

6. The bucket dredger



Figure 6- 1

6.1. General Considerations

The bucket dredger is one of the mechanical dredgers.

A bucket dredger is a stationary dredger that is equipped with a continuous chain of buckets, which are carried through a structure, the ladder (Figure 6- 2). This ladder is mounted in a U-shaped pontoon. The drive of the bucket chain is on the upper side. The bucket dredger is anchored on six anchors. During dredging, the dredger swings round the bow anchor by taking in or paying out the winches on board. The buckets, which are filled on the underside, are emptied on the upper side by tipping their contents into a chute along which the dredged material can slide into the barges moored alongside. The chain is driven by the so called upper tumbler at top of ladder frame, which is connected either via a belt to the diesel or directly to an electro motor or hydro-motor.

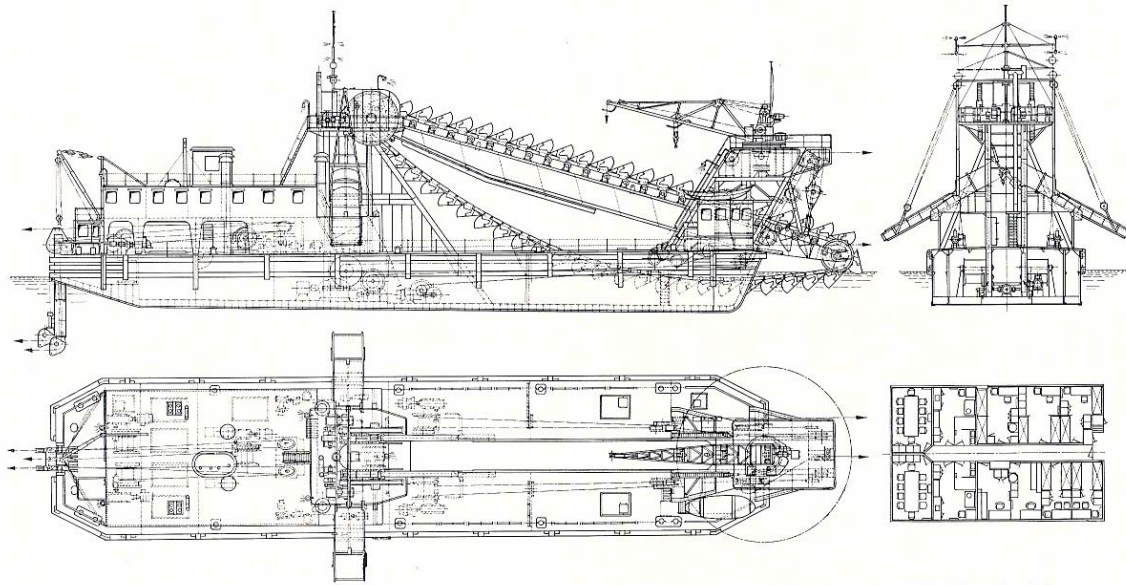


Figure 6- 2

Since 1960, bucket dredgers (also called bucket line dredge(r) or bucket chain dredge(r)) that were much used before the Second World War, have been almost entirely replaced by Backhoe dredgers or trailing suction hopper dredgers and cutter suction dredgers. The reason for this is that the bucket dredger, with its six anchors, is a big obstacle to shipping. Moreover maintenance costs are high and the bucket dredger requires many highly skilled operatives. But above all, their production has not kept pace with the increase in scale that has taken place in the suction dredgers.

6.2. Area of application

Bucket dredgers are only used in new or maintenance dredging projects when the initial depth of the area to be dredged is too shallow for trailing suction hopper dredgers and the distances involved are too long for hydraulic transport. For environmental projects, which require the dredging of 'in situ densities', the bucket dredger is suitable piece of equipment.

When dredging for construction materials such as sand and gravel, or for minerals such as gold and tin ores, bucket dredgers are still frequently used.

Bucket dredgers also come in a variety of types. For example:

- Dredgers with or without the means of propulsion (Figure 6- 3)
- Dredgers with a conveyor belt system (Figure 6- 4)
- Dredgers with equipped with pumps



Figure 6- 3



Figure 6- 4

The maximum dredging depth is highly dependent on the size of the dredger. There are dredgers with a maximum dredging depth of more than 30 metres. Such large dredgers the minimum dredging depth is often 8 metres. Dredging in shallow water is certainly not the strongest point of the bucket dredger.

Bucket dredgers can be used in almost every type of soil, from mud to soft rock. When rock has been fragmented by blasting, bucket dredgers are often used, because of their relative lack of sensitivity to variations in the size of the stones.

Bucket dredgers cannot be used in areas with waves and swell. Furthermore, because of the amount of noise they produce, in urban areas they are often subject to restrictions in relation to the working time or the permitted number of decibels measured at a specific distance from them.

The capacity of a bucket dredger is expressed in terms of the content of the buckets. The capacity of a bucket can vary between 50 and 1200 litres. Rock bucket dredgers often have a double set of buckets, the small rock buckets and the large mud buckets. This is in order to make better use of the power of the dredger and to widen the range of its use.

6.3. The history

From a historical point of view, the bucket dredger derives from the ‘mud mill’ that was invented in the Netherlands in 1589. In the earliest days this ‘mill’ was powered by a treadmill driven by manpower.

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In 1622 the drive system was improved and horses could replace the men. Around the beginning of the 19th century the first steam driven bucket dredgers came into existence.

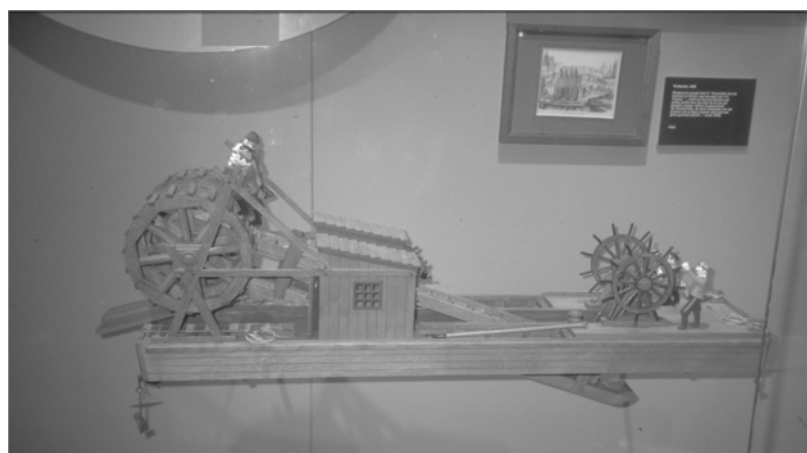


Figure 6- 5 MUD Mill Dredging Museum at Sliedrecht

Still, it was not until the second half of the century that steam dredgers had replaced those powered by horses. Over the course of the years preceding 1915, both the power of the dredgers and the capacity of the buckets increased. There was no further increase after that time. The great advantage of the bucket dredger is that it can attain a reasonable production in most types of soil from soft clay to soft rock.

For this reason, by about 1900 the bucket dredger had grown to be the most important type of dredger in Europe; a position that it maintained until just after the Second World War. The two last steam powered bucket dredgers were built in the Netherlands in 1956. At the end of the fifties and beginning of the sixties, because of the big increase in the tonnage of oil and ore tankers, large deep-water ports were needed. This led to large dredging contracts, which created a need for bigger production units that, moreover, could dredge to a greater depth. Increasing the capacity of bucket dredgers is no longer the solution because deeper dredging with larger buckets leads to a very heavy bucket chain. Stationary suction dredgers and cutter suction dredgers could solve this problem in a considerably less expensive way. Besides their bigger production capacity, these suction dredgers also have the advantage that their maintenance costs are much lower. For these reasons bucket dredgers are now only used for the types of work mentioned above.

6.4. The method of working

When a bucket dredger is working the anchoring system plays an important role in both positioning the dredger in the cut and in the excavation by the buckets.

