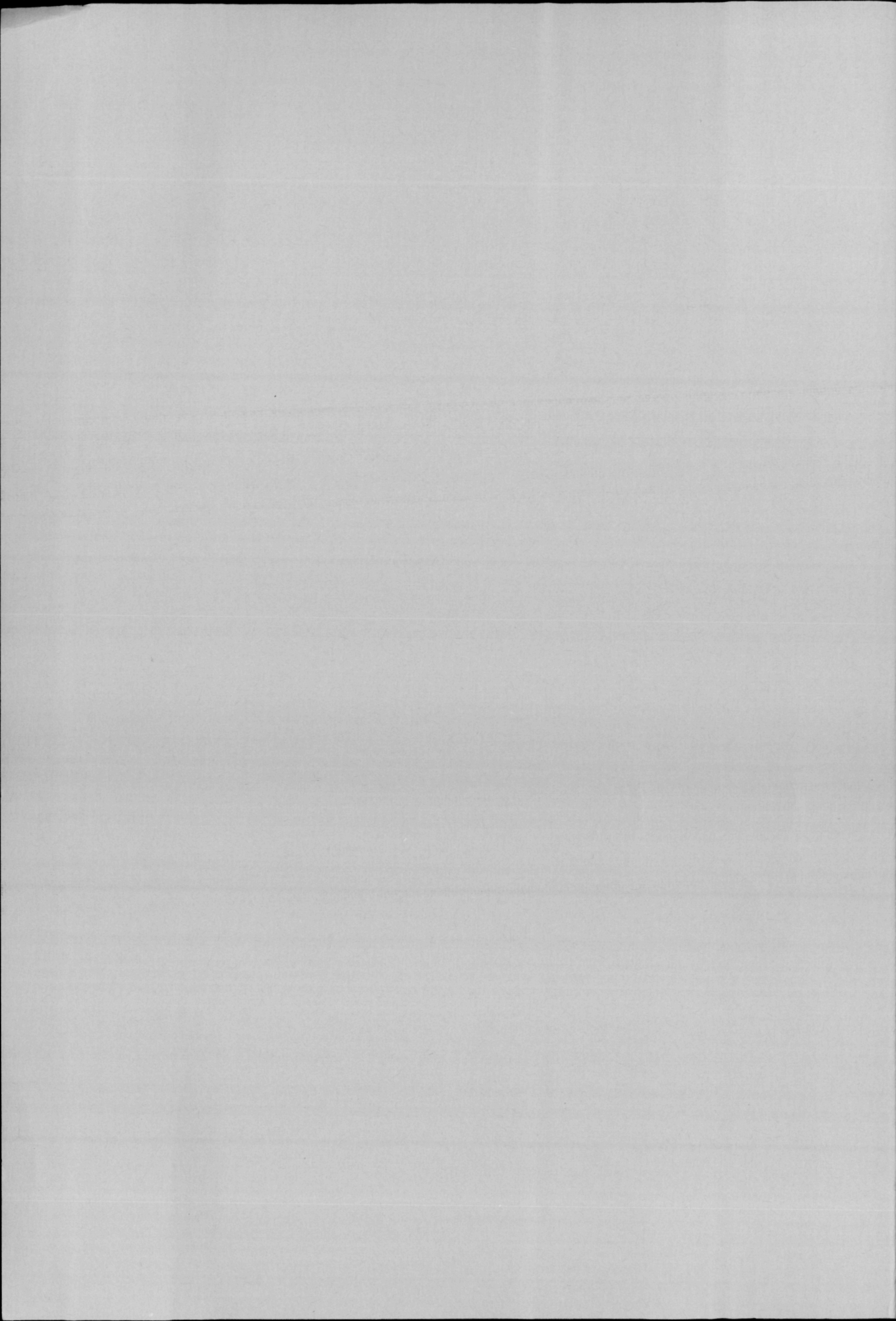


PROJECT MUD TRAP

K.U. Leuven
ATLAS COPCO Wilrijk
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MUD CAPTURE INSTALLATION AT THE SEA LOCK OF ZEEBRUGGE

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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.

