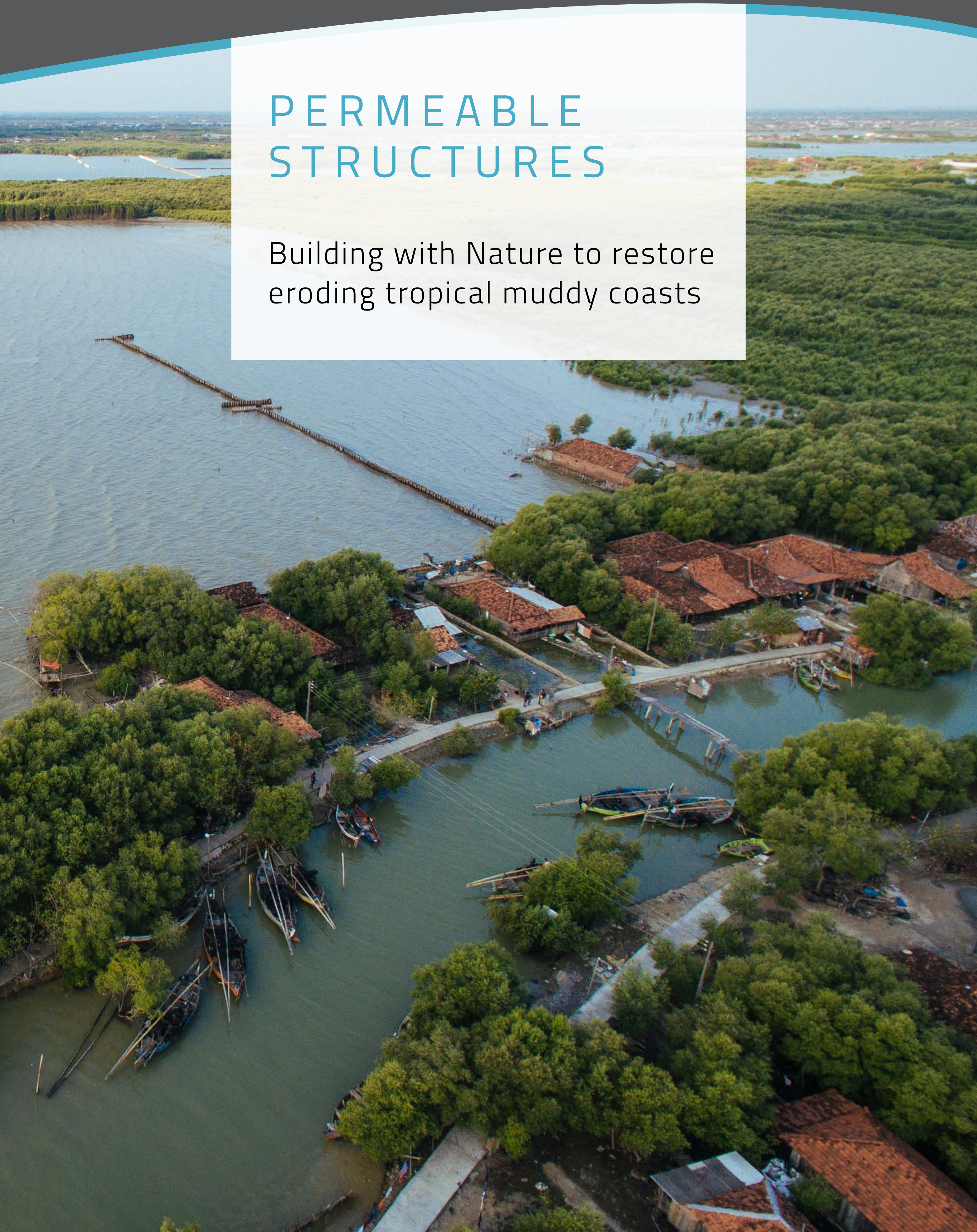
TECHNICAL
GUIDELINES # 3

PERMEABLE STRUCTURES

Building with Nature to restore eroding tropical muddy coasts



Bombana, © MMAF

TECHNICAL GUIDELINES SERIES

This guideline is part of a series of Technical Guidelines on technical and socio-economic Building with Nature. They bring together experiences and lessons learned from the Building with Nature Indonesia programme which restores eroding tropical muddy coasts. Successful implementation requires in-depth system understanding, extensive stakeholder engagement, and adaptive management on the basis of monitoring and evaluation. Stakeholders interested in replicating our approach are strongly recommended to adhere to this guidance and bear full responsibility for the success and sustainability of the approach.

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EXECUTIVE SUMMARY

To allow re-colonization of mangroves to stabilize eroded coastlines, permeable structures are used to create sheltered zones with reduced flow velocities and wave impact, thereby facilitating accretion of suspended sediments. Permeable structures are most applicable along muddy coastlines with abundant suspended sediments in the water column. Generally, permeable structures are fence-like constructions and consist of two rows of vertical poles with brushwood fill in between. The implementation of permeable structures is low-tech, but it requires a sophisticated design based on comprehensive understanding of biophysical processes, continuous monitoring and adaptive management (learning by doing).

Successful re-colonization is most effective when recreating abiotic conditions and allowing natural regeneration to take place. Permeable structures can be regarded as a temporary measure to allow recruitment of mangroves. They only need to stay in place long enough for mangroves to recolonize, after which the ecosystem may sustain itself. Until then the structures require regular maintenance. Under certain boundary conditions such as significant land subsidence or reduced sediment input, the effectiveness of permeable structures decreases. Depending on the durability of available materials and the geographic location of the structures in relation to extreme weather events, these structures may be quite vulnerable to debilitating damage. Hence their utility will also depend on a variety of local factors which need to be taken into account when deciding where and how to use such structures. Further research on material durability and structural design matters should prove valuable as this approach is developed and perfected in the years to come.

Permeable structures are not a stand-alone solution. Further technical and socioeconomic measures are required to achieve a sustainable solution for the causes of erosion, such as sustainable aquaculture management, maintenance of the mangrove belt and sustainable land and groundwater and fresh water use. The structures and the subsequent natural mangrove regeneration are measures of erosion protection and they reduce the extent of flooding inland by attenuating waves. However, they do not form a physical barrier against coastal floods. To address flooding in the villages other measures are needed, such as levees or strengthened infrastructure and houses.

To be effective, permeable structures need to be part of an integrated coastal zone management approach and they need to be accepted and supported by policy and planning. In particular, strong local governance arrangements are a precondition to successful implementation. Community involvement is required for the entire process consisting of training and guidance, preparation, planning, procurement, construction, monitoring and maintenance.

Figure 1. Permeable structures in Timbulsloko (Demak, Indonesia) © Tom Wilms, Witteveen+Bos

Figure 2. Construction of permeable structures by local women in Timbulsloko (Demak, Indonesia) © Nanang Sujana

1 INTRODUCTION

Healthy mangrove forests are essential for balanced sediment dynamics at tropical mud coasts. Mangroves can stabilize coastlines by reducing erosion and increasing accretion through reduction of waves and currents (Winterwerp et al. 2005, McIvor et al. 2014). However, in recent years, man-made removal of mangroves and installation of coastal infrastructure has disturbed this dynamic equilibrium of sediment influx and outflux. This has led to severe erosion of tropical mud coastlines (van Wesenbeeck et al. 2016, Schmitt et al. 2013), which is accelerated by larger-scale effects such as subsidence caused by ground water extraction, changing hydrodynamic conditions including rising sea levels and an increasing frequency and intensity of storms resulting from global climate change. In order to stop coastal erosion and regain a stable coastline, one of the key steps is to reduce or stop the loss of sediments. Coastal managers often try to fight coastal erosion with hard structures, but generally these measures are only effective locally and are not sustainable since they form another interference in the natural sediment dynamics (Winterwerp et al. 2013).

This technical guideline discusses the application of permeable structures as a close-to-nature and sustainable solution to increase sedimentation along eroded coastlines to allow re-colonisation of mangroves and thus a stabilization of the intertidal area. Mangrove recolonization using permeable structures is currently being applied in Central Java (Indonesia), in the Mekong Delta (Vietnam, see Appendix 1) and near Paramaribo (Surinam). The same technique has been applied very successfully for centuries in the Netherlands and in Germany to create salt marshes and floodplains protecting the sea defence.

This guideline is designed for governmental agencies at national, provincial and district level that execute tender for the restoration of coastlines. It also provides guidance to the private sector to support the design and construction of permeable structures in restoration programs. In addition the guideline will be useful for the international community working with Building with Nature and green and natural infrastructure.

Chapter 2 contains a detailed description of the design of the permeable structures differentiated in the overall spatial and the structural design. All elements of the structure are described in detail. In Chapter 3 the construction process including the general schedule, site preparation, tender process and training is explained. The operational phase is defined in Chapter 4. It contains instructions on the monitoring and according maintenance works. Chapter 5 concludes the guidelines with where to get more information and support.

2 DESIGN

This chapter discusses the design of permeable structures at landscape level and individual level. The spatial arrangement of the permeable structures at landscape level should be based on thorough understanding of the system so that the solution addresses root causes of the problems. System understanding is the topic of a separate guideline, and its investigation includes the physical, socio-economic and institutional systems at the project location. At the spatial level the various processes of the system need to be understood to maximise their use and benefit, this is explained in 'System understanding' of this series. At the level of individual permeable structures, a detailed technical design is required that ensures a proper function of the structure.

2.1 SPATIAL DESIGN (LANDSCAPE LEVEL)

The permeable structures should be part of an integrated coastal zone management plan. This often means that the structures will be constructed over various years, and thus holistic planning and design are required.

2.1.1 Purpose and functional requirements

At a landscape level, the purpose of permeable structures is:

1. To halt erosion and regain a stable coastline by restoring the sediment balance at the coast from erosive to accreting.
2. To create conditions for mangrove recolonization, so that they can prevent erosion, stabilise the coastline and provide additional ecosystem services.

Healthy mangrove mud coasts are in a dynamic equilibrium between erosion and accretion of sediment as a result of wave action, tidal currents and sediment transport (Winterwerp et al. 2005). For accreting coasts, the residual sediment transport is positive. That is, the coastal system is able to keep pace with gradual and slow levels of sea level rise and natural subsidence and recovers naturally after erosive events such as major storms.

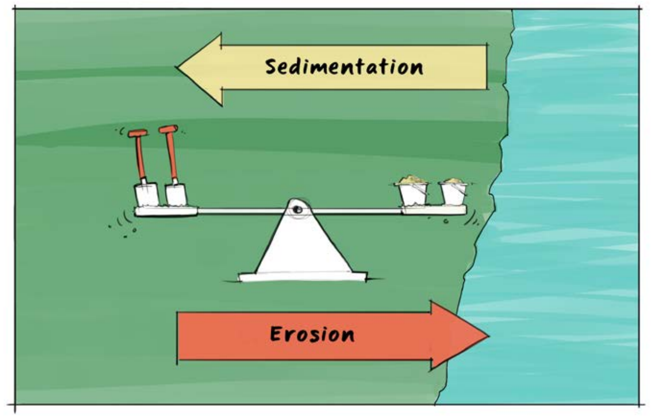


Figure 3. Sediment balance under undisturbed conditions © Joost Fluitsma, JAM Visual Thinking

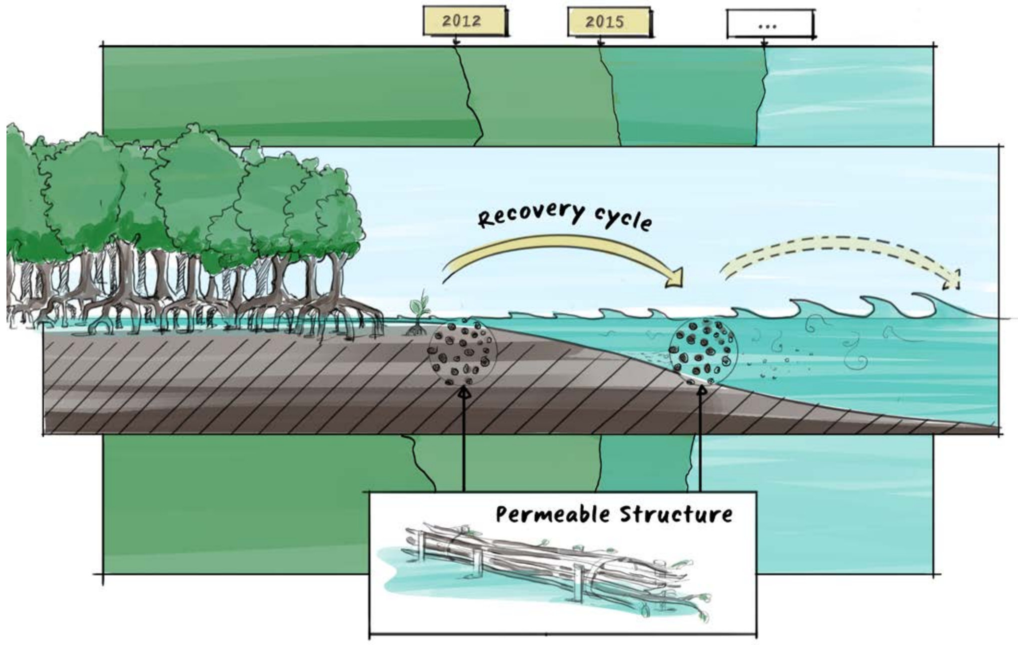


Figure 4. New structures can be placed seaward once sufficient sediment has been trapped behind the existing structures © Joost Fluitsma, JAM Visual Thinking

In order to stop the erosion process and regain a stable coastline, the first necessary step is to restore the natural sediment balance. By creating conditions under which sedimentation is promoted, more sediment is deposited on the coast than is eroded. This can be achieved by applying permeable structures to create zones with reduced flow and turbulence. Fine sediments can settle and deposit and are not re-suspended by waves and thus not transported seawards during the next tidal cycle. The result is a net onshore sediment flux. Once erosion has decreased sufficiently and accretion has started, mangroves can recover as the water depth decreases and the intertidal areas remain dry long enough for saplings to establish. In addition, the low energy zones created behind the permeable structures further enhance mangrove recovery by providing a sheltered area for mangrove saplings to grow as they are no longer washed away by the currents and waves.

