Some learning cases in the Port of Rotterdam

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Some learning cases in the Port of Rotterdam

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Abstract. This paper present several cases in the Port of Rotterdam where both in the design and construction phase several different did not marched as expected. These cases are interesting for both the design as well the construction phase of a project. People will make mistakes however the mistakes describes in this paper have to be judged in time as not always everything was understood during the design and construction and the people of that time still these huge structures.

1. Introduction

Since about the year 1400 port infrastructure has been designed and built in the Port of Rotterdam. The first quay was built near the Boompjes in 1600. Within the design process and construction phase things might go wrong because of lack of knowledge and human error. In addition the understanding of the design and behaviour of structures also improved considerably with time. Making choices which may lead to problems is basically not wrong as long as we learn from these decisions and no people are getting hurt.

This paper discusses about 20 design and construction cases of port infrastructures that did not go as well as they should, both in the design and construction phase. In addition also some accidents will be discussed with its implications. Therefore the following divisions are used to indicate what went wrong or what was not optimal, i.e.: 1) design mistakes in the context of the available knowledge, 2) construction errors in the context of available knowledge, 3) accidents.

2. History of the Port of Rotterdam

The start of the Port of Rotterdam is marked with the building of the Boompjes quay wall.

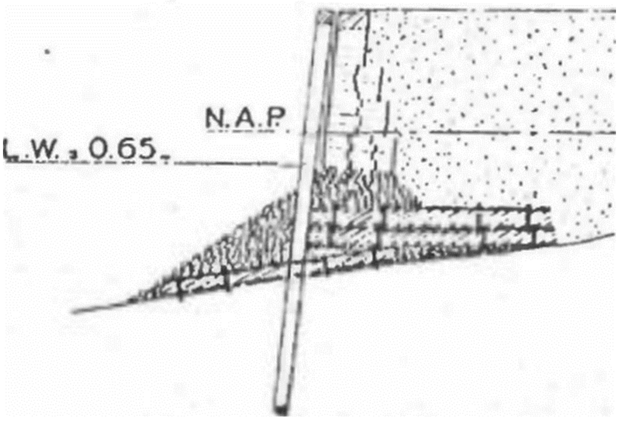

Figure 1. Quay wall along the Boompjes, Rotterdam.

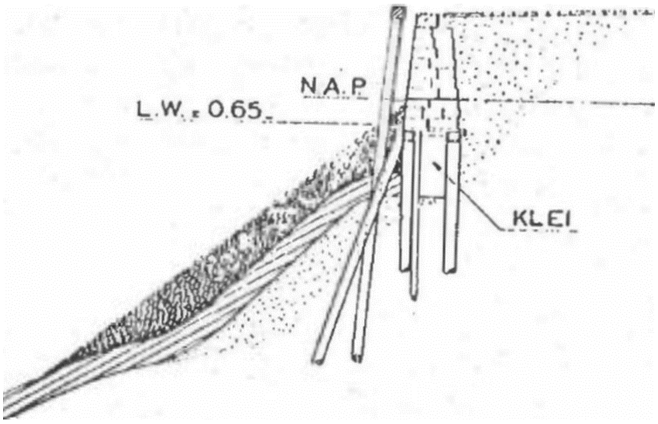

Figure 2. The reconstruction of the old Boompjes quay wall using batterpiles to increase horizontal stability.

As can be observed the retaining height is about 5 meters [7]. Since that time the port developed in western direction to the North Sea. The last extension was Maasvlakte 2, reclaimed from the sea. In figure 3 this development is indicated.

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Figure 3. Development of the port of Rotterdam.

With this extension of the port to the North Sea as indicated in figure 3 also the depth of the harbour increased roughly from 7 m near the city up to 25 m at the Maasvlakte. The retaining height of the quay walls increased from 3 m up to 30 m. This development enabled the biggest ships to enter the Port of Rotterdam. This also implies that a solution must be found to cope with these increasing retaining heights and loads, especially installation and anchor structures being therefore extremely important.

