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COASTAL ZONE MANAGEMENT WITH RELATION TO LOW INVESTMENT SOLUTIONS

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by: H.J. Verhagen and J.T.L. Yap [1]

Introduction
Copying solutions from the western, industrial countries for application in developing countries is in general not the best solution for solving the problems of developing countries. The main reason for that is that the available resources in the developing world are different from the resources in western countries. In the industrialised countries there is a strong tendency to solve problems in such a way that the amount of required labour decreases. Thus, a capital-intensive solution is searched for. The reason for this is the very costly social system and the high standard of living. This causes a large deference between the hourly income and the hourly costs of labour, which is much less in developing countries.

On the other hand it is difficult and expensive to import industrial products from abroad. Also it is difficult to have sufficient financial resources available. For those countries it is more economic and more attractive to search for solutions which require hardly any investments, but are relatively labour-intensive. These solutions generally require often more maintenance. However, increased maintenance costs may even be advisable, provided initial investment is very low. The total cost of the solution, i.e. investment plus maintenance, can be spread over a longer period without financial indebtedness.

The above described philosophy is valid in many sectors of society, but is especially true in the coastal zone. Works in the coastal zone are generally of a large scale, requiring a long planning and very often designed using capital intensive methods.

Interactions
When planning works in the coastal zone it is essential to have a thorough knowledge of the interaction between the various functions intervening in the coastal zone. Coastal Zone Management always applies a very integrated approach to problems. The coastal zone is not only the coastal strip; it includes the estuaries, the tidal rivers and adjacent settlements, agricultural and aquacultural farmland as well. Development plans, which affect the rivers and estuaries, also influence the coastal zone. This paper will be limited to control structures and their maintenance.

In solving these coastal problems, one should always analyze the cause of the problem. Sometimes it is easier to change something in the estuary or river, than to combat the erosion.
When it is not possible to take away the cause of the problem, then a number of technical tools (control structures) is available. Standard tools are groynes, revetments, artificial beach nourishment, dredging operations, offshore breakwaters etc. In the design of these methods in most cases a low-investment approach can be followed.

maintenance
Maintenance has to be done on the right moment. The main problem with construction requiring maintenance is that often there is no organisation with is responsible for maintenance on an active way.

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There has to be a maintaining agency and there has to be a maintenance plan. In this chapter the elements of the maintenance plan with emphasis on the inspection and monitoring system will be worked out for a dike system.

The main function of a dike is to protect inland area from flooding. In addition the dike may perform other functions such a road-transport, agriculture, and very often dikes have also an ecological function. The dike-system should be designed, constructed and maintained in such a way that the relevant functions will be fulfilled during the required life-time.

A dike system forms part of a total water retaining system, consisting of different type of structures. If one part of the system fails, flooding of the inland area may occur. In order to guarantee an acceptable safety level under extreme loading conditions the contribution of the total length of the dike sections to the overall probability of failure of the potential flooding area may not exceed a specified value.

Each of the dike sections is composed of a number of structure components, termed as elements. These elements can be related to the detailed water retaining function as derived from the main function. Examples are:

dike element	function
slope revetment:	hydraulic erosion control
dike crest:	control overflow and overtopping
slope:	ensure geotechnical stability.

The elements can be described by a number of characteristic condition parameters, mainly geometrical and material (=strength) parameters. For example the dike crest can be described just by the geometrical parameters height and width of the crest, whereas the description of a slope revetment necessitates specifications of the type, geometry, weight an strength of the successive layers of the revetment.

In common engineering practice of dike design for each of the relevant condition parameters functional requirements have to be specified that should meet the overall safety requirements of the total dike system. After construction of a new dike of enlargement of existing dikes, the actual value of the condition parameters should at least satisfy the specified range.

However, during the service life of the dike a number of deterioration mechanisms may occur that will affect the strength of the structural elements. I other words these deterioration processes may change the values of the condition parameters.
Examples of these processes are gradual settlement of the dike crest due to consolidation of underlying soft soil layers, washing out of finer particles of a stone revetment due to wind, rain and temperature effects and damage effects of slopes due to biological activities such as vegetation and animal burrowing.

These alterations caused by deterioration mechanisms, which will be recognized as characteristic damage patterns, can be of such significance that the dike-safety will no longer be sufficient. This means that the actual quality of the condition parameters may decrease to a level at which the extreme loading condition cannot be sustained.

