# MONITORING AND DREDGING TECHNOLOGY IN MUDDY LAYERS

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## ABSTRACT

Development of strategies in order to minimise costs in maintenance dredging means decreasing of dredging expenditure and quantities to be dredged. It`s in no case sufficient to determine the navigable depth by means of echosounding only because echo sounding devices are working mainly with high frequencies (beginning with 100 kHz) and therefore they detect soft or very soft layers as the highest sediment horizon. An echo sounding device can never give an answer to the question if these layers can be passed by a vessel with out any problems. The only proof of navigability is represented by a vertical scan of the consistency of the material throughout the water column.Up to now the most common proof for navigability was the density of the muddy water layers. This approach never gave an answer to the question if the sediment starts to flow after contacted by a ships hull. The definition of fluidability requires an additional measurement of rheological properties, e.g. yield stress, shear rate or viscosity *(Wurpts, 2005).* Measurement devices for these purpose should:

1. deliver at least one out of these parameters, which
2. can be controlled without any postprocessing procedures directly from a moving survey vessel and
3. the measurement technique should be practical in practice.

**Keywords**: Cost reduction by remedial dredging (ISCRED – Method); parametric depth; isoyields; ultrasonic sediment profiling; keep sediment in system (KSIS) method

## INTRODUCTION

The ADMODUS Ultrasonic Sonar System records <u>all the three criteria</u> (including parallel determination of the density). Numerous tests with this system in the ports of Emden, Brunsbüttel, Rotterdam Botlek area *(de Wit et al. 2003)* and Bremerhaven confirmed reliable results. Vertical and horizontal spectra of strata could be analysed and on that occasion it was found, that fluid mud or silt formations stirred up by dredging activities or ship movements went into resuspension and became navigable again after years of settlement or consolidation. Since that time the dredging management responsible in the port of Emden started with the so called recirculation method in order to achieve a low cost level in maintenance dredging by conditioning the sediment and keeping around 1,2 Mm³ of detectable fluid mud intentional in situ in its equilibrial status *(KSIS- Method; Wurpts, 2004).*

In Emden Port the ADMODUS results could be tested since 1997 by rheological tests in the laboratory and in the meantime the survey department has changed from a `normal echo sounding `work into an ADMODUS campaign dealing with strata of lines of equal yields. This innovative technique in comparison with the conventional ADCP-systems allows reliable measurements directly down to the solid harbour bottom. With this technique it is possible to measure the exact sediment and mud strata even there, where stiff material in a high concentration is in a water column.

The ADMODUS measurement technique shows:

- which sediment levels are navigable up to what depths;
- which quantities of non navigable material are to be removed in order to restore the depth required (selective dredging);
- the distribution of recirculated and refluidised dredged material over the water column;
- in what time this material reconsolidates and how strong its reconsolisation is (Greiser et al., 2004).

This presentation represents with different examples the successful application of the ADMODUS technique in order to prove the nautical depth and the monitoring of innovative dredging methods e.g. fluidisation of mud in situ, sediment conditioning and the KSIS (keep sediment in the system) – strategy.

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## MAINTENANCE DREDGING IN EMDEN

Dredging in most ports along the North Sea coast is `normal` traditional dredging work , where a lot of cubic meters are to be removed or dumped somewhere or stored onshore. At the Port of Emden dredging was executed historically also in this way; until 1988 maintenance dredging was tendered out based upon unit rates. Around 4,0 mio m³ of silt or mud were pumped ashore and used to convert deep marshlands into fruitful agricultural areas. Excavating the harbour was similar to the work of Sysiphus due to immediate natural refill with mud. Measures were taken to keep this mud navigable as long as possible. A biological examination delivered some remarkable results:

- The mud contained a very high organic content supported by cultures of adjacent nitrifying bacteria which need oxygene (aerobic conditions)
- The higher this organic content is, the more fluid the mud behaves
- If fluid mud rests undisturbed for a long period with less or no oxygenic content it converts to silt or Schlick (anaerobic conditions)

In the meantime the dredging management discussed in this paper holds around 15 years of experience in dealing with this mud and proved successful in `refreshing` of anaerobic (so called dead) conditions. The main philosophy is: leave the mud in situ and keep it fluid and navigable by keeping the aerobic circumstances going. The main theme at this moment is: In Situ Conditioning by Remedial Dredging (ISCRED – Method).

