DEEPING METHODS OF QUAY WALLS

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ABSTRACT

The rapid expansion of trade has led to fast growth in the handling of goods in many ports. Quay walls are one of the essential components, with growing volumes of cargo and increasing vessel sizes. The demand for these structures is increasing. This report summarizes the previous studies on upgrading techniques and conceptual solutions used for deepening quay safely, numerically, and in nature and the effect of using the constructive elements to solve the technical problems that resulted from worsening. Generally, from the previous studies due to the high costs and the environmental boundaries, the complete demolition of an existing quay wall and replacement with a new structure is not preferred to be the first option. Therefore, the deepening and upgrading of the existing quay walls is the next option, also these studies show that the VHP grouting and installation of ground anchors have already proven to be an economical and technical solution for deepening quay walls and Multi anchored sheet-walls are common in construction engineering, but rarely used in quay walls. Finally, I noticed that not all presented options are used in practice, so I recommended that the researchers try all available solutions presented in this report to get the safest and most economical solution.

Keywords: Quay wall, Ports, Walls, Upgrading, Constructive elements, VHP grouting.

1 INTRODUCTION

One of the most common challenges for ports are increasing the depth in front of the toe of the existing quay wall structures. A set of complex technical problems arises when the deepening has to be performed near quay wall structures. In addition to the deepening challenges, it usually entails higher operation loads (mooring, berthing, cranes) and sometimes also storage loads on the structures due to the need to berth larger ships.Therefore, constructive adjustments have to be made to the quay walls, to provide sufficient strength and stability (PIANC, 2015). Recently, Finite Element Method, FEM, has become more popular as a soil response prediction tool. This has led to increase pressure on researchers to develop more comprehensive descriptions for soil behavior, which in turn leads to more complex constitutive relationships. Some authors in the literature take into account the ability of using the numerical work to examine the behavior of quay wall structures to solve the technical problems arises due to deepening and upgrading.The use of additional anchored tie rods grouted into the backfill soil and arranged along the exposed wall height is one of the most appropriate solutions adopted for rehabilitation and upgrading of the existing quay wall. An extensive parametric study through the finite element program, PLAXIS was carried out to investigate the enhancement of using grouted anchors technique on the load response of sheet-piling quay wall as the following authors

Elskensl and Bols, (1998) concluded that combining the techniques of the Very High Pressure (VHP) grouting and installation of ground anchors and drains had already proven to be an economical and technical solution for deepening quay walls. Both El-Naggar, (2010) and Mollahasani (2014) investigated numerically the rehabilitation of steel sheet piling quay walls using additional grouting tie-rods. The results showed that the VHP grouting, installation of ground anchors and drains has already proven to be an economical and technical solution for deepening quay-walls.The effect of deepening in front of quay wall structure without constructive adjustments to provide sufficient strength and stability has been investigated Habets et al., (2016) investigated the suitability of the performance-based design method to evaluate permanent deformations and amounts of (repairable) damage under seismic loading for anchored sheet pile quay walls that were not purposely designed for seismic loads. Galal, E.M., (2017) evaluated numerically the possibility to upgrade the open-piled quay wall structure of the container terminal of Port Said West port, the results showed that the structure after upgrading was able to keep the stability of the soil to its previous levels before upgrading and quay wall structure elements were able to resist the deepening effect plus the increase in crane loads. The effect of deepening on piles and diaphragm wall-supported berthing structures has been investigated by Muthukkumaran and Sundaravadivelu (2007), research on application of the analytical method to study the effect of dredging on piles and diaphragm wall-supported berthing structures, Sincil (2006), carried out a numerical analysis of anchored concrete pile walls and a comparison of field measurements and numerical values in terms of the stability of the structure and soil. Ong et al. (2016), made a comparison of finite element modeling of a deep excavation using 2-D finite element software, SAGE-CRISP version 5.1 and PLAXIS version 8.2. Premalatha et al., (2011) carried out a numerical study on pile group supporting the berthing structures subjected to berthing/mooring forces and the forces resulted from deepening operations. Subha, (2012) analyzed the lateral response of pile and diaphragm wall during dredging and seismic loading on the dredged soil numerically. Recently, Tolba et al., (2017) demonstrated a verification study for the ability of developing the diaphragm quay wall existing at the container terminal of Port Said East Port.

