1 INTRODUCTION

Eroded coast (North Holland), courtesy Rijkswaterstaat

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.

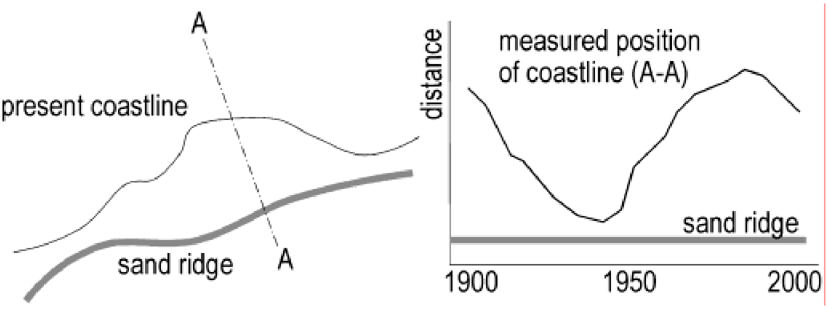

Figure 1-1 To protect or not to protect, that's the question

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.

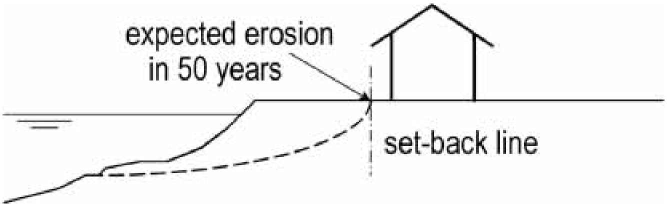

Figure 1-2 Building code in eroding area

Besides erosion as a natural phenomenon, nature can also offer protection. Coral reefs are excellent wave reductors. Vegetation often serves as protection: reed along river banks and mangrove trees along coasts and deltas reduce current velocities and waves and keep the sediment in place. Removal of these natural protections usually mark the beginning of a lot of erosion trouble and should therefore be avoided if possible. So, a first measure to fight erosion, should be the conservation of vegetation at the interface. Moreover, vegetation plays an important role in the ecosystems of banks. Chapter 12 deals with these aspects and with the possibilities of nature-friendly protections.

Finally, it should be kept in mind that, once a location is protected along a coast or riverbank that has eroded on a large scale, the protected part can induce extra erosion and in the end the whole coast or bank will have to be protected. So, look before you leap, should be the motto.

A lot of cases remain where protection is useful. Figure 1-3 gives some examples of bed, bank and shore protections. Along canals, rivers and estuaries, bank protection is often needed to withstand the loads caused by flow, waves or ships. Shore protection structures include seawalls, revetments, dikes and groynes. Bed protection is necessary where bottom erosion could endanger structures, like bridge piers, abutments, in- or outlet sluices or any other structures that let water pass through.

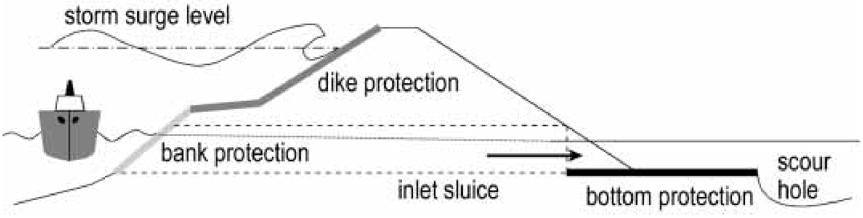

Figure 1-3 Examples of protection

1.1.2 Design

Protections of the interface of land or soil and water are mostly part of a larger project: e.g. a navigation channel, a sea defence system, an artificial island or a bridge. Therefore, the design of a protection should be tuned to the project as a whole, as part of an integrated design process, see De Ridder,1999. In general it can

be said that the resulting design should be *effective* and *efficient*. Effective means that the structure should be functional both for the user and the environment. This implies that the structure does what it is expected to do and is no threat for its environment. Efficient means that the costs of the (effective) structure should be as low as possible and that the construction period should not be longer than necessary.
A design that combines effectiveness and efficiency can be said to be "*value for money*" The intended value becomes manifest in the *terms of reference* (ToR) which contains the demands for a structure. This ToR has to be translated into concepts (possible solutions). Demands and concepts do not match one to one and a fit between the two is to be reached with trial and error. Promising concepts are engineered and compared. One comparison factor, of course, is costs. The designer's task to get value for money can be accomplished by compromising between four elements, see Figure 1-4.

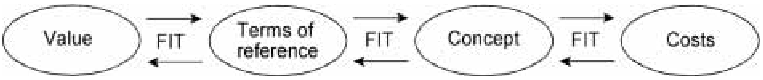

Figure 1-4 Value for money

The design process is of a cyclic nature because it is impossible to go directly from left to right in Figure 1-4. In the first phase, the designer works with a very general notion of the ToR and with some concepts in mind, based on his own or others' experiences. An integrated design process starts with a rough approach to all four elements in Figure 1-4, refining them in subsequent design phases. Effectivity can be evaluated in terms of functionality, environment and technology, while efficiency is expressed in terms of costs and construction although, of course, there are several overlaps and links between these aspects. They all play a role in each of the design phases, but the focus gradually shifts as indicated in Figure 1-5.

