Article, Published Version

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Hydrographische Nachrichten

Monitoring of sand and gravel mass movements at a dredging pond using multi-beam sonar

An article by *Kristoffer Eberle*

Dredging companies cannot realise their yearly extraction loss, without knowledge of geomorphologic underwater structures, how they occur and how they can be prevented. In order to localise and quantify movements of sand and gravel masses within a dredging pond a continuously mined pond was monitored over a period of eight weeks. In this period the pond was surveyed a total of four times with a Reson Seabat 8101. The effecting range and the amount of masses and movements can be identified by comparison of the gained bathymetric data. Furthermore, they can be interpreted regarding the extraction loss and behaviour of the mining procedure. For this investigation a dredging pond in southern part of Germany was chosen because of its surveying conditions and the possibility for high dynamic movements, due to steep embankments being dredged against.

multi-beam echo-sounder | sand | gravel | mine dredging | monitoring | mass movements

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Introduction

Many people underestimate the amount of sand and gravel being dredged annually. The worldwide yearly amount was 2002 on first place followed by coal, gas and oil (cf. Patzold et al. 2008). Sand and gravel deposits created during the glacial periods along the Upper Rhine Plain are well known by dredging companies. The material exploitation is primarily used for industrial constructions, road building but also provide the chemical, glass, steel and petroleum industries. This investigation was evoked by the discussions where the true sea bottom lies, held between surveying companies, dredging companies and the federal institutes. These disputes began with the differences in mass calculations of the surveying company and the weighted mass being exploited of the dredging companies causing financial recalculations. These calculated masses depend on the surveyed depth compared to a previous survey. First thoughts of a changing water depth were the irrigation of fine sand in the upwards moving clamshell and its colmation on the sea floor. A preliminary investigation by the Karlsruher Institute for Technology confirmed this (Nestmann et al. 2009). Not taken into account were other aspects such as slope slides which a grab dredger causes during mining process. The thesis investigates primarily the mass movements caused by slope slide at steep embankments and was enabled by the surveying company. Goal was to identify the amount of masses and its relocation.

Legal aspects

Taking a closer look towards the legal aspects, gives an insight why the above named disputes between the involved parties play such an important role for mine dredging. In order to achieve a sustainable and economical mine dredging process controlled by the federal institutes mining licenses are issued. These licenses are based on the federal laws of Nature Conservation and Water Resources Law. Each and every mine dredging pond is individually observed regarding the licenses which define, for example, the maximum dredging depth, lateral expansion of the pond, the maximum amount of exploitable masses and the resulting slope of embankments. A biennial hydrographic survey assess the current status of mine

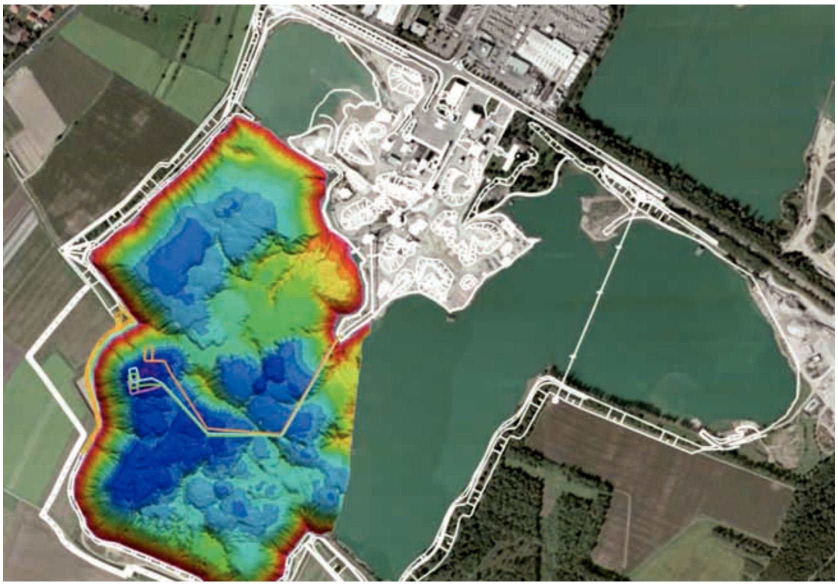

Fig. 1: Location of grab dredger

Fig. 2 (right): Floating grab dredger

Fig. 3: Steep embankment being dredged against

dredging process. With the results the parties can identify their process, possible exceeding limits, remaining masses and financial planning. Knowing this is important for the running low of masses and its consequences of applying for new mining licenses.

