

Water injection dredging

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Abstract

Some twenty years ago WIS-dredging has been developed in the Netherlands. By injecting water into the mud layer, the water content of the mud becomes higher, it becomes fluid mud and will start to flow. The advantages of this system are that there is no need of transporting the mud in a hopper, and no need for a pipeline. Also from an energetic point of view the solution is attractive. The system requires however a different way of payment. Most efficient is a maintenance contract with a dredging company in such a way that the company guarantees a given nautical depth for a fixed sum per year. For the port authority it makes budgeting much easier, because the maintenance dredging will become a fixed amount per year. The limitations are that WIS-dredging is only possible in case the material consists mainly of mud, the mud has to be quite clean, and the disposal should not be too far away from the dredging site.

Introduction and History

Wherever there is flowing water, a continuous gathering and depositing of solids occur. The turbulence and velocity of the waterflow determine the capacity of sediment transport. At locations where the velocity decreases, such as in harbours, riverbeds and channels, suspended sediment material is deposited. This mechanism makes areas, where water transport systems are in use, vulnerable to siltation. Siltation can reach a level at which efficient water transport is no longer possible.



Figure 1: A traditional hopper dredge and a WIS dredger

Maintenance dredging is a necessity in nearly all ports. It is usually a costly operation. Therefore improving the efficiency of dredging always results in a direct benefit. In many ports the main dredging volume consists of mud. And mud consists mainly of

water. Consequently, a large part of the dredging costs are the costs of transporting water. It is clear that this is very inefficient.

From a morphological point of view the material should stay into the morphological system. Storing the mud in depots causes a shortage of material in the dynamics of the system. However, this is of course only possible in case the mud is not polluted.

In case of non-polluted mud a very good solution can be transporting the mud artificially from harbour basins into deeper parts or the estuary or in the sea. The standard approach for this is usually dredging the material with a hopper dredge, and dumping the material at the selected dumping site. Basically this is a good solution for clean mud. Instead of a hopper dredge, material is sometimes removed by a bucket dredge or a grab dredge, and then transported to the dumping site by barges.

These types of dredging systems are based on the principle that solids are picked up from the sea- or riverbed and transported above water for delivery in a disposal area.



Figure 2: A WIS-dredger (HAM 307)

However, it is a costly solution. As mentioned before, the material consists mainly of water. Also, most of the time the hopper dredge is sailing, and only during a short part of the cycle time the dredge is really dredging. Using a suction dredge with a floating pipeline may solve this efficiency problem, but requires a floating pipeline. Such a pipe interferes strongly with normal harbour operations, and is therefore not acceptable.

In the eighties Mr. Van Wezenbeek, a Dutch Engineer, developed the method of Water Injection System Dredging (WIS-dredging). By injecting water into the mud layer, the water content of the mud becomes higher and it becomes fluid mud. Because the density is still more than the surrounding water, this fluid mud layer will start to flow. When the operation is conducted in the right way, gravity will take care that the mud layer will flow into the area where the mud is not hampering navigation any more. The advantages of this system are that there is no need of transporting the mud in a hopper (so the WIS-dredge can be quite small), and also there is no need for a pipeline. Also from an energetic point of view the solution is attractive. Only water is injected in the mud, which requires less energy than pumping (more heavy) mud. The wear of the equipment is less, because only water flows through the pumps, instead of mud.

The limitations are that WIS-dredging is only possible in case the material consists mainly of mud, the mud has to be quite clean, and the disposal should not be too far away from the dredging site.

Commercialization of the process

The inventor has worked this idea out to a practical solution with the help of some smaller dredging companies. After a merger of dredging companies, the patent on WIS-dredging came into the HAM dredging company. HAM has constructed several water injection dredgers, and is now carrying out this type of dredging in many places in the world.

WIS and agitation dredging

Often WIS-dredging is confused with agitation dredging. However, this is a completely different process. In case of agitation dredging the muddy material from the bed is brought into suspension, and is then (hopefully) transported away by tidal currents. The effect of agitation dredging is that the material is moved away from the location where the dredging work is carried out, but there is hardly any control on the position where it will settle down. Usually it settles in a thin layer, dispersed over a very large area.