Figure 1 shows the relationship of the damage patterns and the deterioration mechanisms (at daily loading conditions) on one hand and the ultimate failure mechanisms (at extreme loading conditions) on the other hand.

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┌────────────────┐      ┌─────────┐   ┌───────────────┐        ┌─────────┐
│ deterioration  │      │damage   │   │alteration of  │        │ultimate │
│ mechanism      │====>│pattern  │==>│condition      │======>│failure  │
│                │      │         │   │parameter      │        │mechanism│
└────────────────┘      └─────────┘   └───────────────┘        └─────────┘
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figure 1: Relationship of damage patterns and failure mechanisms

By means of an adequate maintenance and control system of the dike the managing authority aims to secure that the actual quality of the relevant condition parameters do not decrease to a level lower that the acceptable failure limit.
For this purpose the actual state of the condition parameter has to be assessed by periodical inspection and monitoring of the dikes. In addition based on these observations an supported by theoretical interpretations predictions have to be made of the expected behaviour in the near future. From these two conditions, i.e. the actual state and the expected behaviour, the necessary maintenance measures can be planned.
These measures may vary from "do nothing (=zero option)" or "increase inspection frequency" till "repair or replacement of structural elements".

Low investment solutions
Sometimes so-called "low-cost solutions" are presented, especially developed for use in developing countries. The argument to use these is that developing countries cannot effort high-cost solutions. This reasoning is not correct! Also the industrialized countries are very much interested in cheap solutions. Even in cases when enough money available, why choose a more expensive solution if a low-cost solution is feasible?

In practice however, the cost of these "low-cost solutions" are not really low. The total cost for every structure comprise the initial investments and maintenance costs. In fact the total costs are of the same order of magnitude for the low as well as for the high cost solutions. Only the distribution of the costs is different. Current practice to compare various structures is to capitalise the costs. This means that all costs are transformed to one single year using a formula, which takes both the rate of interest and inflation into account.

As an example in table 1 and 2 a cost comparison for a groyne is presented. It is a groyne with relatively low wave attack, but located in an area with a strong tidal current, which is typical for groynes in an estuarine environment. To reduce tidal currents wooden piles are placed on top of the groynes. A bed protection with boulders around the groyne is required to prevent scouring.

Such a groyne (which was recently build in the Netherlands) requires an investment of 725,000 MU (=Monetary Units, this can be dollars, or some other currency; the absolute value of the MU is not relevant for this paper). The yearly maintenance costs of the structure amounts 3600 MU. The economic lifetime of a good-quality groyne is approximately 30 years, after which the residual value is assumed at zero. Applying an interest rate of 4%, the total maintenance costs during 30 years are capitalised to the present value, which is 17.3 times the required yearly maintenance cost, arriving at 62,000 MU. This is only 8.5% of the total cost.

In a developing country a labourer costs much less, for example only 10% of hat in an industrialized country. However, geotextile is much more expensive. Making the same calculation with unit costs form a developing country gives quite a different result. An alternative design has been made. See table 2. Geotextile has been replaced by jute, the concrete blocks by pitched stone, etc. Phosphorous slag is easily available in the Netherlands, because it is a rest-product of nearby industries. It has been replaced by quarry stone. The stone-weight of the various stones is somewhat lower. Also less asphalt and bituminous grout is used. The consequence of this alternative is more damage to the groyne during storms, and thus significant higher maintenance costs.

In an industrialised country the alternative design is absolutely not attractive. Apart from the higher initial costs (920,000 MU vs. 725,000 MU), the maintenance costs are a real problem (284,000 MU vs. 62,000 MU). For a developing country the situation is completely different. There the alternative is on the long run 18% cheaper (450,000 MU vs. 554.000 MU). Very important and attractive is the 35% lower initial investment (345,000 MU vs. 531,000 MU). Of course this is a very rough example. Differences in productivity of labourers are not accounted for. The price of the boulders depends on the availability of a quarry in the vicinity. Further, the price of the wooden piles may be different.

As can be seen from this example, on the long run the "low-cost solution" would be (in industrial countries) more expensive than the "high-cost solution". Therefore it is better to speak about low-investment solutions. When the availability of money is no problem, the cheapest solution on the long run should be selected. In the industrialized world that is generally the high investment solution.