A number of cases studies had been reported in the literature which gives the relationship between soil properties, structural properties, dredging sequence and the wall deflection Among these studies, Dibiagio and Myrvoll, (1972); Davies, (1982); Tedd et al., (1984); Clough and O'Rourke, (1990) and Tamano et al., (1996). The aspects of their studies included effects of wall construction on ground movements, changes in lateral earth pressure, water pressure and a numerical modeling of the effects of wall construction and ground movements.

A number of case histories about the deepening and upgrading of existing quay walls have been studied. Among these studies, Paparis et al., (2004) studied the effect of berth deepening and strengthening to accommodate larger vessels for Port Elizabeth Container Terminal. Deblauwe et al., (2013) reported that in order to deepen and renovate the existing container Zeebrugge quay wall, a new front combi-wall consisting of a concrete relieving floor on driven concrete piles and a steel sheet pile retaining wall was erected. Varatharaj et al., (2016) proposed that an effective constructing a new wharf in front of the existing wharf was found to be the most effective solution to meet the current seismic standards and deepening operation. A new sheet pile bulkhead walls approximately 10.7 m away from the existing sheet pile bulkhead will be constructed and the space between the new and old sheet pile bulkheads will be filled with improved granular backfill. Oung and Brassinga, (2015) discussed widely the risks of upgrading existing quay walls such as deepening in front of quay walls and increasing the loads on the quay surface. Among the various concepts evaluated to upgrade the existing X-Ray wharf located on the southeastern corner of inner Apra Harbor located in U.S. Cornell et al., (2007) suggested a system consisting of soldier piles and sheet pile panels to allow berth deepening in front of the berth structure. Douairi, (2013) studied many options for creating extra depths in front of quay walls of which not all have been used in practice. De Gijt and Broeken, (2013) introduced a number of upgrade, repair, or deepening of quay walls examples all over the world.

This paper focuses on studying the deepening of different types quay walls as it's one of the most common challenges for ports is its need to increase the depth in front of the toe of the existing quay wall structures.Stabilizing measures to the existing quay wall were required to ensure that the deepening adjacent to the quay wall, the increased vertical and horizontal loads (from the larger crane, mooring and berthing forces) and the seismic loads did not reduce the factor of safety for the quay wall against a circular slip failure to an unacceptable level.

2 QUAY WALLS

2.1 Functions of quay walls

A Quay wall is a soil retaining structure, which occurs in many shapessee figure 1. All these structures have the same function;

•Mooring place for ships.
•Soil retaining function.
•Bearing capacity for crane loads, goods and storage.
•Sometimes a water retaining function.

Figure 1: Block quay wall

2.2 Features of Quay Walls

The requirements of the quay wall show variety according to the users. As for the handling of freight, there must be a big enough storage area and that has sufficient bearing capacity to provide for future transshipment storage and transport and for the ships, there must be sufficient draught for the biggest vessels to berth. In addition, the following requirements are

•The design and construction of quay wall must be well and there mustbe reasonable price quality relationship during the design and construction stages.
•The quay should have a low maintenance requirement and a long Lifetime.
•The area must be sufficiently elevated to remain dry at high tide. Water levels, tidal influences, soil characteristics of the ground and the climatic conditions of every place in the world are different, so great deal of experience, ingenuity and creativity should be gathered to make an optimum design essential in the design of quay walls.In order to provide berthing facilities for ships, the wall must retain soil behind the quay, provide bearing capacity to carry loads imposed by the transshipment of quay, provide bearing capacity to carry loads imposed by the transshipment of freight and cranes and freight storage facilities, and possibly also serve as a water retaining wall for the areas lying behind during periods with high water.

2.3 Main Types of Quays Walls

In general quay wall designs can be categorized in three basic designs Broeken and de Gijt, (2014)see figure (2).

•Gravity walls.
•Sheet piles.
•Open berth quay walls.

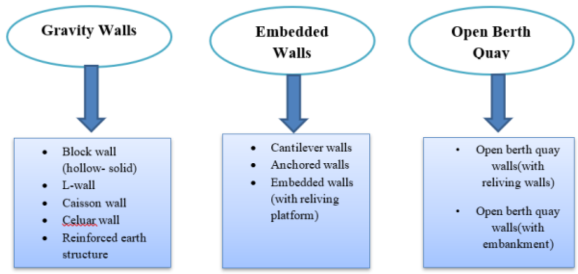

Figure 2: Main types of quay walls

3 UPGRADING TECHNIQUES FOR DEEPENING QUAY WALLS

Deepening leads to higher retaining height than the facilities are designed for. As a first approach to this problem conceptual solutions are presented to ensure sufficient stability and strength the following general formula can be applied as shown in equation (1) below, GIJT, D.J.,and DOUAIRI,M (2013)

$$SF = \frac{F_{Resisting}}{F_{Sliding}} \geq 1 \qquad (1)$$

Assuming that the SF (Safety factor) has to remain approximately the same value (same level of safety) according to equation (1), there are three possibilities to achieve this figure (3).

