APPLICATION OF CSD’S IN DEEP WATER: ARCHIMEDES VS NEWTON

G.A.P.L Teheux[1]

ABSTRACT

While plain suction dredgers and the newest generation trailing suction hopper dredgers in the market are equipped to work at great dredging depths, the cutter suction dredgers (CSD’s) in the market stay behind. In dredging practice most CSD’s are capable of dredging up to maximum depths 100ft. Only few CSD’s are capable of dredging deeper than this. However the demand and necessity to dredge deeper is only increasing.

When the general applied concept of a CSD is maintained, dredging deeper at least means a longer ladder construction. One of the main problems with ladder extension in a conventional way is that in order to carry all the loads (increase of weight with increasing length) it has to be reinforced. Furthermore in order to hoist and lower the ladder, higher winch power or more winches are necessary. There is no need to explain that a substantial cost-increase is a result.

In an alternative concept, the ladder is constructed in such a way that a substantial part of the total load on the ladder is eliminated. The buoyancy law of Archimedes is the key in this concept. As a consequence a substantial part of the own weight of the ladder is eliminated, hence the stresses in the ladder will be lower. In the context of a long ladder construction (as is the case in deep dredging), the gain compared to a conventional ladder construction can be imagined.

This paper describes the main features, technical explanation, advantages and disadvantages of the alternative CSD concept.

It comes out that this concept is a very cost effective and flexible solution for dredging at great depths, especially for the application of dredging deep at inland waters (e.g. sand and gravel pits, alluvial mining).

Keywords: deep dredging, Archimedes, transportable, extendible, sand and gravel

INTRODUCTION

While plain suction dredgers and the newest generation trailing suction hopper dredgers in the market can work at depths of 300 ft, most of the cutter suction dredgers are capable of only dredging up to 100 ft.

One of the criteria that make dredging deeper more expensive is the higher purchase price of the dredger. If we focus mainly on the construction (design) of the dredger we see the following. When the ladder construction is lengthened, in order to dredge deeper, the influence of the own weight of the ladder compared to the other forces working on the dredger increases rapidly. As a consequence the necessity of reinforcement increases with length, and the total cost will grow fast. In addition to extra construction costs, bigger hoisting winches are necessary to carry this increased ladder weight.

In order to make a cost-effective dredger, an alternative concept is discussed. In this concept the influence of the own weight of the ladder on strength and costs is nullified.

The focus in this paper is to describe the main differences in this concept compared to conventional CSD's. This difference can mainly be found in the construction of the dredger. Since the dynamic behavior of the concept will almost be the same as for a conventional CSD, it will (though very important for the dredging process) not be discussed in this paper.

[1] Asst. Project Manager and R&D Coordinator, VOSTA LMG, Klaprozenweg 75[e], 1033 NN Amsterdam, The Netherlands, Tel: +31-20-4936666, Fax: +31-20-4936670, teheuxg@vostalmg.com

In order to explain the main features of the concept, some important basic parameters for the design of a CSD are discussed in chapter 2. In chapter 3 the consequences of ladder extension in a conventional way are described. In order to deal with some of the difficulties when dredging deeper with a conventional CSD, an alternative concept is presented and discussed in chapter 4. Finally in chapter 5 it is concluded that the alternative concept is a cost effective alternative for dredging deeper with a CSD.

DETERMINATION OF THE MAIN DESIGN CRITERIA FOR A CSD

Focusing on the construction of the CSD, all forces working on it during the dredging process have to be determined, in order to construct a CSD with sufficient strength and stiffness. Some of the main forces necessary for the design are discussed briefly in this chapter.

