A nature-based solution for sustainable port development in Port of Kuala Tanjung, Indonesia

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SUSTAINABLE PORT DEVELOPMENT: A CASE STUDY OF PORT OF KUALA TANJUNG, INDONESIA

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The Building with Nature (BwN) approach developed by Ecoshape suggests that nature-based solutions can be sustainable and cost-effective alternatives for traditional engineering solutions. Widening the solution space by studying and understanding the physical and ecological system in the early stages of port planning and design is more likely to result in sustainable ports with opportunities for multi-functionality and respect for nature. This paper applies the BwN philosophy to a case study, i.e., the ongoing port development in Kuala Tanjung in Indonesia and examines the technical and financial feasibility of a nature-based concept, i.e., a mangrove breakwater instead of a traditional 'hard' breakwater. Mangroves can realize significant wave attenuation, and at the same time, they are productive eco-systems that can result in long-term benefits through multifunctional land use. A berm built of dredged material with a mild slope which 'grows' naturally by accretion behind permeable dams can create the right conditions for mangrove trees to grow. This mangrove protection can develop into a sustainable barrier which grows with the (relative) sea level rise by trapping sediments. A preliminary design was made on the basis of information available in literature. A rough cost comparison considering only the supply and placing of fill material showed that mangrove breakwater is about 25% more expensive than a hard breakwater for the case under study. In view of the numerous port projects being planned in Indonesia, the technical and financial feasibility of mangrove breakwaters that can also enhance nature create added value for the surroundings is a promising finding.

Keywords: port master planning, Building with Nature, sustainable port, mangrove breakwater, Ecosystem Services.

INTRODUCTION

Background

Large scale infrastructure development usually has a lasting impact on the surrounding environment. A growing consensus acknowledges this fact and recognizes the need for more sustainable approaches for port development aimed at balancing social, environmental and economic aspects. However, large scale infrastructure planning traditionally follows a Building in Nature approach with a focus on the mitigation and compensation of the negative effects of a pre-defined design. The new Building with Nature (BwN) approach developed by Ecoshape (2018) constitutes a paradigm shift from the traditional approach to design by focusing on natural ecosystems and the benefits and services they can provide to humankind[1]. It attempts to deploy the properties of ecosystems to create viable, nature-based solutions that meet functional design requirements. It is based on the understanding that widening the solution space by studying and understanding the physical and ecological system is more likely to result in win-win solutions with respect for nature, that are acceptable to both project proponents and environmental stakeholders.

Research objective and method

The objective of the paper is to investigate the potential of the BwN design approach for the development of sustainable ports by comparing port masterplans resulting from applying the two approaches (Building in Nature and BwN) for the selected case study i.e., the Port of Kuala Tanjung or PoKT in Indonesia (van der Hoek 2018). The identified promising nature-based solutions can be widely applied for the numerous future port developments announced by the Indonesian government, thereby contributing to the United Nations Sustainable Development Goals.

The research methodology followed required the following steps, which are described in detail further on in the paper:

- A literature study pertaining to sustainable development (CBD 2010, UN 2018, PIANC 2014,).
- An extensive literature study of the BwN guidelines and applications worldwide for state-of-the-art developments (Ecoshape 2018, Laboryie 2018). Special attention was paid to the case study location in Indonesia (Ecoshape 2018a).
- A detailed study and evaluation of the existing masterplan of PoKT and related documents

[1] The term Ecosystem services is widely used since first defined by 2006 Millennium Ecosystem Assessment (MA) as the benefits people obtain from ecosystems. Four categories of ecosystem services are delineated: supporting, provisioning, regulating and cultural.

- Application of the BwN design approach to the case study

BUILDING WITH NATURE DESIGN APPROACH

A traditional approach to infrastructure projects is generally known to have a negative impact on nature, undermining the systems integrity, sustainability, and resilience. BwN requires us to pay attention to the ecosystem services, either in place or those that can be created, in order to achieve sustainable development. BwN philosophy is not only about deploying natural processes but also stimulating them in a way that the infrastructure fits sustainably within the natural environment and new opportunities for nature are created.