During "conventional dredging" in the eighties and early nineties around 90 % oft the work in Emden was done by a CSD and 10 % by a TSHD supporting the CSD. In 2001 90% of the work had changed over to the TSHD and from 2002 it was 100% In Situ Conditioning by a TSHD without any onshore disposal. The dredging technology made use of here can be called Remedial Dredging: Anaerobic formations are pumped into the hopper where they come in touch with oxygen all over the hopper surface. This procedure changes the <u>anaerobic</u> conditions into <u>aerobic</u> ones. The enrichment with oxygen increases the buoyancy of the mud and avoids immediate settlement. Microbiological and rheological investigations on the composition and consistency of the dredge material revealed that nearly all of the excavated sediments could be kept navigable in situ for a long time. Only if that fluid mud becomes anaerobic does it consolidate to silt then having properties like consistency and cohesion. If stirred up again, even this solid silt will recover its fluid consistency. Based on these findings maintenance dredging in Emden has now been completely changed to in situ conditioning (ISC): Anaerobic mud is pumped into the load a suction hopper dredger (TSHD), gets into contact with air, and is released to the harbour bottom again.

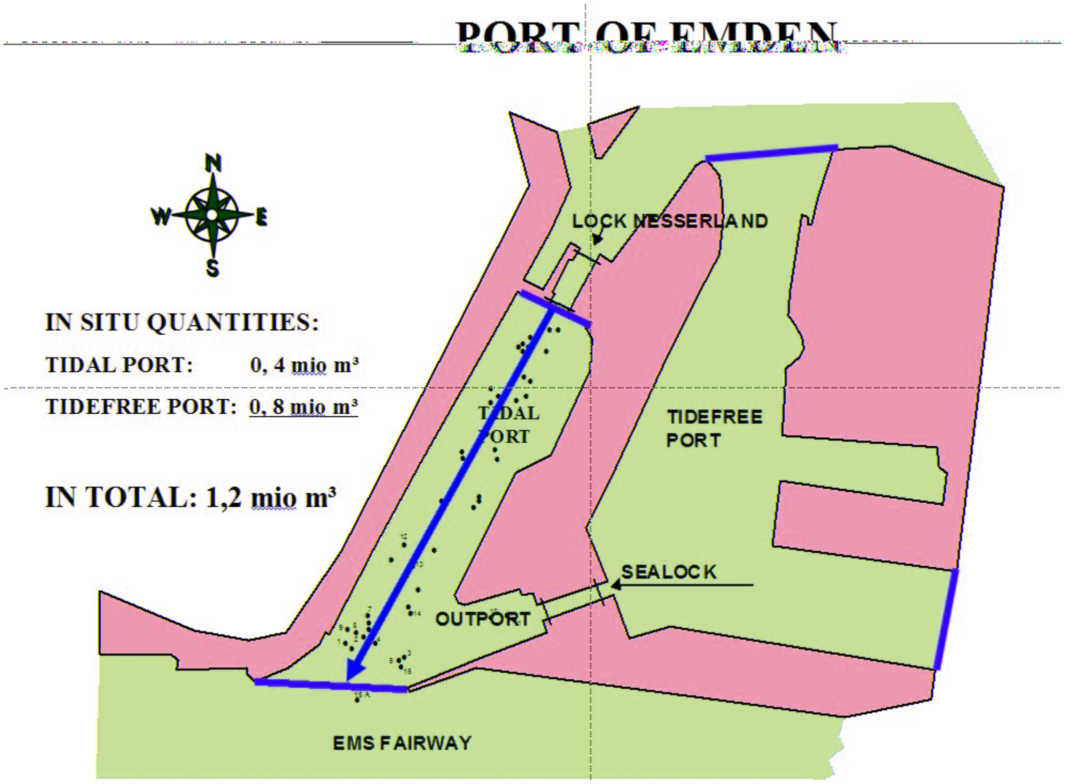


**Figure 1. Port of Emden, general layout.**

Since 5 years the harbour basins in Emden Port contain a roughly constant in situ quantity of 1,2 mio m³*( Figure 1)* it can be assumed that this layer is in an equilibrial status. This layer has to be refreshed around once a year. It is quite clear that former properties for determination of a nautical depth like kilocycles or densities or apparent (continiously variable) viscosities are not applicable anymore in this dredging system in order to prove navigability. The nautical bottom is determined by a parametric depth. In the port of Emden the yield stress was chosen in order to define a nautical depth. Survey therefore has to be done by delivering a monthly map showing isoyields (lines of equal yield stress points) of the mud layer measured from a moving survey vessel. As soon 70 Pa in situ-yield is reached conditioning activities have to start. Testing the ISO- YIELD s is done by Ultrasonic sounding.

The Ultrasonic Admodus Sonar System has shown the most suitable results so far. The aim of this survey is to distinct different layers depending from their yields in order to allocate layers to be conditioned by the dredger or not to be conditioned. In this way real SELECTIVE DREDGING can be achieved. This presentation shows applicability of the ISCRED – method *( In Situ Conditioning by Remedial Dredging)*in other ports as well as the full accordance with the EU- Water Framework Directive and gives an overview of the maintenance dredging system in the Port of Leer, where an Under Water Pump System removes the mud with under aid of the fluidity of that mud. Parallel to the change from \`Dredging\` to \`Conditioning \` Emden Ports annual maintenance costs decreased significantly from 26 mio DM per year in 1985 to 2,6 mio DM = €1,3 mio annually in 2002 although the harbour basins in Emden Port contain a nearly constant in situ quantity of 1,2 million m³ fluid mud which has to be treated about once a year by ISC in order to maintain its navigability.

