Recent and future developments in quay wall structures

Les développements récents et futurs dans les structures du mur de quai

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ABSTRACT
The worldwide growth in container handling and other ship traffic leads to enormous challenges for harbour construction. Concerning container ships actually design studies are made for ship sizes of more than 15 000 TEU with a length of more than 400 m, a width of 70 m and a draft of 21 m. Along with these ship sizes the traffic loads and the operation loads of container cranes increase dramatically.

This development has to be anticipated by new quay concepts with extended dimensions especially in the height between harbour bottom and top of the structure.

Thus a number of innovations in quay wall design have established during the last 10 years. New calculation techniques permit better modelling of earth and water pressure, the interaction between structure and soil becomes the leading parameter for the design. This opens the possibility for extension of existing quay walls for higher water depth and higher loads and leads at the very end to entirely different types of structural forms of quay walls than the conventional ones.

RÉSUMÉ
L'accroissement à l'échelle internationale de la manutention des conteneurs et du trafic maritime a entraîné l'apparition d'énormes défis pour la construction des ports. Pour les navires porte-conteneurs, des études de construction sont réalisées sur des bâtiments de plus de 15 000 EVP avec une longueur supérieure à 400 m, une largeur de 70 m et un tirant d'eau de 21 m. Avec de telles tailles de navire, les charges transportées et les charges de travail des portiques à conteneurs augmentent de manière considérable.

Ce développement doit être anticipé par les nouveaux concepts de quai avec des dimensions étendues, particulièrement en ce qui concerne la hauteur entre le fond du port et le haut de la structure.

Ainsi, de nombreuses innovations dans le domaine de la conception des quais se sont établies au cours des 10 dernières années. De nouvelles techniques de calcul ont permis une meilleure modélisation de la pression des terres et des eaux, l'interaction entre la structure et le sol étant le principal paramètre pour la conception. Ceci offre la possibilité d'étendre les murs de quai existants pour une profondeur d'eau et des charges plus importantes afin d'aboutir au final à des formes structurelles des murs de quai complètement différentes des formes conventionnelles.

Dans la phase de construction, la qualité de la structure a pu être améliorée in situ et en même temps, des éléments préfabriqués à haute résistance avec des efforts au tambour jusqu'à 4000 tonnes peuvent être précisément obtenus par de nouvelles technologies.

Keywords : quay wall, harbour, Containerkaje, multi – anchored, combined sheet pile wall, JadeWeserPort

1 DEVELOPMENT OF QUAY WALL DESIGN

The direction in which quay walls will develop is influenced by many aspects. One of the most important surely is the development of ship dimensions. This is surely different for specific ship types, and it is controlled by factors as economic growth, ship building technology and logistic concepts. Limitations arise from the dimensions of water ways like the Suez Canal, the Panama Canal or the Straits of Malacca. These limitations play an important role, especially in containerships, but also in ore carriers, car carriers and oil tankers. Nowadays the largest containerships (Emma Maersk class) have a length of nearly 400 m, the beam is 56,4 m and the depth 16,5 m. The capacity is officially 11.000 TEU's, nonofficial 15.200 TEU's. Two years ago it was believed that this grow in dimensions and capacity will continue, this is actually (February 2009) rather unlikely.

Still the design of quay walls is based on relatively simple and conventional static models, in which the interaction between soil and structure is modelled according to classical earth pressure theories and correction factors are used for the adaption to realistic interaction behaviour. As a matter of experience quay walls are understood as simple structures with clearly defined paths of load and force transfer (EAU 2004).

A typical example of a modern quay wall is the Containerkaje in Bremerhaven. The wall is formed by a combined sheet pile structure PSp 1001 with secondary piles PZa 675. A concrete superstructure is placed on top of the sheet pile wall on raked steel piles, the wall is anchored by an inclined anchor pile. The container crane rests on the combined sheet pile wall and a pile founded crane beam. The structure was constructed in the water and backfilled. The tidal water level in the river Weser is between NN + 1,75 m (MHW) and NN -1,89 m (MLW), the harbour bottom is NN – 18,5 m. So the "Emma Maersk" could only operate during tidal high water when she first visited Bremerhaven in September 2006.

