NEW APPROACH OF DEEP SEA DREDGING

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ABSTRACT

A new approach of trailing suction dredging is presented. This approach is especially useful for dredging at depths over 100m.

Normally a Jumbo Trailing Suction Hopper Dredger is used for dredging at depths of more than 100m. This requires a large investment. The expensive dredging equipment is only used while dredging. This equipment is mainly “dead cargo” when sailing to the place of delivering the sand. Our new approach requires a significantly lower investment. As the equipment is used continuously, idle time is decreased. Separation of the dredging and transport system gives the owner an optimum use of the invested capital resulting in lower cost per m³ dredged material. The dredging depth is independent of the length of the trailing suction pipe and thus the length of the ship, unlike a normal Trailing Suction Hopper Dredger. The barges and Tugs for transporting the sand can be rented to reduce the direct investment costs.

Our approach consists of modular dredging equipment placed on e.g. a standard Platform Supply Vessel. Using the dredging equipment on this vessel, standard barges are continuously supplied with sand while sailing along the Platform Supply Vessel. The dredging equipment consists of a submersible dredging unit connected to a hose. This dredging unit is suspended by wires from the Platform Supply Vessel. The application of the dredging unit is like a normal Trailing Suction Hopper Dredger.

An extensive research project is initiated with recognized technology institutes as MARIN and the TU-Delft. Several scale model tests are performed at MARIN. Another test was performed at TU Delft to investigate the transport of sand/water mixture through a hose stored on a reel.

This new concept is a reliable, inexpensive system to dredge at sea at great depths over 100m.

Keywords: Dredging at great depths over 100m, submersible dredging unit, hose on reel, continues process.

INTRODUCTION

Sand winning on land is getting more and more difficult. A solution for this is to win sand from the bottom of the sea. The sand near the coast is getting scarce, so it has to be obtained from greater depths. Sourcing of sand is not the only dredging activity at great depths, also dredging trenches for pipelines, winning sand for land reclamation and mining is done at deep sea. The main problem is the cost for dredging at these depths.

Due to the great depth, the length of the trailing suction pipe is equally long. The length of the ship must be adequate to accommodate the trailing suction pipe while sailing. This results in the use of Jumbo Trailing Suction Hopper Dredgers for dredging at depths of more than 100m.

These ships require a large investment and the running costs are considerable. The expensive dredging equipment, such as dregge pump, ganttries and trailing suction pipe, is only used while dredging. As the sand has to be transported the dredging activity is not a continuous operation. The dredging equipment is mainly “dead cargo” when sailing to the place of delivering the sand, which reduces the amount of sand which can be carried.

LAYOUT OF OUR NEW APPROACH

To reduce the length of the ship, the length of the trailing suction pipe had to be made independent of the dredging depth. The solution for the trailing suction pipe, consists of a submersible dredging unit, connected to a hose,
through which the sand is transported. The hose can be rolled on and rolled off a storage reel placed on deck, hence a Ro-Ro Deep Dredge system.

The submersible dredging unit consists of a drag head, suction tube, an electrically driven dredge pump and electrically driven jet water pump. This dredging unit is suspended by wires. It is lowered to the required dredging depth by winches, just as a normal Trailing Suction Hopper Dredger does.

Another goal was to have a modular dredging system, which could be placed on a commonly used, therefore commonly available ship. The ideal ship proved to be the Platform Supply Vessel. This type of vessel has a sufficiently dimensioned flat deck to accommodate the dredging equipment. All auxiliary dredging equipment, such as engines and electronics, is containerized. With the use of twist-locks this equipment can be fitted effortlessly on the Platform Supply Vessel.

To optimize the profitability of the investment, the operating time of the equipment has to be maximized. Separation of the dredging and transport system gives the owner an optimum use of the invested capital resulting in lower cost per m³ dredged material. The barges are loaded by the delivery spreaders of the Platform Supply Vessel while sailing alongside. These barges and tugs for transporting the sand can be sourced temporarily from the local market to reduce the direct investment costs. This resulted in a system as shown in Figure 1.

