J.E. BERLAMONT, J. VAN GOETHEM, E. BERLEUR and A. VAN BRUWAENE

A permanent mud pumping installation as an alternative for local maintenance dredging

KEYWORDS: mud flow, mud pumping, stratified mud, equilibrium profile, air jets.

ABSTRACT: A mud capture installation, provided with a fixed pump may be a substitute for conventional local maintenance dredging. If the mud deposits are stratified however the mud layer must be homogenized prior to the pumping. This can succesfully be done using air jets. In the paper a theoretical background is provided for understanding the different behaviour of homogeneous and stratified mud.

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J.B. BERLAMONT, Professor of Hydraulics, University of Leuven, Belgium
J. VAN GOETHEM, Research Engineer, University of Leuven, Belgium
E. BERLEUR, Director of research, S.B.B.M., General Contractors, Mettewielaan 74-76, 1080 Brussels (Belgium)
A. VAN BRUWAENE, retired Director of research, S.B.B.M., General Contractors

A PERMANENT MUD PUMPING INSTALLATION AS AN ALTERNATIVE FOR LOCAL MAINTENANCE DREDGING

SUMMARY To avoid difficult and expensive maintenance dredging at a harbour or dock entrance, in front of a navigation lock or under a landing-stage, it was suggested to build a mud capture installation, provided with a fixed pump. The idea is basically to remove the mud by (cheap) pumping, while it is still fluid, instead of (expensive) dredging of the consolidated mud.

A mud pumping installation may be very effective, provided that the mud layer is homogeneous, and the mud density is moderate. Stratified mud layers however, cannot be removed by pumping with the same efficiency. Therefore, layered mud deposits have to be homogenized before pumping e.g. using air jets, arranged as an air mattress, placed underneath the suction heads of the pumps.

RESUME Afin d'éviter des travaux de dragage locale, pour maintenir les profondeurs dans des ports, dans des chenaux d'accès des écluses, sous des pontons ou le long des quais, on a suggèré de construire une "trappe de vase", munie d'une pompe de vase fixe. Essentiellement l'idée consiste à enlever la vase lorsqu'elle est encore fluide, par pompage, au lieu de l'enlever après consolidation par un dragage coûteux.

On peut démontrer que le pompage de vase peut être très efficace, pourvu que la couche soit homogène et pas trop dense. Par contre le pompage de couches de vase stratifiées s'avère beaucoup plus difficile. Ces couches doivent d'abord être homogénisées par exemple à l'aide de jets d'air, montés sur un matelas, installé en dessous des bouches d'aspiration des pompes.

1 INTRODUCTION

Since the early sixties siltation has been a source of trouble for many Port Authorites. 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 (Belgium) and at several sites in Antwerp (Belgium).

In many cases the ship channel is considerably deeper than the surroundings, which may cause a steady fluid mud flow from the sea or the estuary towards the deeper parts of the harbour.

On the other hand in harbours, along quay walls, under pontoons and in small marinas, the mud which enters with the flood, settles down at slack water and forms a mud layer of increasing thickness, which hinders the commercial exploitation of the harbour.

To avoid the difficult and expensive maintenance dredging at a harbour or dock entrance; in front of a navigation lock or under a landing-stage, it was suggested to build a mud capture installation, provided with a fixed pump. The idea is basically to remove the mud by (cheap) pumping, while it is still fluid, instead of (expensive) dredging of the consolidated mud.

2 LABORATORY TESTS

To study the feasibility of such a device, and to determine the design parameters, extensive Laboratory tests have been carried out at the Hydraulics Laboratory of the University af Leuven. In particular, a number of pumping tests were carried out in a 12 x 0.5 x 0.5 m³ and a 2.4 x 2.4 x 1.2 m³ flume to study the dynamic behaviour of North Sea mud under pumping conditions.
It follows from the tests that a *homogeneous* mud layer can be pumped without difficulties up to densities of 1.150 and even 1.180 kg/m³ (The static shear stress then being of the order of 1 to 3 N/m²). The equilibrium slope of the water-mud interface being between 1/30 and 1/50. At the same densities and static shear stresses, *stratified* mud layers, built up by the precipitation of mud at slack water, behave in a very different way. The equilibrium slope, in the vicinity of the pump is much larger (1/1 !), which means that the "influence radius" of a pump can be very limited. This phenomenon was observed during a prototype test and was reproduced in the Laboratory.
In the subsequent sections a theoretical explanation is provided to explain why layered mud is much more difficult to remove by pumping than a layer of homogeneous mud.

