Wild Dragon®
Developing a draghead for dredging *extreme* fine, hard packed aquatic soils

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Abstract: When the 12,888m³ trailing suction hopper dredger Xin Hai Long was handed over to the Shanghai Dredging Corporation (SDC) in November 2002, after having been tested successfully, it appeared unable to produce more than turbid water when dredging over an ***extremely*** unyielding bank in the Yangtze estuary. Although this bank could only be dredged by cutter dredgers before, for navigation reasons one preferred the approach channel to be dredged by hopper dredgers, which led to the try. In fact nobody had thought of such unusually fine (60 to 100 µm) hard compacted sand when the vessel's specifications were drafted. The wish to make dredging of this kind of soil also possible set in motion a process that ultimately delivered a new, patent pending trailer head with a new type of teeth and jet water supply, which made an efficient trailing dredging process possible.
A project group was formed by IHC Holland Merwede business units Parts & Services, MTI Holland and Dredgers. Subsequently MTI Holland could begin tests, with input from the projects they had already been busy with. While the laboratory tests were running, a completely new type of trailer head was being designed: the 'Wild Dragon®' draghead.
After the design phase the draghead was tested on board of the Xin Hai Long. While systematically adjusting settings, the new trailer head was tried at selected locations with densely compacted sand and clay. It produced beyond expectations: 50 to 100% improvement on earlier performance in the same soils.
In this paper the results of our research and development efforts that have led to this new type of draghead for dredging ***extreme*** fine, hard compacted aquatic soils will be presented. Also will be gone into consequences and benefits for design and exploitation of trailing suction hopper dredgers provided with this type of draghead, such as specific trailing force, loading process and wear.

keywords: Wild Dragon, draghead, jetting, cutting

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1 INTRODUCTION

When the 12,888m³ trailing suction hopper dredger Xin Hai Long was handed over to the Shanghai Dredging Corporation (SDC) in November 2002, it began its dredging career in the Yangtze estuary (China). The performance in the usual bottom soils was very well indeed, even in rather compacted clayey sands.
Given this experience, the thought arose to let this new dredger work on an extremely compacted bank in the Yangtze estuary. This had hitherto been the monopoly of cutter dredgers, but the obstructions that stationary dredgers and their outlaying anchors, floating pipelines, or barges ferrying on and off, present to navigation in Shanghai's crowded approach channels, make trailing suction hopper dredgers a much safer choice.

The limited production capacity of trailing suction hopper dredgers working in hard packed fine sands is a traditional dredging problem. Thus as was to be expected, Xin Hai Long initially produced barely more than turbid water when dredging over the unusually fine (60 to 100 μm), compact sand and clay bank. Clearly, an even more active trailer head was needed than anything in existence at that moment.
Hereto a project group was formed by several business units of IHC Holland Merwede. Subsequently MTI Holland could begin tests, this with input from research projects regarding dragheads they had already been busy with. Simultaneous with the laboratory tests a new draghead was designed. During this period, researchers and hardware designers mutually influenced each other's work, so that by creative trial and error a succession of draghead concepts was developed. Ultimately a concept was chosen, which was further worked out and fine tuned with ongoing laboratory research, before it was built.
In July 2004 trials with the new draghead could begin. While systematically adjusting settings, the new draghead, officially registered as the 'Wild Dragon®' draghead, was tried at selected locations with densely compacted fine sand and clay. It produced beyond expectations: 50 to 100% improvement on earlier performance in the same soils.

Following this introduction section 2 of this paper gives some background on why till recently the production of hopper dredgers working in hard packed fine sands was disappointing. Where after section 3 and 4 describe the laboratory and field tests that ultimately led to the new design trailer head for which a patent is in the pipeline. The final section 5 contains the conclusions and recommendations.

Fig. 1: 12,888m³ trailing suction hopper dredger Xin Hai Long.

2 BACKGROUND

The dredging of hard packed fine sands is traditionally the terrain of mechanical and stationary dredgers such as cutter, wheel, bucket or clamshell dredgers. This section gives some background on why the production of Trailing Suction Hopper Dredgers in this type of material is very limited.