As showed above, low-investment solutions generally require more maintenance than capital intensive solutions. Therefore, the structure has to be designed in such a way that maintenance can be conducted easily with local means, i.e. local material, local labourers and local equipment. These requirements are not new and obviously not very special which can be met easily. The snag is to be aware of these requirements during the design phase.

For example a rubble shoreline protection. It has to be designed in such a way that repair works can be done directly from the shoreline. To facilitate this a maintenance road has to be available. The boulders have to be place with local cranes, generally with a short boom. In addition, the weight of the individual boulders should not be too heavy. These boulders should have to be available from local quarries. When the construction is designed with concrete elements, these elements should be simple to manufacture and handle. Concrete cubes are to be preferred above fancy elements like dolosses, akmons and tetrapods.

<u>The need for maintenance</u>
Problems related to maintenance of coastal and river engineering works are increasing in almost all developing countries in view of the fast development of water resources schemes without proportional maintenance efforts and budgets. It is a general rule that maintenance costs increase with construction of new works and operation expansions, especially relative to other direct and indirect costs. These problems are not limited to budgeting only, but are related to management, institutional and ill-defined maintenance strategies. In most cases, clear maintenance policies do not exist, as they are mainly established on and ad-hoc basis and tend to be crisis oriented by nature. Maintenance is a logical follow up of the construction phase. It is required to realize the project benefits, which were used to justify project implementation.

Maintenance policies should be shifted from a crisis oriented towards a performance-oriented approach. Performance-oriented maintenance is to carry out maintenance activities on a scheduled basis and avoid "crash" situations that accompany heavy damages and failures. Maintenance is time invariant and is a lifetime chain of activities. Maintenance should be performed to protect capital investments and to keep them operating at a high level of performance. If the value of the investment is to be fully realized, regular maintenance is inevitable.

<u>Types of maintenance</u>
Maintenance activities can be distinguished into Routine and Non-routine maintenance. Routine maintenance work encompasses those repetitive activities that are performed on a cyclical basis at planned pr\frequencies. Non-routine maintenance includes repair because of failure. It is non-cyclical and may be of an emergency nature. Frequently, maintenance is distinguished into Corrective and Preventive Maintenance.

Corrective maintenance activities are carried out to prevent re-occurrences of failures and damages of a facility, taken based on analysis of previous failures. The procedures is such that whenever a failure occurs, it is studied as to the cause, what repairs were made and what further actions are needed to ensure that the failure will not become repetitive. Corrective maintenance is thus conducted after failure of a structure.

Preventive maintenance activities are carried out to maintain optimum functioning of a facility and its components according to a pre-scheduled program. It aims at preventing a facility from failure at an as early as possible stage. The basic idea is to concentrate on selected parts, sections or structures and inspect these thoroughly and conscientiously. Preventive maintenance is carried out before failure of a facility.

Preventive maintenance can be Use-based or Condition based. use based preventive maintenance is carried out after a predetermined time period or intensity of use. This type of maintenance is popular in mechanical engineering. In hydraulic engineering however, condition-based maintenance is apparently more suitable. Here, maintenance is carried out after a selected condition parameter of the structure reach a predetermined standard.

Characteristic Condition Parameters

A structure consists of Critical and Non-critical components. Maintenance of non-critical parts could be routine or at random or let it operates until failure and then conduct corrective maintenance. Critical parts should be maintained according to the preventive maintenance principle. Each structure of component has a function it was designed for. Sometimes it has more than one function, i.e. primary function, secondary, etc. Further it was designed for a certain required lifetime and service level. From these elements Characteristic Condition Parameters (CCP's) for the structure can be defined.

To illustrate the elements and CCP's consider a flood protection embankment (dike). A number of critical elements and their functions are:

embankment slope	secure sliding of the slope
embankment crest	control overtopping
embankment berm	increase lope stability
toe filter	control seepage

All these components were designed for a certain lifetime with an acceptable safety or service level. A CCP can be defined for each element. For example the angle of the slope, the height and width of the berm, etc. Taking its functions, safety level, etc. into consideration, one can specify a range for each CCP. Hence, the CCP's should be inspected, measured, monitored and observed during regular inspections.

Although implementation of a structure of a scheme in coastal zone eliminates a number of constraints to developments, the improved zone will still slit up and coast erosion will still advance, the structures will progressively deteriorate under hostile environmental conditions and due to normal wear and tear. These deterioration processes are indicated as Characteristic Damage Patterns and would obviously change the CCP's.