**Figure 1. Dredging system.**

**RESEARCH**

To study the feasibility of the system an extensive research project has been undertaken with approved technology institutes as MARIN and the TU-Delft. There were four areas which required research:

1. Behaviour of the submersible unit while dredging
2. Loading of the barges along side the Platform Supply Vessel
3. Construction of the hose
4. Behaviour of transporting sand through a reel

Damen Dredging Equipment’s partner Trelleborg is responsible for the research regarding the properties of the hose. For assessment of the dynamic behaviour of the submersible unit, numerical simulation studies as well as scale model tests have been performed. An extensive model validation was carried out by IMOTEC.†
BEHAVIOUR OF THE SUBMERSIBLE UNIT WHILE DREDGING

To get a first impression of the behaviour of the ship some numerical simulations were conducted by MARIN. Seven locations including Kuanta area (Malaysia), Skagerrak area (North sea) and Gulf of Biscay area (Atlantic Ocean) were selected to simulate. The wave statistics have been collected from the nearest available point (source: ECMWF and/or NOAA) and used for the operability analysis.

![Figure 2. Example of wave statistics.](image)

The ship motion characteristics, the prevailing wave climate and the maximum tolerable behaviour govern the performance of the ship. This is related to criteria for human comfort and for safety. The locations of the points of interest are: Bridge, Working deck at aft peak, Working deck aft and the hoisting wires. The study showed that the most demanding areas of operation are the Scotland and Bretagne area. While dredging a downtime of 13% is expected. In the other areas the vessel is nearly 100% operable.

With multi-body simulation aNySim the following forces and motions involved were predicted: Propulsion, movements of vessel, movements of drag head and forces in the hoisting wires. These predictions were used to size the sensors and propulsion used at the scale model tests.

FIRST SET OF SCALE MODEL TESTS

To study the behaviour of the submersible unit while dredging, scale model tests were done by MARIN. The main objectives of the model tests had been defined as follows:

- To test the feasibility of the concept.
- To provide average required thruster force for track control of the flexible pipe dredger, both when the drag head is resting on the seabed and when hovering about 5m above the seabed.
- To provide motions of the vessel in operational conditions.
- To provide line loads in the control lines for the drag head.
- To provide the forces acting on the hose.
- To provide more insight to the limiting sea states.

On the drag head weights were placed to simulate the suction force. The submersible unit was fabricated as shown in Figure 3.
Also the flexible hose was modelled. The required properties were given by Trelleborg. The hose is shown in Figure 4.

The main conclusions after the tests were:
- The model tests showed a working concept for ship speeds between 2 and 4 knots and Hs up to 3 to 4 meters.
- Analysis of the model tests in waves indicate that the limiting operational dredging conditions are beyond levels restricting the workability, without taking into account the offloading part.

LOADING OF THE BARGES ALONG SIDE THE PLATFORM SUPPLY VESSEL

The first scale model tests gave new insights for optimization of the layout of the submersible unit. For instance the connection of the hose was altered and the suction tube of the unit was lengthened. This new layout was incorporated in the second series of scale model tests conducted by MARIN. Comparable environmental conditions were used as during the first set of model tests, which were based on the Metocean® data.

Loading the barge is accomplished by connecting the two ships together, then filling the barge with systems delivery spreaders. The mooring of one ship to another was tested earlier, and proved to be practical. The dredging concept consists of three vessels, which are a tug, barge and a standard platform supply vessel. The three scale models sailing along each other at the MARIN test facility are shown in Figure 5.

Various model tests were performed to test the offloading concept and possibly to improve this concept. The main objectives of the model tests had been defined as follows:
- Establish the feasibility of the offloading concept.
- To provide motions of the vessel and the barge in operational conditions.
- To provide line loads in the side by side mooring lines.
- To provide fender loads.
- To provide relative motions between the vessel and the barge at different locations.
- To provide more insight to the limiting sea states.
The manoeuvring tests were carried out with the barge moored PS (Port Side) to the dredging vessel in loaded conditions in calm water and irregular waves. During the manoeuvring tests the barge was the leading vessel.

To establish the limiting conditions during which the offloading could be safely performed in total forty two (42) wave tests were carried out. During these tests the barge was moored PS to the dredging vessel under realistic and harsh environmental conditions. Some tests were repeated with the dredging vessel leading instead of the barge.