In general a draghead loosens the soil by a combination of erosion, jetting and cutting. Hereto the energy for erosion is developed by the dredgepump, the jetting energy by the jetpumps and the cutting energy is developed by the vessel's propulsion through the suction pipe (Koert, Vercruijsse & Kramers, 2001).
Typically in hard packed fine sands the draghead has difficulties to penetrate the soil and tends to drag on top of the surface. In this situation ample dredgepump, jetting and propulsion power is available but still the production is disappointing.

The penetration of a draghead is the resultant of the (available) weight of this draghead and lower suction pipe on one hand, and the (required) excavation forces on the other, see also figure 2:

1. The moment $M_{available}$ forcing the draghead into the soil results from the weight (distribution) of the lower suction pipe and draghead together with the tension in the hoisting wire, current/drag forces, the weight of the mixture, the vacuum and impuls forces originating from the mixture flow.
2. The moment $M_{required}$ forcing the draghead out of the soil results from the excavation forces.

It is the equilibrium of the available and required moment around the cardan that determines how thick a layer one can excavate. Typical for hard packed fine sands with its characterising low permeability are the relatively large (required) excavating forces (Miedema, 1987). Given the equilibrium of available and required moment these large excavating forces logically result in a limited penetration of the draghead teeth.

With the desire to have more control over the process of slurry formation, and herewith the slurry's density, a recent trend in the design of dragheads is to rely less and less on erosion (as in Californian type dragheads). Instead one nowadays relies more and more on the controlled use of jetwater in combination with a carefully chosen cutting system (as in excavating 'active' type dragheads).
However, erosion has very little effect on hard packed soils and as we learned from above the teeth of excavating 'active' type dragheads have difficulties in penetrating this type of soil. Traditional options to improve the production of both California type as well as excavating 'active' type dragheads are:

- increase the power available for the vertical oriented jet nozzles in the heel of the draghead, and/or
- in the case of an excavating 'active' type draghead increase the weight.

Practical experience proves that these options work well in medium sized sands. However, in soils with an extreme low permeability like hard packed fine sands the results of both options are disappointing. Clearly new ways have to be found to improve the production of hopper dredgers working in these types of soils.

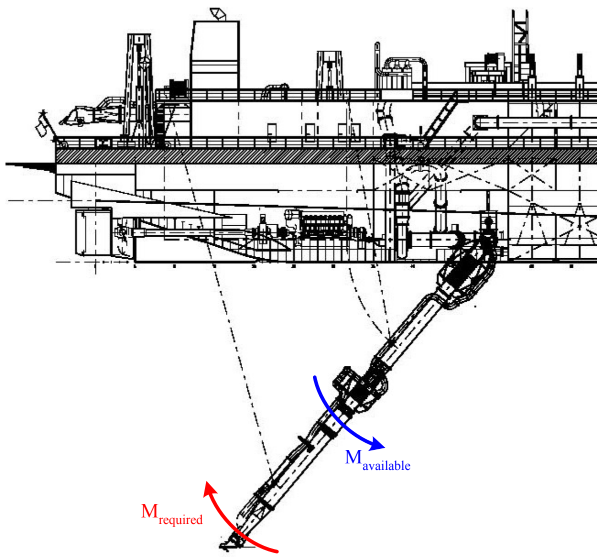

Fig. 2: The equilibrium of available and required moment around the cardan.

3 LABORATORY TESTS

Section 2 illustrated why conventional California and Excavating type dragheads have a limited production in hard packed fine sands. Obviously new solutions had to be found.
As first starting point for these new solutions it was assumed that the primary lay-out of a draghead will be maintained. This based on the evidence that it works fine in normal circumstances. Next laboratory tests were conducted to investigate the various processes involved. Amongst others, the primary processes studied were cutting (by the teeth) and erosion (by the jets), the assumption being that the cutting process will remove material unaffected by the jets. Finally it is assumed that in densely compacted sands there is little erosion of material along the sides of the draghead.
As the timescale did not permit an extensive fully instrumented testing program, a slightly different approach was chosen. It was decided to test various theories and assumptions, from literature and practical experience, in a practical setup which would make it possible to gain insights into the processes involved.

