Sediment management in the Port of Rotterdam

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1. Introduction

The Rotterdam port has been an important European maritime complex since the end of XIII century, when a dam was built on the Rotte river, after which human settlements were formed boosting the fishing industry in the region. By developing its infrastructure and investing in innovations over the centuries, the Port of Rotterdam has become the Europe's largest and most sustainable port with outstanding reputation among the Dutch public. With an area of over 100 square kilometres, the Port of Rotterdam has a length of 42 kilometres with a pier length of about 89 kilometres. The port has nearly 95 depots for liquid and dry cargo, cruise liners and also for vessels navigating internally. Along with this, the port also has tug boat facilities and piloting boat facilities.

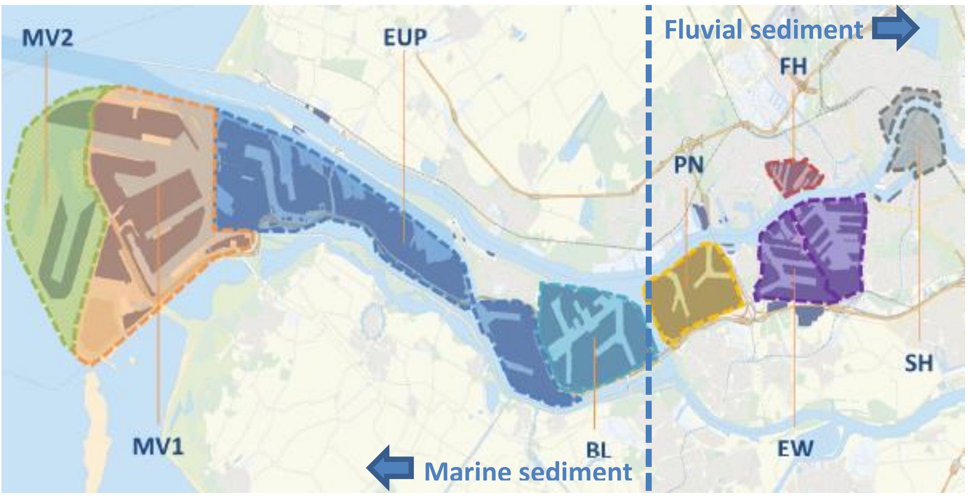

Figure 1. Map of the port basins: Maasvlakte II (MV2),Maasvlakte I (MV1), Europoort (EUP), Botlek (BL), Pernis (PN), Eem-Waalhaven (EW), Fruithavens (FH) and Stadhavens (SH)

The Port of Rotterdam is the busiest port in Europe. Shipping transport is a worldwide growing industry and vessels are increasing in size to meet the demand of supply. This results in higher drafts of the incoming vessels. In order to keep the port accessible for the vessels with the highest drafts, the Port of Rotterdam requires intensive maintenance dredging that yields 12–15 million m^3 of dredged material annually. This paper addresses the common practice of sediment management at the Port of Rotterdam. In particular the information about the surveying strategies, maintenance dredging, relocation and confinement of dredged materials is provided. In addition, the results of ongoing research on innovative maintenance strategies is presented.

2. Sedimentation processes

The Port of Rotterdam is located in the Rhine-Meuse estuary, which is the transition zone between a river environment (Rhine and Meuse flowing from the east on Figure 1) and a maritime environment (adjacent to the North Sea on the west on Figure 1). In this way the area of the Port of Rotterdam is influenced by the river discharge as well as the sea conditions resulting in sedimentation of both fluvial and marine types of deposited sediment.

The material to be dredged is sand and marine silts originating from the southern part of the North Sea and alluvial sediments (mainly silt) from the Rhine and Meuse. The dredge spoils consist predominantly of clean to slightly contaminated marine silt from the mouth of the port plus smaller volumes of moderately contaminated sediments from the inner harbours. During the 1980s and 1990s, the concentrations of metals and PCBs in Dutch coastal sediments fell significantly as a result of both the confined disposal of contaminated sediments and the cleaner emissions from sources in the Rhine catchment.

