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Hopper Load Measurement; Some Recent Experiences with a Remote-Operated Data Acquisition and Analysing System



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Abstract

Hopper load measurement is still a lively field of research and development and several systems have been developed. This paper presents a remote-operated data acquisition and analysing system designed by HMT for the calculation of hopper loads discharged by pipeline. It has successfully been used in a number of land reclamation and beach nourishment projects. The resulting experiences cover both aspects of this work; the data logging and transfer process as well as the analyses of hopper operation.

Operational data, acquired with the ship's measurement system, can be picked up from a serial interface and transferred to a remote location, e.g. the client's office, using GSM mobile phones. Intranet technology proved to be a reliable and easy way to handle network structure for this task. Considerable savings in labour and a very detailed presentation of the hopper operation are typical results of this system.

A measurement concept for the analyses of the hopper discharge process has been developed which uses redundant, independent measurement systems for the calculation of the discharged load. The systems use density and velocity measurement and the TDS (Tonne Dry Stuff) system. A graphical comparison of both results provides a quickly accessible and highly reliable statement about the validity of the measurement. If the soil volume is the basis for payment, the decrease of hopper weight is plotted together with the ship's displacement. Results from this electronic measurement differ less than 1% compared to manual sounding.

However, because of the specific disadvantages of volume measurement, it is recommended that the

discharged solids mass be used as the basis for payment. In this case, the density and velocity measurement is compared with the results of the TDS system to reach redundancy. Being more independent from the soil properties, this method is applicable to all conceivable discharge processes.

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Introduction

Hopper load measurement is still a lively field of research and development. This is owing to the great variety of influencing parameters emerging with the various processes of loading and unloading, the type and design of the vessel, and the nature of the soil to be dredged. Scrutinising existing hopper load measurement systems clearly shows that there is no single solution to the problem; instead a careful analyses for each individual hopper operation is necessary.

In this context, HMT has developed a data-logging and analysing system for hopper dredgers, which can be regarded as a purpose designed method, taking advantage of some recent developments in computer technology and telecommunication including the fact that:

- handling large amounts of data is no longer a problem even for a standard PC
- network telephone and Intranet technology offer new ways of data transfer
- advanced data processing software eases the analysis process

Designed for the calculation of hopper discharge by pipeline, the system's general approach is to use multiple, independent measurements for the evaluation of a single parameter. In this way, the discharged soil quantity is developed from density and velocity measurement in the pipeline and simultaneously checked with the additional measurement of the ship's draft or the TDS results. A graphical comparison of all results in a single diagram provides a quickly accessible and highly reliable statement about the validity of the measurement. Initial calibration can be performed with manual sounding of the load.

The system gets the data from the ship's measurement and control installation and is operated from a remote location, e.g. the office, to where the data are transferred with intranet technology. In addition to soil discharge, the system makes possible the recording and analysing of all associated process data, such as

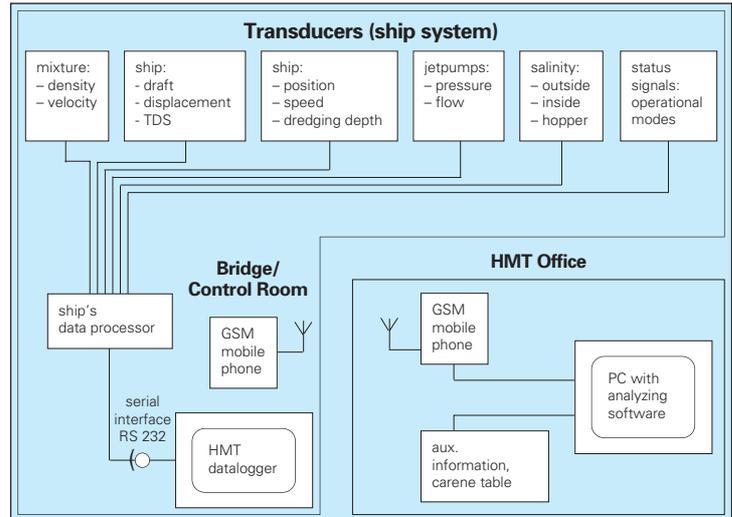


Figure 1. Basic sketch of hopper operation monitoring with remote data acquisition system.

the dredged profile and the effect of desalination of sand loads.