An elaboration of the conceptual solution into more concrete solutions is presented in figure (4).

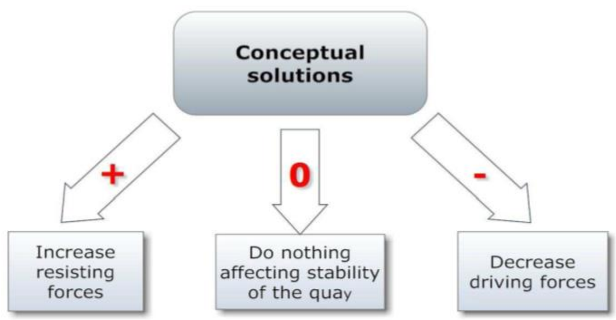

Figure 3: Conceptual solutions (GIJT and DOUAIRI, 2013)

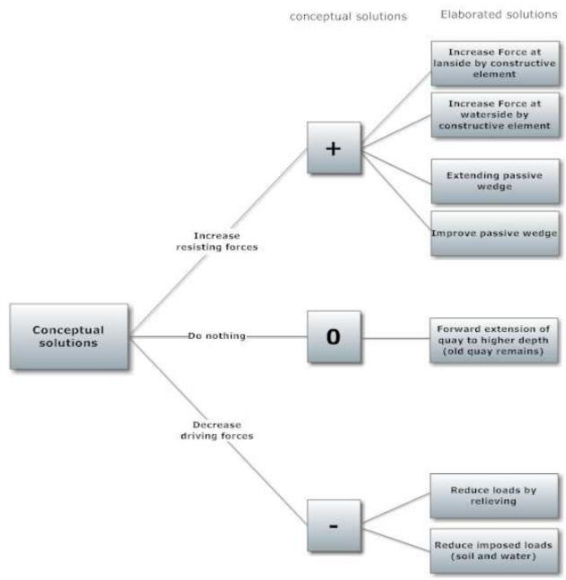

Figure 4: Elaborated conceptual solutions (GIJT and DOUAIRI, 2013)

4 A VARIETY OF SOLUTIONS

The elaborated conceptual solutions lead to a variety of solutions. These solutions are presented in the following overview diagramsas shown in figure (5).

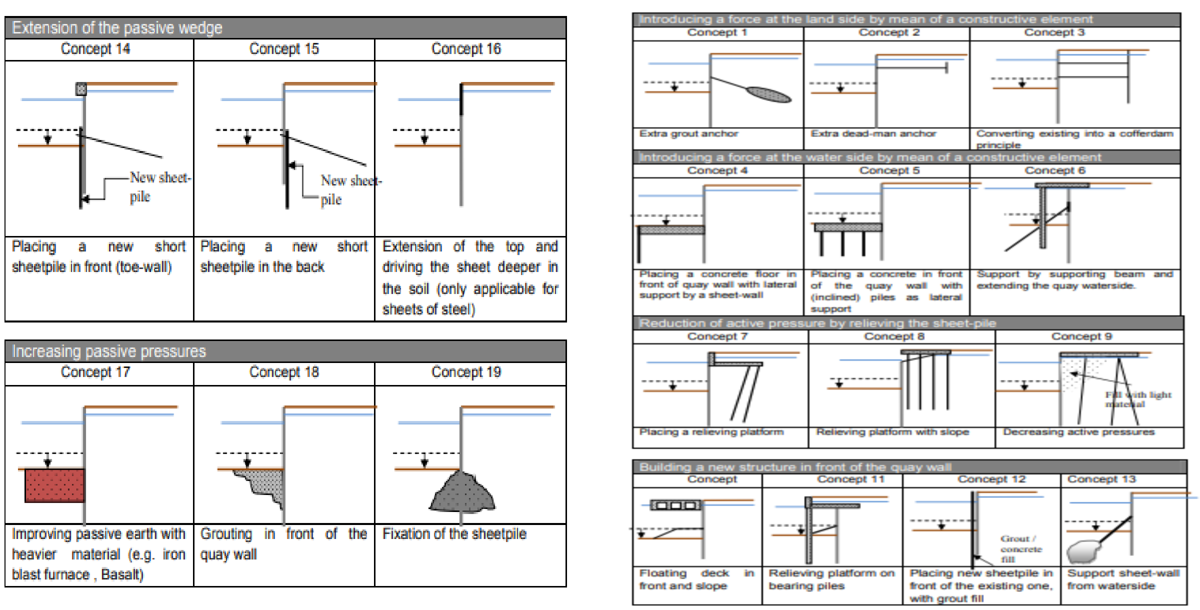

Figure 5: conceptual solutions for degrading (GIJT and DOUAIRI, 2013)