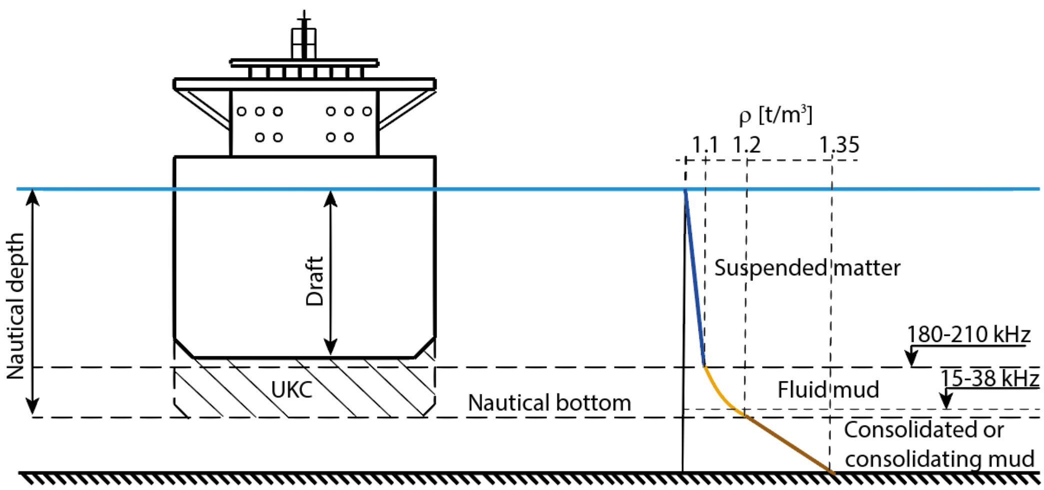

Figure 2. The nautical bottom concept at the density limit of 1.2 t/m^3. (From Kirichek et al., 2018)

3. Surveying strategies

The waterways are regularly monitored by surveying vessels, that use multi-beam echo-sounders for providing the hydrographic data. The multi-beam echo-sounder covers a large area during surveying as a result of the vertical fan shape and is therefore well suited for primary sounding. Traditional mapping is executed by emitting an acoustic pulse (of 200 kHz and 400 kHz) that propagates through the water column and reflects back from the bottom of the waterways. The depth in the waterways is derived from the travel time of acoustic signal inside the water column.

From the hydrographic data, the bathymetry charts are integrated with the Dredging Atlas, were the Nautical Guaranteed Depth (NGD) is compared to the acoustic measurements. If the survey shows that the NGD is higher than the measurements, the maintenance dredging has to be carried out in the area.

In the 70s, it was recognized that sonar measurements are not reliable in the areas with substantial fluid mud layers and, therefore, are no longer normative (Kirby, R. et al. (1980)). On the basis of full scale experiments in the Port of Rotterdam, in Bangkok and along the coast of Suriname, it was found that densities up to 1.2 t/m^3 had a tolerable influence on manoeuvrability of vessels. The "Nautical Depth" was defined accordingly (PIANC, 2014). The illustration of this concept is shown in Figure 2.

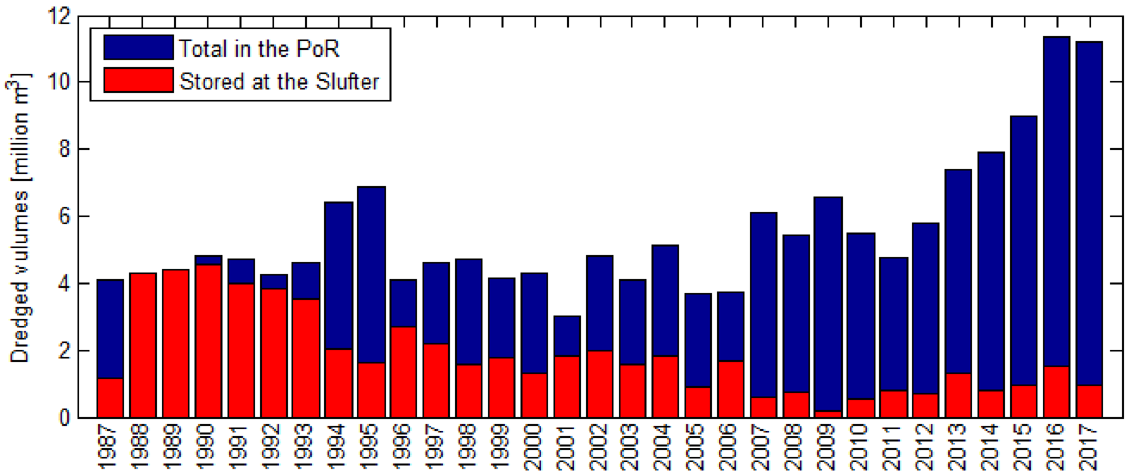

Figure 3. Dredged sediment volumes at the Port of Rotterdam from 1987 till 2017.