Cutting forces

The cutting forces resulting from the excavation of soil are determined by the soil characteristics together with the desired production (assuming the cutter head geometry fixed) (G.A.P.L.Teheux 2002). When these two are known, the necessary cutter power can be determined and basically the strength requirement for the construction of the dredger is determined. That is, all main forces (Figure 1) necessary for achieving that production in a certain soil are determined

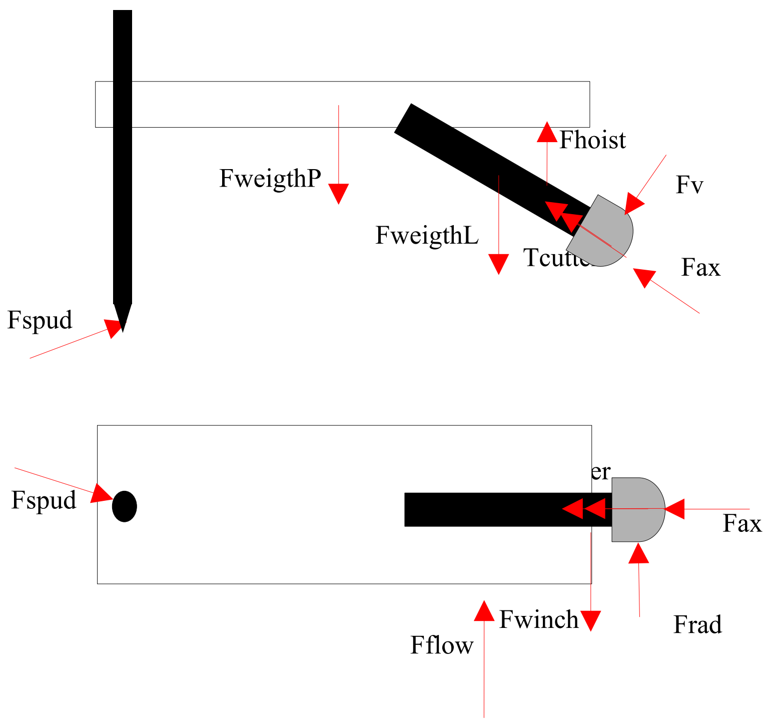

Figure 1: The main forces working on a CSD

Due to the complex shape of a modern cutterhead, and the non-linear behavior of the cutting forces, exact determination of these 3D cutting forces is difficult. Assuming linear cutting theories and some rules of thumb, for design purposes the following relationships are valid for determination of the cutting forces (W.J. Vlasblom 1998).

Taking the cutter torque as a starting point:

$$T_{cutter} = \frac{P_{cutter}}{2 \cdot \pi \cdot n} \tag{1}$$

With P_{cutter} the cutter power, and n the cutterspeed

The radial cutting force F_{rad} is determined by:

$$F_{rad} = C_r \cdot \frac{T_{cutter}}{R_{cutter}} \tag{2}$$

The constant Cr in the above equation has the following values

$C_r \approx 0.6$	dredging sand
$C_r \approx 0.75$	dredging clay
$C_r \approx 1\text{-}1{,}5$	dredging rock

The winch force F_{winch} has to generate this force.

The 'vertical' cutting force F_v is determined by:

$$F_v = C_v \cdot \frac{T_{cutter}}{R_{cutter}} \tag{3}$$

The constant C_v in the above equation has the following values

$C_v \approx 0.9$	dredging sand
$C_v \approx 0.1$	dredging clay
$C_v \approx 1{,}5\text{-}2$	dredging rock

In over-cutting mode this force has to be generated by the weight of the ladder construction, and in under-cutting mode by the displacement of the dredger (via the hoisting wires)

The axial cutting force F_{ax} is determined by:

$$F_{ax} = C_a \cdot \frac{T_{cutter}}{R_{cutter}} \tag{4}$$

The constant C_a in the above equation has the following values

$C_a \approx 0.5$	dredging sand
$C_a \approx 0.3$	dredging clay
$C_a \approx 1\text{-}1{,}5$	dredging rock

Gravitational and flow forces

Besides the forces following directly from the excavation process, inertia, flow resistance and gravitational forces also work on the construction. The bigger (heavier) the total construction, the higher and more dominant these forces become for the strength and stiffness of the construction. (in comparison to the process forces).

