Dredging of Heavy Minerals

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Summary

After a short discussion of the mining prodedure used for dredging heavy minerals, the current dredging techniques are reviewed. Successful full-scale tests proved that an underwater bucket wheel can be applied for dredging purposes up to depths of 100 m and that this bucket wheel shows the same favourable results as bucket wheels used on land-based excavators.

1. Introduction

Heavy mineral deposits, called placers, contain a large number of different metals such as gold, tin, titanium, and iron. Dredging of these minerals has a long history, the most spectacular example being the gold-rush of the last century.

Mining in the early days was fairly easy because in some areas the deposits forming sand dunes or river banks were easily accessible. Today, from a general point of view, the placer deposits include a wide range of different soil types with different geotechnical properties. Despite the same origin, during the weathering of a primary deposit a variety of transport, settlement and rebuilding processes may occur, forming the actual deposit.

There are various classification methods possible for placer deposits, e.g., by gravity or by the transportation and settlement process. With the gravity classification, heavy mineral placers — such as gold and cassiterite — and light mineral placers — such as magnetite, rutile and ilmenite — can be separated.

For the transportation process it is important whether the barren material or only the minerals of value have been removed from the location of the primary deposit.

2. Problems Encountered in Dredge Mining

Decisive for the mining procedure is the question, whether the minerals are continuously distributed over a large area or concentrated in pockets in the bedrock. In marine estuaries the process of transport and settlement is dominated by the drag forces of waves and river currents. Due to variations of the sea level during the ice age periods, these deposits can be found to a depth of approximately 150 m.

The diverse soil properties in placer deposits create problems for the choice of a suitable dredging tool. The difficulty is that despite a large number of standardized soil mechanical test procedures, only very few criteria have been developed which give information as to by which method a special type of soil should be dredged.

This data will have to be determined separately for different kinds of soil as well as for different dredging processes; a task hitherto only partly completed. At present one manages by obtaining standard soil mechanics data and trying to interpret these for the special dredging task. (see Table 1).

Empirical data for the classification of soils for dredging purposes

Type of soil	Grain size (mm)	Shear strength (N/cm²)	Specific cutting resistance (N/cm)
Sand and gravel low compactness	0.2-20	-	200 - 500
Sand Medium compactness	0.06-2	-	300 - 800
Sand and silt High compactness	0.006-0.2	-	400 -1000
Clay, very soft	-	less than 1.7	100 - 200
Clay, soft	-	1.7 - 4.5	200 - 500
Clay, firm	-	4.5 - 9.0	500 -1000
Clay, stiff	-	9.0 -13.4	1000 -1500
Clay, hard	-	more than 13.4	more than 1500
Consolidated material e.g. limestone, sandstone	-	-	more than 2000

Table 1: Empirical data

An example of this is the correlation of the specific cutting force per unit cutting blade length of cutter heads to measured mechanical properties of soils. It is, for coherent soils, sensible to determine the cohesion, the unconfined

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compression strength and the angle of internal friction. For incoherent soils, the dredging process is best investigated with static and dynamic penetration tests.

Besides the soil characteristics, the action of waves and currents are major influencing factors for dredge design. As in most cases the dredging tool is suspended from a floating pontoon, the motion must be kept within special limits in order to get a constant maximum output and to keep the floating treatment plant operating.

The first step in this direction is to carefully examine the sea conditions at the location of the deposit. If these data are known then adequate measures to overcome the wave problem can be taken. Some of these are:

- design of special hulls or semi-submersibles;
- design of flexible connections between dredging tool and hull;
- use of passive and active motion compensators;
- use of seasonal change of the main wind direction for dredging in sheltered areas.

3. Review of Current Dredging Techniques

Selecting a mining method for a known placer deposit should of course start with a review of existing dredgers that have proved their operating performance in previous mining ventures.

The basic types will be discussed using as examples some civil type dredgers recently delivered by O&K. Although the operating conditions of civil type dredgers are to some extent different from mining applications, the dredging procedure is the same.