We apply the BwN philosophy in the following steps:

1. Understand the system (physical, socio-economic and governance) and define project objectives.
2. Identify feasible alternatives which include opportunities for nature-based solutions. Feasibility refers to both technical and financial feasibility.
3. Compare and evaluate alternatives based on preselected criteria. Bring the risks and benefits, associated with the design and implementation, into the picture.
4. Carry out the detailed design of the selected alternative.

CASE STUDY: PORT OF KUALA TANJUNG

Description

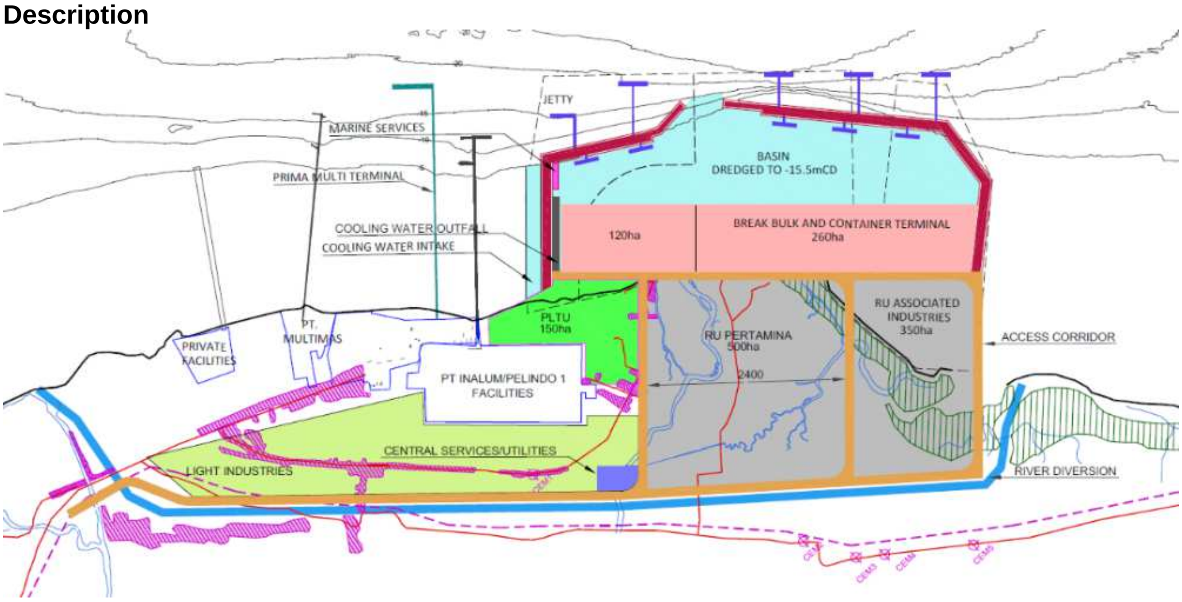

Figure 1. Master plan PoKT final phase.

Kuala Tanjung (PoKT) is a planned to be a large port-industrial complex situated in North Sumatra, Indonesia, north west of Singapore on the strait of Malacca. It is currently a small-scale industrial port with stand-alone facilities that can handle palm oil and aluminum. Further development of PoKT has a great potential to stimulate the local and national economy. A plan for the extension of the port that could become the country's largest international hub once finished, was presented in December 2017. Five development phases are planned and the final phase of the existing Masterplan (PoRIndonesia, internal report, 2017, RHDHV, internal report, 2017) can be seen in Figure 1.

Two breakwaters provide shelter for the 24/7 terminal operations and form a base and access road for exposed jetties and for sheltered jetties. Land reclamation is required to provide deep water access for large container vessels. River diversion is required to create new area for industry and terminals and to avoid discharging sediment from the existing river into the port basin. Population resettlement is necessary to obtain land for the large-scale industrial complex but also to ensure the safety of the residents of KT.

Figure 2. Situation Kuala Tanjung, 2017.