Over last decades, different tools has been used for mapping the depth level, where the density can reach 1.2 t/m^3. Currently, the profiler DensX is used by the Port of Rotterdam and Rijkswaterstaat to measure the density over the water column. Due to the nature of the profiler, the spatial resolution of these tools is limited to 1D vertical profiles. Therefore, the SILAS software is utilised to provide the NGD by matching the level of density 1.2 t/m^3, that is derived from DensX measurements, to the acoustic data that is measured by the single beam echo-sounder (of 38 kHz and 200 kHz).

4. Maintenance of navigation channels

The maintenance dredging over the port area is governed by two parties. The Port of Rotterdam maintains the port basins shown in Figure 1. The rivers and waterways are dredged by Rijkswaterstaat, that is part of the Ministry of Infrastructure and Water Management of the Netherlands. Figure 3 shows the dredged volumes at the Port of Rotterdam from 1987 till 2017. Note, the information and numbers in this section is only presented from the perspective of the Port of Rotterdam.

The Port of Rotterdam uses typically three types of dredging vessels for maintaining the waterways and preventing sedimentation in ports and waterways:
- Trailing suction hopper dredgers;
- Bed leveler;
- Grab dredger.

These types of dredging vessels are used in combination with each other in the port, each type of dredging vehicle has namely his own specialism. It is not possible to dredge the entire system with only one type of dredging technique. Certain soils and port basins require a specific dredging method. The statistical evaluation of dredging activities by different methods is shown in Figure 4.

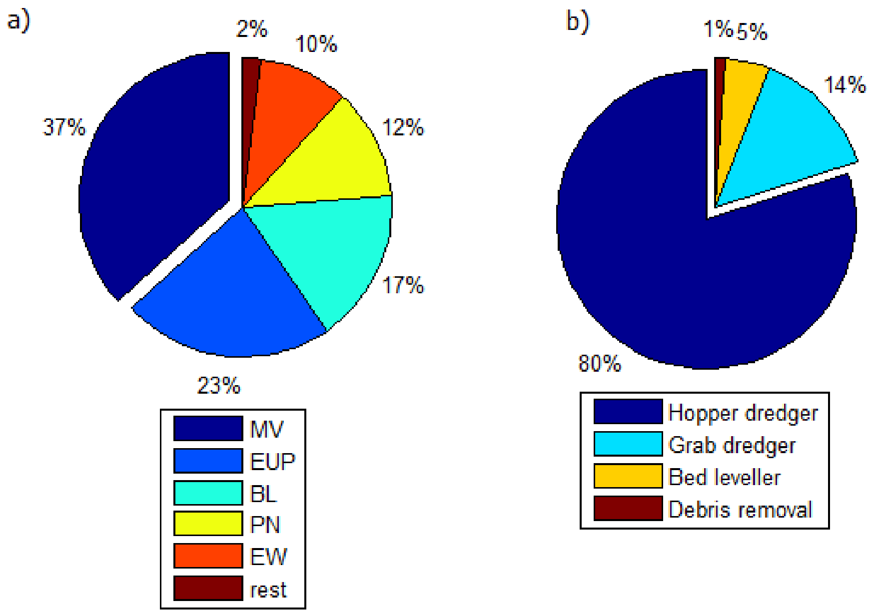

Figure 4. a) Dredged volumes at the port areas (see Figure 1) in 2017. b) Dredging methods by means of costs in 2017.

The dredging activities in the port of Rotterdam are divided among various contractors, on the one hand to ensure the continuity of the dredging effort and on the other hand to reduce the costs of this effort by keeping the monopolism down.