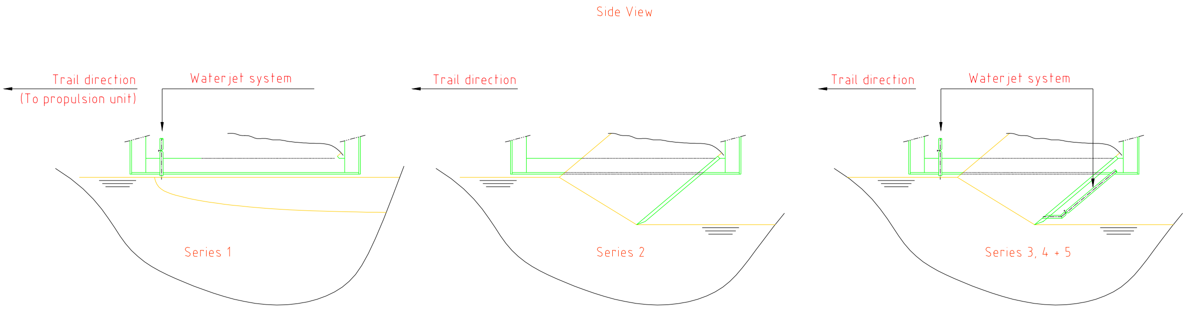

Fig. 3: Test setup – Schematic.

A small scale test setup was erected at MTI's research laboratory consisting of a flume filled with fine sand (d_{50}≈90µm) through which small scale models (1:10) could be towed. The sand was then compacted using a vibratory needle system. This to such a degree that the resulting SPT and permeability could be reasonably expected to approach that found in the Chinese banks. Based on a given excavation depth, tests were carried out according to table 1 to determine the efficiency of the various means of excavation.

Table 1: Test series, see also figure 3.

Series	Subject
1	Jetting (vertical)
2	Cutting (unassisted)
3	Cutting (jet assisted)
4	Jetting (vertical) + cutting (unassisted)
5	Jetting (vertical) + cutting (jet assisted)

At first a series of jet tests were carried out during which excavation profiles were observed (figure 4) and measured (figure 5 left). A significant observation was that the un-eroded material along the sides of the trench collapsed very slowly, if at all.

Fig. 4: Jetting in MTI's laboratory

Another very interesting, but unwelcome, observation could also be made. The profiles clearly showed that the time needed by the jets to achieve the required depths was greater than the time available (as defined by the trail speed and the distance between the heel of the draghead and the tooth position). This can be seen in figure 5(right). This means that the jetting system has only a limited effect, another solution has to be found for the rest of the material to be excavated.
Finally it was also observed that an increase of the stand-off distance of the jet (distance between soil and jet) led directly to a large reduction of the jet penetration. In practice, it will be necessary to limit the stand-off distance as much as possible.

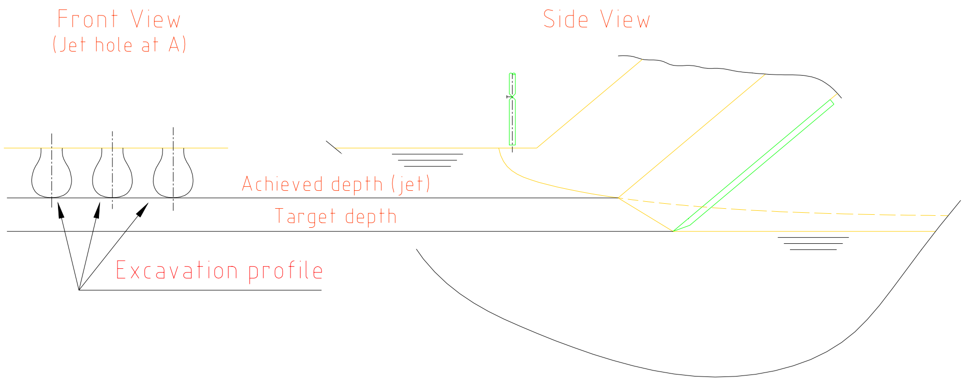

Fig. 5: (a) left and b (right)

The second series, unassisted cutting, was performed and confirmed earlier expectations. The teeth could either not penetrate the sand or, when positioned at a predetermined depth, were forced up and out. The cutting forces required were far in excess of the forces available. This compares very well with the onboard observations.