Figure 2 shows the situation at the time of the study. The PoKT project was in the initiation phase and a first feasibility study had been executed. This meant that the project location was fixed but various design choices were still available, providing the flexibility to incorporate new BwN solutions, thus improving the current masterplan.

Evaluation of existing PoKT Masterplan

In order to carry out an evaluation of the existing masterplan, the information was derived, among others, from the commercial, technical, socio-economic, and financial analysis of the current masterplan, Terms of Reference for the Environmental and Social Impact Assessment, the Economic Impact Assessment, and the Stakeholder Analysis (unpublished internal reports). The identified relevant social issues included lack of proper stakeholder management, land acquisition and resettlement of residents, influx of outsiders/migrants and urbanization, security and safety, loss of agricultural land and heritage sites. The relevant environmental issues included changes in river morphology due to river diversion, water quality disturbance, subsidence due to ground water extraction, changes in coastal morphology, disturbance of mudflats and mangroves, and the impact of construction activities in port and industrial area.

The impact of (implementation of) the current masterplan on the natural system is depicted in Figure 3. Resettlement of a village of fishermen, the diversion of main Bah Bolon river, and the

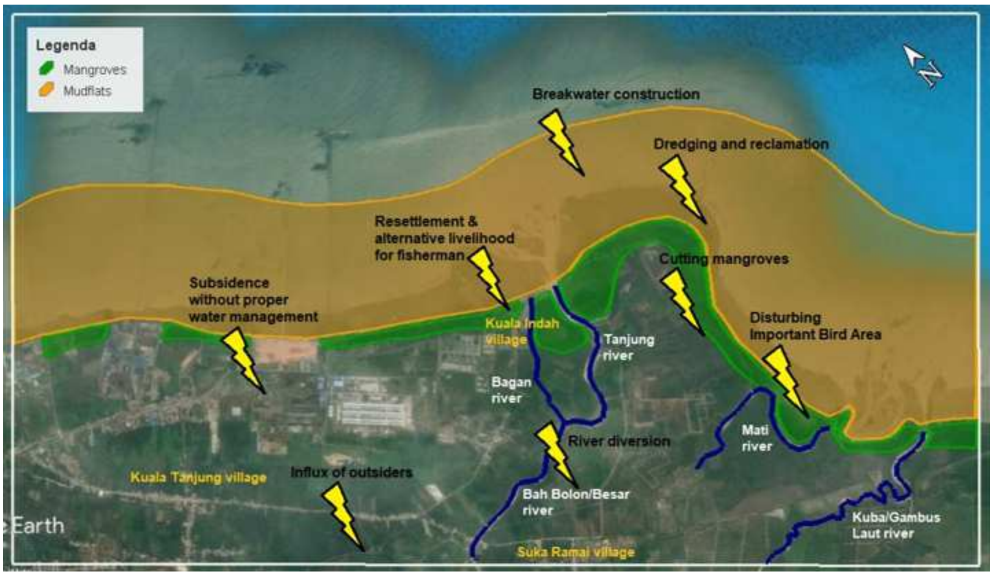

Figure 3. Impact of the Kuala Tanjung Masterplan on the surroundings.

availability of sand for the planned reclamations were identified as the major concerns. The measures proposed to mitigate the impact of the port development are mostly compensation measures. The importance of the delta, which forms the interface between salt and fresh water, is mentioned several times and so are the mangrove areas as sources for biodiversity and coastal protection. Replanting mangroves is not incorporated in the design. Moreover, the reuse of the material dredged during the Bah Bolon river diversion and the construction of the approach was not mentioned.

Clearly, the current PoKT masterplan was driven by functional requirements and economic growth, with an intention to mitigate and compensate the resulting negative impacts at a later stage. The evaluation helped to identify opportunities to improve the masterplan, not only through including mitigation and compensation measures but by proposing an adaption of the design.