5 EXAMPLES OF REPAIR OR DEEPENING OF QUAY WALLS

Technological progress is the most important stimulus to the adaptation of the functionality of quays. They must be restored or rebuilt for ships with a deeper draught and with greater capacity or for the increased weight of cranes and greater loads of cargo. This section gives a number of examples.

5.1 Walls Renovation of harbour areas, London, United Kingdom

On the abandoned and decaying dockland area in the East End of London, a new business center is under construction. As part of the development of the entire area, the old warehouses are being converted for other uses and the quays are being renovated. For the repair of the quays, a system has been chosen in which the new sheet pile wall is placed in front of the old one and the vertical ground anchors together with the tubular piles are used as an anchorage for the entire structure see figure 6.

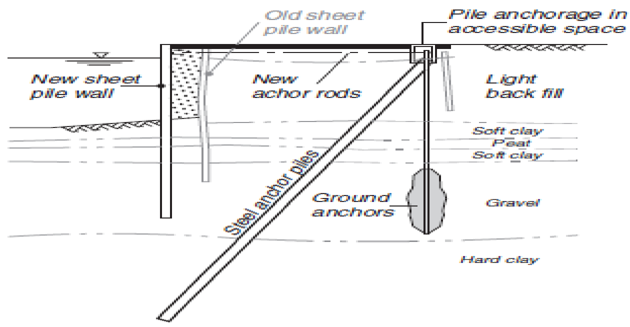

Figure 6 Quay pontoon dock, London (Broeken and De Gijt, 2014)

5.2 Deepening of water at the existing container quays in Rotterdam, Netherlands

The following renovation or deepening measures can be taken:

•Adaptation of ships and logistics.
•Regular inspection and monitoring.
•Adaptation of quay structure.
•Reinforcement of the front of the quay.
•Fixation of the bottom.

Three such projects are shown in Figure 7 a, b and c.

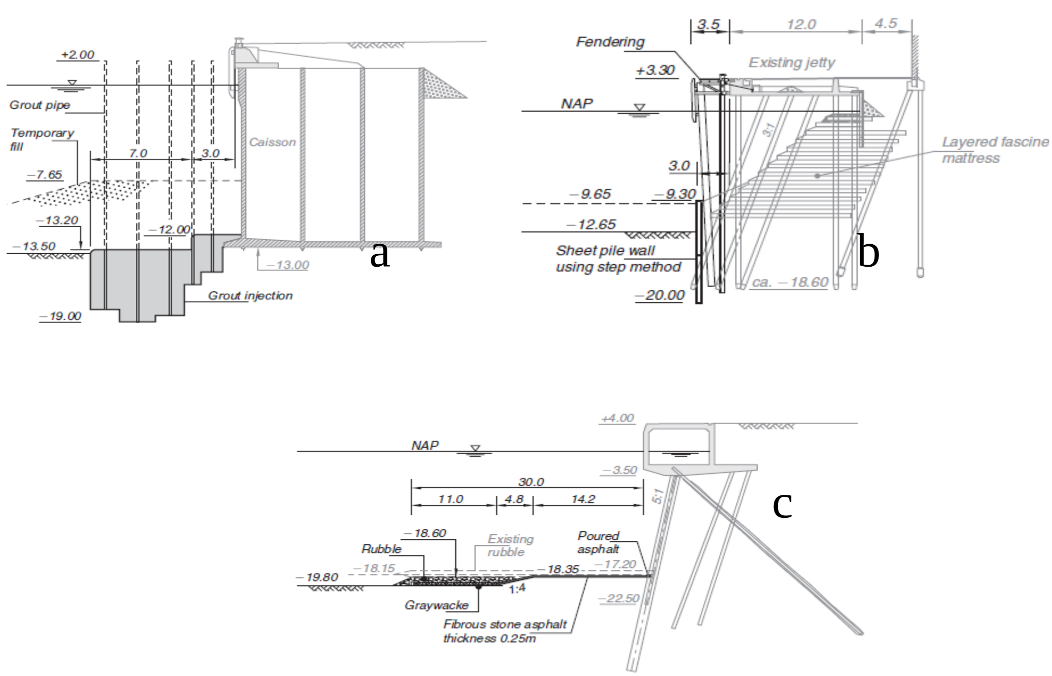

Figure (7) a) protection of erosion and restoration the stability with a grout body added to the toe of the caisson, b) wall safeguardation the stability of the layered fascine mattress with a short staggers sheet pile wall, c) An open textured fibrous stone asphalt mattress is used to increase the depth of this quay (Broeken and De Gijt, 2014)