3.1 Grab Dredges

The grab dredge (Fig. 1) is one of the oldest dredging tools. The main characteristics are: simple construction, comparatively great water depth, moderate production. To increase the production the dredge is equipped with a number of grabs. The grabs positioned on the port and starboard sides are staggered and operated in a cyclic programme. However, the control of a large number of grabs operating in great water depths creates problems. Especially in severe water conditions a steady production seems to be difficult.

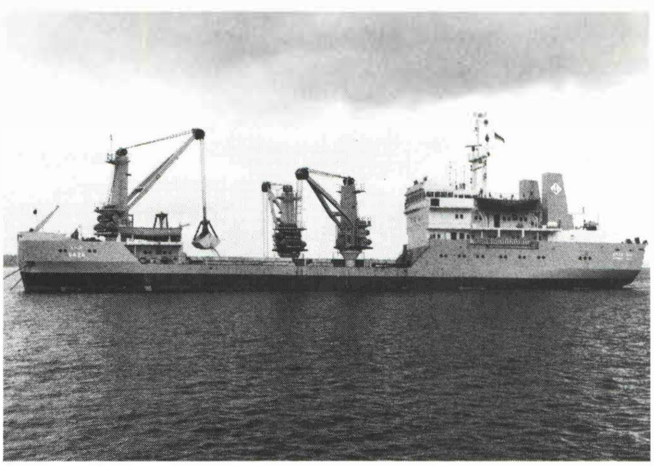

Fig. 1: Multi grab dredger "GAZA"

For a period of 10 years a large grab dredge was operating offshore of Phuket at a maximum water depth of 36 m. In 1967 the dredge was replaced by a bucket chain dredge.

3.2 Backhoe Dredge

If very hard soils are encountered, a backhoe dredge (Fig. 2) is the most efficient tool. Mounted on a pontoon this dredge is able to precisely mine pockets and traps and even remove the top level of the bedrock. The disadvantage, however, is the discontinuous process and the moderate production. Backhoe dredges are often used in gold dredging projects.

Fig. 2: Pontoon-mounted hydraulic backhoe as bucket dredger

3.3 Cutter Suction Dredge

Very high production and very high digging forces are the main characteristics of the cutter suction dredge (Fig. 3). The dredge shown is designed for a mixture discharge of 8,600 m³/h achieving an output of up to 2,500 m³/h in sandy bottoms.

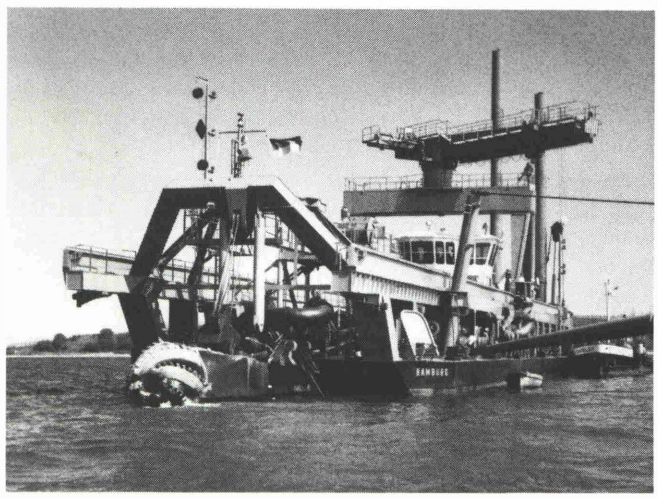

Fig. 3: Cutter suction dredger

The main disadvantage of this system in mining operations is that due to the suction process the heavier mineral grains may escape being transported. Attempts to overcome this problem were made using different shapes of cutterheads but the principle "once moved — no escape" could not be completely fulfilled.

The most spectacular example of a cutterhead dredge in mining operations is the "TEMCO II" operating offshore of Phuket.