BWN DESIGN APPROACH APPLIED TO POKT

System study and development of alternatives

In the current masterplan, the 'hard' rubble mound breakwaters forms a major part of the total capital expenditure. The use of hard structures (e.g. using stones and concrete) on muddy beds has the following disadvantages (Winterwerp et al. 2005): wave reflection and higher erosive stresses; small bearing capacity, low permeability and risks of liquefaction, require bed protection, and likely to be very expensive, both in construction and maintenance. Therefore, breakwaters could offer an opportunity to improve the current master plan by designing a nature-based alternative.

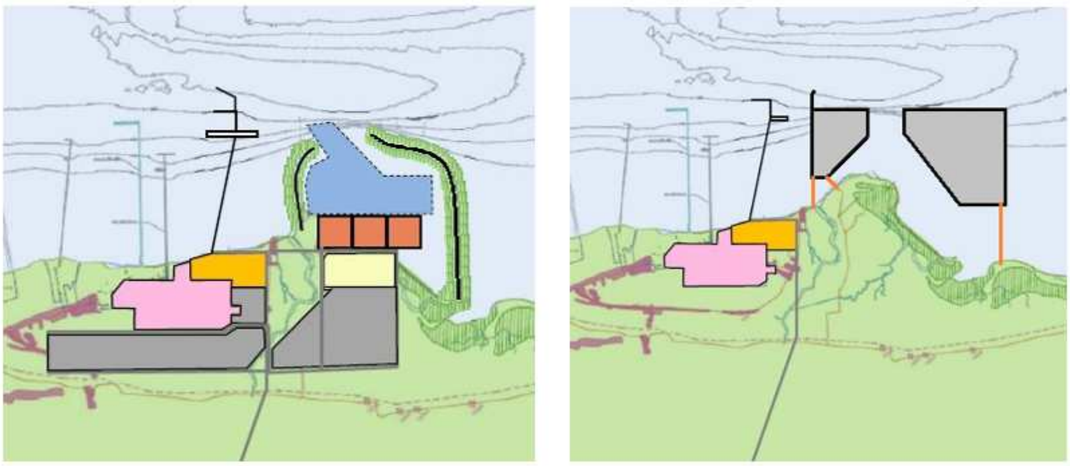

Figure 4. Onshore alternative with mangrove breakwater (left) and offshore alternative (right).

In keeping with the steps outlined in Section 2, a study of the physical system was undertaken which included the topography and bathymetry, the geotechnical aspects, and the coastal processes including wind, waves, water, and currents. Based on the system study, two alternatives were conceptualized as shown in Figure 4. These onshore and offshore alternatives were further investigated to identify opportunities for nature-based improvements.

The offshore alternative consists of terminals constructed offshore and connected to land by bridges. This avoids river diversion in all phases of the project, minimizes the need for land reclamation, and the proposed concrete deck on piles structure limits the impact on the ecology of the estuary. Under the decks, the ecosystem can be stimulated in a BwN approach by applying E-concrete and other materials on which shellfish can grow. However, though the social and environmental impact would be the least when working offshore, creating effective hinterland connections for the port is problematic, and the alternative is expensive. In the absence of breakwaters, the downtime for breakbulk and container ships to be served in the final phase is likely to be unacceptable.

Consequently, the onshore alternative considers a port protected by breakwaters. A study of the ecological system, the coastal and marine habitat, mangrove habitat, and the river and wetland habitat revealed that most of the 17.000 islands of Indonesia are protected from the sea by mangroves which stabilize the coast, attenuate waves and trap sediments, thereby providing ecosystem services.

A checklist for habitat requirements for mangroves was made in order to assess if these conditions could be created at the potential breakwater locations. The type of mangrove (species), the time of the year (monsoon or not) and the hydrodynamic conditions are key factors in determining whether mangroves can grow. An initial assessment concluded that the conditions at PoKT meet the habitat requirements for mangroves to grow. Therefore, a breakwater where mangroves are integrated in the design to attenuate waves and enhance nature at the same time was proposed.

The location and the layout of the mangrove breakwater is assumed to be similar to the breakwater in the master plan. With this approach, sufficient data is available for the preliminary design of the breakwater. Moreover, the functional design requirements for the port are fulfilled. There are implications for the overall dimensions of the breakwater as well as the phasing of the construction (breakwater and adjacent terminals) and the river diversion. The details can be found in (van der Hoek 2018).