The work with trailing suction hopper dredgers in the port is divided into three plots. A separate tender is issued for each lot. Every contractor can register on a plot and submit a tender. It is up to the Port Authority in collaboration with Rijkswaterstaat to choose the best valued offer. After a decision is made, the contract is granted, usually for a fixed period of 3-5 years. The Port of Rotterdam also issues framework contracts, this means that the Port Authority can call the contractor for a specific period to perform dredging work within set frameworks. These are long-term contracts with a minimum term of three years, but with no agreed commitment. A framework contract is also drawn up for the smaller grab dredgers, bed-levelers, with different contractors. These contracts apply to the entire port area. The work with the grab crane pontoons is carried out on the basis of a long-term contract as well.

5. Sediment quality monitoring and policy

To be able to determine the ultimately preferred areas for the relocation of the Port of Rotterdam dredged material, insight into the chemical and physical quality of the dredged material is required. The quality of the sediment in the port basins and quality has been monitored via an annual monitoring campaign for several decades. There is, therefore, a detailed overview of the quality of the dredged material (see Figure 5) in the various parts of the port and the trend over the different years.

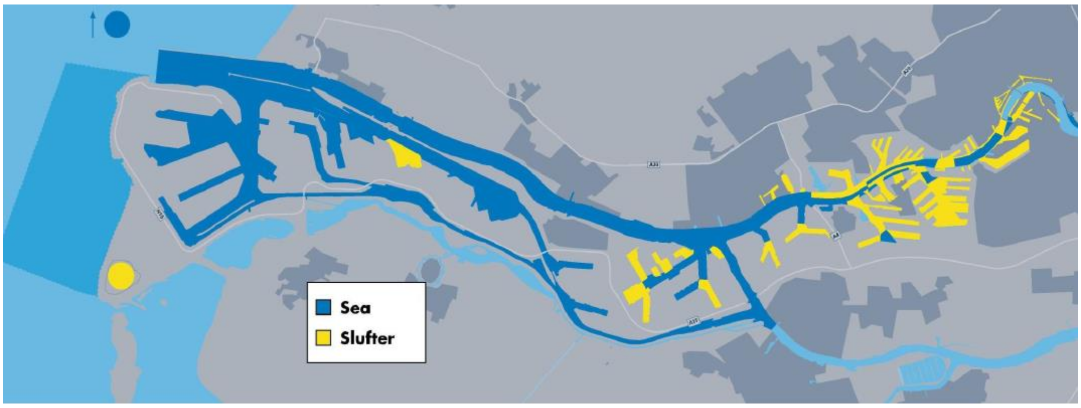

Figure 5. The location of clean and contaminated dredged material shown in dark blue and yellow colors, respectively. The former is relocated to sea, the latter is stored at Slufter.

For many years, dredged material from ports and channels has been disposed of over various relocation areas at sea (including Lowered Relocation Area, North West Relocation Area and Ijmuiden Relocation Area). Some of the sand from waterway maintenance (Maasgeul) is relocated within the coastal foundation. The destination of dredged material is subject to the Soil Quality Decree (in Dutch: Besluit bodemkwaliteit; Bbk). The silt from waterways is monitored annually based on physical and chemical criteria. Only dredged material that meets the standards for salty dredged material in accordance with the Soil Quality Regulations (in Dutch: Regeling Bodemkwaliteit; Rbk) may be relocated to sea (see Figure 6). The rest is stored in confined disposal facility such as the Slufter on the Maasvlakte.

5.1 Clean sediment

In order to keep Dutch ports and waterways accessible millions of m^3 of dredged material are relocated in the North Sea every year. Various relocation areas have been used for several years for this purpose (see Figure 6).

The present relocation areas for dredged material from the Port of Rotterdam and Rotterdam waterways are almost filled to capacity with dredged material. This means that, in the short term, the dredged material from the Port of Rotterdam and Rotterdam waterways will need to be relocated elsewhere. However, the Dutch legislative framework for the relocation of dredged material at sea, the Soil Quality Decree, does not immediately make it clear to the parties involved where dredged material can be relocated in accordance with this decree.

The Soil Quality Decree provides the Dutch interpretation in legislation for the various international treaties that regulate the management of dredged material. A condition that is included is that the relocation of dredged material must be of beneficial use (i.e. the relocation has to contribute to a functional and sustainable fulfilment interpretation of the morphological and ecological functions of the sediment).