New permeable structures can be placed seaward once sufficient sediment has been trapped behind the existing structures. In this way, the intertidal area can grow out towards a target coastline. This target coastline needs to be determined taking into account the presence of seagrass beds, coral reefs, mudflats or sand barriers to avoid damage to these valuable habitats and to respect and restore the natural transition between different habitat types.

Using permeable structures to trap sediment in combination with mangrove recovery is suitable in muddy coastal systems where there is still a large availability of fine sediment (mud) and where mangroves grew previously. It is optimal when there are still mangroves present in the surrounding landscape. Fruit, propagules and seedlings of the existing trees can then be naturally transported to locations where they can grow. When mangroves are no longer present, regeneration may need to be assisted by sowing or planting with the appropriate species distribution. When the target coastline has been re-established, permeable structures may be required permanently on the front to dissipate wave energy.

These functional requirements form the basis of the spatial design of the permeable structures, their implementation and subsequent monitoring. Specifics of mangrove recovery and socio-economic measures will be discussed in more detail in separate technical guidelines of this series. The role of mangroves for coastal defenses is explained in detail in a separate guideline for decision makers (Spalding et al. 2014).

2.1.2 Spatial design

The spatial design must consider factors such as the offshore bathymetry, morpho-dynamics, hydrology and long-time development of the coastline as they effect the locations for the structures. In the longer term mangrove re-establishment on restored intertidal areas results in the recovery of a natural coastal mangrove belt consisting of a mix of native species.

LOCAL CONDITIONS

Main aspects are that the location should be a muddy coast with erosion. The stiff soil layer should be less than 1.5 m from the high water level mark. The grade of the slope should be mild and land subsidence minor. There should be a tidal environment and it is preferable that there is a local source of mangrove seeds.

WAVE SHELTER

Permeable structures need to be placed in a way that they provide shelter from waves. At first, some basic data about the wave climate is required, such as main wave direction, significant and maximum wave heights. The maximum wave height is 1.0m to 1.5 m and the maximum period 8 s. The permeable structures in this report cannot withstand larger waves. Structures should then be orientated perpendicular to the main wave direction so that sheltered areas are created that will enable sediment accretion and subsequent natural recolonization by mangroves.

LOCATION OF CREEKS

In addition, the spatial arrangement of the structures should consider the location of existing creeks but also the development of creeks. Creeks are essential for watering and drainage of the area and the transport of suspended sediments and mangrove seedlings. Structures should not block existing creeks. The width of the opening between the structures depends on the tidal prism and wave climate. Minimal width of the opening is determined by the tidal prism. The opening should be wide enough for the tidal flow to enter the area behind the permeable structure unrestricted-ly. Maximal width of the opening is determined by the wave climate. The opening should not be so wide that waves can enter the area behind the permeable structure and stir up sediment. Openings with a width between 5m and 10m are effective in areas with a mean tidal ranges around 1m. This allows the tide to flow in freely and maximise sediment transportation behind the structures. In the Dutch case (mesotidal) the opening constitutes 10% of total front structure length. In the Indonesian case (microtidal) the opening varies between 5-10% of the front structure length. No signs of restrictive effects of the opening have been observed.

DISTANCE BETWEEN STRUCTURES

Generally, a distance of 100 m from the shoreline is recommended for the installation of the permeable structures. This distance is applied in the Netherlands and in Demak, Indonesia. Grids of 200m by 200m turned out to be too large due to internal wave set-up (Dijkema et al. 2011). Adaptive management is advised to achieve optimal distances between permeable dams. This process includes field measurements, modelling, data analyses, evaluation and optimization of design. Where possible, structures should be connected to revetments, forests or land to avoid severe scouring and improve stability of the structure. The length of an individual structure depends on the local conditions, such as the grain size and amount of suspended sediment, tidal range and wave parameters. Building several rows of permeable structures in front of each other simul-taneously is not advised, because the source of the sediment for the structures is in the coastal zone and the sediment will no longer be able to reach the back, as it settles directly behind the structure, resulting in possible water logging.

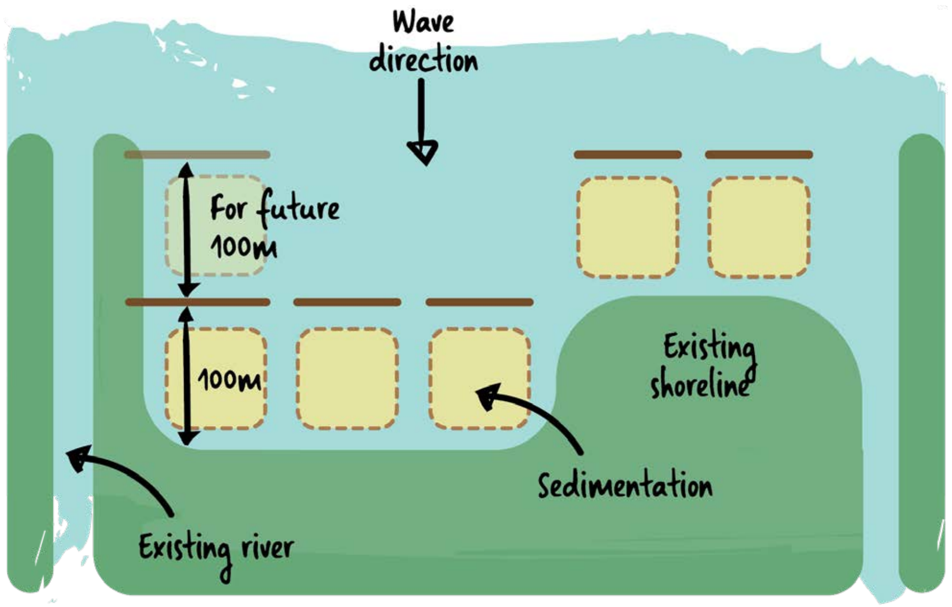


Figure 5. Sketch of distances of structures from existing shoreline and each other. All structures can be placed at once. Priority are the ones most landward © Witteveen+Bos

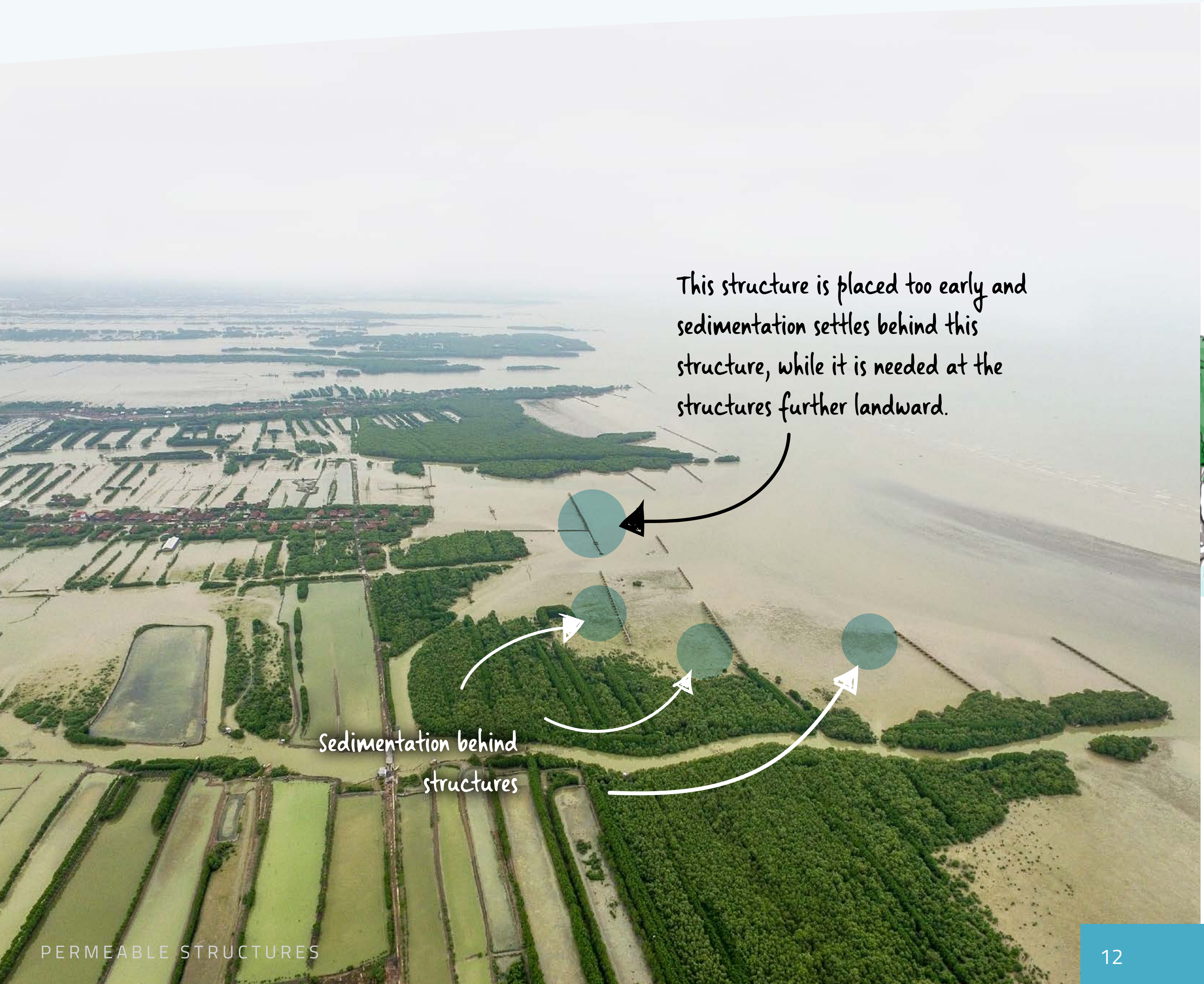
USEFUL STRONG SOIL LAYERS IN THE SYSTEM

The spatial design should always take into account the position of useful strong soil layers such as former aquaculture bunds. The structures should be placed on top or at the side of remnants of abandoned ponds. These old pond bunds consist of stiff soil and are strong enough to provide a sound foundation, minimizing local scour around the poles and underneath the brushwood. The exact location of the permeable structures should be discussed with the local community and based on field surveys.

Figure 6 shows the spatial design of permeable structures in Demak, Indonesia. The aerial photo is taken at low tide in February 2016, half a year after construction. The following is visible:

- Structures are placed adjacent to the existing coastline with the aim to build out from existing mangrove areas. At the lower part of the figure the sediment is clearly visible above low water and mangroves are starting to naturally recolonize.
- The structure in the centre of the area was constructed too early. Sediment settles directly behind this structure and does not reach the landward side of the areas.

Figure 6. Example of spatial design in Timbulsloko (Demak, Indonesia) © Pro57



2.2 PERMEABLE STRUCTURE DESIGN (INDIVIDUAL LEVEL)

2.2.1 Purpose and functional requirements

A permeable structure needs to fulfil several requirements. First, it needs to generate areas of reduced orbital velocities and turbulence. It has to provide sufficient wave energy dissipation so that the significant wave height decreases when waves pass through the permeable structure. Fill material, in particular, accommodates this. Second, the permeability of the structure through the structure needs to be sufficient to let suspended sediments pass through. This increases the amount of sediment input into the sheltered area allowing sediments settle, deposit and consolidate. Third, the wave reflection should be limited so erosion at the base (scouring) is avoided and structural collapse is prevented. The permeable structures need to stay in place at least long enough for mangroves to recover, which is the sum of the estimated sediment accretion rate (2 – 5 years) and rate of mangrove recovery (3 – 5 years).