The system has been tested and successfully used in a number of projects including beach nourishment at the island of Sylt and land reclamation for the port of Hamburg. The dredgers involved include some very new designs such as *Cristoforo Colombo*, *Pearl River*, *Amsterdam*, *Gerardus Mercator*, and *W.D. Fairway*.

GENERAL ARRANGEMENT OF THE SYSTEM

Tracing and documentation of hopper dredge performance generally needs an extensive measurement system to cover all operational modes. As the client is obviously not in a position to install equipment of that size, the only solution is to make use of the ship's measurement and control system. With this approach, it becomes the contractor's duty to operate and carefully maintain the various transducers and deliver the measurement results as raw data for further handling by the client.

Modern hopper dredgers use a great number of sensors for the control and monitoring of the dredging process. The sensors send their signals to the ship's main processor, where they are used for the various control functions.

From this existing measurement system, the parameters necessary for the analyses are chosen according to the special needs of the client. Figure 1 shows a list of basic parameters, which have been used during this year's projects. Using a software module, which is a part of the ship's software package, the signals are grouped and transformed according to a pre-defined data protocol and then delivered to a serial interface (RS232).

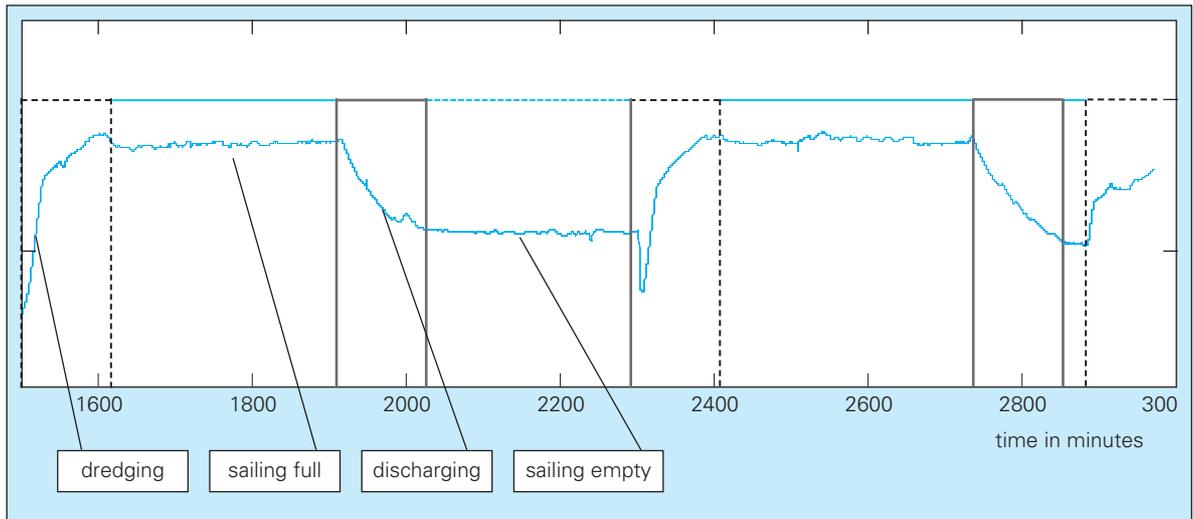


Figure 2. Displacement and status signals versus operational time.

The client uses a standard PC which is assembled on board the hopper dredge. Using data-logger software, the data are picked up from the serial interface and written to the hard disk of the PC. This procedure runs continuously from the beginning to the end of the project, thus creating a continuously growing data matrix. Data format is plain ASCII. Experience shows that the measurement interval (time between two consecutive sets of data) should be in a range of 15 to 20 seconds. An individual set of data comprises a number of approx. 40 to 50 parameters.

The receiving PC is running in multi-tasking mode, making simultaneous operation of data logging and data transfer possible. The data transfer is done with a GSM mobile phone, using Intranet technology as basis network structure. Projects done this year clearly showed that the D2-Net is suitable for the offshore areas of Sylt and Cuxhaven. If the transfer has to be done from areas, where no GSM net is accessible, a satellite phone should be used.

With this system it is possible, to collect data from the ship's data logger at any time. When a section of the data matrix is transferred to the office, data evaluation starts with an overview of the operation, which the hopper has performed since the last checking interval. Figure 2 shows an example of this overview.