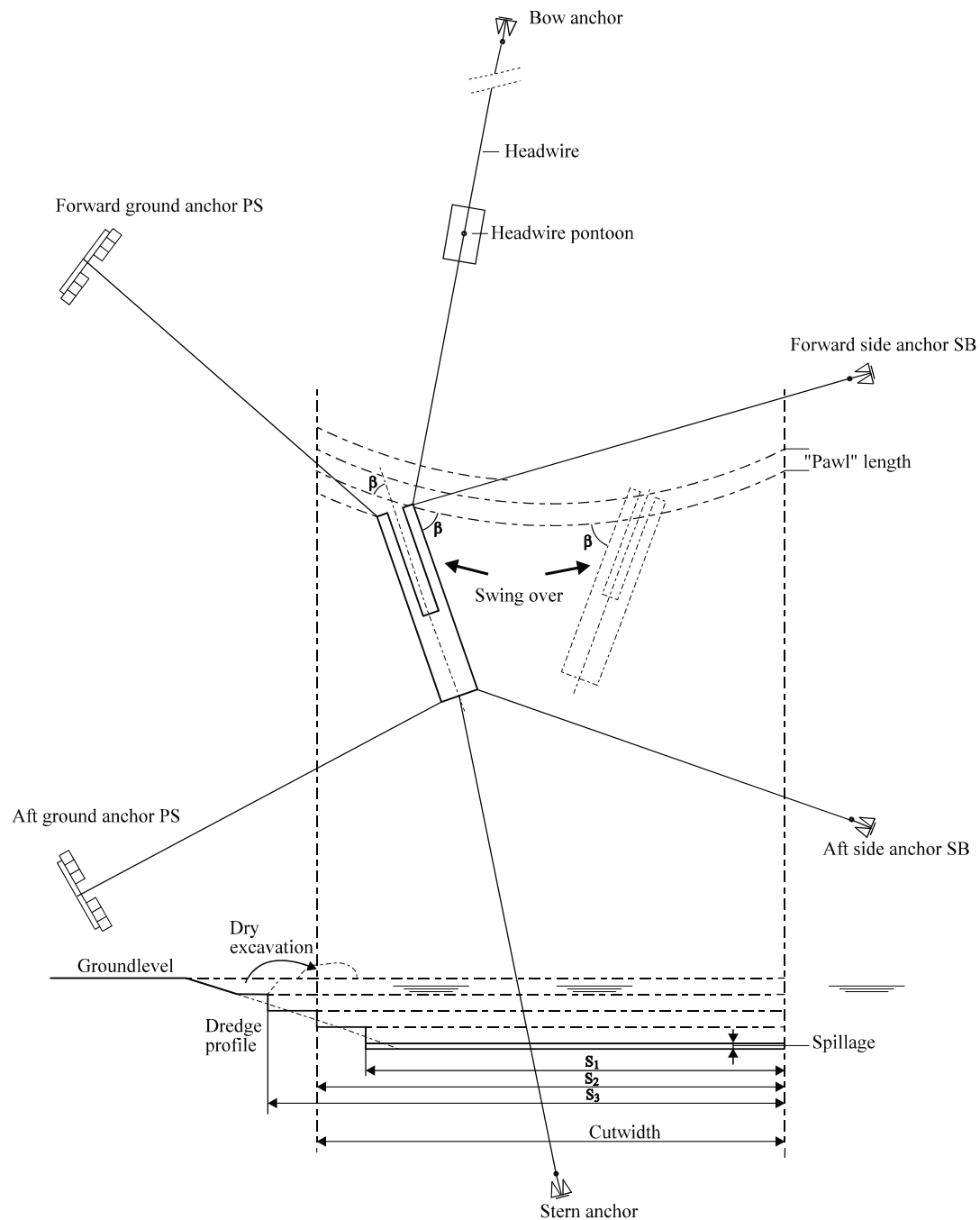


Figure 6- 6 Positioning of the dredger in the cut

As mentioned previously, the dredger swings round the bow anchors (Figure 6- 6) The bow wire has a length of 1 to 2 times the bucket capacity in litres. This means that for large dredgers it may be 1 to 2 km long. It will be clear that with such great lengths, measures must be taken to prevent the radius of the swing circle from being reduced by the bow wire being dragged over the bottom. Over water, therefore, one or more pontoons/floats/bow barges are positioned under the bow wire. If the bow wire runs mainly over land it is placed on a drum roller.

The swinging of the dredger and the provision of the excavation forces is mainly carried out by the side winches. The side winch velocity used depends on the type of soil and also on the **step length** and the height of the cut. For the most effective possible transition of forces the side wires must make an angle with the bow wire that is a little smaller than 90° .

When swinging round the bow anchor the swing angle (β) that the dredger makes with the swing circle (Figure 6- 6), must be kept as constant as possible. The choice of the swing angle is related to the clearance between the buckets on the lower part of the chain over the bottom or the slope. If this is not done it is possible that the bucket chain will run off the bottom tumbler as a result of the lateral forces that act on it. At the beginning of a new cut the swing angle is brought to the desired value as quickly as possible. If there is a current in the dredging area the swing angle must be kept as large as possible, that is at 90° . The stern winch controls the swing angle. The stern anchor is used to obtain the required tension in the bow wire. When dredging in tidal waters the stern anchor is usually used as a flood anchor if the winch and the wire are strong enough for this.

The step length, the cut thickness and the swing velocity along the cut determine the amount of soil that is cut per unit of time. This amount must be at least in balance with the number of buckets per unit of time multiplied by the capacity of the buckets. In other words the bucket capacity and the bucket speed are related to the factors mentioned above. Some dredgers have more than one type of bucket, so that, depending on the soil type, the capacity can be adapted to the expected production. Because with high excavation forces the dredger will not be able to completely fill the buckets, so that they are partly filled with water. This is of course not economical.

The position of the ladder, particular the ladder angle, also affects the maximum filling degree of the buckets. If the bucket rim is not horizontal, fluid soil will partly flow out of the bucket.

After being carried upwards, the buckets are turned upside-down as they pass over the upper tumbler or the pentagon and, depending on the time, the material will fall out of the buckets. In order to accommodate to this time effect **the discharge chute** into which the dredged material falls, is adjustable in relation to the upper tumbler. Depending on the type of soil, extra measures may be necessary to promote the emptying of the buckets.

From the discharge chute the material slides directly into the barge that is moored alongside the dredger or it is transported to it via conveyor belts. To obtain the most even possible filling of the barge it must be frequently warped along the side of the dredger.

6.5. The design

When designing bucket dredgers the following design parameters are important:

- Production capacity
- Dredging depth (minimum and maximum)
- Soil type
- The discharge of the dredged material (barges or via pipeline)

As previously mentioned, the bucket dredger can be used in all types of soil from clay to soft rock which has not been blasted and hard rock which has been fragmented by blasting. The type of soil to be dredged has a big influence on the design and the construction of the dredger. Considerable forces arise during the dredging of rock. For all types of soil it is necessary to know the required cutting capacity and the energy that is needed to transport the dredged material via the bucket chain to the upper tumbler.

6.5.1. The production capacity

The production capacity of a bucket dredger cannot be increased indefinitely. Increasing the production capacity of bucket dredgers implies increasing the bucket capacity. This means that the forces in the bucket chain resulting from the weight of the buckets and links themselves is also greatly increased. This in turn demands an even heavier construction. The production capacity of bucket dredgers therefore seldom rises above $100.000 \text{ m}^3/\text{week}$. The same goes, to an even greater degree, for the dredging depth, because greater dredging depths demand longer bucket ladders and thus more buckets.

In principle, the product of the bucket capacity and the bucket velocity determines the production capacity, thus: $Q_b = I_b \cdot v_b$; with: Q the production capacity in m^3/s , I_b the effective volume of the bucket and v_b the bucket speed in buckets per second.

The maximum bucket size is 1200 litres and the maximum bucket velocity approximately 30 buckets per minute or .5 buckets per second. Often this bucket velocity can only be reached with empty buckets. With full buckets and when some excavation force is needed, the bucket velocity is quickly reduced to values of 15 to 20 buckets per minute. Moreover factors such as the filling rate of the bucket and the bulking factor of the soil play a part.

For a bank height h [m], a step size s [m] and a lateral or swing speed v_s [m/s], the insitu production Q_s dredged is:

$$Q_s = h \cdot s \cdot v_s \quad [\text{m}^3/\text{s}]$$

This insitu production must be in balance with the bucket production Q_b corrected for the filling degree F_{Db} and the bulking factor B , thus:

$$Q_s = h \cdot s \cdot v_s = \frac{I_b \cdot F_{Db} \cdot v_b}{B}$$

Note: The filling degree $F_{Db} < 1$ and $B > 1$

Because it is impossible to fill every bucket for 100% it is advisable to take as first assumption the filling degree a value of 0.85 and bulking factor depending on the soil to be dredge:

Type of soil	Bulking factor
Very soft silts and clay	1.05
Clay	1.3-1.5
sand	1.05- 1.25
Rock	1.3-1.4

6.5.2. The dredging depth

As with other dredgers both the maximum and minimum dredging depths are very important in relation to the use of the dredger. Requirements in relation to these values are closely related to market demands. The difference between the maximum and minimum dredging depth determine the change of the angle of the bucket rim with the horizon.

6.5.2.1. De maximum dredging depth

For large bucket dredgers the maximum dredging depth is about 25 m. and exceptional 30 m. By adjusting the height of the mounting of the ladder on the ladder gantry or by lengthening the ladder, it is possible to dredge to a maximum depth of 35 m (see 5.4.3). It will be apparent that by adjusting the setting of the ladder or lengthening it, the number of buckets will increase. The figure below gives a general view of the dredging depths used. For the smaller bucket dredgers the dredging depth is around 10 m.