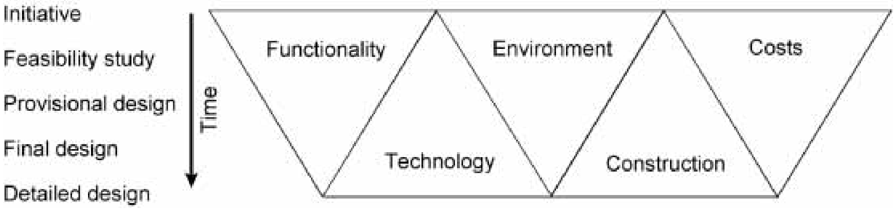

Figure 1-5 Focus during design process

Level of detail

In any project it is possible to discern various levels of detail. It is good to be aware of the level of detail one is working on and to keep an eye on the adjacent levels. An example of these levels (other divisions are, of course, possible):

1. System	(Macro level)
2. Components	(Meso level)
3. Parts	(Mini level)
4. Elements	(Micro level)

Examples of the macro level are e.g. a coastal zone, a watersystem (river, lake etc.) a harbour or a polder. On the meso level, one can think of components like a sea defence (dike, sea wall etc.), a river bank, a breakwater, a closure dam or an outlet sluice. On the mini level we look at dike protections, bank protections or bottom protections. The micro level, finally, consists of elements like stones, blocks etc. In this hierarchy, the title of this book indicates that it treats subjects on the third level. Level 1 should always play a role in the background, see e.g. section 1.1.1. Level 2 will be treated where and when adequate, while sometimes level 4 also plays a role e.g. when it comes to defining stone sizes. As a consequence of these levels, it can be said that the design of protections in a large project is usually more in the lower part of Figure 1-5, when it comes to the technical development of a plan.

1.1.3 Science or craftmanship

Protections of the interface of land and water have been made for more than 1000 years. Science came to this field much later, as a matter of fact very recently. The second world war boosted the understanding of waves and coasts. In the Netherlands after 1953, the Delta project had an impact on the research into protection works. In the last decades, major contributions to the design practice have been made, thanks to new research facilities, like (large scale) wind wave flumes, (turbulent) flow measurement devices, numerical models etc. progress has been made in The scientific basis of our knowledge has progressed considerably, but even after 50 years, much of the knowledge of these matters is of an empirical nature. Most formulas in this book are also empirical, based on experiments or experience.

Working with these empirical relations requires insight, in order to prevent misconceived use. The idea underlying this book is to start with a theoretical approach of the phenomena, focussing on understanding them. In the design of protections, especially in the unusual cases, a mix of science and experience is required. Since undergraduates, by definition, lack the latter, a sound theoretical basis and insight into the phenomena is paramount. This book goes one step further than simply presenting empirical design relations; it aims to create a better understanding of these relations. Engineering is an applied science, which then, by definition, means that science is the basis but not the core. Creativity, experience and common sense are just as important.

Computer models play an increasing role in engineering. For a hydraulic engineer, however, a sheet of white paper and a pencil are still essential, especially in the preliminary stage of a design. A hand made sketch of a current or wave pattern is as valuable as the correct application of calculation rules. For both, a good insight into the physics of the processes involved is indispensable.

1.2 How to deal with protections

1.2.1 Protection against what?

Interfaces between land and water exist in all sizes and circumstances. Figure 1-6 gives an idea of typical values for the loading phenomena in various watersystems (of course it is always possible to find an example with different figures).

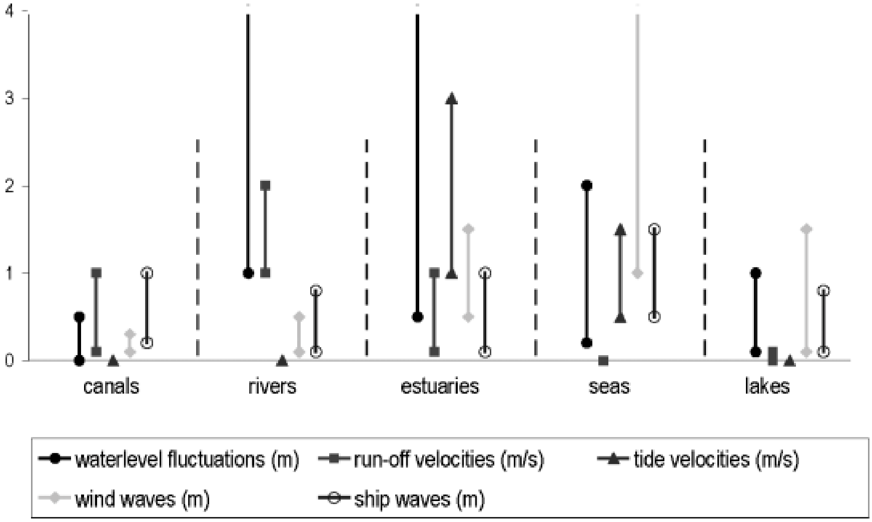

Figure 1-6 Hydraulic conditions in watersystems

This book treats the interface stability by looking at the phenomena instead of the watersystems. This is more exceptional than it seems, because most textbooks deal with shore protection or river training works or navigation canals etc. Much of the knowledge of these protection works is based on experience and experience is often gained in one of the mentioned fields, not in all of them. This is a pity because many of the phenomena involved are similar: ship waves and wind waves have different sources, but behave very much the same. The same holds for flow in a river, through a tidal closure or an outlet sluice, when it comes to protecting the bed or the bank. Moreover, in river bank protections, wind waves can sometimes play a role, which is often neglected in textbooks on river engineering. Therefore, an attempt is made to find the physical core of all these related problems.