Nevertheless structures of single anchored sheet pile type have reached a final state of evolution since due to large span between harbour bottom and top of the structure, after all 26 m in the case of the Containerkaje, and the high operation loads in

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-1457

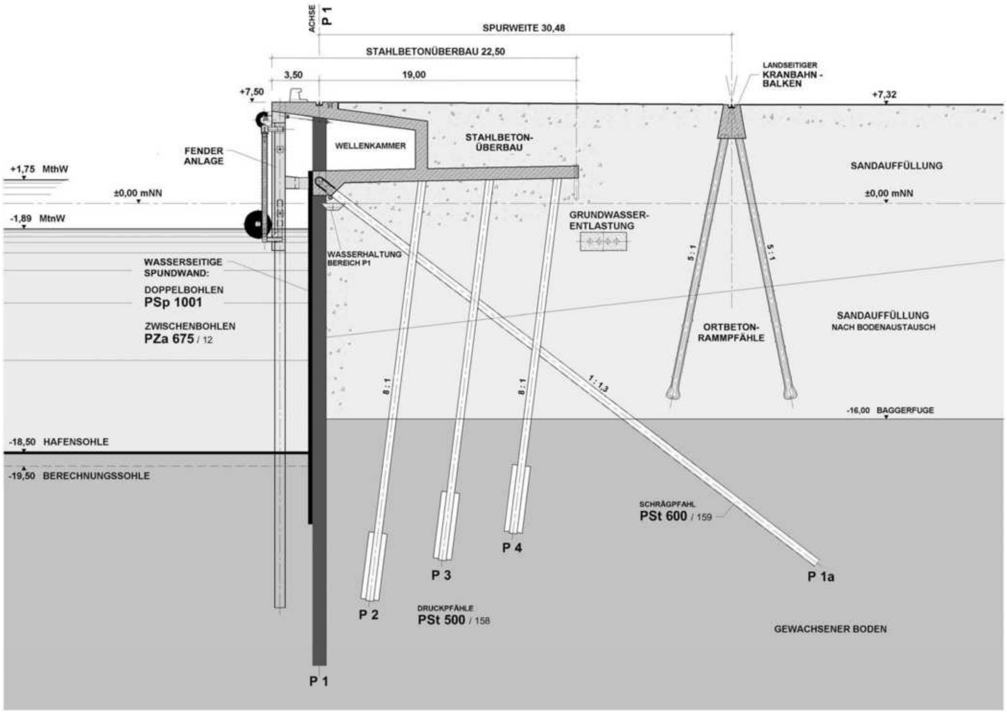


Figure 1. Containerkaje Bremerhaven

modern harbours. The bending moments become very large, so that even the heaviest primary piles on the market are not sufficient to cover the bending moments of the structure.

In case that the quay wall is constructed at land an option could be to construct the quay wall from concrete as a gravity retaining wall (Fig. 2).

Other concepts under discussion use steel structures over slopes (Fig. 3) and even floating structures, anchored by suction anchors (Fig. 4).

Figure 2. Deurgangsdock Antwerpen

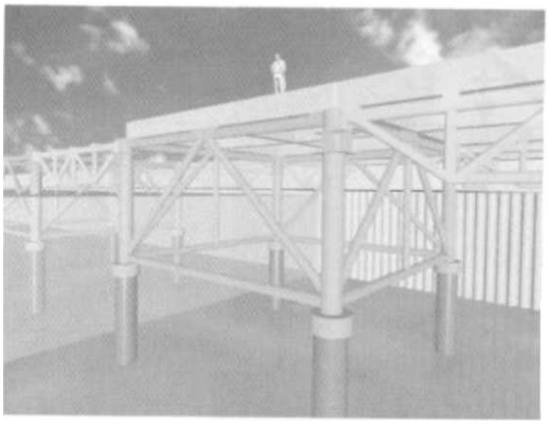


Figure 3. Steel structure with concrete elements (Handbook Quay Walls).

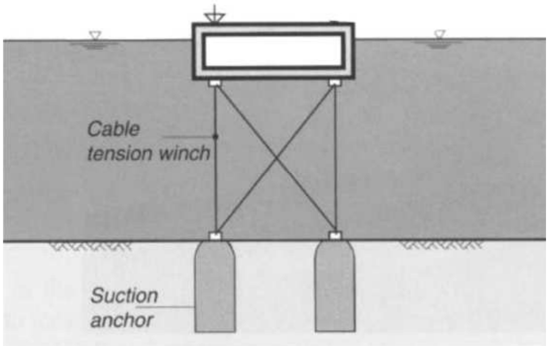


Figure 4. Floating concrete structure, anchored by suction anchors (Handbook Quay Walls)

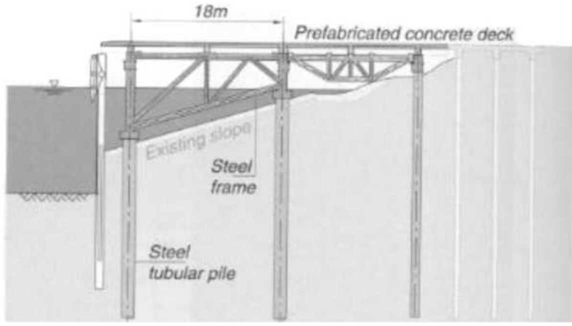
2 JADEWESERPORT, WILHELMSHAVEN

Actually the JadeWeserPort in Wilhelmshaven is under construction. the 1500 m long quay wall is constructed at a distance of about 1,5 km from the existing coast line in a water depth of about 10 m. The quay wall is backfilled with sand up the final height of NN + 7,5 m.