The example displays a one-day section of the data matrix including two complete trips. Normally, the operational modes of the hopper dredger are determined by the status signals alone. However, as experience shows that these signals tend to fail frequently, they are plotted together with the displacement. Using this method the individual dredging modes can be distinguished very accurately.

Owing to the great operational differences, each indi-

vidual dredging mode must be analysed separately. The discharged soil quantities and the desalination process were the focus of interest during recent projects, therefore the analysing work was confined to the discharging and the sailing full mode. Analysing the dredging mode is also possible, but this work has not yet been carried out.

ANALYSING THE DISCHARGE OPERATION

Electronic measurement of hopper load volume

The new method, which introduces electronic measurement, is in competition with the traditional system of manual sounding of the hopper load volume. As in the past there was no other way possible, soil volume is still the contractual basis for the discharge, although obviously the volume may change according to the treatment of the sand mass.

Calculating the soil volume from a measured array of mixture-density and -flow data is fairly easy, if the necessary soil parameters are known:

$$V_b = \sum_i \left[\left(\frac{\pi}{4} \cdot dr^2 \cdot vm_i \right) \cdot \left(\frac{\rho_{gt} - \rho_w}{\rho_b - \rho_w} \right) \cdot \delta ts_i \right] \quad (1)$$

where,

V_b	m^3	soil volume of hopper load
i	-	number of data sets
dr	m	pipe diameter
vm	m/s	mean mixture velocity at measuring interval
ρ_{gt}	t/m^3	mean mixture density at measuring interval
ρ_w	t/m^3	density of water
ρ_b	t/m^3	density of soil (saturated)
δts	sec	time interval

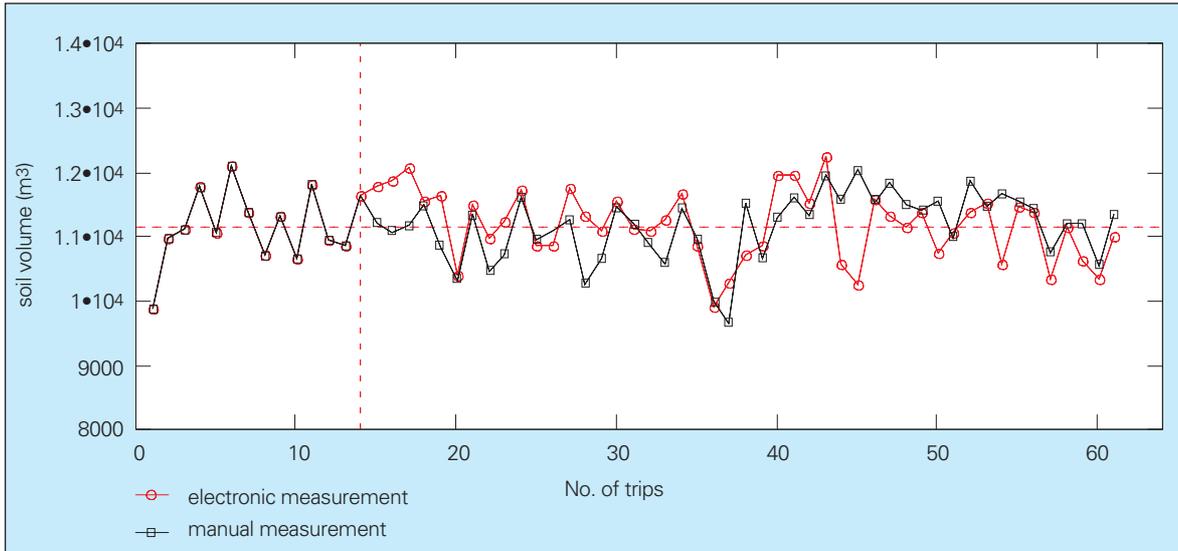


Figure 3. Volume measurement, hopper dredger Amsterdam.

The parameter in question is the saturated soil density (in the hopper), which is dependent on soil properties and therefore dependent on the dredging location. As different hopper dredgers working at the same location have shown different values of soil density, the type of hopper also has an influence on this parameter.