The weight ($F_{weightL}$) of the ladder construction is guided to the pontoon via the hoisting wires (F_{hoist}) and hinges (F_{hinge},) where it together with the pontoon weight ($F_{weightP}$) is counterbalanced by the water displacement.

$$F_{weightL} = F_{hoist} + F_{hinge} \tag{5}$$

$$F_{weightL} + F_{weightP} = F_{waterdisplacement} \tag{6}$$

Flow resistance depends on the projected underwater surface (pontoon and ladder), perpendicular to the velocity (v) of the dredger (swing winces), and can be determined by the following relationship:

$$F_{flow} = \frac{1}{2} \cdot C_w \cdot (A_{pontoons} + A_{ladder}) \cdot \rho_{water} \cdot v^2 \tag{7}$$

Together with the radial cutting force F_{rad}, this flow resistance has to be generated by the swing winch force Fw.

$$F_{winch} = F_{flow} + F_{rad} \tag{8}$$

For completing the total force balance, the spud reaction F_{spud} force is necessary:

$$F_{spud} = \sum F_i \tag{9}$$

These are the most important forces for the basic design of the dredge as they are often used in engineering practice.

DESIGN CONSEQUENCES WHEN DREDGING DEEPER

When excavation at grater depths is required the construction becomes larger, especially the ladder construction. As already mentioned in chapter 2, the forces due to the dredgers own weight will become more decisive for the design of the dredge. Flow forces will also increase with increasing ladder length, however slightly decreasing the side winch speed will reduce this effect.

Focusing on the ladder construction: when the ladder length is increased by a factor two and the construction is kept the same, the total mass is also increased by the same factor. However the bending stresses in the material will increase with a factor 4. This means that eventually the ladder will collapse under its own weight, and lowering of the material stresses is necessary. In general this can be achieved the following ways:

1 By installing extra hoisting points on locations where the bending forces are too high. As a consequence extra hoisting winches have to be installed on the dredge to carry these loads. This of course has consequences for the costs (both material and additional equipment) of the ladder and hoisting winches.

2 Another option is reinforcement of the ladder by adding extra material into the construction or more specific, to put the material where it is necessary (more material in places with high stresses and less material in places with low stresses). There are lots of ways to accomplish this but the fabrication costs in will become higher, resulting in higher prices per ton of material.

3 Using other materials for the construction, with better stiffness and strength characteristics than standard construction steel. However also in this case, the cost per kg material will become very high.

Though a lot of other factors influence the costs and behavior of the dredge, it is clear that, only looking at costs for the construction, designing a dredge for great dredging depths increases the price of the dredge and as a logical consequence the costs per m3 of excavated material.

AN ALTERNATIVE CONCEPT[2]

In the previous chapter three methods of dealing with increased ladder length and its consequences where mentioned. All are very suitable methods when dredging at large dredging depths (long ladder construction) is necessary. For almost all conventional cutter ladders, one or combinations of the 3 methods are used to construct a long cutter ladder that has sufficient strength and stiffness.

The Archimedes solution

There is another way to overcome strength problems in case of lengthening the cutter ladder. That is eliminating the forces that cause the ladder to bend under its own weight. The solution can be found in one of the basic law of physics, knowing Archimedes' law of buoyancy.

Construct the ladder in such a way that its own (underwater) weight is compensated by the weight of the volume water that is pushed away. The easiest and cheapest way to accomplish this is to construct the entire cutter ladder of

[2] This patent pending concept is developed and optimized in close cooperation with C. Heuvelman.

standard industrial pipe elements connected to each other by means of closed (blind) flanges. This way every pipe part forms an enclosed space of air.