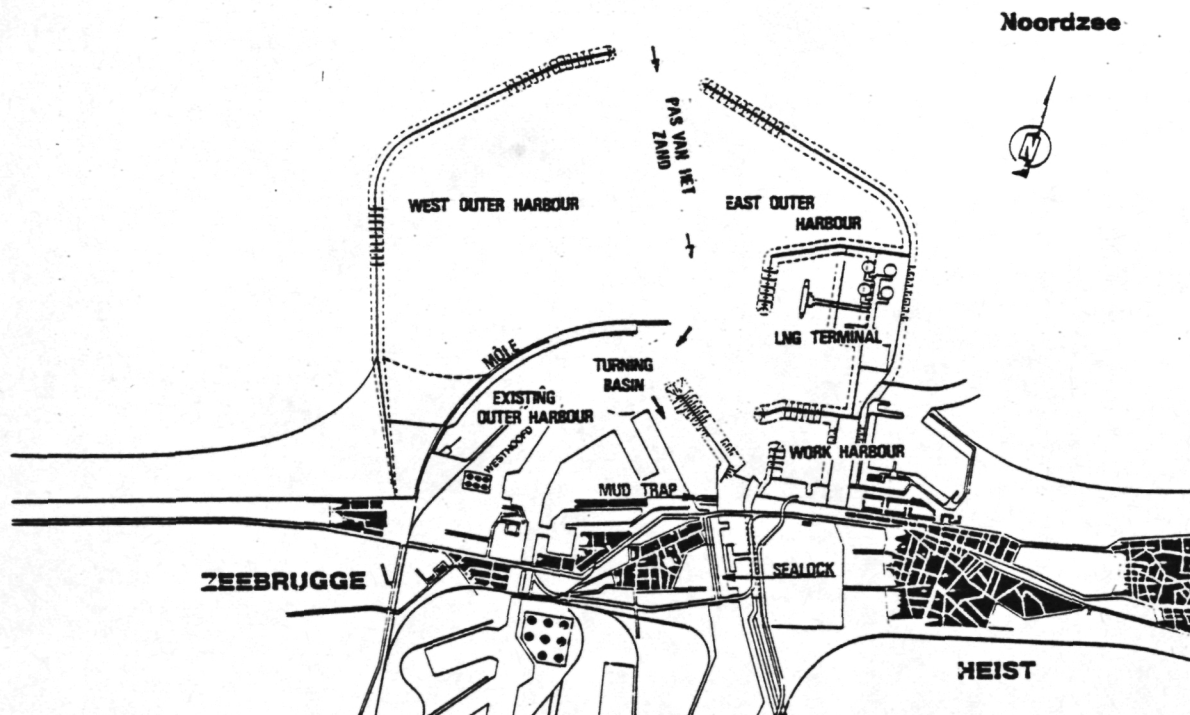


Fig. 1 general lay-out of the outer-harbour at Zeebrugge, the entrance channel and the sea lock.

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 ($< 40 \mu$)
- 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 m³ 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 cylindrical 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/m³ 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.

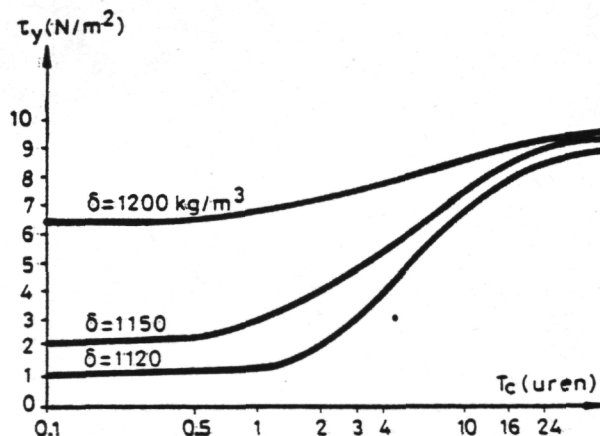


Fig. 2 thixotropic behaviour

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 cylinder, 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 ($1080 < \delta < 1200 \text{ kg/m}^3$) however, is at the very outskirts of the test range at LCHF, so that the extrapolation of the regression curve (Fig. 3b) may not be justified in this range.