Further optimisation of ISC is now possible since the dredging process is constantly monitored by multi frequency echosounding and high frequency vertical scanning of the sediments with the multiparameter *admodus*-USP-probe. Its density, sound velocity, backscattering and attenuation values are taken to determine the consistency of the sediment layers in situ. For instance isoyield maps (lines of equal yield stress) are delivered monthly showing the navigable depth in terms of its specific rheological properties. This paper explains which kinds of sediments are suitable for active nautical depth formation and how this ISC maintenance dredging method can be adopted to other harbours in order to get considerably reduced costs and less impact on the environment (Greiser et al., 2002).

**RHEOLOGICAL PROPERTIES FOR OPTIMISATION OF DREDGING ACTIVITIES**

The most important properties of liquid sediments are the presence of viscosity $\eta$ (changing values depending from shear rate) and a yield stress $\tau_0$ which is time dependent. Another important property is the thixotropy *(Wurpts, 2005)*. A further precondition for the fluidity of sediments is that the stream of the fluidised mud is a laminar one. The relationship between the shear force $\tau$ and the shear rate D provides numerous apparent viscosities. They are called àpparent viscosities` because they are not constant. Their value changes with different shear rates or deformation speeds but in contradiction to that there is <u>one</u> yield point only. Measurement devices for determination of nautical depths should therefore been calibrated upon this one yield stress and not upon varying viscosities.

