Introduction to
bed, bank and shore protection

Cover:
“De machtige grijper, overwinnaar in den strijd tegen de zee” (The mighty grab, victor of the battle against the sea).
Johan Hendrik van Mastenbroek (1875 - 1945), Oil on canvas, Zuiderzeemuseum, Enkhuizen, The Netherlands.

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Gerrit Jan Schiereck
updated by Henk Jan Verhagen

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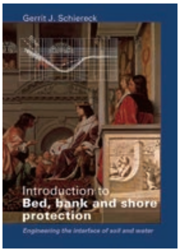
A little learning is a dangerous thing;
Drink deep or taste not the Pierian spring.
Alexander Pope (1688-1744)

Preface

Every book is unique. This one is because of a combination of two things:

- the coverage of subjects from hydraulic, river and coastal engineering which are normally treated in separate books
- the link between theoretical fluid mechanics and practical hydraulic engineering.

On the one hand many fine textbooks are available on fluid motion, wave hydrodynamics etc. while on the other hand one can find many manuals on hydraulic engineering topics. The link between theory and practice is seldom covered, making the use of manuals without understanding the backgrounds a "dangerous thing". Using a cook book without having learned to cook is no guarantee for a tasty meal and distilling whisky without a thorough training is plainly dangerous. Manuals are often based on experience, either in coastal or river engineering, or they focus on hydraulic structures such as weirs and sluices. In this way the overlap and analogy between the various subjects is missed which is a pity, especially in non-standard cases where insight into the processes is a must. This book makes an attempt to bridge the gap between theoretical hydrodynamics and the design of protective structures. The imagination and visualisation of what happens at an interface between soil and water is one of the key aspects to be learnt. However, this can only partly be derived from a text book. Using one's eyes every time one is on a river bank, a bridge or a beach is also part of this process. In the same sense a computer program should never completely replace experimental research and every student who wants to become a hydraulic engineer should spend some time doing experiments whenever the possibility presents itself. Anyway, the purpose of this book is to offer some know-how, but even more importantly, some know-why.



The painting on the cover represents three major elements in protection against water. The inset right under pictures the power of water, symbolised by Neptune who is enthousiastically trying to enter the gate while money and knowledge, symbolised by Mercury and Minerva, respectively, are the means to stop this. The painting itself depicts the granting of the right to establish an administrative body by the people of Rhineland, a polder area, by the count of Holland in 1255. People's participation is always a major issue in hydraulic engineering, as most projects serve a public goal. People's participation and money is not what this book offers, but I do hope that it will contribute to the knowledge to be able to make durable and sustainable protections.

Gerrit Jan Schiereck, Dordrecht, December 2000

Preface to the 2nd edition

The main reason to make a 2nd edition of this book was that we run out of copies. The basic setup of the book has not been changed. Also the fundamentals did not change in the last decade. Some new findings on turbulence have been added; the chapters on execution have been updated to the latest level of technology. Also a number of new examples from the last decade have been included. Finally the book is again in line with the latest standards. To indicate that this is a new version of the book a new cover has been designed. On the first cover an allegoric painting from the office of the waterboard of Rhineland was shown. For this edition I have selected a painting of Mastenbroek (1932) depicting the closure of the Afsluitdijk. A situation where the stability of the bed material was essential for the completion of the works. The painting expresses the strength of the grab, needed to combat the strength of the water.

Henk Jan Verhagen, Delft, July 2012

Preface to the 2nd edition, third revision

And again we ran out of copies, the book remains popular! As I am now the third lecturer updating the book, I did not feel like adding too much after having been a few years at TU Delft – and the basic hydraulics still have not changed. However, when reprinting, we took the liberty to correct several mistakes and make textual improvements in many parts. Only one important topic has been added, in Appendix C: scaling rules for physical modelling. This tool remains the primary source for the knowledge on bed, bank, and shore protections. I therefore feel it is important that the basics on scaling rules are part of the book.

Bas Hofland, Delft, September 2019

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Xbloc	Delta Marine Consultants (BAM Infraconsult), Netherlands

Contents

1 INTRODUCTION

Coastal protection along the Javanese coastline (photo Verhagen)

1.1 How to look at protections

1.1.1 Why and when

The interface of land and water has always played an important role in human activities; settlements are often located at coasts, river banks or deltas. When the interface consists of rock, erosion is usually negligible, but finer material can make protection necessary. In a natural situation, the interface moves freely with erosion and sedimentation. Nothing is actually wrong with erosion, unless certain interests are threatened. Erosion is somewhat like weed: as long as it does not harm any crop or other vegetation, no action is needed or even wanted. There should always be a balance between the effort to protect against erosion and the damage that would occur otherwise.