To overcome this problem, a calibration method has been chosen so that the value of the soil density is developed from a number of manual soundings at the beginning of a project. During the calibration phase, which may include approx. 10 to 15 trips, the manually measured volume is introduced into the rearranged Equation 1, to calculate the soil density. The mean of these calculated density-values is then chosen for the calculation of the volume for the rest of the project.

The main advantage of this method is that there is no need for a totally correct calibration of the density and velocity transducers, as any constant error is compensated by the calculated factor. The main disadvantage of this method is its dependency on the location. At every new location the calibration process has to be repeated. This method has been used for all the projects listed later in this paper. From the great number of results an example is shown in Figure 3. See also Figure 4.

During the first 14 trips, the value for the soil density has been calculated to be 1.8871 t/m³. The respective standard deviation is 2.142 %. After the calibration procedure, the volume has been measured both manually and electronically. The result shows, that although there are differences during the individual trips, the mean values are nearly identical (Table I).

Taking normal accuracy levels of dredging into consideration, this result can be regarded as very accurate. After experiencing similar results with other projects,



Figure 4. The Amsterdam working on harbour filling in Hamburg.

Table I. Volume measurements

	Manual	Electronic
Total volume	680,432 m ³	681,555 m ³
Mean volume per trip	11,155 m ³	11,173 m ³
Difference	0.165 %	0.165 %

the conclusion can be drawn that this type of electronic measurement can be recommended as a reliable tool. The fact that there are enormous savings if the work can be done from any remote site should also be mentioned.

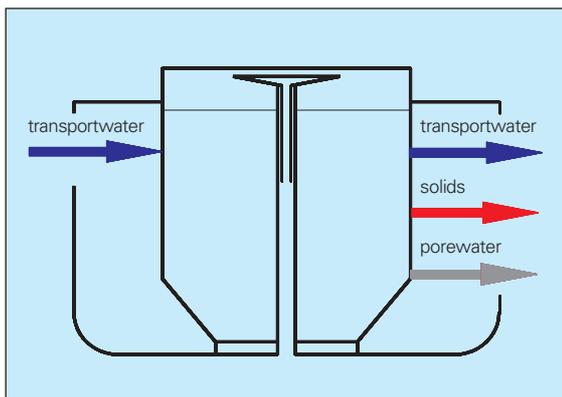


Figure 5. Mass balance during hopper discharge.

Checking the results with additional measurement

It may be regarded a disadvantage of the electronic measurement that the parameter which is the key issue for the economic success of the project is developed from a single measurement system only. As all systems are susceptible to failure, an additional measurement system with which the results of the density and velocity transducers can be checked is needed. The method chosen is based on the idea that the discharge of soil must be proportional to the decrease of the ship's displacement.

As a first approach it can be assumed that the water fed to the hopper to prepare the soil for hydraulic transport is of the same magnitude as the discharged transport water. In this case the loss of weight is only owing to the discharged solids and the pore water

(Figure 5). Although practical experience shows that this assumption is not continuously valid, it opens a possibility for a first order check of the volume calculation. For this reason the accumulated loss of weight is calculated according to Equation 2 and plotted together with the displacement curve in a single diagram. (Figure 6). See also Figure 7.