3. Discussion of the cases

2" Katendrechtse haven ± 1980

Figure 4. Failed quay wall Katendrecht.

This quay wall, built in 1938 and consists of a foundation of wooden piles while the underwater slope was stabilized with fascine mattresses[7]. This quay wall failed in 1990 due to increased scour by propeller loads from the containerships and lack of inspection. The quay wall collapsed over a length of 100m. The design in 1938 was a proper design, however the scour effect of the ships propellers was underestimated. This caused the failure of the quay walls after 50 years.

3.1. Failed jetty in the Botlek area

The jetty, figure 5, failed due to overloading. The acceptable loads were 20 kN/m^2, however the jetty was loaded up to 80 kN/m^2. This high load and the combination of bad soil conditions lead to this failure.

Figure 5. Failed jetty.

This jetty, figures 4 and figure 5, failed twice in three years time due to unsafe mooring maneuvers together with a relatively high current in the Meuse at that location [7]. Apparently it was very difficult when starting the mooring maneuver to adapt quickly to the high currents. So the front wall was damaged and the sand in caisson was washed out, creating a hole. This was a very dangerous situation as that area was used as parking area as well and high voltage electrical cables were present along the quay.

3.2. Scour hole due collision by ship with caisson quay wall

Figure 6. Hole in front wall of caisson quay wall.

damage was due to an failed mooring manoeuvre [7]. The captain of the ship could not get the machine in the reverse position in time. So the bulbous bow penetrated in the 0,25 m thick front wall of the caisson structure. So the front wall was damaged and the sand in caisson was washed out, creating a hole. This was a very dangerous situation as that area was used as parking area as well and high voltage electrical cables were present along the quay.

3.3. Collision of ship with ECT quay wall

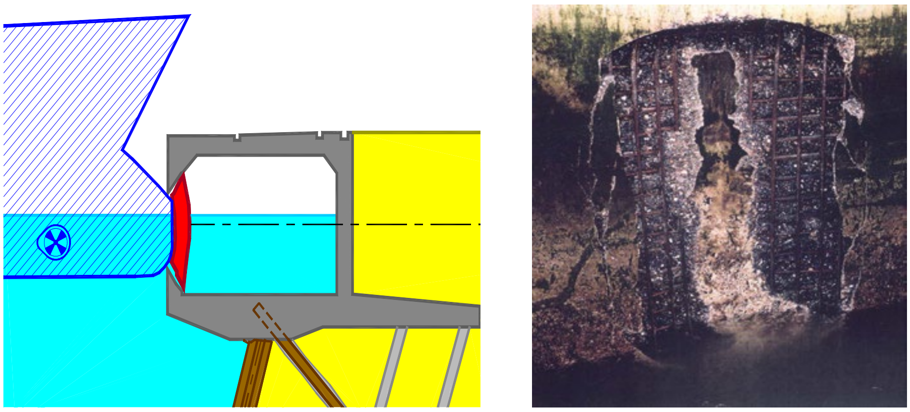

Figure 7. Damaged quay wall and impression of the damage of front of quay wall.

The ECT terminal on the Maasvlakte consists of a quay wall with a box structure founded on a comb wall and prefab concrete piles [7]. In 1992 a ship could not stop in time so the bulbous bow severely damaged the front wall. After inspection it was shown that only the front wall was displaced over ca 0,7 m. Due to the MV-piles the damage was limited to the front wall only. The rest of the structure remained intact.

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3.4. After collision with oil jetty

Figure 8. Damaged oil jetty.

The oil jetty at the Maasvlakte consists of a long concrete structure founded on steel piles, see figure 8 [7]. This jetty was severely damaged by a container ship which sailed through the jetty. The container ship was hardly damaged, however the jetty was severely damaged which is shown in figure 8. There was a considerable oil spill as well, which had to be cleaned up.

3.5. Pile damage

Figure 9. Pile damage.

Within structural design the foundation was first designed as mat foundation and later by wooden piles [7]. The wooden piles were replaced by prefab concrete piles and they are still used. However, on the Maasvlakte in 1990 severe damage was observed with prefab concrete piles both at the head the pile as well as at the tip. This damage was caused by heavy driving in very dense sand layers. Since then that vibro piles are mostly used in Rotterdam and recently even steel tubex piles are used to prevent damage a the pile tip.