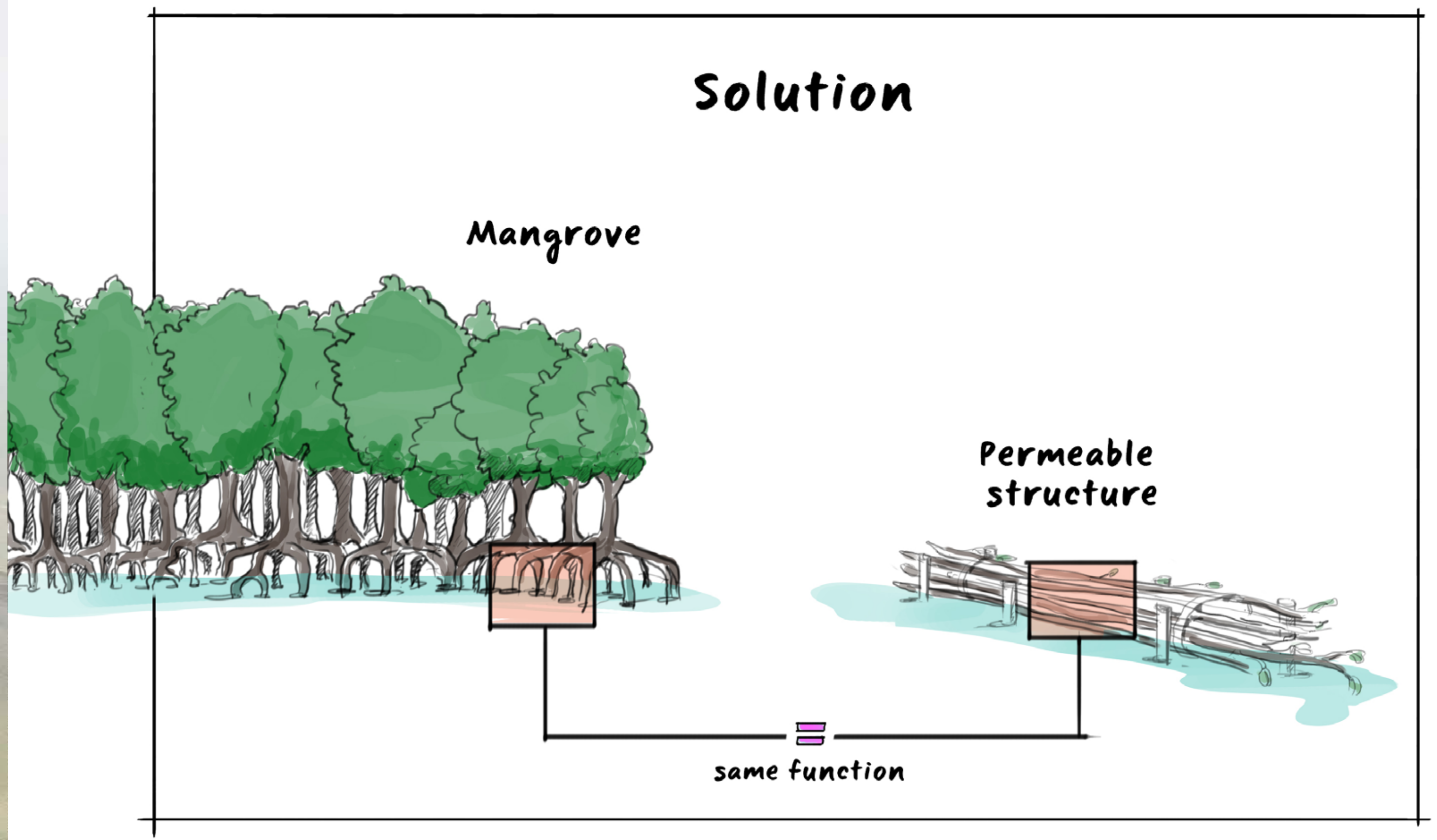


Figure 7. Permeable structures mimic the root system of natural mangroves that breaks incoming waves, reduces orbital velocities and turbulences and traps sediments. © Joost Fluitsma – JAM Visual Thinking

2.2.2 Structural Design

Generally, permeable structures are fence-like structures and consist of two rows of vertical poles with brushwood fill in between. A wire is tied over the fill material to keep it in place. The wire is tied to the horizontal bars that are attached to the vertical poles. A net can be used to fix the fill material. In this section, various design concepts of individual permeable structure are presented, taking into account the purpose and functional requirements (section 2.1 and 2.2). Designs of permeable structures are developed and built at various locations, often with different designs due to different local conditions or other restraints. Knowledge gained from these experiences are shared and possible risks are addressed.

COMPONENTS OF PERMEABLE STRUCTURES

The functional requirements of an individual structure can be linked to different components of the permeable structure shown in figure 8, which are:

- The fill material, which is the material between the poles, has the following functions: wave attenuation, reduction of flow velocity and permeability for suspended sediments.
- The vertical poles, which keep the fill in place. The strength of the construction comes primarily from the embedding of the poles in the ground.
- The horizontal beams, which connect the vertical poles and are used to attach the wire keeping the fill in place. They do not have to keep the poles together. They also do not need to withstand loading by large floating elements.
- The wire and net keep the fill between the poles and prevent the fill from being washed away.

Each component can be made from different materials. The choice of materials and dimension of each component is the core of the design process. Figure 8 shows the general design of the permeable structure with the four components. Table 1 describes several alternative materials for each component of a permeable structure, based on experience in Demak.

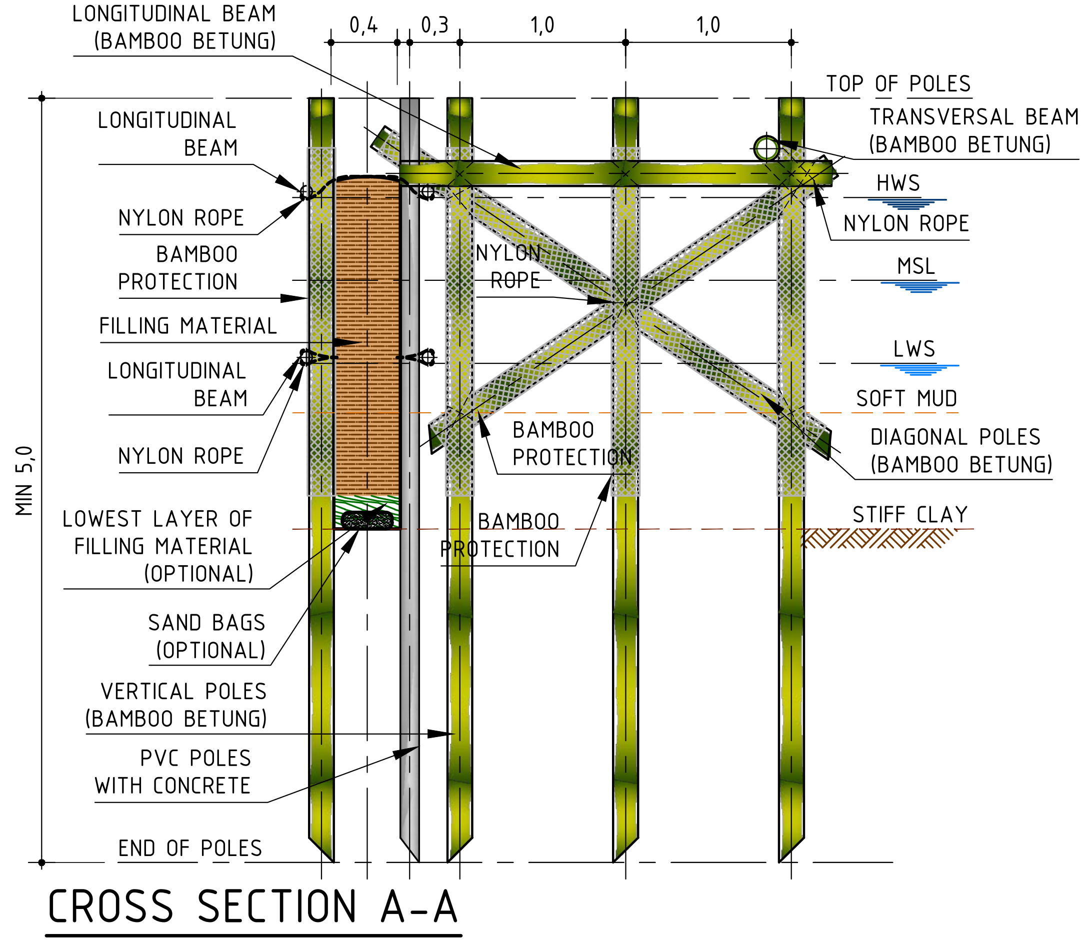


Figure 8 (part 1). Components of a permeable structure © Witteveen+Bos

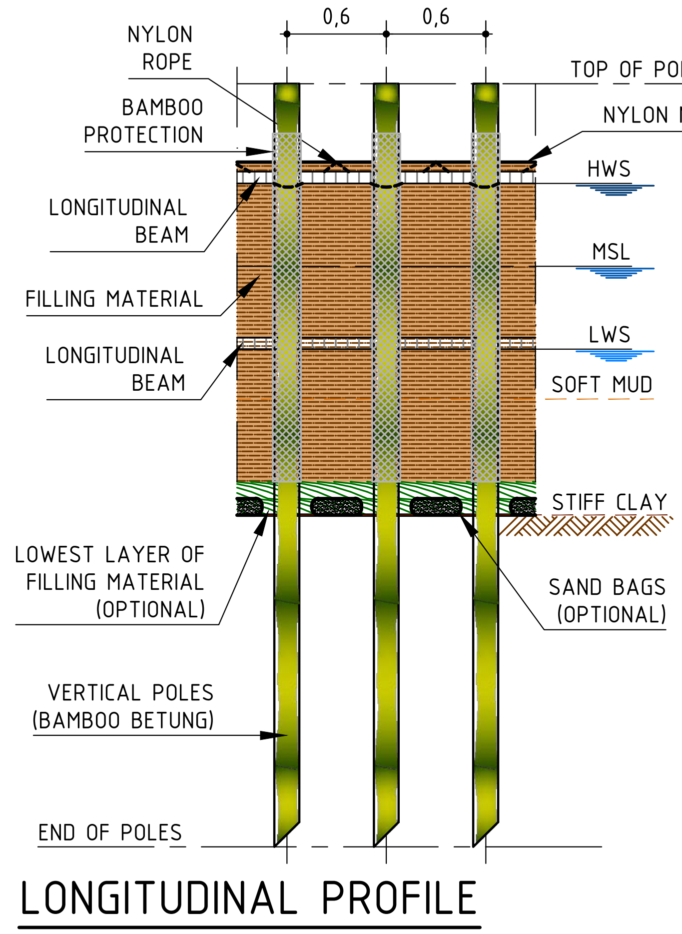


Figure 8 (part 2). Components of a permeable structure © Witteveen+Bos

Table 1. Several alternative materials for each component of a permeable structure, based on experience in Demak.

ASPECTS	VERTICAL POLES	FILL + BASE LAYER	NET + ROPE	WIRE ON TOP	HORIZONTAL BEAMS
Function	**Vertical poles** keep the entire structure in place and dissipate most of the hydro-dynamic loads. If the vertical poles fail, the structure fails.	The **fill** attenuates the waves and lets sediment through. The **base layer** creates a transition to the mud layers.	The **net** keeps all bundles of fill material together. The **rope** keeps the individual bundles together.	The **wire on top** keeps the fill material fixed in its place. It prevents movement of the fill material which can wash away.	**Horizontal beams** are used to attach the wire to and they give some additional strength.
Require-ments	The strength of the vertical poles is essential for overall stability.	The fill needs to be in place at all times to attenuate the wave energy. It should not be able to move in any direction. In horizontal direction it has to be pressed between the vertical poles. In vertical direction it has to be fixed between the stiff bed layer and the top wire. The fill material needs some permeability to limit reflection and dampen the waves.	The net and rope for the bundles can be of lower quality. The mesh of the net needs to be wide enough not to trap animals.	This wire has to be strong, durable and easy to tie in knots.	They need to resist the force of the wire. They do not have to keep the poles together.
SPECIFICATIONS					
Diameter	0.12m - 0.15m at both ends.[1]	**Branches fill:** between 0.02m and 0.10m.	**Mesh size of net:** large enough not to trap animals, 0.10m. **Diameter rope net:** 3mm. **Diameter rope:** small, locally available.	8mm nylon.	At least 0.10m.
Length	At least 4m.	Longer than the distance between 3 poles (3 x 0.60m = 2.00m).		3m to 5m to limit damage when lost.	At least 4m.
Toe	2/3 of the length should be in the stiff soil layer. Minimum is 2m in stiff layer.[2]	Directly on top of the stiff bed material. Often there is a layer of soft mud. Fill should be pushed inside this layer until it rests on the hard bed.			0.10m above Mean High Water Spring (MHWS). At that level the beams are rarely submerged and their durability will be higher.
Top	At least 0.50m above the Mean High Water Spring (MHWS).	At least 0.30m above Mean High Water Spring (MHWS) to compensate for sinking and compression of fill.			
Durability - required	Required 5 years or longer.	Required 5 years or longer.	Required 5 years or longer.	Required 5 years or longer.	Required 5 years or longer.