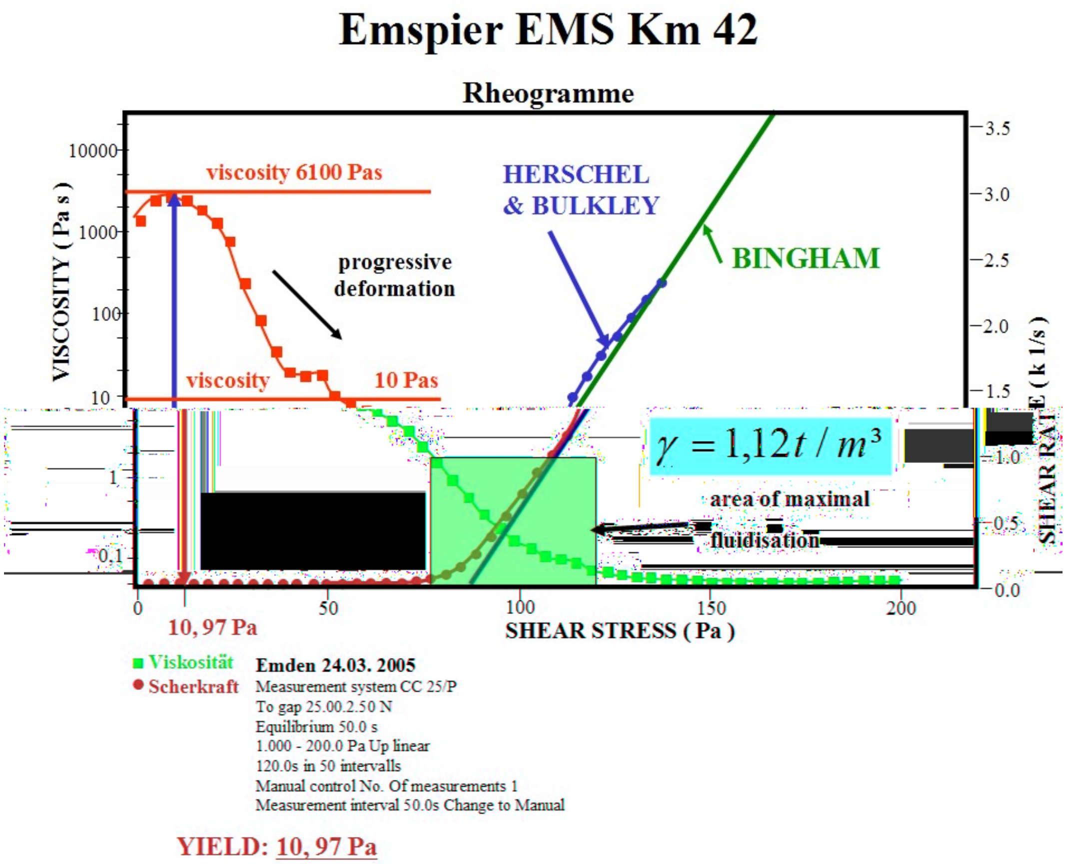


**Figure 2. Rhelogical properties of Ems mud.**

The result of a rheological test of a sediment sample out of the Emden Port is shown in Figure. 2. Before a modern rheometer was applied, the straight Bingham line was extended in direction of the ordinate showing a yield $\tau_0$ of roughly 75 Pa which means: not navigable because the criterion for navigability in this area is 70 pa maximum. But in contradiction to this the rheometer shows depending from different shear rates a parabolic distribution of the shear forces with <u>one</u> yield point (10,97 Pa) but hundreds of different viscosity values. Instead of a 70 Pa the yield in this sample the yield is only 10,97 Pa which is a `breaking force` of 1,097 kg exerted upon one square meter of ships hull. This low value will not affect the ship`s movement at all. As soon this value is overcome the mud at the bottom in that position starts to flow and the range of maximal fluidisation occures where the yield curve and viscosity curve (red) will meet. This mud is definitely shear thinning. The parallel recorded viscosity distribution confirms this result also: Mathematically a mud sample starts to flow where the viscosity shows a maximum, in this case the viscosity is 6.100 Pas. This is quite clear because a viscosity represents a property of a fluid and therefore never a force against fluidisation. Considering the dimensions only the yield owns a dimension (N/m² or Pa) of a force.

The curves in Figure 2 confirm again that depth measurements carried out with devices calibrated upon a viscosity of 10 Pas will never supply a reliable result for the navigability of a sediment. Placing a viscosity of 10 Pas into this diagramme in Figure 2 at this point shows that a maximal fluidisation has already started. The line of 10 Pas is clearly far behind the yield point and is therefore absolutely useless to say anything about navigability. This viscosity represents no shipping obstruction and furthermore after application it will lead into more quantities to be dredged which could be easily left at the harbour bottom. The 10 Pas – limit obstructs any minimisation of dredging and expenditure.

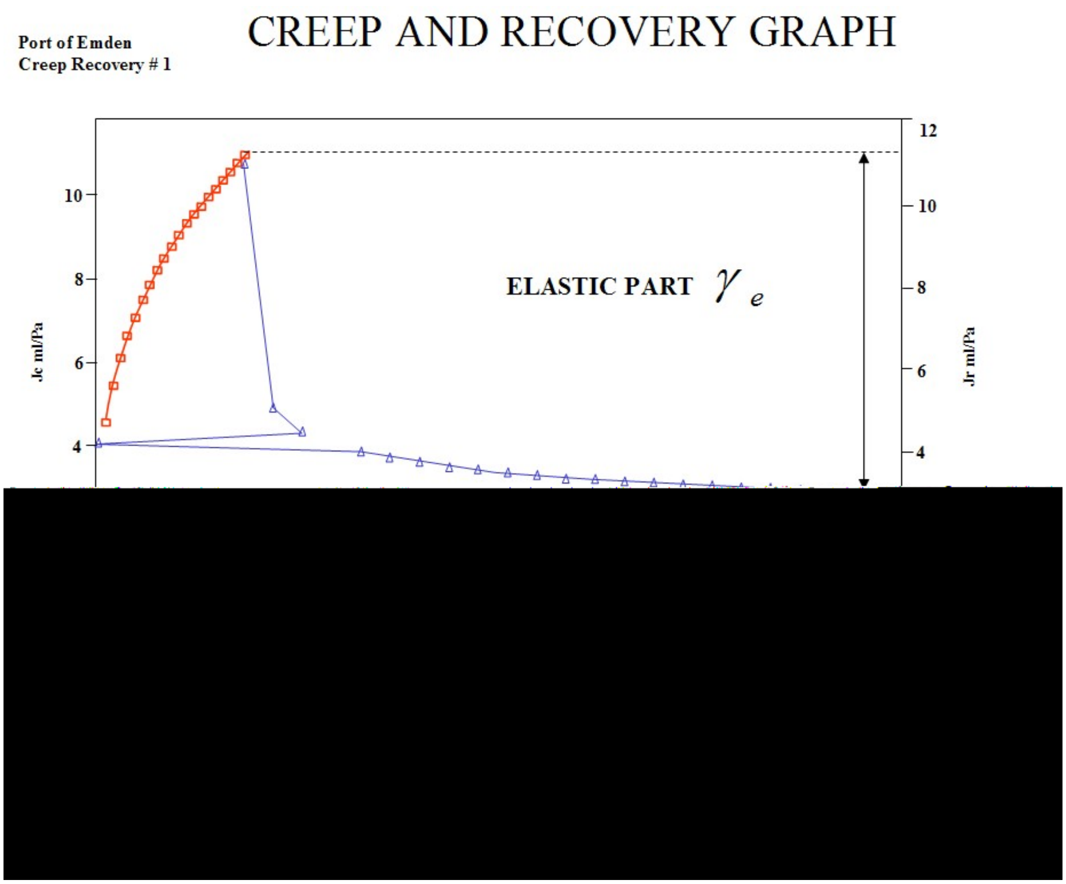


**Figure 3. Creep and recorvery graph of Ems mud.**

An other important rheological information for the consistency of mud is the Creep and Recovery Measurement (Figure 3; Greiser et al., 2004). This test splits a mud sample up into a viscous part and an elastic part. In order to decide about an efficient dredging strategy the viscous part $\gamma_v$ can be neglected because it behaves like a Newtonian fluid as part of the water column and should never been dredged out. Against that the remaining elastic part $\gamma_e$ causes a redeformation together with a certain shear strength and only this elastic mud formations in a harbour area should be dredged or better to be `treated` (Wurpts , 2005)