After evaluating the alternatives together with experts involved in the Kuala Tanjung project, it was concluded that the onshore alternative is more realistic from a functional point of view, while still offering opportunities for applying the BwN philosophy. This alternative requires river diversion in the final phase when space is required for a container terminal. The location onshore is more efficient for port operation and is more amenable for creating a port-industrial complex where utilities can be shared. Moreover, In the onshore alternative, it was found possible to reuse the dredged material to stimulate mangrove growth for additional ecosystem services, and eventually creating a bird island on the shoal area with the dredged material.

In addition to dissipating waves, mangroves also have other advantages: removing nutrients from the water reducing the Biological Oxygen Demand, providing shelter for species and a nursery function for juvenile marine animals (such as shrimps, crabs and fish), positively affecting coastal fisheries, providing organic matter that forms the basis of the local food web including many shrimps, crabs and fish species, increase nesting, resting and feeding habitat for migrating and local birds, carbon sequestration, providing wood and charcoal, and water quality improvement.

DESIGN OF MANGROVE BREAKWATER

A reasonably detailed design of the mangrove breakwater was required to establish first the technical feasibility, and thereafter estimate the costs.

An initial assessment concluded that the conditions at PoKT meet the habitat requirements for mangroves to grow. However, several measures are needed to make it suitable for juvenile mangrove trees. According to (Winterwerp et al. 2005), mangrove establishment can be promoted by artificial infill with mud to raise the bed to mean sea level and/or by planting juvenile mangrove trees. This can be done in a BwN approach by: 1) installing permeable dams which facilitate accretion of suspended sediments resulting in a ‘naturally growing breakwater’ and 2) by creating the right conditions for mangroves to attract a variety of mangrove species and thereby creating a more resilient and sustainable breakwater.

The breakwater will grow naturally by accretion behind the permeable dams (Figure 6). To initiate the sedimentation process, a 150 m stretch of land could be artificially elevated up to +1.6 m Chart Datum to be able to construct permeable dams. The dredged material (silty sand) is reused to create the right conditions for mangroves to grow. At the deepest locations of the breakwater, the original design of the breakwater is used but E-concrete blocks are applied to support habitat for crabs, shellfish, and fish.

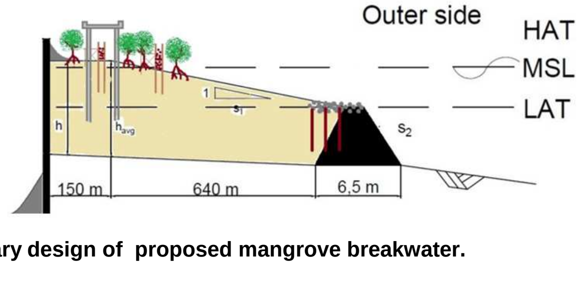

Figure 6. Preliminary design of proposed mangrove breakwater.

COMPARISON OF BREAKWATER ALTERNATIVES

Though the cost of mangrove breakwaters depends on many factors including planting, placing permeable dams and transportation distance, excavation or fill constitute a significant part of the costs. Therefore for an initial comparison, only the costs for supply and placing of fill material were estimated by multiplying fill volumes with a uniform unit rate. Under these assumptions, the first comparison showed that mangrove breakwater is about 25% more expensive than the traditional breakwater. Since the mangrove breakwater is largely self-sustaining and grows along with the sea level rise, maintenance costs are likely to be lower in the future. Moreover, the reuse of dredged material can reduce the costs of this design.

As stated earlier, mangroves are very productive eco-systems and many benefits need be commercially exploited. In order to build successful business models for a project, which reflect the direct, indirect, and intangible value created over the long-term, more research is required.

CONCLUSIONS AND DISCUSSION

The Building with Nature (BwN) design philosophy provided the guidance to identify opportunities for sustainable port development for the Port of Kuala Tanjung. It resulted in a nature-based solution for the breakwaters. Though, numerous scientific articles over the ability of mangroves to realize significant wave attenuation can be found in literature, practical application are required to add the knowledge and learning.