An inventory has to be made of possible failure mechanisms of the st5ructrue. In this way the behaviour of the structure could be predicted. Base don these analysis and supported by inspection reports, decisions on the required maintenance activities can be made. The decision may vary from "do nothing" , "increase inspection frequency" "repair" or "replacement of the structure".

The so-called preventive condition-based maintenance strategy distinguishes three limits of quality levels of condition parameters (see fig. 2).

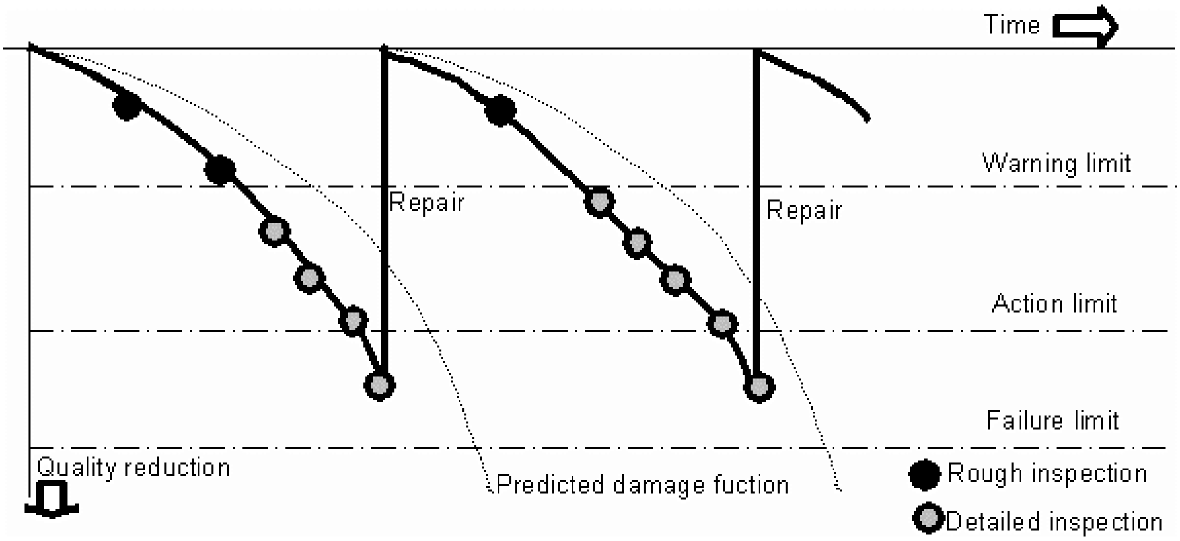

figure 2: Preventive condition based maintenance, from [1]

These three limits are:

- 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.
An optimum maintenance and control strategy will be obtained by considering the minimum costs of repair and inspection, on the condition that the probability of exceeding the failure limit is sufficiently low.

organization of maintenance
From the above example follows that a construction, requiring more maintenance, needs to be inspected regularly. The only way to organize this in a proper way is to establish local based agencies with sufficient independence in order to take care of this maintenance.
It is very difficult and very cumbersome to work out the above system of rational maintenance in all details on paper. Very often, maintenance is obvious. When there is a stone removed from a shoreline protection of pitched stones, this stone has to be replaced. When not, the damage will be progressive. No advance science is needed to decide upon this.
However, the local authority responsible for maintenance should:
* monitor the slope protection, so that one realises that a stone is missing;
* have the authority to send a men to the place immediately to do the work.

The above points seems very clear. But in reality very often, no one is looking after a civil work like a slope protection. An when there is someone doing it, it is very often extremely difficult to have the job done because of red tape. Often permission is required from a head-office before maintenance can start.

Institutional aspects
Maintenance should be managed by a special unit, which should have its own budgeting section that prepares and controls maintenance budgets. Management of the unit should cover aspects ad defining responsibilities and authorities, planning, accountancy and budgeting, performance control, review, evaluation. Budget allocation is the major constraint in maintenance planning of hydraulic engineering works. Budgets are frequently prepared in a rush and without relevant data to base the cost estimates on. Preparing a maintenance budget is based on planning and scheduling, i.e. a maintenance program.