3.6. Damage due to interlock openings

Since 1927 sheet pile elements are used to realize a retaining wall for quay walls up to a retaining height of 10 m [1]. Since 1950 the so called combi wall came into use and still is which consists of sheet pile elements with steel piles. One of the critical issues for building this type of walls is the challenge to prevent damage to the connection of the sheet pile elements and the piles. Today combined sheet piles are used for retaining heights of 30m. The evolution in time is presented in figure 10. In earlier days this wall was composed of sheet pile elements and Peiner profile sand since 1960 tubular piles are used as the main bearing element. Using this complex combi walls systems regularly interlock openings occurred.

The maximum interlock openings that occurred were with Amazone harbour quay walls 80 and with the ECT quay wall 180. Of course this raised the question could we continue with this type of structures. Therefore also other types of quay wall structures have been considered like fe caisson quay and jetties. Then in 1992 it was decided to improve the installation method which includes no driving on the sheet pile elements. These must be installed by vibrating and jetting at the same time. This of installation method appears to be a good method. In 2003 this method was further improved by drilling with bentonite.

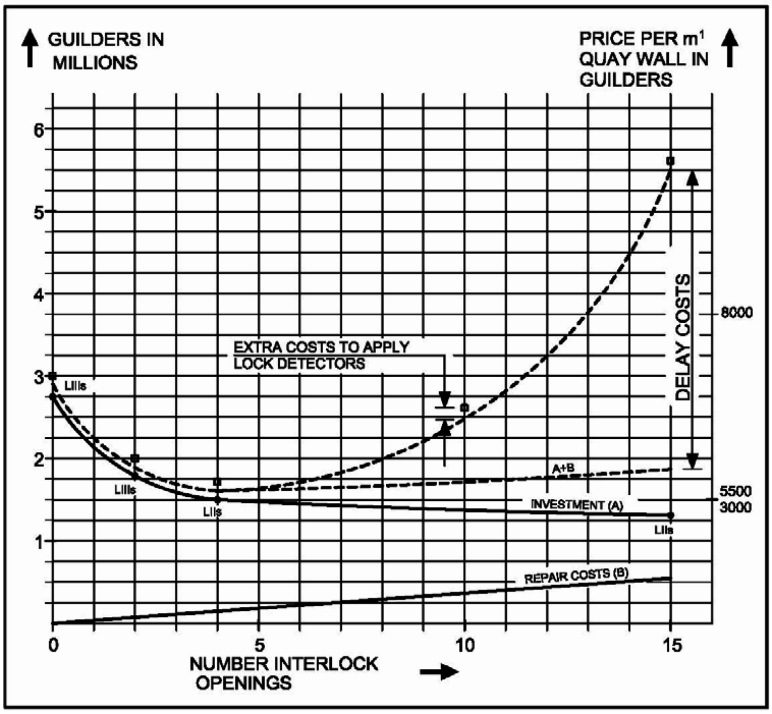


Figure 10. Investment in risk to prevent interlock openings.

Within the study conducted it was concluded that 2 interlock openings per 500 m quay wall is acceptable. The cost of repair of an interlock opening is approximately 30000 euro for each interlock damage.

3.7. Bund failure due to high speed of hydraulic filling

During the reclamation of the central area of Maasvlakte 1 by the method of hydraulic filling, the boundary dam, a bund of mine stone, failed [7]. This failure was initiated by the high speed of reclamation and an overlap which was too little within the mine tailing dam structure. In figure 11, it can be observed how the extent of the flow was developed.