One thing protections have in common, is that their function is to *withstand the energy of moving water*. Water in motion contains energy: currents, wind waves, ship movement, groundwater-flow etc, which can become available to transport material.

The energy comes from external sources, like wind or ships, and eventually ends up as heat by means of viscous friction. This is not an energy loss but an energy transfer, from kinetic energy, via turbulence, to heat. Turbulence plays an important role and will be discussed in more detail in the next chapter. For now it is sufficient to say that turbulence is related to the transformation of kinetic energy into heat. During this transfer, turbulence contributes to the attack of the interface.

Hydraulic engineering research is often empirical and fragmented. This leads to an avalanche of relations for each subject, while the connections remain unclear. One of the basic ideas of this book is to show similarities and differences between the various phenomena and therefore between the various formulas, in order to clarify the overall picture. Chapter 2 deals with open-channel flow, chapter 5 with porous flow (flow through pores of granular structures like soil or rock), chapter 7 with waves and chapter 9 with ships. These subjects can and will be treated separately, but there are more similarities than many textbooks reveal.

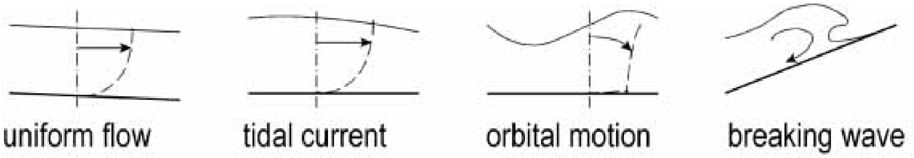

Figure 1-7 Flow and wave situations

Uniform flow is the starting point for many hydraulic considerations, see Figure 1-7. The equilibrium between gravity and wall friction completely determines the flow. The boundary layer, connected with the wall friction, takes up the whole waterdepth, is turbulent and shows a logarithmic velocity profile. The velocity profile of tide waves (very long waves with typical periods of 12 hours and wave lengths of several hundreds of km's) only slightly differs from the uniform flow velocity profile. It is therefore justified, when designing a protection, to consider tidal currents as a succesion of uniform flow situations with different velocities. For wind waves (typical periods of 5 – 10 s and wave lengths of 50 – 150 m), the situation is completely different with a non turbulent orbital motion and a thin turbulent boundary layer, although such a wave in very shallow water will again approach the situation with a tidal wave. Finally, a wave that breaks on a slope, leads to turbulence over the whole waterdepth.

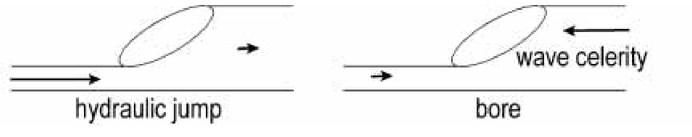

Figure 1-8 Jump and bore

A hydraulic jump and the roller of a broken wave (the bore) are very much the same. This can be seen when the jump is observed from a fixed position and the bore from a position that moves at wave celerity. The turbulence characteristics, caused by the friction between roller and flowing water, are also similar. Chapter 7 will show this in detail.

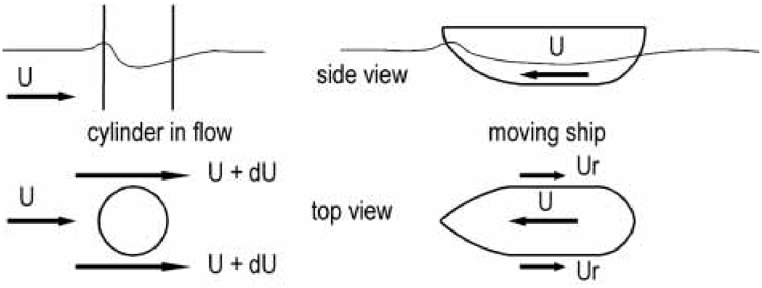

Figure 1-9 Flowing water versus moving object

The same similarity exists between a fixed object in flowing water and a ship sailing in still water. The water around the object accelerates, while around the ship a return current occurs, both leading to a water level depression.

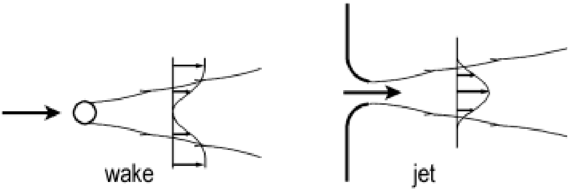

Figure 1-10 Mixing layers in wake and jet

Behind an object in flow or behind a ship, a wake occurs, where there is a velocity deficit compared with the environment. This velocity difference causes a so-called mixing layer where relatively slowly and quickly moving water mix which leads to a lot of turbulence. In a jet (an outflow in stagnant or slowly moving water) the same velocity differences (but now due to an excess velocity) occur, causing the same mixing layer and turbulence.

The last analogy in this chapter is between pipe flow and porous flow (see Figure 1-11) which is flow through a porous medium like sand or stones. In a straight pipe the (uniform) flow is determined by the wall friction. In an irregular pipe, uniform flow will never really occur, due to the irregularities in the cross section. Even with a constant discharge, accelerations and decelerations will always occur and, at sharp discontinuities, even flow separation with a mixing layer will take place. The flow between grains, when considered on a micro level, also show continuous accelerations and decelerations and the same basic equations describe this type of flow, including laminar and turbulent flow. In practice, however, the flow is integrated over many grains and pores, because it is not feasible and not necessary to have velocity information of every pore.