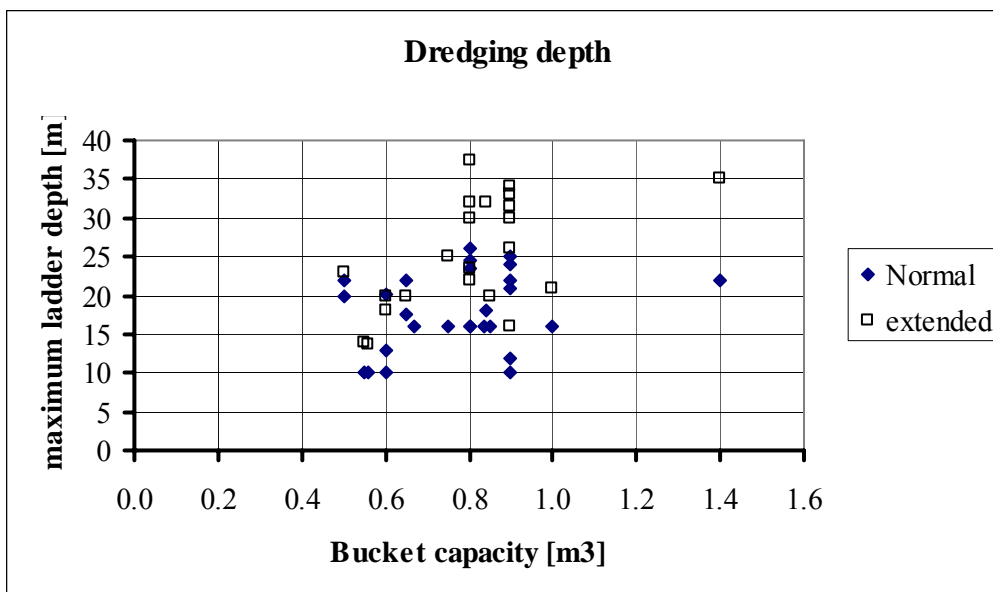
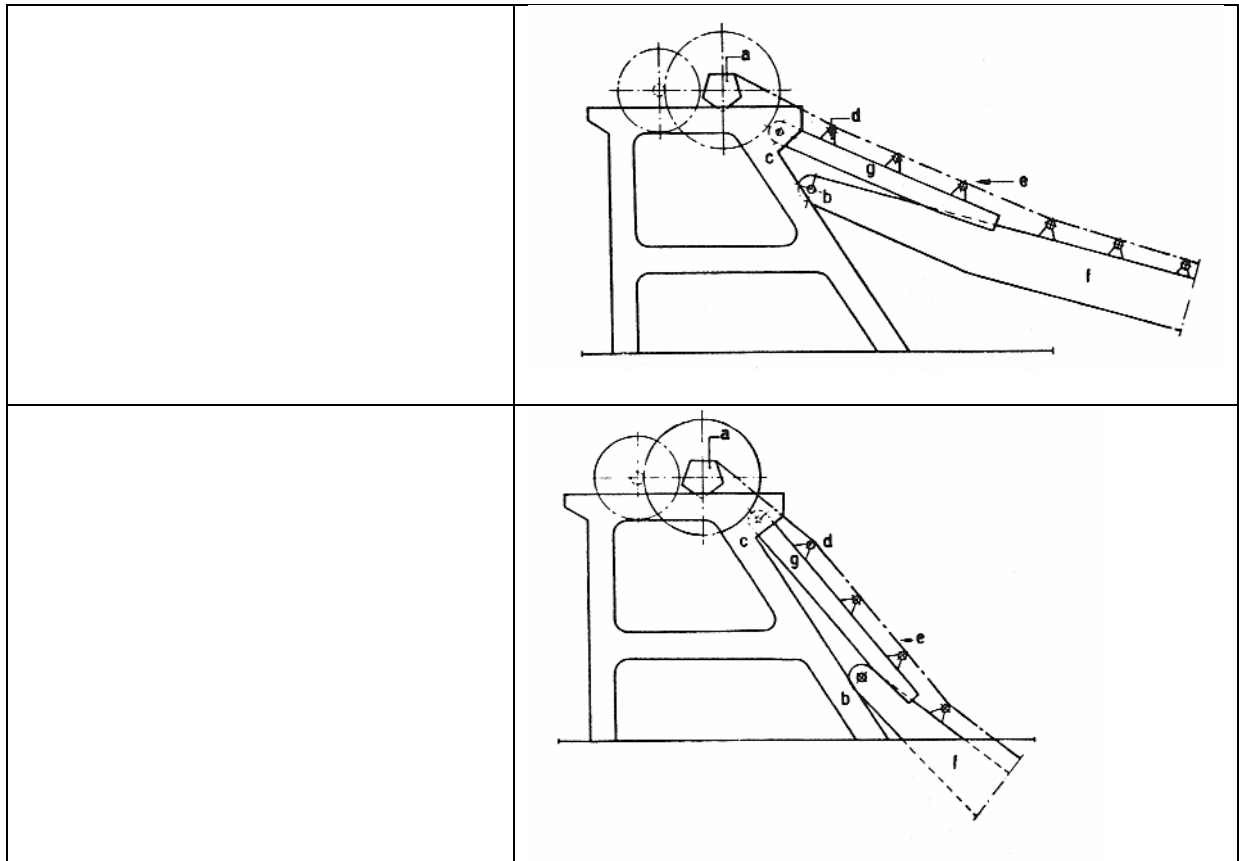
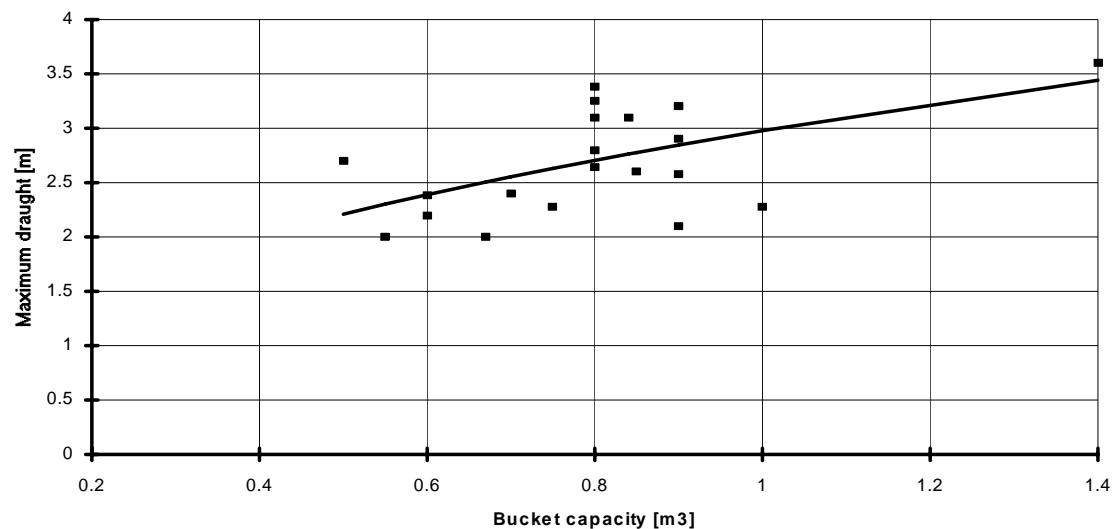


Figure 6- 7

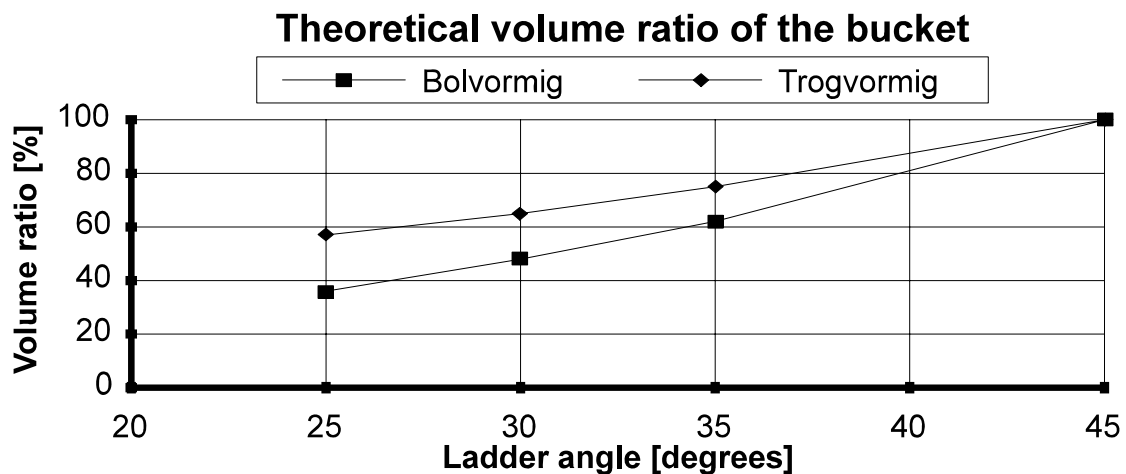
5.2.2.2. The minimum dredging depth

The minimum draught is, on one hand, determined by the required clearance including *navigational/keel clearance and, on the other hand, by the *filling degree of the buckets at the minimum dredging depth. In Figure 5.4 below, the maximum draught of the bucket dredger is shown as a function of the bucket capacity. From the graph it can be seen that for bucket dredgers with a bucket capacity of 300 litres the minimum dredging depth must lie between 3 and 4 metres.



