidation time, suggesting that the ultimate rigidity is independent of the initial density of the sample.

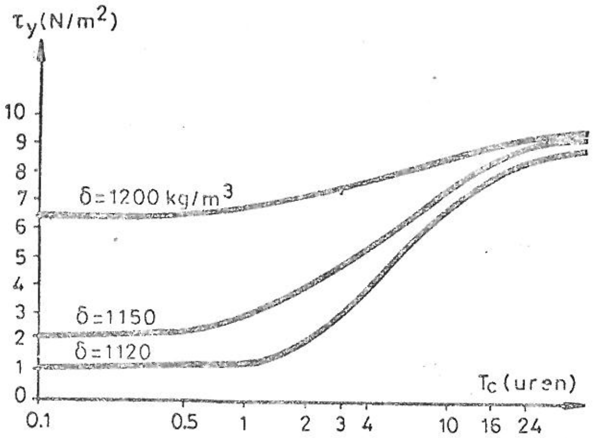

Fig. 2 thixotropic behaviour

τ_y was also measured as a function of δ according to the LCHF standard conditions (Ref. 1) : T_C = 10 minutes, reading at "appreciable" motion of the cilinder, etc...
These values have, strictly speaking, no physical meaning, but only allow a comparison between different muds and different samples (δ) of the same mud.

These values are shown in Fig. 3 (regression curves for the mean value, the 95 % confidence interval on the mean and the 95 % confidence interval on a single measurement). They indicate higher values of τ_y, than those found by LCHF for "pure mud".
The mud-density range of interest to our experiments ($1080 < \delta < 1200$ kg/m^3) however, is at the very outskirt of the test range at LCHF, so that the extrapolation of the regression curve (Fig. 3b) may not be justified in this range.

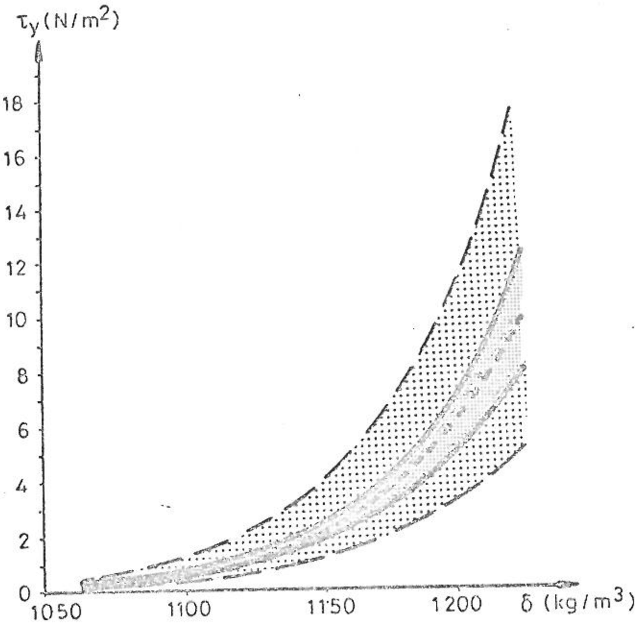

Fig. 3a

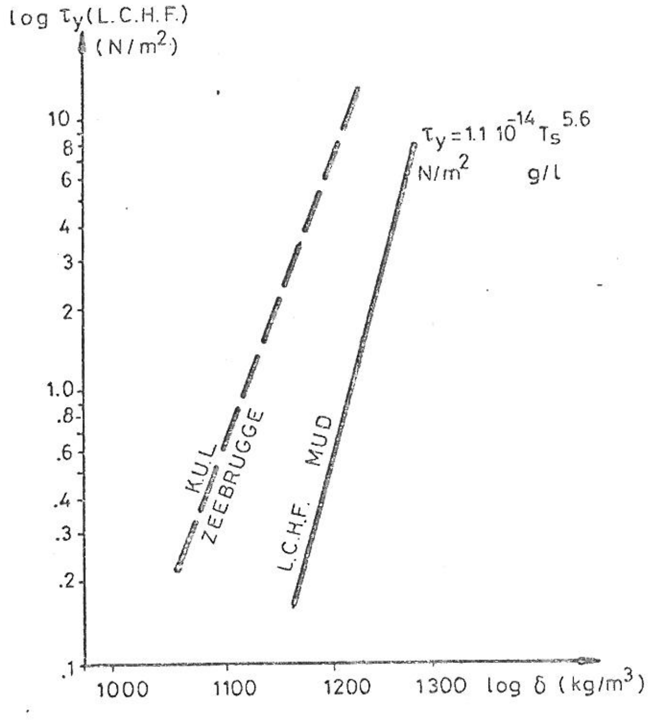

Fig. 3b

Fig. 3a,b yield shear stress vs. mud density
— mean value
— 95 % confidence interval on the mean
— — 95 % confidence on a single measurement

The test-results show a tendency to join the LCHF "pure mud curve" for the higher values of δ. Anyhow, it is seen from 3b that the mud taken from the outer Port of Zeebrugge behaves in a totally different way from the samples taken from the 'Pas van 't Zand' and off the Belgian East coast, as studied by LCHF.