The main conclusions after the tests were:
- Workability of the barge in loaded condition is hardly ever restricted by 1.5m waves. An exception to this is the bow (quartering) conditions, when the dredging vessel is placed at the windward side of the barge. Above statement is based on the criteria for the permissible maximum mooring line and fender loads. However, the maximum tolerable line load can be increased by using a different type of line, and thus improving the downtime.
- On average the preferred relative wave direction is having the dredging vessel placed at the leeward side of the barge.
- For the tested conditions the turning circle to PS is between 6 and 10 times the ship length. The turning circle to SB is between 2 and 4 times the ship length. Based on these figures it follows that the manoeuvrability to SB is satisfactory and to PS moderate.

**CONSTRUCTION OF THE HOSE**

Trelleborg was asked to develop a hose applicable for the new dredging system. At first glance it was possible to develop a hose which had to fulfil the following criteria:
- Allow storage of the hose on a reel
- Withstand a pump pressure 10 bar
- Allow for winding up and off reel while dredging
- Limited container-size (Length of 11.8m)

After the first trials at MARIN, the forces involved were better understood and a final design could be made. Other criteria were added:
- Relatively limited weight of hose
- Smaller flange diameter smaller than outer diameter of hose

A few aspects had to be reviewed. Due to of bending of the hose while using a reel as storage of the hose, the steel sections had to be as short as possible. Also the possibility of flattening the hose while winding it during dredging had to be prevented. This meant that additional spiral inlays had to be foreseen.
Because of the forces applied to the hose the composition, quantity and directions of the layers of the hose had to be investigated very carefully. The forces involved indicated that the layers used had to be tough.

With all these criteria a final design was made, called the Subsealine. Two hoses were made for testing purpose. With the test hoses the physical properties like Stiffness (EI), Force-length diagram and fail force were determined. A test can be seen in Figure 6.

Also a Vortex-Induced Vibrations analysis of the flexible hose was committed. When a cylinder is placed in a cross flow, a flow field will develop that depends on the flow velocity, the geometry and the surface roughness. The vortex-shedding causes the pressure on the body surface to oscillate. As a response of this oscillating pressure, the structure vibrates and this phenomenon is called Vortex-Induced Vibrations (VIV). In Figure 7 is the pressure distribution due to vortex-shedding shown.

![Figure 7. Pressure distribution around the cylinder changes due to vortex-shedding.](image)

Resonant type VIV happens when the vortex shedding frequency becomes close to the natural frequency. At “lock-in”, the otherwise uncorrelated vortex shedding synchronises over a large section of the risers, thereby dramatically increasing the cross flow excitation and VIV response. Lock-in also leads to vortex-induced vibrations over a much wider range of oscillation frequencies than would be expected for normal resonant behaviour. The fatigue damage can be extensive, due to the high frequency of the stress variations and the concentration of the maximum stress variations in the anti-nodes of the excited modes.

The VIVARRAY software used allows for three-dimensional analysis of rigid drilling risers, free standing risers, steel catenary risers and flexible risers.

The analysis was made for dredging at -110m with a velocity of 2, 3 en 4 knots. The flexible hose should be designed for fatigue resistance of 1.5e6 cycles per year, with a cycle loading of 34.6 kNm amplitude in the anti-nodes. This was not a relevant design issue, as wear is much more relevant.

**BEHAVIOUR OF TRANSPORTING SAND THROUGH A REEL**

A study on the behaviour of transporting sand through a reel has been done at the TU Delft. A drawing of the test facility is shown in Figure 9. A hose with an internal diameter of 200mm and reel (See Figure 8) were made to measure the pressure losses while transporting sand. Moreover the critical velocity and various methods to get the settled sand in motion after clogging the hose were investigated. Another aspect was to determine if a standard turning gland was suitable as rotating connection in a reel.
Figure 8. Arrangement of reel with hose.

The test was conducted with two types of sand (D50 of 330μm and of 600μm) and different densities of the sand-water mixture (being 1165, 1330, 1495kg/m³). For the grain distribution (see Figure 10). The density was measured by a U-tube. The velocity was measured by an electromagnetic velocity meter. Between the sections of the hose, pressure transmitters were installed. The hose consisted of 5 sections of 7.44m length each. This calculated length coincides with the circumference of the reel to ensure that the pressure transmitters were positioned at the same height. All measurements were done in two positions, the rotating axis horizontal and vertical, to determine the best solution. All measurements were logged with 1 mps.

