

## MANAGEMENT AND MAINTENANCE OF DIKES AND BANKS

### Introduction

As a low-lying and highly developed country, the Netherlands is continuously facing potential flooding disasters. That's why we need strong safe water-retaining structures like sea and river-dikes. Moreover half of the country lies below mean high water level. Without dikes more than half of the country would be endangered by flooding. About 60% of the total Dutch population lives in low lying areas.

The history of the Netherlands is marked by storm surge disasters. The most recent major flood disaster occurred in 1953. Nearly 90 dikes were breached and 150.000 ha of polderland was inundated. This caused the death of 1850 people and 100.000 persons had to be evacuated.



This disaster gave a new impulse for improving the whole sea defence system in the Netherlands. Moreover research into failure mechanisms of flood control structures was started. Over the last decades this has resulted, together with the experience obtained by the execution of the flood control structures improvements, in a considerable amount of high standard guidelines for the design of dikes, seawalls, revetments and other coastal structures.

The basic strengthening of the existing sea defences in the Netherlands is now completed. Together with the closing dams in the estuaries and tidal rivers, the low-lying "polderland" of the Netherlands has already reached a relative high degree of safety against storm surges. The strengthening of the river dikes is still under construction.

It is clear that the reconstructed and improved water retaining constructions need to be maintained to hold their high degree of safety against storm-surges. In this lecture management and maintenance of water-retaining structures will be discussed.

## **MANAGEMENT and MAINTENANCE**

Management and maintenance are two separate things, but they are directly connected.

### **Management**

Management is the care that, in general, public works, require to be able to answer the purpose for which they were constructed. In The Netherlands, and I presume in Bangladesh too, these works are, in general, in the care of public authorities.

This care should be carried out as a joint effort between policy-makers and coastal engineers, taking full account of the growing pressures upon the coastal zone from use by the community.

The management of flood control structures is, as already mentioned, crucial for the permanent safety of the Netherlands. Therefore in the Netherlands the management of all dikes is in the hands of 41 water-boards. These are public authorities of which the area of jurisdiction has a historical origin, often dating back to the fifteenth century. The governing body of a water-board is selected by means of elections by the inhabitants and land-owners living within the area of the water-board.

In order to adequately carry out the task of caring for dikes and banks the water-boards have legal powers to enforce sanctions. These provisions are necessary to underline the importance of care and maintenance and if necessary implement maintenance by force.

### **Maintenance**

The duty of maintenance is normally connected to management. In general the water-board itself is responsible for maintenance and carries this out by itself. If necessary with the support of contractors.

It's not always necessary that the duty of carrying out maintenance is connected to the task of management. The duty of maintenance can also be carried out by a third party. In that case the water-board ensures that the third party carries out its duty correctly.

### **Finances**

The water-board finance their work entirely from taxes which they levy on those concerned: the residents, the owners and users of land and property in the area covered by the water-board. Therefore the governing body is made up of representatives of these groups of people because they have an interest in the work of the water-board.

That's why the water-board has a functional nature because it has only one purpose which is dike or water management. This in contrast to a general governing body with several general purposes. Characteristic of water-boards is that the execution of the tasks that they have to do is, in fact, put in the care of the residents and users of land and property. In addition to which all the taxes are spent on only one purpose.

Flood control works always have to compete for resources with the demands from other types of public service. That is why the responsible manager has to take care of efficient management. He has to present the cost and benefits of his product in such a way that the water-board, which is responsible for a socially acceptable appropriation of budgets, can make justified decisions.

To underline the fact that a good maintenance of sea and river dikes is a general issue, the central government contribute towards the cost of maintenance. The reason is that flooding nearly always affects the surrounding and not simply the area covered by the water-board. So the consequences of flooding are also perceptible there. The contribution is a percentage of the normal amount of the direct cost of maintenance of the water-board, which has been agreed previously.

### **What do we understand by maintenance?**

Maintenance can be defined as: *the upkeep of previously invested (sometimes considerable) capital* or in other words: *keeping works permanently in a good working condition.*

To keep a dike in permanently good working condition, it is clear that carrying out maintenance is necessary. Maintenance however depends on, and is influenced by:

- design
- choice of applied materials
- manner of execution

### **Design and choice of applied materials**

These depend on the available (financial) resources and what is technical possible. The kind and the amount of maintenance is already determined by this in an indirect way; for example if in the case of equal technical designs, a choice is made for budgetary reasons for a design with the lowest cost of interest, depreciation and maintenance. A choice for a less durable design in general means lower cost of construction, but often implies higher maintenance costs. This in contrast to a design of which the cost of maintenance is lower, but the cost of construction is higher because of a more durable design. Particularly if specific knowledge and experience is required for maintenance, this can lead to a choice for a durable and more expensive design with lower costs of maintenance.

It is also important to consider in which way the aspects of employment during the execution of the works are best served. These aspects are important limiting conditions in many countries. Added to this, discrepancies can arise if during the construction of a revetment with concrete blocks, a choice for hand-made blocks is made. This is good for employment, but factory-made blocks are more durable.