5. 1

With small dredging depths, depending on the ladder angle, because the buckets are tilted so far back *the filling degree may well be so low so that dredging in this situation becomes uneconomic. In the figure below (Figure 5.5), the *filling degree of the buckets is given as a function of the maximum dredging depths. The shape of the buckets is such that the maximum filling degree is obtained at the maximum dredging depth. Naturally the buckets can also be designed for the average dredging depth.



5. 2

5.2.3. The soil

The influence of the soil to be dredged is seen in the power of the upper tumbler, the strength of the ladder, links and buckets and also in the bucket capacity and shape. If a bucket dredger is equipped with buckets for both soft soil and rock, the capacity of the rock buckets is roughly 60 to 70% of that of the soft soil buckets. Naturally, the length of the links must be the same for both types of bucket. The length of the link must be the same. (Why?) Moreover rock buckets are usually cast and soft soil buckets are often welded.

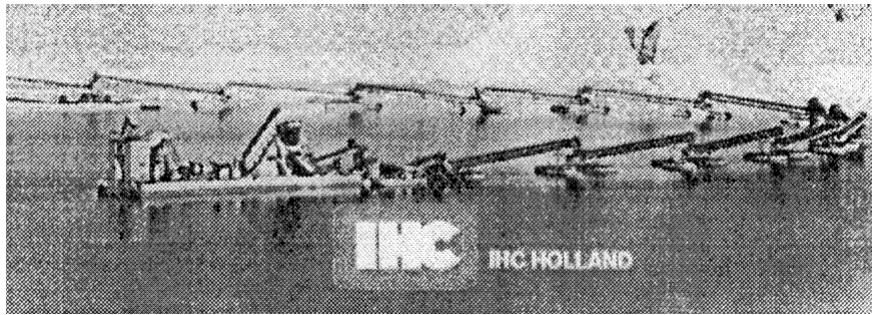
5.2.4. The transport of the dredged material

Usually barges that are loaded while moored alongside the dredger are used to transport the dredged material. The height of the main gantry must be such that the soil falling from the buckets can slide down into the barges moored alongside via the chute.

5.2.4.1. The bucket dredger with a pipeline discharge system

Sometimes the dredged material is carried away directly. In these cases it is collected in a hopper and mixed with the right amount of water to be transported by means of a dredged pump and pipeline. As in the case of a cutter suction dredger, the floating pipeline is attached to the stern of the dredger. Naturally a barge with a dredge pump can also be moored alongside the dredger for this purpose. This option is increasingly rarely used; indeed, unless the work stipulates the use of a bucket dredger the contractor will employ the much cheaper cutter suction dredger.

5.2.4.2. Discharge by conveyor belts



5. 3

Conveyor belts are frequently used to discharge the dredged material when excavating sand and gravel for the cement industry. This type of discharge system can be easily fitted to the normal bucket dredger.

The conveyor belts are mounted on floats that are attached to the stern of the dredge. Because no discharge chutes are used the main gantry can be lower.

5.2.5. The main drive

The choice of the source of power for the drive of the bucket chain is now limited to a diesel with a direct belt drive, a diesel-electric drive or a diesel-hydraulic drive. When electricity can be obtained from landlines, for example during sand or gravel dredging, it is also possible to use an electric drive. The power/energy needed for the excavation, lifting of the soil, the friction of the buckets over the guiding rollers and the tumblers, the friction of the tumblers, resulting from tension in the bucket chain are transferred to the upper tumbler via the bucket chain.

The required cutting power can be determined in a way similar to that described for the cutter suction dredger. Thus with the aid of the specific energy. If the desired cutting production is Q_s and the specific cutting energy E_s , the required cutting power is:

$$P_s = Q_s \cdot E_s \quad (5.1)$$

The required cutting power must be multiplied by a factor that represents the relation between the average and peak loads.

When lifting the soil the number of buckets under or above water plays a role. Since:

$$P_0 = Q_e \cdot g[(\rho_e - \rho_w)H_{bw} + \rho_z \cdot H_{ow}] \quad (5.2)$$

With:

Q_e	= the bucket production	$[m^3/s]$
g	= acceleration due to gravity	$[m/s^2]$
ρ_e	= the density of the dredged material in the bucket	$[kg/m^3]$
H_{ow}	= the dredging depth	$[m]$
H_{aw}	= the height above water that the soil must be lifted.	$[m]$

In principle, the cutting production cannot exceed the production of the bucket chain, thus:

$$Q_s \leq \frac{I_e \cdot E_v \cdot v_e}{B} = Q_e \quad (5.3)$$

Here:

E_v	= the bucket *filling
v_e	= the bucket velocity
I_e	= the bucket capacity
B	= the bulking factor

If it is assumed that the quotient E_v is equal to 1 and $Q_s=Q_e$, the power required to lift the soil, is known. With a filling degree lower than 1 the weight of the water above the soil must also be included.

Because the number of buckets that goes upwards is equal to the number of buckets that goes downwards it is not necessary to take into account lifting the weight of the buckets themselves. Naturally the friction of the guide rollers over which the buckets slide must be taken into account.

The effect of the tensile forces also makes an extra contribution to the required drive power, with the exception of the friction in the bearings of the lower tumblers.

To calculate the reactions and the tensile forces see Section 5.7

The total power required is thus:

$$P_t = P_s + P_o + P_{wl} + P_{wT} \quad (5.4)$$

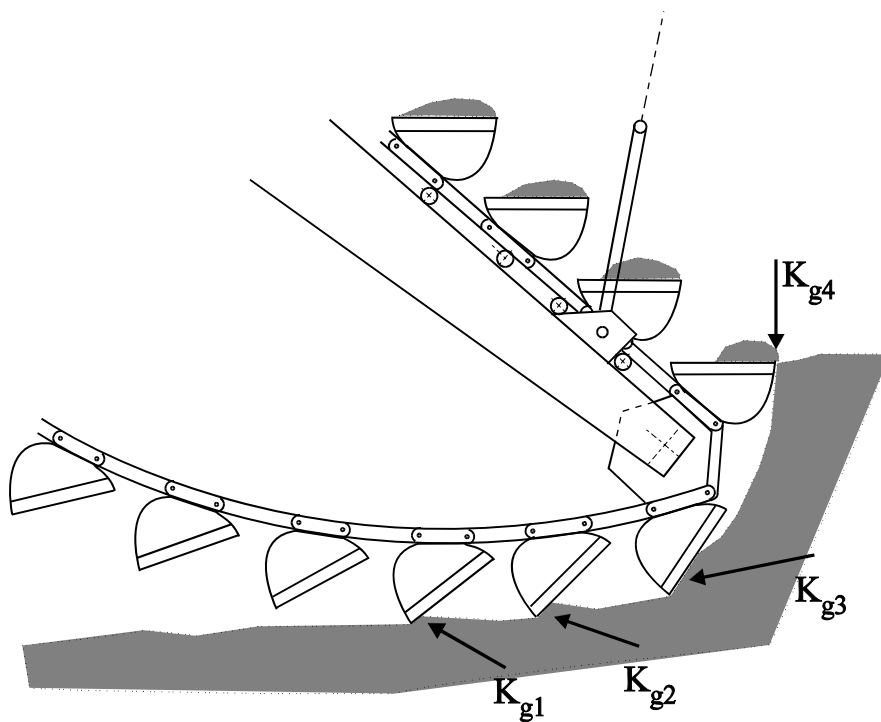
P_t	= the power to be installed
P_s	= the cutting power
P_o	= the lifting power
P_{wl}	= the friction power/work of the guide rollers/pulleys
P_{wT}	= the friction power/work of the tumblers

The friction forces that, as described above, can arise are the cause of the fact that the gross energy requirement to lift the soil with a ladder angle of 45° , are roughly two times as high as the nett energy requirement. At small dredging depths this can increase to a factor 4!

So the relation between the length of the lower/under-bend of the bucket chain and the length of the ladder has a big influence on the horizontal force (Figure 5.7).