The tender design was made as a conventional sheet pile construction (Fig. 5). The vertical combined sheet pile wall is placed 4,5 m behind of the front of the concrete superstructure, the primary piles of the wall and the fender piles reach down to a depth of NN – 45 m, where pleistocene sand with cone penetration resistance up to 40 MN/m² provides a good load transfer mainly of the load from the front crane rail to the subsoil. To reduce earth pressure and thus the bending moments in the wall, beneath of the superstructure an open chamber was foreseen with the bottom at NN – 3,0 m, closed ant its rear end by a sheet pile wall Larssen 605k. Even with this design trick the largest available profiles (PSp 1035 S) are needed, to cover the bending moments. The superstructure rests on raked steel piles, the rear crane rail is founded separately.

3 SPECIFIC PROPOSAL

During competition a specific proposal was presented (Fig. 6). In this specific design the retaining wall is a multi anchored construction. Thus the bending moments become much smaller than in the case of a single anchored structure. As consequence the section modulus of the primary piles is smaller compared to the conventional only once anchored structure.



The construction was planed to start with the driving of the combined sheet pile wall in the open water, fixed by an auxiliary construction to cover loads from waves and tidal flow in this early phase. The first anchor layer then should be placed on the excavation base at NN – 17 m. The bidder consortium had developed a special sliding connection of the anchors, with which the anchor together with the rear anchor plate could be hooked over the flanges of the primary piles above water level and then lowered to the sand surface by a special guide. After the anchor plates are brought in the right position by help of a vibrator, the first sand layer should be filled hydraulic up to NN – 12,5 m.

The quay wall has a relatively light concrete superstructure, which rests on the wall and on the fender piles and which bears the front crane rail. the rear crane rail was planed as separately founded concrete beam.

In this design the elastic section modulus of the primary elements of the combined wall is smaller, so that the needed profile is a HZ 775 A with secondary elements AZ 26.

4 COMPARISION OF TENDER DESIGN AND SPECIFIC PROPOSAL

At the first sight the specific proposal is recognized as a multi anchored retaining wall, a construction which is well known since long from deep excavation pits and from cofferdams. It forms a multi-hyperstatic system with the advantage that the total span is cut in small sections, thus reducing the bending moments in the wall. Consequently the needed elastic section modulus for the primary elements of the wall becomes only W = 7.230 cm³ compared to W = 16.656 cm³ for the tender design.

Apparently the structural safety of the multi-anchored quay wall and its operational deformations depend highly on the deformation characteristics of the sand behind of the structure. The anchor loads are determined from the earth pressure caused by the backfill, it is well known that the earth pressure decreases when the soil density and thus the friction angle increases. On the other hand the anchor forces are counterbalanced by the passive earth pressure in front of the anchor plates, which is depending on the soil density too. Furthermore both, the active and the passive earth pressure, depend on the deformations of the quay wall and the anchor plates. These interactions between soil and structure are however relatively complicated and it is thus nearly impossible to evaluate the deformations of the structure during construction and in operation.

It is however of paramount importance for the serviceability of the structure, that its deformation behaviour is identified clearly during design. Mainly due to this reason the JadeWeserport Realisierungsgesellschaft did not commission the specific proposal.

5 CONCLUSIONS

The classical design concepts of quay walls for large vessels with only one anchor placed close to the top and a free span down to the harbor bottom has reached dimensions which hardly allows for the ship dimensions needed for today traffic. If it is realistic that the development of ships draught will increase in future as in the past, new concepts for the quay walls are needed urgently. A very promising one is multi-anchored combined sheet pile wall. The statical concept is well known from deep excavation pits, the static stability of the ready build structure is relatively robust. Open question remain however with respect to structural deformations during lifetime.