5.3 Jet grouting technique for harbour repairs in Antwerp

To repair and increase the water depth at the old quay walls of the Albert Dock in the port of Antwerp, Fig. (8) the very high-pressure grouting technique was used. The method of working was as follows: a hole was drilled through the existing masonry gravity wall and a hollow rod was introduced into this. Next a cement water mixture, grout, was injectedunder very high pressure while rotating and lifting the rod. The high pressure causes intense mixing of grout and soil under the quay. After setting, a round pile is created in and under the quay wall. A row of such piles can be made next to each other to form a closed screen in front of the wall. The harbor can now be deepened without the soil behind the wall being washed out. To ensure safety, a double row of grout piles is made. To take up the higher horizontal forces the quay is anchored at the rear.

Figure (8): Renovation of a gravity wall, Antwerp (Broeken and De Gijt, 2014)

5.4 Sheet piles for harbour repair in Hamburg, Germany

For the renovation of a seriously damaged gravity wall in Hamburg, first the bearing piles of the combined wall were driven. These were PSp 802 double H-section profiles. Next short intermediate piles were driven betweenthe back flanges of the double H-section profiles.

to take up the existing slope. This made it possible to dredge away the obstacles in front of the quay wall and to excavate the harbour to the required depth. Finally, the permanent intermediate piles, PZ 612 were driven down between the front flanges of the bearing H-piles to a depth of −16m and the anchorage Pst 370/106 tension piles were installed.

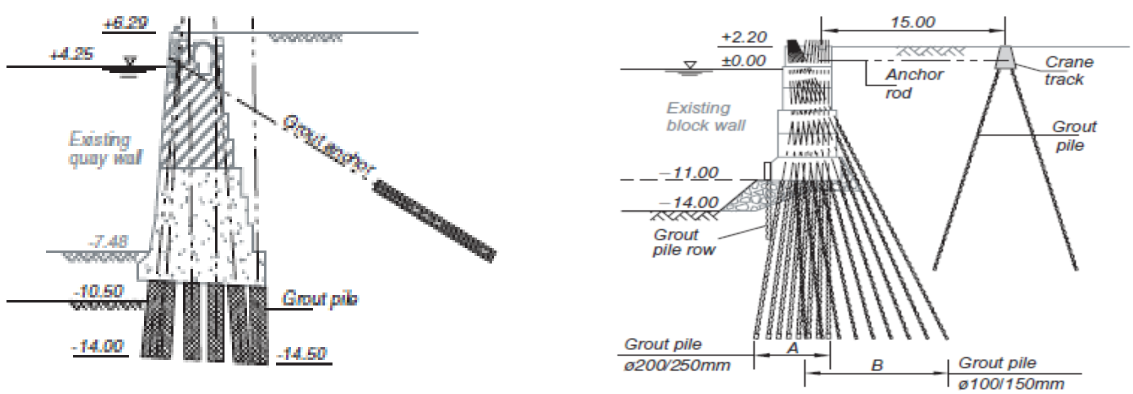

Figure (9): Provisional intermediate piles for harbour repair, Hamburg (Broeken and De Gijt, 2014)

5.5 Renovation of quay walls in Naples, Italy

In Italy too, the trend towards ships with increasingly deeper draughts and greater engine capacity has led to the renovation of existing quays. Interesting examples include.

Figure 10.a shows an example of the construction of a new quay wall behind the existing quay in Naples. Here the need to extend the water area was greater than the demand for land area, so a diaphragm wall connected with two rows of piles with a diameter of 1.20m was built behind the existing quay. Upon completion of the works the original quay wall was removed.