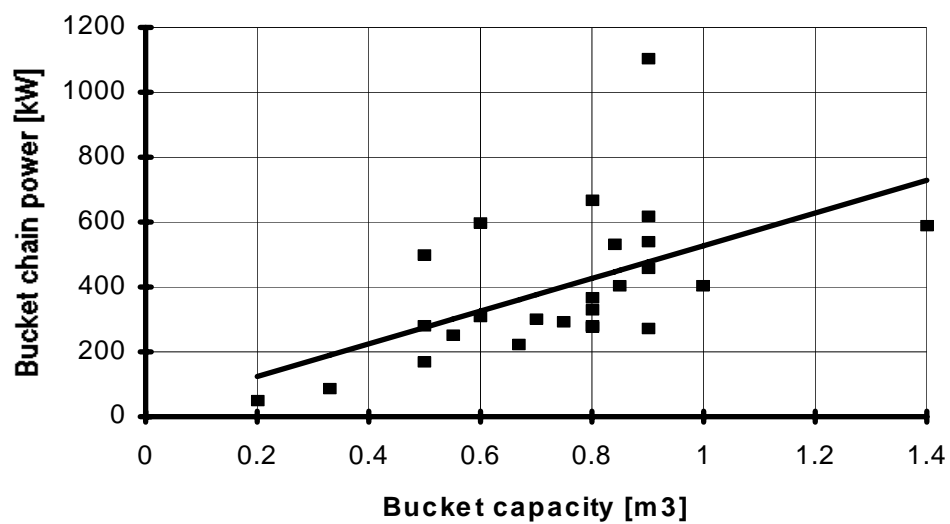
For small dredging depths this may increase to a factor 4!

Thus the relation between the length of the lower bend and the ladder S/L a big influence upon the horizontal tensile force (Figure 5. 4)



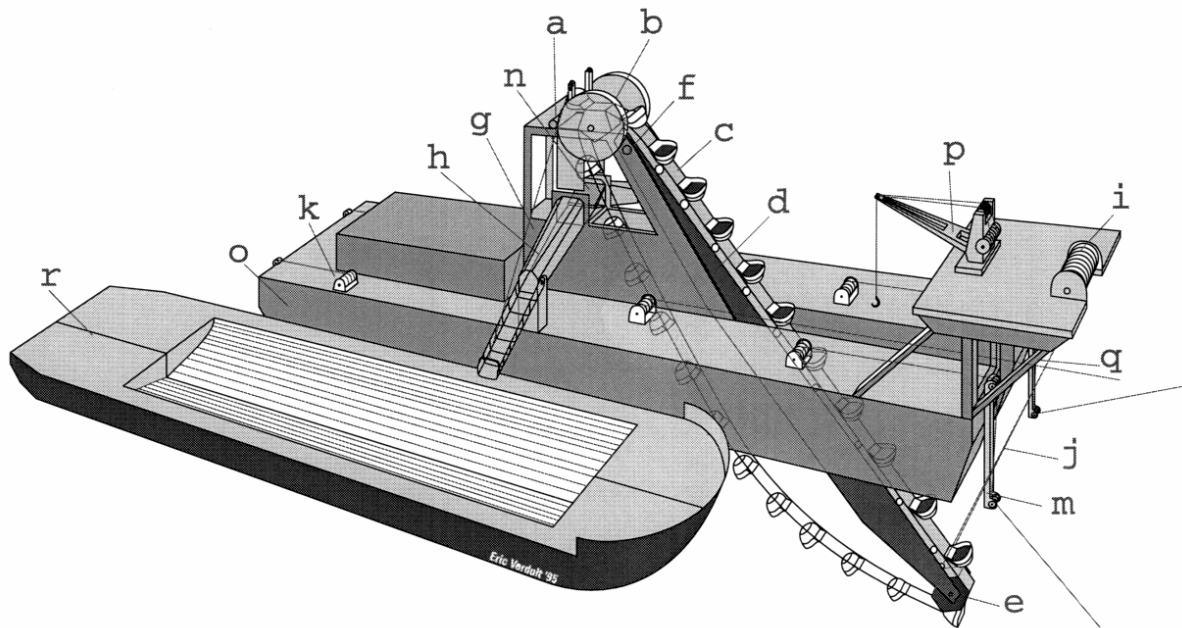
5. 4

As a guideline it can be assumed that the installed power in kW for the drive of the chain in soft soil is roughly 1/2 and for heavy soil at 2/3 of the bucket capacity in litres. (Figure 5. 5)



5. 5

5.2.6. The winches



5. 6 Simplified diagram of a barge loading bucket dredger

The winches on a bucket dredger have various functions and therefore various requirements with regard to the power, the forces and band velocity, which differ from winch to winch.

5.2.6.1. The ladder winch

The ladder winch (letter i in Figure 5. 6), which is used to adjust the required dredging depth is usually mounted on the ladder gantry of the larger bucket dredgers, while the smaller demountable dredgers usually have the ladder winch mounted on deck.

Owing to the great weight of the ladder and the buckets this is the strongest winch on the bucket dredger. The installed power is often in the order of magnitude of $\frac{1}{4}$ of the bucket drive. The ladder winch velocity is roughly between 6 and 10 m/min. Currently the drive is usually a slow running electric or hydraulic engine. Because of the need to set the dredging depth it is necessary to have an adjustable winch.

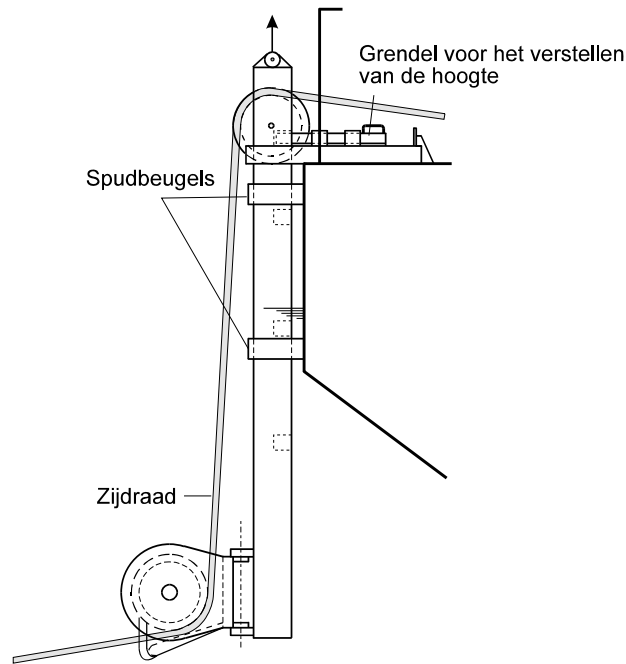
5.2.6.2 The bow side winches

As in the cutter suction dredger, the side winches (see Figure 5. 6) make a major contribution to the excavation process. The installed bow side winch power is between 10% and 20% of the main drive. The side winch velocity of the bucket dredger is generally lower than that of the cutter suction dredger. Nominal side winch velocities lie between 10 and 15 m/min. It will be clear that the excavation process requires a winch that can be well controlled and adjusted. The control must be such that any desired velocity can be set and remain as constant as possible, even when side winch forces vary.

As in the cutter suction dredger, when paying out, the wire being loosened must be kept under control by braking while paying out. The winches are mounted on the fore deck.

5.2.6.3 The stern side winches

The stern side winches have a secondary function and do not determine the production. The stern winches control the dredger with regard to the cut (swing angle β , (see Figure 5.2)). The requirements relating to the control and force are thus considerably less than for the bow side winches. The power is roughly half that of the bow side winches. The nominal side winch velocities are of course equal. The stern side winches are usually mounted on the afterdeck. To avoid hindering the arrival and departure of barges, as well as the warping of the barges alongside the dredger, the side wires are led down to a sufficient depth directly beside the dredger in vertical guides, also called wire spuds (Figure 5. 7).



5. 7 The wire spud construction

5.2.6.4 The bow winch

The bow winch is used to pull the dredger forwards when a new cut is started. The required force for this lies in the same order of magnitude as for the side winch. The required velocity, however, is considerably lower (nominally 2 - 3 m/min). Higher speeds are, of course, necessary when positioning the bow anchor.