[1] *Larger diameters are stiffer, but more difficult to place and more expensive. A structural study is not performed on the required diameter, as the strength of the pole is influenced by many factors that are uncertain, like the behaviour of the sediment, the stress of the waves combined with the permeability, the wall thickness, other material specifications and the fill material.*

[2] *The poles are preferably over 2/3 embedded into the stiff bed layer to be able to resist the horizontal forces by waves and currents. For example, a pole with a total length is 4.50 m should be 3.00 m embedded and 1.50 m above the bed level. The poles that were inserted at least 2 m into the stiff bed layer remained stable in the recent years in Demak. Poles that were placed less deep, were washed away during storms.*

Table 1. Several alternative materials for each component of a permeable structure, based on experience in Demak.

ASPECTS	VERTICAL POLES	FILL + BASE LAYER	NET + ROPE	WIRE ON TOP	HORIZONTAL BEAMS
SPECIFICATIONS					
Durability - experienced in Demak	**Wooden poles:** 1 year, due to shipworm. **Bamboo:** 2 years, due to shipworm. **PVC-concrete:** more than 3 years.	Within 2 years full replacement.	2 years.	More than 3 years.	2 to 3 years.
Component specific	**Distance within a row:** 0.60m centre to centre between poles, see figure 8. **Distance between rows:** 0.40m, see figure 8. **Weight:** suitable for manual placement.[1]	**Bundles:** the fill is tied in bundles, to create more strength and make the placement easier. **Placement:** bundles must be placed staggered, see figure 10. **Quantity:** sufficient fill for construction and maintenance.[2]	Small sand bags (1kg each) can be used to keep the net down.		
Possible materials	- Bamboo (Apus and Betung), - Wooden poles (Gelam, mangrove and Nibung: Oncosperma tigillarium), - Coconut trunk, - PVC (filled with concrete and empty, they can be reused), - Steel (I or H beams). Natural poles require protection against shipworm, such as wrapping with plastic, carpet or tarpaulin.	**Fill:** - woven bamboo of 2x3m, - branches and brushwood (sustainably sourced), - coconut fronds, - Nipah palms. **Base layer:** straw, palm or banana leaves.	**Net:** - Nylon. **Not recommended:** - Polyethylene will degrade due to UV, - All natural materials that are tried in Java project have low durability. - Steel containers (gabions) are not taken into account, because they are very costly.	**Wire:** - thick nylon wire, which can be tied in knots, - steel cable with plastic coating, though this is difficult to tie knots.	- Bamboo (Apus and Betung), - Wood (Gelam and Nibung), - PVC, steel (pipe, rebar). Bamboo is recommended as it is natural, cheap and more durable than wood. The bamboo beams can be repaired, when the fill is replenished.
Additional information		Local brushwood plantations could provide material over time and as such become an additional source of local income.			

[1] *The weight of the material needs to be taken into account. For PVC-concrete poles with a diameter of 4" (around 0.10 m) and a length of 4.00 m weight around 100 kg. Poles with a diameter of 6" (around 0.15 m) and a length of 4.00 m are almost 200 kg in mass.*

[2] *To calculate the quantity of fill needed for the first year of construction and maintenance the following pointers need to be taken into account: 1) the top of the stiff bed layer needs to be taken as the lowest level of the fill material, since the soft mud layer on top of it may be eroded; 2) Loss and decay of brushwood is around 20%; 3) compaction of brushwood is around 10%; 4) the vertical poles will move away from each other requiring extra fill of around 10%.*

Figure 9 shows the configuration of the vertical poles. Figure 10 shows a front view of a permeable structure with the staggered placement of the bundles.

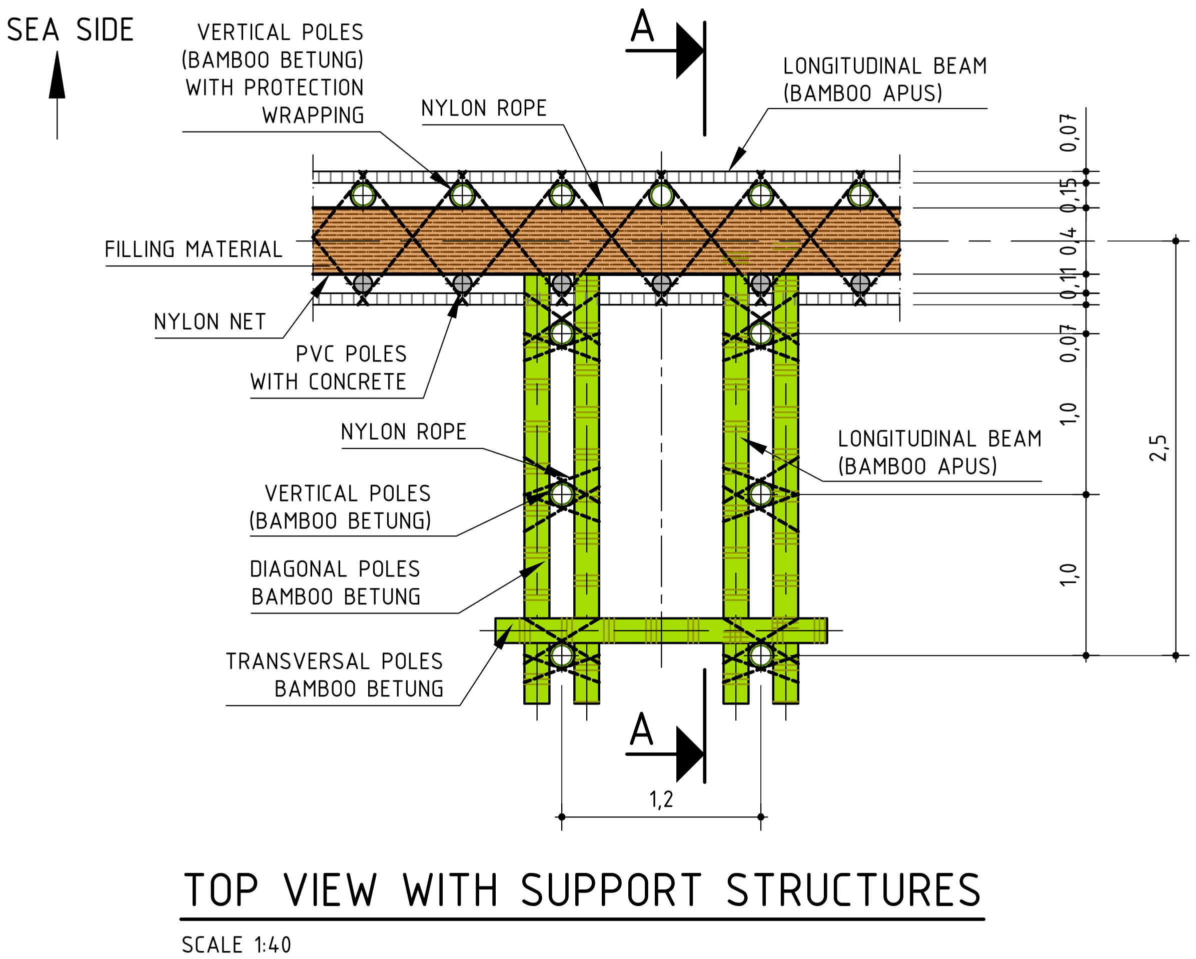


Figure 9. Configuration of the vertical poles © Witteveen+Bos

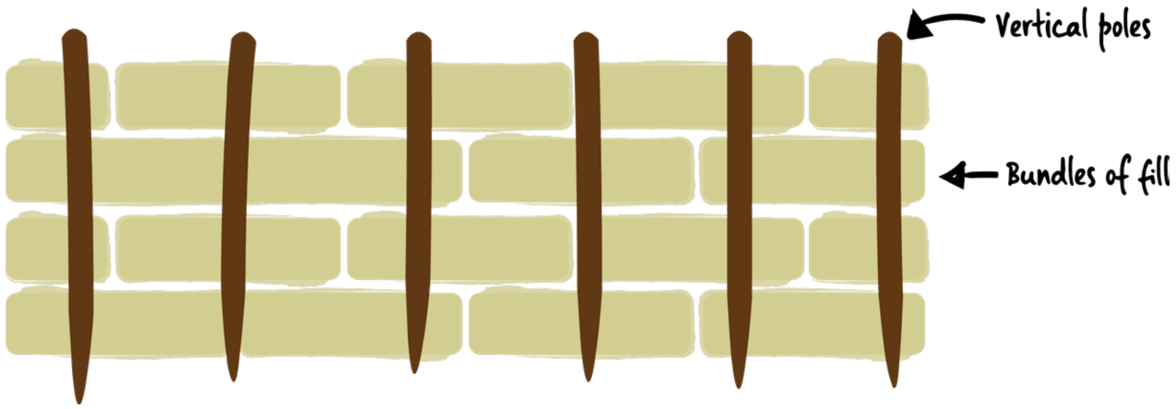


Figure 10. Front view of staggered configuration of the bundles of fill material © Witteveen+Bos

ALTERNATIVE DESIGNS

There are various designs possible for the individual structures. The first example, in figure 11, is a T-piece at the sides of each long-shore structure and also along openings. It is a perpendicular structure of 10m (5m in front and 5m in back) which creates extra stability and prevents scour around the main part of the structure. The effectiveness of these stabilising end T-parts and whether their length is sufficient is tested in Demak. The first results are promising and further results will be shared in an updated version of this document.

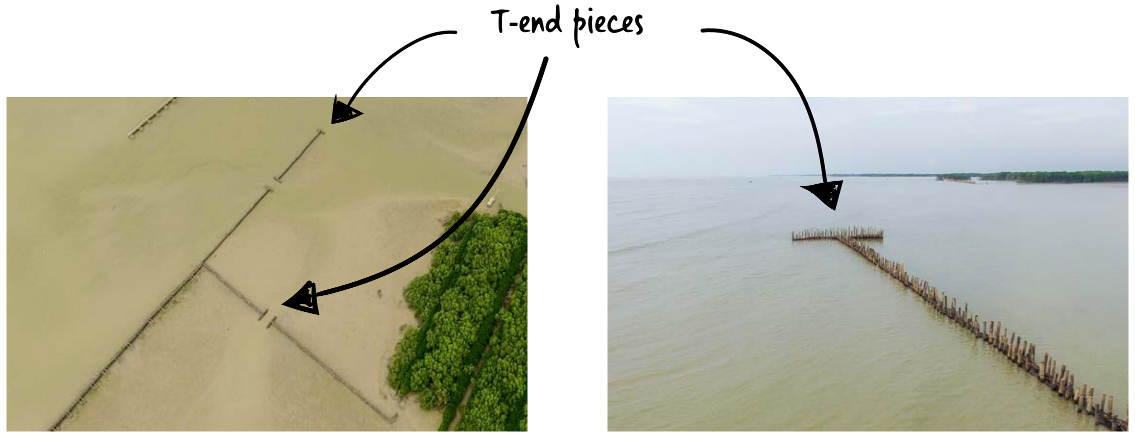


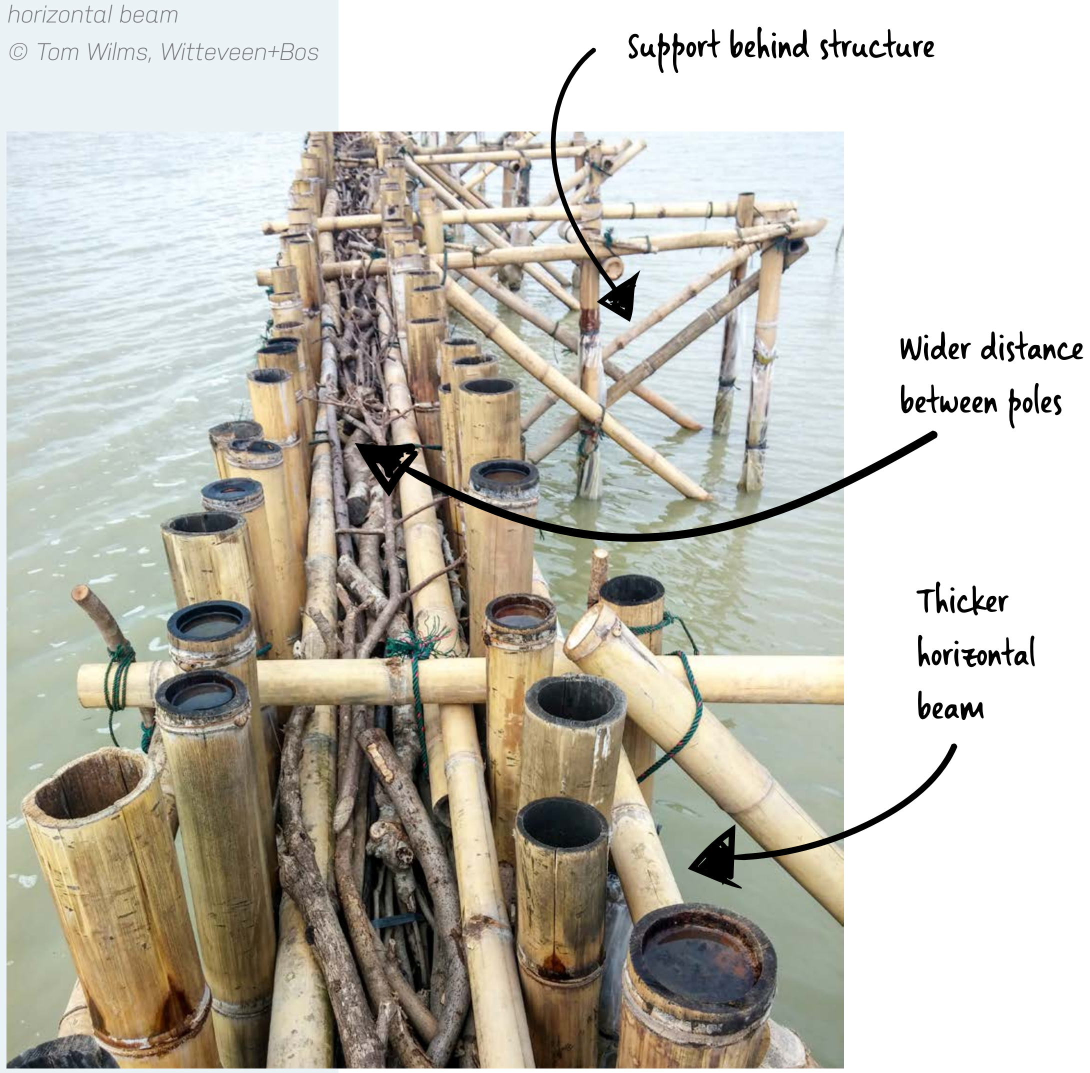
Figure 11. T-piece sides of each long-shore structure and also along openings © Pro57

Table 2 and figure 12 show other alternative designs: more width between poles, support structures at the back and thicker horizontal beams.