The third series were carried out with the same teeth used in the previous series. The only change was the addition of a jetting system that jetted water through the teeth into the sand. Results from these tests showed a significant reduction of the cutting forces. Instead of barely scratching the surface of the sand, the teeth were capable of penetrating the surface and excavating a layer of material.

The next step was to determine the efficiency of the various combinations. The tests combining the use of jetting and unassisted cutting, which is actually current dredging practice, showed that only a part of the material was excavated. Achieving the required excavation depths was not possible.

Finally, tests were carried out using both the jetting system and the assisted cutting process. The results were even better than expected! Not only was the required excavation depth achieved, it was actually exceeded on a number of occasions, sometimes resulting in clogging of the setup.

Summarizing the conclusions from the laboratory experiments:
Regarding the Excavating type dragheads with vertical jets in the heel:

- To significantly reduce cutting forces, the profile of jet excavations need to overlap in densely packed fine sand. However this use of jetwater is inefficient due to the excess water
- When the teeth are not able to penetrate the jetting has a limited effect due to stand off distance. In this case a controllable variable visor is needed to reduce this stand off distance.

Regarding the new design:

- Jetting through the teeth results in a significant improvement (reduction) of the cutting forces.
- The resulting ability to penetrate is such that a controllable variable visor is needed to limit the cutting depth.

These conclusions substantiated our hypothesis that by smartly using jet water at the right locations, at the right rates of flow and at the right pressure rates, one can significantly reduce cutting forces when working in dilatant materials like hard packed fine sands.

Next step in the process was to incorporate the results of laboratory experiments into the new design of the draghead. In other words: How to transfer jetwater from the manifold on the visor to the front side of the teeth?
To find the answer to this question a lot of tests were performed at MTI's laboratory, and by a practical trial and error method the ultimate design was chosen. Hereby points of attention were amongst others; the equal distribution of jetwater from the manifold towards the various nozzles (see figure 6, left hand side) and the sealing between tooth and adaptor (see figure 6, right hand side).

Fig. 6: Testing the jetwater distribution from the manifold and the sealing between tooth and adaptor.

Naturally the final design had to be "dredging proof". This means the design must be robust, not expensive and easy to replace, because basically a dredger is able to break everything.
The final design, which is already operational, consists of an adapted IHC 20CB adapter & tooth. The adapter is equipped with a jetwater-channel which is provided with a connector where a hose can be placed inside easily. The connector creates also the sealing between the adapter and the hose. In this way, jetwater is transported to the teeth without leakage. For this system a patent is pending.

Fig. 7: The final design in operation.

4 FIELD TESTS

The proof of the pudding is in the eating. From the 22nd of July 2004 to the 25th of July 2004 dredging comparative tests were done with the TSHD “Xin Hai Long” of Shanghai Waterway Bureau provided with both the new type - “Wild Dragon®” – draghead, see figure 8 and the existing IHC-Excavating draghead equipped with a conventional jet system (vertical orientated jets in the heel). In order to establish the result of all the laboratory tests performed and designs made, dredging tests were carried out comparing the dragheads in similar circumstances. Both dragheads had to show their performance in two different aquatic soils: hard, densely packed very fine sand and silt to clayey material.

During the dredging tests parameters like penetration depth, jetwater pressure, jetwater flow and trailing speed were varied in order to analyse the penetration and the relation between the cutting forces and production.

Goal for the field tests was to substantiate the results from the laboratory tests, namely:

- An improved penetration. Given the equilibrium on the suction tube a reduction of the cutting forces leads to an improved production
- A reduction in cutting forces when using the Wild Dragon® draghead;
- An improved production.

Fig. 8: The Wild Dragon® draghead showing its teeth and jetwater system.

Penetration
The penetration of the draghead was found by comparing the calculated cutting production with the measured suction production. The cutting production is calculated by using the lower suction tube angle, the visor angle and the trailing speed. The suction production was measured by using the on board velocity and density meters. When both the calculated cutting production and the suction production are equal it can be concluded that the draghead has fully penetrated the soil from heel to teeth and that there are not too many losses. However, when the calculated cutting production is much higher than the suction production, it can be concluded that the visor does not fully penetrate the soil and the draghead is lifted out of the ground.