3 BASIC EQUATIONS

Assuming that the mud behaves as a viscous fluid, and that the mud flow can be assumed to be a steady and uniform density current in a prismatic channel, the simplified eq. of motion is (Kranenburg, Graf) :

$$U_2 \frac{\partial U_2}{\partial x} - g' S_o + \frac{\tau_2 - \tau_1}{\langle \rho_2 \rangle a_2} = 0 \qquad (1)$$

in which (Fig. 1) :

U_2 : the mean velocity of the fluid mud

a_2 : the thickness of the mud layer

S_o : the channel slope

$g' = g\,[\frac{\langle \rho_2 \rangle - \rho_w}{\langle \rho_2 \rangle}]$ (reduced bouyancy)

ρ_w : the density of the water

$\langle \rho_2 \rangle$: the mean density of the mud

τ_1 : the shear stress at the water mud interface
τ_2 : the shear stress at the channel bottom
Taking into account the continuity equation, and since $\tau_1 = 0$, unless a massive sliding of the mud layer occurs, Eq. 1 reduces to

$$\tau_2 = g' \langle \rho_2 \rangle a_2 S_o \qquad (2)$$

Since : $\rho_2 = \rho_w + \alpha X$
in which X : the solids concentration (kg/m³)

$$\alpha = \frac{\rho_d - \rho_w}{\rho_d}$$

ρ_d : the density of the solid mud particles
Eq. 2 may be written as

$$\tau_2 = \alpha\, g\, a_2 \langle X \rangle S_o \qquad (3)$$

Assuming that X increases linearly over the depth of the mud layer (Fig. 1)

$$\langle X \rangle = X_o + \frac{1}{2} m\, a_2 \qquad (4)$$

in which X_o : the solids concentration at the mud-water interface
m : the concentration gradient
For a steady uniform mud flow the eq. of motion thus reduces to

$$\tau_2 = \alpha\, g\, a_2 \left(X_o + \frac{1}{2} m\, a_2\right) S_o \qquad (5)$$

This relation between S, a_2 and X_o is schematically represented in Fig. 2, and for specific values of the parameters in Fig. 3.
From these diagrams, several interesting conclusions may be drawn :

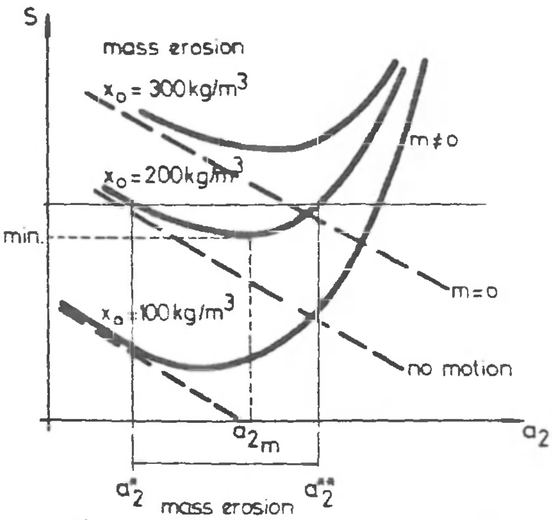

Figure 2 Channel slope S versus thickness of the sliding mud layer a_2 for different values of X_o and m and fixed values of A and n.