World wide social acceptance is beginning to play a more important role. In particular the influence on the environment has become an issue. Indirectly these factors can influence the maintenance as well.

The following pages show examples of designs of dike reconstructions along the coast of Surinam in South America. The designs of solutions 1, 2 and 3 were constructed near the town of Nickerie. Solutions 4 and 5 were part of a feasibility study. Unfortunately solution 5 was carried out as a definitive construction along the coast near Coronie, though it is only recommended for a temporary construction. After a few storm surges the dike has already collapsed because of several dike

breaches and an area of about 400 ha has been inundated (see photos on one of the following pages).

### **The method of execution**

The method chosen for building a dike has an important effect on maintenance at a later stage. Maintenance is affected by it directly, for example:

- Clay for dike heightening must be built in layers and compacted layer by layer, for instance with bulldozers or vibration rolls. If this does not happen layer by layer or if compacting is not carried out in a mechanical way, but only using the tracks or bucket of the hydraulic excavator, this always causes settlement later on.  
The consequence of this is that a dike crest will appear to be lowered after a lapse of time and revetments will settle and lose their mutual connection.  
If a dike or bank revetment is constructed during a wet period there is a big chance that the underlying layers of clay settle, because it is impossible to compact clay sufficiently in wet periods.
- If an under water slope has not been completely covered with rip-rap over the whole breadth, a transition has to be formed between the rip rap and the area covered with other materials. From experience it is known that such joints are often the cause of damage and therefore maintenance.
- Materials delivered to the site have to be compared with the specifications as laid down in the bill of quantities. Otherwise it can cause maintenance later on, for instance because fine materials can move internally but also wash out through a surface layer.

It is clear that design, construction and maintenance are not stand alone activities. They are so closely connected to each other that they form one system. Managers should pursue an optimisation in technical and economic respect within this system.

### **Previous history**

Knowledge of the design, choice of applied materials and the construction of dikes and banks is of great importance for maintaining these works. It is thus important to be aware of the previous history. With this knowledge adequate measures can be taken when calamities to the water-retaining structure occur. You are aware of what can happen in an emergency and are not in the dark about the situation.

In fact it is recommended that the manager is involved from the beginning in the design and the later execution. By using the experiences of the manager it is possible to take into account future management and construction works. Information feed back from the manager to the designer is also important for the design itself. That is why saving and at the same time keeping accessible data files of design, construction and maintenance are of great importance for the technical section of the organisation. If there are no data files available, they can be collected by means of:

- files investigations;
- measurements made only once such as: level survey, air photos, drillings, soundings and so on.

So-called permanent data that needs to be measured only once are:

- situation, structure and geometry of foreshore;
- structure subsoil of the dike by soil investigations;
- structure and geometry dike body (types of soil and cross section);
- revetments and transition constructions;
- objects such as sluices, pumping stations, roads, fences and so on;
- hydraulic limiting conditions (water levels, wave heights with representative wave direction attack);
- management and property borders.

Of course variable fixed data which can change over a period of time, for example crest height, the height just before the toe of the dike, changes in the geometry of the dike and the position of cables and service-pipes, have to be updated regularly. Also new service-pipes and cables, objects and so on have to be measured regularly.

Both the fixed and the variable data have to be arranged and updated **systematically**. At the same time they ought to be **accessible**, preferably by a technical management register. An inspection system with maintenance program in fact can be mapped out with the help of the data from such a technical management register. In this register variable data can be updated after each inspection and after carrying out every measure of maintenance. The fixed data of new or improvement works have to be added to the register only once.

Difference can be made between that which is **required** of the water-retaining structure and the **actual situation**. In general that which is required, concerns the design dimensions of the water-retaining structure and the management limits of jurisdiction. This data is recorded in a separate register (see maps F,G and H). In fact this register is more or less permanent. This in contrast to the technical management register.

### **Management register**

The data that has to be saved in the register can be conveniently arranged by description of the following three categories:

- basic data for more or less uniform sections of a dike;
- detailed data for the determination of quality(standard)values as a reference when damage occurs;
- elements that occur out from other uses of dike or bank.

Setting up a management register for the first time, the checklist mentioned below can be used The most important parts are mentioned for the three categories. In all events, these parts have to be described if they are present on the dike or bank.