Human Resources, Skill and Training Needs
The results of a preventive maintenance program cannot be successful unless all personnel involved are well qualified. Alert and experienced inspectors are the backbone and the key to success of such a program. Human resources, their skill and crafts are the essential parts of a maintenance organization. An analysis of their availability is essential and a training program devoted to maintenance of coastal and river engineering works should be developed focussed on maintenance management, inspection procedures and reporting techniques, and construction supervision. A training program should address the following levels of staff:
- Management
- Inspectors
- Supervisors

Both maintenance and training is a never-ending process

Conclusions
From the above the following conclusions can be drawn:
- It is more adequate to speak about low-investment instead of low-cost solutions.
- For developing countries low-investment solutions are often very attractive. For the industrialized countries this type of solutions is often too expensive because of maintenance aspects.

- Low-investment solutions require good maintenance. The main constraint to proper maintenance is weak maintenance institutions, which call for strengthening.
- Problems related to maintenance are increasing in view of the fast development of water resources schemes without proportional maintenance efforts and budgets.
- Maintenance is a never-ending process. The developing countries should conduct maintenance without engaging expensive foreign consultants.
- Training of maintenance staff is essential in maintenance strengthening. A training need assessment is required prior to training development.

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Table 1: Construction Groyne (Design from the Netherlands)

Element	no	Unit	Indust. Cntry Rate	Indust. Cntry Cost	Develop Cntry Rate	Develop Cntry Cost
Construction costs						
Wooden piles, 3.5 m	193	pc	40	7720	20	3860
Wooden piles, 5 m	252	pc.	70	17640	35	8820
Wooden piles, 6 m	12	pc	85	1020	42	504
Wooden piles, 7 m	24	pc	100	2400	50	1200
Wooden piles, 8 m	4	pc	120	480	60	240
Wood. sheetpile 2.5 m	608	m	170	103360	85	51680
Wood. Sheetpile 3 m	206	m	200	41200	100	20600
Geotextile	6390	m2	2	12780	10	63900
Placing geotextile	500	hr	40	20000	4	2000
Concrete blocks	3483	m2	40	139320	30	104490
Placing blocks	2200	hr	40	88000	4	8800
Hydraulic asphalt	194	t	190	36860	150	29100
Stones 25/80	820	t	60	49200	40	32800
Stones 80/200	310	t	35	10850	60	18600
Phosph.s slag 40/250	310t	t	35	10850	60	18600
Bituminous grouting	460	t	250	115000	250	115000
Extra labour	50	hr	40	2000	4	200
Use of shovel	25	hr	60	1500	10	250
Use of vibration crane	20	hr	70	1400	12	240
contingencies				5000		5000
total				706880		518434
unforeseen, risk, etc.	3%			17672		12961
grand total				724552		531395
Maintenance						
Labourers	50	hr	40	2000	4	200
Use of Shovel	10	hr	60	600	10	100
Extra stones & Geotex.				1000		1000
total				3600		1300
Interest rate 4%, 30 years, multiplier 17.29						
Capitalised Maintenance cost				62251		22480
Total Project Cost				786803		553874

Table 2: Construction Groyne (Alternative design)

Element	no	Unit	Indust. Cntry Rate	Indust. Cntry Cost	Develop Cntry Rate	Develop Cntry Cost
Construction costs						
Wooden piles, 3.5 m	193	pc	40	7720	20	3860
Wooden piles, 5 m	292	pc.	70	20440	35	10220
Wood. sheetpile 2.5 m	608	m	170	103360	85	51680
Wood. Sheetpile 3 m	206	m	200	41200	100	20600
Jute filtercloth	6390	m2	3	19170	1	6390
Placing jute filter cloth	500	hr	40	20000	4	2000
Pitched stones	3483	m2	60	208980	25	87075
Placing pitched stone	5000	hr	55	275000	6	30000
Low graded asphalt	250	t	150	37500	75	18750
Stones 25/80	2500	t	60	150000	40	100000
Extra labour	200	hr	40	8000	4	800
Use of shovel	25	hr	60	1500	10	250
contingencies				5000		5000
total				897870		336625
unforeseen, risk, etc.	2.5%			22447		8416
grand total				920317		345041
Maintenance						
Labourers	200	hr	40	8000	4	800
Use of Shovel	20	hr	60	1200	10	200
replacement of piles	50	pc	85	4250	42	2100
Extra stones & Jute				1000		1000
total				16450		6100
Interest rate 4%, 30 years, multiplier 17.29						
Capitalised Maintenance cost				284453		105481
Total Project Cost				1204770		450522