The measurement of the rigidity of the mud is of great importance since it was stated (Ref. 1) that the mud is "fluid", and could be pumped provided that $\tau_y < 1$ to 2 N/m².
From fig. 3a it is seen that this could be possible for δ < 1150 kg/m³.

As a matter of fact the rigidity should be measured "in situ" (in the harbour or in the laboratory flume) instead of in a 1 liter beaker. This however is not possible, at least not in a way comparable to the standard tests.

Mud-density profiles measured in the test flume, always appeared to be S - shaped : a relatively high density near the bottom and a low density at the water interface. In between, the density was found to be approximately constant.

Static tests

One part of the test flume was filled with mud, the other one with (synthetic) sea water. Both parts were separated by a gate, which was lifted gradually (0.10 m/min). The final equilibrium slope (S_∞) of the mud surface was measured.

For a consolidation time $T_C = 0$, S_∞ was found to increase with δ , but much steeper for δ > 1160 kg/m³. (Fig. 4).

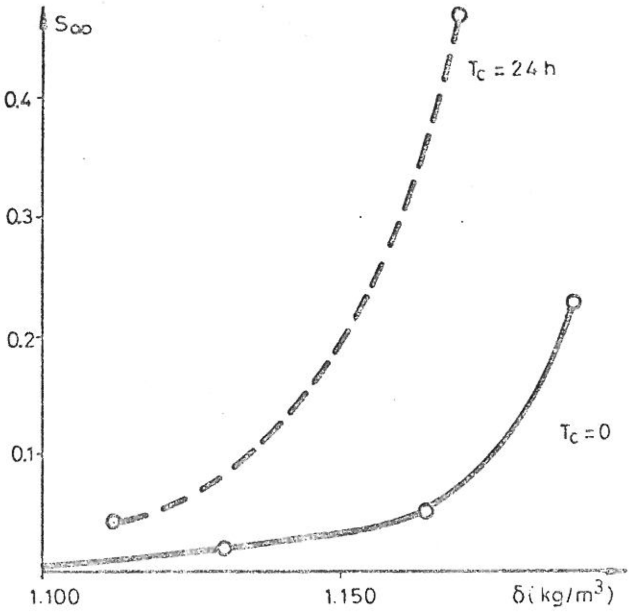

Fig. 4 static equilibrium slope vs. mud-density

Just like in the rheological tests δ = 1150 to 1160 seems to be critical. The effect of thixotropy was well pronounced, since S_∞ increased approximately with a factor 5 for T_C = 24 hours. It should however be noted that important scale effects may occur since the settling in a laboratory flume (d = 0.40 m) goes on much faster than on the site (d = 2 to 5 m).

Again there was an important discrepancy with the results obtained by LCHF. The actual equilibrium slopes were found to be well in excess of the values found by LCHF (Ref. 1).

Pumping tests

The mud was pumped at constant discharge from the central section of the test flume
(12 x 0,5 x 0,5 m^3).
Test were performed for different values of δ, T_C and the pumping rate.
It was found that the slope of the mud surface at approximately 10 times the thickness of the mud layer, was of the order of 1/50.
From fig. 5 it can be seen that for different values of δ both the "influence zone" of the pump and the slope of the mud-water interface may vary in an important way.

Flow of mud on a sloped surface

Mud was pumped into the inclined test flume (1/40), the bottom of which was covered with a thin layer of mud (δ ≃ 1200 kg/m^3). The propagation speed of the mud front was found to vary with density : 0.10 m/s for δ ≃ 1080 and 0.02 m/s for δ ≃ 1125 kg/m^3.
In both cases the surface profile of the mud was almost parallel to the bottom of the flume.

Conclusion from the tests

These tests were carried out to study the feasibility of a mud pumping plant in the access channel to the new lock at Zeebrugge. From the first test the following preliminary results are obtained.

- the effectiveness of the installation, its capacity and the dimensions depend greatly upon the rheologic properties of the mud, which in turn depend upon its density, the consolidation time and the time history of the mud (i.e. its thixotropic properties).

- at first glance δ ≃ 1150 to 1160 kg/m^3 seems to be critical for the mud of Zeebrugge. At higher densities the "rigidity" and the "static" equilibrium slope increase sharply.

- A lot of research and experimental work remains to be done to understand thoroughly the dynamic behaviour of the mud. This is due to the heterogeneity of the mud, the variation of its properties with time and the complexity of the experiments.