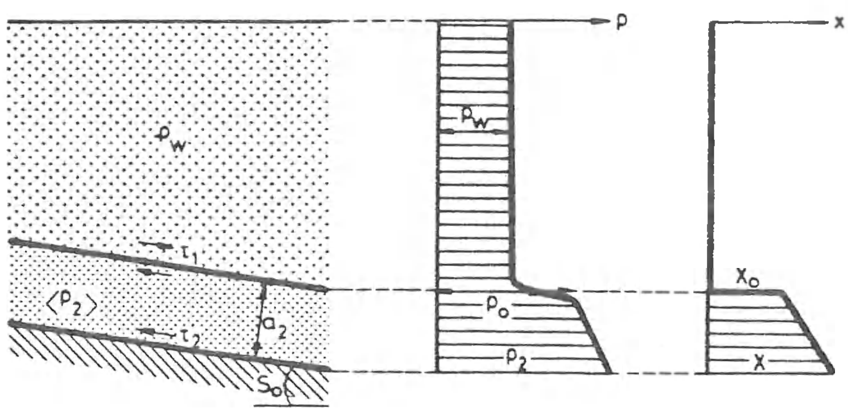

Figure 1 Illustration of the notations

4 NECESSARY CONDITION FOR MASS EROSION

Eq. 5 represents the equilibrium condition at the start of, and during the mass erosion of the mud layer : the shear stress induced by gravity is then balanced by frictional resistance.

Since however mud behaves approximately as a pseudo-plastic (or Bingham) fluid, the static shear stress must be overcome to initiate a sliding of the mud layer. The static (or yield shear stress ("rigidity") is generally expressed as (Migniot)

$$\tau = A\, X^n$$

in which A and n are physical characteristics of the mud.

To obtain sliding of a layer of thickness a_2

$$\alpha\, g\, a_2 \left(X_o + \frac{1}{2} m\, a_2\right) S_o > \tau_o$$
$$\tau_o = A\,(X_o + m\, a_2)^n \qquad (6)$$

1. A mud layer, in which the density increases linearly with depth, can only slide under the influence of gravity, if the channel slope equals or exeeds S_{min}. The value of S_{min} depends on the density of the mud layer. To obtain mass erosion at S_{min} the layer should have a thickness of a_{2m}. If the mud layer is *thicker*, only a layer of thickness a_{2m} will move. *Thinner* layers however cannot slide, since the shear stress due to gravity is not sufficient to overcome the static shear stress in the mud.

2. On channel slopes $S > S_{min}$, mud layers can slide down, provided that their thickness, a_2 is in excess of a_2^{**}. Of mud layers thicker than a_2^{**}, only a layer of thickness a_2^{**} would slide.