VARIATION	PROS	CONS
Wider distances between the vertical poles	Increases the wave damping effect	Requires more fill material. More expensive.
Support behind the structure at exposed locations	Considered to give more stability	More expensive. Effect is not proven yet.
Thicker horizontal beam	Gives more stability between the vertical poles. Considered to be more robust. Easier to walk along the structure for maintenance.	More expensive. Not proven to be necessary.
Extra horizontal support beam at the bed level, or at low water level	Considered to give more stability. Social support by the local community, as they experience it as stronger. Might provide stability at more exposed locations.	More expensive. Placement under low water is difficult.

Table 2. Variation in lay-out of the different components

Figure 12. Alternative design that has more width between poles, support structure at the back, thicker horizontal beam
© Tom Wilms, Witteveen+Bos



2.2.3 Materials for the components

This section discusses the possible materials for the four components of the permeable structure. More information is available in the hardware plan, see chapter 5, such as specifications and trade-offs.

Figure 13. Permeable structure
© Tom Wilms, Witteveen+Bos

VERTICAL POLES

These poles must be durable for the entire lifetime of the permeable structure (5 years or longer). The following materials are investigated and elaborated in this guideline: bamboo (Apus and Betung), wooden poles (wood Gelam), mangrove (Rhizophora mucronata) and Nibung (Oncosperma tigillarium), coconut trunk (Cocos nucifera), PVC (filled with concrete and empty) and steel (I or H beams).

Ideally, bamboo poles, both Apus and Betung, are recommended as they are durable with a wrapping to prevent damage by shipworm, as experienced in Demak. The second best option are PVC poles with concrete. Concrete makes the poles more durable, but is also heavy, more expensive and not natural. PVC poles with a thicker shell are as stiff as PVC filled with concrete, based on rough field tests. PVC degrades due to sunlight and saline water. It should be investigated whether HDPE is a better alternative. (Environmental) permits might require that they be removed at the end of the project.

In other tropical locations Nibung, Coconut trunks and Walaba wood gave good results with a durability of 10 years. The latter is used in Surinam. In temperate locations material durability is less of a problem. Off the coast of The Netherlands, good durability for brushwood is attained with willow (Salix spp.) and juniper (Juniperus communis) branches.

The reason the other materials are not recommended are:

- Wooden poles (Gelam) are infested by shipworm and mollusc.
- Wooden poles (mangrove) were attacked by 'teredo worms' at locations. Furthermore, the sustainability of mangroves usage is limited.
- Steel beams are very expensive and heavy.
- Wooden poles might be protected with semi-pyrolysis. It is not tested due to its impact on the environment. Its use is forbidden in several countries around the world. The process would bring out some protective compounds and rid some of the specimens that natural agents of biological degradation like to eat.

The lifetime of the bamboo and wooden poles is often less than the required 5 years due to shipworm and other local threats and results in high maintenance requirements. The lifetime can be increased by covering them with carpet or other materials, protecting them from the shipworm (tritip). These wrappings have to be resistant against puncture and tearing by brushwood when placed. This is currently being tested. The results will be incorporated in this guideline as soon as they become available.

HORIZONTAL BEAMS

The following materials can be considered for the horizontal beams: bamboo (Apus and Betung), wood (Gelam and Nibung), PVC steel, (pipe, rebar). Bamboo is recommended as it is natural, cheap and more durable than wood. The bamboo beams can be repaired when the fill is replenished. This is more labour intensive, but still relatively low cost.

FILL
The fill consists of a base layer of leaves with brushwood on top. For the base layer palm leaves should be used. For the brushwood, options include: woven bamboo of 2x3m, branches, brushwood of mangrove, bamboo branches, coconut fronds, and Nipah palms. In Demak, brushwood from bushes and trees is used. This material still poses challenges to keep in place as it decays, compacts, and damages the vertical poles as it floats and gives high horizontal loads with high waves. It requires regular maintenance. Improvement of the fill material is required. Solutions can be in non-floating material, permeable plates, porous sponge-like materials, horizontal beams or dense rows of vertical poles.

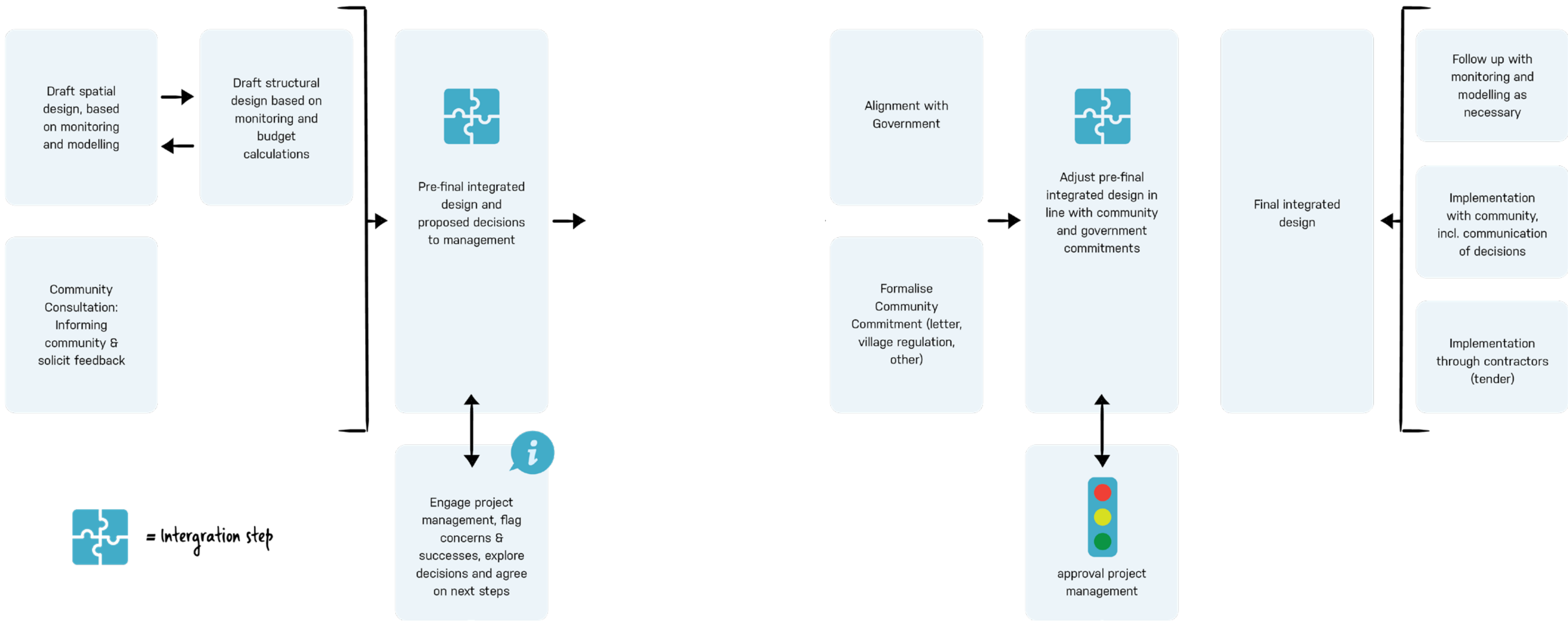
WIRE AND NET
For the wire, a Nylon rope is recommended for tying knots. Steel cables with coating are difficult to tie and leave holds soon after their installation. The wire to bind the small bundles can be of low quality with a durability of 2 to 3 years. The net can also be of low quality as is does not need to withstand the loads in ultimate state. A net made from Nylon would be good. Polyethylene will degrade due to UV. Natural materials are not used as the durability is low. Steel containers (gabions) are not taken into account due to expense.

SUSTAINABILITY
During permeable structure design and material selection it is important to take into account the impact of the materials on the environment. For example, the impact of the material on the creation of new habitats, hard substrate for oysters and molluscs. Or the impact on biodiversity, like net mesh size to prevent fish getting caught. The impacts of degradation and damage also has to be taken into account, such as the degradation of the PVC poles or the protective wrapping of the bamboo poles. Additionally, the life time of the materials is important as it effects the supply and maintenance and possibility of reuse. Sustainable sourcing will be discussed as part of the tender process in section 3.5.

2.3 DESIGN PROCESS

The design of the solutions at a specific location involves a spatial design, a design of the permeable structures and the social aspects of the project will be implemented in a community. As explained in the separate guideline, in this series on the Building with Nature approach, the project requires input from the various systems, the biophysical, socio-economical and institutional. At the start of the design process input from these systems need to be collected and discussed with the team. After that discussion the spatial, structural and social aspects need to be brought to the fore. A second discussion should take place to facilitate draft designs. Bringing that design to a final version requires final design phase. Figure 14 shows a flow diagram for the design process to construction.

Figure 14. Process from design to construction for permeable structures © Wetlands International Indonesia



3 CONSTRUCTION

This chapter discusses the construction phase of the permeable structures. It consists of a time schedule where all activities of the construction are projected, scheduled and optimized. The major steps in the construction phase are discussed including site visits, the tender process, training of workers and the actual construction works.

3.1 TIME SCHEDULE

To be able to execute the construction works a work schedule is needed. An example is shown in table 3 and explained. The schedule needs to consist of all relevant activities as well as limitations, like a wet season, which has storms with high waves creating downtime. It also needs to include public holidays like Christmas, Ramadhan and Idul Fitri. For example, in Central Java, Indonesia, the construction needs to be finished before the start of the wet season, so, at latest, September and October.

	ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Spatial plan												
2	Stakeholder involvement												
3	Permits (environmental) in Indonesia AMDAL, UKL-UPL												
4	Site visit and preparation												
5	Tender of construction (supervision)												
6	Training for construction												
7	Construction (and supervision)												
8	Monitoring and maintenance												
	Wet season												
	Dry season												
	Holidays (Ramadhan, Idul Fitri, Christmas)												

Table 3. An example of a draft schedule of the activities over the year

1. Make a spatial plan based on system understanding, available (historical) data and monitoring. It is explained in the previous chapter (finish in February).
2. The stakeholder engagement (January to May).
3. Permits, apply and comply. This can be continuous.
4. Visit the location, discuss the spatial plan with the community, ask about improvements and obstacles at the proposed locations, survey the location to determine depth and obstacles, place end-markers (March).
5. Tender for construction: prepare documents, drawings and allocate budget (June-July). Tender for supervision: prepare documents and allocate budget. When possible involve the supervisor in the construction tender. This activity ends with the award of the contracts (April and May).
6. Training for construction (May and June).
7. Construction and supervision (June to September).
8. Monitoring and maintenance already starts during the construction works and continues (from July)

Wet season in Indonesia (November-March)
Dry season in Indonesia (April - October)
Public holidays

3.2 STAKEHOLDER INVOLVEMENT

Stakeholder engagement is an important aspect, which includes the community engagement and awareness raising, see figure 15. At an early start the local community needs to be informed about the project, the plans, as well as gauging their opinion and possible involvement. Early involvement means they can support the project as well as collaborate in the design, implementation, monitoring, maintenance and replication. The community needs to understand and support the recovery and protection of mangrove area, to avoid degradation and deforestation at a later stage. Community engagement should ideally be documented in the form of a support letter, contract and/or village regulation. Stakeholder involvement is addressed in other technical guidelines in this series.

Another topic is the transferring of landownership if needed. Land tenure can be a potential risk, undermining success of mangrove recolonization. Therefore, land should preferably be government owned and protection of restored mangrove areas should be ensured. The affected governmental agencies should be involved as much as possible. This involvement should already start when the spatial planning is done.