Another remarkable difference is that agitation dredging causes a high turbidity in the water. Test in the USA showed that the visible plumes from WIS-dredging were less than the plumes caused by conventional dredging



WIS process description

Jet penetration

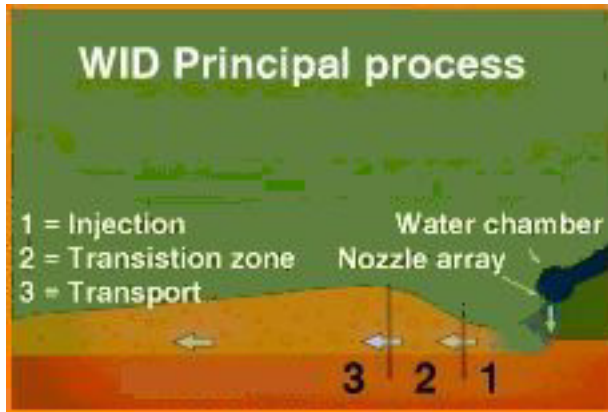
Large volumes of water are injected in the sediment under low pressure. The maximum quantity of suspended material will be obtained when the relations between the jet

configuration, the jet water pressure, the jet water volume, the forward velocity of the jet pipe and the soils characteristics are optimal.

The initial vertical flow will curve away horizontally. The resulting turbulent water-sediment mixture then will disperse because of the presence of eddies, which absorb water from the surroundings. A homogeneous suspension layer is created.

Density current

Once the water-sediment mixture has been formed, the difference in density between the mixture and the surrounding water can make it flow. Where the forces, working at the forefront of the density cloud, are not in equilibrium, the mixture will start to move



until a balance is established. The density current than is created.

The thickness of this moving suspension layer varies between one and three metres, with a distinct separation level between the suspension layer and surrounding water. The suspended soil particles will eventually settle under the influence of gravity, which in fact determines the ultimate transport distance.

Basic principles

The velocity of a density current depends on the density differences between the two layers. In case friction is neglected, the velocity will become automatically the critical velocity. The condition for the critical density current velocity is given by:

$$\frac{q^2}{\frac{\Delta\rho}{\rho} gh^3} = 1$$

This equation can be reworked, and introducing a factor α , which consequently leads to:

$$v_{fm} = \alpha \sqrt{\frac{\Delta\rho}{\rho} gh_{fm}}$$

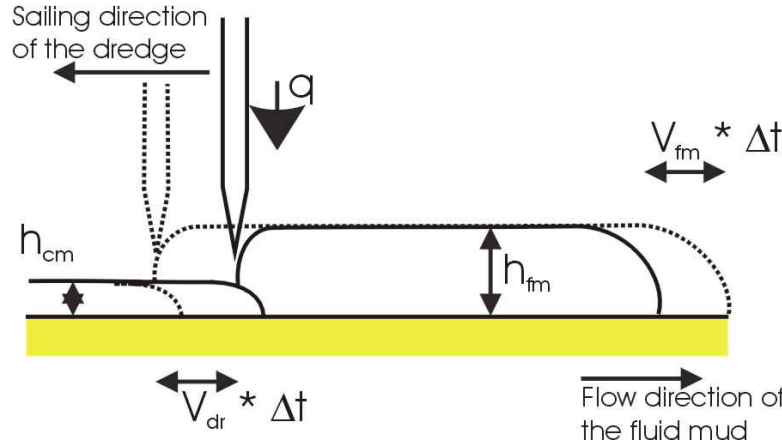
in which:

- $\Delta\rho$ density difference between water and the fluid mud
- ρ density of water
- h_{fm} thickness of the fluid mud layer
- v_{fm} velocity of the fluid mud layer
- α correction factor for the friction (is in the order of 0.9)

Other notations used:

- h_{cm} thickness of the layer to be dredged (thickness of the consolidated mud layer)
- v_{dr} velocity of the dredge
- c_{fm} concentration of solids in the fluid mud
- c_m concentration of solids in the consolidated mud layer

See also the schematic representation of the process in the diagram. In this diagram the dredge is moving from right to left. The fluid mud tongue (density current) moves to the right. Indicated are the changes in a small interval Δt . Now three basic equations can be derived:



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- Balance of water
- Balance of sediment
- Velocity of the fluid mud tongue

This results in the following three equations:

$$q = h_{fm} (v_{fm} + v_{dr}) - h_{cm} v_{dr}$$

$$v_{fm} = \alpha \sqrt{\rho \frac{\Delta \rho}{\rho} g h_{fm}}$$

$$h_{cm} v_{dr} c_m = h_{fm} (v_{fm} + v_{dr}) c_{fm}$$

In these equations the values of ρ , g and α are constants. The values of q , v_{dr} , h_{cm} and c_m are input parameters [c_m is a soil parameter, the q and v_{dr} are directly influenced by the dredge master and h_{cm} depends on the injection pressure of the dredge). So, the unknown output parameters are: h_{fm} , v_{fm} , and c_{fm} . In fact the value of $\Delta \rho$ is directly related to c_{fm} . This system can be solved by assuming a value of $\Delta \rho$, compute the three output parameters and see if the found c_{fm} equals the assumed $\Delta \rho$.

Combining equation (1) and (2) results in the following equation:

$$\frac{\Delta \rho}{\rho} g \alpha^2 (q + h_{cm} v_{dr}) = v_{fm}^3 + v_{fm}^2 v_{dr}$$

This is a cubic equation of the type $z^3 + a_1 z + a_0 = 0$, which can be solved analytically. As an example the following input values are used:

- $\Delta \rho = 300 \text{ kg/m}^3$
- $q = 0.3 \text{ m}^3/\text{s per meter}$ (this is $12000 \text{ m}^3/\text{hr}$ for a 12 m wide injection vessel)
- $v_{dr} = 0.5 \text{ m/s}$
- $h_{cm} = 0.35 \text{ m}$

Output:

- $h_{fm} = 0.36 \text{ m}$
- $v_{fm} = 0.85 \text{ m/s}$

The production of this dredge is then:

$$P = v_{dr} h_{cm} w$$

in which P is the production and w is the width of the dredge (e.g. 12 m).

So:

$$P = 0.5 * 0.35 * 12 * 3600 = 7500 \text{ m}^3/\text{hr}.$$

In reality the production rate will be somewhat lower, because not 100 % of the material is moved away. But this figure shows that the efficiency of WIS-dredging is very high.

Application of WIS-dredging

- Maintenance dredging
This is the most widely used application of the WIS-dredging. The method is for instance not only fully accepted by large organisations, such as the Ministry of Transport in the Netherlands and the Corps of Engineers in the United States, but also by minor ports, like the port of Itajai in Brazil.
- Assistance to trailing suction hopper dredgers
Main uses are to: minimise overdepth; trim slopes; remove silt from shallow sections
- Prevention of clay or silt inclusions
- Making and keeping rock dumpsites sand free

The efficiency of the Water Injection System

The Water Injection System is based on the physical principle that by injecting water into a mud layer, a somewhat thicker fluid mud layer is created. This new layer has a density that is much more than normal water, but less than the original mud layer.

Because the water is injected in the layer, the new fluid mud layer behaves like a layer of thick fluid, and the mud is not dispersed into the whole water column, like it is done with normal agitation dredging.

The density differences causes the fluid mud layer starts to flow, basically in any direction. However, because the dredging is done in an existing channel, the flow can only move either upstream or downstream. By starting the dredging process downstream, the mud can only flow in downstream direction, because the mud layer that is not yet fluidised prevents the flow in upstream direction.

Because of the density difference between the water and de fluid mud layer, the material can flow over a large distance; this distance can be in the order of kilometres.