A checklist with habitat requirements for mangroves was developed to make the findings more usable. The checklist makes it possible to evaluate if mangroves can be considered as a potential ecosystem service for a Building with Nature design at a site. Ideally, this is done at an early stage of

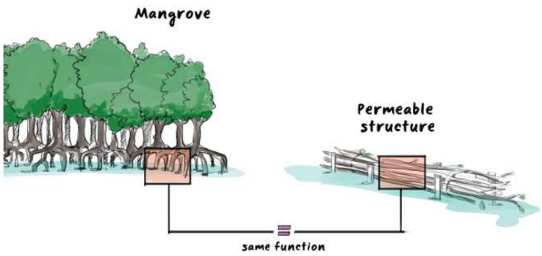

Figure 5. Permeable structures mimic the root system of mangroves that breaks incoming waves, reduce orbital velocities and turbulences and trap sediments (Wetlands International 2018).

the design process so that an optimal habitat for mangroves can be created. Later in the design process, the design is locked in and the possibilities for adaptation are limited.

Instead of a traditional ‘hard’ breakwater, a breakwater was proposed that has a mild slope of dredged material around the Mean Sea Level and ‘grows’ naturally by accretion behind permeable dams creating the right conditions for mangrove trees to grow. This mangrove protection can develop into a sustainable barrier which grows with sea level rise by trapping sediments, in addition to providing numerous other ecosystem services.

The key lessons learned from this research are that a combination of a thorough understanding of the physical, socio-economic and governance aspects, and an early stakeholder involvement results in higher benefits, reduces costs and provides the setting for sustainable design solutions.

Applying the Building with Nature approach to the PoKT project places emphasis on the positive impact instead of the negative impact. By communicating this innovative approach to stakeholders in an inclusive approach and connecting to political agendas, PoKT development is likely to gain more support.

There is ongoing research on mangroves and use of permeable dams to initiate the natural process of accretion. Therefore, opportunities to creating a ‘naturally growing’ breakwater for a small (marina) port development are being sought by port developers. It is likely that the concept of a mangrove breakwater finds application in shallow ports if the site conditions meet the habitat requirements for mangroves.

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REFERENCES

CBD (Convention on Biological Diversity). 2011. "X/2.Strategic Plan for Biodiversity 2011-2020". Accessed 23 May, 2018. https://www.cbd.int/decision/cop/?id=12268.

EcoShape. 2018. "Building with Nature Guidelines." Accessed 23 May, 2018. https://buildingwithnatureguidelines.org.

EcoShape. 2018a. "Building with Nature Indonesia". Accessed 23 May, 2018. https://www.ecoshape.org/en/projects/building-with-nature-indonesia/.

Laboyrie, P., Van Koningsveld, M., Aarninkhof, S.G.J., Van Parys, M., Lee, M., Jensen, A., Csiti, A. and Kolman, R. 2018. *Dredging for Sustainable Infrastructure Development*, CEDA / IADC. The Hague, The Netherlands.

PIANC (World Association for Waterborne Transport Infrastructure). 2014. Report 150: Sustainable Ports - A Guide for Port Authorities. Brussel: PIANC.

UN (United Nations). 2018. "Sustainable Development Goals". Accessed 23 May, 2018. https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

van der Hoek, A.P.L. 2018. "Applying the Building with Nature philosophy for sustainable port development." MSc thesis, Delft University of Technology, the Netherlands. https://repository.tudelft.nl/islandora/object/uuid%3A7754d39f-b744-4421-b07b-bed6c58a62cf.

Wetlands International. 2018. "Technical Guidelines #3 Permeable Structures – Building with Nature to restore eroding tropical muddy coasts." Accessed 23 May, 2018. https://www.wetlands.org/publications/technical-guidelines-permeable-structures/

Winterwerp, J.C., Borst, W.G., and De Vries, M.B. 2005. Pilot study on the erosion and rehabilitation of a mangrove mud coast. *Journal of Coastal Research* 21(2), 223–230.