Figure 15. Visit to village to discuss the proposed design © Witteveen+Bos and Wetlands International Indonesia

3.3 PERMITS

To construct the permeable structures law and regulations have to be adhered to. Often permits need to be acquired requiring, for example, an Environmental Impact Assessment. The required permits vary per country and also depend on the size of the project. In Indonesia an Environmental Impact Assessment, or a monitoring and management plan, are needed. Often a certified consultant needs to apply for such a permit. After the permit is acquired, monitoring and management is often needed before, during and after construction works and reports need to be submitted. Often there is an overlap between the requirements and what the project wishes to monitor.

3.4 SITE VISIT AND PREPARATION

SITE VISIT

After the general spatial design is developed, based on maps and aerial views, the site is visited to explain the situation and discuss the design with the local community. Their local area knowledge can give useful advice regarding locations. For example, on top of old bunds or on avoiding obstacles like housing foundations or very thick shell layers. In this meeting the engagement of the community can be discussed. After the advice is incorporated the exact locations are visited to measure the top of the stiff soil layer every 20m to 25m relative to the nearest benchmark (HWS). To determine that level, a stick (2cm²) should be pushed into the soil until it cannot be pushed further (not without your full weight), see figure 16. With this information the required lengths of the vertical poles can be determined. The ends of the structures need to be marked with poles of approximate 3m length and limited diameter (0.10m) to indicate the dimensions of the construction.

BENCHMARK - TIDAL LEVEL

One of the first activities is the installation of a benchmark, a vertical reference level, at each construction site. This is needed to measure levels relative to the tide. This benchmark can be a pole or hard structure like a bridge or a stone wall. Marks have to be placed at the Mean Low Water Spring (MLWS) and the Mean High Water Spring (MHWS).

Figure 16. Measurement of level of stiff soil layer © Bagus Maulana

Figure 17. Natural elements to mark the benchmark © Tom Wilms, Witteveen+Bos

Often animals and vegetation can indicate these levels, which is shown in figure 16, the green colour from the algae shows the tidal level and the tritip shows the rough Mean Sea Level as they grow until that level. MHWS is recommended as 0 for the reference level, as it is emerged most of the time.

3.5 TENDER FOR CONSTRUCTION

The tender activity results in the award of the construction of the structures to a contractor and the supervision works to a supervisor. First the tender documents need to be prepared based on the spatial design, site visit and the legal requirements. These documents consist of the requirements the contractor has to comply with on various aspects like technical, legal, time, financial and quality. As part of the technical aspects the Bill of Quantities (BoQ) and an Owner Estimate (OE) need to be prepared. The latter should be based on the life cycle cost. Besides the initial investments the cost for maintenance, removal, or reuse, has to be taken into account. At this moment, the average investment costs are below 100 EUR per running meter permeable structure (around 1.5 million IDR/m). The annual maintenance costs are around 50 EUR/m (0.75 million IDR/m), with the majority of the cost for the replacement of the fill material.
A cost estimate should be developed per section and should be included in the cost estimate for the entire project. The estimate for the initial construction and first year of construction consists of:

- Purchase of material and transport (this is for initial construction and first year of maintenance)
- Construction costs
- Maintenance cost
- Profit for the contractor (approximately 10% of total cost)
- Tax (approximately 10% of total cost)
- Contingency, uncertainty (approximately 20%, this is not a fixed percentage yet)
- Unforeseen (approximately 10% of total cost)

Costs for the maintenance in subsequent years should be based on the monitoring of the degradation of the materials. As a first estimate, the annual maintenance cost of the permeable structure stated in this guideline is 50% of the initial construction cost.

The quality aspects of the tender documents can consist of various aspects like social security and sustainability such as sustainable sourcing of materials. Relevant topics for sustainable sourcing are:

- Location of purchase of materials. This influences the transport distance and carbon footprint. A solution is to grow materials for permeable structures in the project area.
- Negative effects on the environment induced by the production of these materials.
- Availability of the materials in sufficient quantity and potential influence on the market. For example, the fill material as fire wood, or the bamboo as construction material.
- The application of other low-tech measures to increase the durability of the structures, like the wrapping of the bamboo.

When the tender documents are ready they need to be shared with contractors. The contractors can be contacted directly, informed via an advertisement, or by organising a public tender. Often the contractors are invited to a pre-tender meeting where the project is explained, the tender documents are distributed and questions can be asked. This is also a good moment for a site visit. After this meeting the contractors prepare their offer and bid. After submission their documents are reviewed by the client and a clarification meeting is organised so contractors can clarify their bid. With all the information available the client selects the winner and the project is awarded to the contractor. A similar process can be followed for the selection of a supervisor.

3.6 TRAINING FOR CONSTRUCTION AND MAINTENANCE

The purpose of training is to increase the knowledge and the skills of the community members who will participate in the construction process. Participants include the contractor, supervisors and workers. The training should be scheduled around the start of the construction works.

It is recommended to use an approach of Training of Trainers (ToT). This means that the training is done for a small group of people, for example the representatives of each group of workers from each village. These people are trained in such a way that they can train their fellow group workers and also other people over time. With this approach the effort of the initial training is limited and effective. This approach is used in the Coastal Field Schools for the aquaculture revitalisation, which is another part of the Building with Nature project in Demak.

Every training should consist of at least: a general introduction to project, Building with Nature approach, construction process, maintenance and Health, Safety and Environment (HSE), see table 4. The training for the construction should focus on the construction steps presented later in this document. Attention has to be paid to the quality of the material, the correct construction method, connection of the different components and maintenance during the construction period. The training for the maintenance needs to focus on the inspection frequency, the features that need to be inspected, the follow up when maintenance and repair are needed and the methods to maintain and repair the structures. The training for the workers has to be at a very practical level, so they are able to construct and maintain the permeable structures, see figure 18. This technical guideline and others in this series can be used as training material.

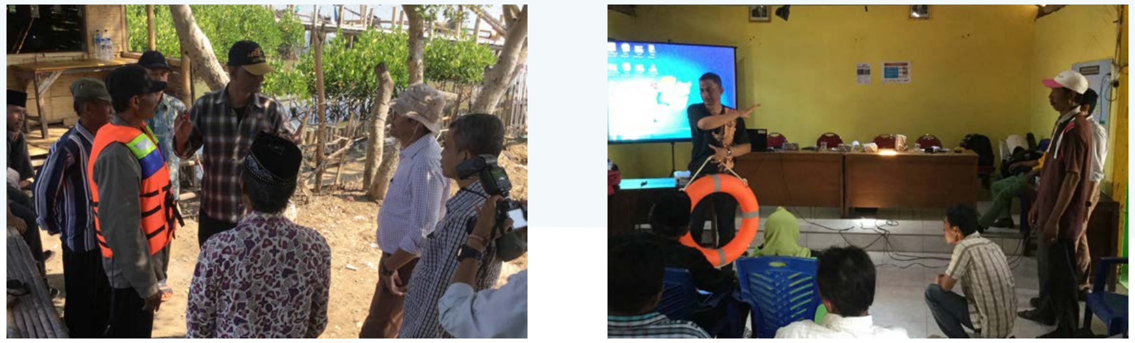


Figure 18. Training by Coastal Field School (right), Health Safety Environment training of local community (right) © Deinar Santayana, Witteveen+Bos

TABLE 4: ISSUES OF HEALTH, SAFETY AND ENVIRONMENT (HSE) DURING CONSTRUCTION

- Stop working during unsafe working conditions (due to storm, waves or currents).
- Provide sufficient drinking water.
- Provide and check protection against the sun.
- Provide and check personal protection equipment (PPE), such as life buoy and life vests, wear boots and gloves.
- Work in teams of preferably 3 or more people; of which half of them can swim (always more than 2 people).
- Provide and check safe working procedures, equipment and materials; for example, use a thick horizontal beam and a strong rope or chain when placing vertical poles.
- Provide first aid kits.
- Have necessary transportation available to get to a safe location when unsafe conditions develop.
- Maintain communication and leadership in the group.

3.7 CONSTRUCTION WORKS

The construction of a permeable structure is low-tech. It can be built by the local community with minimal tools or machines. At many locations of permeable structures, it is difficult to bring mechanical equipment to the construction site. Machines can also more easily damage the material. Machines are not necessary. In Demak one team of 6 to 8 workers can build 4m of permeable structure during a working day of 8 hours. A checklist for the construction works is on page 35.

Labour and contractor

Availability of labour depends on the size of the community and on other work in the area. It is recommended to align your project with other tenders in the area or at least discuss with those projects on materials and wages to keep the workload manageable and wages reasonable.

Determine if the construction can be done without a contractor. This needs good alignment with the local community. Topics to be thought of are: sufficient funds, cash flow, contracts with suppliers and construction management, including transport and logistics.

Figure 19. Stockpiling and quality control of material © Deinar Santayana, Witteveen+Bos

Administration and quality management

Good administration is essential to coordinate the works and perform the required steps of construction and quality management, see figure 19. If more than one group works at one section, the importance of coordination increases. For the workers the required procedure must be as clear as the consequences in case they do not comply. The transfer of responsibility to the workers helps to increase their engagement.

Stockpiling and transport

The fill material will lower already during construction. This lowering is due to the erosion of the soft mud and compaction. To be able to keep the top of the fill at the required level material needs to be available at site. A stockpiling of materials is required to add material as soon as it is needed. A stockpile is also needed for maintenance and repair as damage is observed during monitoring. At the start of the project an area has to be allocated for the stockpile. In the tender for the construction the quantities required for stockpile also have to be included.

The transport to the project location is often done with small trucks or 3-wheeled vehicles, as roads are often small near site. Materials are brought to the construction location by floating equipment, see figure 20.

Figure 20. Floating transport and stockpiling © Bagus Maulana

Construction of the permeable structure

The vertical poles are pushed in by jumping on a horizontal beam that is attached to the pole by a belt, rope, or chain, see figure 21. The first pushing/jumping can be done with a team of 6 people. To get a pole to sufficient depth at several moments 12 people can be needed. Tree roots of coconut trees are difficult to push through, but are not a problem with sufficient people. It is optional to make a hole with a drill or auger for each vertical pole. It can still occur during construction that very hard and stiff layers are encountered, despite all previous precautions. In that case workers have to find the best solution. Discuss with the engineers and the solution can be implemented. Options include: i) make T-end sections and create an opening or ii) place a part of the permeable structure more seaward or landward. After the horizontal beams are tied to the vertical poles and the net and fill material are placed and compacted a rope is tied over the fill material to keep it in place, see also the checklist on page 35.

A bridge over the opening between 2 structures is practical. Such a bridge can be 3 or 4 bamboo poles wide and for safety a hand rail is recommended.

Figure 21. Placement of vertical poles and other components © Deinar Santayana, Witteveen+Bos

Figure 22. Manual installation of an individual pole © Deinar Santayana, Witteveen+Bos

Great Egret Casmerodius albus © Yus Rusila Noor

CHECKLIST FOR THE STEPS OF THE CONSTRUCTION PROCESS

1 PREPARATION
- ☐ Materials brought to the stock pile at the project location
- ☐ Materials double-checked by contractor and supervisor regarding length, diameter, damage, etc.
- ☐ Materials brought to construction site
- ☐ Boundaries and structures' axis defined and checked before start
- ☐ Bowplank double-checked by contractor and supervisor (bowplank is a tool to keep the distance between the vertical poles fixed over a long distance)

2 INSTALLATION OF VERTICAL POLES
- ☐ Lower tip sharpened
- ☐ Each pole marked at a predefined distance from the lower tip
- ☐ Poles are pushed in
- ☐ Regular check of structures' axis
- ☐ Actual and required depths of embedment are regularly checked
- ☐ Check if poles can be pushed deeper on the next day
- ☐ Damage to the poles due to installation is minimised
- ☐ Check that bamboo poles are not cut off too high above a node, to prevent still water in it
- ☐ Placement of protective wrapping

3 INSTALLATION OF HORIZONTAL BEAMS
- ☐ Horizontal beams are knotted to the vertical poles

4 PLACEMENT OF NET
- ☐ Net is placed and connected to the horizontal beams
- ☐ Optional sandbags are placed

5 PLACEMENT OF FILL
- ☐ After stabilization of vertical poles (1-2 days later)
- ☐ Palm leaves are placed and compacted as lowest layer (0.3 m thick)
- ☐ Fill material is placed and compacted (by jumping)
- ☐ Top of fill needs to be at least 0.3 m above MHWS. This is checked regularly
- ☐ Fill is added as soon as the top of the fill gets below the horizontal beam

6 PLACEMENT OF WIRE
- ☐ After fill is at the required height the net is closed and tied
- ☐ Wire is placed and tightened over a small stretch
- ☐ Tightening is done during low water level
- ☐ Length of the wire is maximum 5 m

4 OPERATIONAL

This chapter discusses the operational phase of the permeable structures focusing on the monitoring and the maintenance.

4.1 MONITORING

In the first years of a new project at a new location, not all the required information is readily available and each year more information on system functioning will be gained. This makes it possible to optimize the spatial designs with respect to the distance between structures, the length of the structures, the width of the openings between structures, the accretion levels of the sheltered areas and time and labour needed for construction of structures. A systematic monitoring supports the optimization of the design and construction.

