Breakwaters and closure dams

On the cover picture:

Ship approaching a harbour, Willem Gruijter jr, (1817-1880)

Oil on Panel, 23 × 34 cm, Belasting- en Douanemuseum, Rotterdam

A ship is approaching a harbour, protected by a breakwater made from woodwork (palisade). Harbour approach indicated by a lighthouse, with an oil lamp. On the breakwater is fire basket as leading light. A wooden buoy is floating in front.

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Preface

This book is primarily a study book for graduate students. It has been prepared for students in Coastal Engineering at the Delft University of Technology. The consequence is that, in addition to treating the latest insights into the subject matter, it places the developments in their historic perspective, at least when this contributes to better understanding. It also means that this book cannot replace comprehensive textbooks or original scientific publications. The book focuses on understanding of the design process, but is certainly not a design manual. The reader is strongly advised to consult the original references rather than blindly following this textbook.
In the curriculum of Delft University, the course on breakwaters and closure dams is preceded by a variety of courses on subjects such as fluid mechanics, hydraulic engineering, coastal engineering and bed, bank and shore protection, design process, and probabilistic design. Therefore it is assumed that the reader is familiar with this knowledge and it will not be discussed in detail in this book.

At first sight it seems strange to combine in one book the design of two rather dedicated types of structures with distinctly different purposes, however from an educational point of view this is not so.
In both cases the design process requires that due attention should be paid to:

- the functional requirements
- the various limit states to which a structure will be exposed in relation to the requirements
- the various limit states that occur during construction phases
- the relation between these limit states and the occurrence of certain natural conditions

The differences between closure dams and breakwaters will enable us to focus attention on the above mentioned considerations.

In addition to this, there are also quite a number of similarities. In this respect, we refer to the construction materials, such as quarry stone, concrete blocks and caissons, which are widely used in both types of structures. The same applies to a wide range of construction equipment, both floating and rolling, and, last but not least, the interdependence between design and construction.
It is good to mention here that the design of closure dams, and more specifically closure dams in estuaries, has undergone a major development in the period between 1960 and 1985, when the Delta Project in the Netherlands was being executed. Only recently in Korea similar closures works have been executed. Also some experiences from these works are included in this book. In the view of the accelerated sea level rise it is anticipated that more works of this kind will be needed in future.
Breakwaters, and specifically various kinds of rubble mound breakwaters, underwent a tremendous development in the period 1985-1995. After that, the pace of innovation seemed to slowing down, although monolithic breakwaters were gaining attention in the following decade. In the most recent years focus of research was on the effect of shallow water conditions, optimising the use of the quarries (the Icelandic breakwaters) as well as research on variations on the rubble mound breakwater, like the (semi-)submerged structures, breakwaters with a longer berm and new concrete elements. Therefore, the present study book does not represent a static subject. This necessitates that both the teacher and the student should continuously observe the latest developments.

The first edition of this book (2001) was written by Kees d'Angremond and Ferd van Rooden. This second edition has been updated by Henk Jan Verhagen. New additions to the book to be mentioned are the treatment of wave statistics, the spectral approach in the stability formula, the shallow water conditions and the Icelandic breakwaters. The book has been brought in line with the Rock Manual (2007) and with the European Standard on Armour Stone (EN 13383).
Valuable contributions in the form of comments and/or text were received from: Marcel van Gent (Deltares), Jentsje van der Meer (independent consultant), Jelle Olthof (Delft University of Technology and Royal Boskalis Westminster), Gerrit Jan Schiereck, (Delft University of Technology), Sigurður Sigurðarson (Icelandic Maritime Administration) and Shigeo Takahashi (Japanese Port and Airport Research Institute). Many others contributed in a variety of ways, including correcting text and preparing figures. We are especially grateful to Margaret Boshek, who checked both the English spelling as well as the readability of the book.

Henk Jan Verhagen, Kees d'Angremond
Delft, January 2009

Contents

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1 INTRODUCTION

1.1 Scope

For this book we have deliberately chosen that the text should follow a more or less logical design procedure for both breakwaters as well as closure dams. This means that in each step of the procedure attention is paid to both breakwaters and closure dams and that every time the two types of structures are compared the similarities and differences are emphasized.
With respect to breakwaters, all existing types are discussed briefly but only the types that are frequently used all over the world (i.e. rubble mound breakwaters, berm breakwaters and monolithic breakwaters) are treated in detail.
With regard to closure dams, it is emphasized that only the constructural aspect of stopping the water movement is considered in this book. This means that only the closing operation itself is treated; the transformation of the closing dam into a permanent structure like an embankment is beyond the scope of this book.
It is expected that the reader possesses basic knowledge of hydraulic engineering. Only in some cases, where they are deemed useful for a proper understanding of the actual design process, are aspects of basic hydraulic engineering presented.