In the first moment it looks complicated to make a distinction between the elastic and the viscous part within a muddy area to be dredged but in practice it`s quite sufficient to treat or dredge a calculated quantity pro rata: if the test shows an elastic part $\gamma_e$ of for example 40 % only 40 % of the total calculated volume are due to be maintained by a dredger. Consequent following up this measurement results the expenditure of the trailer suction dredger decreased in the period between 1998 and 2005 from 2.500 hrs annually in 1998 to 1.000 hrs in 2005. In the same time the quotient of quantities `treated` in the hopper room against those present in situ decreased from 3,5 to 1,0. In 2006 this factor was 0,95.

An ultrasonic attenuation value of 2,9 dB/cm (with 2 Mhz) is applied in Emden Port for determination of navigability. This value corresponds obvious with the earlier mentioned criterion for navigability -the yield point 70 Pa - which represents a breaking force of 7, 0 kg exerted upon 1 square meter of ships hull. On *Figure 4* an example of the monthly executed measurements in Emden with Ultrasonic Sonar is shown: The drawing on the right shows the depths required in the outer port area. The graph on the left explains depth lines correlated with a yield of 70 Pa, so called isoyields. After a 4 months period of `doing nothing` there are three spots only (green marked) where a little `treatment work`is necessary; but most of the area shows partly significant overdepths.

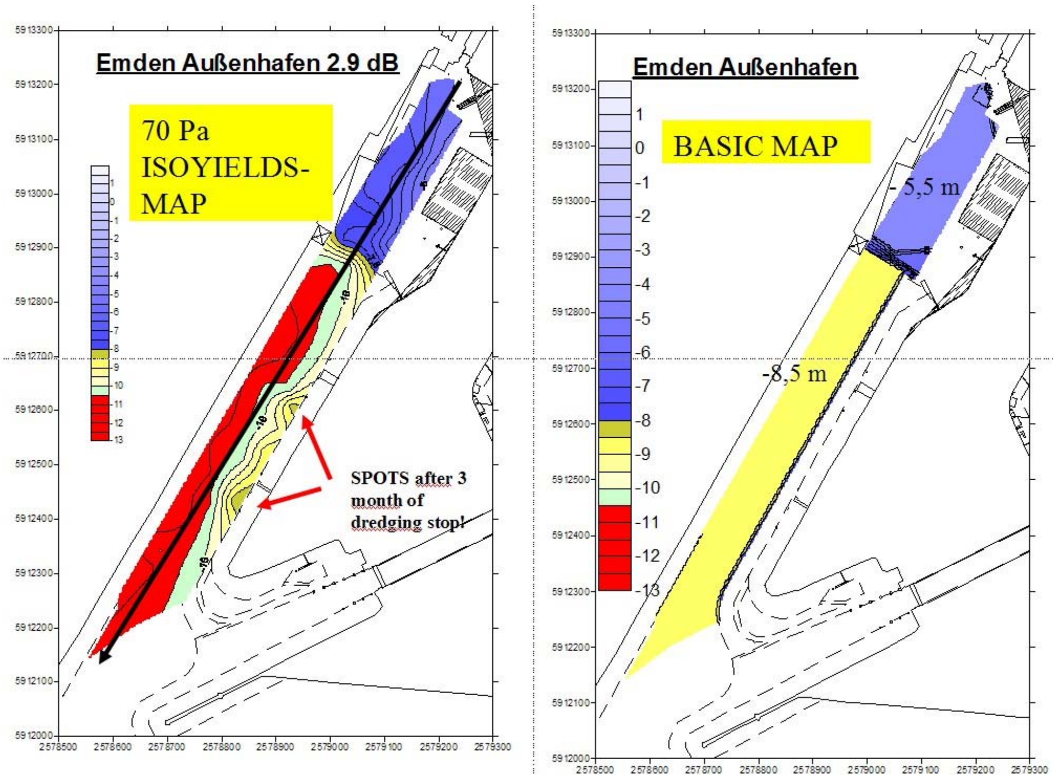


**Figure 4. Isoyield map of Emden port.**

In this way it is possible to employ a dredger very economically and effectively by completely selective dredging. After roughly four months of no treatment a few high spots had to be removed only. The results of the monthly iso - yields map are saved into the track plot computer of the dredger and the spots concerned are automatically treated.