When dredging in hard compacted sand for the Excavating Draghead the difference between calculated cutting production and measured suction production is high. This can be seen in figure 9. This implies that the Excavating draghead cannot penetrate the ground. This assumption is supported by the low mixture densities and high mixture velocities indicating the draghead is not connecting to the bottom properly.

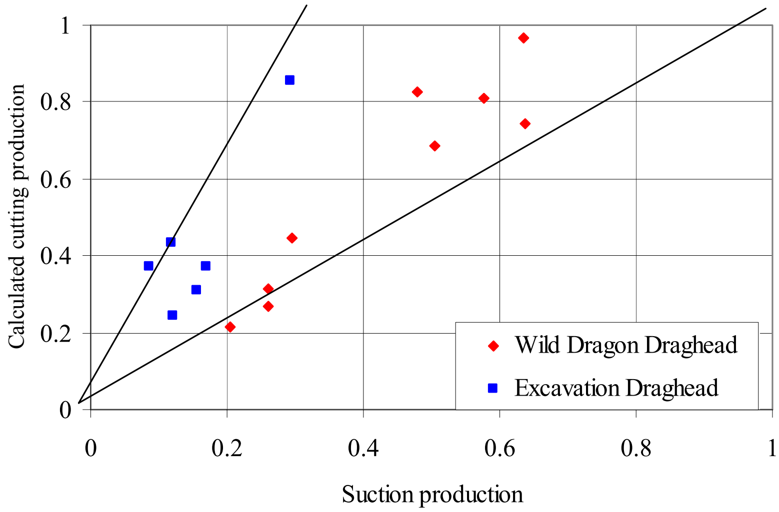

Fig. 9: Indication of penetration (hard packed sand).

Cutting forces and thrust power
The fundamental principle behind the increase in production is a change in the cutting forces. To substantiate this principle the relation between thrust power and suction production was determined. This for the Excavating type as well as the new Wild Dragon® type draghead, see figure 10.
Figure 10 clearly illustrates that when dredging hard packed soil the new draghead demands relatively less thrust power than the Excavating draghead at a certain cutting depth. Besides, the new draghead is not limited in increasing the cutting depth, enabeling the trailing suction hopper dredger to increase the cutting production and use its full thrust power for the purpose of excavation, without the draghead being lifted out of the ground.

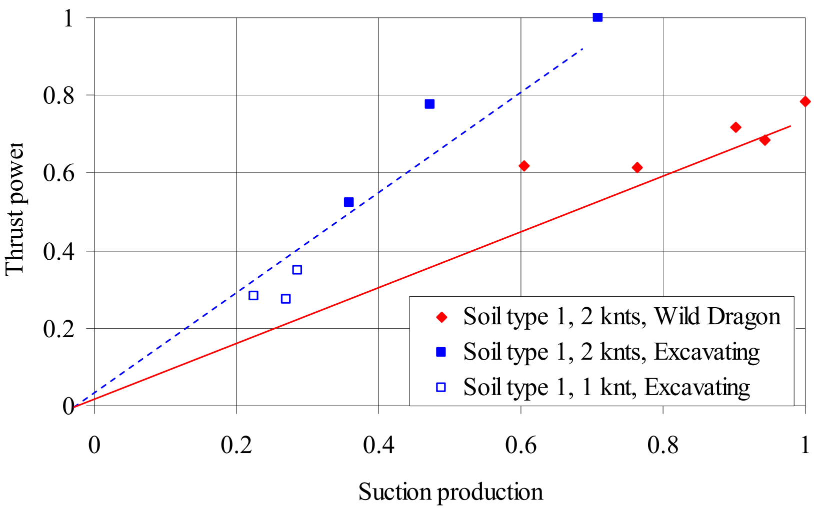

Fig. 10: Thrust power versus suction production.

Comparing production

The improvements in cutting forces and penetration lead to an improved production. This improvement is illustrated clearly in the timeplot shown in figure 11 and on the display of the dredgemaster shown in figure 13 (see next page). From the measurements a difference between both dragheads showed an improvement in the average production of 60% in and up to 100% in hard compacted sand.

