COST OF QUAY WALLS
(CM-024)

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ABSTRACT

Port authories and other organisations involved in designing and building of port infrastructure are at first glance interested in predicting adequatly the expected costs. This paper discusses the costs development of quay walls versus time. The basis for the costs development of quay walls is discussed on the basis of two methods. The MTI method and MII method. These methods are compared and discussed. Further a database with the construction costs of approximately three hundred quay walls from between 1850 to 2008 enables the composition of relations of the construction costs for several countries and port cities. In addition also relations are developed for different types of quay walls. With the developed model predictions can be made for the costs of quay walls in the future under the assumptions of certain boundary conditions. In addition to the initial costs also the the overall costs are including the effects of lifecycle concepts. Finally some conclusions and recommendations for the application of the developed model are presented and for further research.

Keywords: Quay wall, costs, history, port, indexing.

1. INTRODUCTION

The cost of building port infrastructure depends on several components like materials, functional requirements, technical requirements. The translation of these technical factors into economic factors and finally into the total building costs is obtained by pricing the structural elements. For the decision maker it is important that, in addition to technical considerations, an economic evaluation of the different technical options from which to select the most economic option can be made. To perform this economic evaluation several methods are available. The most frequently used methods are listed below.

Economic evaluation methods:

- Present Discounted cash flow: This method considers the predictions of the future cash flows transferred to present day value. No cost are considered
- Net present value method (NPV): This method discounts the costs and revenue flows for a project. These values of the costs and revenue are computed for a selected life time and interest rate at the present value. This method is sensitive for the chosen interest rate and considered time.
- Internal rate of return method: This method is equal to the NPV method, however, the interest rate of the project is calculated by assuming the NPV =0. In this way the internal interest rate can be calculated.
- Cost /benefit analysis: This method compares the benefits and the costs of the project. This includes not only the financial aspects of the project values but also other aspects such as employment and social considerations.

For this study the 'Net Present Value Method' has been chosen because only the costs are considered and this method is widely used to evaluate the financial aspects of infrastructural projects. This method involves considering the construction, maintenance and demolition costs during the life cycle of a structure as well as the revenues generated by this structure.

Today designs must fulfil their function for a design life of 50 years but for different structures and situations an other time span may be agreed. In this study the attention is focused on the lifetime costs and not on the revenues. The revenues include items like harbour dues, quay wall dues and pilot dues. These types of costs are not considered. However the decision to build a quay wall structure in a port is based on the comparison of costs and revenues according to the "Net Present Value Method".

In the following equation expresses the "Net Present Value Method":

$$NPV = PV_{(R)} - PV_{(C)}$$

$$NPV = \sum \frac{\left(R_{(t)} - C_{(t)}\right)}{(1+r)^t}$$

NPV = Net Present Value (€)
R = Revenues (€)
C = Costs (€)
r = Interest (-)
t = Time span considered (years

When NPV is > 0 a profit is generated, while if the NPV is <0 a loss occurs. This method provides a means to evaluate the financial feasibility of alternative projects.

When considering the costs during the entire life cycle of a structure, the following costs or investment components can be distinguished: Planning, Design and Engineering (PDE), Construction Costs (C) Maintenance Costs (M) and Demolition Costs (D). The planning-, design-, engineering and construction costs are the initial costs of building a structure and are therefore called the initial costs of the project. The maintenance costs are those costs which must be met to ensure that the required functionality is maintained. These maintenance costs are spread over the lifetime of the structure. The demolition costs arise when it becomes necessary to remove the structure. These components are elaborated and discussed in the next section.

2. THE MODEL OF INVESTMENTS

The total project costs are composed of the initial construction costs, the maintenance costs and the demolition costs. These are illustrated graphically in Figure 1.

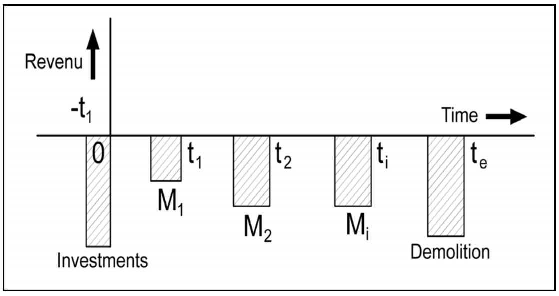

Figure 1. Costs versus time

The Total Costs (TC) are:

$$TC = I_0 + M_1 + M_2 + M_i + D$$

Where:
TC = Total Costs
I_0 = Construction costs
M_1, M_2, M_i = Maintenance costs in year i
D = Demolition costs

Experience in the Port of Rotterdam has indicated that, on average, the following relation between construction-, maintenance-, and demolition costs is valid for quay walls.