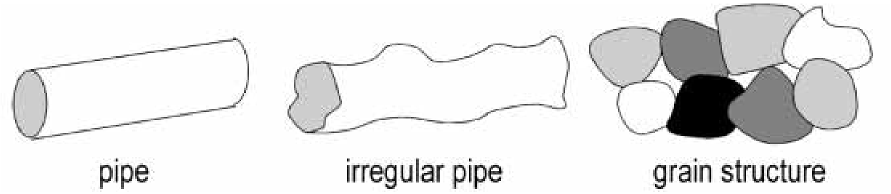

Figure 1-11 Pipe flow and porous flow

All of the above examples contain elements of three phenomena: *wall flow, mixing layer and oscillating flow (wave)* with turbulence playing a role in all three of them. Wall flow is present in uniform (pipe) flow, tidal flow and in the boundary layer of wind waves. A mixing layer is visible in hydraulic jumps and bores (between main flow and roller) and in wakes and jets. On a micro scale, porous flow includes both wall flow and mixing layers. It is a simplification to say that every flow situation can be reduced to these three basic phenomena or a combination of them but every situation contains at least one of these three features. It is therefore indispensable to be able to recognize and understand their elementary properties. This is what the chapters on loads are about: chapter 2 on flow, chapter 5 on porous flow and chapter 7 on waves.

Hydraulics and geotechnics

In general, hydraulic and soil-mechanical mechanisms determine the stability of a structure. Cause and effect can lie in both fields: failure of a protection can cause settlements of a structure, but vice versa is also possible. Figure 1-12 gives some examples.

In case (a) the sill under a water-retaining structure is a malfunctioning filter. Due to erosion, the structure will settle. As the maximum gradient inside the filter possibly occurs at the entrance side of the flow, the settlement can be against the head difference. In case (b) a canal is situated above groundwater-level. To prevent waterlosses, the bottom of the canal is coated with an impermeable protection. If the dike along the canal settles, due to insufficient strength of the subsoil, a fracture in the protection can occur and the canal water can drain into the subsoil. Case (a) looks like a soil mechanical problem but it has a hydraulic cause while in case (b) it is the other way around.

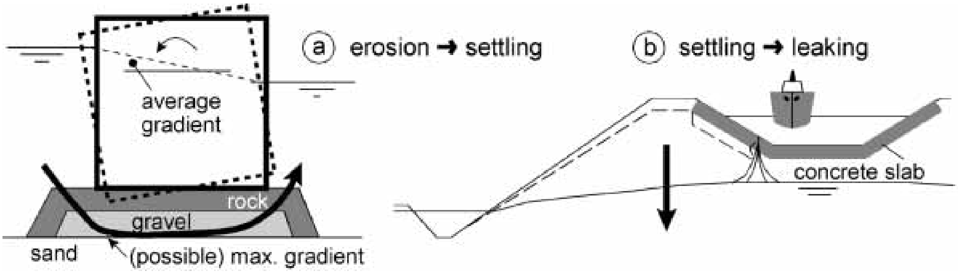

Figure 1-12 Cause and effect

1.2.2 Failure and design

The previous section already stressed that insight in phenomena is paramount for the design of a reliable interface protection. Neglectance of a relevant phenomenon can lead to a protection that causes more damage than it prevents or that shifts the problem to the neglected phenomenon, see Figure 1-13.

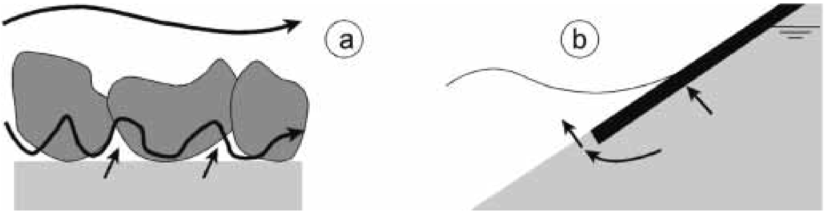

Figure 1-13 Ill-designed protections

In case (a), large rocks have been dumped on a sandy bottom which erodes because of currents. The rocks lead to a slightly lower velocity at the bottom, but to a considerable increase in turbulence and hence, maybe even an increase of erosion. Case (b) shows an asphalt-protection on a slope which would otherwise erode due to wave action. The protection now causes a difference between the water-tables inside and outside of the slope during low water. This head difference causes pressures on the protection which can result in lifting the protection layer. It also causes a concentrated groundwater-flow at the edge of the asphalt which leads to erosion at that spot.

Figure 1-14 shows the forces that act on a protected slope. A represents the loads from the water-side of the interface, the external load due to waves and currents. C is the load from inside due to a relatively high groundwater-potential in the soil-mass. B is the interaction between the external load and the inside of the structure. Although the external forces are usually rather violent and spectacular, many protections fail because of B or C.

The external forces A require a *strong* protection. This strength can be obtained by using large, heavy stones. The example in Figure 1-13 has shown that a protection should also be *sandtight* due to process B. To make the protection sandtight, some layer is needed between the top-layer and the subsoil e.g. a filter, a cloth or a foil. But if that layer is impermeable, C can become a threat. That means *permeability* can be required (unless there are other reasons to make the protection impermeable; in that case the protection has to be designed to withstand the possible pressures). Another way of increasing strength is ensuring coherence in the top-layer e.g. by using concrete or asphalt instead of dumped rocks. The protection can then become impermeable or stiff which can cause problems if settlements are expected. So *flexibility* is another factor to reckon with. Figure 1-14 gives an idea of the contradicting factors in design of a protection.