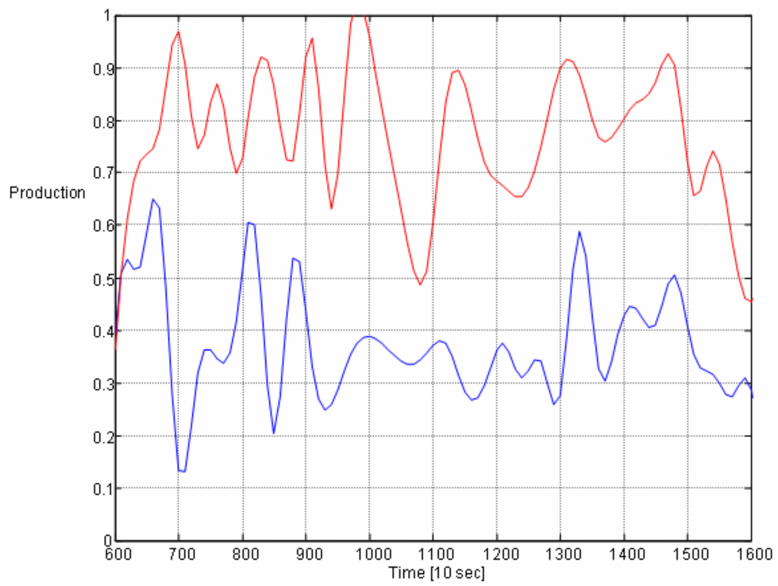

Fig. 11: Time plot of the suction production.
The lower line is the excavating type draghead, the top line is the Wild Dragon® type draghead.

Besides this improvement in production a maybe even more important improvement in the density was found. The new draghead dredged with a stable relatively low flow and a high density. When dredging fine sand this combination has an important influence on the settlement of the fine sand in the hopper leading to an even more efficient loading process, resulting in lesser overflow losses, a more effective use of the hopper's loading capacity and a significant reduction of the loading time (van Rhee, 2002). For illustration:

- when working with the Excavating type draghead it takes about 169 minutes to load the hopper (up to a 75% effective hopperload) with a mixture velocity of 8 m/s and a mixture density of 1,150 kg/m^3, whereas
- when working with the Wild Dragon® type draghead it takes about 78 minutes to load the hopper (75% effective hopperload) with a mixture velocity of 4.5 m/s and a mixture density of 1,400 kg/m^3.

The Wild Dragon® type draghead takes thus less than half the time to load the hopper. Naturally this reduction in loading time will result in an overall reduction of the cycle time and therewith an improvement of the overall production rate as illustrated in figure 12. This figure 12 shows from left to right the time taken for: sailing (laden), dumping, sailing (empty) and loading the hopper.

Finally it has to be noted that it is well known that working with relatively low velocities results in great improvements regarding the power and fuel consumption of pumps and the wear of lines and pumps. The use of a Wild Dragon® type draghead thus not only raises production but also lowers operating costs.

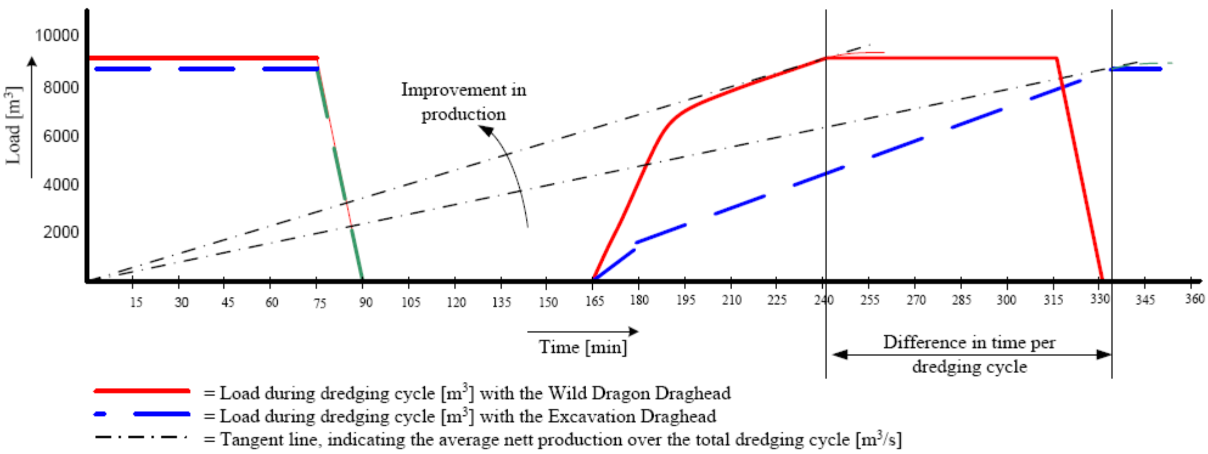

Fig. 12: Time plot of the total dredge cycle.