In principle, the current relocation areas meet the conditions for beneficial use as outlined in the Soil Quality Decree. When establishing the current locations for relocation (see Figure 6) in the past, components of these conditions were implicitly taken into account. The relocation of dredged material is functional (no options for use on land and does not negatively impact other activities in the North Sea). In addition, a detailed assessment of ecological effects was carried out in the

Environmental Impact Assessment (EIA), which is the basis for the present North West Relocation Area (in Dutch: Loswal Noord West) and the Lowered Relocation Area (in Dutch: Verdiepte Loswal) relocation areas. According to the competent authorities these are locations where experience and research have shown that the relocation activity is not harmful for nature and does not obstruct other functions of use.

Figure 6. Relocation areas for dredged material (from Ebbens, 2013). The PoR uses only Verdiepte Loswal and Loswal Noord West for maintenance dredging.

Since 2009, the pits are not seen as a disposal site, but as sustainable location areas. Following this policy, the marine sediment can be returned to the sea environment and fluvial sediment can be moved forward to the sea. The lowered location will feed the sediment river along the Dutch coast.

5.2 Contaminated sediment

Confined Disposal Facility (CDF) Slufter (www.slufter.com, Figure 7) was constructed in 1986 aiming to create a solution for the storage of contaminated sediments from the basins of the Port of Rotterdam and surrounding fairways. With years the Slufter became the solution for the storage of contaminated sediment from the other parts of the Netherlands.

Since the construction of the CDF, the quality of the water in the port basins and fairways improved enormously due to the measures taken at the source of the contamination in the Rhine basin. Therefore, the yearly volume of contaminated dredged material from the port of Rotterdam stored at the Slufter dropped from 5 million m^3 in 1990 to 0.9 million m^3 in 2017 (see Figure 3), prolonging the lifecycle of the Slufter from an operational period to 2050. Due to this surplus of capacity the Port of Rotterdam Authority has considered other possibilities to store contaminated sediments into the CDF Slufter, for instance from other countries. The main reason for this is that upstream of the major rivers in the Netherlands, there are still several locations with historically contaminated sediments. These sediments can potentially contaminate large areas of the Dutch waterways if they get released into the rivers.

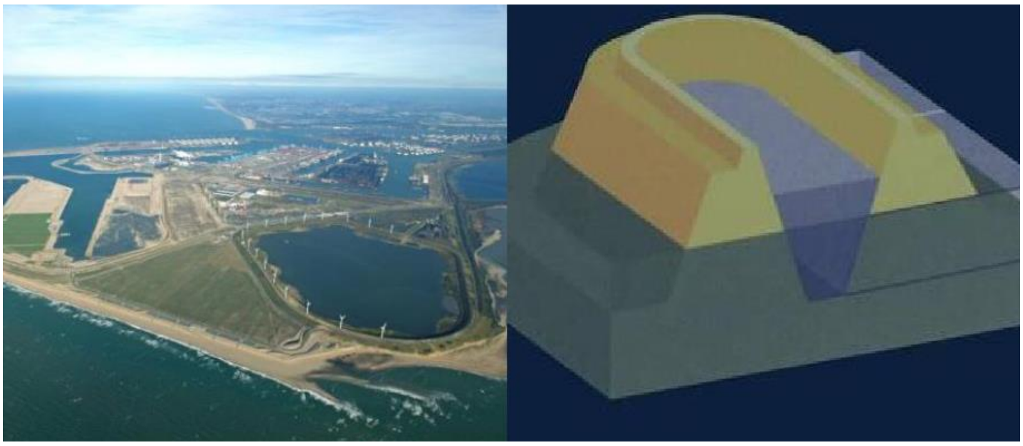

Figure 7. Slufter: confined disposal facility

To allow contaminated sediments from outside of The Netherlands to be stored in the Slufter, the environmental permit of the Slufter had to be changed. Since November 2010 CDF Slufter the environmental permit of the Port of Rotterdam Authority has been revised accordingly.

For contaminated sediments originating from outside of the Netherlands to be accepted for storage in the Slufter, first an official application by the applicant has to be entered that has to comply with the prevailing Acceptance Conditions. If this is the case the application can be accepted.