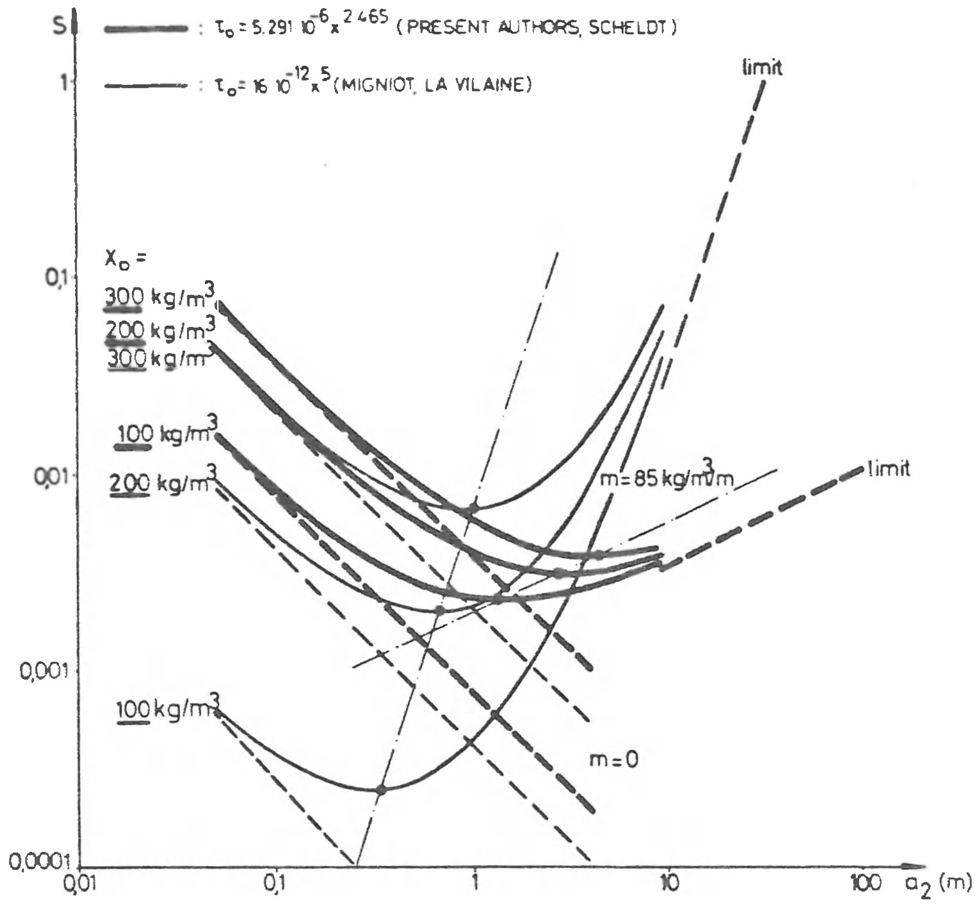

Figure 3 Channel slope versus thickness of the sliding mud layer, for m = 0 and 85 kg/m³/m, and two different muds (α = 0.625)

3. The minimum slope, under which no mass erosion occurs, increases with the mud density X_o and decreases with increasing thickness a_2 (provided that $a_2 < a_{2m}$). As a consequence, the slope needed to set on a global slide in a hydraulic model, may be considerably larger than in the prototype (scale effect).

4. If the density of the mud layer is constant (m = 0), no S_{min} exists. Neither does a maximum thickness a_2^{**}. For a mud of given density, a minimum thickness to obtain mass erosion exists for each channel slope.

5 STATIC EQUILIBRIUM SLOPE AND EQUILIBRIUM PROFILE OF THE MUD WATER INTERFACE

It follows from the previous paragraph that for mud of a given density in a prismatic channel at a given slope, a minimum thickness a_2 of the layer exists under which no (uniform) motion is possible. It is the value a_2 at which the static shear τ_o is in equilibrium with the shear stress induced by gravity. It is suggested here, that mud can only be pumped provided that the slope of the water-mud interface is in excess of the static equilibrium slope, determined by the thickness of the layer.

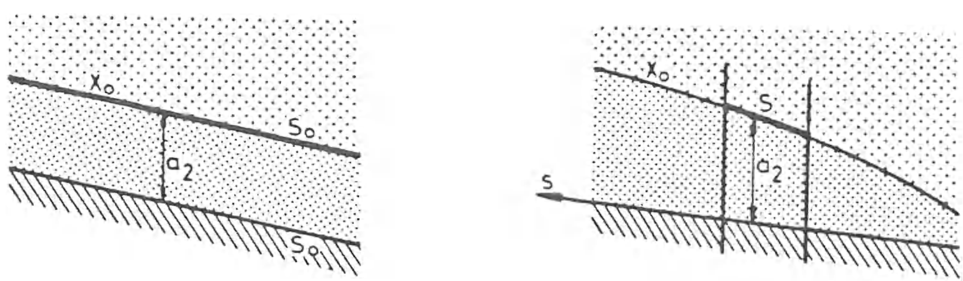

Figure 4 Comparison of uniform flow with gradually varied flow

Assuming that the theory for uniform flow holds approximately true for gradually varied flow, the static equilibrium profile of the mud water interface can be obtained by integrating the relation between S and a_2 : from Eq. 6 it follows :

$$\frac{da_2}{ds} = S = \frac{\tau_o}{\tau_2} = \frac{A\ (X_o + m\ a_2)^n}{\alpha\ g\ a_2\ (X_o + \frac{1}{2}\ m\ a_2)} \qquad (7)$$

Fig. 5 shows some equilibrium profiles for different values of X_o.