Looking at Figure 2, the ladder can be divided in two parts, knowing the cutter ladder after part, and the cutter ladder front part. On the rigid front part (triangular shaped), all the main dredging components are installed. On the after part the discharge pipe and necessary power supplies (electric our hydraulic cables and hoses) are led to the consumers (pump and cutter motor).

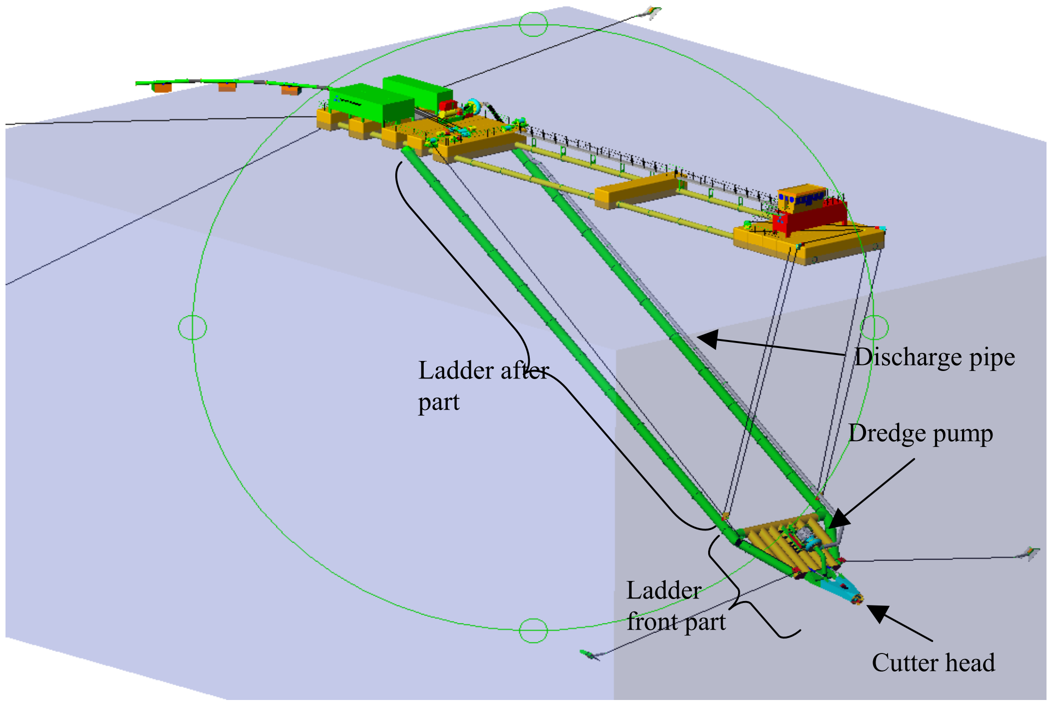

Figure 2: Arrangement of the alternative concept

The total ladder construction with all its dredging components assembled to it, is designed in such a way that the construction is floating, only constrained by the hinges on the after pontoon. In this situation all components mounted on the ladder are just above water level, so that there is easy access for assembly and maintenance. This is the situation before dredging (during build up).

In order to generate the weight necessary to get the ladder down and to compensate the forces as a result of the cutting process, ballast water is added in the pipe elements in the ladder front part ($F_{ballast}$). Simplified it can be said that the ladder after part is floating (F_{buoy}=$F_{weightL}$), so there are zero resultant forces and as a consequence no bending forces (Figure 3). The necessary normal force to keep the cutter in the soil, is concentrated in the ladder front part ($F_{ballast}$), and can be freely chosen by adding or removing water in the front part ballast pipes (Figure 4).