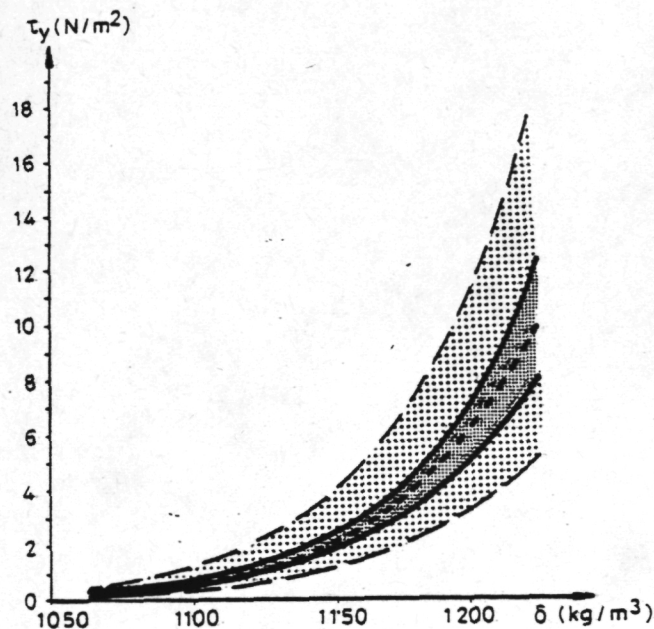


Fig. 3a

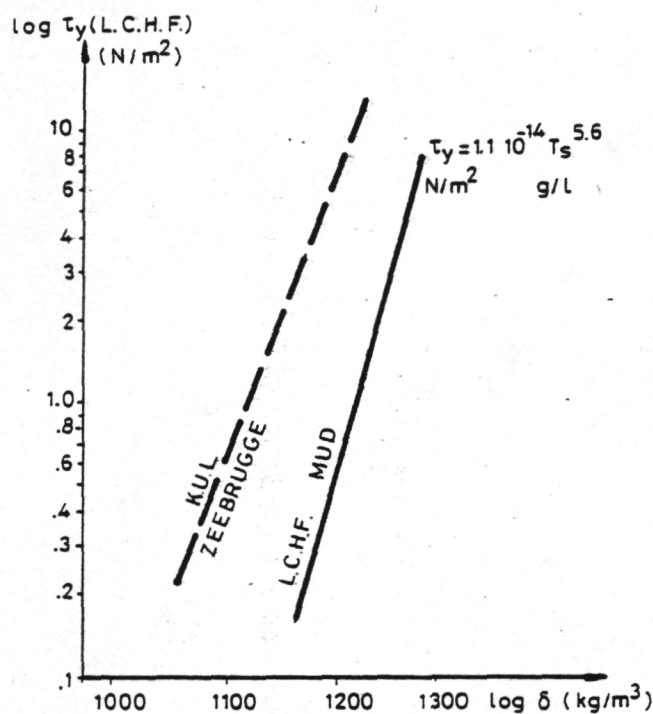


Fig. 3b

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 $\delta < 1150$ 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 $\delta > 1160$ kg/m³. (Fig. 4).

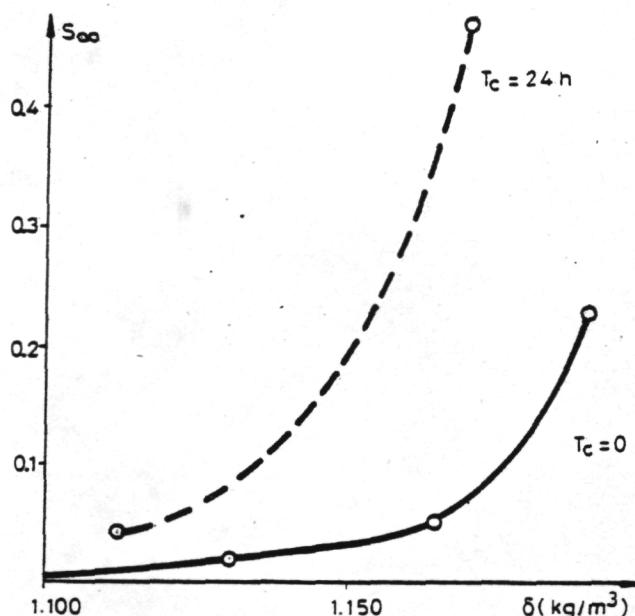


Fig. 4 static equilibrium slope vs. mud-density

1.160 Just like in the rheological tests $\delta = 1150$ 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 ($12 \times 0.5 \times 0.5$ m³). 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 ($\delta = 1200$ kg/m³). The propagation speed of the mud front was found to vary with density: 0.10 m/s for $\delta = 1080$ and 0.02 m/s for $\delta = 1125$ kg/m³. 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 $\delta = 1150$ to 1160 kg/m³ 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.