CHECKLIST MANAGEMENT REGISTER	
BASIC-DATA ON BEHALF OF SECTIONS OF THE DIKE AND BANK	
1.	Outline maps
2.	General and administrative data <ul style="list-style-type: none"> <li>a. starting-points of design and loads</li> <li>b. other use of dike or bank</li> </ul>
3.	Characteristic geo-technical longitudinal section
4.	Characteristic cross section of dike and foreshore
5.	Secondary dikes

DATA DETAILS FOR DETERMINATION OF QUALITY(STANDARD)VALUES	
6.	Structure of dike and bank
7.	Structure of foreshore
8.	Revetments
9.	Transition constructions
10.	Special constructions

ELEMENTS ARISING OUT OF OTHER USES OF THE DIKE OR BANK	
11.	Roads
12.	Cables and service pipes
13.	Buildings
14.	Pumping stations
15.	Fencing and road signs
16.	Vegetation
17.	Culverts and barrages
18.	Sheet piling and quay walls
19.	Moles and groynes

An example is mentioned below

hectometre							
103.5	103		102		101		100

### 1. Outline maps

See maps A and B

### 2a. Starting-point design and loads

*Representative high water level (m) with exceedance probability 1/1250*

+5.83		+5.85					+5.87
-------	--	-------	--	--	--	--	-------

*Design crest height (m)*

+6.53		+6.55					+6.57
-------	--	-------	--	--	--	--	-------

*Present height (m)*

+6.89	+6.75	+6.78	+6.68	+6.68	+6.66	+6.73	+6.73
-------	-------	-------	-------	-------	-------	-------	-------

**2b. Other uses of dike or bank**

Road hectometre 100 – 103.5

Grazing hectometre 100 – 101.7

**3. Characteristic geo-technical longitudinal section**

See map E

**4. Characteristic cross section**

See map D (profile hectometre 102)

**5. Secondary dikes**

None

**6. Structure of dike and bank**

See also map D and E

Hectometre 100 – 102 dike on subsoil clay and sand

Hectometre 102 – 103.5 dike on subsoil clay, peat, peat with clay, clay and sand

**7. Structure of foreshore**

Grass-land with trenches between hectometre 101.40 and 102.60

**8. Revetments**

Asphalt concrete on dike crest (road); grass on the remaining revetments

**9. Transition constructions**

Transition between the grass-verge and the asphalt concrete of the road

**10. Special constructions**

None

**11. Roads**

Road surface is composed of asphalt concrete and the foundation of crushed bricks

**12. Cables and service pipes**

An electricity cable is laid in the inner-bank of the dike

See also map C

---

**13. Buildings**

There are buildings in the stability zone

**14. Pumping stations**

There are no pumping stations in this dike compartment

**15. Fencing and road signs**

There is no fencing in this dike compartment

There are hectometre stones

Here and there, there are road signs

**16. Vegetation**

The road verges on the dike crest and the dike slopes are covered with grass

**17. Culverts and barrages**

There are no culverts and barrages in this dike compartment

**18. Sheet piling and quay walls**

There are no sheet piling and quay walls in this compartment

**19. Moles and groynes**

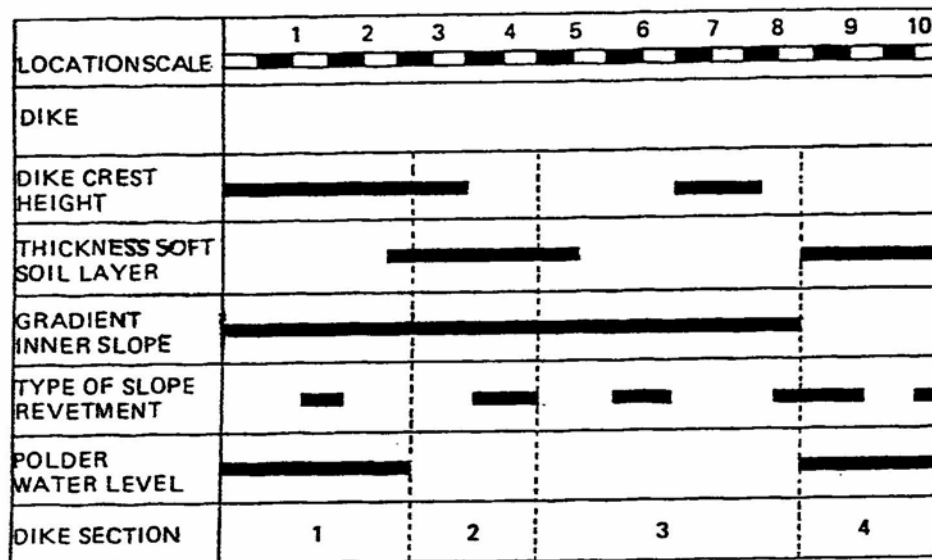
There are no moles and groynes in this compartment

**INSPECTION SYSTEM**

In order to carry out an inspection system correctly, the dike should be divided in sections with lengths as large as possible. The sections should be selected in such a way that they are relatively uniform with respect to:

- cross section;
- subsoil, revetment and loading conditions;
- use of dike or bank for which such features as:  
road function, buildings, industry, recreation, landing stages and so on.

The selection can be simplified if the main characteristics of the total dike length are represented by a bar-chart as illustrated in the following figure:



Example of bar-chart for the selection of dike sections

The first selection of sections can also only be set up on the basis of knowledge and experience gathered in practice by the manager.

If a hectometre measuring indication is placed along the dike, the sections can be fixed to that. Otherwise the sections have to be fixed to bench marks in the field.