Integration of system components

For the investigations the following components were equipped, interfaced and integrated. Multi-beam system was a Reson Seabat 8101 which provided the depth measurements in a total swath of 150°, 75° each side with a spacing of 1.5°. The measure rate was 15 Hz, due to the water depths of up to 50 metres. For coordinating the depth measurements a GNSS by Leica receives WGS 84 coordinates. The three dimensional coordinates are directly transformed in the German Gauss-Krueger-System. The heights are transformed by using the Digital Finite Height Reference System – DFHRS. The DFHRS research project of the Hochschule Karlsruhe – University of Applied Sciences (HSKA) aims at the parametric modelling and computation of height reference surfaces (HRS) from geometric and physical observation components in a hybrid adjustment approach. The high accuracy of the position is acquired by applying the SAPOS corrections to achieve a real time kinematic precise differential positioning. The next aspect is to monitor the vessel motions by implying the »Teledyne TSS MAHRS Surface«, a meridian attitude and heading reference system, which gives us mainly the roll, pitch and heading attitudes. To combine all incoming component data a navigation software such as »Reson PDS2000« is used. It calculates the x-, y- and z- coordinates of the measured depths on the fly.

Physical behaviour of sand and gravel

Sand is just as exciting as a complicated matter, which shows some surprising behaviour partly as a solid and partly as a fluid one. Especially the fluid behaviours are from interest with respect to the slope slides. If sand trickles down on the same spot a conical structured pile is built. By continuously adding more and more sand, the slopes reach a critical value. Exceeding this value the sand regains its natural slope, normally round about 30° to 35° depending on the grain size and the surface structure, also known as »self-organised criticality«. By observing more closely these avalanches caused by the self-organised criticality another process can be identified, which is known as a fining upwards process. By downwards movement the smaller particles sort themselves out by moving and depositing above the coarse material. These two behaviours can even reach a more complexity by combining it with water as it is in dredging ponds. Comparing the relation of water-sand mixture the water can increase the natural slope over 90° by working similar to glue. If the water content reaches a critical ratio the mixture reacts as a plastic and flows literally apart. The water acts as a »lubricant« which decreases the friction between the grain particles and destroys its stable architecture, better known as quicksand (cf. Mitari et al. 2006). Referring now to slope slides their origin and behaviour can be understood. By exceeding the critical water ratio within the slopes underwater and an initial shockwave, for example, the

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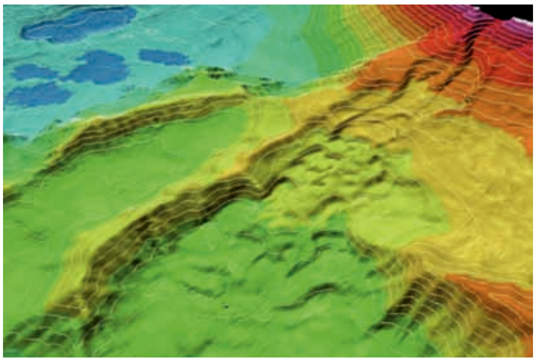

Fig. 4: Inlet area of sand reclamation

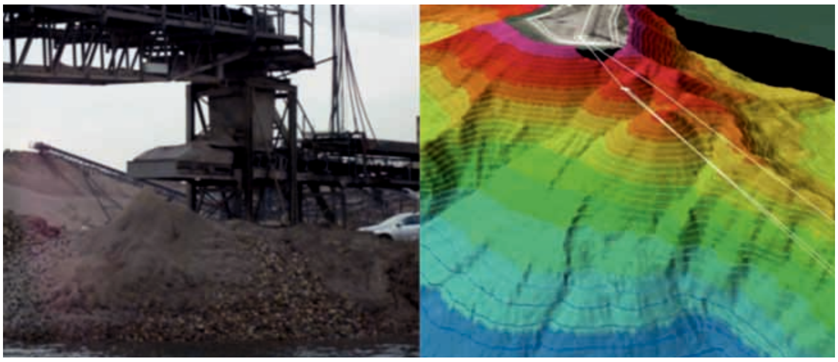

Fig. 5: Pile of sand above and below water

dredging process, the slides are caused. By sliding downwards the finer material fines itself upwards ending up in the water column. The more coarse and heavy material stays close to the bottom and acts as a debris flow.

Practical project realisation

For the survey planning it is not as easy as on open sea. At a dredging pond many things have to be taken into account which interferes with straight survey profiles. These aspects are the curved shoreline of the pond, anchoring lines fixing the grab dredger just above water level, the dispatch line transporting the material onshore and active mine dredging process resulting in a bad multi-beam data quality. The goal is to achieve with a minimum of survey profiles a maximum of seafloor coverage. During survey the beam angles were limited to 50° on both sides and 60°/30° along the shoreline in order to achieve a similar two way travel time for both sides especially close to steep embankments. The beams close to the embankment have shorter travel time than the ones away from it, which result in a halo effect, prevented by limiting the opening angles.

Survey journal:

- 10.-11. May: Reference survey
- 16. May: Second survey
- 30. May: Third survey
- 4. July: Fourth survey

The surveys were executed on Mondays before the grab dredger started its mining. The grab dredger was idle during the weekends giving the particles within the water column time to settle down. This allowed very good survey conditions. For an independent verification of the gained results a sub-bottom survey was conducted with the fourth and last survey at areas were deposits have been located.