5.2.6.5. The stern winch

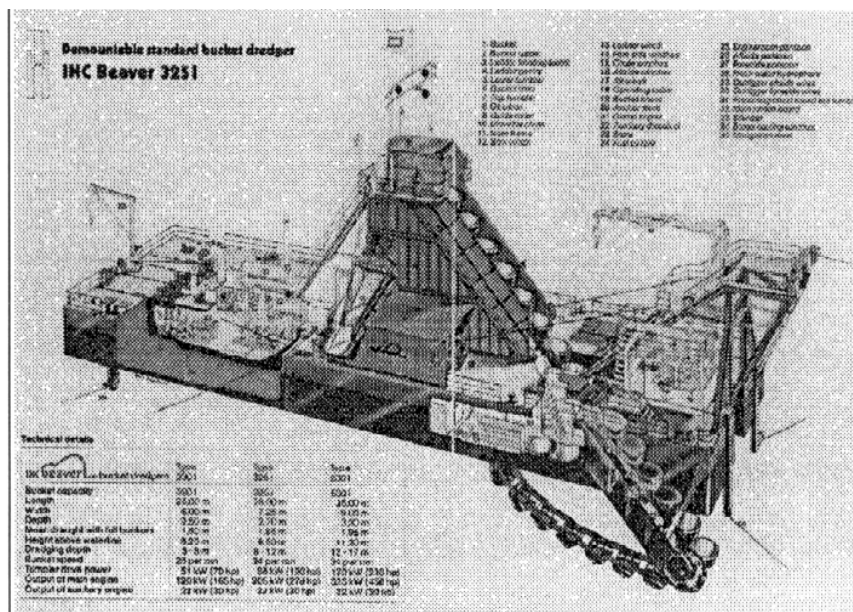
The function of the stern winch is to ensure the required tension in the bow wire. This consideration demands that the required force is roughly equal to that of the bow wire, however, the need to move the bucket dredger backward quickly to the adjacent cut places higher demands on the velocity (5-10 m/min).

6.6. 5.3. The general layout

5. 8

The hull consists of a U-shaped pontoon with long forward pontoons. The dimensions of the pontoon are primarily determined by the required dredging depth and the necessary stability. The well is rather long compared to that of a cutter suction dredger, roughly 60 % *of the length of the dredger. The pontoon is divided into a number of compartments for the engine room, crew accommodation, stores, and fuel and ballast tanks. The latter are often located for and aft in the pontoon. The engine room is located in the pontoon aft of the main gantry and its layout depends on the type of main drive. To satisfy the need for longitudinal stability the bottom of the dredger slopes upward at the stern or the forward end may be wider (Figure

5. 8.). The main gantry is roughly in the middle of the pontoon. Although formerly the crew quarters were often located in the pontoon, in modern dredgers they are now often situated on deck.



5. 9 Tekening IHC

6.7. 5.4. The technical construction

5.4.1. The hull

The hull consists of a U-shaped pontoon with almost horizontal deck and bottom plates. Often the bottom plate slopes up at the stern to ensure the correct longitudinal weight distribution of the ship. The corners of the pontoon are rounded off to make it easier for the barges to come alongside.

5.4.2. The main gantry

Because of the way in which the buckets are emptied and the need to load barges that are moored alongside, the main gantry is high and heavy. The construction of the main gantry is often carried through to the bottom ribs.

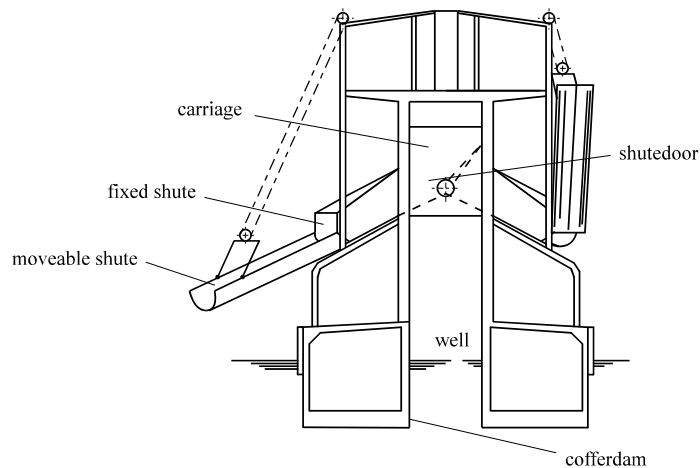
In modern bucket dredgers the drive of the tumblers is mounted on the main gantry. The *stort wagons/fixed chutes are located on each side of the main gantry. They catch the dredged material from the buckets that have been turned over by the tumbler and convey it to the movable chutes, which discharge into the barges,

5.4.3. The bucket ladder

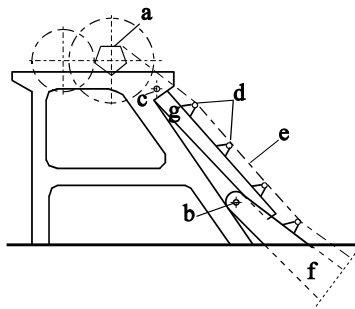


5. 10 Bucket ladder of the demountable bucket dredger “Big Dalton”

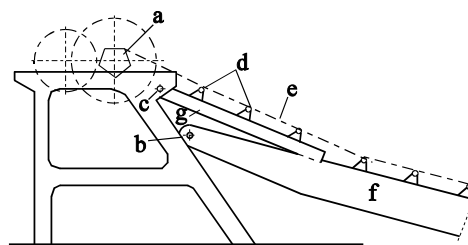
The vertically rotating upper end of the ladder is suspended from two axle boxes which are mounted on the sloping legs of the main gantry (Figure 5. 10). If necessary, these axle boxes, which are attached by bolts, can be moved along the legs of the main gantry in order to dredge more deeply. When they are in the lowest position it is necessary to add an auxiliary ladder to support the bucket guides. **/If they were in the lowest position the upper part of the bucket guides would come to be suspended in the air. To prevent this from happening an auxiliary ladder is added.** The shape of the auxiliary ladder is such that the bucket chain is also carried over the upper part. (Figure 5. 11) and is suspended at the lower end via the ladder wire which runs from the ladder gantry.



Cross section over main gaintry



Ladder in extended position



Ladder in normal position

5. 11

The weight of the full buckets is transferred to the ladder by rollers. These rollers are mounted at a distance of twice the link length apart. To guide the buckets these rollers are fitted with flanges, hence the name ***ladder rollers/guide rollers**

The bucket ***chain/leiding** is driven by the upper tumbler (often five-sided) and pulled round the underside by the lower tumbler (often six-sided). As a rule of thumb the total tensile force exercised by the upper tumbler on the bucket chain is 700 kN per 100 litre bucket capacity. The weight of the descending buckets that form a chain provides the tensile force in the tumblers. ***These tensile forces**, are dependent not only on the ladder angle, but also on the relation between the arc and the chord, which generally amount to 1.1 to 1.15 and if necessary can be changed by adding or removing buckets. **/These tensile forces**, excepting the ladder angle are dependent on the relation between the arc and the chord, which generally amount to 1.1 to 1.15 and if necessary can be changed by adding or removing buckets. See Section 5.7. ****NB not included in Dutch version).**

Summarising, the following forces act on the ladder:

1. The weight of the ladder itself, including the guide rollers.
2. The weight of the bucket chain, including the links and bolts.
3. The weight of the contents of the buckets.
4. The tensile forces generated in the under bend.
5. The excavation forces in both longitudinal and transverse directions if necessary multiplied by a factor for impact loading.

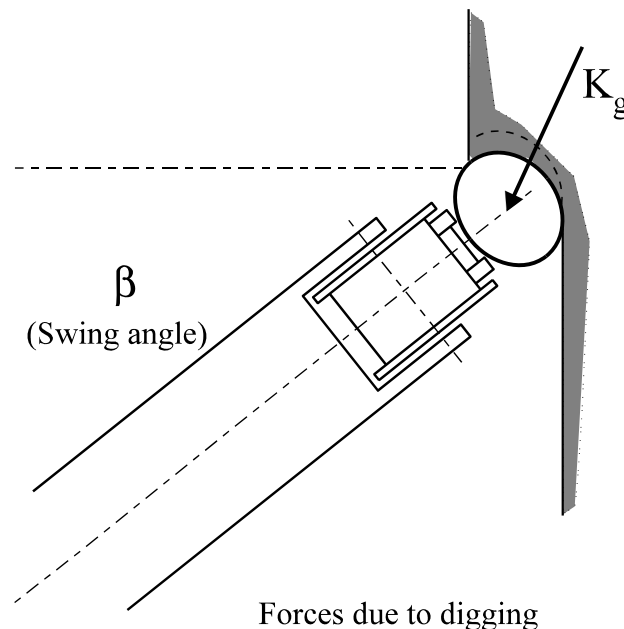
5.4.4. Dredge buckets

Dredge buckets may be either welded or cast. Welded buckets are most often used on small dredgers or dredgers that are suitable only for soft types of soil. The buckets are either welded onto the links or cast as one unit with the links. The weight is then very high; 30 to 40 times the bucket capacity in kN. For welded buckets the weight is 13 to 15 times the bucket capacity.

The front of the upper edge of the buckets is equipped with a cutting edge or with cutting teeth (Figure 5. 13). The latter are most often found on rock buckets.

The shape of the bucket is always a compromise.