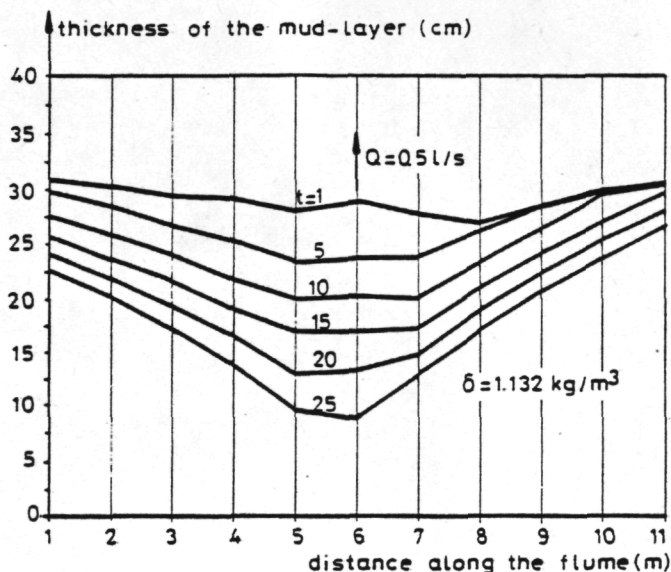


Fig. 5a

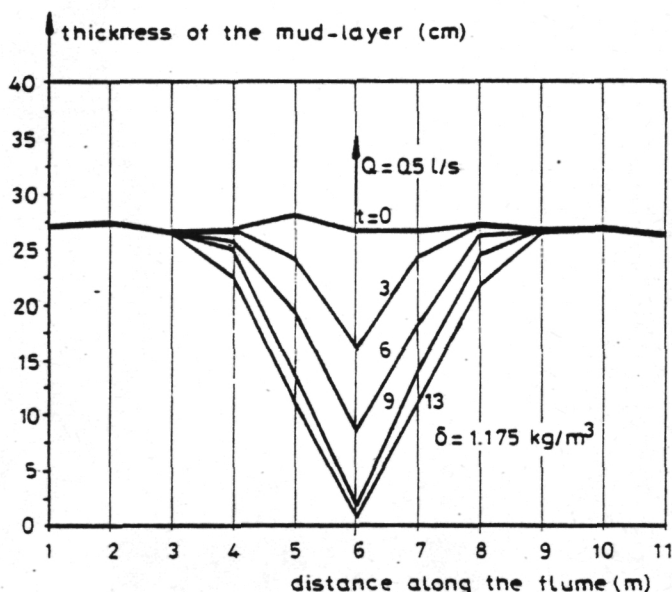


Fig. 5b

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 another 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 caught 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 1.161 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 fluoresceine) 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.

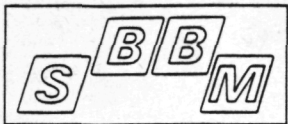
5. The mud trap has to be accurately designed

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.



Ontwerp : Slibgemaal zeesluis Zeebrugge
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Sedert 1945 is de SBBM aan het werk geweest te Zeebrugge

45-46 : Herstellen môle
62-70 : Bouw Westhoofd
73 : Toegang sluis
74 : Insteekdok
75 : Zeesluis

Als partner in de combinatie Zeebouw voor de uitbouw van de buitenhaven, nam zij actief deel aan studie en uitvoering. In deze studie was de aanslibbing een voornaam punt. In samenwerking met de K.U. Leuven en Atlas Copco werd getracht de idee van een slibgemaal in een ontwerp om te zetten.

Door verdieping van de toegangsgeul zijn slibafzettingen in Zeebrugge evenals in meerdere havens een probleem. De bank van 't Zand ligt op -6 onder laagwater. Nu gaat de Pas naar -12 à -13. Hij functionneert als een slibvang voor het zwevend en bodemtransport van zand en slib. Het slibniveau stijgt hierdoor tot -10 à -11. Het slib uit de pas stroomt in de zwaai kom en naar lagergelegen punten waaronder de sluis met drempel op -15. Aanslibbing over meerdere meters zou de werking ervan ten zeerste bemoeilijken (zie tekening).