3.4 Hopper Suction Dredge

Trailing hopper suction dredgers (Fig. 4) do not play a major role in mining heavy minerals. They are, however, used with considerable success in mining marine aggregates such as sand and gravel.

Fig. 4: Hopper suction dredger

The great advantages of a hopper dredge are the great flexibility, the good performance in rough sea, and the possibility to mine large areas of a thin deposit. Difficulties emerge with the attempt to combine the dredging procedure with an onboard treatment plant. The gravel dredgers discharge the barren material during the dredging process, spoiling the deposit for the next working cycle.

Consequently the only hopper dredger used in tin mining, which was operated by Southern Kinta Consolidated to mine the Takuapa deposit, was systematically guided across the deposit by side mines discharging tailings into an area that had already been completely mined.

3.5 Bucket Chain Dredge

Up to now the bucket chain dredger (Fig. 5) is the most common mining equipment for placer deposits. Over many decades bucket chain dredgers have seen a continuous development resulting in a remarkably high state of technology. Today these dredgers provide a maximum operational reliability, a long service lifetime, a high digging capacity and high production rates. The latest designs even comprise heave compensators and automatic operation control.

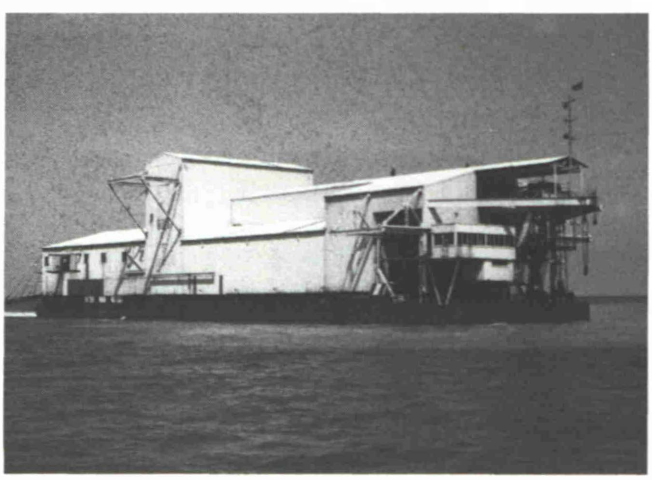

Fig. 5: Bucket chain dredger for tin placer mining

The operational limits of the bucket chain dredgers determine the targets which are to be matched by new developments.

For tin mining, most important actual targets are for mining at greater depths (down to 100 m), for better performance in rough seas, and for avoiding any spillage of minerals.

To achieve this, the development of a new mining system with separate elements for loosening, picking up and transporting the soil is essential. An underwater bucket wheel in connection with a hydraulic transport system seemed to be the best solution.

The excellent experience made with onshore bucket wheels is one reason for the attempt to introduce this earth moving tool for placer mining operations.

It is of great value for the realization of this idea that O&K has extensive know-how in both fields of technology — onshore excavators and floating dredgers. A great number of questions emerging with the design of an underwater bucket wheel can be answered from the experience obtained from onshore excavator operation.

4. Development of a Bucket Wheel Dredge

The O&K development of the underwater bucket wheel started with comparative model tests to find out the optimum shape and location of the suction chamber. It was realized that the best results could be achieved with closed buckets discharging into a suction chamber situated at the upper part of the wheel body. By using closed buckets the principle "once moved — no escape" is completely realized. The transition of soil from the buckets into the suction chamber is effected by gravity and by suction forces.

The resulting design is quite similar to existing excavator wheels with discharge elements in the wheel's upper part and drive elements in the centre. The prototype underwater bucket wheel (Fig. 6) was therefore built according to a very successful excavator series and mounted on an existing suction dredger (Fig. 7) with an underwater dredge pump.

The first impression gained from operation of the underwater bucket wheel was the very high production achieved with astonishingly quiet running of the dredger.