1.2 References

This book is an educational textbook, not a design manual or a reference book. The focus of this book is the understanding of the basic principles. It is not an overview of all existing formulas pertaining to breakwater or closure dam design. Also, because the results of new research will modify existing formulas, it is not useful to focus on the minute details of such formulas, but more on the physical concepts behind the formulas. Although a study book has its purpose, there are some outstanding reference books in the field cited by this textbook and these are often far more comprehensive than any study book. Therefore a number of books and

periodicals that are available to any engineer in charge of the design or construction of breakwaters or closure dams are mentioned here.
For *breakwaters* such books include: Coastal Engineering Manual [US ARMY CORPS OF ENGINEERS, 2002]), The Rock Manual (CIRIA/CUR/CETMEF [2007]) and various PIANC/MarCom Working Group reports. For *closure dams* reference may be made to: The Closure of Tidal Basins (HUIS IN 'T VELD, STUIP, WALTHER, VAN WESTEN [1984]) and the Manuals of the Expertise Network Water defences (ENW, formerly TAW, in Dutch). For wave-structure interaction, refer to the European Overtopping Manual (PULLEN *ET.AL* [2007]). Useful periodicals include the journals of the ASCE, the journal "Coastal Engineering" (from Elsevier) as well as the "Coastal Engineering Journal" (from World Scientific) and the yearly proceedings of the international conferences on Coastal Engineering and on Coastal Structures.
Additional educational material (PowerPoint presentations, videos) is on-line available via the educational platform of TU Delft (http://blackboard.tudelft.nl). To have guest access to this website, one should not log-in, but click on "courses" and search for "ct5308".

1.3 Miscellaneous

To avoid misunderstandings, a glossary of the terms used in this book is added as Appendix 9. For Dutch students an English-Dutch glossary is available on the above mentioned "blackboard" site. The reader is also referred to a more general vocabulary on hydraulic engineering (http://www.waterdictionary.info).
In this book, the metric (mks) system (based on the definition of mass [kg], length [m], and time [s] has been used, except for some widely accepted nautical and hydrographic terms such as knots, fathoms and miles.

2 POSITIONING THE SUBJECT

2.1 General

Breakwaters are widely used throughout the world. This type of structure is primarily designed for the protection of vessels harboured within ports and for port facilities from wave action, but sometimes breakwaters are also used to protect beaches from erosion or to protect valuable habitats that are threatened by the destructive forces of the sea. Although the threat is usually a product of wave action, protection against currents is also important. Additionally, breakwaters can prevent or reduce the siltation of navigation channels. In some cases, breakwaters also accommodate loading facilities for cargo or passengers.

Closure dams are constructed for a variety of very different purposes; such as the creation of a separate tidal basin for power generation or as sea defence structures to increase safety. Compared to closure works, few other engineering works have such an extensive impact on the environment in all aspects. For instance, the main purpose of the construction of the Afsluitdijk closure dam in the Netherlands was to provide protection against high storm surge levels and to facilitate land reclamation. Additional advantages were fresh water conservation and a road connection between the provinces of Holland and Friesland. The purpose of a closure dam may be one or more of such objectives, but these are automatically accompanied by other side effects, some of which may be negative. A thorough study of these impacts is part of the design process. A feasibility study that does not detail and forecast the negative aspects of the closure works is incomplete and valueless. These unforeseen negative effects for the Afsluitdijk include: the drastic change in tidal amplitude in the Waddenzee, consequential impact on the morphological equilibrium of the tidal flats and channel system, the social impact on life and employment in the bordering cities, the influence on drainage and the ground water table in the surrounding land areas, the changes to the fisheries industry, and effects on flora and fauna.

after which, for future safety, the desired definite dam profile can be made. This structure is based on construction in no-flow conditions.

2.2 Types of breakwaters

There are many different types of breakwaters that can be divided into categories according to their *structural features*:

Mound types

Mound types of breakwaters are simply large heaps of loose elements, such as gravel and quarry stone or concrete blocks. The stability of the exposed slope of the mound depends on the ratio between load and strength i.e. wave height (H) versus size and the relative density of the elements (Δd). On one extreme, for example, is a gravel beach that is subject to continuous changes in the equilibrium profile as the wave characteristics change and also due to longshore transport. On the other extreme, for example, is the 'statically stable breakwater', where the weight of the elements in the outer armour layer is sufficient to withstand the wave forces. Between these two extremes is the 'berm breakwater', where the size of the armour is not sufficient to guarantee stability under all conditions, but where some extra quantity of material is provided so that the slope of the structure can reshape between given limits. Typical values of $H/\Delta d$ for the three types of structures are given in Table 2-1.

Type of structure	$H/(\Delta d)$
Sandy Beach	> 500
Gravel Beach	20 – 500
Rock slope	6 – 20
Berm Breakwater	3 – 6
(Stable) Rubble Mound Breakwater	1 – 4
Caisson	< 1

Table 2-1 Characteristic values of $H/(\Delta d)$

Monolithic types

Monolithic breakwaters have a cross-section which acts as one solid block. Types of monolithic structures include caissons, a block wall, or a masonry structure. This type of structure can be categorized by a typical value of $H/\Delta d$ that is given (as caisson) in Table 2-1. The main differences between the mound and the monolithic types of breakwaters are caused by the interaction between the structure and the subsoil and also by the behaviour at failure. The mound-type structures can be considered flexible (i.e. they can follow uneven settlement of the foundation layers), whereas monolithic structures require a solid foundation that can cope with high and often dynamic loads. The behaviour of the structures when close to failure is also quite different. When a critical load value is exceeded, a monolithic structure will