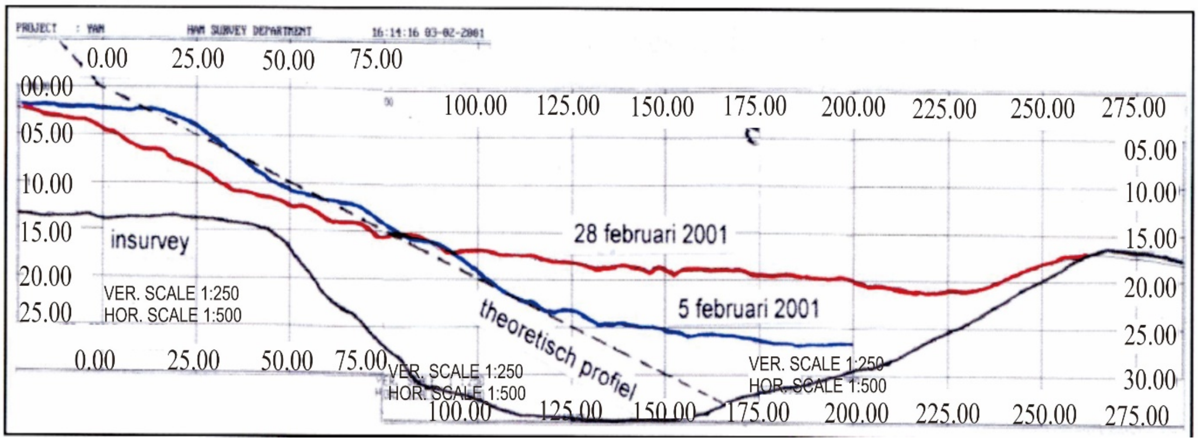


Figure 11. Bund construction and failed slopes.

3.8. Building pit flooded with water

Figure 12. Flooded excavation.

This figure 12 shows a construction pit flooded due to high water at the riverside [7]. The contractor was warned and advised to construct a protecting wall at a higher level as in winter and springtime high water can be expected. However the contractor took the risk not to take these precautions and the result was a flooded construction pit and a lot of damage.

At the Maasvlakte area the quay wall of the Amazon harbour was completed in two phases. During the first phase construction took place in a so-called ‘”wet situation, while the second phase was in a building pit, a so-called dry condition. However, the seepage screen separating the two building sites appeared to be too short so the construction pit was flooded with approximately 5 meters of water. Of course this created a lot of machine damage and delayed the construction time of the quay wall.

3.9. Container crane beam foundation at Maasvlakte

This crane beam was founded as a mat foundation however without densification of the subsoil 7. That created excessive settlements. To reduce this deformation the crane beam track has to be elevated to reduce the deformations This solution is principle a fine solution as preloading of the rail track is carried before installing the crane beam.

This solution also needed lifting when the settlements increased more than 20 cm as this has negative effects on the moments due to the horizontal force. However is noted here that already a mat foundation has been applied successfully in 1990 and 2008. At both locations the soil has been densified. Both locations behave very well for already 10 to 25 years.

3.10. Quay wall Brittannie harbor

With this quay wall the piles have been driven in upside the slope direction [7]. This resulted in a high deformation of the lower installed piles of deformations of 0,30 to 0,40 m. Fortunately it appears that the piles were not broken. However, the lesson learned in this case is that the installation of the piles should always start at the top of the slope so that the piles can move and damage the piles lower on the slope.

Figure 13. Failure due hydraulic fill behind quay wall.

The wall as shown in figure deformed too much due to high hydraulic loads during the construction period [7]. Thus due to time constraints the area at land side must be filled up. The sheet pile elements should be designed to make that possible.

Figure 14. Cracking of concrete structure due to wrong connection.

This figure 14 shows a wrong connection of two sections of a quay wall in the Waalhaven [7]. Normally the sections of the super structure are only connected with teeth construction. However In this case the reinforcement was continued over the cross sections of the quay wall which initiated cracking due to uneven settlement.