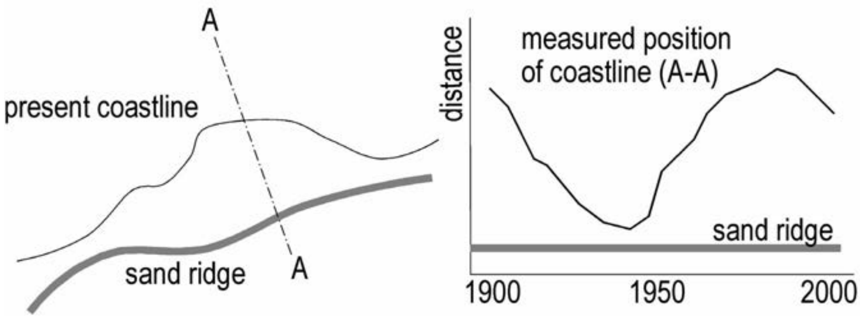
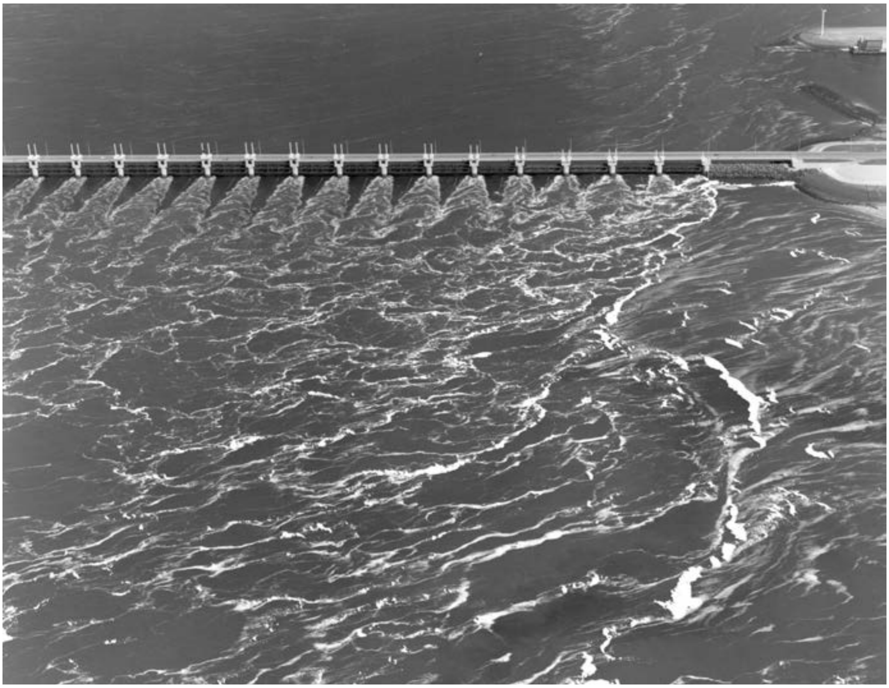


Figure 1-1 To protect or not to protect, that's the question

Figure 1-1 shows cyclic sedimentation and erosion of silt (with a period of many decades) seaward of a natural sand ridge. In a period of accretion people have started to use the new land for agricultural purposes. When erosion starts again, the question is whether the land should be protected and at what cost. Sea-defences are usually very costly and if the economic activities are only marginal, it can be wise to abandon the new land and consider the sand ridge as the basic coastline. If a complete city has emerged in the meantime, the decision will probably be otherwise. With an ever increasing population, the pressure on areas like these also increases. Still, it is good practice along a natural coast or bank to build only behind some set-back line. This set-back line should be related to the coastal or fluvial processes and the expected lifetime of the buildings. For example, a hotel has a lifetime of, say 50 years. It should then be built at a location where erosion will not threaten the building within 50 years, see Figure 1-2. So, in fact the unit for a set-back line is not meters but years! These matters are Coastal Zone Management issues and are beyond the scope of this book.

2 FLOW – Loads



Oosterschelde barrier (photo Rijkswaterstaat)

2.1 Introduction

When designing a protection it is necessary to have rather detailed information about the velocity field. For many projects flow data is available from historical records or from a numerical network model which calculates overall quantities, like discharges Q and hence, given the geometry of the situation, average velocities: $\bar{u} = Q/A$.