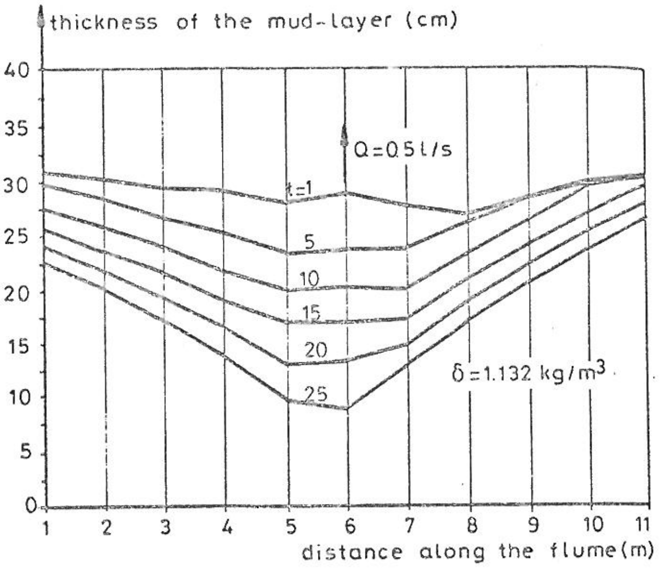

Fig. 5a

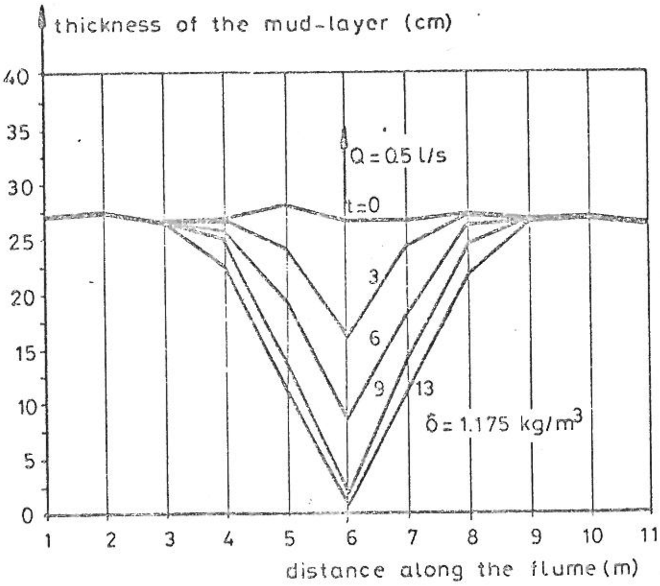

Fig. 5b

Fig. 5 typical draw-down curves of the mud - water interface during pumping tests

General Conclusions

In order to keep a mud trap operational on a permanent basis one should bear in mind following conditions, gathered from literature and above reported tests.

1. Mud supply must come from density currents

Silt settling from upper water layers (70 g/m^3 has been measured in the North Sea) results only in a very thin membrane on the seabottom. Consolidation occurs very fast (after a few minutes).

The volume of consolidated silt is consequently insignificant and its removal by pumping will only be possible within a very small radius.

2. The path of the turbidity currents has to be known and to be invariable

Access channels to locks - along the river Scheldt for instance - are usually perpendicular to the axis of the river.
Consequently, vortices will appear during filling and emptying of those accesses with the tide.

In addition, density currents - owing to the percentage of salt and/or silt gradient in the water - will result in mixed velocity profiles. This means for instance that during ebb lighter upperwater will enter the access channel, while at the bottom salty and/or silty water will return to the river.

The above explains why in such channels silt deposits differ from one point to an other and consequently why it is almost impossible to predict how silt deposition will be.

In the harbour of Zeebrugge on the other hand a several meters thick mud layer coming from the Pas van het Zand gets caugth at the bottom of the turning basin, which is like an almost infinite reservoir (20 ha or 50 acres).
If this mud accumulation is not dredged, a mud flow from the turning basin towards the access channel to the new lock will occur, the bottom level at this access channel being 5 meters lower than the one of the turning basin.

This mud flow of course drives the lighter upperwater out of the access channel.

3. Mud properties have to be such that it can be kept flowing over a long distance

The mud supplied to the outer harbour of Zeebrugge is quite pure (less than 10 % sand). The composition of this mud is such that, especially for thicker layers, it consolidates very slow.

From laboratory tests one can learn that mud with a 1140 t/m^3 density (190 kg/m^3) needs 1 month to consolidate to 210 kg/m^3. After one day it shows hardly any consolidation. This mud stays fluid for a long period.

Density profiles measured either in the Pas van het Zand or in a laboratory flume show always the same S-shape : a transition layer of water and mud with increasing density, a constant density layer (1140 to 1200 kg/m^3) and at the bottom a high density layer.

Experiments show (after adding fluorescine) that by stirring the upper layer (owing to pumping or currents or waves) always a mixing of the mud with the water above it occurs.

From the pumping tests one can also learn that mud-layers with a 1180 kg/m^3 density can be pumped, as a result of the water penetrating into newly formed cracks.

4. Mud supply has to be sufficient in order to guarantee the use of the mud trap on a regular base

It follows from measurements that the "rigidity" of the mud increases with time as a result of thixotropy, whatever the density is.

Keeping a mud trap for a longer period out of operation will consequently lead to problems.

5. The mud trap has to be accurately designed

The upper mud level may not rise above the lock sill and a steady flow towards the pumps has to be ensured.

It appears that all above mentioned requirements are fulfilled at Zeebrugge.

Reference

1. "Etude Rheologique des vases de Zeebrugge", rapport général, L.C.H.F., novembre 1978.