$$M1_i = dpl_0 - \left(\sum_{i=0}^i \delta Vb_i \right) \cdot \rho b \tag{2}$$

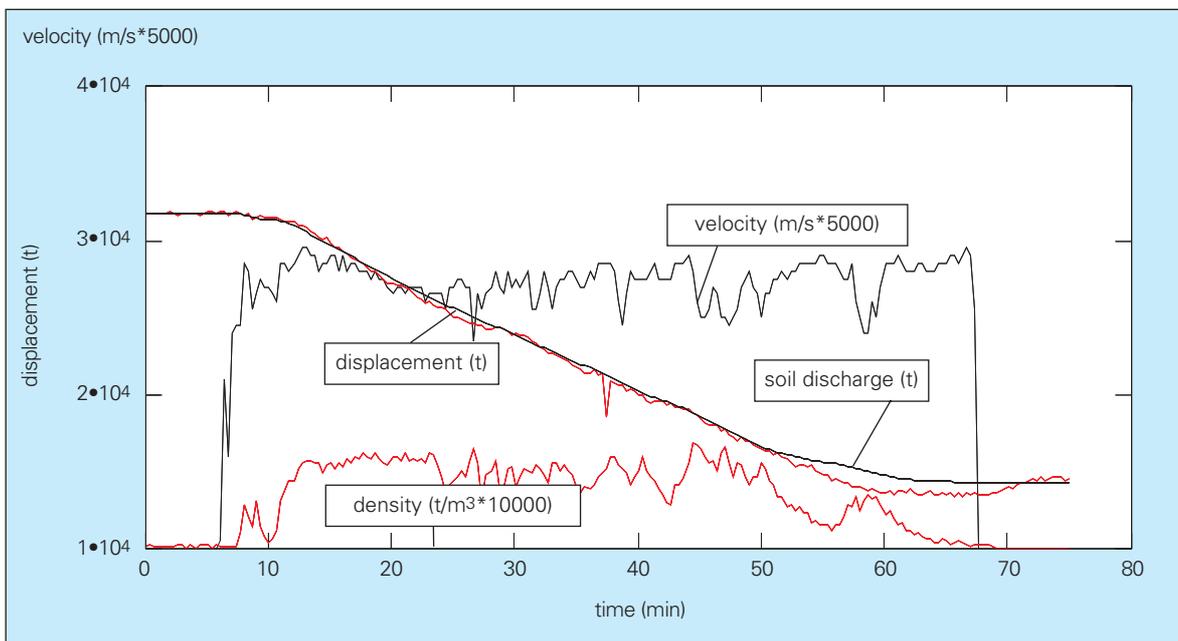
where,

M1	t	accumulated loss of weight owing to soil discharge
dpl ₀	t	displacement at start of discharge
δVb	m ³	soil volume at measurement interval
ρb	t/m ³	density of soil

The example shows a nearly perfect coincidence between the displacement and the soil discharge. As both parameters are measured with completely different systems, the correctness of the results is most probable. If density or velocity measurement fail, or if the soil density value is not correct, these incidents can directly be seen from the diagram. In that case, there is a deviation of the curves at the time of the incident.

The process of supervising the discharged lodes from the office location comprises picking up the data from the ship and evaluating the volume with discharge diagrams. Carried out once or twice a day, this procedure takes only very little time, but offers a very comprehensive analyses of the hopper operation.

Figure 6. Example: Discharge diagram hopper dredger Pearl River.



Other parameters such as desalination, ship's speed and heading, dredging depth and such, and a complete breakdown of operational time periods can, of course, also be documented. These items are, however, not the subject of this paper.

IMPROVED METHODS

As mentioned above, measurement of the soil volume is the crucial point of all electronic measurement systems. Unfortunately, the soil density varies with different soil types at different locations and the assumptions of Figure 5 cannot always be met. Consequently, the described method is confined to those projects where the necessary calibration work is only a small portion of the total work. In addition, the checking function of the displacement curve cannot be used for all types of hopper design.

All these problems can be overcome if, instead of the soil volume, the solids volume or mass are taken as basis for the load calculation. While the soil density varies greatly, the solids density is confined to very close limits. This is also the basic idea of the TDS system, which uses the draft and the load level as basic parameters for load calculation. See under "References" Rijkswaterstaat for a detailed description of the TDS system.

However, if the TDS system is the only tool for load measurement, this again does not meet the demand for redundancy. Problems may emerge, if one of the many elements of the system do not work properly.



Figure 7. The Pearl River working on land reclamation, Hamburg.

It is also known, that the TDS system has difficulties coping with swell, e.g. if the discharge is done via an offshore SBM. It is for that reason, that the combination of the TDS system with the density and velocity measurement seems to be the best solution.

To compare the results of both systems, a comparable parameter has to be chosen. Preferably this should be the discharged solids mass, which is the key parameter of the TDS system. The corresponding value of the density and velocity measurement is calculated with the introduction of the solids density into Equation 1:

$$V_f = \sum_i \left[\left(\frac{\pi}{4} \cdot dr^2 \cdot vm_i \right) \cdot \left(\frac{\rho_{gt} - \rho_w}{\rho_f - \rho_w} \right) \cdot \delta t_{s_i} \right] \quad (1a)$$

Figure 8. Example: Discharge diagram hopper dredger Amsterdam.