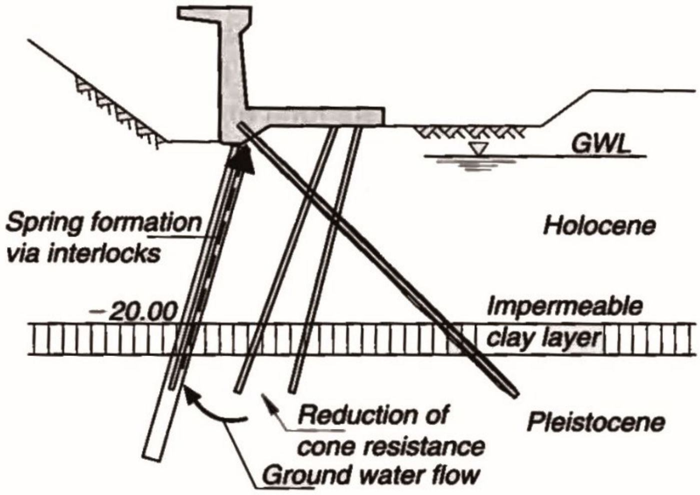


Figure 15. Building pit.

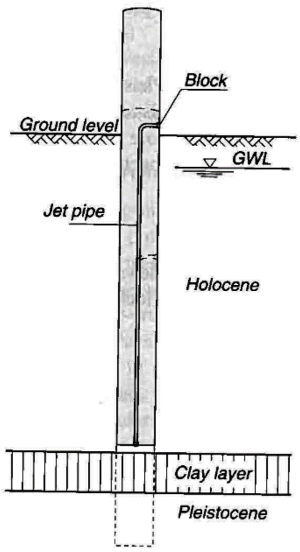


Figure 16. Pile jetting device.

Figure 15 and figure 16 show the cross section of quay wall with the building pit [8]. The concrete piles were installed with a jetting device for easier driving. However it occurred that the jetting pipes were not closed before driving started in the foundation layer. In that case the water flowed through the jetting pipe in the building pit and also reducing the bearing capacity of the piles.

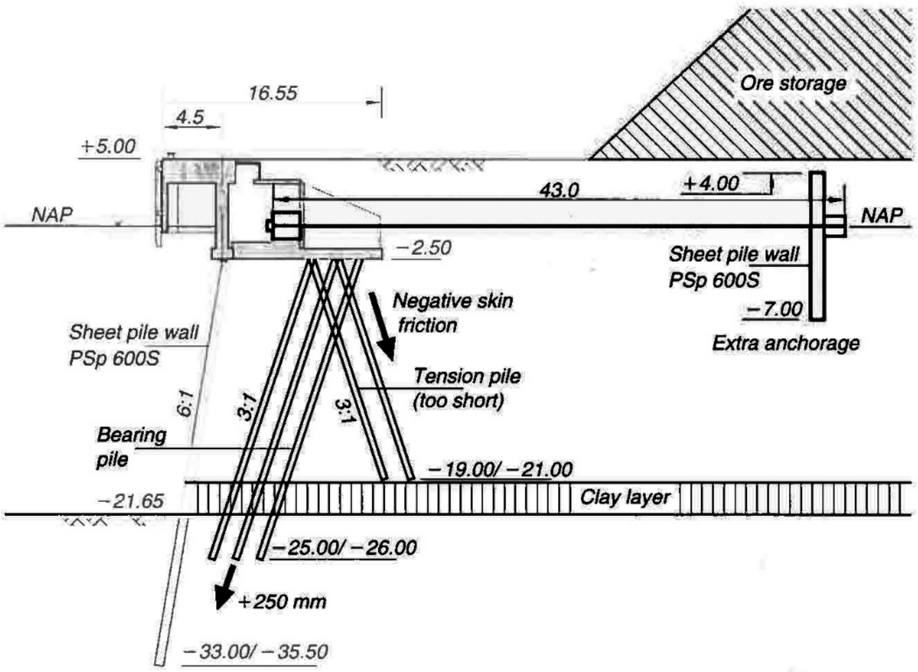


Figure 17. Quay wall with relieving floor.