4.1.1 Monitoring on landscape level

At landscape level the project needs to be monitored to assess if the permeable structures are performing according to the purpose and functional requirements defined in Chapter 2. Monitoring of the effectiveness of the permeable structures focuses on the accretion of sediment behind the structures and on natural mangrove recolonization. If feasible, the compactness of the mud should be measured and analyzed over time since it describes the degree of consolidation. Natural mangrove recolonization occurs when sufficient sediment has accreted and when mangrove seedlings are available. The presence, survival and development of mangroves is also monitored. Figure 23 shows the spatial distribution of the sediment monitoring poles and a close up of one pole.

Figure 23. Monitoring sedimentation with sedimentation poles © Tom Wilms, Witteveen+Bos

4.1.2 Monitoring of permeable structures

Over the course of the project monitoring of the individual structures will be done to assess the durability of the permeable structures and implement gained information and further planning to increase the efficiency of the construction. The durability of materials used and of the constructed permeable dams is variable from situation to situation. The structures may be quite vulnerable to debilitating damage depending on the type of locally available materials, local environmental conditions and their geographic location in relation to extreme weather events. Monitoring of the permeable structures is required at several stages and regarding different aspects. The different stages of monitoring and their frequency are as follows:

- Weekly monitoring during the construction works and in the first two months after construction.
- After each storm during the wet season (In Indonesia approximately from November to March).
- At the end of the storm season.
- In September, to ensure that the structures are in good shape before the storm season starts.

The structures have to be monitored for damages and tightness. Tests should be done at low tide and contain the following activities:

- The poles should be monitored visually on holes and shipworm (tritip, trocok) and tested physically. Every 10 metres one pole should be pulled or hit at mean water level with a large diameter hammer to check if it is strong enough. If many poles are damaged the number of tested poles needs to be increased to assess the percentage of the damage.
- The horizontal beams should be pulled, to check if they are strong enough and fixed properly.
- The netting should be intact; this check is visual.
- The wire has to be tight; this is a visual and physical test. The latter is performed by pulling the wire.

Appendix II gives a flow chart of the monitoring of the elements of the permeable structure. If damages are observed, the relevant component has to be replaced immediately. All monitoring has to be documented and reported with photos and a log.

More information on technical monitoring of the permeable structures, maintenance monitoring and sediment monitoring can be found in the monitoring protocol available via the contact persons.

4.1.3 Durability

Durability of permeable dams can be a problem, as has been experienced at our Java project site. While poles were expected to need to last at least 5 years, Galam (presumed Melaleuca cajeputi) only lasted one year while bamboo (Bambusa spp.) only lasted two years (Table 1). Better results with the same species appear to have been obtained in other locations (for in example Vietnam estuaries with much lower salinity that keeps shipworm at bay). The durability of materials used and of the constructed permeable dams is clearly variable from situation to situation. Depending on the type of locally available materials, local environmental conditions, and also their geographic location in relation to the risk of extreme weather events, these structures may be quite vulnerable to debilitating damage. Hence their utility will also depend on a variety of local factors which need to be taken into account when deciding where and how to use permeable structures for coastal restoration. At the extremes are locations like Surinam and The Netherlands. Surinam is not affected by major extreme weather events but also has readily available, high-quality native hardwood (Eperua spp.) that is able to resist shipworm. In the Netherlands permeable dams can also last for years based on construction using local natural materials, thanks to low shipworm presence.


© Cynthia Boll

4.2 MAINTENANCE AND REPAIR

Permeable structures need continuous maintenance. Without maintenance the fill material lowers and decreases and wave attenuation reduces, with the result that the structure can no longer perform. Maintenance of the structures needs to follow the monitoring stated in section 4.1 and needs to be executed directly after monitoring shows it is required. If stormy conditions occur more often, the monitoring and maintenance frequency should be increased. This also implies that at the start of the project a life cycle cost analysis has to be made and budgets for the entire lifetime need to be allocated.

Maintenance and repair are based on the monitoring stated in section 4.1. Each component of the structure is discussed below:

- Vertical poles:
  - › New vertical poles are difficult to place in the existing rows.
  - › When a small number of poles is not strong enough, these areas have to be strengthened with extra horizontal beams.
  - › When more than 40% of the poles are not stable at one side of the structure, a new row has to be placed at the other side of the structure which is still stable. Fill needs to be placed between the new row and the old stable row.
  - › When more than 40% of the poles are not stable at both sides of the structure, a new structure has to be constructed 1 or 2 metres seaward of the existing structure.
- Horizontal beams. Each understrength beam needs to be replaced by a beam that fulfils the requirements.
- Netting. Damage of the netting is hard to repair as it is stuck between the fill and the poles. The only maintenance is to tie wire around the top metre of fill material to create extra connectivity.
- Wire. The wire can let go, because knots leave hold, the fill material lowers, the wire is damaged or stolen:
  - › When the wire is damaged, it needs to be replaced.
  - › When the wire is loose and the top of the fill is above the horizontal beam, the wire should be tightened directly.
  - › When the wire is loose and the fill material is below the horizontal beam, fill material has to be added (within the net) up to 0.1m above the horizontal beam and the wire has to be tightened over the fill.
- Fill material: see above. Fill material needs to be added when its level gets below the horizontal beam. Experience in Demak shows that fill material needs to be added regularly. A rough estimate indicates replacement rates of 50% per year.

All maintenance and repair has to be documented with photos and receipts.

5 MORE INFORMATION AND SUPPORT

This guideline touches on many topics relevant for the permeable structures as measures to restore a mangrove coastline. Background information can be found in other guidelines of this series and in the following documents:

- Documents prepared at in the initiation phase of the project Building with Nature Indonesia
  - › Design and engineering plan
  - › Hardware plan
  - › Monitoring plan
- Building with Nature approach by Ecoshape: www.ecoshape.org
- Other guidelines in this series to which this chapter refers:
  - › Building with Nature approach
  - › System understanding
  - › Ecological Mangrove Restoration
  - › Policy & (community) planning, regulations, funds
  - › Bio-rights mechanism and Introducing alternative livelihoods
- References:

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Support is available for all the topics stated in this guideline. The table below gives the contact persons.

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X APPENDIX 1

By: Sub-Directorate of Disaster Mitigation and Climate Change Adaptation, Directorate of Coastal and Small Islands Utilization, Directorate General of Marine Space Management, Ministry of Marine Affairs and Fisheries

MAINSTREAMING BY THE INDONESIAN MINISTRY OF MARINE AFFAIRS AND FISHERIES (MMAF)

Since 2015, the Indonesian Ministry of Marine Affairs and Fisheries (MMAF) has been one of the consortium partners that implemented the Building with Nature approach to rehabilitate ecosystems in the north coast of Java and in several other places outside Java to stop coastal abrasion.

The ecosystem engineering programme, also called Hybrid Engineering (HE), is contained in the MMAF work plan (Regulation numbers 08 of 2016, 55 of 2017, and 65 of 2018) and includes the construction of semi-permeable structures or Hybrid Engineering structures to halt coastal abrasion.

In Demak, in phases 9 kilometres of permeable structures have been build, of which 4.4 kilometres by MMAF, preventing erosion of the heavily subsiding area. MMAF has mainstreamed the approach throughout Indonesia with the construction of in total 23,5 kilometres of structures between 2015-2019 (see table A.1).

The Hybrid Engineering structures that are basically made of up only two main components, brushwood filling between two bamboo fences, trap sediment in an eroding coastal areas. At high tide the waves come and carry suspended material behind the structures, and at low tide the mud material will settle there. The structures do not function as a wave breaker, but rather as a sediment trap that mimics the function of the mangrove root system in ideal conditions. The site specific design depends on the results of wave analysis and stability criteria of the HE-structures when exposed to waves. Additional bamboo couplings (crossed positions of bamboo main poles) and reinforcing bamboo structures can be needed.

NO.	DISTRICT/CITY	PROVINCE	LENGTH (METER)
	YEAR 2015		14.160
1	Cirebon District	West Java Province	2.910
2	Brebes District	Central Java Province	910
3	Semarang City	Central Java Province	3.145
4	Demak District	Central Java Province	915
5	Jepara District	Central Java Province	3.140
6	Pati District	Central Java Province	3.140
	YEAR 2017		7.450
1	Cirebon District	West Java Province	1.850
2	Demak District	Central Java Province	3.300
3	Rembang District	Central Java Province	1.100
4	Gresik District	East Java Province	1.200
	YEAR 2019		1.900
1	East Lombok District	Nusa Tenggara Barat Province	200
2	Bombana District	Southeast Sulawesi Province	1.100
3	Bone District	South Sulawesi Province	600
		TOTAL	23.510

Table A.1 Location of HE structures built by MMAF with the year and length

Monitoring results and lessons learnt

Under ideal conditions, the permeable structures can quickly restore sediments in coastal areas affected by abrasion. This can be seen in several MMAF structure locations such as in Rembang District and Gresik District (figure A1 and A2). These locations showed sedimentation rates ranging from 0.1-0.5 meter per month during the first three months after the construction of the HE-structure. Based on information from the community, besides trapping the sediment, the structures also reduce the waves and as such protect the mangroves, ponds and settlements behind the structures.

Figure A.1 Bombana 2019 © MMAF

One of the most important lessons learned in implementing the HE-structures program by MMAF is the importance of maintaining and repairing damaged structures so that structures can last longer and function properly. HE-structures that are damaged due to large waves will not be optimal in trapping sediments or holding trapped sediments, as they are no longer able to function properly. Sediments that have been trapped behind the structure can also be lost again when exposed to the waves that come through the damaged structures.

Monitoring results of the HE-structures that were built by MMAF in 2015 and 2017, show that in several locations such as Brebes, Demak (Timbulsloko and Babalan Village), and Jepara sedimentation formed behind the structure, but then it disappeared again, because the structure was damaged and unable to trap the sediment.

Different conditions can be seen in Semarang, Demak (Purworejo Village), Pati, Rembang, Cirebon, and Gresik, where sediments remain trapped due to structural maintenance efforts and mangrove planting with the aim of helping to hold sediments and encourage natural mangrove regrowth around it. The monitoring results also show structures that are still in good condition as they are at a location protected from large waves, for example in a bay or behind a sandbar. High sedimentation rates result from a location near an adequate sediment source.

Therefore, another key to the success of the MMAF's HE-structures programme is effort to keep sediment trapped behind the structure, so that the sediment becomes stable and can be a place for mangrove growth and develop well.

Permeable structures also still require improvement in terms of the material used and in terms of its construction design, so that the structure is able to trap and hold sediments well and have a longer durability.

Another threat is human activity, because the sediments formed, also become a habitat for various marine biota that can attract local residents to be used as food or sold.

Figure A.2 Demak Purworejo, © Apri Susanto Astra, Wetlands International Indonesia

Involvement of community groups and local government

Local communities and local governments play an important role in the maintenance of the semi-permeable structures. Community groups carry out maintenance or repair activities independently after a monitoring and maintenance training provided by MMAF. The local government provides support by allocating a program or funds for the maintenance of the structures in a district or urban area, which ensures sustainability of the Building with Nature interventions.

Such local involvement is however hindered by Law No. 3 of 2014 concerning Regional Government which regulates the transfer of authority to manage the marine sector from the district/city government to the provincial government. Therefore, MMAF must work closely with the provincial, district/city and village governments to ensure that the HE-structure program can run synergistically and in harmony at every government level.

Land tenure

Land resulting from sedimentation in some areas has the potential to cause problems in legal aspects such as ownership and management. Therefore, agreement is needed between the beneficiary community and the land owners so that the utilization of new land after the rehabilitation process no longer returns to the previous unsustainable land use.

Figure A.3 Bombana 2019, © MMAF

X APPENDIX 2

APPLICATION OF PERMEABLE BAMBOO FENCES IN THE LOWER MEKONG DELTA, VIETNAM

The unsustainable use of natural resources in the coastal zone of the Lower Mekong Delta in Vietnam is threatening the protection function of the local mangrove forests. Thus, the muddy coastlines are subject to erosion and prone to the impacts of climate change, particularly by the increased intensity and frequency of storm surges. In sites where severe erosion has destroyed the mangrove belt, restoration of floodplains and mangrove rehabilitation is only possible after the wave energy has been reduced by physical barriers. Sophisticated and site-specific approaches to coastal protection become increasingly important within this context. Permeable bamboo fences are appropriate to reduce erosion and stimulate sedimentation. This box text addresses the design and monitoring of permeable bamboo fences, of which a total of 7,500m were installed on the east coast of the Lower Mekong Delta in Vietnam (Albers & Schmitt, 2016).