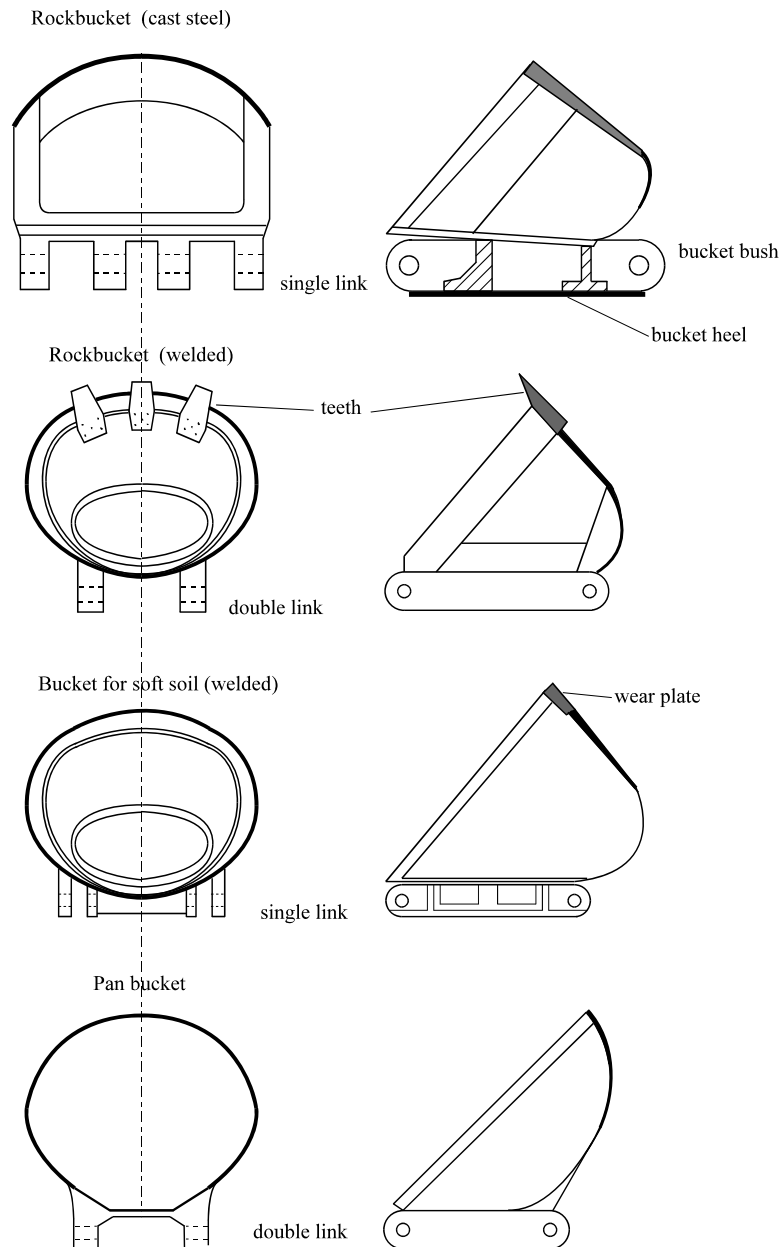
- Because a good shape for excavation and the required strength do not give the optimum content.
- The shape of the buckets is also determined by the required swing force (Figure 5. 12).
- The theoretical filling degree, the amount of water that the bucket can contain in relation to the total bucket capacity, is highly dependent on the dredging depth (Figure 5. 4).
- A bucket shape from which the soil readily falls is equally difficult to combine with a good excavation shape.
- The price of the bucket.



5. 12

Rock buckets are small heavy buckets, somewhat egg-shaped, which must be able to resist impact loads. Soft soil buckets, termed mud buckets, are much bigger and lighter. The relation rock bucket capacity to mud bucket capacity lies between 60 and 70 %.

The so-called *pan buckets have good soil discharging properties; their disadvantage is that the *filling degree is very sensitive to the angle of the bucket.



Different types of buckets.

5. 13

The links are fastened to each other by **bucket bolts**. The holes in the links, through which the bucket bolts pass are equipped with wearing bushes, termed, **bucket bushes**. These are forged steel *bushes/sleeves that are hydraulically pressed into the link. This simple means of attachment makes these bucket bushes very prone to wear and so they must be frequently replaced. (Figure...). *The lubrication of the guide rollers and tumblers is now carried out centrally. Nowadays *caterpillar tracks are sometimes used instead of links and bushes (Figure 5. 14).

5. 14 Undercarriage van Caterpillar

5.4.5 The ladder gantry

The ladder gantry straddles the outer end of the well. On it are found:

- The ladder winch that is used to set the dredging depth.
- The control cabin of the dredge master. From this it is now possible to operate all the winches.
- The crane.

The free height of the ladder gantry is determined by the height required to rotate the entire ladder above water.

Because of the large well, in order to give sufficient stiffness to the dredger the ladder gantry construction must be very heavy.

5.4.6 The main drive

Although in the past many steam powered dredgers were built, nowadays the choice is limited to:

- Diesel-direct driven via belt
- Diesel-electric drives.
- Diesel-hydraulic drive.
- Direct power supplies from the shore; sometimes used for sand and gravel extraction.

This means that the upper tumbler may be electric or driven by a hydraulic engine.

In steam powered dredgers or those powered by diesel engines with a direct drive the energy is transferred to the upper tumbler by driving belts.

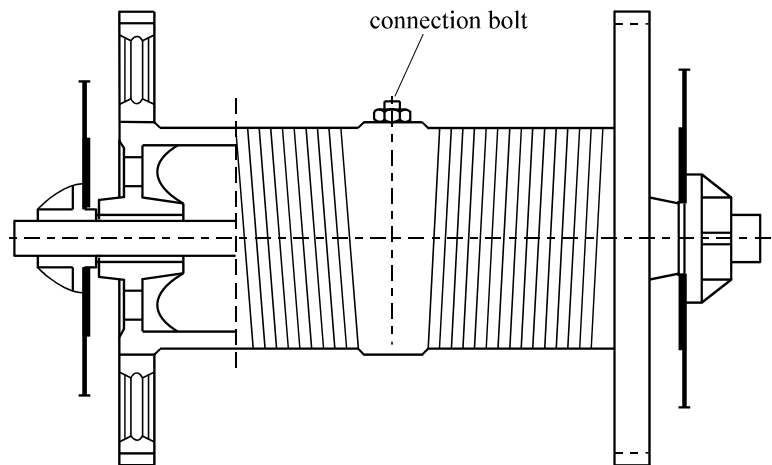
The control of the revolutions of the upper tumbler and thus of the bucket velocity is simple when using the above mentioned modern control systems. With an upper tumbler that is directly driven by a diesel engine control is limited and switchable or hydrodynamic gears are needed.

The drives of auxiliary equipment such as winches and chutes present no problems when modern drives are used.

5.4.7 The winches

5.4.7.1 The ladder winch

Because of the great weight of the ladder two wires are usually used to hoist it. For this purpose the winch drum is grooved on both sides in such a way that when the ladder is raised the wires are on the outer sides of the drum (Figure 5. 15).



Wire reel drum of a ladder winch

5. 15

5.4.7.2 The bow winch

With the aid of the bow winch the dredger is held against the cut. This winch also serves to pull the dredger forward to the following cut during stepping. The revolution speed of this winch is very important.

When moving the bow anchor this winch is paid out. Bow winches may be mounted above or below the deck. Because of the great length of the bow wire the bow winch has a very large drum.

5.4.7.5 The auxiliary winches

Separate winches are used to operate the discharge chutes and for the warping of the barges.

A jib crane is needed to lift out stones and debris that has been dredged, and also when changing the buckets during repairs. The winches used by this crane must satisfy the stipulations that apply to lifting cranes.

6.8. 5.5 The stability

Under working conditions the stability of the bucket dredger is seldom in question. After all, the greatest weight is always under water.

If the ladder is raised, however, the situation is entirely different. The great weight of the ladder is then entirely above water.

For this reason, when a bucket dredger is being towed at sea it must be unrigged. The entire bucket chain must be dismantled and, if possible, stowed below deck.

6.9. 5.6. The dredging process

The dredging process of the bucket dredger includes only the excavation and lifting of the dredged material. Barges carry out the transport.

As previously mentioned, the bucket dredger swings on the bow anchor along the arc of a circle *following a curving path. The axis of the dredger makes an angle β , the **swing angle** with the tangent to this arcuate path. The size of the swing angle depends primarily on the clearance between the lower bend and the bottom and on the slope of the breach/bank.

At the end of the cut the dredge master will allow the swing angle to slowly increase to 90° . After this a step will be taken or, if necessary, the cutting of the following layer will be started.

By means of this movement back and forth, the bucket dredger makes concentric arcs/curves that lie at a distance of one step length from each other. During this swinging back and forth the dredge master closely observes/keeps an eye on the tension in the bow wire and the loading of the bucket chain. The tension of the bow wire is controlled with the aid of the stern winch.

The amount of soil that is cut per unit of time depends on:

- The thickness of the cut. This is the thickness of the layer that can be dredged in one swing.
- The step length; the forward motion of the dredger during one swing.
- The warping velocity of the dredger along the cut.