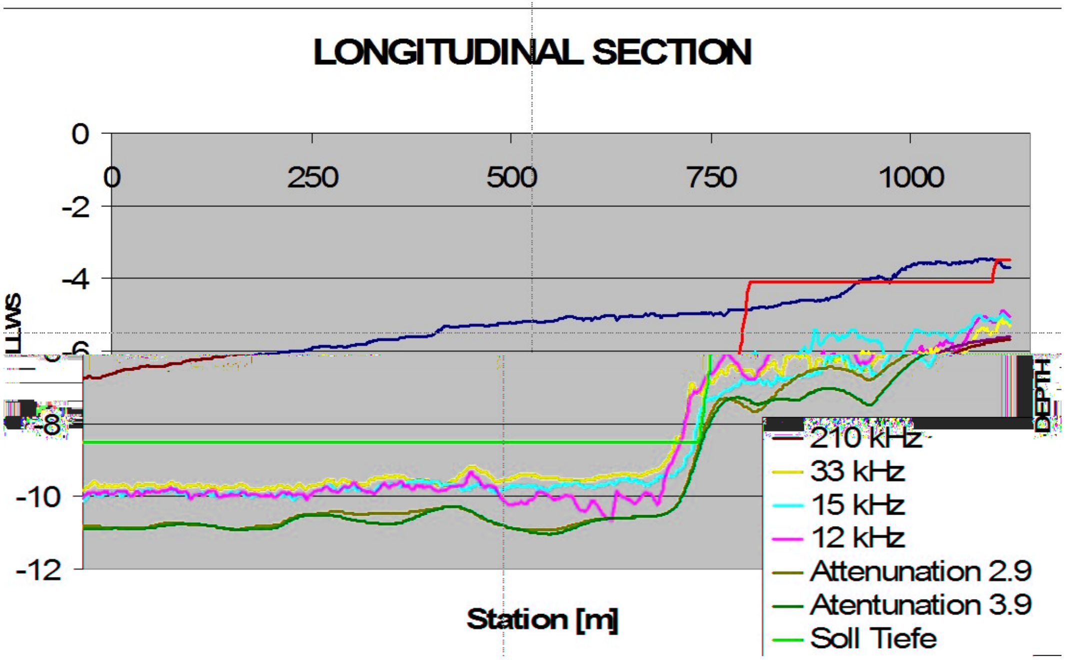


**Figure 5. Longitudinal soundings of Emden port (different sounding frequencies).**

Quite interesting are the depth circumstances along the yellow double arrow in the left hand drawing (Figure 5): All three small echo sounding frequencies are deeper than – 8,5 meters depth required which confirms that the in 1988 at the first time recorded over depth is still present after more than 17 years. It is furthermore fascinating that the iso yield line with 70 Pa yield is still approximately 20 cm deeper than the lowest echo sounding frequency which confirms that depth soundings with 12 kHz are still `on the "safe side". More significant is the distance between 12 and 33 kHz: roughly one meter. Taking 33 kHz as a measure for determination of the nautical depth will lead to an increase in dredging of around 25 % in the outer port of Emden.

## THE CONDITIONING OF FLUID MUD

The dredger employed in Emden was modified several times in the past but the most advantage was gained by placing the pump outside of the vessel within the suction pipe. In this way working as an under water pump it will be supported by an incoming pressure resulting from the water column above the pump. The mixture in the suction pipe is therefore the same one than in the fluid mud layer under treatment at the harbour bottom and not thinned by suction water in case of an inboard mounted pump. Together with an installed degassing system the density arriving in the hopper is higher than the density in situ. The flow behaving of fluid mud is strictly a laminar one *(Wurpts, Terra et Aqua, June 2005).*