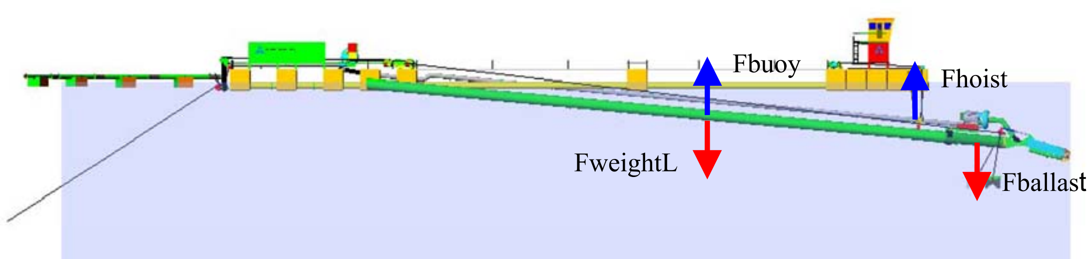

Figure 3: Simple force balance during ladder hoisting lowering

Lengthening of the ladder construction is achieved by adding extra (closed) pipe elements in the ladder after part The influence of the ladder weight as a result of ladder extension is nullified, hence great dredging depths are possible.

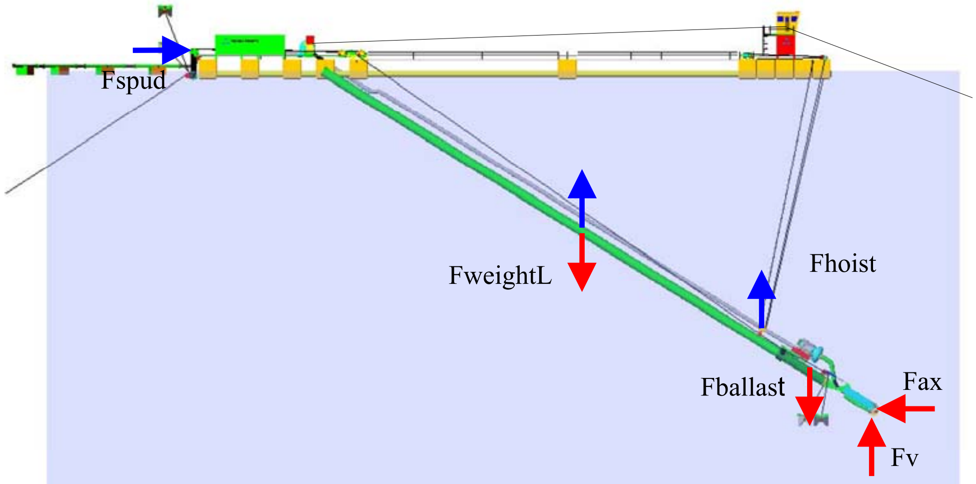

Figure 4: Simple force balance during operation

Cutter torque

In case of a conventional CSD, the ladder construction and the connection to the pontoons have to be strong and stiff enough, to resist the cutter torque. In this concept the ladder front part has a lot of strength in all directions, but the ladder after part has a low resistance against torsion, that decreases with increasing ladder length. This means that due to the cutter torque, the ladder wants to wind up (Figure 5).