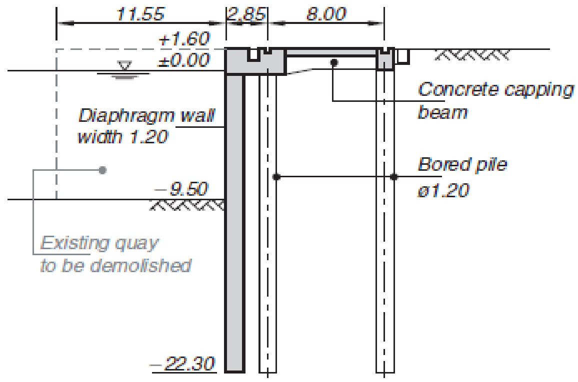

Figure (10.a): Renovation with a diaphragm wall to the rear of the existing quay, Naples (Broeken and De Gijt, 2014)

Strengthening of the existing wall. A good example of this is shown in Figure 10.b, a quay in Naples, in which both land and water sides had to be retained. A system with a network of piles was driven through the old structure and deep into the subsoil to give the quay sufficient stability for the required deepening of the harbour.

Figure 10.c shows a front extension in the harbour basin in which a sheet pile wall is driven into the harbour bottom in front of the old block wall. In addition, a pile trestle system of grout piles is linked to the sheet pile wall by a new superstructure.If there is sufficient space, the harbour can be deepened by using an open berth quay. Figure 10.d shows such a structure. A jetty like structure is built over a slope. In front of the existing block wall, heavy piles have been introduced to support a new deck.

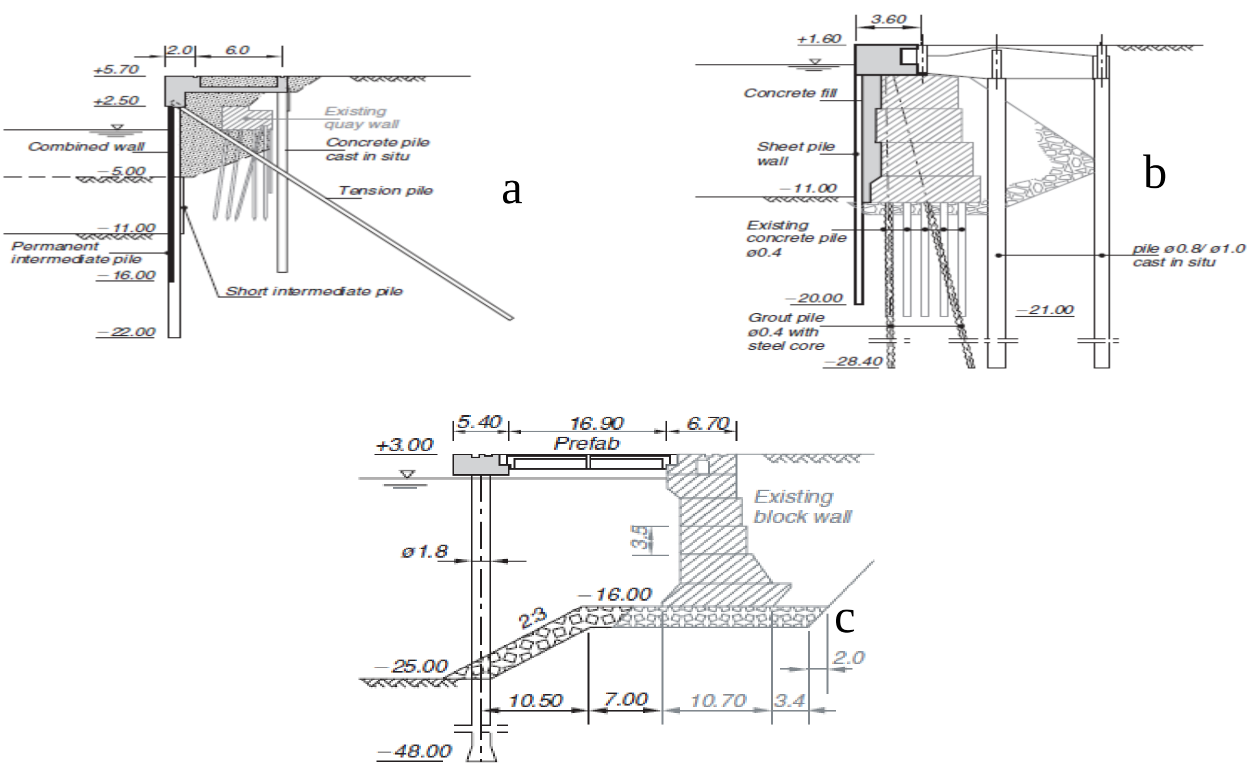

Figure 10a) Renovation with piles through the existing structure, Naples, b) Renovation with sheet piling in front of the existing quay, La Spezia, c) Deepening and seaward extension, with open berth, Tarente (Broeken and De Gijt, 2014)