The inspection system should provide information on:

- *what* (the kind of damage pattern characteristics),
- *where* (location and depth),
- *when* (how often),
- *how* (which measuring method) and  
by *whom* data should be collected, saved, and evaluated.

With this data a manager is able to determine the actual condition of the water retaining structure and with that to diagnose changes in strength of the dike on later inspections. After that, if necessary, reduction of strength can be corrected by maintenance or improvement.

However it is difficult to give a detailed description of an inspection system because it depends very much on the actual situation. Nevertheless some remarks will be given as a guideline in the following.

An inspection system is mainly determined by:

- *accuracy* of inspection method;
- *frequency* of inspections;
- which *difference* between initial quality levels (standard) and the action limit, where maintenance or other measurements are necessary, is acceptable.

### **Accuracy**

Inspection can vary from rough, mostly visual observation, to carrying out special measurements with, if necessary, special measuring equipment to detect hidden damage. However carrying out inspections in a quick and cheap way, should always be the aim.

Rough inspection is normally quick and cheap and will often be carried out first for that reason. However for dike elements, where failure has a direct influence on the water-retaining ability of the dike, the following phased inspection system should be chosen:

1. *Rough visual inspection*: observation of peculiarities and subsidence of top-layers.
2. *Detailed inspection*: periodical measurements, for example cracks in asphalt concrete layers or bearings along the toe of the dike.
3. *Special inspection*: for example to detect cavities under revetments of asphalt and concrete layers.

### **Frequency**

Inspections should be performed once or twice a year at fixed points in time. Incidental inspections should be performed after every storm surge and extreme high water and will generally start with a rough visual inspection of the total dike length. Inspections also depend on the age of the dike elements that have to be inspected and the results of the preceding inspections. Of course the following frequency aspects have to be taken into account as well:

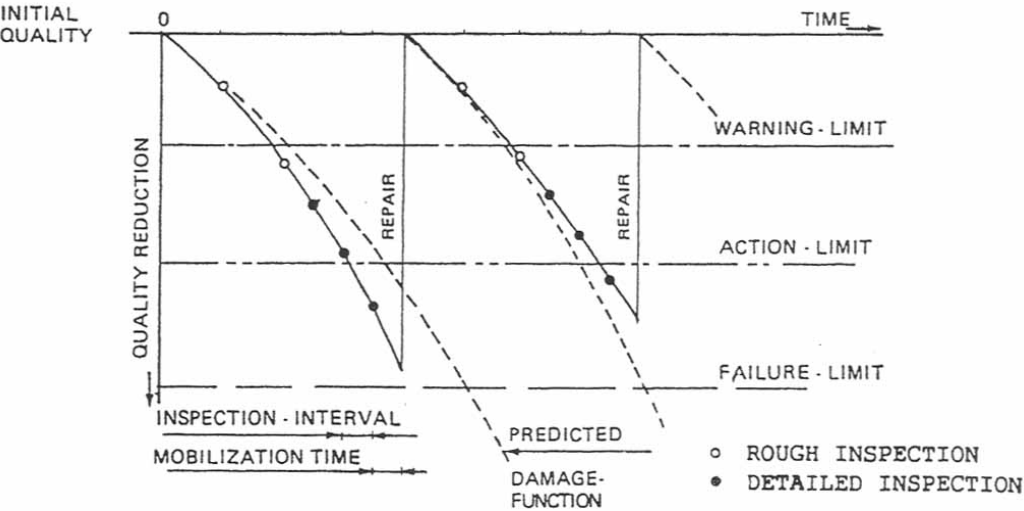
- the expected velocity of damage increase in the next period, varying from a very gradual increase to a sudden progressive increase;
- the predictability of the damage increase, varying from very good (small uncertainty) to very poor (great uncertainty);
- the actual condition with respect to the warning, action and failure limits.

To illustrate the effects of these last aspects, two extreme combinations of damage patterns and associated inspection strategies are outlined in the following table:

Aspects of Inspection strategy	Aspects of damage increase	
	progressive great uncertainty	gradual increase small uncertainty
Inspection method	detailed	rough
Inspection frequency	high	low
Action-failure limit	great margin	small margin

To determine the point of time when **difference** between the **required** quality level and the **actual** condition of dike elements is so great that performance of maintenance or other measurements are necessary, the following three distinguishing limits are used:

- *warning limit*: quality level at which a more intensive control of the condition parameter is needed (higher inspection frequency);
- *action limit*: quality level at which repair measures should be prepared and carried out before the failure limit has been reached;
- *failure limit*: quality level that is just acceptable from the safety requirement. If the condition decreases below this level the dike system will not provide sufficient safety.



The margin between the action limit and the failure limit will depend on the inspection frequency and the mobilization time for the execution of repair measures.

With respect to the margin it should be mentioned that, in contrast to steel and concrete structures, dike and bank works show a very different ageing behaviour. This may be caused by the considerable length of the dike sections and the heterogeneous composition of the dike elements including the variability of the soil layers. As a consequence the variability of the failure mechanisms and associated damage patterns is also variable.