Indien niet opgewoeld, zet slib zich af als een "soep" onder water. Deze soep is bij geringe densiteit of beweging zeer vloeibaar. (kleine rigiditeit). Het laat zich zonder veel menging, onder zeer kleine hellingen, verpompen. Indien een slibvang onder de bodem voor de sluis wordt gegraven waarin pompen zijn aangebracht kan het slib voor de sluisdrempel worden weggezogen en verwijderd naar zee. In Zeebrugge zijn de omstandigheden daarvoor gunstig. (zie perspektief)



Uit proeven blijkt dat opdat een slibvang zou functionneren o.a. aan volgende voorwaarden moet voldaan zijn :

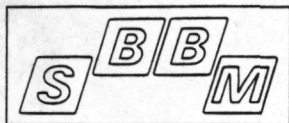
- slib moet komen van een "slibstroom" met een wel bepaalde weg
- het slib moet "voldoende lang" vloeibaar blijven
- er moet regelmatig na enkele uren onderbreking, gepompt worden (om consolidatie te vermijden)
- de omvang van de slibvang en talud hellingen zijn te bepalen in functie van de hoeveelheid en eigenschappen van het slib

Voordelen van het systeem

- een slibgemaal is een vaste installatie, die kan geautomatiseerd worden. Het werkt met weinig personeel, weinig investeringen, weinig energie. Het is dus veel goedkoper dan gewoon baggeren. Het werkt doorlopend, men kan dus het slibniveau regelen.
- het kan werken onder het doorgaand scheepsverkeer
- het kan werken onder of vóór vaste pontons of steigers zonder hinder voor de scheepvaart

Toepassingen

- vermijden aanslibbing voor sluizen en deuren van droogdokken
- baggeren onder pontons voor Ro-Ro, drijvende droogdokken enz...
- baggeren in yachthavens met één toegangsgewel zonder verwijderen van de drijvende installaties
- behouden van de nodige waterdiepte voor steigers, en slipways (v.b. Canvey Island - 1976)
- vermijden slibbezwaar in dokken met een ingang aan de stroom.



Projet : Piège à vase pour l'écluse de Zeebrugge
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La SBBM participe à la construction du Port de Zeebrugge depuis 1945.

45-46 : Réparation môle
 62-70 : Presqu'île Ouest
 73 : Accès écluse
 74 : Darse containers
 75 : Ecluse de mer

Comme partenaire de l'association Zeebouw chargée de la construction de l'extension de l'avant-port, elle s'est occupée activement de l'étude et de l'exécution.

La présence de vase est un aspect important dans cette étude. En collaboration avec la K.U. Leuven et Atlas Copco, elle a essayé de transformer une idée en un projet.

L'approfondissement continu des chenaux d'accès à engendré un problème d'envasement qui est devenu un réel souci pour tous les ports de la Mer du Nord et de Zeebrugge en particulier.

Le banc du "Zand" se situe normalement à -6 sous basse mer.

Maintenant le fond du chenal se trouve à -12 à 13.

Le sable et la vase transportés par charriage et en suspension est piégé par le chenal.

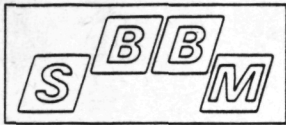
Le niveau de la vase monte ainsi à -10 à 11.

De ce piège, la vase s'écoule vers le bassin de virement et de là vers les points bas du port e.a. l'écluse dont le radier se trouve à -15.

Un envasement sur plusieurs mètres rend son exploitation difficile (voir schéma)

La vase décante comme "une soupe" dans de l'eau calme.