5.6 Renovation of a quay wall, Goa, India

In the port of Mormugao, Goa, on the west coast of India, a new quay wall was built to replace a block wall that had been built by the Portuguese 200 years earlier and had collapsed. The quay was constructed with an anchorage in the bedrock. The depth of the water is 11.00 m. The front wall is a diaphragm wall that is 1100mm thick and has 5m wide panels. The second wall is 12.00m behind this. Owing to lack of space, it was not possible to build an anchor wall so the 2000 kN heavy anchors were fixed into the rock bed at an angle see figure 11.

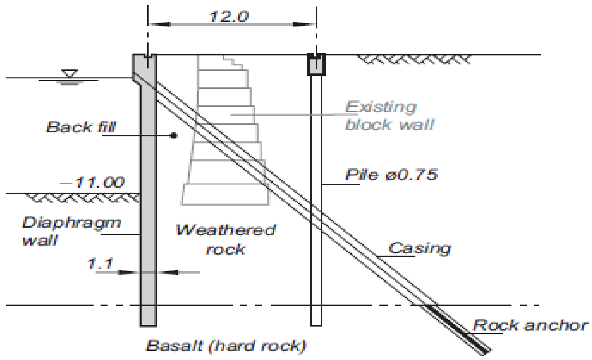

Figure. (11) Renovation of a quay wall, Goa, India. (Broeken and De Gijt, 2014)

5.7 Adaptation of existing quay walls in Gdansk, Poland

To meet changing demands, a number of new concepts for the adaptation of quays were developed for the port of Gdansk in Poland. These are shown in Figure 12 a to e:

•The existing quay is used as a bearing element for the superstructure.

•The new quay is built over the old one, bearing the L-shaped superstructure. The old quay reduces the earth pressure on the new quay.

•The front element is anchored by means of the old caisson structure.

•The old quay serves as an anchorage for the new quay.

•With this front structure, the space between old and new quay wall is filled with coarse material. The new structure is anchored separately.

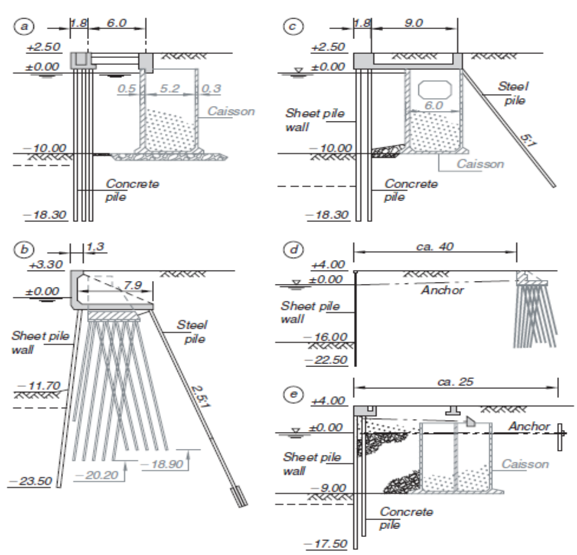

Figure (12): Renovations in Gdans (Broken and De Gijt, 2014)

CONCULATION AND RECOMMENDATIONS

Based on the results from the listed previous studies several solutions could be adapted for safely increasing depth in front of quay walls plus resisting deepening effect, some of these solutions are:

1.Water pressures have the highest contribution to lateral pressure on the quay-wall. Solutions in reducing those pressures can lead to significant excavation of the harbour bed without endangering the strength and stability of the quay wall.

2.The different designs of the quay walls are not flexible from upgrading aspects. Therefore, it is recommended to think about more flexible solutions that are suitable for upgrading.

3.Investigation of the behavior of a multi anchored quay-wall over time by using FEM models. Multi anchored sheet-walls are common in construction engineering, but rarely used in quay walls.

4.Research to heavy weight material with high internal friction is recommended. Proposed in the report iron furnace blast. Further research to this material (or other heavy weight materials) is recommended.

5.Calculations for the intended quay wall should always be made taking into account the “current” strength capacity of the quay walls and not from original technical drawings, as materials degrade over time.

REFERENCES

Cornell, C., Bohlen, W., Kumar, V., & Reyes, A. (2007). Upgrade of Berth 15 for Gantry Cranes, Panama Ports Company, Balboa, Republic of Panama. In *Ports 2007: 30 Years of Sharing Ideas: 1977-2007* (pp. 1-10).