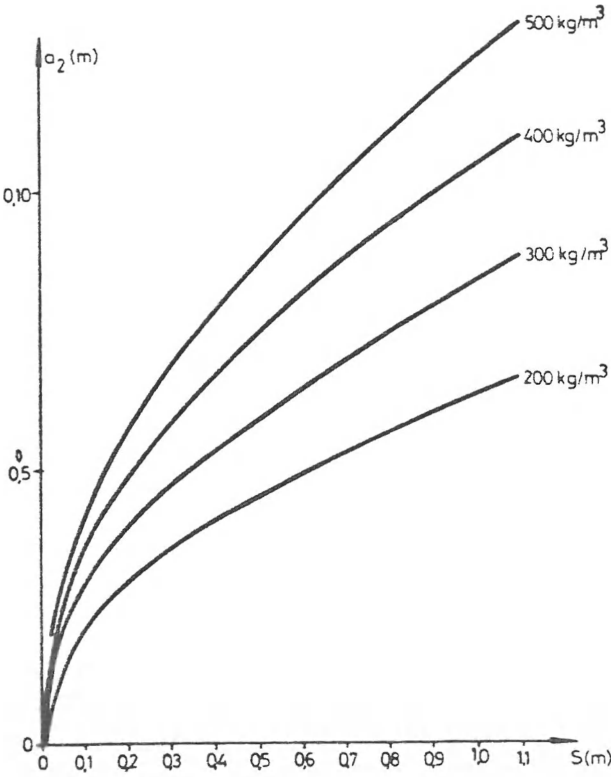

Figure 5 Static equilibrium profiles

6 EVOLUTION OF THE EQUILIBRIUM PROFILES IN THE CASE OF LAYERED MUD DEPOSITS

To explain the strong difference between the behaviour of homogeneous and stratified mud under pumping conditions, the following theory is put forward.

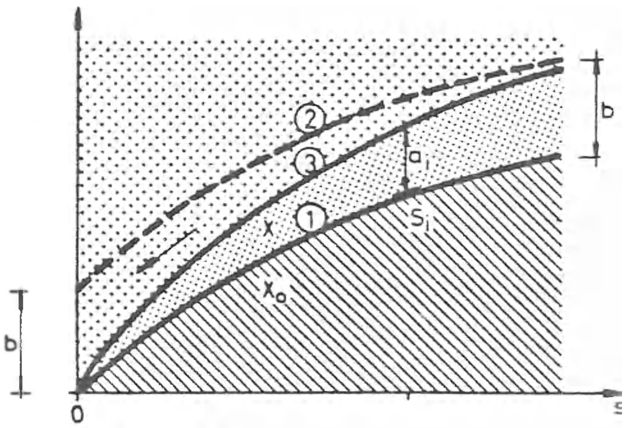

Figure 6

After the first pumping in O of homogeneous mud of solids concentration X_o, the mud water interface is formed by the static equilibrium profile of the mud X_o (① in Fig. 6). Suppose that, due to tidal effects a layer of thickness b and density X settles out of a suspension : a new mud water interface is formed (② in Fig. 6). Due to a renewed pumping action the mud X flows towards the pumping point under the influence of gravity (the mud X_o cannot be pumped since it is situated under its static equilibrium profile). At each distance s from O the static equilibrium profile of the X_o mud, is in fact the "bottom" for the X mud flow, having a slope S_i. On this slope X mud can flow downward under the effect of gravity, provided that the thickness of the X mud layer exceeds the minimum value a_i, determined according to Eq. 6. Integrating this equation

LAYER i	X kg/m³ X_i
0	300
1 → 9	100

LAYER i	X kg/m³ X_i	SUBSIDENSE FACTOR
0	300	0,85 - 0,75 - 0,65
1 → 9	100	0,65 - 0,55 - 0,45

A : AFTER 5 CYCLES
B : AFTER 10 CYCLES
C : LAYER 10 BEFORE PUMPING

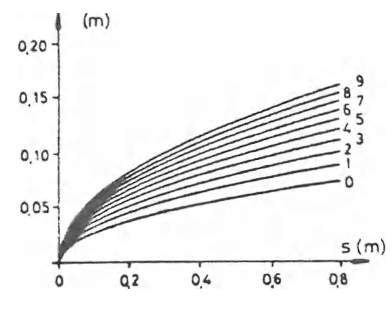

Figure 7 a)

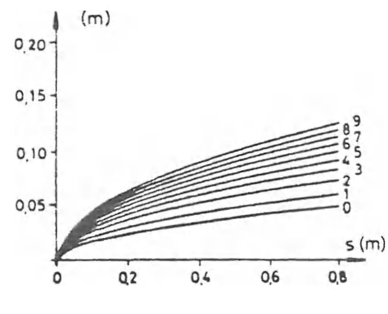

Figure 7 b)