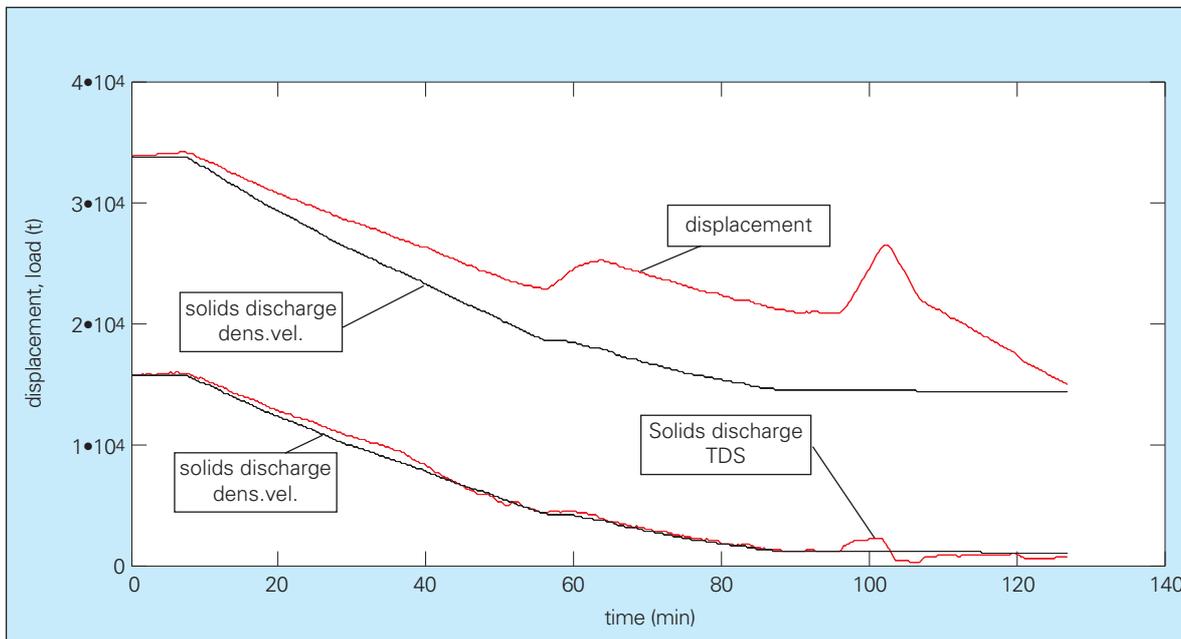




Figure 9. Geopotes 14, harbour filling at Hamburg.



Figure 10. Gerardus Mercator, harbour filling at Hamburg.

where,

V_f m³ solids volume of hopper load
 ρ_f t/m³ solids density

The corresponding solids (mass) discharge is:

$$M1f_i = tdsto_0 - \left(\sum_{i=0}^i \delta Vf_i \right) \cdot \rho_f \quad (2a)$$

where,

$M1f_i$ t accumulated loss of weight due to solids discharge
 $tdsto_0$ t solids mass at start of discharge

With this calculation both values for solids mass discharge can be plotted in a single diagram (bottom lines of Figure 8).

The example shows, that there is a perfect coincidence of both curves, although they are measured with com-

pletely different systems. As already stated above, this coincidence of results of two independent systems is a guarantee for a correct measurement. From another viewpoint, this presentation of results can be regarded as a method for double-checking both measurement systems. In this way the oscillation of the TDS curve at the end of the discharge process can clearly be detected as a temporary failure.

During this year's activities it was experienced, that the solids presentation was always applicable with good results, even in those situations where the soil presentation as described under "Checking the results with additional measurement" did not offer a realistic solution.

This too can be demonstrated with the example of Figure 8, where the upper two lines show the soil method. It is obvious, that the results of the density and velocity measurement cannot be checked with the displacement curve, as the unloading process of this ship does not follow the assumptions expressed in Figure 5. Instead this hopper uses an increasing water level during the discharge process.

SUMMARY OF PROJECTS USING THE HMT DATA ACQUISITION AND ANALYSING SYSTEM

The methods described in this paper have been developed since 1993, with test projects in 1993 and 1996 and full operational application at a number of projects in 1997. As every project has its own specific history, this paper can only present some significant experiences (Figures 9, 10, 11 and 12). The individual projects are listed in Table II.