Maintenance = 0,5 to 1,5 % * I_0 per year and Demolition = 15 to 20 % * I_0 per year according to Gemeentewerken Rotterdam. The maintenance and demolition costs may be expressed as a percentage of the construction costs.

$$TC = I_0 + 0.010 I_0 + 0.175 I_0$$

The equation above can be translated into PV -value by the equation

$$PV = I_0 + \left(\frac{0.010 I_0}{r}\right) \cdot \left(1 - \frac{1}{(1+r)^t}\right) + \left(\frac{0.175 I_0}{(1+r)^t}\right)$$

For investment decisions it is recommended that 1.0% of the initial construction costs be allocated to cover maintenance and 15-20% to cover demolition.

Assuming an interest rate of 4% per year and a lifetime of 50 years, the relation for PV becomes PV = 1.24 I_0. This excludes the planning, design and engineering costs (PDE).

Experience indicates that the PDE costs vary with the level of construction costs. Depending on the extent of the project these costs may vary between 4 and 8% with an average of 6% of capital expenditure I_0 [De Gijt 2010]. The PV relation then changes into: PV=1.30 I_0. Recently other contract options such as Design and Construct, Design, Construct and Maintaince and possibly also Finance, tend to be used more frequently. Despite these changes in contracting the use of the above expression for PV to establish the total costs over the life time period it is still applicable.

3. INDEXING

It is both interesting and important to make a comparison of costs versus time when making decisions for future projects. Indeed, if a project is to be successful it is important that knowledge based on past experience is included, since this will certainly assist in the evaluation of the financial decisions relating to the proposed project. Knowing the price fluctuations and the price developments over time may enable one to predict the cost of future investments, although the uncertainties tend to increase when one looks far back and far ahead in time.

These uncertainties are caused by lack of information about:

- construction habits: habits may change slowly or abruptly.
- technical developments: over time alternative construction methods and designs may become available and also new materials or different ways of using existing ones may be found. Such innovations tend to reduce the costs.
- changing of social interests: the community may change its behaviour and thus the demand for certain structures will also change.
- changes in the use of materials or shortages of specific materials: it is possible that the supply of construction materials is limited and, depending on the economic developments, shortages of materials may occur and these materials will be substituted by other materials which are more available.
- inflation and deflation rates: over time the value of money changes. This may be caused by wars, natural disasters or by an imbalance between supply and demand.

All these aspects differ over time and will also differ from each other.

Economists have developed methods to measure these changes in prices by defining ‘index numbers’. The best known and most widely used of these is the consumer price index (CPI), which is also the index that has been the longest in use. This index presents the changes in the prices of consumer goods (such those relating to housing and the cost of living) over time. Economists use this index to attempt to predict and explain the trends in the market. An overview of the most frequently used index methods is presented below and the relevance of these indexes to each other is shown.

4. INDEXING METHODS

By using index numbers one is able to follow the price changes over time for a defined commodity or a defined group of commodities. To compute indexes one must define a base year for comparison and one must make assumptions of improvement and changes within the originally assumed group also known as “the basket”.

At present the following indexing methods are mostly frequently used to compute the indexes:

- Laspeyres index
- Van Paassche index
- Fisher index
- Tornquist index, Chain index.

The difference between the computed index numbers varies by less than 1%.This margin is considered acceptable for this study, so the greater problem is how to obtain sufficient data and to define the basket rather than how to refine the method of indexing.[de Gijt 2006].

Methods of Indexing

The Method of individual indexing (MII-method,) uses a weighted index composed of other indexes, incorporates factors such as material, equipment and labour and the contribution and changes of value over time [de Gijt 2006]. This means that for each item in the equation an index number should be available to determine the influence of each component on the total construction costs. If this data is available the MII method can be used. However if insufficient data is available, as is usually the case, and certainly if historical situations are under consideration, the costs may be estimated according to the Method of Total Indexing (MTI –Method).

5. COMPARISON OF THE MII AND MTI METHODS

The comparison between both methods can best be analyzed by using an example. In this example two quay wall structures, a gravity wall (Deurganckdok) and a combi-wall structure with a relieving floor (Amazonehaven), are analyzed. These quay walls were selected because these type of structures have a completely different composition and building method.

The typical distribution of the costs of these quay walls is presented in Table 1

Table 1. Typical distribution of costs

	Deurganckdok	Amazonehaven
Concrete	60%	20%
Steel	10%	40%
Wages and groundwork	30%	40%

Comparing the two methods, MMI and MTI, for these two types of quay wall structures, Deurganckdok and Amazonehaven which are composed of 60% and 20% concrete and steel 10 % and 40% respectively. The groundwork contributions in both cases are 30% and 40% for the Deurgangckdok and Amazonehaven.