Measuring the condition of dike elements is often difficult and expensive, that is why these works are mostly only visually inspected. Behaviour models of these construction elements are actually not known. Nevertheless more information, based on the grounds of inspection reports, is possible with regard to:

- 
- increased knowledge of ageing processes;
- decisions to change over to a more detailed inspection;
- decisions to arrange maintenance;
- determination of a following inspection.

Yet it has to be said that periodical measurements are very important to manage and maintain water-retaining constructions. Measurements give the manager insight into the actual condition of the dike. But measurements also mean: finding out..., for example how the dike is built up. If such measurements are not carried out there will be a lack of data. When inspecting for damage and the reason for it, definitions such as:

*“damage to the dike was the consequence of a combination of water, wind and ageing of the construction”*, should be prevented.

When carrying out measurements, it is of course always necessary to see if the delivered effort conforms with the intended profit. In addition practical experience and insight of the manager of the constructions remains essential for timely maintenance diagnoses. Especially on account of the knowledge of regional circumstances.

When choosing an inspection system it is important that the observations can be related to failure limits (see next table). On the basis of which decisions can be made for taking measures, like executing maintenance or more detailed inspection.

As mentioned before there are no behaviour models available in hydraulic engineering to decide the behaviour over a period of time of the strength of the construction. Therefore failure limits for water retaining structures are, in general, mostly based on descriptions of experience and engineering judgement. For instance admitted changes in crest height of the dike by settlements, amount of uplift of individual stones in a dike revetment after storm surges and changes in block shapes and material parameters as well. The damage caused by those changes in the dike elements are called failure mechanisms. These can be distinguished in:

- a. *Mechanisms by extreme loadings*, such as concrete blocks or columns lifted out;
- b. *Ageing mechanisms during circumstances of use*, in general these mechanisms mostly cause a gradual decrease in the strength of the construction, for example settlement of the dike crest caused by the settling of the subsoil.

An example of condition parameters, damage patterns and described failure limits are presented in the following scheme:

<b>Condition parameter</b>	<b>Damage pattern</b>	<b>Failure limits</b>	<b>Ultimate failure mechanism</b>
slope of foreshore	steepend slope along the toe	no steeper than 1:3	geotechnical stability
crest height	change of crest height	design height without calculated measurements for settlements	erosion of crest and inner slope
quality toe protection	decreasing height of rip rap covering	max. reduction of height 0.30 m	erosion
quality of stake row	visual deterioration	no rotting	erosion of outer slope
strength of stone revetment	one or several blocks lifted out or settled	no stones lifted out and close connections	erosion of outer slope
washed in joints of concrete columns	washed out joint materials	more than 1/3 of stone height is washed out	erosion of outer slope
quality of grass revetment	visual lacking of grass	covering degree reasonable	erosion

On the basis of the selected damage patterns the following inspection and maintenance scheme can be made for a dike section:

<b>Damage pattern</b>	<b>Inspection</b>	<b>Repair measure</b>
steepend slope	bathymetrical survey foreshore one month before and after storm season	sand supplement or bottom protection of foreshore
change of crest height	geodetical survey once per 1 to 5 year depending on last inspection results	heightening of the dike
decreasing height of rip rap covering	visual observation of height reduction	supply of toplayer stones
visual deterioration stake rows	visual observation of stake rows, if needed pull a test pile	replacement of rotten stake rows
one or several blocks lifted out or settled	visual observation one month before and after storm season and after every storm surge	replacement of lifted out or settled blocks
washed out joint materials	visual observation one month before storm surge	refill the joints with proper material
visual lacking of grass	visual observation of grass revetment during growing season	adapt grazing, combat vermin, sow grass seed

Apart from the damage patterns mentioned before unpredictable damage patterns may also occur. To detect this last type of damage in time, a rough visual inspection of the total dike length should be executed two months before the storm season.

In addition every two years after completion of a dike the cross section geometry of the dike should be surveyed to detect unexpected deformations of the construction.

## MAINTENANCE

Maintenance measurements have the purpose of improving the condition of the water-retaining structure. Therefore the manager has three options:

- to repair to the original condition;
- to repair to a reduced condition than the original (mostly temporary repair);
- to repair to a better condition than the original.

Weighing up the costs plays an important role in the choice of repair. It may be more efficient to execute combined maintenance measurements.

Maintenance should be executed on the basis of inspection reports or after damage has occurred. Preferably maintenance should be carried out before the storm surge season, because during this period there is a much smaller chance for extreme load circumstances so that failure of the dike will be much reduced.

If the managing organisation does not have its own maintenance service at its disposal, maintenance is carried out by contractors. A disadvantage of executing maintenance by contractors often means that quality is more or less under pressure. Therefore supervision of the work is nearly always necessary. An execution of maintenance carried out by using own employees, generally guarantees a better quality. However, the choice for execution of maintenance by contractors or using own employees, depends on the amount of the expected maintenance as well.