It is not necessary that there is any tidal flow; however an outward tidal flow will ease the process, and an inward tidal flow will slow down the process.

Basic conditions for dredging with the Water Injection System are that:

- the layer to be removed is within an existing channel;
- the layer contains mainly mud;
- the total length of the layer to be removed should be no more that a few kilometres;
- when the length to be removed is too long, removal can be done into two steps;
- more than two steps are not recommended, consequently one cannot use the system for long estuaries;
- there has to be a (low) place at the end of the dredged channel where the mud is allowed to flow to, without causing problems with siltation;
- the mud to be removed has to be not polluted.

The efficiency depends very much of the capabilities of the dredge-master. When the system can be used and the contractor has a well-qualified dredge-master, Water Injection Dredging is in nearly all cases more efficient than other ways of dredging.

If dredging is done in a situation where the tidal flow is in the direction of the density current, the efficiency is much higher. In some cases it is even possible to carry out the dredging operation by moving in the same direction as the direction in which you want that the fluid mud tongue is moving. This is only possible in case there is also a strong (tidal or river) current in the same direction as the moving direction of the dredge.

In some test it proved to be even possible to move the material up slope. Of course the slope should not be too steep. This has been tried at a location where the material was deposited in a small pit in front of a quay wall. Because of the forces due to the density differences, the material started to move out of the pit, over a bar, into the deeper area of a tidal channel.

Because the quantity of material removed by this system is quite difficult to measure, the basis of the contract should not be a given volume or a given mass of material to be removed, but a given depth after dredging. As will be discussed later, the preferred depth is the Nautical Depth (i.e. a depth were the 1200 kg/m^3 layer can be found), and not the reflection layer of a given echosounder frequency (i.e. the 200 kHz layer).

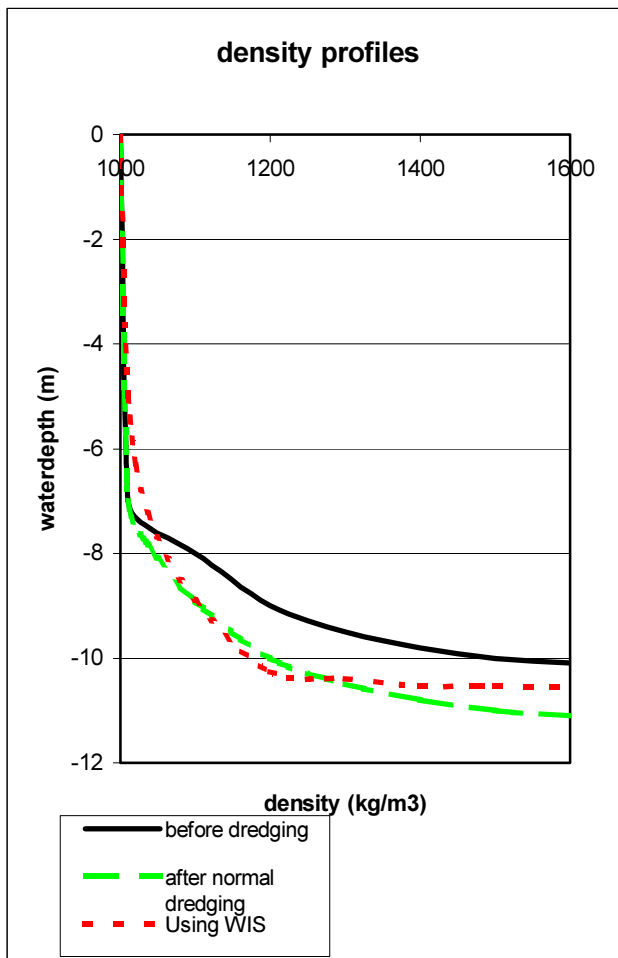
Effect of Water Injection Dredging on Ship Manoeuvring

Basically the method of dredging has no influence on ship manoeuvring. However, it is clear that differences in densities in the water column do have influence on ship manoeuvring. Directly after the application of the Water Injection System, the density profile is different from other types of dredging. Therefore the behaviour of the ship is different.