Cette soupe est très fluide (rigidité faible) si la densité est faible ou si elle est en mouvement. La vase se laisse pomper sans mélange avec l'eau, sous des pentes de talus extrêmement faibles. Si un piège à vase muni de pompes est creusé devant l'écluse et sous le niveau du radier, la vase peut être aspirée devant le seuil et rejetée en mer. Les circonstances sont favorables à ce système à Zeebrugge. (voir perspective)



Des essais, il apparaît qu'il faut satisfaire e.a. aux conditions suivantes pour qu'un pompage de vase puisse fonctionner :

- la vase doit provenir d'un "courant" avec un chemin invariable
- la vase doit rester assez longtemps à faible rigidité
- pour éviter une consolidation excessive, il faut pomper régulièrement (quelques heures d'intervalle)
- le volume du piège et ses talus sont à choisir judicieusement en fonction de la qualité et quantité de vase.

Avantages du système

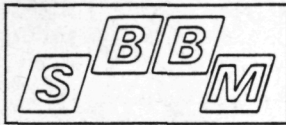
Un piège avec pompes est une installation fixe qui se prête facilement à être automatisée. Il nécessite peu d'investissement, personnel et énergie.

Ses frais d'exploitation sont donc faibles par rapport à un dragage normal.

- Il fonctionne d'une façon continue; ce qui rend possible le réglage du niveau de la vase
- Il se trouve sous le fond du chenal et n'entrave pas la navigation
- il peut fonctionner sous ou devant des pontons fixes ou estacades sans ennui pour le trafic.

Exemples d'applications

- Eviter l'envasement devant des portes d'écluses ou de câles sèches.
- Dragage sous pontons Ro-Ro ou câles sèches flottantes etc...
- Dragage dans des ports de plaisance avec un seul accès, sans évacuation des installations flottantes
- Dragage devant estacades et slipways pour maintenir la profondeur requise (exemple : Canvey Islands 1976)
- Eviter l'envasement de darses avec un accès depuis le fleuve ou la mer.



Concept of mud-trap for lock of Zeebrugge

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Since 1945 the Entreprises SBBM have taken a part in the construction of the Harbour of Zeebrugge.

- 45-46 : Reconstruction of the mole
- 62-70 : Construction of the Western peninsula
- 73 : Access channel to the sealock
- 74 : Dock in the inner harbour
- 75 : Sealock

As a leading partner of the joint venture ZEEBOUW for the construction of the outer harbour, SBBM has intensively taken part in the study and the execution. Siltation was an important item to be studied.

SBBM cooperates with the K.U. Leuven and Atlas Copco to convert the mud trap concept into a project.

Bij deepening and widening of the approach channel, siltation has become a source of trouble for many Port Authorities, especially for the harbour of Zeebrugge.

While the natural bottom of the former "Bank van het Zand" was 6 meters below low water, these days the "Pas van het Zand" goes down to 12 to 13 meters below LLWS. The "Pas van het Zand" works as a mud trap as well for the bed load as for the suspended load.

Consequently the mud level rises to -10 to -11 and the mud flows to the turning basin and to all deeper parts of the harbour including the new lock with a sill at -15. A several meters thick siltation would make the operation of the lock very difficult. (see drawing)

If not stirred up, the silt is settling down like creating a mud layer (see test tank). At low density this mud layer stays very fluid (low rigidity). It can be pumped under a very flat slope without being mixed with the water above. In case a pit would be digged below the level of the locksill and in which pumps would be installed to form a mud trap, it will be possible to keep the silt away from the locksill and to dump it into the sea.

It appears that the circumstances at Zeebrugge are favourable for such purpose (see perspective)



From the flume tests it appears that a mud trap would be effective under the following conditions :