The increase in costs during 1995 en 2005 is a factor 1.50 and 1.59 for the MII method and for the MTI values a value of 1.48 was computed in both cases The results of this comparison are presented in Table 2.

Table 2. Results of computations according the MMI-and MTI methods

Method	Deurganckdok	Amazonehaven
MII	1.50	1.59
MTI	1.48	1.48
Ratio MTI/MII	0.99	0.93

If the MTI method is concidered as the reference method a difference of 1-7% is found between the two methods. Therefore making the comparison based on the MTI method when using the CPI index seems to be justified.

6. CONSTRUCTION COSTS OF QUAY WALLS

Introduction

In this section the costs of quay walls are presented. The total database includes approximately 300 quay walls around the world [de Gijt 2010]. The costs of the quay walls for 2008 are presented in Euros. The costs of quay walls from other countries are calculated by using the exchange rates between the country and the Netherlands and the MTI method. Most of this data derives from Europe, although data from other continents, such as Asia, Africa and America are also included. The data from Europe is about 70% of the total.This data provided sufficient information to formulate conclusions that are also valid outside Europe.

Costs of quay walls around the world

In Figure 2 the costs per running metre versus the retaining height are presented for the quay walls around the world.

When considering the costs of quay walls it was already stated [de Gijt 2010] that the contribution of the retaining height to the total costs is more than 75 % of the total cost. This can also be illustrated as follows.

Gravity structures derive their stability from their massive structural and/of addition weight in collaboration with the supporting force from the subsoil.

Sheet pile structures derive their stability by using the rigidity of the sheet pile to create an equilibrium between the active and passive earth pressure.

This results in an expected formula for the costs in relation to the retaining height:

$$C = \text{factor } H^{1\text{-}3}$$

Where:
C = costs
H = retaining height

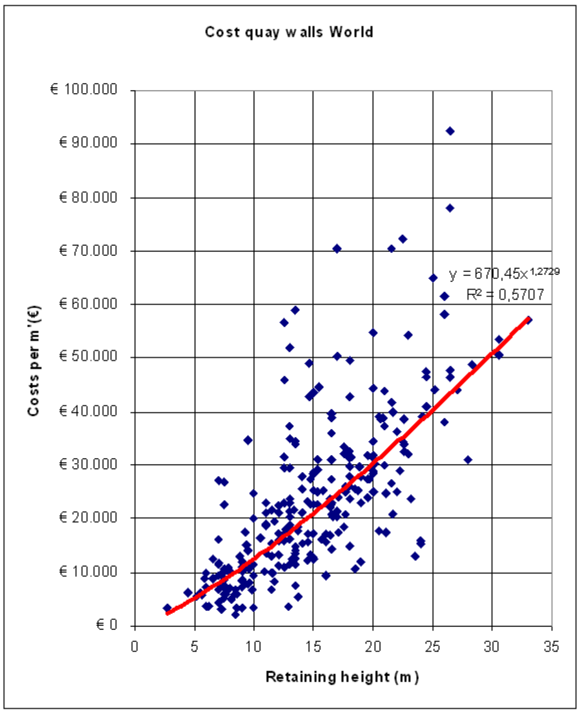

Figure 2: Costs of quay walls in euro (2008 values) around the world as a function the retaining height

The correlation coefficient is 0.57, which indicates a relatively strong relationship between retaining height and costs. This graph includes all available data though some anomalies can be observed. These anomalies are attributable to special circumstances like very difficult soil conditions and or special structures, which is the case for a few quay walls in France and England. In other situations the time at which the quay wall was built may have coincided with unfavourable market conditions. The costs of quay walls vary within a band width of approximately +/-25 %, irrespective of the soil conditions, tidal ranges and types of structures.

7. ECONOMICS OF SCALE

The costs of quay walls versus time are shown Figure 3 as a function of retaining heights. It can be observed that the decrease in costs is about 25% for the retaining heights greater than 25 metres, while this reduction is decreased almost to zero to 5% for retaining heights up to 4.9 metres.

This is because for quay walls with greater retaining heights the improvement in logistics and the development of special equipment is warranted, while for lower retaining heights these improvements are not feasible. Thus with high and long quay walls advantages are obtained from the scale effects.