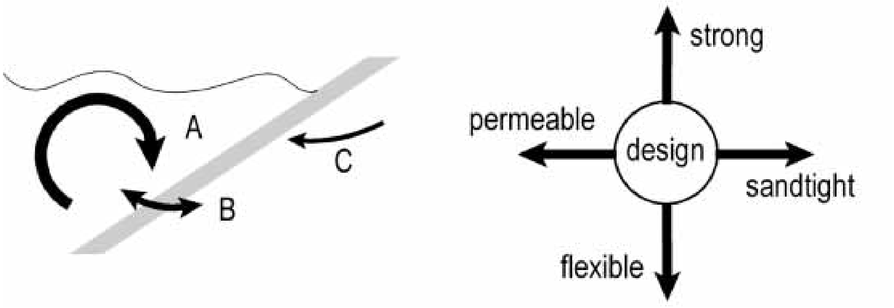

Figure 1-14 Contradicting demands

Failure mechanisms

In general, it is always necessary to keep the overall picture in mind. Figure 1-15 shows the relevant failure mechanisms for a revetment.

Even if these mechanisms are not completely open to computation, a mere qualitative understanding can help to prevent an unbalanced design. Insight is more important than having an accurate formula to compute dimensions of some part of the structure. *Protections seldom fail because of an underestimation of the loads of 10 %; most protections fail because a mechanism has been neglected***!**

Sometimes, designers put most of their energy into the first failure mechanism, the instability of the protection layer, also including the filter action (mechanism B in Figure 1-14). But if the protection is too low, wave overtopping can destroy the revetment. Toe protection is often neglected or underestimated. Instability of the slope can be of a micro or macro nature, both connected with the slope angle; chapter 5 gives more details. Collision or agression is self evident, but hard to include in a design. A collision proof design will be unnecessarily expensive, unless the protection is situated at a notorious accident spot. A better approach can be to keep repair material in stock and to anticipate repair works in the maintenance programme.

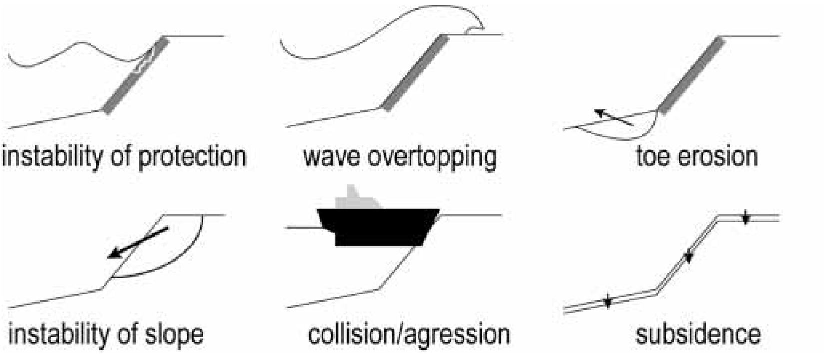

Figure 1-15 Failure mechanisms

The failure mechanisms of a structure can be combined in a fault tree (Figure 1-16), which gives the relations between the possible causes and the failure of the revetment on top of the tree. If you are able to assign probabilities to the events, it is possible to determine the total probability of failure of the structure and to find weak spots. But also without that quantitative information it is useful to draw a fault tree to get the overall picture. An experienced designer does so intuitively but even then, it is a useful tool.

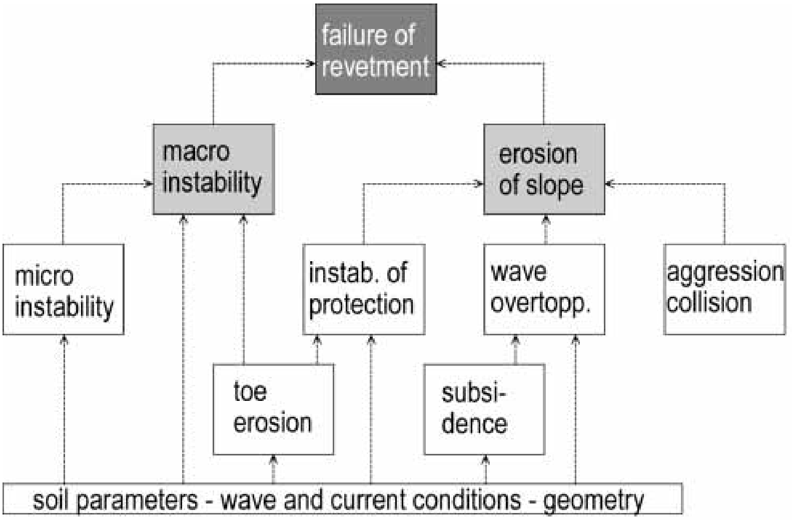

Figure 1-16 Fault tree

1.2.3 Load and strength

The core item in this book is the design of protections that can withstand the loads due to currents, water-level differences or waves. For structures consisting of relatively small elements (rocks, stones, blocks etc.) the definition of strength is somewhat ambiguous. A comparison with a steel structure is made to clarify this point (Figure 1-17).