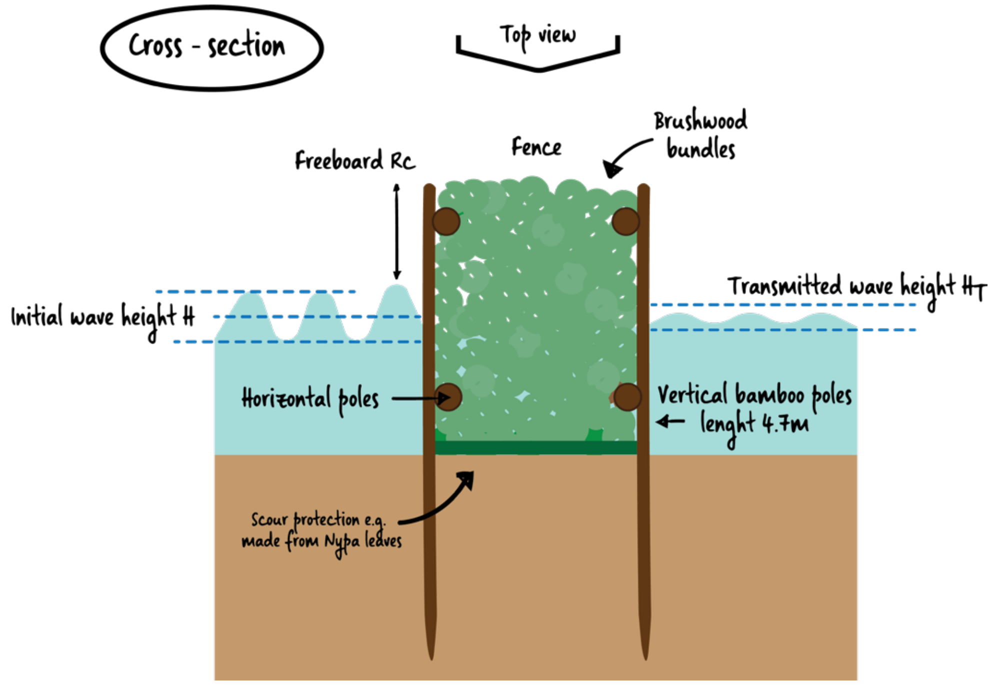


Figure A.4 – Design of the permeable bamboo fences and resulting wave transmission

The fences consist of two rows of vertical bamboo poles with a mean diameter of 8cm and brushwood bundles in the gap. The distance between the two rows is 0.40m for cross-shore sections and 0.50m for the long-shore sections. The distance between two poles in a row is approximately 0.30m. Two rows of horizontal poles are connected to the vertical poles on each side. The brushwood bundles between the rows consist of small bamboo branches. The material used to lash the joints should be stainless steel wire to assure a durable and stable connection. As scour protection at the bottom, a double layer of Nypa palm leaves was installed. However, scouring cannot be completely avoided and, thus, the embedded depth of the vertical poles in the mud was chosen to be large enough so that local scouring does not affect the stability of the fences.

The general arrangement of the permeable bamboo fences consists of a long-shore part, which dampens the incoming wave energy and a cross-shore part, which decreases the long-shore currents. This T-shaped layout is shown in figure 2. The long-shore elements close the eroded gap in the mangrove forest by connecting the remaining headlands. The reduction in wave height and thus in orbital velocities under waves leads to accelerated sedimentation rates. The results from benchmarks in Bac Lieu Province showed a deposition of approximately 17cm of sediments within 7 months. The reduction of wave action on the landward side of the fences also accelerates the consolidation of the mud and thus increases the stability of the sediments against erosion. This was shown through mud density monitoring in Soc Trang Province and can be seen in figure 3 (photo bottom left). The colour of the mud and the colonization by Avicennia indicate consolidation of sediments from the land edge towards the gaps in the T-fences

Figure A.5 – Restoration of eroded floodplains using bamboo T-fences in Bac Lieu Province (Mekong Delta, Viet Nam). © Cong Ly and G.E. Wind 2013.

Figure A.6 – Natural regeneration of Avicennia on restored floodplains in Soc Trang Province from the construction of the T-fences in October 2012 until January 2015. © GIZ Soc Trang, R. Sorgenfrei

In the photo top left in figure A3 from November 2012 the coast parallel elements of the T-fences are still clearly visible. The photo top right (February 2013) shows the beginning of the sedimentation. In November 2013 consolidation of sediments has started from the edge towards the gaps in the T-fences and natural regeneration of Avicennia starts to occur (Figure A.3 photo bottom left). The photo bottom right in Figure A.3 (January 2015) shows the growth of mangroves, which are not disturbed by wave action (due to the high/restored floodplain) or human impacts.

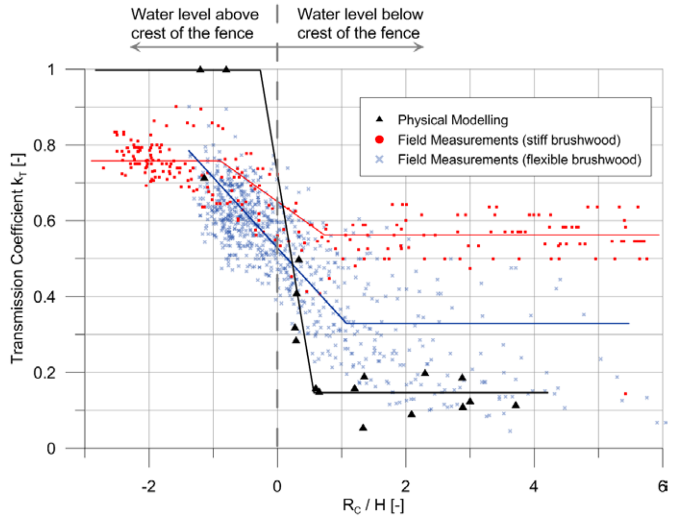


Figure A.7 – Wave transmission coefficients of the bamboo fences under various hydrological conditions

Within the monitoring program wave measurements to quantify the wave transmission effect of the bamboo fences during various storm and tidal conditions were analyzed. Waves were measured at two locations on the seaward and the landward sides of the bamboo fence, each at a distance of approximately 5m from the fence. Pressure transducers were used for the measurements, which were recorded continuously for approximately six months with a frequency of 10 Hz. The wave data were analyzed and summarized in significant wave heights of 15-minute periods.

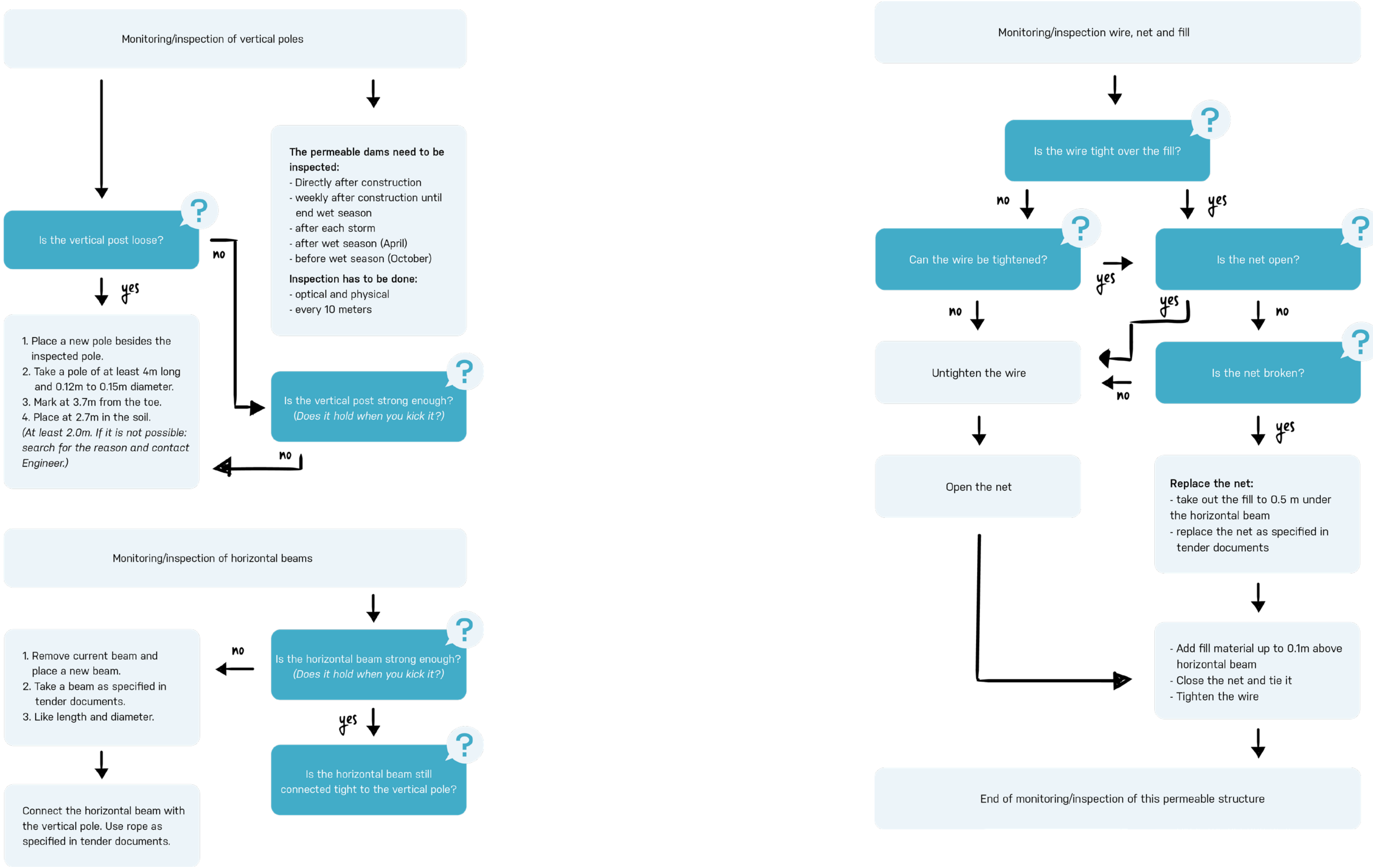
Figure 4 shows the results of the field measurements in comparison with the results of physical modelling. It shows the wave transmission coefficient kT in relation to a quotient of the freeboard RC and the initial significant wave height HS. Flexible bundles lead to smaller wave transmission coefficients (blue dots) than stiff bundles (red dots), and thus have a larger wave dampening effect. They can reach up to an 80% reduction of the initial wave height. The blue, red and black lines represent the best-fit through the measured values.

Along coastal sections without mangrove belts, bamboo T-fences are an effective coastal protection measure for restoring floodplains and creating conditions for mangrove regeneration. Their wave transmission effect is sufficient to reduce wave heights significantly and stimulate sedimentation on the landward side. The construction is cost-efficient and often more feasible than massive structures on the soft soil.

Albers, Schmitt (2016): Dyke design, floodplain restoration and mangrove co-management as parts of an area coastal protection strategy for the mud coasts of the Mekong Delta, Vietnam. In: Wetlands Ecology and Management. Springer. Volume 23, Issue 6 (2015), Page 991-1004. DOI 10.1007/s11273-015-9441-3

X APPENDIX 3

FLOW CHART FOR MONITORING AND MAINTENANCE OF A PERMEABLE STRUCTURE




Lombok Timur 2019, © MMAF

X APPENDIX 4

This appendix includes:

- overview of the species mentioned in this document and their scientific names;
- list of abbreviations;
- list of figures
- list of tables

LIST OF SPECIES

NAME IN DOCUMENT	SCIENTIFIC NAME
Bamboo	Bambusa spp.
Bamboo Apus and Betung	There are more than 1000 bamboo species. The two varieties distinguished for the Java project may each be one or more species.
Brushwood	In the Java project area, brushwood was composed of one or more of the following species: Tectona grandis (teak), Leucaena leucocephala, Hybiscus roseus or Mangifera indica (mango)
Coconut trunk	Kelapa (Cocos nucifera)
Kayu Gelam	Gelam (cf. Melaleuca cajuputi)
Nibung	Oncosperma tigillarium The name Nibung might also refer to the very similar related species known as the "Mountain Nibung" O. horridum, also known in Indonesia as "Bayeh". This species possesses the same high quality characteristics as O. tigillarium.
Nipah palm	Nypa fruticans
Walaba wood	One or more South American tree species from the genus Eperua (E. falcata, E. grandiflora, E. jenmanii, E. schomburgkiana), most typically E. grandiflora

LIST OF ABBREVIATIONS

Abbreviation	Description
AMDAL	Indonesian Environmental Impact Assessment (Analisa Dampak Lingkungan)
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BoQ	Bill of Quantity
cm2	centimeter/square meter
EUR	Euro
HWS	High Water Spring
HS	Significant wave height
HSE	Health, Safety and Environment
Hz	Herz (frequency)
IDR	Indonesian Rupiah
IKI (ICI)	International Climate Initiative
kg	kilogram (weight)
kT	Wave transmission coefficient
LWS	Low Water Spring
m	meter (distance)
mm	millimeter (distance)
MMAF (KKP)	Indonesian Ministry of Marine Affairs and Fisheries (Kementrian Kelautan dan Perikanan)
MLWS	Mean Low Water Spring
MHWS	Mean High Water Spring
MSL	Mean Sea Level
OE	Owner Estimate
PPE	Personal Protection Equipment
PU (PUPR)	Indonesian Ministry of Public Work and Human Settlement
RC	Freeboard
s	second (time)
ToT	Training of Trainers
UKL-UPL	Indonesian Management and Monitoring plan (Upaya Pengelolaan Lingkungan Upaya Pemantauan Lingkungan)

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PERMEABLE STRUCTURES

Building with nature to restore eroding tropical muddy coasts