In order to explain this will be referred to the following graph, in which the density is plotted as a function of the waterdepth. It is good to realise that the normal echosounder of 200 kHz indicates a density of something in the order of 1100 kg/m^3 , while for the behaviour of ships the layer of 1200 kg/m^3 is of relevance.

It can be seen that both in case of normal dredging, as well as dredging with WIS the 200 kHz level are at the same position

Studies, commissioned by PIANC and others have indicated that safe navigation is no problem as long as a Nautical Depth of $1,200 \text{ kg/m}^3$ is respected. As indicated above, ships will sail in these conditions in "thick water". The effect is that the ship reacts differently on rudder-action and propeller. Operations are completely safe provided the pilot is aware of these differences. Modern dredging is therefore focussed on maintaining this nautical depth instead of maintaining a given horizon from an echosounder.



Traditionally pilots base their actions on experiences build up in many years in the port. This implies that when the environmental conditions change, pilots have to adjust their experience. Because of the risks involved in navigating large ships in the approaches of waters of a harbour, pilots are quite reluctant to do experiments with navigating large ships. This is especially the case, because a wrong manoeuvre may cause blocking last year of the complete harbour. The following photograph shows a container vessel blocking the port of Itajai in Brazil. Of course it is clear that the pilot in charge does not like this situation, and he wants to be sure that this is not caused by the changes in the density near the bed.

In order to help the pilots in coping with the somewhat changed situation caused by WIS-dredging, in combination with the very large ships calling the port, the following approach is suggested:



- Informing the pilots about the differences between sailing in pure water and in "thick water" on the basis of various graphs available in literature.
- Purchase of a ship simulator. This simulator can be placed in the Pilots office and pilots can prepare their operations on beforehand. They can try out several manoeuvres and find out the best manoeuvre. The simulator allows the pilot to carry out manoeuvres he would never try out in reality because of the high risk. Another advantage is that the pilot can try out these operations in the privacy of the pilots office.

A ship manoeuvring simulator is highly recommended, because apart from the above mentioned advantages of training of pilots, the same tool can be used for optimisation of the dredging work. Using such a simulator the optimum channel width and channel depth can be calculated. Also one can calculate the financial benefits of removing the rock outcrops in the harbour entrance (just between the breakwaters). When one knows both costs and benefits a well balanced decision can be made,

Contract forms for WIS-dredging

Traditional dredging contracts are usually based on either payment of the difference between the sounding before and after the dredging, or on payment of the amount of solids transported away (measured in the barges). In a very few situation clients still pay on the basis of hours worked, but this is not a very reliable basis for payment (because it does not stimulate efficient working).

Nowadays one sees that also other methods of payment become quite popular. One of them is to put the risk completely to the contractor. This means that the port and contractor make a contract for maintaining a predefined depth. Also with conventional dredging, this method has a number of advantages both for the client as well as for the contractor. This method is very well fitted to be used in combination with WIS-dredging.

The payment base should not be the transported volume of material, but the guarantee of a predefined depth. From a principle point of view, this is exactly the product the client is interested in (a port is not interesting in removing material, but in maintaining a certain depth). Most efficient is a maintenance contract with a dredging company in such a way that the company guarantees a given nautical depth for a fixed sum per year. This implies also that the risk is totally on the side of the contractor. Because the risk is at the side of the contractor, in first instance this implies a higher m³-price. For the port authority it makes budgeting much easier, because the maintenance dredging will become a fixed amount per year (and it will be lower than the average of the fluctuating dredging costs in the past). And because there are no fluctuations any more in the budget it will finally result in cheaper dredging. An additional advantage is that the contractor is very keen on improving the dredging performance, because that pays off directly to the contractor. And eventually that also results in lower dredging costs.

Acknowledgements

Most photographs are made available by HAM dredging company. The photo of the port of Itajai is made available by Antonio Klein of the University of Itajai (Brazil).

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