Results of monitoring and conclusion

The main result is the refilling of the excavated pit with coarse material and the sedimentation of finer material behind the grab dredger leading to the conclusion that even in untouched areas the sea bottom changes within a range of 200 metres around the dredging area. More interesting is the refilling of the excavation pit with the coarse debris flow resulting in a change of water depth of up to 5 metres. Finer materials deposit only with a thickness of up to 0.75 metres behind the grab dredger. This result has been confirmed at selected areas by the Innomar SES-2000 light system. The refilled pit has, for example, chaotic and irregular sediment structures compared to the slowly depositing materials, which have constant and parallel structures.

Another aspect is the loss of material from the dispatch line. To keep the dispatch line more agile pivot points are integrated. These points are also weak spot where already lifted material is lost back into the pond. It could be quantified that round about 100 cubic metres of material per week per pivot point are lost.

Taking these aspects into account it can be realised that the sea bottom undergoes a continuous change due to the dredging processes. After recalculating the masses from the hydrographic survey they match together with the weighted material. With the feedback of the involved dredging company a total extraction loss of 20 % could be identified, which can be prevented by changing the mining procedure. The grab dredgers re-mine already mined positions to extract the refilled pits before they get overlaid by the finer material layer.

Further conclusion may affect the legal and financial aspects. Regarding the legal aspects new limits can be obtained because of the extraction loss of 20 %, but can be also denied because there is still enough material in the pond. Therefore, it is inevitable for the future to figure out if the refilled material is usable or not which also influences the financial calculations for the company. □

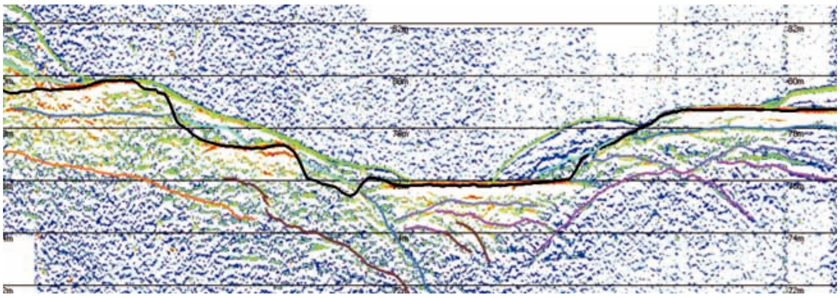

Fig. 6 (top): SBP profile showing the refilled excavated pit in the middle part

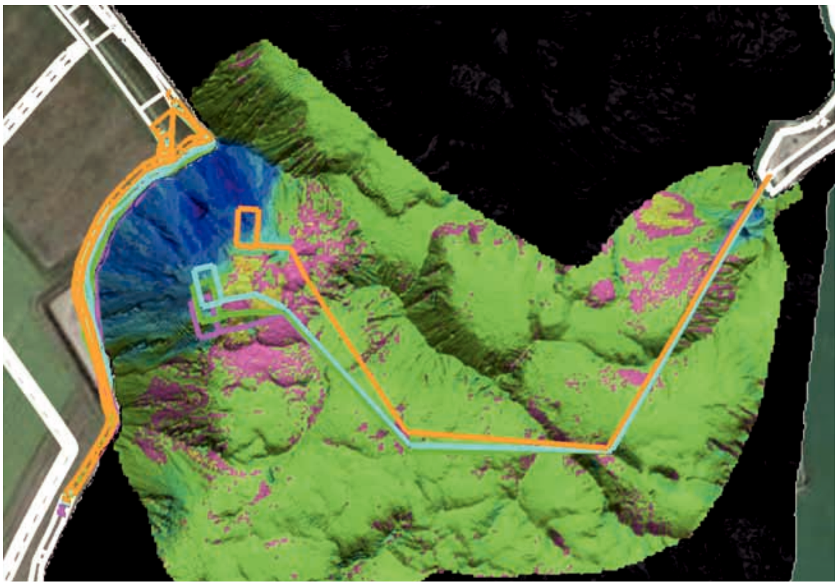

Fig. 7 (middle): Difference model between first and last survey showing the total cuts and fills of the 8 week period. Coloured lines stand for the grab dredgers position which moved from magenta to orange

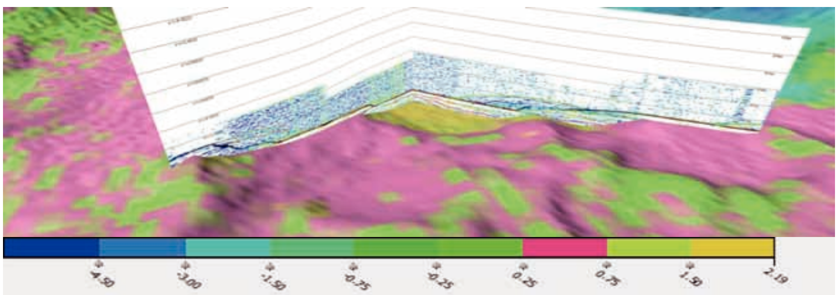

Fig. 8 (bottom): Combined survey data SBP profiles and bathymetric difference model – colour table symbolises the cuts and fills close to the grab dredgers position