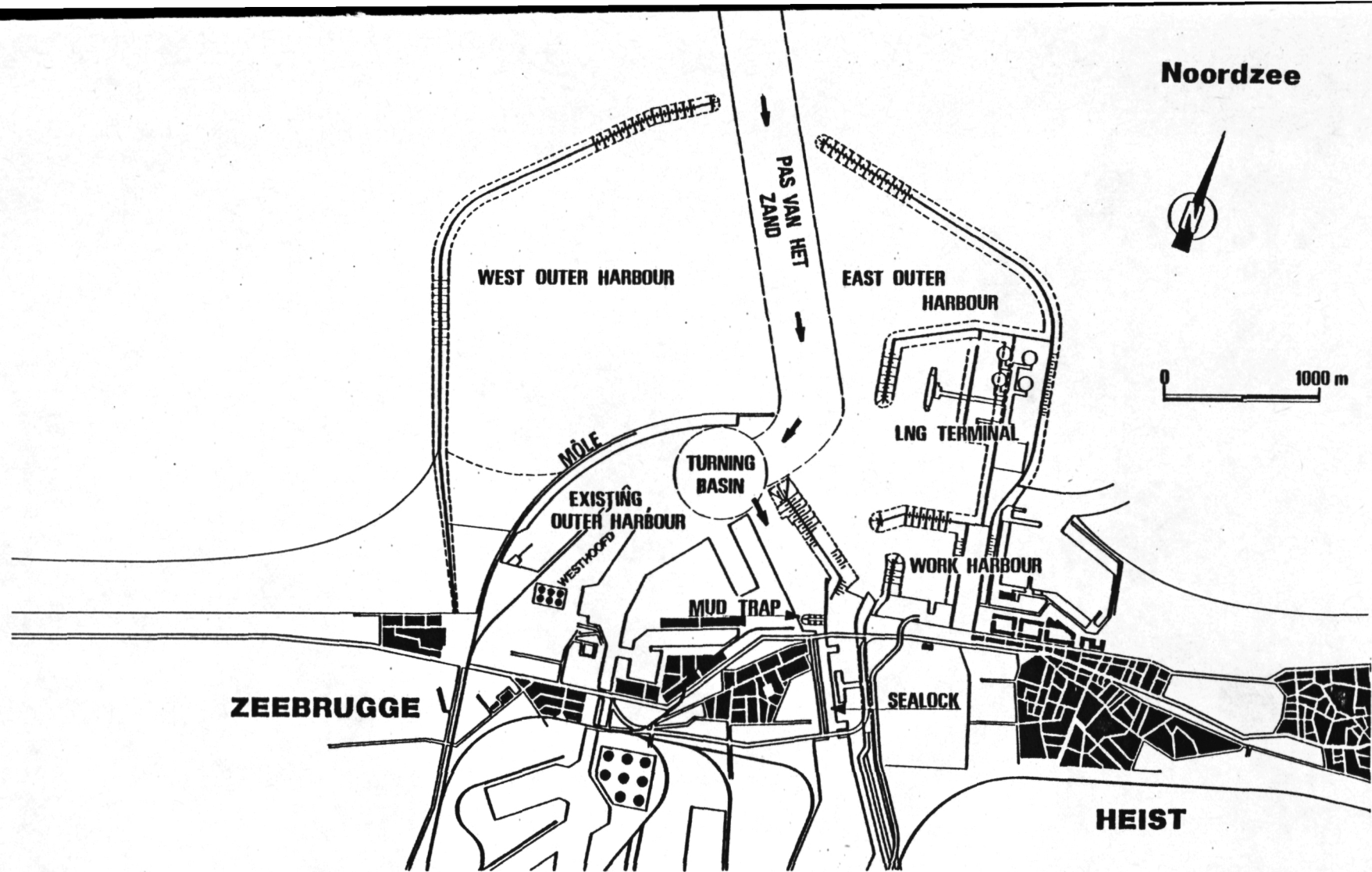
- the path of the mud flow has to be known
- the mud has to stay fluid for a long period
- in order to avoid consolidation pumping may not be interrupted for more than a few hours
- the dimensions and the slopes of the mud trap have to be determined following the quantity and the properties of the silt

Advantages of the system

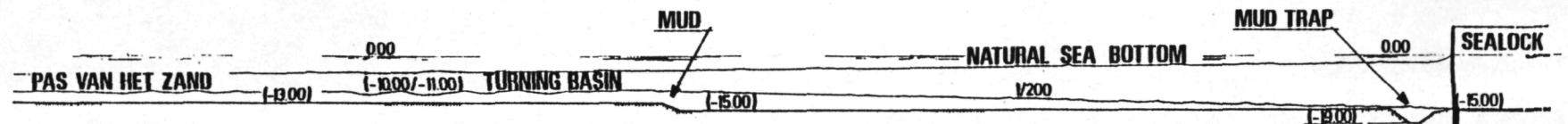
- a mud trap is a fixed installation with an automatic steering. It needs only a small staff, a small investment and a little power. It is a great deal cheaper than conventional dredging. It works continuous, so that the silt level can be regulated.
- it is able to work without disturbing navigation
- it can be installed underneath pontoons or piers