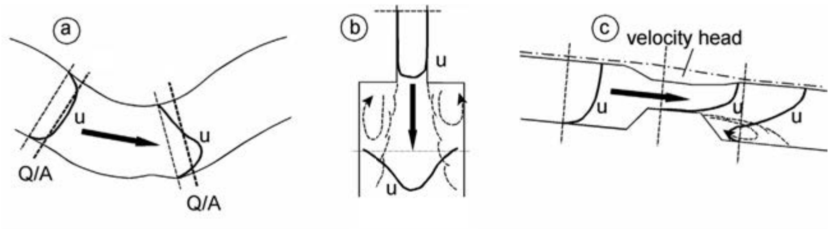


Figure 2-1 Velocity field in various situations

For the design of a bank protection in a river bend (see Figure 2-1a), the velocity near the bank must be known, which can be deducted from measurements in the river or in a scale model, from a numerical model or from a sketch, based on some understanding of the flow. In Figure 2-1b, it is inappropriate to work with a velocity averaged over the cross-section downstream of the outflow, since the flow direction in some parts is opposite to the main flow direction due to separation between the main flow and the flow near the side-walls. Figure 2-1c shows a similar situation in a vertical cross-section. Working with averaged velocity values ($\bar{u} = Q/A$), e.g. with Chezy's law for uniform flow: $\bar{u} = C\sqrt{Ri}$, would produce nearly the same value for the velocity upstream and downstream of the sill, since the geometry is the same. The figure, however, shows a completely different flow situation. Upstream, the velocity is well represented with a logarithmic profile, as can be expected in a (stationary) uniform flow. Downstream of the sill there is a flow separation with an eddy in which the flow direction near the bottom is opposite to the mainstream. The eddy can be seen as an ill-defined boundary for the flow, which also influences the turbulence level. In practice, the flow is always turbulent, but at the transition between main flow and eddies, the turbulence will be much greater and will persevere, far downstream from the transition. Protections of the interface between water and soil in these areas need to be relatively strong, because without protection, the erosion will be considerable.

Understanding the way water flows is paramount for every hydraulic engineer and a sketch of the velocity field should mark the start of every project. For such a sketch it is necessary to go from average values of the velocity to a local value and requires some understanding of the turbulence. In general one can say that it is necessary to have some insight in what is happening *inside* the water. Although turbulence is one of the most complex subjects in hydraulics, some basic facets of turbulence will be reviewed in the following section, focussing on phenomena rather than on formulas.

7 WAVES – Loads

Wave loads during Coastal Engineering Fieldwork in Bulgaria (photo H.J. Verhagen)

7.1 Introduction

A "wave" is the generic term for any (periodic) fluctuation in water height, velocity or pressure. This chapter will be restricted to wind-generated waves. The term **sea** is often used for "fresh" waves, where the driving wind force is still active, in contrast to **swell**. Swell is the name for waves that were caused by wind, but possibly long ago (days) and far away on the ocean (thousands of km). Sea is typically short-crested and irregular, while swell waves typically are more regular with long periods and wide crests.

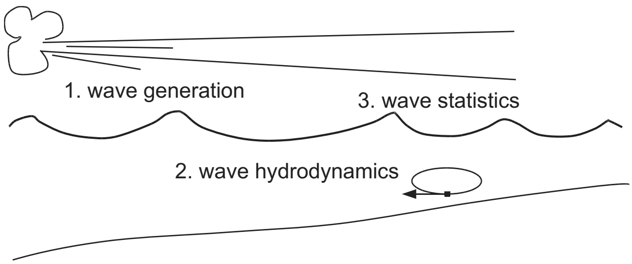


Figure 7-1 Wave aspects

The technical treatment of (wind) waves can be divided roughly into three categories, see Figure 7-1:

1. **Generation**
   The generation of waves by wind is described with relations of the type: $H, T_{characteristic} = f(u_{wind}, h, fetch)$. When for a coastal project no measured wave data and no advanced software to predict waves are available, Appendix 7.7.3 gives some useful relations for a first estimate. See also SPM,1984.

2. **Hydrodynamics**
   Velocities and forces in waves are, of course, important when dealing with erosion and protection. These parameters are described with relations of the type: $u, p, \tau = f(H,T,h)$. The wave generating forces no longer play a central role, the starting point is now wave height and period. Phenomena like refraction and diffraction, also being part of wave hydrodynamics, are beyond the scope of this book.