Clough, G., O’Rourke, T., “Construction induced movements of in-situ wall”. Proceedings of Conference of Design and Performance of Earth retaining Structures, New York: 439– 470, 1990,

De Gijt, J. G., &Broeken, M. L. (Eds.). (2005). *Handbook of Quay Walls*. CRC Press.

De Gijt, J.G., and Broeken, M.L., (2013), “Quay Walls, SecondEdition”, CRC Press, 2013 ISBN: 978-1-315-77831-0.

Deblauwe, B., Sanders, F., de Clerck, D., & van Parys, D. (2013). Port of Zeebrugge–deepening of container handling Zeebrugge quay wall. In *IABSE Conference: Assessment, Upgrading and Refurbishment of Infrastructures, Rotterdam, The Netherlands, 6-8 May 2013* (pp. 636-637).

Douairi M., (2013), “Research into deepening options for quay walls”,MSc. Thesis, Delft University of Technology.

Dibiagio, E., & Myrvoll, F. (1972). Full scale field test of a slurry trench excavation in soft clay. In *Fifth Eur Conf On Soil Proc/Sp/* (No. Conf Paper).

El-Naggar, M. (2010). Enhancement of steel sheet-piling quay walls using grouted anchors. *Journal of Soil Science and Environmental Management*, *1*(4), 69-76.

Elskens, F., & Bols, L. (1970). Innovative techniques for quay wall renovation and stabilisation. *WIT Transactions on The Built Environment*, *39*.

Galal, E. (2017). A numerical study for upgrading the container terminal of port-said west port. *Port-Said Engineering Research Journal*, *21*(2), 88-97.

GIJT, D.J.,and DOUAIRI, M., (2013), “Upgrading Techniques for Quay Walls”, article Delft University of Technology , 2013.

Habets, C. J. W., Peters, D. J., De Gijt, J. G., Metrikine, A. V., & Jonkman, S. N. (2016). Model solutions for performance-based seismic analysis of an anchored sheet pile quay wall. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *10*(3), 278-290.

Mollahasani, A. (2014). Application of submerged grouted anchors in sheet pile quay walls.

Muthukkumaran, K., &Sundaravadivelu, R. (2007). Numerical modeling of dredging effect on berthing structure. *Acta Geotechnica*, *2*, 249-259.

Oung, O., &Brassinga, H. (2015, October). Uncertainties in redesigning an existing quay wall. In *The 5th International symposium on geotechnical safety and risk. Rotterdam, The Netherlands* (pp. 407-412).

PIANC MarCom (2015), "Upgrade of Port Terminals by increasing dredged depth", Working Group no. 164 of the Maritime Navigation Commission, International Navigation Association.

Premalatha, P. V., Muthukkumaran, K., &Jayabalan, P. (2011). Effect of dredging and tie-rod anchor on the behavior of berthing structure. *International Journal of Engineering Science and Technology*, *3*(6), 5099-5115.

Paparis, B., Quadagno, M., Buzzoni, G., McQueen, J., & Lizzo, J. (2004). Modernizing A Three Decade Old Wharf Structure For The Next Generation of Containerships. In *Ports 2004: Port Development in the Changing World* (pp. 1-11).

Subha, I. P. (2012). Behaviour of an open type berthing structure under earthquake condition–a numerical approach. *International Journal of Engineering Research and Applications (IJERA)*, *2*(1), 36-40.

Sincil, K. (2006). *Numerical analysis of anchored concrete pile wall: A case study* (Master's thesis, Fen BilimleriEnstitüsü).

Tolba, R.E., Galal, E.M., and Mourad, M.H., (2017), "Effect of the frontal deepening of quay wall for the East Port of Port Said", Malaysian Journal of Civil Engineering, Vol 29 (2).

Tamano, T., Fukui, S., Suzuki, H., & Ueshita, K. (1996). Stability of slurry trench excavation in soft clay. *Soils and Foundations*, *36*(2), 101-110.

Tedd, P., Chard, B. M., Charles, J. A., & Symons, I. F. (1984). Behaviour of a propped embedded retaining wall in stiff clay at Bell Common Tunnel. *Géotechnique*, *34*(4), 513-532.

Varatharaj, R. S., Pratheepan, P. K., Arulmoli, A. K., Schulze, C., & Chan, D. (2016). Seismic improvements and upgrade of a wharf using an innovative ground improvement scheme. In *Ports 2016* (pp. 462-471).