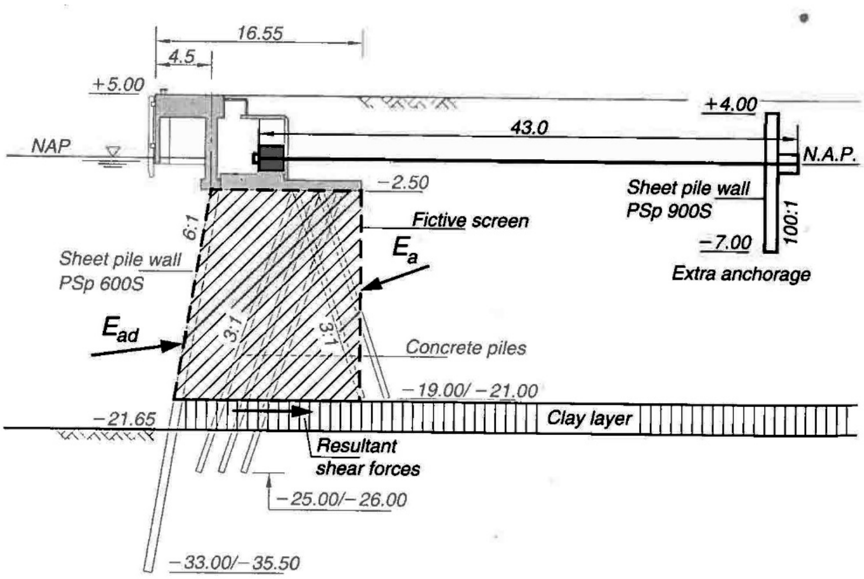


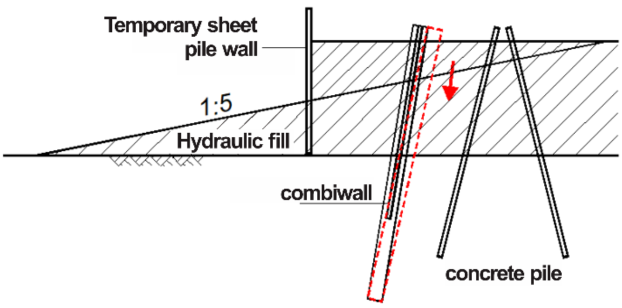
Figure 18. Quay wall with relieving floor.

Both figure 17 and figure 18 basically show the same structure [8]. However, in figure 17 the anchor force has to be taken by inclined concrete piles. However, they are so close together that the relieving floor in principle did not work. This caused a deformation of 30 cm in 20 years time. This required installation of an anchor screen.

The figure 18 shows the same structure. However, the concrete piles at the back site should have been driven deeper. As this was not realized due the very dense sand layer the structure showed too much deformation as well. It had to be anchored too with a horizontal anchor screen.

Figure 19. Deformed crane beam due too heavy densification of reclaimed sandfill.

This crane rail suffered too much deformation which was caused by too severe densification of the hydraulic fill [7]. Fortunately the crane could be properly installed without much extra work.



.**Figure 20.** Deformation combi wall due to severe densification.

Figure 21. Hole due interlock opening in combi wall.

3.11. Roro terminal Brittaniehaven

The roro terminal in this harbour basin has to be constructed [7]. The recommendation has been to make two cone penetration tests (CPT) at the two pile locations of the roro terminal bridge foundations. However, it was decided that nearby CPTs was enough to perform the design.

During the installation of the piles questions arose about the bearing capacity of the piles. It was then decided to perform two CPTs. It appeared that the soil conditions were worse than anticipated on the basis of the nearby CPTs. Due to this choice the bearing capacity has to be secured by grouting around and under the tip of the piles to obtain the required bearing capacity. This was a very expensive lesson to reduce costs on site investigation.

4. Conclusions and recommendations

This paper discussed and analysed several cases with quay wall design and construction that went not as expected.

The omissions and or mistakes have to be placed in time as some aspects of quay walls design and construction were not properly understood or building material was not available and people still dare to construct a structure.

People will continue to make mistakes, that can't be avoided. However, the aim should be to minimize the mistakes and as long no casualties occur it is only a matter of money.

In this respect the interlock openings with a combi wall system is an excellent example of a learning process. As to date hardly interlock openings occur with combi wall systems in the port of Rotterdam.

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