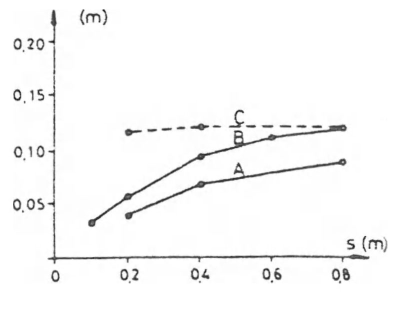

Figure 7 c)

Comparison between calculated mud water interfaces both without taking into account the subsidence effect a) and with the subsidence effect b), and experimental values c). The subsidence is simulated during the first thee cycles for each layer; for layer 0 with subsidence factors 0.85, 0.75 and 0.65 respectively, and for layers 1 to 9 with factors 0.65, 0.55 and 0.45 respectively.

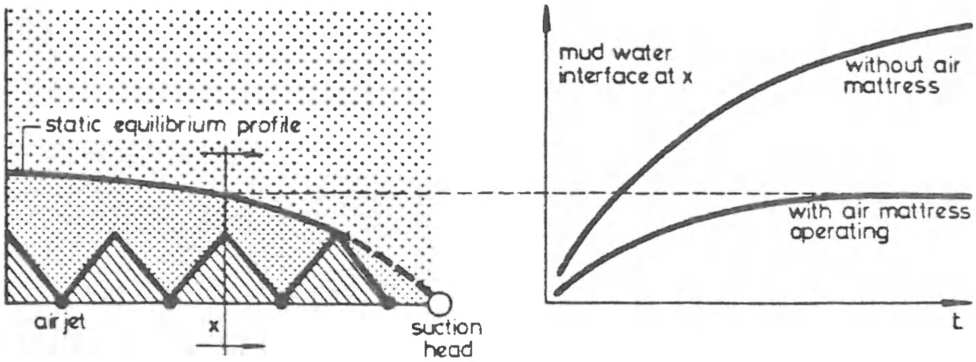

Figure 8 Schematic representations of the evolution of the mud water interface under the effect of pumping and homogenizing with air jets

starting at O gives the new equilibrium profile (③ in Fig. 6), under which the mud cannot be removed by pumping. The whole procedure is repeated during the succesive sedimentation and pumping cycles. It thus becomes clear that the mud water interface builds up, regardless the action of the pump. Carrying out the simulation of the described phenomenon on a computer, the effect of the subsidence of the successive layers may be taken into account (Fig. 7).

7 CONCLUSION

It became evident from experiments both in the laboratory and in situ, and can be explained by theory, that homogeneous and layered mud behave in a quite different way when pumped. In the particular case of layered mud, after each pumping cycle, always a layer of mud remains, which cannot be removed by pumping : the bottom builds up regardless the pumping. Homogeneous mud however can be pumped until the equilibrium profile is reached.

As a consequence, to remove layered mud deposits by pumping, the mud must be homogenized before pumping. This could be done by water jetting, or by using an air bubble mattress, located on the fixed bottom underneath the suction heads of the pumps. Because of its moderate energy consumption an air bubble mattress was prefered and its effect tested both in the laboratory and in situ. It was found that using a bubble mattress, combined with a fixed pump installation the mud level can be maintained constant, thus substituting expensive conventional dredging (Fig. 8).

At Leuven, laboratory tests are actually carried out, to optimize the disposition of the air jets, the air discharge, the aeration frequency, the pumping frequency and the mud pumping capacity. The system is covered by international pattent rights by S.B.B.M. (Belgium).

8 ACKNOWLEDGMENT

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9 REFERENCES

GRAF, W.H. (1983). The behaviour of silt-laden current. Water Power and Dam Construction, sept. 1983.

KRANENBURG, C. (1983). Internal knematic waves and the large-scale stability of two-layers stratified flow. Jnl of Hydraulic Research, 21, 1983 no. 4.

MIGNIOT, C. (1977). Action des courants et des houles sur des fonds de vase. Ecole Nationale des ponts et chaussées, Formation continue 1977.