3. **Statistics**
   The water surface of wind waves is irregular because the driving force, the wind, is turbulent. It is therefore necessary to characterize a wave field by means of statistical parameters. Relations of the type: $p(H) = f(H_{characteristic}$, *distribution function*) give the probability of a certain wave height in a wave field. Wave spectra have become the most important description of the joint distribution of wave heights and periods in wave fields.

9 SHIPS

Pushbarge Lianco near Zelzate (photo Panoramico)

9.1 Introduction

This chapter treats the protections of waterways' beds and banks of waterways against loads caused by ships. Ships cause an interesting wave pattern and currents, involving many elements of the previous chapters. A summary of these phenomena will be given, with a focus on the resulting loads. For a more extensive treatment of some aspects the reader is referred to e.g Stoker, 1957 or RWS/DHL, 1988

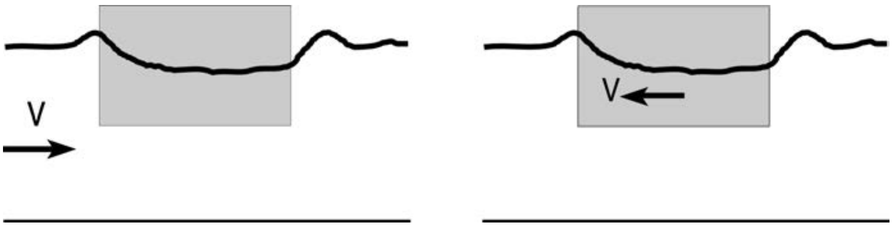


Figure 9-1 Flow around fixed object versus moving object in stagnant water

From a hydrodynamical point-of-view, a moving ship is similar to flow around a body (see Figure 9-1). Figure 9-2 gives an overview of the relevant phenomena. The water level depression along the ship's hull and the so-called return flow, which are well-known from observations of ships in canals, are also present when water flows around a body. This water-level depression is the *primary wave* with a wave length of about the ship's length. From the point of view of an observer on the bank, the primary wave starts with the front wave, followed by the depression and ending with the stern wave. Within the primary wave this stern wave usually results in the most severe attack on the banks.

The much shorter waves that originate from the hull and which are visible on aerial photographs, are the so-called *secondary waves*. Both types of waves behave like "normal" water waves, which means that the relations for wavelength, celerity etc. in Chapter 7 are valid. In practice, the primary wave can be long or short, depending on the same depth-length relations as mentioned in Chapter 7; secondary waves are practically always short, except for secondary waves produced by high-speed boats. In relatively narrow navigation channels the primary waves are important, otherwise only the secondary waves play a role.

The currents caused by the ship's propeller, the so called *propeller wash,* have the characteristics of a jet. This jet is particularly important when ships manoeuvre near a berthing place or a jetty. When sailing, the jet flow is partly neutralized by the speed of the ship.

Many investigations into ship motion have been carried out in the past, but most of them were for shipbuilders. The results of the investigations by Delft Hydraulics (Deltares) for the Dutch Rijkswaterstaat in the seventies are an important source of information. Although this research was set up primarily for inland waterways, the on top of concrete blocks. During this closure, high velocities occur between the gates and the concrete blocks, due to the growing head difference across the barrier, which causes a severe load on the bed. When the gates are closed, the head difference across the barrier causes a large parallel gradient inside the sill.

Figure 11-2 Overview Storm surge barrier Rotterdam Waterway (photo Aero Lin)

Figure 11-3 gives the cross-section of the barrier which shows the complete bed protection with the stone classes of the top layer. At the sea side, the maximum stone weight is 300-1000 kg and at the riverside 3000-6000 kg. This is because the critical situation is closing the gates during a strong flood flow. In that case, the flow accelerates at the sea side while it decelerates downstream of the gate. Chapter 2 and 3 explain that deceleration is associated with a high degree of turbulence, hence the top layers at the sea side and at the river side differ. When the barrier is open, normal ebb and flood flow occur with much lower velocities. Farther away from the sill, the stone sizes in the top layer decreases.

Figure 11-4 shows the composition of the sill. The design conditions for the filter below the sill are now governed by the situation with closed gates when a large head difference is present across the barrier. The original bed material consists of fine sand and silt. The first filter layer is sand ranging from 0.5 to 5 mm. The other layers below the top layer are gravel 3.5-35 mm, rock 30-140 mm and rock 10-60 kg. This is a good example of a geometrically closed filter.