**THE FLUID- AND BYPASS SYSTEM IN LEER**

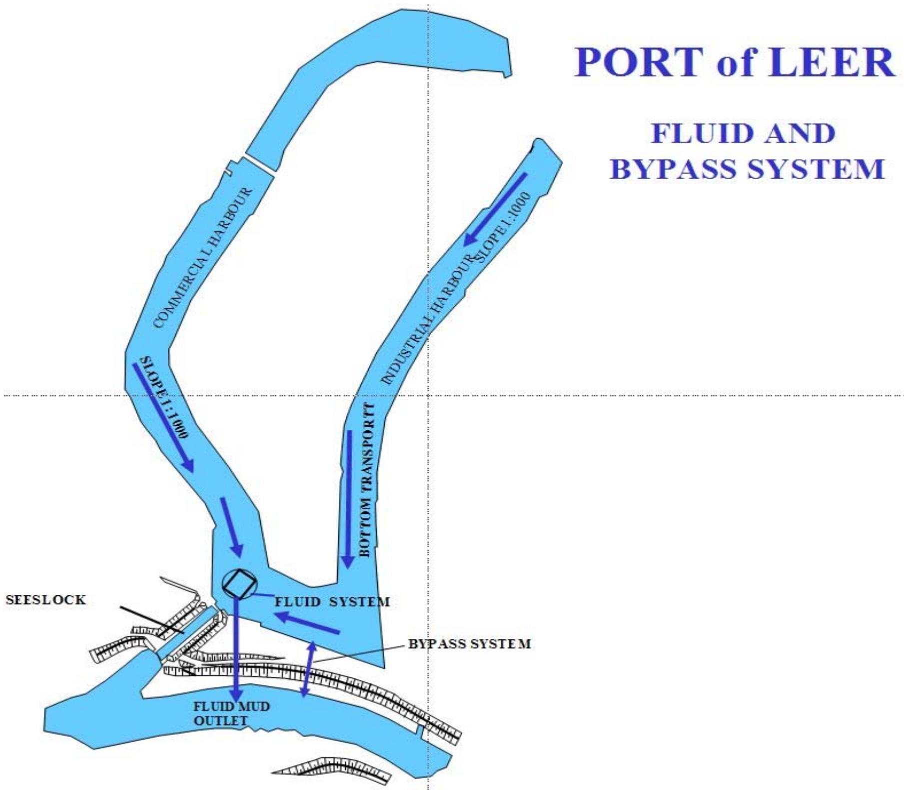


**Figure 6. Fluid and bypass system port of Leer, general layout.**

After the experiences with fluid mud and refluidised mud in Emden Port in the port of Leer an under- water suction system was installed (Figure 6) and (Figure 7). During a trial dredging campaign it was surprisingly discovered that really old and long time settled (27 years of no dredging activities) silt formations could be refluidised by the Emden practiced treatment system. The harbour of Leer consists mainly from two basins, each one averagely 1.100 metres long. Connected by a sealock with the adjacent rivers Ems resp. Leda the harbour authorities have to maintain a navigable depth of 6 meters below NN. The last dredging campaign took place in 1978 and in the meantime a layer of averagely 2 meters thickness was consolidated into unnavigable silt. At least once a year a hopper dredge was hired in to keep up the depths required by relocating the fluidised silt into other parts of the harbour. After having done this the mud came back to it`s former fluidability and returned very soon into the deepening just created. This was a confirmation of the laminar flow of this mud as well of it`s thixotropic behaviour. In order to solve these problems it was decided to place a fluid pump on the bottom of the harbour at it`s deepest point. This position is roughly 50 meters away from the internal lock door. This pump is a normal dredging pump with a horizontal working impeller bedded into a special concrete pump sump (Figure 8). The sump is on 7,0 meters and the suction mouth of the pump on 7,5 meters below NN in order to collect the mud flowing from both harbour basins along a slope 1:1000 by natural gravity resulting from the mud`s thixotropy and laminar flowing. The discharge diameter of the pipe is 12 inch (30 cm) and the pumping distance into the river is 350 meters long.

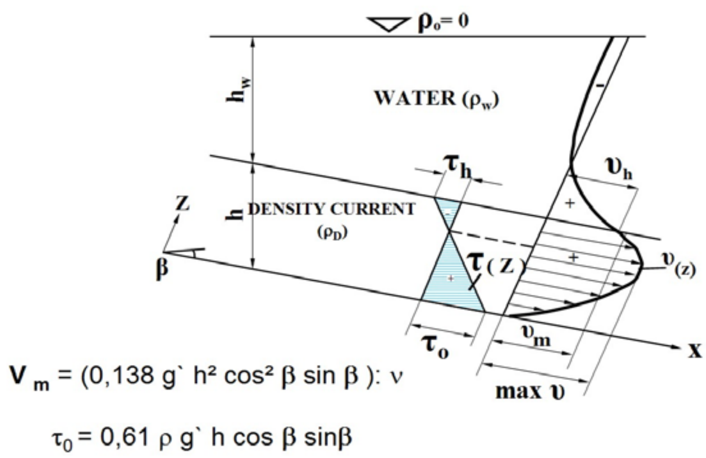


**Figure 7. Velocity and shear distribution in density current.**

The electrically driven pump has a diameter at the suction side from 12 inch also; the permission given by the Federal Waterways Board allows 2 pumping hours per ebb tide, in total 4 pumping hours per day. The monthly production is around 48.000 m³.

During a test campaign in 2004 the fluid pump was surcharged with 4 TSHD- loads of in total 4.200 m³ dumped directly at it`s position. It could be shown that this fluid pumping system had the correct dimensions. It`s discharge increased up to maximal 130 g/l in suspension during that campaign whereby the pump motor was working far below his limit of capacity. A connected concentration measurement system stops the pump motor immediately in case of suspension concentrations less than 30 g/l. The main task of this fluid pumping system was:

1. removal of the fluidable mud out of the harbour; this mud can also be fluidised and conveyed to the pump sump by a little water injection dredger and
2. pumping back suspension clouds floating in through the lock together with ship traffic in order to avoid immediate settlement of this clouds.