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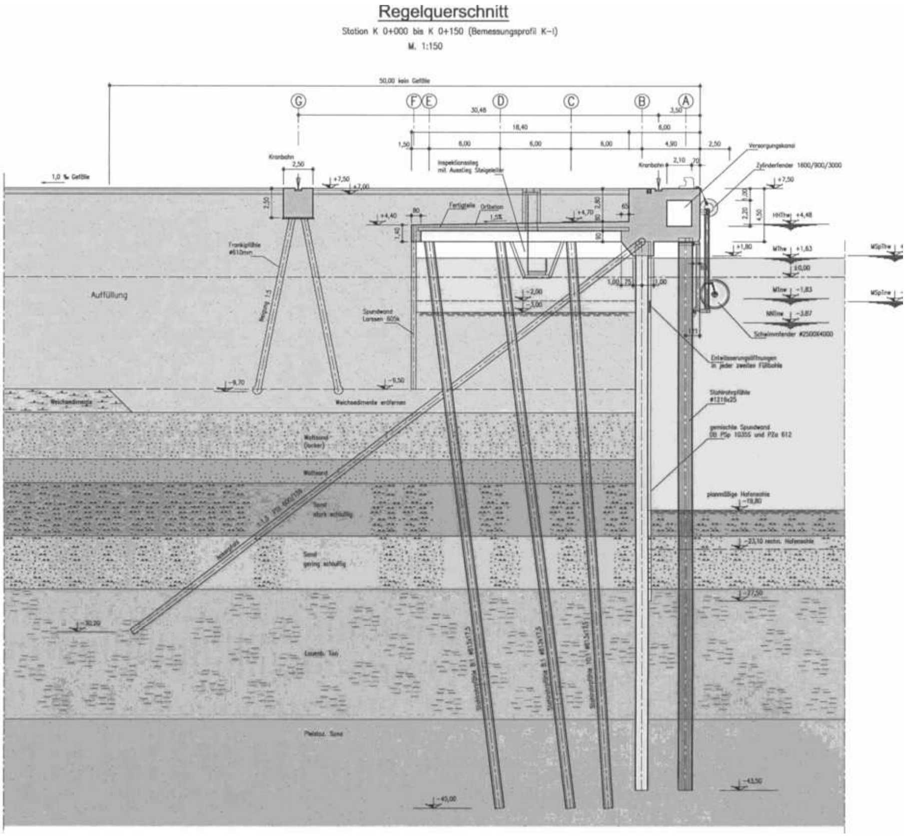

Figure 5. JadeWeserPort, tender design, cross section of the quay wall

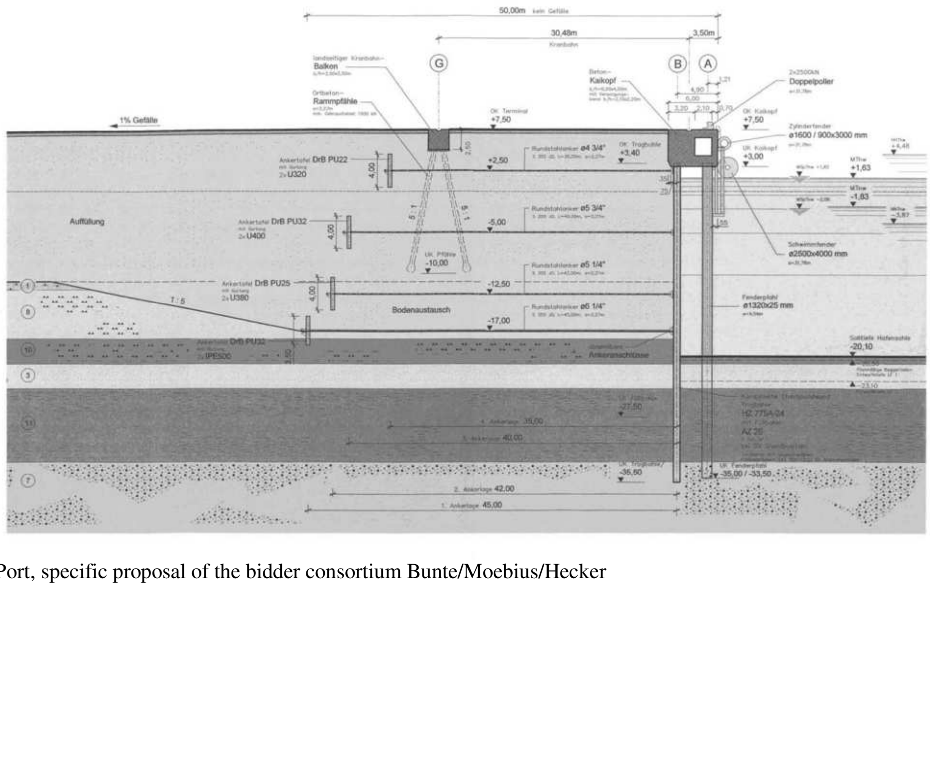

Figure 6. JadeWeserPort, specific proposal of the bidder consortium Bunte/Moebius/Hecker