To prevent spillage, the cutting production must be less than or equal to the product of the bucket velocity and the bucket capacity.

The *cutting thickness* depends on the total thickness of the layer to be dredged. If this is not too thick, generally less than 5 m, the dredge master will try to dredge it in a single cut. If the layer exceeds 5 m thick the entire breach/bank will be dredged by making several cuts. In any case the first cut must be so thick that the dredger can create sufficient draught for itself.

The *step length* is roughly equal to the length of the links. As rule of thumb, 0.6 to 0.8 times the cube root of the bucket capacity may also be taken. For both cases the swing velocity must be sufficiently high ($> 5\text{ m/min}$).

The *warping velocity* selected is such that either the buckets are full with a minimum spillage or that the loading on the bucket chain is the limiting factor.

If possible, a *width of the cut* is selected that is so wide that the total width of the work can be covered in one swing. The wider the cut the fewer the anchor movements. If that is not possible the total width is divided into a number of equal cutting widths.

There is also a minimum cutting width for every bucket dredger. The required depth for the dredger and the space for manoeuvring the barges play a role in determining this (Figure 5.2). This is roughly 1.5 times the length of the bucket dredger.

The *dredging depth* also determines the position of the buckets on the ladder and thus for the *filling degree.

The available *excavation energy* of a bucket dredger is highly dependent on the energy needed to carry/lift up the dredged material. This depends on:

1. The nett weight of the bucket contents. Part of this is under water and part is above water. The weight of the buckets themselves plays no role because there is an equal number of buckets under and above the ladder.
2. The friction resistance in the ladder/guide rollers results from the weight of the buckets and their contents.
3. The friction resistance in the axles of the tumblers results from the tensile forces of the bucket chain.
4. The impact loads that develop as a result of the bumping of the buckets.

The cutting production of the buckets is:

$$Q_s = h \cdot s \cdot v \quad [\text{m}^3/\text{s}] \quad (5.5)$$

with:

$$\begin{aligned} h &= \text{cutting thickness usually } < 5\text{m} & [\text{m}] \\ s &= \text{step length} & [\text{m}] \\ v &= \text{swinging velocity} & [\text{m/s}] \end{aligned}$$

The cutting production must balance with the amount that can be transported by the buckets per unit of time thus:

$$Q_s = hsv = \frac{I_e \cdot E_v \cdot v_e}{60 \cdot B} = \frac{Q_e}{B} \quad [\text{m}^3/\text{s}] \quad (5.6)$$

$$\begin{aligned} I_e &= \text{bucket capacity} & [\text{m}^3] \\ v_e &= \text{bucket velocity } e_v & [\text{buckets/min}] \\ E_v &= \text{filling degree} & [-] \\ B &= \text{bulking factor} & [-] \\ Q_e &= \text{bucket production} & [\text{m}^3/\text{s}] \end{aligned}$$

On the basis of the specific energy concept, the cutting energy for this production is:

$$P_{snij} = Q_s \cdot E_{sp} = \frac{I_e \cdot E_v \cdot v_e}{60 \cdot B} \cdot E_{sp} \quad (5.7)$$

The energy needed to lift sand and water is:

$$P_{opv} = \frac{I_e E_v v_e}{60B} g \left[(\rho_e - \rho_w) H_{ow} + (\rho_e + (1 - E_v) \rho_w) H_{bw} \right] \quad (5.8)$$

$$\begin{aligned} \rho_e &= \text{density of the soil in the bucket} & [\text{kg/m}^3] \\ \rho_w &= \text{density of water} & [\text{kg/m}^3] \\ E_e &= \text{bucket filling} & [-] \\ H_{ow} &= \text{lifting height under water} & [\text{m}] \\ H_{bw} &= \text{lifting height above water} & [\text{m}] \end{aligned}$$

If the friction in the ladder/guide rollers and tumblers is assumed to be a linear function of the weight and the velocity then:

$$P_{wr} = \frac{Q_e \cdot A(n_e, \alpha) v_e}{60} = \frac{I_e E_v v_e}{60B} A(n_e, \alpha) \frac{v_e}{60} \quad (5.9)$$

Here $A(n_e, \alpha)$ is the influence of the friction force on the ladder/guide rollers and the tumblers. Thus here the influence of the tensions is *taken into account /verdisconteerd.

The total power required is thus:

$$P_{tot} = P_{snij} + P_{opv} + P_{wr} \quad (5.10)$$

$$P_{tot} = \frac{I_e E_v v_e}{60B} \left\{ E_{sp} + gB \left[(\rho_e - \rho_w) H_b + (\rho_e + (1 - E_v) \rho_w) H_o \right] + BA(n_e, \alpha) \cdot \frac{v_e}{60} \right\} \quad (5.11)$$

Because the installed power must be higher than the average required power, it must be true that:

$$P_{\text{tot}} = P_{\text{inst}} \cdot w \quad (5.12)$$

Here w is the relation between the average and the peak power.
The relation between installed power and production is therefore:

$$P_{\text{inst}} = \frac{I_e E_v v_e}{60wB} \left\{ E_{\text{sp}} + gB[(\rho_e - \rho_w)H_b + (\rho_e + (1 - E_v)\rho_w)H_o] + BA(n_e, \alpha) \cdot \frac{v_e}{60} \right\} \quad (5.13)$$

If the bucket chain is driven by a top tumbler the relation between ω and v_e is:

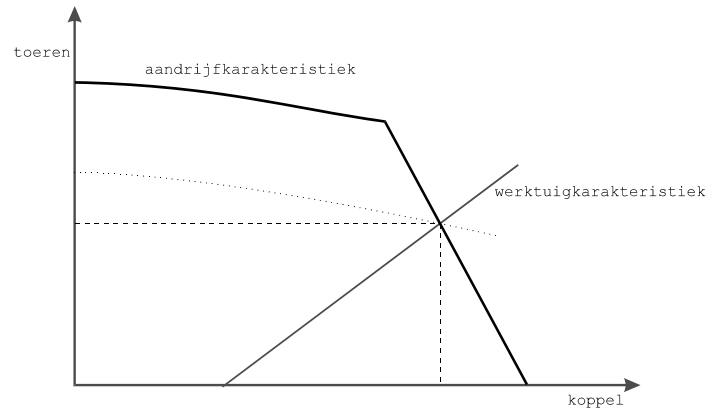
$$v_e = 5n = 5 \cdot \frac{60\omega}{2\pi} = \frac{150\omega}{\pi} \quad (5.14)$$

$$M\omega = M \frac{v_e \pi}{150} = \frac{I_e E_v v_e}{60B} \left\{ E_{\text{sp}} B + g[(\rho_e - \rho_w)H_b + (\rho_e + (1 - E_v)\rho_w)H_o] + A(n_e, \alpha) \cdot \frac{v_e}{60} \right\}$$

$$M = \frac{2.5 I_e E_v}{\pi B} \left\{ E_{\text{sp}} B + g[(\rho_e - \rho_w)H_b + (\rho_e + (1 - E_v)\rho_w)H_o] + A(n_e, \alpha) \cdot \frac{v_e}{60} \right\} \quad (5.15)$$

This is the machine characteristic.

When the drive characteristic is known, the bucket velocity and the associated torque are known and thus the production.



5. 16

The filling degree is determined by the equation:

$$E_v = \frac{60hvsB}{I_e v_e} \quad (5.16)$$

So, for a given step length and cutting thickness the desired warping velocity is also known.

As long as $Q_e \geq Q_s$ is valid the spillage during cutting will be limited. The spillage that occurs during the turning of the buckets is an entirely different question. Here factors such as cohesion, adhesion, the shape of the buckets and the position of the fixed chute all play a part.

Cohesive soil and also fine sands can give great problems on this point. In principle, this is a problem of timing. Although the fixed chute is indeed adjustable, the range over which it is adjustable is closely linked with the dredging depth and the shape of the lower bend. With soil that is not easily loosened the bucket velocity must be reduced, as otherwise there will be too much spillage behind the dredger. Measures are also taken to get rid of the under-pressure, which develop in the buckets when discharging cohesive soils.

As with the barge-loading dredger/reclamation dredger, a situation may also arise in which the supply of barges is the limiting factor. This situation may be caused by many different factors, such as:

- Weather and wave conditions
- Shipping movement
- Bridges and locks
- Differences in the speed of the barges.
- Differences in the size of the barges.
- Delays of the barge
- Delays of the *reclamation dredger/barge unloading dredger
- Delays at the discharge site

Clearly, with a bucket dredger, there is always a chance that sometimes there will be no barge available.

Because the above mentioned delays can be reasonably well estimated with regard to their average values and standard deviations, the Monte Carlo Simulation can provide insight into the probability of delay resulting from the absence of barges. Clearly, when using a barge-loading dredger there is always a chance of delays due to the absence of a barge.