In sandy bottoms it was, for example, possible to reach a constant output of 2,000 m³/h (soil) with a wheel of 5 m diameter. This output was achieved with a very steady transport concentration of 45 % which corresponds to a mixture density of 1.4 t/m³; even in very hard boulder marl an average production of 1,250 m³/h was possible.

The outstanding performance of the underwater bucket wheel can be summarized as follows:

- high effective output due to the continuous operation;
- low losses when picking up the soil;
- exact soil cutting conditions resulting in:
  high digging forces
  low lateral forces
  digging capacity not affected by the depth
  equal digging capacity in both slewing directions;

Fig. 6: Underwater bucket wheel — prototype

— greater achievable depth due to lower weight of the ladder;
— less vibration as compared to bucket chain dredgers.

This summary shows that there is no economical alternative to an underwater bucket wheel with hydraulic transport system when dredging hard soils at great dredging depths. As its operation has been examined and its design tested under the hardest conditions, its profitable application in dredging and marine mining can be predicted.

5. Practical Example

One example for such an adaptation is the development of a dredger for mining of cassiterite placers, equipped with an underwater bucket wheel and reaching down to depths of 100 m (Fig. 8).

The type of wheel used has a diameter of 6.3 m and achieves a maximum production of 3,050 m^3/h with 600 kW power installed. The design of the wheel is such that special ancillary features for application in sticky clay mentioned before can be incorporated as needed.

In the case on hand, a rigid ladder was chosen for the operational depth of 100 m as it was designed for operation on a dredge pond. For offshore operation, however, a flexible ladder is planned, compensating any movements of the hull with respect to the seabed.

A dredging depth of 100 m seems to be the limit for any system using a bucket wheel attached to a floating pontoon. For greater depths, seabottom vehicles can be developed which serve as supporting structures for underwater bucket wheels.

The successful full-scale test on an underwater bucket wheel has proved that it is possible to use the favourable properties of on-land bucket wheels for marine applications.