Before transport of the sediment to the Slufter can start, the holder of the sediment, called notifier in this procedure, has to submit a notification in accordance with EU Regulation (EC) No. 1013/2006 (EVOA) to receive the ex- and import permits. This notification has to be sent to the competent authorities in the country where the sediments originate. If the notification meets the requirements, the notification file is subsequently send by the authority of the country of origin to the competent authority in The Netherlands, and if necessary, to the authority or authorities of transit countries. The transport of the sediment can only start when all authorities agree with the transport and all permits are issued.

Since November 2010, the Slufter has been used on three occasions to store contaminated sediments from Germany and Belgium. Getting all the different authorities to agree with the transport takes time. Storing contaminated sediments in a CDF in another country has rarely been done. In some cases legislation in the country of origin makes transport challenging. Authorities from other countries don't have any knowledge of the CDF Slufter and how it is operated. Therefore they can be unwilling to issue a permit for transport. To overcome this, the Port of Rotterdam Authority informs, in collaboration with its competent authorities, the authorities from other countries about the operation of the CDF Slufter as an environmental safe solution for the storage of contaminated sediments from Europe.

6. Ongoing research

During last decade various innovative maintenance concepts have been tested at the Port of Rotterdam. In particular, the utility of water injection dredging (WID) has been investigated. The WID was carried out for liquefying the top layers of the sediment around a man-made pit, so that the mud would flow into the pit (500 m × 200 m × 1.5 m). From the DensX and multi-beam measurements it was concluded that the pit collected the fluid mud layer up to 1.5 m thickness from the surrounded area. The Graviprobe was used to capture the shear strength development in the collected fluid mud layers over 2 month period. The measurements are presented in Figure 8.

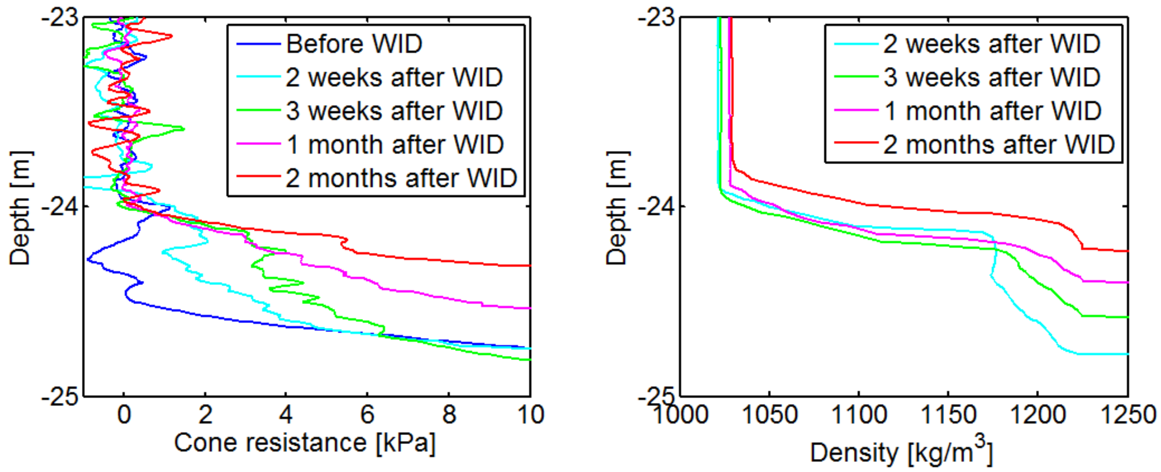

Figure 8. Fluid mud development in time, that is measured by Graviprobe (left) and DensX (right).

The recordings of the Graviprobe are shown as the cone resistance measurements as function of depth. The dark blue profile represents the measurements in the pit conducted before mobilizing of fluid mud into the pit by water injection. The cyan, green, magenta and red profiles show the fluid mud strength development in the deepening after 2 weeks, 3 weeks, 1 month and 2 months after the water injection, respectively. The same colors are used to show the density profiles that were measured with DensX. From the measurements, it can be concluded that the density of fluid mud develops faster than its strength.

It is concluded that the water injection dredging method can be efficiently used for liquefying and mobilizing weak fluid mud layers. In-situ measuring tools are available for characterizing the behaviour of fluid mud. Based on experimental investigations, it can be concluded that new cost effective port maintenance strategy is feasible in the ports and waterways with fluid mud layers.

7. References

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