During all projects, measurement of soil volume during the discharge process was the most important issue. For this reason, the electronic measurement described earlier was used, incorporating individual calibration procedures at every location and for every hopper dredger.

The results show that a high overall precision (less than 1% difference compared with manual sounding) can be reached if the calibration procedure is carried out carefully. It also became clear that under certain environmental conditions, such as discharging in swell, the density velocity measurement is the only method possible.



Figure 11. Volvox Scaldia, beach nourishment at Sylt.

RECOMMENDATIONS

Although the system has proven to be practical, the disadvantages, i.e., the dependency on different soil properties at the individual locations, became visible. With one project there were so many different locations, that the necessary calibration work nearly

Table II. Test projects using the HMT data acquisition and analysing system.

Year	Project	Hopper Dredger	Status / Results
1996	Beach nourishment, Sylt	Christoforo Colombo	successful test
1996	Harbour filling, Hamburg	W. D. Gateway	successful test
1997	Maintenance dredging, Hamburg	Ijssel Delta	measurement of dredging performance
1997	Harbour filling, Hamburg	Amsterdam	measurement of dredging performance and desalination
1997	Harbour filling, Hamburg	Geopotes 14	measurement of dredging performance and desalination; volume measurement impossible because of too many dredging locations
1997	Land reclamation, Hamburg	Pearl River	measurement of dredging performance and desalination; volume measurement impossible because of problems with velocity sensor
1997	Harbour filling Hamburg	Gerardus Mercator	measurement of dredging performance and desalination; volume measurement impossible because of problems with density sensor
1997	Beach nourishment, Sylt	Coronaut	measurement of dredged volume is the basis for payment
1997	Beach nourishment, Sylt	Volvox Scaldia	measurement of dredged volume is the basis for payment
1997	Land reclamation, Hamburg	W.D. Fairway	desalination measurement



Figure 12. W.D. Fairway working on land reclamation, Hamburg.

covered the total duration of the project, thus jeopardising the success of the electronic measurement.

To overcome these disadvantages, it is highly recommended that the solids mass calculation be used as a basis for payment for future projects. The recommended method should combine density and velocity as well as TDS measurement and present the results in single diagrams as described under "Improved methods". This procedure guarantees high precision and reliability.

A further major experience was the dependency of the electronic measurement on the reliable function of the measurement equipment, mainly the density and velocity transducers. Although self evident, this simple demand could not be met at a number of projects, thus preventing the application of the system. Future contracts definitely have to put more emphasis on this issue.

The method of remote data acquisition and transfer proved to be very successful. All elements including hardware and software showed excellent operational performance with only very little downtime. The D2 network can be regarded a useful tool, although it must be accepted that there are certain time periods where data transfer is difficult.

The fact that all hopper operations can be electronically monitored from the client's office, offers a number of benefits for the client. Compared to manual survey, there is of course a great reduction of necessary manpower. Moreover, in case of any discussions with the contractor, the detailed recording of all operational procedures, which comes as a by-product of this method, can be regarded as an indisputable basis.

Conclusions

A remote-operated data acquisition and analysing system designed by HMT for the calculation of hopper loads discharged by pipeline has successfully been used in a number of land reclamation and beach nourishment projects, covering both data logging and transfer process as well as the analyses of hopper operation.

Operational data, acquired with the ship's measurement system, can be picked up from a serial interface and transferred to a remote location, e.g. the client's office, using GSM mobile phones. Intranet technology proved to be a reliable and easy to handle software for this task. Considerable savings in labour and a very detailed presentation of the hopper operation are typical results of this system.

A measurement concept for the analyses of the hopper discharge process has been developed which uses redundant, independent measurement systems for the calculation of the discharged load. The systems use density and velocity measurement and TDS. A graphical comparison of both results provides a quick accessible and highly reliable statement about the validity of the measurement. If the soil volume is the basis for payment, the decrease of hopper weight is plotted together with the ship's displacement. Results from this electronic measurement differ less than 1% compared to manual sounding.

However, owing to the specific disadvantages of volume measurement, it is recommended to use the discharged solids mass as basis for payment. In this case the density and velocity measurement is compared with the results of the TDS system to reach redundancy. Being more independent from the soil properties, this method is applicable to all conceivable discharge processes.

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