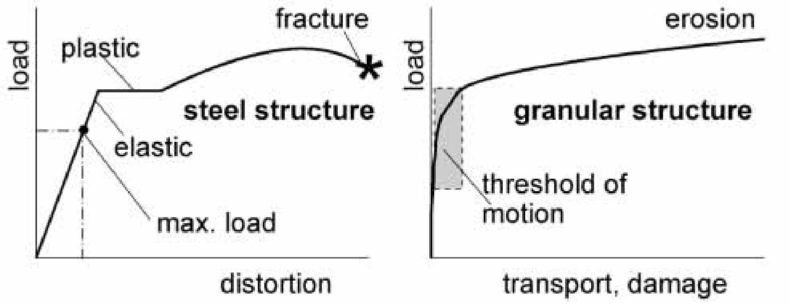

Figure 1-17 Load and strength for steel and granular structure

When steel is loaded, at first the distortion is elastic, obeying Hooke's law. At a certain point, without increase of the load, the distortion becomes plastic. After that, some strengthening occurs until the steel yields. The strength of steel is normally chosen well under the plastic limit, based on the statistics of the steel quality. The clear change of material behaviour serves as an indicator for the permissible strength For a granular structure, things are less clear. When the load is small compared to the strength, nothing happens at all. At a certain load, some elements move and stop again after some time. Further increase of the load leads to more displacements, finally leading to complete erosion. Usually some damage, like the displacement of some stones on a slope, is not much of a problem, this also depends on the maintenance policy. A clear limit between acceptable and not-acceptable erosion is lacking and the threshold of motion has to be defined. This will be done for the various phenomena in the following chapters.

Another difference between steel and stones is that, for steel, both load and strength can be expressed in the same unit: Newton. For a protection this could be achieved by expressing the load on an individual stone in N and defining the strength as the weight of that stone (mass*$g = N$), but that is not very practical. It is customary to express the load in terms of the wave height or the current velocity. The strength is then indicated with a diameter or thickness, d, often as well as the relative density of the material ($\Delta = \rho_m - \rho_w/\rho_w$), which contributes to the strength. This leads to dimensionless parameters like $H/\Delta d$ or $u^2/\Delta g d$.

This can lead to confusion because, in hydraulic engineering, these dimensionless parameters are used both as *mobility* parameters and as *stability* parameters. The difference becomes clear when you consider the mobility parameter as an independent variable in a transport equation and the stability parameter as a dependent variable in a stability equation:

*Transport, damage = f (**mobility parameter**, geometry, etc)*

Stability (parameter) *= f (accepted damage, geometry, etc)*

The first type of equation includes many sediment transport equations, e.g. in this book the Paintal equation in chapter 3 or, in a modified form, in scour relations in chapter 4. Most relations in this book are of the second type, like those by Shields and Izbash in chapter 3 or those by Van der Meer and Hudson in chapter 8. It is good to be aware of the difference, as the use of these parameters in textbooks is not always consistent.

When used as a *mobility* parameter, a large value indicates more mobility (high load versus low strength). When used as a *stability* parameter, a larger value of $H/\Delta d$ indicates more stability (the same stone size can resist a larger wave or for the same wave, a smaller stone can be used). The *stability* parameter can be seen as a *critical value of the mobility* parameter, since the amount of acceptable damage or transport has been chosen. This may be confusing, but is essential in working with the different formulas.

The difference can be illustrated by the stability of stones on a slope in breaking waves (See Figure 1-18) based on the Van der Meer relations, see chapter 8. In the $H/\Delta d$ - damage plane, $H/\Delta d$ is a *mobility* parameter, in the $H/\Delta d$ – α plane it is a *stability* parameter. For a certain slope angle, α, and given stone dimensions (Δd), a higher wave, hence a greater $H/\Delta d$, gives more mobility or more damage. For a certain acceptable damage, a given stone (Δd) can stand higher waves when the slope is gentler (smaller α). This has to do with gravity, which reduces the strength of a stone on a steep slope, but also with the different behaviour of breaking waves on different slope angles, resulting in different loads. This, again, illustrates that load and strength are not defined unambiguously the way they are for a steel structure, when both can be expressed in Newtons.

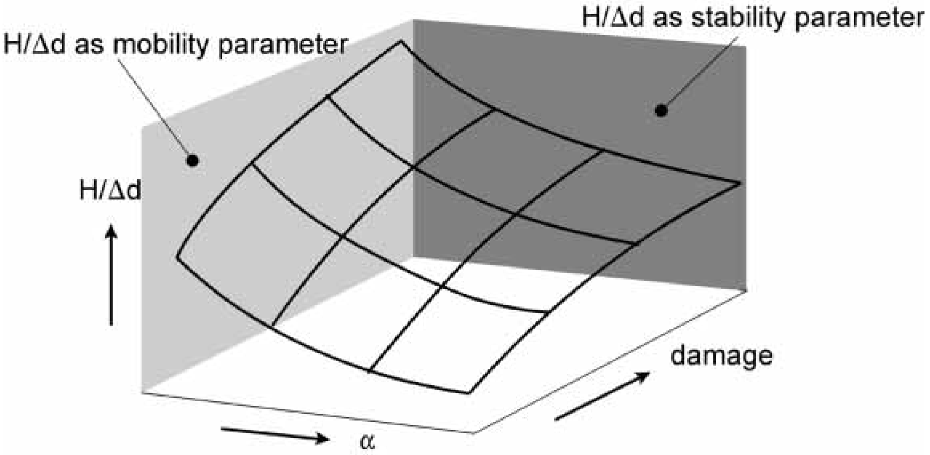

Figure 1-18 Mobility versus stability

Example 1-1

A beach coast with a wave height of 3 m during a storm and sand with a grain size of 0.2 mm gives a H/Δd of about 10000. During that storm, a lot of sand will be transported. The same wave height with a concrete caisson wall will give an H/Δd of less than 1 and no movement at all. So, a higher value of the mobility parameter indicates less stability.
The same coast is going to be protected with stones on a slope. From experiments it is found that the stability parameter for a slope 1:2 is about 2 (with hardly any movement of stones) and for a slope 1:4 is about 2.5 (with the same degree of damage). With the given wave height in a design storm of 3 m, this would lead to a stone size of 0.9 m for the 1:2 slope and 0.7 for the 1:4 slope. So, a higher value of the stability parameter indicates more stability.