Figure 3 implies that when adjusted for inflation the costs of quay wall construction are relatively constant with time. If we compare the increase in the rate of production during the construction process and realize that this is balanced by the increased wages, the constant costs are then entirely due to greater and better use of equipment, serial production, efficient material use and improvements in construction logistics. So with larger quantities the costs are reduced, a situation which is comparable to that for the production of manufactured goods such computers and cars. However, the scale advantages for quay construction tend to be limited, since the construction of a quay wall is not a continuous production process. In every port within a single contract quay wall construction lengths of 500-1000 metres are relatively commonly encountered and sometimes quays of 2000 to 3000 metres long are being constructed. This means that in fact no optimum repetition effect can be achieved.

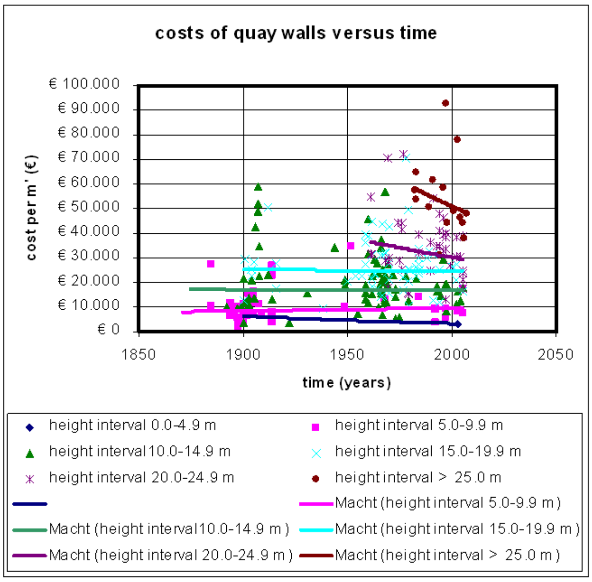

Figure 3: Cost of quay walls in euro (2008 values) versus time.

8. COSTS COMPARISON FOR GRAVITY AND SHEET PILE QUAY WALLS

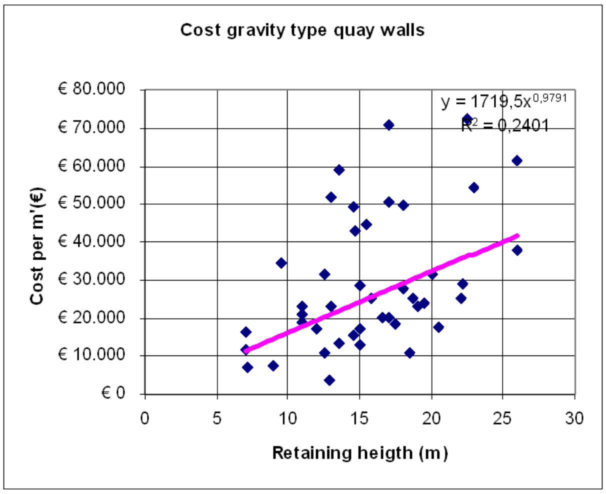

Figure 4: Costs for gravity structures in euro (2008 values)

Figure 4 indicates that there is a considerable variation in the cost of gravity structures. This can be explained by the fact that these structures are built of concrete and steel. To build these structures a construction pit is often required, which of course will increase the costs. In such cases the distance between the construction pit and the final location is important as this determines the transport costs and may contribute considerably in the total costs.

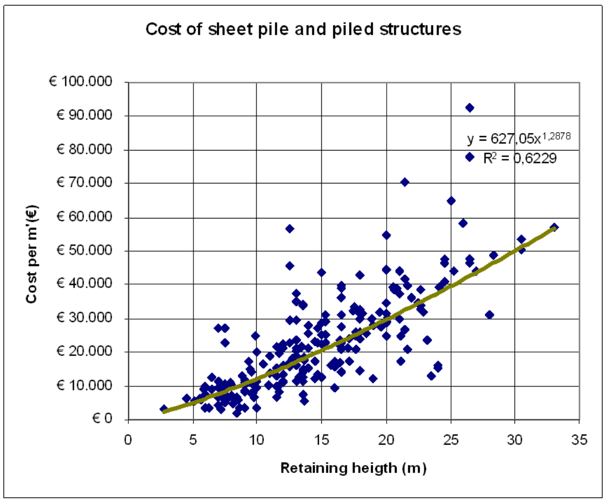

Figure 5: Costs of sheet piles and piled structures in euros (2008 values)

For sheet pile wall like structures the relation is considered fairly good and is explained by the fact that these types of structure are not dependent on construction pits and transport.

9. CONCLUSIONS

- The initial cost of quay wall structures is relatively independent of the location.
- For large length of quay wall projects due to improved logistics costs saving is possible.
- The costs of maintenance is not a major aspect concerning in the selection of the structural type of quay walls.
- The variation in costs for gravity type quay wall structures is significantly higher then for piled type structures.

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