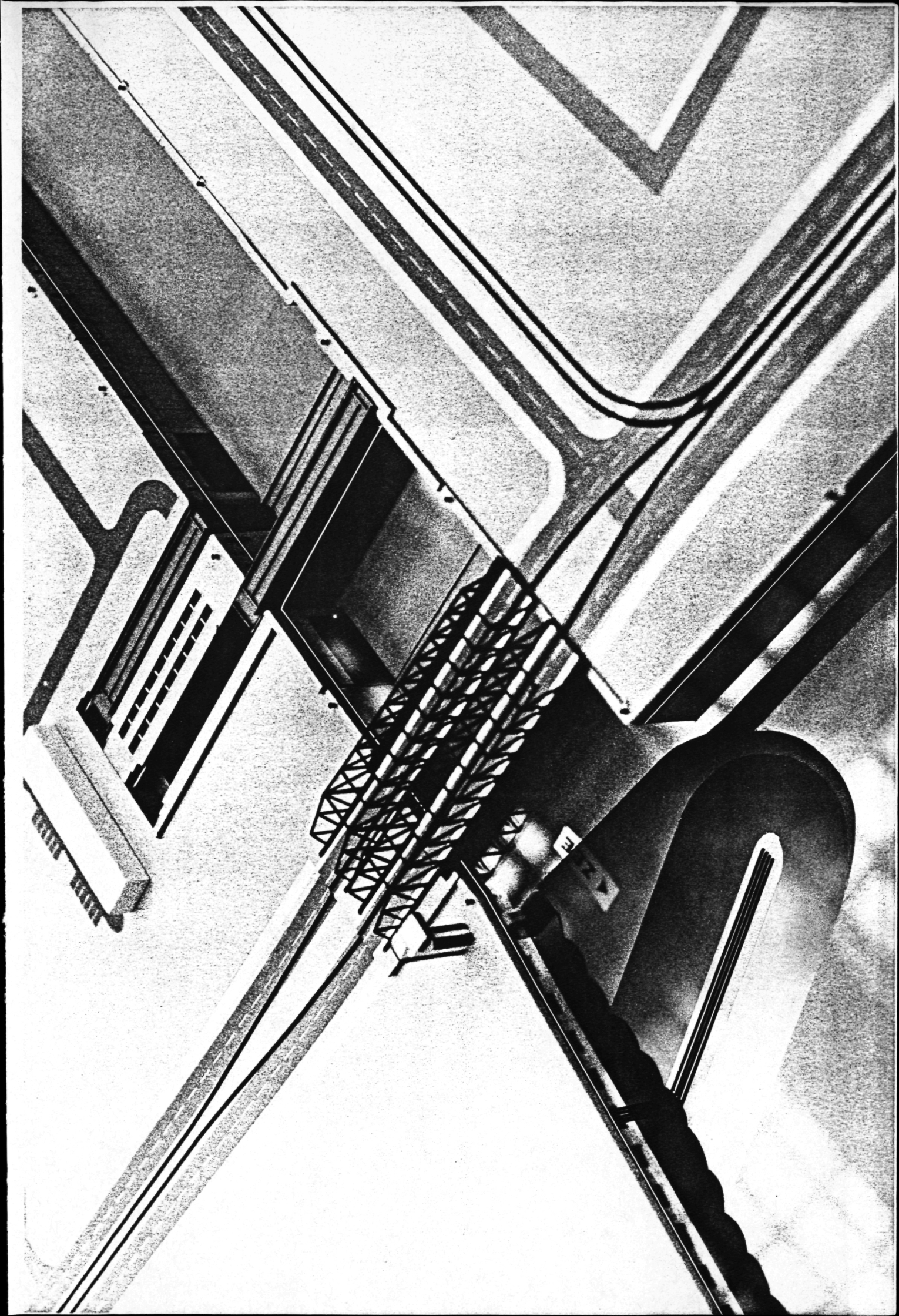
Applications

- avoiding siltation in front off locks and gates of dry docks
- dredging underneath Ro-Ro pontoons, floating dry docks
- dredging marinas with one entrance channel without having to evacuate all yachts and floating installations
- maintaining the required waterdepth in port or before piers and slipways (e.g. Canvey Island 1976)
- avoiding siltation in tidal docks with one entrance channel



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