But whether maintenance is carried out by the organisation itself or by contractors, the possibility of carrying out maintenance in a practical way should always be aimed for, so therefore:

- It should be possible to carry this out quickly and easily, preferably using mechanical equipment;
- It should be accessible or created with easy accessibility for maintenance equipment;
- It should be financially attractive.

The conditions therefore should already be created at the moment of the design of the dike. As already said before, this is possible if design and choice of applied materials are in accordance with each other.

For coastal engineering works, such as dike and bank constructions, no behaviour models are available. Therefore the **certainty** of the moment of failure is rather **small**, but on the contrary the results of failure of the dike are generally **great**. That is why maintenance of dikes and banks is dependent on the conditions actually found. On the basis of this condition preventive or corrective maintenance can be executed.

Maintenance can be distinguished in two types: minor (normal) and major (extensive). The difference between both types of maintenance is artificial in all respects. That also appears from many criteria on the basis of which that difference can be made. The most important are:

- extent of the works;
- amount of costs;
- purpose of major or minor maintenance;
- frequency of execution (annually or every few years);
- manner of execution (contractors or using own employees);
- possibility for planning those activities.

*Minor or normal maintenance can be defined as:*

*All measures and work required to protect and preserve the construction.*

This maintenance could be characterised as a group of measures:

- which are more or less local;
- which costs are relatively limited;
- that are executed with a greater frequency than other kinds of maintenance;
- of which the annual costs can be calculated on the basis of experience.

*Major or extensive maintenance can be defined as:*

*Bringing the quality of the construction to such a level that it once more conforms to the same requirements, with regard to strength and durability, as agreed at the moment of construction.*