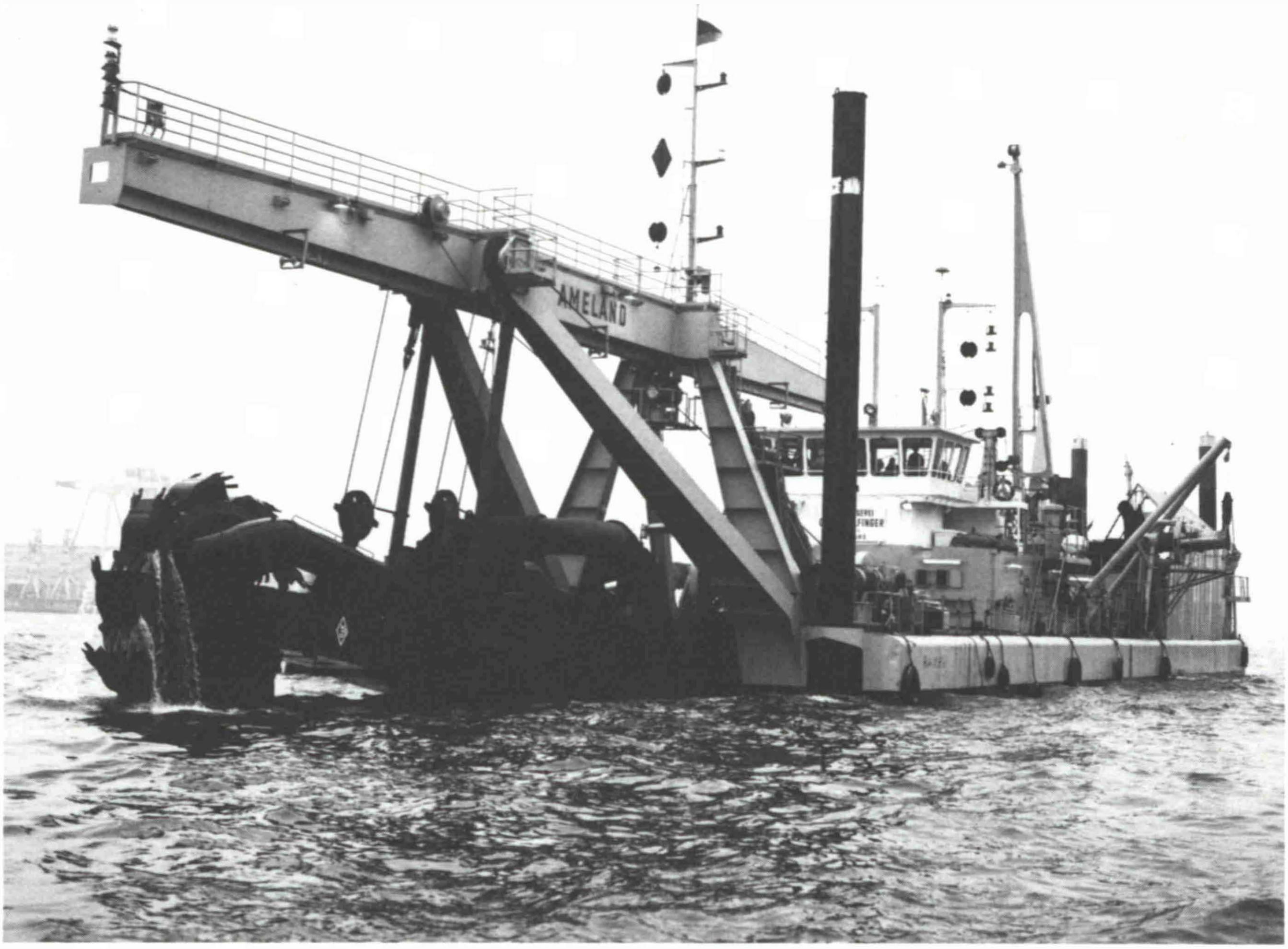

Fig. 7: Suction dredger with underwater bucket wheel

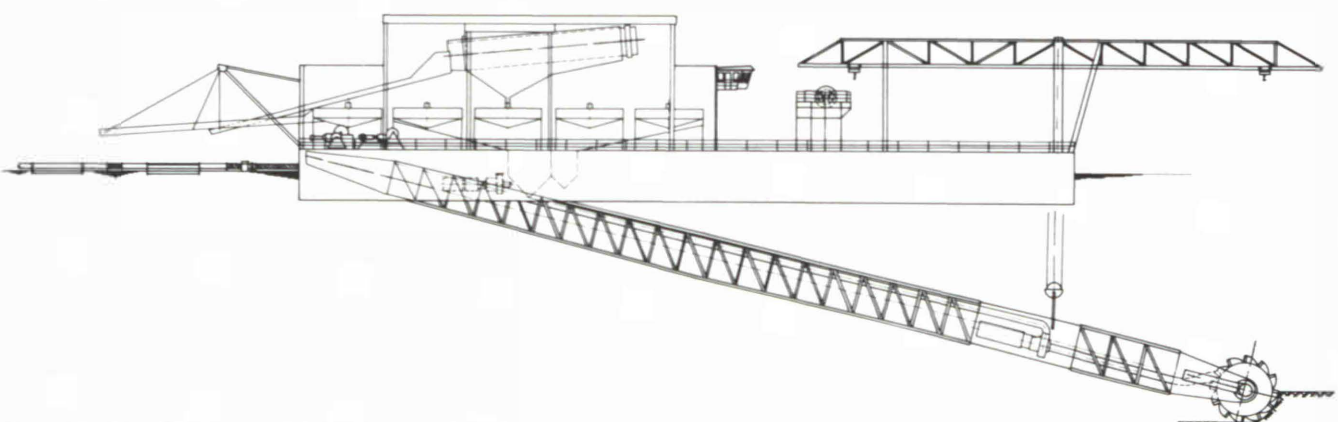

Fig. 8: Tin mining dredger with a dredging depth of 100 m