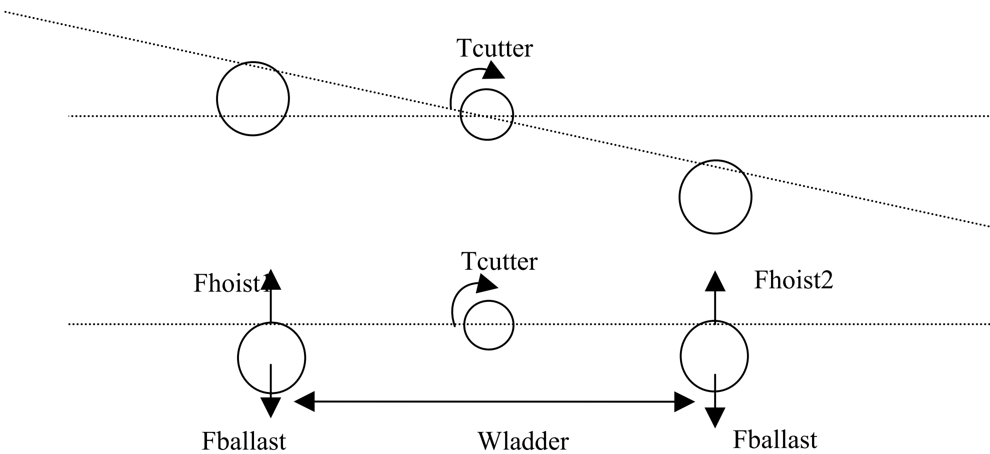

Figure 5: Wind up of the cutter ladder as a result of the cutter torque

However by means of the ballast water in the stiff ladder front part and the forces in the hoisting wires, this cutter torque (T_{cutter}) is controlled. Therefore the total width (W_{ladder}) of the ladder in relation to the ladder weight and cutter torque is important. For static equilibrium at all times the following relationship has to be fulfilled.

$$T_{cutter} + (F_{hoist1} + F_{ballast}) \cdot (\frac{W_{ladder}}{2}) = (F_{hoist2} + F_{ballast}) \cdot (\frac{W_{ladder}}{2}) \quad (9)$$

Again the majority of the forces is concentrated in the ladder front part, and is transported to the pontoons by the wire (hoisting and swing wires) system. As a consequence the loads acting on the ladder after part and the pivoting points remains low, nullifying the influence of ladder length.

Other forces

Regarding the other forces working on the dredge (see chapter 2) the same relations are valid, as for a conventional CSD, hence they will not be discussed in this chapter.

Additional advantages of the concept

The construction of the invention is for the major part composed of 'standard' obtainable and easy transportable construction elements, having the size and format of a normal container. This makes the dredge extremely suitable for short during projects (where assembly and disassembly time is an important cost driver), and for projects at difficult accessible locations (e.g. dams).

Finally, another important advantage of this concept is that the distance of the pump (installed on the ladder front part) relative to the soil to be dredged stays the same. The pump can always be placed at the end of the ladder. This means that when the ladder is lengthened no suction problems will occur.

CONCLUSIONS

It is proven that by using the basic laws of physics, a cost effective and flexible type of CSD that is able to work at great dredging depths can be designed. This is accomplished by using standard industrial steelwork which is easy obtainable all over the world. Furthermore when keeping all components within the limits of standard (ISO), freight containers the transportation and handling costs of the dredger will stay relatively low in comparison with conventional dismountable/transportable dredgers. This makes the concept also extremely suitable for projects of short duration at difficult accessible locations (e.g. dams). Assembly of the dredger can for the majority be accomplished by using standard tools.

NOMENCLATURE

Symbol	Description	SI-Unit
C_w	Flow resistance coefficient (dependent on geometry)	[-]
C_r	Empirical constant	[-]
C_v	Empirical constant	[-]
C_a	Empirical constant	[-]
F_{winch}	swing winch force	[N]
F_{rad}	Cutting force in radial direction	[N]
F_v	Cutting force in 'vertical' direction	[N]
F_{ax}	Cutting force in axial direction	[N]
$F_{weightL}$	Weight of the ladder construction	[N]
$F_{weightP}$	Weight of the pontoon construction	[N]
F_{hoist}	Force in the ladder hoisting wires	[N]
F_{hinge}	Force in the ladder hinges	[N]
$F_{waterdisplacement}$	Buoyancy force working on pontoons	[N]
F_{flow}	Force as a result of water resistance	[N]
F_{spud}	Reaction force on the spud (or wire system)	[N]
$F_{ballast}$	Force as a result of ballast water in ladder front part	[N]
n	Cutter rotational speed	[r.p.m.]
P_{cutter}	Cutter power	[Watt]
R_{cutter}	Mean radius of the cutter head	[m]
T_{cutter}	Cutter torque	[Nm]
W_{ladder}	Width of ladder construction	[N]

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