Load and strength as design options

When the load exceeds the strength and measures have to be taken, there are two possible approaches: the strength can be increased or the load can be reduced. Figure 1-19 illustrates these possibilities. A bank, eroding due to wave action, can be protected by making a revetment (case A) or by constructing a wave reductor in front of the bank (case B). The latter can be chosen when the "natural" look of the bank has to be preserved, see also chapter 12.

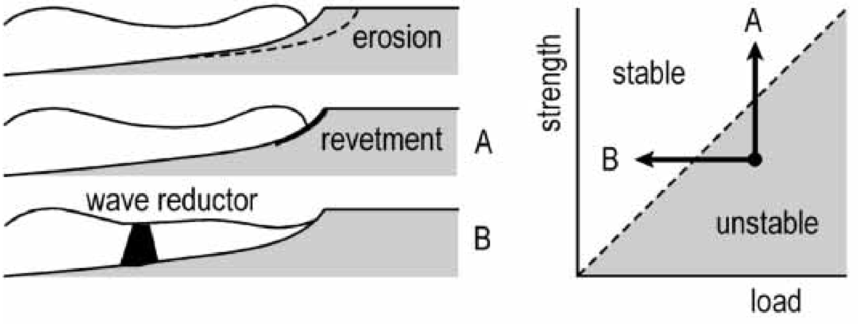

Figure 1-19 Strength increase or load reduction

Load and strength statistics

Loads in nature show a lot of variation. Waves depend on wind, velocities in a river depend on rainfall, so loads heavily depend on meteorology which has a random character. Probabilistic design methods, therefore, are important for protections. In a feasibility study it is often sufficient to work with a representative load. The choice of that load should be based on the relevant failure mechanisms (see Figure 1-15) and on the consequences of exceeding the load. Stability of the top layer of a bottom protection behind a sluice (e.g. see Figure 1-3) is mainly sensitive for exceptional loads and should therefore be based on an extreme event, while erosion behind the

protection is also determined by everyday flow. The use of different exceedance frequencies results in different design values for the same loading phenomenon!
More in general, the performance of a structure should be judged under various circumstances related to different limit states, see e.g. Vrijling et al, 1992. Two widely used limit states are:

Ultimate limit state (ULS): This limit state defines collapse or such deformation that the structure as a whole can no longer perform its main task. It is usually related to extreme load conditions. Related to the levels of section 1.1.2, it can mean e.g. the collapse of a dike (meso level). In the fault tree in Figure 1-16 the ULS is represented by the higher part of the tree.

Serviceability limit state (SLS): This limit state defines the required performance, e.g. the wave reduction by breakwaters in a harbour. In the context of this book it describes a state that needs to be maintained. Related to the levels of section 1.1.2 it means e.g. the damage of a dike protection (mini level).
Note: for the top layer of the protection this could be seen as the ULS to show that these definitions also depend on the level of detail. In Figure 1-16 the SLS is related to the bottom part of the tree.

The accepted probability of reaching both limit states is a function of the damage caused by exceeding that state. It is obvious that the chance of reaching the ULS should be much lower than reaching the SLS. Maintenance policy is closely related to these limit states. The strength of the structure *as a whole* can drop below the level that is needed under extreme conditions (see Figure 1-20). As long as these conditions do not occur, the ULS will not be reached. When deterioration goes on for a long time, the strength can become too small even for daily conditions and collapse will occur out of the blue. The extreme load in Figure 1-20 has some probability. When the strength is greater than the extreme load, the probability of reaching the ULS is considered acceptable. Without maintenance, the strength decreases and the failure probability increases until it reaches about 100 % when the strength becomes lower than the ever present loads. See chapter 10 for more detail.

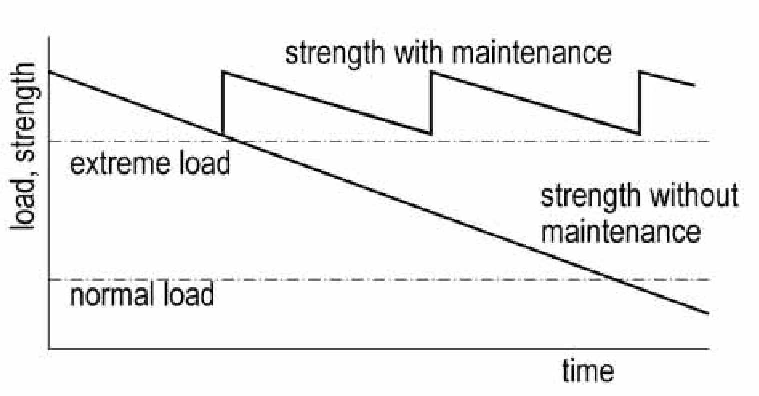

Figure 1-20 Strength as a function of time and maintenance

1.3 How to deal with this book

There are many textbooks on protection design. They are often aimed at professionals and deal with specific practical applications without treating the theoretical backgrounds. There are also many books on the theoretical backgrounds of flow and wave phenomena without practical application. This book aims to introduce protection design with a focus on the link between theory and practice. It is intended for use as a textbook in a graduate course on university level. The reader is supposed to be familiar with basic knowledge of hydraulics and soil mechanics; only the most important elements thereof will be treated in this book.