5 CONCLUSIONS

This article describes the process from a traditional dredging problem to the found solution. The problem being the limited production capacity of trailing suction hopper dredger working in hard packed fine sands, the solution being the Wild Dragon® type draghead.
This patented new type draghead achieves its higher production rates by a combination of improved penetration and reduction of cutting forces. A production that is achieved at a relatively low mixture velocity and high mixture concentration leading to shorter loading times, less fuel consumption and lower wearing rates.
All in all it can be concluded that the Wild Dragon® type draghead significantly lowers the operating costs of a trailing suction dredger working in hard packed fine sands.
What thus began as traditional dredging problem has now been turned into a major advance in trailer dredging. Possibly, other kinds of soil may require different equations, but the idea is very promising and a clear example of symbiotic client-shipyard cooperation.

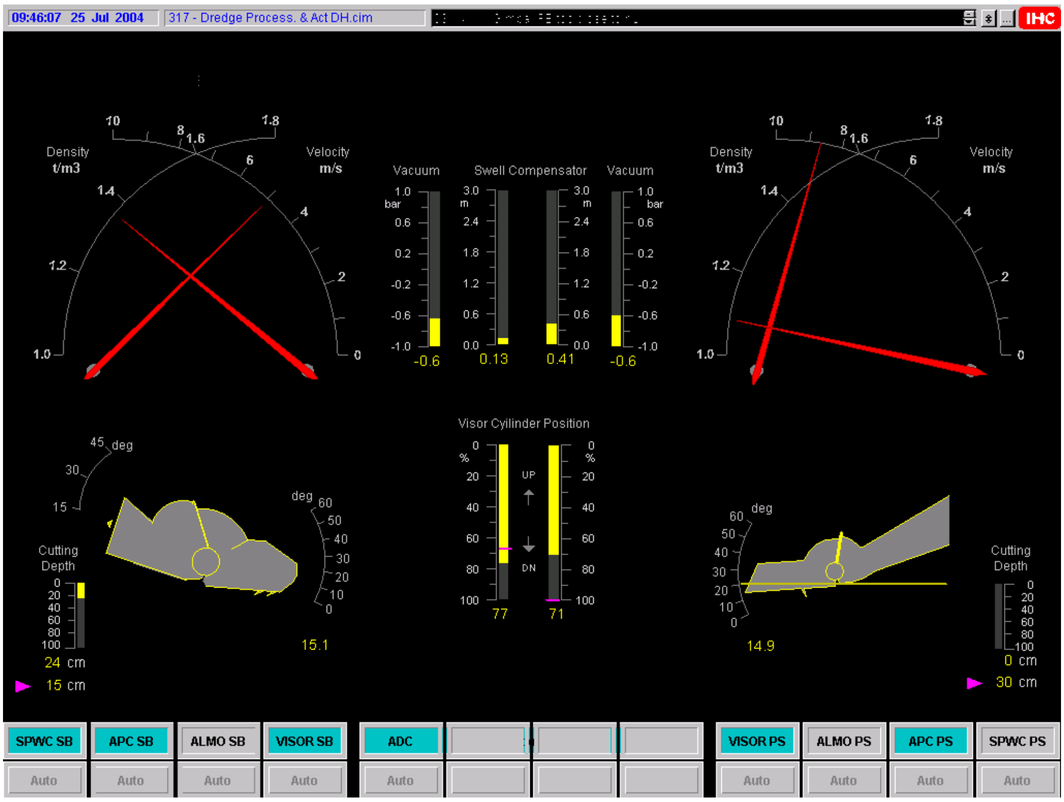

Fig. 13: The display of the dredgemaster, showing:
On the left hand side the indicators for the Wild Dragon® type draghead.
On the right hand side the indicators for the Excavating type draghead.

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