The average flowing velocity of fluid mud formations and the shear stress distribution (Figure 7) which are sufficient for practical calculations are as follows:

$$v_m = 0{,}138\ g' * h^2 * \cos^2 \beta * \sin \beta * 1/ \nu$$

$$\tau_0 = 0{,}61 * \rho * g' * h * \cos \beta * \sin \beta \qquad \text{( Wurpts, 2005)}$$

with:

$v_m$ = maximal flow velocity
$\beta$ = angle of slope
$\nu = \eta / \rho$ = kinematic viscosity
h = water depth
$\tau_0$ = shear force between mud layer and bottom
$g' = (1 - \rho_w / \rho) * g$ = reduced earth acceleration
$\rho_w$ = density of the water;
$\rho$ = density of the fluid mud;
$\eta$ = dynamic viscosity

Using these formulas the mud in Leer`s harbour flows with a theoretical speed of 0,77 meters per second in the direction of the pump sump but after experiences and measurements in the basins of Emden harbour a more reliable practical speed is in the range of 0,30 m/sec. This difference is he result of the uneven, not straightlined morphology of the bottom of the harbour.

As the harbour in Leer has no connection to the hinterland all losses of water caused by locking of ships (averagely 30.000 m³ per day) have to be replaced with water taken out of the adjacent river Leda. Opening the lock in order to fill this lack of water is possible 37 minutes per tide only. During this short time the water level in the river Leda is higher than the level in the harbour. Filling up the water level in the past within that short time caused intrusion of a lot of sediments.

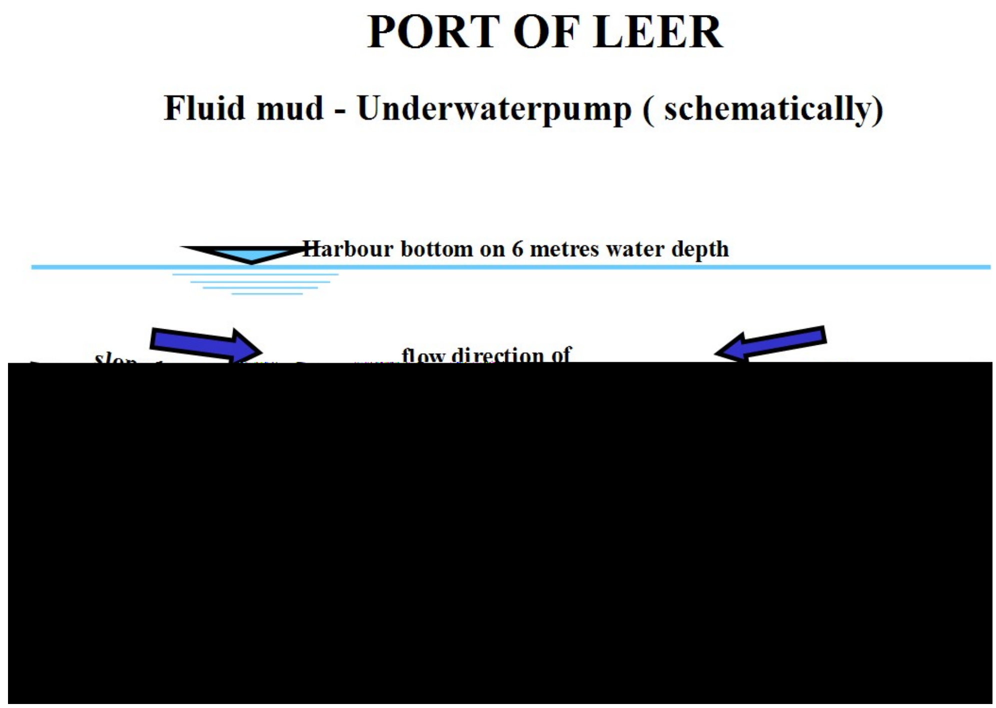


**Figure 8. Port of Leer, setup of underwater pump.**

Therefore in addition to the fluid system a bypass system was installed. The conduit has a diameter from 1,2 meters with an integrated water pump which can flush water into both directions (Figure 8 ). This bypass system pumps water directly into the river without using the lock in case of a too high water level in the harbour basins and – more important – it transports water with a high oxygen content from the river into the harbour as soon lack of oxygen occurs.

Both pumps are started and stopped by the sluice master. Before installation of this fluid – and bypass system the town community spent 0,4 mio € annually for maintaining harbours depths. The costs for employment of this system amounted to 1,3 mio € in total.

## CONCLUSIONS AND RECOMMANDATIONS

1. Instead of a production contract based upon cubic metres and fixed unit prices a lump sum contract should be chosen in order to allow selective and remedial dredging.
2. In case of echo sounding 12 kHz are recommended.
3. Density and viscosity are not parameters for determination of navigability in muddy areas.
4. Yield stress is the most suitable parameter for determination of the nautical depth.
5. Testing the navigability by application of the ADMODUS Ultrasonic Sonar System.
6. Application of this system is possible in other ports also.

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