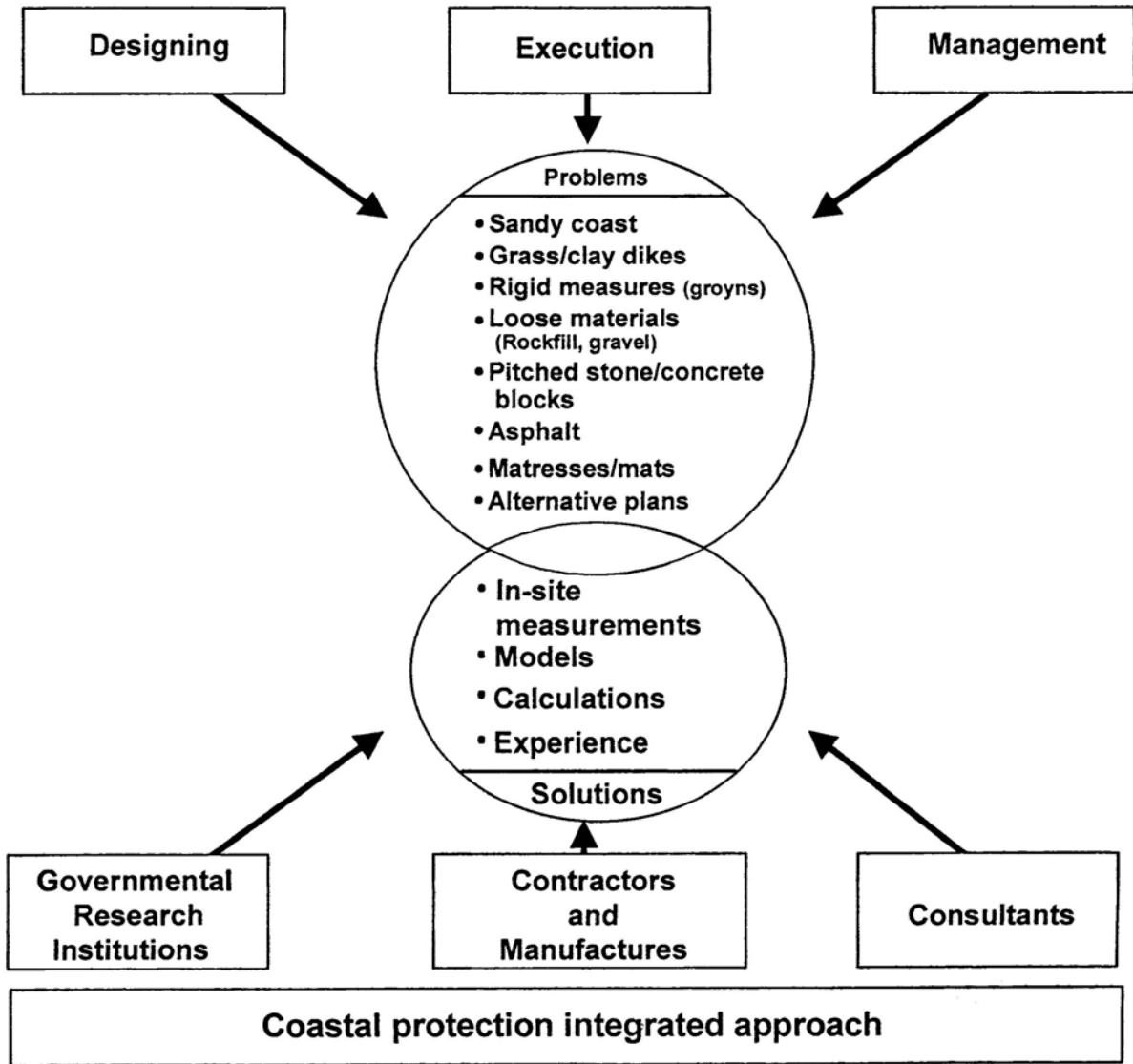
## REFERENCES

Pilarczyk, K.W. , Coastal Protection

Pilarczyk, K.W. , Dikes and Revetments

CUR, Masterplan 147, Periodical judgement on the strength of dikes (in Dutch), 1991, Gouda

The Association of Water Boards, Model technical management register (in Dutch), 1991, The Hague

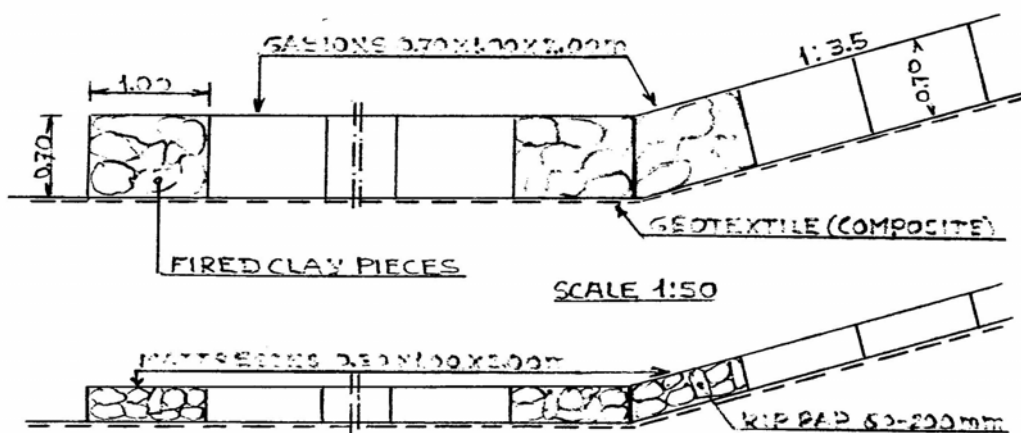
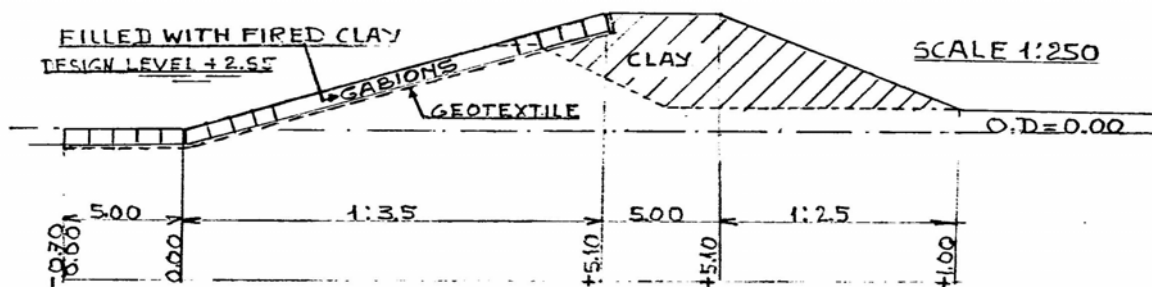






## DIKE IMPROVEMENT ALONG THE COAST IN SURINAM ( SOUTH AMERICA)

### Solution 3 and 4



### ALTERNATIVE FILLED WITH RIP RAP (THICKNESS DECREASES)

Storm-surge	+ 2.45 m	(frequency of exceedance 1/50)
		(significant wave height = 1.35 m)
Sea-level rise	0.10 m	
Design level	+ 2.55 m	(mean High Water = + 1,00 m)
		(mean Low Water = - 0,90 m)
Wave run-up	2.30 m	
Settlements	0.25 m	
Crest height	+ 5.10 m	(with wave overtopping 0.5 l/m/s)