Some engineers are addicted to formulas and computing. Formulas are indispensible to calculate dimensions, but again, it is stressed that insight is often more important than numbers. There are many formulas in this book, and of course, they are meant to be used to calculate the dimensions of protections but there is also another way to look at them. Formulas are a very special form of language; they are the most concise way to express a phenomenon. By reading them carefully in this way, it is possible to gain some insight because they show the relations between different parameters, thus describing a phenomenon. The worst thing that can happen to a formula is to be learned by heart without being understood. Another accident that can happen with a formula is that it is considered algebra instead of physics. When doing so, cause and effect can be interchanged freely, sometimes with funny computational results.

The best way to read a formula is to start with the parameters. Do they seem logical for the process described, are any parameters missing? When a parameter's value doubles, what happens to the result and does that seem reasonable? What is the domain in which the formula is valid? Empirical relations are only valid in the range of experiments; theoretical formulae are often based on simplifications.

Another essential element in the book is made up of pictures. These too, present a concise language, either by means of "real life" pictures of some phenomenon or by means of graphs describing the relation between parameters. Text, formulae and pictures together tell the story of protecting the interface between soil and water. Interpretation of these three requires the ability to imagine what is happening to the water, the sediment and the structures. Keeping an open eye and mind when walking along a bank or coast, or in any other place where water moves, surely helps.

This introductory chapter tries to reveal the core of the whole subject and therefore also sometimes resembles a summary. The reader is advised to read it before and after studying this book. Much of what is not clear when reading this chapter the first time, might be recognized immediately when reading it again later. There is a saying: *"Understanding is nothing but getting used to"* which contains some truth.

The contents of the rest of the book can be divided into a more theoretical part (Chapter 2–9, an application of theoretical hydrodynamics and soil mechanics) and a part that deals with the applications of protections (Chapter 10-13). Chapter 2 to 9 contain the technical heart of the matter and have a logical composition. It starts with flow phenomena and related erosion and stability problems (2, 3 and 4). Porous flow is the next step with a small addition concerning geotechnical issues (5 and 6). Wind wave phenomena are treated in chapter 7 and related erosion and stability problems in chapter 8. Chapter 9 deals with all aspects of erosion and stability related to ships. This chapter refers to many of the previous chapters, since the ship-related phenomena contain both elements of flow and waves.

Chapter 10 is on dimensioning of protections and mainly deals with probabilistic methods. Chapter 11 contains examples of protections as made in several places in the world, the focus being on The Netherlands. Chapter 12 looks into environmental aspects, with a focus on nature-friendly protections. The construction of protection works is the subject of chapter 13.

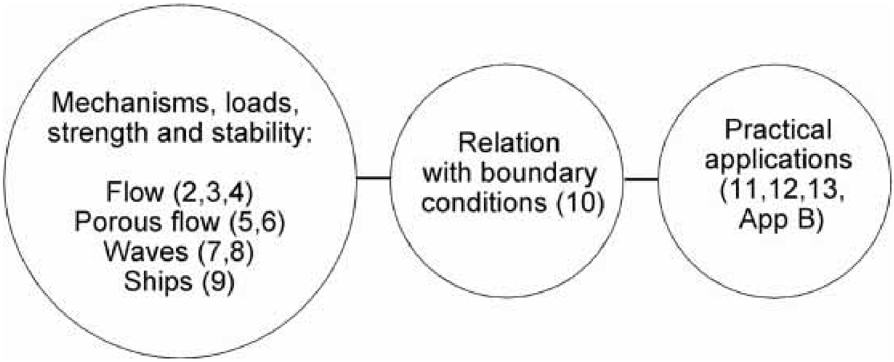

Figure 1-21 Main structure of this book

Consequently implementing the order of subjects appeared to be impossible. Filters e.g. are treated in chapter 6, including filters under wave loads, while waves are not treated until chapter 7. This has been done because a special section on filters in chapter 7 appeared to become too insignificant. The alternative of treating porous flow and filters after waves was not attractive, as porous flow plays a role in the stability of block revetments.

The main text in each chapter contains the basic message of this book with a one-page *summary* at the end of the chapter. *Intermezzo's* sometimes clarify the main text or give some historic background. *Examples* are intended to illustrate the application of formulas. Some chapters have *appendices*. These are, by definition, no part of the main text. They serve as background information on subjects that are supposed to have been studied but that have possibly been forgotten somewhat. The same is valid for *Reminder I* which contains simple equations that you should know by heart already, but the reminder comes in handy when you do not. *Reminder II* contains some interesting details about the contents of this book. They may sometimes be overlooked easily in the avalanche of information, but can come in handy when one is confronted with a protection problem.

There are two general appendices: A and B. Appendix A gives information on materials, to be used in the many formulas in the book. Appendix B gives some elaborated example cases.

Finally, the *Suggestions for further reading* are for those who think that not everything is in this book, which is indeed the case.