Figure 9. Test facility at the TU Delft.
The density of the mixture was controlled by releasing sand from the depot into the pipeline. Sand would also be extracted from the mixture by an overflow system in the depot. Hence the desired density was adjusted accurately.

The velocity was adjusted by regulating the speed of the pump. For every situation (density, speed, grain size) the speed of the pump had to be adjusted. For regulating velocities below 3 m/s the velocity in the section containing the hose reel a shunt was used. Thus the section with the dredge pump maintained a high velocity, reducing the risk of clogging this part of the system.

The critical velocity of the hose on the reel, appeared to be between 2 – 3 m/s. This is lower than the critical velocity of a straight pipe, as shown in Figure 11 above. The reduction in critical velocity is more pronounced when the axis of the reel are horizontal. The reason for the lower critical velocity is the continues uphill and downhill stream in the hose on the reel. During the uphill stream a bed of sand will grow, which will be suspended again during the downhill stream. The mixture in the hose on the reel does not have the opportunity to settle. This means that a hose on a reel actually reduces the chance of clogging the pipe.

It was easy to get the settled sand in motion again, even if the sand had settled for 5 hours. The 3 solutions tested, which all worked well, are:

1. Just start the dredge pump to get the mixture in motion again.
2. Rotate the reel 180 degrees, and get the mixture in motion again by using the dredge pump.  
3. Unroll the whole hose off the reel, and get the mixture in motion again by using the dredge pump.

During the tests we discovered a unusual pressure peak just prior to the reel. See Figure 12. This pressure peak was most striking when there were a few windings (1 or 2). It also occurred with more windings at lower velocities and high densities.

![Figure 12. Pressure development in hose on reel horizontal.](image)

![Figure 13. Pressure development in hose on reel vertical.](image)

The pressure peak was more pronounced when the rotating axis of the reel was horizontal. Also the peak is at measuring point 5 instead of 6 (Figure 13). This pressure peak was also noticed by M.J.B. Cartigny\textsuperscript{x}. In a layered flow, with a stationary bed of sand, where the helical flow moves the bed of sand, the average velocity decreases, hence the pressure increases.

The resistance of the hose on the reel appeared to be less than in the case of a straight line. The resistance of the hose, when the rotating axis is horizontal, is less than in the case of vertical alignment. In all cases the pressure drop
was linear with the windings on the reel. A theoretical model for the resistance is still to be developed. The current models of bends were not applicable. The new model should incorporate the alignment of the winding of the hose.

After the test the conclusion was drawn that a standard turning gland can be used as rotating connection for the reel. With the speed and forces applied, no changes in temperature and leakage were measured. After disassembling the turning gland, no damage or wear were noticed.

The conclusion is that a reel is usable in a dredging application. The clogging of the hose is unlikely and easy to overcome. Also a turning gland is useable as hinge for the reel.

CONCLUSIONS

The research resulted in the following:

- Low downtime for the selected areas
- Accurate model for predicting forces and motions
- Special purpose subsealine hose developed
- Critical velocity on reel lower than in rest of system
- Design guidelines for Ro-Ro Hose Reel

The research substantiates that the Ro-Ro Deep Dredge is a reliable, cost effective system to dredge at important depths. The monopoly position of the Jumbo Trailing Hopper Suction Dredgers is challenged by the new Ro-Ro Deep Dredge system (Figure 14). The new dredging solution Ro-Ro Deep Dredge as presented here makes the Jumbo Trailing Hopper Dredgers not the only solution for sand wining projects at these depths. A new era has come, where the Ro-Ro Deep Dredge will flourish.

![Figure 14. Platform supply vessel as Ro-Ro Deep Dredge.](image)
REFERENCES


iv ECMWF: European Center for Medium range Weather Forecasting (www.ecmwf.int)

v NOAA: National Oceanic and Atmospheric Administration (www.noaa.gov)

vi aNySim: Analysis of multi body dynamics in dynamic positioning

vii Metocean: Metocean Services International (www.metoceanservices.com)

viii VIVARRAY software: VIV Analysis for Riser Array (Vivarray) programs were developed and are continuously improved through a continuous series of joint industrial projects (JIPs) of VIVA, Vivarray and New-VIVA. These programs have adopted a pragmatic analysis methodology based on experimental tests and rigorous structural modeling, and start to incorporate data from field measurements.


CITATION