COST: ABOUT US\$ 1100 PER METRE OF DIKE

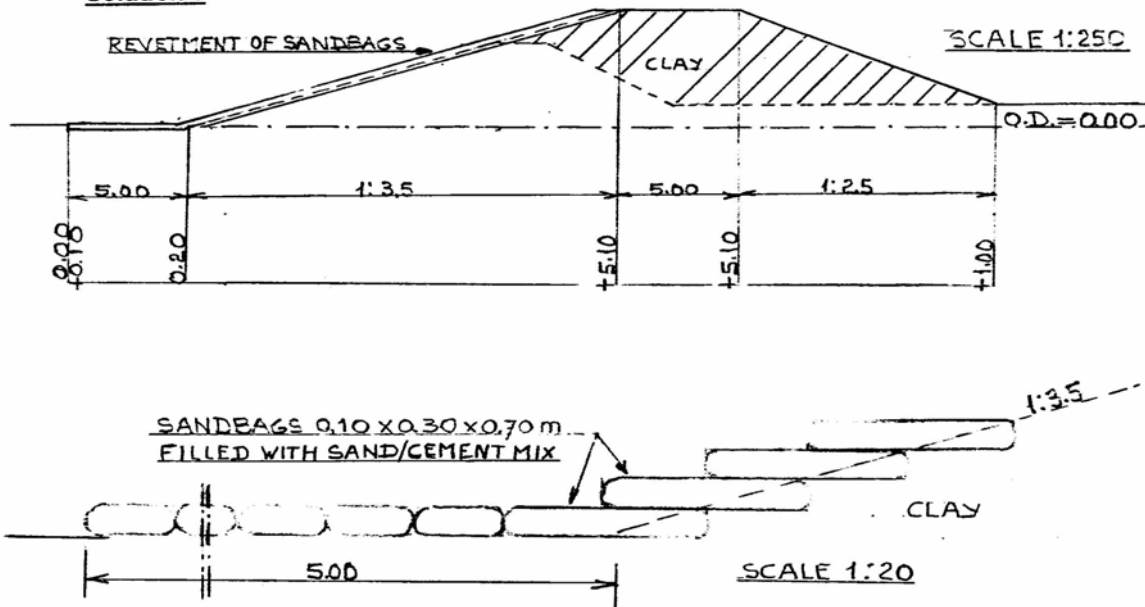
The same construction:

However now the gabion (mattress) is filled with rip rap. Because the thickness of the mattress is relatively thin, the roughness coefficient is 0,6. That's why the wave overtopping increases to 1,0 l/s/m with a crest height of + 5.10 m.

COST: ABOUT US\$ 1050 PER METRE OF DIKE

## DIKE IMPROVEMENT ALONG THE COAST IN SURINAM ( SOUTH AMERICA)

### Solution 5

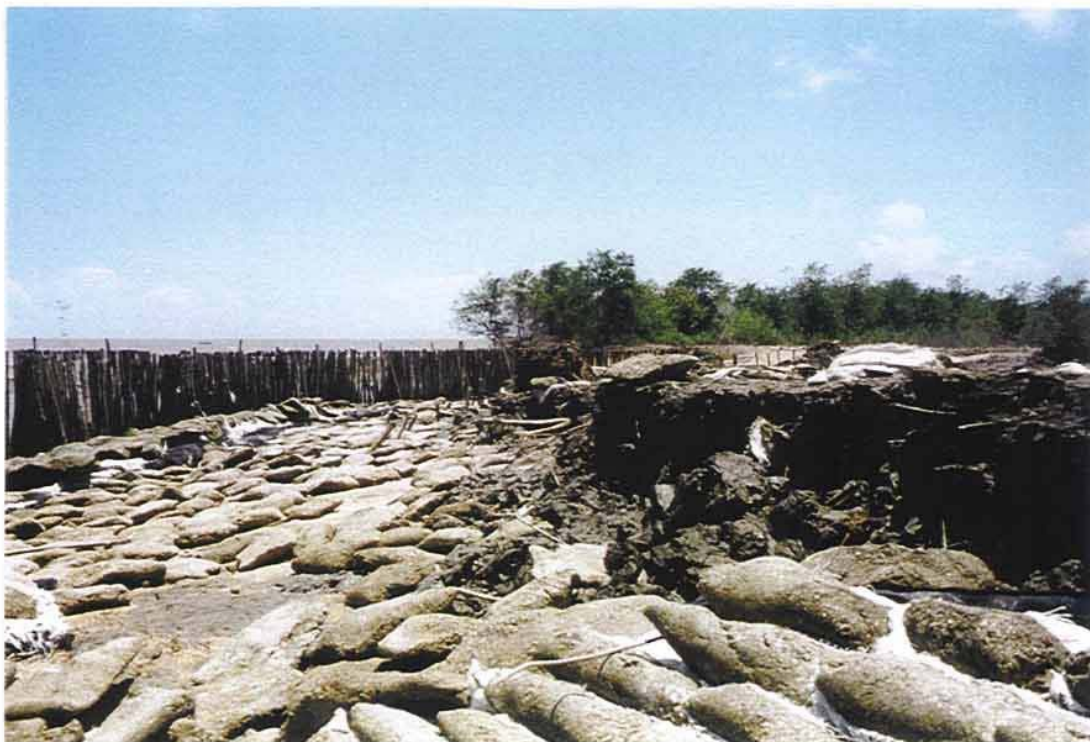


The proposed solution with sandbags is not durable. It's only be able to resist a significant wave attack of about 0.30 m !!  
Therefore this construction can only be executed for temporary situations and quick repair activities.

COST: ABOUT U\$ 1000 PER METRE OF DIKE



Sandbag revetment in Surinam (Coronie)



Collapsed sandbag revetment in Surinam (Coronie)